Software Engineering

Lecture 1
Introduction, principles & architecture

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MPRI

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Introduction
Prehistory

Main control panel of ENIAC (1946)

First Turing-complete computers

- Huge and expensive (30 tons, $167 m^2$, 150 kW, 6M$)
- One-off, built for specific purposes (military computations)
- Focus on making hardware reliable
Industrialization

IBM System/360 (1964)

Mainframe computers

- Wide range of applications, scientific to commercial
- Separation of architecture and implementation
- Software complexity rises
Birth of software engineering

1960’ software crisis

- Spectacular failures: bugs, cost, overtime, cancellation

Frederick P. Brooks about OS/360: The flaws in design and execution pervade especially the control program. [. . .] The product was late, it took more memory than planned, the costs were several times the estimate, and it did not perform very well until several releases after the first.

1968 NATO conference on Software Engineering

Need for software manufacturers to be based on the types of theoretical foundations and practical disciplines that are traditional in the established branches of engineering.
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## Software Engineering

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**Approach:**
- Social sciences $\leftrightarrow$ Computer science $\leftrightarrow$ Hacking

- Principles behind good software products and processes.
- Methodologies that apply and promote those principles.
- Tools to implement and help follow methodologies.
**Software Engineering**

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# Software Engineering

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Scope

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<th>Activities</th>
<th>spec.</th>
<th>design</th>
<th>implem.</th>
<th>validation</th>
<th>evolution</th>
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<td>Products</td>
<td>doc</td>
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<td>code</td>
<td>tests</td>
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Rigor
Rigor

How to ensure correctness?

▶ Ideally, formal methods!
▶ In practice, mostly through rigorous methodologies.

“There are two ways to write error-free programs; only the third works.” (Alan J. Perlis)

▶ Be paranoid, seek to detect anomalies early on
▶ Design precise tests, run them after each change
Rigor

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Correctness is meaningless without a spec!

- Always specify precisely what you need, and no more
- Informal specs (i.e., doc) are much better than nothing
- Make sure the spec is visible to the implementer

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Change
Anticipation of change

Code will evolve

- Bugs will have to be fixed
- Requirements and the environment may change
- Components could be re-used in a (slightly different) context
Anticipation of change

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Anticipation of change

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- Requirements and the environment may change
- Components could be re-used in a (slightly different) context

Brace yourself
- Actively work to identify potential changes
- Design code so that change and re-use is facilitated
- Use tools that help to keep track of change
- Organize work around upcoming changes
Software development processes

Waterfall model

- Requirements
- Design
- Implementation
- Maintenance

Prevalent at least until 70's
- Probably inspired from other engineering fields
- DoD guidelines for military software: mandatory until 88, remains reference after that (until recently?)
Software development processes

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Incrementality

Proceed step by step to get early feedback and adjust.

- Start by implementing a subset of features.
- Start with functional correctness only.

Incremental development model

```
| Specification | Development | Validation |
```

Incrementality

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- Start by implementing a subset of features.
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**Incremental development model**

![Diagram of Step by Step Process]

**Pros/cons**

⊕ Early feedback. Opportunity to fix requirements and design.
   May be necessary if requirements are not initially clear.

⊕ Good for the morale of developers and clients!

⊖ Requires refactoring to maintain good structure.

⊖ Hard to keep track of change in large projects.
The main invention in Linux is ...
The main invention in Linux is its development model.

- Wide distribution and invitation to contribute, thanks to personal computers and the internet.
- Active integration of patches and frequent releases, initially by hand, then with dedicated tools.
- Pre-requisites in the code:
  - precise documentation
  - extensibility through modules for drivers, file system, etc.

More development models

Collaborative software development
Incremental with collaboration and involvement of the public
Main model for open-source software:
  ▶ More testers → earlier bug reports
  ▶ Massive peer review (?)
More development models

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Agile software development
Incremental process + focus on collaboration & self-organization
http://agilemanifesto.org/principles.html
Various methodologies (XP, SCRUM...)

Modularity
Modularity

Segment project in modules with clearly defined interfaces.
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Segment project in **modules** with clearly defined **interfaces**.

**A slogan: High Cohesion, Low Coupling**

- Maximize modularity:
  parallelizability of the software process, chances of re-use
- Minimize interactions:
  separately test, modify... understand, then integrate

**Example (types of cohesion)**

- Coincidental: no (good) reason
- Temporal: executed around the same time, e.g., init
- Functional: realize a task, e.g., convert file
- ...
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What is a good modularization?
Modularity

A possible modularization for a KWIC index generator:

**Input**: lines of text  
**Output**: all permutations of those lines, sorted alphabetically

Modules export arrays
No text in shifted/sorted arrays

Modularity

- Input
  - Shift
  - Sort
  - Output

Modules export arrays
No text in shifted/sorted arrays

vs.

- Input
  - Shift
  - Sort
  - Output
  - Lines

Modules export `get/set()`

---

Modularity

- Modules export arrays
- No text in shifted/sorted arrays
- Modules export `get/set()`

Modularity

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- Coincidental: no (good) reason
- Temporal: executed around the same time, e.g., init
- Functional: realize a task, e.g., convert file
- Informational: independent operations on same data, e.g., list

Modularization goes hand in hand with information hiding, aka...
Abstraction
Ignoring details

Design

- Do not specify implementation *details.*
Ignoring details

Design

▶ Do not specify implementation details.
▶ Details are things that can easily change:
  max. waiting time, password length, graphics library, etc.

Code

▶ Code in a high-level language, far from the machine.
▶ Code for correctness first, then optimize if needed.
  “Premature optimization is the root of all evil.” – Knuth
▶ Don’t hardcode:
  no magic numbers, any constant should be justified.
Modularity + Abstraction

Segment project in modules with clearly defined interfaces.

Maximize information hiding in interfaces:
- Minimize coupling.
- Plan for evolution.

Language support
More or less constraining/helpful
- Modules and abstract types in ML-like languages
- Classes in object oriented programming
- Separate compilation units in other languages
- Procedures in structured programming languages!
Proof assistants

Concerns of computer-aided theorem proving

- **Soundness**: the whole point is to have trustworthy proofs!
- **Usability**: undo, notations, automation, efficiency, user extensions, etc.
Proof assistants

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- **Soundness**: the whole point is to have trustworthy proofs!
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Edinburgh LCF (70’s)

- Proof objects cannot be maintained for performance reasons
- Small **trusted kernel** provides sound manipulations of abstract datatype theorem
- Tactics and tacticals built on top of this sound kernel
- By-product: ML language and module system!

Proof assistants

Concerns of computer-aided theorem proving

- **Soundness**: the whole point is to have trustworthy proofs!
- **Usability**: undo, notations, automation, efficiency, user extensions, etc.

Coq v7 (2000)

- Proof objects are maintained: relevant, non-local checks
- **Isolated** kernel: breaking dependency on undo-able objects
- (OCa)ML modules still used: abstraction ensures safety
- Kernel is **purely functional**, 1/3 of the code
- 2013, v8.4p12: same design, impure kernel, 1/10 of the code

Software architecture
examples / success stories
Layers

Monolithic kernel architecture

User space

Kernel space

Applications

Syscall API

file system
scheduler
IPC
networking
pager

Hardware

Unix

Powerful abstractions such as processes and file descriptors.

The success of Unix lies not so much in new inventions but rather in the full exploitation of a carefully selected set of fertile ideas.

Layers

Monolithic kernel architecture

User space

Kernel space

file system
scheduler
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Hardware

Applications

Syscall API

Modern kernels not strictly layered, for performance.
Layers

Monolithic kernel architecture

- User space
  - Applications
  - file system
  - scheduler
  - ... IPC
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Kernel space

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Pipes and filters

- Parser generators are engineering pearls in themselves

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- Reason separately about individual “filters” (cf. CompCert)
- Easy extension with new front-ends, back-ends or optimizers?
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- Easy extension with new front-ends, back-ends or optimizers?
- LLVM took this architecture seriously: truly decoupled phases, documented interfaces, ships as library, provides dynamic configuration tools
  \( \rightsquigarrow \) maximum re-use, huge community, lots of features

That’s all for now!

Today

We’ve seen the main principles, aka. the rules of the game:

▶ Rigor, Adaptability
▶ Modularity, Abstraction

Next

▶ Methods:
  ▶ rigorous software development, notably through testing
  ▶ software modelling to guide design
▶ Tools:
  ▶ git, basic and advanced
  ▶ during project, or on demand: documentation generators, debuggers, profilers...
▶ Experience through the project
References


...and many others cited in the slides.