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Software Engineering for High Performance Computing course (SE4HCP)

Instructors

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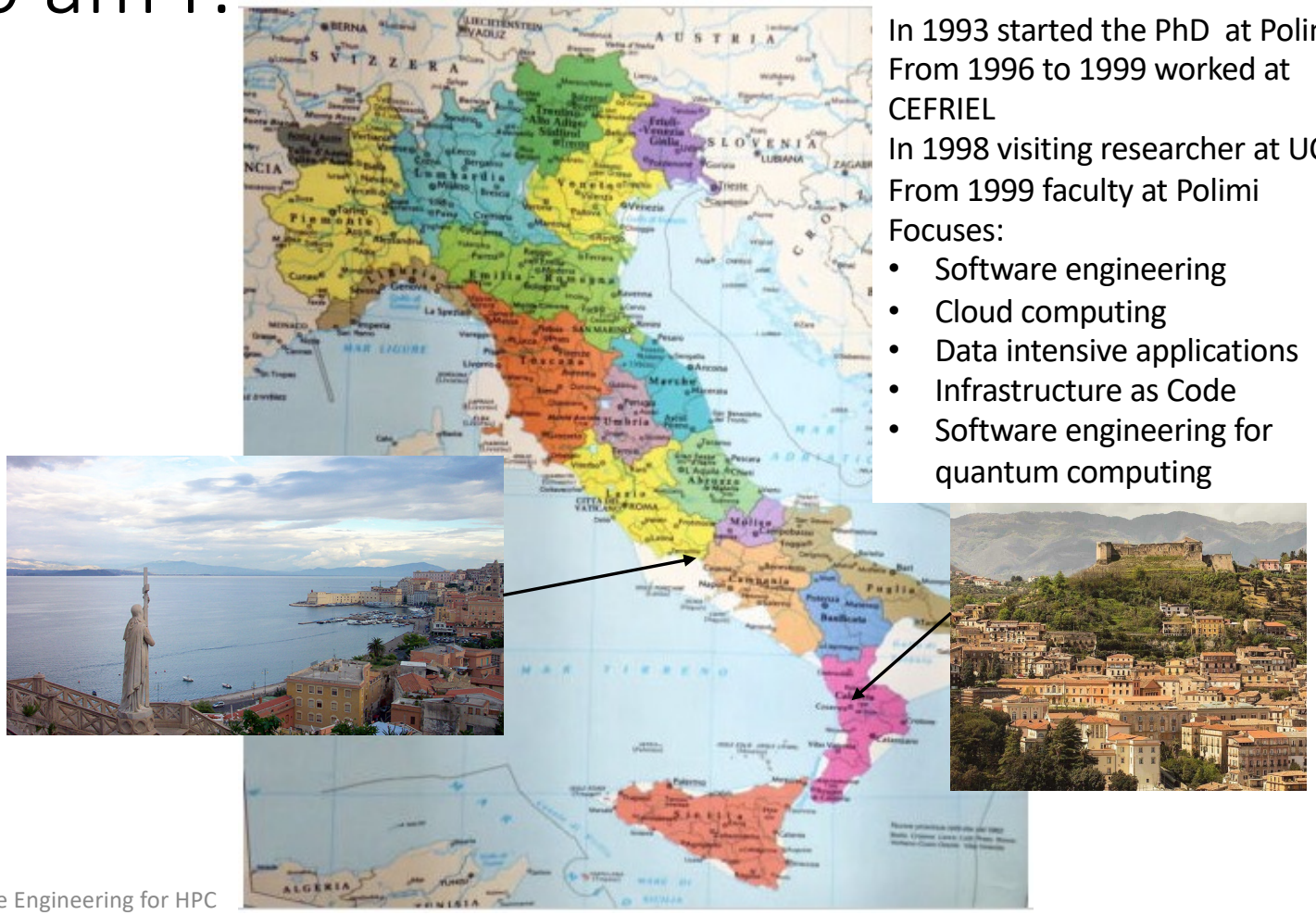
- Elisabetta Di Nitto
  - Office address: Via Golgi, 42
  - email elisabetta.dinitto@polimi.it
  - phone: 02-2399-3663
  - http://dinitto.faculty.polimi.it
- Teaching assistant: Simone Reale
  - Office address: Via Golgi, 42
  - email simone1.reale@polimi.it

Who am I?

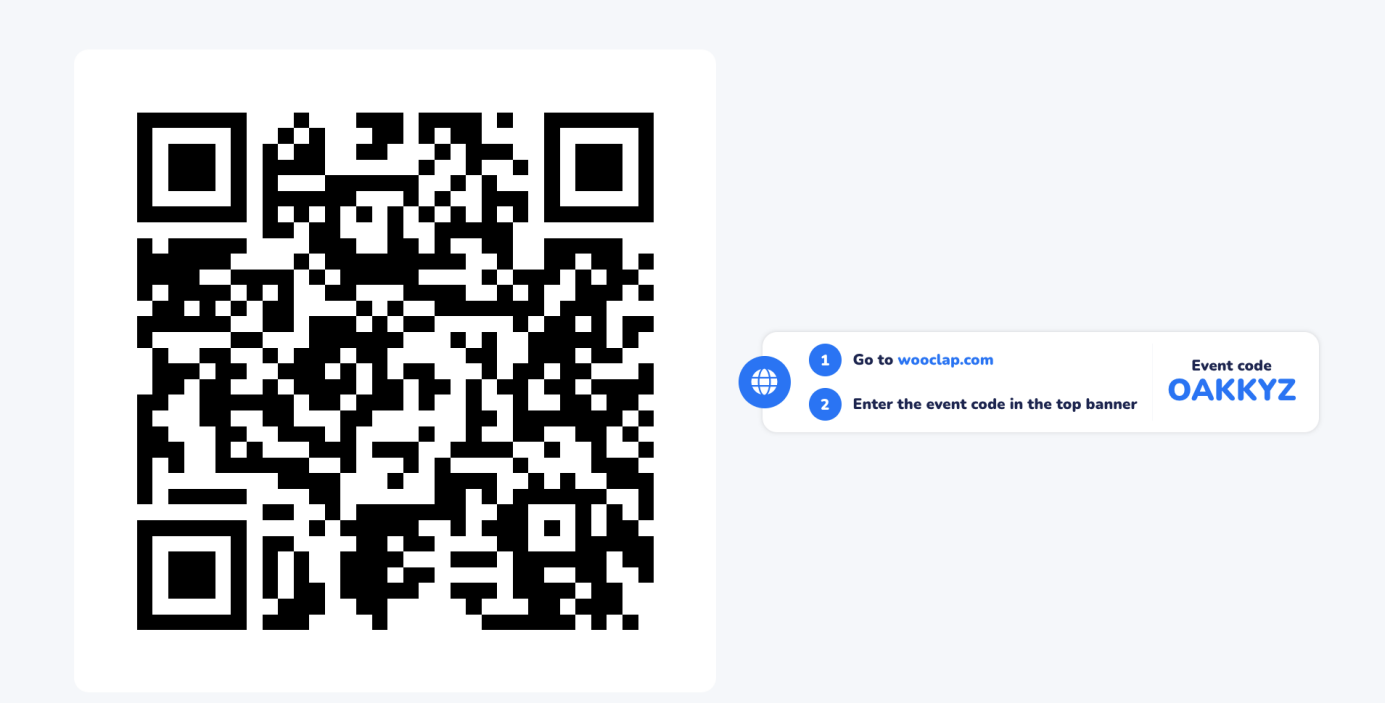


In 1993 started the PhD at Polimi
From 1996 to 1999 worked at CEFRIEL
In 1998 visiting researcher at UCI
From 1999 faculty at Polimi
Focuses:

- Software engineering
- Cloud computing
- Data intensive applications
- Infrastructure as Code
- Software engineering for quantum computing

Info about yourself…

- https://app.wooclap.com/OAKKYZ



Course logistics

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- Lectures will be in person (exceptional cases will be handled on the fly, and case-by-case)
- Schedule
  - Monday 8.15-10.15, room 3.1.6
  - Wednesday 12.15-14.15, room 3.1.12
- Lectures will be recorded and made available to help you during the exam preparation
- Course website is available on webeep. It will kept updated with
  - Course material, online books, announcements, course schedule, links to lecture recordings, homework assignments, …
- Monitor it regularly!

Course objective

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- Present the main software engineering methodologies and techniques to organize the **development** and **operation** of HPC applications.

Topics

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- Introduction to the software lifecycle
- Characteristics and qualities of HPC software
- Requirement engineering
- Software design and peculiarities of HPC software
- Software verification and peculiarities of HPC software
- Software configuration management and CI/CD pipelines
- Containment, scheduling and orchestration

Exams rules

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- A written exam and some practical activities (the project) developed during the course
- Written exam (up to 16 points, minimum required: 8 points)
  - Software testing and analysis exercises
  - Exercises focusing on design aspects
- Practical activities (up to 16 points, minimum required: 8 points)
  - A simple requirement analysis and software design assignment
  - Setup of a tool pipeline automating software integration, deployment, some operation steps

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Software Engineering

Definitions
The process and product
Phases of the development process
Flexible lifecycles

Why software engineering is important

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- Software is everywhere and our society is now totally dependent on software-intensive systems
- Society could not function without software
  - Transportation systems
  - Energy Systems
  - Manufacturing Systems
- Software failures cannot be tolerated

CrowdStrike Outage on July 19th, 2024

Travelers waiting to check in at the airport in Hamburg, Germany, on Friday. Bodo Marks/DPA, via Associated Press

Chaos and Confusion: Tech Outage Causes Disruptions Worldwide

Airlines, hospitals and people's computers were affected after CrowdStrike, a cybersecurity company, sent out a flawed software update.

Share full article 951

Details here : CrowdStrike 2024, External Technical Root Cause Analysis — Channel File 291
https://www.crowdstrike.com/wp-content/uploads/2024/08/Channel-File-291-Incident-Root-Cause-Analysis-08.06.2024.pdf

911 Outage in April 2014

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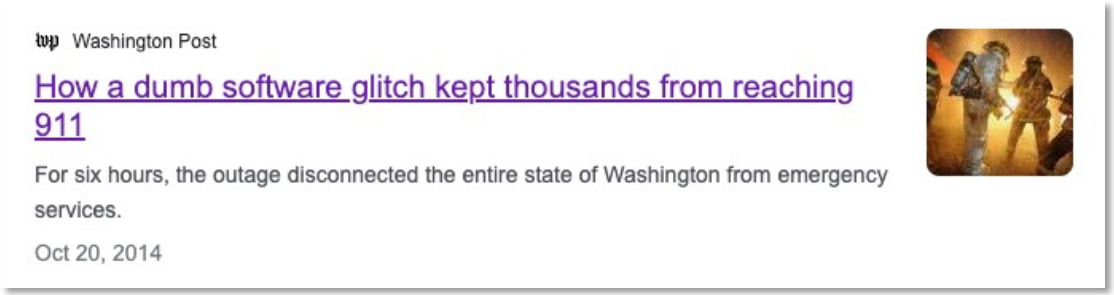
- [April 10, 2014] Washington State had **no 911 service for six hours**
  - 911 is the phone number for emergency service in USA
  - People calling were getting the busy signal
    - A woman called more than 37 times while a stranger was breaking into her house
  - People at the central office were not aware of the problem
  - More at: https://www.theatlantic.com/technology/archive/2017/09/saving-the-world-from-code/540393/



911 Outage in April 2014

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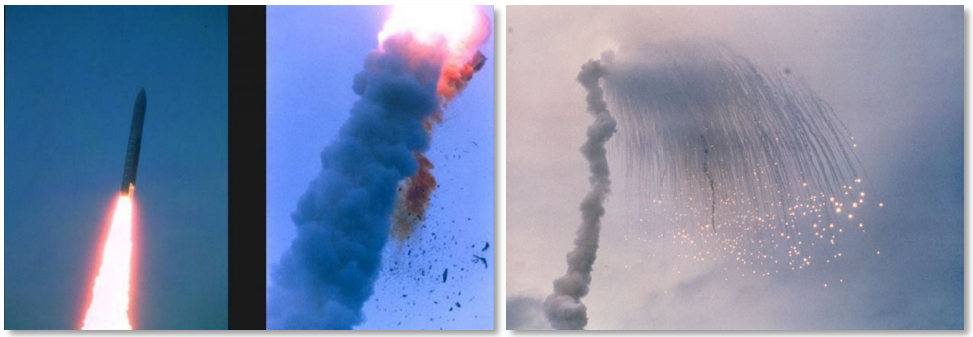
- Why did this happen? **Software issue!**
  - The software dispatching the calls had a counter used to assign a unique identifier to each call
  - The counter went over the threshold defined by developers…
  - All calls from that moment on were rejected

More on failures… Ariane 5, 1996

- [June 4, 1996] 40s after take off, Ariane 5 broke up and exploded
  - The total cost for developing the launcher has been of 8000M$
  - The launcher contained a cluster of satellites for a value of 500M$
  - More at
    - http://sunnyday.mit.edu/accidents/Ariane5accidentreport.html (accident tech report)
    - https://www.youtube.com/watch?v=PK_yguLapgA (video)



More on failures… Ariane 5, 1996

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- The explosion has been caused by a software failure
- From the tech report:
  - “The failure […] was caused by the complete loss of guidance and altitude information […]. This loss of information was due to **specification and design errors** in the software of the inertial reference system.”
  - “The extensive reviews and tests carried out during the Ariane 5 Development Programme **did not include adequate analysis and testing** of the inertial reference system or of the complete flight control system, which could have detected the potential failure.”

Software engineering: definition

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- Field of computer science dealing with software systems
  - large and complex
  - built by teams
  - exist in many versions
  - last many years
  - undergo changes
- Multi-person construction of multi-version software

Software engineer: required skills

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- **Programming skills not enough!**
  - Programmer:
    - develops a complete program
    - works on known specifications
    - works individually
  - Software engineer:
    - identifies requirements and develops specifications
    - designs a component to be combined with other components, developed, maintained, used by others; component can become part of several systems
    - works in a team

Skills of software engineers

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- Technical
- Project management
- Cognitive
- Enterprise organization
- Interaction with different cultures
- Domain knowledge

- The quality of human resources is of primary importance

Process and product

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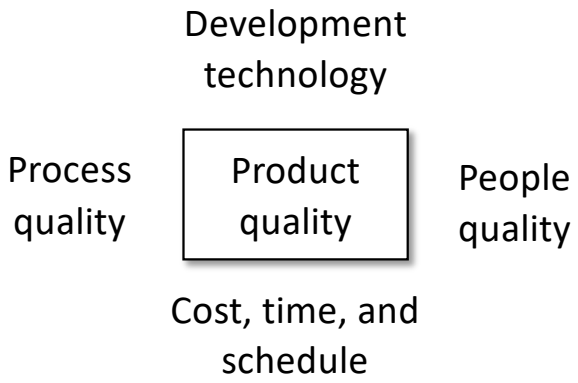
- Our goal is to develop **software products**
- The **process** is how we do it
- Both are extremely important, due to the nature of the software product
- Both have qualities
  - in addition, quality of process affects quality of product
  - …even though, other aspects such as the quality of the development team are important as well

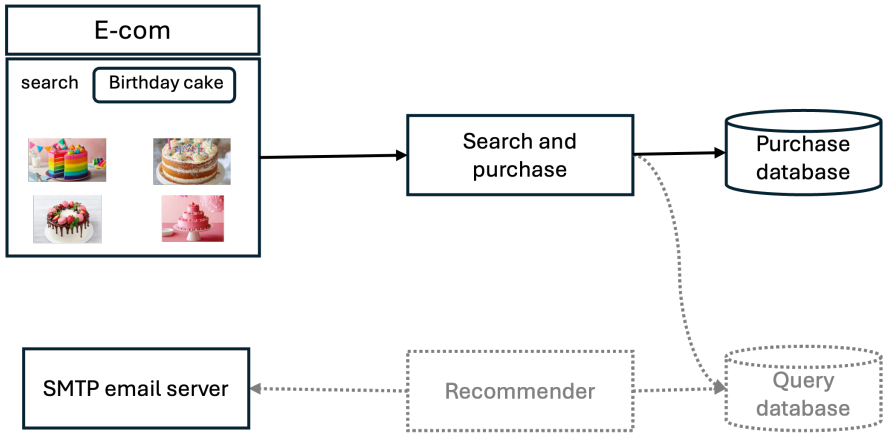
The software product

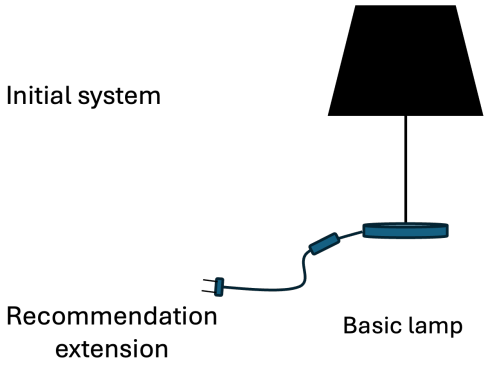
- Different from traditional types of products
  - intangible
    - difficult to describe and evaluate
  - malleable
  - human intensive
    - does not involve any trivial manufacturing process
- Aspects affecting product quality

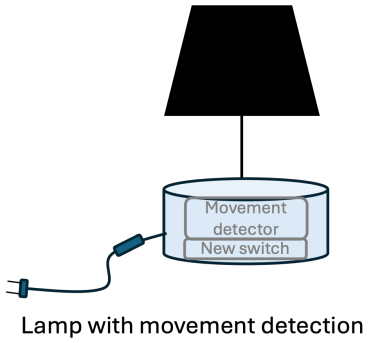


What does it mean for software to be malleable?

- Modifying an e-commerce system and a table lamp…

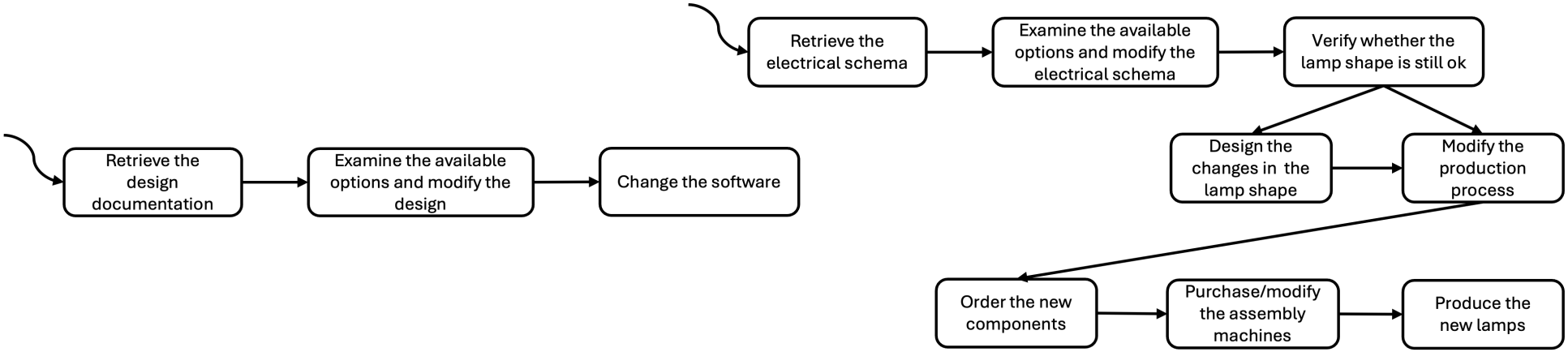






What does it mean for software to be malleable?

- E-commerce system vs table lamp: impact on the development process



Software product qualities – ISO/IEC 25010:2024 Software Quality Model

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SOFTWARE PRODUCT QUALITY								
FUNCTIONAL SUITABILITY	**PERFORMANCE EFFICIENCY**	**COMPATIBILITY**	**INTERACTION CAPABILITY**	**RELIABILITY**	**SECURITY**	**MAINTAINABILITY**	**FLEXIBILITY**	**SAFETY**
FUNCTIONAL COMPLETENESS FUNCTIONAL CORRECTNESS FUNCTIONAL APPROPRIATENESS iso25000.com	TIME BEHAVIOUR RESOURCE UTILIZATION CAPACITY	CO-EXISTENCE INTEROPERABILITY	APPROPRIATENESS RECOGNIZABILITY LEARNABILITY OPERABILITY USER ERROR PROTECTION USER ENGAGEMENT INCLUSIVITY USER ASSISTANCE SELF-DESCRIPTIVENESS	FAULTLESSNESS AVAILABILITY FAULT TOLERANCE RECOVERABILITY	CONFIDENTIALITY INTEGRITY NON-REPUDIATION ACCOUNTABILITY AUTHENTICITY RESISTANCE	MODULARITY REUSABILITY ANALYSABILITY MODIFIABILITY TESTABILITY	ADAPTABILITY SCALABILITY INSTALLABILITY REPLACEABILITY	OPERATIONAL CONSTRAINT RISK IDENTIFICATION FAIL SAFE HAZARD WARNING SAFE INTEGRATION

https://iso25000.com/index.php/en/iso-25000-standards/iso-25010

Process qualities: productivity

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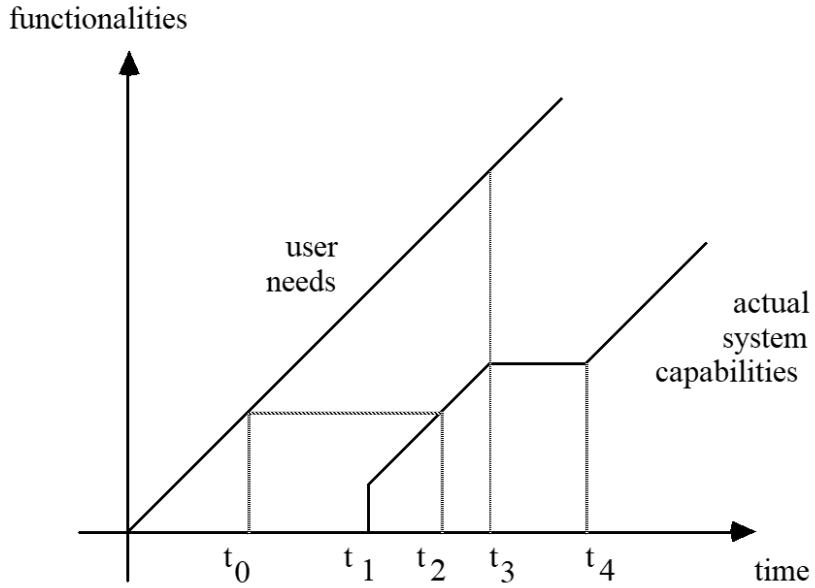
- Ability to produce a “good” amount of product
- How can we measure it? → Delivered items by unit of effort

lines of code (and variations)
function points

person month
WARNING: persons and months cannot be interchanged

Process qualities: timeliness

- Ability to respond to change requests in a timely fashion



Software lifecycles

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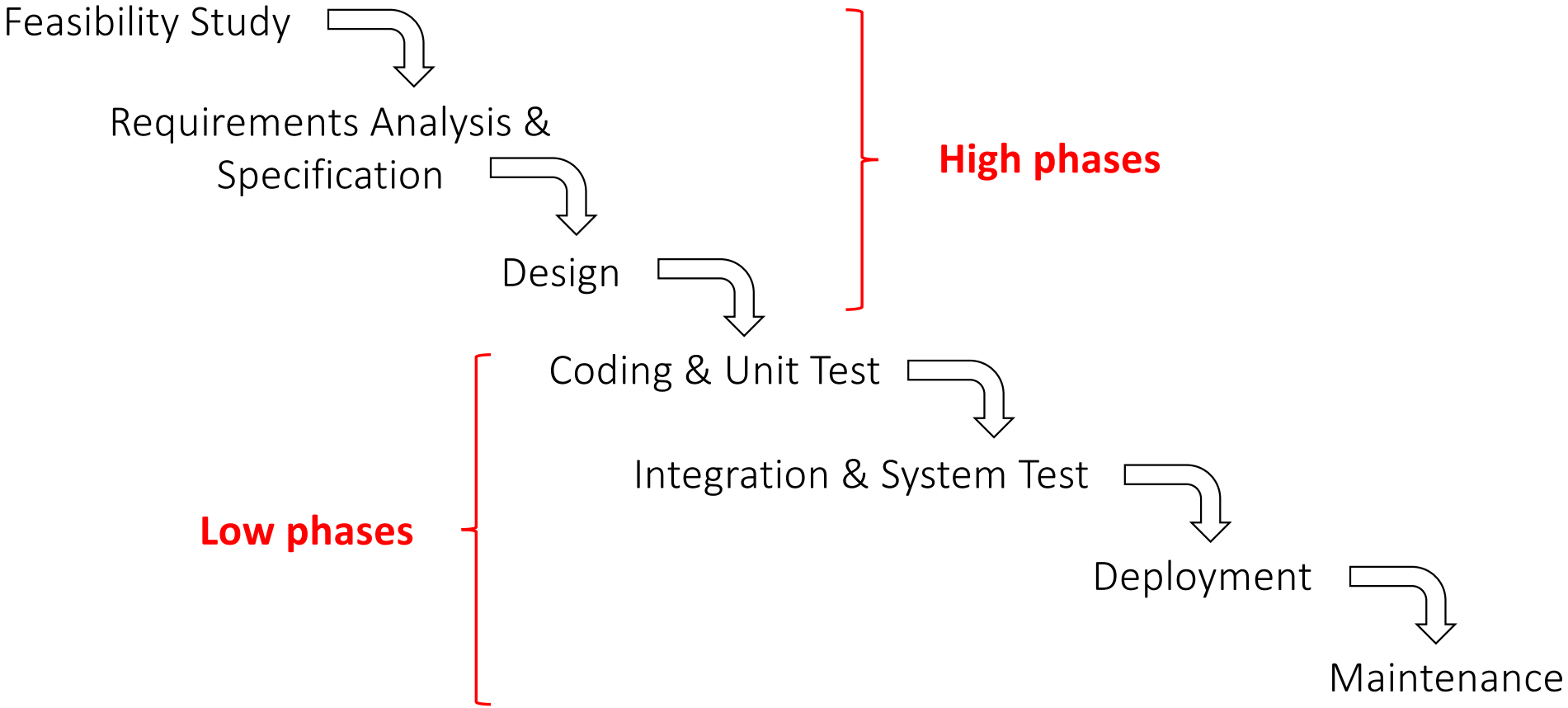
- Initially, no reference model: Just code & fix
- As a reaction to the many problems: traditional “waterfall” model
  - identify phases and activities
  - force linear progression from a phase to the next
  - no returns (they are harmful)
    - better planning and control
  - standardize outputs (artifacts) from each phase
  - Software like manufacturing
- Then, flexible processes: iterative models, agile methods, DevOps

A waterfall organization



Feasibility study & project estimation

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- Cost/benefit analysis
- Determines whether the project should be started (e.g., buy vs make), possible alternatives, needed resources
- Outcome
  - **Feasibility Study Document**
    - Preliminary problem description
    - Scenarios describing possible solutions
    - Costs and schedule for the different alternatives

Requirement analysis and specification

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- Analyze the domain in which the application takes place
- Identify requirements
- Derive specifications for the software
  - Requires an (continuous) interaction with the user
  - Requires an understanding of the properties of the domain
- Outcome
  - **Requirements Analysis and Specification Document (RASD)**

Design

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- Defines the software architecture
  - Components (modules)
  - Relations among components
  - Interactions among components
- Goal
  - Support concurrent development, separate responsibilities
- Outcome
  - **Design Document**

Coding&Unit level quality assurance

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- Each module is implemented using the chosen programming language
- Each module is tested in isolation by the module developer
- Inspection can be used as an additional quality assurance approach
- Programs include their documentation

Integration&System test

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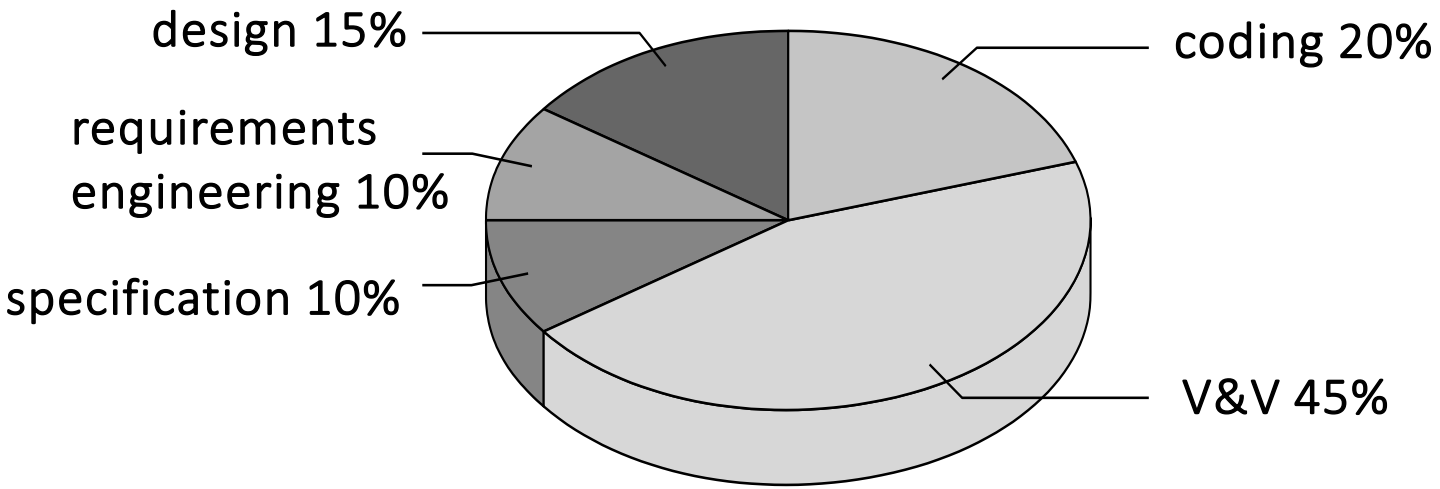
- Modules are integrated into (sub)systems
- Integrated (sub)systems are tested
- Follows an incremental implementation scheme
- Complete system test needed to verify overall properties
- Sometimes we have **alpha test** and **beta test**

Effort distribution (van Vliet 2008)



Maintenance

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- Corrective maintenance: deals with the repair of faults or defects found ≈ 20%
- Evolution
  - **adaptive** maintenance: consists of adapting software to changes in the environment (the hardware or the operating system, business rules, government policies…) ≈ 20%
  - **perfective** maintenance: mainly deals with accommodating to new or changed user requirements ≈ 50%
  - **preventive** maintenance: concerns activities aimed at increasing the system's maintainability ≈ 10%

Correction vs evolution

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- Distinction can be unclear, because specifications are often incomplete and ambiguous
- This causes problems because specs are often part of a contract between developer and customer
  - early frozen specs can be problematic, because they are more likely to be wrong

Problems of software evolution

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- It is (almost) never anticipated and planned; this causes disasters
- Software is very easy to change
  - often, under emergency, changes are applied directly to code
  - inconsistent state of project documents

How to face evolution

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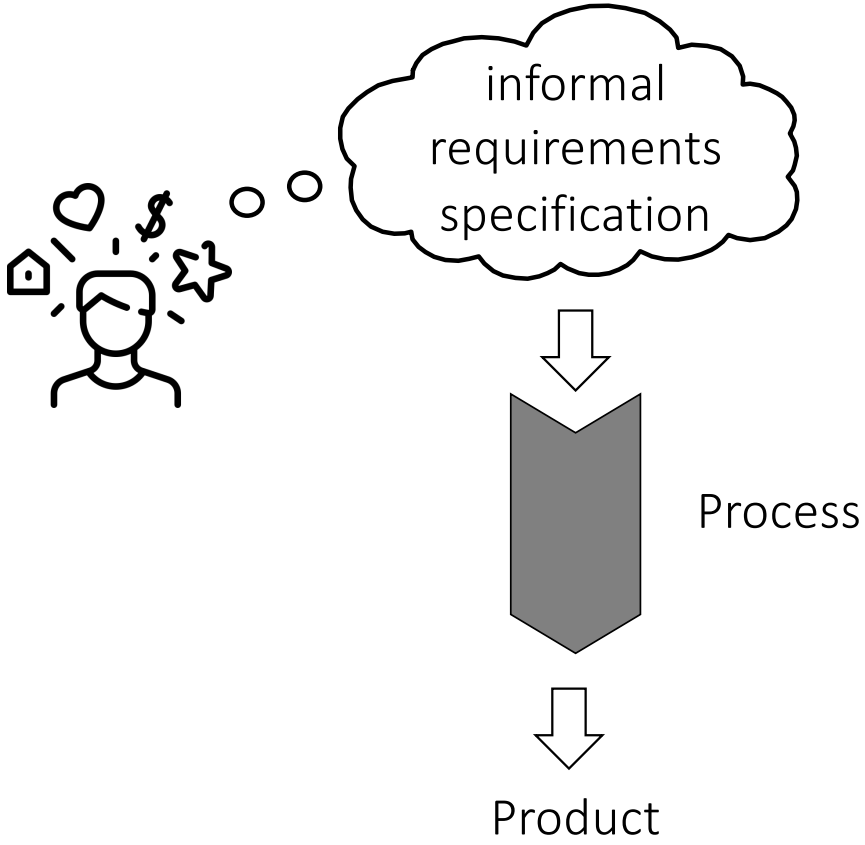
- Good engineering practice:
  - first modify design, then change implementation
  - apply changes consistently in all documents
- Likely changes must be anticipated
- Software must be designed to accommodate changes in a cost-effective way

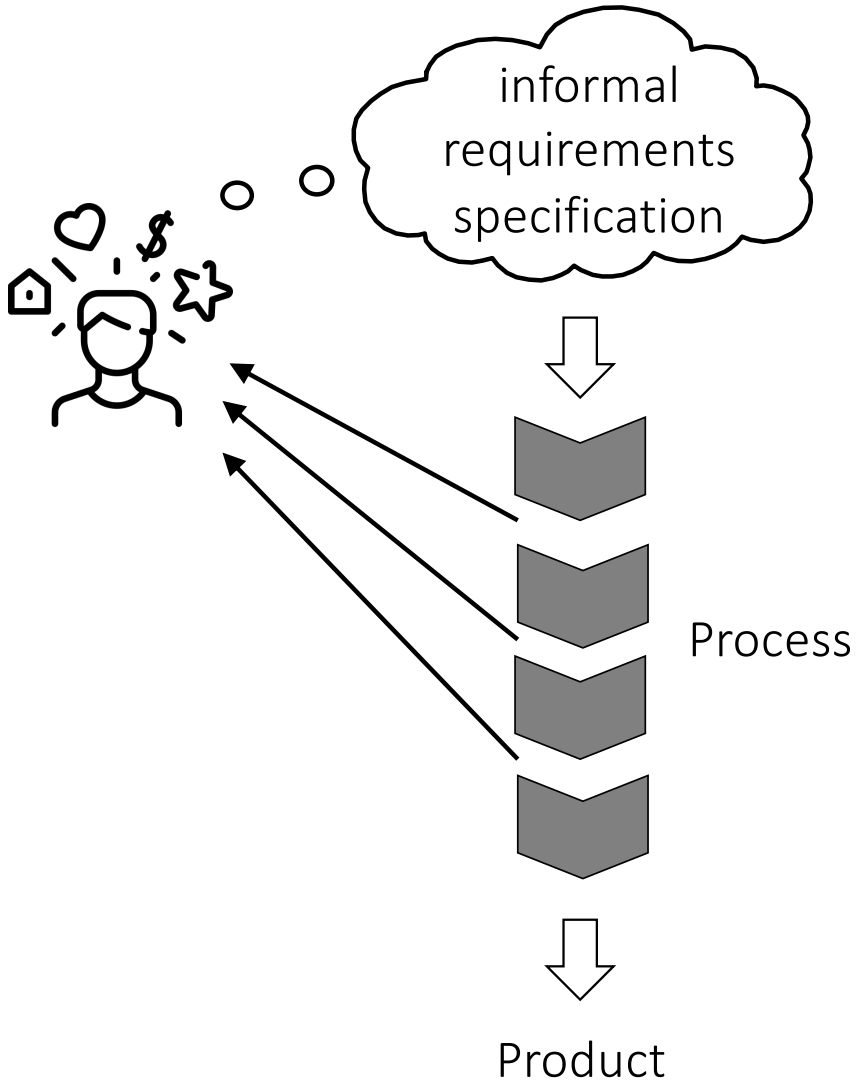
- **This is one of the main goals of software engineering**

Waterfall is “black box”

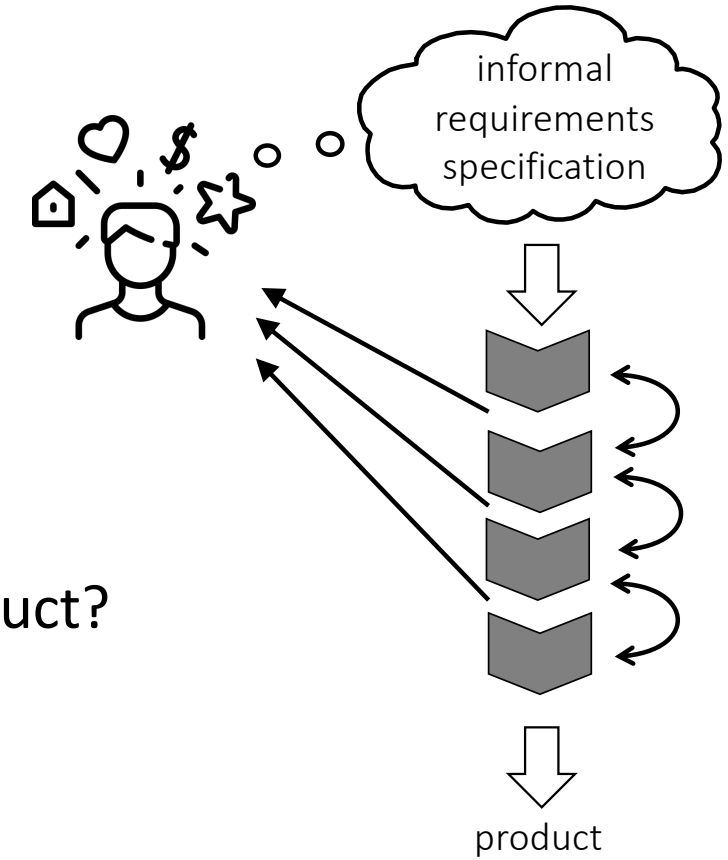


Need for transparency

- Transparency allows early check and change via feedback
- It supports flexibility



Verification and validation



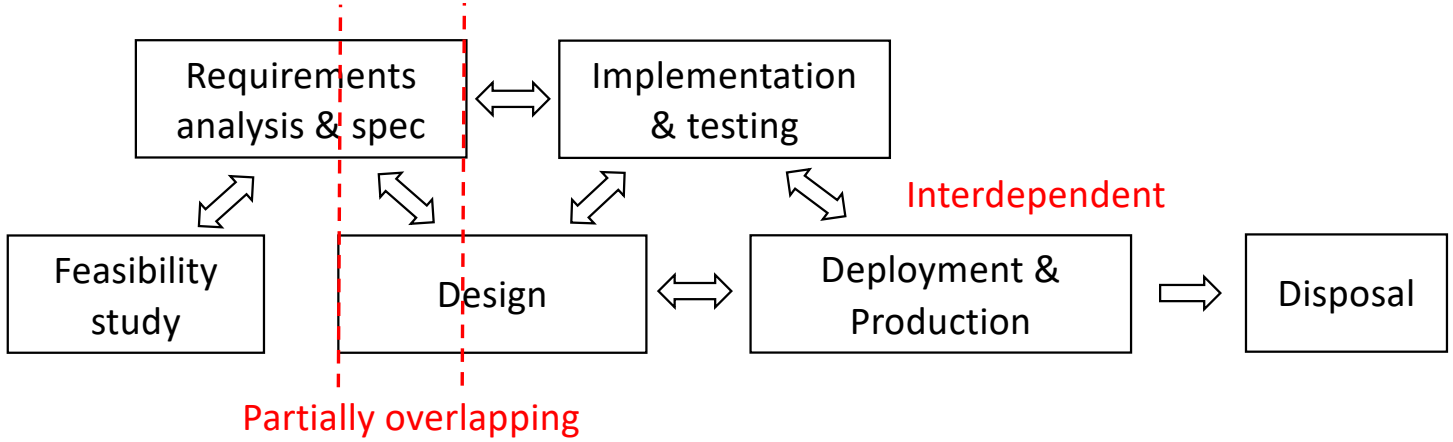
Validation:
are we making
the ”right” product?

Verification:
are we doing
the product right?

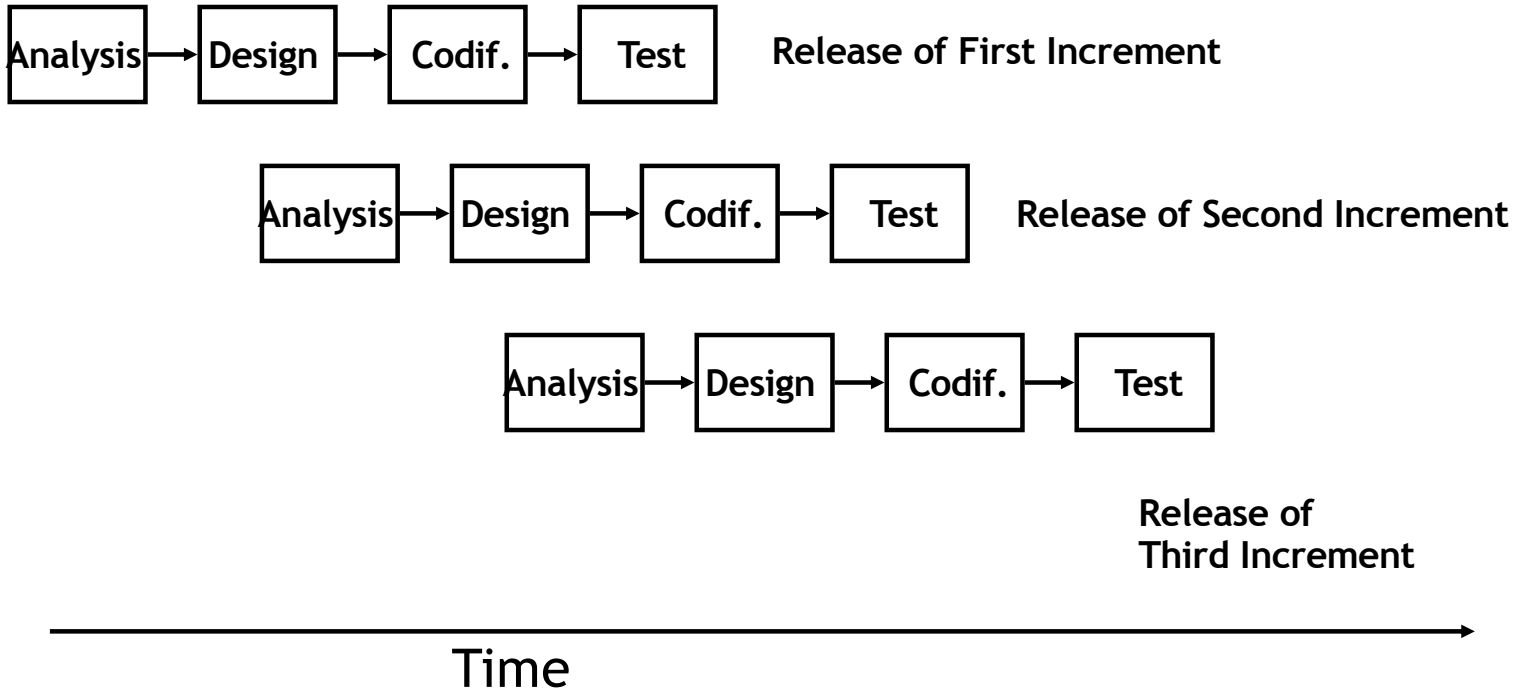
Flexible processes

- Main goal: adapt to changes (especially in requirements and specs)
- The very idea:
  - stages are not necessarily sequential
  - processes become iterative and incremental

Example



Incremental delivery



The agile manifesto - principles

https://agilemanifesto.org/

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- Our highest priority is to satisfy the customer through early and continuous delivery of valuable software.
- Welcome changing requirements, even late in development. Agile processes harness change for the customer's competitive advantage.
- Deliver working software frequently, from a couple of weeks to a couple of months, with a preference to the shorter timescale.
- Business people and developers must work together daily throughout the project.
- Build projects around motivated individuals. Give them the environment and support they need, and trust them to get the job done.
- The most efficient and effective method of conveying information to and within a development team is face-to-face conversation.
- Working software is the primary measure of progress.

The agile manifesto - principles

https://agilemanifesto.org/

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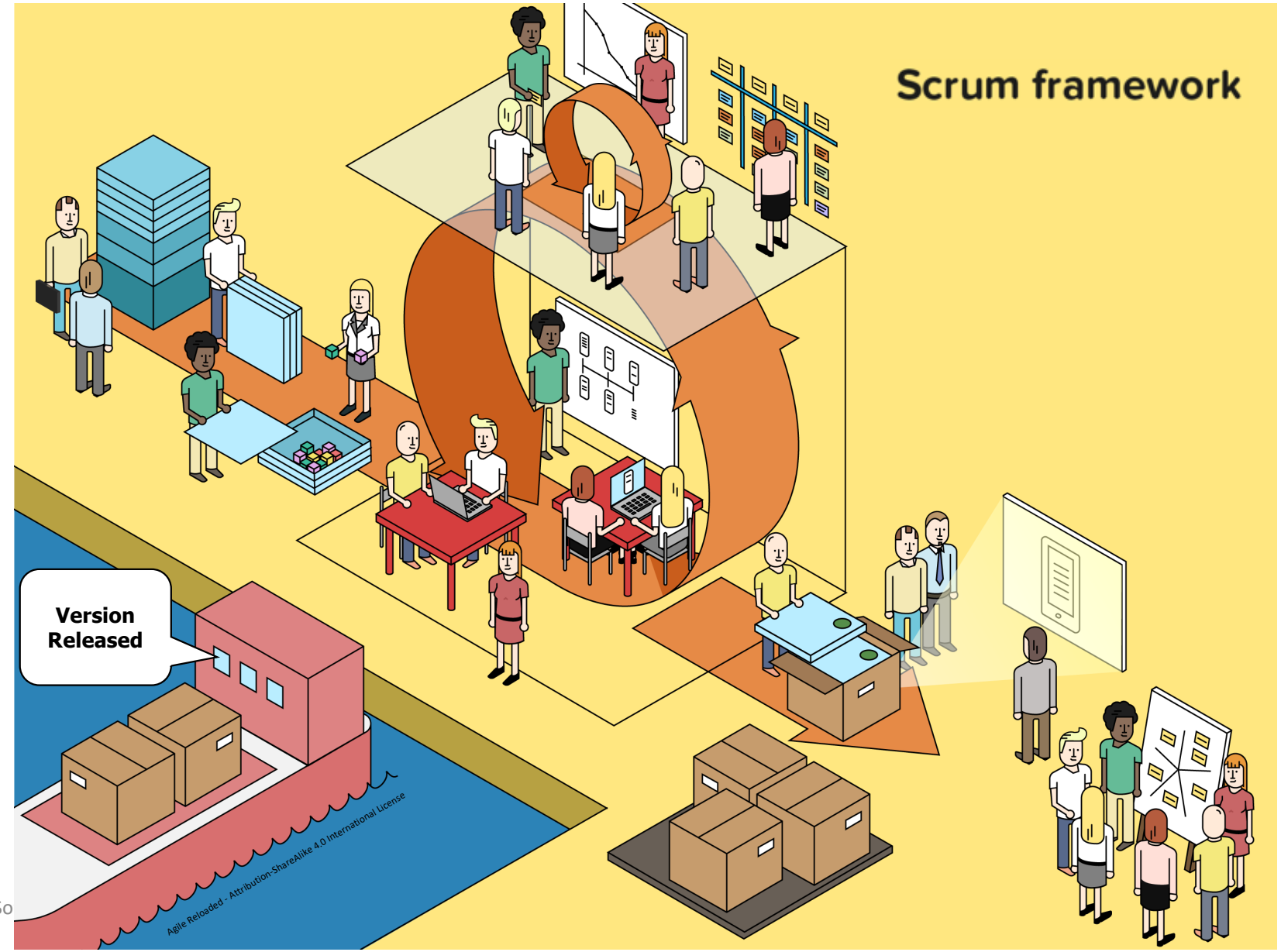
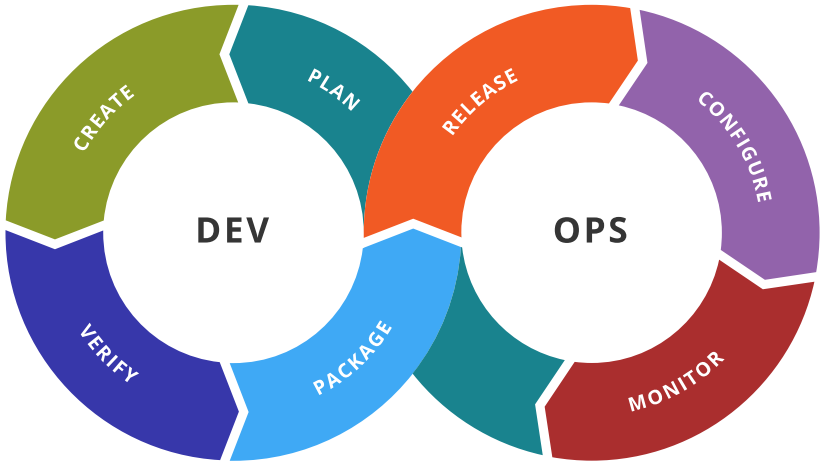
- Agile processes promote sustainable development. The sponsors, developers, and users should be able to maintain a constant pace indefinitely.
- Continuous attention to technical excellence and good design enhances agility.
- Simplicity--the art of maximizing the amount of work not done--is essential.
- The best architectures, requirements, and designs emerge from self-organizing teams.
- At regular intervals, the team reflects on how to become more effective, then tunes and adjusts its behavior accordingly.


Scrum framework
Version Released
Agile Reloaded - Attribution-ShareAlike 4.0 International License

So

DevOps (Development and Operation)



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Waterfall vs. Agile vs. DevOps

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Concerns	Waterfall	Agile	DevOps
Main Focus	Design and development	Design and development	**Whole application life-cycle**
Attention to Operation	Minimal or none	Minimal or none	**Main concern**
Role of Maintenance	Maintenance seen as a redevelopment phase	Maintenance seen as a redevelopment phase	**Replaces a running system with a running system**
Process Outcome	A packaged system ready to be deployed	*Various intermediate demo versions of the system*	**A continuously updated running system**
Quality Assurance	Testing typically performed toward the end of the process	*Test-driven development*	**Test-driven development and monitoring-driven operation with feedback to Dev**

“Assignment” for next lecture (Wednesday)

- Prepare your own answers to the following questions
  - What is High Performance Computing?
  - What are the qualities a HPC software should offer?
  - What are the most critical issues we should pay attention to during the lifecycle of HPC software?