Modeling and metamodeling in Model Driven Development

What is a metamodel: the OMG’s metamodeling infrastructure

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Structure of the seminar

What is a model: syntax and semantics → On the difference between analysis and design models

What is a metamodel: the OMG’s metamodeling infrastructure

Metamodeling directed relationships in UML

By the way, what does this diagram mean, what is its syntax?
Sources

• Jean Bézivin
  – Model Engineering for Software Modernization.
  – On the unification power of models.
• Colin Atkinson, Thomas Kühne
  – Model-Driven Development: A Metamodeling Foundation.
  – Reducing Accidental Complexity in Domain Models.
• My own ideas and elaboration.

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Introduction: definitions of metamodel

What is a metamodel: the OMG’s metamodeling infrastructure

What is a metamodel (according to Google definitions)

- If someone still believes there is a commonly accepted definition...
  - Metamodeling, or meta-modeling, is the analysis, construction and development of the *frames, rules, constraints, models and theories* applicable and useful for modeling a predefined class of problems.
  - A meta-model typically defines the *languages and processes* from which to form a model.
  - The meta-model in *neuro-linguistic programming* (or meta-model of therapy) is a heuristic set of questions intended to elaborate and clarify...
  - According to the Meta-Object Facility (MOF) standard, a metamodel is a model that defines the *language for expressing a model*.
  - A model that explains a set of related models.
  - Metamodel is model’s model that serves for explanation and definition of relationships among the various components of the applied model itself.
  - A *CIM component* that describes the entities and relationships representing managed objects. For example, classes, instances, and associations are included in the metamodel.
  - A *concept map* showing all the main classes of concepts and relationships between them. Used for setting up a k-base ontology and templates.
What is a metamodel (according to “authorized” UML)

- UML meets the following requirements:
  - A formal definition of a common MOF-based metamodel that specifies the abstract syntax of the UML. The abstract syntax defines the set of UML modeling concepts, their attributes and their relationships, as well as the rules for combining these concepts to construct partial or complete UML models.
  - A detailed explanation of the semantics of each UML modeling concept. The semantics define, in a technology-independent manner, how the UML concepts are to be realized by computers.
  - A specification of the human-readable notation elements for representing the individual UML modeling concepts as well as rules for combining them into a variety of different diagram types corresponding to different aspects of modeled systems.
  - A detailed definition of ways in which UML tools can be made compliant with this specification. This is supported (in a separate specification) with an XML-based specification of corresponding model interchange formats (XMI) that must be realized by compliant tools.

What is a metamodel (according to “authorized” MDA)

  - In Language specifications the abstract syntax of the language is specified as a MOF-compliant metamodel.
- A Proposal for an MDA Foundation Model (2005-04-01), p. 2:
  - A metamodel is a special kind of model that specifies the abstract syntax of a modeling language. It can be understood as the representation of the class of all models expressed in that language. Metamodels in the context of MDA are expressed using MOF.
- So, according to OMG standards:
  - metamodel = abstract syntax.
  - a data model to store, manipulate and interchange models.
  - the metamodel has very little semantics content (very little meaning).
- However...
What is a metamodel (according to other authors)

  - A metamodel is a model of a modeling language. The metamodel defines the \textit{structure}, \textit{semantics} and \textit{constraints} for a family of models.
  - A metamodel is a model of a language that captures its essential properties and features. These include the \textit{language concepts} it supports, its textual and/or graphical \textit{syntax} and its \textit{semantics} (what the models and programs written in the language mean and how they behave).

- It seems even among experts there is \textit{no agreement}...
- Difference in terminology is an issue if it provokes \textit{confusion}.

\textbf{Representation and conformance}
What is a model (revisited)

A model is a simplified representation of a certain reality.

There can be many different maps of the same territory, depending on the purpose:
- riding a bike,
- visiting museums,
- analyzing votes,
- etc.


Each model captures a certain aspect/view of the system

What is modeling

  - Modeling, in the broadest sense, is the cost-effective use of something in place of something else for some cognitive purpose. It allows us to use something that is simpler, safer or cheaper than reality instead of reality for some purpose. A model represents reality for the given purpose; the model is an abstraction of reality in the sense that it cannot represent all aspects of reality. This allows us to deal with the world in a simplified manner, avoiding the complexity, danger and irreversibility of reality.
  - A model is focused in one particular aspect of a system:
    - A model is not intended to capture all the aspects of a system, but mainly to abstract out only some of these characteristics.
    - A system is usually represented by a set of different models, each one capturing some specific aspects.
    - Which aspects to capture depends on the purpose of the model.
    - A model must not represent the system with absolute preciseness.
      - Think of a map at the 1:1 scale!
      - A UML model must not try to capture the totality of aspects of a Java program.
    - A model is useful because it is a simplified copy.

The representation relationship

Characterized by contextual substitutability: a model should be able to answer a given set of questions in the same way the system would answer these same questions.

You can ask the map certain questions, but not others.
What is the distance from Madrid to Warsaw?
How many whales are there in the oceans?
A model is a partial analogy of a system

The analogy between the model and the represented reality is partial. The properties of the model are not identical to the properties of the reality. I can’t smoke with this pipe!


René Magritte
“This is not a pipe”

The conformance relationship

A model is a simplified representation of a certain reality, according to the rules of a certain modeling language.

The map conforms to its legend.

The legend defines the language to read the map.

Jean Bézivin, On the unification power of models, 2005.
The two basic metamodeling relationships

- **What is a model?**
  - A model is a simplified representation of a certain reality,
  - according to the rules of a certain modeling language.

![Diagram of the two basic metamodeling relationships]

A model **represents** a system and **conforms** to a metamodel.

**The four metamodeling layers**
A metamodel is the model of a language

- Let’s recall (from “A Proposal for an MDA Foundation Model”):
  - A metamodel is a special kind of model that specifies the abstract syntax of a modeling language. It can be understood as the representation of the class of all models expressed in that language. Metamodels in the context of MDA are expressed using MOF.
- What does a metamodel represent?
  - Not a model, or a set of models, but the abstract syntax of a modeling language.
  - The expression “model of a model” is particularly confusing.
  - A metamodel is a model of a (modeling) language.
- What does a metamodel conform to?
  - To a meta-metamodel, of course.

The four metamodeling layers

A metamodel is a “class of models”.

Is a model an instance of a metamodel?

Many meanings of the “instance-of” relationship.

Traditional OMG’s metamodeling infrastructure. Are all instance-of relationships fundamentally of the same kind?

Bézivin's version of metalayers: 3+1

The M0 layer is the real system.

A model represents this system at level M1.

This model conforms to its metamodel defined at level M2.

The metamodel itself conforms to the meta-metamodel at level M3.

The meta-metamodel conforms to itself.

Jean Bézivin, On the unification power of models, 2005.

Are they really “layers”?

A model conforms to a language whose abstract syntax is represented by a metamodel.

Transitively, we can say that a model conforms to a metamodel.

The represented-by and conforms-to relationships are essentially different.

Arranging them in the same direction may be confusing.

The metamodel substitutes the modeling language in the transitive conforms-to relationship.
A *metamodel* conforms to a language whose abstract syntax is represented by a *meta-metamodel*.

Transitively, we can say that a metamodel conforms to a meta-metamodel.

The meta-metamodel substitutes the metamodeling language in the *transitive conforms-to* relationship.

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A *reflexive meta-metamodel* conforms to a language whose abstract syntax is represented by *itself*.

Transitively, we can say that a metametamodel conforms to itself.

The meta-metamodel substitutes the metamodeling language in the *transitive conforms-to* relationship.
Metamodel and semantic domain

Semantic domain

- What is a semantic domain?
  - *Semantic domain = Real world?* Well, not exactly...
  - A semantic domain is *focused on certain entities and aspects* of the “real world” in which we are interested, excluding others.
  - The selection of relevant entities and aspects is driven by our modeling *purpose*.
- The semantic domain is:
  - An abstraction (a representation, *a model*) of the real world.
  - A conceptualization of some part of the “real world”, a closed world of concepts, with rules governing the relationships between those concepts (*a rational world*).
- We, software engineers, don’t need to worry about the “true structure of the world”.
  - The correspondence between the concepts and the world beyond is a *philosophical issue* (most interesting, indeed!). Do universal concepts exist?
  - We are concerned only about *the world as we speak about it* (the “universe of discourse”), the information world.
Metamodel and semantic domain

- The semantic domain is a closed world of concepts and relationships.
- The metamodel gives *names* to these concepts and relationships.
  - The metamodel (= abstract syntax) gives *no meaning*, no interpretation.
  - Safe for the meaning *conveyed by the names* (so, be careful with the selection of names).
- Each language defines, or is associated with, a particular semantic domain.
- **What is the domain of Natural Language?**
  - The entire world: we can speak about everything.
  - Or, better, there is a domain for each language (Polish, Spanish, Japanese...).
  - Each language conceptualizes the world in its own way (Weltanschauung).
- The semantic domain is defined in the metamodel, *not in the model*.
  - Each model uses the language of its particular semantic domain / metamodel.
  - Each model receives its meaning from the *semantic mapping* MM → SD.
- **What about domain models?**
  - Either they are metamodels, or they do not properly define a new domain.

The metamodel / semantic domain of UML

- **What is the metamodel of UML?**
  - Read the Standard.
- **What is the semantic domain of UML?**
  - Again, read the Standard, but this time it is not so easy to answer.
  - Informally described in (rather interconnected) natural language discussions.
  - More or less, *the world of object orientation*: classes, objects, messages...
    - It does not correspond to any particular programming language.
    - In fact, it has defined a *new object-oriented paradigm*.
  - UML does not specify clearly and rigorously its semantic domain.
    - Too many “semantic variation points”.
    - Trying to accommodate everybody, it accommodates nobody.
- **Source for the proliferation of Domain Specific Languages.**
  - Each DSL has its own metamodel and semantic domain.
  - Interoperability is easier between MOF-compliant DSLs.
Metamodel / semantic domain and the real world

- To be useful, the concepts and rules defined in a modeling language must adequately correspond with reality. 
  - Why is Newtonian physics so useful?
  - Do personal debts behave in the RW as we have conceptualized them?

- A bad conceptualization of the “real world” in a semantic domain (and metamodel) has several drawbacks:
  - It can produce models that are useless for predictions.
  - It can produce models that are twisted representations of reality.

- Everything is an object...
  - does not express a property of the “real world”,
  - but a property (a limitation?) of the domain modeler.

- For a person who holds a hammer, everything is a nail...

A case of metamodel/domain mismatch
The “two level” modeling paradigm

The UML metamodel (following many OOPLs) consecrates the principle that the universe of discourse consists of classes and objects (types and instances).

Collie \( \xrightarrow{\text{instance of}} \) Lassie

\( M_0 \)

Collie \( \xrightarrow{\text{instance of}} \) Lassie

\( M_1 \)

Conforms to

\( M_2 \)

Adapted from:
Colin Atkinson, Thomas Kühlne,

Instance and type at the same time

\( ? \xrightarrow{\text{instance of}} \) \( \text{Class} \)

Conforms to

\( \text{Breed} \)

\( \text{Collie} \)

\( \text{Lassie} \)

\( M_1 \)

\( M_2 \)

- How can I represent that Collie is an instance of Breed?
  - In the “real world”, an entity can be an instance and a type at the same time.
- **Twisted solutions:**
  - Stereotype Collie as «Breed».
  - Use the Type-Object pattern.
  - Extend the metamodel with new metaclasses.
What is a metamodel: the OMG’s metamodeling infrastructure

Breaking the “two level” modeling paradigm

- Allows an arbitrary long chain of instance-of relationships at M0.
- More difficult to translate into traditional OOPLs.
- Some solutions:
  - Powertypes.
  - Deep instantiation (see details in Atkinson & Kühne).
- UML allows other constructs difficult to implement (multiple generalization).

Conclusions
Conclusions

- **Metamodel = abstract syntax** (with very little semantics content).
- Two basic metamodeling relationships:
  - A model **represents** a system and **conforms to** a metamodel.
  - A metamodel is a special kind of model that represents the abstract syntax of a modeling language and conforms to a meta-metamodel.
- The represented-by and conforms-to relationships are essentially different.
  - Arranging them in the same direction may be confusing.
  - Instead of a **stack of layers**, a **stair of layers** may be more clarifying.
- A metamodel is closely related to its semantic domain.
  - A semantic domain is a conceptualization of some part of the “real world”.
  - A metamodel **gives names** to the concepts of the semantic domain.
  - But **the meaning of names** is properly out of the metamodel.
  - A bad conceptualization of the RW is the source of **modeling problems**.
- Example: **the “two-level” modeling paradigm**.

Questions?