Software Design, Modelling and Analysis in UML

Lecture 10: Constructive Behaviour, State Machines Overview

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Contents & Goals

Last Lecture:

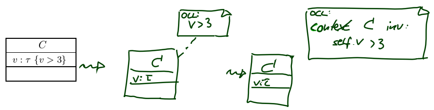
- (Mostly) completed discussion of modelling **structure**.

This Lecture:

- **Educational Objectives:** Capabilities for following tasks/questions.
  - Discuss the style of this class diagram.
  - What's the difference between reflective and constructive descriptions of behaviour?
  - 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
  - Constructive vs. Reflective
  - UML Core State Machines (first half)

OCL Constraints in (Class) Diagrams

Invariant in Class Diagram Example



If $\mathscr{CD}$ consists of only $\mathcal{CD}$ with the single class C, then

- $Inv(\mathscr{CD}) = Inv(\mathcal{CD}) =$ { context C inv : v > 3 }

Constraints vs. Types

Find the 10 differences:

C
$x : Int\ \{x = 3 \vee x > 17\}$

C
$x : T$

$\mathscr{D}(T) = \{3\} \cup \{n \in \mathbb{N} \mid n > 17\}$

- $x = 4$ is well-typed in the left context, a system state satisfying $x = 4$ violates the constraints of the diagram.
- $x = 4$ is not even well-typed in the right context, there cannot be a system state with $\sigma(u)(x) = 4$ because $\sigma(u)(x)$ is supposed to be in $\mathscr{D}(T)$ (by definition of system state).

Rule-of-thumb:

- If something **"feels like" a type** (one criterion: has a natural correspondence in the application domain), then make it a type.
- If something is a **requirement** or restriction of an otherwise useful type, then make it a constraint.

Semantics of a Class Diagram

Definition. Let $\mathscr{CD}$ be a set of class diagrams.

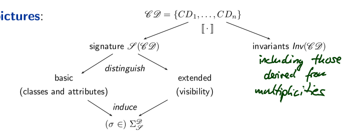
We say, the semantics of $\mathscr{CD}$ is the signature it induces and the set of OCL constraints occurring in $\mathscr{CD}$, denoted

$$[\![\mathscr{CD}]\!] := \langle \mathscr{S}(\mathscr{CD}), Inv(\mathscr{CD}) \rangle.$$

Given a structure $\mathscr{D}$ of $\mathscr{S}$ (and thus of $\mathscr{CD}$), the class diagrams describe the system states $\Sigma_{\mathscr{S}}^{\mathscr{D}}$. Of those, **some** satisfy $Inv(\mathscr{CD})$ and some don't.

We call a system state $\sigma \in \Sigma_{\mathscr{S}}^{\mathscr{D}}$ consistent if and only if $\sigma \models Inv(\mathscr{CD})$.

In pictures:



Pragmatics

Recall: a UML **model** is an image or pre-image of a software system.

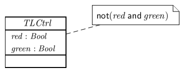
A set of class diagrams $\mathscr{CD}$ with invariants $Inv(\mathscr{CD})$ describes the **structure** of system states.

Together with the invariants it can be used to state:

- **Pre-image**: Dear programmer, please provide an implementation which uses only system states that satisfy $Inv(\mathscr{CD})$.
- **Post-image**: Dear user/maintainer, in the existing system, only system states which satisfy $Inv(\mathscr{CD})$ are used.

(The exact meaning of "use" will become clear when we study behaviour — intuitively: the system states that are reachable from the initial system state(s) by calling methods or firing transitions in state-machines.)

Example: highly abstract model of traffic lights controller.



Addendum: Semantics of OCL Boolean Operations

- semantics of operator is monotone
  (⊥ propagates through, once a sub-expression evaluates to ⊥, the whole expression does)
- $I(+)(x,y) = \begin{cases} x+y, & \text{if } x \neq \bot \text{ and } y \neq \bot \\ \bot, & \text{otherwise} \end{cases}$

  ok...
- if
  $I(or)(p,q) = \begin{cases} true, & \text{if } p = true \text{ or } q = true \text{ and } p \neq \bot \text{ and } q \neq \bot \\ \bot, & \text{otherwise} \end{cases}$

  then
  not oclUndefined (self.n) implies self.n.x > 0
  ⟺ oclUndefined (self.n) or self.n.x > 0
  would not do what we want

Correct Semantics of OCL Boolean Operations

Table A.2 - Semantics of boolean operations

b_1	b_2	b_1 and b_2	b1 or b_2	b_1 xor b_2	b_1 implies b_2	not b_1
false	false	false	false	false	true	true
false	true	false	true	true	true	true
true	false	false	true	true	false	false
true	true	true	true	false	true	false
false	⊥	false	⊥	⊥	true	true
true	⊥	⊥	true	⊥	⊥	false
⊥	false	false	⊥	⊥	⊥	⊥
⊥	true	⊥	true	⊥	true	⊥
⊥	⊥	⊥	⊥	⊥	⊥	⊥

188 Object Constraint Language, v2.0

Design Guidelines for (Class) Diagram

(partly following [Ambler, 2005])

Be careful whose advice you buy, but, be patient with those who supply it.

Baz Luhrmann/Mary Schmich

Main and General Modelling Guideline *(admittedly: trivial and obvious)*

Be good to your audience.

"Imagine you're given **your** diagram $\mathcal{D}$ and asked to conduct task $\mathcal{T}$.

- Can you do $\mathcal{T}$ with $\mathcal{D}$?
  (semantics sufficiently clear? all necessary information available? ...)
- Does doing $\mathcal{T}$ with $\mathcal{D}$ cost you more nerves/time/money/... than it should?"
  (syntactical well-formedness? readability? intention of deviations from standard syntax clear? reasonable selection of information? layout? ...)

In other words: *answer should be*

- the things **most relevant** for $\mathcal{T}$, do they **stand out** in $\mathcal{D}$? —— YES
- the things **less relevant** for $\mathcal{T}$, do they **disturb** in $\mathcal{D}$? —— NO

for a good diagram

Main and General Quality Criterion *(again: trivial and obvious)*

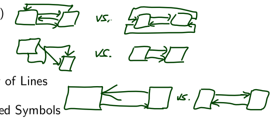
- **Q:** When is a (class) diagram a good diagram?
- **A:** If it serves its purpose/makes its point.

Examples for purposes and points and rules-of-thumb:

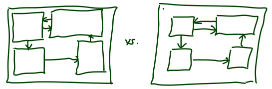
- **Analysis/Design**
  - realizable, no contradictions
  - abstract, focused, admitting degrees of freedom for (more detailed) design
  - platform independent – as far as possible but not (artificially) farer
- **Implementation/A**
  - close to target platform
    ($C_{0,1}$ is easy for Java, C_* comes at a cost — other way round for RDB)
- **Implementation/B**
  - complete, executable
- **Documentation**
  - Right level of abstraction: "if you've only one diagram to spend, illustrate the concepts, the architecture, the difficult part"
  - The more detailed the documentation, the higher the probability for regression
    "outdated/wrong documentation is worse than none"

General Diagramming Guidelines [Ambler, 2005]

(Note: "Exceptions prove the rule.")



- **2.1 Readability**
  - 1.–3. Support Readability of Lines
  - 4. Apply Consistently Sized Symbols
  - 9. Minimize the Number of Bubbles/Things
  - 10. Include White-Space in Diagrams



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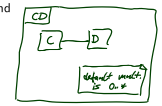
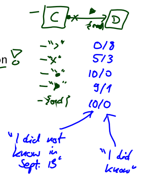
  - 10. Include White-Space in Diagrams
  - 13. Provide a Notational Legend

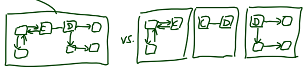


General Diagramming Guidelines [Ambler, 2005]

- **2.2 Simplicity**
  - 14. Show Only What You Have to Show
  - 15. Prefer Well-Known Notation over Exotic Notation
  - 16. Large vs. Small Diagrams
  - 18. Content First, Appearance Second

depends on audience





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- **2.3 Naming**
  - 20. Set and (23. Consistently) Follow Effective Naming Conventions
- **2.4 General**
  - 24. Indicate Unknowns with Question-Marks
  - 25. Consider Applying Color to Your Diagram
  - 26. Apply Color Sparingly

Class Diagram Guidelines [Ambler, 2005]

- **5.1 General Guidelines**
  - 88. Indicate Visibility Only on Design Models **(in contrast to analysis models)**
- **5.2 Class Style Guidelines**
  - 96. Prefer Complete Singular Nouns for Class Names
  - 97. Name Operations with Strong Verbs
  - 99. Do Not Model Scaffolding Code **[Except for Exceptions]**

e.g. get/set methods

Class Diagram Guidelines [Ambler, 2005]

- **5.2 Class Style Guidelines**
  - 103. Never Show Classes with Just Two Compartments
  - 104. Label Uncommon Class Compartments
  - 105. Include an Ellipsis (...) at the End of an Incomplete List
  - 107. List Operations/Attributes in Order of Decreasing Visibility

Class Diagram Guidelines [Ambler, 2005]

- **5.3 Relationships**
  - 112. Model Relationships Horizontally
  - 115. Model a Dependency When the Relationship is Transitory
  - 117. Always Indicate the Multiplicity *(or have good defaults)*
  - 118. Avoid Multiplicity "∗" *(explicitly use 0..∗ or 1..∗)*
  - 119. Replace Relationship Lines with Attribute Types *(to have fewer lines)*

Class Diagram Guidelines [Ambler, 2005]

- **5.4 Associations**
  - 127. Indicate Role Names When Multiple Associations Between Two Classes Exist
  - 129. Make Associations Bidirectional Only When Collaboration Occurs in Both Directions
  - **131. Avoid Indicating Non-Navigability** *(it depends, often ... is meant to be ...)*
  - 133. Question Multiplicities Involving Minimums and Maximums
- **5.6 Aggregation and Composition**
  - → exercises

[...] But trust me on the sunscreen.

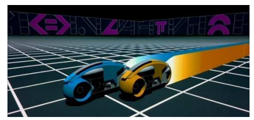
Baz Luhrmann/Mary Schmich

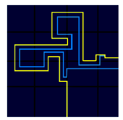
Example: Modelling Games

Task: Game Development

Task: **develop** a **video game**. **Genre**: **Racing**. **Rest**: **open**, i.e.

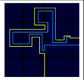
Degrees of freedom:	Exemplary choice: 2D-Tron
• simulation vs. arcade	arcade
• platform (SDK or not, open or proprietary, hardware capabilities...)	open
• graphics (3D, 2D, ...)	2D
• number of players, AI	min. 2, AI open
• controller	open (later determined by platform)
• game experience	minimal: main menu and game



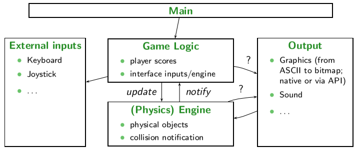


Modelling Structure: 2D-Tron

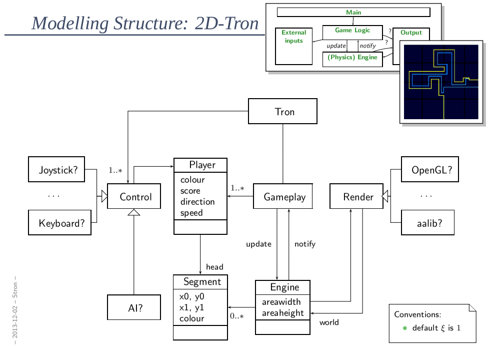
2D-Tron
- arcade
- platform open
- 2D
- min. 2, AI open
- controller open
- only game, no menues



- In many domains, there are canonical architectures – and adept readers try to see/find/match this!
- For games:



Modelling Structure: 2D-Tron



Modelling Behaviour

Stocktaking...

Have: Means to model the **structure** of the system.

- Class diagrams graphically, concisely describe sets of system states.
- OCL expressions logically state constraints/invariants on system states.

Want: Means to model **behaviour** of the system.

- Means to describe how system states **evolve over time**, that is, to describe sets of **sequences**

$$\sigma_0, \sigma_1, \dots \in \Sigma^\omega$$

of system states.

not real-time, just counting steps here

What Can Be Purposes of Behavioural Models?

(We will discuss this in more detail in Lecture 22.)

Example: Pre-Image **Image**
(the UML model is supposed to be the blue-print for a software system).

A description of behaviour could serve the following purposes:

- **Require** Behaviour. **"System definitely does this"**
  "This sequence of inserting money and requesting and getting water must be possible."
  (Otherwise the software for the vending machine is completely broken.)
- **Allow** Behaviour. **"System does subset of this"**
  "After inserting money and choosing a drink, the drink is dispensed (if in stock)."
  (If the implementation insists on taking the money first, that's a fair choice.)
- **Forbid** Behaviour. **"System never does this"**
  "This sequence of getting both, a water and all money back, must not be possible." (Otherwise the software is broken.)

Note: the latter two are trivially satisfied by doing nothing...

Constructive vs. Reflective Descriptions

[Harel, 1997] proposes to distinguish constructive and reflective descriptions:

- *"A language is **constructive** if it contributes to the dynamic semantics of the model. That is, its constructs contain information needed in executing the model or in translating it into executable code."*
  A constructive description tells **how** things are computed (which can then be desired or undesired).
- *"Other languages are **reflective** or **assertive**, and can be used by the system modeler to capture parts of the thinking that go into building the model – behavior included –, to derive and present views of the model, statically or during execution, or to set constraints on behavior in preparation for verification."*
  A reflective description tells **what** shall or shall not be computed.

Note: No sharp boundaries!

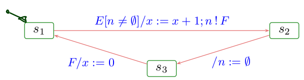
Constructive UML

UML provides two visual formalisms for constructive description of behaviours:

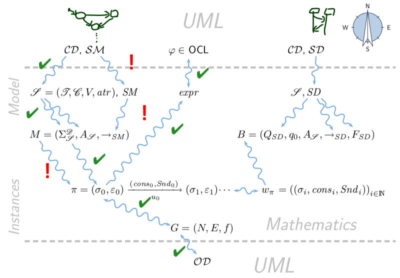
- **Activity Diagrams**
- **State-Machine Diagrams**

We (exemplary) focus on State-Machines because

- somehow "practice proven" (in different flavours),
- prevalent in embedded systems community,
- indicated useful by [Dobing and Parsons, 2006] survey, and
- Activity Diagram's intuition changed (between UML 1.x and 2.x) from transition-system-like to petri-net-like...
- Example state machine:



Course Map



References

References

[Ambler, 2005] Ambler, S. W. (2005). *The Elements of UML 2.0 Style*. Cambridge University Press.

[Crane and Dingel, 2007] Crane, M. L. and Dingel, J. (2007). UML vs. classical vs. rhapsody statecharts: not all models are created equal. *Software and Systems Modeling*, 6(4):415–435.

[Dobing and Parsons, 2006] Dobing, B. and Parsons, J. (2006). How UML is used. *Communications of the ACM*, 49(5):109–114.

[Harel, 1987] Harel, D. (1987). Statecharts: A visual formalism for complex systems. *Science of Computer Programming*, 8(3):231–274.

[Harel, 1997] Harel, D. (1997). Some thoughts on statecharts, 13 years later. In Grumberg, O., editor, *CAV*, volume 1254 of *LNCS*, pages 226–231. Springer-Verlag.

[Harel and Gery, 1997] Harel, D. and Gery, E. (1997). Executable object modeling with statecharts. *IEEE Computer*, 30(7):31–42.

[Harel et al., 1990] Harel, D., Lachover, H., et al. (1990). Statemate: A working environment for the development of complex reactive systems. *IEEE Transactions on Software Engineering*, 16(4):403–414.

[OMG, 2007a] OMG (2007a). Unified modeling language: Infrastructure, version 2.1.2. Technical Report formal/07-11-04.