Object Management Group (OMG) and Model-based Systems Engineering (MBSE)

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Boeing

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Welling Bio

- **B.S., Math and Physics, Michigan State, 1970**
- **US Army 1971-1980: Infantry, Armor**
- **Army Reserves: Nuclear Wpns Officer, 1986-91**
- **BDM, Emerson Electric: Loran, GPS, avionics 1980-84**
- **McDonnell Douglas/Boeing: 1984-present**
  - **Life cycle cost analyst: Adv Tactical Fighter, LHX helicopter, AH-64D (Apache)**
  - **Systems engineer: AH-64D/E**
- **INCOSE: Reviewer for International Symposium MBSE track papers since 2011**
- **OMG: Advanced SysML certification; voting member of the SysML 1.5 Revision Task Force**

Today’s discussion

- **OMG**
- **UML**
- **fUML**
- **bUML**
- **Other things**

- **Goal: Explain why UML (SysML) is important, why it’s the way it is, its weaknesses, and future direction**

What OMG says about itself

- **Founded in 1989, the Object Management Group® (OMG®) is an international, open membership, not-for-profit technology standards consortium.**
- **Membership includes information technology vendors, end users, government agencies, and academia.**
- **OMG member organizations write, adopt, and maintain its specifications following a mature, open process in Revision Task Forces (RTFs).**

- **Largely, its about modeling and modeling languages.**

Languages, natural and formal

- **Language is a symbolic means for communication.**
- **A language provides grammatical rules for constructing *statements* that communicate meaning.**
- ***Natural language* rules can change over time.**
- ***Formal language* rules are constructed artificially to create statements more precise than natural language.**
- **UML is a formal language, but only to a point.**

Semantics of a Foundational Subset for Executable UML Models (FUML), v1.1

The Unified Modeling Language (UML®)

- “The” UML was originally intended as a graphical modeling language for software.
- Traditionally used for documenting software architectures and developing test cases.
- Language elements and their associations are preserved in a database.
- Theoretical foundation is set theory.
- A supplemental declarative language for constraints: OCL, Object Constraint Language.
- Has become the *lingua franca* for defining modeling languages of any kind.
- SysML has extended UML itself to general systems.

Need for executable UML

- **Graphical models need validation, otherwise they are only pictures (albeit with an underlying database).**
- **Validity checks limited to *syntax* (well-formedness).**
- **Goal: Make models executable to check behavior, etc.**
- **So far, tool vendors have addressed this with proprietary work-arounds.**
- **Problem: Ultimately, UML is defined by itself; in other words, it has no formal definition.**
- **Reference implementation is not possible; spec conformance is by inspection.**
- **Solution: Foundational Subset for Executable UML Models (fUML).**

Executable UML: Issues

- **Making models detailed enough for machine execution defeats the purpose of models for human communication.**
- **UML is not specified precisely enough to be executed.**
- **Graphical modeling notations are not good for detailed programming.**

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Executable UML: Issue Resolutions

- **Making models detailed enough for machine execution defeats the purpose of models for human communication.**
  - **Executable models can still be more understandable than executable code.**
  - **Non-executable models are still useful, too.**
- **UML is not specified precisely enough to be executed.**
  - **The Foundational UML (fUML) standard specifies precise semantics for an executable subset of UML.**
  - **fUML version 1.1 formal specification now available.**
- **Graphical modeling notations are not good for detailed programming.**
  - **The Action Language for fUML (Alf) standard specifies a textual action language with fUML semantics.**
  - **Alf Version 1.0 specification now available.**

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(Model Driven Solutions)

Syntax & Semantics

- **A formal language attaches meaning only to statements that are *well formed* (correctly constructed).**
- **The *syntax* of the language provides the rules for**
  - **How to construct well-formed statements**
  - **Equivalently, for validating that a proposed statement is actually well-formed (grammatically correct).**
- **The *semantics* of the language then provides the specification of the meaning of these well-formed statements *with respect to a certain domain*.**

Semantics of a Foundational Subset for Executable UML Models (FUML), v1.1

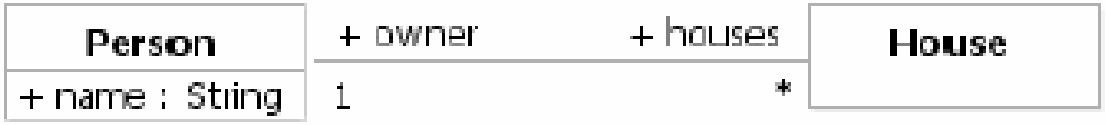
Syntax vs. Semantics

- **Specifying syntax is relatively straightforward.**
- **Semantics is rather more problematical.**
  - **Meaning requires a semantic *domain* (universe of discourse)**
  - **Meaning requires an *interpretation* of syntax**
- ***Interpretation* is the mapping of syntax to a semantic domain to determine the truth value of a statement.**
- **Statement: “Jack owns that house.”**
- **“Jack” and “house” are *interpreted* as real world objects; “owns” is *interpreted* as a legal relationship between them.**
- **If Jack does, indeed, own that house then we can say the statement is true *under that interpretation*.**

Semantics of a Foundational Subset for Executable UML Models (FUML), v1.1

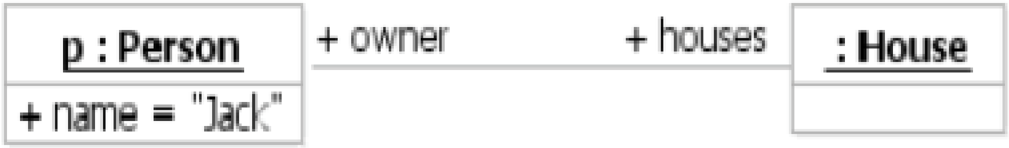
Example

- **A possible semantic domain is the set (class) of all people and houses, plus an ownership relation.**



M1

- **This model *requires* that the name of an instance of Person have a String value and it *allows* the instance to have zero or more houses associated with it.**
- **This model *instance* is consistent under that interpretation.**



M0

- **Or, if the semantic domain is a Java program, then each model class is interpreted as a corresponding Java class.**

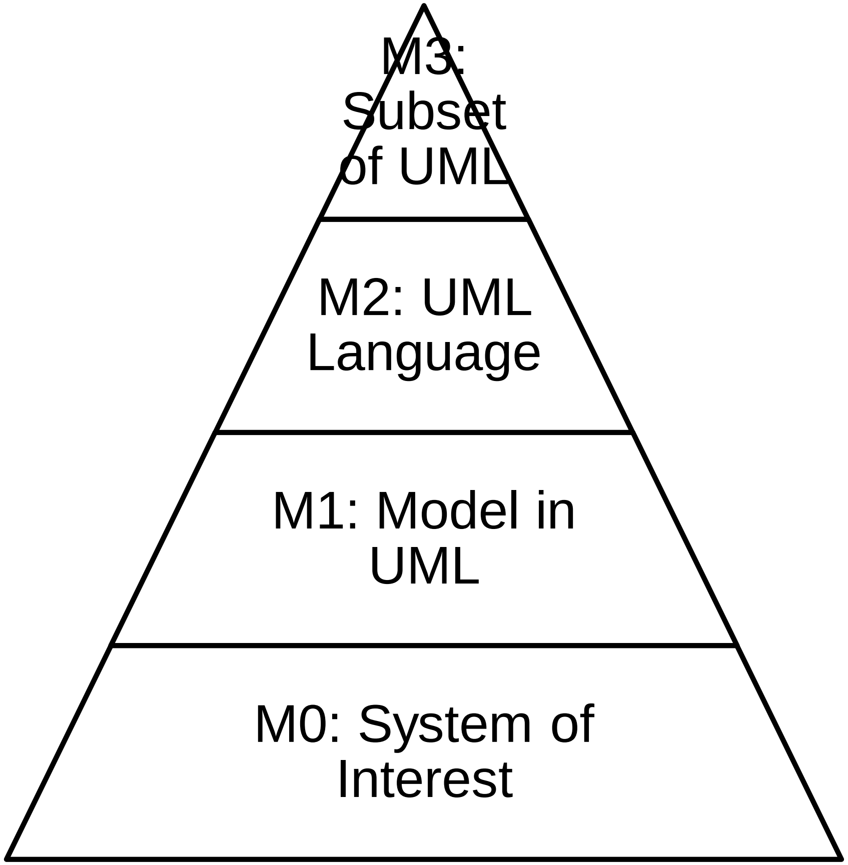
Semantics of a Foundational Subset for Executable UML Models (FUML), v1.1

The OMG Metamodel Stack

M3 -	The reflexive meta-modeling language specification (the meta-metamodel)	MOF – Meta-Object Facility; UML subset
M2 -	The modeling language specification (the metamodel)	UML, SysML; set theory
M1 -	The user specification (the model)	Planes, cars, etc; 2nd order logic
M0 -	The domain under study (the “objects” of the model)	777, Ford, etc.: 1st order logic

Semantics of a Foundational Subset for Executable UML Models (FUML), v1.1

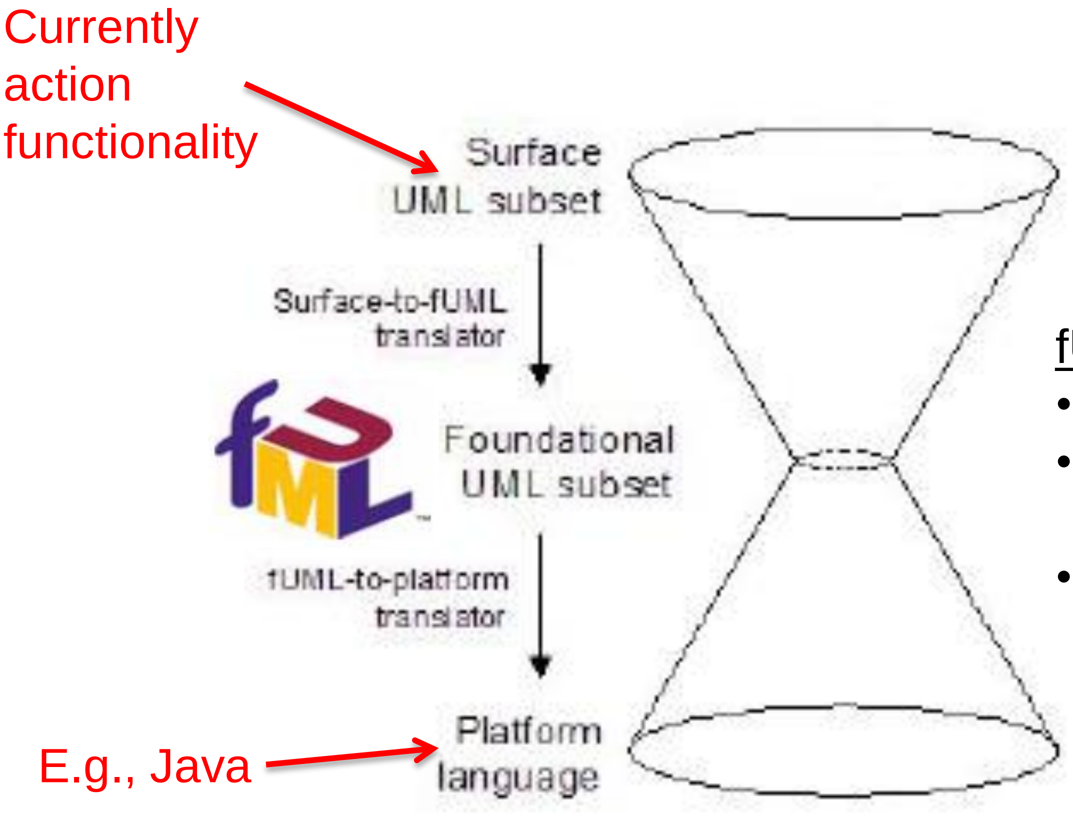
UML Infrastructure = Language for UML



- **UML (M2) is written in a subset of UML itself (M3), the UML “Infrastructure.”**
- **To formally define the semantics of MOF (M3), this circularity must be “broken.”**
- **A fUML goal is to provide a true abstract base formal semantics for the foundation of UML.**

Semantics of a Foundational Subset for Executable UML Models (FUML), v1.1

fUML Subset Translation Scheme


Currently action functionality
Surface UML subset
Surface-to-fUML translator
fUML
Foundational UML subset
fUML-to-platform translator
Platform language
E.g., Java

fUML subset criteria

- Compactness
- Ease of translation to common platform languages
- Primitive functionality

Semantics of a Foundational Subset for Executable UML Models (FUML), v1.1

Semantic structure of UML

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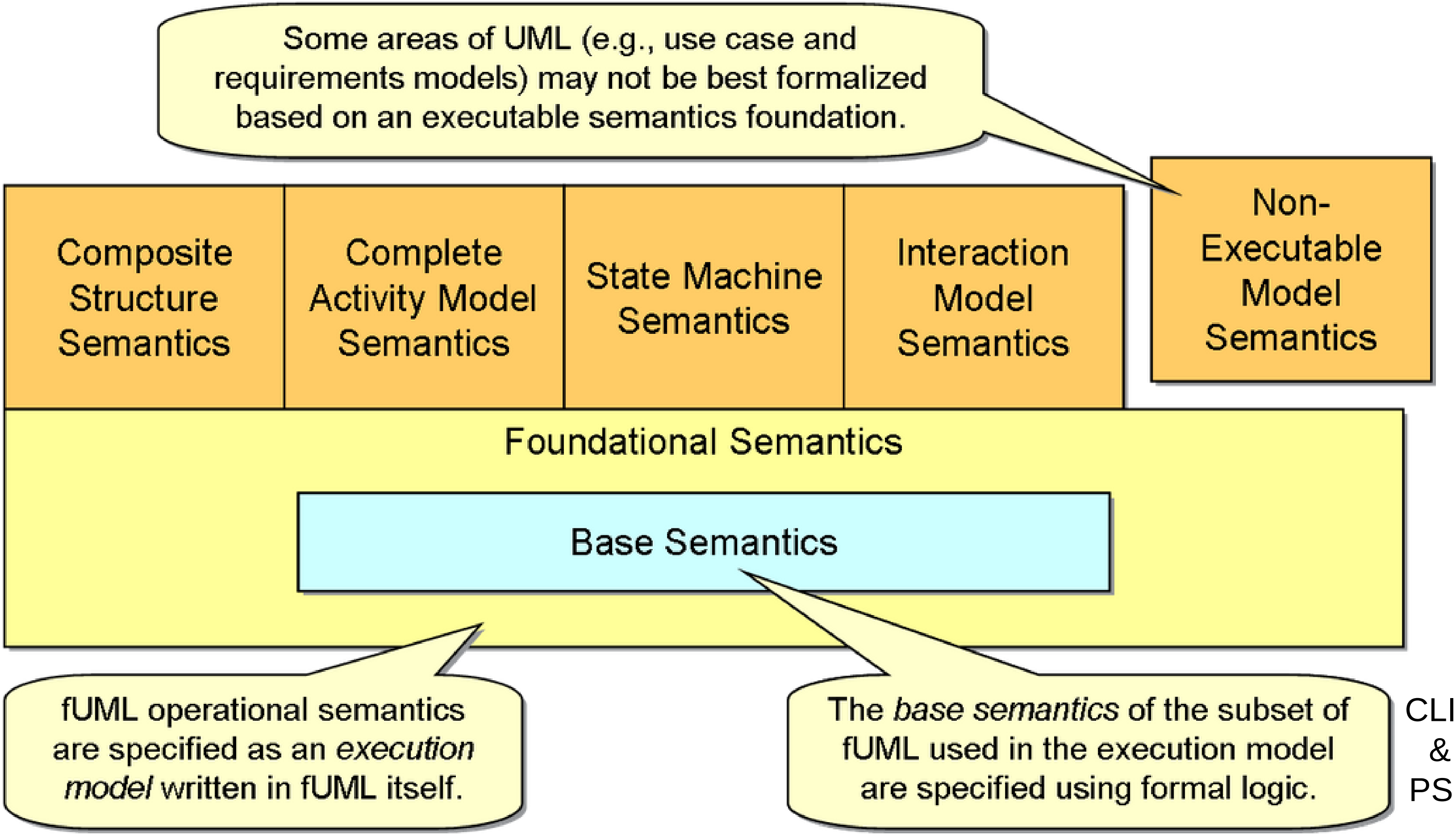

Composite Structure Semantics
Complete Activity Model Semantics
State Machine Semantics
Interaction Model Semantics
Non-Executable Model Semantics
Foundational Semantics
Base Semantics

Some areas of UML (e.g., use case and requirements models) may not be best formalized based on an executable semantics foundation.

fUML operational semantics are specified as an *execution model* written in fUML itself.

The *base semantics* of the subset of fUML used in the execution model are specified using formal logic.

CLIF
&
PSL

Base UML (bUML)

- **The base semantics (bUML) is expressed in axioms of first order logic**
  - **Common Logic Interchange Format (CLIF), the language in which the axioms are written**
  - **Process Specification Language (PSL), a foundational axiomitization of processes**
- **Completely explicit, rather than using text to explain behavior (as in UML).**
- **Enables automatic determination of whether an execution conforms to the execution model.**
- **Disadvantage of requiring axioms for the semantic interpretation of all syntactic patterns used in the execution model.**

Semantics of a Foundational Subset for Executable UML Models (FUML), v1.1

Long-Term Vision: A Suite of Specifications

- **Executable UML Semantics**
  - **Foundational Semantics for UML Model Execution**
  - **Precise Semantics of Composite Structures**
  - **Precise Semantics of Activities**
  - **Precise Semantics of State Machines**
  - **Precise Semantics of Interactions**
  - **Precise Semantics of Time**
  - **…**
- **Action Language for Executable UML (ALF)**
  - **Action Language for Structural Modeling**
  - **Action Language for Composite Structures**
  - **Action Language for Activities**
  - **...**

Ed Seidewitz, OMG TC, SE DSIG, Reston VA, 25 March 2015

Long-Term Vision: Domain-Specific Executable UML

- **Precise Semantics of Profiles**
  - **Specification of the semantics, in general, for defining profiles of executable UML**
  - **Should include a standard framework for defining domain-specific semantics of profiles, as well as abstract and concrete syntax**
- **Precise Semantics of Specific Profiles**
  - **Precise Semantics of SysML**
  - **Precise Semantics of MARTE**
  - **Precise Semantics of SoaML**
  - **…**

PSCS Specification already provides non-normative, partial examples of extensions for SysML and MARTE semantics.

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Some Implications of fUML

- **Complete formal specification of UML (or at least a significant subset)**
- **Enables a reference implementation**
  - **Spec compliance can be tested explicitly**
  - **Test suite should be part of spec**
  - **"In theory there's no difference between theory and practice. In practice there is." – Professor Lawrence P. Berra, NYYU**
- **Language should become a true "standard"**
  - **Dialect proliferation reduced**
  - **Modeling more efficient**
- **The "mystery" of UML/SysML may be solved**

New in SysML 1.4

- **Directed Relationship Property Path**
- **Element Path Multiplicity**
- **Adjunct Property**
- **Bound Reference**
- **End Path Multiplicity**
- **Nested Connector End**

SE DSIG activities

- Property-based requirements
  - Requirement formalization
  - Explicit part of the system model
  - Beyond “trace” relationships
- “SysML 2.0”
  - Address slow adoption of SysML
  - Views SysML as part of an MBSE environment
  - Better define the environment
  - Language features constrained by that environment
  - Redefine the language: no longer a profile of UML

SE DSIG = Systems Engineering Domain Special Interest Group

Related Activities: Open-MBEE and the K-language (JPL)

- **MBSE users are starting to perform analysis**
  - **Most diagrams are class diagrams, which show structure**
  - **Some diagrams are state machines or other forms of behavior**
  - **Looking to encode a lot of *requirements* or *constraints***

- **Formal methods community is all about analysis**
  - **Static and dynamic analysis**
  - **Semantic and syntactic analysis**
  - **Automated theorem proving**

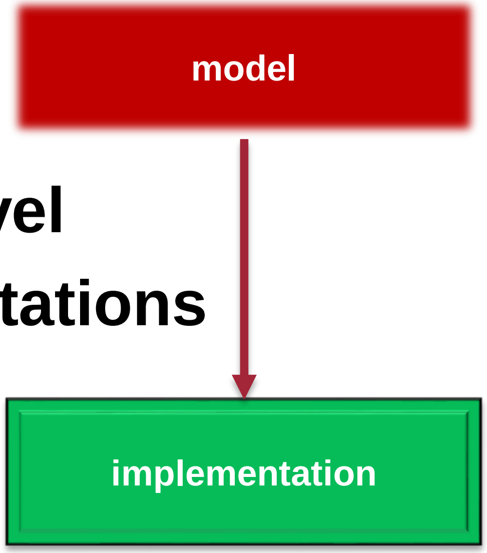
Our job is to make these worlds become one!

C. Delp, et al, K language, JPL, https://github.com/Open-MBEE/K/blob/master/presentations/K.pptx

Questions?

The modeling path

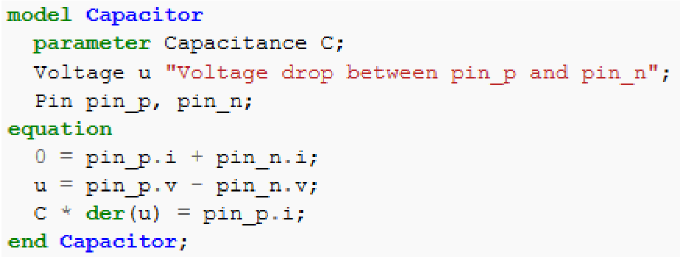
- **Create models**
- **Analyze for correctness**
- **Discover problems at each level**
- **Eventually produce implementations**
- **Rinse and repeat…**



C. Delp, et al, K language, JPL, https://github.com/Open-MBEE/K/blob/master/presentations/K.pptx

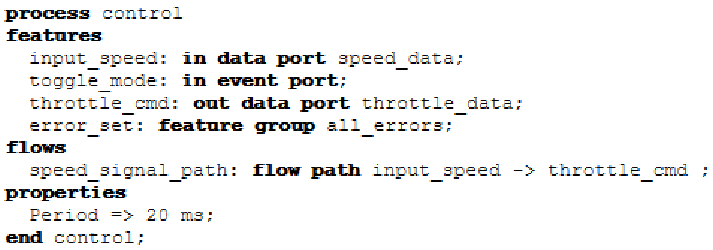
General Purpose vs Domain Specific

- **Modelica is based on a object-oriented, declarative language for modeling the physical systems domain.**



```
model Capacitor
  parameter Capacitance C;
  Voltage u "Voltage drop between pin_p and pin_n";
  Pin pin_p, pin_n;
equation
  0 = pin_p.i + pin_n.i;
  u = pin_p.v - pin_n.v;
  C * der(u) = pin_p.i;
end Capacitor;
```

- **AADL also has a well-defined language for real-time embedded systems.**



```
process control
features
  input_speed: in data port speed_data;
  toggle_mode: in event port;
  throttle_cmd: out data port throttle_data;
  error_set: feature group all_errors;
flows
  speed_signal_path: flow path input_speed -> throttle_cmd ;
properties
  Period => 20 ms;
end control;
```

- **UML/SysML is general purpose; the others are domain-specific**