Software Architecture and Engineering

Introduction

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Chair of Programming Methodology

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1. Introduction

Approach

- This course will focus entirely on **object-oriented** software engineering
- You will have to carry out a **project** from the problem statement to deployment
- Exercise sessions will be used for
  - Student presentations
  - Discussions
  - Introductions to software engineering tools

After this Course, you should

- Be able to produce **high-quality software**
- Be able to deal with **complexity** and **change**

- Have the **technical knowledge** (main emphasis)
- Have an overview of the **managerial knowledge**
- Have an overview of relevant **tools**

Course Outline (tentative)

Part I: Software Development

1. Introduction
2. Requirements Elicitation
3. Analysis
4. System Design
5. Detailed Design
6. Implementation

Part II: Quality Assurance

7. Testing Basics
8. Test Data
9. Testing Concurrent Programs

Part III: Project Management

10. Introduction
11. Project Planning
12. Cost Management
13. Change and Risk Management

Guest Lecture

- Dr. Andreas Leitner, Google Zurich:
  Testing at Google

Course Infrastructure

- Web page: www.pm.inf.ethz.ch/education/courses/sae
- Slides will be available on the web page two days before the lecture (Thursday and Monday)

Literature

- No single book covers course content
- Recommended books:
  - Bernd Bruegge, Allen H. Dutoit: Object-Oriented Software Engineering. Prentice Hall, 2004.
  - Carlo Ghezzi, Mehdi Jazayeri, Dino Mandrioli: Fundamentals of Software Engineering. Prentice Hall, 2002.
  - Mauro Pezzè, Michal Young: Software Testing and Analysis. Wiley, 2008.
- **See course web page for a comprehensive list**

Grading

- Projects
  - Ungraded, but **must be completed successfully** to be admitted to the exam
  - If you obtain
    50% of the total number of points and
    25% of the points for each of the five deliverables
    you will be admitted to the exam
- Exam
  - Written exam in the **exam session**
  - Knowledge from the project will be **essential**!
- Grade is determined entirely by the exam

The Projects

- **Software Engineering** projects
  - Not programming projects
- Topic: Audio player for musicians
  - Focus on **development process rather than result**
- Projects need to be done in **teams of three or four**
- Details will be explained in first exercise session

Background Knowledge

- The lecture focuses on **concepts**
- For the projects, you will also need knowledge about the **technology**
  - UML
  - C#
  - Various tools
- **We expect you to acquire this knowledge!**

Exercise Sessions

- Monday, 15:00-18:00

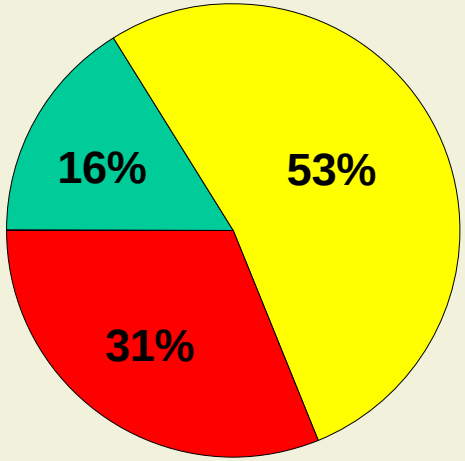
- Dimitar Asenov (ETZ F91)
- Maria Christakis (CHN G22)
- Uri Juhasz (NO D11)
- Valentin Wüstholz (ML H34.3)

- **Exercises start today!**

1. Introduction

Software – a Poor Track Record

- Software bugs cost the U.S. economy an estimated $59.5 billion annually, or about 0.6 percent of the gross domestic product
- 84% of all software projects are unsuccessful
  - Late, over budget, less features than specified, cancelled
- The average unsuccessful project
  - 222% longer than planned
  - 189% over budget
  - 61% of originally specified features

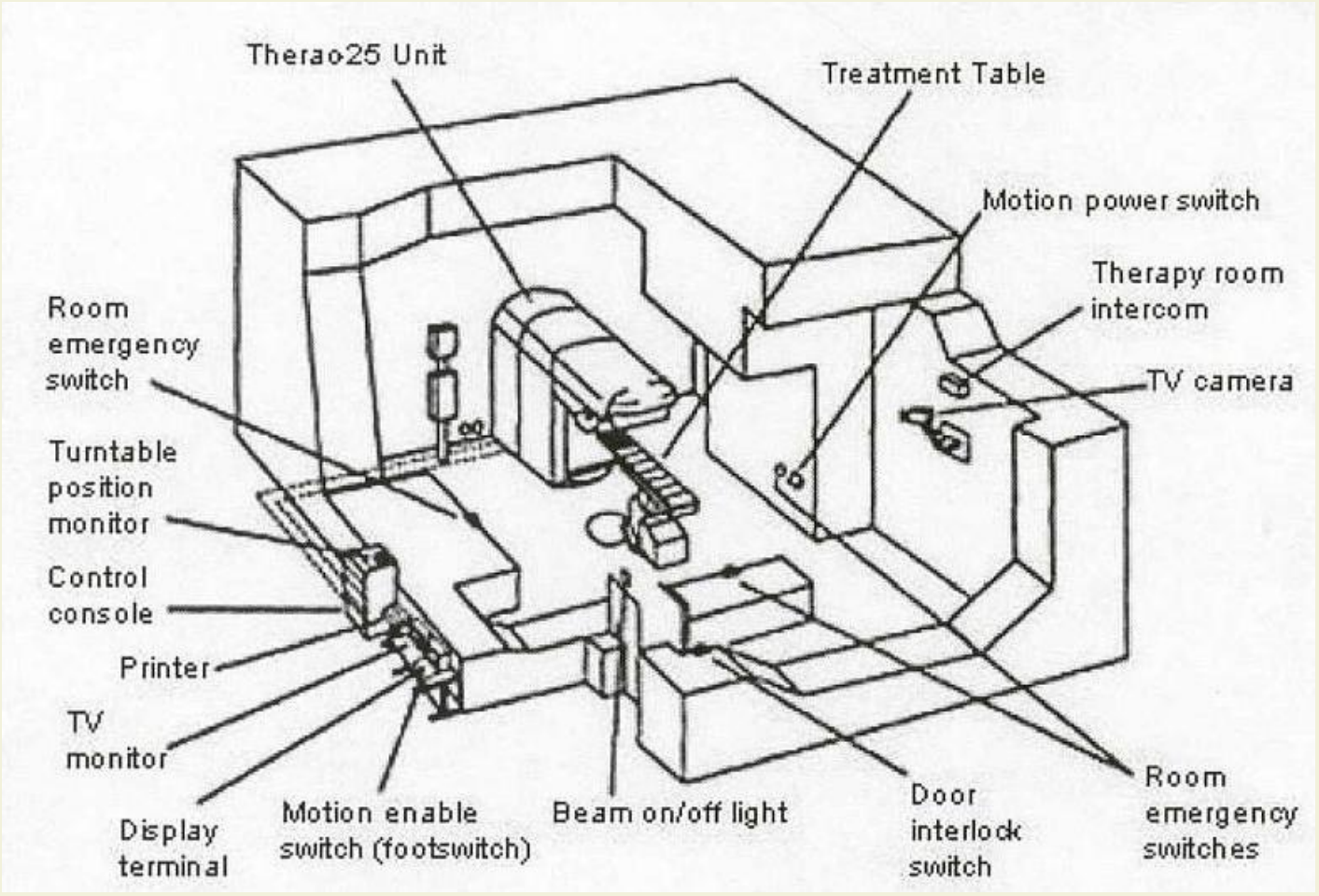


Quality of Today's Software …

… Has Major Impact on Users

The Therac-25 Accident

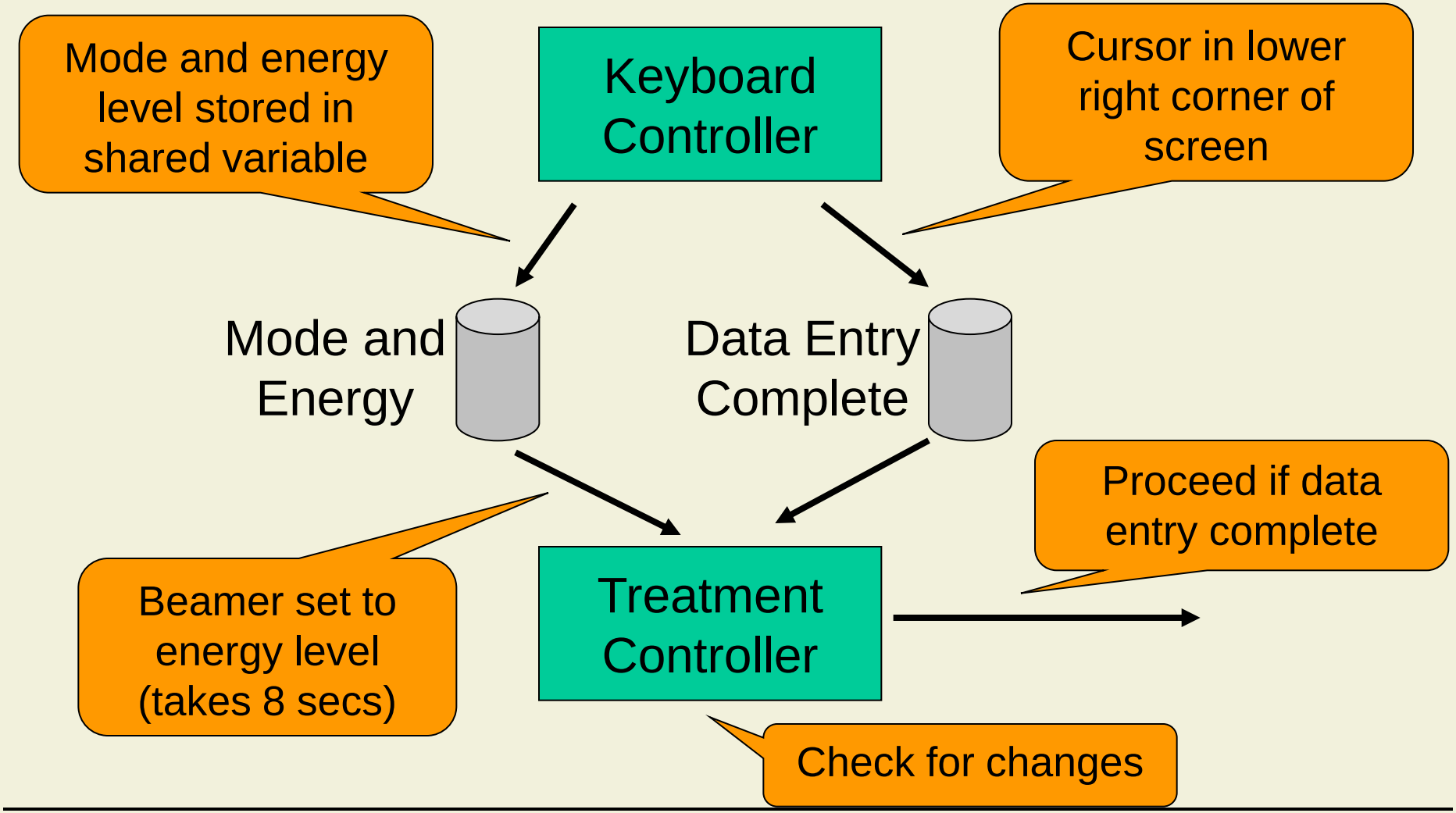
- Therac-25 is a medical linear accelerator
- High-energy X-ray and electron beams destroy tumors



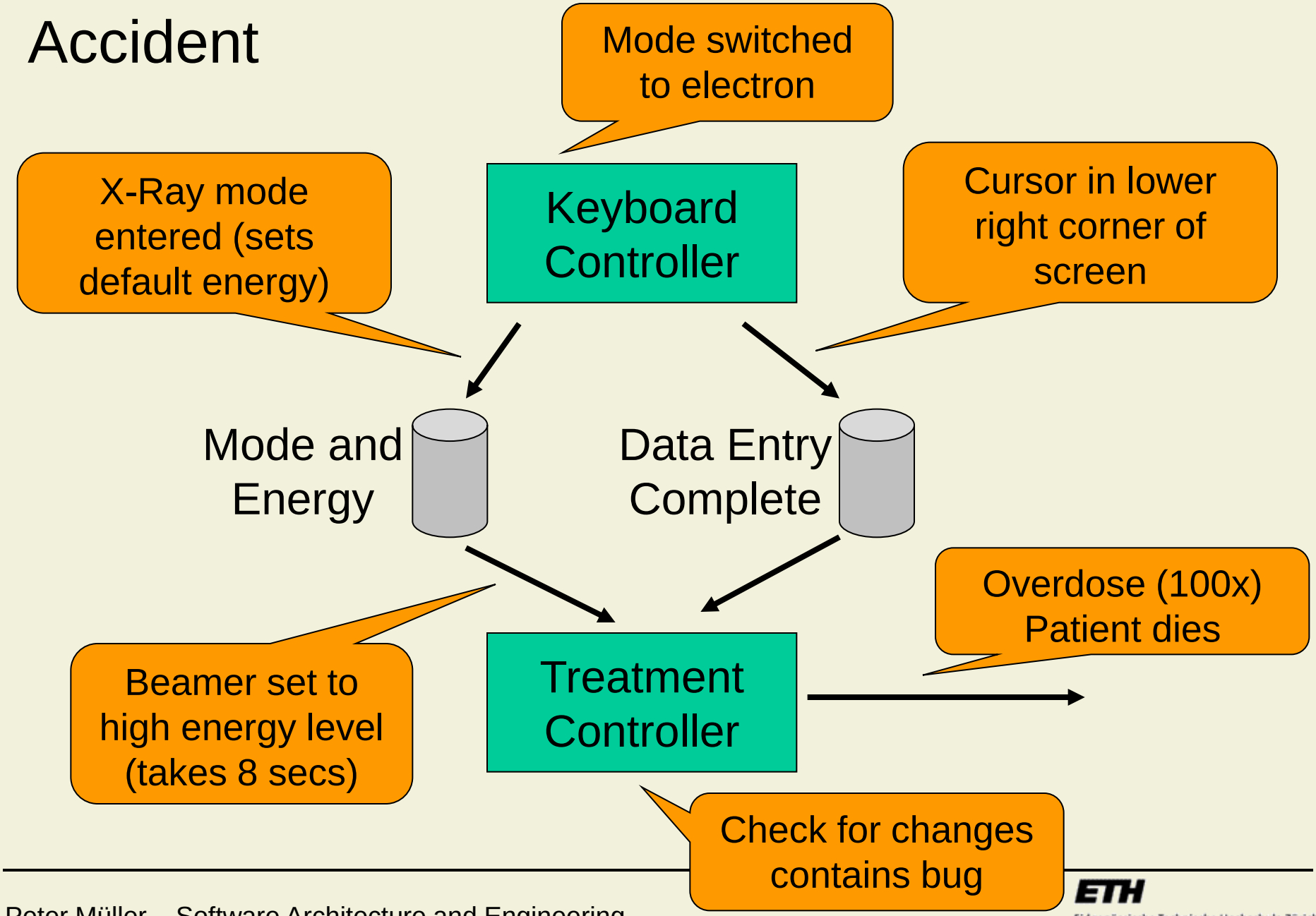
Therac-25 System Design

- Therac-25 is **completely computer-controlled**
  - Software written in assembler code
  - Therac-25 has its own real-time operating system
- **Software** partly taken **from ancestor** machines
  - Software functionality limited
  - Hardware safety features and interlocks
- Hazard analysis
  - Extensive testing on hardware simulator
  - Program software does not degrade due to wear, fatigue, or reproduction process
  - Computer errors are caused by hardware or by alpha particles

Therac-25 Software Design



Accident


Mode switched to electron
X-Ray mode entered (sets default energy)
Keyboard Controller
Cursor in lower right corner of screen
Mode and Energy
Data Entry Complete
Overdose (100x) Patient dies
Beamer set to high energy level (takes 8 secs)
Treatment Controller
Check for changes contains bug

Analysis of the Therac-25 Accident

- **Changed requirements** were not considered
  - In Therac-25 software is safety-critical
- **Design** is too **complex**
  - Concurrent system, shared variables (race conditions)
- **Code** is **buggy**
  - Check for changes done at wrong place
- **Testing** was **insufficient**
  - System test only, almost no separate software test
- **Maintenance** was **poor**
  - Correction of bug instead of re-design (root cause)

Challenge: Complexity

- Complexity is caused by
  - Complexity of the problem domain
  - Complexity of the development process
  - Flexibility of software

- Aspects of complexity
  - Multi-person construction (team-effort)
  - Multi-version software
  - Often conflicting objectives
  - Development and operation lasts many years

Challenge: Change

- Change is caused by
  - Bug fixes
  - Changing requirements
    (adding, enhancing, removing features)
  - Changing environment
  - Changing development team

- Each implemented change erodes the structure of the system, which makes the next change even more expensive

Software Engineering: Definition 1

- *A collection of techniques, methodologies, and tools that help with the production of*
  - *a high quality software system*
  - *with a given budget*
  - *before a given deadline*
  - *while change occurs*

[Brügge]

- Constraints are important

Software Engineering: Definition 2

- *The application of a systematic, disciplined, and quantifiable approach to the development, operation, and maintenance of Software; that is, the application of engineering to software*

  [IEEE, ANSI]

- Software engineering spans whole product lifecycle

Science vs. Engineering

Engineering

- The **application of science** to the **needs of humanity**
- **Application of knowledge, mathematics, and practical experience** to the design of useful objects or processes

Science

- Knowledge covering **general truths** or the operation of **general laws**

Computer Science vs. Software Engineering

Software Engineering

- The **application of computer science,** mathematics, project management **to build** high quality **software**

Computer Science

- Computability, algorithms and complexity, programming languages, data structures, databases, artificial intelligence, etc.

Related Areas

Is this requirement addressed on hardware or software level (or both)?

- Systems Engineering
  - Complex systems with software and hardware
  - Interdisciplinary
  - Example: Therac-25

Will the project be completed in time and budget?

- Project Management
  - Organizes and leads the project work to meet project requirements
  - Concerned with time, budget, procurement, communication, etc.

1. Introduction

1.1 Course Outline

1.2 Motivation

1.3 Software Qualities

1.4 Software Engineering Principles

Representative Software Qualities

- Correctness
- Maintainability
- Performance
- Verifiability
- Robustness
- Understandability
- Scalability
- Reusability
- Reliability
- Evolvability
- Usability
- Portability
- Security
- Repairability
- Interoperability

Correctness

- Correct software meets its **functional requirements** specification
- Correctness is a **mathematical property**
- Can be enhanced by
  - Appropriate tools (e.g., high-level languages)
  - Standard algorithms and libraries
  - An established development process
- Example: security control system of the "Meteor" line of the Paris metro is proven to be correct

Robustness

- Robust software **behaves "reasonably"**, even in circumstances **not covered by the specification**
- Can be enhanced by
  - Assertions (Design by Contract)
  - Software monitoring
  - Defensive programming
- Example: database system performs a controlled shutdown when hardware error occurs
  - No data is corrupted
  - Behavior is logged for later analysis or retry

Security

- Secure software is **protected against unauthorized access** to or **modification** of information
  - Confidentiality, integrity, availability
- Can be enhanced by
  - Cryptography
  - Proven protocols
- Example: internet banking uses cryptography to protect transmitted data from leaking and manipulation

Reliability

- Reliable software has a high **probability** to **operate as expected** over a specified interval
- Reliability is a **statistical property**
- Can be enhanced by
  - Fault avoidance (e.g., careful design)
  - Fault tolerance (e.g., redundancy)
  - Fault detection (e.g., testing)
- Example: telephone system establishes a connection > 99.9% of the time

Performance

- High-performance software is **fast** and consumes a **small amount of memory**
  - Response time
  - Throughput
  - Memory usage
- Can be enhanced by
  - Considering performance when designing the software architecture
  - Code optimization (performance tuning)
- Example: a stock trading system handles up to 100’000 orders per hour

Scalability

- Scalable software shows **increased performance** under an increased load **when resources** (typically hardware) **are added**
- Can be enhanced by
  - De-centralized architectures
  - Low complexity of algorithms
- Examples
  - Peer-to-peer file exchange systems scale easily to millions of users
  - A routing protocol is scalable if the size of the routing table grows as O(log N), where N is the number of nodes

Usability (User Friendliness)

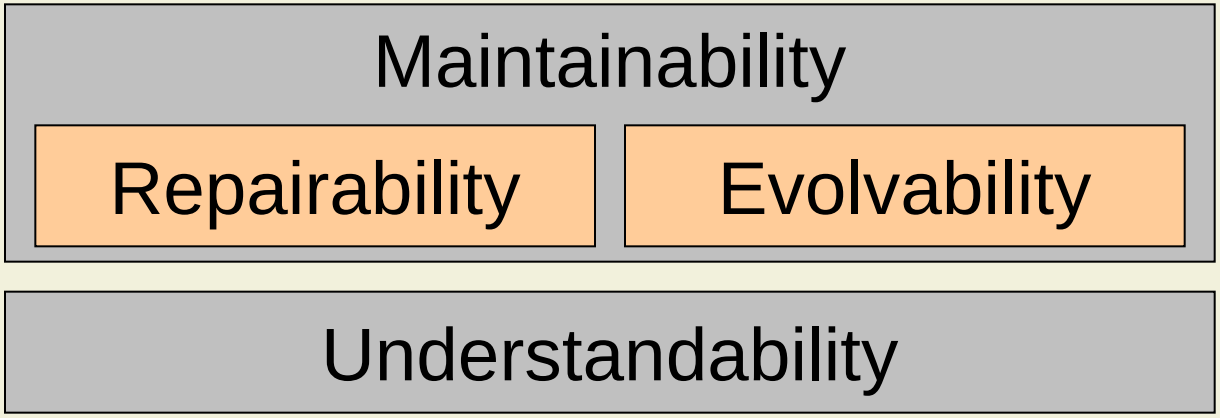
- Usable software is found **easy to use by humans**
  - Subjective (e.g., experts and novices have difference requirements)
- Can be enhanced by
  - Offering different user interfaces
  - Adaptable user interfaces (maybe even automatically)
  - New forms of human computer interaction (e.g., speech)
- Example: order system offers a GUI for occasional users and a command line interface for experts

Interoperability

- Interoperable software can **coexist** and **cooperate** with other systems
- Can be enhanced by
  - Well-documented interfaces (e.g., file formats, protocols)
  - Standard interface formats (e.g., XML)
- Examples
  - A word processor can incorporate a spreadsheet table or graph
  - By using a web service, any application can query Google

Maintainability

- Maintainable software enables or simplifies **modification after initial development**
  - **Corrective** maintenance (bug fixing)
  - **Adaptive** maintenance (adaptation to changed environment, e.g., new version of operating system)
  - **Perfective** maintenance (improvement, e.g., new functions)



Maintainability (cont'd)

- Can be enhanced by
  - Modular design, narrow interfaces
  - Good documentation
  - Extensive test suite (preferably automated)
- Example: An order system was developed in 1960s and has been maintained since then
  - New hardware, operating system, database system
  - New functionality (internet banking, intraday trading)

Verifiability

- **Properties** of verifiable software **can be verified** easily
  - Testing
  - Formal verification
- Can be enhanced by
  - Software monitors (e.g., to measure performance)
  - Modular design
- Example: Assertions (contracts) enable runtime assertion checking to find bugs

Reusability

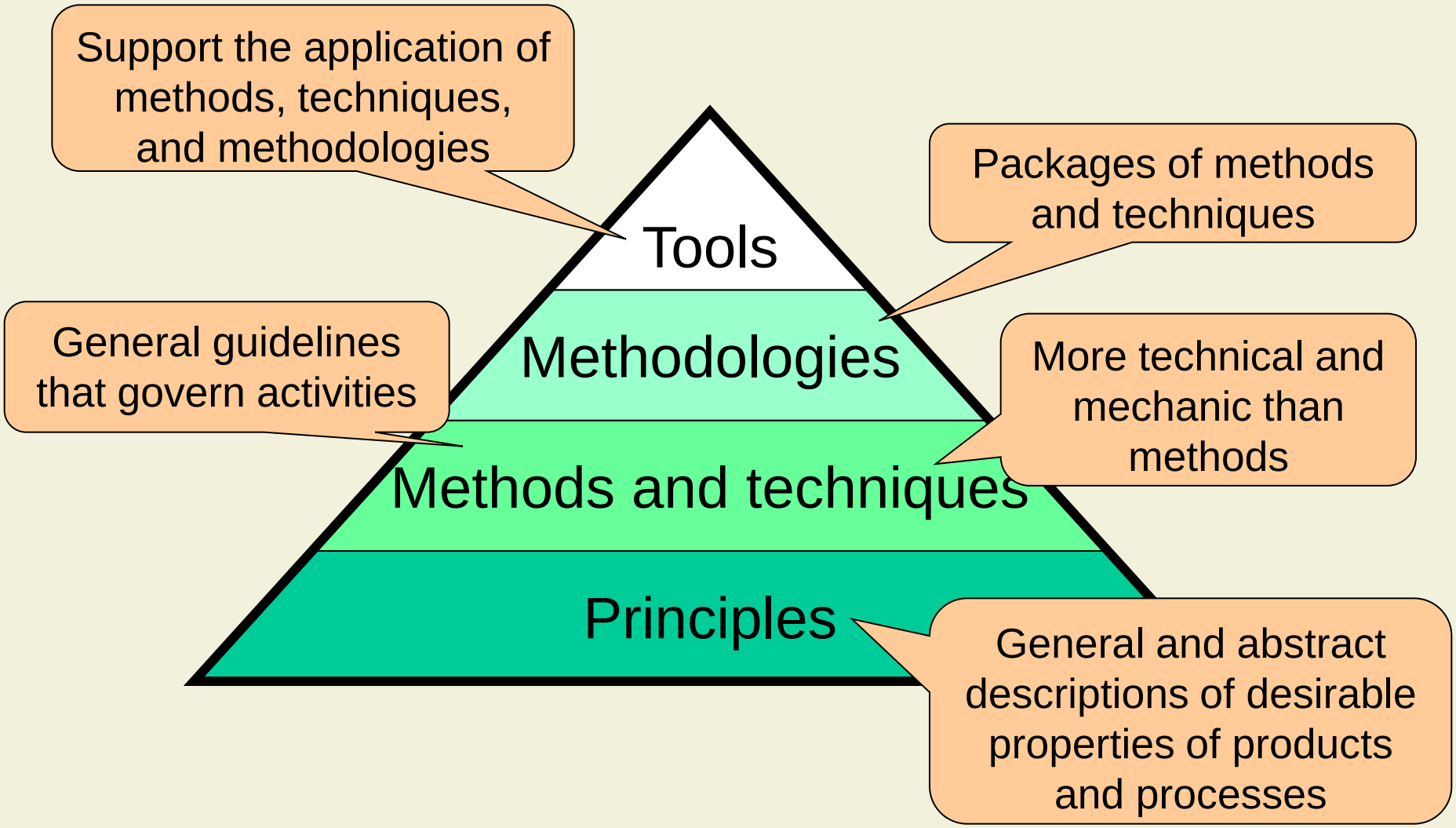
- Reusable software can be **reused, adapted, and composed** to develop new products
  - Different levels of granularity from methods to applications
- Can be enhanced by
  - Modular design, narrow interfaces, parameterization
  - Good documentation
  - Object technology (inheritance, overriding)
- Example: class libraries of OO-languages such as C#, Eiffel, Java, etc.

Portability

- Portable software can **run in different environments** (e.g., hardware, operating system)
- Can be enhanced by
  - Isolation of dependencies on environment
  - Layered architectures
  - Virtual machines
- Example: Java applications can run in any environment that provides a virtual machine (“write once, run anywhere”)

1. Introduction

The Role of Principles



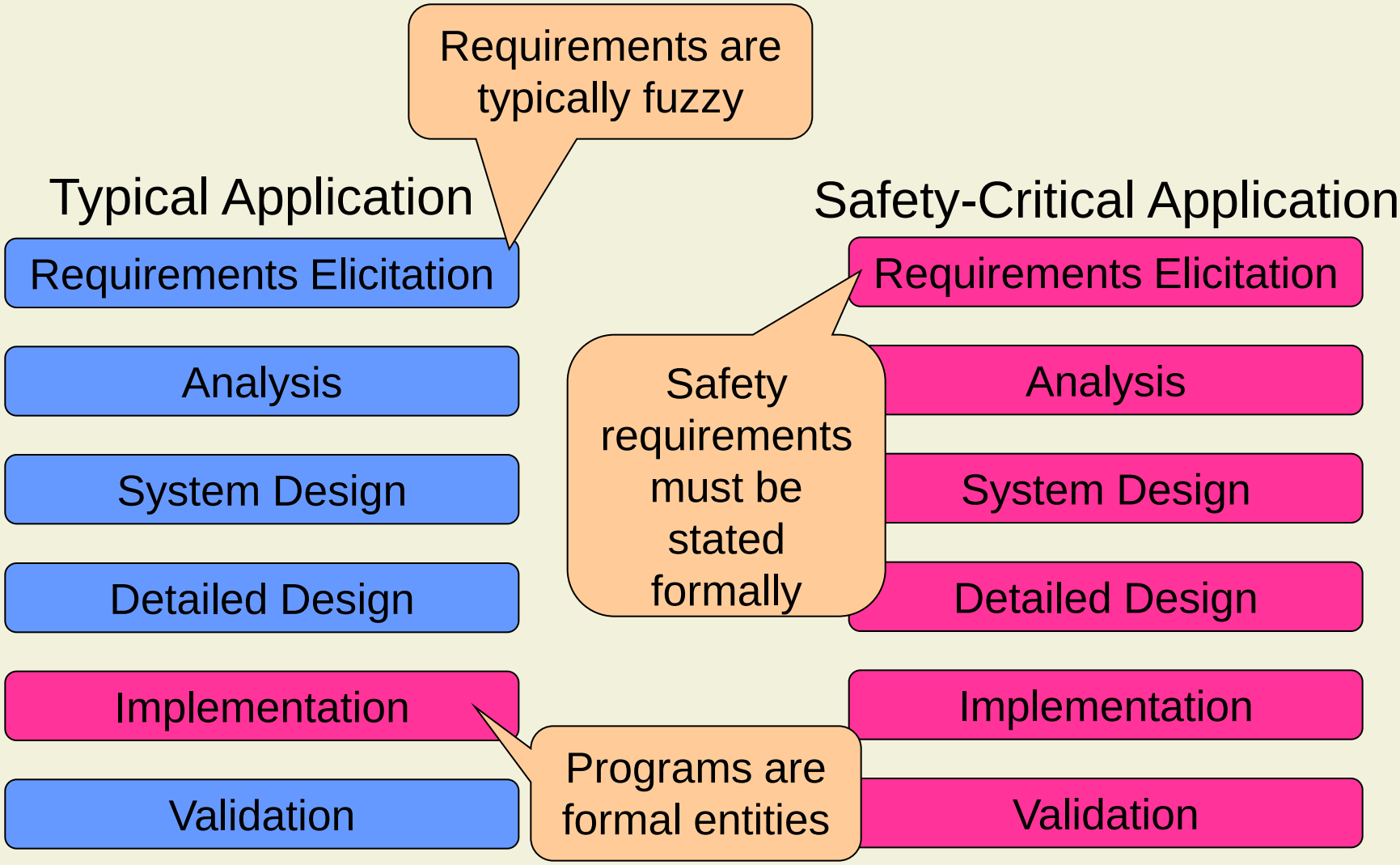
Important Software Engineering Principles

- Rigor and formality
- Separation of concerns
- Modularity
- Abstraction
- Anticipation of change
- Generality
- Incrementality

Rigor and Formality

- Rigor means **strict precision**
  - Various degrees of rigor can be achieved
  - Example: mathematical proofs
- Formality is the **highest degree of rigor**
  - Development process driven and evaluated by mathematical laws
  - Examples: refinement
  - Formality enables tool support
- Degree of rigor **depends on application**

Rigor and Formality: Examples



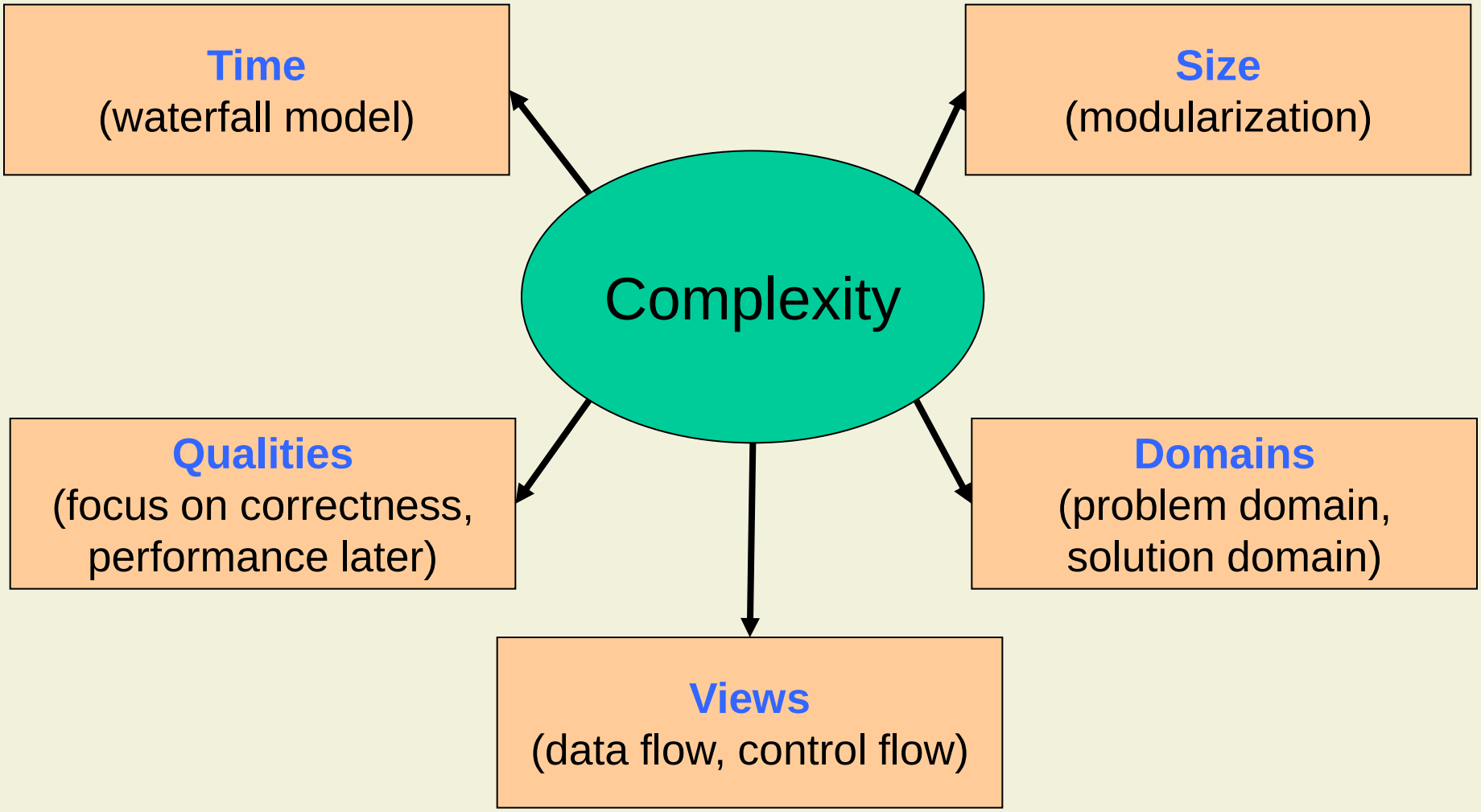
Rigor and Formality: Compiler Case Study

- Compilers are **critical products**
  - Errors are multiplied on a mass scale
- Very **high** degree of **formalization**
  - Syntax: regular expressions, grammars, BNF
  - Semantic analysis: attribute grammars
- Formalization enables **tool support**
  - Scanner generators (lex)
  - Parser generators (yacc)

Separation of Concerns

- Deal with **different aspects** of a problem **separately**
  - **Reduce complexity**
  - Functionality, reliability, performance, environment, etc.
- Many aspects are **related** and **interdependent**
  - Separate unrelated concerns
  - Consider only the relevant details of a related concern
- **Tradeoff**
  - Risk to miss global optimizations
  - Chance to make optimized decisions in the face of complexity is very limited

Ways to Achieve Separation of Concerns



Separation of Concerns: Compiler Case Study

- **Correctness** is primary concern
- Other concerns
  - **Efficiency** of compiler and of generated code
  - **User friendliness** (helpful warnings, etc.)

- Example for interdependencies: runtime diagnostics vs. efficient code
  - Example: runtime assertion checking
  - Diagnostics simplify testing, but create overhead
  - Typical solution: option to disable checks

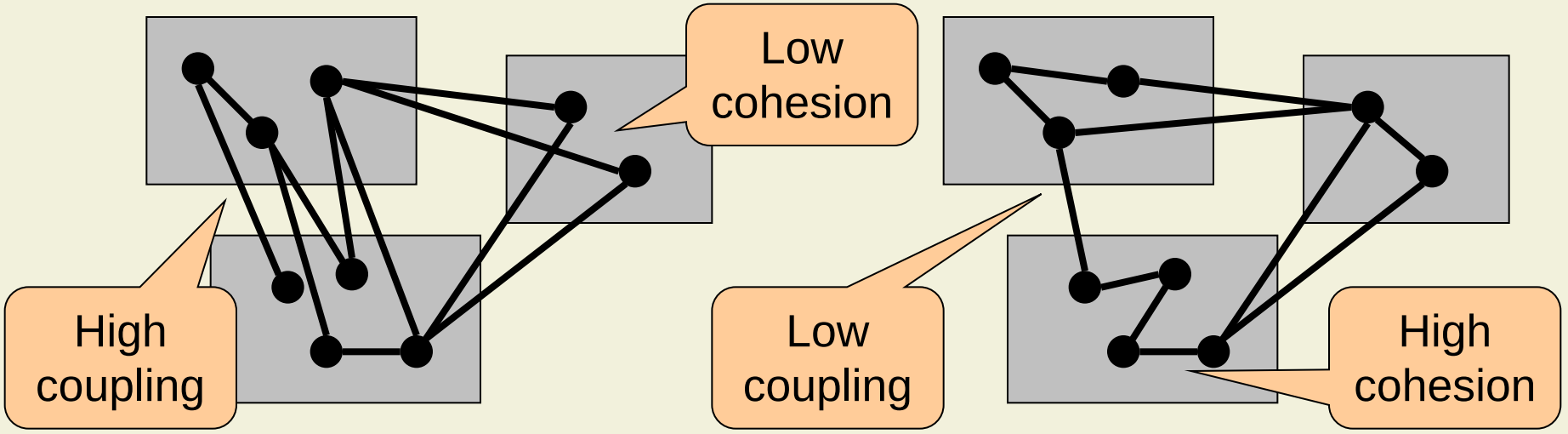
Modularity

- Divide system into modules to **reduce complexity**

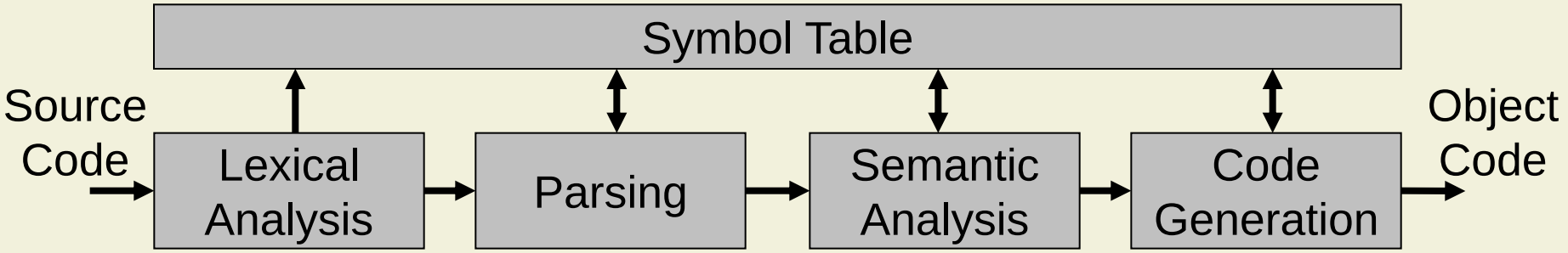
- **Decompose** a complex system into simpler pieces
- **Compose** a complex system from existing modules
- **Understand** the system in terms of its pieces
- **Modify** a system by modifying only a small number of its pieces

Cohesion and Coupling

- Cohesion measures **interdependence** of the elements of **one module**
- Coupling measures **interdependence between** different **module**
- Goal: **high cohesion** and **low coupling**



Modularity: Compiler Case Study



- Compilers are modularized into **phases**
- Each phase has precisely defined input and output
  - High cohesion: common functionality in each phase
  - Low coupling: pipe-and-filter architecture, symbol table

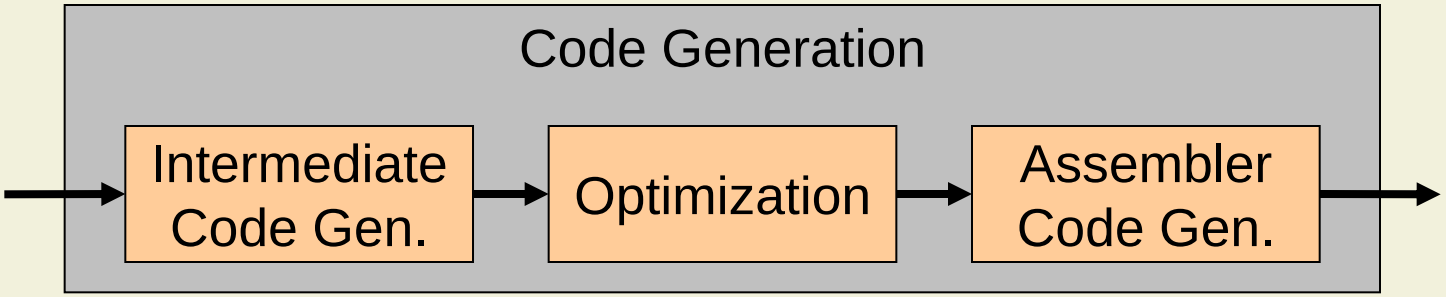
Abstraction

- **Identify** the **important aspects** and **ignore** the **details**

- Abstraction in software engineering
  - **Models** of the real world (omit irrelevant details)
  - **Subtyping** and inheritance (factor out commonalities)
  - Interfaces and **information hiding** (hide implementation details)
  - Parameterization (templates)
  - Structured programming (loops, methods)
  - Layered systems (hide deeper layers in the stack)

Abstraction: Compiler Case Study

- Abstract syntax
  - Abstract while loop syntax: while(*BoolExpr Stmt*)
  - Concrete Pascal syntax: **WHILE** *BoolExpr* **DO** *Stmt* **;**
  - Concrete Java syntax: **while (** *BoolExpr* **)** *Stmt*
- Abstract machines
  - Generate intermediate code for abstract machine
  - Simplifies code generation for different hardware



Anticipation of Change

- **Prepare** software **for changes**
  - **Modularization**: single out elements that are likely to change in the future
  - **Abstraction**: narrow interfaces reduce effects of a change
- Risk: developers spend too much time to make software changeable and reusable
- Software product lines
  - Many similar versions of software (e.g., for different hardware)
  - Examples: software for cell phones, sensors

Anticipation of Change: Example

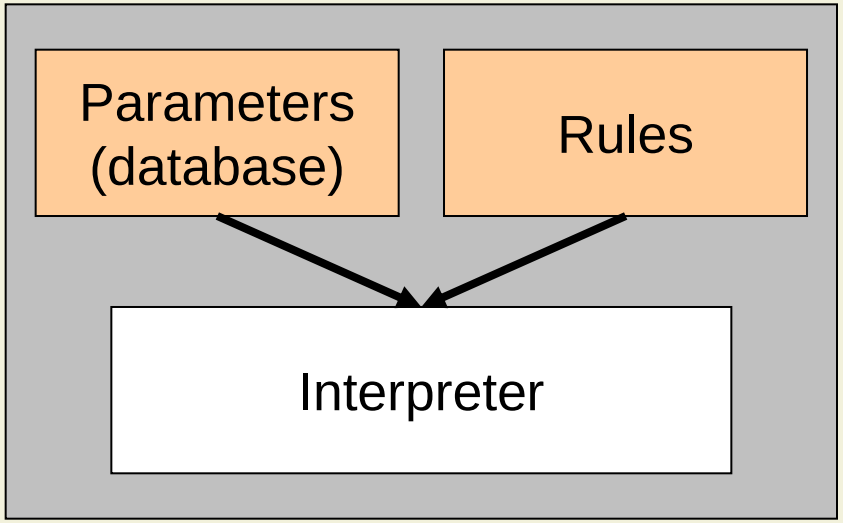
- Fee computation for bank accounts
- Original design: computation and values hard-coded

```
int computeFee( ) {
  if( balance >= 2000)
    return 0;
  else
    return monthlyFee;
}
```

- Changes (within two years)
  - Different values → required program change
  - Different rules → required program change
  - Different groups of clients → required additional logic

Anticipation of Change: Example (cont'd)

- Better design: interpreter



- Parameters and rules can be changed by banker
  - For instance, by editing an Excel file
- Code remains unchanged (less testing)

Anticipation of Change: Compiler Case Study

- Typical changes
  - New versions of processors and operating systems
  - New target machines
  - Language and library extensions (e.g., standards)

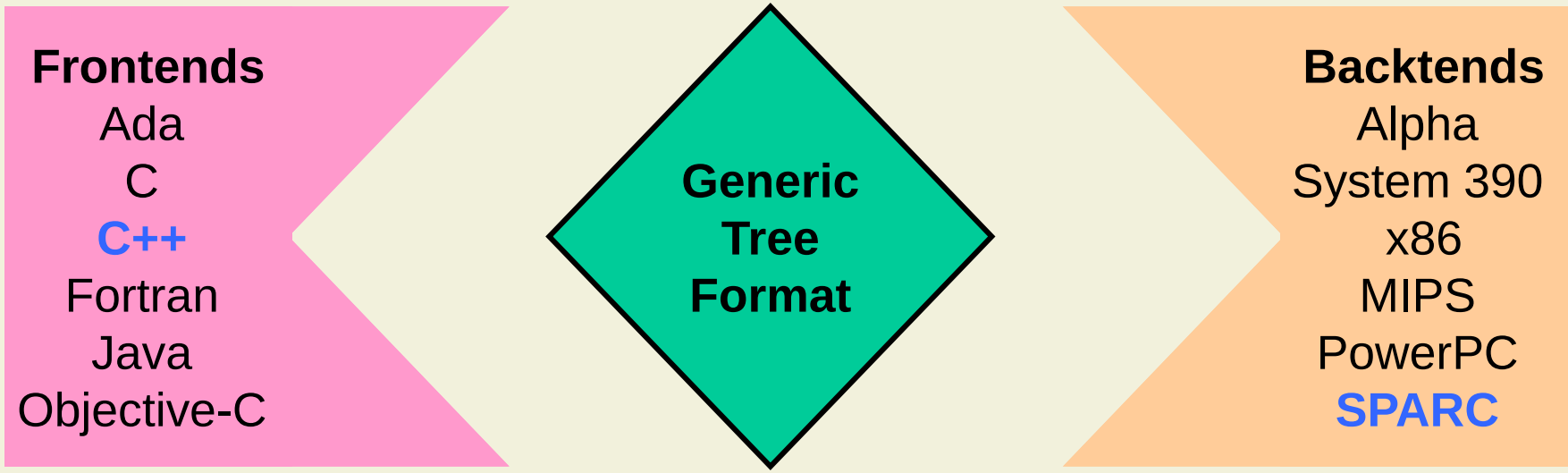
- Preparation
  - Use intermediate code
  - Put machine-dependent code (e.g., I/O, threads) into standard library

Generality

- Attempt to **find more general problem** behind problem at hand
  - Apply **standard solutions and tools**
- A general solution is more likely to be reusable
  - Examples: spreadsheets, database
- General solution may be less efficient
- Example
  - Semantic analysis: Is C a subclass of D?
  - Subclass relation is an acyclic graph
  - Use adjacency matrix and compute transitive closure

Generality: Compiler Case Study

- The GNU compiler decouples
  - Frontend (scanner, parser, analysis)
  - Backend (code generation, optimization)
- Frontends and backends can be combined in various ways



Incrementality

- Characterizes a process which **proceeds in a stepwise fashion**
  - The desired goal is reached by creating successively closer **approximations** to it
- Examples
  - Incremental software life cycles (e.g., spiral model)
  - Prototypes, early feedback
  - Project management is inherently incremental

Incrementality: Compiler Case Study

- Language can be extended incrementally
  - Java 1.0: core language
  - Java 1.1: inner classes
  - Java 1.2: Swing GUI library
  - Java 1.4: enhanced libraries
  - Java 5: genericity, boxing
  - Java 6: annotations
- Compiler can be enhanced incrementally
  - Supported language subset
  - Runtime diagnostics
  - Optimizations