Distributed HiL Simulation

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Outline

- Problem formulation
- SPRINT Distributed HiL Simulation
- Challenges
- Technology enablers
- Architecture
  - Role of the SPRINT platform
  - Interaction among simulation actors
- Conclusions
SPRINT Integration/verification scenario

- **System Design**: Holistic, high level design of the overall system. Teams are in same physical location.
- **System Functional Decomposition**: The system is broken into independent components.
- **Networked Subsystem Design**: The virtual networked organization refines its design with seamless connectivity between design artifacts. (Co-developing the SW/HW subsystems with seamless connectivity to the physical devices)
- **Networked Subsystem Implementation**: Continue and iterative integration of the system from the different subsystems.

**The Internet of Systems Engineering**
Network of Designers, Design Models, and Physical Devices
Problem formulation

Design process goes through different abstraction of a system component
- Contracts, Models, Implementations

Design of the system components is distributed at different sites
- Exchange of the component prototypes during the design is not always possible

How to verify system integration during the distributed design process?
SPRINT Distributed HiL Simulation

Verify system integration by simulation with monitors over the Internet
Current practice

**Simulation techniques**

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**Co-simulation**
- Heterogeneous models
- Distributable
- Sync/coord overhead

**Hosted simulation**
- Heterogeneous models
- Not distributed
- Model export required
- High performance

**HiL simulation**
- Model + physical device
- Distributed
- Tight sync/coord
- Physical device interface
Challenges

Simulation over the Internet

Co-Simulation

HiL Simulation

Virtual time

Real time

Poor performance!

System slows down!
Challenges

Simulation over the Internet

**Internet QoS?**

<table>
<thead>
<tr>
<th>Destination</th>
<th>Round-Trip Delay [ms]</th>
</tr>
</thead>
<tbody>
<tr>
<td>New York to London</td>
<td>75.63</td>
</tr>
<tr>
<td>New York to Rio De Janeiro</td>
<td>111.65</td>
</tr>
<tr>
<td>San Francisco to Tokio</td>
<td>111.99</td>
</tr>
<tr>
<td>Singapore to Los Angeles</td>
<td>190.62</td>
</tr>
<tr>
<td>Tokio to London</td>
<td>254.33</td>
</tr>
</tbody>
</table>

AT&T Global IP Network, Average latency last 12 months
Source: AT&T

$$f_{\text{max}}^{\text{sim}_\text{loop}} = \frac{1}{2 \times \text{Lat} + \text{Comp}}$$

RTD=254 ms, Comp=0 ms

$$f_{\text{max}}^{\text{sim}_\text{loop}} \approx 4 \text{ Hz}$$
Enabling Distributed HiL Simulation

*Latency-insensitive prototypes and properties*

- Use device prototypes insensitive to network latency and jitter
  - Example: Stallable devices
    - Devices that can be suspended in a state without affecting the device behaviour in the next states
  - Property: stuttering-invariance
- Verify just device properties insensitive to latency
  - Latency-insensitive contracts

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**Stuttering-invariance**

- System is invariant under time change

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Enabling Distributed HiL Simulation

**Synchronization algorithms**

Simulation: Performance vs Accuracy trade-off

- Execution scheduling
  - Sequential execution
  - Parallel execution
- Scheduling slot length
  - Fixed
  - Adaptive (event-based)
    - Same for all
    - Per actor
- Roll-back capabilities
  - Optimistic synchronization

**Simulation + device: SimTime=RealTime**

- Local synchronization with RealTime
Enabling Distributed HiL Simulation

Communication middlewares

Role

- Abstract the distributed architecture
- Provide efficient data exchange mechanisms
- Provide enhanced transport services (e.g., RT middlewares)

Candidate middleware technologies

- CORBA (OMG spec)
  - Communication by method call of local and remote objects
  - Largely used
- Data Distribution Service (DDS) (OMG spec)
  - Data distribution based on a publish/subscribe paradigm
  - QoS management
- High Level Architecture (IEEE1516)
  - Complete platform for distributed simulation
- Web-services (SOAP or REST)
  - Hot topic
  - Firewall friendly
Improved QoS management
  - Flow labeling
  - Priority
Single step fragmentation
Fixed size packet header
  - more efficient to handle
Larger multicast support
Jumbograms
Distributed HiL Simulation Architecture

- **Simulation tool**
  - Model execution
  - Server

- **Simulation tool**
  - Server

- **Physical device**
  - Adapter
  - Server

- **Modeling tool**
  - Simulation front-end

- **Internet of Things**
  - Monitor generation
  - Simulation synthesis tool
  - Simulation coordinator

- **Device operation**

- **Inventory of simulation resources**

- **SPRINT platform**
Distributed HiL Simulation
Role of the SPRINT platform

- **Modeling tool**
- **Contract authoring tool**
- **Simulation tool**
- **Physical device**
- **Monitor synthesis tool**
- **Simulation coordinator**

**Publish models**

**Retrieve models**

**Publish contracts**

**Register provided services**

SPRINT platform
Distributed HiL Simulation

Example of interaction among actors

1. Select subsystem prototypes and contracts
2. Get monitors out of contracts
3. Integrate subsystems and monitors
4. Request system model execution
5. Dispatch and coordinate simulation execution
6. Deliver simulation results
Distributed HiL Simulation

Relevant standards and specifications

High Level Architecture (IEEE 1516)
- Distributed simulation platform
  - Distributed simulation setup, coordination and communication

Functional Mock-up Interface (MODELISAR ITEA EU project)
- Format for model export
  - Hosted simulation and co-simulation
- Models: Ordinary Differential equations

SPEEDS Hosted Simulation (SPEEDS EU project)
- Format for model export and HS execution protocol
- Models: Discrete time and hybrid models
- Monitor synthesis to SPEEDS HS format

OLE for Process Control (OPC foundation)
- Standard Interface for communication with and among physical devices
- Domain: Industrial Automation
Conclusions

• Distributed HiL Simulation as key component of SPRINT Internet of Systems engineering

• Enable to verify integration of subsystem prototypes
  – Distributed at different sites
  – At different levels of abstractions

• Distributed HiL Simulation occurs over the Internet
  – Face challenges due to communication QoS
  – Simulation actors as service providers/consumers
  – SPRINT platform to support distributed simulation setup
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