Systeme hoher Qualität und Sicherheit
Universität Bremen, WS 2013/14

Lecture 03 (04.11.2013)
Quality of the Software Development Process

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Your Daily Menu

- Models of Software Development
  - The Software Development Process, and its rôle in safety-critical software development.
  - What kind of development models are there?
  - Which ones are useful for safety-critical software – and why?
  - What do the norms and standards say?

- Basic Notions of Formal Software Development:
  - How to specifiy: properties
  - Structuring of the development process

Where are we?

- Lecture 01: Concepts of Quality
- Lecture 02: Concepts of Safety and Security, Norms and Standards
- Lecture 03: Quality of the Software Development Process
- Lecture 04: Requirements Analysis
- Lecture 05: High-Level Design & Detailed Specification

- Lecture 06: Testing
- Lecture 07 and 08: Program Analysis
- Lecture 09: Model-Checking
- Lecture 10 and 11: Software Verification (Hoare-Calculus)

- Lecture 12: Concurrency
- Lecture 13: Conclusions

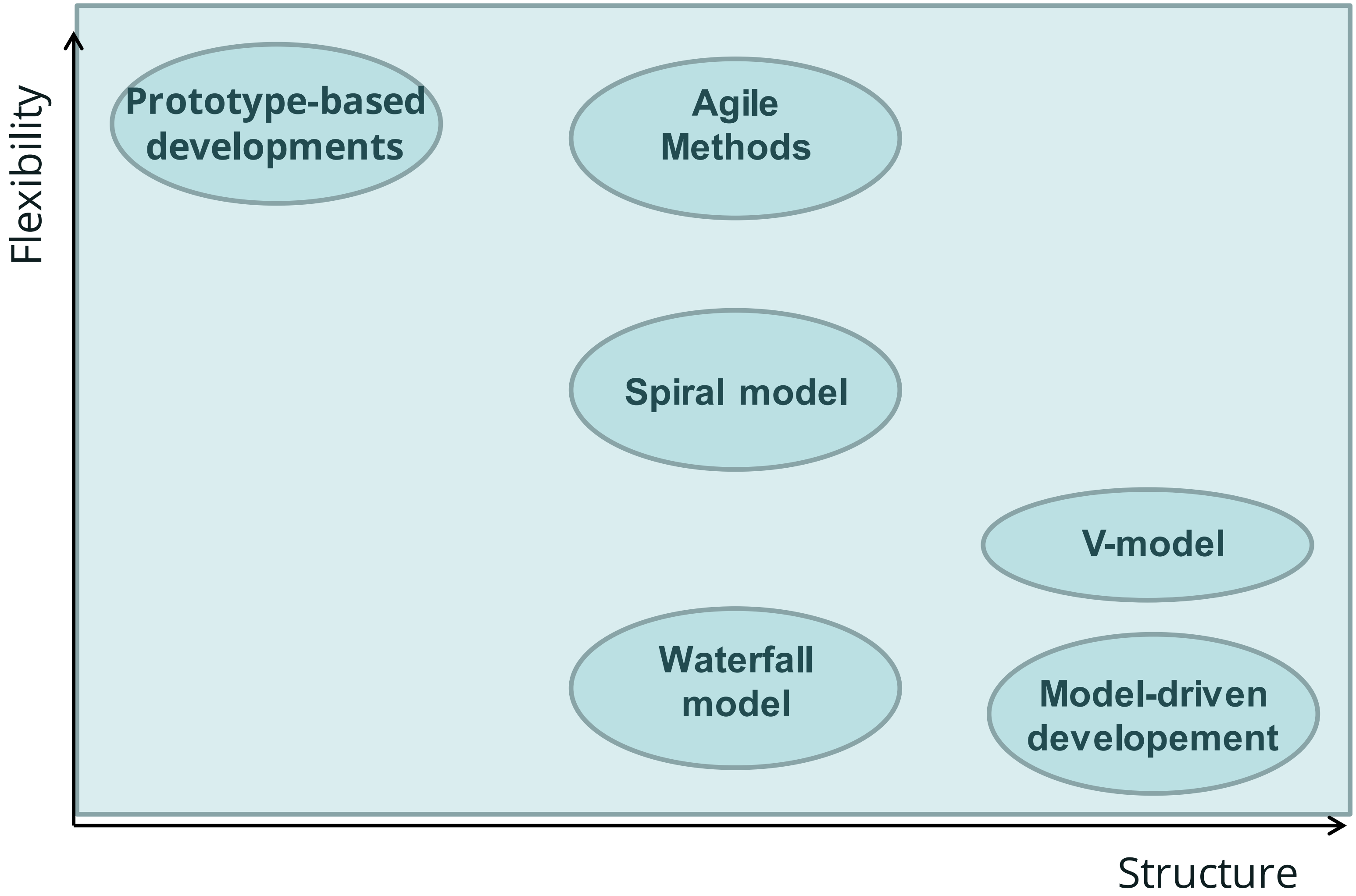
Software Development Models

Universität Bremen

Software Development Process

- A software development process is the **structure** imposed on the development of a software product.
- We classify processes according to *models* which specify
  - the artefacts of the development, such as
    - the software product itself, specifications, test documents, reports, reviews, proofs, plans etc
  - the different stages of the development,
  - and the artefacts associated to each stage.
- Different models have a different focus:
  - Correctness, development time, flexibility.
- What does quality mean in this context?
  - What is the *output*? Just the sofware product, or more? (specifications, test runs, documents, proofs…)

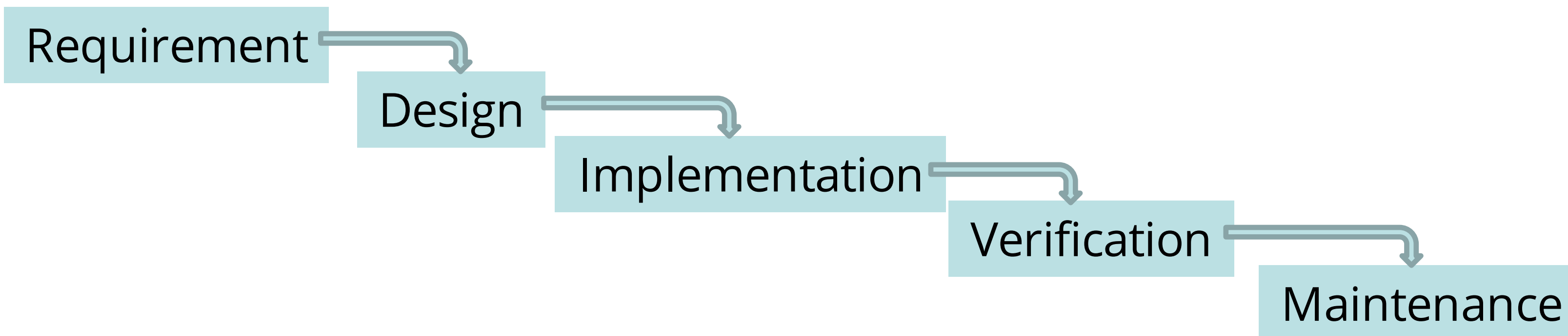
Software Development Models



from S. Paulus: Sichere Software

Waterfall Model (Royce 1970)

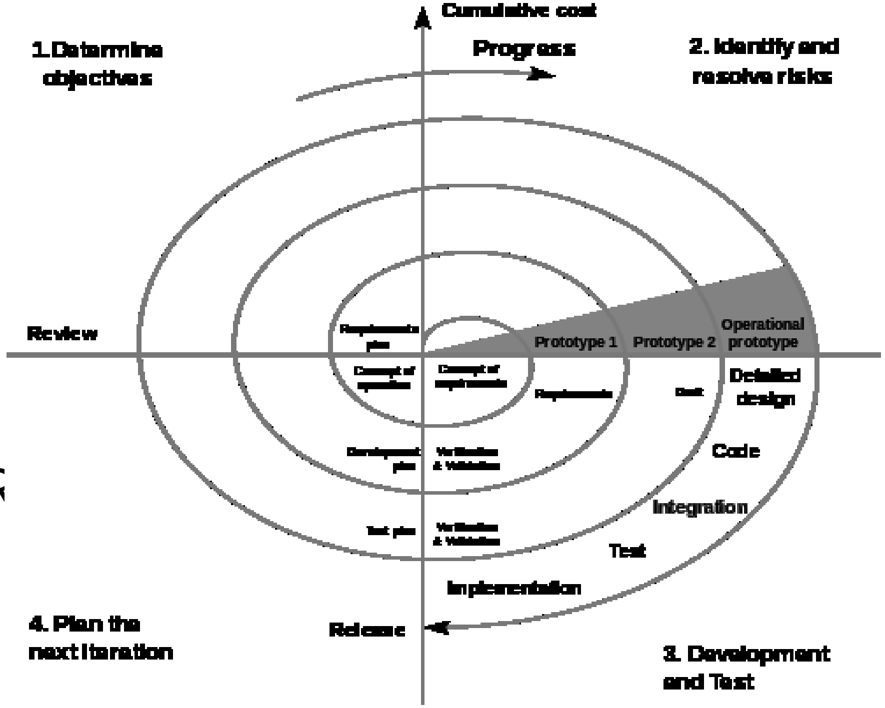
- Classical top-down sequential workflow with strictly separated phases.



- Unpractical as actual workflow (no feedback between phases), but even early papers did not *really* suggest this.

Spiral Model (Böhm, 1986)

- Incremental development guided by **risk factors**
- Four phases:
  - Determine objectives
  - Analyse risks
  - Development and test
  - Review, plan next iteration
- See e.g.
  - Rational Unified Process (R



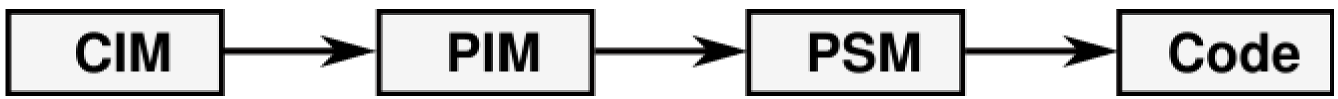
- Drawbacks:
  - Risk identification is the key, and can be quite difficult

Agile Methods

- Prototype-driven development
  - E.g. Rapid Application Development
  - Development as a sequence of prototypes
  - Ever-changing safety and security requirements
- Agile programming
  - E.g. Scrum, extreme programming
  - Development guided by functional requirements
  - Less support for non-functional requirements
- Test-driven development
  - Tests as *executable specifications:* write tests first
  - Often used together with the other two

Model-Driven Development (MDD, MDE)

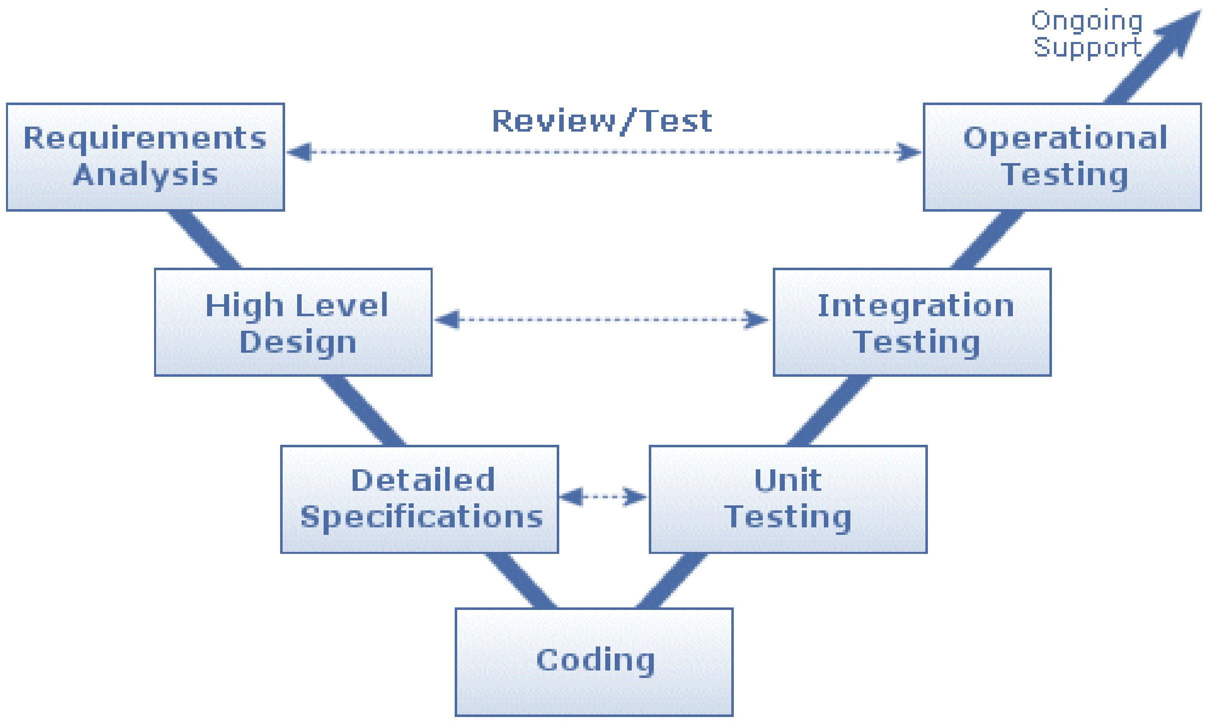
- Describe problems on abstract level using *a modelling language* (often a *domain-specific language*), and derive implementation by model transformation or run-time interpretation.
- Often used with UML (or its DSLs, eg. SysML)



- Variety of tools:
  - Rational tool chain, Enterprise Architect
  - EMF (Eclipse Modelling Framework)
- Strictly sequential development
- Drawbacks: high initial investment, limited flexibility

V-Model

- Evolution of the waterfall model:
  - Each phase is supported by a corresponding testing phase (verification & validation)
  - Feedback between next and previous phase
- Standard model for public projects in Germany
  - … but also a general term for models of this „shape“



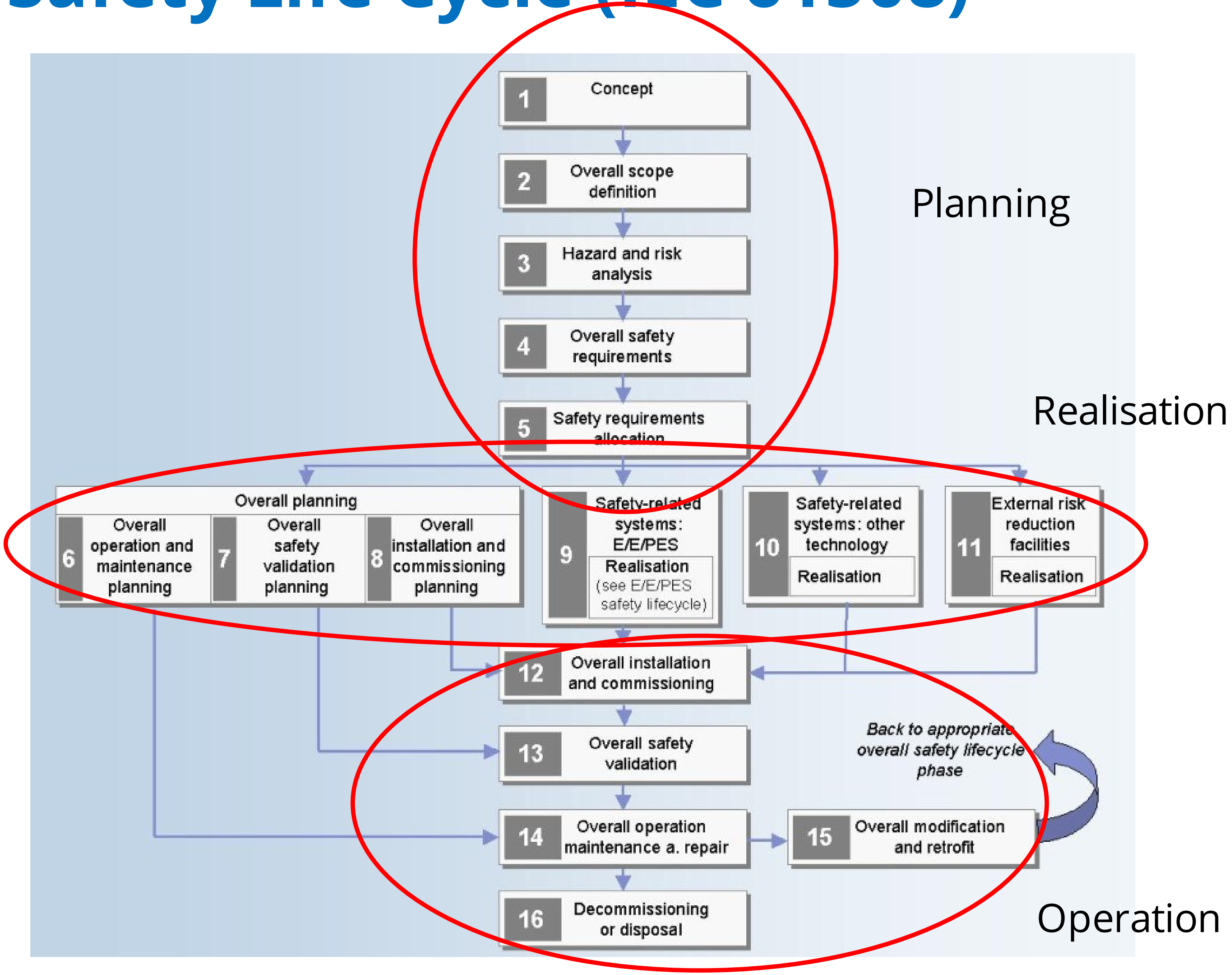
Development Models for Critical Systems

- Ensuring safety/security needs structure.
  - ...but *too much* structure makes developments bureaucratic, which is *in itself* a safety risk.
  - Cautionary tale: Ariane-5

- Standards put emphasis on *process*.
  - Everything needs to be planned and documented.

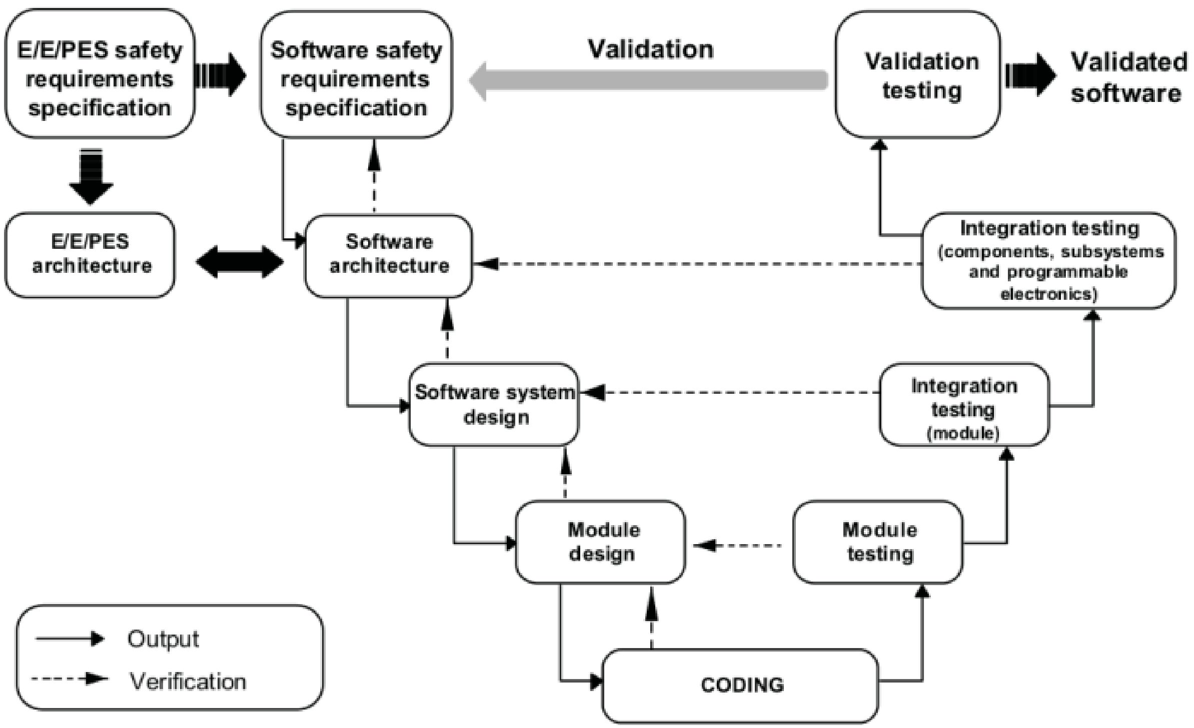
- Best suited development models are variations of the V-model or spiral model.

The Safety Life Cycle (IEC 61508)



Development Model in IEC 61508

- IEC 61508 prescribes certain activities for each phase of the life cycle.
- Development is one part of the life cycle.
- IEC *recommends* V-model.



Development Model in DO-178B

- DO-178B defines different *processes* in the SW life cycle:
  - Planning process
  - Development process, structured in turn into
    - Requirements process
    - Design process
    - Coding process
    - Integration process
  - Integral process

- There is no conspicuous diagram, but these are the phases found in the V-model as well.
  - Implicit recommendation.

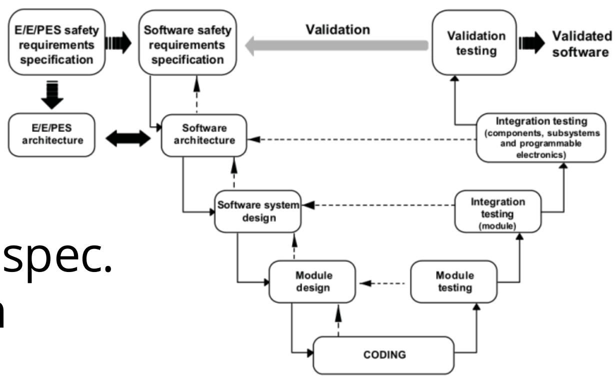
Artefacts in the Development Process

Planning:
- Document plan
- V&V plan
- QM plan
- Test plan
- Project manual

Specifications:
- Safety requirement spec.
- System specification
- Detail specification
- User document (safety reference manual)

Implementation:
- Code

Verification & validation:
- Code review protocols
- Tests and test scripts
- Proofs



Possible formats:
- Word documents
- Excel sheets
- Wiki text
- Database (Doors)
- UML diagrams
- Formal languages:
  - Z, HOL, etc.
  - Statecharts or similar diagrams
- Source code

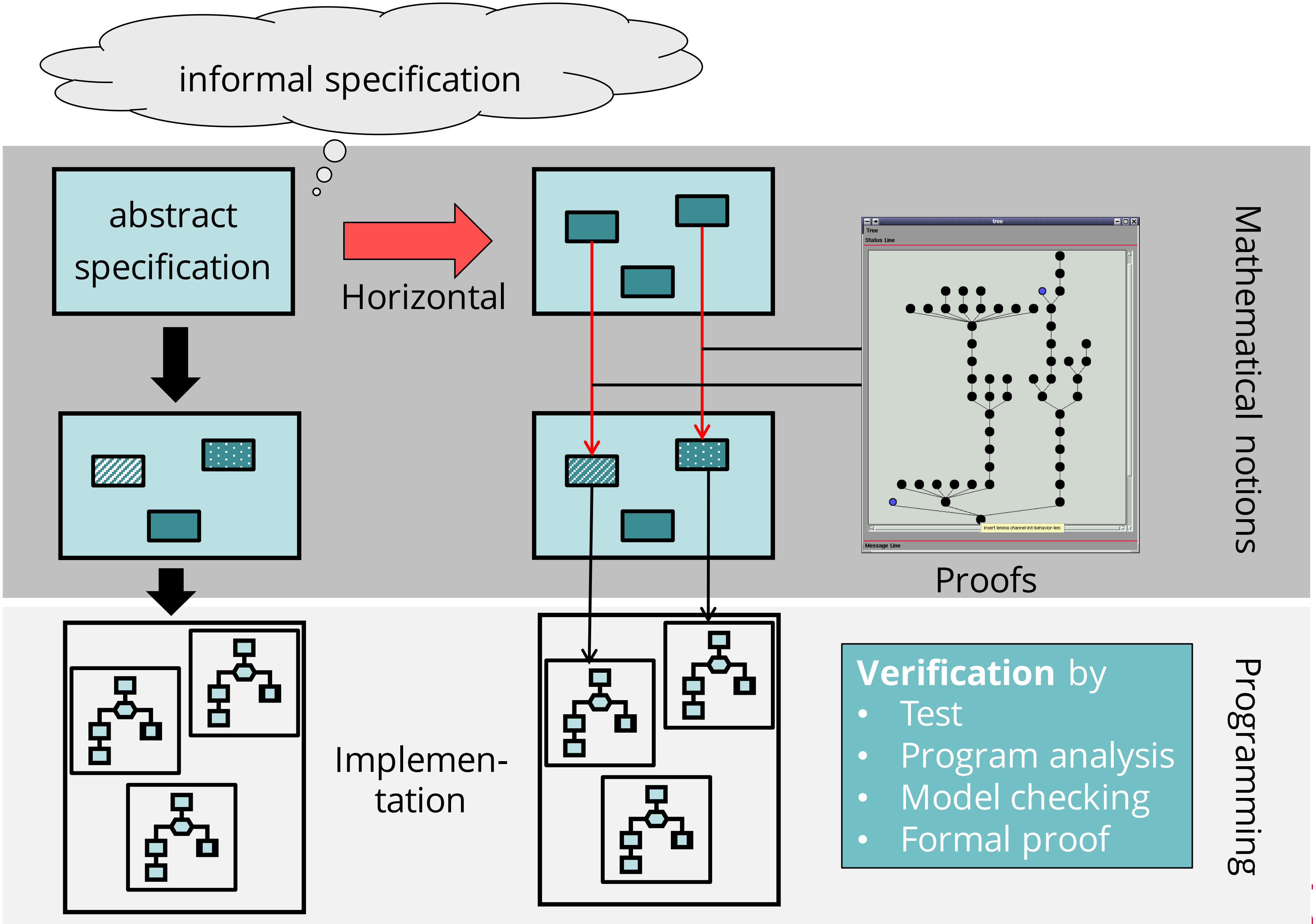
Documents must be *identified* and *reconstructable*.
- Revision control and configuration management *obligatory*.

Basic Notions of Formal Software Development

Formal Software Development

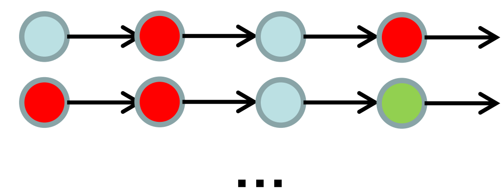
- In **formal** development, properties are stated in a rigorous way with a precise mathematical semantics.
- These formal specifications can be **proven**.
- Advantages:
  - Errors can be found **early** in the development process, saving time and effort and hence costs.
  - There is a higher degree of trust in the system.
  - Hence, standards recommend use of formal methods for high SILs/EALs.
- Drawback:
  - Requires **qualified** personnel (that would be *you*).
- There are tools which can help us by
  - **finding** (simple) proofs for us, or
  - **checking** our (more complicated proofs).

Formal Software Development

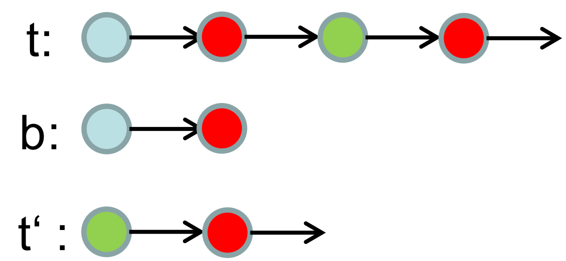


Properties

- A general notion of **properties**.
- Properties as set of infinite execution traces (i.e. infinite sequences of states)



- Trace t satisfies property P, written $P \models t$, iff $t \in P$



- $b \leq t$ iff $\exists\, t' .\ t = b \bullet t'$
  - i.e. b is a *finite* prefix of t

Safety and Liveness Properties

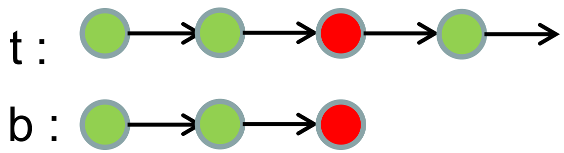
Alpen & Schneider (1985, 1987)

- **Safety** properties
  - *Nothing bad happens*
  - partial correctness, program safety, access control
- **Liveness** properties
  - *Something good happens*
  - Termination, guaranteed service, availability

- **Theorem**: $\forall P \,.\; P = Safe_P \cap Live_P$
  - Each property can be represented as a combination of safety and liveness properties.

Safety Properties

- Safety property S: „Nothing bad happens“
- A bad thing is *finitely* observable and *irremediable*
- S is a safety property iff
  - $\forall t.\, t \notin S \;\rightarrow (\exists b.\, \text{finite } b \wedge b \leq t \;\rightarrow \forall u.\, b \leq u \rightarrow u \notin S)$

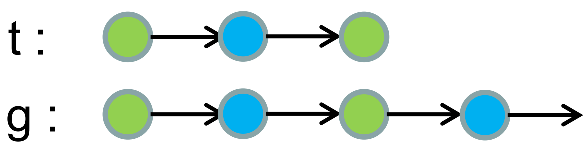


  - a finite prefix b always causes the bad thing

- **Safety is typically proven by induction**
  - Safety properties may be enforced by run-time monitors.

Liveness Properties

- Liveness property L: „Good things will happen“
- A good thing is always possible and possibly infinite:
- L is a liveness property iff
  - $\forall\, t.\ \text{finite}\ t\ \rightarrow \exists g.\, t \leq g \wedge g \in L$
  - i.e. all finite traces t can be extended to a trace g in L.



- **Liveness is typically proven by well-foundedness.**

Underspecification and Nondeterminism

- A *system* S is characterised by a *set of traces*.
- A system S *satisfies* a property P, written

$$S \models P \text{ iff } S \subseteq P$$

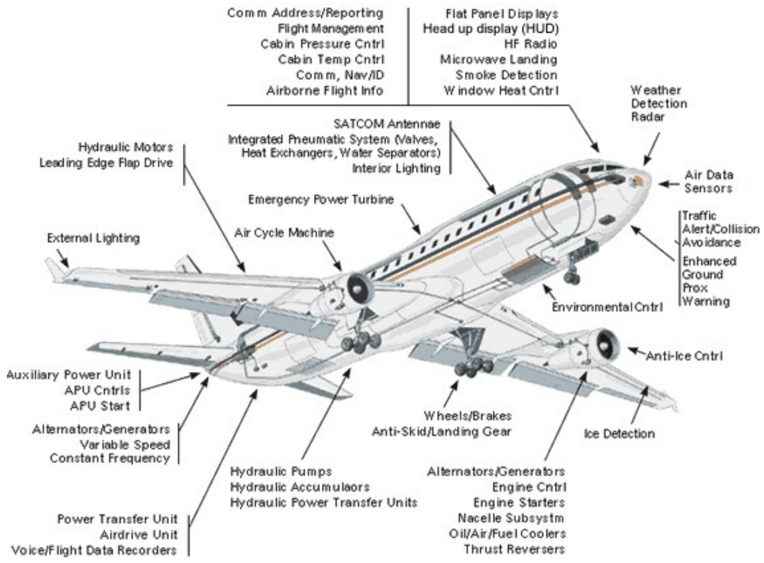
  (i.e. $\forall t \in S.\, t \in P$, all traces satisfy the property P).
- Why more than one trace? Difference between:
  - *Underspecification* or *loose specification* – we specify several *possible* implementations.
  - Non-determinism – different program runs might result in different traces.
- Example: a simple can vending machine.
  - Insert coin, chose brand, dispense drink.
  - Non-determinisim due to *internal* or *external* choice.

Structure in the Development

- Horizontal structuring
  - Modularization into components
  - Composition and Decomposition
  - Aggregation
- Vertical structuring
  - Abstraction and refinement
    from design specification to implementation
  - Declarative vs. imparative specification
  - Inheritence
- Layers / Views
  - Adresses multiple aspects of a system
  - Behavioral model, performance model, structural model, analysis model(e.g. UML, SysML)

Horizontal Structuring (informal)

- Composition of components
  - Dependent on the individual layer of abstraction
  - E.g. modules, procedures, functions,...
- Example:



Horizontal Structuring: Composition

- Given two systems S_1, S_2, their *sequential composition* is defined as

$$S_1; S_2 = \{s \cdot t | s \in S_1, t \in S_2\}$$

  - All traces from S_1, followed by all traces from S_2.

- Given two traces s, t, their *interleaving* is defined (recursively) as
  $<> \parallel t = t$
  $s \parallel <> = s$
  $a \cdot s \parallel b \cdot t = \{ a \cdot u \mid u \in s \parallel b \cdot t \} \cup \{ b \cdot u \mid u \in a \cdot s \parallel t\}$

- Given two systems S_1, S_2, their *parallel composition* is defined as

$$S_1 \parallel S_2 = \{ s \parallel t \mid s \in S_1, t \in S_2\}$$

  - Traces from S_1 interleaved with traces from S_2.

Vertical Structure - Refinement

- Data refinement
  - Abstract datatype is „implemented“ in terms of the more concrete datatype
  - Simple example: define stack with lists
- Process refinement
  - Process is refined by excluding certain runs
  - Refinement as a reduction of underspecification by eliminating possible behaviours
- Action refinement
  - Action is refined by a sequence of actions
  - E.g. a stub for a procedure is refined to an executable procedure

Refinement and Properties

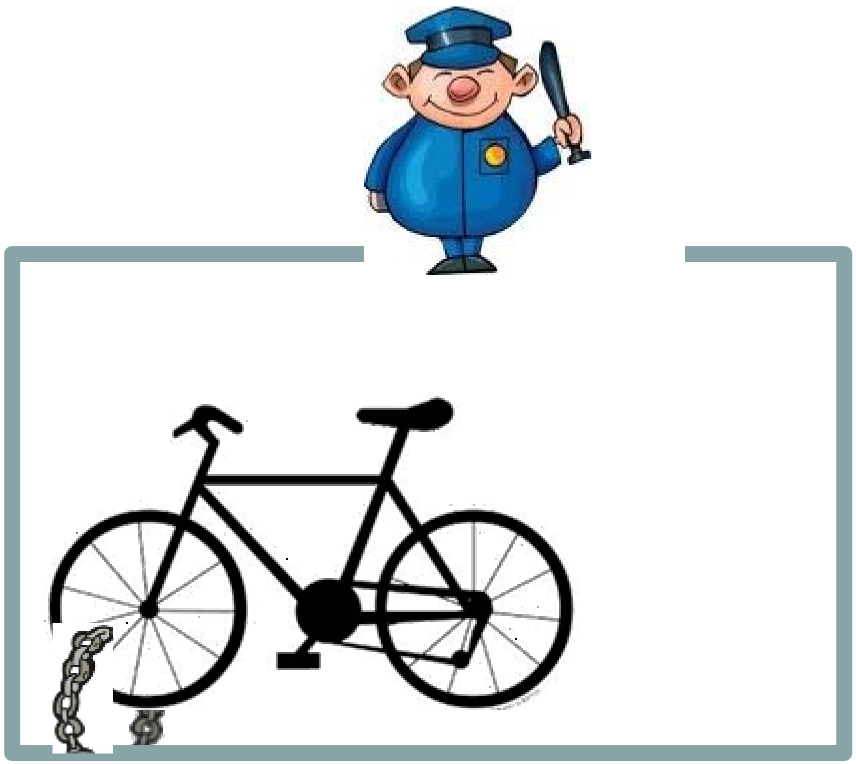
- Refinement typically preserves safety properties.
  - This means if we start with an abstract specification which we can show satisfies the desired properties, and refine it until we arrive at an implementation, we have a system for the properties hold *by construction*:

$$SP \rightsquigarrow SP_1 \rightsquigarrow SP_2 \rightsquigarrow \ldots \rightsquigarrow Imp$$

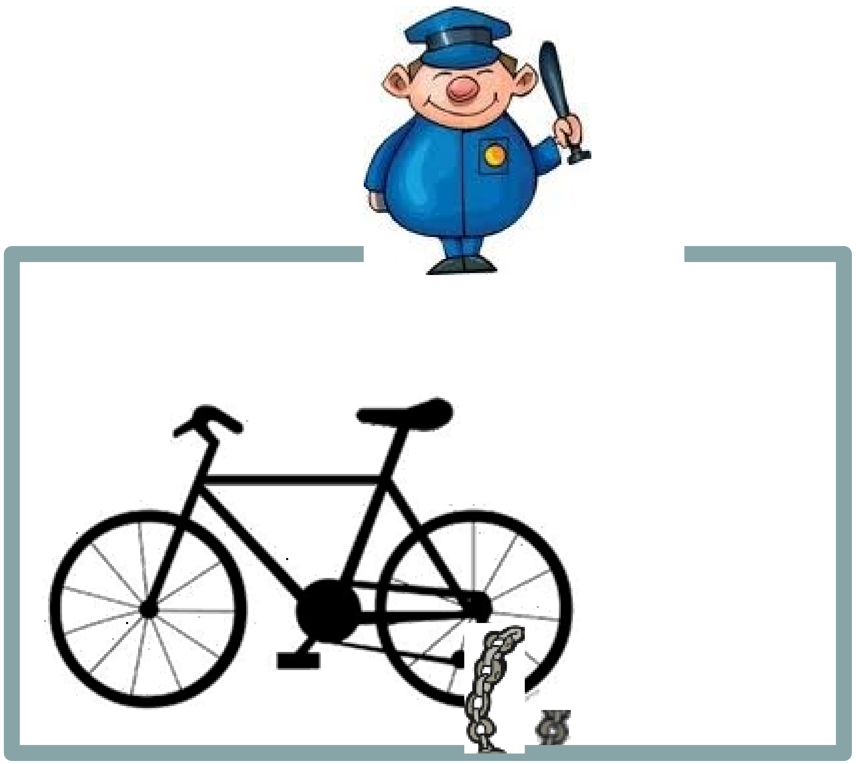
- However, **security** is typically **not** preserved by refinement nor by composition!

Security and Composition

Only complete bicycles are allowed to pass the gate.



Secure !



Secure !

Security and Composition

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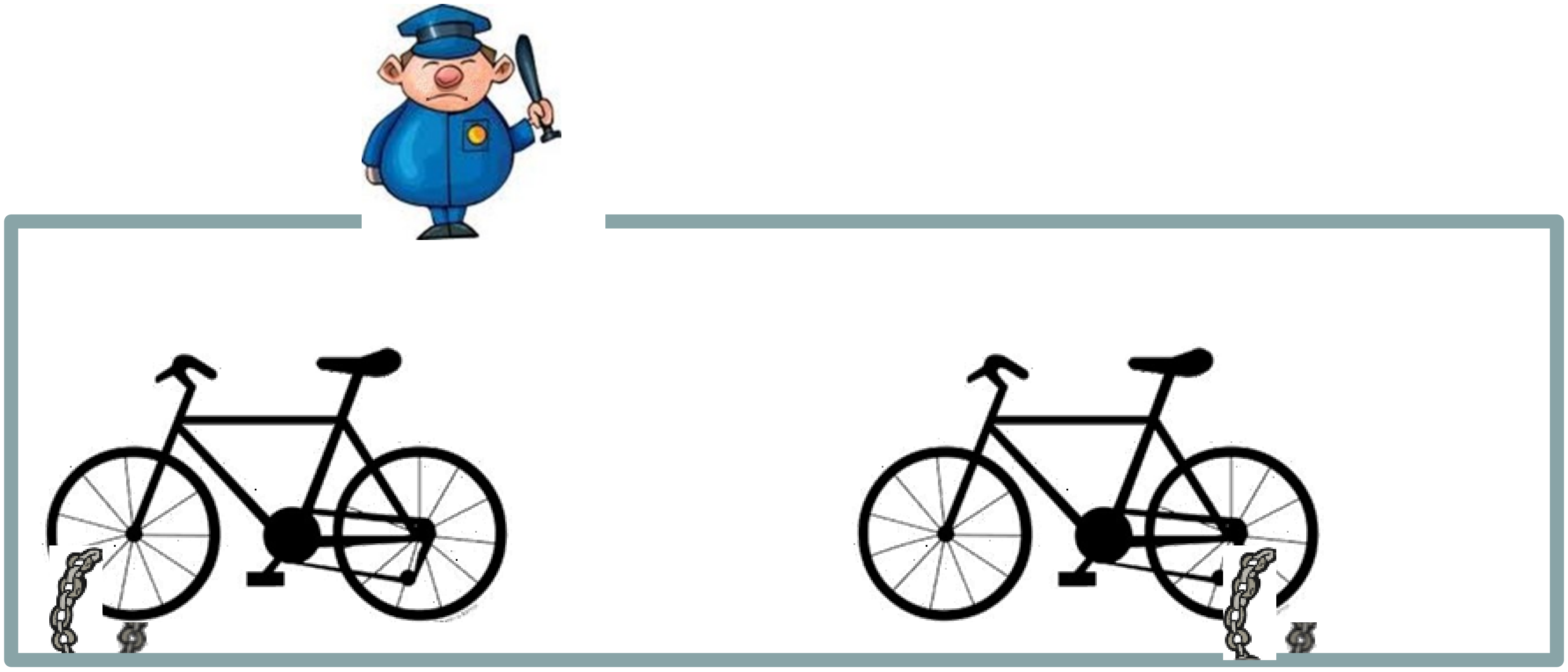

Insecure !

Conclusion & Summary

- Software development models: structure vs. flexibility
- Safety standards such as IEC 61508, DO-178B suggest development according to V-model.
  - Specification and implementation linked by verification and validation.
  - Variety of artefacts produced at each stage, which have to be subjected to external review.

- Properties include safety and liveness properties.
- Structuring of the development:
  - Horizontal – e.g. composition
  - Vertical – refinement (data, process and action ref.)