Integrating Systems Modeling with Engineering Analysis

Conrad Bock

U.S. National Institute of Standards and Technology

-

NIST
National Institute of Standards and Technology

Overview

- **NIST organization**
- **Motivation and approach**
- **Areas for integration**
- **Summary**

Overview

- **NIST organization**
- Motivation and approach
- Areas for integration
- Summary

NIST

- **A U.S. federal agency**
  - **Part of Department of Commerce**
- **Funded by Congress.**
  - **Starting with requests from the President.**
- **Seven laboratories**
  - **Two information-focused.**
  - **Four for physical sciences.**
  - **One engineering lab, concerned with physical and informational topics.**

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**

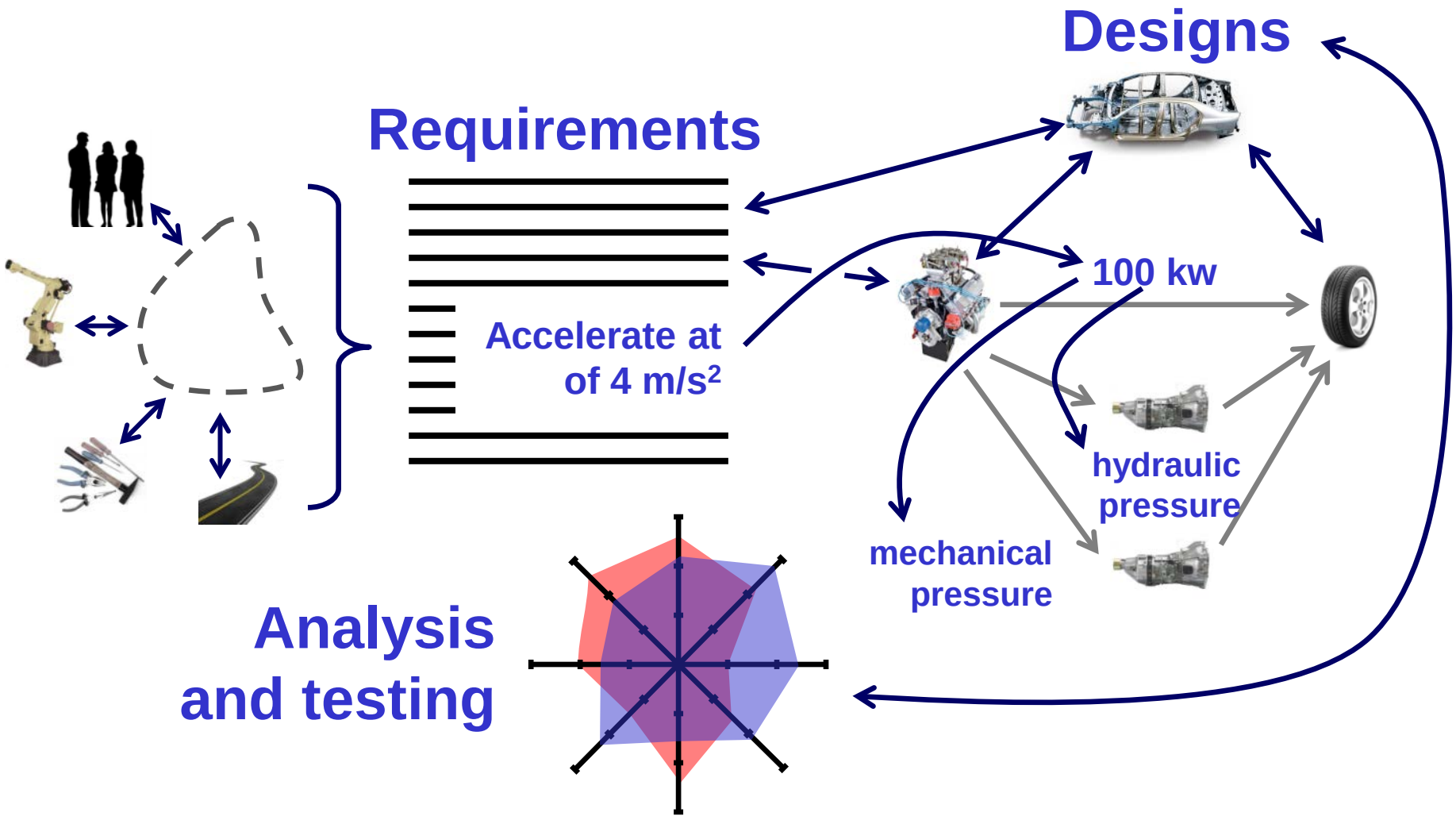
SM Systems Interoperability

- **Five year project**
  - **Started work recently, four years left.**
- **Concerned with integrating information between systems engineers and other engineers.**
  - **Will focus on integration of SE and engineering analysis information.**
- **Four multi-year cooperative agreements awarded recently.**
- **One full time federal project leader.**

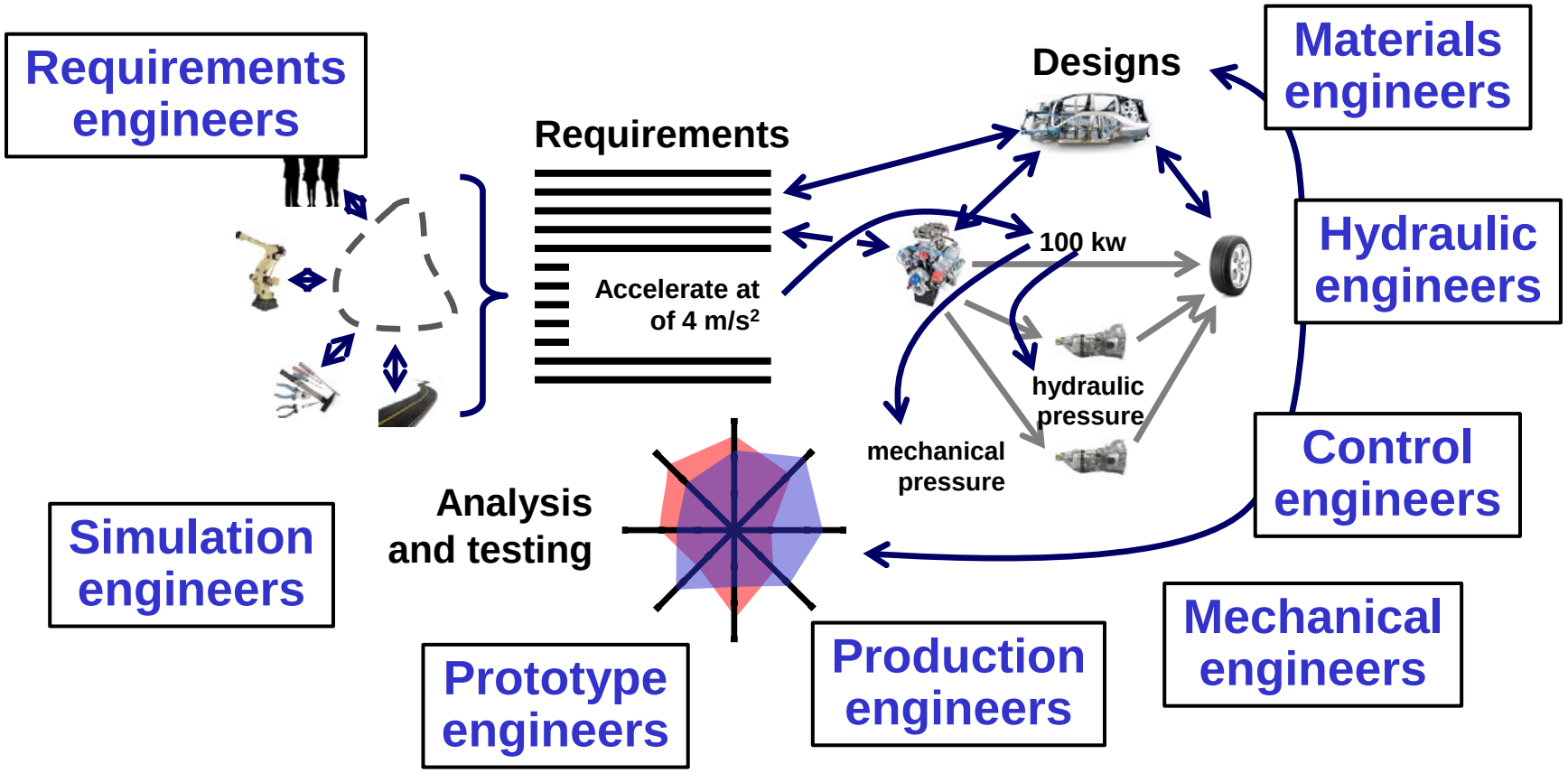
Overview

- NIST Organization
- **Motivation and approach**
- Areas for integration
- Summary

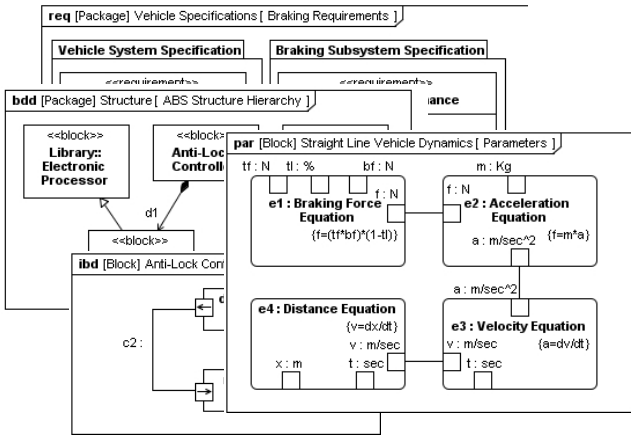
Systems Engineering



Systems Engineers



Model-Based Systems Engineering



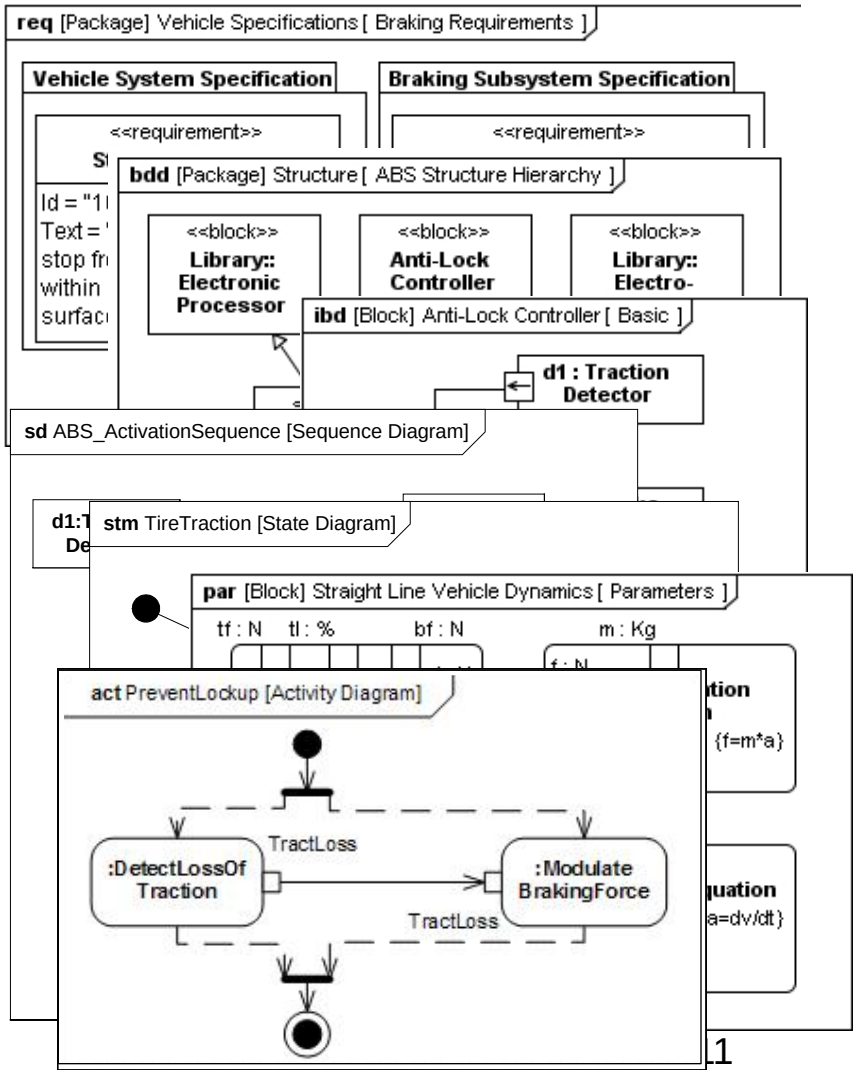
Paper

Electronic Documents

Computerized Models

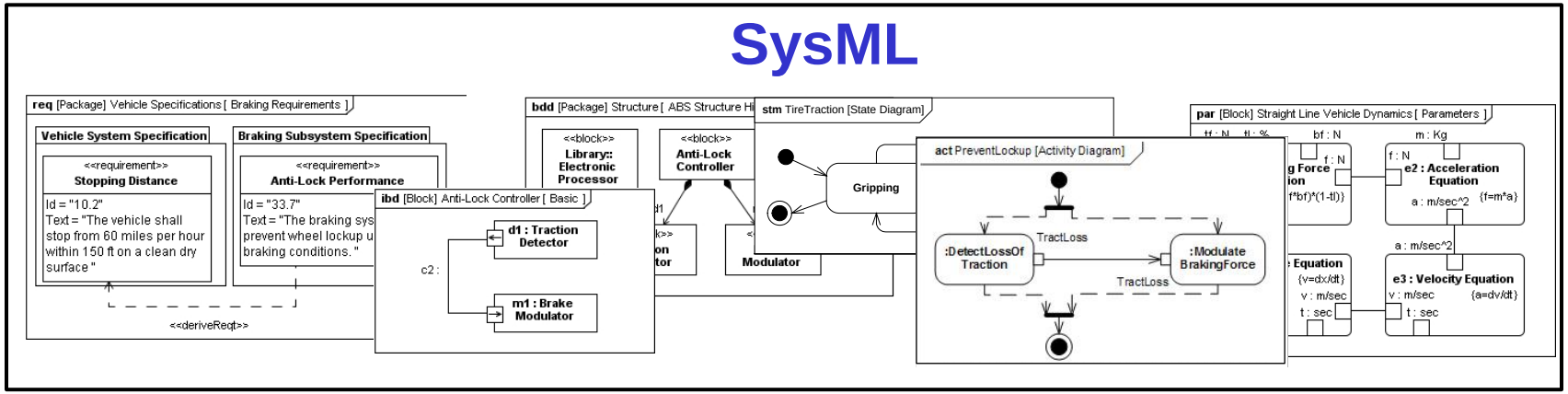
Systems Modeling Language (SysML)

- **Most widely used graphical modeling language for systems engineering.**
- **International standard since 2007.**
- **Diagrams for:**
  - **Requirements, component breakdown and interconnection, behavior, parametrics.**



Engineering Language Integration

- **Overlapping and inconsistent system specifications in multiple languages.**



? ?

Material languages

Hydraulic languages

Production languages

Simulation languages

Require languages

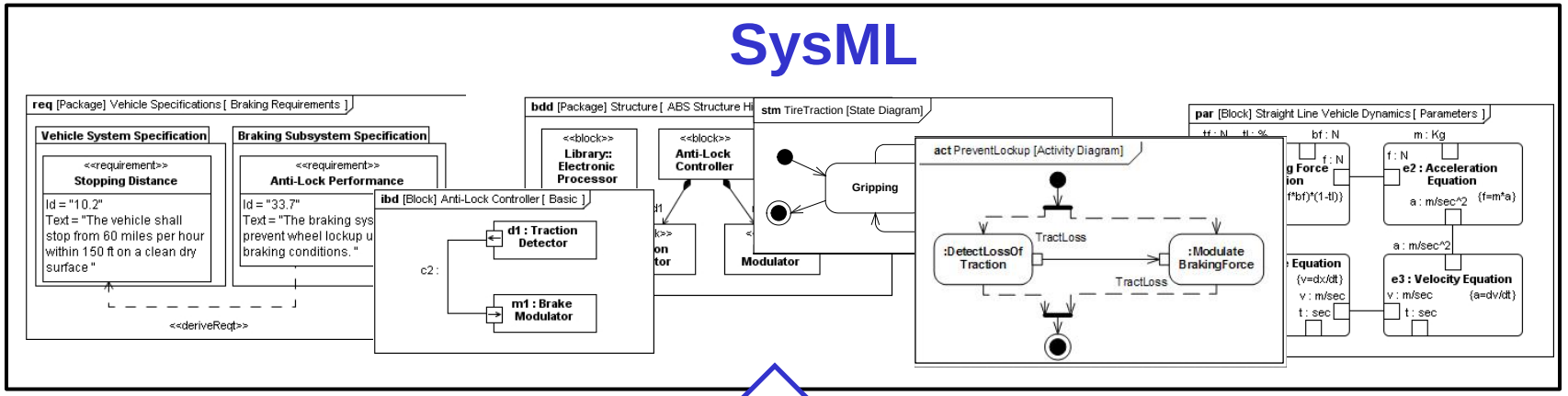
Control languages

Mechani languages

Prototy languages

Physical Interaction and Signal Flow Simulation Language Integration

- **Covers multiple engineering disciplines.**
- **Fewer languages involved.**



?

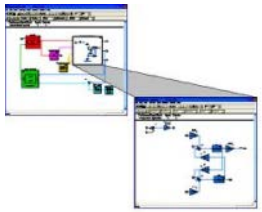
?

PI & SF simulation languages & tools

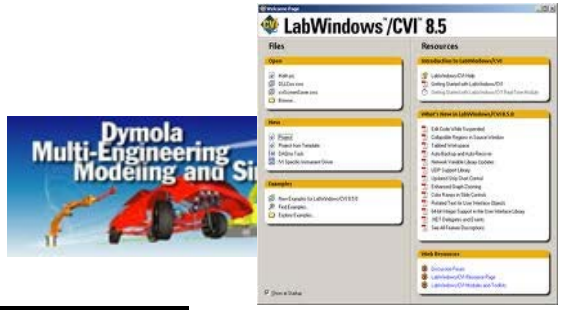
MATLAB SIMULINK

MODELICA OpenModelica

NATIONAL INSTRUMENTS LabVIEW



Scilab



SE Modeling & PI&SF Simulation

- **Systems engineering models and simulators are concened with overlapping aspects of flow.**

Domain	Kind of item flowing
Electrical	Charge
Mechanics, translational	Momentum
Mechanics, angular	Angular momentum
Fluid	Volume (uncompressable fluid)
Thermal	Heat energy

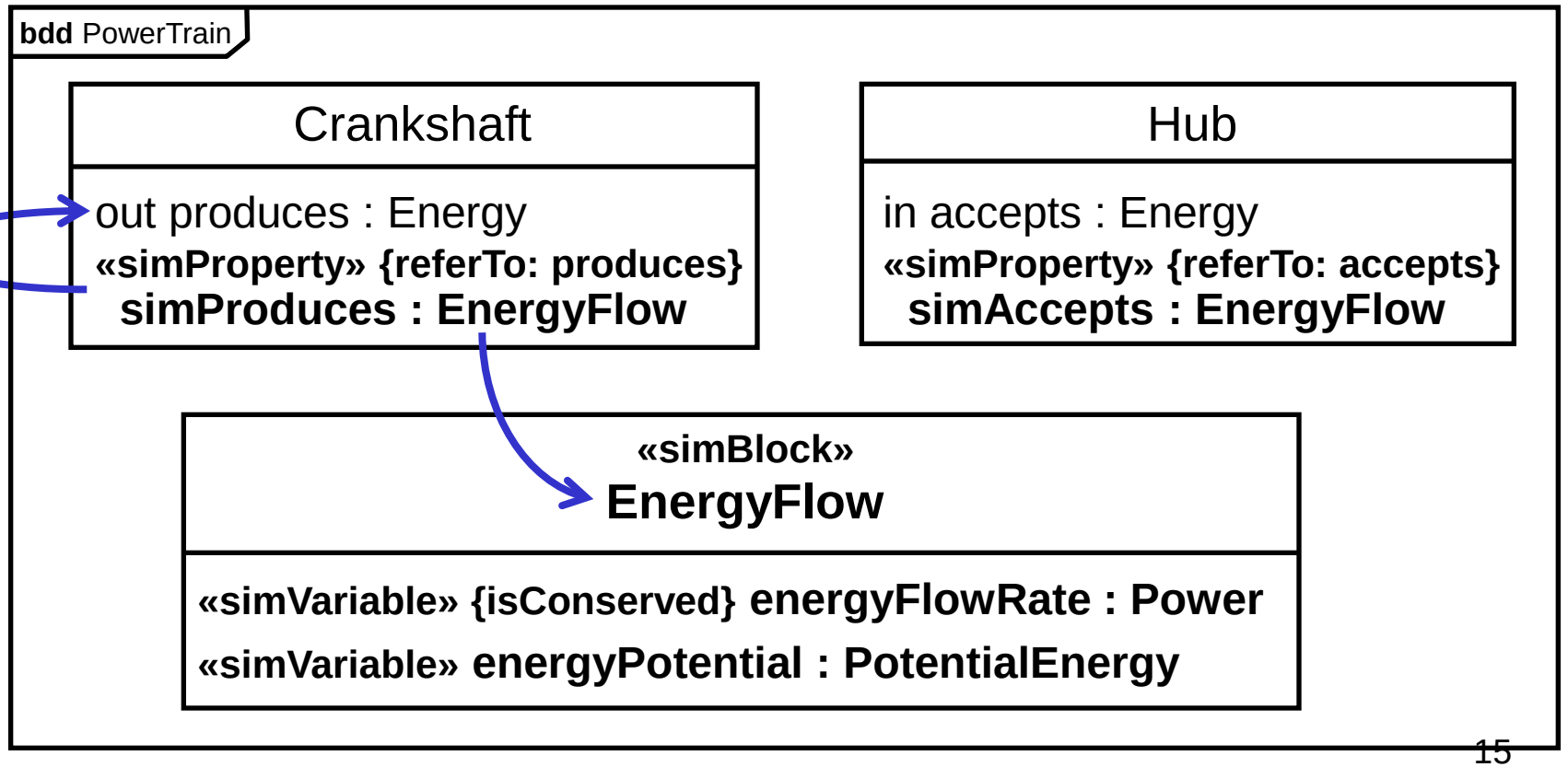
Direction of flow

Flow Rate	Potential to flow
Current	Voltage
Force	Velocity
Torque	Angular velocity
Volumetric rate	Pressure
Heat flow rate	Temperature

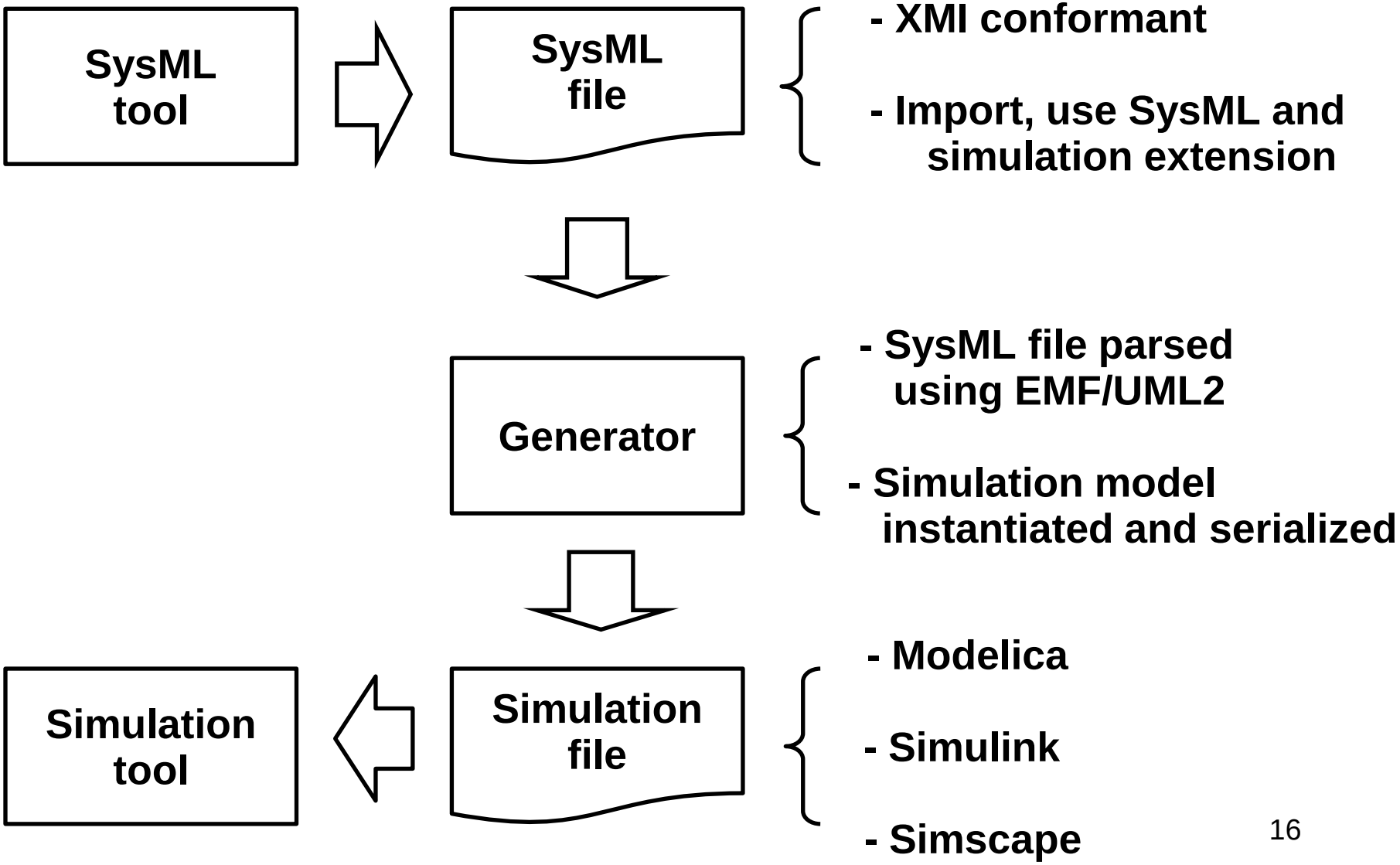
Systems Engineering **PI & SF Simulators**

Extending SysML for PI&SF

- **Bring flows and potentials into SysML for generating simulator input.**



Demonstration Architecture



General Technical Approach

1. Select analysis areas to address.
2. Examine the literature and widely-used tools in those areas.
3. Develop information 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.

Standardization

- **Involve industrial partners during technical work and standardization.**
  - **Engineering users and tool developers.**
- **Compare integration techniques used in technical work.**
- **Examine standards organizations for likely candidates.**
  - **Industrial involvement and timeliness.**
- **Begin standardization process.**

Overview

- NIST Organization
- Motivation and approach
- **Areas for integration**
- Summary

Areas for Integration

1. **Physical interaction / signal flow simulation (continued).**
2. **Tradeoff analysis and optimization.**
3. **Thermal / fluid flow and structural analysis.**
4. **Mathematical unification of systems and analysis models.**

Physical Interaction and Signal Flow Simulation

Next Steps for PI&SF Integration

1. **Beyond proof-of-concept**
   - **Proof of scaling**
     - **More components and inter-connections, using more capabilities of the extension.**
   - **Model synchronization.**
     - **Alternatives to SysML extensions?**
2. **Expanded coverage**
   - **Identify additional capabilities**
     - **In common or not.**
   - **Application of other SysML diagrams**
     - **Activity diagrams for signal processing.**

Tradeoff Analysis & Optimization

Trade Studies (Definition)

- **Test alternative system designs against conflicting requirements.**

1. **Formulation**
   - **Develop tests that are executable on off-the-shelf software.**
2. **Analysis**
   - **Make design decisions based on test results.**
   - **Manage test results and relate them to decisions for knowledge reuse and rationale lookup.**

Challenges to Integration

- **Multiple system and variant models.**
  - **Redundant, potentially incompatible system and variant specifications.**
  - **Incompatible tools & file formats.**
- **Manual formulation of trade studies.**
  - **Not integrated into systems models.**
- **Manual management of results & decisons.**
  - **Unmodeled and unintegrated tangle of information (system, trade problems, results, decisions).**

Tasks

1. **Classify and characterize trade study problems.**
2. **Develop tool-independent model of trade study problems.**
3. **Build proofs-of-concept (see general technical approach)**
4. **Report results publically.**

Thermal / Fluid Flow and Structural Analysis

Thermal / Fluid Flow and Structural Analysis

- **Apply the general technical approach to these areas.**
  - **Wil include geometry and other areas as needed for proofs-of-concept.**
- **Develop and apply best practices for**
  - **Extending SysML for analysis integration.**
  - **Mathematical relationships between SysML and analysis properties.**
  - **Modeling design / analysis workflows.**

Tasks

- **Develop integration cases with example engineering models.**
- **Define mathematical relationships between SysML and analysis models.**
- **Develop transformations between SysML and analysis models.**
- **Develop and apply best practices for creating and exchanging engineering information.**
- **Report results publically.**

Mathematical Unification of Systems and Analysis Models

Lumped & Distributed Models

- **Lumped models are “node and arc”**
  - **SysML, PI & SF, bond graphs, and other “model-based” approaches.**
  - **Single-variable functions and derivatives on those variables (ordinary DEs)**
- **Distributed models are “spread out”**
  - **Geometry and other spatially distributed physical phenomena (FEA).**
  - **Multi-variable functions and single variable derivatives (partial DEs).**

Unifying Lumped & Distributed

- **Engineering models break systems into *cells* for efficient computation of interactions.**
- **Quantities distributed over cells are are *cochains*:**
  - **0-cochains for points (eg, temperature), vectors, coordinate systems.**
  - **1-cochains for lines (eg, electrical currents, deformations).**
  - **2-cochains for surfaces (eg, flux)**
  - **3-cochains for volumes (eg, mass)**

Research Plan

- **Apply co-chains to unify SysML diagrams and analysis models.**
- **Develop computational framework.**
- **Develop MBSE proofs-of-concept.**
- **Report results publically.**

Overview

- NIST 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**
  - **Tradeoff analysis and optimization.**
  - **Fluid/thermal flow and structural analysis.**
  - **Unification of systems and analysis math.**
- **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**

Area Leads

1. **Physical interaction / signal flow simulation**
   - **Raphael Barbau (Engisis)**
   - **raphael dot barbau at engisis dot com**
2. **Tradeoff analysis and optimization**
   - **Manas Bajaj (InterCAX)**
   - **manas dot bajaj at intercax dot com**
3. **Thermal / fluid flow & structural analysis**
   - **Axel Reichwein (Koneksys)**
   - **axel dot reichwein at koneksys dot com**
4. **Mathematical unification of systems and analysis models**
   - **Vadim Shapiro (University of Wisconsin)**
   - **vshapiro at engr dot wisc dot edu**