Introduction to Software V&V

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Synopsis of the course

- Introduction
- Verification in the requirement phase
- Architecture verification and evaluation
- Verification of the detailed design
  - Classic techniques
  - Formal methods: model checking, equivalence checking
  - Advanced methods: formal verification of extra-functional properties and timed behavior, handling complex designs (large state spaces)
- Verification of the source code
  - Code review, abstract interpretation, symbolic execution
  - Classic techniques of proving program correctness
- Testing and test case generation
  - Test design at unit level
  - Integration and system testing
  - Model based testing and test case generation
- Validation and assessment
- V&V in the maintenance phases
- Integrated approaches

Contents of the lecture

- Motivation
  - What are the quality needs regarding software and what is offered by the software industry?
  - What is the role of software verification and validation techniques?
- Overview of the techniques of software V&V
  - What are the typical techniques in the development process?
- Development life cycle models
  - What is the role of V&V in the different life cycle models?

Motivation

What are the quality needs regarding software and what is offered by the software industry?

What is the role of software verification and validation techniques?

High expectations

- Service Level Agreements (SLA) in IT infrastructure
  - Availability (telco servers): 99,999% (5 min/year outage)
- Safety critical systems:
  - Tolerable hazard rate (THR)
  - Categorized into Safety Integrity Levels (SIL)

SIL	Probability of dangerous failure per hour per safety function
1	$10^{-6} \leq PFH < 10^{-5}$
2	$10^{-7} \leq PFH < 10^{-6}$
3	$10^{-8} \leq PFH < 10^{-7}$
4	$10^{-9} \leq PFH < 10^{-8}$

15 years lifetime:
1 failure in case of
750 equipment

Operation without
failure for approx.
11.000 years???

Reality: Different kinds of faults

Development phase

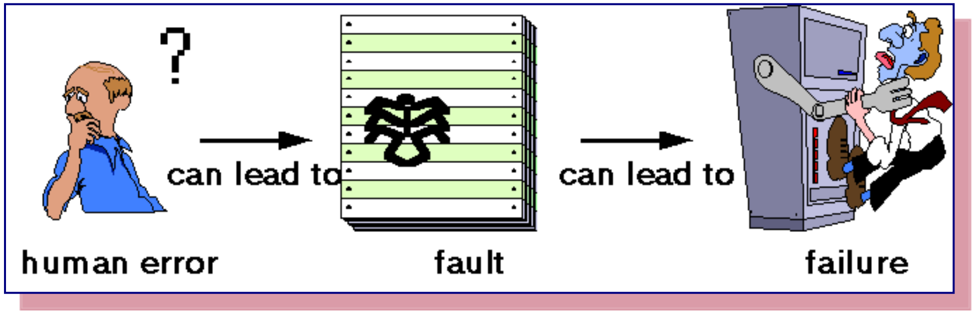
- Specification faults
- Design faults
- Implementation faults

V&V during development

Operational phase

- Hardware faults
- Configuration faults
- Operator faults

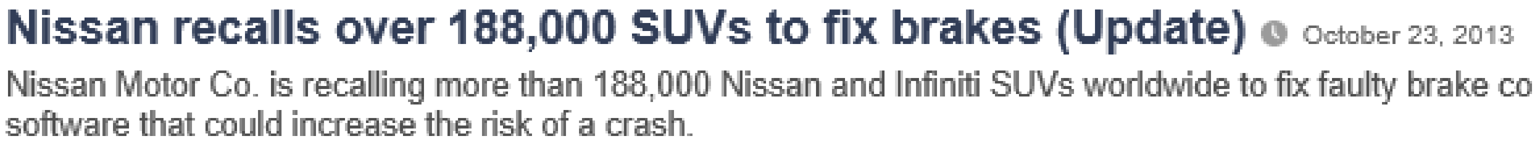
Fault tolerance (e.g. redundancy)



Software quality problems due to development faults

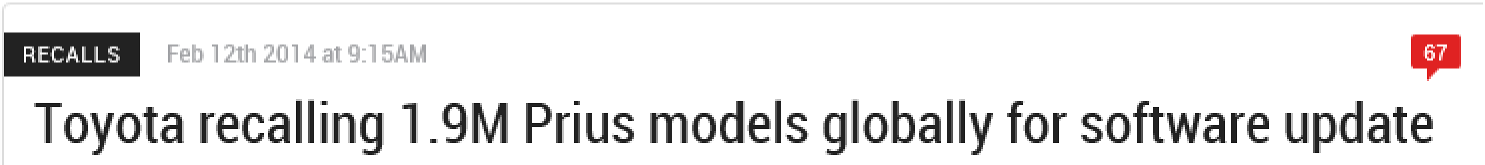
„Defibtech issues a worldwide recall of two of its defibrillator products due to faulty self-test software that may clear a previously detected low battery condition.” (February 2007)

„Cricket Communications recalls about 285,000 of its cell phones due to a software glitch that causes audio problems when a caller connects to an emergency 911 call. (May 2008)”



Nissan recalls over 188,000 SUVs to fix brakes (Update) October 23, 2013

Nissan Motor Co. is recalling more than 188,000 Nissan and Infiniti SUVs worldwide to fix faulty brake control software that could increase the risk of a crash.



RECALLS Feb 12th 2014 at 9:15AM 67

Toyota recalling 1.9M Prius models globally for software update

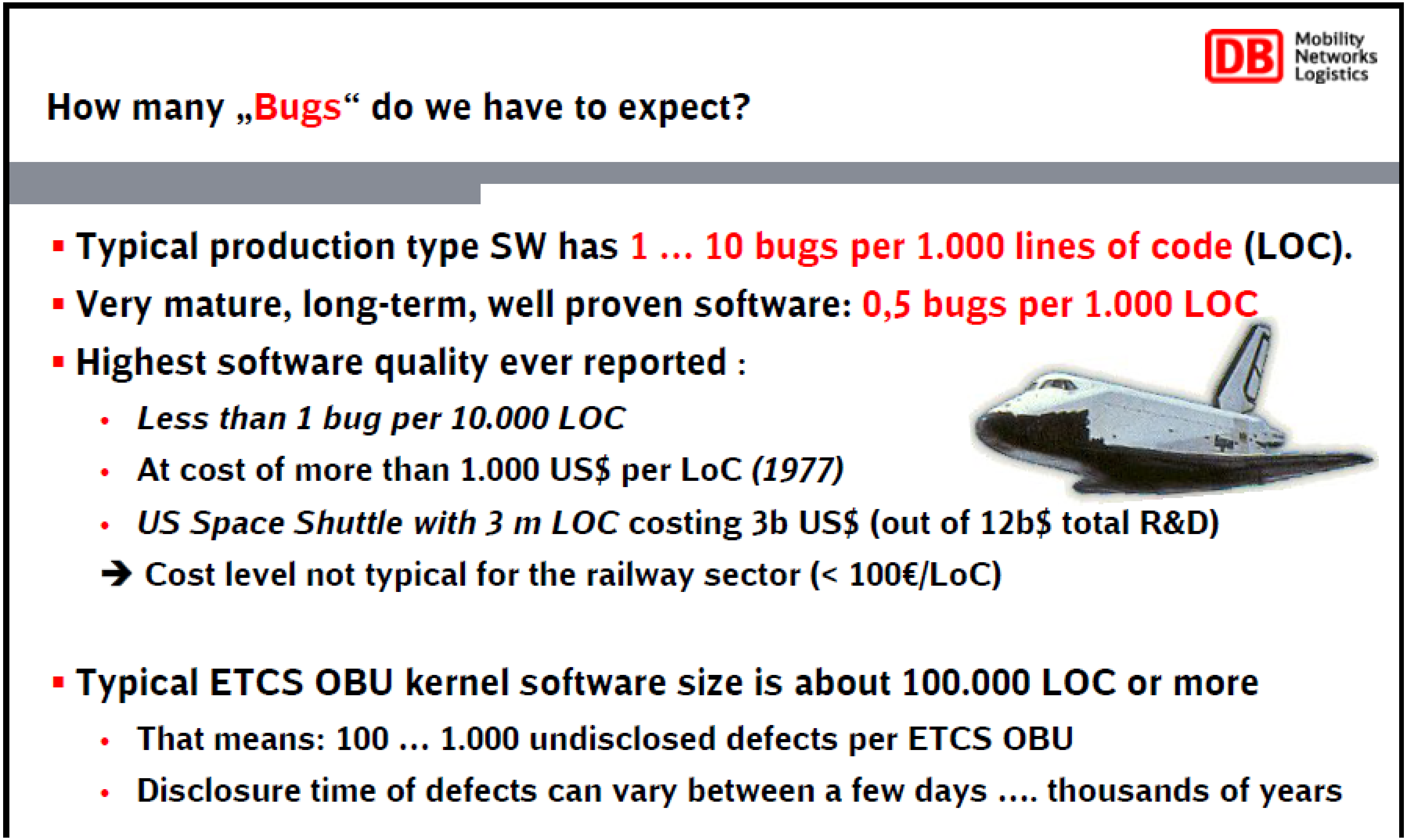
Statistics for software projects

- Typical code size of complex applications
  - 10 kLOC … 1000 kLOC
- Development efforts:
  - Big but average software: 0.1 – 0.5 person months / kLOC
  - Safety critical software: 5-10 person months / kLOC
- Fault removal (review, testing, corrections):
  - 45 - 75% of the whole development efforts
- Change of fault density
  - 10 - 200 faults / kLOC occurring during development

    ↓ Verification and fault removal techniques

  - 0.1 - 10 faults / kLOC before operation

How many bugs do we have to expect?



Mobility Networks Logistics

How many „Bugs“ do we have to expect?

- Typical production type SW has 1 … 10 bugs per 1.000 lines of code (LOC).
- Very mature, long-term, well proven software: 0,5 bugs per 1.000 LOC
- Highest software quality ever reported :
  - *Less than 1 bug per 10.000 LOC*
  - At cost of more than 1.000 US$ per LoC *(1977)*
  - *US Space Shuttle with 3 m LOC* costing 3b US$ (out of 12b$ total R&D)

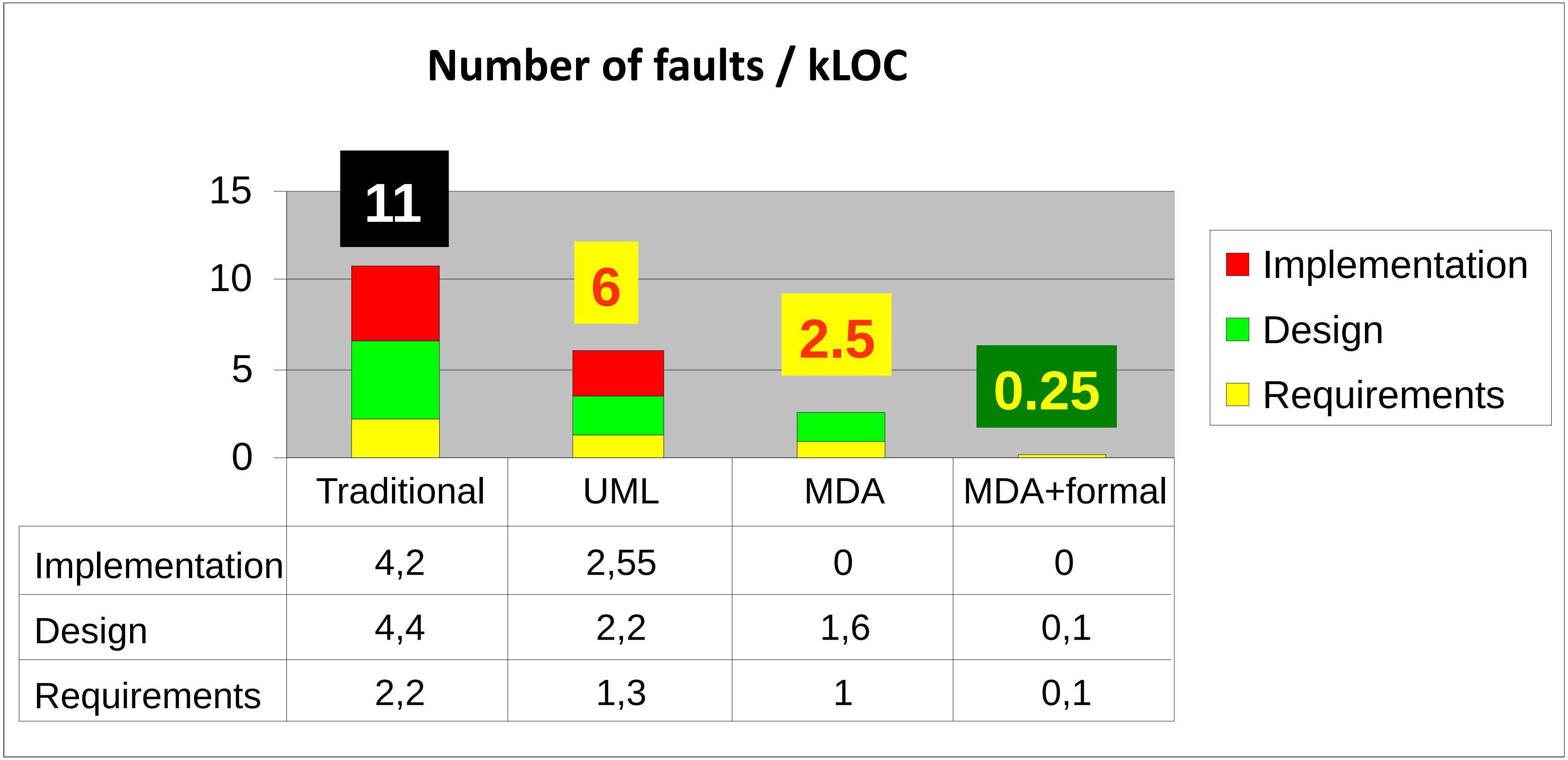
  ➔ Cost level not typical for the railway sector (< 100€/LoC)

- Typical ETCS OBU kernel software size is about 100.000 LOC or more
  - That means: 100 … 1.000 undisclosed defects per ETCS OBU
  - Disclosure time of defects can vary between a few days …. thousands of years

Source: K-R. Hase: „Open Proof in Railway Safety Software”, FORMS/FORMAT Conference, Braunschweig, Germany

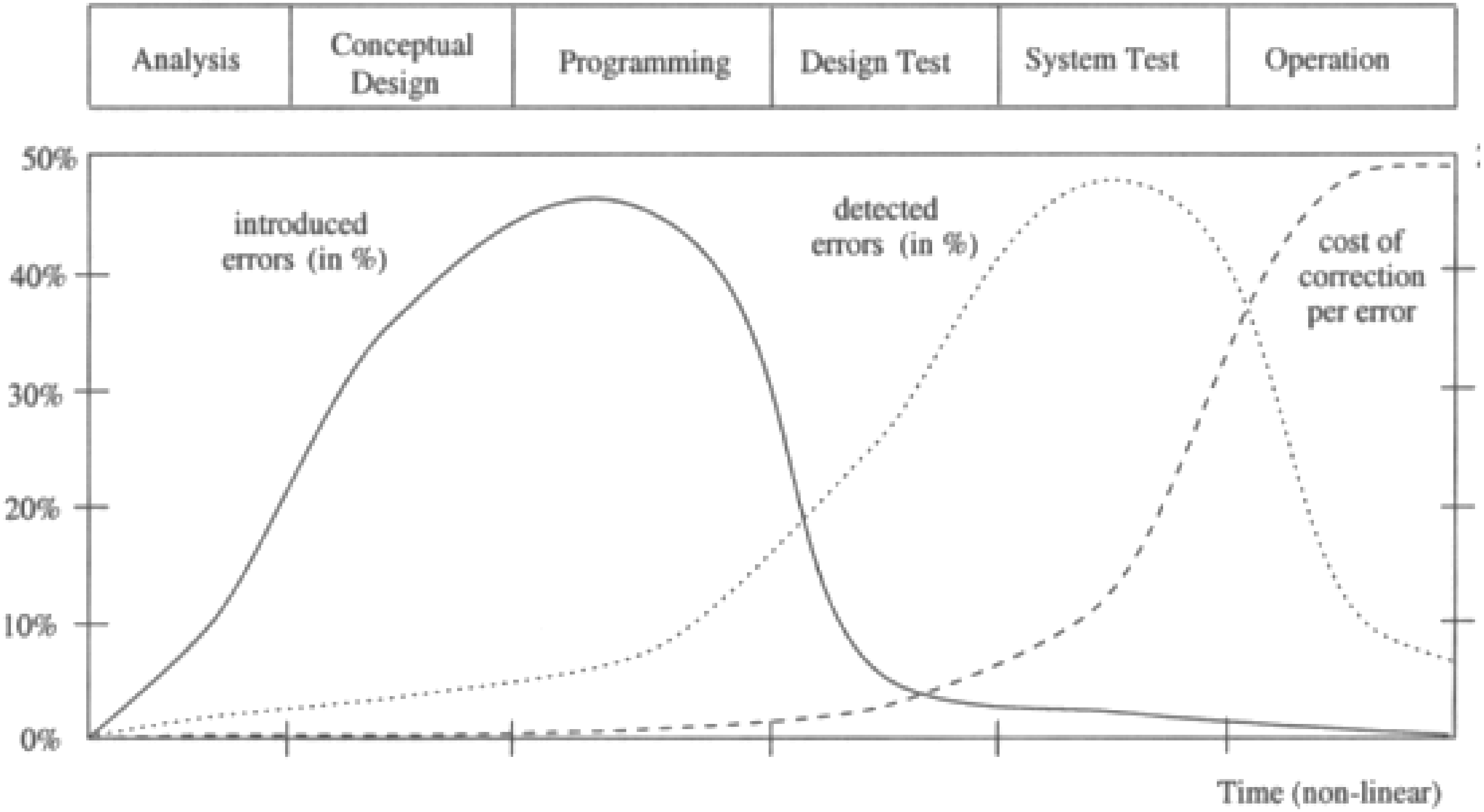
A study in Hungary

- Number of faults in 1 kLOC (embedded software):
  - Manual development and testing: ~ 10 faults
  - Tool-supported automated development: ~ 1-2 faults
  - Automated development with formal methods: < 1 faults



	Traditional	UML	MDA	MDA+formal
Implementation	4,2	2,55	0	0
Design	4,4	2,2	1,6	0,1
Requirements	2,2	1,3	1	0,1

Distribution and cost of bugs

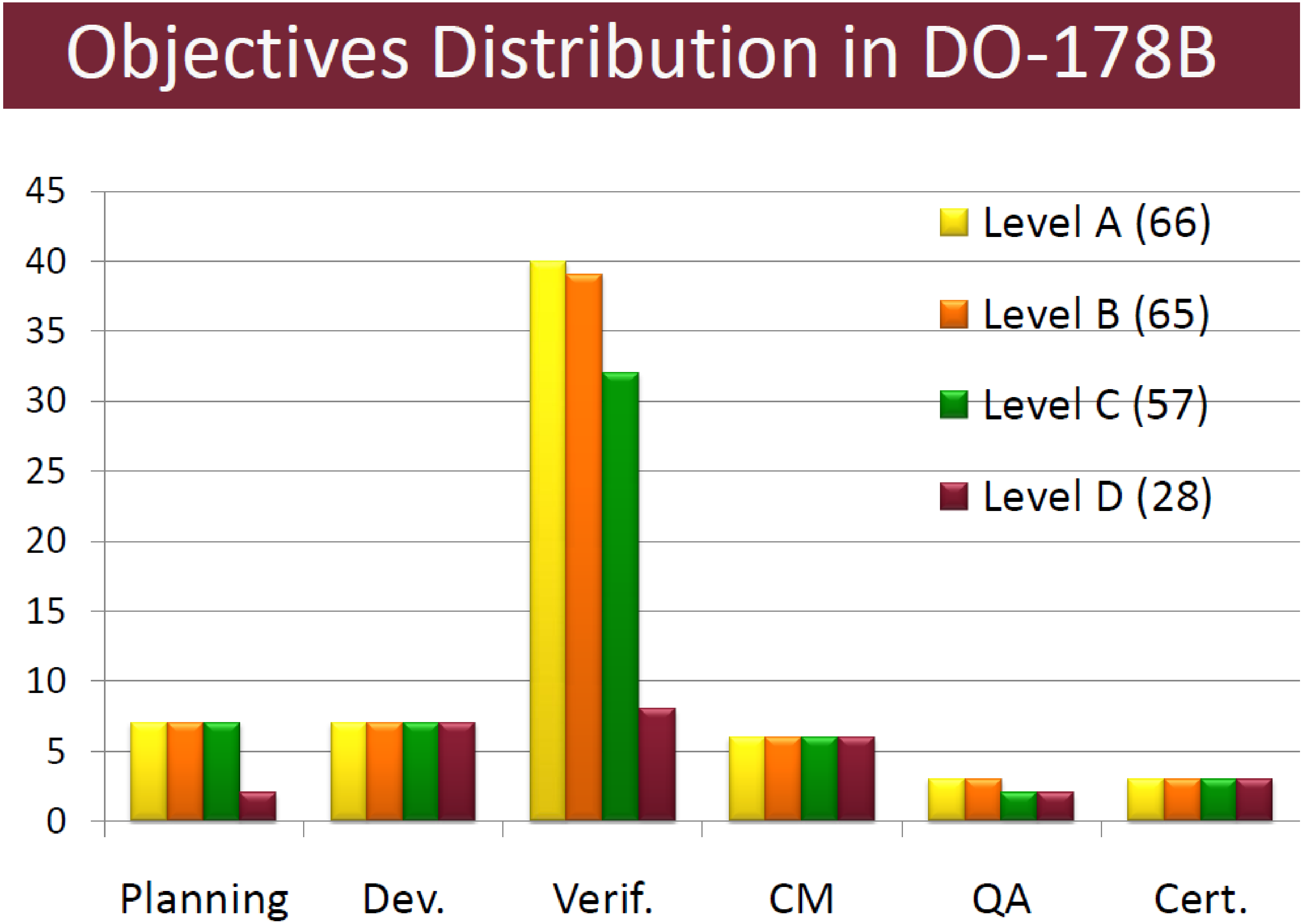


Early V&V reduces cost!

V&V: Verification and Validation

Verification	Validation
„Am I building the system right?”	„Am I building the right system?”
Check correctness and consistency of development phases	Check the result of the development
Conformance of designs/models and their specification	Conformance of the (finished) system and the user requirements
Objective (based on facts); can be automated	Subjective (influenced by user expectations); checking acceptance
Fault model: Faults in the design and implementation	Fault model: Faults in the requirements are also included
Not needed if implementation is automatically generated from specification	Not needed if the specification is correct (very simple)

Example: Development of flight control SW



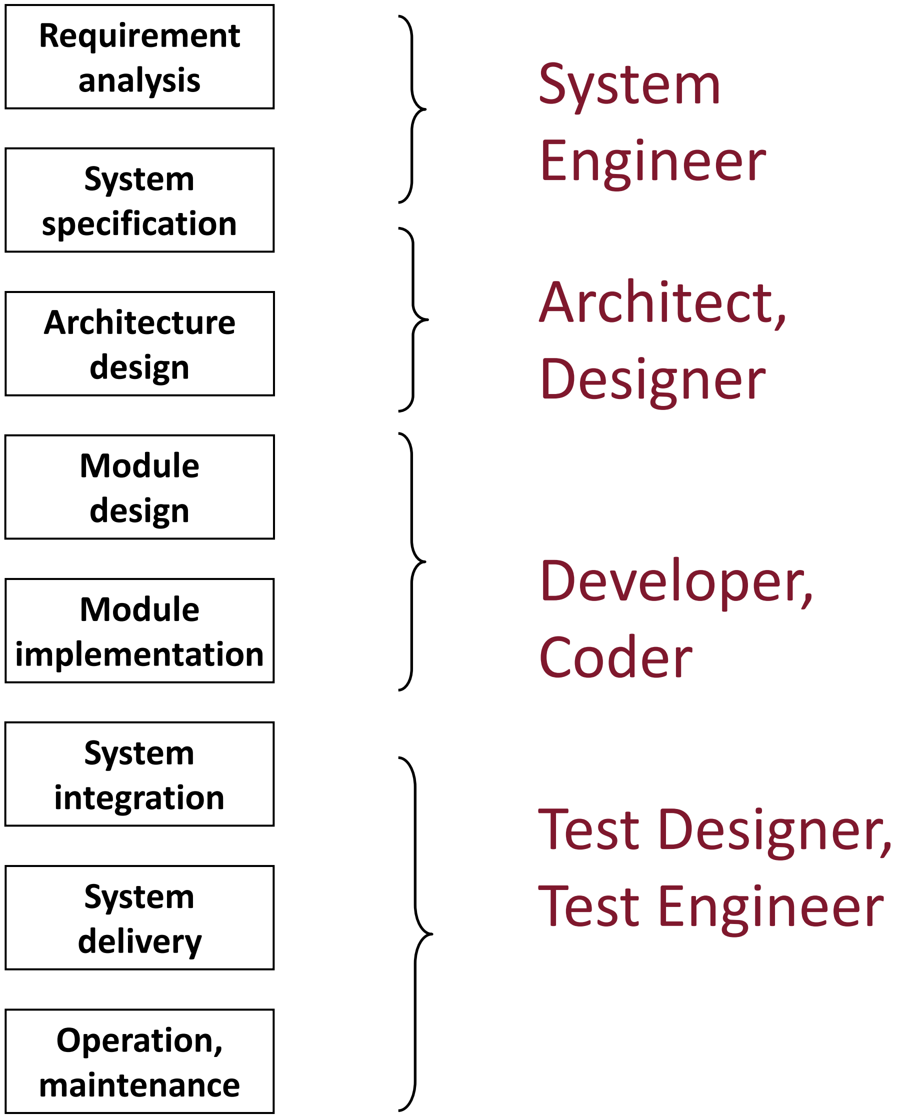
Overview of the techniques of software V&V

What are the typical techniques in the development process?

Who is concerned by V&V?

System Engineer	• Verifying requirement specification
Architect, Designer	• Modeling and verifying designs
Developer, Coder	• Verifying source code, unit testing
Test Designer	• Designing test processes and techniques
Test Engineer	• Test automation, integration and system tests
Safety Engineer	• Assessment w.r.t. development standards

What are the typical development steps?

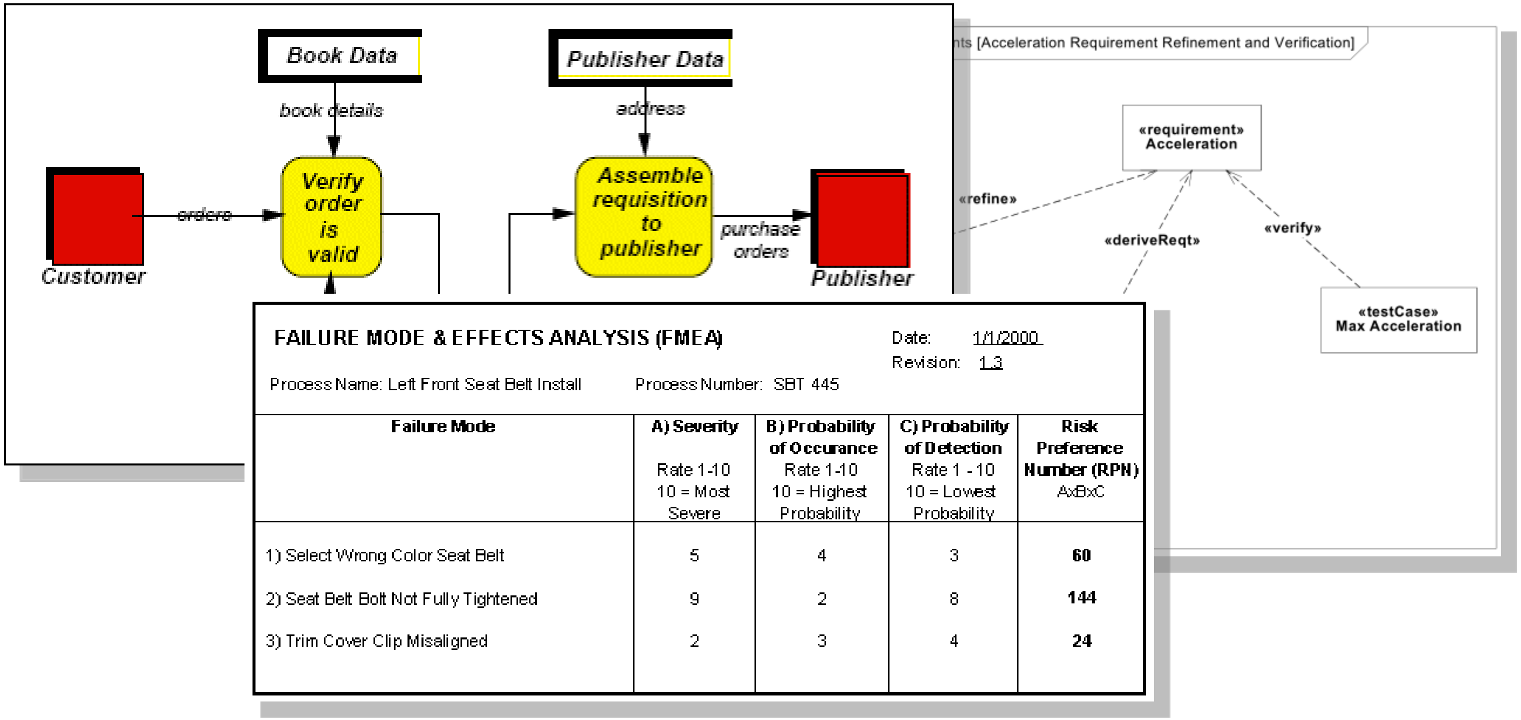


Schedule and sequencing depends on the lifecycle model (see later)

Requirement analysis

- **Requirement analysis**
- **System specification**
- **Architecture design**
- **Module design**
- **Module implementation**
- **System integration**
- **System delivery**
- **Operation, maintenance**

Task	V&V criteria	V&V technique
Defining system functions, actors, use cases	- Risks - Criticality	- Checklists - Failure mode and effects analysis


Book Data
book details
Publisher Data
address
Customer
orders
Verify order is valid
Assemble requisition to publisher
purchase orders
Publisher
nts [Acceleration Requirement Refinement and Verification]
«requirement» Acceleration
«refine»
«deriveReqt»
«verify»
«testCase» Max Acceleration

FAILURE MODE & EFFECTS ANALYSIS (FMEA)

Date: 1/1/2000
Revision: 1.3

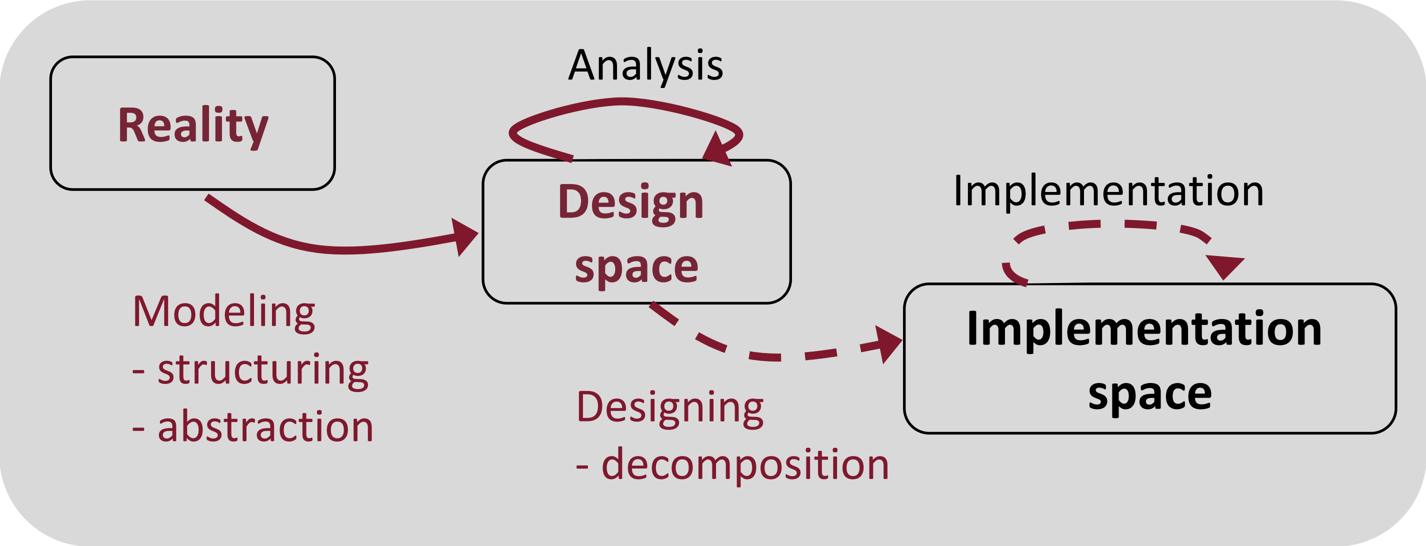
Process Name: Left Front Seat Belt Install   Process Number: SBT 445

Failure Mode	A) Severity Rate 1-10 10 = Most Severe	B) Probability of Occurance Rate 1-10 10 = Highest Probability	C) Probability of Detection Rate 1 - 10 10 = Lowest Probability	Risk Preference Number (RPN) AxBxC
1) Select Wrong Color Seat Belt	5	4	3	**60**
2) Seat Belt Bolt Not Fully Tightened	9	2	8	**144**
3) Trim Cover Clip Misaligned	2	3	4	**24**

System specification

- Requirement analysis
- System specification
- Architecture design
- Module design
- Module implementation
- System integration
- System delivery
- Operation, maintenance

Task	V&V criteria	V&V technique
Defining functional and non-functional requirements	- Completeness - Consistency - Verifiability - Feasibility	- Reviews - Static analysis - Simulation



Reality

Analysis

Design space

Implementation

Implementation space

Modeling
- structuring
- abstraction

Designing
- decomposition

System specification

Requirement analysis

System specification

Architecture design

Module design

Module implementation

System integration

System delivery

Operation, maintenance

Task	V&V criteria	V&V technique
Defining functional and non-functional requirements	- Completeness - Consistency - Verifiability - Feasibility	- Reviews - St c analysis tion

Review:

1. Assembling a checklist
2. Presentation by the developer
3. Answering the questions of reviewers
4. Discussion, preparing the review report

Types of peer review:

- Round robin: Different leader for reach module
- Walkthrough: The developer “guides” the reviewers
- Inspection: Based on a (formal) checklist

System specification

- Requirement analysis
- **System specification**
- Architecture design
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Task	V&V criteria	V&V technique
Defining functional and non-functional requirements	- Completeness - Consistency - Verifiability - Feasibility	- Reviews - Static analysis - Simulation

Example: Formal specification of an access control system:

Persons:	$prs \neq 0,\ p \in prs$	(set)
Buildings:	$bld \neq 0,\ b \in bld$	(set)
Authorization:	$aut \in prs \leftrightarrow bld$	(binary relation)
Situation:	$sit \in prs \rightarrow bld$	(complete function)
Invariant:	$sit \subseteq aut$	

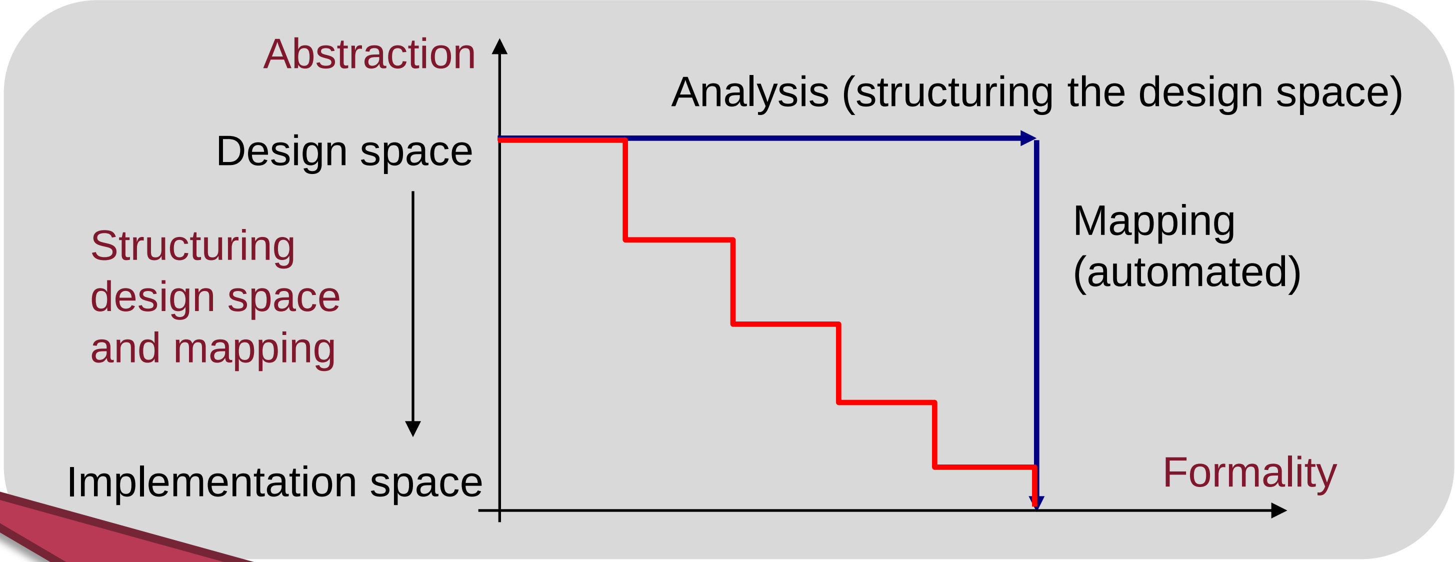
An event (change of situation):

```
pass = ANY p,b WHERE (p,b)∈aut ∧ sit(p)≠b
    THEN  sit(p):=b END
```

Automated analysis is possible: Checking the invariant for each event

Architecture design

- Requirement analysis
- System specification
- **Architecture design**
- Module design
- Module implementation
- System integration
- System delivery
- Operation, maintenance


Abstraction
Analysis (structuring the design space)
Design space
Structuring design space and mapping
Mapping (automated)
Implementation space
Formality

Task	V&V criteria	V&V technique
- Decomposing modules - HW-SW co-design - Designing communication	- Function coverage - Conformance of interfaces - Non-functional properties	- Static analysis - Simulation - Performance, dependability, security analysis

Module design (detailed design)

Requirement analysis

System specification

Architecture design

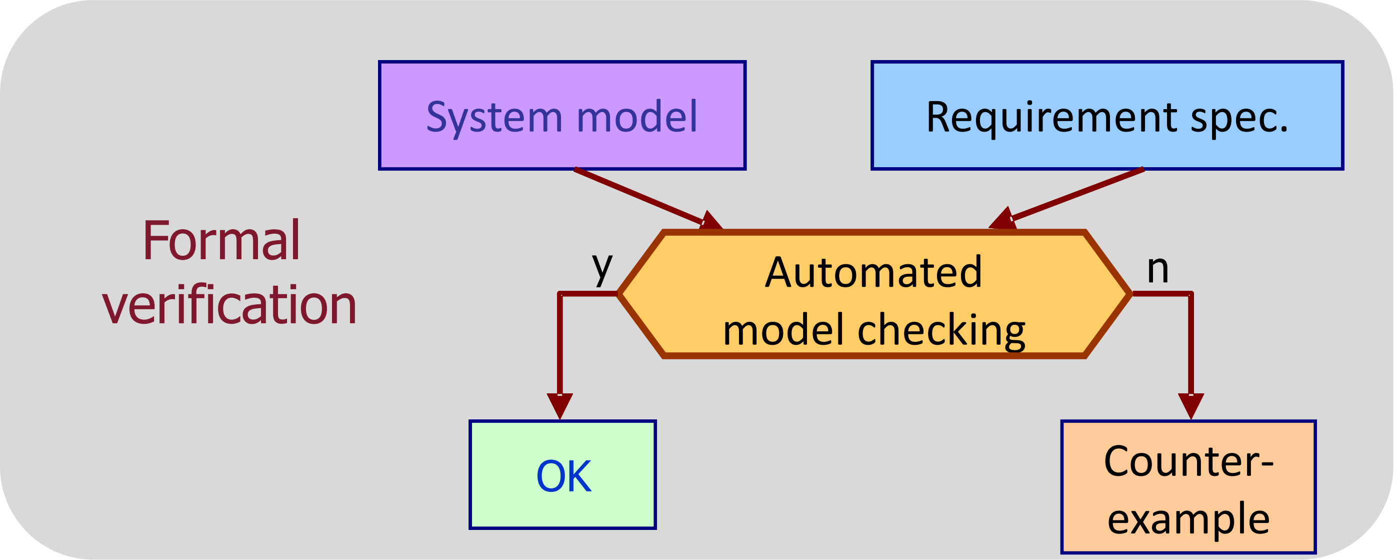
Module design

Module implementation

System integration

System delivery

Operation, maintenance



Formal verification

System model

Requirement spec.

Automated model checking

y

n

OK

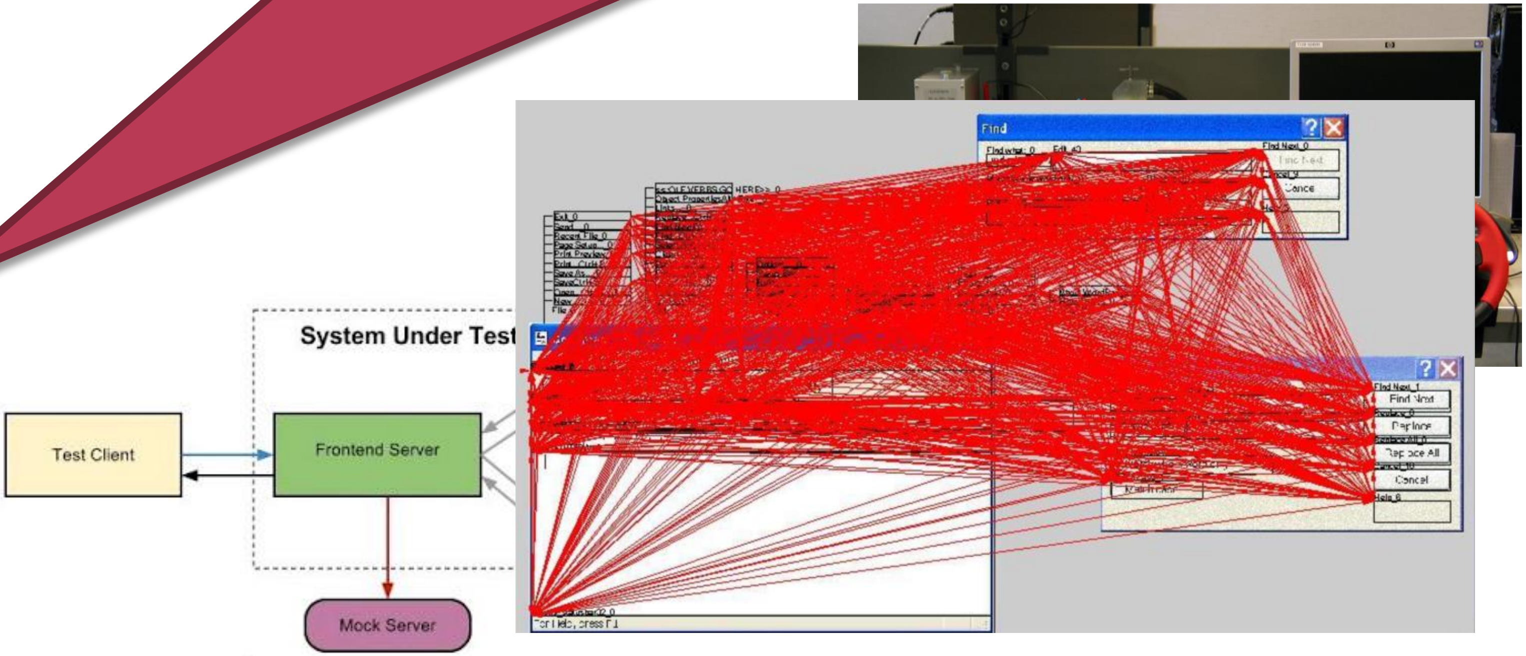
Counter-example

Task	V&V criteria	V&V technique
- Designing detailed behavior (data structures, algorithms)	- Correctness of algorithms and protocols	- Static analysis - Simulation - Formal verification - Rapid prototyping

System integration

- Requirement analysis
- System specification
- Architecture design
- Module design
- Module implementation
- **System integration**
- System delivery
- Operation, maintenance

Task	V&V criteria	V&V technique
- Integrating modules - Integrating SW with HW	- Conformance of integrated behavior - Correct interactions	- Integration testing (incremental)



System delivery and deployment

- Requirement analysis
- System specification
- Architecture design
- Module design
- Module implementation
- System integration
- **System delivery**
- Operation, maintenance

Task	V&V criteria	V&V technique
- Assembling complete system	- Conformance to system specification	- System testing - Measurements, monitoring
- Satisfying user expectations	- Conformance to requirements and expectations	- Validation testing - Acceptance testing - Alfa/beta testing

Operation and maintenance

Requirement analysis

System specification

Architecture design

Module design

Module implementation

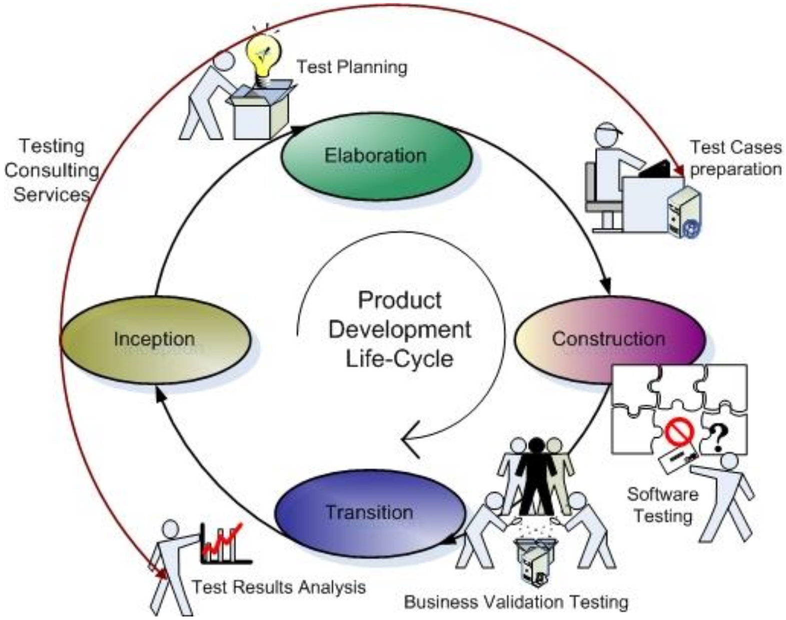
System integration

System delivery

Operation, maintenance

Tasks during operation and maintenance:
- Failure logging and analysis (for failure prediction)
- V&V of modifications depending on the affected life cycle phases

“Mini-lifecycle” for each modification



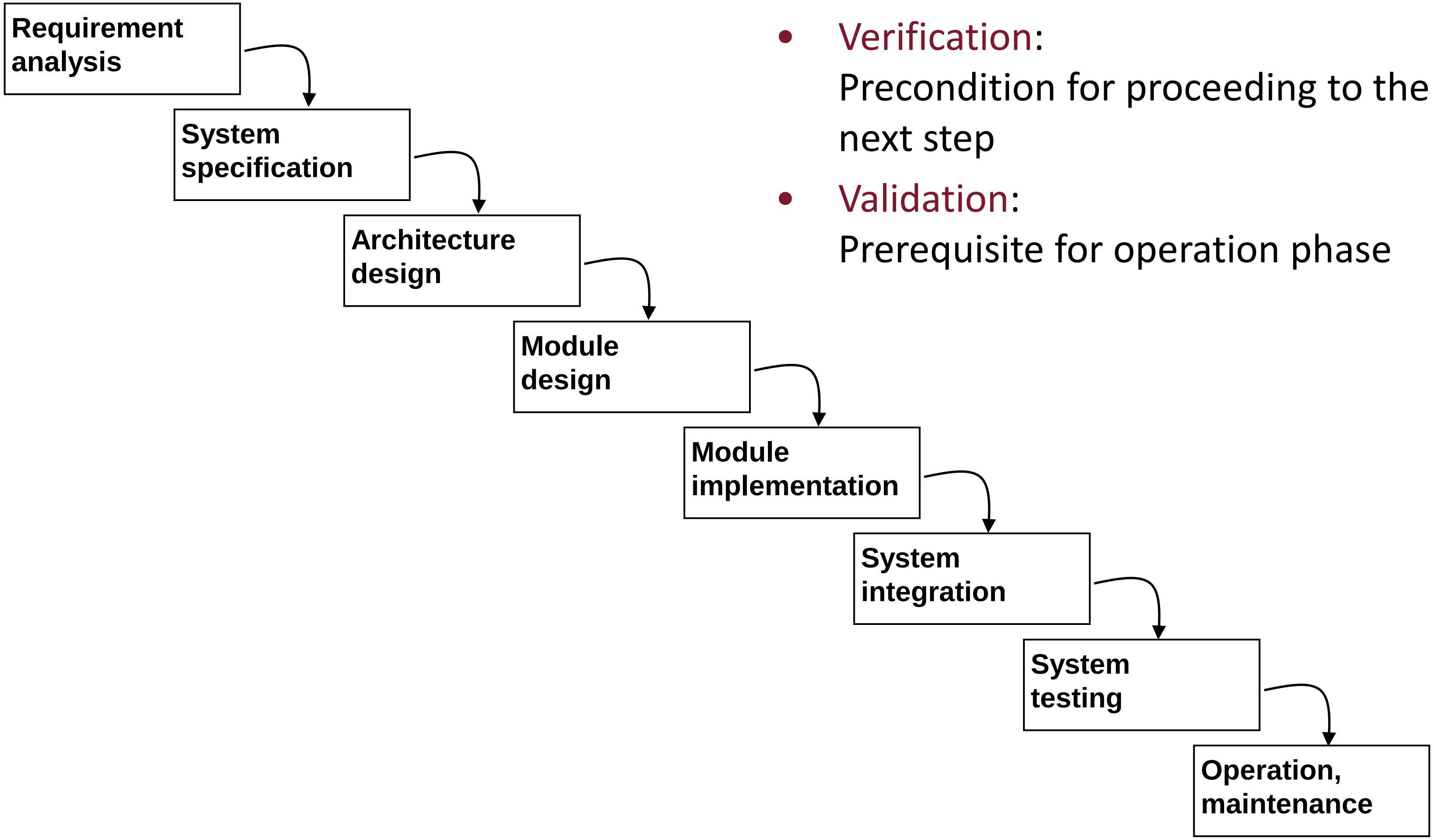
Development life cycle models

What is the role of V&V in the different life cycle models?

Development life cycle models

- The role of life cycle models
  - Handling the complexity of development
    - Dividing the development into phases, milestones
    - Basis for distributed / concurrent design and then integration
  - Change management
    - Handling the effects of requirement changes, modification and maintenance
    - Introduction of new methods and tools
- Generic models of software development:
  - Sequential development: Waterfall and V-model
  - Evolutionary development: Rapid application development
  - Iterative development: Spiral model
  - Model based development: 4G model
  - Iterative-incremental development: Unified Process

1. Waterfall model



Requirement analysis

System specification

Architecture design

Module design

Module implementation

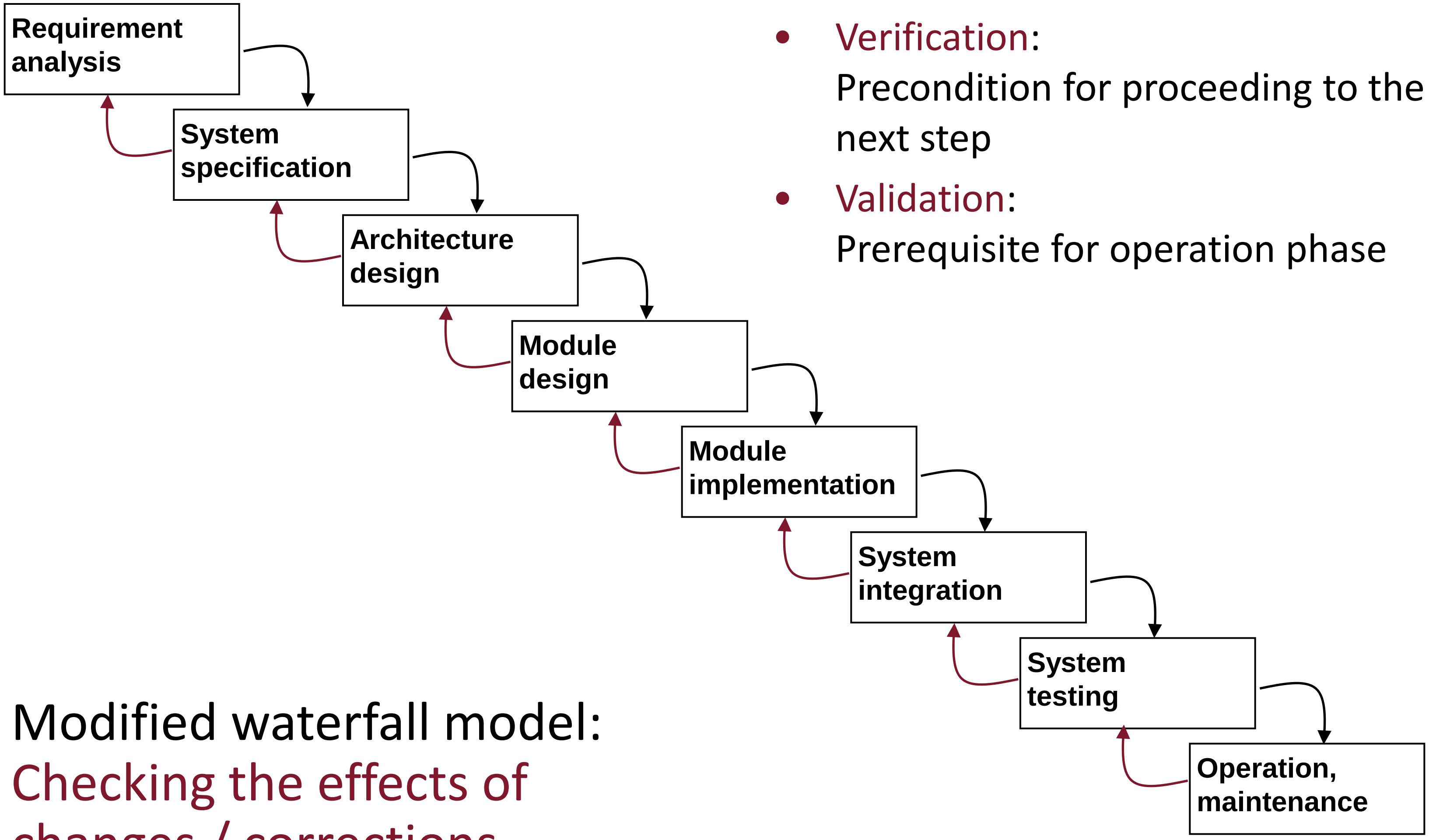
System integration

System testing

Operation, maintenance

- Verification:
  Precondition for proceeding to the next step
- Validation:
  Prerequisite for operation phase

1. Waterfall model



Requirement analysis

System specification

Architecture design

Module design

Module implementation

System integration

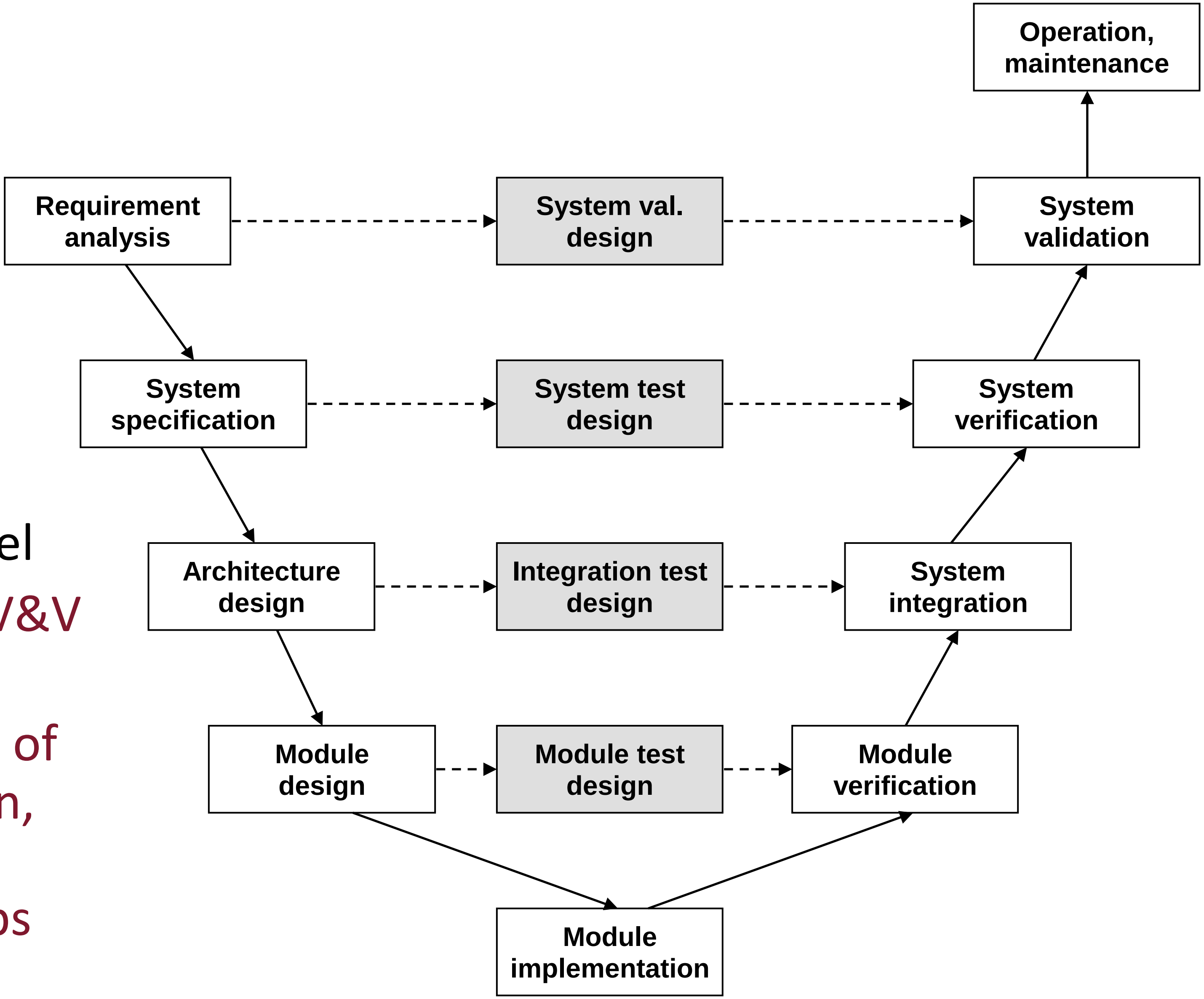
System testing

Operation, maintenance

- Verification:
  Precondition for proceeding to the next step
- Validation:
  Prerequisite for operation phase

- Modified waterfall model:
  Checking the effects of changes / corrections
  (e.g., regression testing)

2. The V-model



- Based on the waterfall model
- Well-defined V&V for each step
- Precise design of the verification, testing and validation steps

Model based design: From V to Y model

Life cycle

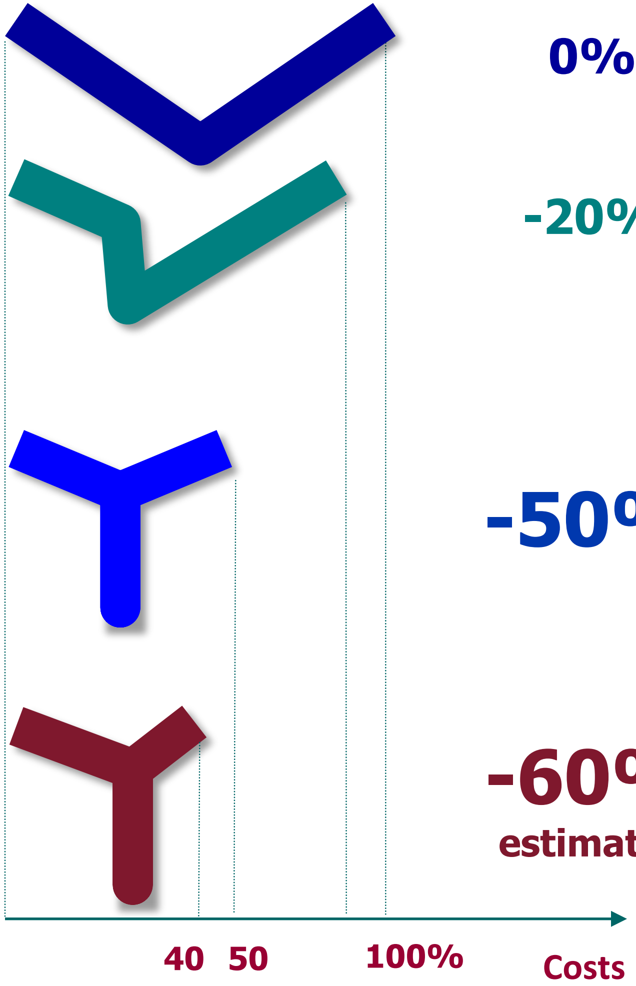
Reduction of efforts

Manual coding — **0%**

"Common" automated code generator is used — **-20%**

Certified automated code generator is used — **-50%**

Design using formal methods and tools — **-60%** **estimated**



Classic method: Cleanroom Software Engineering

- Origin:
  - IBM proposal (1980s)
  - US military developments (1990s)
- Goal:
  - Verification based on formal models
  - Fault avoidance instead of removal
- Principles:
  - Use and verification of formal models
  - Incremental development with quality control (step-by-step increase of complexity)
  - Statistical testing based on formal models
    - Selecting the representative trajectories
    - Manual validation of modeling

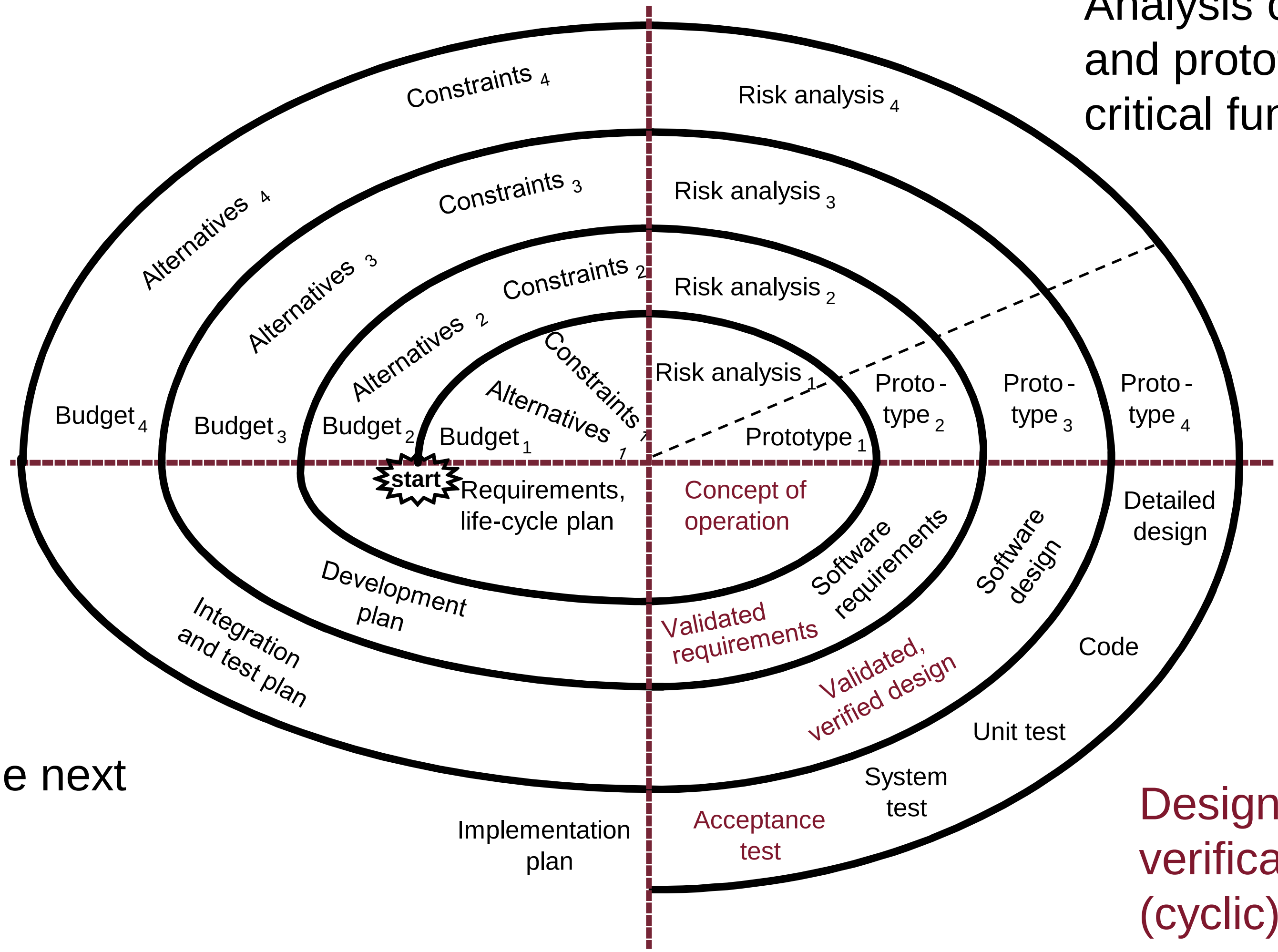
3. Evolutionary development (RAD)

- Refinement of an initial implementation through several versions, based on user feedback
  - Explorative development: Discussed with users
    - First version: Based on known requirements
  - Rapid prototypes for the critical functions
    - Validation using the prototype, re-working the prototype
  - Can be applied in case of incompletely specified systems
- V&V characteristics:
  - Increased role of prototype testing
  - Increased role of integration testing
    - Adding new functions
  - Regression testing after modifications
    - Existing functions remain correct

4. Iterative development: Spiral model

Goals, alternatives, constraints

Analysis of risks and prototype for critical functions

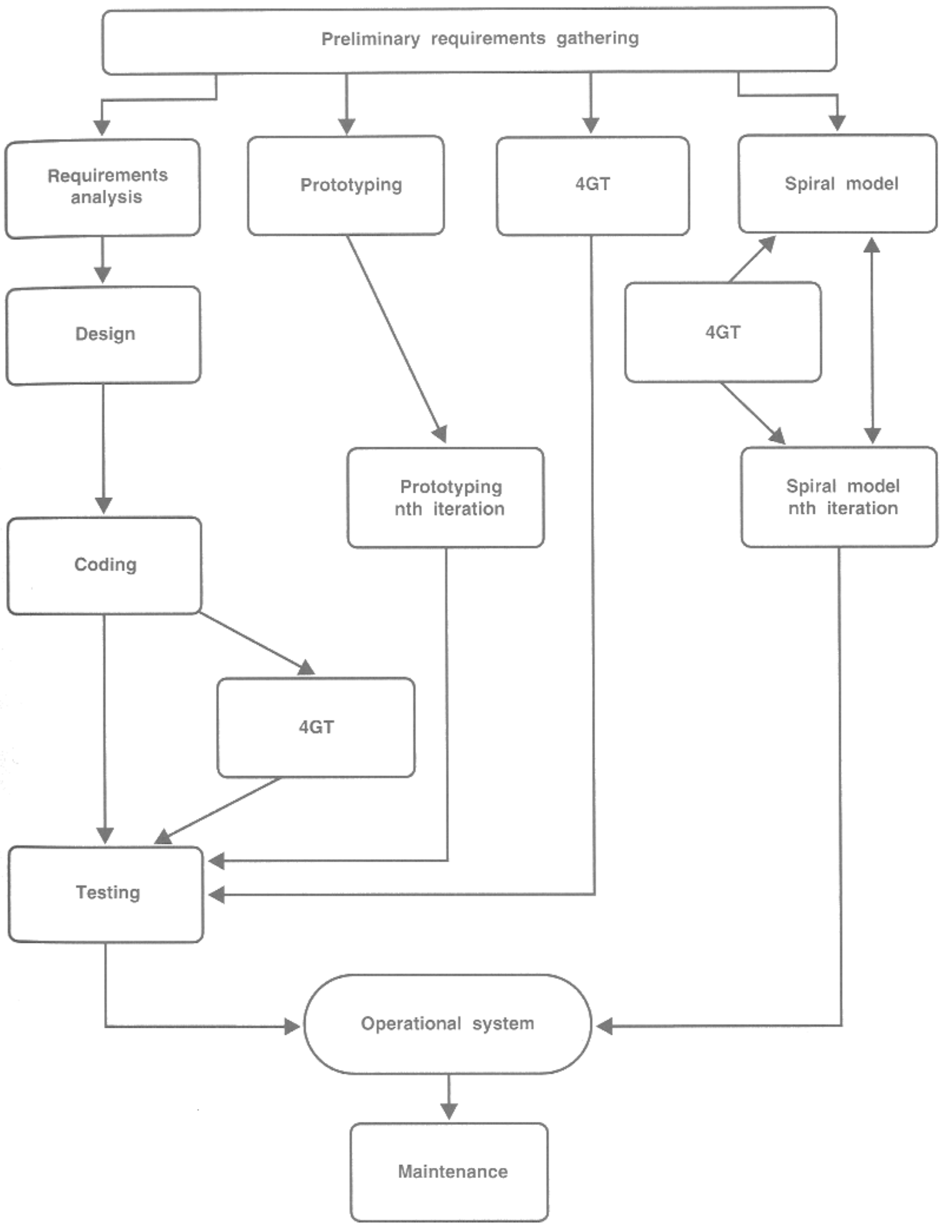


Planning the next phase

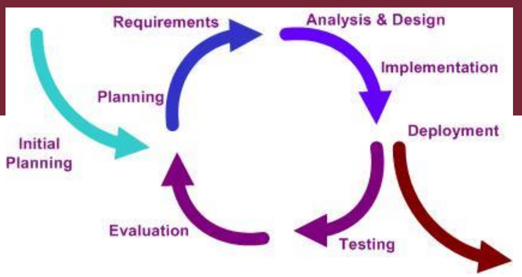
Design and verification (cyclic)

5. The “4G” model

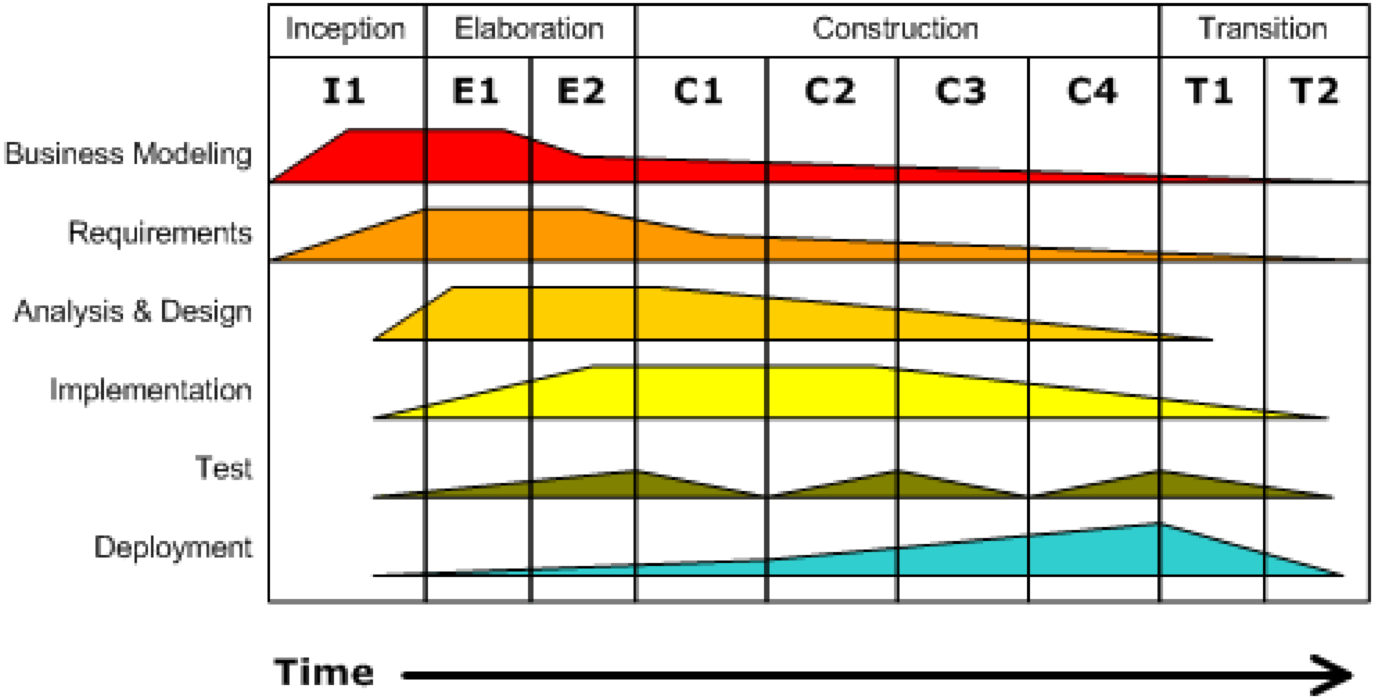
- Model based development
  - CASE tools
  - Property preserving refinement
  - Model based verification
- Integration of approaches
  - Well-specified requirements: “Traditional” development
  - Incompletely specified requirements: Rapid prototype development
  - Formally specified requirements: Model based development
  - With iterative design



6. Unified Process



- Incremental and iterative
  - Phases divided into iterations (bound in time)
  - Different focus of verification in each phase
    - Integration and regression testing is important



7. Agile software development

- Extreme Programming
  - Short iterations, focusing on operational code, regular (daily) integration and status tracking (developers, users)
    - Using build frameworks, testing is included
  - ”Test first programming” concept:
    - Functional tests based on “story card”
    - Testing after each modification (new functions)
- Test Driven Development
  - Incremental, steps for each new function:
    1. Writing test for the new function (test will fail)
    2. Coding (for successful test)
    3. Refactoring of the code with re-testing
  - Uses automated unit testing