M&S and MBSE:
Individual Challenges and Mutual Opportunities

Andrea D’Ambrogio
Department of Enterprise Engineering
University of Rome Tor Vergata
Rome (Italy)

http://www.sel.uniroma2.it/dambro
Agenda

- Modeling & Simulation (M&S) and Systems Engineering (SE) disciplines
  - Model Based Systems Engineering (MBSE)

- **M&S-based Systems Engineering** (*M&S for SE*)
  - Lifecycle integration

- **Simulation Systems Engineering** (*MBSE for M&S*)
  - Distributed Simulation (DS)
  - Model-based approaches for DS Engineering
Simulation and SE

- Simulation-based and SE-based approaches have been employed ever since mankind started building complex systems
  - More recently, the term *systems engineering* may be traced back to the early 1900s, with examples observed during the Second World War
  - Similarly, what is commonly referred to as *(computer-based) simulation* is traced back to the Second World War
- Both approaches have then evolved into mature disciplines, frequently crossing their paths
  - nevertheless, several projects still experience time and cost overruns or fail to deliver systems that meet the needs of customers, users and other stakeholders
**Simulation** is just a part of the story..

- A simulation must always have a model and modeling is an essential part of a simulation.
- To emphasize the modeling involved in a simulation, simulation should be better referred to as **Modeling and Simulation (M&S)**.
- **Modeling** and *simulation* are central activities of our thinking process.
  - we think by “constructing mental models and then simulating them (i.e., executing over time) in order to draw conclusions or make decisions”
MBSE

- Modeling has also achieved a key role in the SE field with the introduction of *Model Based Systems Engineering (MBSE)*

- MBSE refers to the formalized application of modeling to support the system development, along all the different development phases

- With MBSE, a common model of the system architecture is used to support and drive the engineering process
  - bringing significant advantages over the *document-centric* approach
M&S for SE

- M&S and SE may support each other around the *executable model* concept
- M&S promotes executable models and proposes simulation as the native mechanism to address measures of performance and effectiveness throughout conceptual design, development and later systems life cycle phases
  - facing the well-known SE challenges in terms of budget/time overruns and systems quality

M&S Based Systems Engineering
As the system complexity increases, the executable system architecture (i.e., the simulation model) may become so complex that it is necessary to assess it not only as a valid support of SE processes but also as an objective of SE efforts.

Executing an interdisciplinary systems engineering process for developing, maintaining and employing simulations, which enable systems engineers to experiment and gain insights about the systems of interest, is referred to as Simulation Systems Engineering.
M&S Based Systems Engineering

- The integrative approach
- Bridging the gap between M&S and SE lifecycles
The adoption of M&S based approaches is widely recognized as:

- a cost-effective alternative to the development of experimental prototypes
- a valuable strategy to mitigate the risk of time/cost overrun due to redesign and re-engineering activities

Nevertheless, their potential and organized implementation in the systems engineering field are not yet fully exploited

- even though there are plenty of applications in specialty engineering fields, as well as in other fields, such as physical science, social science, computing, medical research, military, business and finance
The integrative approach

- A successful implementation of *M&S based systems engineering* requires an effective integration of M&S and systems engineering life cycles, specifically:
  - the *ISO/IEC/IEEE 15288 (Systems and Software Engineering - System Life Cycle Processes)* standard at the systems engineering end
  - the *IEEE 1730-2010 (Recommended Practice for Distributed Simulation Engineering and Execution Process – DSEEP)* standard at the M&S end
ISO/IEC/IEEE 15288

- Describes a set of 30 processes in terms of purpose, outcomes, activities and tasks
- Processes are grouped in:
  - agreement processes
  - organizational project-enabling processes
  - technical management processes
  - technical processes
IEEE 1730-2010 (DSEEP)

- Introduces 7 sequential steps, described using *activities*, recommended *tasks*, *inputs*, *outputs* and *roles*

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<td>Develop Objectives</td>
<td>Develop Conceptual Model</td>
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<td>Prepare Simulation Environment Outputs</td>
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<td>Conduct Initial Planning</td>
<td>Develop Simulation Environment Requirements</td>
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<td>Implement Member Application Designs</td>
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<td>Implement Simulation Environment Infrastructure</td>
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M&S for systems lifecycle processes

M&S to evaluate acquisition/supply strategies

M&S for decision making, risk management and quality assurance

Agreement Processes

Organizational Project-Enabling Processes

Technical Management Processes

Technical Processes

M&S as enabling system

M&S (distributed simulation) for analyzing system behavior

M&S for systems lifecycle processes

dambro@uniroma2.it
Bridging the gap between M&S and SE life cycles

- Integrative approach that allows systems engineers and M&S practitioners to fully catch the benefits of using M&S for systems engineering and vice versa
- Example DSEEP overlay on ISO/IEC 1528 (Systems and Software Engineering - System Life Cycle Processes)

Simulation Systems Engineering

- Distributed Simulation (DS) in the systems development context
- Model-driven Engineering (MDE): a booster for MBSE
- MDE-based approaches for DS engineering
**Distributed Simulation in the system development context**

- The validation of complex systems from the early development phases (*lifecycle validation*) can be effort- and time-consuming.
- M&S is widely recognized as an effective and powerful tool for lifecycle validation of systems, but:
  - M&S methods must scale with growth and evolution of complex systems and ecosystems (e.g., SoS or ULS).
- The use of *distributed simulation (DS)* approaches enable M&S methods that take into account the peculiar complexity/scalability/evolvability of complex systems.
Useful definitions

- **System Under Study (SUS)**
  - the system that has to be simulated to get insights into or to predict its behaviour
  - typically specified at development time by use of system models

- **Simulation Systems Engineering:**
  - the set of activities to be carried out first to build a simulation model of the SUS and then to implement it into a simulation system, i.e., a software system that “executes” the model over time onto a given centralized or distributed platform.

- **Local Simulation (LS) System**
  - A simulation system deployed onto and executed by a single host

- **Distributed Simulation (DS) system**
  - A simulation system that consists of a set of sub-systems deployed onto and executed by a set of geographically distributed hosts
Distributed Simulation (DS)

- The term *distributed* is interpreted in the sense of traditional distributed computing (e.g., based on the C/S paradigm)

- **Goal**
  - synchronize and coordinate remote simulation programs

- **Benefits**
  - Geographical distribution
  - Integrating simulators from different manufacturers
  - Reusability
  - Load balancing
  - Fault tolerance
High Level Architecture (HLA)

- A set of specifications for DS

- Goal:
  improving reusability and interoperability in the simulation field

- Originally introduced by the DoD DMSO

- IEEE standard 1516 since 2000
How HLA simulations work

- **Federate**: a remotely-accessible simulation sub-system
- **Federation**: the overall DS system, composed of a set of Federates
- **RTI**: provides communication and coordination services to the Federates that join into a Federation
What HLA provides

- A distributed simulation framework to be applied, in principle, in different application domains (military, gaming, manufacturing, etc.)
- Simulation-oriented services (time management, information exchange, etc.)
- HLA does not provide:
  - Management of federate internal events
  - Services for specific types of simulation (discrete, continuous, etc.)
  - Guidelines for federate implementation
HLA Federation Object Model (FOM)

- The FOM is a data exchange model that describes information that is to be shared between different federates.
- Using an information bus, such as the HLA, with a shared information model, such as the FOM, enables *composability*.
- A FOM includes the definition of elements according to the HLA Object Model Template (OMT) specification, such as:
  - Shared *object classes* (i.e., persistent entities) with associated attributes.
  - Shared *interaction classes* (i.e., events) with associated *parameters*.
- A carefully designed FOM facilitates long-term reuse of simulations.
- The FOM is part of a federation agreement.
MDE: a booster for MBSE

- Model Driven Engineering (MDE) is a set of well-defined principles and practices based on tools that focus on the *productive use of models*.

- MDE (Model Driven Engineering) further enhances the advantages of MBSE by increasing the *degree of automation* in the production and operation/maintenance lifecycle stages, by use of:
  - *metamodeling* techniques and
  - *model transformations*
MDE and DS Opportunities

- MDE is finding increasing acceptance in the development of complex systems
  - enabler of reuse
  - higher degrees of automation
- DS systems are inherently complex
  - intrinsic concurrency
  - required interoperability
  - intricacies of currently available DS platforms
- MDE provides a promising approach for supporting the development of DS systems of higher quality at largely reduced time, effort and cost
MDE and DS Challenges

❖ On the DS side:
  • code-centric approaches
  • development process:
    ▪ often not starting from scratch
    ▪ often requiring the integration of legacy subsystems
  • interoperability is only dealt with at syntactic level
  • support for simulation-in-the-loop is limited

❖ On the MDE side:
  • model-centric approach
  • tool support for defining and orchestrating model transformations is still limited
  • modeling languages strongly influenced by UML
Bridging the gap between MDE and DS

- Approach based on the standard MDA (Model Driven Architecture) process

- Requires:
  - The choice of a specific DS infrastructure (e.g., HLA)
  - The introduction of proper modeling extension (profiles) for annotating system (SysML) models with DS infrastructure details
  - The specification of a system model to simulation model model-to-model transformation
  - The choice of a given DS implementation
  - The specification of a simulation model to code model-to-text transformation
MDA-based DSEEP (top)

Define Simulation Environment Objectives
- Federation Requirements

Perform Conceptual Analysis
- Annotated System Model (SysML & SysML4HLA)
- Reference FOM Datatype Library

Design Simulation Environment
- Federation Model (SysML & HLA-FOM)

Manual Activity
Automated Activity

System Model (SysML)
SysML4HLA Profile

Model Annotation
Library Specification

Execute Model-to-Model Transformation
Model Refinement

Identify Already Available Federates
Existing Federates

HLA-FOM Profile

Identify Already Available Federates

Document Specification
MDA-based DSEEP (bottom)

1. **Executive Model-to-Text Transformations**
   - **Execute Model-to-Text Transformations**
   - **FOM Modules**
   - **New Federates**

2. **Integrate & Test Simulation Environment**
   - **Integrate Federation Code**
   - **Execute Simulation Test Scenarios**
   - **FOM Modules**
   - **New Federates**

3. **Execute Simulation Environment**
   - **Configure and Execute Simulation Environment**
   - **Simulation Results**
   - **Simulation Scenario Configurations**

4. **Analyze Data and Evaluate Results**
   - **Evaluate Results**
   - **OK**
   - **Not OK**
   - **Proceed to System Implementation**
   - **Re-design System or Revise Requirements**

**Develop Simulation Environment**

**Existing Federates**

**Federation Model (SysML & HLA-FOM)**
Model Transformations

- **M2M transformation**
  - **SysML-to-HLA**
    - from *SysML* to *HLA-based SysML*

- **M2T transformations**
  - **HLA-to-Code**
    - *HLA-based SysML* to *HLA code*
  - **HLA-to-FOM**
    - *HLA-based SysML* to *HLA code*

- **Modeling Extensions**
  - **SysML4HLA Profile**
    - for *SysML* annotation
  - **HLA-FOM Profile**
    - for *HLA-based SysML* annotation
A Tiny Example Application

• An Orbiter federate has been implemented as a component of an existing Space Federation, which in turn must conform to the Space Reference FOM

• It is assumed that the SpaceFOM Datatypes Library is available, to enable the specification of federates compliant to the Space Federation
System Model Annotation

- According to the tailored DSEEP, once the simulation objective has been clearly identified, the **Conceptual Analysis** is executed to specify an *abstract model of the Orbiter system*
- At the next step, the **Design Federation Environment**, the model is annotated with stereotypes provided by the HLA-FOM profile

![Diagram of the annotated Orbiter Conceptual Model]
Model XMI-based serialization (from MagicDraw)

Listing 1: Fragment of Space Reference FOM
```xml
<?xml version="1.0" encoding="UTF-8" standalone="yes"?>
  <dataTypes>
    <simpleData>
      <name>Velocity</name>
      <representation>HLAfloat64LE</representation>
    </simpleData>
    <arrayData>
      <name>VelocityVector</name>
      <dataType>Velocity</dataType>
      <cardinality>3</cardinality>
      <encoding>HLAfixedArray</encoding>
    </arrayData>
  </dataTypes>
  <objectClass>
    <name>HLAobjectRoot</name>
    <objectClass>
      <name>PhysicalEntity</name>
      <sharing>PublishSubscribe</sharing>
      <semantics>A PhysicalEntity is...</semantics>
    </objectClass>
  </objectClass>
</objectModel>
```

Listing 2: Fragment of Orbiter_FOM Module
```xml
<?xml version="1.0" encoding="UTF-8" standalone="yes"?>
<objectModel>
  <modelIdentification>
    <name>Orbiter_FOM Module</name>
    <type>FOM</type>
    <version>0.1</version>
  </modelIdentification>
  <objects>
    <objectClass>
      <name>HLAobjectRoot</name>
      <objectClass>
        <name>PhysicalEntity</name>
        <objectClass>
          <name>Orbiter</name>
          <sharing>PublishSubscribe</sharing>
          <attribute>
            <name>vel</name>
            <dataType>VelocityVector</dataType>
            <updateType>Conditional</updateType>
            <sharing>PublishSubscribe</sharing>
            <transportation>HLAreliable</transportation>
          </attribute>
        </objectClass>
      </objectClass>
    </objectClass>
  </objects>
</objectModel>
```

6 CONCLUSIONS
The paper has introduced a model transformation approach for the automated generation of the Federation Object Model (FOM) in HLA-based distributed simulations. The proposed approach is intended to be used as part of a tailored DS development process, which is founded on the use of modeling techniques and model transformation approaches to enable a more effective DS adoption for model-based systems engineering.

The proposed approach has specifically addressed the generation of modular FOMs, as introduced by HLA Evolved, the latest version of the HLA standard, and can be used to generate FOMs that provide compliance to standardized reference FOMs.

REFERENCES
Conclusions

- A successful synergy between M&S and systems engineering disciplines can be enacted by addressing the mutual support in terms of:
  - *M&S based systems engineering*
  - *Simulation systems engineering*

- In this respect, a significant effort has been spent at educational, theoretical, methodological and professional levels.

- However, additional research and development effort is needed to further investigate and fully exploit the potential of cross-domain solutions.
Modeling and Simulation-Based Systems Engineering Handbook

editors
Daniele Gianni
Andrea D’Ambrogio
Andreas Tolk