# *Software Design, Modelling and Analysis in UML*

## *Lecture 1: Introduction*

*2011-10-25*

Prof. Dr. Andreas Podelski, **Dr. Bernd Westphal**

Albert-Ludwigs-Universität Freiburg, Germany



## *Contents & Goals*

**This Lecture:**

- **Educational Objectives:** After this lecture you should
  - be able to explain the term **model**.
  - know the idea (and hopes and promises) of **model-based** SW development.
  - be able to explain how **UML** fits into this general picture.
  - know **what** we'll do in the course, and **why**.
  - thus be able to decide whether you want to stay with us...
- **Content:**
  - Analogy: Model-based/-driven development by construction engineers.
  - Software engineers: "me too" – Model-based/-driven Software Engineering.
  - UML Mode of the Lecture: Blueprint.
  - Contents of the course
  - Formalia

# *Modelling*



## *Disclaimer*

- The following slides may raise thoughts such as:
  - *"everybody knows this",*
  - *"completely obvious",*
  - *"trivial",*
  - *"clear",*
  - *"irrelevant",*
  - *"oversimplified"*
  - ...

  **Which is true**, in some sense,

- but: "everybody" is a strong claim, and I want to be **sure** that this holds for the audience from now on.

  In other words: that we're talking about the same things.

# An Analogy: The House-Building Problem (Oversimplified)

**Given** a set of **Requirements**, such as:

- The house shall fit on the given piece of land.
- Each room shall have a door, the doors shall open.
- The given furniture shall fit into the living room.
- The bathroom shall have a window.
- The cost shall be in budget.

**Wanted**: a house which satisfies the requirements.

Now, strictly speaking, a house is a **complex system**:

- Consists of a huge number of bricks.
- Consists of subsystems, such as windows.
- Water pipes and wirings have to be in place.
- Doors have to open consistently.
- Floors depend on each other (load-bearing walls).
- ...

**How** do construction engineers **handle** this complexity...?

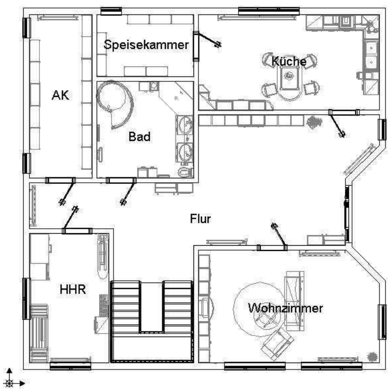


# Approach: Floorplan

**1. Requirements**

- Shall fit on given piece of land.
- Each room shall have a door.
- Furniture shall fit into living room.
- Bathroom shall have a window.
- Cost shall be in budget.

**2. Design**

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**3. System**

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**Observation**: Floorplan **abstracts** from, e.g., ...

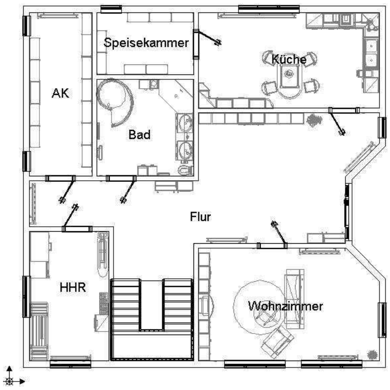
- kind, number, and placement of bricks,
- subsystem details (e.g., window style),
- water pipes/wiring, and

# Approach: Floorplan

## 1. Requirements

- Shall fit on given piece of land.
- Each room shall have a door.
- Furniture shall fit into living room.
- Bathroom shall have a window.
- Cost shall be in budget.

## 2. Design

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## 3. System

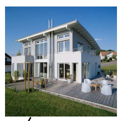
http://wikimedia.org (CC nc-sa 3.0, Bobthebuilder82)

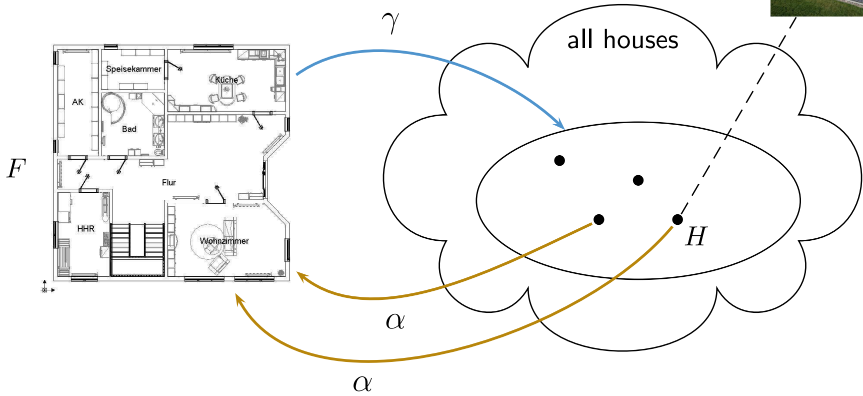
**Observation**: Floorplan **preserves**, e.g., ...

- house and room extensions (to scale),
- presence/absence of windows and doors,
- placement of subsystems (such as windows).



# Floorplan as an Abstraction






- Floorplan $F$ denotes a set $\gamma(F)$ of houses (**concretisations** of $F$), which differ, e.g. in colour of bricks, or making of windows.
- Floorplan $F$ represents house $H$ according to abstraction $\alpha$.
- By adding information to $F$ (such as making of windows), we can narrow down $\gamma(F)$.

## What is it good for? Build by Plan.

- As said before, the floorplan abstraction $\alpha$ **preserves** some properties. For instance, we have:

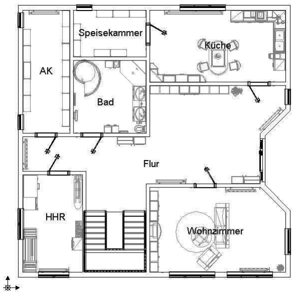
  a floorplan

  Room $R$ has window in $H$ **if and only if** $R$-representation in $\alpha(H)$ has window.

- And we have the general rule:

  **If** a house $H'$ is (or: will have been) built according to plan $F$, and
  **if** plan $F$ has property $\phi$, and **if** $\alpha/\gamma$ preserve this property,
  **then** $H'$ has (or: will have) property $\phi$.

- So we can answer **some** questions about $H$ **before even building it**, e.g.:
  - Bathroom shall have a window.
  - Shall fit on given piece of land.
  - Each room shall have a door.
  - Furniture shall fit into living room.
  - Cost shall be in budget.




- And: it's typically easier (and cheaper) to correct errors in the plan, rather than in the finished house.





## "Silver Bullet" or Can Anything Go Wrong...?

- If the requirements are already **contradictory** (or **inconsistent**), then there is **no sense** in drawing /or following a plan.

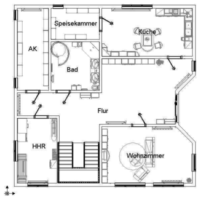
  **Example**:

  - The house shall fit on the given piece of land.
  - The given furniture shall fit into the living room.

  What if the land is 10m narrow and the couch is 11m $\times$ 11m?

# *Good for Anything Else? Documentation.*

- **Given**: a house.
- **Wanted**: a concise description for potential buyers.
- **Approach**: draw a floorplan.




**Distinguish**:

- Sometimes the plan $F$ is **first**, and the realisation $H \in \gamma(F)$ comes **later**.
- Sometimes the realisation $H$ is **first**, and the "plan" $F = \alpha(H)$ comes **later**.



# *What's the Essence?*

common def., not by Mr. Folk

**Definition.** [Folk] A model is an abstract, formal, mathematical representation or description of structure or behaviour of a (software) system.

**Definition.** [Glinz, 2008, 425]
A model is a concrete or mental image (Abbild) of something or a concrete or mental archetype (Vorbild) for something.

Three properties are constituent:

(i) the image attribute (Abbildungsmerkmal), i.e. there is an entity (called original) whose image or archetype the model is,

(ii) the reduction attribute (Verkürzungsmerkmal), i.e. only those attributes of the original that are relevant in the modelling context are represented,

(iii) the pragmatic attribute, i.e. the model is built in a specific context for a specific purpose.

# *Model-Based/-Driven Software Engineering*





## *Software System (Very Abstract View)*

We see **software** $M$ as a **transition system**.

- It has a (possibly infinite) set of states $S$, (**structure**)
- an initial state $s_0$, and
- a (possibly $L$-labelled) transition relation

$$\rightarrow \subseteq S \times L \times S. \qquad \text{(behaviour)}$$

Software may have infinite and finite **runs**, i.e. sequences of consecutive states.

$s_0 \rightarrow s_1 \rightarrow s_2 \rightarrow \dots$

initial state

$(s_i, s_{i+1}) \in \rightarrow$ for all $i \in \mathbb{N}$

## *Software System (Very Abstract View)*

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Software may have infinite and finite **runs**, i.e. sequences of consecutive states.

The **software engineering problem**:

- **Given**: **informal** requirements $\varphi$.
- **Desired**: correct software, i.e. software $M$ such that $M$ satisfies $\varphi$.

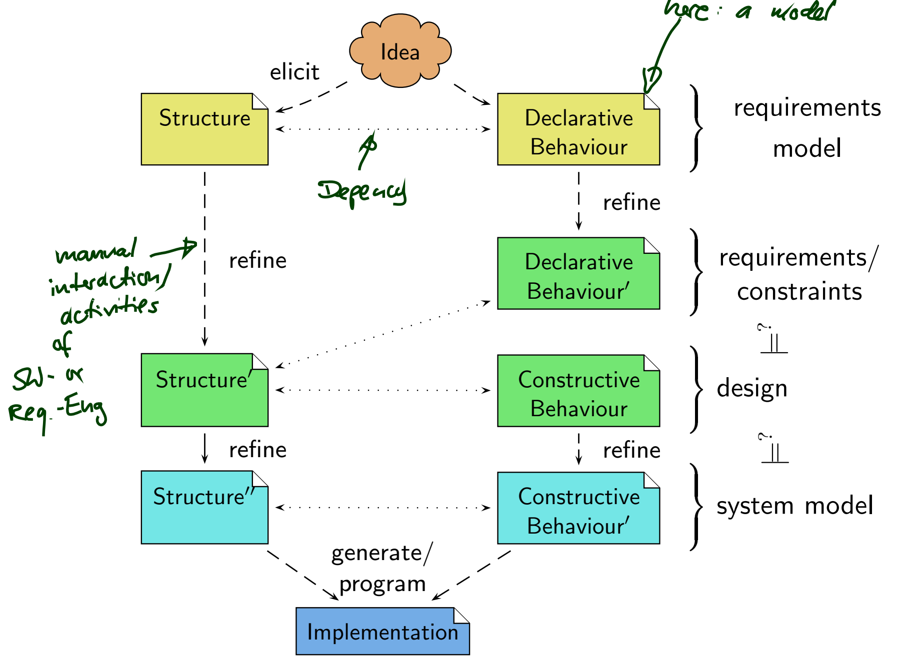
Two prominent **obstacles**:

- Getting $\varphi$ **formal** in order to reason about $\varphi$ and $M$, e.g. **prove** $M$ correct.
- $M$ typically **too large** to "write it down" at once.

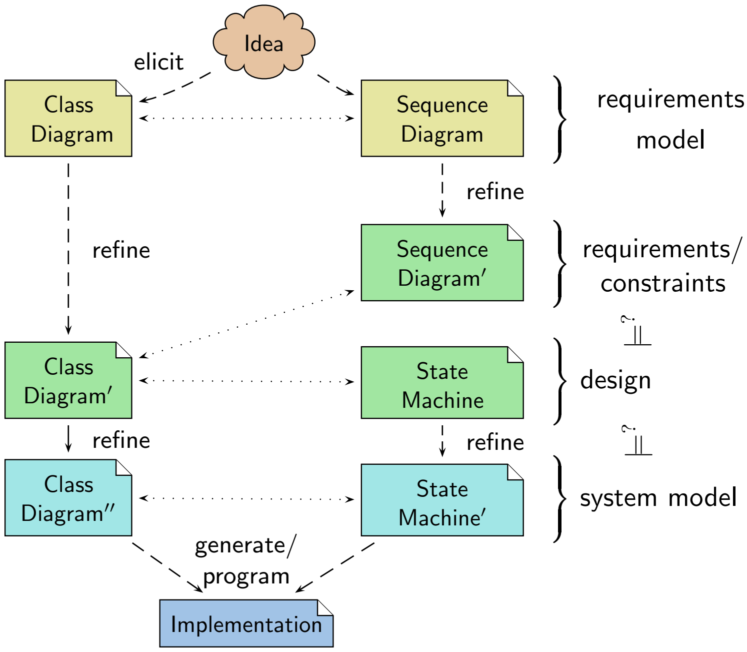


## *Model-Driven Software Engineering*

a document/artifact
here: a model



# *Model-Driven Software Engineering with UML*



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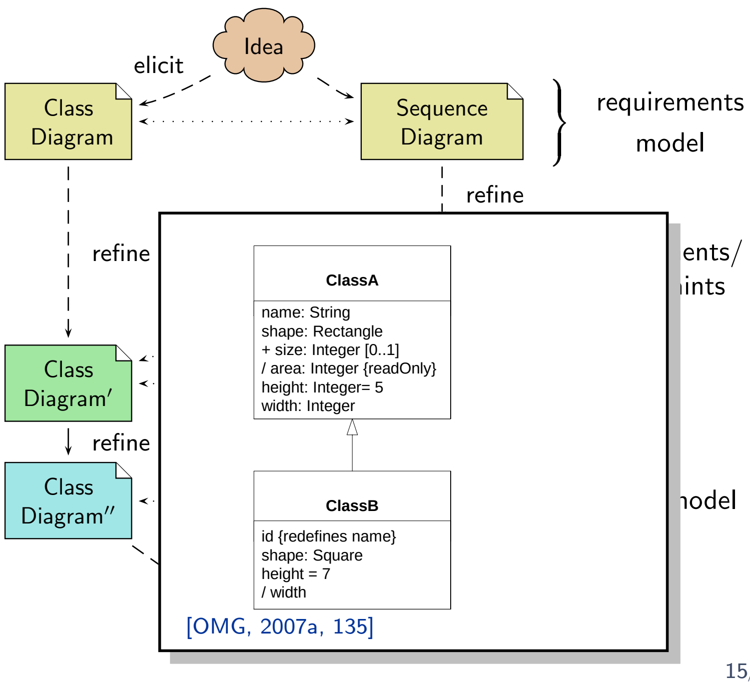

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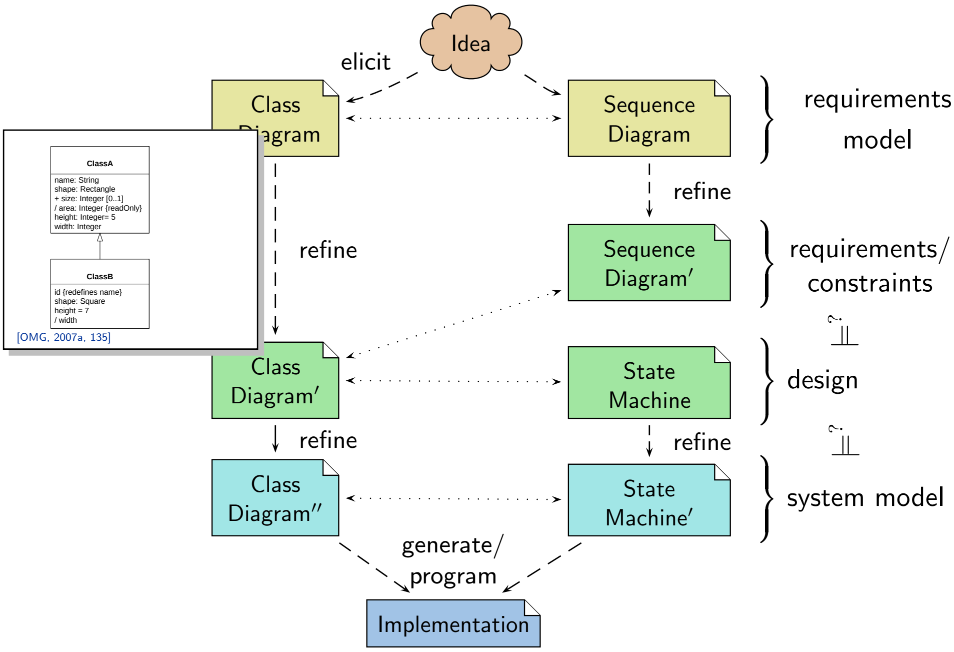




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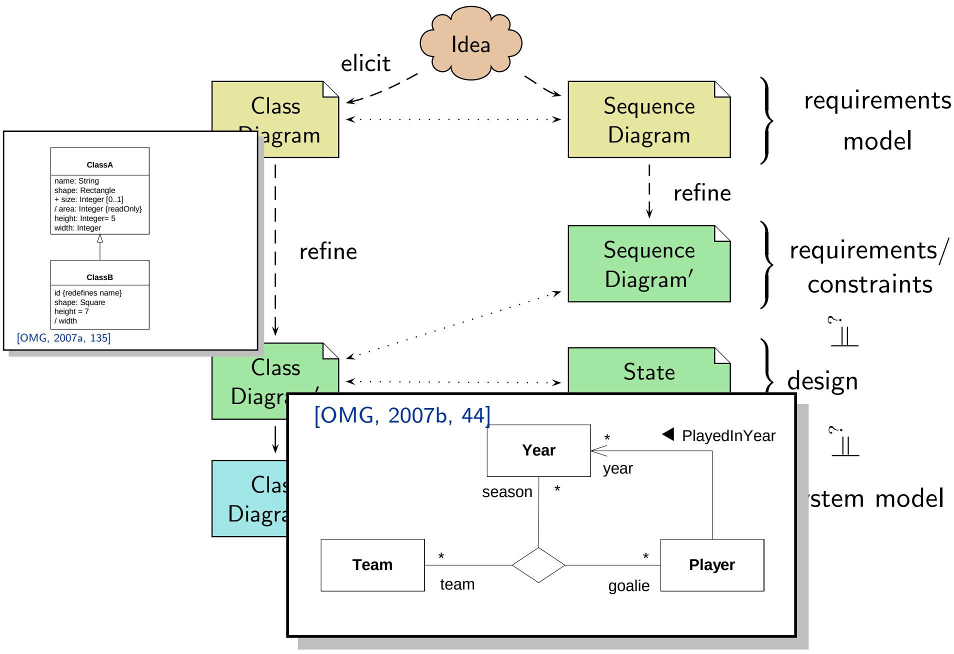

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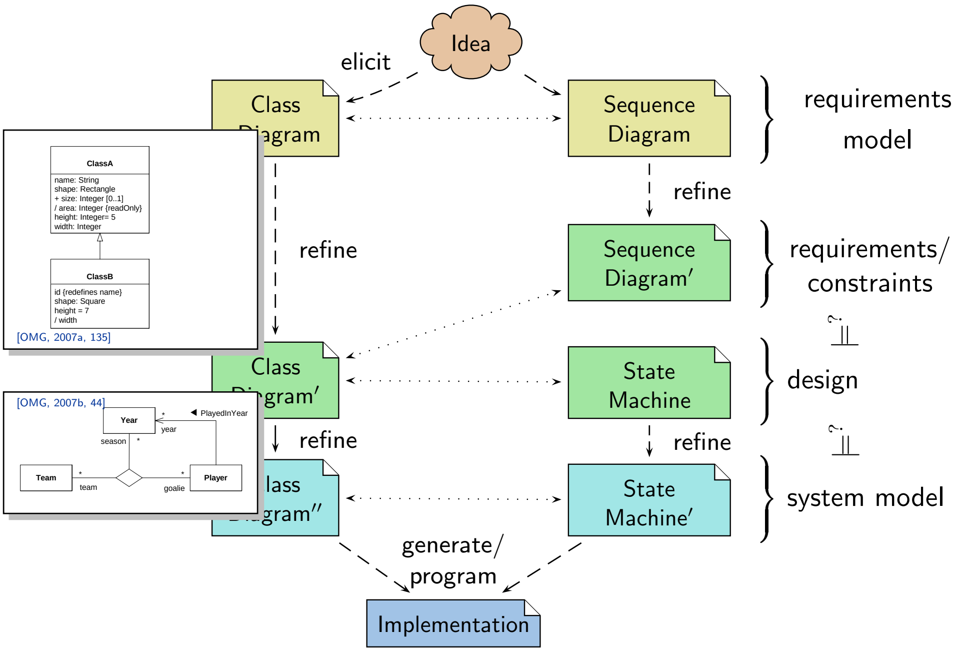




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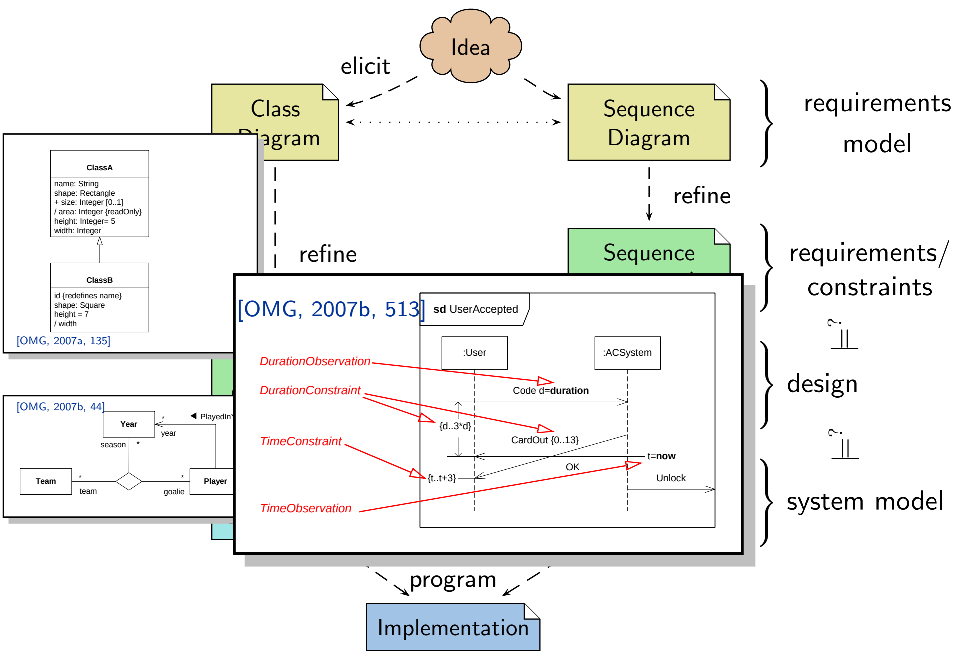

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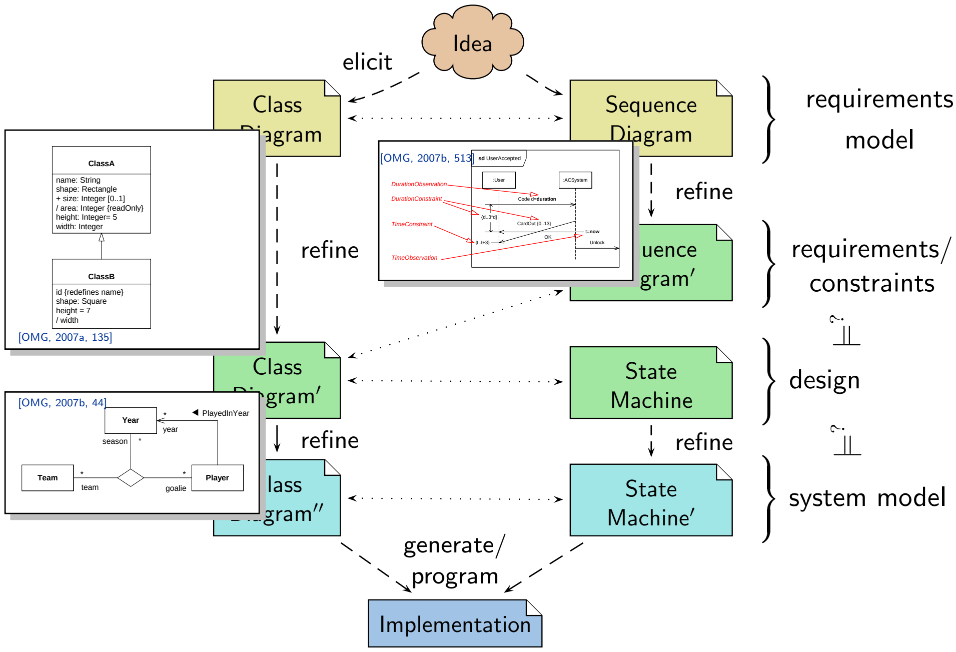




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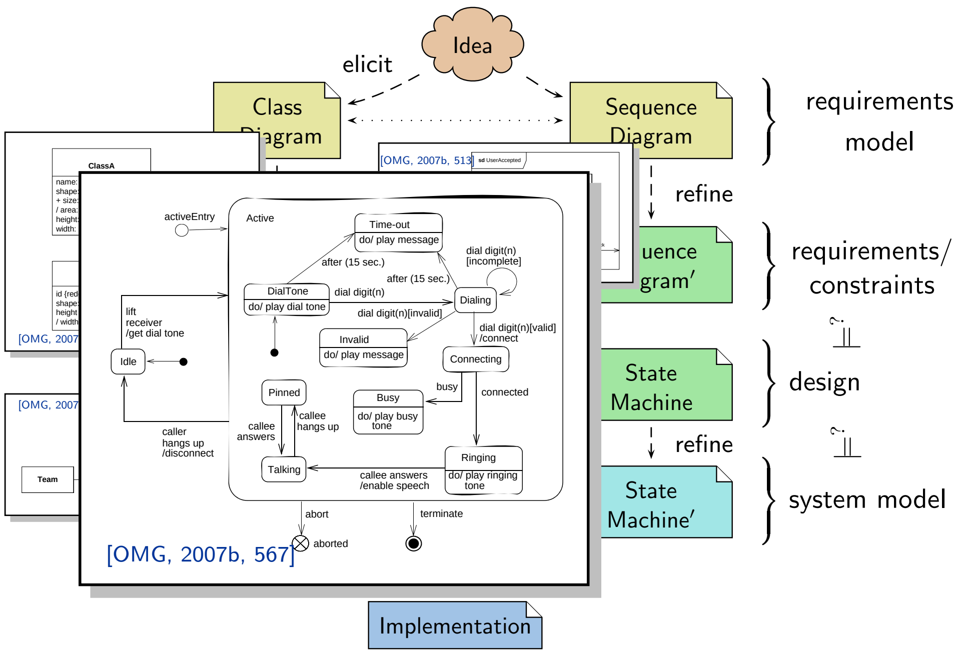


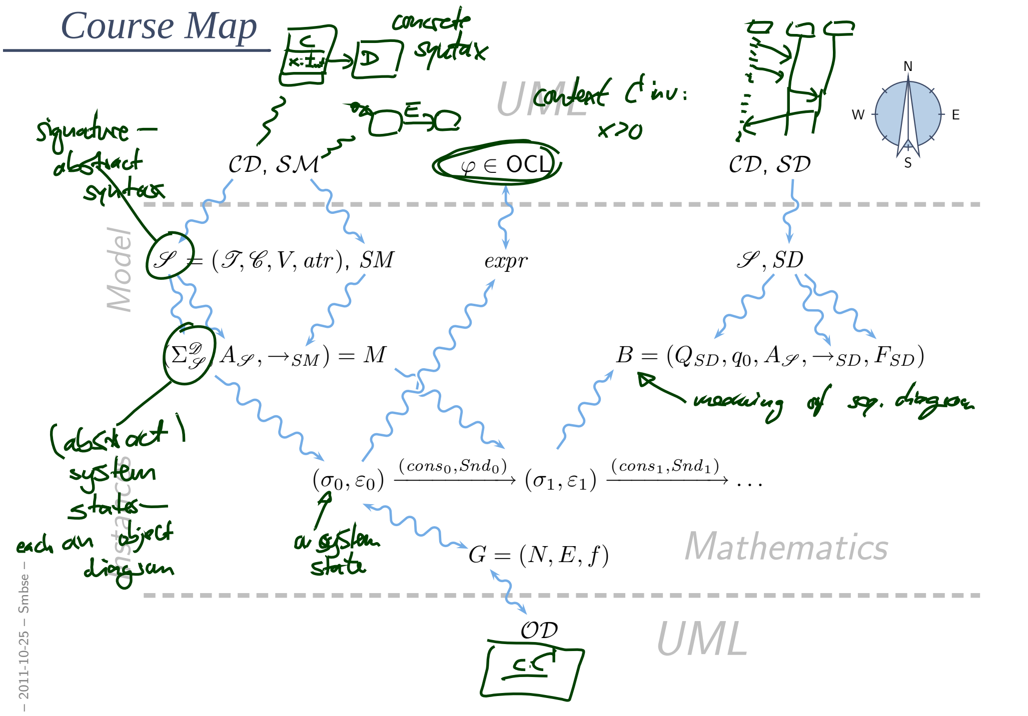
## *Needed: A Modelling Language for SW-Engineering*

- What would be a "from scratch" approach?
  - (i) Define a **formal** language to define requirements and designs.
  - (ii) Equip it with a **formal** semantics.
  - (iii) Define consistency/satisfaction relation in terms of semantics.

- The approach in this course:
  - (i) Introduce a common semantical domain — what is a very abstract mathematical characterisation of **object based transitions systems**?
    *Why? Because in the end SW-Engineering is about the* **creation** *of (object based) transitions systems and Modeling is about* **describing** *them.*
  - (ii) Take (a fragment of) the visual formal language **UML** as **syntax**.
  - (iii) Introduce an abstract mathematical **representation of diagrams**.
    *Why? Because it is easier to handle than "pictures"; it abstracts from details such as graphical layout (which don't contribute to the semantics — note: in floor plans it does).*
  - (iv) Study the **UML** standard documents for the **informal semantics**.
  - (v) Define a mapping from (abstract representations of) diagrams to the semantical domain: **assign meaning to diagrams**.
  - (vi) Define (in terms of the meaning) when a diagram is, e.g., **consistent**.



## *Course Map*



# *UML Mode*



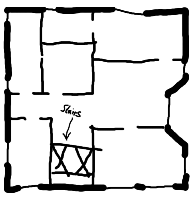
## *Consequences of the Pragmatic Attribute*

Recall [Glinz, 2008, 425]:

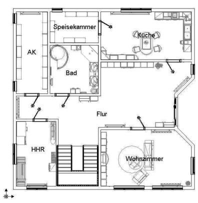
> [...] (iii) the pragmatic attribute, i.e. the model is built in a specific context for a specific purpose.

**Examples for context/purpose:**

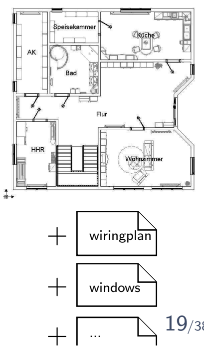
**Floorplan as sketch:**



**Floorplan as blueprint:**



**Floorplan as program:**



## With UML it's the Same [http://martinfowler.com/bliki]

Actually, the last slide is inspired by **Martin Fowler**, who puts it like this:

> *"[...] people differ about what should be in the UML because there are* **differing fundamental views about what the UML should be**.
>
> *I came up with three primary classifications for thinking about the UML:* **UmlAsSketch**, **UmlAsBlueprint**, *and* **UmlAsProgrammingLanguage**.
> *([...] S. Mellor independently came up with the same classifications.)*
>
> *So when someone else's view of the UML seems rather different to yours, it may be because they use a different* **UmlMode** *to you."*

Claim:

- And this not only applies to UML **as a language** (what should be in it?)
- but at least as well to individual UML **models**.



## With UML it's the Same [http://martinfowler.com/bliki]

Ac

**Sketch**

*In this UmlMode developers use the UML to help communicate some aspects of a system. [...]*

*Sketches are also useful in documents, in which case the focus is communication rather than completeness. [...]*

*The tools used for sketching are lightweight drawing tools and often people aren't too particular about keeping to every strict rule of the UML. Most UML diagrams shown in books, such as mine, are sketches.*
*Their emphasis is on selective communication rather than complete specification.*
*Hence my sound-bite "comprehensiveness is the enemy of comprehensibility"*

**Blueprint**

*[...] In forward engineering the idea is that blueprints are developed by a designer whose job is to build a detailed design for a programmer to code up.*
*That design should be sufficiently complete that all design decisions are laid out and the programming should follow as a pretty straightforward activity that requires little thought. [...]*

*Blueprints require much more sophisticated tools than sketches in order to handle the details required for the task. [...]*

*Forward engineering tools support diagram drawing and back it up with a repository to hold the information. [...]*

**ProgrammingLanguage**

*If you can detail the UML enough, and provide semantics for everything you need in software, you can make the UML be your programming language.*
*Tools can take the UML diagrams you draw and compile them into executable code.*

*The promise of this is that UML is a higher level language and thus more productive than current programming languages.*

*The question, of course, is whether this promise is true.*
*I don't believe that graphical programming will succeed just because it's graphical. [...]*

Cl

# *UML-Mode of the Lecture: As Blueprint*

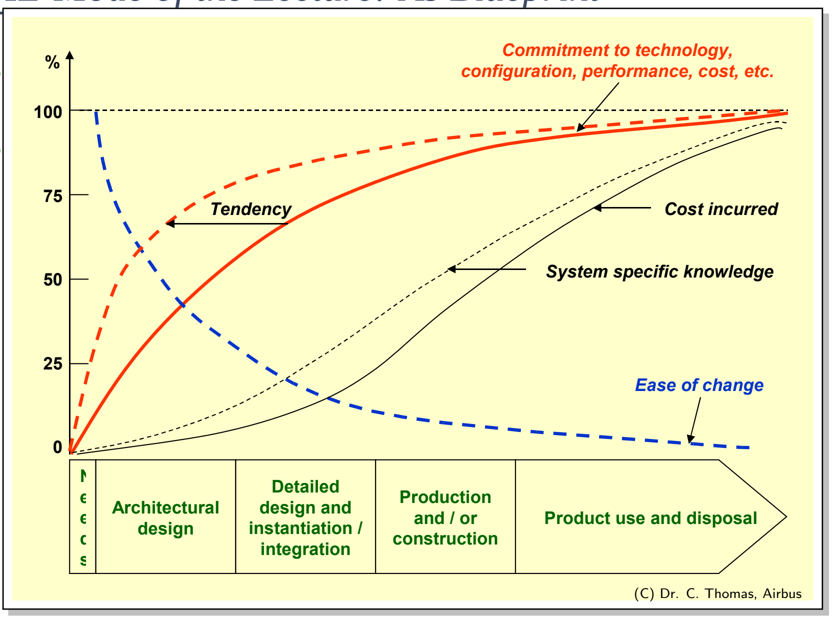
- The "mode" fitting the lecture best is **AsBlueprint**.

- The purpose of the lecture's formal semantics is:
  - to be precise to **avoid misunderstandings**.
  - to allow formal **analysis of consistency/implication** on the **design level** — find errors early.

  while being consistent with the (informal semantics) from the standard [?, OMG, 2007b] as far as possible.



# *UML-Mode of the Lecture: As Blueprint*

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  while being consistent with the (informal semantics) from the standard [?, OMG, 2007b] as far as possible.

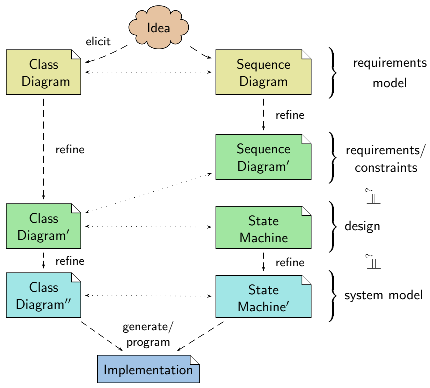
- Being precise also helps for mode **AsSketch**: it should be easier to "fill in" missing parts or resolve inconsistencies.
- Lecture serves as a starting point to define **your** semantics for **your** context/purpose (maybe obtaining a **Domain Specific Language**).
- Lecture could be worked out into mode **AsProgrammingLanguage**.



## *Course Overview*

## Table of Contents

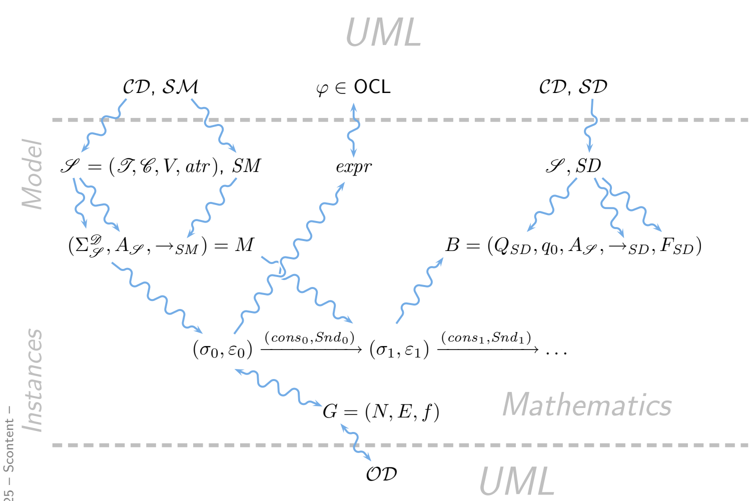






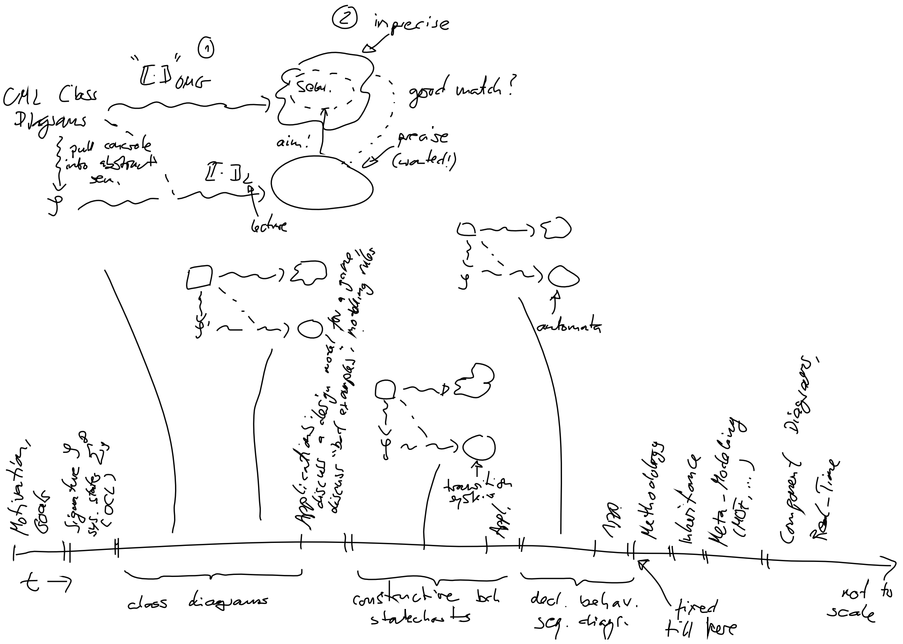



## Course Path: Over Map




- Motivation
- Semantical Domain
- OCL
- Object Diagrams
- Class Diagrams
- State Machines
- Live Sequence Charts
- Real-Time
- Components
- Inheritance
- Meta-Modeling
- MDA, MDSE

# Course Path: Over Time






# Table of Non-Contents

**Everything else**, including

- **Development Process**
  UML is only the language for artefacts. But: we'll discuss exemplarily, where in an abstract development process which means could be used.
- **How to come up with a good design**
  UML is only the language to write down designs. But: we'll have a couple of examples.
- **Requirements Management**
  Versioning, Propagation of Changes
- **Every little bit and piece of UML**
  Boring. Instead we learn how to read the standard.
- **Object Oriented Programming**
  Interesting: inheritance is one of the last lectures.

# *Formalia*



## *Formalia: Event*

- **Lecturer:** Dr. Bernd Westphal
- **Support:** Evis Plaku
- **Homepage:**

  `http://swt.informatik.uni-freiburg.de/teaching/winter-term-2011-2012/sdmauml/sdmauml`

- **Questions:**
  - **"online"**:
    (i) ask immediately or in the break
  - **"offline"**:
    (i) try to solve yourself
    (ii) discuss with colleagues
    (iii) • Exercises: contact tutor by mail (cf. homepage)
    • Rest: contact lecturer by mail (cf. homepage) or just drop by: Building 52, Room 00-020

## *Formalia: Dates/Times, Break*

- **Location:**
  - Tuesday, Wednesday: here (bldg. 106, room 00-007)

- **Schedule:**

| | | | | |
|---|---|---|---|---|
| Week $N$, | Wednesday, | 12–14 | **lecture** | (exercise sheet $K$ **online**) |
| Week $N+1$, | Tuesday, | 12–14 | **lecture** | |
| | Wednesday, | 12–14 | **lecture** | |
| Week $N+2$, | Monday, | 9:00 | | (exercises $K$ **early submission**) |
| | Tuesday, | 12:00 | | (exercises $K$ **late submission**) |
| | | 12–14 | **tutorial** | |

  With a prefix of lectures, see homepage for details.

- **Break:**
  - Unless a majority objects **now**,
    we'll have a ~~15~~ 10 **min. break** in the middle of each event from now on.



## *Formalia: Lectures*

- **Course language: English**
  (slides/writing, presentation, questions/discussions)

- **Presentation:**
  half slides/half on-screen **hand-writing** — for reasons

- **Script/Media:**
  - slides with annotations on **homepage**, 2-up for printing,
    typically soon **after** the lecture
  - recording on eLectures portal with max. 1 week delay
    (link on **homepage**)

- **Interaction:**
  absence often moaned but **it takes two**,
  so please ask/comment immediately.

## *Formalia: Exercises and Tutorials*

- **Schedule/Submission:**
  - **hand-out** on Wednesday after lecture,
    **early turn in** on following Monday by 9:00 local time
    **regular turn in** on following Tuesday by 12:00 local time
  - should work in groups of + max. **approx. 3**, clearly give **names** on submission
  - please submit **electronically** by Mail to B. Westphal (cf. homepage),
    **paper submissions** are **tolerated**
- **Rating system:** "most complicated rating system **ever**"
  - **Admission points** (good-will rating, upper bound)
    ("reasonable proposal given student's knowledge **before** tutorial")
  - **Exam-like points** (evil rating, lower bound)
    ("reasonable proposal given student's knowledge **after** tutorial")

  10% **bonus** for **early** submission.
- **Tutorial:** Plenary.
  - Together develop **one** good proposal,
    starting from discussion of the early submissions (anonymous).



## *Formalia: Exam*

- **Exam Admission:**

  Achieving 50% of the regular **admission points** in total
  is **sufficient** for admission to exam.

  Typically, 20 regular admission points per exercise sheet.
- **Exam Form:**
  - oral for BSc and on special demand,
  - **written** for everybody else (if sufficiently many candidates remain).

  Scores from the exercises **do not** contribute to the final grade.

## *Formalia: Evaluation*

- **Mid-term Evaluation:**
  - We will have a mid-term evaluation
    (early December, roughly $1/3$ of the course's time).
  - If you decide to leave the course earlier you may want to do us a favour and tell us the reasons – by participating in the mid-term evaluation (will be announced on homepage).
  - Note: we're **always** interested in

    comments/hints/proposals/wishes/...

    concerning **form** or **content**.

    Feel free to approach us (tutors, me) in any form.
    **We don't bite.**



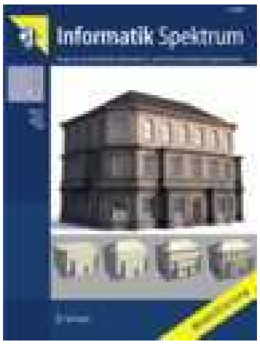
## *Literature*

## Literature: UML


- OMG: Unified Modeling Language Specification, Infrastructure, 2.1.2
- OMG: Unified Modeling Language Specification, Superstructure, 2.1.2
- OMG: Object Constraint Language Specification, 2.0
  All three: `http://www.omg.org` (cf. hyperlinks on course homepage)
- A. Kleppe, J. Warmer: The Object Constraint Language,
  Second Edition, Addison-Wesley, 2003.
- D. Harel, E. Gery: Executable Object Modeling with Statecharts,
  IEEE Computer, 30(7):31-42, 1997.
- B. P. Douglass: Doing Hard Time, Addison-Wesley, 1999.
- B. P. Douglass: ROPES: Rapid Object-Oriented Process for Embedded Systems, i-Logix Inc., Whitepaper, 1999.
- B. Oesterreich: Analyse und Design mit UML 2.1,
  8. Auflage, Oldenbourg, 2006.
- H. Stoerrle: UML 2 für Studenten, Pearson Studium Verlag, 2005.




## Literature: Modelling

- 



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- M. Glinz: Modellierung in der Lehre an Hochschulen: Thesen und Erfahrungen, Informatik Spektrum, 31(5):408-424, 2008.

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*Questions?*



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