Lecture 12: Proto-OCL, Modularisation & Design Patterns

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Introduction and Vocabulary

Software Modelling I

(i) views and viewpoints, the 4+1 view
(ii) model-driven/-based software engineering
(iii) Modelling structure
   a) (simplified) class diagrams
   b) (simplified) object diagrams
   c) (simplified) object constraint logic (OCL)
   d) Unified Modelling Language (UML)

Principles of Design

(i) modularity, separation of concerns
(ii) information hiding and data encapsulation
(iii) abstract data types, object orientation
(iv) Design Patterns

Software Modelling II

(i) Modelling behaviour
   a) communicating finite automata
   b) Uppaal query language
   c) basic state-machines
   d) an outlook on hierarchical state-machines
Content

• **Proto-OCL**
  - syntax, semantics,
  - Proto-OCL vs. OCL.
  - Proto-OCL vs. Software

• An outlook on **UML**

• **Principles of (Good) Design**
  - modularity, separation of concerns
  - information hiding and data encapsulation
  - abstract data types, object orientation
  - ... by example

• **Architecture Patterns**
  - Layered Architectures, Pipe-Filter, Model-View-Controller.

• **Design Patterns**
  - Strategy, Examples

• **Libraries and Frameworks**
Partial vs. Complete Object Diagrams

- By now we discussed "object diagram represents system state":

\[
\begin{align*}
1_C & \leftrightarrow \{p \mapsto \emptyset, n \mapsto \{5_C\}\}, \\
5_C & \leftrightarrow \{p \mapsto \emptyset, n \mapsto \emptyset\}, \\
1_D & \leftrightarrow \{p \mapsto \{5_C\}, x \mapsto 23\}
\end{align*}
\]

What about the other way round...?

- **Object diagrams** can be **partial**, e.g.

\[
\begin{array}{c}
1_C : C \\
p = \emptyset
\end{array} \quad n \quad \begin{array}{c}
5_C : C \\
p = \emptyset
\end{array} \quad p \quad \begin{array}{c}
1_D : D \\
x = 23
\end{array}
\]

→ we may omit information.

- Is the following object diagram **partial** or **complete**?

\[
\begin{array}{c}
1_C : C \\
p = \emptyset
\end{array} \quad n \quad \begin{array}{c}
5_C : C \\
p = \emptyset
\end{array} \quad p \quad \begin{array}{c}
1_D : D \\
x = 23
\end{array}
\]

- If an object diagram
  - has values for **all** attributes of **all** objects in the diagram, and
  - **if we say that** it is meant to be complete

then we can **uniquely** reconstruct a system state \(\sigma\).
Special Case: Anonymous Objects

If the object diagram

\[
\begin{align*}
1_C &: C \\
p &= \emptyset
\end{align*}
\]

\[
\begin{align*}
: C \\
p &= \emptyset \\
n &= \emptyset
\end{align*}
\]

\[
\begin{align*}
: D \\
x &= 23
\end{align*}
\]

is considered as complete, then it denotes the set of all system states

\[
\{1_C \mapsto \{p \mapsto \emptyset, n \mapsto \{c\}\}, c \mapsto \{p \mapsto \emptyset, n \mapsto \emptyset\}, d \mapsto \{p \mapsto \{c\}, x \mapsto 23\}\}
\]

where \( c \in \mathcal{D}(C), \quad d \in \mathcal{D}(D), \quad c \neq 1_C \).

Intuition: different boxes represent different objects.
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Towards Object Constraint Logic (OCL)
— “Proto-OCL” —
How do I **precisely, formally** tell *my developers* that

All D-instances having a link to the same C object should have links to the same A.

That is, the following system state is **forbidden** in the software:

Note: formally, it is a **proper system state**.

Use **(Proto-)OCL**: “Dear developers, please only use system states which satisfy:”

\[
\forall d_1 \in \text{allInstances} \bullet \forall d_2 \in \text{allInstances} \bullet c(d_1) = c(d_2) \implies a(d_1) = a(d_2)
\]
Constraints on System States

- **Example**: for all $C$-instances, $x$ should never have the value $27$.

$$\forall c \in \text{allInstances}_C \bullet x(c) \neq 27$$

- **Proto-OCL Syntax** wrt. signature $(T, C, V, atr, F, mth)$, $c$ is a logical variable, $C \in C$:

$$F ::= c : \tau_C \quad \{(\star)\}$$

$$| \quad \text{allInstances}_C : 2^{\tau_C}$$

$$| \quad v(F) : \tau_C \rightarrow \tau_\bot, \quad \text{if } v : \tau \in \text{atr}(C), \quad \tau \in \overline{\mathcal{J}} \quad \{(\star\star)\}$$

$$| \quad v(F) : \tau_C \rightarrow \tau_D, \quad \text{if } v : D_{0,1} \in \text{atr}(C)$$

$$| \quad v(F) : \tau_C \rightarrow 2^{\tau_D}, \quad \text{if } v : D_* \in \text{atr}(C)$$

$$| \quad f(F_1, \ldots, F_n) : \tau_1 \times \cdots \times \tau_n \rightarrow \tau, \quad \text{if } f : \tau_1 \times \cdots \times \tau_n \rightarrow \tau \quad \{(\star\star\star)\}$$

$$| \quad \forall c \in F_1 \bullet F_2 : \tau_C \times 2^{\tau_C} \times \mathbb{B}_\bot \rightarrow \mathbb{B}_\bot$$

- The formula above in prefix normal form:

$$\forall c \in \text{allInstances}_C \bullet \not\equiv \left( x(c), 27 \right)$$
**Semantics**

• **Proto-OCL Types:**
  - $\mathcal{I}[\tau_C] = \mathcal{D}(C) \cup \{\bot\}$, $\mathcal{I}[\tau_\bot] = \mathcal{D}(\tau) \cup \{\bot\}$, $\mathcal{I}[2^\tau_C] = \mathcal{D}(C^*) \cup \{\bot\}$
  - $\mathcal{I}[\mathbb{B}_\bot] = \{true, false\} \cup \{\bot\}$, $\mathcal{I}[\mathbb{Z}_\bot] = \mathbb{Z} \cup \{\bot\}$

• **Functions:**
  - We assume $f_\mathcal{I}$ given for each function symbol $f$ (→ in a minute).

• **Proto-OCL Semantics** (interpretation function):
  - $\mathcal{I}[c](\sigma, \beta) = \beta(c)$ (assuming $\beta$ is a type-consistent valuation of the logical variables).
  - $\mathcal{I}[\text{allInstances}_C](\sigma, \beta) = \text{dom}(\sigma) \cap \mathcal{D}(C)$,
  - $\mathcal{I}[v(F)](\sigma, \beta) = \begin{cases} \sigma(\mathcal{I}[F](\sigma, \beta))(v), & \text{if } \mathcal{I}[F](\sigma, \beta) \in \text{dom}(\sigma) \\ \bot & \text{otherwise} \end{cases}$ (if not $v : C_{0,1}$)
  - $\mathcal{I}[v(F)](\sigma, \beta) = \begin{cases} \sigma(u')(v), & \text{if } \mathcal{I}[F](\sigma, \beta) = \{u'\} \subseteq \text{dom}(\sigma) \\ \bot & \text{otherwise} \end{cases}$ (if $v : C_{0,1}$)

• $\mathcal{I}[f(F_1, \ldots, F_n)](\sigma, \beta) = f_\mathcal{I}(\mathcal{I}[F_1](\sigma, \beta), \ldots, \mathcal{I}[F_n](\sigma, \beta))$.

• $\mathcal{I}[\forall c \in F_1 \bullet F_2](\sigma, \beta) = \begin{cases} true, & \text{if } \mathcal{I}[F_2](\sigma, \beta[c := u]) = true \text{ for all } u \in \mathcal{I}[F_1](\sigma, \beta) \\ false, & \text{if } \mathcal{I}[F_2](\sigma, \beta[c := u]) = false \text{ for some } u \in \mathcal{I}[F_1](\sigma, \beta) \\ \bot, & \text{otherwise} \end{cases}$
• Proto-OCL is a **three-valued** logic: a formula evaluates to *true*, *false*, or ⊥.

• **Example**: $\land_I (\cdot, \cdot) : \{\text{true, false, ⊥}\} \times \{\text{true, false, ⊥}\} \rightarrow \{\text{true, false, ⊥}\}$ is defined as follows:

<table>
<thead>
<tr>
<th>$x_1$</th>
<th>$x_2$</th>
<th>$\land_I(x_1, x_2)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>true</td>
<td>true</td>
<td>true</td>
</tr>
<tr>
<td>false</td>
<td>false</td>
<td>false</td>
</tr>
<tr>
<td>⊥</td>
<td>false</td>
<td>⊥</td>
</tr>
<tr>
<td>false</td>
<td>⊥</td>
<td>false</td>
</tr>
<tr>
<td>⊥</td>
<td>⊥</td>
<td>⊥</td>
</tr>
</tbody>
</table>

We assume common logical connectives $\neg, \land, \lor, \ldots$ with canonical 3-valued interpretation.

• **Example**: $+_I (\cdot, \cdot) : (\mathbb{Z} \cup \{⊥\}) \times (\mathbb{Z} \cup \{⊥\}) \rightarrow \mathbb{Z} \cup \{⊥\}$

$$+_I(x_1, x_2) = \begin{cases} x_1 + x_2, & \text{if } x_1 \neq ⊥ \text{ and } x_2 \neq ⊥ \\ ⊥, & \text{otherwise} \end{cases}$$

We assume common arithmetic operations $-, /, \ast, \ldots$ and relation symbols $>, <, \leq, \ldots$ with **monotone** 3-valued interpretation.

• And we assume the special unary function symbol *isUndefined*:

$$\text{isUndefined}_I(x) = \begin{cases} \text{true}, & \text{if } x = ⊥, \\ \text{false}, & \text{otherwise} \end{cases}$$

*isUndefined$ is **definite**: it never yields ⊥.
Example: Evaluate Formula for System State

\[ \sigma: \begin{array}{c} 1_C: C \\ x = 13 \end{array} \in \Sigma^p \]

\[ \mathcal{P}: \begin{array}{c} C \\ x: \text{Int} \end{array} \]

\[ \forall c \in \text{allInstances}_C \cdot x(c) \neq 27 \]

- **Recall prefix notation:** \( \forall c \in \text{allInstances}_C \cdot \neq (x(c), 27) \)

**Note:** \( \neq \) is a binary function symbol, 27 is a 0-ary function symbol.

- **Example:**

\[ \mathcal{I}[\forall c \in \text{allInstances}_C \cdot \neq (x(c), 27)](\sigma, \emptyset) = \text{true, because...} \]

\[ \mathcal{I}[\neq (x(c), 27)](\sigma, \beta), \quad \beta := \emptyset[c := 1_C] = \{ c \mapsto 1_C \} \]

\[ = \neq_{\mathcal{I}}(\mathcal{I}[x(c)](\sigma, \beta), \mathcal{I}[27](\sigma, \beta)) \]

\[ = \neq_{\mathcal{I}}(\sigma(\mathcal{I}[c](\sigma, \beta)))(x), 27_{\mathcal{I}}) \]

\[ = \neq_{\mathcal{I}}(\sigma(\beta(c)))(x), 27_{\mathcal{I}}) \]

\[ = \neq_{\mathcal{I}}(\sigma(1_C))(x), 27_{\mathcal{I}}) \]

\[ = \neq_{\mathcal{I}}(13, 27) = \text{true} \quad \text{...and } 1_C \text{ is the only } C\text{-object in } \sigma: \mathcal{I}[\text{allInstances}_C](\sigma, \emptyset) = \{1_C\} \]
More Interesting Example

\[ \sigma = \{ C \mapsto \{ x \mapsto 13, \ n \mapsto \beta \} \} \]

\[ \forall c : \text{allInstances}_C \cdot x(n(c)) \neq 27 \]

- Similar to the previous slide, we need the value of

\[ I[x(n(c))](\sigma, \beta) = \{ c \mapsto 1_C \} \]

- \[ I[c](\sigma, \beta) = \beta(c) = 1_C \]

- \[ I[n(c)](\sigma, \beta) = \bot \text{ since } \sigma(I[c](\sigma, \beta))(n) = \emptyset \neq \{ u' \} \text{ by rule} \]

\[ I[v(F)](\sigma, \beta) = \begin{cases} u' & \text{if } I[F](\sigma, \beta) \in \text{dom}(\sigma) \text{ and } \sigma(I[F](\sigma, \beta))(v) = \{ u' \} \\ \bot & \text{otherwise} \end{cases} \] (if \( v : C_{0,1} \))

- \[ I[x(n(c))](\sigma, \beta) = \bot \text{ since } I[n(c)](\sigma, \beta) = \bot \text{ by rule} \]

\[ I[v(F)](\sigma, \beta) = \begin{cases} \sigma(I[F](\sigma, \beta))(v) & \text{if } I[F](\sigma, \beta) \in \text{dom}(\sigma) \\ \bot & \text{otherwise} \end{cases} \] (if not \( v : C_{0,1} \))
More Interesting Example

\[
\sigma : \begin{array}{c|c}
1_C : C & x = 13 \\
\hline
\end{array} \quad n
\]

\[
\begin{array}{c|c}
C & n \\
\hline
x : \text{Int} & 0..1 \\
\end{array}
\]

\[\forall c : \exists x(n(c)) \neq 27\]

- Similar to the previous slide, we need the value of

\[
\sigma(\sigma(\mathcal{I}[c](\sigma, \beta))(n))(x)
\]

- \(\mathcal{I}[c](\sigma, \beta) = \beta(c) = 1_C\)

- \(\sigma(\mathcal{I}[c](\sigma, \beta))(n) = \sigma(1_C)(n) = \emptyset\)

- \(\sigma(\sigma(\mathcal{I}[c](\sigma, \beta))(n))(x) = \bot\)

by the following rule:

\[
\mathcal{I}[v(F)](\sigma, \beta) = \begin{cases}
\sigma(u')(v), & \text{if } \mathcal{I}[F](\sigma, \beta) = \{u'\} \subseteq \text{dom}(\sigma) \\
\bot, & \text{otherwise}
\end{cases} \quad (if \ v : C_{0,1})
\]
Object Constraint Language (OCL)

OCL is the same – just with less readable (?) syntax.

Literature: (OMG, 2006; Warmer and Kleppe, 1999).
TeamMember
- name : String
- age : Integer

Meeting
- title : String
- numParticipants : Integer
- start : Date
- duration : Time
- move(newStart : Date)

Location
- name : String

**context** Meeting
- **inv**: self.participants->size() = self.numParticipants

**context** Location
- **inv**: name="Lobby" implies meeting->isEmpty()

\[ \forall \text{self} \in \text{All instances Meeting} . \]

\[ \text{size}(\text{participants}(\text{self})) = \text{numParticipants}(\text{self}) \]
Object Constraint Language
OMG Available Specification
Version 2.0
formal/06-05-01
Where To Put OCL Constraints?

- **Notes**: A UML note is a diagram element of the form

```
[ text ]
```

text can principally be everything, in particular comments and constraints.

**Sometimes**, content is explicitly classified for clarity:

**OCL**:

```
F
```

- **Conventions**:

```
F
```

 stands for

```
∀ self ∈ allInstances_C • F
```
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Putting It All Together
Definition. **Software** is a finite description $S$ of a (possibly infinite) set $\llbracket S \rrbracket$ of (finite or infinite) computation paths of the form $\sigma_0 \xrightarrow{\alpha_1} \sigma_1 \xrightarrow{\alpha_2} \sigma_2 \cdots$ where

- $\sigma_i \in \Sigma$, $i \in \mathbb{N}_0$, is called state (or configuration), and
- $\alpha_i \in A$, $i \in \mathbb{N}_0$, is called action (or event).

The (possibly partial) function $\llbracket \cdot \rrbracket : S \mapsto \llbracket S \rrbracket$ is called interpretation of $S$.

- The set of **states** $\Sigma$ could be the set of **system states** as defined by a class diagram, e.g.

  \[
  \Sigma := \Sigma_P
  \]

  \[\mathcal{I} : \begin{array}{c}
  \hline
  C \\
  x : \text{Int} \\
  \hline
  \end{array}\]

- A corresponding **computation path** of a software $S$ could be

  \[
  \begin{array}{c}
  27C : C \\
  x = 0 \\
  \xrightarrow{\tau} \\
  27C : C \\
  x = 1 \\
  \xrightarrow{\tau} \\
  27C : C \\
  x = 3 \\
  \xrightarrow{\tau} \\
  27C : C \\
  x = 4 \\
  \xrightarrow{\tau} \\
  \cdots
  \end{array}
  \]

- If a requirement is formalised by the Proto-OCL constraint

  \[
  F = \forall c \in \text{allInstances}_C \cdot x(c) < 4
  \]

  then $S$ does not satisfy the requirement.
More General: Software vs. Proto-OCL

- Let $\mathcal{S}$ be an **object system signature** and $\mathcal{D}$ a **structure**.

- Let $S$ be a **software** with
  - states $\Sigma \subseteq \Sigma^\mathcal{D}$, and
  - computation paths $\llbracket S \rrbracket$.

- Let $F$ be a Proto-OCL constraint over $\mathcal{S}$.

- We say $\llbracket S \rrbracket$ **satisfies** $F$, denoted by $\llbracket S \rrbracket \models F$, if and only if for all $\sigma_0 \xrightarrow{\alpha_1} \sigma_1 \xrightarrow{\alpha_2} \sigma_2 \cdots \in \llbracket S \rrbracket$

  and all $i \in \mathbb{N}_0$, $\mathcal{I}[F](\sigma_i, \emptyset) = \text{true}$.

- We say $\llbracket S \rrbracket$ **does not satisfy** $F$, denoted by $\llbracket S \rrbracket \not\models F$, if and only if there exists $\sigma_0 \xrightarrow{\alpha_1} \sigma_1 \xrightarrow{\alpha_2} \sigma_2 \cdots \in \llbracket S \rrbracket$ and $i \in \mathbb{N}_0$, such that $\mathcal{I}[F](\sigma_i, \emptyset) = \text{false}$.

- **Note:** $\neg(\llbracket S \rrbracket \not\models F)$ does not imply $\llbracket S \rrbracket \models F$. 
Tell Them What You’ve Told Them…

- **Class Diagrams** can be used to graphically
- visualise code,
- define an **object system structure** \( \mathcal{S} \).

- An **Object System Structure** \( \mathcal{S} \) (together with a structure \( \mathcal{D} \))
- defines a set of **system states** \( \Sigma^\mathcal{D} \).

- A **System State** \( \sigma \in \Sigma^\mathcal{D} \)
  - can be **visualised** by an **object diagram**.

- **Proto-OCL** constraints can be evaluated on **system states**.

- A **software** over \( \Sigma^\mathcal{D} \) satisfies a Proto-OCL constraint \( F \) if and only if \( F \) evaluates to **true** in all system states of all the software’s computation paths.
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**Once Again, Please**

**System** consists of 1 or more **Component** has **Component Interface**

**Software System** is a **Software Component** may be a **Module**

**Software Architecture** is an **Architecture** is the result of **Design** is described by **Architectural Description**

---

*software architecture* – The software architecture of a program or computing system is the structure or structures of the system which comprise software elements, the externally visible properties of those elements, and the relationships among them. (Bass et al., 2003)
Goals and Relevance of Design

- The **structure** of something is the set of **relations between its parts**.
- Something not built from (recognisable) parts is called **unstructured**.

**Design**...

(i) **structures** a system into **manageable** units (yields software architecture).
(ii) **determines** the approach for realising the required software, 
(iii) provides **hierarchical structuring** into a **manageable** number of units at each hierarchy level.

Oversimplified process model “Design”:
Principles of (Architectural) Design
1.) **Modularisation**
   - split software into units / components of **manageable size**
   - provide well-defined interface

2.) **Separation of Concerns**
   - each component should be **responsible for a particular area of tasks**
   - group data and operation on that data; functional aspects; functional vs. technical; functionality and interaction

3.) **Information Hiding**
   - the “need to know principle” / information hiding
   - users (e.g. other developers) need not necessarily know the algorithm and helper data which realise the component’s interface

4.) **Data Encapsulation**
   - offer operations to access component data, instead of accessing data (variables, files, etc.) directly

→ many programming languages and systems offer means to **enforce** (some of) these principles **technically**; use these means.
1.) Modularisation

**modular decomposition** – The process of breaking a system into components to facilitate design and development; an element of modular programming.  
IEEE 610.12 (1990)

**modularity** – The degree to which a system or computer program is composed of discrete components such that a change to one component has minimal impact on other components.  
IEEE 610.12 (1990)

- So, modularity is a **property** of an architecture.
- Goals of modular decomposition:
  - The **structure** of each module should be **simple** and **easily comprehensible**.
  - The **implementation** of a module should be **exchangeable**; information on the implementation of other modules should not be necessary. The other modules should not be affected by implementation exchanges.
  - Modules should be designed such that **expected changes** do not require modifications of the **module interface**.
  - **Bigger changes** should be the result of a set of **minor changes**. As long as the interface does not change, it should be possible to test old and new versions of a module together.
2.) Separation of Concerns

- **Separation of concerns** is a fundamental principle in software engineering:
  - each component should be **responsible for a particular area of tasks**, 
  - components which try to cover different task areas tend to be unnecessarily complex, thus hard to understand and maintain.

- **Criteria** for separation/grouping:
  - in **object oriented design**, data and operations on that data are grouped into classes,
  - sometimes, functional aspects (features) like printing are realised as separate components,
  - separate **functional** and **technical** components,
  - assign flexible or variable functionality to own components. **Example:** different networking technology (wireless, etc.)
  - assign functionality which is expected to need extensions or changes later to own components.
  - separate system **functionality** and **interaction**
    **Example:** most prominently graphical user interfaces (GUI), also file input/output
3.) Information Hiding

- By now, we only discussed the **grouping** of data and operations. One should also consider **accessibility**.
- The “**need to know principle**” is called **information hiding** in SW engineering. (Parnas, 1972)

**information hiding**— A software development technique in which each module’s interfaces reveal as little as possible about the module’s inner workings, and other modules are prevented from using information about the module that is not in the module’s interface specification. (IEEE 610.12, 1990)

- **Note**: what is hidden is information which other components **need not know** (e.g., how data is stored and accessed, how operations are implemented).

  **In other words**: **information hiding** is about **making explicit** for one component which data or operations other components may use of this component.

- **Advantages / goals**:
  - Hidden solutions may be **changed** without other components noticing, as long as the visible behaviour stays the same (e.g. the employed sorting algorithm). IOW: other components cannot **unintentionally** depend on details they are not supposed to.
  - Components can be verified / validated in isolation.
4.) Data Encapsulation

- Similar direction: **data encapsulation** (examples later).
- Do not access data (variables, files, etc.) directly where needed, but encapsulate the data in a component which offers operations to access (read, write, etc.) the data.

**Real-World Example:** Users do not write to bank accounts directly, only bank clerks do.

```cpp
public member function

```std::vector::insert```

```cpp
C++98  C++11

| single element (1) | iterator insert (iterator position, const value_type& val);
|--------------------|---------------------------------------------------------------
| full (2)           | void insert (iterator position, size_type n, const value_type& val);
| range (3)          | template <class InputIterator>
|                    | void insert (iterator position, InputIterator first, InputIterator last);
```

**Insert elements**

The `vector` is extended by inserting new elements before the element at the specified `position`, effectively increasing the container `size` by the number of elements inserted.

This causes an automatic reallocation of the allocated storage space if-and only if-the new vector `size` surpasses the current vector `capacity`.

Because vectors use an array as their underlying storage, inserting elements in positions other than the vector end causes the container to relocate all the elements that were after `position` to their new positions. This is generally an inefficient operation compared to the one performed for the same operation by other kinds of sequence containers (such as `list` or `forward_list`).

The parameters determine how many elements are inserted and to which values they are initialized:

**Parameters**

- `position`
  - Position in the `vector` where the new elements are inserted.
  - Iterator is a member type, defined as a `random access iterator` type that points to elements.

- `val`
  - Value to be copied (or moved) to the inserted elements.
  - Member type `value_type` is the type of the elements in the container, defined in `deque` as an alias of its first template parameter (1).
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- Do not access data (variables, files, etc.) directly where needed, but encapsulate the data in a component which offers operations to access (read, write, etc.) the data.
  
  **Real-World Example**: Users do not write to bank accounts directly, only bank clerks do.
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• Do not access data (variables, files, etc.) directly where needed, but encapsulate the data in a component which offers operations to access (read, write, etc.) the data.

  **Real-World Example:** Users do not write to bank accounts directly, only bank clerks do.

• **Information hiding** and **data encapsulation** – when enforced technically (examples later) – usually **come at the price** of worse efficiency.

  • It is more efficient to read a component’s data directly than calling an operation to provide the value: there is an overhead of one operation call.

  • Knowing how a component works internally may enable more efficient operation.

  **Example:** if a sequence of data items is stored as a singly-linked list, accessing the data items in list-order may be more efficient than accessing them in reverse order by position.

  **Good modules** give usage hints in their documentation (e.g. C++ standard library).

  **Example:** if an implementation stores intermediate results at a certain place, it may be tempting to “quickly” read that place when the intermediate results is needed in a different context.

  → **maintenance nightmare** – If the result is needed in another context, add a corresponding operation explicitly to the interface.

Yet with today’s hardware and programming languages, this is hardly an issue any more; at the time of (Parnas, 1972), it clearly was.
A Classification of Modules (Nagl, 1990)

- **functional modules**
  - group computations which belong together logically.
  - do not have “memory” or state, that is, behaviour of offered functionality does not depend on prior program evolution,
  - **Examples**: mathematical functions, transformations

- **data object modules**
  - realise encapsulation of data,
  - a data module hides kind and structure of data, interface offers operations to manipulate encapsulated data
  - **Examples**: modules encapsulating global configuration data, databases

- **data type modules**
  - implement a user-defined data type in form of an abstract data type (ADT)
  - allows to create and use as many exemplars of the data type
  - **Example**: game object

- In an object-oriented design,
  - classes are **data type modules**,
  - **data object modules** correspond to classes offering only class methods or singletons (→ later),
  - **functional modules** occur seldom, one example is Java’s class Math.
Proto-OCL
  • syntax, semantics,
  • Proto-OCL vs. OCL.
  • Proto-OCL vs. Software

An outlook on UML

Principles of (Good) Design
  • modularity, separation of concerns
  • information hiding and data encapsulation
  • abstract data types, object orientation
  • ... by example

Architecture Patterns
  • Layered Architectures, Pipe-Filter, Model-View-Controller.

Design Patterns
  • Strategy, Examples

Libraries and Frameworks
Architecture Patterns
Over decades of software engineering, many clever, proved and tested designs of solutions for particular problems emerged.

**Question**: can we generalise, document and re-use these designs?

**Goals**:
- “don’t re-invent the wheel”,
- benefit from “clever”, from “proven and tested”, and from “solution”.

**architectural pattern** – An architectural pattern expresses a fundamental structural organization schema for software systems. It provides a set of predefined subsystems, specifies their responsibilities, and includes rules and guidelines for organizing the relationships between them.

*Buschmann et al. (1996)*
**architectural pattern** – An architectural pattern expresses a fundamental structural organization schema for software systems. It provides a set of predefined subsystems, specifies their responsibilities, and includes rules and guidelines for organizing the relationships between them.

*Buschmann et al. (1996)*

- **Using** an architectural pattern
  - *implies* certain characteristics or properties of the software (construction, extendibility, communication, dependencies, etc.),
  - *determines* structures on a high level of the architecture, thus is typically a central and fundamental design decision.

- The information that (where, how, ...) a well-known architecture / design pattern *is used* in a given software can
  - make *comprehension* and *maintenance* significantly easier,
  - avoid errors.
Layered Architectures
(Züllighoven, 2005):

A layer whose components only interact with components of their direct neighbour layers is called protocol-based layer.

A protocol-based layer hides all layers beneath it and defines a protocol which is (only) used by the layers directly above.

Example: The ISO/OSI reference model.
• **Object-oriented layer**: interacts with layers directly (and possibly further) above and below.

• **Rules**: the components of a layer may use
  - **only** components of the protocol-based layer directly beneath, or
  - **all** components of layers further beneath.
Example: Layered Architectures Cont’d

- **Object-oriented layer**: interacts with layers directly (and possibly further) above and below.
- **Rules**: the components of a layer may use
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![Diagram of layered architectures with components such as GNOME, GTK+, Pango, GDK, ATK, GIO, Cairo, and GLib.](image-url)
Example: Three-Tier Architecture

- **presentation layer** (or **tier**): user interface; presents information obtained from the logic layer to the user, controls interaction with the user, i.e. requests actions at the logic layer according to user inputs.

- **logic layer**: core system functionality; layer is designed without information about the presentation layer, may only read/write data according to data layer interface.

- **data layer**: persistent data storage; hides information about how data is organised, read, and written, offers particular chunks of information in a form useful for the logic layer.

- **Examples**: Web-shop, business software (enterprise resource planning), etc.
Layered Architectures: Discussion

- **Advantages:**
  - **protocol-based:** only neighbouring layers are coupled, i.e. components of these layers interact,
  - coupling is low, data usually encapsulated,
  - changes have local effect (only neighbouring layers affected),
  - **protocol-based:** distributed implementation often easy.

- **Disadvantages:**
  - performance (as usual) – nowadays often not a problem.
Pipe-Filter
Example: Compiler

Example: Pipe-Filter
Example: Pipe-Filter

Example: Compiler

Example: UNIX Pipes

```bash
ls -l | grep Sarch.tex | awk '{ print $5 }'
```

- **Disadvantages:**
  - if the filters use a common data exchange format, all filters may need changes if the format is changed, or need to employ (costly) conversions.
  - filters do not use global data, in particular not to handle error conditions.
Model-View-Controller
Example: Model-View-Controller

- **Controller**: Sees the model, uses the view, and manipulates data.
- **View**: Sees changes in visualisation and notifications of updates.
- **Model**: Accesses data and manipulates updates.

Image: https://commons.wikimedia.org/wiki/File:Maschinenleitstand_KWZ.jpg (Dergenaue, CC-BY-SA-2.5)
Example: Model-View-Controller

- Controller
  - Uses: Change of visualisation
  - Sees: Notification of updates
  - Manipulates: Data
  - Accesses: Data

- View
  - Sees: Change of visualisation

- Model
  - Sees: Changes of visualisation
  - Notification of updates
  - Uses: Data

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Example: Model-View-Controller

- **Advantages:**
  - one model can serve multiple view/controller pairs;
  - view/controller pairs can be added and removed at runtime;
  - model visualisation always up-to-date in all views;
  - distributed implementation (more or less) easily.

- **Disadvantages:**
  - if the view needs a lot of data, updating the view can be inefficient.
Design Patterns
• In a sense the same as **architectural patterns**, but on a lower scale.
• Often traced back to *(Alexander et al., 1977; Alexander, 1979)*.

**Design patterns** ... are descriptions of communicating objects and classes that are customized to solve a general design problem in a particular context.

A design pattern names, abstracts, and identifies the key aspects of a common design structure that make it useful for creating a reusable object-oriented design.

*(Gamma et al., 1995)*
Tell Them What You’ve Told Them...

- **Architecture & Design Patterns**
  - allow **re-use** of practice-proven designs,
  - promise easier **comprehension** and **maintenance**.

- **Notable Architecture Patterns**
  - Layered Architecture,
  - Pipe-Filter,
  - Model-View-Controller.

- **Design Patterns**: read (*Gamma et al.*, 1995)

- **Rule-of-thumb**:  
  - library modules are called from user-code,
  - framework modules call user-code.
References
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1970’s, Software Crisis™
- Idea: learn from engineering disciplines to handle growing complexity.
  Modelling languages: Flowcharts, Nassi-Shneiderman, Entity-Relation Diagrams

Mid 1980’s: Statecharts (Harel, 1987), StateMate™ (Harel et al., 1990)

Early 1990’s, advent of Object-Oriented-Analysis/Design/Programming
- Inflation of notations and methods, most prominent:
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A Brief History of the Unified Modelling Language (UML)

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- Late **1990’s**: joint effort of “the three amigos” UML 0.x and 1.x
  Standards published by Object Management Group (OMG), “international, open membership, not-for-profit computer industry consortium”. Much criticised for lack of formality.

- Since **2005**: UML 2.x, split into infra- and superstructure documents.
Figure A.5 - The taxonomy of structure and behavior diagram

Dobing and Parsons (2006)