Software Design, Modelling and Analysis in UML

Lecture 21: Meta-Modelling

2016-02-11

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Contents & Goals

Last Lecture:

- Liskov Substitution Principle
- Inheritance: Domain Inclusion Semantics

This Lecture:

- **Educational Objectives:** Capabilities for following tasks/questions.
  - What is the idea of meta-modelling?
  - How does meta-modelling relate to UML?
- **Content:**
  - The UML Meta Model
  - Wrapup & Questions

Meta-Modelling: Idea

Meta-Modelling: Why and What

- **Meta-Modelling** is one major prerequisite for understanding
  - the standard documents OMG (2007a,b), and
  - the MDA ideas of the OMG.
- The idea is somewhat **simple**:
  - if a **modelling language** is about modelling **things**,
  - and if UML models are **things**,
  - then why not **model** UML models using a modelling language?
- In other words:

  Why not have a model $\mathcal{M}_U$ such that
  - the set of legal instances of $\mathcal{M}_U$

  is
  - the set of well-formed (!) UML models.

Meta-Modelling: Example

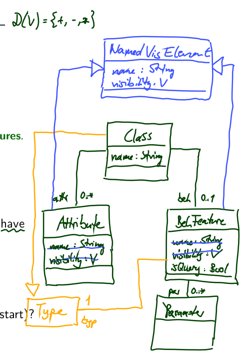
For example, let's consider a class.

- A **class** has (**among others**)
  - a **name**,
  - any number of **attributes**,
  - any number of **behavioural features**.

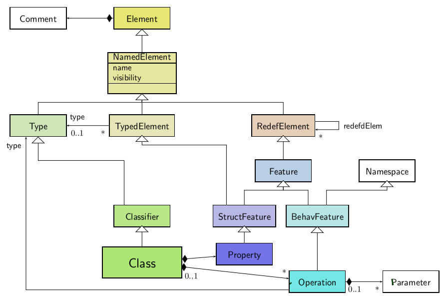
  Each of the latter two has
  - a **name** and
  - a **visibility**.

  Behavioural features in addition have
  - a boolean attribute **isQuery**,
  - any number of parameters,
  - a return type.

Can we model this (in UML, for a start)?

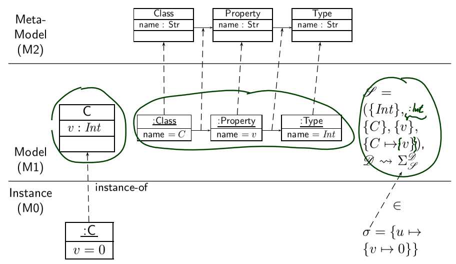


UML Meta-Model: Extract from UML 2.0 Standard

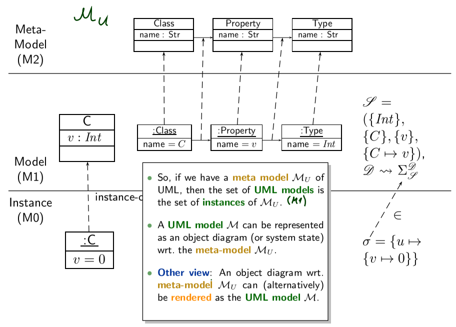


Meta-Modelling: Principle

Modelling vs. Meta-Modelling



Modelling vs. Meta-Modelling



- So, if we have a **meta model** $\mathcal{M}_U$ of UML, then the set of **UML models** is the set of **instances** of $\mathcal{M}_U$. (*)
- A **UML model** $\mathcal{M}$ can be represented as an object diagram (or system state) wrt. the **meta-model** $\mathcal{M}_U$.
- **Other view**: An object diagram wrt. **meta-model** $\mathcal{M}_U$ can (alternatively) be **rendered** as the **UML model** $\mathcal{M}$.

Well-Formedness as Constraints in the Meta-Model

- The set of **well-formed UML models** can be defined as the set of object diagrams satisfying all constraints of the **meta-model**.

  Constraint example,

  > "[2] Generalization hierarchies must be directed and acyclical. A classifier cannot be both a transitively general and transitively specific classifier of the same classifier.
  >
  > not self . allParents() -> includes(self)" (OMG, 2007b, 53)

- The other way round:

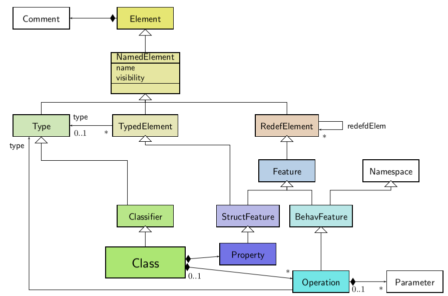
  Given a **UML model** $\mathcal{M}$, unfold it into an object diagram O_1 wrt. $\mathcal{M}_U$.

  If O_1 is a **valid** object diagram of $\mathcal{M}_U$ (i.e. satisfies all invariants from $Inv(\mathcal{M}_U)$), then $\mathcal{M}$ is a well-formed UML model.

  That is, if we have an object diagram **validity checker** for of the meta-modelling language, then we have a **well-formedness checker** for UML models.

The UML 2.x Standard Revisited

Claim: Extract from UML 2.0 Standard



Classes (OMG, 2007b, 32)

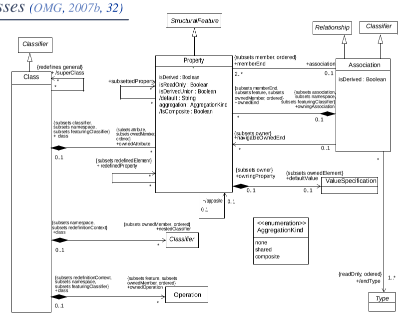


Figure 7.12 - Classes diagram of the Kernel package

Operations (OMG, 2007b, 31)

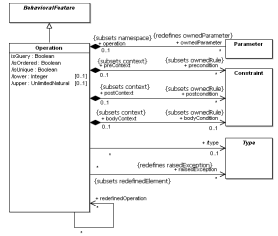


Figure 7.11 - Operations diagram of the Kernel package

Operations (OMG, 2007b, 30)

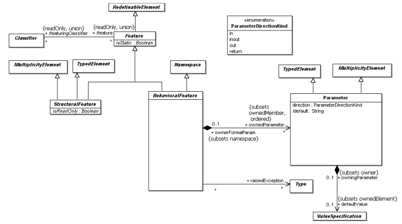


Figure 7.10 - Features diagram of the Kernel package

Classifiers (OMG, 2007b, 29)

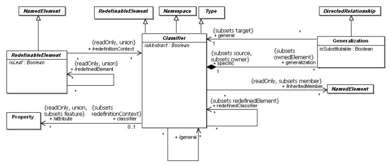


Figure 7.9 - Classifiers diagram of the Kernel package

Namespaces (OMG, 2007b, 26)

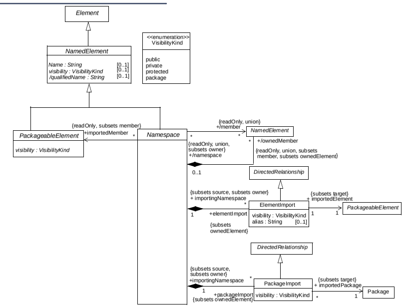


Figure 7.4 - Namespaces diagram of the Kernel package

Root Diagram (OMG, 2007b, 25)

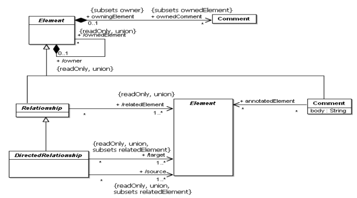


Figure 7.3 - Root diagram of the Kernel package

Interesting: Declaration/Definition (OMG, 2007b, 424)

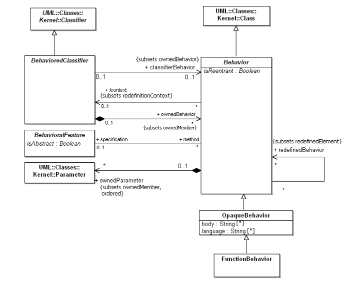
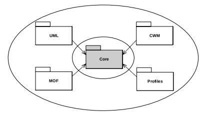


Figure 13.6 - Common Behavior

UML Architecture (OMG, 2003, 8)

- Meta-modelling has already been used for UML 1.x.
- For UML 2.0, the request for proposals (RFP) asked for a separation of concerns: **Infrastructure** and **Superstructure**.
- **One reason**: sharing with MOF (see later) and, e.g., CWM.



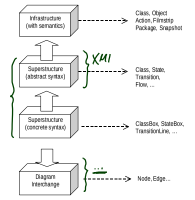


Figure 0-1 *Overview of architecture*

UML Superstructure Packages (OMG, 2007a, 15)

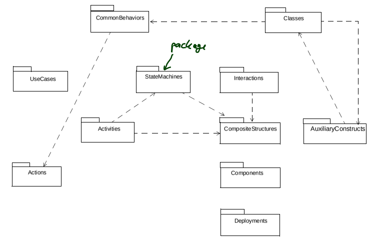


Figure 7.5 - The top-level package structure of the UML 2.1.1 Superstructure

Reading the Standard

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UML Superstructure Specification, v2.1.2 i

Reading the Standard

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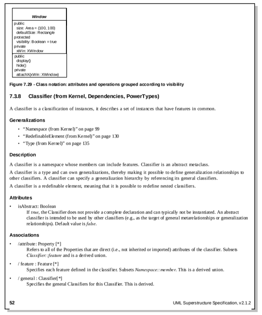
Reading the Standard

UML Superstructure Specification, v2.1.2 iii

Reading the Standard Cont'd



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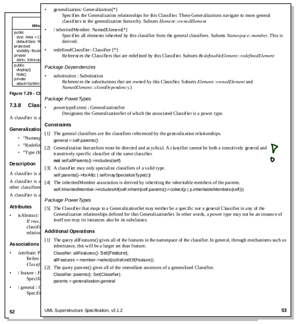

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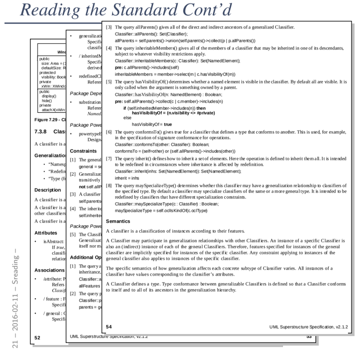

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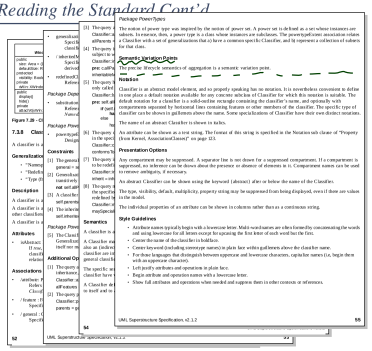

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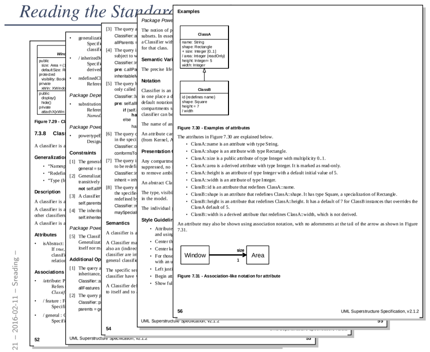

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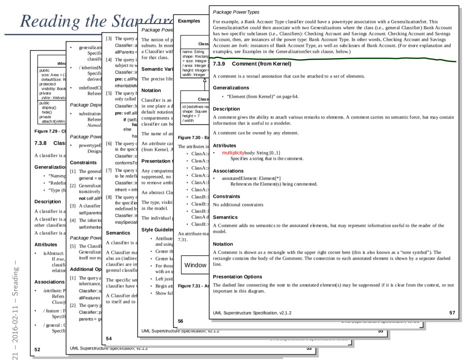


Meta Object Facility (MOF)

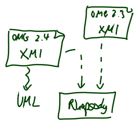
Open Questions...

- Now you've been "**tricked**".
  - We didn't tell what the **modelling language** for meta-modelling is.
  - We didn't tell what the **is-instance-of** relation of this language is.
- **Idea**: have a **minimal object-oriented core** comprising the notions of **class**, **association**, **inheritance**, **etc.** with "self-explaining" semantics.
- This is **Meta Object Facility** (MOF), which (more or less) coincides with UML Infrastructure OMG (2007a).
- So: things on meta level
  - M0 are object diagrams/system states
  - M1 are **words of the language UML**
  - M2 are **words of the language MOF**
  - M3 are **words of the language** MOF ?

MOF Semantics

- One approach:
  - Treat it with **our signature-based theory**
  - This is (in effect) the right direction, but may require new (or extended) signatures for each level.
- Other approach:
  - Define a **generic**, **graph based** "is-instance-of" relation.
  - Object diagrams (that **are** graphs) then **are** the system states — not **only graphical representations** of system states.
  - If this works out, good: We can easily experiment with different language designs, e.g. different flavours of UML that immediately have a semantics.
  - Most interesting: also do generic definition of behaviour within a closed modelling setting, but this is clearly still research, e.g. Buschermöhle and Oelerink (2008).

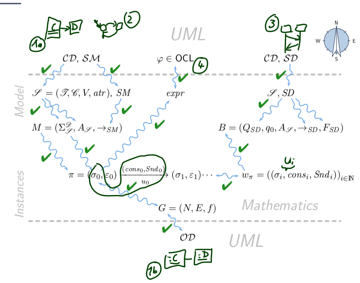
Benefits



- In particular:
  - Benefits for **Modelling Tools**.
  - Benefits for **Language Design**.
  - Benefits for **Code Generation and MDA**.

And That's It!

The Map



Content

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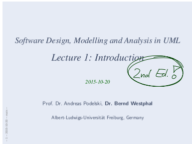

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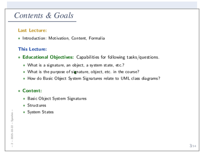
- **Lecture 1**: Introduction
- **Lecture 2**: Semantical Model



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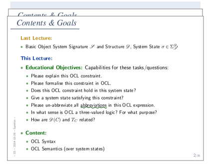

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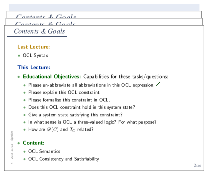

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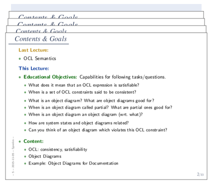

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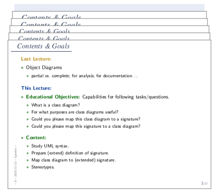

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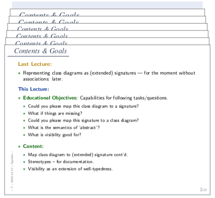

Contents & Goals

Last Lecture:
- Representing class diagrams as (extended) signatures — for the moment without associations: later.

This Lecture:
- **Educational Objectives:** Capabilities for following tasks/questions.
  - Could you please map this class diagram to a signature?
  - What if things are missing?
  - Could you please map this signature to a class diagram?
  - What is the semantics of 'abstract'?
  - What is visibility good for?
- **Content:**
  - Map class diagram to (extended) signature cont'd.
  - Stereotypes – for documentation.
  - Visibility as an extension of well-typedness.

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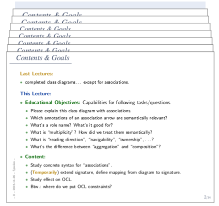

Contents & Goals

Last Lectures:
- completed class diagrams... except for associations.

This Lecture:
- **Educational Objectives:** Capabilities for following tasks/questions.
  - Please explain this class diagram with associations.
  - Which annotations of an association arrow are semantically relevant?
  - What's a role name? What's it good for?
  - What is "multiplicity"? How did we treat them semantically?
  - What is "reading direction", "navigability", "ownership", ...?
  - What's the difference between "aggregation" and "composition"?
- **Content:**
  - Study concrete syntax for "associations".
  - (Temporarily) extend signature, define mapping from diagram to signature.
  - Study effect on OCL.
  - Btw.: where do we put OCL constraints?

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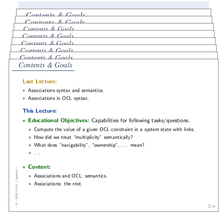

Contents & Goals

Last Lecture:
- Associations syntax and semantics.
- Associations in OCL syntax.

This Lecture:
- **Educational Objectives:** Capabilities for following tasks/questions.
  - Compute the value of a given OCL constraint in a system state with links.
  - How did we treat "multiplicity" semantically?
  - What does "navigability", "ownership", ... mean?
  - ...
- **Content:**
  - Associations and OCL: semantics.
  - Associations: the rest.

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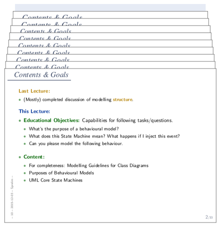

Contents & Goals

Last Lecture:
- (Mostly) completed discussion of modelling structure.

This Lecture:
- **Educational Objectives:** Capabilities for following tasks/questions.
  - What's the purpose of a behavioural model?
  - What does this State Machine mean? What happens if I inject this event?
  - Can you please model the following behaviour.
- **Content:**
  - For completeness: Modelling Guidelines for Class Diagrams
  - Purposes of Behavioural Models
  - UML Core State Machines

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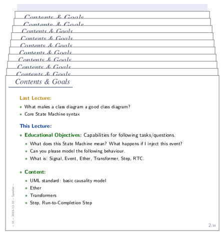

Contents & Goals

Last Lecture:
- What makes a class diagram a good class diagram?
- Core State Machine syntax

This Lecture:
- **Educational Objectives:** Capabilities for following tasks/questions.
  - What does this State Machine mean? What happens if I inject this event?
  - Can you please model the following behaviour.
  - What is: Signal, Event, Ether, Transformer, Step, RTC.
- **Content:**
  - UML standard: basic causality model
  - Ether
  - Transformers
  - Step, Run-to-Completion Step

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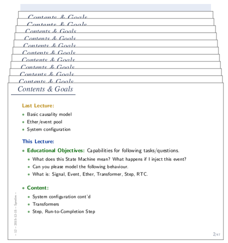

Contents & Goals

Last Lecture:
- Basic causality model
- Ether/event pool
- System configuration

This Lecture:
- **Educational Objectives:** Capabilities for following tasks/questions.
  - What does this State Machine mean? What happens if I inject this event?
  - Can you please model the following behaviour.
  - What is: Signal, Event, Ether, Transformer, Step, RTC.
- **Content:**
  - System configuration cont'd
  - Transformers
  - Step, Run-to-Completion Step

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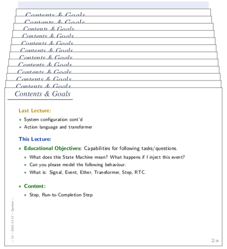

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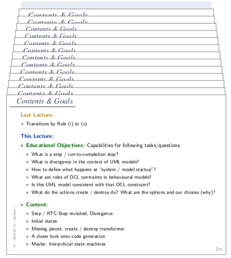

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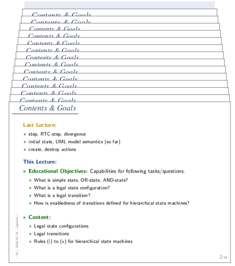

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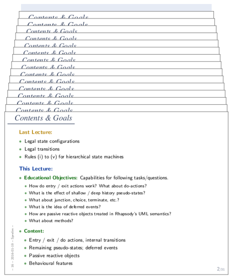

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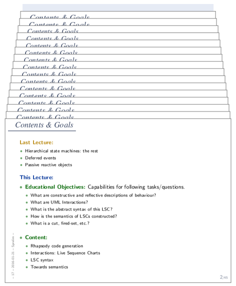

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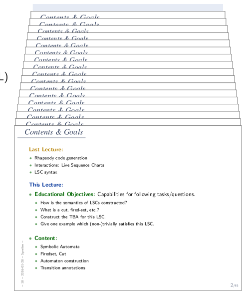

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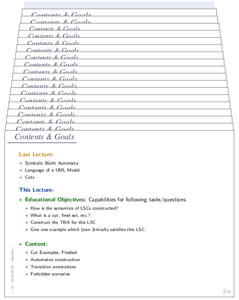

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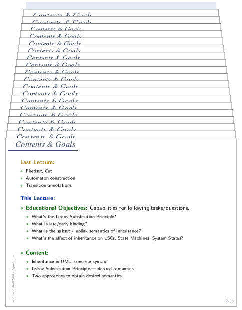
- **Lecture 20**: Inheritance



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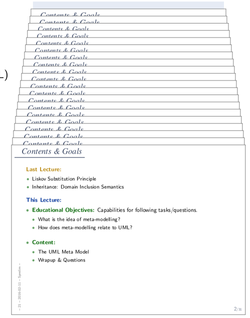

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