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The Distributed Independent-Platform Event-Driven Simulation Engine Library (DIESEL)

Reejo Mathew
Old Dominion University

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THE DISTRIBUTED INDEPENDENT-PLATFORM EVENT-DRIVEN SIMULATION ENGINE LIBRARY (DIESEL)

by

Reejo Mathew
M.S. December 2002, Old Dominion University

A Dissertation submitted to the Faculty of Old Dominion University in Partial Fulfillment of the Requirement for the Degree of

DOCTOR OF PHILOSOPHY

ELECTRICAL AND COMPUTER ENGINEERING

OLD DOMINION UNIVERSITY
May 2007

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The Distributed, Independent-Platform, Event-Driven Simulation Engine Library (DIESEL) is a simulation executive, capable of supporting both sequential and distributed discrete-event simulations. A system level specification is provided along with the expected behavior of each component within DIESEL. This behavioral specification of each component, along with the interconnection and interaction between the different components, provides a complete description of the DIESEL behavioral model. The model provides a considerable amount of freedom for an application developer to partition the simulation model, when building sequential and distributed applications with respect to balancing the number of events generated across different components. It also allows a developer to modify underlying algorithms in the simulation executive, while causing no changes to the overall system behavior so long as the algorithms meet the behavioral specifications.

The behavioral model is object-oriented and developed using a hierarchical approach. The model is not targeted towards any programming language or hardware platform for implementation. The behavioral specification provides no specifics about how the model should be implemented. A complete and stable implementation of the behavioral model is provided as a proof-of-concept, and can be used to develop
commercial applications. New and independent implementations of the complete model can be developed to support specific commercial and research efforts. Specific components of the model can also be implemented by students in an educational environment, using strategies different from the ones used within the current implementation. DIESEL provides a research environment for studying different aspects of Parallel Discrete-Event Simulation, such as event management strategies, synchronization algorithms, communication mechanisms, and simulation state capture capabilities.
This dissertation is dedicated to the saying
"The day you are through learning, you are through."
ACKNOWLEDGMENTS

I would like to extend special thanks to Dr. James F. Leathrum, Jr., my mentor and dissertation advisor, for the knowledge and guidance that he has given me during the last seven years. I will fondly remember our spirited discussions about Yankees baseball (my passion) and Duke basketball (his passion), although we have yet to find common ground on either topic. I would like to believe that he has learned as much about soccer (or football as it is known in the rest of the world) and cricket from me, as I have learned about baseball traditions and the Princeton offense in basketball from him.

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I would like to thank my friends Shruti, Paul, Avi, Anand, Hrishi and lots of others for helping me keep my sanity intact and my disposition cheerful during the times that I needed it most.

My family has played a big role in all my achievements in my life and my career. My brother, Rishi, though younger than me, has been a source of inspiration for me throughout my career. I owe everything in my life to my parents, Annie and V.C.
Mathew. This doctorate is a testament to everything that I have learned from them and my most cherished gift to them. Last but definitely not least, I dedicate this dissertation to my sister, Reenu for her words of encouragement, her voice of reason, her generosity and her inability to refuse whenever I asked her for monetary assistance. I love and respect her for who she is and what she has done for me.
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<td>IDE</td>
<td>Integrated Development Environment</td>
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<td>IID</td>
<td>Independent Identically Distributed</td>
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<td>IOC</td>
<td>Initial Operational Capability</td>
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<td>LP</td>
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<td>MIS</td>
<td>Management Information System</td>
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Chapter I

INTRODUCTION

The Distributed, Independent-Platform, Event-Driven Simulation Engine Library (DIESEL) is a behavioral model for a simulation executive, capable of supporting both sequential and distributed Discrete-Event Simulation (DES). The behavioral model provides a system level specification for the simulation executive by describing the different components of the system, specifying the behavior of each component, and detailing the interconnection and interaction between the components. The model is generic, language-independent and platform-independent, and is developed using an object-oriented approach.

DIESEL specifies interfaces for each component of the behavioral model, along with the expected behavior of each procedure within the component interface. This can be used to develop new and independent implementations of one or more components of the model. It also provides support for developing commercial applications by using the same interfaces to build the application in a hierarchical manner.

DIESEL has been developed to bring research into different aspects of sequential and distributed DES under a common research and development platform. A new implementation can be developed for one or more components within the model and can then be inserted into the complete system with no change in system behavior. At a system level, the entire implementation of the behavioral model can be redefined by using

different algorithms and data structures without affecting any applications that are built using the simulation executive.

1.1 Overview

Simulations are used extensively to model real-world systems, both existing and proposed, and analyze problems and scenarios that occur within them. Simulations are often a cost-effective method for modeling a complex physical system with a level of detail that adequately represents the real-world system under consideration. Simulations are often a relatively cheap approach for experimenting with an existing or proposed system and for evaluating future modifications and additions to the system when compared to building the actual system. The processing involved in the system needs to be modeled with appropriate detail so that the developed model provides an accurate representation of the system necessary to meet the stated objectives of the simulation. An analysis of the simulation results can then be used to aid in the decision-making to improve the performance and efficiency of the system. Simulations can also provide a safe alternative to evaluating scenarios such as war planning, where it is too dangerous and costly to conduct actual exercises during planning and training.

1.2 Background

The following terms are commonly used within a DES:

- **Physical Time:** Physical Time is the time within the real-world or proposed system being simulated. In a digital circuit, the physical time might be in terms of microseconds or nanoseconds, while in a port simulation, the physical time might
be in terms of days, weeks, or months.

• **Simulation (Virtual) Time:** Simulation or Virtual Time is an abstract concept used by a simulation to represent physical time. Fujimoto in [1] describes simulation time as a totally ordered set of values where each value represents a unique instant of physical time in the system being simulated.

• **Wallclock Time:** Wallclock time refers to the advancement of real time during the execution of the simulation. For analytical simulations, wallclock time could start from zero, while for real-time simulations wallclock time could be synchronized with a true wallclock.

• **Event:** At any instant within a simulation, the state of the system can be derived from the simulation state variables. An event is defined as an act which changes the state of the system by modifying its state variables. In addition, an event can schedule other events to be executed in the future.

A DES uses events to model discrete changes of state within a modeled system, and the simulation progresses with events being processed in order of their timestamps. A DES can be executed on a single processor with common time management for all components of the simulation. A DES can also be mapped to a collection of processors connected by a network (with each processor on the network modeling a particular component) and then executed in parallel. This is known as a Parallel Discrete-Event Simulation (PDES) [1, 2]. PDES can offer several advantages over executing a simulation on a single sequential processor, such as model parallelism and reduced execution time for the simulation.

Simulations are usually composed of different components interacting with each
other. Each component represents an individual process or set of processes within the modeled system. These components can be intuitively mapped onto processors in the network within a PDES with a single processor simulating one component or a group of related components, thus preserving their natural structure. This structure can also take advantage of any potential parallelism within the model, with each component executing in isolation, independent of another component, until it needs to interact or synchronize with another component.

Mapping a large simulation model to a network of processors by dividing the model into distinct components and providing each component within the simulation local access to its data and code potentially speeds up the execution of the whole simulation model. The maximum speedup possible within a PDES is a factor of $n$, where $n$ is the number of processors available. It is rarely possible to achieve this ideal speedup due to interconnection and synchronization delays among components. However, the goal of a PDES is to generally execute faster than the equivalent sequential simulation.

Simulation users might need access to individual components of the simulation, without having to worry about other components, or interfering with their execution. A PDES can provide this isolation of components. This property is even more beneficial when the users are at separate geographical locations, with the PDES providing the user with access to the relevant components of the simulation model. Distributed interaction by different users also requires distributed time management within the simulation which is provided by the PDES.

The development of a PDES system can be described with a hierarchical, top-down approach as shown in Figure 1. Given a system of interest to be modeled, the first
Figure 1. Distributed Simulation Methodology

A PDES system consists of multiple processes interacting with each other to complete the simulation task. Each such process simulates either an actual process within the system of interest or a process to support simulation execution, such as complex statistical analysis or construction of graphical images. Such a process is called a logical process (LP). A PDES can be executed either on a single processor or a network of processors with a communication medium connecting the processors. The number of LPs is independent of the number of processors available for the simulation. All the LPs can reside on the same processor in a single-processor environment or can be distributed across the network. In concept, LPs interact with each other by transmitting messages among each other. Messages are used by LPs to schedule events on other LPs, to transmit synchronization information, to report errors, etc. The actual content of a message might
include additional information unique to the synchronization paradigm being employed.

Within any simulation, the happened before relation needs to be defined for the ordering of events. Let \( \rightarrow \) denote the happened before relation. Then

- If \( a \) and \( b \) are events within the same LP, and \( a \) comes before \( b \) in simulation time, then \( a \rightarrow b \).
- If \( a \) is the act of sending a message by one LP, and \( b \) is the receipt of the same message by another LP, then \( a \rightarrow b \).
- If \( a \rightarrow b \) and \( b \rightarrow c \), then \( a \rightarrow c \).
- Two distinct events \( a \) and \( b \) are said to be concurrent if \( a \not\rightarrow b \) and \( b \not\rightarrow a \).

Lamport [3] defines a virtual clock as:

- A virtual clock \( C \) is a logical structure with no relation to physical time.
- \( C_i \) exists in each LP \( P_i \).
- \( C_i \) assigns a timestamp \( C_i(a) \) to each event in \( P_i \).

Then, Lamport’s clock conditions state that:

For any events \( a, b \)

\[
\text{if } a \rightarrow b, \text{ then } C_i(a) < C_i(b)
\]

This can be expanded to include the happened before relation as:

- If \( a \) and \( b \) are events within the LP \( P_i \) and \( a \rightarrow b \), then \( C_i(a) < C_i(b) \).
- If \( a \) is the act of sending a message by LP \( P_i \), and \( b \) is the receipt of the same message by LP \( P_j \), then \( C_i(a) < C_j(b) \).
- If \( C_i(a) < C_j(b) \) and \( C_j(b) < C_j(c) \), then \( C_i(a) < C_j(c) \).
- If \( a \) and \( b \) are simultaneous events, i.e. events that have the same timestamp, then no happened before relation exists between \( C_i(a) \) and \( C_i(b) \).
A DES when executed as a sequential simulation should process events in increasing order of their timestamps so that the happened before relation can be maintained for the events. A DES when executed as a distributed simulation should also process events, whether generated locally within a LP or generated by other LPs, in increasing order of their timestamps. This is known as the Local Causality Constraint [1] and is a sufficient condition for a DES. If each LP within a distributed simulation adheres to the Local Causality Constraint, then the distributed simulation will produce identical results to the equivalent sequential simulation, provided that both the sequential and distributed simulations execute simultaneous events in the same order.

A distributed simulation can reorder events in violation of the Local Causality Constraint provided that the reordering does not violate inherent computational dependencies between events. This is rarely done since the simulation executive requires knowledge of the computational dependencies between events in order to select an appropriate event to execute. This knowledge requires a higher level of interaction than that required by the Local Causality Constraint between the simulation executive and the application, and requires the application to have a higher level of understanding of these dependencies.

A PDES system can employ either of two types of synchronization algorithms to satisfy the Local Causality Constraint, conservative and optimistic, as discussed below.

**Conservative Synchronization Algorithms**

Conservative synchronization algorithms strongly enforce the Local Causality Constraint by blocking all LPs from processing any event until it is determined to be safe.
by the simulation executive. Determining what events are safe to process is an important part of any conservative algorithm. A simple method is for each LP to send a null message to every other LP indicating the lower bound on the time stamp of messages it will send at any point in the future. This lower bound is calculated by adding a quantity called lookahead to the local simulation time of the LP. Fujimoto [1] states that if a LP at simulation time \( T \) can only schedule new events with timestamp of at least \( T + L \), then \( L \) is the lookahead for the LP. The lookahead is determined by the simulation application, and can change during the simulation. However, this method can lead to deadlock within the simulation, with LPs waiting for each other to process events further.

An approach known as barrier synchronization can be used to address deadlock, where each LP executes its safe events and then waits for every other LP to reach an agreed upon synchronization point. Once each LP has reached that point, all LPs are allowed to execute their next batch of safe events. Barriers can be implemented in a variety of ways by organizing LPs to reduce the messages that need to be sent between LPs to execute the barrier primitive [1].

The advantages of conservative algorithms are decreased complexity of the simulation executive, the absence of causality errors, and modest memory requirements. The disadvantages of these algorithms are LPs waiting for a notification that its next event is safe to be processed and the possibility of deadlocks with each LP waiting for a notification from all other LPs.

**Optimistic Synchronization Algorithms**

Optimistic synchronization algorithms, on the other hand, allow violations of the
Local Causality Constraint, by allowing the LPs to continue executing events and then returning to a safe state when causality errors occur. Optimistic algorithms account for causality violations by rolling back to a saved safe state (which has been checkpointed), undoing all state changes which occurred after the checkpoint, and by sending special messages called anti-messages to reverse the effect of improperly sent messages after the checkpoint. The execution of an event is provisional; it is conditional on the fact that no message arrives at the LP with a timestamp less than the event’s timestamp. Optimistic algorithms have been developed on the premise that improved simulation performance can be achieved even with the overhead of undoing and possibly repeating one or more event computations.

The Time Warp paradigm [4, 5] is one of the most widely discussed optimistic synchronizing mechanisms for a PDES system. The Time Warp paradigm derives its name from the behavior that virtual clocks of different LPs go back and forth, independent of each other, reverting back to correct causality errors, while generally progressing for the duration of the simulation. At any point in the simulation, some LPs are allowed to progress ahead in terms of virtual time, while other LPs lag behind in terms of their local simulation times. The paradigm is independent of any underlying computer architecture. However, a reliable communication medium is assumed so that no messages are lost in transit.

The Time Warp paradigm requires each LP to have the following:

- A process identifier unique to an LP indicating the virtual space co-ordinate of the LP. The set of all process identifiers constitute the virtual space of the simulation.
- A local virtual clock $C_i$ showing the current virtual time of the LP to indicate the
virtual time co-ordinate of the LP.

- A state denoting the current state of the LP including its state variables, execution stack, etc.

- A state queue containing saved states of the LP called checkpoints for rollback purposes. It is assumed that the state of each LP is saved after every event computation.

- An input queue containing all processed and unprocessed messages received from other LPs along with their timestamps. Messages which have been processed are saved in case a rollback is necessary and the messages need to be reprocessed.

- An output queue containing faithful copies (with a negative sign) of messages sent to other LPs during an event computation, called anti-messages. Anti-messages are stored to undo the effect of positive messages in the event of a rollback.

A Time Warp Logical Process (TWLP) is shown in Figure 2. Causality of executed events is achieved within Time Warp by two major components: the local control mechanism and the global control mechanism. The local control mechanism within Time Warp deals with the execution of events within a TWLP and receipt of messages from other TWLPs in order of their timestamps. The value of \( Q \) at a TWLP never changes during the processing of an event, it only changes between events. However, in the absence of a global clock, it is likely that one TWLP will send a message to another TWLP with a timestamp that is in the past of the destination TWLP. Such a message is called a straggler message. In this case, the destination TWLP has to roll back to a state earlier than the timestamp of the straggler message, and then start processing all
events in its input queue that have timestamps greater than that of the straggler message. When a straggler message arrives, all events that have been processed might have modified state variables as well as scheduled new events by sending messages to other TWLPs. Therefore, to undo the incorrect modification of state variables, the state of the TWLP needs to be restored to a state prior to the incorrect modification. Various state saving techniques exist in literature [6 – 11].

It also becomes necessary to undo the effects of messages that may have been sent incorrectly because the straggler message was not processed. Therefore, for every message that a TWLP sends to another TWLP, the original message is stored in the input queue at the destination TWLP, and a faithful copy of the message with a negative sign, called an anti-message, is stored in the output queue of the source TWLP. This is shown in Figure 3. Whenever a message and an anti-message encounter each other in the same queue, they cancel out each other. This is known as message annihilation. Since
messages and anti-messages are created in pairs, the algebraic sum of all messages and anti-messages in a Time Warp system at any instant of time is zero.

The local control mechanism consumes more and more memory as the simulation progresses because states need to be saved for rollback purposes, and positive messages and anti-messages need to be saved even after they have been executed. A more global mechanism is required to reclaim memory allotted for history information. Moreover, certain event operations such as I/O operations cannot be rolled back easily, and the TWLP needs to be certain that no rollback is necessary for the current point before it proceeds with such operations. Therefore, a lower bound on the timestamp of any future rollback needs to be determined both for claiming memory allotted for state saving before the lower bound and for safely performing I/O operations in the past of the lower bound. This lower bound is known as the Global Virtual Time (GVT).

Fujimoto [1] describes Global Virtual Time at wallclock time $T$ (GVT$_T$), as the minimum time stamp among all unprocessed and partially processed messages and anti-
messages in the system at wallclock time $T$. GVT can be computed periodically or in emergency situations, when the simulation is running low on memory or an I/O or interrupt operation needs to be performed. Various techniques for computing the GVT exist in literature [12, 13, 14].

1.3 Related Work

This section describes past work that has been done in Parallel and Discrete-Event Simulation (PDES) and other related fields.

1.3.1 Parallel and Discrete-Event Simulation (PDES)

Research in the field of PDES is focused towards different aspects of the system. Simulation tools and languages have been developed to support building computer simulations. Tools have also been developed to help an application developer build a simulation more efficiently. To support simulation execution, many simulations executives and environments that support sequential and parallel discrete-event simulations have been developed. Simulation frameworks to support linking together simulations have also been defined. Most of these applications are focused towards distinct aspects of the field of PDES.

Object-oriented programming was originally developed with the basic intention of supporting the simulation of the states and activities of different entities [15, 16]. Attributes represent the state of an entity, while a method modifies the behavior of the entity by manipulating its attributes. A real-world system usually involves multiple entities interacting with each other through the lifetime of the system. Object-oriented
methodology aids in simulating this process by dynamically instantiating multiple objects to represent the different entities and representing the interaction among the objects as objects invoking methods on other objects. Commercial simulation languages such as MODSIM [17] and SIMSCRIPT [18] and simulation tools such as PROMODEL [19], ARENA [20] and MODELICA [21] have been developed to build simulations. Many of these languages are built using a specific general-purpose programming language and are focused on simplifying the development of stable simulation applications. Distributed simulation languages such as Maisie [22], MOOSE [23], APOSTLE [24], PARSEC [25], POMSim [26], Silk [27] and Sim++ [28] have also been developed before. Maisie and PARSEC are purely C-based simulation languages, Silk is Java-based, Sim++ is C++-based, while MOOSE is an object-oriented extension to Maisie. APOSTLE employs a single optimistic algorithm, the Breathing Time Buckets (BTB) synchronization algorithm. POMSim exclusively simulates manufacturing systems.

Considerable work has also been done to provide a formal framework for specifying and building application models. The DEVS formalism was conceived by Zeigler [29, 30] to provide a rigorous approach for discrete-event modeling and simulation. The DEVS formalism facilitates modular, hierarchical model specification, using a top-down approach to model development. DEVS allows for the description of system behavior at two levels: the basic model which can be used to develop larger models and how basic models are interconnected to form a complete system. Frey et al. [5] present a formal specification of the Time Warp paradigm, the structure of its components, the properties necessary for its validity and correctness, and a formal verification of the Time Warp specification. A reusable specification framework to extend
the basic *Time Warp* specification and define and verify new properties is also described.

Simulation environments focus at the core simulation executive and support different aspects of the parallel and distributed simulation paradigm by providing the ability to use different algorithms and mechanisms. The Georgia Time Warp (GTW) [31] is a parallel simulation executive which implements the *Time Warp* specification for shared-memory multiprocessors. SPEEDES (Synchronous Parallel Environment for Emulation and Discrete-Event Simulation) [32] is an object-oriented distributed discrete-event simulation framework written in C++. SPEEDES supports a variety of conservative and optimistic synchronization schemes for distributed simulations and has been designed to run on a variety of hardware platforms. It also provides interfaces for developing external simulations to interact asynchronously with the SPEEDES simulation. However, SPEEDES is not a general purpose programming language nor does it provide a behavioral specification to develop new implementations of various components. It provides a modeling framework that allows other simulation scripting languages to be written on top.

Simulator Networking (SIMNET) [33, 34], developed by Defense Advanced Research Projects Agency (DARPA) provides an architecture for networking processors in real-time for combat simulation and wargaming. Distributed Interactive Simulation (DIS) [35] extends SIMNET by connecting diverse simulations using a communication medium to provide a common battlefield on which the different simulations can interact with each other in real-time. The High Level Architecture (HLA) [36, 37, 38] that evolved from DIS provides a specification of a common technical architecture to address the need for interoperability among new and existing simulations within the US.
Department of Defense. HLA defines a set of rules to link diverse existing simulations (each called a **federate**) while providing a framework to incorporate new simulations in order to create a collection of simulations operating together (called a **federation**). The Object Model Template (OMT) within HLA provides a standard format for describing information of common interest to more than one **federate**, while the Runtime Infrastructure (RTI) provides the means for **federates** to coordinate the execution and exchange of information.

### 1.3.2 Research / Educational Frameworks

A strength of the DIESEL model is that it provides a platform for further research, allowing new implementations to be developed and evaluated within the prescribed behavior. Similar work has been done in the field of operating systems to simulate a real operating system, while providing a platform for changing components within the simulation. NACHOS (Not Another Completely Heuristic Operating System) [39] developed at the University of Berkeley, California is used to teach operating systems at an undergraduate level. NACHOS allows the study and modification of an operating system by providing a simulation environment for an instructional operating system. It implements a CPU and device simulators, and simulates the general low-level facilities of typical machines, including file systems, threads, remote procedure calls, interrupts, virtual memory, and interrupt-driven device I/O. NACHOS allows students to write new implementations for each major component of an operating system, enabling them to understand aspects of real operating systems in terms of reliability, performance, and simplicity of the system.
Research frameworks have also been developed in the field of Management Information Systems (MIS) [40] for understanding and classifying existing research into different categories and for generating potential hypotheses for future research.

1.4 Chapter Plan

Chapter II explains the rationale behind this research and lists the requirements of the behavioral model. Chapter III provides a complete specification for the sequential simulation executive. It also includes a brief description of the implementation of the main components of the simulation executive. Chapter IV provides a complete specification for the distributed simulation executive. Chapter V describes various case studies that have been conducted to demonstrate the use of the behavioral model. Chapter VI concludes the dissertation and offers suggestions on improvements and additions to the model.
Chapter II

PROBLEM STATEMENT

An architectural model defines the components of a system, specifies the manner in which they interact with one another, and details the interconnection among these components. The Distributed, Independent-Platform, Event-Driven Simulation Engine Library (DIESEL) is a behavioral model for a simulation executive that aims to provide a common platform for research and development in the field of Parallel and Discrete-Event Simulation (PDES). The model has been designed to be generic, language-independent and platform-independent using a hierarchical, object-oriented approach. The model defines how time management will be handled in the simulation. It also provides the application developer a tremendous amount of flexibility in the partitioning of his model from an event management standpoint. The model is defined behaviorally so that various algorithms and data structures can be implemented internally without requiring modification of applications that are developed using the model.

The rest of this chapter is organized as follows. Section 2.1 explains the rationale behind this research, Section 2.2 outlines the requirements of the architectural model, and Section 2.3 defines various terms used in this dissertation.

2.1 Problem Statement

DIESEL has been developed to allow research into the development of simulation executives, under a common research and development platform. It does not attempt to address simulation modeling or the associated formalisms as done in DEVS [29, 30].
DIESEL focuses on providing a software framework for algorithmic development to support time management, entity management, and other simulation management issues within the simulation executive. The DIESEL behavioral model is an abstraction of the simulation executive not previously found in literature.

DIESEL aims to provide a standard Application Programming Interface (API) as shown in Figure 4 for a simulation executive, capable of supporting both a sequential and distributed DES. The DIESEL API separates the development of applications from the underlying structure of the core simulation executive. The executive manages the advancement of simulation time within the application for the duration of the simulation. The application schedules events to be executed in the simulation future and the executive executes the events at the appropriate simulation time. A different implementation can be developed for the DIESEL API, without affecting any applications that are built using the API. The DIESEL interface provides an API for developing both sequential and distributed simulation applications. Any component implementing the DIESEL interface can be modified or changed as long as it does not...
modify the expected behavior of the interface.

The DIESEL interface described in Chapters III and IV provide various structures for developing applications. The interface also manages simulation time for both a sequential and distributed application. Events are executed in increasing order of their timestamps to satisfy the Local Causality Constraint. The interface also provides a mechanism to deal with simultaneous events, i.e. events with the same timestamp. This mechanism allows the next state of the simulation to be computed totally based on the current state of the simulation, and not on any intermediate computations while transitioning from the current state to the next state. The interface however, does not address race conditions between simultaneous events modifying the same state variable. Resolving these race conditions is expected to be the responsibility of an application developer or a specific implementation of the DIESEL interface.

2.2 Research Purpose

The research described in Chapter I addresses different distinct issues in the field of PDES both at the application development level and the core simulation executive level. SPEEDES provides a framework for developing discrete-event simulations using the C++ programming language and provides interfaces to link external simulations written in C++, to itself. However, SPEEDES does not specify a behavioral model or interfaces to support the development of alternative implementations on different platforms. HLA provides both a behavioral specification and an interface specification to support simulations using different languages like C++, Ada, Java, and CORBA among others. The interface specification, however, requires the application to have a high level
of knowledge of the underlying time management. The specification requires each simulation to know its own internal time management and how it will interact with other simulations employing different time management strategies. HLA focuses on linking existing simulations rather than partitioning a new simulation model into components for parallelism.

At the core simulation executive level, DIESEL proposes to provide interfaces to support development of different implementations of the behavioral model thereby allowing different implementations to interact with each other. It would support conservative synchronization algorithms, as well as optimistic synchronization algorithms such as *Time Warp*. DIESEL does not attempt to mix synchronization algorithms within a single simulation, but rather proposes to create a research environment to study simulation behavior and interaction while utilizing a single time management paradigm and communication mechanism for the whole simulation.

At an application level, DIESEL proposes to provide an application developer the ability to partition the model in different ways and map different components of the model to the processors available for the simulation.

DIESEL provides a common, standardized interface for developing applications, for both sequential and distributed discrete-event simulations. A common interface is specified for both a sequential and distributed simulation executive. DIESEL also provides a fair amount of flexibility to the developer to partition the simulation model into components in terms of event handling. The developer can employ a central event management scheme to handle all events generated within the simulation, group together similar components, and handle their events together, or designate that each object within
the simulation handles its own events. For research purposes, this varies the size of the event list and can aid in the development of appropriate strategies to manage them.

DIESEL does not specify a particular algorithm or strategy to implement different components of the behavioral model. This is extremely useful to:

- Compare application behavior while partitioning the model in different ways.
- Compare application behavior on a sequential and distributed executive.
- Compare existing event insertion and management algorithms on a common platform.
- Develop and compare new event management algorithms under the same platform.
- Compare different synchronization algorithms (conservative and optimistic) for a distributed simulation executive.
- Verify simulation behavior while employing a new synchronization algorithm.
- Compare different communication mechanisms for a distributed executive.

The only constraints imposed on any employed algorithm or mechanism is that it satisfy the expected behavior of that component in the behavioral model and not modify the interconnections among components. Moreover, DIESEL functionality is defined using a behavioral model and is generic. It defines the expected behavior of the simulation executive and is not focused on any platform or programming language. DIESEL can be implemented using any programming language suitable for a particular research or commercial purpose.

The DIESEL behavioral model has been primarily developed as a research tool to
aid in comparing existing solutions while also providing a great level of support for research into implementation strategies for different components of both a sequential and distributed simulation executive. Implementations are provided for all components specified in the behavioral model, with each component implementation managed separately and independently in order to isolate errors and also to encourage further development. Implementations can be developed for specific components within the model with no change to other components, thus ensuring that the complete system continues to work. New implementations can also be developed for the whole model using various programming languages and on different hardware platforms.

A stable environment and implementation for the DIESEL behavioral model is also provided for developing commercial applications, even though DIESEL has been primarily developed as a research tool.

2.3 Model Requirements

The architectural model for DIESEL has been developed with the intention of satisfying the following basic requirements:

- **Support for Discrete-Event Simulation**: DIESEL should be capable of supporting discrete-event simulations.

- **Support for a Sequential and Distributed Simulation Executive**: DIESEL should support both a sequential and distributed simulation executive, with the same interface to the programming world.

- **Generic Design**: The DIESEL behavioral model should be as generic as possible
with simple interfaces between DIESEL and the outside world, as well as within	DIESEL itself.

- **Object-Oriented Design:** The DIESEL architecture should be defined to be object-oriented and developed using a hierarchical, top-down approach.

- **Language and Platform Independent:** The DIESEL behavioral model should not be tailored to any particular language or platform for implementation. It is a research goal to implement the model in different languages on various platforms to provide proof of its generic design.

### 2.4 Definitions

The following terms are used in this document to describe various components of the DIESEL behavioral model:

- **SimObject:** A SimObject is any object created and used within a simulation that needs to pass simulation time during the simulation.

- **SimulationCluster:** A SimulationCluster is a set of SimObjects interacting with a single SimulationEngine.

- **SimulationEngine:** A SimulationEngine handles all the time management for the entire duration of a simulation. It keeps track of all simulation objects within a simulation and controls the execution of events by the respective objects.

- **SimulationEngineComponent:** A SimulationEngineComponent handles the scheduling and execution of events on an individual SimObject. All interaction between the application layer (SimObjects) and the SimulationEngine are performed through the SimulationEngineComponent as a communication layer.
Every SimObject should be associated with a SimulationEngineComponent.

- **Interrupt:** An interrupt is used to stop the execution of a particular event method within a SimObject before its scheduled execution time. The event is removed from the list of events scheduled to be executed. If an interrupt routine has been defined for the particular event, then that routine is executed.

- **Delegate:** A Delegate is the primary method of scheduling events on different SimObjects within this architecture. It encapsulates all the information required to make a method call for an event at the scheduled time.

- **SimulationForest:** A SimulationForest is a set of SimulationClusters, with the SimulationEngine within each SimulationCluster interacting with SimulationEngines of other SimulationClusters to manage simulation time.
Chapter III

INTERFACE SPECIFICATION FOR THE
DIESEL SEQUENTIAL MODEL

This chapter provides a complete description of the sequential component of the DIESEL behavioral model. Section 3.1 describes the interaction between different components within the DIESEL architectural model. Sections 3.2 to 3.9 provide the specification for various interfaces for the DIESEL sequential model. The names for different attributes and methods within an interface or class definition are based on recommended guidelines [41]. Although these guidelines are primarily for standard C++ programming, the same guidelines have been used here.

The complete DIESEL behavioral model has been implemented in C++ and is fully operational. All the structures described in this chapter have been implemented and extensively tested. Section 3.10 describes the implementation classes for the DIESEL Engine interface and also discusses event management within DIESEL. Section 3.11 discusses examples to demonstrate the operation and correctness of the behavioral model.

3.1 Interaction between components within DIESEL

A simulation involves different SimObjects interacting with the simulation executive for scheduling and executing events. The simulation executive for a sequential simulation has a single global SimulationCluster controlling the simulation. A SimObject interacts with the SimulationCluster in a controlled manner through the DIESEL Interface as shown in Figure 5. The DIESEL Interface requires that each

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SimulationEngineComponent should be registered with the SimulationEngine when it is initialized. It also requires that every SimObject be associated with a single SimulationEngineComponent. A SimulationEngineComponent handles the scheduling and execution of events on an individual SimObject. All interaction between the application layer (SimObjects) and the SimulationEngine are performed through the SimulationEngineComponent as a communication layer.

A SimObject can be associated with a SimulationEngineComponent in different ways allowing an application developer a considerable level of freedom to partition the simulation.

- A SimObject can inherit a SimulationEngineComponent as shown in Figure 6. This results in each SimObject having its own SimulationEngineComponent.
- A single global SimulationEngineComponent can exist for all SimObjects in the simulation as shown in Figure 7.
- A single static SimulationEngineComponent can exist for all SimObjects.
Figure 6. Inherited \textit{SimulationEngineComponent}

Figure 7. Global \textit{SimulationEngineComponent}

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belonging to a particular class as shown in Figure 8. All object instantiations of a class will in this case, share a common SimulationEngineComponent.

- SimulationEngineComponents can be dynamically created during simulation execution and SimObjects existing within the simulation can be partitioned across the created SimulationEngineComponents as shown in Figure 9. This provides a high level of flexibility for an application to define the model partitioning.

The different ways that a SimObject can be associated with a SimulationEngineComponent enables application developers to partition events that are expected to be generated within the simulation, in any suitable manner. A single global SimulationEngineComponent implies that all generated events are stored in a single event list even if they are to be executed on different SimObjects. In this case, a single SimulationEngineComponent is registered with the SimulationEngine, and the SimulationEngine calls it continuously to execute events in order of their timestamps.

Alternatively, each SimObject inheriting a separate SimulationEngineComponent implies that only events scheduled on that SimObject will be stored on that SimulationEngineComponent. This means that multiple event lists will exist within the simulation, with the number of events being distributed across the event lists. Moreover, the number of SimulationEngineComponents registered with the SimulationEngine depends on the number of SimObjects within the simulation. This reduces the overhead related with the number of events within each event list for any event management strategy compared to a central list with a single global SimulationEngineComponent, while increasing the overhead within a SimulationEngine to manage the increased number of SimulationEngineComponents.
Figure 8. Static SimulationEngineComponent

Figure 9. Dynamic SimulationEngineComponents
There is no particular association between a SimObject and a SimulationEngineComponent described earlier, that performs significantly better than any other type for all simulations and, therefore, can be recommended as the best possible association. The most likely scenario in any simulation would be the existence of all the types of associations described earlier, with the application developer choosing one that suits his purpose the best for different model components.

A SimObject can schedule events to be executed on itself or on other SimObjects. Events are always scheduled on the SimulationEngineComponent associated with the SimObject on which the event is to be executed.

3.2 DIESEL Engine Interfaces

This section defines interfaces to introduce initial SimObjects into the simulation, to schedule events to be executed on those SimObjects and to manage arguments to be used when the events are executed.

3.2.1 Delegate Interface

A Delegate is the primary method of scheduling events on different SimObjects within this architecture. A Delegate is the information required to execute an event at a future point in wallclock time. Since an event is not directly invoked but scheduled to be executed, sufficient information needs to be encapsulated within the Delegate to make a method call for an event at a later point in wallclock time. A Delegate is stored in the event list of the SimulationEngineComponent associated with the SimObject when it is scheduled. The Delegate is later invoked at its scheduled simulation time. The execution
of a Delegate can be cancelled before its execution. When an event is scheduled, an
interrupt routine can be specified along with a set of arguments to be used for the
interrupt routine. This interrupt routine is executed if and when the execution of the
Delegate is cancelled. A Delegate holds the following information:

- The SimObject on which the event method should be executed.
- The event method to be executed by the SimObject.
- The list of arguments to be used during the execution of the method at its
  scheduled execution time.
- The interrupt routine to be executed if the execution of the event method is
  interrupted before its scheduled execution time. (Optional)
- The list of arguments to be used during the execution of the interrupt method.
  (Optional)
- Priority of execution of event method relative to other event methods scheduled at
  the same simulation time. (Optional)

All Delegates are scheduled to be executed with next-to-highest priority among
events scheduled on a SimulationEngineComponent at the same simulation time, unless a
priority is specified for the Delegate. The highest priority for execution of events is
reserved for DIESEL. A priority can be specified for a Delegate to lower the priority of
the event relative to other Delegates scheduled at the same simulation time. If two
Delegates have the same priority, then the Delegates are executed in first-come-first-
served order.

The Delegate interface is shown in Figure 10. The StateSave and Replicable
interfaces, which the Delegate interface inherits, are discussed in Sections 3.4 and 3.5.
The "Invoke" method executes the event method within a Delegate with the specified list of arguments. The "Interrupt" method cancels the event method invocation within a Delegate, with the interrupt method being executed using the specified list of arguments for the interrupt.

3.2.2 ArgumentList Interface

Argument lists manage the arguments to be used when a scheduled event is executed by invoking a method within a SimObject. DIESEL supports three types of argument lists: ARGUMENT_FIFO, ARGUMENT_LIFO and ARGUMENT_INDEXED, with a single type allowed to be used with a particular argument list. The behavior of an argument list is defined by its type. Once a type is defined, arguments must be entered and retrieved in the same order. An argument list of type ARGUMENT_FIFO or ARGUMENT_LIFO does not require an index to be specified when arguments are added or accessed from the list. The arguments are removed in first-in-first-out manner for an ARGUMENT_FIFO list, and in last-in-first-out manner for an ARGUMENT_LIFO list. In the case of an ARGUMENT_INDEXED

Figure 10. Delegate Interface
list, an index needs to be specified each time an argument is added or accessed from the list. An ARGUMENT_INDEXED list can be accessed in any arbitrary order.

Arguments are provided either by reference in which a pointer is passed or by value where a pointer is again passed, but the value is copied to an internal data structure. Arguments that are passed by value while scheduling a method need to be accessed by value when the method is executed. The same is true for arguments passed by reference. A single return value can be assigned to the argument list before the list is used during the execution of the event method.

The ArgumentList interface is shown in Figure 11. The "SetArgument" and "GetArgument" methods are used to store and retrieve arguments within the argument list, while the "SetReturnArgument" and "GetReturnArgument" methods are used to access the return value within the list.

A drawback of the ArgumentList interface is that it stores no type information for an argument, just its size and a reference to it. The result is that there exists no type checking on the arguments when the arguments are used during Delegate invocation.
since the arguments are treated as a block of memory identified by a reference to the argument and the size of memory that the argument occupies. The type checking is assumed to be done by the application, when the arguments are retrieved by the application. The DIESEL behavioral model does not explicitly require support for type checking. This is a common approach in parallel programming languages [42] since it is difficult, if not impossible, to enforce type checking of arguments across networked computers. However, the lack of an explicit specification for type checking within the model does not preclude any implementations from using strong type checking on the arguments. An extension to the interface would be to store the type information of the argument when it is added to the ArgumentList, similar to the C# programming language. The type of the argument that would be application based can then be used to perform type checking when the arguments are stored in or retrieved from the ArgumentList.

3.2.3 SimulationEngineComponent Interface

The SimulationEngineComponent interface defines scheduling Delegates within the simulation. Each SimulationEngineComponent maintains its own list of Delegates to be executed on the associated SimObjects. The SimulationEngineComponent interface is shown in Figure 12. The "ScheduleEventAtTime" method is used to schedule a particular method in a SimObject at a specific simulation time, while the "ScheduleEventInTime" method is used to schedule a particular method in a SimObject after a given simulation time has elapsed. The "GetAveragePendingEventSetSize" and "GetAverageEventWaitTime" methods are used to gather various statistics associated with the event list within the SimulationEngineComponent.
### 3.3 DIESEL Delayed State Commitment Interfaces

An important component of the DIESEL model is the *Delayed State Commitment* for attributes of objects within a simulation. If one event modifies a state variable and then a second event executed at the same simulation time uses the same state variable, then the order in which the events are executed determines the final state of the state variable after that simulation time. The result of the second event can be different depending on whether the first event has been executed or not. For example,

- **$a$** is an event that assigns the value of variable "$y$" to "$x$" i.e. $a: x \leftarrow y$
- **$b$** is an event that assigns the value of variable "$z$" to "$y$" i.e. $b: y \leftarrow z$

If $a$ and $b$ are both scheduled for execution at simulation time $t$ and $a$ is executed before $b$, then the values of $x$ and $y$ after both events have been executed, i.e. at simulation time $(t+\delta)$ are:

$$x = y$$

If $a$ is executed after $b$, then the values of $x$ and $y$ at simulation time $(t+\delta)$ are:

$$y = z$$

One solution to the problem is to define the current state (CS) to be the set of state

---

**Figure 12. SimulationEngineComponent Interface**

<table>
<thead>
<tr>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>New()</code></td>
</tr>
<tr>
<td><code>Delete()</code></td>
</tr>
<tr>
<td><code>ScheduleEventAtTime</code></td>
</tr>
<tr>
<td><code>RescheduleEvent</code></td>
</tr>
<tr>
<td><code>InterruptEvent</code></td>
</tr>
<tr>
<td><code>GetEventTime</code></td>
</tr>
<tr>
<td><code>IsPendingEventSetEmpty</code></td>
</tr>
<tr>
<td><code>GetAveragePendingEventSetSize</code></td>
</tr>
<tr>
<td><code>GetAverageEventWaitTime</code></td>
</tr>
</tbody>
</table>

---

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variable values at a time \( (t-\delta) \) immediately prior to the current simulation time \( t \). Then the next state (NS) is defined as the resulting set of state variable values at a time immediately \( (t+\delta) \) after the current simulation time \( t \). The *Delayed State Commitment* presented here defines the NS state variable values \( (SV(NS)) \) to be solely a function of the CS state variable values \( (SV(CS)) \),

\[
SV(NS) = f(SV(CS))
\]

and not a function of the order of computation of events at simulation time \( t \).

Thus, the *Delayed State Commitment* ensures a more consistent behavior, by making all events act on the same value of the state variable and updating the state variable with its new value after all events have finished executing at that simulation time. *Delayed State Commitment* makes the next state of a simulation truly dependent on its current state, instead of the transition from the current state to the next state. An attribute can be initialized as a *DelayedCommit* attribute instead of a standard type like Integer, Double, Boolean, etc. with an initial value. When the value of the *DelayedCommit* attribute is changed, it is not updated immediately. The *DelayedCommit* attribute is added to a list maintained by the simulation executive. After all events scheduled to be executed at the current simulation time have been executed by their respective *SimObjects*, the simulation executive updates the value of every *DelayedCommit* attribute within its list with its new value. If there are multiple updates to a *DelayedCommit* attribute at the same simulation time, the last update to the attribute has permanence beyond that simulation time.

*Delayed State Commitment* does not resolve race conditions when two events modify the same state variable at the same simulation time. DIESEL currently does not
support the breaking of ties to resolve which event to execute first at a particular simulation time. Race conditions can be resolved by an application developer by lowering the priority of one event with respect to another event scheduled at the same simulation time when scheduling the delegate.

The **DelayedCommit** interface is shown in Figure 13. The "SetAttribute" and "GetAttribute" methods store and retrieve values of the **DelayedCommit** attribute.

### 3.4 DIESEL State Capture and Restore Interfaces

DIESEL has the ability to capture the state of the simulation at a desired simulation time. DIESEL can then resume execution of the simulation from that saved state at a later time. This ability to save the simulation state is an important tool for simulation analysis at a state other than its final state.

Every interface and class defined within DIESEL inherits the **StateSave** base interface shown in Figure 14. It is also required that every class or interface defined within an application should inherit the **StateSave** interface. The **StateSave** interface should be the first class in the inheritance tree of any user-defined class or interface.

During a state capture operation, DIESEL treats every object within the simulation as a **StateSave** object and calls its "ResolveReferences" method to resolve references for...
Figure 14. StateSave Interface

dynamically initialized attributes within the object. The "RestoreReferences" method restores these same references within an object during a state restore operation. The "Create" method creates an empty shell for a new object, and the "DuplicateState" copies the state of the original entity to the newly created entity during a state duplication process for a non-terminating state save operation. These methods should be defined for each class or interface that inherits the StateSave interface.

A state capture operation can be scheduled at an offset from the current simulation time, similar to a regular event, before the start of the simulation or at any point during simulation execution. When a state capture event is executed, all references within the simulation must be resolved so that they can be later restored. DIESEL resolves all references within the simulation executive, by calling "ResolveReferences" for all of its components. DIESEL then calls "ResolveReferences" for all entities within the application to resolve their references. After all references have been resolved, DIESEL writes the entire state of the simulation to an output file.

DIESEL has the ability to perform two types of state capture: terminating and non-terminating. A terminating state capture terminates the simulation after the state of the simulation has been captured and saved. A non-terminating state capture is identical to checkpointing the state of the simulation. During a non-terminating state capture, the entire simulation is duplicated by creating a clone for the simulation. Since references are resolved in place, a clone is created so the references can be resolved for the clone. The
The StateSaveSupport interface shown in Figure 15 provides various procedures for the simulation application to access the state save support infrastructure for both a state capture and state restore operation. Every event method within the application should be registered with the state save support infrastructure using the "RegisterEventMethod" procedure. The "GetReferenceID" method registers an object with the state save support infrastructure as well as retrieves the ID for a registered event method. The "GetReference" method restores the reference for an object registered with the state save support infrastructure as well as retrieves a registered event method.

3.5 DIESEL Base Interfaces

DIESEL defines base interfaces to support cloning of objects and programmatically changing the properties of an object during simulation execution. Each object that needs to be cloned should inherit the Replicable interface shown in Figure 16.
The "Clone" method creates a clone of the object and should be defined for every object that inherits the `Replicable` interface.

The `ProgrammaticEvent` interface shown in Figure 17 allows a user to schedule the modification or adjustment of the attributes of an object within a simulation. The "Modify" method modifies the attributes of an object, the "Adjust" method adjusts the attributes by a delta value (positive or negative), and the "Transfer" method copies properties of one object to another object. All these methods should be defined for every object that inherits the `ProgrammaticEvent` interface.

### 3.6 DIESEL Random Variate Model Interfaces

Any stochastic process has a certain amount of uncertainty associated with it. This uncertainty or randomness is introduced in a simulation through random numbers. Characteristics such as unknown delay times, process times, and inter-arrival times are often represented in a program in the form of random numbers. These random numbers
are generated using a random number generator. The generated random stream is not actually random in nature, but rather derived using a mathematical formula. The random stream is therefore said to be generating pseudo-random numbers. A random number generator consists of an algorithm to generate independent, identically distributed (IID) random numbers from the continuous distribution Uniform \((0, 1)\). A good random number generator should have a long cycle length, so that it would be highly unlikely that the pseudo-random numbers would be repeated with a simulation. A good random number generator should also have long sub-streams (sub-segments of the main random stream) for variance reduction.

Any existing random number generator can be used to generated random numbers from the Uniform distribution \((0, 1)\) [43, 44]. Random numbers from other distributions namely, Triangular, Unit, Normal Gamma, Beta, Weibull, etc, are derived by performing computations on the random number obtained from the random number generator with the computed random number still remaining random [45].

DIESEL supports complex distributions including the ability for a random number requested from a particular distribution during the execution of one event to be dependent on a previous request to the same distribution during the execution of a previous event. The capabilities include:

- **Single mode distributions**: A wide variety of distributions is available including Constant, Unit, Exponential, Triangular, Normal, Beta and Weibull.
- **Multimodal distributions**: Multimodal distributions support situations where with one probability, a given distribution is employed, and with another probability, a different distribution is employed.
**Ordered distributions:** Ordered distributions guarantee that subsequent events cannot get out of order by preventing the next event from completing prior to the current event.

**Blocking distributions:** A blocking distribution is a multimodal distribution where once a given mode is entered, all following calls will remain in that mode for a period defined by another distribution.

The `RNG` interface shown in Figure 18 encapsulates the functionality to generate integer random numbers, floating-point random numbers, and random numbers from specific distributions within DIESEL. The `AdvancedDistributions` interface is used to generate complex distributions within DIESEL, and supports the following modes of operation:

- **Multimodal:** This mode essentially provides a combination of two or more simple distributions that cannot be represented using a single simple distribution. An associated probability is used to choose between these different distributions.

- **Ordered:** The entities that arrive for a certain process complete the process and leave in a first-in-first-out order. No entity can complete its processing before a preceding entity, in this mode.

- **Blocked:** In any process, if an entity were delayed in its processing time, it would...
have a delaying effect on entities that follow. The delayed entity is a special case in the process and would be represented by a certain mode of the process.

- **Indexed**: Two or more distributions can be used to specify a process. An associated index is used to choose between the different distributions.

- **Work Shift Adjusted**: A random number obtained from a distribution can be adjusted by a work shift for a day within the simulation (0 < work shift ≤ 24). A start time can also be specified for a work day within the simulation.

The `AdvancedDistributions` interface is shown in Figure 19. The interface defines various methods to define a complex distribution and each distribution within a complex distribution. It also defines methods to generate random numbers from the specified distribution which can also be adjusted by a work shift time.

### 3.7 DIESEL Synchronization Interfaces

Certain processes within a simulation need to wait until some specified event or
another process has occurred. The time that the process needs to wait within the simulation is mostly unspecified; only the event that needs to occur for the process to proceed is specified. This is similar to a Petri network where input and output functions specify the transition to a finite set of places within the network. Triggers and joins are used within DIESEL to achieve the purpose of arbitrary synchronization within a simulation.

During a simulation, Delegates that need to wait for another event to be executed before being scheduled for execution are added to a trigger. When the event is executed and the trigger is fired, the trigger schedules the immediate execution of all Delegates waiting for the specified event to be executed on their associated SimObjects. A trigger can also have a collection of other triggers waiting for the parent trigger to fire as shown in Figure 20. DIESEL supports two types of triggers:

- **Trigger**: A Trigger can be set up to trigger an arbitrary number of Delegates and an arbitrary number of other Triggers. When a Trigger is triggered, it triggers all Delegates and other Triggers that have been registered with it until that instant. The Trigger interface is shown in Figure 21.
• **TriggerCounter**: A **TriggerCounter** can be set up to trigger a certain specified number of **Delegates**. When a **TriggerCounter** is triggered, it triggers all **Delegates** and other **TriggerCounters** that have been registered with it. If not all the specified number of **Delegates** have been added to it when it is triggered, all **Delegates** added to it after it has been triggered are immediately executed. The **TriggerCounter** interface is shown in Figure 22.

Certain processes within a simulation need to wait for multiple events to be executed before proceeding further. This is an extension of triggers where the process waits for a single event. DIESEL provides this capability by allowing multiple events to
control the execution of a single event method. The event method is executed only when all of the events controlling it have been executed. A join can also be set up with another
join representing one of the events to be executed as shown in Figure 23. There are two types of joins within the DIESEL architecture:

- **Join**: A *Join* is set up to wait for specific events to be satisfied. The *Join* interface is shown in Figure 24.

- **JoinCounter**: A *JoinCounter* is set up to wait for just a number of events to be executed. The *JoinCounter* interface is shown in Figure 25.

### 3.8 DIESEL Entity Management Interfaces

Simulations regularly need to group together similar entities for better management and to direct them towards specific processes within the simulation. Another common requirement of simulations is the notion of requesting and acquiring entities (resources) from a holding pool for a particular task and releasing them back to the pool after the task has been completed. When a request is made for a certain number of entities, the request should be immediately satisfied if the entities are available. If not, then the request should be queued and satisfied on first-come-first-served basis. If a new request should arrive when there are pending requests, then the new request should be queued. This should occur even if the number of entities requested by the second request may be less than the first waiting request and there may be enough entities to serve the second request but not the first request. This ensures that a request for a large number of entities cannot be blocked by numerous requests for fewer entities [46].

DIESEL provides the following interfaces for management of entities.

- **Set**: A *Set* is a container capable of maintaining a collection of arbitrary entities. The *Set* interface is shown in Figure 26.
• **FIFO**: A FIFO maintains a collection of arbitrary entities in a first-in-first-out manner. The FIFO interface is shown in Figure 27.

• **LIFO**: A LIFO maintains a collection of arbitrary entities in a last-in-first-out
manner (stack). The LIFO interface is shown in Figure 28.

- **BinaryTree**: A BinaryTree maintains a ranked collection of arbitrary entities. The BinaryTree interface is shown in Figure 29.

- **PriorityQueue**: A PriorityQueue maintains a collection of arbitrary entities based on a given priority. The PriorityQueue interface is shown in Figure 30.

- **QueueWithStatistics**: A QueueWithStatistics maintains a collection of arbitrary entities in a first-in-first-out manner, and tracks and reports various statistics associated with itself. The QueueWithStatistics interface is shown in Figure 31.

- **EntityCounter**: An EntityCounter holds a count of available entities, but does not hold actual entities. The availability of resources is indicated by a count within the EntityCounter. It satisfies requests on a first-come-first-served basis. The EntityCounter interface is shown in Figure 32.

- **EntityPool**: An EntityPool behaves identically to an EntityCounter except that it
holds a collection of actual available entities as shown in Figure 33.
3.9 DIESEL Sequential Simulation Executive

The DIESEL simulation executive provides various methods for an application to initialize a simulation and to control and track its progress. The `SequentialSimulationExecutive` interface is shown in Figure 34.

An application can be built using sequential DIESEL by first initializing the DIESEL simulation executive using the "StartSequentialSimulation" method. This method initializes a single global `SimulationCluster` for the simulation. It also initializes the state support infrastructure in case a state save operation (terminating or non-terminating) needs to be performed during simulation execution. The next step is to create `SimObjects` and their associated `SimulationEngineComponents` and to schedule events to be executed on the `SimObjects` on their respective `SimulationEngineComponents`. The simulation can then be executed using the "ExecuteSequentialSimulation" method. The "CleanUpSequentialSimulation" method cleans up all DIESEL structures after executing a sequential simulation. This basic procedure to build an application using DIESEL is shown in Figure 35. The "SetSimTime" and "GetSimTime" methods provide access to the current simulation time, while the "GetWallClockTime" method returns the current wallclock time within a sequential simulation.
3.10 Implementation Classes for the DIESEL Engine Interfaces

This section provides the class definitions for implementing the core functionality for the DIESEL simulation executive. A basic simulation executive can be built by implementing the class definitions in this section.

3.10.1 SimulationCluster Class

The SimulationCluster class shown in Figure 36, implements most of the functions required of the simulation executive described in Section 3.9. A single global SimulationCluster object is automatically initialized when the "StartSequentialSimulation" method within the simulation executive interface is invoked.
3.10.2 SimulationEngine Class

The SimulationEngine class shown in Figure 37 is used to implement each individual SimulationEngine within a SimulationCluster. It holds information about the state of the simulation as well as all the SimObjects within the simulation. It maintains a record of all SimulationEngineComponents in the simulation at the current simulation time within "SECWithMinEventTimeList". Each entry in the list has a reference to the
SimulationEngineComponent as well as the minimum execution time of all events for the SimulationEngineComponent. The "SECWithMinEventTimeList" list should ideally be sorted based on the minimum event execution time of the events within the SimulationEngineComponents so that the next SimulationEngineComponent to be allowed to execute events can be determined easily. Other techniques can be also be implemented to identify the SimulationEngineComponent with the minimum event execution time.

The SimulationEngine uses the "RunSimulation" method to execute the simulation. The method first calculates the current simulation time, which is the smallest execution time of all the events scheduled on all SimulationEngineComponents. If multiple events are found with the same least scheduled execution time, then the SimulationEngineComponents on which they are scheduled are added to the "currentList". If a state save event exists with a scheduled time less than the calculated current simulation time, then the state save event is executed and the state of the simulation is saved. If not, the SimulationEngine proceeds to inform each SimulationEngineComponent in turn to execute these events. While each SimulationEngineComponent is executing events at the current simulation time, the SimulationEngine populates and maintains the "delayedCommitList" that holds all DelayedCommits whose values have to be updated after executing all events scheduled to be executed at the current simulation time. After all SimulationEngineComponents have executed their events at the current simulation time, the SimulationEngine informs all DelayedCommits within its "delayedCommitList" to commit their values. This process is continued until no more events exist within the simulation.
The `SimulationEngineComponent` class shown in Figure 38 implements the `SimulationEngineComponent` interface. It maintains its own list of events to be executed on SimObjects associated with it within "eventManager". The "ExecuteSimTimeEvents" method is used to execute event(s) in "eventManager" that have an execution time equal to the current simulation time.

The `SimulationEngine` class interacts with the `SimulationEngineComponent` class using the "ExecuteSimTimeEvents" method. The `DelayedCommit` class interacts with the `SimulationEngineComponent` class using the "RegisterDelayedCommit" method. These methods are protected and are not accessible to the application layer.
3.10.4 EventManager Class

An important component of any simulation executive is the management of events scheduled to be executed on various objects within the simulation. Various issues need to be addressed to make event management as fast and efficient as possible so that the simulation runs more efficiently.

Event management within DIESEL is the shared responsibility of all SimulationEngineComponents within the simulation. The event management structure is distributed, i.e., each SimulationEngineComponent manages the collection of events to be executed by it for the duration of the simulation itself. This structure avoids a central event management mechanism within the SimulationEngine. There are advantages and disadvantages to avoiding a central structure; every SimulationEngineComponent does not need to communicate with the SimulationEngine, while scheduling an event within the simulation, and the size of a single list of events may not become too large. At a particular simulation time, the SimulationEngine pings each SimulationEngineComponent to execute all its events scheduled at that simulation time. However, an application developer, if he so chooses, can still have a single event list within the simulation, by initializing a single global SimulationEngineComponent for all SimObjects to schedule events on.

An EventManager within a SimulationEngineComponent encapsulates all the functionality to handle events to be executed by each SimObject. The EventManager stores all the events to be executed by the SimObject within "pendingEventSet". The "pendingEventSet" can be implemented in any manner from a simple linked list to a more complex structure, as long as it can interact with the EventManager and support all
functions to be performed by the `EventManager`.

It is a DIESEL design decision to keep event handling completely isolated within a `SimulationEngineComponent`. The `EventManager` has a reference to the `SimulationEngineComponent` that is associated with its parent `SimObject(s)` (Multiple `SimObjects` might be associated with the same `SimulationEngineComponent`). The "ExecuteMinEvents" method is used by the `SimulationEngineComponent` to ask the `EventManager` to execute all its events at the current simulation time. After it is done executing all events at the current simulation time, it returns the next lowest simulation time that it has events to be executed. This aids the `SimulationEngine` to know when to call the `SimulationEngineComponent` again to execute events. The `EventManager` class is shown in Figure 39.

Communication is allowed among various `SimObjects` in the simulation, as part of the standard interaction between `SimObjects`. Communication is allowed between a `SimObject` and its associated `SimulationEngineComponent` allowing a `SimObject` to schedule events on itself. Communication is also allowed between a `SimObject` and the
SimulationEngineComponents of other SimObjects, allowing a SimObject to schedule events to be executed on other SimObjects.

Different SimulationEngineComponents can communicate with each other directly or through the SimulationEngine both for event scheduling and time management. A SimulationEngineComponent can communicate with SimObjects associated with it for execution of events scheduled on the SimObjects. There can be no direct communication between a SimObject and the SimulationEngine. Communication between a SimObject and the SimulationEngine is only possible through the SimulationEngineComponent the SimObject it is associated with.

3.11 Examples

This section describes two examples to demonstrate the operation of the DIESEL behavioral model. The first example shows a simple timing diagram for event execution while the Dining Philosophers’ problem is implemented in the second example.

3.11.1 Timing diagram for execution of events

This example demonstrates the interaction between the SimulationEngine and SimulationEngineComponent classes and various SimObjects with an example scenario. The scenario shows the timing characteristics of the interaction between these classes. The exact order of execution of events scheduled at a particular simulation time depends on the strategy used to maintain the list of objects within the simulation, i.e. the strategy used to implement "SECWithMinEventTimeList" and "currentList" within the SimulationEngine class.
The following representation is used in the example scenario:

- Each SimObject ($SO_1 - SO_3$) is associated with a single SimulationEngineComponent ($SEC_1 - SEC_3$).
- Each entry in the table represents an event with its scheduled execution time as the first integer.
- [ ] represents the set of events created when the current event is executed.
- (a, b) provides details about the created event. "a" is the particular SimObject on which the event is to be scheduled, and "b" is the execution time of the event.

At SimTime = 0, the list of events to be executed by each SimulationEngineComponent is as shown in Figure 40(a).

At SimTime = 1, the SimulationEngine goes through the list of SimulationEngineComponents ($SEC_1 - SEC_3$) to find the minimum scheduled execution time of all events. SimulationEngineComponents are added to currentList within the SimulationEngine, if they have events scheduled at the minimum execution time. In this case, SEC$_1$ and SEC$_2$ are added to the CurrentList. The SimulationEngine then passes control to the first SimulationEngineComponent in the list, i.e., SEC$_1$ using the ExecuteSimTimeEvents method. SEC$_1$ executes its event and schedules two events, an event at SimTime = 3 on itself and an event at SimTime = 5 on SEC$_2$. SEC$_1$ then returns control back to the SimulationEngine, which in turn passes control to SEC$_2$ again, using the ExecuteSimTimeEvents method. SEC$_2$ executes its event and schedules a single event at SimTime = 6 on SO$_3$. SEC$_2$ then returns control back to the SimulationEngine. This process is shown in Figure 40(b).

At SimTime = 2, SEC$_3$ is added to the currentList. The SimulationEngine passes
control to SEC₃ again using the `ExecuteSimTimeEvents` method. SEC₃ executes its event and schedules two events, an event at SimTime = 5 on itself and an event at SimTime = 5 on SEC₂. SEC₃ then returns control back to the `SimulationEngine`. This process is shown.
Figure 40c. Timing Diagram: Event execution and events at SimTime = 2

Figure 40d. Timing Diagram: Event execution and events at SimTime = 3

in Figure 40(c).
At SimTime = 3, SEC₁ is added to the *currentList*. SEC₁ executes its event and schedules no events as shown in Figure 40(d).

At SimTime = 4, SEC₁ and SEC₃ are added to the *currentList*. The *SimulationEngine* passes control to SEC₁ again using the *ExecuteSimTimeEvents* method.
SEC₁ executes its event and schedules two events, an event at the current SimTime = 4 on SEC₂ and an event at SimTime = 6 on itself. Since an event has been scheduled at the current SimTime, SEC₂ calls the `SimulationEngine` to update its `currentList` using the `UpdateSECMinTime` method. SEC₂ has its minimum event execution time updated and

---

**Figure 40f.** Timing Diagram: Event execution and events at SimTime = 5

<table>
<thead>
<tr>
<th>SO₁</th>
<th>SO₂</th>
<th>SO₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 [-]</td>
<td>7 [-]</td>
<td>6 [-]</td>
</tr>
<tr>
<td>6 [-]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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has now been added to the currentList. SEC2 returns control to SEC1, which in turn returns control to the SimulationEngine. The SimulationEngine then passes control to the
next `SimObject` in the list, SEC3 which executes it event and schedules two events, an
event at SimTime = 6 on SEC1 and an event at SimTime = 7 on SEC2. SEC3 then returns
control to the `SimulationEngine`. The `SimulationEngine` then passes control to the next
`SimulationEngineComponent` in the list, i.e., SEC2. SEC2 now executes its event and then
returns control back to the `SimulationEngine`. This process is shown in Figure 40(e).

At SimTime = 5, SEC1, SEC2 and SEC3 are added to the `currentList`. The
execution of events proceeds as shown in Figure 40(f).

At SimTime = 6, SEC1 and SEC3 are added to the `currentList`. The execution of
events proceeds as shown in Figure 40(g).

At SimTime = 7, SEC2 is added to the `currentList`. The execution of events
proceeds as shown in Figure 40(h).

### 3.11.2 Dining Philosophers’ Problem

The dining philosophers’ problem is a common concurrency problem set forth by
Edsger Dijkstra [47] and demonstrates the problems associated with multi-process
synchronization. The dining philosophers’ problem has five philosophers seated at a
table. They spend their time alternating between thinking and eating a bowl of spaghetti
at the center of the table. Each philosopher requires a pair of chopsticks to eat the
spaghetti. However, there are only five chopsticks at the table, one between each pair of
philosophers. This implies that a maximum of two philosophers can be eating at any
point of time. After thinking for a certain time, each philosopher tries to eat, by picking
up one chopstick at a time. A potential for deadlock exists with adjoining philosophers
picking up the chopsticks on their same sides and then waiting for the other chopstick to
become available, without releasing the chopstick that they have already acquired. A possible solution to avoid such deadlock is that if only one chopstick is available, then the philosopher puts down the chopstick, waits for a while and then attempts to eat again.

There are various modifications of this basic problem. In this example, the basic problem has been modified to include a centralized resource pool. The chopsticks are placed at the center of the table in an EntityCounter beside the spaghetti. Each philosopher starts by thinking for a random amount of time. Then, the philosopher requests the EntityCounter for 2 chopsticks. If the chopsticks are available, then each philosopher eats for a random amount of time and then returns the chopsticks to the EntityCounter. The requests, if not satisfied immediately, are queued in the order that they are received. The aim is to demonstrate that no philosopher is starved by waiting an inordinately long time for the required chopsticks to eat.

The times that a philosopher spends thinking and eating are both random numbers
Graph 1. Time spent by Philosophers eating, thinking and waiting

from Uniform (0, 1). Figure 41 shows a snapshot of the time interval between SimTime = 1 and SimTime = 3. The thick lines shows a philosopher eating, a thin line shows a philosopher thinking, while the gaps show the time that a philosopher is waiting for chopsticks to start eating. The figure shows that not more than two philosophers are eating at the same instant of time. Graph 1 shows the percentage of time that each philosopher spends thinking, eating, and waiting for chopsticks to eat. The graph shows that each philosopher spends approximately the same amount of time eating and thinking for the entire duration of the simulation.
Chapter IV

INTERFACE SPECIFICATION FOR THE
DIESEL DISTRIBUTED MODEL

This chapter provides a complete description of the distributed component of the DIESEL behavioral model. The sequential model described in Chapter III describes the interfaces required to build a sequential application using a single SimulationCluster and details the communication between components within a SimulationCluster. The distributed model describes the initialization of multiple SimulationClusters and the required communication between different SimulationClusters to manage and execute a distributed simulation. Most of the interfaces described in Chapter III can be used with no changes within the distributed application. Some new interfaces are defined to support communication between SimulationClusters. An interface for a distributed simulation executive that creates SimulationClusters, registers SimulationClusters and application objects, and executes the distributed simulation is specified. This interface can be extended to support different synchronization algorithms and communication mechanisms.

4.1 Interaction between components within DIESEL

A distributed simulation involves SimObjects residing on different SimulationClusters interacting with each other. This collection of SimulationClusters is known as a SimulationForest and is shown in Figure 42. These SimulationClusters can exist on the same processor or different processors depending on the number of
processors used for the simulation.

The first step in building a distributed application is to create the required number of SimulationClusters on the available processors and make the simulation executive aware of each of them. An application can also be built using a single SimulationCluster with the extra overhead associated with SimulationCluster interconnection and management. A simulation executive should exist on each processor in the simulation and hold the location of all SimulationClusters on all processors in the simulation. A simulation executive receives messages from another processor and relays it to the appropriate SimulationCluster existing on that processor. This registry of processors within every simulation executive is shown in Figure 43.

A distributed simulation differs from a sequential simulation in the manner a
<table>
<thead>
<tr>
<th>SimulationCluster ID</th>
<th>Processor Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>MATRIX-1</td>
</tr>
<tr>
<td>1</td>
<td>MATRIX-2</td>
</tr>
<tr>
<td>2</td>
<td>MATRIX-2</td>
</tr>
<tr>
<td>3</td>
<td>MATRIX-1</td>
</tr>
</tbody>
</table>

**Figure 43.** Registry of processors within simulation executive

*SimObject* accesses other *SimObjects*. *SimObjects* within a sequential simulation access other *SimObjects* directly, since they exist on a single processor for the entire simulation. *SimObjects* within a distributed simulation, on the other hand, can exist within different *SimulationClusters* and on different processors. A *SimObject* has no knowledge of the location of another *SimObject* and, therefore, cannot access it directly.

A distributed application implemented with DIESEL is required to generate unique references for all *SimObjects* and other objects that are created by the application and interact with each other. The unique references can be generated by DIESEL or by the application. This unique reference is required to be public knowledge across the simulation for an object within one *SimulationCluster* to refer to an object from another *SimulationCluster*. Publishing of this reference is currently left to the application. As an alternative, HLA [36, 37, 38] manages its objects by publishing shareable federation objects in the Federation Object Model (FOM) and Simulation Object Model (SOM). An object that is completely private to another object and interacts with no other object does not need a unique reference, since no other application object will ever attempt to access it.

Each unique reference that is generated for an application object must be registered with the simulation executive by the application with the following
<table>
<thead>
<tr>
<th>Unique Reference</th>
<th>SimulationCluster ID</th>
<th>Object</th>
<th>SimulationEngine Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>NULL</td>
<td>NULL</td>
</tr>
<tr>
<td>22</td>
<td>1</td>
<td>Obj1</td>
<td>SEC1</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>Obj2</td>
<td>SEC2</td>
</tr>
<tr>
<td>13</td>
<td>0</td>
<td>NULL</td>
<td>NULL</td>
</tr>
</tbody>
</table>

**Figure 44.** Registry of objects within a *SimulationCluster*

information:

- the unique reference
- the application object
- the *SimulationCluster* on which the application object has been created
- the associated *SimulationEngineComponent* if the object is a *SimObject*

The simulation executive informs each *SimulationCluster* of the new object that has been registered. Each *SimulationCluster* has a registry of all registered objects along with their unique references as shown in Figure 44. The object registry is shared among all *SimulationClusters* and is synchronized every time a reference is created or removed from an object registry within any *SimulationCluster*. The registry has a valid entry for each object that has been created on that *SimulationCluster* and a null value in the object and *SimulationEngineComponent* fields for objects on other *SimulationClusters*.

Each application object when requiring access to another object, asks its parent *SimulationCluster* to resolve the reference of the object and pass the required data to that object as shown in Figure 45. The *SimulationCluster* resolves all references by accessing its object registry. If the object exists within the *SimulationCluster*, it passes the message to the object directly. If the object does not exist within the *SimulationCluster*, it asks the
simulation executive resident on the processor it exists on to relay the message to the appropriate SimulationCluster, which holds the object that is being accessed.

There is an overhead attached to the access between application objects within the distributed model. Every application object needs to use its parent SimulationCluster as an intermediary to access another object, irrespective of the location of both objects. This is different from the direct access method within the sequential model where objects can access each other directly. However, this type of access does not require the application to know what type of access it is requesting, local or remote, thereby making it completely transparent to the application.

The simulation executive, when asked to relay a message, determines which SimulationCluster holds the object that is being asked for. If the SimulationCluster exists on the current processor, it relays the message directly to the SimulationCluster. If the
SimulationCluster exists on another processor, then the simulation executive asks the communication mechanism to transmit the message to the appropriate processor. The simulation executive on the destination processor then relays the message to the appropriate SimulationCluster. This process is shown in Figure 46.

A reliable communication mechanism is assumed between processors such that no messages passed between processors are lost. However, no assumption is made in the order of delivery of the messages, i.e. that the messages are received in the order that they were sent. Messages can also be bunched together depending on the communication protocol. Different communication mechanisms exist in literature from as simple as socket communication [48] to more advanced protocols such as Message Passing Interface (MPI) [49], Distributed Component Object Model (DCOM) from Microsoft©
Corporation [50, 52], Common Object Request Broker Architecture (CORBA) [51, 52] from Object Management Group (OMG), and Java/Remote Method Invocation (Java/RMI) from JavaSoft [52].

4.2 Extensions to the DIESEL Interface

All interfaces defined in Chapter III can be used with no modifications unless a modified interface has been defined in this section. Most interfaces require minimal or no changes to be used within the distributed model. The distributed model extends rather than make radical changes to the sequential interface. The SimulationEngineComponent interface described in Section 3.2.3 requires a new parameter, specifying the SimulationCluster it belongs to while being initialized. This is shown in Figure 47.

A new interface needs to be defined to support the distributed model. The SimulationCluster interface, shown in Figure 48, initializes a new SimulationCluster and manages all objects that are created within the SimulationCluster. An application uses the "ScheduleEvent" method to schedule an event to be executed on another SimObject.

4.3 DIESEL Distributed Simulation Executive

The DistributedSimulationExecutive interface shown in Figure 49 has various methods to initialize a distributed simulation and to create and register SimulationClusters. The interface uses the "EventsExist" and "ExecuteDistributedSimulation" to execute the simulation. The "EventsExist" method determines if any SimulationCluster has at least one event to be executed to continue simulation execution, while the "ExecuteDistributedSimulation" method executes the
simulation with the specified synchronization algorithm. The application can use the "GetUniqueReference" method to specify a unique reference for an object or SimObject.

The application uses the "RegisterObject" method to register a new object, its unique

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reference, and its location with the simulation executive. The "RemoveObject" method is used to migrate the object to a new SimulationCluster. The interface can be extended with new methods to support different synchronization algorithms for a distributed simulation. Two synchronization algorithms are included within the Distributed DIESEL interface to manage time within the distributed model. The different methods to manage the execution of the simulation using these algorithms are discussed in the following subsections.

4.3.1 Barrier Synchronization Algorithm

The barrier synchronization algorithm described in Chapter I is included to demonstrate that the interface can support conservative algorithms within PDES. The first step is to calculate the lookahead within the application, which is different for each application [1]. Then the "ExecuteDistributedSimulation" method calculates the next set of safe events to process and executes the simulation as shown by the following algorithm:

```plaintext
Procedure
begin
while (EventsExist())
    minTime = minimum event execution time of all SimulationClusters
    for all SimulationClusters
        execute events with timestamp <= (minTime + lookahead)
end
```

4.3.2 Time Warp Paradigm

The Time Warp paradigm described in Chapter I is implemented to demonstrate how the interface supports optimistic algorithms within PDES. A Time Warp Logical Process (TWLP) can be mapped onto DIESEL in the following ways:
- Each SimObject can be treated as a TWLP. In this case, its associated SimulationEngineComponent would be part of the TWLP and could be part of multiple TWLPs. This would involve a SimulationEngineComponent being distributed across processors, if TWLPs are on different processors.

- Each SimulationEngineComponent can be treated as a TWLP. In this case, all SimObjects associated with it would be part of the same TWLP.

- A collection of SimulationEngineComponents can be treated as a TWLP. In this case, all SimObjects associated with them would be part of the same TWLP.

- Each SimulationCluster can be treated as a TWLP. In this case, all SimulationEngineComponents (and associated SimObjects) would be part of the same TWLP.

- A collection of SimulationClusters can be treated as a TWLP.

The selected mapping should have an input queue to receive messages from other TWLPs and an output queue to store anti-messages of messages sent to other TWLPs. It should also have the ability to save its state so that it can perform rollback in case a message arrives with a timestamp in its past.

Avril and Tropper [53] describe another technique in which TWLPs are grouped together into clusters (different from a SimulationCluster). The technique then identifies each TWLP by its name and the cluster it belongs to and assigns an input queue and output queue to each cluster instead of each TWLP. This grouping reduces some of the overhead required of each TWLP in Time Warp by associating the overhead of managing the input and output queues with the cluster rather than each individual TWLP. This technique can be mapped onto DIESEL by defining an interface for a
SimulationClusterGroup (collection of related SimulationClusters) and then assigning the input and output queues to the SimulationClusterGroup.

4.4 Support Classes for the DIESEL Distributed Interface

This section provides definitions for support classes within the distributed DIESEL simulation executive to support a distributed simulation and the two synchronization algorithms described in the previous section. The application interfaces defined in Sections 4.2 and 4.3 cannot be modified. This section describes the internal support to the interface and has been defined so that the same structure can be used for different communication mechanisms. The classes defined here can be used within an implementation or new classes can be defined and implemented to support the interface.

4.4.1 ObjectRegistry Class

The ObjectRegistry class, shown in Figure 50 implements the registry of all application objects within a SimulationCluster. It stores information about all objects that have been registered with the simulation executive by the application. An ObjectRegistry exists within each SimulationCluster and holds unique references for all application objects and a reference to the object if it exists on the SimulationCluster that the ObjectRegistry is associated with. If the application object exists on another SimulationCluster, then the object field has a null value for that object within the current ObjectRegistry. An ObjectRegistry also holds a reference to the associated SimulationEngineComponent if the registered object is a SimObject.
4.4.2 Message Class

The Message class is used to communicate between SimulationClusters for both synchronization algorithms. The Message class shown in Figure 51 encapsulates all information required for objects to communicate with each other in a distributed simulation. It supports one object scheduling an event method to be executed on a SimObject residing on a different SimulationCluster. Once the message has been relayed to the appropriate SimulationCluster, the SimulationCluster uses the "GetReference" and "ScheduleEvent" methods to schedule the event for execution.

4.4.3 MessageQueue Class

The MessageQueue class shown in Figure 52 implements the input and output queues within a SimulationCluster for the Time Warp implementation. When a message or an anti-message is added to the MessageQueue, the MessageQueue first ascertains if
the message can be annihilated. If not, it is added in timestamp order. The MessageQueue also stores all processed messages until a GVT computation by the simulation executive proclaims that it is safe to dispose processed messages older than the GVT. The MessageQueue class can also capture various statistics associated with itself.

4.4.4 StateSaveQueue Class

The StateSaveQueue class implements the ability to store the saved states of a SimulationCluster for the Time Warp implementation as shown in Figure 53. It retrieves a state older than a specific simulation time when a rollback needs to be performed. It disposes old states older than the GVT, once it is notified of a GVT computation.

4.5 Analytical Support within DIESEL

DIESEL provides considerable amount of support to analyze an application. This
support is built in to the \textit{SimulationEngineComponent} and \textit{SimulationCluster} interfaces. The "GetAveragePendingEventSetSize" and "GetAverageEventWaitTime" methods are used to gather various statistics associated with the pending event list within a single \textit{SimulationEngineComponent}. The "GetAveragePendingEventSetSize" method captures the average length of the pending event list within a \textit{SimulationEngineComponent} for the duration of the simulation. This helps to determine if there are too many \textit{SimObjects} associated with the \textit{SimulationEngineComponent}, and whether the \textit{SimObjects} should be associated with new or other existing \textit{SimulationEngineComponents}.

Similarly, the "GetAveragePendingEventSetSize" method within the \textit{SimulationCluster} interface captures the average size of the pending event list within each \textit{SimulationCluster}. This is an average of the size of the pending event lists of all \textit{SimulationEngineComponents} within a \textit{SimulationCluster}. This allows the application developer to analyze the current partitioning of the simulation model by demonstrating if a particular model component is being overloaded with work, while other components are underused within the simulation, thereby helping to develop better model partitions. The "GetAverageMessageQueueSize" method captures the average queue size of the communication buffer. In a distributed simulation, it is desirable to keep communication among processors at a minimum. This involves keeping \textit{SimulationClusters} that interact with each other a lot on the same processor to avoid communication delays.

The interfaces specified in this chapter can be used to build a distributed application. The application can be executed using either a conservative or an optimistic synchronization algorithm. Different synchronization algorithms can be evaluated by implementing these algorithms within the interfaces provided. Various communication
mechanisms can also be used to connect the different SimulationClusters and networked processors within the distributed simulation.
Chapter V

CASE STUDIES

This chapter describes how an implementation of the DIESEL behavioral model can be used for various purposes, both at the core simulation executive level as well as the application development level. An implementation of the DIESEL behavioral model has been developed in C++ as a proof-of-concept. All case studies described in this chapter have been conducted using the DIESEL C++ implementation.

A comparison study of various event management strategies is described in Section 5.1. A study demonstrating the number of messages passed among SimulationClusters on a distributed system is shown in Section 5.2. A comparison of the performance of optimistic and conservative synchronization algorithms within the same application is also discussed. The use of DIESEL in building a high-level application model is described in Section 5.3. Platform-independence of the DIESEL model is discussed in Section 5.4.

5.1 Event Management Study

The insertion of events into a pending event list and the removal of the event(s) with the shortest timestamp for execution should be as fast as possible. The insertion of events in time-sorted order makes the retrieval of the event with the shortest timestamp an $O(1)$ operation. Various techniques for managing the pending event list such as linear lists, binary trees, and priority queues exist in literature [54 – 61]. This section describes the event management structure used in the DIESEL implementation, which has been
implemented both as a linear and a non-linear list. Various strategies are described to make the insertion of events into the pending event list as close to an $O(1)$ operation as possible. A comparison study is then performed on the performance of these strategies. The comparison of these strategies on a single platform is made possible since the DIESEL behavioral model does not specify or promote a single method; the standardized interface of DIESEL, in fact, encourages employment and comparison of diverse strategies, as long as they satisfy the expected behavior of the EventManager within a SimulationEngineComponent.

5.1.1 Implementation of the Event Management Structure

The sequential DIESEL behavioral model described in Chapter III is implemented using the C++ programming language on a Win32 hardware platform. The DIESEL C++ implementation is fully representative of the behavioral model and includes the full functionality described in Chapters II and III. The C++ implementation uses the classes defined in Section 3.10 as the basic building blocks. Functionality has been added to these basic classes and new classes have been defined to satisfy the behavior expected of each component.

The EventManager class holds the collection of events to be executed on each SimulationEngineComponent. The event management structure for this study has been implemented both as a linear list and a non-linear list. Four different strategies are used to insert an event into a linear list within the EventManager. A binary tree structure is used to implement a non-linear list within the EventManager.
**EventList**

An EventList is a linked list of events to be executed at a particular simulation time. The EventList is sorted based on relative priority of the events within the list, as shown in Figure 54. An EventListNode wraps an interface around each event to be integrated into the EventList. Each EventListNode is a unique event to be executed. The class declarations for an EventListNode and EventList are shown in Figures 55.

**LinearPendingEventSet**

A LinearPendingEventSet is a linked list of distinct simulation times, i.e. the scheduled execution times for events to be executed by the SimObject. A LinearPendingEventSet is shown in Figure 56. The "currentSimTime" and
"currentSimTimeList" attributes are used to manage events whose timestamps are the same as the current simulation time. The "ExecuteMinEvents" method within the EventManager removes the first LinearPendingEventSetNode and assigns its EventList to "currentSimTimeList". When an event is encountered with a timestamp equal to "currentSimTime", it is added to "currentSimTimeList", thereby avoiding inserting the event into the main list. When "currentSimTimeList" becomes empty, the SimObject has no more events to be executed at the current simulation time and returns the simulation time associated with its first LinearPendingEventSetNode to the SimulationEngine, to notify the SimulationEngine of the next minimum execution time of its remaining events. This information helps the SimulationEngine determine which SimulationEngineComponent to ask to execute its events next.

A LinearPendingEventSetNode wraps an interface around each simulation time to be integrated into the LinearPendingEventSet. Each LinearPendingEventSetNode is a
unique simulation time and has at least one event to be executed at that simulation time by that `SimObject`. The class declarations for a `LinearPendingEventSetNode` and `LinearPendingEventSet` are shown in Figure 57.

### NonLinearPendingEventSet

A `NonLinearPendingEventSet` is implemented as a binary tree, where the nodes in the tree are the simulation times of events. Each node, called a `NonLinearPendingEventSetNode`, has a list of events to be executed at that time, similar to a `LinearPendingEventSet` described earlier. The "Rank" method is used to sort the
nodes based on their simulation times, while inserting an event into the binary tree. The class declarations for a NonLinearPendingEventSetNode and NonLinearPendingEventSet are shown in Figure 58.

The event management structure here is used to study different strategies for inserting an event into the pending event list, both linear and non-linear. These strategies involve starting the search for an appropriate insertion point at different points in the event list and are described in the next sub-sections.

5.1.2 Event Insertion Strategies for a LinearPendingEventSet

Four strategies for inserting an event within the LinearPendingEventSet are described below. The first two strategies involve starting the search for an appropriate node at the head and tail of the list respectively, i.e., either from the "firstNode" of the
LinearPendingEventSet or the "lastNode" of the LinearPendingEventSet. The remaining two strategies involve starting the search from some middle node in the list that is maintained within the list.

**Insert from front of linear list**

The search for an appropriate node to insert a new event starts from the first existing LinearPendingEventSetNode in the list. This is the most basic strategy and might be enough for a LinearPendingEventSet with a limited number of events. However, with a large number of events, it will take the maximum average time among all the strategies discussed here, since it is a fair assumption that new events will have timestamps closer to the tail of the list. This strategy starts the search at the head of the list and would therefore have to search through most of the nodes to find an appropriate insertion point.

**Insert from rear of linear list:**

The search for an appropriate node to insert a new event starts from the last existing LinearPendingEventSetNode in the list. This strategy is better than the previous strategy because it is a fair assumption that an appropriate insertion point will be at the tail of the list. This strategy is again appropriate for a limited number of events, where the overhead of maintaining and adjusting a middle node might increase the execution time without providing any substantial benefits.

**Insert from a midpoint in linear list based on the number of events**

The search for an appropriate node to insert a new event starts from a midpoint in
the list. The midpoint is a node in the list such that approximately half the total number of events is above it and half below it, i.e., it is based on the number of the total events in the list. This strategy is based on the assumption that since previous events have been added to a particular node, there is a very high probability that a new event will be added to the same node. Thus, this strategy searches a sub list that contains half the total number of events in the list.

The "totalEvents", "middleEvent" attributes, and the "AdjustMiddleNodeSingle" and "AdjustMiddleNodeMultiple" methods within the LinearPendingEventSet class are used to adjust the midpoint. The "AdjustMiddleNodeSingle" method is used to adjust the middle node while adding or removing a single event from the list, where an offset of +1 indicates adding an event and -1 indicates removing an event. The "AdjustMiddleNodeMultiple" method is used to adjust the middle node when the top node (with multiple events) is removed for executing events at the current simulation time. The "nEvents", "nEventAbove", and "nEventsBelow" attributes within the LinearPendingEventSetNode class track the number of events relevant to each node.

The "shift" attribute within the LinearPendingEventSet indicates a variable bias (between 0.0 and 1.0) towards the rear end of the sub list. A "shift" of 1.0 starts the search at the head of the sub list, while a value of 0.0 starts the shift at the tail of the sub list. The lower the value of "shift" the more likely that the search for an appropriate node to insert an event will start at the tail end of the sub list and continue upward towards the head of the list. The middle node needs to be adjusted after each new event is added and after the top node is removed while executing events with the minimum execution time.

The algorithm for inserting a new event into the list is:

Note:
currentTime = simTime associated with first node in list
lastTime = simTime associated with last node in list
midTime = simTime associated with middle node
newTime = simTime of new event to be added
shift = bias towards either the front or the rear of the sublist.

Preconditions:
None.
Post-conditions:
1) Event is added to appropriate node.

Procedure
begin
  if (newTime < firstTime)
    add event to a new node at the head of the list
  else if (newTime = firstTime)
    add event to node at the head of the list
  else if (newTime > lastTime)
    add event to a new node at the tail of the list
  else if (newTime = lastTime)
    add event to node at the tail of the list
  else
    if (newTime <= midTime)
      if ((time > (((midTime-firstTime)*shift)+firstTime))
        look up from middle node to insert event
      else
        look down from first node to insert event
    else
      if (time > (((lastTime-midTime)*shift)+midTime))
        look up from last node to insert event
      else
        look down from middle node to insert event
  Adjust the middle node
end

The algorithm for adjusting the middle node after adding an event is shown below:

Preconditions:
1) nEvents for the node the event is added to has been incremented by 1
2) totalEvents has been incremented by 1
Post-conditions:
1) middleEvent is adjusted to appropriate value
2) middleNode is adjusted to appropriate node

Procedure
begin
  newMiddleEvent = totalEvents DIV 2
  if (totalEvents MOD 2 != 0)
    newMiddleEvent++
  if (eventAdded.simTime < middleNode.simTime)
    middleNode.nEventsAbove++
  else
    middleNode.nEventsBelow++
end
middleNode.nEventsBelow++

if (newMiddleEvent > middleNode.nEventsAbove) AND
    (newMiddleEvents <= (middleNode.nEventsAbove +
    middleNode.nEvents))
    [no change in middleNode]
else
    if (eventAdded.simTime < middleNode.simTime)
        newMiddleNode = middleNode.topNode
        newMiddleNode.nEventsAbove = middleNode.nEventsAbove -
            newMiddleNode.nEvents
        newMiddleNode.nEventsBelow = middleNode.nEvents +
            middleNode.nEventsBelow
    else
        newMiddleNode = middleNode.bottomNode
        newMiddleNode.nEventsAbove = middleNode->nEvents +
            middleNode->nEventsAbove
        newMiddleNode.nEventsBelow = middleNode->nEventsBelow -
            newMiddleNode->nEvents
    middleNode = newMiddleNode
    middleEvent = newMiddleEvent
end

The algorithm for adjusting the middle node after removing events is as shown below:

Preconditions:
1) nEvents for the node the event(s) have been removed from
    has been decremented by appropriate value
2) totalEvents for the LinearPendingEventSet has been
    decremented by appropriate value
Post-conditions:
1) middleEvent is adjusted to appropriate value
2) middleNode is adjusted to appropriate node

Procedure
  begin
    begin
    newMiddleEvent = totalEvents DIV 2
    if (totalEvents MOD 2 != 0)
        newMiddleEvent++
    if (eventRemoved.simTime < middleNode.simTime)
        middleNode.nEventsAbove = middleNode.nEventsAbove -
            nEventsRemoved
    else
        middleNode.nEventsBelow = middleNode.nEventsBelow -
            nEventsRemoved
    while NOT ((newMiddleEvent > middleNode.nEventsAbove) AND
        (newMiddleEvents <= (middleNode.nEventsAbove +
        middleNode.nEvents))]
        if (eventRemoved.simTime <= middleNode.simTime)
            newMiddleNode = middleNode.bottomNode
            newMiddleNode.nEventsAbove = middleNode->nEvents +
                middleNode->nEventsAbove
            newMiddleNode.nEventsBelow = middleNode->nEventsBelow
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- newMiddleNode->nEvents
else
newMiddleNode = middleNode.topNode
newMiddleNode.nEventsAbove = middleNode.nEventsAbove
- newMiddleNode.nEvents
newMiddleNode.nEventsBelow = middleNode.nEvents +
middleNode.nEventsBelow
middleNode = newMiddleNode
middleEvent = newMiddleEvent
end

Insert from a midpoint in linear list based on the time of events

The search for an appropriate node to insert a new event starts from a midpoint in
the LinearPendingEventSet. The midpoint is a node in the list such that exactly half the
nodes are above it and half below it, i.e., it is based on the times of the existing nodes in
the list. Thus, this strategy searches a sub list that has half the number of nodes compared
to the original list.

The "nNodes", "middleNodePosition", "nodeAdded", and "totalEvents" attributes
and the "AdjustMiddleNodeOnAdd" method within the LinearPendingEventSet class are
used to adjust the midpoint of the list after inserting an event. While adding an event to
the LinearPendingEventSet, the middle node needs to be adjusted only if a new node is
created, i.e., "nodeAdded" value is TRUE. The "AdjustMiddleNodeOnRemove" method
adjusts the midpoint after event(s) are removed from the list.

The "shift" attribute is used in the same manner as the previous strategy, and the
algorithm for inserting a new event into the list based on this strategy is the same as the
previous strategy. The algorithm for adjusting the middle node after adding an event is
shown below:

Preconditions:
1) new node has been created and event added to it
Post-conditions:
1) middleNodePosition value is adjusted to appropriate value
2) middleNode is adjusted to appropriate node
Procedure
begin
    newMiddleNodePosition = nNodes DIV 2
    if (nNodes MOD 2 != 0)
        newMiddleNodePosition++

    if (newMiddleNodePosition NOT EQUAL TO middleNodePosition)
        if (time > midTime)
            middleNode = middleNode->bottomNode
        else
            middleNode = middleNode->topNode
    middleNodePosition = newMiddleNodePosition
end

The algorithm for adjusting the middle node after removing events is shown below:

Preconditions:
1) new node has been removed
Post-conditions:
1) middleNodePosition value is adjusted to appropriate value
2) middleNode is adjusted to appropriate node

Procedure
begin
    newMiddleNodePosition = nNodes DIV 2
    if (nNodes MOD 2 != 0)
        newMiddleNodePosition++

    if (newMiddleNodePosition NOT EQUAL TO middleNodePosition)
        if (time < midTime)
            middleNode = middleNode->bottomNode
        else
            middleNode = middleNode->topNode
    middleNodePosition = newMiddleNodePosition
end

The last two strategies described here might perform similarly for most simulations. The strategy based on the number of events might perform better when there are simultaneous events, i.e., when multiple events are scheduled at the same discrete simulation times. This implies that new events are added to the same nodes and, therefore, the insertion procedure does not involve searching through a large number of nodes. On the other hand, the strategy based on the time of events might perform better when events are scheduled at distinct simulation times, with not many simultaneous
events during the simulation.

5.1.3 Timing Results

The event insertion strategies are tested using an example of a snooker table. The snooker table is spatially divided into regions called BallGroups as shown Figure 59, where each BallGroup constitutes a SimObject. Each BallGroup is assigned a certain number of balls and the balls are assigned initial velocities and positions within the region. The balls then move between regions or collide with the edges of the table, with both actions generating events within the same SimObject (if the ball collides with an edge) or on an adjoining SimObject (if the ball crosses into an adjoining BallGroup). The collisions between the balls themselves are ignored for this study.

The insertion strategies are tested by assigning initial values to the X-component and Y-component of the velocities of each ball from the following distributions:

- **Constant**
- **Exponential**: with mean values of 0.3, 0.5, and 0.7.
- **Triangular**: with minimum = 0, maximum = 1, and mid values of 0.25, 0.5, 0.75.
• **Normal**: with $\mu = 0.1, 0.2, 0.3$.

• **Beta**: with $\alpha_1 = 0.8, 1.5, 2, 5$ and $\alpha_2 = 0.8, 1.5, 2, 5$.

Assigning values from these distributions varies the velocities of each ball and in turn varies the time taken by the ball to either cross a BallGroup or collide with an edge. This generates events with timestamps mirroring the parent distribution that need to be added to the list. The aim is to calculate which of the strategies works best for all the distributions.

Readings are obtained by assigning 1000 balls each to 6 regions on the snooker table, and then varying the number of events to be executed between 100000 – 5000000. It is assumed that the time to execute the event is the same for all readings and the difference between execution times is due to the insertion times. The readings are normalized for each set of readings and then by calculating the average for each type of distribution. The readings for the insertion strategies based on the time of events and the number of events are taken for different shifts between 0.0 and 1.0. These readings indicate that a shift of 0.2 works best for the maximum number of distributions, implying that the search for the insertion point starts towards the tail end of the sub list. Therefore a shift of 0.2 is used in all subsequent graphs for comparison with the other two strategies.

Graph 2 shows the average execution time for a single event using each strategy described previously. The implementation of the pending event set as a binary tree proves to be the best strategy for all distributions except a Beta distribution. Graph 3 shows the graph of the average number of nodes searched to insert a single event using each strategy. The insertion of an event into a binary tree requires the least number of nodes to be searched. The number of nodes searched for the insertion strategies based on the time
Graph 2. Average execution time for different distributions

Graph 3. Average nodes searched for different distributions

of events and the number of events are identical due to the lack of many simultaneous events. In the absence of any simultaneous events, the insertion strategies based on the time and number of events are identical. The insertion strategies from the front and rear of the list perform the worst among all the strategies due to the large number of events in
the study.

5.2 Distributed Simulation Study

In a distributed simulation, SimulationClusters communicate with each other by transmitting messages between each other. It is desirable to reduce network traffic by keeping communication among processors at a minimum. This involves keeping SimulationClusters that communicate with each other a lot on the same processor. This section describes an example to study the number of messages transmitted among SimulationClusters, when the application model is mapped to different organizations of SimulationClusters. The purpose of the study is to identify an organization that results in the least number of messages among SimulationClusters.

5.2.1 Distributed Implementation

The distributed DIESEL behavioral model described in Chapter IV is implemented using the C++ programming language on a Win32 hardware platform. The DIESEL C++ implementation is fully representative of the behavioral model and includes the full functionality described in Chapter IV. The sequential implementation is extended to support distributed simulations. In particular, support for the barrier synchronization and Time Warp synchronization algorithms has been added to the distributed implementation.

A set of procedures have been defined under the DistributedExecutiveSupport interface, shown in Figure 60, to support the distributed simulation executive to execute the simulation using the specified synchronization algorithm. These procedures are
implementation-specific and are transparent to the application. A distributed simulation involves SimulationClusters transmitting and receiving messages between each other. If a SimulationCluster needs to send a message to another SimulationCluster, it calls the "RelayMessage" procedure to send the message to the appropriate SimulationCluster. SimulationClusters on the same processor are connected by the simulation executive on the processor, while simulation executives on different processors are connected using socket communication between processors. A procedure has been defined to support the barrier synchronization algorithm. The "SetLookAhead" procedure sets the estimated lookahead for the simulation.

The Time Warp algorithm requires regular computation of GVT, so that each SimulationCluster can clear its history information and reclaim memory assigned to it. The following procedures are defined to support the GVT computation:

- The simulation executive uses the "StartGVT" procedure to notify each SimulationCluster to start a GVT computation.
- Each SimulationCluster on receiving notification, stops processing events and uses the "ReceivedStartGVT" procedure to notify the simulation executive that it has received notification of a GVT computation.
- After the simulation executive has received notification from all SimulationClusters, it uses the "ComputeLocalMinimum" procedure to ask each
SimulationCluster to calculate its local minimum time.

- After the simulation executive has received the local minimum from each SimulationCluster, it computes the GVT and sends it to each SimulationCluster, using the "SendGVT" procedure.

- Each SimulationCluster on receiving the GVT, clears all saved history information for timestamps which are in the past of the GVT, and resumes processing events.

5.2.2 Communication Study

The snooker table example described in the previous section is used to study communication among SimulationClusters in a distributed simulation. The snooker table is again spatially divided into 6 BallGroups, and these BallGroups transmit messages to each other while scheduling events on each other. The lookahead for the simulation is calculated as follows:

Let "length" be the length of the table
Let "width" be the breadth of the table
Let "XDistance" be the length of each BallGroup
Let "YDistance" be the width of each BallGroup
Let "XPosition" be the x-component of a ball’s position within a BallGroup
Let "YPosition" be the y-component of a ball’s position within a BallGroup
Let "XVelocity" be the x-component of the velocity assigned to a ball within a BallGroup
Let "YVelocity" be the y-component of the velocity assigned to a ball within a BallGroup

\[
\begin{align*}
\text{length} & = 3569 \text{ mm} \\
\text{width} & = 1178 \text{ mm} \\
\text{XDistance} & = \frac{\text{length}}{3} \approx 1189 \text{ mm} \\
\text{YDistance} & = \frac{\text{width}}{2} = 589 \text{ mm} \\
\text{XPosition} & = 1 \leq \text{XPosition} \leq 1189 \\
\text{YPosition} & = 1 \leq \text{YPosition} \leq 589 \\
\text{XVelocity} & = 10 \text{ mm/sec} \\
\text{YVelocity} & = 10 \text{ mm/sec} \\
\text{Lookahead} & = \text{Minimum} \{ (\text{XPosition}/\text{XVelocity}), (\text{YPosition}/\text{YVelocity}) \}
\end{align*}
\]
The BallGroups are assigned to different available SimulationClusters, and the messages that they send to each other is noted. The number of available SimulationClusters is varied from 2 to 6. The BallGroups are assigned to different SimulationClusters as shown in Figure 61. Each BallGroup is assigned a certain number of balls and the balls are assigned initial velocities and positions within the region, similar to the previous section.
Table 1a. Messages passed

Table 1. Messages passed and average pending events with 6 SimulationClusters

Table 1b. Average Events

Table 2a. Messages passed

Table 2. Messages passed and average pending events with 3 SimulationClusters

5.2.3 Results

Table 1(a) shows the number of messages passed among different SimulationClusters with 6 SimulationClusters, while Table 1(b) shows the average size of the pending event set within each SimulationCluster. Table 2(a) shows the number of messages passed when the number of SimulationClusters is reduced to 3 and the BallGroups are assigned as shown in Figure 61 (b). This partition decreases the total number of messages passed among all SimulationClusters by 70%, while the average size of the pending event set remains the same. Table 3 shows the number of messages and the average events with 2 SimulationClusters as shown in Figure 61 (c). The average pending event size decreases, but the number of messages doubles as compared to 3.
Table 3a. Messages passed

<table>
<thead>
<tr>
<th>Source SimulationCluster</th>
<th>Destination SimulationCluster</th>
<th>0</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>18573</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>18873</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 3b. Average Events

<table>
<thead>
<tr>
<th>Simulation Cluster</th>
<th>Average Events</th>
<th>0</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>166</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>167</td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Messages passed and average pending events with 2 SimulationClusters

Table 4a. Messages passed

<table>
<thead>
<tr>
<th>Source SimulationCluster</th>
<th>Destination SimulationCluster</th>
<th>0</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>10494</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>10243</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 4b. Average Events

<table>
<thead>
<tr>
<th>Simulation Cluster</th>
<th>Average Events</th>
<th>0</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>165</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>167</td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Messages passed and average pending events with 2 SimulationClusters with L-shape organization

SimulationClusters. Table 4 shows the statistics when the BallGroups are reorganized within the same 2 SimulationClusters. The average size of the pending event size remains the same as the previous organization, but the total number of messages transmitted decreases by half.

The execution time for the simulation using the Time Warp algorithm is considerably slower than when using the barrier synchronization algorithm. This is expected, since the state capture ability within DIESEL captures the entire state of the simulation, even though there are few state variables that change a lot within this example. Similarly, a state restore operation due to rollback restores the state of the entire simulation. These are very detailed processes which account for most of the execution time. This state capture ability is specific to this implementation and can be replaced with other state saving techniques [6 – 11] that save the state of variables rather than the whole.
system. With an application that has a lot of state variables which change often, the state capture ability within DIESEL would be a valuable tool to capture the system state, rather than attaching the overhead to each state variable.

5.3 Port Simulation (PORTSIM)

The Port Simulation (PORTSIM) system [62, 63, 64] is a discrete-event simulation that facilitates the analysis of movements of military unit equipment through worldwide seaports and allows for detailed infrastructure analysis. PORTSIM simulates the use of seaports within the defense cargo transportation system and assists planners in comparing and selecting ports. It determines port throughput capability given explicit assumptions on assets, resources, and scenarios. It tracks utilization of critical resources as well as potential bottlenecks and limiting resources to movement through the seaport.

The Programmable Process Flow Network (PPFN) is a process flow language developed at Old Dominion University to describe the process activities at a cargo terminal [65]. Previous versions of PORTSIM had processes statically coded into the simulation, preventing the analyst from modifying them when a specific scenario required it. By having the processes programmable, the analyst has full control of the simulation processes. PPFN is partitioned into a high level language where the analysts develop their processes and an assembly language that corresponds to data structures internal to the simulation. The assembly-level instructions are interpreted by a virtual machine called the Process Engine. This approach enables implementation of the simulation given an appropriate set of process instructions. Meanwhile, the high level language's grammar and semantics are further defined to suit the needs of the analyst.
without affecting simulation development.

Previous versions of PORTSIM were implemented in MODSIM, originally in MODSIM II and later in MODSIM III [17, 66, 67]. MODSIM is an object-oriented simulation language developed by CACI. However, CACI sold the rights to the language and the language has since been unsupported. This necessitated the movement of the simulation to another language. The Army decided on a general purpose language, requiring adopting a third party simulation executive (deemed undesirable for similar reasons to the MODSIM issues) or development of a simulation executive to support the project. This gave the first justification and opportunity for the development of DIESEL.

A functional prototype has been developed for the new PORTSIM simulation model with PPFN support, utilizing the DIESEL C++ implementation as the supporting simulation language with Windows XP OS on a Win32 platform. The current PORTSIM system is shown in Figure 62. The Process Engine and the Cargo Terminal Architecture
components within PORTSIM interact with the DIESEL simulation engine, to initialize, control, and execute the simulation. The *Cargo Terminal Architecture* within PORTSIM is defined as a network of nodes, with each node defined by a process or by another network thus allowing a hierarchical structure. A MapNode, shown in Figure 63, represents cargo terminals within the cargo transportation network as well as the individual terminal areas within a single cargo terminal. The architecture also supports the routing of entities (cargo and transports) through the network by defining a starting node, a destination node with a sequence of nodes to be traversed en route. Once a node that can handle a given entity is identified, the entity must request space in the selected

![Figure 63. MapNode within PORTSIM Architecture](image-url)
node before transiting to the node. This is important to avoid infinite queuing in the interconnection segments and to provide a level of flow control, thereby assisting in the avoidance of deadlock.

A MapNode is one of the many SimObjects within PORTSIM with an associated SimulationEngineComponent. Events are scheduled to be executed on a MapNode by the arrival of cargo and transport at the MapNode at a particular simulation time, through the routing infrastructure that exists between MapNodes. Requests for space by an entity within a destination MapNode also create events on the source MapNode, once space has been identified for the entity within the destination MapNode. Resources and transports within a MapNode are modeled with the EntityCounter and EntityPool interfaces in DIESEL, while cargo pools are modeled using other entity management interfaces within DIESEL.

The Cargo Terminal Architecture is a shell around the cargo processing model that is unique to each MapNode. A ProcessFlow is defined for each MapNode using PPFN to represent the cargo processing model. A ProcessFlow is also a SimObject with an associated SimulationEngineComponent. It is defined as a sequence of activities that must be traversed in order by cargo or transports to be processed through a MapNode. An example process flow is shown in Figure 64. Activities such as "ProcessTimeDelay" that involve passing simulation time, cause events to be scheduled on the associated SimulationEngineComponent. This causes the activity to be suspended until the specified simulation time, after which it resumes execution. Activities also use the Trigger, TriggerCounter, Join, and JoinCounter interfaces to achieve synchronization between themselves within a single ProcessFlow or multiple ProcessFlows.
The PORTSIM system uses the DIESEL state capture ability to save the state of the simulation and restore it at a later time. The state capture ability has also been used for debugging purposes, since a state save operation involves resolving all references within the simulation, which is extremely useful to find stranded references.

Results over the past four years have shown the DIESEL behavioral model and its C++ implementation to be more than adequate for supporting the development of real-world applications. An Initial Operational Capability (IOC) release of PORTSIM utilizing the sequential version of DIESEL is scheduled for June 2007.

Figure 64. Example PORTSIM ProcessFlow using PPFN
5.4 DIESEL Platform Independence

One of the main requirements of the DIESEL behavioral model is that it should not be focused on a particular programming language or hardware platform. The DIESEL behavioral model described in Chapter II, III and IV is defined at a high level of abstraction. The behavior expected of each component within the model has been captured. However, the implementation of the behavioral model is completely independent; each component can be implemented in a different manner, as long as they satisfy the behavior that is expected of that component. Each new implementation of a component should implement the interface that has been specified for that particular component. This allows each new component to be inserted into the complete model and cause no change to the behavior of the complete model.

Language Independence

The DIESEL behavioral model has been implemented in C++, Java and C#. The DIESEL C++ implementation is fully representative of the behavioral model and includes the full functionality described in Chapters II, III and IV. Java and C# implementations with the core simulation engine functionality have been developed as prototypes by Mr. Saurav Mazumdar from the Department of Electrical and Computer Engineering at Old Dominion University. These implementations prove that the behavioral model is not focused towards any language in particular. Complete Java and C# implementations can be developed depending on user requirements.
**Compiler Independence**

Various applications including the example timing diagram and the Dining Philosophers' problem described in Chapter III, using the DIESEL C++ implementation, have been tested on different C++ compilers. These compilers include the Visual Studio 2005 SP1 C++ compiler developed by Microsoft© Corporation and the GCC 4.1.1 compiler developed by Free Software Foundation in support of the GNU project using the Anjuta Integrated Development Environment (IDE).

**Platform Independence**

The example timing diagram and the Dining Philosophers' problem have been tested on the Windows 2000 and Windows XP operating systems from Microsoft© Corporation and the Fedora Core 6 operating system from Red Hat, installed on different hardware platforms, using the DIESEL C++ implementation and the GCC compiler.

The complete source code for the C++ implementation is made available for further research and development through the Department of Electrical and Computer Engineering at Old Dominion University. Source code is extremely valuable while debugging simulations that are developed using DIESEL as the underlying simulation executive. Moreover, one of the goals of this research is to encourage development of new implementations for a small component or for a set of interconnected components. This development is greatly aided if complete source code is available so that the developer can study the behavior of the component that is being replaced in the context of the entire model.
Should an application desire to use DIESEL without concern for the internal implementation, stable libraries that have been built for the complete implementation are made available through ODU too. These implementations can be used for developing applications with no changes or further development required within the underlying DIESEL implementation. This makes DIESEL an attractive option for commercial applications, since the simulation executive along with its implementation is free and easily modified to suit specific application needs.
Chapter VI

CONCLUSION

This chapter concludes the work presented in this dissertation and offers suggestions on future work based on the behavioral model presented here.

6.1 Achievements

DIESEL specifies a behavioral model for a simulation executive and is capable of supporting sequential and distributed application development. The model is defined at a high level of abstraction and the expected behavior of each component within the model is described. The model also describes the interconnection among the model components. However, the model specification implies no implementation details. The implementation of each component or the whole behavioral model itself can be developed independently with no change to system behavior, as long as each component satisfies its expected behavior. The behavioral model is independent of any underlying network communication protocols or synchronization algorithms while executing a distributed application.

A complete and functional implementation of the behavioral model has been developed in C++. The C++ implementation is independent of the compiler that is used to compile the program or the hardware and software platform that it is executed on. Prototypical implementations of the model with core engine functionality have also been developed in Java and C#. Support for the conservative barrier synchronization algorithm
and the optimistic *Time Warp* algorithm has been implemented to show that the model can support different synchronization algorithms.

The behavioral model for a simulation executive described in this dissertation can be used for research and development into different aspects of PDES. The simulation executive in its current form can be used to develop discrete-event simulations. The underlying implementation can be changed with no changes required in the application. Different event management strategies, communication mechanisms, and synchronization algorithms, both new and existing, can be compared using the same behavioral model. The model described here and its implementation can be used in classes to teach the basics of a sequential and distributed simulation. It is also extremely stable and can therefore be the underlying simulation executive for commercial applications.

### 6.2 Enhancements

Several enhancements are possible to the work described in this dissertation:

**High Level Architecture (HLA) Compliance**

The DIESEL simulation executive could be extended so that any applications developed using DIESEL could be written to be HLA compliant, if needed. HLA compliance could be achieved by specifying the HLA Simulation Object Model (SOM) for DIESEL and its interface to the Runtime Infrastructure (RTI). An application would then need to develop and specify its Federation Object Model (FOM) to achieve compliance. Simulations built using DIESEL (called federates in HLA terminology) would have to use the time management services of the RTI to manage local time in order...
to be HLA compliant. This would involve the DIESEL time management infrastructure interacting with the RTI to manage and advance the simulation time within an application, which could involve extensions to the DIESEL interface specification.

**Support For Continuous-Time Simulations**

The DIESEL simulation executive currently supports discrete-event simulations. The behavioral model can be extended to support continuous-time simulations. Simulation time within continuous-time simulations is non-discrete. Therefore, the simulation time would have to be incremented by delta values to advance the simulation, thereby simulating the non-discrete nature of a continuous simulation. The *Delayed State Commitment* that already exists within the current specification can be an important tool. If multiple processes modify the same state variable at the same simulation time, then the order in which the processes act on the variable plays an important role in the final outcome of the simulation. *Delayed State Commitment* makes all processes act on the same value of the state variable and then updates the state variable with its new value after all processes have finished executing at that simulation time.

**Support For Process Flow Modeling**

The DIESEL model can also be extended to support process flow modeling, which represents a system as a Data Flow Diagram (DFD) [68]. A DFD shows the flow of information through the system using processes where each process transforms a set of inputs to a set of outputs. The DFD can be mapped onto DIESEL by converting the DFD
to an event-driven model, with each event representing the transformation from input to output within a process.

**Support for Real-Time Simulations and Animation**

Another extension to the DIESEL model could be support for real-time simulations and animation within a simulation. The behavioral model currently executes as fast as possible. This execution would have to be slowed down to synchronize it with the wallclock time, such that each event execution would correspond to an activity within real-time. The application model would have to be defined in such a way that a single event computation takes no longer than the time it would take to happen in real-time. If an event is executed faster than real-time, then the simulation would have to be suspended until the wallclock time caught up with the simulation time.

Animation support can be built in as an after-the-fact effort by using DIESEL to keep track of each event that an application object executed. This data could then be used to represent the simulation and the entity interaction within the application.
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APPENDICES

A. DIESEL Sequential Interface Specification

A.1 State Capture Interfaces

A.1.1 StateSave Interface

**Interface Diagram:**

```
@interface StateSave
+ResolveReferences()
+RestoreReferences()
+Create(): StateSave
+DuplicateState(in original: StateSave)
```

Figure A1. StateSave Interface

**Methods:**

- **ResolveReferences**
  - **Objective:** This method resolves references for dynamically initialized attributes within an entity. This method should be defined for each class or interface that inherits the StateSave interface.
  - **Parameters:** None.
  - **Return Value:** None.
  - **Exceptions:** None.

- **RestoreReferences**
  - **Objective:** This method restores references for dynamically initialized attributes within an entity. This method should be defined for each class or interface that inherits the StateSave interface.
  - **Parameters:** None.
  - **Return Value:** None.
  - **Exceptions:** None.

- **Create**
  - **Objective:** This method creates an empty shell of an entity during the state duplication process of a non-terminating state save operation. This method should be defined for each class or interface that inherits the StateSave interface.
  - **Parameters:** None.
  - **Return Value:** None.
  - **Type:** StateSave.
  - **Function:** Empty shell of entity.
  - **Exceptions:** None.

- **DuplicateState**
  - **Objective:** This method copies the state of "original" to the current entity during the state duplication process of a non-terminating state save operation. This
method should be defined for each class or interface that inherits the StateSave interface.

Parameters:

**original**

- **Mode:** Input.
- **Type:** StateSave.
- **Presence:** Required.
- **Function:** Specifies entity whose state is to be copied.
- **Return Value:** None.
- **Exceptions:** None.

### A.1.2 StateSaveSupport Interface

**Interface Diagram:**

```
<interface>StateSaveSupport
+RegisterEventMethod(in eventMethod: EventMethodReference)
+RegisterMethod(in method: EvaluateMethodReference)
+StartDuplicate()
+GetDuplicateReference(in reference: Reference): Reference
+DuplicateDone()
+ScheduleStateSave(in stateSaveFileName: string, in eventDelegate: Delegate, in outputDelegate: Delegate, in delta: double, in terminate: boolean)
+GetReferencelD(in reference: StateSave): ReferencelD
+GetReferencelD(in eventMethod: EventMethodReference): ReferencelD
+GetReferencelD(in method: EvaluateMethodReference): ReferencelD
+CaptureState(in stateSaveFile: FileStream)
+CaptureDone()
+RestoreState(in stateSaveFileName: string)
+GetReference(in referencelD: ReferencelD): Reference
+GetReference(in referencelD: ReferencelD): EventMethodReference
+GetReference(in referencelD: ReferencelD): EvaluateMethodReference
+RestoreDone()
+GetStateSaveFile(): FileStream
```

**Figure A2. StateSaveSupport Interface**

**Methods:**

- **RegisterEventMethod**
  - **Objective:** This method registers an event method with the state save support infrastructure.
  - **Parameters:**
    - **eventMethod**
      - **Mode:** Input.
      - **Type:** EventMethodReference.
      - **Presence:** Required.
      - **Function:** Specifies the event method to be registered.
  - **Return Value:** None.
  - **Exceptions:** None.

- **RegisterMethod**
  - **Objective:** This method registers a method that evaluates two elements with the state save support infrastructure.
  - **Parameters:**
    - **method**
      - **Mode:** Input.
      - **Type:** EvaluateMethodReference.
      - **Presence:** Required.
      - **Function:** Specifies the method to be registered.
  - **Return Value:** None.
Exceptions: None.

- **StartDuplicate**
  Objective: This method initializes a state duplication process for a non-terminating state save operation.
  Parameters: None.
  Return Value: None.
  Exceptions: None.

- **GetDuplicateReference**
  Objective: This method returns the reference for the duplicate of a StateSave object.
  Parameters:
  
<table>
<thead>
<tr>
<th>name</th>
<th>Mode</th>
<th>Type</th>
<th>Presence</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>reference</td>
<td>Input</td>
<td>StateSave</td>
<td>Required</td>
<td>Specifies the original StateSave object.</td>
</tr>
</tbody>
</table>
  Return Value:
  
<table>
<thead>
<tr>
<th>Type</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
<td>Reference to the duplicate of the StateSave object.</td>
</tr>
</tbody>
</table>
  Exceptions: None.

- **GetDuplicateReference**
  Objective: This method returns the reference for the duplicate of a non-StateSave object.
  Parameters:
  
<table>
<thead>
<tr>
<th>name</th>
<th>Mode</th>
<th>Type</th>
<th>Presence</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>reference</td>
<td>Input</td>
<td>Reference</td>
<td>Required</td>
<td>Specifies the original non-StateSave object.</td>
</tr>
</tbody>
</table>
  Return Value:
  
<table>
<thead>
<tr>
<th>Type</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
<td>Reference to the duplicate of the non-StateSave object.</td>
</tr>
</tbody>
</table>
  Exceptions: None.

- **RegisterDuplicateReference**
  Objective: This method registers a non-StateSave object and its duplicate with the state save support infrastructure.
  Parameters:
  
<table>
<thead>
<tr>
<th>name</th>
<th>Mode</th>
<th>Type</th>
<th>Presence</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>reference</td>
<td>Input</td>
<td>Reference</td>
<td>Required</td>
<td>Specifies the original non-StateSave object.</td>
</tr>
<tr>
<td>duplicate</td>
<td>Input</td>
<td>Reference</td>
<td>Required</td>
<td>Specifies the duplicate of the original non-StateSave object.</td>
</tr>
<tr>
<td>size</td>
<td>Input</td>
<td>Reference</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
• **DuplicateDone**
  
  **Objective:** This method ends and cleans up a state duplication process for a non-terminating state save operation.
  
  **Parameters:** None.
  
  **Return Value:** None.
  
  **Exceptions:** None.

• **ScheduleStateSave**
  
  **Objective:** This method schedules a state save operation at an offset of “delta” from the current simulation time.
  
  **Parameters:**
  
  **stateSaveFileName**
  - **Mode:** Input.
  - **Type:** String.
  - **Presence:** Required.
  - **Function:** Specifies the name of the state save file.
  
  **eventDelegate**
  - **Mode:** Input.
  - **Type:** Delegate.
  - **Presence:** Required.
  - **Function:** Specifies the delegate to be executed to save the state of the simulation.
  
  **dataDelegate**
  - **Mode:** Input.
  - **Type:** Delegate.
  - **Presence:** Required.
  - **Function:** Specifies the delegate to be executed to save the data within the application.
  
  **delta**
  - **Mode:** Input.
  - **Type:** Double.
  - **Presence:** Required.
  - **Function:** Specifies the offset of state save operation from current simulation time.
  
  **terminate**
  - **Mode:** Input.
  - **Type:** Boolean.
  - **Presence:** Required.
  - **Function:** Specifies if the simulation is to be terminated at the end of the state save operation.
  
  **Return Value:** None.
  
  **Exceptions:** None.

• **GetReferenceID**
  
  **Objective:** This method registers a StateSave object with the state save support infrastructure.
  
  **Parameters:**
  
  **reference**
  - **Mode:** Input.
Type: StateSave.
Presence: Required.
Function: Specifies the StateSave object to be registered.

Return Value:
Type: ReferenceID.
Function: ID of the StateSave object.
Exceptions: None.

- **GetReferenceID**
  
  **Objective:** This method registers a non-StateSave object with the state save support infrastructure.

  **Parameters:**
  
  - `reference`
    
    - Mode: Input.
    - Type: Reference.
    - Presence: Required.
    - Function: Specifies the non-StateSave object to be registered.
  
  - `size`
    
    - Mode: Input.
    - Type: Integer.
    - Presence: Required.
    - Function: Specifies the size of the non-StateSave object.

  **Return Value:**
  
  - Type: ReferenceID.
  - Function: ID of the non-StateSave object.

  **Exceptions:** None.

- **GetReferenceID**
  
  **Objective:** This method returns the ID for an event method.

  **Parameters:**
  
  - `eventMethod`
    
    - Mode: Input.
    - Type: EventMethodReference.
    - Presence: Required.
    - Function: Specifies the event method.

  **Return Value:**
  
  - Type: ReferenceID.
  - Function: ID of the event method.

  **Exceptions:** None.

- **GetReferenceID**
  
  **Objective:** This method returns the ID for an evaluate method.

  **Parameters:**
  
  - `method`
    
    - Mode: Input.
    - Type: EvaluateMethodReference.
    - Presence: Required.
    - Function: Specifies the method.

  **Return Value:**
  
  - Type: ReferenceID.
  - Function: ID of the method.

  **Exceptions:** None.

- **CaptureState**
  
  **Objective:** This method initiates writing the simulation state
to the state save file for a state save operation.

Parameters:

**stateSaveFile**
- **Mode:** Input.
- **Type:** File Stream.
- **Presence:** Required.
- **Function:** State Save File.
- **Return Value:** None.
- **Exceptions:** None.

- **CaptureDone**
  - **Objective:** This method ends and cleans up a state save operation.
  - **Parameters:** None.
  - **Return Value:** None.
  - **Exceptions:** None.

- **RestoreState**
  - **Objective:** This method initializes the support infrastructure for a state restore operation and initiates a state restore operation from the specified state save file.
  - **Parameters:**
    - **stateSaveFileName**
      - **Mode:** Input.
      - **Type:** String.
      - **Presence:** Required.
      - **Function:** Specifies the name of the state save file.
      - **Return Value:** None.
      - **Exceptions:** None.

- **GetReference**
  - **Objective:** This method restores the reference for an object registered with the state support infrastructure.
  - **Parameters:**
    - **referenceID**
      - **Mode:** Input.
      - **Type:** ReferenceID.
      - **Presence:** Required.
      - **Function:** Specifies the registered object.
      - **Return Value:**
        - **Type:** Reference.
        - **Function:** Reference to the registered object.
      - **Exceptions:** None.

- **GetReference**
  - **Objective:** This method restores the reference for an event method registered with the state support infrastructure.
  - **Parameters:**
    - **referenceID**
      - **Mode:** Input.
      - **Type:** ReferenceID.
      - **Presence:** Required.
      - **Function:** Specifies the ID of the registered event method.
Return Value:
  Type: EventMethodReference.
  Function: Reference to the registered event method.
Exceptions: None.

• **GetReference**
  Objective: This method restores the reference for an evaluate method registered with the state support infrastructure.
  Parameters:
  referenceID
    Mode: Input.
    Type: ReferenceID.
    Presence: Required.
    Function: Specifies the ID of the registered method.
  Return Value:
    Type: EvaluateMethodReference.
    Function: Reference to the registered method.
Exceptions: None.

• **RestoreDone**
  Objective: This method ends and cleans up a state restore operation.
  Parameters: None.
  Return Value: None.
  Exceptions: None.

• **GetStateSaveFile**
  Objective: This method returns the state save file to the simulation application, to save or retrieve information.
  Parameters: None.
  Return Value: None.
  Type: File Stream.
  Function: State Save File.
Exceptions: None.

A.2 Application Support Interfaces

A.2.1 Replicable Interface

**Interface Diagram:**

![Interface Diagram](image)

Figure A3. Replicable Interface

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Methods:

- **Clone**

  Objective: This method creates a clone of the entity. This method should be defined for each class or interface that inherits the Replicable interface.

  Parameters: None.

  Return Value:
  
  Type: Replicable.

  Function: Clone of the object.

  Exceptions: None.

A.2.2 *ProgrammaticEvent Interface*

**Interface Diagram:**

![Interface Diagram](image)

**Figure A4. ProgrammaticEvent Interface**

Methods:

- **Modify**

  Objective: This method modifies the attributes of an entity. This method should be defined for each class or interface that inherits the ProgrammaticEvent interface and desires the ability to programmatically modify its attributes.

  Parameters:
  
  **modifications**
  
  Mode: Input.

  Type: ArgumentList.

  Presence: Required.

  Function: Specifies the information required for modifying properties of an entity.

  Return Value: None.

  Exceptions: None.

- **Adjust**

  Objective: This method adjusts the attributes of an entity. This method should be defined for each class or interface that inherits the ProgrammaticEvent interface and desires the ability to programmatically adjust its attributes.

  Parameters:
  
  **adjustments**
  
  Mode: Input.

  Type: ArgumentList.

  Presence: Required.

  Function: Specifies the information required for adjusting properties of an entity.

  Return Value: None.

  Exceptions: None.
• **Transfer**  
  **Objective:** This method transfers properties of an entity to another entity. This method should be defined for each class or interface that inherits the ProgrammaticEvent interface and desires the ability to programmatically transfer its properties.

  **Parameters:**
  
  **transferInformation**  
  **Mode:** Input.  
  **Type:** ArgumentList.  
  **Presence:** Required.  
  **Function:** Specifies the information required for transferring properties an entity.

  **Return Value:** None.  
  **Exceptions:** None.

A.2.3 **Routine Interface**

**Interface Diagram:**

![Interface Diagram](image)

**Figure A5. Routine Interface**

**Methods:**

• **New**  
  **Objective:** This method initializes a Routine.  
  **Parameters:**
  
  **objectReference**  
  **Mode:** Input.  
  **Type:** Reference to a SimObject.  
  **Presence:** Required.  
  **Function:** Specifies the reference to a SimObject on which the routine method should be executed.

  **routineReference**  
  **Mode:** Input.  
  **Type:** EvaluateMethodReference.  
  **Presence:** Required.  
  **Function:** Specifies the routine method.

  **Return Value:** None.  
  **Exceptions:** None.

• **Delete**  
  **Objective:** This method disposes a Routine.  
  **Parameters:** None.  
  **Return Value:** None.  
  **Exceptions:** None.
• **Perform**
  Objective: This method executes the specified routine method with an element as its input.
  Parameters:
  - **element**
    Mode: Input.
    Type: Element.
    Presence: Required.
    Function: Specifies the element which is to be used as input for the routine method.
  Return Value: None.
  Exceptions: None.

A.2.4 **Condition Interface**

**Interface Diagram:**

![Interface Diagram](image)

**Methods:**

• **New**
  Objective: This method initializes a Condition.
  Parameters:
  - **objectReference**
    Mode: Input.
    Type: Reference to a SimObject.
    Presence: Required.
    Function: Specifies the reference to a SimObject on which the routine method should be executed.
  - **conditionReference**
    Mode: Input.
    Type: EvaluateMethodReference.
    Presence: Required.
    Function: Specifies the condition method.
  Return Value: None.
  Exceptions: None.

• **Delete**
  Objective: This method disposes a Condition.
  Parameters: None.
  Return Value: None.
  Exceptions: None.
• **Evaluate**

  **Objective:** This method executes the specified condition method with an element as its input.

  **Parameters:**

  **element**

  - **Mode:** Input.
  - **Type:** Element.
  - **Presence:** Required.
  - **Function:** Specifies the element which is to be used as input for the condition method.

  **Return Value:**

  - **Type:** Boolean.
  - **Function:** Result of the evaluated condition.

  **Exceptions:** None.

A.3 Application Interfaces

A.3.1 *SequentialSimulationExecutive* Interface

**Interface Diagram:**

```
<interface> SequentialSimulationExecutive
+StartSequentialSimulation()
+ExecuteSequentialSimulation()
+CleanUpSequentialSimulation()
+SetSimTime(in simTime: double)
+GetSimTime(): Double
+GetWallClockTime(): Double
+GetAveragePendingEventSize(): Integer
+GetAverageEventWaitTime(): Double
```

*Figure A7. SequentialSimulationExecutive Interface*

**Methods:**

- **StartSequentialSimulation**
  - **Objective:** This method initializes DIESEL for a sequential simulation.
  - **Parameters:** None.
  - **Return Value:** None.
  - **Exceptions:** None.

- **ExecuteSequentialSimulation**
  - **Objective:** This method executes a sequential simulation.
  - **Parameters:** None.
  - **Return Value:** None.
  - **Exceptions:** None.

- **CleanUpSequentialSimulation**
  - **Objective:** This method cleans up DIESEL after executing a sequential simulation.
  - **Parameters:** None.
  - **Return Value:** None.
  - **Exceptions:** None.
- **SetSimTime**
  
  Objective: This method sets the current simulation time for a sequential simulation.
  
  Parameters:
  
  `time`
  
  Mode: Input.
  Type: Double.
  Presence: Required.
  Function: Specifies the current simulation time.
  
  Return Value: None.
  Exceptions: None.

- **GetSimTime**
  
  Objective: This method returns the current simulation time within a sequential simulation.
  
  Parameters: None.
  Return Value:
  
  Type: Double.
  Function: Current simulation time.
  Exceptions: None.

- **GetWallClockTime**
  
  Objective: This method returns the wall clock time within a sequential simulation.
  
  Parameters: None.
  Return Value:
  
  Type: Double.
  Function: Current wall clock time.
  Exceptions: None.

- **GetAveragePendingEventSize**
  
  Objective: This method returns the average size of the pending event set for all SimulationEngineComponents within a sequential simulation.
  
  Parameters: None.
  Return Value:
  
  Type: Integer.
  Function: Average size of pending event set.
  Exceptions: None.

- **GetAverageEventWaitTime**
  
  Objective: This method returns the average waiting time for an event before it is executed within all SimulationEngineComponents in a sequential simulation.
  
  Parameters: None.
  Return Value:
  
  Type: Double.
  Function: Average event wait time.
  Exceptions: None.
A.3.2 ArgumentList Interface

**Interface Diagram:**

```
+Clone(): Replicable
+ResolveReferences()
+RestoreReferences()
+Create(): StateSave
+DuplicateState(original : StateSave)

+New(in numArguments : Integer, in listType : ArgumentListType)
+Delete()
+GetNArguments(): Integer
+GetArgument(in index : Integer): ArgumentReference
+GetArgument(in index : Integer, inout reference: ArgumentReference)
+GetReturnArgument(): ArgumentReference
+GetReturnArgument(inout reference: ArgumentReference)
```

**Figure A8. ArgumentList Interface**

**Methods:**

- **ResolveReferences**
  
  **Objective:** This method resolves references for dynamically initialized attributes within an ArgumentList.
  
  **Parameters:** None.
  
  **Return Value:** None.
  
  **Exceptions:** None.

- **RestoreReferences**
  
  **Objective:** This method restores references for dynamically initialized attributes within an ArgumentList.
  
  **Parameters:** None.
  
  **Return Value:** None.
  
  **Exceptions:** None.

- **Create**
  
  **Objective:** This method creates an empty shell of an ArgumentList during the state duplication process of a non-terminating state save operation.
  
  **Parameters:** None.
  
  **Return Value:**
  
  - **Type:** StateSave.
  
  - **Function:** Empty shell of ArgumentList.
  
  **Exceptions:** None.

- **DuplicateState**
  
  **Objective:** This method copies the state of “original” to the current ArgumentList during the state duplication process of a non-terminating state save operation.
  
  **Parameters:**
  
  - **original**
  
  - **Mode:** Input.

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Type: StateSave.
Presence: Required.
Function: Specifies ArgumentList whose state is to be copied.
Return Value: None.
Exceptions: None.

**Clone**
Objective: This method creates a clone of an ArgumentList.
Parameters: None.
Return Value: Type: Replicable.
Function: Clone of an ArgumentList.
Exceptions: None.

**New**
Objective: This method initializes an ArgumentList.
Parameters:
- **numArguments**
  - Mode: Input.
  - Type: Integer.
  - Presence: Required.
  - Function: Specifies the number of arguments in the ArgumentList.
- **listType**
  - Mode: Input.
  - Type: ArgumentListType.
  - Presence: Required.
  - Function: Specifies the type of ArgumentList to be created.
Return Value: None.
Exceptions:
  - "Invalid number of arguments"
  - Cause: "arguments" <= 0.
  - Effect: Simulation terminates.

**Delete**
Objective: This method disposes an ArgumentList.
Parameters: None.
Return Value: None.
Exceptions: None.

**SetArgument**
Objective: This method adds an argument to an ArgumentList. An index needs to be specified for an ARGUMENT_INDEXED ArgumentList. If no size is specified, then the reference to the argument is stored within an ArgumentList. In this case, the argument cannot be disposed within the application. If a size is specified, then a copy of the argument is made and stored within the ArgumentList, so that the original argument can be disposed within the application.
Parameters:
- **index**
  - Mode: Input.
  - Type: Integer.
  - Presence: Optional.
Function: Specifies the index of argument within the ArgumentList.

**scalar**
- Mode: Input.
- Type: Boolean.
- Presence: Required.
- Function: TRUE if argument is a scalar, else FALSE.

**byValue**
- Mode: Input.
- Type: Boolean.
- Presence: Required.
- Function: TRUE if argument is passed by value, else FALSE.

**reference**
- Mode: Input.
- Type: Reference to an argument.
- Presence: Required.
- Function: Specifies the reference to an argument.

**size**
- Mode: Input.
- Type: Integer.
- Presence: Required.
- Function: Specifies the size of argument in bytes.

Return Value: None.

Exceptions:
- "No index specified for an indexed list"
  - Cause: No index specified while adding an argument to an INDEXED list.
  - Effect: Simulation terminates.
- "Index out of bounds"
  - Cause: (index < 0) OR (index > (nArguments - 1)) for an INDEXED list.
  - Effect: Simulation terminates.
- "Attempt to index a non-indexed list"
  - Cause: An index is specified while adding an argument to a NON-INDEXED list.
  - Effect: Simulation terminates.

**SetReturnArgument**

Objective: This method adds a return argument to an ArgumentList. If no size is specified, then the reference to the return argument is stored within the ArgumentList. In this case, the return argument cannot be disposed within the application. If a size is specified, then a copy of the return argument is made and stored within the ArgumentList, so that the original return argument can be disposed within the application.

Parameters:

**scalar**
- Mode: Input.
- Type: Boolean.
- Presence: Required.
- Function: TRUE if return argument is a scalar, else FALSE.

**byValue**
- Mode: Input.
- Type: Boolean.
Presence: Required.
Function: TRUE if return argument is passed by value, else FALSE.

**Reference**
- Mode: Input.
- Type: Reference to an argument.
- Presence: Required.
- Function: Specifies the reference to return argument.

**Size**
- Mode: Input.
- Type: Integer.
- Presence: Required.
- Function: Specifies the size of return argument in bytes.

Return Value: None.
Exceptions: None.

**GetNArguments**
Objective: This method is used to get the number of arguments within an ArgumentList.
Parameters: None.
Return Value:
- Type: Integer.
- Function: Number of arguments.
Exceptions: None.

**GetArgument**
Objective: This method is used to return the reference to an argument stored within an ArgumentList.
Parameters:

**Index**
- Mode: Input.
- Type: Integer.
- Presence: Optional.
- Function: Specifies the index of argument within the ArgumentList.

Return Value:
- Type: Reference to an argument.
- Function: Reference to the argument.
Exceptions:
- "Accessing a non-existent argument"
  - Cause: Accessing an argument that was not stored.
  - Effect: Simulation terminates.
- "Accessing an argument by reference that was passed by value"
  - Cause: Accessing an argument by reference that was passed by value.
  - Effect: Simulation terminates.
- "No index specified for an indexed list"
  - Cause: No index specified while retrieving an argument from an INDEXED list.
  - Effect: Simulation terminates.
- "Index out of bounds"
  - Cause: (index < 0) OR (index > (nArguments - 1)) for an INDEXED list.
  - Effect: Simulation terminates.
- "Attempt to index a non-indexed list"
  - Cause: An index is specified while retrieving an argument
*GetArgument*

Objective: This method is used to return the value of an argument stored within an ArgumentList. The value of the argument is copied into the memory location pointed to by "reference".

Parameters:

**index**
- **Mode:** Input.
- **Type:** Integer.
- **Presence:** Optional.
- **Function:** Specifies the index of argument within the ArgumentList.

**reference**
- **Mode:** Input/Output.
- **Type:** Reference to an argument.
- **Presence:** Required.
- **Function:** Specifies the reference to an argument.

Return Value: None.

Exceptions:
- "Accessing a non-existent argument"
  - **Cause:** Accessing an argument that was not stored.
  - **Effect:** Simulation terminates.
- "Accessing an argument by value that was passed by reference"
  - **Cause:** Accessing an argument by value that was passed by reference.
  - **Effect:** Simulation terminates.
- "No index specified for an indexed list"
  - **Cause:** No index specified while retrieving an argument from an INDEXED list.
  - **Effect:** Simulation terminates.
- "Index out of bounds"
  - **Cause:** (index < 0) OR (index > (nArguments - 1)) for an INDEXED list.
  - **Effect:** Simulation terminates.
- "Attempt to index a non-indexed list"
  - **Cause:** An index is specified while retrieving an argument from a NON-INDEXED list.
  - **Effect:** Simulation terminates.

*GetReturnArgument*

Objective: This method is used to return the reference to the return argument from an ArgumentList.

Parameters: None.

Return Value:
- **Type:** Reference to an argument.
- **Function:** Reference to the return argument.

Exceptions:
- "Accessing a non-existent return argument"
  - **Cause:** Accessing an argument that was not stored.
  - **Effect:** Simulation terminates.
- "Accessing return argument by reference that was passed by value"
  - **Cause:** Accessing an argument by value that was passed by reference.
Effect: Simulation terminates.

- **GetReturnArgument**
  
  **Objective:** This method is used to return the value of the return argument stored within an ArgumentList. The value of the return argument is copied into the memory location pointed to by “reference”.

  **Parameters:**
  
  - **reference**
    
    **Mode:** Input/Output.
    
    **Type:** Reference to an argument.
    
    **Presence:** Required.
    
    **Function:** Specifies the reference to return argument.
    
    **Return Value:** None.
    
    **Exceptions:**
    
    - "Accessing a non-existent return argument"
      
      **Cause:** Accessing an argument that was not stored.
      
      **Effect:** Simulation terminates.
    
    - "Accessing return argument by value that was passed by reference"
      
      **Cause:** Accessing an argument by value that was passed by reference.
      
      **Effect:** Simulation terminates.

**A.3.3 Delegate Interface**

**Interface Diagram:**

![Interface Diagram](image)

**Methods:**

- **ResolveReferences**
  
  **Objective:** This method resolves references for dynamically initialized attributes within a Delegate.

  **Parameters:** None.
  
  **Return Value:** None.
  
  **Exceptions:** None.

- **RestoreReferences**
  
  **Objective:** This method restores references for dynamically initialized attributes within a Delegate.
- **Create**
  Objective: This method creates an empty shell of a Delegate during the state duplication process of a non-terminating state save operation.
  Parameters: None.
  Return Value: None.
  Type: Empty shell of Delegate.
  Function: None.
  Exceptions: None.

- **DuplicateState**
  Objective: This method copies the state of "original" to the current Delegate during the state duplication process of a non-terminating state save operation.
  Parameters: original
  Mode: Input.
  Type: StateSave.
  Presence: Required.
  Function: Specifies Delegate whose state is to be copied.
  Return Value: None.
  Exceptions: None.

- **Clone**
  Objective: This method creates a clone of a Delegate.
  Parameters: None.
  Return Value: Replicable.
  Type: Clone of a Delegate.
  Function: None.
  Exceptions: None.

- **New**
  Objective: This method initializes a Delegate.
  Parameters: object
    Mode: Input.
    Type: Reference to a SimObject.
    Presence: Required.
    Function: Specifies the reference to a SimObject on which the event method should be executed.
    method
      Mode: Input.
      Type: EventMethodReference.
      Presence: Required.
      Function: Specifies the reference to an event method.
    methodList
      Mode: Input.
      Type: ArgumentList.
      Presence: Required.
      Function: Specifies the list of parameters to be used when the event method is executed.
interrupt
Mode: Input.
Type: EventMethodReference.
Presence: Optional.
Function: Specifies the reference to an interrupt method to be executed if the Delegate is interrupted.

interruptList
Mode: Input.
Type: ArgumentList.
Presence: Optional.
Function: Specifies the list of parameters to be used when the interrupt method is executed.
Return Value: None.
Exceptions: None.

• SetArgumentList
Objective: This method assigns an ArgumentList to a Delegate for invoking an event method.
Parameters:
methodList
Mode: Input.
Type: ArgumentList.
Presence: Required.
Function: Specifies the list of parameters to be used when the event method is executed.
Return Value: None.
Exceptions: None.

• GetArgumentList
Objective: This method returns the ArgumentList to be used for event method invocation from a Delegate.
Parameters: None.
Return Value:
Type: ArgumentList.
Function: Specifies the list of parameters to be used when the event method is executed.
Exceptions: None.

• Invoke
Objective: This method executes the event method within a Delegate with the specified ArgumentList.
Parameters: None.
Return Value: None.
Exceptions: None.

• Interrupt
Objective: This method cancels the event method invocation within a Delegate. The interrupt method is executed with the specified interrupt ArgumentList.
Parameters: None.
Return Value: None.
Exceptions: None.
A.3.4 SimulationEngineComponent Interface

Interface Diagram:

```
+New()
+Delete()
+ScheduleEventAtTime(in eventDelegate: Delegate, in simTime: double, in priority: EventPriority): EventID
+ScheduleEventInTime(in eventDelegate: Delegate, in delta: double, in priority: EventPriority): EventID
+RescheduleEvent(in eventID: EventID, in delta: double)
+RescheduleAllEvents(in delta: double)
+InterruptEvent(in eventID: EventID)
+InterruptAllEvents()
+GetEventTime(in eventID: EventID): Double
+IsPendingEventSetEmpty(): Boolean
+GetAveragePendingEventSetSize(): Double
+GetAverageEventWaitTime(): Double

+ResolveReferences()
+RestoreReferences()
+Create(): StateSave
+DuplicateState(in original: StateSave)

+ResolveReferences()
+RestoreReferences()
+Create(): StateSave
+DuplicateState(in original: StateSave)
```

Figure A10. SimulationEngineComponent Interface

Methods:

- **ResolveReferences**
  
  Objective: This method resolves references for dynamically initialized attributes within a SimulationEngineComponent.
  
  Parameters: None.
  
  Return Value: None.
  
  Exceptions: None.

- **RestoreReferences**
  
  Objective: This method restores references for dynamically initialized attributes within a SimulationEngineComponent.
  
  Parameters: None.
  
  Return Value: None.
  
  Exceptions: None.

- **Create**
  
  Objective: This method creates an empty shell of a SimulationEngineComponent during the state duplication process of a non-terminating state save operation.
  
  Parameters: None.
  
  Return Value: Type: StateSave.
  
  Function: Empty shell of SimulationEngineComponent.
  
  Exceptions: None.

- **DuplicateState**
  
  Objective: This method copies the state of “original” to the current SimulationEngineComponent during the state duplication process of a non-terminating state save operation.
  
  Parameters:
• **New**

Objective: This method initializes a SimulationEngineComponent and registers itself with the SimulationCluster.

Parameters: None.

Return Value: None.

Exceptions: None.

• **Delete**

Objective: This method disposes a SimulationEngineComponent and de-registers itself the SimulationCluster.

Parameters: None.

Return Value: None.

Exceptions: None.

• **ScheduleEventAtTime**

Objective: This method schedules a Delegate to be executed on a SimObject associated with the SimulationEngineComponent at a specific simulation time. A priority can be specified for a Delegate to lower the priority of the Delegate relative to Delegates scheduled at the same simulation time. The Delegate is added to the collection of Delegates scheduled on the SimulationEngineComponent.

Parameters:

- **eventDelegate**
  
  Mode: Input.
  Type: Delegate.
  Presence: Required.
  Function: Specifies the Delegate having reference to the event method.

- **simTime**
  
  Mode: Input.
  Type: Double.
  Presence: Required.
  Function: Specifies the scheduled execution time of the Delegate.

- **priority**
  
  Mode: Event Priority.
  Type: Double.
  Presence: Optional.
  Function: Specifies the priority of the Delegate relative to other delegates scheduled at the same simulation time.

Return Value:

Type: EventID.
Function: Unique ID of the Delegate added to the SimulationEngineComponent. This ID is used to refer
to the event for activities such as interrupting the Delegate or changing its scheduled execution time.

Exceptions:

"Execution time for delegate less than current simulation time"
  Cause: \((\text{simTime} < \text{current simulation time})\).
  Effect: Simulation terminates.

"Invalid priority for delegate"
  Cause: \((\text{priority} <= 0)\).
  Effect: Simulation terminates.

• **ScheduleEventInTime**

  Objective: This method schedules a Delegate to be executed on a SimObject associated with the SimulationEngineComponent, after a given simulation time has elapsed. This method is similar to the ScheduleEventAtTime method.

  Parameters:

  - **eventDelegate**
    Mode: Input.
    Type: Delegate.
    Presence: Required.
    Function: Specifies the Delegate having reference to the event method.

  - **delta**
    Mode: Input.
    Type: Double.
    Presence: Required.
    Function: Specifies the offset of Delegate execution from current simulation time.

  - **priority**
    Mode: Event Priority.
    Type: Double.
    Presence: Optional.
    Function: Specifies the priority of the Delegate relative to other delegates scheduled at the same simulation time.

  Return Value:

  - Type: EventID.
    Function: Unique ID of the Delegate added to the SimulationEngineComponent. This ID is used to refer to the event for activities such as interrupting the Delegate or changing its scheduled execution time.

  Exceptions:

  "Execution time for delegate less than current simulation time"
  Cause: \((\text{delta} < 0)\).
  Effect: Simulation terminates.

  "Invalid priority for delegate"
  Cause: \((\text{priority} <= 0)\).
  Effect: Simulation terminates.

• **RescheduleEvent**

  Objective: This method reschedules a specific Delegate within a SimulationEngineComponent, by applying a certain simulation time as offset to its current execution time. The offset can be positive or negative. However, to reschedule a Delegate earlier than its
original execution time, the offset should be smaller than the difference between the current simulation time and original event execution time.

Parameters:

`eventID`
- Mode: Input.
- Type: EventID.
- Presence: Required.
- Function: Specifies the ID of the Delegate to be rescheduled.

`delta`
- Mode: Input.
- Type: Double.
- Presence: Required.
- Function: Specifies the offset of Delegate execution time from its current execution time.

Return Value: None.

Exceptions:

"Delegate to be rescheduled not found"
- Cause: Specified delegate does not exist within the collection of delegates.
- Effect: Simulation terminates.

"Attempt to reschedule delegate at time less than current simulation time"
- Cause: New scheduled execution time for delegate less than current simulation time.
- Effect: Simulation terminates.

### RescheduleAllEvents

Objective: This method reschedules all Delegates within a SimulationEngineComponent by applying a certain simulation time as offset to their current execution time. The restrictions on the offset value are identical to that for the offset within the RescheduleEvent method.

Parameters:

`delta`
- Mode: Input.
- Type: Double.
- Presence: Required.
- Function: Specifies the offset of Delegate execution time from its current execution time.

Return Value: None.

Exceptions:

"Attempt to reschedule delegates at time less than current simulation time"
- Cause: New scheduled execution time for at least one Delegate less than current simulation time.
- Effect: Simulation terminates.

### InterruptEvent

Objective: This method cancels the execution of a specific Delegate within a SimulationEngineComponent.

Parameters:

`eventID`
- Mode: Input.
- Type: EventID.
Presence: Required.
Function: Specifies the ID of the Delegate to be interrupted.
Return Value: None.
Exceptions:
  "Delegate to be interrupted not found"
Cause: Specified Delegate does not exist within the collection of Delegates.
Effect: Simulation terminates.

- **InterruptAllEvents**
  Objective: This method cancels the execution of all Delegates within a SimulationEngineComponent.
  Parameters: None.
  Return Value: None.
  Exceptions: None.

- **GetEventTime**
  Objective: This method returns the scheduled execution time of a specific Delegate within a SimulationEngineComponent.
  Parameters:
    - eventID
      Mode: Input.
      Type: EventID.
      Presence: Required.
      Function: Specifies the ID of the Delegate for which the execution time is required.
  Return Value:
    - Type: Double.
    - Function: Scheduled execution time of the Delegate.
  Exceptions:
    "Delegate not found"
    Cause: Specified Delegate does not exist within the collection of events.
    Effect: Simulation terminates.

- **IsPendingEventSetEmpty**
  Objective: This method ascertains whether a SimulationEngineComponent has any pending Delegates to be executed.
  Parameters: None.
  Return Value:
    - Type: Boolean.
    - Function: TRUE if collection of Delegates is empty, else FALSE.
  Exceptions: None.

- **GetAveragePendingEventSetSize**
  Objective: This method returns the average size of the pending event set within the SimulationEngineComponent.
  Parameters: None.
  Return Value:
    - Type: Integer.
    - Function: Average size of pending event set for the duration of the simulation.
• **GetAverageEventWaitTime**
  
  **Objective:** This method returns the average wait time of an event to be executed within the SimulationEngineComponent.
  
  **Parameters:** None.
  
  **Return Value:** Double.
  
  **Function:** Average wait time of an event to be executed.
  
  **Exceptions:** None.

---

### A.3.5 DelayedCommit Interface

#### Interface Diagram:

![Diagram of DelayedCommit Interface](image)

**Figure A11. DelayedCommit Interface**

#### Methods:

- **ResolveReferences**
  
  **Objective:** This method resolves references for dynamically initialized attributes within a DelayedCommit.
  
  **Parameters:** None.
  
  **Return Value:** None.
  
  **Exceptions:** None.

- **RestoreReferences**
  
  **Objective:** This method restores references for dynamically initialized attributes within a DelayedCommit.
  
  **Parameters:** None.
  
  **Return Value:** None.
  
  **Exceptions:** None.

- **Create**
  
  **Objective:** This method creates an empty shell of a DelayedCommit during the state duplication process of a non-terminating state save operation.
  
  **Parameters:** None.
  
  **Return Value:** StateSave.
  
  **Type:** StateSave.
  
  **Function:** Empty shell of DelayedCommit.
  
  **Exceptions:** None.
• **DuplicateState**

Objective: This method copies the state of "original" to the current DelayedCommit during the state duplication process of a non-terminating state save operation.

Parameters:

- **original**
  - Mode: Input.
  - Type: StateSave.
  - Presence: Required.
  - Function: Specifies DelayedCommit whose state is to be copied.

Return Value: None.

Exceptions: None.

• **New**

Objective: This method initializes a DelayedCommit.

Parameters:

- **parentSEC**
  - Mode: Input.
  - Type: SimulationEngineComponent.
  - Presence: Required.
  - Function: Specifies the associated SimulationEngineComponent.

- **value**
  - Mode: Input.
  - Type: Attribute Value.
  - Presence: Required.
  - Function: Specifies the initial value of the DelayedCommit attribute.

Return Value: None.

Exceptions: None.

• **Delete**

Objective: This method disposes a DelayedCommit.

Parameters: None.

Return Value: None.

Exceptions: None.

• **SetAttribute**

Objective: This method assigns a new value to a DelayedCommit attribute. The value of the attribute is not updated immediately.

Parameters:

- **newValue**
  - Mode: Input.
  - Type: Attribute Value.
  - Presence: Required.
  - Function: Specifies the new value of the DelayedCommit attribute.

Return Value: None.

Exceptions: None.

• **GetAttribute**

Objective: This method returns the value of a DelayedCommit attribute.

Parameters: None.

Return Value: None.
Type: Attribute Value.
Function: The value of the DelayedCommit attribute.
Exceptions: None.

A.4 Synchronization Interfaces

A.4.1 Trigger Interface

Interface Diagram:

![Interface Diagram](image)

Figure A12. Trigger Interface

Methods:

- **ResolveReferences**
  Objective: This method resolves references for dynamically initialized attributes within a Trigger.
  Parameters: None.
  Return Value: None.
  Exceptions: None.

- **RestoreReferences**
  Objective: This method restores references for dynamically initialized attributes within a Trigger.
  Parameters: None.
  Return Value: None.
  Exceptions: None.

- **Create**
  Objective: This method creates an empty shell of a Trigger during the state duplication process of a non-terminating state save operation.
  Parameters: None.
  Return Value: StateSave.
  Type: None.
  Function: Empty shell of Trigger.
  Exceptions: None.

- **DuplicateState**
  Objective: This method copies the state of "original" to the current Trigger during the state duplication process
of a non-terminating state save operation.

Parameters:
original
  Mode: Input.
  Type: StateSave.
  Presence: Required.
  Function: Specifies Trigger whose state is to be copied.
Return Value: None.
Exceptions: None.

• New
  Objective: This method initializes a Trigger.
  Parameters: None.
  Return Value: None.
  Exceptions: None.

• Delete
  Objective: This method disposes a Trigger.
  Parameters: None.
  Return Value: None.
  Exceptions: None.

• RegisterChild
  Objective: This method adds a child Trigger that is to be triggered when the current Trigger is triggered.
  Parameters:
    child
      Mode: Input.
      Type: Trigger.
      Presence: Required.
      Function: Specifies the child Trigger to be added.
  Return Value: None.
  Exceptions: None.

• DeRegisterChild
  Objective: This method removes a child Trigger from the current Trigger.
  Parameters:
    child
      Mode: Input.
      Type: Trigger.
      Presence: Required.
      Function: Specifies the child Trigger to be removed.
  Return Value: None.
  Exceptions: None.

• AddDelegate
  Objective: This method adds a Delegate to be scheduled for execution, when the Trigger is triggered, to a Trigger.
  Parameters:
    eventDelegate
      Mode: Input.
      Type: Delegate.
      Presence: Required.
Function: Specifies a Delegate to be executed when the Trigger is triggered.

SEC
Mode: Input.
Type: SimulationEngineComponent.
Presence: Required.
Function: Specifies the SimulationEngineComponent on which the Delegate is to be scheduled.

priority
Mode: Input.
Type: EventPriority.
Presence: Optional.
Function: Specifies a priority for the Delegate relative to other Delegates scheduled at the same simulation time.

Return Value: None.
Exceptions: None.

• **FireFirst**
Objective: This method schedules the immediate execution of the first Delegate scheduled (first-come-first-served) within a Trigger.
Parameters: None.
Return Value: None.
Exceptions: None.

• **Fire**
Objective: This method schedules the immediate execution of all delegates within a Trigger. This method also triggers all child Triggers to schedule the immediate execution of all their delegates, and to trigger any of their child Triggers. If a condition is specified, only delegates satisfying the condition are scheduled for execution within each Trigger.
Parameters:

condition
Mode: Input.
Type: Condition.
Presence: Optional.
Function: Specifies the condition to be satisfied.

Return Value: None.
Exceptions: None.

• **InterruptDelegate**
Objective: This method cancels the execution of a specific delegate within a Trigger.
Parameters:

thisDelegate
Mode: Input.
Type: Delegate.
Presence: Required.
Function: Specifies the Delegate to be interrupted.

Return Value: None.
Exceptions:

"Delegate to be interrupted not found"
Cause: Specified delegate does not exist within the collection of delegates within the Trigger.

Effect: Simulation terminates.

- **InterruptAllDelegates**
  
  Objective: This method cancels the execution of all delegates within a Trigger.
  
  Parameters: None.
  Return Value: None.
  Exceptions: None.

### A.4.2 TriggerCounter Interface

**Interface Diagram:**

![Interface Diagram](image-url)

**Figure A13. TriggerCounter Interface**

**Methods:**

- **ResolveReferences**
  
  Objective: This method resolves references for dynamically initialized attributes within a TriggerCounter.
  
  Parameters: None.
  Return Value: None.
  Exceptions: None.

- **RestoreReferences**
  
  Objective: This method restores references for dynamically initialized attributes within a TriggerCounter.
  
  Parameters: None.
  Return Value: None.
  Exceptions: None.

- **Create**
  
  Objective: This method creates an empty shell of a TriggerCounter during the state duplication process of a non-terminating state save operation.
  
  Parameters: None.
  Return Value:
  - Type: StateSave.
  - Function: Empty shell of TriggerCounter.
  Exceptions: None.
• **DuplicateState**
  Objective: This method copies the state of “original” to the current TriggerCounter during the state duplication process of a non-terminating state save operation.
  Parameters:
  - **original**
    Mode: Input.
    Type: StateSave.
    Presence: Required.
    Function: Specifies TriggerCounter whose state is to be copied.
  Return Value: None.
  Exceptions: None.

• **New**
  Objective: This method initializes a TriggerCounter.
  Parameters:
  - **count**
    Mode: Input.
    Type: Integer.
    Presence: Optional.
    Function: Specifies the number of delegates to be triggered.
  Return Value: None.
  Exceptions: None.

• **Destroy**
  Objective: This method disposes a TriggerCounter.
  Parameters: None.
  Return Value: None.
  Exceptions: None.

• **IncrementCount**
  Objective: This method increments the count of Delegates to be triggered within the TriggerCounter.
  Parameters: None.
  Return Value: None.
  Exceptions: None.

• **RegisterChild**
  Objective: This method adds a TriggerCounter that is to be triggered when the current TriggerCounter is triggered.
  Parameters:
  - **child**
    Mode: Input.
    Type: TriggerCounter.
    Presence: Required.
    Function: Specifies the child TriggerCounter to be added.
  Return Value: None.
  Exceptions: None.

• **DeRegisterChild**
  Objective: This method removes a child TriggerCounter from the current TriggerCounter.
Parameters:

child
Mode: Input.
Type: TriggerCounter.
Presence: Required.
Function: Specifies the child TriggerCounter to be removed.
Return Value: None.
Exceptions: None.

- **AddDelegate**
  
  Objective: This method adds a Delegate to be scheduled for execution, when a TriggerCounter is triggered, to a TriggerCounter. If the TriggerCounter has been triggered, then the Delegate is immediately scheduled for execution.

Parameters:

  eventDelegate
  Mode: Input.
  Type: Delegate.
  Presence: Required.
  Function: Specifies a Delegate to be executed when the TriggerCounter is triggered.

SEC
Mode: Input.
Type: SimulationEngineComponent.
Presence: Required.
Function: Specifies the SimulationEngineComponent on which the Delegate is to be scheduled.

priority
Mode: Input.
Type: EventPriority.
Presence: Optional.
Function: Specifies a priority for the Delegate relative to other Delegates scheduled at the same simulation time.

Return Value: None.
Exceptions: None.

- **Fire**
  
  Objective: This method schedules the immediate execution of all delegates within a TriggerCounter. This method also triggers all child TriggerCounters to schedule the immediate execution of all their delegates, and to trigger any of their child TriggerCounters. If a condition is specified, only delegates satisfying the condition are scheduled for execution within each TriggerCounter.

Parameters:

  condition
  Mode: Input.
  Type: Condition.
  Presence: Optional.
  Function: Specifies the condition to be satisfied.

Return Value: None.
Exceptions: None.
**InterruptDelegate**

Objective: This method cancels the execution of a specific delegate within a TriggerCounter.

Parameters:
- **thisDelegate**
  - Mode: Input.
  - Type: Delegate.
  - Presence: Required.
  - Function: Specifies the Delegate to be interrupted.

Return Value: None.

Exceptions:
- "Delegate to be interrupted not found"
- Cause: Specified delegate does not exist within the collection of delegates within the TriggerCounter.
- Effect: Simulation terminates.

**InterruptAllDelegates**

Objective: This method cancels the execution of all delegates within a TriggerCounter.

Parameters: None.

Return Value: None.

Exceptions: None.

A.4.3 *Join Interface*

**Interface Diagram:**

![Join Interface Diagram](image)

**Methods:**

- **ResolveReferences**
  - Objective: This method resolves references for dynamically initialized attributes within a Join.
  - Parameters: None.
  - Return Value: None.
  - Exceptions: None.

- **RestoreReferences**
  - Objective: This method restores references for dynamically initialized attributes within a Join.
  - Parameters: None.
  - Return Value: None.
Exceptions: None.

- **Create**
  
  **Objective:** This method creates an empty shell of a Join during the state duplication process of a non-terminating state save operation.
  
  **Parameters:** None.
  
  **Return Value:**
  
  **Type:** StateSave.
  
  **Function:** Empty shell of Join.
  
  **Exceptions:** None.

- **DuplicateState**
  
  **Objective:** This method copies the state of "original" to the current Join during the state duplication process of a non-terminating state save operation.
  
  **Parameters:**
  
  **original**
  
  **Mode:** Input.
  
  **Type:** StateSave.
  
  **Presence:** Required.
  
  **Function:** Specifies Join whose state is to be copied.
  
  **Return Value:** None.
  
  **Exceptions:** None.

- **New**
  
  **Objective:** This method initializes a Join with a specified number of paths, with each path specifying an event to wait for.
  
  **Parameters:**
  
  **nPaths**
  
  **Mode:** Input.
  
  **Type:** Integer.
  
  **Presence:** Required.
  
  **Function:** Specifies the number of input paths.
  
  **Return Value:** None.
  
  **Exceptions:**
  
  "Invalid number of paths"
  
  **Cause:** (nPaths < 1)
  
  **Effect:** Simulation terminates.

- **Delete**
  
  **Objective:** This method disposes a Join.
  
  **Parameters:** None.
  
  **Return Value:** None.
  
  **Exceptions:** None.

- **RegisterParent**
  
  **Objective:** This method sets the parent Join for the current Join, and indicates the specific path on which the current Join exists on the parent Join.
  
  **Parameters:**
  
  **parent**
  
  **Mode:** Input.
  
  **Type:** Join.
Presence: Required.
Function: Specifies the parent Join.

**parentPath**
Mode: Input.
Type: Integer.
Presence: Required.
Function: Specifies the path on which this Join exists on "parent".

Return Value: None.
Exceptions: None.

- **DeRegisterParent**
  Objective: This method removes the parent Join from the current Join.
  Parameters: None.
  Return Value: None.
  Exceptions: None.

- **SetDelegate**
  Objective: This method sets the Delegate to be executed after the Join has been satisfied. If all paths have been satisfied at least once,
  - The Delegate is scheduled for immediate execution
  - If a parent Join exists, it is updated on the specified path.
  - The number of events satisfied on each path is decremented by 1.
  Parameters:
    **eventDelegate**
    Mode: Input.
    Type: Delegate.
    Presence: Required.
    Function: Specifies a Delegate to be executed when the Join is triggered.
    SEC
    Mode: Input.
    Type: SimulationEngineComponent.
    Presence: Required.
    Function: Specifies the SimulationEngineComponent on which the Delegate is to be scheduled.
    priority
    Mode: Input.
    Type: EventPriority.
    Presence: Optional.
    Function: Specifies a priority for the Delegate relative to other Delegates scheduled at the same simulation time.
  Return Value: None.
  Exceptions: None.

- **Update**
  Objective: This method indicates that an event has occurred on a specific input path. If all paths have been satisfied at least once, and a Delegate has been specified,
The Delegate is scheduled for immediate execution
If a parent Join exists, it is updated on the specified path.
The number of events satisfied on each path is decremented by 1.

Parameters:

- **pathNumber**
  - **Mode:** Input.
  - **Type:** Integer.
  - **Presence:** Required.
  - **Function:** Specifies the number indicating the path that just received an input (numbered starting from 1).

Return Value: None.

Exceptions:
- "Path number out of bounds"
  - **Cause:** (pathNumber < 0) OR (pathNumber > (nPaths - 1)).
  - **Effect:** Simulation terminates.

### A.4.4 JoinCounter Interface

**Interface Diagram:**

![Interface Diagram](image)

**Methods:**

- **ResolveReferences**
  - **Objective:** This method resolves references for dynamically initialized attributes within a JoinCounter.
  - **Parameters:** None.
  - **Return Value:** None.
  - **Exceptions:** None.

- **RestoreReferences**
  - **Objective:** This method restores references for dynamically initialized attributes within a JoinCounter.
  - **Parameters:** None.
  - **Return Value:** None.
  - **Exceptions:** None.

- **Create**
  - **Objective:** This method creates an empty shell of a JoinCounter during the state duplication process of a non-

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• **DuplicateState**

Objective: This method copies the state of "original" to the current JoinCounter during the state duplication process of a non-terminating state save operation.

Parameters:
- **original**
  - Mode: Input.
  - Type: StateSave.
  - Presence: Required.
  - Function: Specifies JoinCounter whose state is to be copied.

Return Value: None.

Exceptions: None.

• **New**

Objective: This method initializes a JoinCounter with a specified number of events to wait for.

Parameters:
- **count**
  - Mode: Input.
  - Type: Integer.
  - Presence: Optional.
  - Function: Specifies the number of conditions to be satisfied.

Return Value: None.

Exceptions: None.

• **Delete**

Objective: This method disposes a JoinCounter.

Parameters: None.

Return Value: None.

Exceptions: None.

• **IncrementCount**

Objective: This method increments the number of events to occur, before the Delegate within a JoinCounter can be executed.

Parameters: None.

Return Value: None.

Exceptions: None.

• **RegisterParent**

Objective: This method sets the parent JoinCounter for the current JoinCounter

Parameters:
- **parent**
  - Mode: Input.
  - Type: JoinCounter.
  - Presence: Required.
  - Function: Specifies the parent JoinCounter.
• **DeRegisterParent**
Objective: This method removes the parent JoinCounter from the current JoinCounter.
Parameters: None.
Return Value: None.
Exceptions: None.

• **SetDelegate**
Objective: This method sets the Delegate to be executed after the JoinCounter has been satisfied. If the specified number of events have occurred,
  - The Delegate is scheduled for immediate execution
  - If a parent JoinCounter has been registered, it is updated.
  - The JoinCounter is reset.
Parameters:
  
  **eventDelegate**
  Mode: Input.
  Type: Delegate.
  Presence: Required.
  Function: Specifies a Delegate to be executed when the JoinCounter is satisfied.

  **SEC**
  Mode: Input.
  Type: SimulationEngineComponent.
  Presence: Required.
  Function: Specifies the SimulationEngineComponent on which the Delegate is to be scheduled.

  **priority**
  Mode: Input.
  Type: EventPriority.
  Presence: Optional.
  Function: Specifies a priority for the Delegate relative to other Delegates scheduled at the same simulation time.

Return Value: None.
Exceptions: None.

• **Update**
Objective: This method indicates that an event has occurred. If the specified number of events have occurred, and a Delegate has been specified,
  - The Delegate is scheduled for immediate execution
  - If a parent JoinCounter has been registered, it is updated.
  - The JoinCounter is reset.
Parameters: None.
Return Value: None.
Exceptions: None.
A.5 Random Number Generation Interfaces

A.5.1 RNG Interface

**Interface Diagram:**

<table>
<thead>
<tr>
<th>Method</th>
<th>Objective</th>
<th>Parameters</th>
<th>Return Value</th>
<th>Exceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>SetRNGSeed</td>
<td>This method sets the seed for the random number generator.</td>
<td>seed</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Random</td>
<td>This method returns a random floating-point number from the random number generator.</td>
<td>min, max</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Random</td>
<td>This method returns a random integer between “min” and “max” from the random number generator.</td>
<td>min, max</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>
Return Value:
Type: Integer.
Function: Random integer.
Exceptions: None.

- Constant
Objective: This method returns a random floating-point number from a Constant distribution between "min" and "max".
Parameters:
  - min
    Mode: Input.
    Type: Double.
    Presence: Required.
    Function: Specifies the minimum value of the random floating-point number.
  - max
    Mode: Input.
    Type: Double.
    Presence: Required.
    Function: Specifies the maximum value of the random floating-point number.
Return Value:
Type: Double.
Function: Random floating-point number from a Constant distribution.
Exceptions: None.

- Unit
Objective: This method returns a random floating-point number from a Unit distribution.
Parameters: None.
Return Value:
Type: Double.
Function: Random floating-point number from a Unit distribution.
Exceptions: None.

- Triangular
Objective: This method returns a random floating-point number from a Triangular distribution.
Parameters:
  - min
    Mode: Input.
    Type: Double.
    Presence: Required.
    Function: Specifies the minimum value for the Triangular distribution.
  - most
    Mode: Input.
    Type: Double.
    Presence: Required.
    Function: Specifies the most likely value for the Triangular distribution.
  - max
    Mode: Input.
Type: Double.
Presence: Required.
Function: Specifies the maximum value for the Triangular distribution.

Return Value:
Type: Double.
Function: Random floating-point number from a Triangular distribution.
Exceptions: None.

- **Exponential**

  Objective: This method returns a random floating-point number from an Exponential distribution.

  Parameters:
  - **mean**
    Mode: Input.
    Type: Double.
    Presence: Required.
    Function: Specifies the mean value for the Exponential distribution (mean > 0).

  Return Value:
  Type: Double.
  Function: Random floating-point number from an Exponential distribution.
  Exceptions: None.

- **Normal**

  Objective: This method returns a random floating-point number from a Normal distribution.

  Parameters:
  - **mean**
    Mode: Input.
    Type: Double.
    Presence: Required.
    Function: Specifies the mean value for the Normal distribution.
  - **standardDeviation**
    Mode: Input.
    Type: Double.
    Presence: Required.
    Function: Specifies the standard deviation for the Normal distribution.

  Return Value:
  Type: Double.
  Function: Random floating-point number from a Normal distribution.
  Exceptions: None.

- **Beta**

  Objective: This method returns a random floating-point number from a Beta distribution.

  Parameters:
  - **alpha**
    Mode: Input.
    Type: Double.
    Presence: Required.
Function: Specifies the alpha value for the Beta distribution
(alpha > 0).

**beta**
Mode: Input.
Type: Double.
Presence: Required.
Function: Specifies the beta value for the Beta distribution
(beta > 0).
Return Value:
Type: Double.
Function: Random floating-point number from a Beta
distribution.
Exceptions: None.

- **Gamma**
Objective: This method returns a random floating-point number
from a Gamma distribution.
Parameters:
  scale
    Mode: Input.
    Type: Double.
    Presence: Required.
    Function: Specifies the scale for the Gamma distribution
(scale > 0).
  shape
    Mode: Input.
    Type: Double.
    Presence: Required.
    Function: Specifies the shape for the Gamma distribution
(shape > 0).
Return Value:
Type: Double.
Function: Random floating-point number from a Gamma
distribution.
Exceptions: None.

- **Weibull**
Objective: This method returns a random floating-point number
from a Weibull distribution.
Parameters:
  scale
    Mode: Input.
    Type: Double.
    Presence: Required.
    Function: Specifies the scale for the Weibull distribution
(scale > 0).
  shape
    Mode: Input.
    Type: Double.
    Presence: Required.
    Function: Specifies the shape for the Weibull distribution
(shape > 0).
Return Value:
Type: Double.
Function: Random floating-point number from a Weibull
distribution.
A.5.2 AdvancedDistributions Interface

Interface Diagram:

![Interface Diagram](image)

Figure A17. AdvancedDistributions Interface

**Methods:**

- **ResolveReferences**
  
  **Objective:** This method resolves references for dynamically initialized attributes within an AdvancedDistributions.
  
  **Parameters:** None.
  
  **Return Value:** None.
  
  **Exceptions:** None.

- **RestoreReferences**
  
  **Objective:** This method restores references for dynamically initialized attributes within an AdvancedDistributions.
  
  **Parameters:** None.
  
  **Return Value:** None.
  
  **Exceptions:** None.

- **Create**
  
  **Objective:** This method creates an empty shell of an AdvancedDistributions during the state duplication process of a non-terminating state save operation.
  
  **Parameters:** None.
  
  **Return Value:**
  
  **Type:** StateSave.
  
  **Function:** Empty shell of AdvancedDistributions.
  
  **Exceptions:** None.
• **DuplicateState**
  Objective: This method copies the state of “original” to the current AdvancedDistributions during the state duplication process of a non-terminating state save operation.
  Parameters:
  - `original`
    - Mode: Input.
    - Type: StateSave.
    - Presence: Required.
    - Function: Specifies AdvancedDistributions whose state is to be copied.
  Return Value: None.
  Exceptions: None.

• **Clone**
  Objective: This method creates a clone of an AdvancedDistributions.
  Parameters: None.
  Return Value: None.
  Type: Replicable.
  Function: Clone of an AdvancedDistributions.
  Exceptions: None.

• **Modify**
  Objective: This method modifies an AdvancedDistributions by providing a new set of parameters. If any dependencies exist from the current AdvancedDistributions, it is transferred to the new parameters.
  Parameters:
  - `modifications`
    - Mode: Input.
    - Type: ArgumentList.
    - Presence: Required.
    - Function: Specifies the new parameters.
  Return Value: None.
  Exceptions: None.

• **Adjust**
  Objective: This method is not defined for an AdvancedDistributions.
  Parameters:
  - `adjustments`
    - Mode: Input.
    - Type: ArgumentList.
    - Presence: Required.
    - Function: Specifies the new parameters.
  Return Value: None.
  Exceptions:
  - “Adjust method not defined for this interface”
    - Cause: Method not defined for an AdvancedDistributions.
    - Effect: Simulation terminates.
• **Transfer**
  Objective: This method is not defined for an AdvancedDistributions.
  Parameters:
  
  `transferInformation`
  
  Mode: Input.
  Type: ArgumentList.
  Presence: Required.
  Function: Specifies the new parameters.
  Return Value: None.
  Exceptions:
  “Transfer method not defined for this interface”
  Cause: Method not defined for an AdvancedDistributions.
  Effect: Simulation terminates.

• **New**
  Objective: This method initializes an AdvancedDistributions.
  Parameters: None.
  Return Value: None.
  Exceptions: None.

• **Delete**
  Objective: This method disposes an AdvancedDistributions.
  Parameters: None.
  Return Value: None.
  Exceptions: None.

• **Initialize**
  Objective: This method initializes an AdvancedDistributions from a file.
  Parameters: None.
  Return Value: None.
  Exceptions: None.

• **SetNIndexedDistributions**
  Objective: This method initializes the number of independent indexed AdvancedDistributions within the current AdvancedDistributions.
  Parameters:
  
  `numIndexes`
  
  Mode: Input.
  Type: Integer.
  Presence: Required.
  Function: Specifies the number of independent indexed distributions.
  Return Value: None.
  Exceptions: None.

• **SetIndexedDistribution**
  Objective: This method initializes the number of independent indexed AdvancedDistributions within the current AdvancedDistributions.
  Parameters:
  
  `index`
Mode: Input.
Type: Integer.
Presence: Required.
Function: Specifies the index of the independent distribution.

distribution
Mode: Input.
Type: AdvancedDistributions.
Presence: Required.
Function: Specifies the independent indexed distribution.

similar
Mode: Input.
Type: Boolean.
Presence: Required.
Function: Specifies if the indexed distribution is the same as any other indexed distribution. TRUE if distribution is similar, else FALSE.

Return Value: None.
Exceptions:

"Attempt to index a non-indexed AdvancedDistributions"
Cause: AdvancedDistributions does not have indexed distributions.
Effect: Simulation terminates.

"Index out of bounds"
Cause: (index < 0) OR (index > (number of indexed types - 1)).
Effect: Simulation terminates.

• SetTotalModes
Objective: This method initializes the total number of modes for an AdvancedDistributions.
Parameters:

  total
  Mode: Input.
  Type: Integer.
  Presence: Required.
  Function: Specifies the total number of modes.
Return Value: None.
Exceptions: None.

• SetOrderedFlow
Objective: This method sets an ordered flow of operation within an AdvancedDistributions.
Parameters:

  order
  Mode: Input.
  Type: Boolean.
  Presence: Required.
  Function: Specifies if the distribution is ordered. TRUE if distribution is ordered, else FALSE.
Return Value: None.
Exceptions: None.

• SetNAssociatedDistributions
Objective: This method initializes the number of distributions associated with an AdvancedDistributions. More than 1 distribution may be associated with a single
independent distribution to support multimodal, blocked and ordered mode of operations.

Parameters:

**nDistributions**
- Mode: Input.
- Type: Integer.
- Presence: Required.
- Function: Specifies the number of distributions.
- Return Value: None.
- Exceptions: None.

- **SetParameters**

  Objective: This method initializes the parameters for each associated distribution within an AdvancedDistributions.

  Parameters:

  **distType**
  - Mode: Input.
  - Type: Type of Distribution.
  - Presence: Required.
  - Function: Specifies the type of distribution (Constant, Exponential, Normal, Triangular, Beta, Gamma or Weibull).

  **probability**
  - Mode: Input.
  - Type: Double.
  - Presence: Required.
  - Function: Specifies the probability value that is associated with each distribution. If the process is unimodal, then the probability value associated with that single distribution is always 1. If the process is multimodal, there is probability values associated with every modal distribution with the sum of probabilities of all the modes adding up to 1.

  **param1, param2, param3, param4**
  - Mode: Input.
  - Type: Double.
  - Presence: Required.
  - Function: Specifies the parameters for the various distributions (specified in the table below).

<table>
<thead>
<tr>
<th>Distribution</th>
<th>param1</th>
<th>param2</th>
<th>param3</th>
<th>param4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>Value</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Exponential</td>
<td>Mean</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Normal</td>
<td>Mean</td>
<td>Standard Deviation</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Triangular</td>
<td>Minimum</td>
<td>Maximum</td>
<td>Mode</td>
<td>N/A</td>
</tr>
<tr>
<td>Beta</td>
<td>Minimum</td>
<td>Maximum</td>
<td>Alpha</td>
<td>Beta</td>
</tr>
<tr>
<td>Gamma</td>
<td>Mean</td>
<td>N/A</td>
<td>Alpha</td>
<td>N/A</td>
</tr>
<tr>
<td>Weibull</td>
<td>Mean</td>
<td>N/A</td>
<td>Beta</td>
<td></td>
</tr>
</tbody>
</table>

- **index**
  - Mode: Input.
  - Type: Integer.
  - Presence: Required.
  - Function: Specifies the index of the associated distribution.
  - Return Value: None.
  - Exceptions:
"Invalid CONSTANT Distribution"
Cause: (Value < 0).
Effect: Simulation terminates.

"Invalid EXPONENTIAL Distribution"
Cause: (Mean <= 0).
Effect: Simulation terminates.

"Invalid NORMAL Distribution"
Cause: (Standard Deviation < 0).
Effect: Simulation terminates.

"Invalid TRIANGULAR Distribution"
Cause: (Minimum > Maximum) OR (Minimum >= Mode) OR (Mode >= Maximum).
Effect: Simulation terminates.

"Invalid BETA Distribution"
Cause: (Alpha <= 0 ) OR (((Maximum - Minimum) x Beta) <= 0).
Effect: Simulation terminates.

"Invalid GAMMA Distribution"
Cause: (Mean <= 0 ) OR (Alpha <= 0).
Effect: Simulation terminates.

"Invalid WEIBULL Distribution"
Cause: (Mean <= 0 ) OR (Beta <= 0).
Effect: Simulation terminates.

• SetWorkshiftParameters
Objective: This method initializes work shift parameters within an AdvancedDistributions.

Parameters:
workShift
Mode: Input.
Type: Double.
Presence: Required.
Function: Specifies the work shift for a day within the simulation (0 < work shift ≤ 24).

startTime
Mode: Input.
Type: Double.
Presence: Required.
Function: Specifies the work shift start time during a day within the simulation.

Return Value: None.
Exceptions: None.

• Random
Objective: This method returns a random floating-point number from an AdvancedDistributions. If an index is specified, then the specific distribution is used to generate the random number.

Parameters:
index
Mode: Input.
Type: Integer.
Presence: Optional.
Function: Specifies the index of the independent distribution.

Return Value:
Type: Double.
Function: Random floating-point number.
Exceptions:

"Attempt to index a non-indexed AdvancedDistributions"
  Cause: AdvancedDistributions does not have indexed distributions.
  Effect: Simulation terminates.

"Index out of bounds"
  Cause: (index < 0) OR (index > (numIndexedTypes - 1)).
  Effect: Simulation terminates.

• **RandomByWorkShift**
  
  **Objective:** This method returns a random floating-point number based on work shift from an AdvancedDistributions. If an index is specified, then the specific distribution is used to generate the random number.

  **Parameters:**

  `index`
  
  Mode: Input.
  Type: Integer.
  Presence: Optional.
  Function: Specifies the index of the independent distribution.

  **Return Value:**
  
  Type: Double.
  Function: Random floating-point number.

  **Exceptions:**

  "Attempt to index a non-indexed AdvancedDistributions"
  Cause: AdvancedDistributions does not have indexed distributions.
  Effect: Simulation terminates.

  "Index out of bounds"
  Cause: (index < 0) OR (index > (numIndexedTypes - 1)).
  Effect: Simulation terminates.

  "Invalid workshift time"
  Cause: (workShift > 24) OR (workShift not specified).
  Effect: Simulation terminates.

---

**A.6 Entity Management Interfaces**

**A.6.1 ** *Set Interface*

**Interface Diagram:**
Methods:

- **ResolveReferences**
  Objective: This method resolves references for dynamically initialized attributes within a Set.
  Parameters: None.
  Return Value: None.
  Exceptions: None.

- **RestoreReferences**
  Objective: This method restores references for dynamically initialized attributes within a Set.
  Parameters: None.
  Return Value: None.
  Exceptions: None.

- **Create**
  Objective: This method creates an empty shell of a Set during the state duplication process of a non-terminating state save operation.
  Parameters: None.
  Return Value:
  Type: StateSave.
  Function: Empty shell of Set.
  Exceptions: None.

- **DuplicateState**
  Objective: This method copies the state of "original" to the current Set during the state duplication process of a non-terminating state save operation.
  Parameters:
  **original**
  Mode: Input.
Type: StateSave.
Presence: Required.
Function: Specifies Set whose state is to be copied.
Return Value: None.
Exceptions: None.

- **Clone**
  Objective: This method creates a clone of a Set with all entities currently within the Set existing in the clone.
  Parameters: None.
  Return Value:
    - Type: Replicable.
    - Function: Clone of a Set.
  Exceptions: None.

- **New**
  Objective: This method initializes a Set.
  Parameters: None.
  Return Value: None.
  Exceptions: None.

- **Delete**
  Objective: This method disposes a Set.
  Parameters: None.
  Return Value: None.
  Exceptions: None.

- **GetNEntities**
  Objective: This method returns the current number of entities within a Set.
  Parameters: None.
  Return Value:
    - Type: Integer.
    - Function: Current number of entities in the Set.
  Exceptions: None.

- **Add**
  Objective: This method adds an entity to a Set.
  Parameters:
    - **thisEntity**
      - Mode: Input.
      - Type: Entity.
      - Presence: Required.
      - Function: Specifies the entity to be added to the Set.
  Return Value: None.
  Exceptions: None.

- **Union**
  Objective: This method creates a Union Set of the current Set and "set". Each element of "set" is added to the current Set.
  Parameters:
    - **set**
Next

Objective: This method returns the next entity after "thisEntity" within a Set. If "thisEntity" is NULL, it returns the first entity within the Set. A NULL is returned when there is no more unseen entity in the Set. If this method is continuously called till a NULL value is returned, then a new entity is returned each time.

Parameters:
thisEntity
  Mode: Input.
  Type: Entity.
  Presence: Required.
  Function: Specifies the current entity.
Return Value:
  Type: Entity.
  Function: Next entity after "thisEntity".
Exceptions: None.

SelectFirst

Objective: This method returns the first entity within a Set that satisfies a specified condition.

Parameters:
condition
  Mode: Input.
  Type: Condition.
  Presence: Required.
  Function: Specifies the condition to be satisfied.
Return Value:
  Type: Entity.
  Function: First entity that satisfies "condition".
Exceptions: None.

Select

Objective: This method returns a collection of entities within a Set that satisfies a specified condition.

Parameters:
condition
  Mode: Input.
  Type: Condition.
  Presence: Required.
  Function: Specifies the condition to be satisfied.
Return Value:
  Type: Set.
  Function: Set of entities that satisfy "condition".
Exceptions: None.
- **Remove**
  
  **Objective:** This method removes and returns the first entity within a Set that satisfies a specified condition. If a condition is not specified, then it removes and returns the first entity within a Set.

  **Parameters:**
  
  - **condition**
    
    - **Mode:** Input.
    - **Type:** Condition.
    - **Presence:** Optional.
    - **Function:** Specifies the condition to be satisfied.

  **Return Value:**
  
  - **Type:** Entity.
  - **Function:** First entity that satisfies "condition".

  **Exceptions:** None.

- **RemoveThis**
  
  **Objective:** This method removes a particular entity from a Set.

  **Parameters:**
  
  - **thisEntity**
    
    - **Mode:** Input.
    - **Type:** Entity.
    - **Presence:** Required.
    - **Function:** Specifies the entity to be removed.

  **Return Value:** None.

  **Exceptions:**
  
  - "Entity to be removed not found"
    
    - **Cause:** Specified entity does not exist within the Set.
    - **Effect:** Simulation terminates.

- **Includes**
  
  **Objective:** This method ascertains if a particular entity exists within a Set.

  **Parameters:**
  
  - **thisEntity**
    
    - **Mode:** Input.
    - **Type:** Entity.
    - **Presence:** Required.
    - **Function:** Specifies the entity to be checked.

  **Return Value:**
  
  - **Type:** Boolean.
  - **Function:** TRUE if entity exists, else FALSE.

  **Exceptions:** None.

- **Exists**
  
  **Objective:** This method ascertains if at least 1 entity exists within a Set that satisfies a specified condition.

  **Parameters:**
  
  - **condition**
    
    - **Mode:** Input.
    - **Type:** Condition.
    - **Presence:** Optional.
    - **Function:** Specifies the condition to be satisfied.

  **Return Value:**
  
  - **Type:** Boolean.
Function: TRUE if at least one entity that satisfies "condition" exists within the set, else FALSE.
Exceptions: None.

- **Each**
  Objective: This method ascertains if all the entities within a Set satisfy a particular specified condition.
  Parameters:
  condition
  Mode: Input.
  Type: Condition.
  Presence: Optional.
  Function: Specifies the condition to be satisfied.
  Return Value:
  Type: Boolean.
  Function: TRUE if all entities within the set satisfy "condition", else FALSE.
Exceptions: None.

- **ForEach**
  Objective: This method performs a particular operation specified by "routine" on each entity within a Set.
  Parameters:
  routine
  Mode: Input.
  Type: Routine.
  Presence: Optional.
  Function: Specifies a reference to the routine.
  Return Value: None.
Exceptions: None.

- **Dump**
  Objective: This method outputs all entities within a Set, using the specified output routine.
  Parameters:
  routine
  Mode: Input.
  Type: Routine.
  Presence: Optional.
  Function: Specifies a reference to the output routine.
  Return Value: None.
Exceptions: None.

- **Empty**
  Objective: This method empties a Set without disposing any of the entities within the Set.
  Parameters: None.
  Return Value: None.
Exceptions: None.

- **EmptyDispose**
  Objective: This method empties a Set and disposes of its contents using the specified routine.
  Parameters:
  routine
A.6.2 FIFO Interface

Interface Diagram:

![Interface Diagram](image)

**Methods:**

- **ResolveReferences**
  
  Objective: This method resolves references for dynamically initialized attributes within a FIFO.
  
  Parameters: None.
  
  Return Value: None.
  
  Exceptions: None.

- **RestoreReferences**
  
  Objective: This method restores references for dynamically initialized attributes within a FIFO.
  
  Parameters: None.
  
  Return Value: None.
  
  Exceptions: None.

- **Create**
  
  Objective: This method creates an empty shell of a FIFO during the state duplication process of a non-terminating state save operation.
  
  Parameters: None.
  
  Return Value:
  
  Type: StateSave.
  
  Function: Empty shell of FIFO.
• **DuplicateState**  
Objective: This method copies the state of “original” to the current FIFO during the state duplication process of a non-terminating state save operation.

Parameters:  
- `original`
  Mode: Input.
  Type: StateSave.
  Presence: Required.
  Function: Specifies FIFO whose state is to be copied.

Return Value: None.
Exceptions: None.

• **Clone**  
Objective: This method creates a clone of a FIFO with all entities currently within the FIFO existing in the clone.

Parameters: None.
Return Value: None.
Type: Replicable.
Function: Clone of a FIFO.
Exceptions: None.

• **New**  
Objective: This method initializes a FIFO.

Parameters: None.
Return Value: None.
Exceptions: None.

• **Delete**  
Objective: This method disposes a FIFO.

Parameters: None.
Return Value: None.
Exceptions: None.

• **GetNEntities**  
Objective: This method returns the current number of entities within a FIFO.

Parameters: None.
Return Value:  
  Type: Integer.
  Function: Current number of entities in the FIFO.
Exceptions: None.

• **Push**  
Objective: This method adds an entity to a FIFO.

Parameters:  
- `thisEntity`
  Mode: Input.
  Type: Entity.
  Presence: Required.
  Function: Specifies the entity to be added to the FIFO.
Return Value: None.
Exceptions: None.

Next
Objective: This method returns the next entity after “thisEntity” within a FIFO. If “thisEntity” is NULL, it returns the first entity within the FIFO. A NULL is returned when there is no more unseen entity in the FIFO. If this method is continuously called till a NULL value is returned, then a new entity is returned each time.

Parameters:
  thisEntity
    Mode: Input.
    Type: Entity.
    Presence: Required.
    Function: Specifies the current entity.

Return Value:
  Type: Entity.
  Function: Next entity after “thisEntity”.
Exceptions: None.

Pull
Objective: This method removes and returns the first entity within a FIFO.

Parameters: None.
Return Value:
  Type: Entity.
  Function: First entity that satisfies “condition”.
Exceptions: None.

PullThis
Objective: This method removes a particular entity from a FIFO.

Parameters:
  thisEntity
    Mode: Input.
    Type: Entity.
    Presence: Required.
    Function: Specifies the entity to be removed.

Return Value: None.
Exceptions:
  “Entity to be removed not found”
  Cause: Specified entity does not exist within the FIFO.
  Effect: Simulation terminates.

Includes
Objective: This method ascertains if a particular entity exists within a FIFO.

Parameters:
  thisEntity
    Mode: Input.
    Type: Entity.
    Presence: Required.
    Function: Specifies the entity to be checked.

Return Value:
Type: Boolean.
Function: TRUE if entity exists, else FALSE.
Exceptions: None.

• **Foreach**
  Objective: This method performs a particular operation specified by "routine" on each entity within a FIFO.
  Parameters:
  **routine**
  Mode: Input.
  Type: Routine.
  Presence: Optional.
  Function: Specifies a reference to the routine.
  Return Value: None.
  Exceptions: None.

• **Dump**
  Objective: This method outputs all entities within a FIFO, using the specified output routine.
  Parameters:
  **routine**
  Mode: Input.
  Type: Routine.
  Presence: Optional.
  Function: Specifies a reference to the output routine.
  Return Value: None.
  Exceptions: None.

• **Empty**
  Objective: This method empties a FIFO without disposing any of the entities within the FIFO.
  Parameters: None.
  Return Value: None.
  Exceptions: None.

• **EmptyDispose**
  Objective: This method empties a FIFO and disposes of its contents using the specified routine.
  Parameters:
  **routine**
  Mode: Input.
  Type: Routine.
  Presence: Optional.
  Function: Specifies a reference to the routine.
  Return Value: None.
  Exceptions: None.

### A.6.3 LIFO Interface

**Interface Diagram:**

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Methods:

- **ResolveReferences**
  
  Objective: This method resolves references for dynamically initialized attributes within a LIFO.
  
  Parameters: None.
  
  Return Value: None.
  
  Exceptions: None.

- **RestoreReferences**
  
  Objective: This method restores references for dynamically initialized attributes within a LIFO.
  
  Parameters: None.
  
  Return Value: None.
  
  Exceptions: None.

- **Create**
  
  Objective: This method creates an empty shell of a LIFO during the state duplication process of a non-terminating state save operation.
  
  Parameters: None.
  
  Return Value:
  
  Type: StateSave.
  
  Function: Empty shell of LIFO.
  
  Exceptions: None.

- **DuplicateState**
  
  Objective: This method copies the state of "original" to the current LIFO during the state duplication process of a non-terminating state save operation.
  
  Parameters:
  
  original
  
  Mode: Input.
  
  Type: StateSave.
  
  Presence: Required.
Function: Specifies LIFO whose state is to be copied.
Return Value: None.
Exceptions: None.

- **Clone**
  Objective: This method creates a clone of a LIFO with all entities currently within the LIFO existing in the clone.
  Parameters: None.
  Return Value: 
    - Type: Replicable.
    - Function: Clone of a LIFO.
  Exceptions: None.

- **New**
  Objective: This method initializes a LIFO.
  Parameters: None.
  Return Value: None.
  Exceptions: None.

- **Delete**
  Objective: This method disposes a LIFO.
  Parameters: None.
  Return Value: None.
  Exceptions: None.

- **GetNEntities**
  Objective: This method returns the current number of entities within a LIFO.
  Parameters: None.
  Return Value: 
    - Type: Integer.
    - Function: Current number of entities in the LIFO.
  Exceptions: None.

- **Push**
  Objective: This method adds an entity to a LIFO.
  Parameters:
    - **thisEntity**
      - Mode: Input.
      - Type: Entity.
      - Presence: Required.
      - Function: Specifies the entity to be added to the LIFO.
  Return Value: None.
  Exceptions: None.

- **Next**
  Objective: This method returns the next entity after "thisEntity" within a LIFO. If "thisEntity" is NULL, it returns the first entity within the LIFO. A NULL is returned when there is no more unseen entity in the LIFO. If this method is continuously called till a NULL value is returned, then a new entity is returned each time.
Parameters: 
\textit{thisEntity} 
\begin{itemize}
  \item Mode: Input.
  \item Type: Entity.
  \item Presence: Required.
  \item Function: Specifies the current entity.
\end{itemize}
Return Value: 
\begin{itemize}
  \item Type: Entity.
  \item Function: Next entity after "thisEntity".
\end{itemize}
Exceptions: None.

- \textbf{Pop} 
Objective: This method removes and returns the last entity within a LIFO.
Parameters: None.
Return Value: 
\begin{itemize}
  \item Type: Entity.
  \item Function: First entity that satisfies "condition".
\end{itemize}
Exceptions: None.

- \textbf{PopThis} 
Objective: This method removes a particular entity from a LIFO.
Parameters: 
\begin{itemize}
  \item \textit{thisEntity} 
  \item Mode: Input.
  \item Type: Entity.
  \item Presence: Required.
  \item Function: Specifies the entity to be removed.
\end{itemize}
Return Value: None.
Exceptions: 
\begin{itemize}
  \item "Entity to be removed not found"
  \item Cause: Specified entity does not exist within the LIFO.
  \item Effect: Simulation terminates.
\end{itemize}

- \textbf{Includes} 
Objective: This method ascertains if a particular entity exists within a LIFO.
Parameters: 
\begin{itemize}
  \item \textit{thisEntity} 
  \item Mode: Input.
  \item Type: Entity.
  \item Presence: Required.
  \item Function: Specifies the entity to be checked.
\end{itemize}
Return Value: 
\begin{itemize}
  \item Type: Boolean.
  \item Function: TRUE if entity exists, else FALSE.
\end{itemize}
Exceptions: None.

- \textbf{ForEach} 
Objective: This method performs a particular operation specified by "routine" on each entity within a LIFO.
Parameters: 
\begin{itemize}
  \item \textit{routine} 
  \item Mode: Input.
  \item Type: Routine.
\end{itemize}
• **Dump**
  
  **Objective:** This method outputs all entities within a LIFO, using the specified output routine.
  
  **Parameters:**
  - `routine`
    - **Mode:** Input.
    - **Type:** Routine.
    - **Presence:** Optional.
    - **Function:** Specifies a reference to the output routine.
  
  **Return Value:** None.
  
  **Exceptions:** None.

• **Empty**
  
  **Objective:** This method empties a LIFO without disposing any of the entities within the LIFO.
  
  **Parameters:** None.
  
  **Return Value:** None.
  
  **Exceptions:** None.

• **EmptyDispose**
  
  **Objective:** This method empties a LIFO and disposes of its contents using the specified routine.
  
  **Parameters:**
  - `routine`
    - **Mode:** Input.
    - **Type:** Routine.
    - **Presence:** Optional.
    - **Function:** Specifies a reference to the routine.
  
  **Return Value:** None.
  
  **Exceptions:** None.

### A.6.4 BinaryTree Interface

**Interface Diagram:**

---

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Methods:

- **ResolveReferences**
  - Objective: This method resolves references for dynamically initialized attributes within a BinaryTree.
  - Parameters: None.
  - Return Value: None.
  - Exceptions: None.

- **RestoreReferences**
  - Objective: This method restores references for dynamically initialized attributes within a BinaryTree.
  - Parameters: None.
  - Return Value: None.
  - Exceptions: None.

- **Create**
  - Objective: This method creates an empty shell of a BinaryTree during the state duplication process of a non-terminating state save operation.
  - Parameters: None.
  - Return Value:
    - Type: StateSave.
    - Function: Empty shell of BinaryTree.
  - Exceptions: None.

- **DuplicateState**
  - Objective: This method copies the state of "original" to the current BinaryTree during the state duplication process of a non-terminating state save operation.
  - Parameters:
    - **original**
      - Mode: Input.
      - Type: StateSave.
Presence: Required.
Function: Specifies BinaryTree whose state is to be copied.
Return Value: None.
Exceptions: None.

- **Clone**
  Objective: This method creates a clone of a BinaryTree with all entities currently within the BinaryTree existing in the clone.
  Parameters: None.
  Return Value:
    - Type: Replicable.
    - Function: Clone of a BinaryTree.
  Exceptions: None.

- **New**
  Objective: This method initializes a BinaryTree.
  Parameters: None.
  Return Value: None.
  Exceptions: None.

- **Delete**
  Objective: This method disposes a BinaryTree.
  Parameters: None.
  Return Value: None.
  Exceptions: None.

- **GetNEntities**
  Objective: This method returns the current number of entities within a BinaryTree.
  Parameters: None.
  Return Value:
    - Type: Integer.
    - Function: Current number of entities in the BinaryTree.
  Exceptions: None.

- **SetRankRoutine**
  Objective: This method sets a ranking routine for a BinaryTree, to be used when a new entity is added to the BinaryTree.
  Parameters:
  - rankRoutine
    - Mode: Input.
    - Type: EvaluateMethodReference.
    - Presence: Required.
    - Function: Specifies a reference to the ranking routine.
  Return Value: None.
  Exceptions: None.

- **Add**
  Objective: This method adds an entity to a BinaryTree.
  Parameters:
  - thisEntity
    - Mode: Input.
Type: Entity.
Presence: Required.
Function: Specifies the entity to be added to the BinaryTree.
Return Value: None.
Exceptions:
"No ranking routine defined"
Cause: A routine to rank the entities has not been defined.
Effect: Simulation terminates.

• **Next**
  Objective: This method returns the next entity after "thisEntity" within a BinaryTree. If "thisEntity" is NULL, it returns the first entity within the BinaryTree. A NULL is returned when there is no more unseen entity in the BinaryTree. If this method is continuously called till a NULL value is returned, then a new entity is returned each time.

Parameters:
**thisEntity**
- Mode: Input.
- Type: Entity.
- Presence: Required.
- Function: Specifies the current entity.

Return Value:
- Type: Entity.
- Function: Next entity after "thisEntity".

Exceptions: None.

• **Remove**
  Objective: This method removes and returns the first entity within a BinaryTree.

Parameters: None.

Return Value:
- Type: Entity.
- Function: First entity that satisfies "condition".

Exceptions: None.

• **RemoveThis**
  Objective: This method removes a particular entity from a BinaryTree.

Parameters:
**thisEntity**
- Mode: Input.
- Type: Entity.
- Presence: Required.
- Function: Specifies the entity to be removed.

Return Value: None.

Exceptions:
"Entity to be removed not found"
Cause: Specified entity does not exist within the BinaryTree.
Effect: Simulation terminates.

• **Includes**
  Objective: This method ascertains if a particular entity exists
Parameters: 

**thisEntity**
- **Mode:** Input.
- **Type:** Entity.
- **Presence:** Required.
- **Function:** Specifies the entity to be checked.

Return Value:
- **Type:** Boolean.
- **Function:** TRUE if entity exists, else FALSE.

Exceptions: None.

- **ForEach**
  
  Objective: This method performs a particular operation specified by “routine” on each entity within a BinaryTree.

  Parameters:
  - **routine**
    - **Mode:** Input.
    - **Type:** Routine.
    - **Presence:** Optional.
    - **Function:** Specifies a reference to the routine.

  Return Value: None.

  Exceptions: None.

- **Dump**
  
  Objective: This method outputs all entities within a BinaryTree, using the specified output routine.

  Parameters:
  - **routine**
    - **Mode:** Input.
    - **Type:** Routine.
    - **Presence:** Optional.
    - **Function:** Specifies a reference to the output routine.

  Return Value: None.

  Exceptions: None.

- **Empty**
  
  Objective: This method empties a BinaryTree without disposing any of the entities within the BinaryTree.

  Parameters: None.

  Return Value: None.

  Exceptions: None.

- **EmptyDispose**
  
  Objective: This method empties a BinaryTree and disposes of its contents using the specified routine.

  Parameters:
  - **routine**
    - **Mode:** Input.
    - **Type:** Routine.
    - **Presence:** Optional.
    - **Function:** Specifies a reference to the routine.

  Return Value: None.

  Exceptions: None.
A.6.5 PriorityQueue Interface

Interface Diagram:

```
<interface>StateSave
+ResolveReferences()
+RestoreReferences()
+Create(): StateSave
+DuplicateState(in original: StateSave)

<interface>Replicable
+Clone(): Replicable

<interface>PriorityQueue
+New()
+Delete()
+GetNEntities(): Integer
+Add(in thisEntity: Replicable)
+Next(in thisEntity: Replicable): Replicable
+Remove(): Replicable
+RemoveThis(in thisEntity: Replicable)
+Includes(in thisEntity: Replicable): Boolean
+ForEach(in routine: Routine)
+Dump(in outputRoutine: Routine)
+Empty()
+EmptyDispose(in routine: Routine)
```

Figure A22. PriorityQueue Interface

Methods:

- **ResolveReferences**
  - Objective: This method resolves references for dynamically initialized attributes within a PriorityQueue.
  - Parameters: None.
  - Return Value: None.
  - Exceptions: None.

- **RestoreReferences**
  - Objective: This method restores references for dynamically initialized attributes within a PriorityQueue.
  - Parameters: None.
  - Return Value: None.
  - Exceptions: None.

- **Create**
  - Objective: This method creates an empty shell of a PriorityQueue during the state duplication process of a non-terminating state save operation.
  - Parameters: None.
  - Return Value:
    - Type: StateSave.
    - Function: Empty shell of PriorityQueue.
  - Exceptions: None.

- **DuplicateState**
  - Objective: This method copies the state of "original" to the current PriorityQueue during the state duplication process of a non-terminating state save operation.
  - Parameters:
original

Mode: Input.
Type: StateSave.
Presence: Required.
Function: Specifies PriorityQueue whose state is to be copied.
Return Value: None.
Exceptions: None.

• Clone
Objective: This method creates a clone of a PriorityQueue with all entities currently within the PriorityQueue existing in the clone.
Parameters: None.
Return Value:
  Type: Replicable.
  Function: Clone of a PriorityQueue.
Exceptions: None.

• New
Objective: This method initializes a PriorityQueue.
Parameters: None.
Return Value: None.
Exceptions: None.

• Delete
Objective: This method disposes a PriorityQueue.
Parameters: None.
Return Value: None.
Exceptions: None.

• GetNEntities
Objective: This method returns the current number of entities within a PriorityQueue.
Parameters: None.
Return Value:
  Type: Integer.
  Function: Current number of entities in the PriorityQueue.
Exceptions: None.

• Add
Objective: This method adds an entity to a PriorityQueue, based on an assigned priority for the entity.
Parameters:
  thisEntity
  Mode: Input.
  Type: Entity.
  Presence: Required.
  Function: Specifies the entity to be added to the PriorityQueue.
Return Value: None.
Exceptions: None.

• Next
Objective: This method returns the next entity after
"thisEntity" within a PriorityQueue. If "thisEntity" is NULL, it returns the first entity within the PriorityQueue. A NULL is returned when there is no more unseen entity in the PriorityQueue. If this method is continuously called till a NULL value is returned, then a new entity is returned each time.

Parameters:

**thisEntity**
- **Mode:** Input.
- **Type:** Entity.
- **Presence:** Required.
- **Function:** Specifies the current entity.

Return Value:
- **Type:** Entity.
- **Function:** Next entity after "thisEntity".

Exceptions: None.

- **Remove**
  
  Objective: This method removes and returns the first entity within a PriorityQueue.
  
  Parameters: None.
  
  Return Value:
  - **Type:** Entity.
  - **Function:** First entity that satisfies "condition".
  
  Exceptions: None.

- **RemoveThis**
  
  Objective: This method removes a particular entity from a PriorityQueue.
  
  Parameters:
  
  **thisEntity**
  - **Mode:** Input.
  - **Type:** Entity.
  - **Presence:** Required.
  - **Function:** Specifies the entity to be removed.

  Return Value: None.

  Exceptions:
  - "Entity to be removed not found"
  - **Cause:** Specified entity does not exist within the PriorityQueue.
  - **Effect:** Simulation terminates.

- **Includes**
  
  Objective: This method ascertains if a particular entity exists within a PriorityQueue.
  
  Parameters:
  
  **thisEntity**
  - **Mode:** Input.
  - **Type:** Entity.
  - **Presence:** Required.
  - **Function:** Specifies the entity to be checked.

  Return Value:
  - **Type:** Boolean.
  - **Function:** TRUE if entity exists, else FALSE.

  Exceptions: None.
• **ForEach**
  
  **Objective:** This method performs a particular operation specified by "routine" on each entity within a PriorityQueue.

  **Parameters:**
  
  **routine**
  - **Mode:** Input.
  - **Type:** Routine.
  - **Presence:** Optional.
  - **Function:** Specifies a reference to the routine.

  **Return Value:** None.

  **Exceptions:** None.

• **Dump**
  
  **Objective:** This method outputs all entities within a PriorityQueue, using the specified output routine.

  **Parameters:**
  
  **routine**
  - **Mode:** Input.
  - **Type:** Routine.
  - **Presence:** Optional.
  - **Function:** Specifies a reference to the output routine.

  **Return Value:** None.

  **Exceptions:** None.

• **Empty**
  
  **Objective:** This method empties a PriorityQueue without disposing any of the entities within the PriorityQueue.

  **Parameters:** None.

  **Return Value:** None.

  **Exceptions:** None.

• **EmptyDispose**
  
  **Objective:** This method empties a PriorityQueue and disposes of its contents using the specified routine.

  **Parameters:**
  
  **routine**
  - **Mode:** Input.
  - **Type:** Routine.
  - **Presence:** Optional.
  - **Function:** Specifies a reference to the routine.

  **Return Value:** None.

  **Exceptions:** None.

**A.6.6 QueueWithStatistics Interface**

**Interface Diagram:**

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Methods:

• **ResolveReferences**
  Objective: This method resolves references for dynamically initialized attributes within a QueueWithStatistics.
  Parameters: None.
  Return Value: None.
  Exceptions: None.

• **RestoreReferences**
  Objective: This method restores references for dynamically initialized attributes within a QueueWithStatistics.
  Parameters: None.
  Return Value: None.
  Exceptions: None.

• **Create**
  Objective: This method creates an empty shell of a QueueWithStatistics during the state duplication process of a non-terminating state save operation.
  Parameters: None.
  Return Value: Type: StateSave.
  Function: Empty shell of QueueWithStatistics.
  Exceptions: None.

• **DuplicateState**
  Objective: This method copies the state of "original" to the current QueueWithStatistics during the state duplication process of a non-terminating state save operation.
  Parameters:
• **Clone**
  
  **Objective:** This method creates a clone of a QueueWithStatistics with all entities currently within the QueueWithStatistics existing in the clone.
  
  **Parameters:** None.
  
  **Return Value:** None.
  
  **Type:** Replicable.
  
  **Function:** Clone of a QueueWithStatistics.
  
  **Exceptions:** None.

• **New**
  
  **Objective:** This method initializes a QueueWithStatistics.
  
  **Parameters:** None.
  
  **Return Value:** None.
  
  **Exceptions:** None.

• **Delete**
  
  **Objective:** This method disposes a QueueWithStatistics.
  
  **Parameters:** None.
  
  **Return Value:** None.
  
  **Exceptions:** None.

• **Push**
  
  **Objective:** This method adds an entity to a QueueWithStatistics.
  
  **Parameters:**
  
  `thisEntity`
  
  **Mode:** Input.
  
  **Type:** Entity.
  
  **Presence:** Required.
  
  **Function:** Specifies the entity to be added to the QueueWithStatistics.
  
  **Return Value:** None.
  
  **Exceptions:** None.

• **Next**
  
  **Objective:** This method returns the next entity after "thisEntity" within a QueueWithStatistics. If "thisEntity" is NULL, it returns the first entity within the QueueWithStatistics. A NULL is returned when there is no more unseen entity in the QueueWithStatistics. If this method is continuously called till a NULL value is returned, then a new entity is returned each time.
  
  **Parameters:**
  
  `thisEntity`
  
  **Mode:** Input.
• **Pull**

Objective: This method removes and returns the first entity within a QueueWithStatistics.

Parameters: None.

Return Value:
- Type: Entity.
- Function: First entity that satisfies “condition”.

Exceptions: None.

• **PullThis**

Objective: This method removes a particular entity from a QueueWithStatistics.

Parameters: 
- **thisEntity**
  - Mode: Input.
  - Type: Entity.
  - Presence: Required.
  - Function: Specifies the entity to be removed.

Return Value: None.

Exceptions:
- "Entity to be removed not found"
- Cause: Specified entity does not exist within the QueueWithStatistics.
- Effect: Simulation terminates.

• **Includes**

Objective: This method ascertains if a particular entity exists within a QueueWithStatistics.

Parameters: 
- **thisEntity**
  - Mode: Input.
  - Type: Entity.
  - Presence: Required.
  - Function: Specifies the entity to be checked.

Return Value:
- Type: Boolean.
- Function: TRUE if entity exists, else FALSE.

Exceptions: None.

• **ForEach**

Objective: This method performs a particular operation specified by “routine” on each entity within a QueueWithStatistics.

Parameters: 
- **routine**
  - Mode: Input.
• **Dump**

Objective: This method outputs all entities within a QueueWithStatistics, using the specified output routine.

Parameters:
- **routine**
  - Mode: Input.
  - Type: Routine.
  - Presence: Optional.
  - Function: Specifies a reference to the output routine.

Return Value: None.
Exceptions: None.

• **Empty**

Objective: This method empties a QueueWithStatistics without disposing any of the entities within the QueueWithStatistics.

Parameters: None.
Return Value: None.
Exceptions: None.

• **EmptyDispose**

Objective: This method empties a QueueWithStatistics and disposes of its contents using the specified routine.

Parameters:
- **routine**
  - Mode: Input.
  - Type: Routine.
  - Presence: Optional.
  - Function: Specifies a reference to the routine.

Return Value: None.
Exceptions: None.

• **SampleNEntities**

Objective: This method records the current number of entities within a QueueWithStatistics.

Parameters: None.
Return Value: None.
Exceptions: None.

• **GetNEntities**

Objective: This method returns the current number of entities within a QueueWithStatistics.

Parameters: None.
Return Value:
- Type: Integer.
- Function: Current number of entities in the QueueWithStatistics.
Exceptions: None.

- **GetTotalNEntities**
  Objective: This method returns the total number of entities to exist within a QueueWithStatistics for the duration of the simulation.
  Parameters: None.
  Return Value:
  Type: Long.
  Function: Total number of entities in the QueueWithStatistics.
  Exceptions: None.

- **GetMaxNEntities**
  Objective: This method returns the maximum number of entities to exist within a QueueWithStatistics at any instant, for the duration of the simulation.
  Parameters: None.
  Return Value:
  Type: Integer.
  Function: Maximum number of entities in the QueueWithStatistics.
  Exceptions: None.

- **GetAverageNEntities**
  Objective: This method returns the average number of entities to exist within a QueueWithStatistics for the duration of the simulation.
  Parameters: None.
  Return Value:
  Type: Integer.
  Function: Average number of entities in the QueueWithStatistics.
  Exceptions: None.

- **GetAverageWaitTime**
  Objective: This method returns the average time that each entity existed within a QueueWithStatistics for the duration of the simulation.
  Parameters: None.
  Return Value:
  Type: Double.
  Function: Average wait time of each entity in the QueueWithStatistics.
  Exceptions: None.

A.4.7 EntityCounter Interface

Interface Diagram:
Methods:

- **ResolveReferences**
  
  Objective: This method resolves references for dynamically initialized attributes within an EntityCounter.
  
  Parameters: None.
  
  Return Value: None.
  
  Exceptions: None.

- **RestoreReferences**
  
  Objective: This method restores references for dynamically initialized attributes within an EntityCounter.
  
  Parameters: None.
  
  Return Value: None.
  
  Exceptions: None.

- **Create**
  
  Objective: This method creates an empty shell of an EntityCounter during the state duplication process of a non-terminating state save operation.
  
  Parameters: None.
  
  Return Value:
  
  Type: StateSave.
  
  Function: Empty shell of EntityCounter.
  
  Exceptions: None.

- **DuplicateState**
  
  Objective: This method copies the state of “original” to the current EntityCounter during the state duplication process of a non-terminating state save operation.
  
  Parameters:
original
Mode: Input.
Type: StateSave.
Presence: Required.
Function: Specifies EntityCounter whose state is to be copied.
Return Value: None.
Exceptions: None.

• Clone
Objective: This method creates a clone of an EntityCounter with the number of entities in the clone equal to the number of entities currently within the EntityCounter.
Parameters: None.
Return Value: None.
Type: Replicable.
Function: Clone of an EntityCounter.
Exceptions: None.

• Modify
Objective: This method is not defined for an EntityCounter.
Parameters:
modifications
Mode: Input.
Type: ArgumentList.
Presence: Required.
Function: Specifies the new parameters.
Return Value: None.
Exceptions:
"Modify method not defined for this interface"
Cause: Method not defined for an EntityCounter.
Effect: Simulation terminates.

• Adjust
Objective: This method increases or decreases the number of entities within an EntityCounter based on an offset. If insufficient entities currently exist to satisfy a decrease in number of entities, all existing entities are immediately removed, and all entities subsequently released back to the EntityCounter, are removed till the decrease is complete.
Parameters:
adjustments
Mode: Input.
Type: ArgumentList.
Presence: Required.
Function: Specifies the new parameters.
Return Value: None.
Exceptions:
"Insufficient arguments for Adjust method"
Cause: Not enough arguments within "adjustments".
Effect: Simulation terminates.

• Transfer
Objective: This method invokes TransferToEntityCounter or
TransferToEntityPool for an EntityCounter, with the appropriate parameters based on "transferInformation".

Parameters:

- **transferInformation**
  - Mode: Input.
  - Type: ArgumentList.
  - Presence: Required.
  - Function: Specifies the new parameters.
  - Return Value: None.
  - Exceptions:
    - "Insufficient arguments for Transfer method"
    - Cause: Not enough arguments within "transferInformation".
    - Effect: Simulation terminates.

**New**

Objective: This method initializes an EntityCounter.

Parameters:

- **priority**
  - Mode: Input.
  - Type: Boolean.
  - Presence: Required.
  - Function: Specifies if unsatisfied requests are queued based on priority within the EntityCounter.

- **entityCount**
  - Mode: Input.
  - Type: Integer.
  - Presence: Optional.
  - Function: Specifies the initial number of entities within the EntityCounter.

  Return Value: None.
  - Exceptions: None.

**Delete**

Objective: This method disposes an EntityCounter.

Parameters: None.

Return Value: None.

Exceptions: None.

**GetNEntities**

Objective: This method returns the current number of entities within an EntityCounter.

Parameters: None.

Return Value:

- Type: Integer.
- Function: Current number of entities in the EntityCounter.

Exceptions: None.

**AddSingle**

Objective: This method increments the count of entities within an EntityCounter by 1.

Parameters: None.

Return Value: None.

Exceptions: None.
- **AddMultiple**
  
  **Objective:** This method increments the count of entities within an EntityCounter by "nEntities".

  **Parameters:**
  - **nEntities**
    - Mode: Input.
    - Type: Integer.
    - Presence: Required.
    - Function: Specifies the number of entities to be added.

  **Return Value:** None.

  **Exceptions:**
  - "Invalid number of entities to be added"
    - Cause: "nEntities" < 0.
    - Effect: Simulation terminates.

- **RequestSingleAtomic**
  
  **Objective:** This method makes an atomic request for a single entity to an EntityCounter. If an entity is available, then a TRUE value is returned else a FALSE value is returned.

  **Parameters:**
  - **Return Value:** None.

  **Exceptions:**
  - None.

- **RequestSingle**
  
  **Objective:** This method makes a request for a single entity to an EntityCounter. If an entity is available, then the Delegate is immediately scheduled for execution. If an entity is not available, then the request is queued and serviced in a FCFS manner. If a priority has been specified, then the request is queued with the appropriate priority relative to other pending requests.

  **Parameters:**
  - **priority**
    - Mode: Input.
    - Type: Priority Value.
    - Presence: Optional.
    - Function: Specifies the priority of the request relative to pending requests.
  
  - **eventDelegate**
    - Mode: Input.
    - Type: Delegate.
    - Presence: Required.
    - Function: Specifies the delegate to be scheduled when request is satisfied.

  **Return Value:**
  - Type: RequestID.
  - Function: -1 if request is satisfied, else ID of pending request.

  **Exceptions:**
  - None.
**RequestMultipleAtomic**

**Objective:** This method makes an atomic request for "nEntities" to an EntityCounter. If the requested entities are available, then a TRUE value is returned else a FALSE value is returned.

**Parameters:**

- **nEntities**
  - Mode: Input.
  - Type: Integer.
  - Presence: Required.
  - Function: Specifies the number of requested entities.

**Return Value:**
- Type: Boolean.
- Function: TRUE if entities are available, else FALSE.

**Exceptions:**
- "Invalid number of requested entities"
  - Cause: "nEntities" < 0.
  - Effect: Simulation terminates.

**RequestMultiple**

**Objective:** This method makes a request for "nEntities" to an EntityCounter. If the requested entities are available, then the Delegate is immediately scheduled for execution. If the requested entities are not available, then the request is queued and serviced in a FCFS manner. If a priority has been specified, then the request is queued with the appropriate priority relative to other pending requests.

**Parameters:**

- **nEntities**
  - Mode: Input.
  - Type: Integer.
  - Presence: Required.
  - Function: Specifies the number of requested entities.

- **priority**
  - Mode: Input.
  - Type: Priority Value.
  - Presence: Optional.
  - Function: Specifies the priority of the request relative to pending requests.

- **eventDelegate**
  - Mode: Input.
  - Type: Delegate.
  - Presence: Required.
  - Function: Specifies the delegate to be scheduled when request is satisfied.

**Return Value:**
- Type: RequestID.
- Function: -1 if request is satisfied, else ID of pending request.

**Exceptions:**
- "Invalid number of requested entities"
  - Cause: "nEntities" < 0.
  - Effect: Simulation terminates.
- **RequestAvailableAtomic**

  **Objective:** This method makes an atomic request for "nEntities" to an EntityCounter. If no entities are available, then a value of -1 is returned, else the minimum value between "nEntities" and currently available entities in the EntityCounter is returned.

  **Parameters:**
  - **nEntities**
    - Mode: Input.
    - Type: Integer.
    - Presence: Required.
    - Function: Specifies the number of requested entities.

  **Return Value:**
  - Type: Integer.
  - Function: minimum value of "nEntities" and available entities, -1 if none available.

  **Exceptions:**
  - "Invalid number of requested entities"
    - Cause: "nEntities" < 0.
    - Effect: Simulation terminates.

- **RequestAvailable**

  **Objective:** This method makes a request for "nEntities" to an EntityCounter. If at least 1 entity is available, then the Delegate is immediately scheduled for execution, with the number of available entities passed as a return argument by value for the event method ArgumentList within the Delegate. If no entities are available or if the number of available entities is less than "nEntities", then the request is queued and serviced in a FCFS manner. If a priority has been specified, then the request is queued with the appropriate priority relative to other pending requests. The Delegate is scheduled for execution every time new entities become available till the request is completely satisfied.

  **Parameters:**
  - **nEntities**
    - Mode: Input.
    - Type: Integer.
    - Presence: Required.
    - Function: Specifies the number of requested entities.
  - **priority**
    - Mode: Input.
    - Type: Priority Value.
    - Presence: Optional.
    - Function: Specifies the priority of the request relative to pending requests.
  - **eventDelegate**
    - Mode: Input.
    - Type: Delegate.
    - Presence: Required.
    - Function: Specifies the delegate to be scheduled when request is satisfied.

  **Return Value:**
  - Type: RequestID.
Function: -1 if request is satisfied, else ID of pending request.

Exceptions:
"Invalid number of requested entities"
CAUSE: "nEntities" < 0.
Effect: Simulation terminates.

- **ReleaseSingle**
  Objective: This method releases a single entity back to an EntityCounter. It increments the count of entities within the EntityCounter by 1.
  Parameters: None.
  Return Value: None.
  Exceptions: None.

- **ReleaseMultiple**
  Objective: This method releases "nEntities" back to an EntityCounter. It increments the count of entities within the EntityCounter by "nEntities".
  Parameters:
  - `nEntities`
    Mode: Input.
    Type: Integer.
    Presence: Required.
    Function: Specifies the number of entities to be released.
  Return Value: None.
  Exceptions:
  - "Invalid number of entities to be released"
    Cause: "nEntities" < 0.
    Effect: Simulation terminates.

- **ReAssign**
  Objective: This method transfers "nEntities" from a collection of EntityCounters to the "destination" EntityCounter. This method behaves similarly to the RequestAvailable method and tries to satisfy the entire request, or whatever part of the request it can satisfy. If the current EntityCounter cannot completely satisfy the request, then it queues the request within itself, and then passes along the request to the next EntityCounter in "sourcePoolList". If a transfer request is partially satisfied by any EntityCounter subsequently, then all EntityCounters within "sourcePoolList" update their pending requests accordingly. If a transfer request is completely satisfied by any EntityCounter subsequently, then all EntityCounters within "sourcePoolList" remove the request from their collection of pending requests.
  Parameters:
  - `sourcePoolList`
    Mode: Input.
    Type: Set.
    Presence: Required.
    Function: Specifies the collection of source EntityCounters.
  - `destination`
    Mode: Input.
Mode: Input.
Type: EntityCounter.
Presence: Required.
Function: Specifies the destination EntityCounter.

nEntities
Mode: Input.
Type: Integer.
Presence: Required.
Function: Specifies the number of entities to be reassigned.

eventDelegate
Mode: Input.
Type: Delegate.
Presence: Required.
Function: Specifies the delegate to be scheduled when transfer is complete.
Return Value: None.
Exceptions:
"Invalid source EntityCounters"
  Cause: Invalid list of source EntityCounters.
  Effect: Simulation terminates.
"Invalid destination EntityCounter"
  Cause: Invalid destination EntityCounter.
  Effect: Simulation terminates.
"Invalid number of entities to be reassigned"
  Cause: "nEntities" < 0.
  Effect: Simulation terminates.

• ReturnReAssigned
Objective: This method returns the entities back to the source EntityCounters where they were transferred from.
Parameters: None.
Return Value: None.
Exceptions:
"Invalid source EntityCounters"
  Cause: Invalid list of source EntityCounters.
  Effect: Simulation terminates.

• TransferToEntityCounter
Objective: This method permanently transfers "nEntities" from an EntityCounter to the "destination" EntityCounter. If sufficient entities exist to satisfy the transfer, "nEntities" are immediately transferred to "destination". If insufficient entities currently exist, all existing entities are immediately transferred, and all entities subsequently released back to the EntityCounter, are transferred till the transfer is complete.
Parameters:
  destination
  Mode: Input.
  Type: EntityCounter.
  Presence: Required.
  Function: Specifies the destination EntityCounter.
  nEntities
  Mode: Input.
  Type: Integer.
Presence: Required.
Function: Specifies the number of entities to be transferred.
Return Value: None.
Exceptions: None.

"Invalid destination EntityCounter"
Cause: Invalid destination EntityCounter.
Effect: Simulation terminates.

"Invalid number of entities to be transferred"
Cause: “nEntities” < 0.
Effect: Simulation terminates.

• **TransferToEntityPool**

Objectives: This method permanently transfers “nEntities” from an EntityCounter to the “destination” EntityPool. If sufficient entities exist to satisfy the transfer, “entity” is cloned “nEntities” times and immediately transferred to “destination”. If insufficient entities currently exist, all existing entities are immediately cloned and transferred, and all entities released back to the EntityCounter are cloned and transferred till the transfer is complete.

Parameters:

**destination**
- Mode: Input.
- Type: EntityPool.
- Presence: Required.
- Function: Specifies the destination EntityPool.

**nEntities**
- Mode: Input.
- Type: Integer.
- Presence: Required.
- Function: Specifies the number of entities to be transferred.

**entity**
- Mode: Input.
- Type: Replicable.
- Presence: Required.
- Function: Specifies the entity to be cloned during transfer.

Return Value: None.
Exceptions: None.

"Invalid destination EntityPool"
Cause: Invalid destination EntityPool.
Effect: Simulation terminates.

"Invalid number of entities to be transferred"
Cause: “nEntities” < 0.
Effect: Simulation terminates.

"Invalid entity for cloning"
Cause: Invalid entity to be cloned during transfer.
Effect: Simulation terminates.

• **InterruptRequest**

Objectives: This method interrupts a pending request within an EntityCounter. The interrupt method within the Delegate, if defined, is executed.

Parameters:

**requestID**
- Mode: Input.
Type: RequestID.
Presence: Required.
Function: Specifies the ID of the pending request.
Return Value: None.
Exceptions:
  "Request to be interrupted not found"
  Cause: Specified request does not exist within collection of pending requests.
  Effect: Simulation terminates.

A.4.8 EntityPool Interface

Interface Diagram:

```
+Clone(): Replicable
«interface» Replicable
+Modify(in modifications: ArgumentList)
+Adjust(in adjustments: ArgumentList)
+Transfer(in transferInformation: ArgumentList)

+ResolveReferences()
+RestoreReferences()
+Create(): StateSave
+DuplicateState(original: StateSave)

+New(in priority: boolean, in entitySet: Set)
+Delete()
+AddSingle(in entity: Replicable)
+AddMultiple(in entitySet: Set)
+RequestSingleAtomic(in condition: Condition): Replicable
+RequestMultipleAtomic(in nEntities: Integer, in condition: Condition): Set
+RequestAvailableAtomic(in nEntities: Integer, in condition: Condition): Set
+ReleaseSingle(in entity: Replicable)
+ReleaseMultiple(in entitySet: Set)
+ReturnReAssigned()
+TransferToEntityPool(in destination: EntityPool, in nEntities: Integer, in entity: Replicable)
+TransferToEntityCounter(in destination: EntityCounter, in nEntities: Integer)
+InterruptRequest(in requestId: RequestID)

+ResolveReferences()
+RestoreReferences()
+Create(): StateSave
+DuplicateState(original: StateSave)

+New(in priority: boolean, in entitySet: Set)
+Delete()
+AddSingle(in entity: Replicable)
+AddMultiple(in entitySet: Set)
+RequestSingleAtomic(in condition: Condition): Replicable
+RequestMultipleAtomic(in nEntities: Integer, in condition: Condition): Set
+RequestAvailableAtomic(in nEntities: Integer, in condition: Condition): Set
+ReleaseSingle(in entity: Replicable)
+ReleaseMultiple(in entitySet: Set)
+ReturnReAssigned()
+TransferToEntityPool(in destination: EntityPool, in nEntities: Integer, in entity: Replicable)
+TransferToEntityCounter(in destination: EntityCounter, in nEntities: Integer)
+InterruptRequest(in requestId: RequestID)
```

Figure A25. EntityPool Interface

Methods:

- **ResolveReferences**
  Objective: This method resolves references for dynamically initialized attributes within an EntityPool.
  Parameters: None.
  Return Value: None.
  Exceptions: None.

- **RestoreReferences**
  Objective: This method restores references for dynamically initialized attributes within an EntityPool.
  Parameters: None.
  Return Value: None.
  Exceptions: None.
• **Create**
  
  **Objective:** This method creates an empty shell of an EntityPool during the state duplication process of a non-terminating state save operation.

  **Parameters:** None.

  **Return Value:**
  
  Type: StateSave.
  
  Function: Empty shell of EntityPool.

  **Exceptions:** None.

• **DuplicateState**
  
  **Objective:** This method copies the state of "original" to the current EntityPool during the state duplication process of a non-terminating state save operation.

  **Parameters:**
  
  original
  
  Mode: Input.
  
  Type: StateSave.
  
  Presence: Required.
  
  Function: Specifies EntityPool whose state is to be copied.

  **Return Value:** None.

  **Exceptions:** None.

• **Clone**
  
  **Objective:** This method creates a clone of an EntityPool with the number of entities in the clone equal to the number of entities currently within the EntityPool.

  **Parameters:** None.

  **Return Value:**
  
  Type: Replicable.
  
  Function: Clone of an EntityPool.

  **Exceptions:** None.

• **Modify**
  
  **Objective:** This method is not defined for an EntityPool.

  **Parameters:**
  
  modifications
  
  Mode: Input.
  
  Type: ArgumentList.
  
  Presence: Required.
  
  Function: Specifies the new parameters.

  **Return Value:** None.

  **Exceptions:** "Modify method not defined for this interface"

  Cause: Method not defined for an EntityPool.

  Effect: Simulation terminates.

• **Adjust**
  
  **Objective:** This method increases or decreases the entities within an EntityPool based on an offset. An entity should be provided when increasing the number of entities, so that it can be cloned and added to the EntityPool. If insufficient entities currently exist to satisfy a decrease in entities, all existing entities are immediately removed, and all entities
released back to the EntityPool, are removed till the decrease is complete.

Parameters:

**adjustments**
- Mode: Input.
- Type: ArgumentList.
- Presence: Required.
- Function: Specifies the new parameters.
- Return Value: None.
- Exceptions:
  - "Insufficient arguments for Adjust method"
  - Cause: Not enough arguments within "adjustments".
  - Effect: Simulation terminates.

**Transfer**
- Objective: This method invokes TransferToEntityPool or TransferToEntityCounter for an EntityPool, with the appropriate parameters based on "transferInformation".

Parameters:

**transferInformation**
- Mode: Input.
- Type: ArgumentList.
- Presence: Required.
- Function: Specifies the new parameters.
- Return Value: None.
- Exceptions:
  - "Insufficient arguments for Transfer method"
  - Cause: Not enough arguments within "transferInformation".
  - Effect: Simulation terminates.

**New**
- Objective: This method initializes an EntityPool.

Parameters:

**priority**
- Mode: Input.
- Type: Boolean.
- Presence: Required.
- Function: Specifies if unsatisfied requests are queued based on priority within the EntityPool.

**entitySet**
- Mode: Input.
- Type: Set.
- Presence: Optional.
- Function: Specifies the initial set of entities within the EntityPool.

- Return Value: None.
- Exceptions: None.

**Delete**
- Objective: This method disposes an EntityPool.

Parameters: None.

- Return Value: None.
- Exceptions: None.
- **GetNEntities**
  
  **Objective:** This method returns the current number of entities within an EntityPool.
  
  **Parameters:** None.
  
  **Return Value:** None.
  
  **Type:** Integer.
  
  **Function:** Current number of entities in the EntityPool.
  
  **Exceptions:** None.

- **AddSingle**
  
  **Objective:** This method adds an entity to an EntityPool.
  
  **Parameters:**
  
<table>
<thead>
<tr>
<th>entity</th>
</tr>
</thead>
</table>
  
  **Mode:** Input.
  
  **Type:** Entity.
  
  **Presence:** Required.
  
  **Function:** Specifies the entity to be added to the EntityPool.
  
  **Return Value:** None.
  
  **Exceptions:** None.

- **AddMultiple**
  
  **Objective:** This method adds a collection of entities to an EntityPool.
  
  **Parameters:**
  
<table>
<thead>
<tr>
<th>entitySet</th>
</tr>
</thead>
</table>
  
  **Mode:** Input.
  
  **Type:** Set.
  
  **Presence:** Required.
  
  **Function:** Specifies the collection of entities to be added to the EntityPool.
  
  **Return Value:** None.
  
  **Exceptions:**
  
  "Invalid collection of entities to be added"
  
  **Cause:** Invalid set of entities.
  
  **Effect:** Simulation terminates.

- **RequestSingleAtomic**
  
  **Objective:** This method makes an atomic request for a single entity to an EntityPool. If an entity is available, then it is returned, else a NULL value is returned. If a condition is specified, then an entity that satisfies the condition is returned.
  
  **Parameters:**
  
<table>
<thead>
<tr>
<th>condition</th>
</tr>
</thead>
</table>
  
  **Mode:** Input.
  
  **Type:** Condition.
  
  **Presence:** Optional.
  
  **Function:** Specifies the condition to be satisfied.
  
  **Return Value:** None.
  
  **Type:** Entity.
  
  **Function:** Entity if available, NULL if not.
  
  **Exceptions:** None.

- **RequestSingle**

  **Objective:** This method makes a request for a single entity to
the EntityPool. If an entity is available, then the Delegate is immediately scheduled for execution, with the entity passed as a return argument by reference for the event method ArgumentList within the Delegate. If a condition is specified, then an entity that satisfies the condition is returned. If an entity is not available, then the request is queued and serviced in a FCFS manner. If a priority has been specified, then the request is queued with the appropriate priority relative to other pending requests.

Parameters:

**priority**
- Mode: Input.
- Type: Priority Value.
- Presence: Optional.
- Function: Specifies the priority of the request relative to pending requests.

**condition**
- Mode: Input.
- Type: Condition.
- Presence: Optional.
- Function: Specifies the condition to be satisfied.

**eventDelegate**
- Mode: Input.
- Type: Delegate.
- Presence: Required.
- Function: Specifies the delegate to be scheduled when request is satisfied.

Return Value:
- Mode: RequestID.
- Type: RequestID.
- Function: -1 if request is satisfied, else ID of pending request.

Exceptions: None.

- **RequestMultipleAtomic**
  
  Objective: This method makes an atomic request for “nEntities” to an EntityPool. If the requested entities are available, then a Set containing the entities is returned, else a NULL value is returned. If a condition is specified, then entities that satisfy the condition are returned.

Parameters:

**nEntities**
- Mode: Input.
- Type: Integer.
- Presence: Required.
- Function: Specifies the number of requested entities.

**condition**
- Mode: Input.
- Type: Condition.
- Presence: Optional.
- Function: Specifies the condition to be satisfied.

Return Value:
- Mode: Set.
- Type: Set.
- Function: Set containing the entities if available, NULL if
Exceptions:

"Invalid number of requested entities"
Cause: "nEntities" < 0.
Effect: Simulation terminates.

- **RequestMultiple**
  Objective: This method makes a request for "nEntities" entities to an EntityPool. If the requested entities are available, then the Delegate is immediately scheduled for execution, with the Set containing the entities passed as a return argument by reference for the event method ArgumentList within the Delegate. If a condition is specified, then entities that satisfy the condition are returned. If the requested entities are not available, then the request is queued and serviced in a FCFS manner. If a priority has been specified, then the request is queued with the appropriate priority relative to other pending requests.

Parameters:

* **nEntities**
  Mode: Input.
  Type: Integer.
  Presence: Required.
  Function: Specifies the number of requested entities.

* **priority**
  Mode: Input.
  Type: Priority Value.
  Presence: Optional.
  Function: Specifies the priority of the request relative to pending requests.

* **condition**
  Mode: Input.
  Type: Condition.
  Presence: Optional.
  Function: Specifies the condition to be satisfied.

* **eventDelegate**
  Mode: Input.
  Type: Delegate.
  Presence: Required.
  Function: Specifies the delegate to be scheduled when request is satisfied.

Return Value:

Type: RequestID.
Function: -1 if request is satisfied, else ID of pending request.

Exceptions:

"Invalid number of requested entities"
Cause: "nEntities" < 0.
Effect: Simulation terminates.

- **RequestAvailableAtomic**
  Objective: This method makes an atomic request for "nEntities" to an EntityPool. If no entities are available, then a NULL value is returned, else a Set containing
entities equal to the minimum value of "nEntities" and currently available entities in the EntityPool is returned. If a condition is specified, then entities that satisfy the condition are returned.

Parameters:

nEntities
- Mode: Input.
- Type: Integer.
- Presence: Required.
- Function: Specifies the number of requested entities.

condition
- Mode: Input.
- Type: Condition.
- Presence: Optional.
- Function: Specifies the condition to be satisfied.

Return Value:
- Type: Set.
- Function: Set containing the available entities, NULL if none available.

Exceptions:
- "Invalid number of requested entities"
  - Cause: "nEntities" < 0.
  - Effect: Simulation terminates.

• RequestAvailable

Objective: This method makes a request for "nEntities" to an EntityPool. If at least 1 entity is available, then the Delegate is immediately scheduled for execution, with the Set containing the entities passed as a return argument by reference for the event method ArgumentList within the Delegate. If a condition is specified, then entities that satisfy the condition are returned. If no entities are available or if the number of available entities is less than "nEntities", then the request is queued and serviced in a FCFS manner. If a priority has been specified, then the request is queued with the appropriate priority relative to other pending requests. The Delegate is scheduled for execution every time new entities become available till the request is completely satisfied.

Parameters:

nEntities
- Mode: Input.
- Type: Integer.
- Presence: Required.
- Function: Specifies the number of requested entities.

priority
- Mode: Input.
- Type: Priority Value.
- Presence: Optional.
- Function: Specifies the priority of the request relative to pending requests.

condition
- Mode: Input.
- Type: Condition.
Presence: Optional.
Function: Specifies the condition to be satisfied.

**eventDelegate**

Mode: Input.
Type: Delegate.
Presence: Required.
Function: Specifies the delegate to be scheduled when request is satisfied.

Return Value:
Type: RequestID.
Function: -1 if request is satisfied, else ID of pending request.

Exceptions:
"Invalid number of requested entities"
Cause: "nEntities" < 0.
Effect: Simulation terminates.

• **ReleaseSingle**

Objective: This method releases a single entity back to an EntityPool.

Parameters:

**entity**
Mode: Input.
Type: Entity.
Presence: Required.
Function: Specifies the entity EntityPool.

Return Value: None.
Exceptions: None.

• **ReleaseMultiple**

Objective: This method releases a collection of entities to an EntityPool.

Parameters:

**entitySet**
Mode: Input.
Type: Set.
Presence: Required.
Function: Specifies the collection of entities to be released to the EntityPool.

Return Value: None.
Exceptions: None.

• **ReAssign**

Objective: This method transfers “nEntities” from a collection of EntityPools to the “destinationPool” EntityPool.
This method behaves similarly to the RequestAvailable method and tries to satisfy the entire request, or whatever part of the request it can satisfy. If the current EntityPool cannot completely satisfy the request, then it queues the request within itself, and then passes along the request to the next EntityPool in “sourcePoolList”. If a transfer request is partially satisfied by any EntityPool subsequently, then all EntityPools within “sourcePoolList” update their pending requests.

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accordingly. If a transfer request is completely satisfied by any EntityPool subsequently, then all EntityPools within "sourcePoolList" remove the request from their collection of pending requests. If a condition is specified, then entities that satisfy the condition are returned.

Parameters:

**sourcePoolList**
- Mode: Input.
- Type: Set.
- Presence: Required.
- Function: Specifies the collection of source EntityPools.

**destination**
- Mode: Input.
- Type: EntityPool.
- Presence: Required.
- Function: Specifies the destination EntityPool.

**nEntities**
- Mode: Input.
- Type: Integer.
- Presence: Required.
- Function: Specifies the number of entities to be transferred.

**condition**
- Mode: Input.
- Type: Condition.
- Presence: Optional.
- Function: Specifies the condition to be satisfied.

**eventDelegate**
- Mode: Input.
- Type: Delegate.
- Presence: Required.
- Function: Specifies the delegate to be scheduled when transfer is complete.

Return Value: None.

Exceptions:

"Invalid source EntityPools"
- Cause: Invalid list of source EntityPools.
- Effect: Simulation terminates.

"Invalid destination EntityPool"
- Cause: Invalid destination EntityPool.
- Effect: Simulation terminates.

"Invalid number of entities to be transferred"
- Cause: "nEntities" < 0.
- Effect: Simulation terminates.

• **ReturnReAssigned**

Objective: This method returns the entities back to the source EntityPools where they were transferred from.

Parameters: None.

Return Value: None.

Exceptions:

"Invalid source EntityPools"
- Cause: Invalid list of source EntityPools.
- Effect: Simulation terminates.
• **TransferToEntityPool**

Objective: This method permanently transfers “nEntities” from an EntityPool to the “destination” EntityPool. If sufficient entities exist to satisfy the transfer, “entity” is cloned “nEntities” times and immediately transferred to “destination”. If insufficient entities currently exist, all existing entities are immediately cloned and transferred, and all entities released back to the EntityPool are cloned and transferred till the transfer is complete.

Parameters:

- **destination**
  - Mode: Input.
  - Type: EntityPool.
  - Presence: Required.
  - Function: Specifies the destination EntityPool.

- **nEntities**
  - Mode: Input.
  - Type: Integer.
  - Presence: Required.
  - Function: Specifies the number of entities to be transferred.

- **entity**
  - Mode: Input.
  - Type: Replicable.
  - Presence: Required.
  - Function: Specifies the entity to be cloned during transfer.

Return Value: None.

Exceptions:
- “Invalid destination EntityPool”
  - Cause: Invalid destination EntityPool.
  - Effect: Simulation terminates.
- “Invalid number of entities to be transferred”
  - Cause: “nEntities” < 0.
  - Effect: Simulation terminates.
- “Invalid entity for cloning”
  - Cause: Invalid entity to be cloned during transfer.
  - Effect: Simulation terminates.

• **TransferToEntityCounter**

Objective: This method permanently transfers “nEntities” from an EntityPool to the “destination” EntityCounter. If sufficient entities exist to satisfy the transfer, “nEntities” are immediately transferred to “destination”. If insufficient entities currently exist, all existing entities are immediately transferred, and all entities released back to the EntityPool, are transferred till the transfer is complete.

Parameters:

- **destination**
  - Mode: Input.
  - Type: EntityCounter.
  - Presence: Required.
  - Function: Specifies the destination EntityCounter.

- **nEntities**
  - Mode: Input.
Type: Integer.
Presence: Required.
Function: Specifies the number of entities to be transferred.
Return Value: None.
Exceptions: None.

"Invalid destination EntityCounter"
Cause: Invalid destination EntityCounter.
Effect: Simulation terminates.

"Invalid number of entities to be transferred"
Cause: "nEntities" < 0.
Effect: Simulation terminates.

• **InterruptRequest**
Objective: This method interrupts a pending request within an EntityPool. The interrupt method within the Delegate, if defined, is executed.

Parameters:  
*requestID*

Mode: Input.
Type: RequestID.
Presence: Required.
Function: Specifies the ID of the pending request.
Return Value: None.
Exceptions:  
"Request to be interrupted not found"
Cause: Specified request does not exist within collection of pending requests.
Effect: Simulation terminates.

---

B. DIESEL Distributed Interface Specification

B.1 **DistributedSimulationExecutive Interface**

**Interface Diagram:**

```
<interface>DistributedExecutiveSupport
+RelayMessage(in sourceClusterID: Integer, in message: Message)
+SetLookAhead(in lookahead: double)
+StartGVT()
+ReceivedStateGVT(in clusterID: Integer)
+ComputeLocalMinimum()
+LocalMinimum(in clusterID: Integer, in minimum: double)
+SendGVT(in GVT: double)
```

**Figure B1. DistributedSimulationExecutive Interface**

**Methods:**

• **StartDistributedSimulation**
Objective: This method initializes DIESEL for a distributed simulation with the specified number of SimulationClusters.

Parameters:  
*nClusters*

Mode: Input.
Type: Integer.
Presence: Required.

---

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Function: Specifies the number of SimulationClusters in a distributed simulation.
Return Value: None.
Exceptions: None.

- **GetNSimulationClusters**
  Objective: This method returns the number of SimulationClusters in a distributed simulation.
  Parameters: None.
  Return Value:
  Type: Integer.
  Function: Number of SimulationClusters in a distributed simulation.
  Exceptions: None.

- **CreateSimulationCluster**
  Objective: This method creates a SimulationCluster and registers itself with the simulation executive.
  Parameters:
  clusterID
  Mode: Input.
  Type: Integer.
  Presence: Required.
  Function: Specifies the ID of SimulationCluster to be created.
  synchronizationMethod
  Mode: Input.
  Type: Synchronization Algorithm.
  Presence: Required.
  Function: Specifies the synchronization algorithm used.
  Return Value:
  Type: SimulationCluster.
  Function: Created SimulationCluster.
  Exceptions: None.

- **AddSimulationCluster**
  Objective: This method registers a SimulationCluster with the simulation executive.
  Parameters:
  cluster
  Mode: Input.
  Type: SimulationCluster.
  Presence: Required.
  Function: Specifies the SimulationCluster to be registered with the simulation executive.
  Return Value: None.
  Exceptions: None.

- **GetSimulationCluster**
  Objective: This method returns access to a SimulationCluster registered with the simulation executive.
  Parameters:
  clusterID
  Mode: Input.
  Type: Integer.
  Presence: Required.
Function: Specifies the ID of required SimulationCluster.
Return Value: SimulationCluster.
Exceptions: None.

• CleanUpDistributedSimulation
Objective: This method cleans up DIESEL after a distributed simulation.
Parameters: None.
Return Value: None.
Exceptions: None.

• EventsExist
Objective: This method ascertains if any delegates exist on any SimulationClusters in the distributed simulation and returns the minimum execution time of all delegates if they do exist.
Parameters:
  minimumEventTime
  Mode: Output.
  Type: Double.
  Presence: Required.
  Function: Specifies the minimum event execution time of delegates within all SimulationClusters.
Return Value: Boolean.
  Function: TRUE if events exist, ELSE FALSE.
Exceptions: None.

• ExecuteDistributedSimulation
Objective: This method executes a distributed simulation with the specified synchronization algorithm.
Parameters: None.
Return Value: None.
Exceptions: None.

• GetUniqueReference
Objective: This method returns a unique reference for an application object to be used in a distributed simulation.
Parameters: None.
Return Value: Unique Reference.
  Function: Unique reference for an application object.
Exceptions: None.

• RegisterObject
Objective: This method registers an application object with the simulation executive.
Parameters:
  reference
    Mode: Input.
    Type: Unique Reference.
    Presence: Required.
Function: Specifies the unique reference of the application object to be registered.

**clusterID**
- Mode: Input.
- Type: Integer.
- Presence: Required.
- Function: Specifies the ID of the SimulationCluster that the application object belongs to.

**object**
- Mode: Input.
- Type: Object.
- Presence: Required.
- Function: Specifies the application object to be registered.

**SEC**
- Mode: Input.
- Type: SimulationEngineComponent.
- Presence: Required.
- Function: Specifies associated SimulationEngineComponent if the object is a SimObject.

Return Value: None.
Exceptions: None.

**RemoveObject**
Objective: This method de-registers an application object with the simulation executive.

Parameters:
- **reference**
  - Mode: Input.
  - Type: Unique Reference.
  - Presence: Required.
  - Function: Specifies the unique reference of the application object to be de-registered.

Return Value: None.
Exceptions: None.

B.2 Modified SimulationEngineComponent Interface

**Interface Diagram:**

![Interface Diagram](image)

**Figure B2. Modified SimulationEngineComponent Interface**

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### Methods:

**New**

**Objective:**
This method initializes a `SimulationEngineComponent` with the ID of the `SimulationCluster` it belongs to and registers itself with the appropriate `SimulationCluster`.

**Parameters:**
- `clusterID`
  - **Mode:** Input.
  - **Type:** Integer.
  - **Presence:** Required.
  - **Function:** Specifies the `SimulationCluster` on which the `SimulationEngineComponent` has been initialized.

**Return Value:** None.

**Exceptions:** None.

### B.3 SimulationCluster Interface

**Interface Diagram:**

![Simulator Interface Diagram](image)

**Methods:**

**ResolveReferences**

**Objective:**
This method resolves references for dynamically initialized attributes within a `SimulationCluster`.

**Parameters:**
- None.

**Return Value:** None.

**Exceptions:** None.

**Create**

**Objective:**
This method creates an empty shell of a
SimulationCluster during the state duplication process of a non-terminating state save operation.

Parameters: None.
Return Value: None.
Type: StateSave.
Function: Empty shell of SimulationCluster.
Exceptions: None.

• **DuplicateState**
  Objective: This method copies the state of "original" to the current SimulationCluster during the state duplication process of a non-terminating state save operation.

Parameters:
  - **original**
    Mode: Input.
    Type: StateSave.
    Presence: Required.
    Function: Specifies SimulationCluster whose state is to be copied.

Return Value: None.
Exceptions: None.

• **New**
  Objective: This method initializes a SimulationCluster.

Parameters:
  - **clusterID**
    Mode: Input.
    Type: Integer.
    Presence: Required.
    Function: Specifies ID of SimulationCluster.

Return Value: None.
Exceptions: None.

• **Delete**
  Objective: This method disposes a SimulationCluster.

Parameters: None.
Return Value: None.
Exceptions: None.

• **RegisterSEC**
  Objective: This method registers a SimulationEngineComponent with a SimulationCluster.

Parameters:
  - **SEC**
    Mode: Input.
    Type: SimulationEngineComponent.
    Presence: Required.
    Function: Specifies SimulationEngineComponent to be registered with the SimulationCluster.

Return Value: None.
Exceptions: None.

• **RemoveSEC**
  Objective: This method de-registers a SimulationEngineComponent
with a SimulationCluster.

Parameters:

<table>
<thead>
<tr>
<th>SEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode: Input.</td>
</tr>
<tr>
<td>Type: SimulationEngineComponent.</td>
</tr>
<tr>
<td>Presence: Required.</td>
</tr>
<tr>
<td>Function: Specifies SimulationEngineComponent to be de-registered with the SimulationCluster.</td>
</tr>
</tbody>
</table>

Return Value: None.

Exceptions: None.

- **SetSimTime**
  
  Objective: This method sets the current simulation time for a SimulationCluster.

  Parameters:

<table>
<thead>
<tr>
<th>time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode: Input.</td>
</tr>
<tr>
<td>Type: Double.</td>
</tr>
<tr>
<td>Presence: Required.</td>
</tr>
<tr>
<td>Function: Specifies the current simulation time.</td>
</tr>
</tbody>
</table>

Return Value: None.

Exceptions: None.

- **GetSimTime**

  Objective: This method returns the current simulation time within a SimulationCluster.

  Parameters: None.

  Return Value:

  | Type: Double. |
  | Function: Current simulation time. |

Exceptions: None.

- **ScheduleEvent**

  Objective: This method schedules an event on a SimObject if the SimObject exists within a SimulationCluster. If it does not, then the SimulationCluster asks the simulation executive to relay a message with the required information to the appropriate SimulationCluster.

  Parameters:

<table>
<thead>
<tr>
<th>reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode: Input.</td>
</tr>
<tr>
<td>Type: Unique reference to an application object.</td>
</tr>
<tr>
<td>Presence: Required.</td>
</tr>
<tr>
<td>Function: Specifies the unique reference to an application object.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode: Input.</td>
</tr>
<tr>
<td>Type: EventMethodReference.</td>
</tr>
<tr>
<td>Presence: Required.</td>
</tr>
<tr>
<td>Function: Specifies the reference to the event method.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>methodList</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode: Input.</td>
</tr>
<tr>
<td>Type: ArgumentList.</td>
</tr>
<tr>
<td>Presence: Required.</td>
</tr>
<tr>
<td>Function: Specifies the list of arguments to be used when the</td>
</tr>
</tbody>
</table>
event method is executed.

**simTime**
- **Mode:** Input.
- **Type:** Double.
- **Presence:** Required.
- **Function:** Specifies the scheduled execution time of the event method.

**priority**
- **Mode:** Input.
- **Type:** Event Priority.
- **Presence:** Optional.
- **Function:** Specifies the priority of the event method relative to other delegates scheduled at the same simulation time.

- **Return Value:** None.
- **Exceptions:** None.

- **GetAveragePendingEventSize**
  - **Objective:** This method returns the average size of the pending event set for all SimulationEngineComponents within a SimulationCluster.
  - **Parameters:** None.
  - **Return Value:**
    - **Type:** Integer.
    - **Function:** Average size of pending event set.
  - **Exceptions:** None.

- **GetAverageEventWaitTime**
  - **Objective:** This method returns the average waiting time for an event before it is executed within all SimulationEngineComponents in a SimulationCluster.
  - **Parameters:** None.
  - **Return Value:**
    - **Type:** Double.
    - **Function:** Average event wait time.
  - **Exceptions:** None.

- **GetAverageMessageQueueSize**
  - **Objective:** This method returns the average size of the input queue in a SimulationCluster.
  - **Parameters:** None.
  - **Return Value:**
    - **Type:** Integer.
    - **Function:** Average size of input queue.
  - **Exceptions:** None.
VITA

DEGREES:
Doctor of Philosophy (Electrical and Computer Engineering), Old Dominion University, Norfolk, VA, May 2007.

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Journals

Conferences