Principles of Software Construction: Objects, Design and Concurrency

Introduction to Design

15-214

toad

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The four course themes

- Threads and Concurrency
  - Concurrency is a crucial system abstraction
  - E.g., background computing while responding to users
  - Concurrency is necessary for performance
  - Multicore processors and distributed computing
  - Our focus: application-level concurrency
  - Cf. functional parallelism (150, 210) and systems concurrency (213)
- Object-oriented programming
  - For flexible designs and reusable code
  - A primary paradigm in industry – basis for modern frameworks
  - Focus on Java – used in industry, some upper-division courses
- Analysis and Modeling
  - Practical specification techniques and verification tools
  - Address challenges of threading, correct library usage, etc.
- Design
  - Proposing and evaluating alternatives
  - Modularity, information hiding, and planning for change
  - Patterns: well-known solutions to design problems

Learning Goals

- What is software design?
- Making trade offs
- Applying the modeling process from domain model to object model to implementation
- Basic modeling with UML (static and dynamic)
- Separating the different levels of UML use

Goal of Software Design

- For each desired program behavior there are infinitely many programs that have this behavior
  - What are the differences between the variants?
  - Which variant should we choose?
- Since we usually have to synthesize rather than choose the solution…
  - How can we design a variant that has the desired properties?

Sorting with configurable order, variant A

```
void sort(int[] list, String order) {
    …
  boolean mustswap;
  if (order.equals("up")) {
    mustswap = list[i] < list[j];
  } else if (order.equals("down")) {
    mustswap = list[i] > list[j];
  }
  …
}
```

Sorting with configurable order, variant B

```
void sort(int[] list, Comparator cmp) {
    …
  boolean mustswap;
  mustswap = cmp.compare(list[i], list[j]);
  …
}
interface Comparator {
  boolean compare(int i, int j);
}
class UpComparator implements Comparator {
  boolean compare(int I, int j) { return i<j; }}

class DownComparator implements Comparator {
  boolean compare(int I, int j) { return i>j; }}
```

(by the way, this design is called "strategy pattern")

Tradeoffs

```
void sort(int[] list, String order) {
   …
  boolean mustswap;
  if (order.equals("up")) {
    mustswap = list[i] < list[j];
  } else if (order.equals("down")) {
    mustswap = list[i] > list[j];
  }
  …
}
```

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void sort(int[] list, Comparator cmp) {
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  boolean compare(int I, int j) { return i<j; }}

class DownComparator implements Comparator {
  boolean compare(int I, int j) { return i>j; }}
```

Quality of a Software Design

- How can we measure the internal quality of a software design?
  - Extensibility, Maintainability, Understandability, Readability, …
  - Robustness to change
  - Low Coupling & High Cohesion
  - Reusability
  - Testability
  - => **modularity**
- …as opposed to external quality
  - Correctness: Valid implementation of requirements
  - Ease of Use
  - Resource consumption
  - Legal issues, political issues, …

The bad news

it depends

(see context)

depends on what?
what are scenarios?
what are tradeoffs?

"**Software engineering** is the branch of computer science that creates practical, cost-effective solutions to computing and information processing problems, preferentially by applying scientific knowledge, developing software systems in the service of mankind.
Software engineering entails making **decisions** under constraints of limited time, knowledge, and resources. […]

> Engineering quality resides in engineering judgment. […]
>
> Quality of the software product depends on the engineer's faithfulness to the engineered artifact. […]
>
> Engineering requires reconciling conflicting constraints. […]
>
> Engineering skills improve as a result of careful systematic reflection on experience. […]
>
> Costs and time constraints matter, not just capability. […]

Software Engineering for the 21st Century: A basis for rethinking the curriculum Manifesto, CMU-ISRI-05-108

Design Strategies

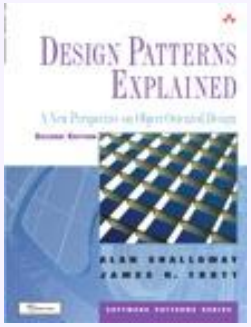
- Design while coding
  - Implement a solution
  - Try-revise, ideally supported by refactorings
- Draw, then code
  - Draw some diagrams
  - Explore solution at a higher level
  - Explore alternatives
  - Then switch to coding
  - Iterate if necessary
  - *Discuss: Worth the overhead? How much drawing?*
- Draw only
  - Generate code from diagrams
  - Diagrams turn into programming language
  - Requires very formal process of using diagramming languages

The design process

1. Object-Oriented Analysis
   - Understand the problem
   - Identify the key **concepts** and their relationships
   - Build a (visual) vocabulary
   - Create a **domain model** (aka conceptual model)
2. Object-Oriented Design
   - Identify **software classes** and their relationships with *class diagrams*
   - Assign responsibilities (attributes, methods)
   - Explore **behavior** with *interaction diagrams*
   - Explore design alternatives
   - Create an **object model** (aka design model and design class diagram) and **interaction models**
3. Implementation
   - Map designs to code, implementing classes and methods

UML: A visual modeling language

- Unified Modeling Language
- Graphical Notation to describe classes, objects, behavior, and more
- You will need:
  - Class Diagrams
  - Interaction Diagrams (Sequence or Communication Diagrams)
- Read chapter 2 of the textbook "Design Patterns Explained"



- Additional readings:
  - **Extra slides on 214 website**
  - Craig Larman, Applying UML and Patterns, Prentice Hall, 2004
  - Martin Fowler. *UML Distilled*. Addison-Wesley, 2003

Code vs Graphical Models

- Graphical models abstract from implementations
- Focus on interfaces and relationships, or on interactions, … while hiding details
  - Easier to communicate
  - Allows focus on higher-level design issues
- Forces to make relationships explicit
- Useful for sketching, trying alternatives, and documentation

Demo / Discussion

Virtual World

A word on notation

- UML notation is broadly known, well documented
- Informal notations/sketching often sufficient, but potentially ambiguous for communication and documentation
- In practice:
  - Graphical modeling very common in general
  - Agree on some notation
  - Adapt/extend as needed
  - UML rarely full heartedly adopted
- In this course
  - Use UML and conventions for communication
  - Keep it simple
  - Clarity is imperative, document your extensions/shortcuts
  - We don't require or recommend a drawing tool

Aside: UML in Practice

- No UML (35/50)
- Retrofit (1/50)
  - don't really use UML, but retrofit UML in order to satisfy management or comply with customer requirements;
- Automated code generation (3/50)
  - UML is not used in design, but is used to capture the design when it stabilizes, in order to generate code automatically (typically in the context of product lines);
- Selective (11/50)
  - UML is used in design in a personal, selective, and informal way, for as long as it is considered useful, after which it is discarded;
- Wholehearted (0/50 – but described in secondary reports)
  - organizational, top-down introduction of UML, with investment in champions, tools and culture change, so that UML use is deeply embedded.

Further Reading: Petre. UML in Practice. ICSE 2013

Aside: UML in Practice

- Reasons for No Use
  - Lack of Context
  - Overheads of Understanding the Notation
  - Issues of Synchronization/Consistency
- Selective Use
  - UML as "Thought Tool"
  - Communication with Stakeholders
  - Collaborative Dialogues (eg. with architects)
  - Significant Adaptation
  - "Keeping it small"

UML diagrams	Number of users	Reported to be used for…
Class diagrams	7	structure, conceptual models, concept analysis of domain, architecture, interfaces
Sequence diagrams	6	requirements elicitation, eliciting behaviors, instantiation history
Activity diagrams	6	modeling concurrency, eliciting useful behaviors, ordering processes
State machine diagrams	3	
Use case diagrams	1	represent requirements

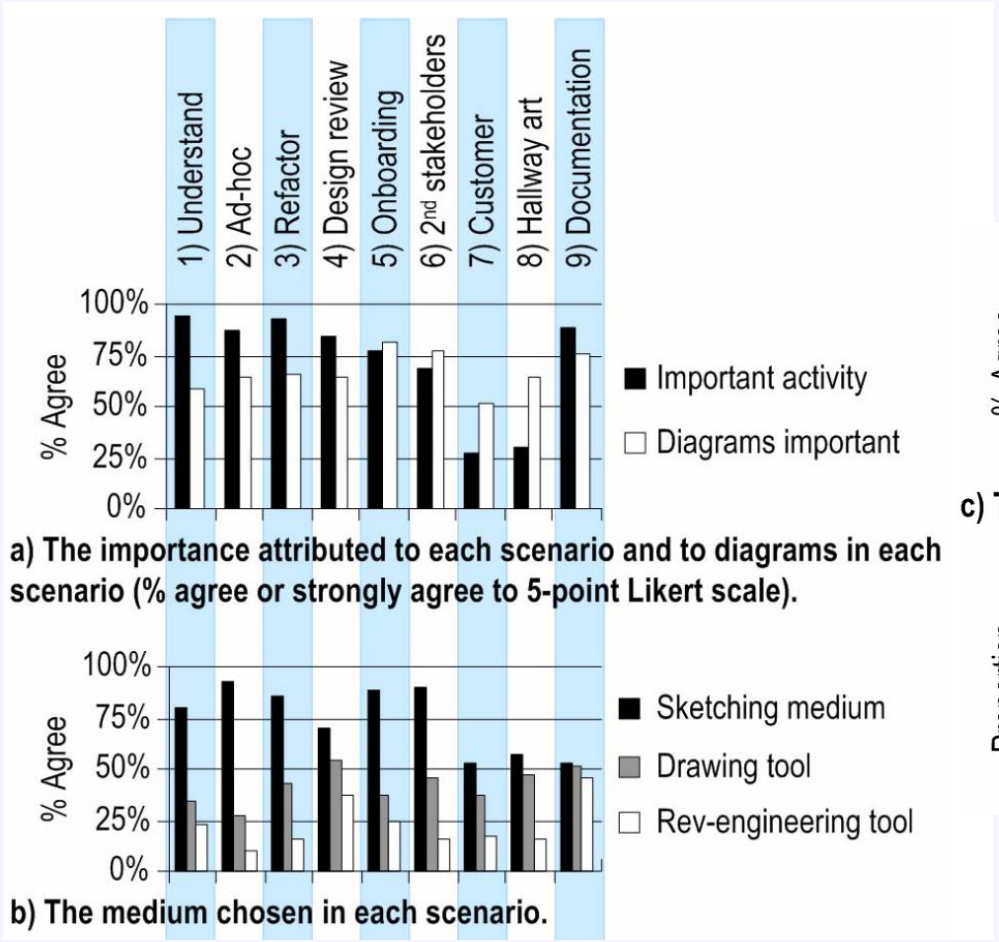
Further Reading: Petre. UML i

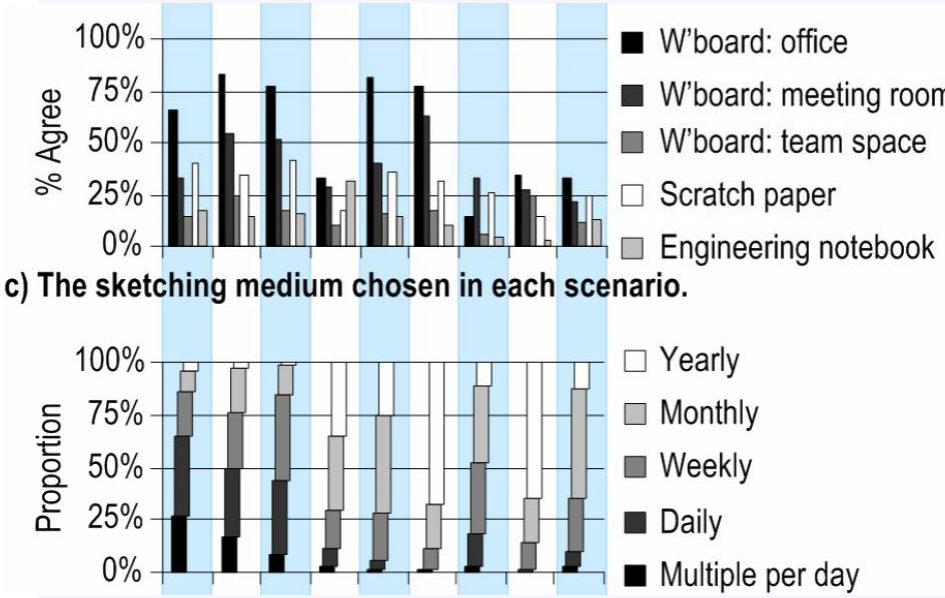
Aside: Diagramming in Practice

↓ Investment	Motivation → Understand	Design	Communicate
Transient	1) Understand	3) Refactor	
Reiterated	2) Ad-hoc		5) Onboarding 6) Secondary stakeholders
Rendered		4) Design review	7) Customer
Archival			8) Hallway art 9) Documentation

Further Reading: Cherubini et al. Let's Go to the Whiteboard: How and Why Software Developers Draw Code. CHI 2007

Aside: Diagramming in Practice





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Empirical Evidence

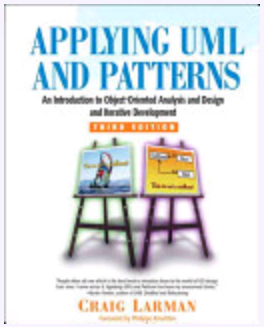
Aside: Key Observations

- How used?
  - transient forms for exploration, permanent solutions for communication with larger groups
  - mostly ad-hoc white-board diagrams during meetings
- Why used?
  - to understand, to design, to communicate
  - "code is king"
- Graphical conventions?
  - Use of formal diagramming language is low
  - too formal for mostly informal visualizations; cost benefit ratio
- Culture?
  - limited adoption of drawing tools;
  - high value diagrams recreated more formally

Literature on OO Design

- Alan Shalloway and James Trott. Design Patterns Explained, Addison Wesley, 2004
  - Brief introduction to UML
  - Introduction to design with design patterns
  - Mandatory reading

- Craig Larman, Applying UML and Patterns, Prentice Hall, 2004
  - Introduction to UML
  - Excellent discussion of object-oriented analysis and object-oriented design with and without patterns
  - Detailed additional material, many guidelines



- Bertrand Meyer, Object-Oriented Software Construction, Prentice Hall, 1997
  - Detailed discussion of design goals and modularity