2017 annual INCOSE international workshop
Los Angeles, CA, USA
January 28 - 31, 2017

Integrating Systems Modeling with Engineering Analysis

Conrad Bock[a], Leon McGinnis[b], & Timothy Sprock[a]

[a] National Institute of Standards and Technology, [b] Georgia Tech

Overview

- Project organization
- Motivation and approach
- Areas for integration
- Summary

Overview

- Project organization
- Motivation and approach
- Areas for integration
- Summary

Engineering Lab

- Five divisions
  - Two are primarily information-focused
    - Systems Integration (*)
    - Intelligent Systems
- Four smart manufacturing programs
  - SM Systems Design and Analysis
  - SM Manufacturing Operations Planning and Control (*)
  - Robotic Systems for SM
  - Measurement Science for Additive Manufacturing

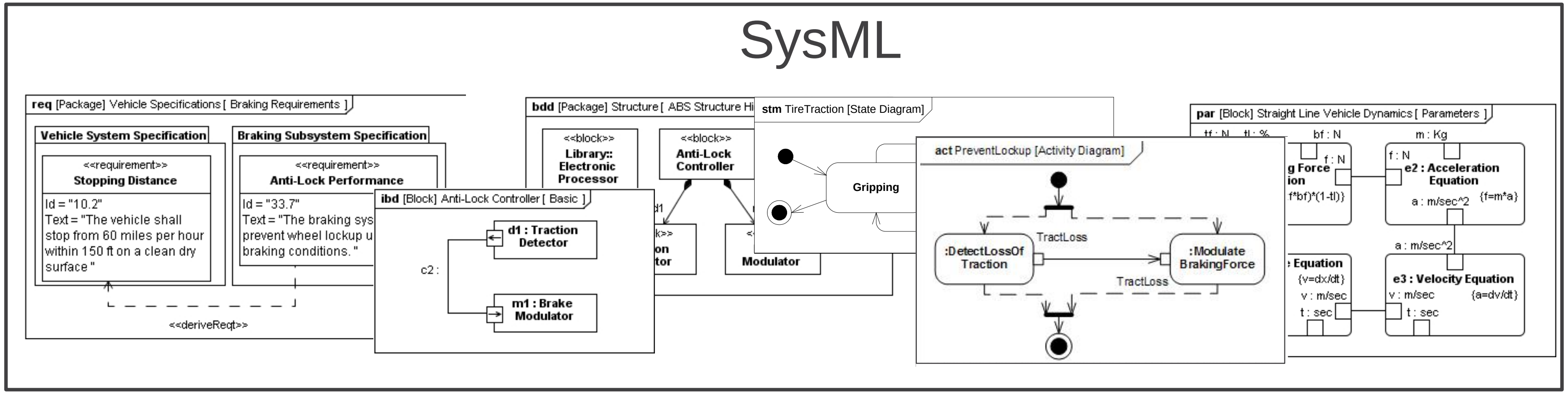
Systems Analysis Integration

- Started later 2014.
- Concerned with integrating systems and other engineering models.
  - Will focus on integration of systems models and engineering analysis information.
- Four multi-year cooperative agreements with universities and industry.
- Two & ½ full time federal employees.

Overview

- Project organization
- Motivation and approach
- Areas for integration
- Summary

Engineering Language Integration



? ?

Requirement languages

Material languages

Hydraulic languages

Mechanical languages

Production languages

Control languages

Prototyping languages

Simulation languages

General Technical Approach

1. Select analysis areas to address.
2. Examine the literature and widely-used tools in those areas.
3. Develop analysis tool-independent abstractions.
4. Identify overlap with SysML concepts.
   – Additional concepts for analyzing SE models.
5. Develop or choose integration technique.
6. Apply technique to SE/analysis gap.
7. Develop proof-of-concept.

Outputs

- All public domain.
- Standards (see next).
- Journal and other papers.
- Proofs of concept (possibly open source).
- Presentations and demonstrations.

Overview

- Project organization
- Motivation and approach
- Areas for integration
- Summary

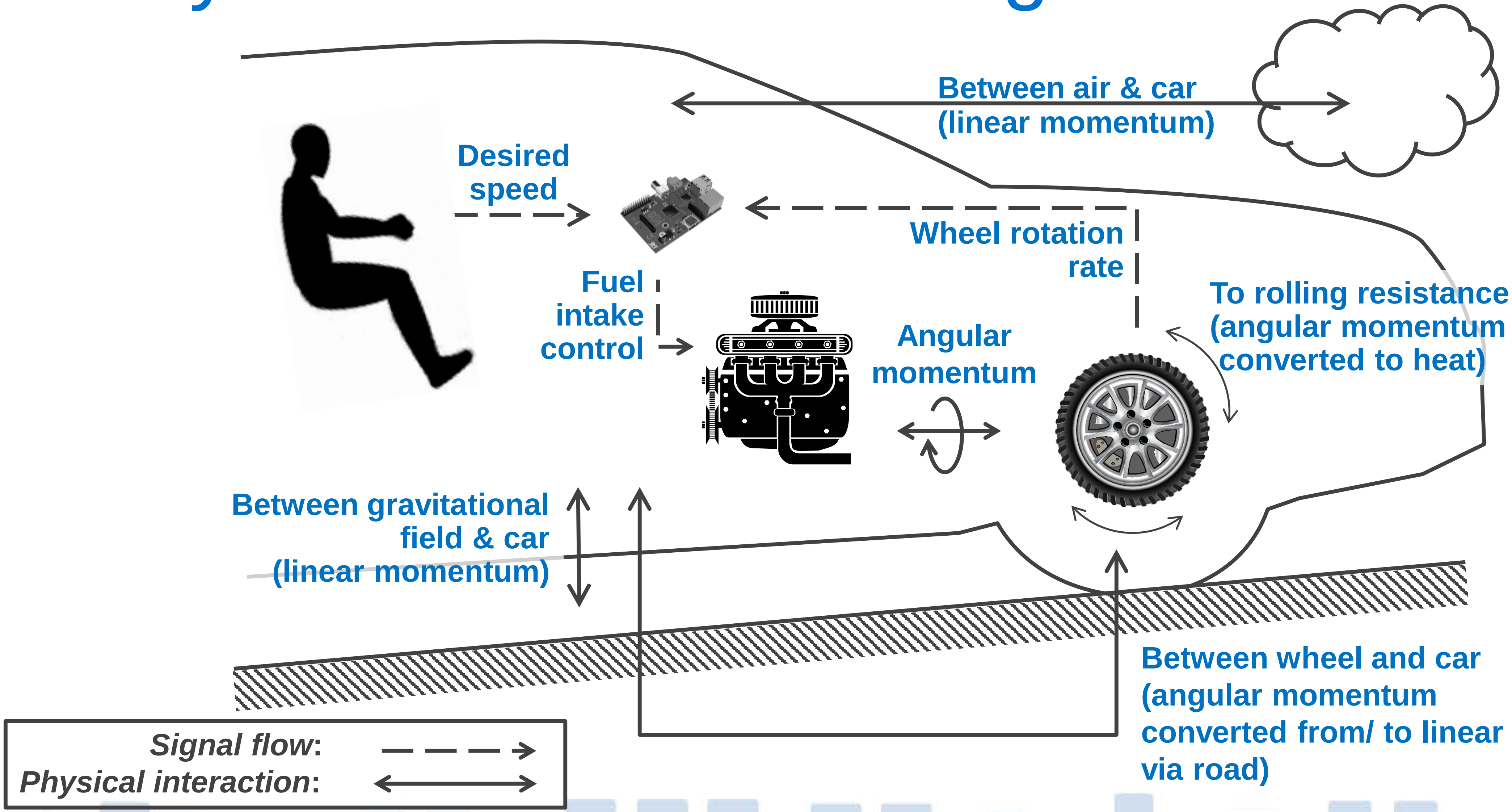
Areas for Integration

1. Physical interaction / signal flow simulation.
2. Finite element analysis.
3. Mathematical unification of systems and analysis models.
4. Discrete event analysis and optimization (production, logistics)

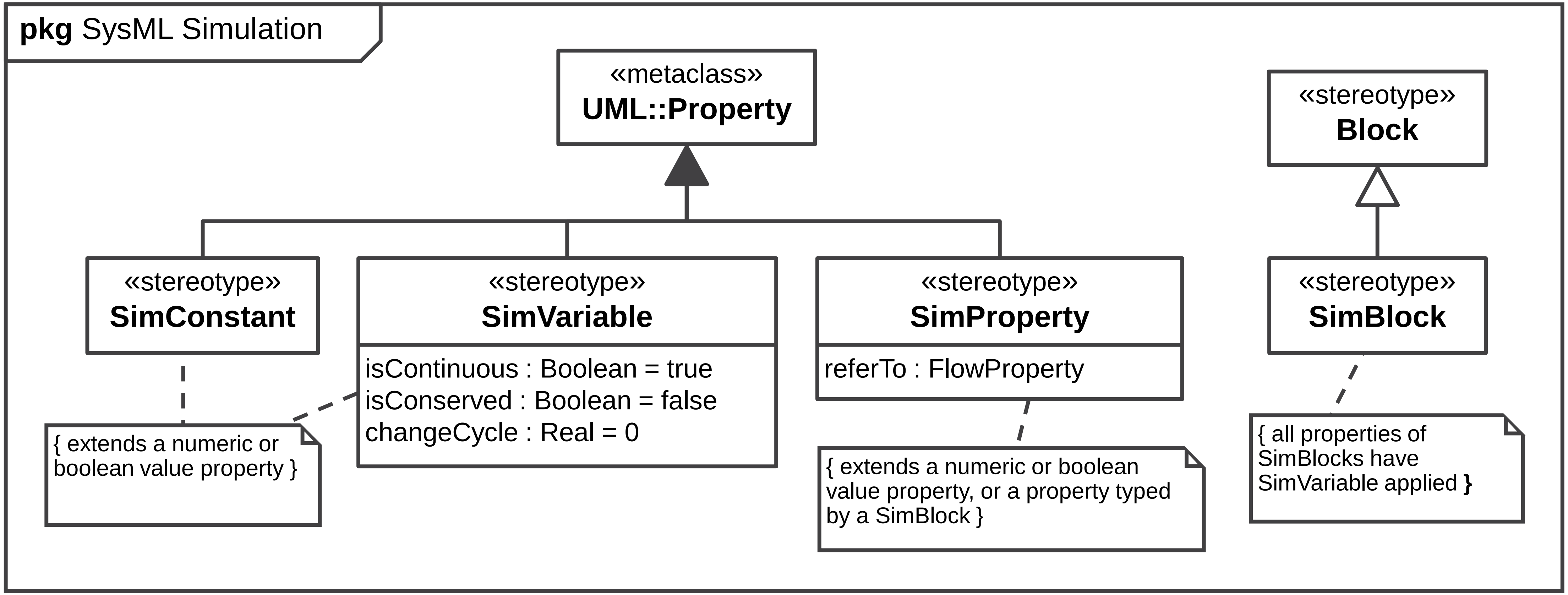
Areas for Integration

1. Physical interaction / signal flow simulation.
2. Finite element analysis.
3. Mathematical unification of systems and analysis models.
4. Discrete event analysis and optimization (production, logistics)

Physical Interaction & Signal Flow

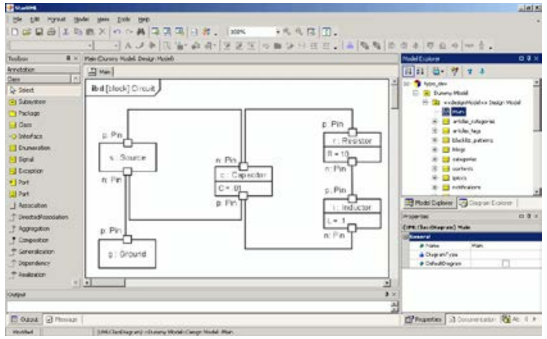


SysML Extension for PI & SF



- In finalization at OMG

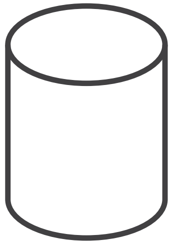
Open Source Translator to Simulators



SysML Tool

```
<xmi:XMI xmi:uml=http://www.omg.org/spec/UML/20110701>
<packagedElement xmi:type="uml:Class" name="Circuit">
  <ownedAttribute xmi:type="uml:Property" name="r"
   type="_17_0_2_1_8340219_1386362605823_957929_2536"/>
  <ownedAttribute xmi:type="uml:Property" name="c"
   type="_17_0_2_1_8340219_1386362584651_224589_2534"/>
  <owned.Attr~bute xm1:type="uml:Property" name="i"
   type="_17_0_2_1_8340219_1386362591582_80360_2535"/>
  <ownedConnector xmi:type="uml:Connector"/>
  <ownedConnector xmi:type="uml:Connector"/>
  <ownedConnector xmi: type-"uml :Connector"/>
  <ownedConnector xmi:type="uml:Connector"/>
</packagedElement>
<packagedElement xmi:type="uml:Class" name="Source"/>
<packagedElement xmi:type="uml:Class" name="Ground"/>
<packagedElement xmi:type="uml:Class" name="Capacitor"/>
<packagedElement xmi:type="um1:Association"/>
<packagedElement xmi:type="um1:Assoc1ation"/>
</uml:Model>
</xmi>
```

SysML Model File



UML Repository

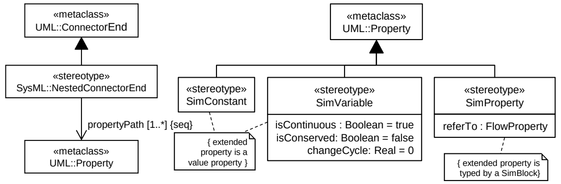
```
model circuit
  Resistor  R1(R=10);
  Capacitor C(C=0.01);
  Resistor  R2(R=100);
  Inductor  L(L=0.1);
  VsourceAC AC;
  Ground    G;
  equation
    connect (AC.p, R1.p);
    connect (R1.n, C.p);
    connect (C.n, AC.n);
    connect (R1.p, R2.p);
    connect (R2.n, L.p);
    connect (L.n,  C.n);
    connect (AC.n, G.p);
end circuit;
```

Modelica and Mathworks

Simulator Input File

loaded into

developed in

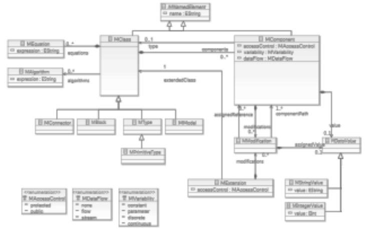


SysML and Simulator Extensions

```
public void generate(Class urootblock, Resource r) {
  sysmlutil = new SysMLUtil(r.getResourceSet());
  slibrary = SimulinkFactory.eINSTANCE.createSLib();
  slibrary.setName(urootblock.getName() + "Library");
  while(toProcess.size()!=0)
  { ReferenceKey rk = toProcess.pop();
    SElement selement = refs.get(rk);
    if (selement instanceof SSystem)
    { SSystem ssystem2 = processSys (rk.getKey()[0]);
      slibrary.getSystem().add(ssystem2.getSubsys());}
    else if (selement instanceof SFunction)
    { processSFunc(rk.getKey()[0], rk.getKey()[1]);}
  }}
```

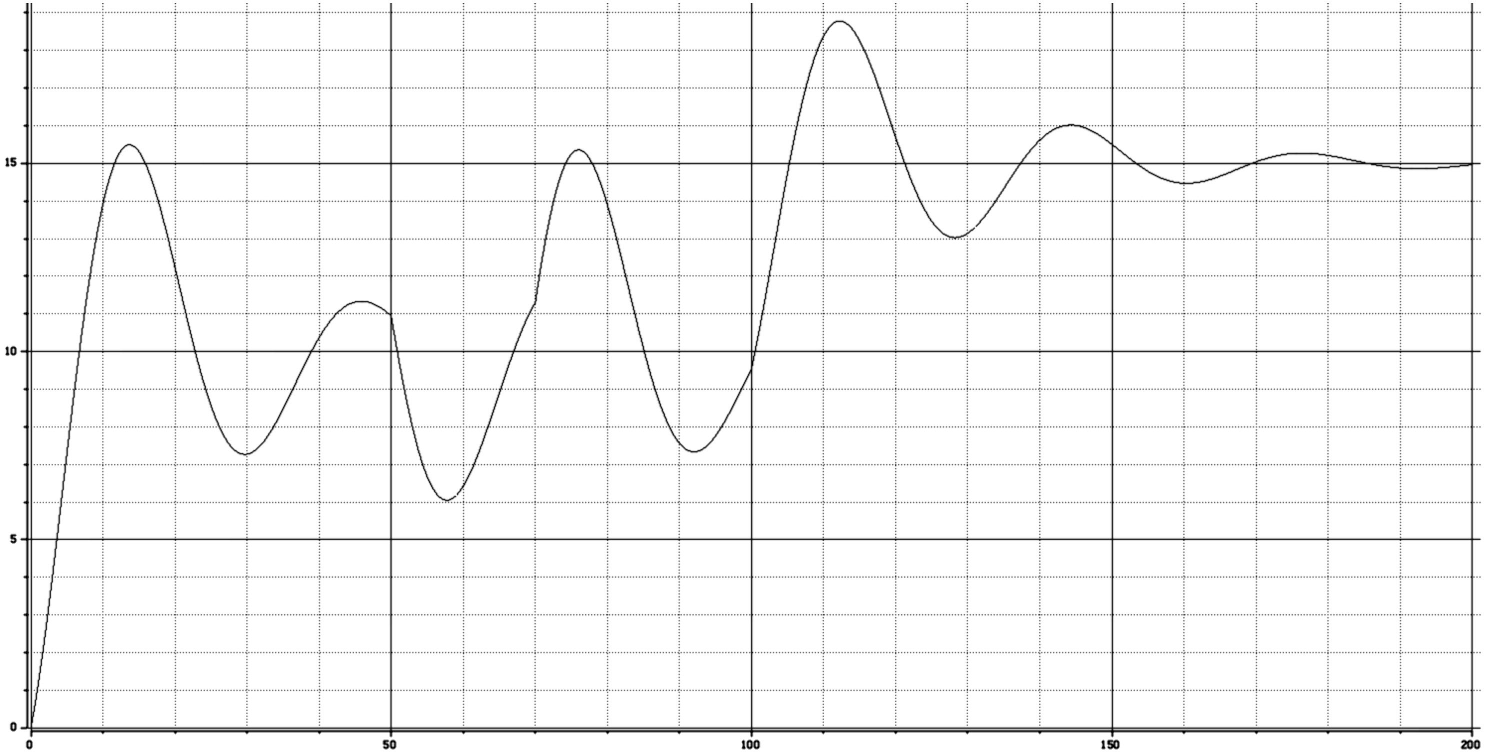
Translator Program

instantiates



Simulation Language Metamodels

Simulation



- Generated simulation files execute the same way on Modelica and Mathworks Tools

Areas for Integration

1. Physical interaction / signal flow simulation.
2. Finite element analysis.
3. Mathematical unification of systems and analysis models.
4. Discrete event analysis and optimization (production, logistics)

Digital Thread

- Digital Thread: platform for information to integrate product design, production and logistics systems design, and later stages of product lifecycle (sustainment)

- Design for Manufacturing: product/production design integration

- Production System Design Methodology: Processes, decision-making support, and analysis tools
    - Without a reference model you can't do it right today in a non ad-hoc way. Even with a reference model, you can't do it throughout the product's lifecycle since all of the analysis models have to be built by hand.

The SE “V” for both product & process

System Development	System Process Development
Con Ops	Global supply chain concept
Requirements/ Architecture	Technical capabilities and capacities, SC architecture
Detailed Design	Sourcing plan, facility design, planning/control concepts
Implement	Virtualize, test concepts, program roll-out
Integrate, Test, Verify	Global SC simulation, contingency analyses, standards, …
System V&V	Deployment
Operations & Maintenance	Operations

Computational support

CAD, FEA, CFD, PDM/PLM, REQUIREMENTS, SysML, and many more; increasing levels of integration and interoperability

Use models to specify, analyze, integrate, simulate, verify, validate—virtually, across disciplines

Excel, Visio, some CAD, optimization, simulation; not integrated, not interoperable

Use documents to specify and communicate, independent *ad hoc* models to support decision making

…velopment	System Process Development
… Ops	Global supply chain concept
…irements/ A… tecture	Technical capabilities and capacities
Deta…ed Design	SC architecture, sourcing plan, facility design, planning/control concepts
Implement	Virtualize, program roll-out
Integrate, Test, Verify	Global SC simulation, contingency analyses
System V&V	Deployment
Operations & Maintenance	Operations

Fundamental Challenges

- (Lack of) Common semantics & syntax for specifying production systems *(reference model)*
  - Difficulty of integration in PDM/PLM systems

- Time and expense of hand-coding analysis models (imagine if every FEA/CFD required a simulation engineer to hand-code the model)
  - Very limited decision support to production system engineers

- (Lack of) An engineering design methodology for production systems
  - Very difficult to capture/re-use learnings from experience—lots of tacit rather than explicit knowledge

What are DELS?

Discrete event logistics systems (DELS) are a class of dynamic systems that are defined by the transformation of discrete flows through a network of interconnected subsystems.

- ➢ These systems share a common abstraction, i.e. *products* flowing through *processes* being executed by *resources* configured in a *facility* (PPRF).

Examples include:

- Supply chains
- Manufacturing systems
- Transportation
- Material handling systems
- Storage systems
- Humanitarian logistics
- Healthcare logistics
- Semiconductor manufacturing
- Reverse and Remanufacturing Logistics
- And many more …

- ➢ Fundamentally, these systems are very similar, and often DELS are actually composed of other DELS.
- ➢ This similarity (and integration) produces a common set of analysis approaches that are applicable across the many systems in the DELS domain.

Interest to MBSE Community

- Bring a different domain into the INCOSE community
  - In the design of logistics systems, we don't have good SE tools and practices
- Why can INCOSE have a big impact on this domain?
  - In addition to the SE best practices, MBSE has been transformative!
  - Explicit modeling and design methods
    - Consensus on how we talk about our artifacts and design them
  - Want to learn from MBSE community
- What are the things we need to do to have an impact:
  - Reference models, common design process, conforming and supporting analysis models and tools.
  - Build a community around a shared vision of DELS MBSE

It's (long past) time to bring the power of (model based) systems engineering to production systems and global supply chains!

What does it take to do that?

Where are we in the journey?

Tuesday @ 8:10am in MBX/Ecosystems

leon.mcginnis@isye.gatech.edu
timothy.sprock@nist.gov
conrad.bock@nist.gov

Overview

- Project organization
- Motivation and approach
- Areas for integration
- Summary

Summary

- Multi-year federal project on integrating systems modeling and analysis.
- General approach following initial work on PI & SF simulation integration.
- Four topic areas so far
  - PI & SF simulation
  - Finite element analysis.
  - Discrete event analysis and optimization (production, logistics).
- Results will be publically available.

More Information

- NIST organization chart
  - http://nist.gov/director/orgchart.cfm
- EL smart manufacturing programs
  - http://www.nist.gov/el/smartcyber.cfm
- SMSI Project description
  - http://www.nist.gov/el/msid/syseng/smsi.cfm
- Project lead
  - Conrad Bock, conrad dot bock at nist dot gov

2017

annual INCOSE international workshop

Los Angeles, CA, USA

January 28 - 31, 2017

www.incose.org/IW2017