## Simulation & Modeling

**PDES: Distributed Virtual Environments**

**Repeatability, Zero Lookahead and Simultaneous Events**

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## Outline

- **Definitions and Motivation**
  - » **Repeatability**
  - » **Zero lookahead events**
  - » **Simultaneous events**
- **Example: High Level Architecture**
  - » **Approach with non-zero lookahead**
  - » **Approach with zero lookahead: NERA/TARA**

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## Repeatability

*Definition: repeatability  A (distributed) simulation program is repeatable if subsequent executions using the same initial conditions and input as some "reference" execution produce exactly the same results (e.g., model statistics) as the reference execution.*

**Repeatability is desirable because:**

- **External agencies may need to re-run simulations to verify simulation results (e.g., the General Accounting Office requires repeatability for certain defense simulations)**
- **Facilitates debugging**

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## Repeatability in Distributed Simulations

- **Each logical process will process events (both local and those generated by other processors) in time stamp order**
  - » **final result of entire distributed execution same as if all events were processed sequentially in time stamp order**
- **Issues**
  - » **Repeatable event computations: must ensure the event computation is repeatable: e.g., not dependent on wallclock time**
  - » **Simultaneous events (events with the same time stamp): must be processed in the same order with each execution**
  - » **Interactive inputs:**
    - – **Values must be identical, and input to the simulation at the same point in its execution on each run**
    - – **Can assign each input a logical time value, and ensure same value is used for each execution**

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## Simultaneous Events

- **The order that simultaneous events are processed will affect the results computed by the simulation, possibly significantly**
  - » **Simultaneous aircraft arrival events: Which airline's flight is delayed?**
  - » **Simultaneous "detonation" events at a target: which weapon system gets credit for the kill?**
  - » **Systematically favoring one outcome may bias results**
- **The modeler must be able to control the ordering of simultaneous events (not the RTI or simulation executive)!**
  - » **Proper ordering requires domain knowledge of the simulation application**

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## Zero Lookahead Events

*definition: lookahead.  If a logical process (LP) at logical time T has a lookahead of L, any event scheduled by the LP (at time T) must have a time stamp greater than or equal to T+L.*

- **A zero lookahead event is an event with time stamp equal to the simulation time of the LP scheduling the event.**
- **The possibility of zero lookahead events affects the approach taken to ensure repeatability**

## Example: High Level Architecture

- **Next Event Request / Time Advance Request**: If the RTI issues a Time Advance Grant (TAG) to T, it guarantees no event will later be delivered to the federate with time stamp T (or less)
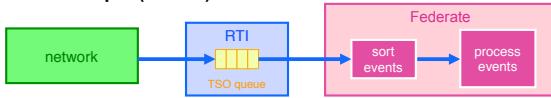


- **A simple approach to ensure repeatability**
  - » Federate invokes NER/TAR, gets a TAG to simulation time T
  - » All simultaneous events (with time stamp T or less) have been delivered to the federate
  - » Federate orders simultaneous events in a repeatable fashion, and processes events in this order
- **What about zero lookahead events?**

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## Zero Lookahead

- **Observation**: If zero lookahead is allowed, a Time Advance Grant to time T *cannot guarantee delivery* of all events with time stamp equal to T
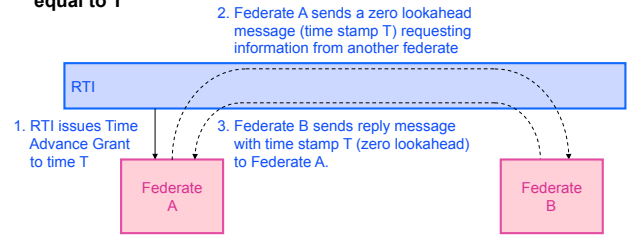


- **Because a federate cannot be guaranteed delivery of all events with time stamp equal to T, it cannot sort them to ensure a repeatable execution.**

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## Idea: Allow Zero Lookahead

1) **Allow zero lookahead federates, but**
2) **Provide a separate mechanism where a federate wishing to receive all events at time T can do so, but at the cost that it must *temporarily* have a non-zero lookahead in order to allow such a mechanism to be implemented**
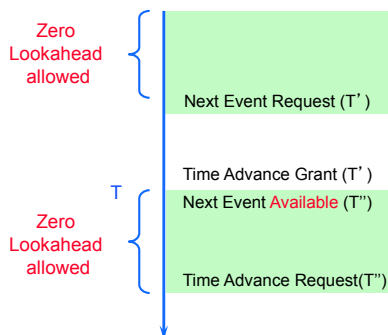
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## Zero Lookahead in the HLA

- **Next Event Request / Time Advance Request**
  - » **The resulting Time Advance Grant to time T guarantees all messages w/ time stamp T or less have been delivered**
  - » **A federate that advanced to its current simulation time via NER/TAR cannot send zero lookahead messages (even if it has declared to the RTI its lookahead is zero)**
- **Two new services:**
  - » **NER Available (NERA) and TAR Available (TARA), same as NER and TAR, except grant to time T does not guarantee delivery of all events with time stamp T**
  - » **Federate may send zero lookahead messages after receiving the resulting Time Advance Grant**
- **Note: Simultaneous events may not be *delivered* in the same order on subsequent executions**

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## Allow Zero Lookahead (continued)



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## Another Approach: Wide Virtual Time

**Basic idea**

- **Ensure there are no simultaneous events by appending "hidden bits" to least significant end of time values to order events with same time value**
  - » **RTI uses hidden bits to order simultaneous events**
  - » **Application ignores hidden bits when computing time values**
- **Use federate id and a per-federate counter to ensure unique time stamps**
  - » **Zero lookahead events: time stamp (including hidden bits) must be greater than current time of federate**
- **Use application defined priority field (in hidden bits) to control ordering of simultaneous events**

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# Summary

- **Repeatability is important for many applications**
- **Ordering of simultaneous event can be important**
  - » **Application must have control over the ordering of simultaneous events**
- **Repeatable, application controlled ordering of simultaneous events is straightforward if no zero lookahead events are allowed**
  - » **Example: HLA NER and TAR services**
- **Another approach is to use hidden time stamps in fields to eliminate possibility of simultaneous events**