

Software Design, Modelling and Analysis in UML

Lecture 02: Semantical Model

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Contents & Goals

Last Lecture:

- Motivation: model-based development of things (houses, software) to cope with complexity, detect errors early
- Model-based (or -driven) Software Engineering
- UML Mode of the Lecture: Blueprint.

This Lecture:

- **Educational Objectives:** Capabilities for these tasks/questions:
 - Why is UML of the form it is?
 - Shall one feel bad if not using all diagrams during software development?
 - What is a signature, an object, a system state, etc.?
What's the purpose of signature, object, etc. in the course?
 - How do Basic Object System Signatures relate to UML class diagrams?
- **Content:**
 - Brief history of UML
 - Course map revisited
 - Basic Object System Signature, Structure, and System State

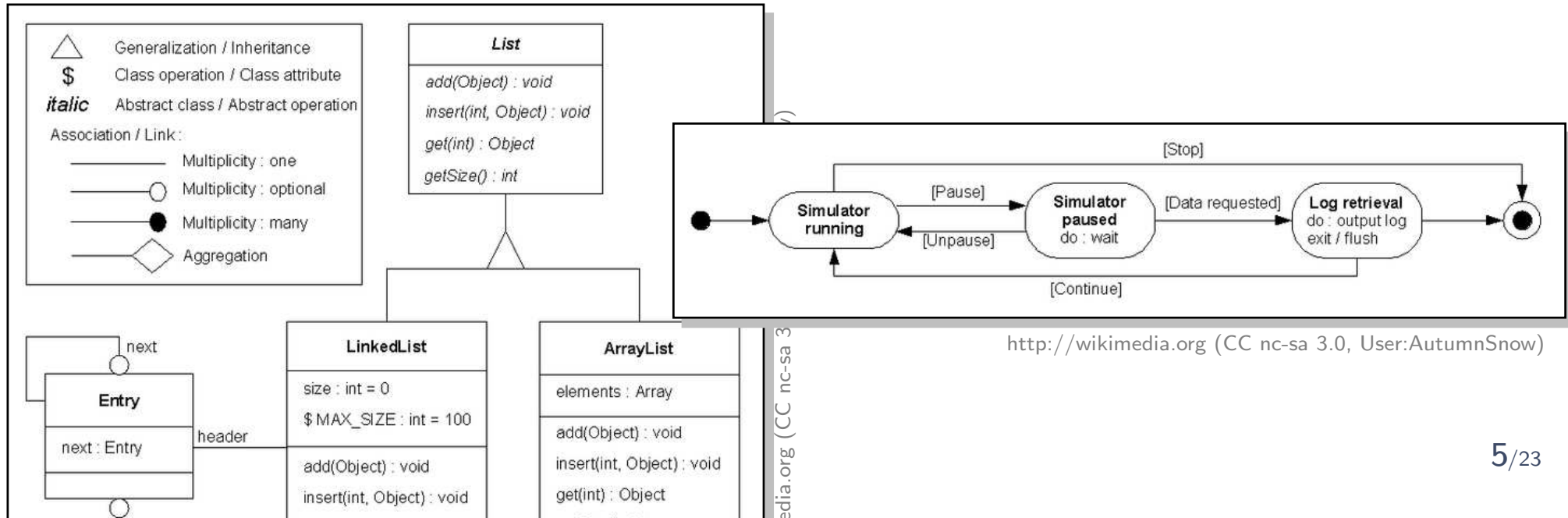
Why (of all things) UML?

Why (of all things) UML?

- Note: being a **modelling** languages doesn't mean being graphical (or: being a visual formalism [Harel]).
- For instance, [Kastens and Büning, 2008] also name:
 - Sets, Relations, Functions
 - Terms and Algebras
 - Propositional and Predicate Logic
 - Graphs
 - XML Schema, Entity Relation Diagrams, UML Class Diagrams
 - Finite Automata, Petri Nets, UML State Machines
- **Pro**: visual formalisms are found appealing and easier to **grasp**. Yet they are not necessarily easier to **write**!
- **Beware**: you may meet people who dislike visual formalisms just for being graphical — maybe because it is easier to “trick” people with a meaningless picture than with a meaningless formula.
More serious: it's maybe easier to misunderstand a picture than a formula.

A Brief History of UML

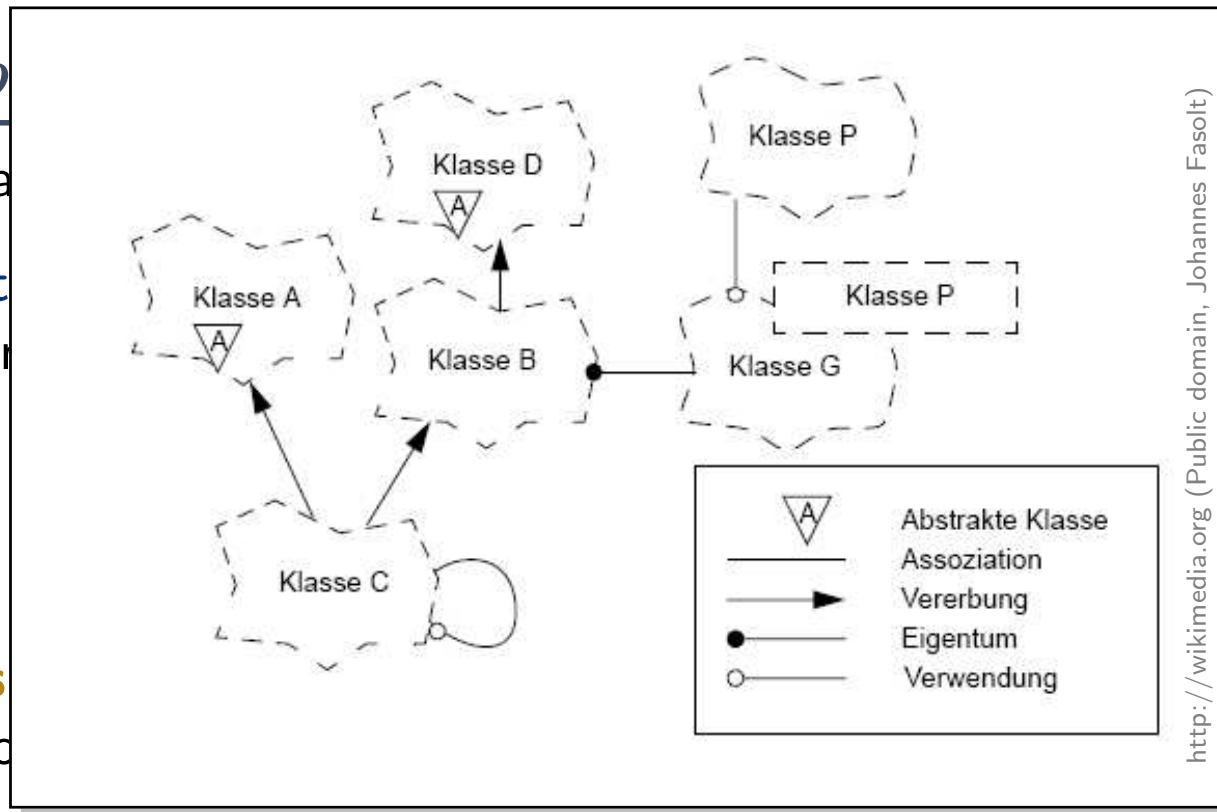
- Boxes/lines and finite automata are used to visualise software **for ages**.
- **1970's, Software Crisis**TM
 - Idea: learn from engineering disciplines to handle growing complexity.
 - Languages: **Flowcharts, Nassi-Shneiderman, Entity-Relation Diagrams**
- Mid **1980's**: **Statecharts** [Harel, 1987], **StateMate**TM [Harel et al., 1990]
- Early **1990's**, advent of **Object-Oriented-Analysis/Design/Programming**
 - Inflation of notations and methods, most prominent:
 - **Object-Modeling Technique (OMT)** [Rumbaugh et al., 1990]



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A Brief History

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 - **Booch Method and Notation** [Booch, 1993]
 - **Object-Oriented Software Engineering** (OOSE) [Jacobson et al., 1992]

Each “persuasion” selling books, tools, seminars. . .

- Late **1990's**: joint effort **UML 0.x, 1.x**
 - Standards published by **Object Management Group** (OMG), “*international, open membership, not-for-profit computer industry consortium*”.
- Since **2005**: **UML 2.x**

UML Overview [OMG, 2007b, 684]

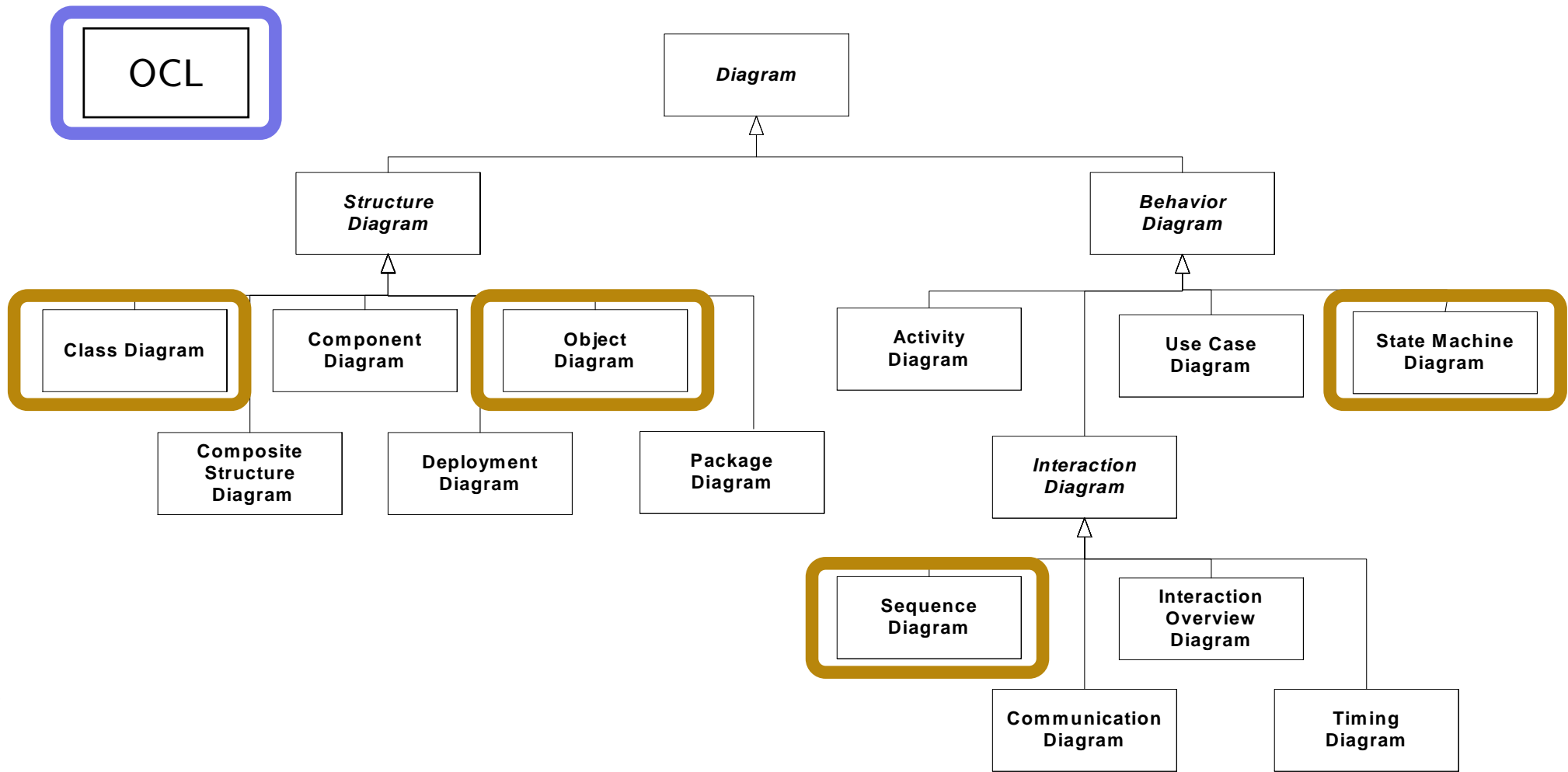


Figure A.5 - The taxonomy of structure and behavior diagram

[Dobing and Parsons, 2006]

Common Expectations on UML

- Easily writeable, readable even by customers
- Powerful enough to bridge the gap between idea and implementation
- Means to tame complexity by separation of concerns (“views”)
- Unambiguous
- Standardised, exchangeable between modelling tools
- UML standard says how to develop software
- Using UML leads to better software
- ...

We will see...

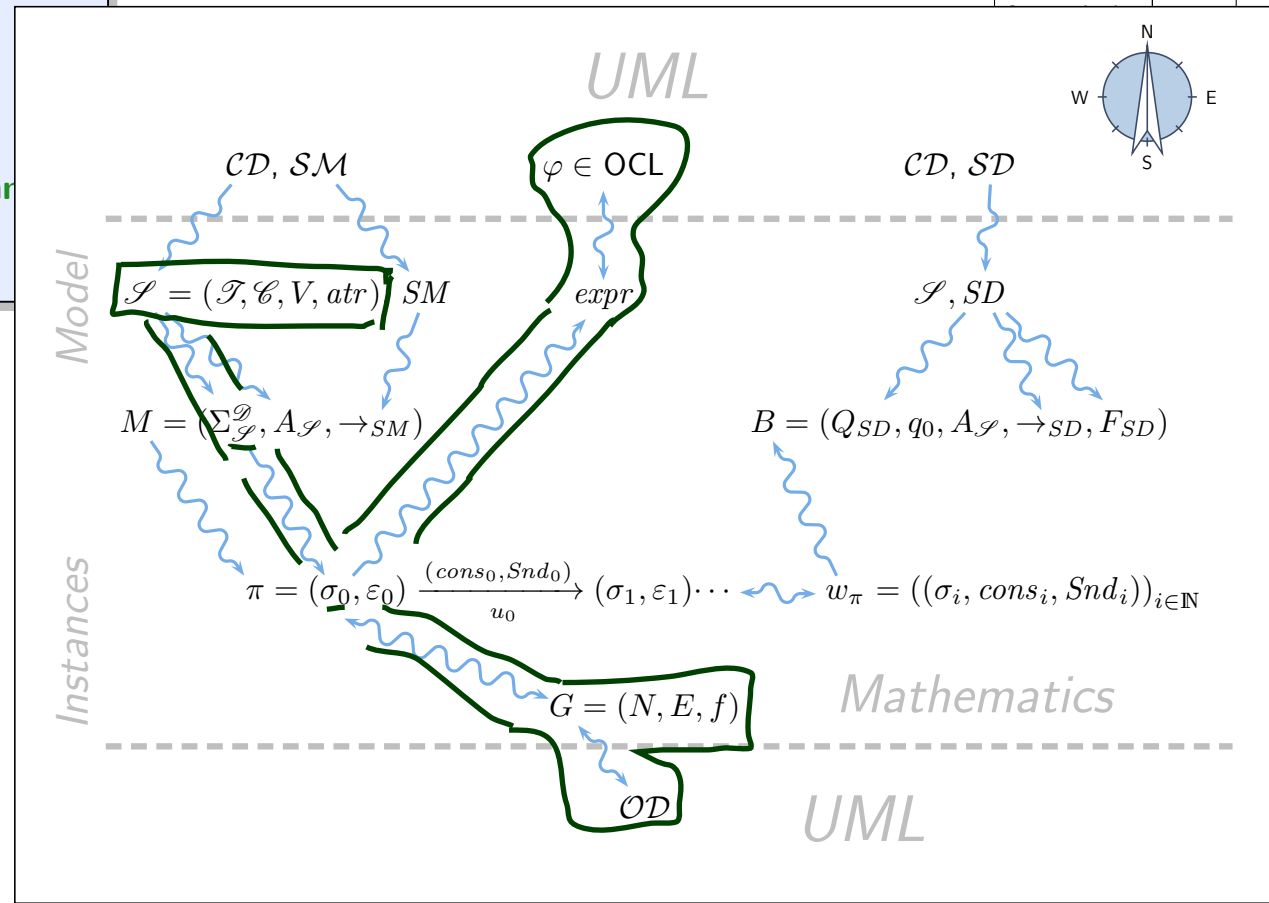
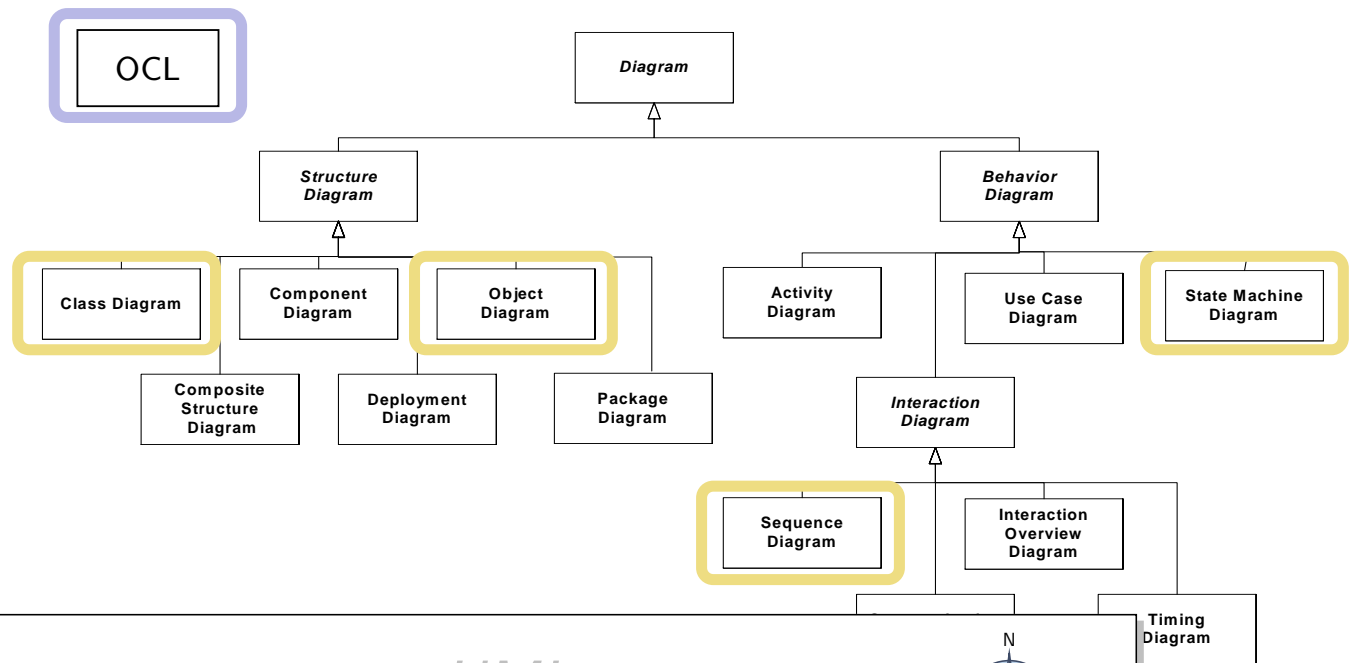
Seriously: After the course, you should have an own opinion on each of these claims. In how far/in what sense does it hold? Why? Why not? How can it be achieved? Which ones are really only hopes and expectations? ...?

Course Map Revisited

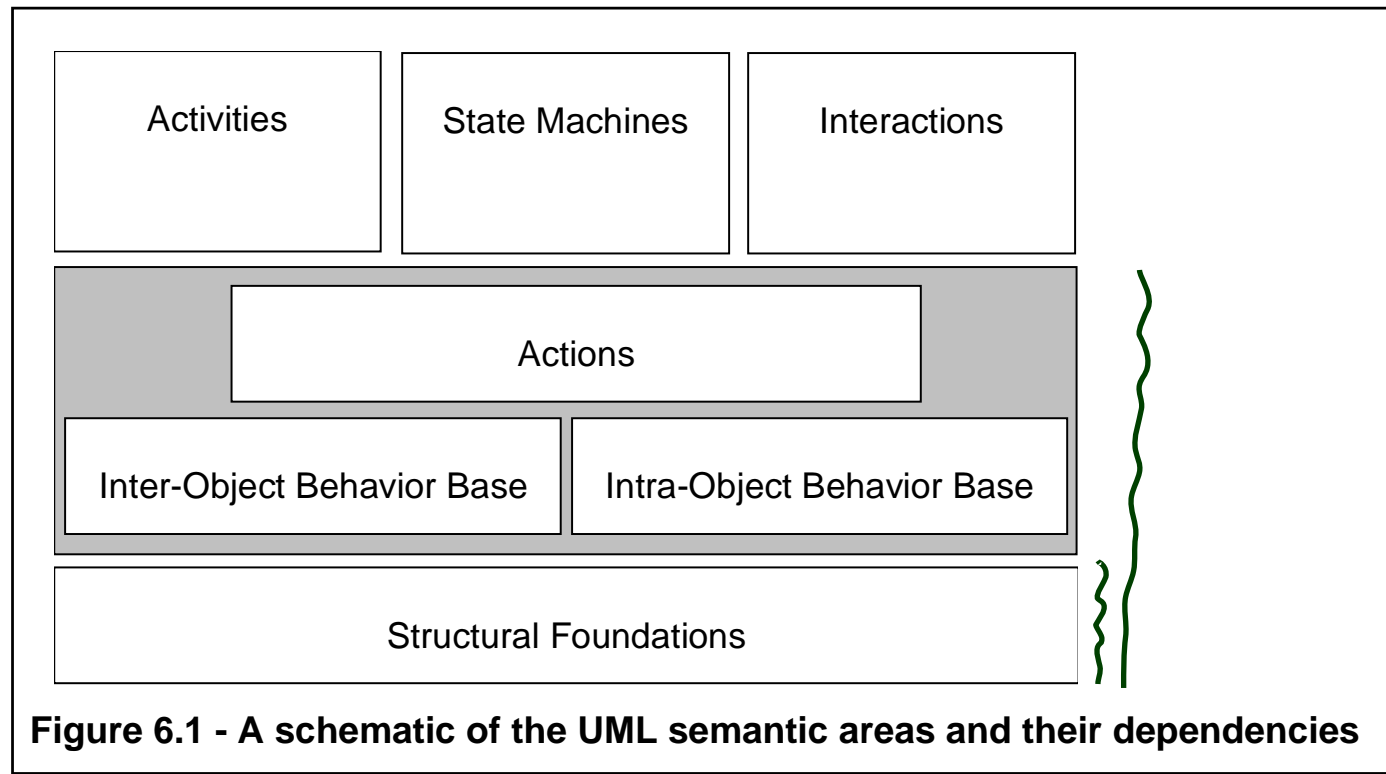
The Plan

Recall:

- **Overall aim:** a formal language for software blueprints.
- **Approach:**
 - Common semantical domain.
 - UML fragments as **syntax**.
 - Abstract **representation of diagrams**.
 - Informal semantics:** UML standard
 - assign meaning to diagrams**
 - Define, e.g., **consistency**.



UML: Semantic Areas



[OMG, 2007b, 11]

Common Semantical Domain

Basic Object System Signature

Definition. A (Basic) Object System **Signature** is a quadruple

$$\mathcal{S} = (\mathcal{T}, \mathcal{C}, V, atr)$$

where

- \mathcal{T} is a set of (basic) **types**,
- \mathcal{C} is a finite set of **classes**,
- V is a finite set of **typed attributes**, i.e., each $v \in V$ has type
 - $\tau \in \mathcal{T}$ or
 - $C_{0,1}$ or C_* , where $C \in \mathcal{C}$
- $atr : \mathcal{C} \rightarrow 2^V$ maps each class to its set of attributes.

for each class $D \in \mathcal{C}$ there are two different types:

• $D_{0,1}$ (or D_{Δ})

• D_* (or D_{\odot})

exactly one

(in other words $typeof : V \rightarrow \{C_{0,1}, C_* \mid C \in \mathcal{C}\} \cup \mathcal{T}$)

total function \rightarrow powerset of V

Note: Inspired by OCL 2.0 standard [OMG, 2006], Annex A.

Basic Object System Signature Example

$\mathcal{S} = (\mathcal{T}, \mathcal{C}, V, atr)$ where

- (basic) **types** \mathcal{T} and **classes** \mathcal{C} , (both finite),
- **typed attributes** V , τ from \mathcal{T} or $C_{0,1}$ or C_* , $C \in \mathcal{C}$,
- $atr : \mathcal{C} \rightarrow 2^V$ mapping classes to attributes.

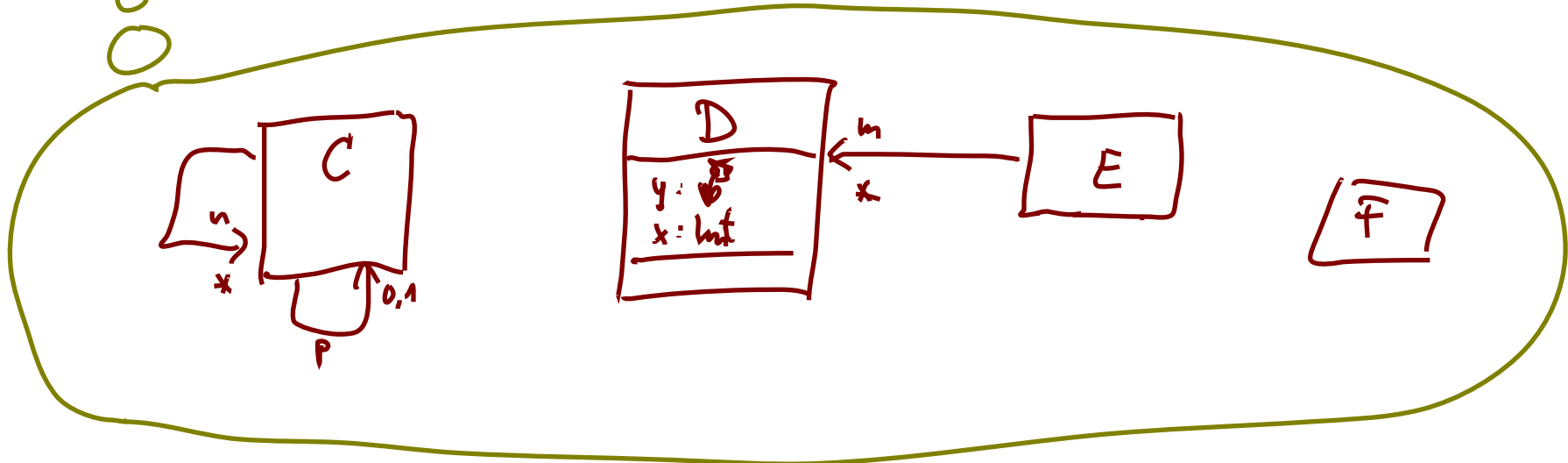
Example:

$\mathcal{S}_0 = (\underbrace{\{\text{Int}_i\}}_{\mathcal{T}}, \underbrace{\{C, D\}}_{\mathcal{C}}, \underbrace{\{x : \text{Int}, p : C_{0,1}, n : C_*\}}_{V}, \underbrace{\{C \mapsto \{p, n\}, D \mapsto \{x\}\}}_{atr})$

Handwritten annotations:

- basic types \mathcal{T} (points to $\{\text{Int}_i\}$)
- classes \mathcal{C} (points to $\{C, D\}$)
- attributes V (points to $\{x : \text{Int}, p : C_{0,1}, n : C_*\}$)
- attribute x of type Int (points to $x : \text{Int}$)
- $atr :$ (points to the mapping set)
- $atr(C) = \{p, n\}$
- $atr(D) = \{x\}$
- $E \mapsto \{m\}, F \mapsto \emptyset$ (under the mapping set)
- "maps to" (arrow from $\{x\}$ to $x : \text{Int}$)

possible extension:



Basic Object System Signature Another Example

$\mathcal{S} = (\mathcal{T}, \mathcal{C}, V, atr)$ where

- (basic) types \mathcal{T} and classes \mathcal{C} , (both finite),
- typed attributes V , τ from \mathcal{T} or $C_{0,1}$ or C_* , $C \in \mathcal{C}$,
- $atr : \mathcal{C} \rightarrow 2^V$ mapping classes to attributes.

Example:

$$\mathcal{S} = \left(\begin{array}{l} \{Int, Float\}, \\ \{C, D\}, \\ \{C::x: Int, \\ D::x: Float, y: Int\}, \\ \{C \mapsto \{C::x, y\} \\ D \mapsto \{D::x, y\}\} \end{array} \right)$$

(name of)
an attribute,

could also

$(C) \otimes$

or
 $x \circ C$

Q: What about
 • class C with attribute x: Int
 • class D with attribute x: Float?
 A: Rename consistently.

Definition. A Basic Object System **Structure** of

$$\mathcal{S} = (\mathcal{T}, \mathcal{C}, V, atr)$$

is a domain function \mathcal{D} which assigns to each type a domain, i.e.

- $\tau \in \mathcal{T}$ is mapped to $\mathcal{D}(\tau)$,
- $C \in \mathcal{C}$ is mapped to an infinite set $\mathcal{D}(C)$ of **(object) identities**.

Note: Object identities only have the “=” operation;
object identities of different classes are disjoint, i.e.

$$\forall C, D \in \mathcal{C} : C \neq D \rightarrow \mathcal{D}(C) \cap \mathcal{D}(D) = \emptyset.$$

- C_* **and** $C_{0,1}$ for $C \in \mathcal{C}$ are mapped to $2^{\mathcal{D}(C)}$.

We use $\mathcal{D}(\mathcal{C})$ to denote $\bigcup_{C \in \mathcal{C}} \mathcal{D}(C)$; analogously $\mathcal{D}(\mathcal{C}_*)$.

Note: We identify objects and object identities, because both uniquely determine each other (cf. OCL 2.0 standard).

Basic Object System Structure Example

Wanted: a structure for signature

$$\mathcal{S}_0 = (\{Int\}, \{C, D\}, \{x : Int, p : C_{0,1}, n : C_*\}, \{C \mapsto \{p, n\}, D \mapsto \{x\}\})$$

Recall: by definition, seek a \mathcal{D} which maps

- $\tau \in \mathcal{T}$ to **some** $\mathcal{D}(\tau)$,
- $c \in \mathcal{C}$ to **some** identities $\mathcal{D}(C)$ (infinite, disjoint for different classes),
- C_* and $C_{0,1}$ for $C \in \mathcal{C}$ to $\mathcal{D}(C_{0,1}) = \mathcal{D}(C_*) = 2^{\mathcal{D}(C)}$.

$$\mathcal{D}(Int) = \mathbb{Z}$$

$$\mathcal{D}(C) = \mathbb{N}^+ \times \{C\} \simeq \{1_C, 2_C, 3_C, \dots\}$$

$$\mathcal{D}(D) = \mathbb{N}^+ \times \{D\} \simeq \{1_D, 2_D, 3_D, \dots\}$$

$$\mathcal{D}(C_{0,1}) = \mathcal{D}(C_*) = 2^{\mathcal{D}(C)}$$

$$\mathcal{D}(D_{0,1}) = \mathcal{D}(D_*) = 2^{\mathcal{D}(D)}$$

also valid: \mathcal{D}_2
 $= \{red, green, blue\}$

$= \{1, 3, 5, \dots\}$

$\rightarrow \{2, 4, 6, \dots\}$

System State

Definition. Let \mathcal{D} be a structure of $\mathcal{S} = (\mathcal{I}, \mathcal{C}, V, atr)$.
 A **system state** of \mathcal{S} wrt. \mathcal{D} is a **type-consistent** mapping

$$\sigma : \mathcal{D}(\mathcal{C}) \rightarrow (V \rightarrow (\mathcal{D}(\mathcal{I}) \cup \mathcal{D}(\mathcal{C}_*))).$$

That is, for each $u \in \mathcal{D}(\mathcal{C})$, $C \in \mathcal{C}$, if $u \in \text{dom}(\sigma)$

- $\text{dom}(\sigma(u)) = atr(C)$
- $(\sigma(u))(v) \in \mathcal{D}(\tau)$ if $v : \tau, \tau \in \mathcal{I}$
- $(\sigma(u))(v) \in \mathcal{D}(D_*)$ if $v : D_{0,1}$ or $v : D_*$ with $D \in \mathcal{C}$

We call $u \in \mathcal{D}(\mathcal{C})$ **alive** in σ if and only if $u \in \text{dom}(\sigma)$.

We use $\Sigma_{\mathcal{S}}^{\mathcal{D}}$ to denote the set of all system states of \mathcal{S} wrt. \mathcal{D} .

all object identities
 partial function
 (partial) functions from V to types' domains

System State Example

Signature, Structure:

$$\mathcal{S}_0 = (\{Int\}, \{C, D\}, \{x : Int, p : C_{0,1}, n : C_*\}, \{C \mapsto \{p, n\}, D \mapsto \{x\}\})$$

$$\mathcal{D}(Int) = \mathbb{Z}, \quad \mathcal{D}(C) = \{1_C, 2_C, 3_C, \dots\}, \quad \mathcal{D}(D) = \{1_D, 2_D, 3_D, \dots\}$$

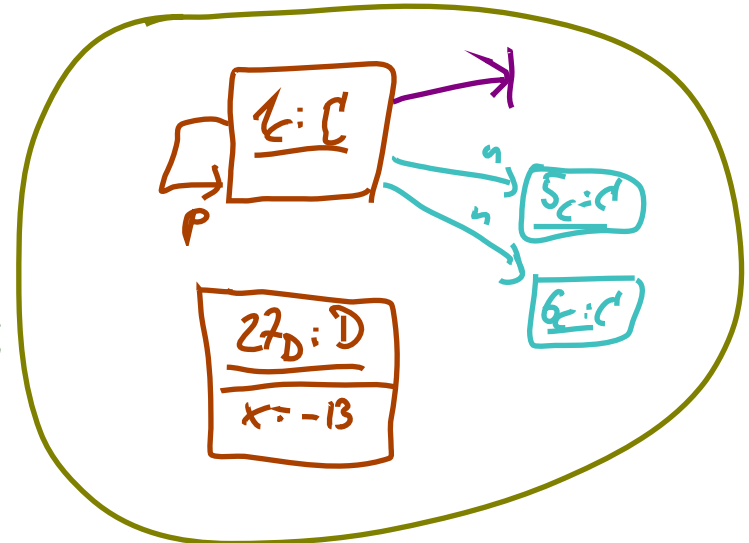
Wanted: $\sigma : \mathcal{D}(\mathcal{C}) \rightarrow (V \rightarrow (\mathcal{D}(\mathcal{I}) \cup \mathcal{D}(\mathcal{C}_*)))$ such that

- $\text{dom}(\sigma(u)) = \text{atr}(C)$,
- $\sigma(u)(v) \in \mathcal{D}(\tau)$ if $v : \tau, \tau \in \mathcal{I}$,
- $\sigma(u)(v) \in \mathcal{D}(C_*)$ if $v : D_*$ with $D \in \mathcal{C}$.

- $\sigma_1 = \emptyset$ ← empty function
- $\sigma_2 = \{ 1_C \mapsto \{ p \mapsto \{1_C\}, n \mapsto \{5_C, 6_C\} \}, 2_D \mapsto \{ x \mapsto -13 \} \}$ (p pointing nowhere): $p \mapsto \emptyset$
- $\sigma_3 = \{ 13_D \mapsto \emptyset \}$ X
- $\sigma_4 = \{ 14_D \mapsto \{ p \mapsto \emptyset, x \mapsto 3 \} \}$ X

Wrt \mathcal{D}_2 :

- $\sigma_3 = \{ 1 \mapsto \{ p \mapsto \{1\}, n \mapsto \{5, 7\} \}, 10 \mapsto \{ x \mapsto \text{red} \} \}$



System State Example

Signature, Structure:

$$\mathcal{S}_0 = (\{\text{Int}\}, \{C, D\}, \{x : \text{Int}, p : C_{0,1}, n : C_*\}, \{C \mapsto \{p, n\}, D \mapsto \{x\}\})$$

$$\mathcal{D}(\text{Int}) = \mathbb{Z}, \quad \mathcal{D}(C) = \{1_C, 2_C, 3_C, \dots\}, \quad \mathcal{D}(D) = \{1_D, 2_D, 3_D, \dots\}$$

Wanted: $\sigma : \mathcal{D}(\mathcal{C}) \rightarrow (V \rightarrow (\mathcal{D}(\mathcal{I}) \cup \mathcal{D}(\mathcal{C}_*)))$ such that

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- $\sigma(u)(v) \in \mathcal{D}(C_*)$ if $v : D_*$ with $D \in \mathcal{C}$.

- **Concrete, explicit:**

$$\text{dom}(\sigma(5_C)) = \{p, n\} = \text{atr}(C) \checkmark$$

$$\sigma = \{1_C \mapsto \{p \mapsto \emptyset, n \mapsto \{5_C\}\}, 5_C \mapsto \{\underline{p} \mapsto \emptyset, \underline{n} \mapsto \emptyset\}, 1_D \mapsto \{x \mapsto 23\}\}.$$

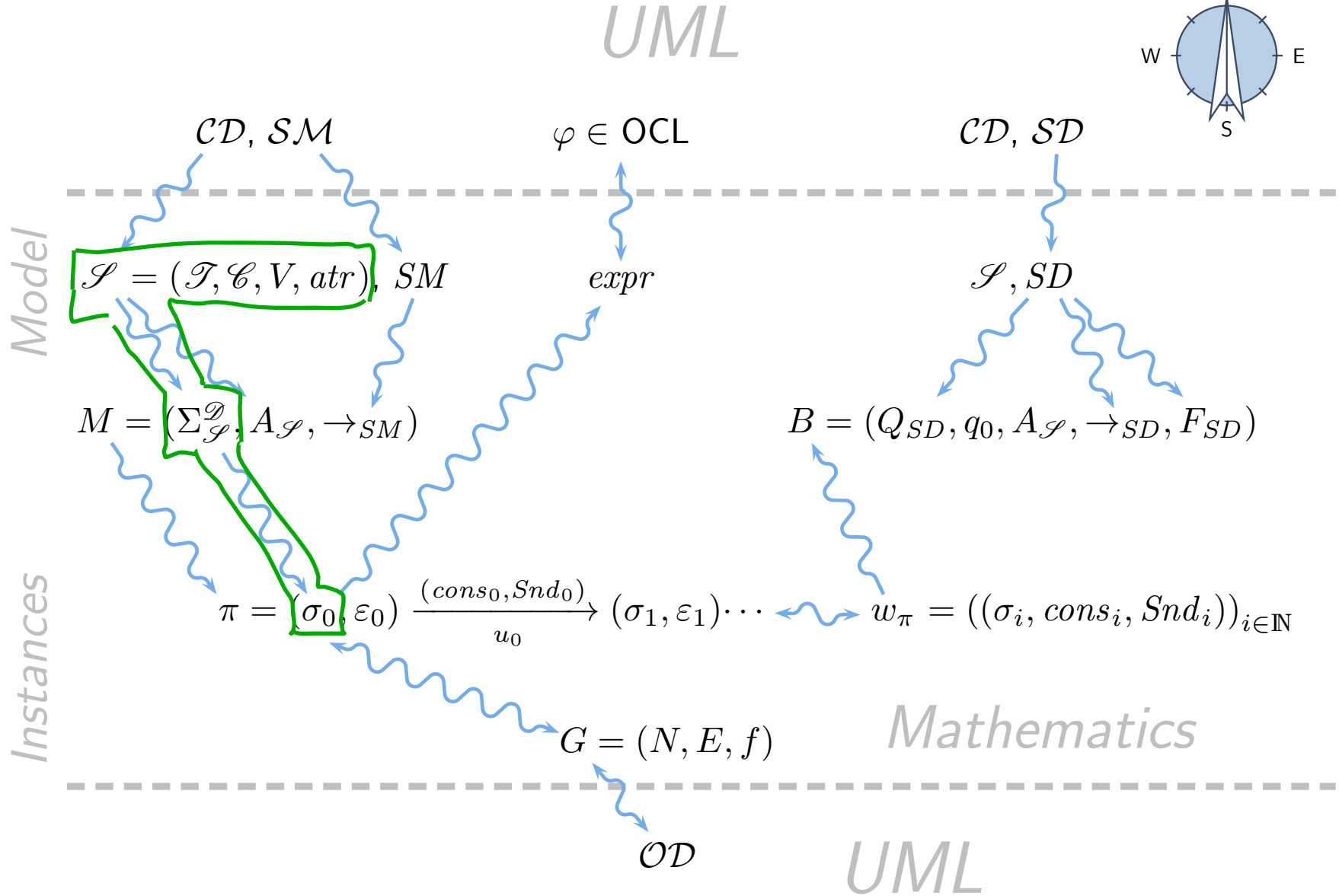
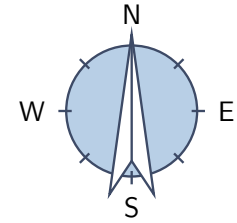
- **Alternative: symbolic** system state

$$\sigma = \{c_1 \mapsto \{p \mapsto \emptyset, n \mapsto \{c_2\}\}, c_2 \mapsto \{p \mapsto \emptyset, n \mapsto \emptyset\}, d \mapsto \{x \mapsto 23\}\}$$

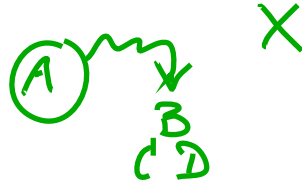
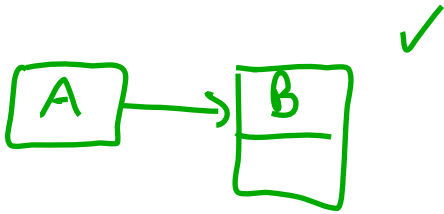
assuming $c_1, c_2 \in \mathcal{D}(C)$, $d \in \mathcal{D}(D)$, $c_1 \neq c_2$.

You Are Here.

Course Map



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