Modeling for Structural Adaptation: Lessons Learned from Model-based Design

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Caltech
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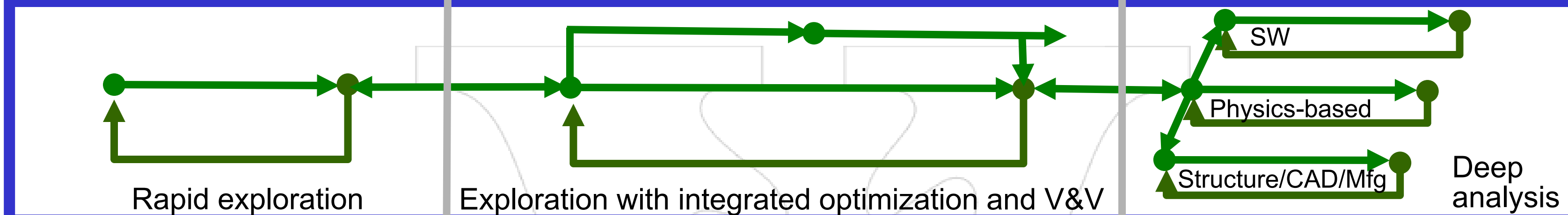
Overview

- Model-Based Design for CPS in META
  - Design flow and design infrastructure
  - Model Integration Challenge
- Formal Semantics of DSMLs
  - Structural Semantics
  - Behavioral Semantics
- Thoughts on Resilience

CPS Design Flow

Architecture Design		Integrated Multi-physics/Cyber Design			Detailed Design	
Modeling	Exploration	Modeling	Simulation	V&V	Modeling	Analysis



Architecture Design

- Rapid architecture exploration
- Engineered design space
- Static constraints (multiphysics)
- 100s of “interesting” configurations remains

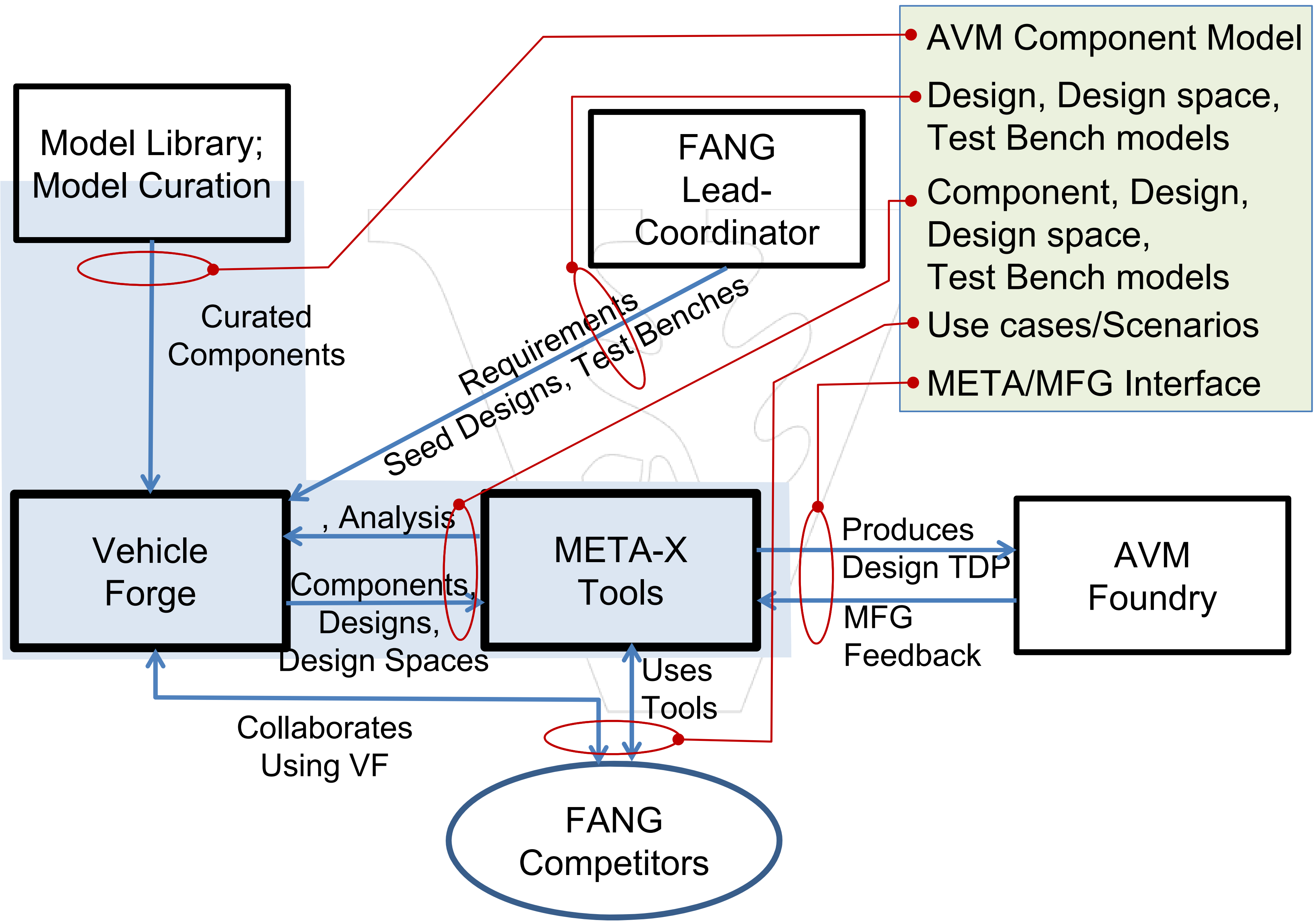
Integrated Multi-physics/Cyber Design

- Behavior exploration using lumped parameter dynamics
- Basic structure synthesis (CAD)
- Manufacturing Constraint Checking
- Composition with testbenches, PCC
- Parametric design tradeoffs
- Selecting few target configurations

Detailed Design

- “Deep”Domain Analysis
  - CAD
  - FEA; thermal, fluid…
  - Surrogate gen.
- Detailed Mfg. modeling
- RT SW modeling, code generation and testing

Interaction Among Major Program Components

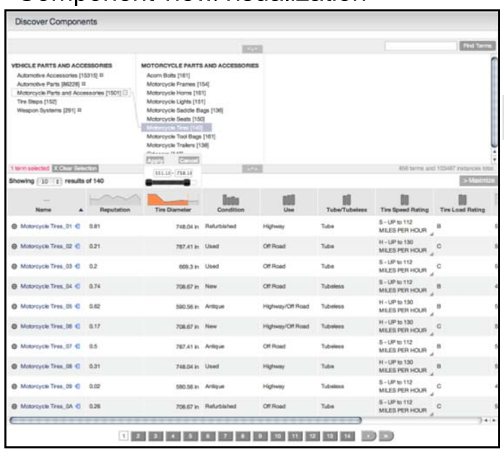


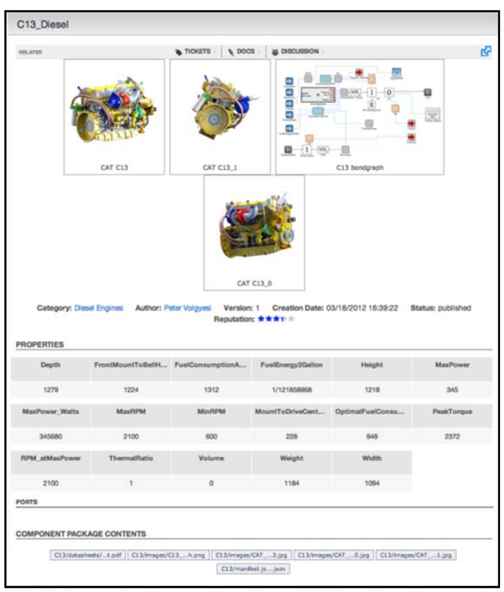
Vehicle.Forge

(or Mechanism for “Horizontal Transfer”)

Components

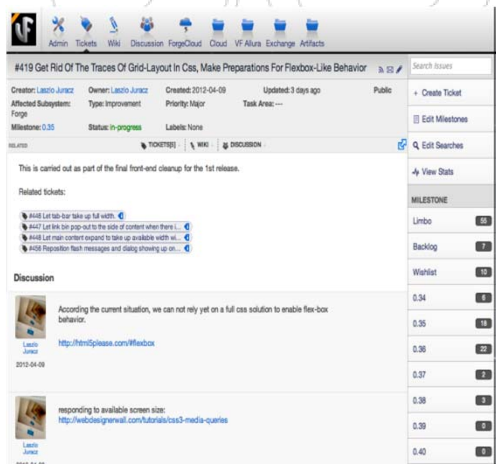
• Component discovery interface based on taxonomical- and faceted search
• Component view/visualization





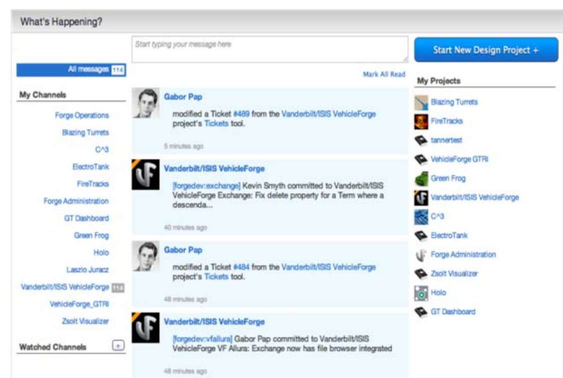
Design Projects

• Self-provisioned collaboration tools
  • Wiki,
  • Discussion Forum,
  • Issue tracking for managing team work.
• Git/SVN repositories for design artifacts
• Project and tool-based permission control
• Notification and Messaging system (in e-mail or as Dashboard messages)
• Set of available tools is extensible



Designers

• Public profile to show recent activities and involvement in design projects
• Designer portfolio publishing résumé and for self-promotion
• Find designers based on expertise and résumé
• Private profile for customizing account and notification settings
• User dashboard showing feeds of activities from projects, public/private messages from other users, announcements from forge-message channels



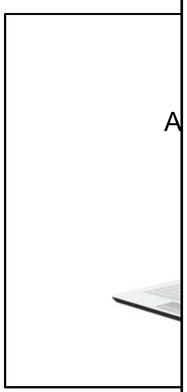
Vehicle.Forge Services

Guided

- Project templat
- Built-in visualiz
- META

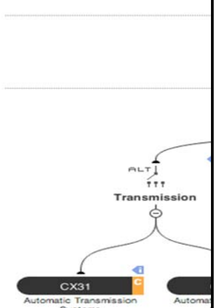
Compo

- Curated
- Taxom discove
- Drag-a subscri
- Chang
- Proven



Design

- Sharing artifacts reposito
- VF uses forge art
- VF agen e.g., by s processi
- Designe individu reposito

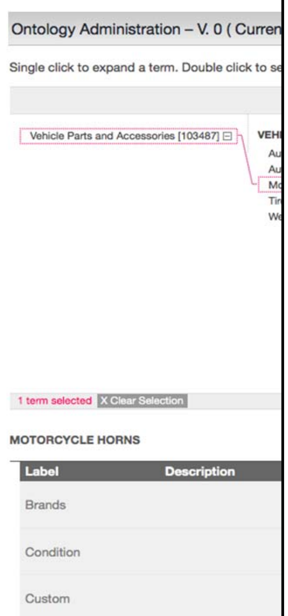


Design W Support

- VF provide tools for pr discussion
- Designers with Electr

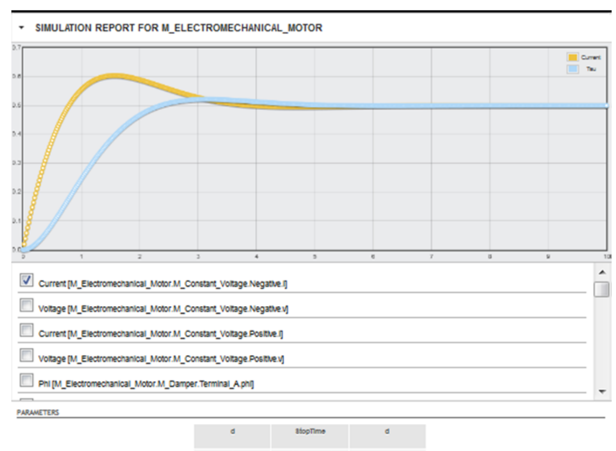
Ontology Administ

- Version-c definition
- Exportabl for tools



Continuous Integration Platform

- Cloud-based analysis job scheduling
- Presentation using built-in and custom web visualizers



Main Research Areas

- Modeling and model integration
  - Heterogeneity of physics and abstraction layers
  - Modeling language design
  - Modeling languages and semantics
- Design space construction and exploration
  - “Good architectures” as parameterized templates
  - Characterization for adaptability; decoupling techniques
  - Layered exploration algorithms
  - V&V tools and Probabilistic Certificate of Correctness (PCC)
- Collaboration platform for design
- Composition platforms
  - TTA, DDS, others...

Main Research Areas

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Model-Based Design

Domain Specific Design Automation Environments:

- *Automotive*
- *Avionics*
- *Sensors…*

Tools:

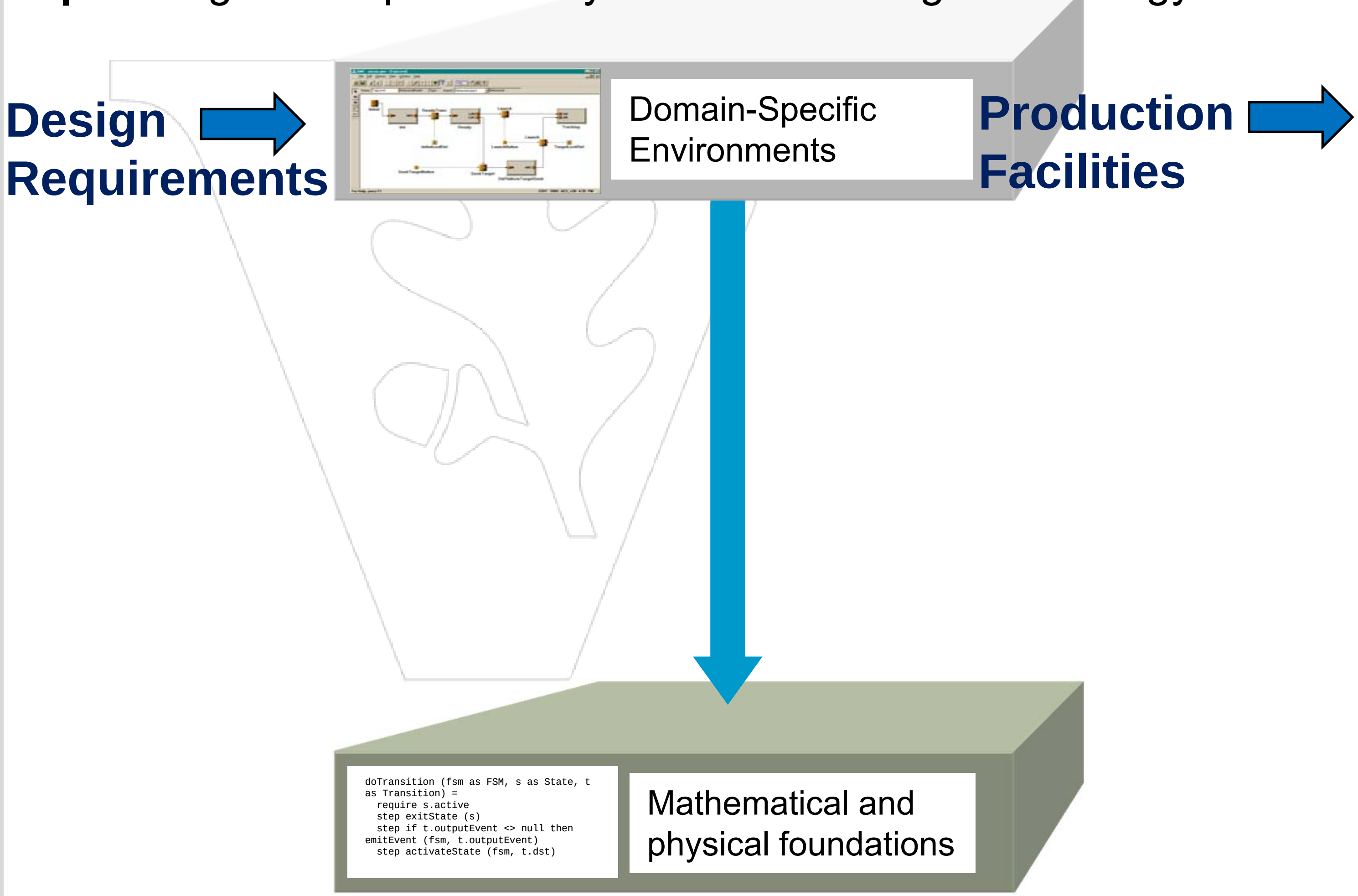
- *Modeling*
- *Analysis*
- *Verification*
- *Synthesis*

Challenges:

- *Cost of tools*
- *Benefit only narrow domains*
- *Islands of Automation*

Key Idea: Use models in domain-specific design flows and ensure that final design models are rich enough to enable production of artifacts with sufficiently predictable properties.

Impact: significant productivity increase in design technology



Metaprogrammable Design Tools

Domain Specific Design Automation Environments:

- *Automotive*
- *Avionics*
- *Sensors…*

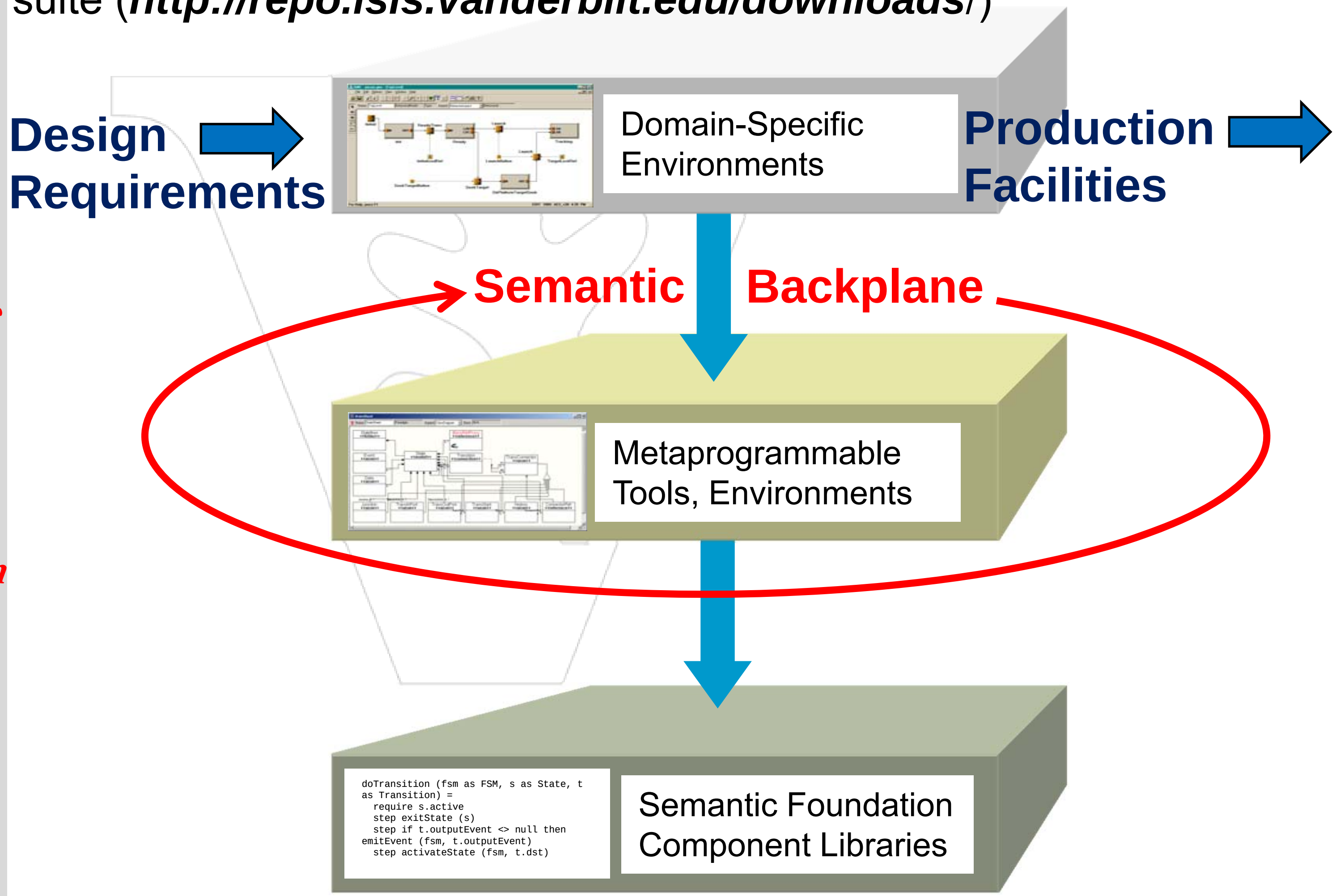
Metaprogrammable Tool Infrastructure

- *Model Building*
- *Model Transf.*
- *Model Mgmt.*
- *Tool Integration*

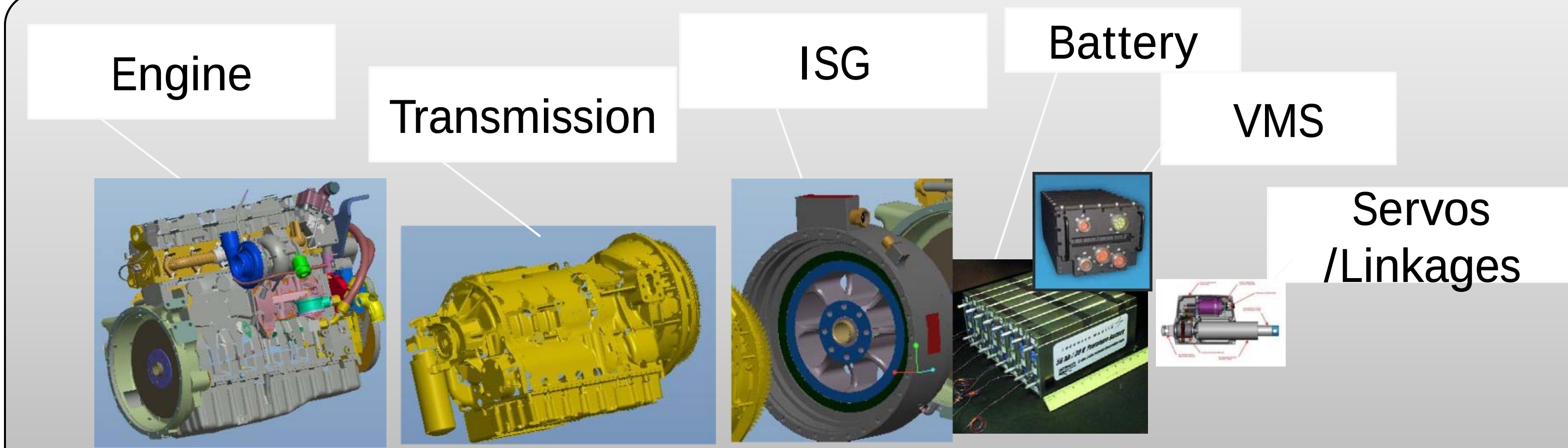
Explicit Semantic Foundation

- *Structural*
- *Behavioral*

Key Idea: Ensure reuse of high-value tools in domain-specific design flows by introducing a metaprogrammable tool infrastructure.
VU-ISIS implementation: Model Integrated Computing (MIC) tool suite (***http://repo.isis.vanderbilt.edu/downloads/***)



Components of a CPS



Components span:

- Multiple physics
- Multiple domains
- Multiple tools

- Physical
  - Functional: implements some function in the design
  - Interconnect: acts as the facilitators for physical interactions
- Cyber
  - Computation and communication that implements some function
  - Requires a physical platform to run/to communicate
- Cyber-Physical
  - Physical with deeply embedded computing and communication

CPS Design Flow Requires Model Integration

Architecture Design		Integrated Multi-physics/Cyber Design			Detailed Design	
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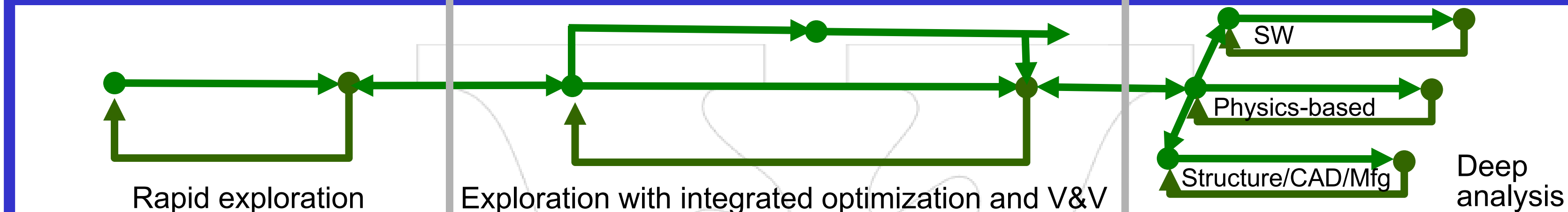


Architecture Design

- Design Space + Constraint Modeling
- Architecture Modeling
- Static Component Modeling (multiphysics)

Integrated Multi-physics/Cyber Design

- Design Space + Behavioral Constraint Modeling
- Architecture Modeling
- Dynamics Modeling (multiple abstractions and multiphysics)
- CAD/assembly modeling
- Coarse Manufacturing Constraint Modeling

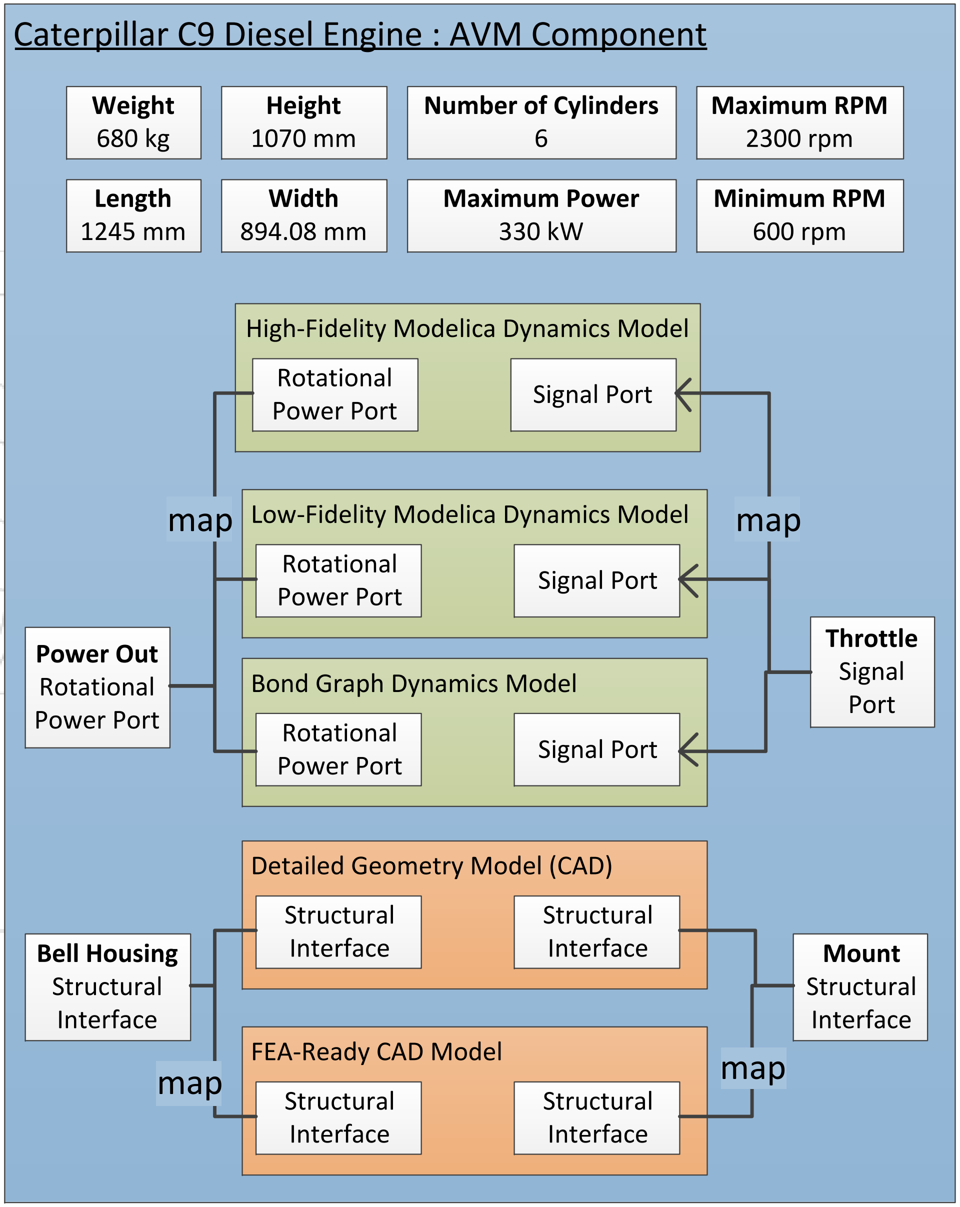
Detailed Design

- Architecture Modeling
- Detailed Domain Modeling
  - CAD
  - FEA; thermal, fluid…
  - Surrogate gen.
- Detailed Mfg. modeling
- RT SW modeling

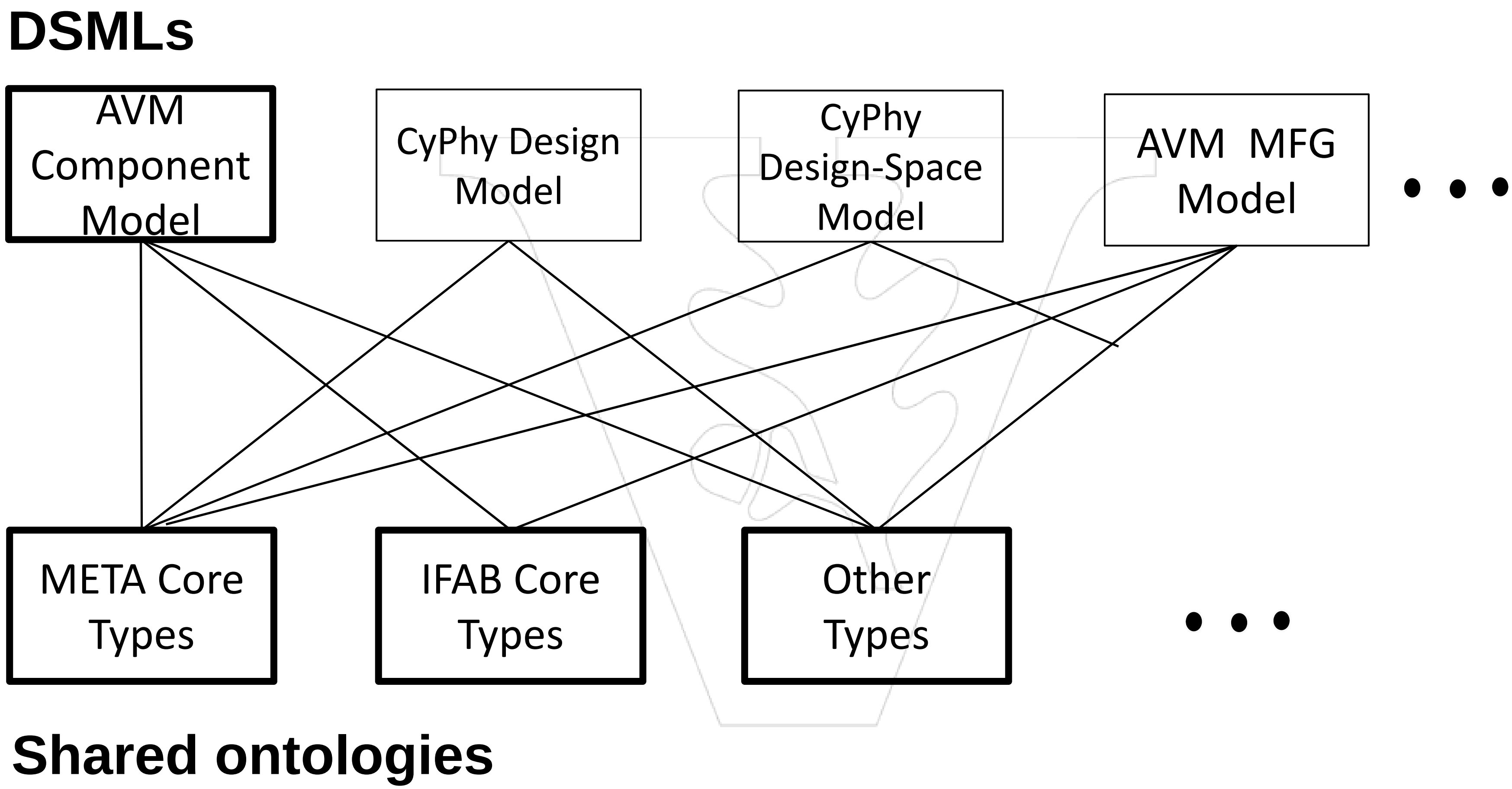
Domain Specific Modeling Languages

AVM Components

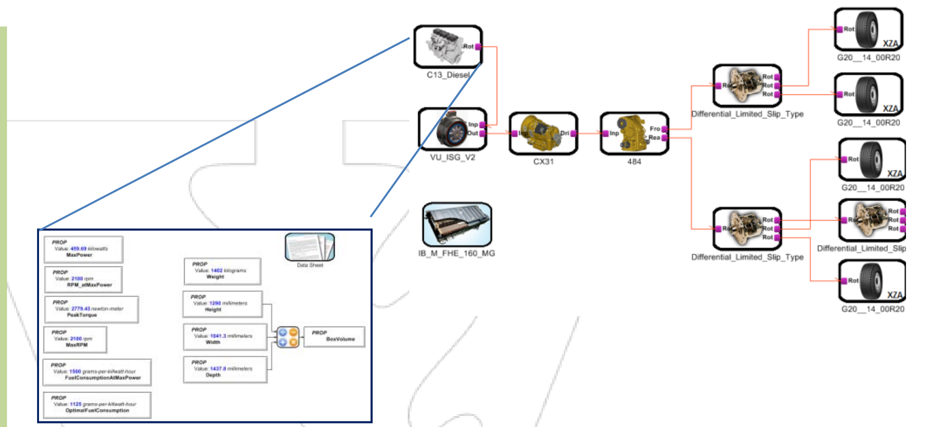
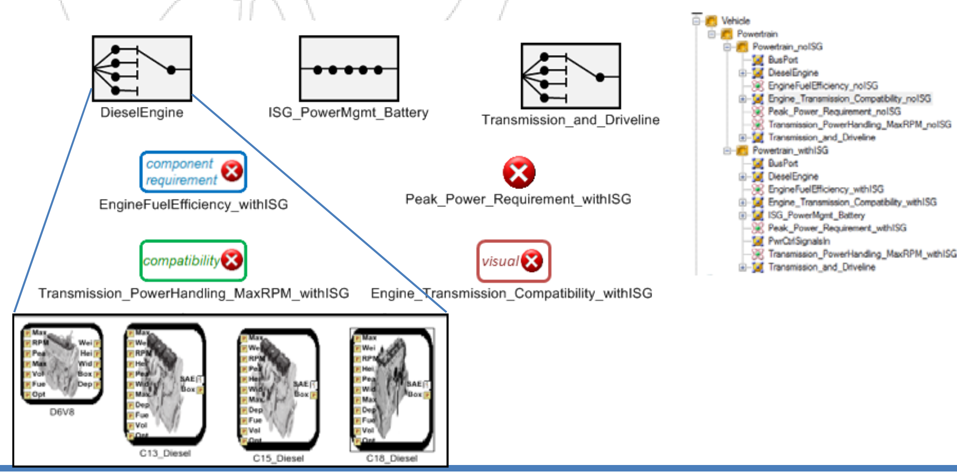
- An **AVM Component** is a well-defined, self-contained entity that can be used in a design.
- Defines the key **Properties** of the component.
- Serves as a wrapper for aggregating **detailed domain models** of the component.
  - Models can vary in level of fidelity and purpose
  - Each model independently represents the component behavior, geometry, etc.
- Aggregates the individual interfaces of these models into a **single set of component interfaces**.



Ontologies and DSMLs



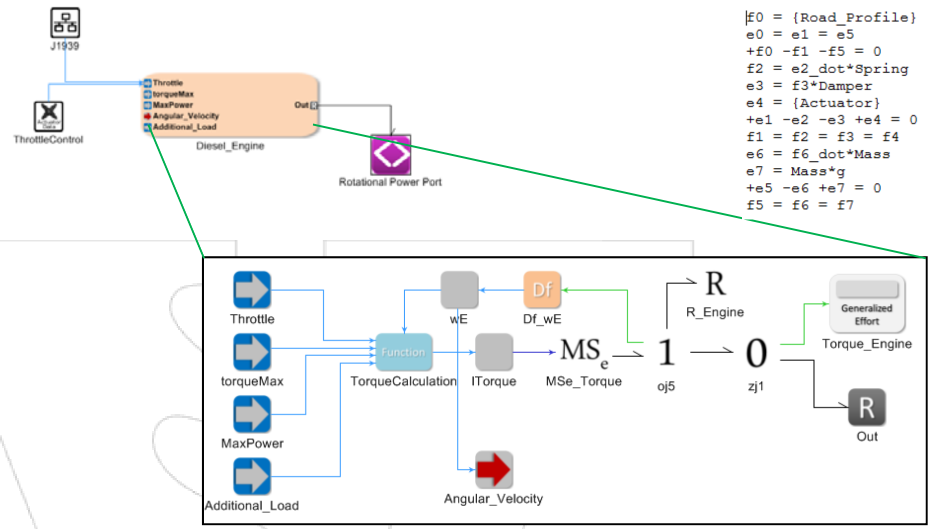
Example: Architecture Modeling

<table>
<tr><th>Sublanguage / Capability</th><th>Formalism, Language Constructs, Examples</th><th>Usage</th></tr>
<tr><td>Architecture Modeling</td><td>Hierarchical Module Interconnect
- Components
- Interfaces
- Interconnects
- Parameters
- Properties

</td><td>Systems Architect
- Explore Design Space
- Derive Candidate Designs</td></tr>
<tr><td>Design Space Modeling</td><td>Hierarchically Layered Parametric Alternatives
- Alternatives/ Options
- Parameters
- Constraints

</td><td>Systems Architect
- Define Design Space
- Define Constraint</td></tr>
</table>

Example: Dynamics Modeling

Physical Dynamics Modeling

Hybrid Bond Graphs
- Efforts, Flows,
- Sources, Capacitance, Inductance,
- Resistance,
- Transformers Gyrators,

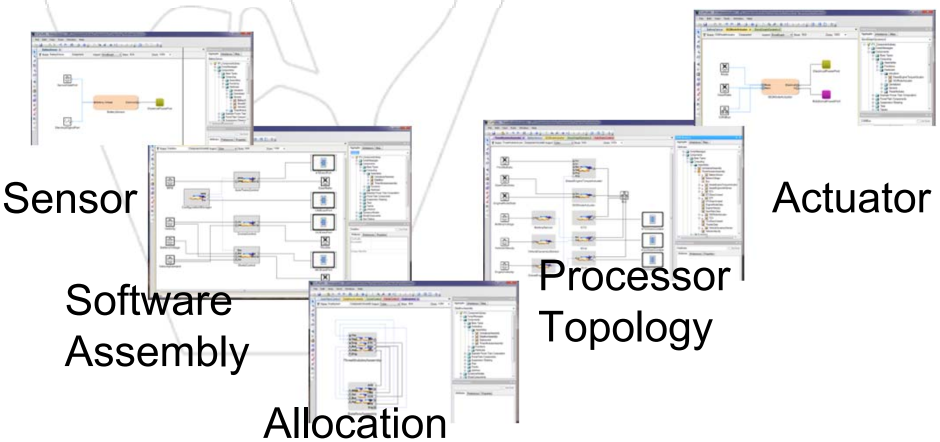


Component Engineer
- model dynamics with Hybrid Bond Graphs

System Engineers
- Compose system dynamics

Computational Dynamics Modeling

Dataflow + Stateflow + TT Schedule
- Interaction with Physical Components
- Cyber Components
- Processing Components



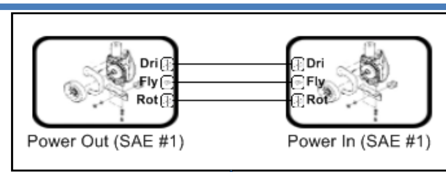
Domain Engineers
- design controller

System Engineers
- Processor allocate
- Platform Effects

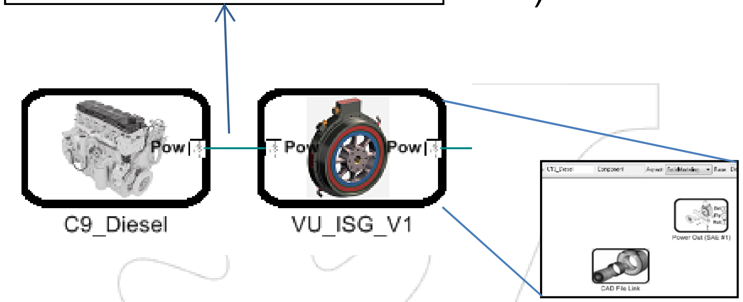
Example: Physical Structure and Manufacturing Modeling

Solid Modeling (CAD / Geometry)

Structural Interfaces
- Defined with Peer Roles:
  - Axis
  - Point
  - Surface
- CAD Links



Standard Structural Interfaces (ex: SAE #1)



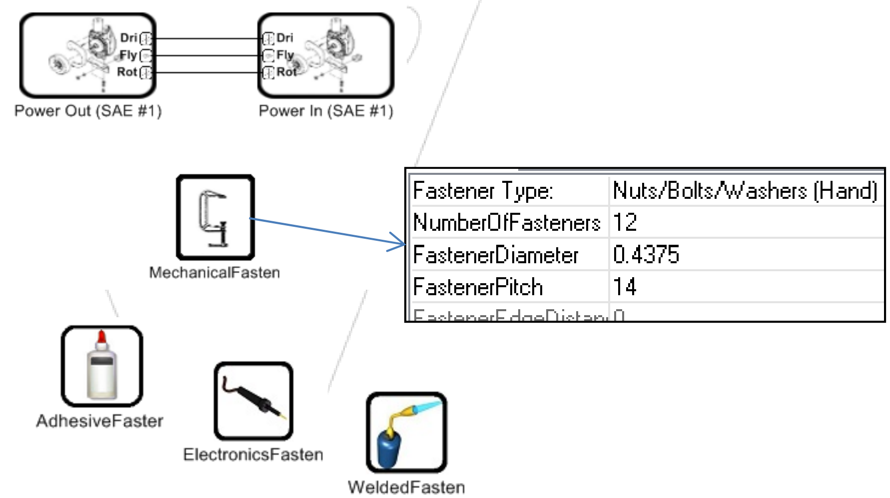
Component Engineer
- Defines Structural Interface

System Engineer
- Defines Architecture

Manufacturing Modeling

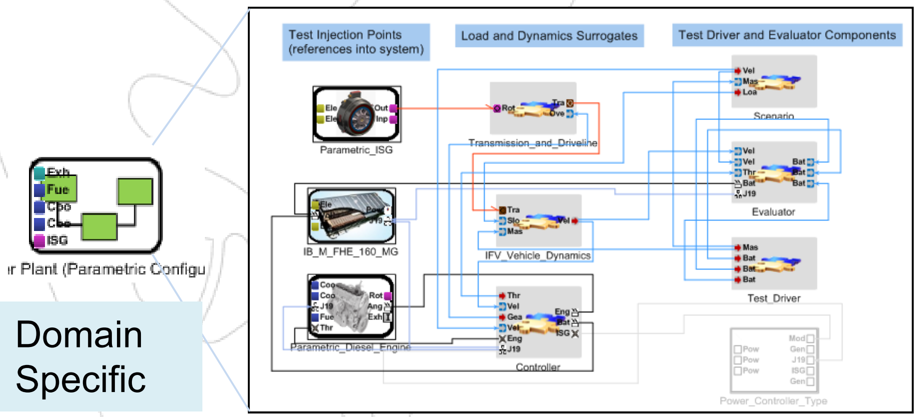
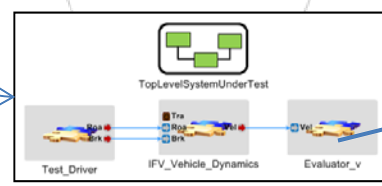
Component Manuf. Cost
- Make
  - Material
  - Fab Proc
  - Complxity
  - Shape/Wt
- OTS: Cost/unit

Structural Interfaces
- Fastener Types, Num# …

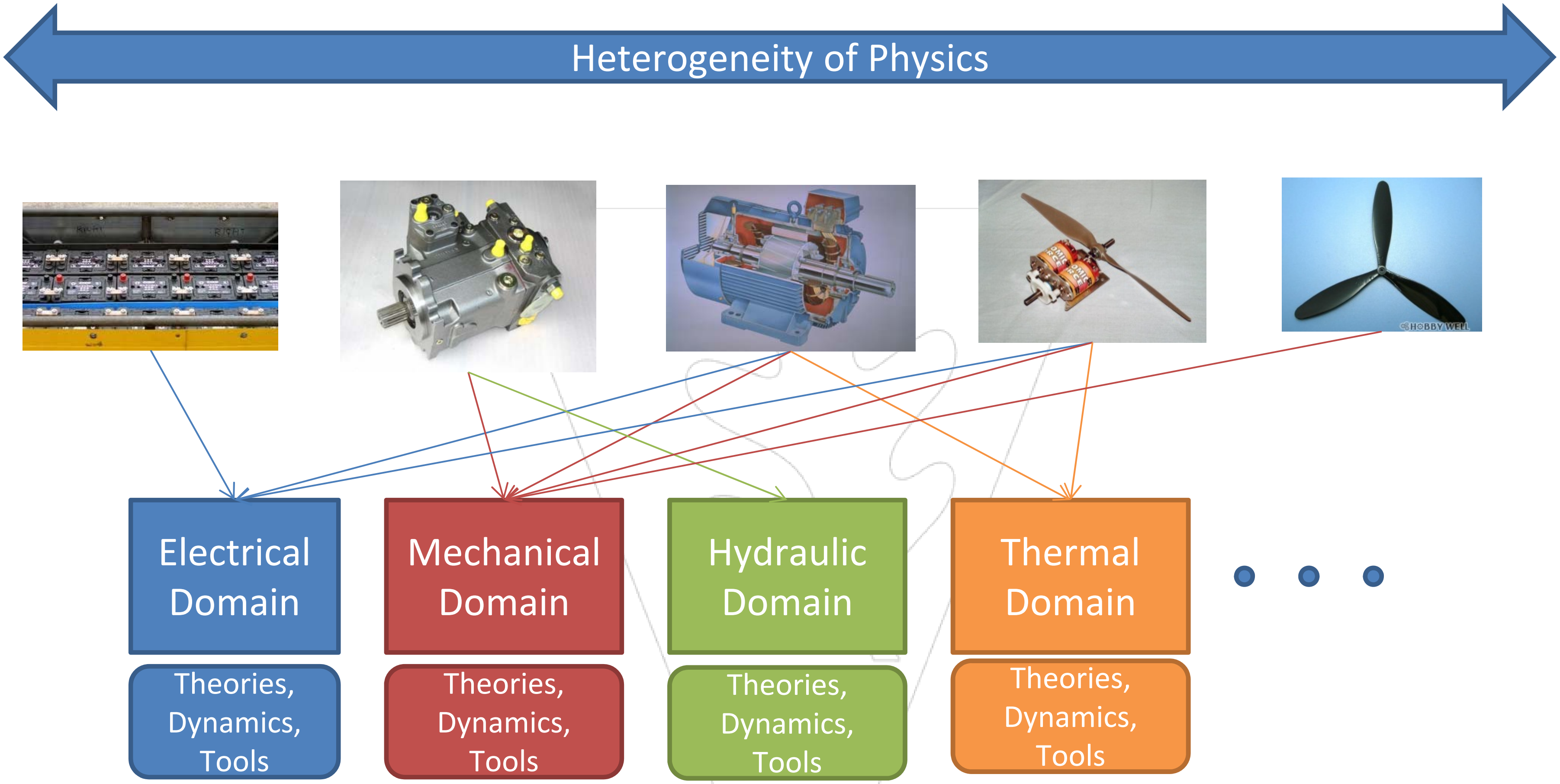


Component Engineer
- Defines Part Cost
- Defines Structural Interface, Fastener

Example: Requirement Modeling

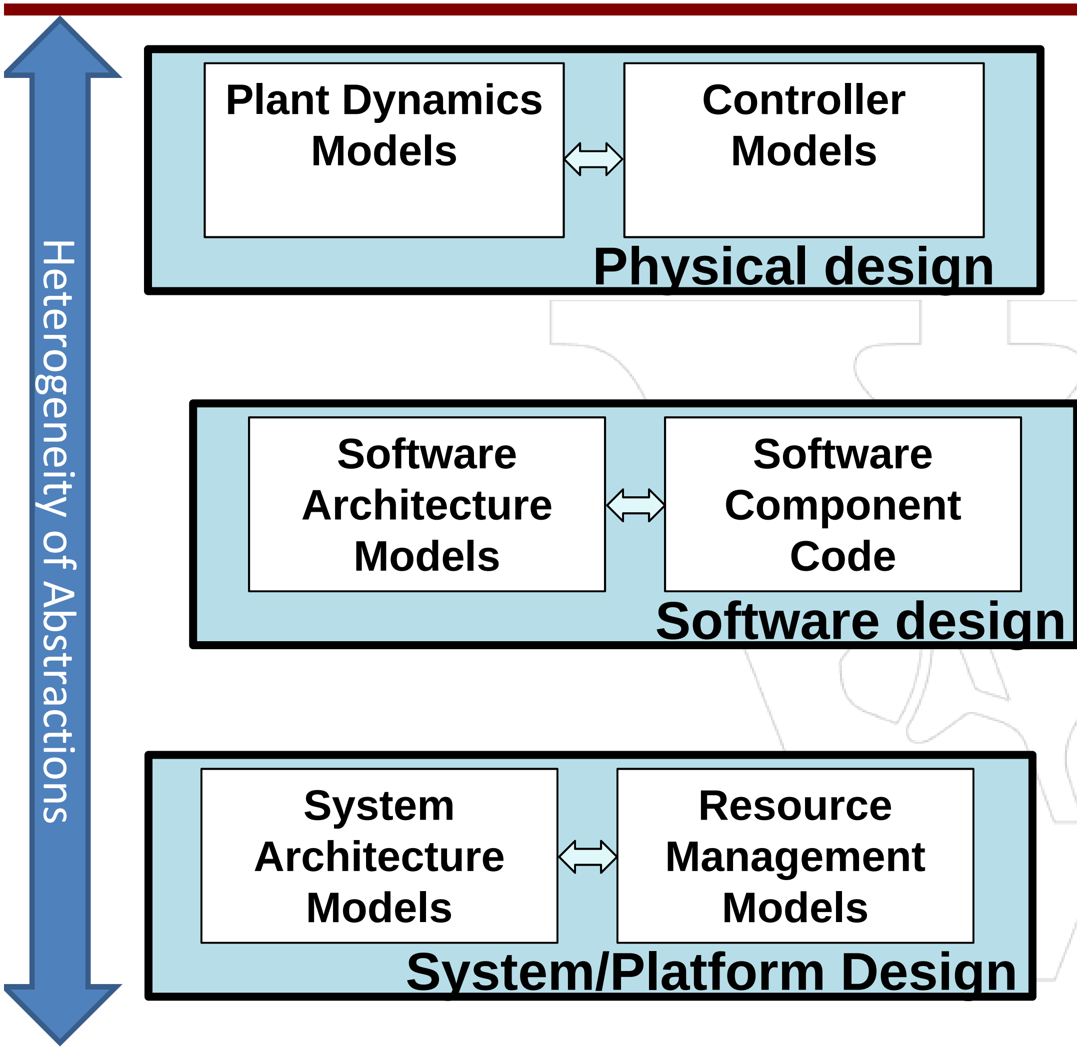
Requirements	DOORS SysML	1.2 | Soldiers.Warfighters | Carry a squad of 9 (6ft, crew-weight-table) | Infantry squad wearing personal Land Warrior 2 3.3 | acceleration | 0-30mph under 8 seconds | 0-20mph under 8 seconds | Derived from M1 Abrams	Customer
Executable Requirements (Constraints)	DESERT Constraint Language	constraint ForceOnGround_TracksArchitecture_withISG() { ((25000 + (self.parent().Weight() * 2.204623)) <= (17 * children("TrackPack").ContactPatch())) } MTBDD Solver	Systems Engineer - Requirement decomposition
Executable Requirements (Test Bench)	Domain-Specific Instantiations - Context - System Configuration - KPP Evaluation	 Domain Specific	Systems Engineer Domain Engineer - Requirement decomposition
Executable Requirements (Verification Test Bench)	- Context - Statistical Parameters - Temporal Monitors	Bayesian Statistical Model Checker (Clarke et al)  MFOTL ~F[0,5.5s](f1 <= 0 && f2 <= 180)	Verification Engineer - Requirement decomposition

Model Integration Challenge: Physics



Physical components are involved in multiple physical interactions (multi-physics)
Challenge: How to compose multi-models for heterogeneous physical components

Model Integration Challenge: Abstraction Layers



Dynamics: $B(t) = \kappa_p(B_1(t), \ldots, B_j(t))$

- *Properties*: stability, safety, performance
- *Abstractions*: continuous time, functions, signals, flows,…

Software : $B(i) = \kappa_c(B_1(i), \ldots, B_k(i))$

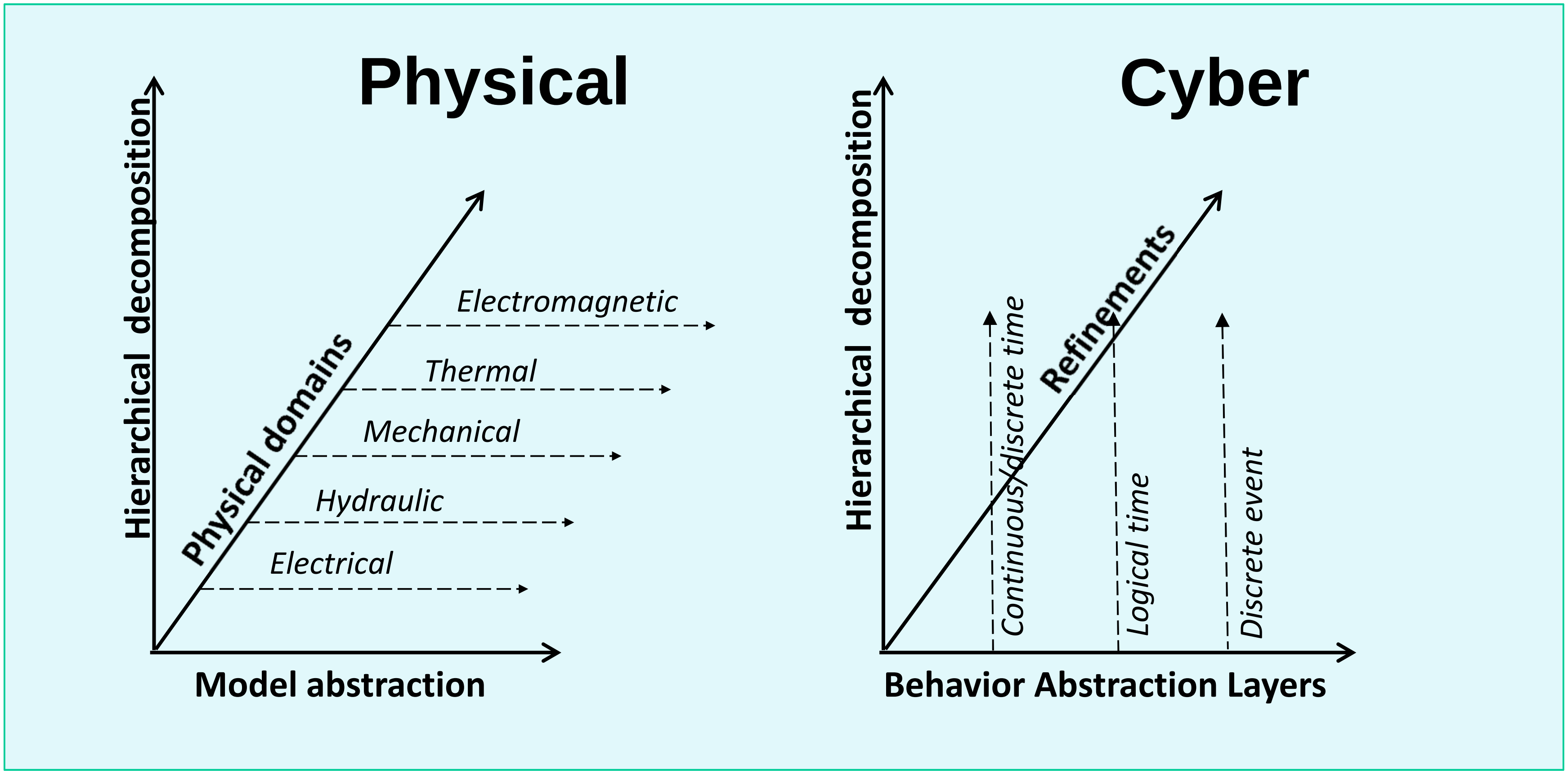
- *Properties*: deadlock, invariants, security,…
- *Abstractions*: logical-time, concurrency, atomicity, ideal communication,..

Systems : $B(t_j) = \kappa_p(B_1(t_i), \ldots, B_k(t_i))$

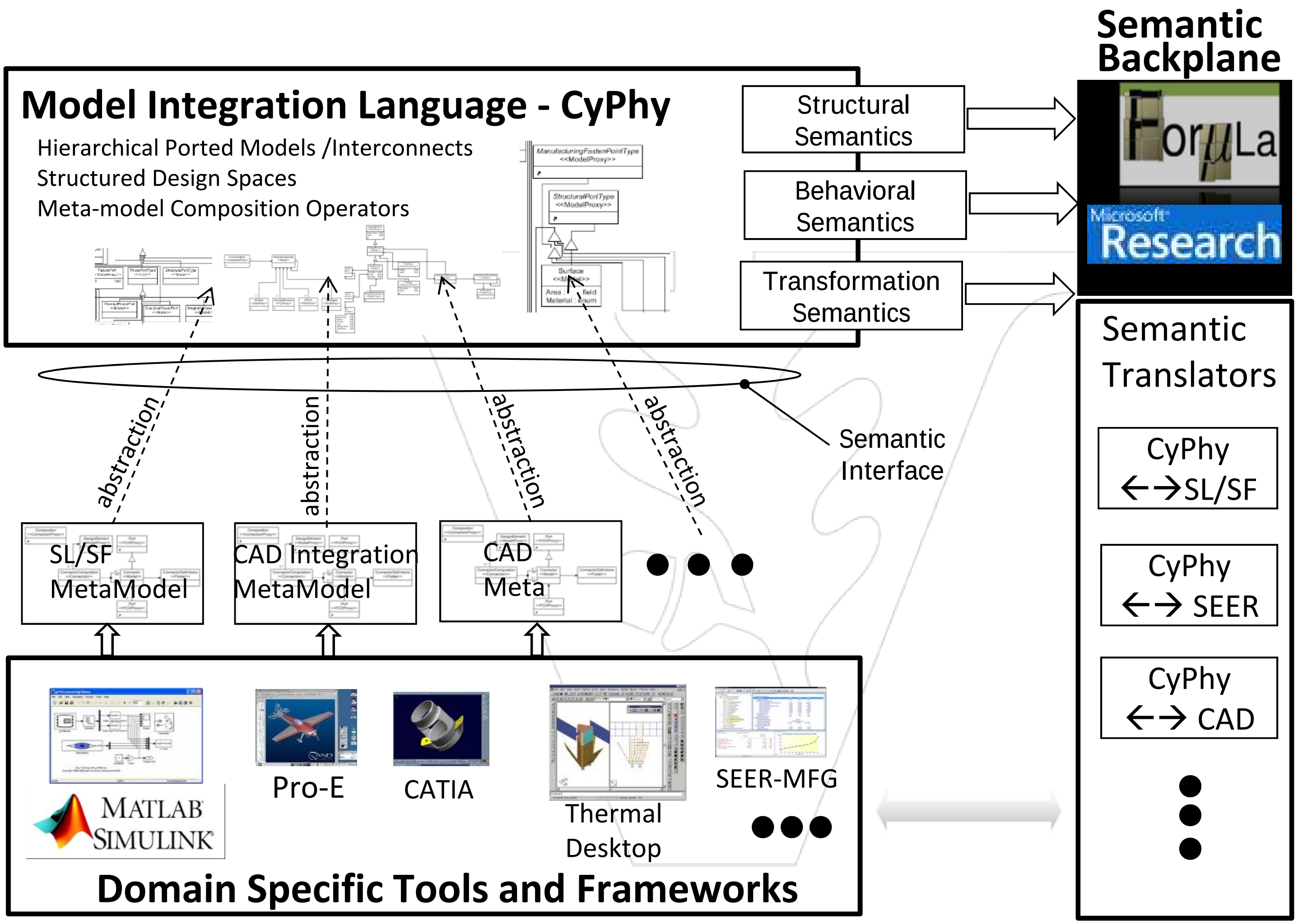
- *Properties*: timing, power, security, fault tolerance
- *Abstractions*: discrete-time, delays, resources, scheduling,

Cyber-physical components are modeled using multiple abstraction layers
Challenge: How to compose abstraction layers in heterogeneous CPS components?

Dimensions of Composition in CPS



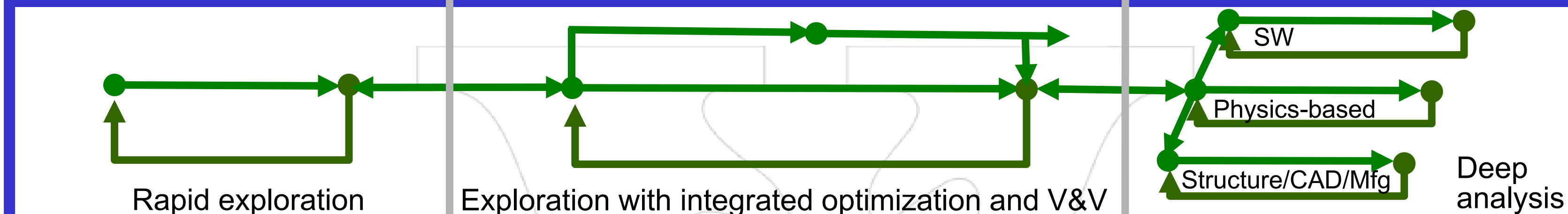
Case for Model Integration Languages…



Impact: Open Language Engineering Environment → Adaptability of Process/Design Flow → Accommodate New Tools/Frameworks , Accommodate New Languages

Example for Model Integration

Architecture Design	Integrated Multi-physics/Cyber Design	Detailed Design
Modeling · Exploration	Modeling · Simulation · V&V	Modeling · Analysis

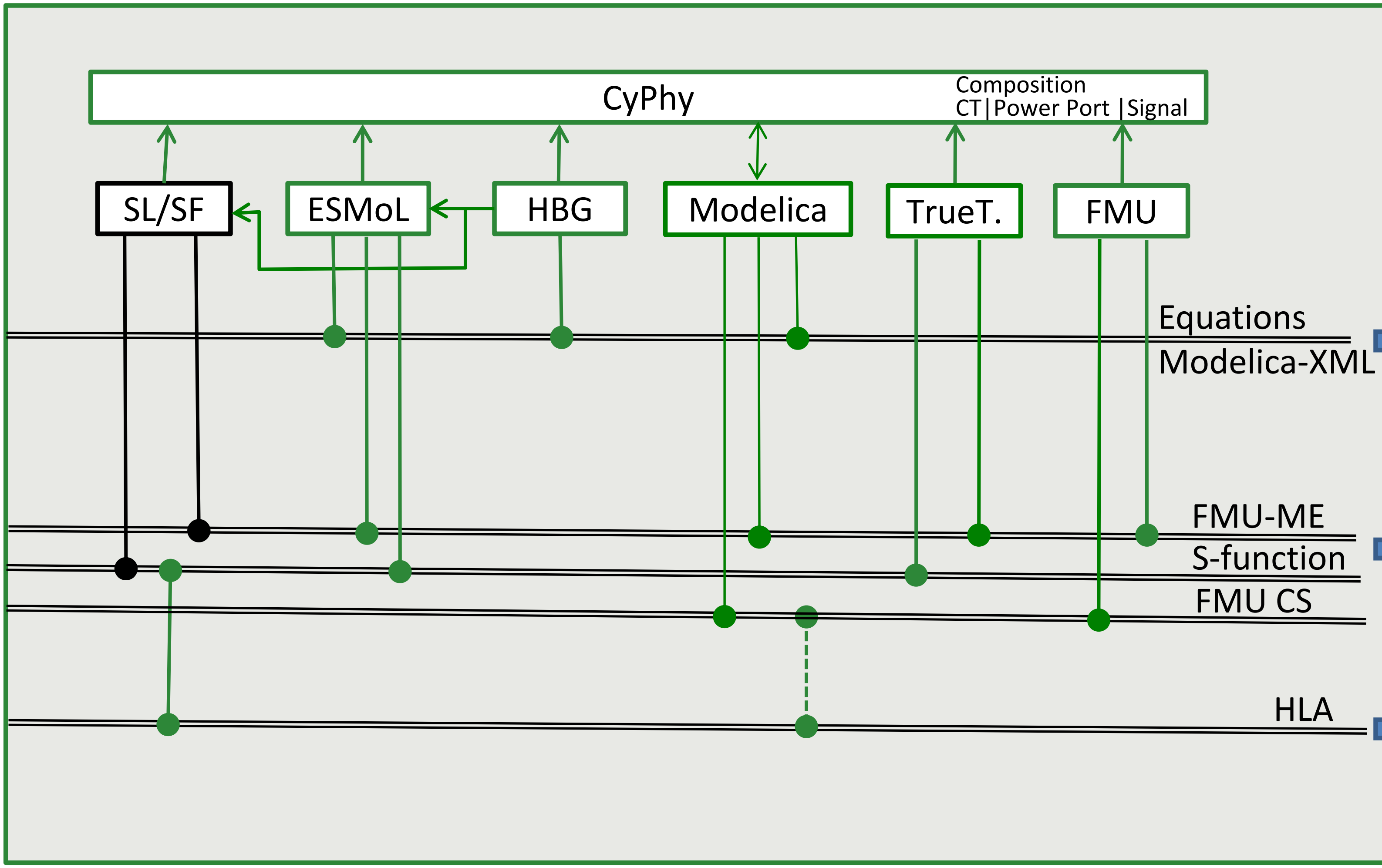


Architecture Design	Integrated Multi-physics/Cyber Design	Detailed Design

• Design Space + Constraint Modeling
• Architecture Modeling
• Low-Res Component Modeling
	• Design Space + Constraint Modeling
	• **Architecture Modeling**
	• **Dynamics Modeling**
	• Computational Behavior Modeling
	• CAD/Thermal Modeling
	• Manufacturing Modeling
		• Architecture Modeling
		• Detailed Domain Modeling
		  – CAD
		  – FEA; thermal, fluid…
		  – Surrogate gen.
		• Mfg. modeling
		• RT SW modeling

Domain Specific Modeling Languages

Example: Model Integration for Lumped Parameter Dynamics

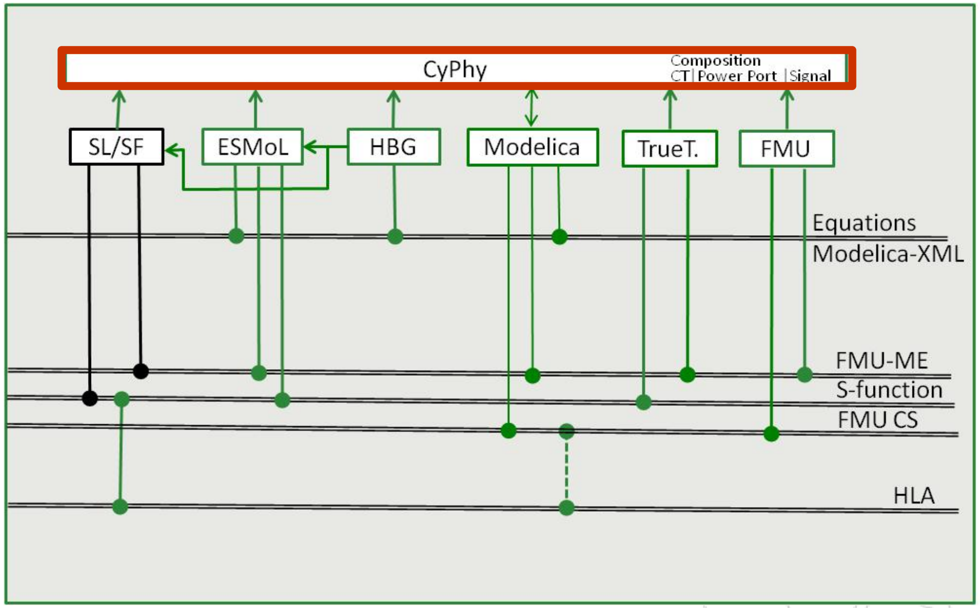


Verification Tools
- QR
- RA
- Analysis

Multimodel Simulation Tools

Distributed Multimodel Simulation
- NS3
- OMNET
- Delta-3D
- CPN

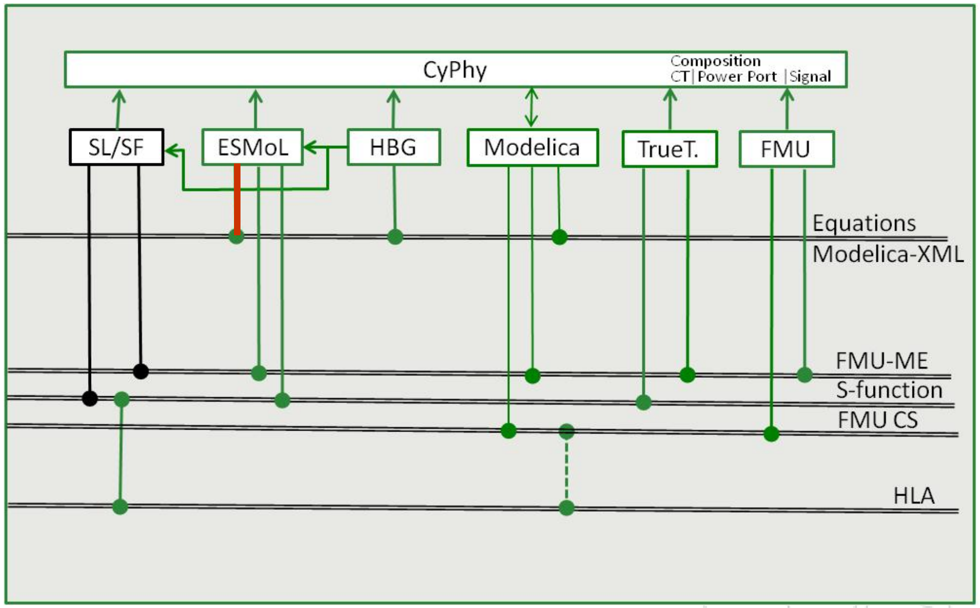
CyPhy Component and Design Interchanges



Specification obligations

- **CyPhy structural semantics**
  - Component Interchange Model
  - Design Interchange Model

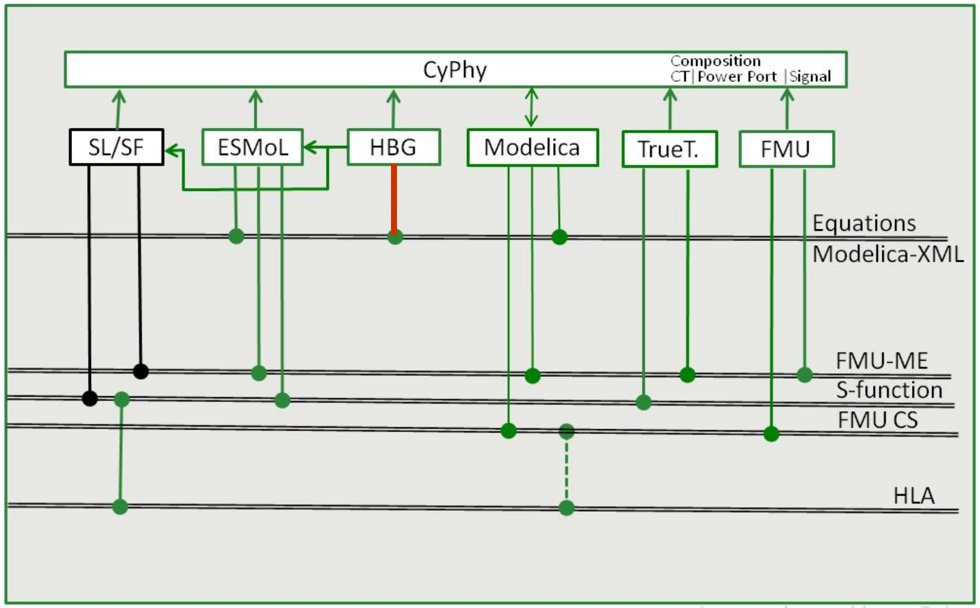
ESMoL Denotational Semantics



Specification obligations

- **CyPhy structural semantics**
- **ESMoL denotational semantics**
  - Signal Flow
  - Statechart

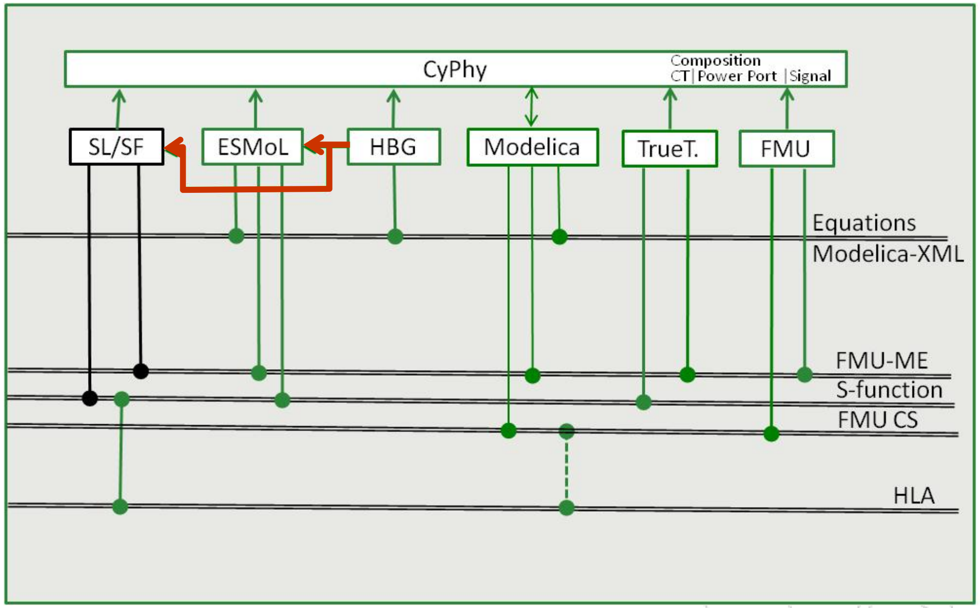
Hybrid Bond Graph Denotational Semantics



Specification obligations

- **CyPhy structural semantics**
- **ESMoL denotational semantics**
- HBG denotational semantics

HBG Behavioral Semantics



Specification obligations

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- **ESMoL denotational semantics**
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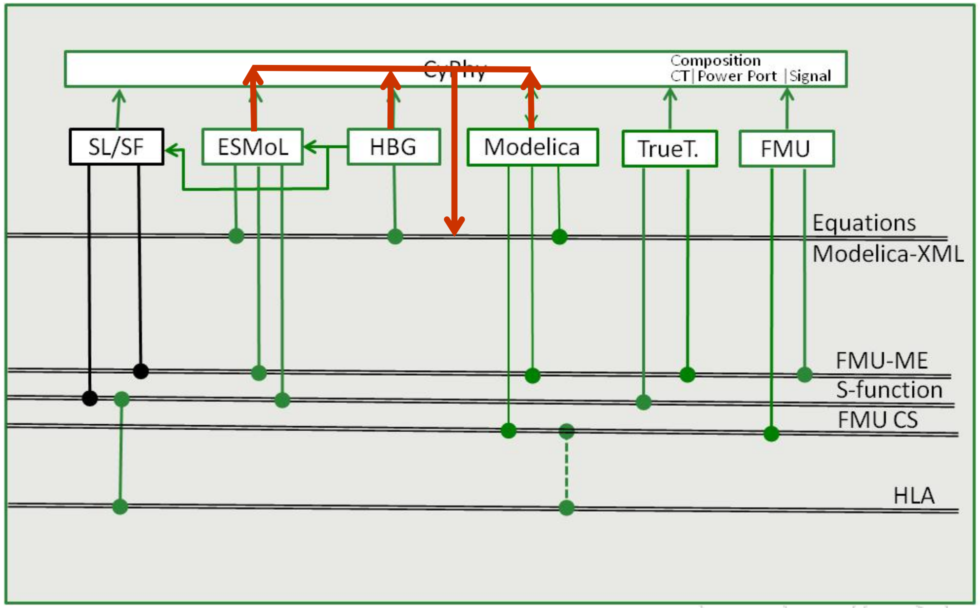
- HBG behavioral semantics

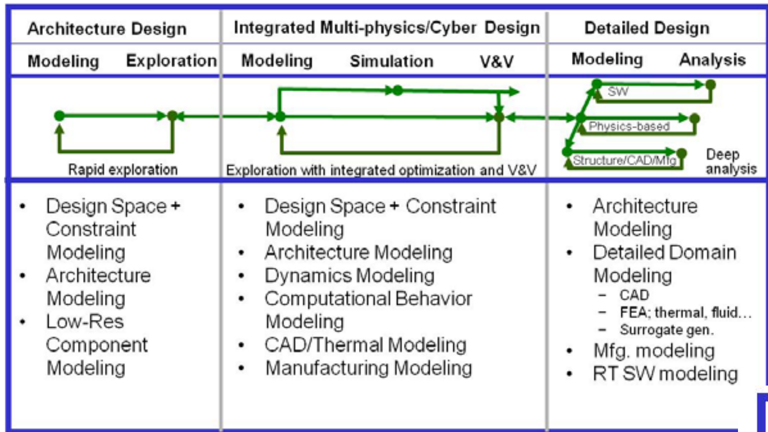
CyPhy Denotational Semantics for Composition (Design Interchange)



Specification obligations

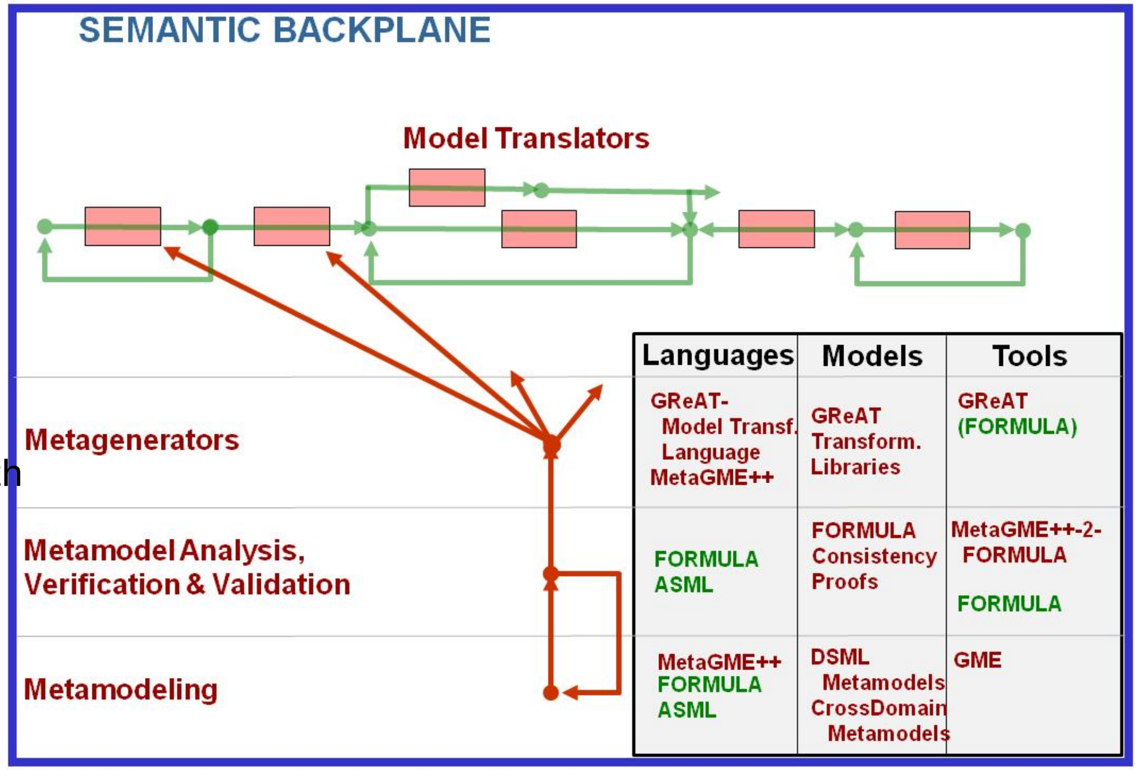
- **CyPhy structural semantics**
- **ESMoL denotational semantics**
- HBG denotational semantics
- HBG transformational semantics
- **CyPhy denotational composition semantics**

Cost of Model Integration Languages: "Semantic Backplane"



- Tight integration from architecture modeling to physics-based modeling
- Integrated multi-physics modeling
- Bridging gap between computation and physics-based domains
- Tight integration of structural and behavioral models
- Emphasis is on automation and scaling
- *The META tool suite must be designed for rapid evolution*

- Agility is achieved by introducing a ***Semantic Backplane***
- The Semantic Backplane is implemented by:
  - tools and methods for modeling language specification, validation and transformation
  - tools and methods for explicit representation of and computation with structural and behavioral semantics
  - metamodel and transformation libraries
  - metaprogrammable tools



Languages	Models	Tools
GReAT- Model Transf. Language MetaGME++	GReAT Transform. Libraries	GReAT (FORMULA)
FORMULA ASML	FORMULA Consistency Proofs	MetaGME++-2-FORMULA FORMULA
MetaGME++ FORMULA ASML	DSML Metamodels CrossDomain Metamodels	GME

FORMULA: http://research.microsoft.com/formula

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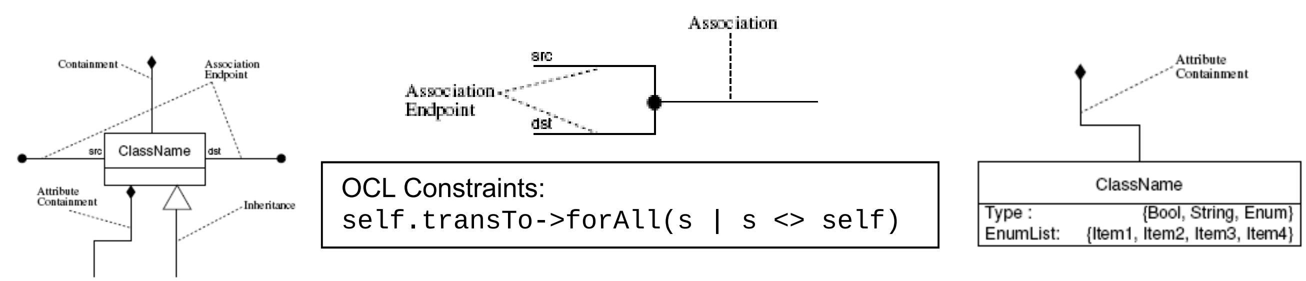
Specification of Domain-Specific Modeling Languages

Abstract syntax of DSML-s are defined by metamodels.

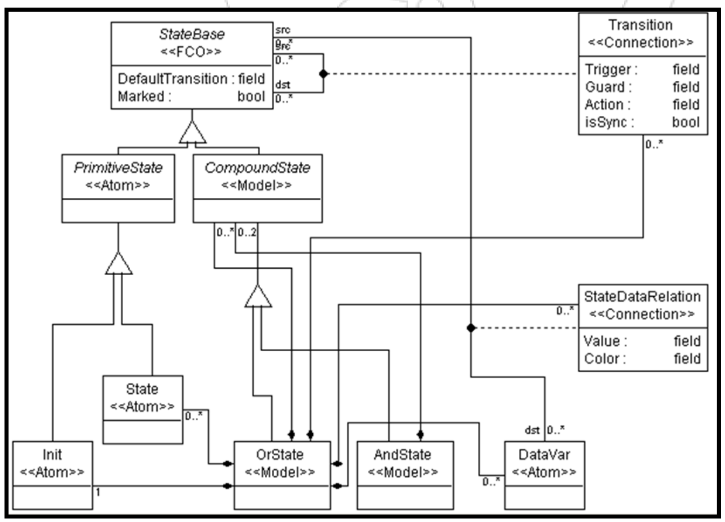
A metamodeling language is one of the DSML-s.

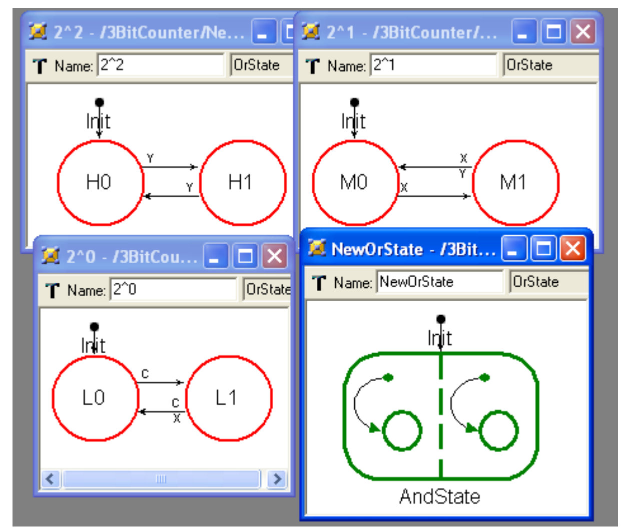
Semantics of metamodeling languages: structural semantics.

<u>Key Concept</u>: Modeling languages define a set *of well- formed models* and their *interpretations*. The interpretations are mappings from one domain to another domain.



Basic metamodeling notation: UML Class Diagram + OCL





MetaGME metamodel of simple statecharts

Model-editor generated from metamodel

Formalization of Structural Semantics

$L = \langle Y, R_Y, C, ([\ ]_i)_{i \in J} \rangle$
$D(Y,C) = \{ r \in R_Y \mid r \models C \}$
$[\ ] : R_Y \mapsto R_{Y'}$

Y: set of concepts,
R_Y: set of possible model realizations
C: set of constraints over R_Y
$D(Y,C)$: domain of well-formed models
[ ]: interpretations

Jackson & Sz. '2007
Jackson, Schulte, Sz. '2008
Jackson & Sz. '2009

Key Concept: DSML syntax is understood as a constraint system that identifies behaviorally meaningful models. ***Structural semantics provides mathematical formalism for interpreting models as well-formed structures*.**

Structural Semantics defines modeling domains using Algebraic Data Types and First-Order Logic with Fixpoints. Semantics is specified by Constraint Logic Programming.

Use of structural semantics:

- Conformance testing: $x \in D$
- Non-emptiness checking: $D(Y,C) \neq \{nil\}$
- DSML composing: $D_1 * D_2 | D_1 + D_2 | D' \ includes\ D$
- Model finding: $S = \{ s \in D | s | = P \}$
- Transforming: $m' = T(m); m' \in X; m \in Y$

Microsoft Research Tool: FORMULA

- Fragment of LP is equivalent to full first-order logic
- Provide semantic domain for model transformations.

Behavioral Semantics

- Given a DSML

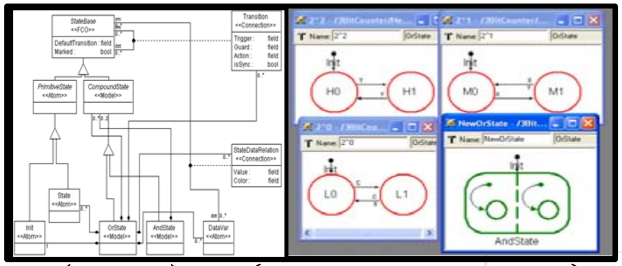
$$L = \langle Y, R_Y, C, ([\ ]_i)_{i \in J} \rangle$$

$$D(Y, C) = \{ r \in R_Y \mid r \models C \}$$

$$[\ ] : R_Y \mapsto R_{Y'}$$

- Behavioral semantics will be defined by specifying the transformation between the DSML and a modeling language with behavioral semantics.

Explicit Methods for Specifying Behavioral Semantics 1/2

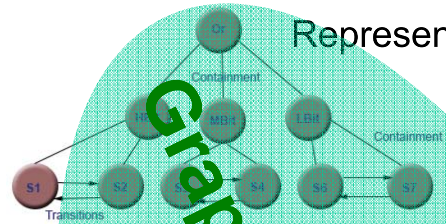


$$D(Y,C)=\{r\in R_Y \mid r \models C\}$$

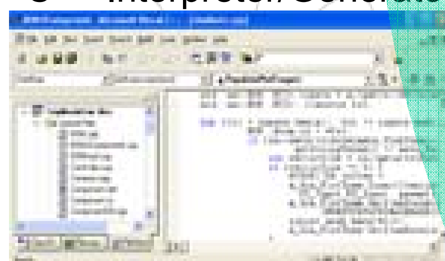
$$[\;]: R_Y \mapsto R_{Y'}$$

$$D(Y',C')=\{r\in R_{Y'} \mid r \models C'\}$$
$$[\;]: R_{Y'} \mapsto R_{Y''}$$

Representation as AST

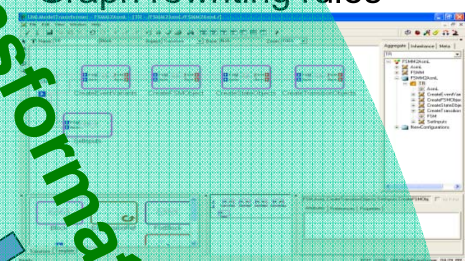


C++ Interpreter/Generator



Explicit

Graph rewriting rules



Graph transformation semantics

Executable Model (Simulators)

Executable Code

Executable Specification

Heterogeneous math domain;
Operational semantics

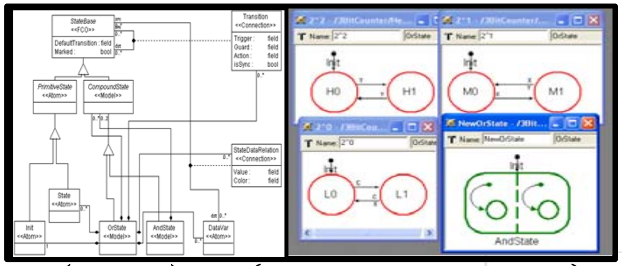
Reasonable tool support;
Easy to understand

Convergence in Formal Framework: FORMULA

- History: Foundations for Embedded Systems ITR; Ethan Jackson at VU 2005-2008
- Microsoft Research (Bellevue & Aachen); Z3 Satisfiability Modulo Theory Solver (Z3); VS distribution
- *http://research.microsoft.com/formula*

- Foundation: Algebraic Data Types (ADT) and First-order logic with fixpoints (FPL)
- Parameterized with background theories (bit vectors, term algebras, etc.
- Semantics is defined by constraint logic programming (CLP)
- Evolving structures; temporal logic

Explicit Methods for Specifying Behavioral Semantics 2/2



$$D(Y,C)=\{r \in R_Y \mid r \models C\}$$

```
domain AcausalBG_elements
{
  primitive Sf ::= (id: String).
  primitive Se ::= (id: String).
  primitive R  ::= (id: String).
  //…
primitive TF ::= (id: String).
  primitive GY ::= (id: String).
  primitive ZeroJunction ::= (id: String).
  primitive OneJunction  ::= (id: String).
  Source   ::= Sf + Se.
  //..
}
```

$$[\ ]: R_Y \mapsto R_{Y'}$$

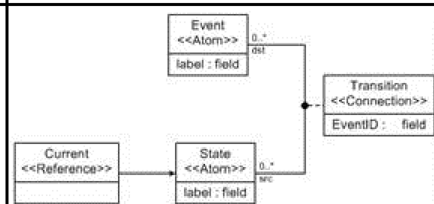
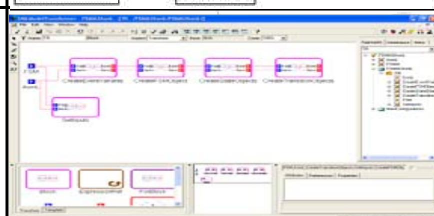
```
transform BG_DenotationalSemantics
  from in1::AcausalBG
  to out1::DAEquations
{
  Eq(e_a,p_x) :- x is Se, Src(a,x).
  Eq(f_a,p_x) :- x is Sf, Src(a,x).
  Eq(e_a, Mul(p_x,f_a)) :- x is R, Dst(a,x).
  DiffEq(e_a, Mul(Inv(p_x),f_a)) :-
    x is C, Dst(a,x).
//…
}
```

$$D(Y',C')=\{r \in R_{Y'} \mid r \models C'\}$$
$$[\ ]: R_{Y'} \mapsto R_{Y''}$$

```
domain DAEquations
{
  primitive Variable ::=
    (name: String, id: String).
  primitive Param ::= (id: String).
  primitive Neg ::= (Term).
  primitive Inv ::= (Term).
  //..
  Term ::= Variable + Param + Neg + Inv + Mul + Sum.
  primitive Eq ::= (Variable, Term).
  primitive DiffEq ::= (Variable, Term).
  primitive SumZero ::= (Sum).
  Equation ::= Eq + DiffEq + SumZero.
}
```

Single math framework

Current Work: Semantic Backplane

Functions	(Meta)Models	Languages	Tools	Role
Metamodeling		MetaGME	• GME • MetaGME-2-Formula	• DSML spec. • Constraint Checking • Metaprog.
Transformation Modeling		UMTL	• GReAT • UDM	• Transf. spec. • Compiling spec to transformer

Formal Metamodeling	`domain DFA {`
	`primitive Event ::= (lbl: Integer).`
	`primitive State ::= (lbl: Integer).`
	`[Closed(src, trg, dst)]`
	`primitive Transition ::= (src: State,`
	`[Closed(st)]`
	`primitive Current ::= (st: State).`
		Formula (MSR)	• Domain Comp.
			• Trace Gen.
				• Metamod. checking
				• Example gen.
				• Semantic units

Formal Transformation Modeling	`transform Step<fire: in1.Event> from DFA`
	`out1.State(x) :- in1.State(x).`
	`out1.Event(x) :- in1.Event(x).`
	`out1.Transition(s, e, sp) :- in1.Trans`
	`out1.Current(sp) :- in1.Current(s), ir`
	`out1.Current(s) :- in1.Current(s), fai`
	`}`
			• Semantic Anchoring	• Semantics for complex DSMLs
				• Compositon

Semantic Specification Example: Structural Semantics for BGML

```
domain BondGraph
{
primitive Se ::= (id: String, effort: String).
primitive Sf ::= (id: String, flow: String).
primitive R  ::= (id: String, resistance: String).
primitive C  ::= (id: String, capacitance: String).
primitive I  ::= (id: String, inductance: String).
primitive TF ::= (id: String, modulus: String).
primitive GY ::= (id: String, gyrator_modulus: String).
primitive OneJunction ::= (id: String).
primitive ZeroJunction ::= (id: String).
Node ::= Se + Sf + R + C + I + TF + GY + OneJunction +
ZeroJunction.
// exactly one outgoing connection, and no incoming
badSe := se is Se, count(Connection(_, se, _)) != 1.
badSe := se is Se, count(Connection(_, _, se)) > 0.
```

```
partial model RC1 of ExtendedBondGraphWithCausality
{
JunctionState(oj1, "ON")

R1 is R("R1", "r1", "R1")
   C1 is C("C1", "c1i", "c1", "C1")
oj1 is OneJunction("oj1", "OFF", "", "", "oj1")
Se1 is Se("Se1", "se1", "Se1")
BondE2J("0", Se1, oj1, "0")
BondJ2E("1", oj1, C1, "1")
   BondJ2E("2", oj1, R1, "2")
}
```

```
domain ExtendedBondGraphWithCausality extends ExtendedBondGraph
{
[Closed(junction)][Function(junction -> State)]
primitive JunctionState ::= (junction: Junction, State:
Enum_BondGraphElements_InitialState).

CausalStrokePosition ::= { SRC, DST, OFF }.

[Closed(bond)][Function(bond -> causal_stroke)]
primitive CausalStrokeJ2J ::= (bond: BondJ2J, causal_stroke:
CausalStrokePosition).
[Closed(bond)][Function(bond -> causal_stroke)]
primitive CausalStrokeJ2E ::= (bond: BondJ2E, causal_stroke:
CausalStrokePosition).
[Closed(bond)][Function(bond -> causal_stroke)]
primitive CausalStrokeE2J ::= (bond: BondE2J, causal_stroke:
CausalStrokePosition).

CausalStroke ::= (A: BGNode, B: BGNode, stroke: CausalStrokePosition).
CausalStroke(A, B, stroke) :-
CausalStrokeJ2J(BondJ2J(_, A, B, _), stroke);
CausalStrokeJ2E(BondJ2E(_, A, B, _), stroke);
CausalStrokeE2J(BondE2J(_, A, B, _), stroke).
CausalStroke(A, B, SRC) :- CausalStroke(B, A, DST).
CausalStroke(A, B, DST) :- CausalStroke(B, A, SRC).
CausalStroke(A, B, OFF) :- CausalStroke(B, A, OFF).

// Description with positive rules
BondE ::= (e: BGNode, j: Junction).
BondE(x,y) :- BondJ2E(_,y,x,_); BondE2J(_,x,y,_).
BondJ ::= (j: Junction, je: BGNode).
BondJ(x,y) :- BondJ2E(_,x,y,_); BondE2J(_,y,x,_); BondJ2J(_,x,y,_); BondJ2J(_,y,x,_).
```

Semantic Specification Example: Denotational Semantics

```
domain DiffEquations
{
primitive Effort ::= (id: Natural). // effort
connection
primitive Flow ::= (id: Natural). // flow
connection
primitive Value ::= (id: String). // parameter
value
primitive Derivative ::= (term: Term). // dx
primitive Add ::= (term1: Term, term2: Term). //
+
primitive Mul ::= (term1: Term, term2: Term). // *
primitive Equals ::= (term1: Term, term2: Term).
// =
primitive Neg ::= (term: Term). // unary -

Term ::= Effort + Flow + Value + Derivative +
Add + Mul + Equals + Neg.
}
```

```
transform T from BondGraph as in1 to DiffEquations as out1
{
// Source of effort
out1.Equals(Effort(id), Value(effort)) :- Connection(id, Se(_,effort), _).

// Source of flow
out1.Equals(Flow(id), Value(flow)) :- Connection(id, sf, Sf(_,flow)).

// Flow = Capacitance * derivative(Effort)
out1.Equals(Flow(id), Mul(Value(capacitance), Derivative(Effort(id)))) :-
Connection(id, C(_, capacitance), _);
Connection(id, _, C(_, capacitance)).

// kcl
out1.Equals(Flow(id1), Flow(id2)) :- Succ(OneJunction(_), id1, id2).

// kvl
out1.Equals(Effort(id1), Effort(id2)) :- Succ(ZeroJunction(_), id1, id2).
}
```

BondGraph → Differential Equations

Example: Formal Operational Semantics for Finite Automata

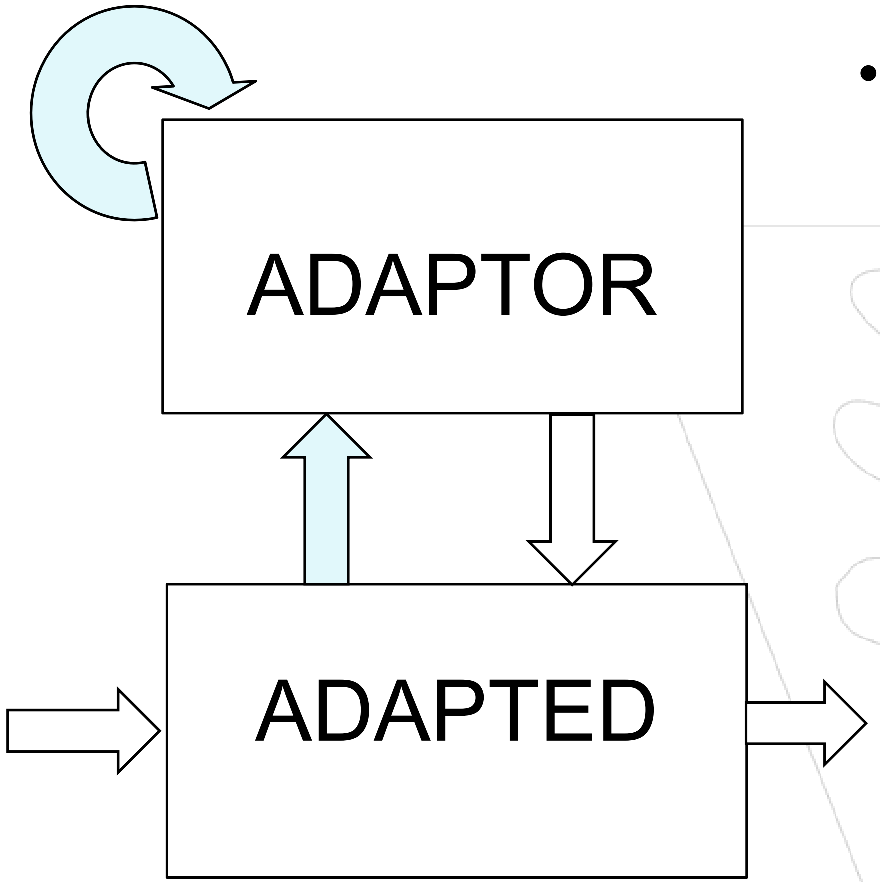
```
domain DFA {
  primitive Event ::= (lbl: Integer).
  primitive State ::= (lbl: Integer).
  primitive Transition ::= (src: State, trg: Event, dst: State).
  primitive Current    ::= (st: State).
  nonDeterTrans := Transition(s, e, sp), Transition(s, e, tp), sp != tp.
  conforms      := !nonDeterTrans.
}
```

```
transform Step<fire: in1.Event>  from in1::DFA  to out1::DFA
 {
  out1.State(x) :- in1.State(x).
  out1.Event(x) :- in1.Event(x).
  out1.Transition(s, e, sp) :- in1.Transition(s, e, sp).
  out1.Current(sp) :- in1.Current(s), in1.Transition(s, fire, sp).
  out1.Current(s) :- in1.Current(s),
  fail in1.Transition(s, fire, _).
 }
```

Overview

- Model-Based Design for CPS in META
  - Design flow and design infrastructure
  - Model Integration Challenge
- Formal Semantics of DSMLs
  - Structural Semantics
  - Behavioral Semantics
- Thoughts on Resilience

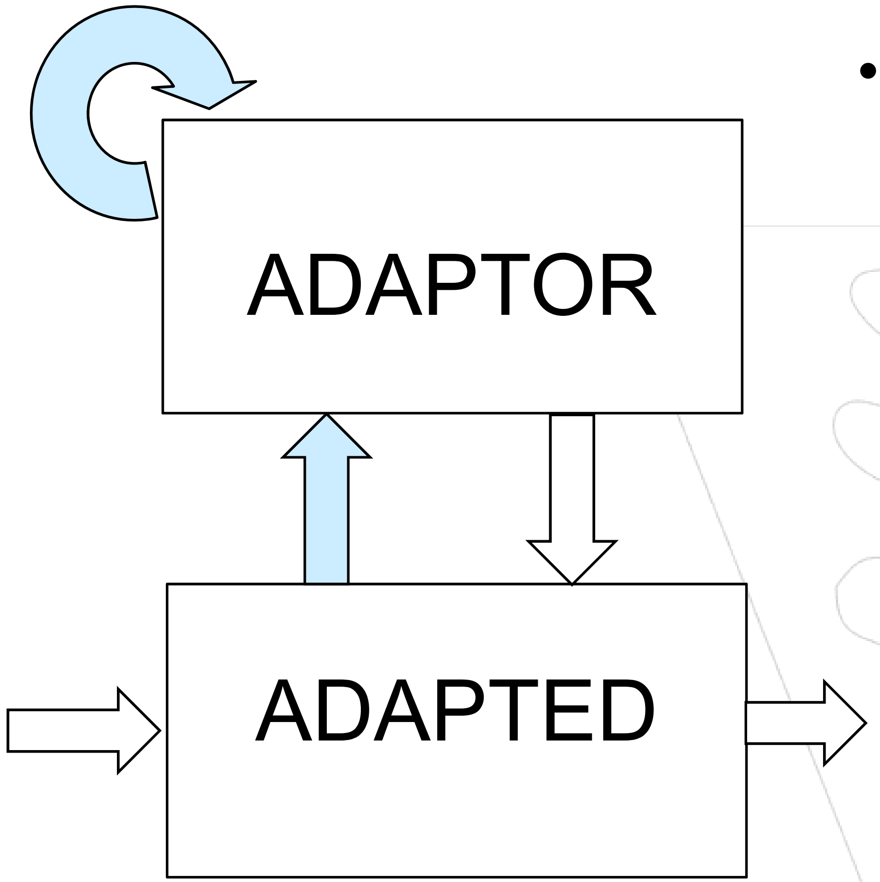
Thoughts on Resilience



(conceptualization)

- **Adaptor:** Reasoning on a different level of abstraction (meta-level)
  - What is the right level of abstraction?
    - structure
    - functionalities
    - dynamics…
  - How to derive them/link them from design models?

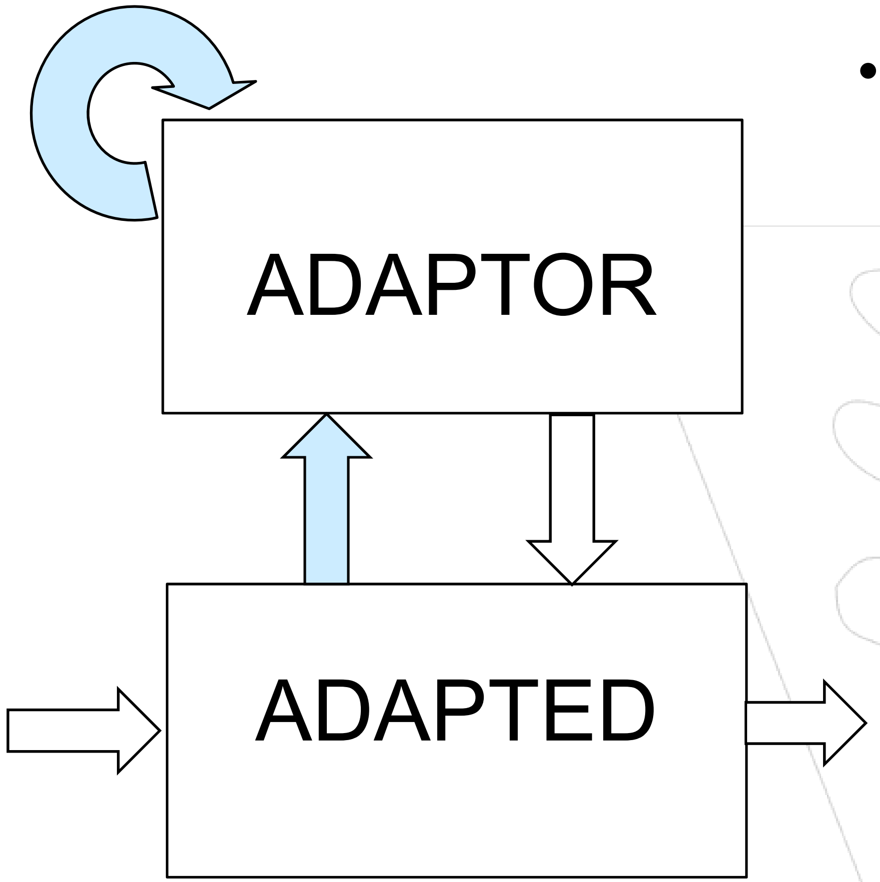
More Thoughts on Resilience



- **Adaptation method:** "embedded" design- space exploration
  - How to construct it?
    - e.g. hierarchically layered alternatives
    - parameterization
  - How to represent it?
    - e.g. OBDD
  - How to characterize it?
    - size
    - tangledness wrt selected properties

Construction of "Embedded Design Space" is the primary way of adjusting flexibility v.s. speed

...More Thoughts on Resilience



- **Engineering the design space**
  - How to achieve decoupling for *selected properties*?
    - stability – time varying delays
      method1: passive dynamics
      method2: masking/isolation layer
  - How to achieve decoupling for *multiple properties*?
    - stability & liveness
    - stability & liveness & safety
    - …….

Ongoing Work

- META and VF beta testing starts in 15 September 2012
- Trial design competition for undergarduates (UC Berkeley, MIT, SUDT, Vanderbilt)
- FANG competition starts in January 2013
- Model Integrated Computing (MIC) tools are available
- Open source META tool suite will be available in January 2013

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