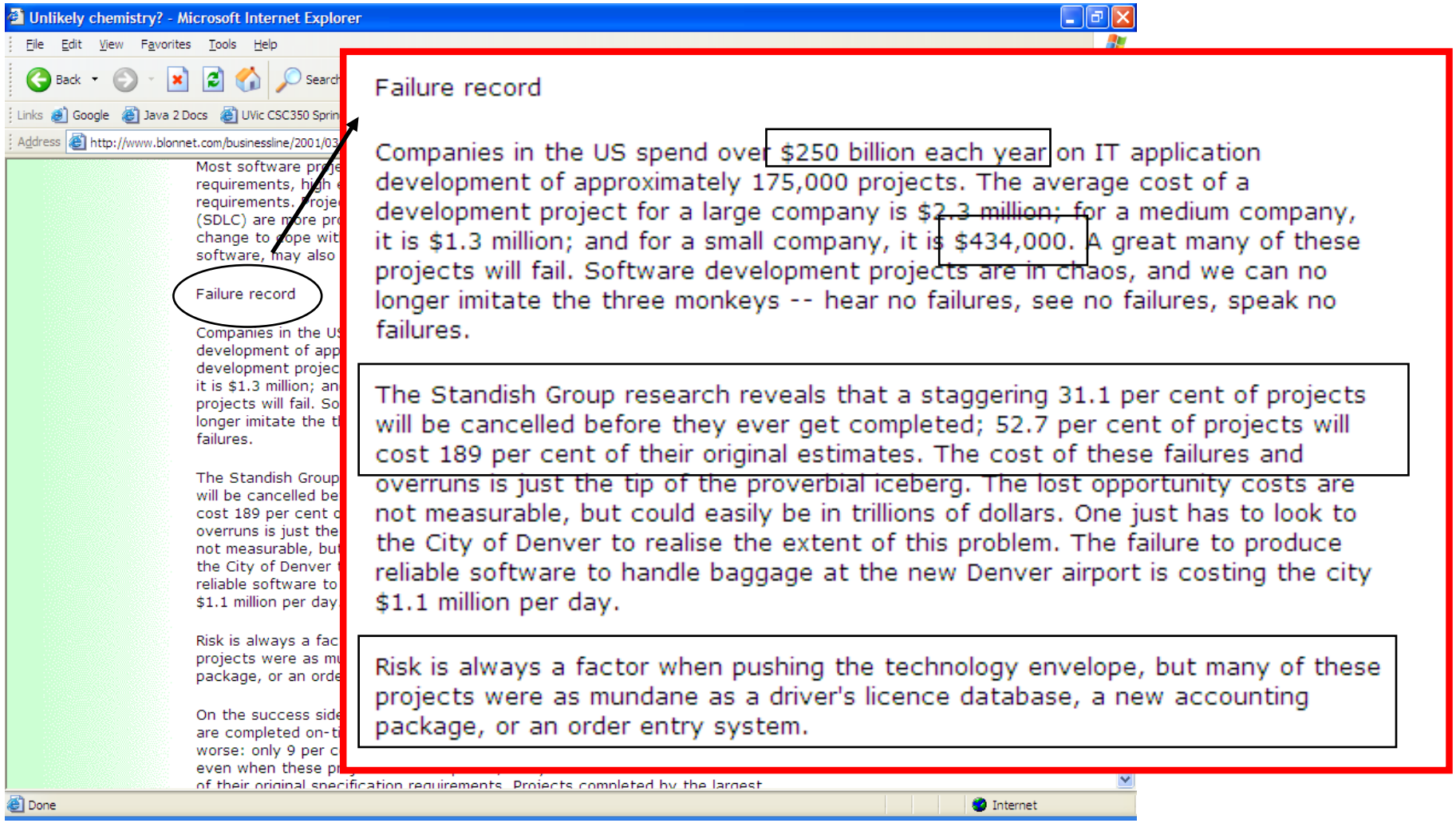
Software Engineering Process: Overview

- Some context, terms & concepts relating to software engineering
- The meaning of process
- Software lifecycle and its standard phases
- Several different software-process models

One reality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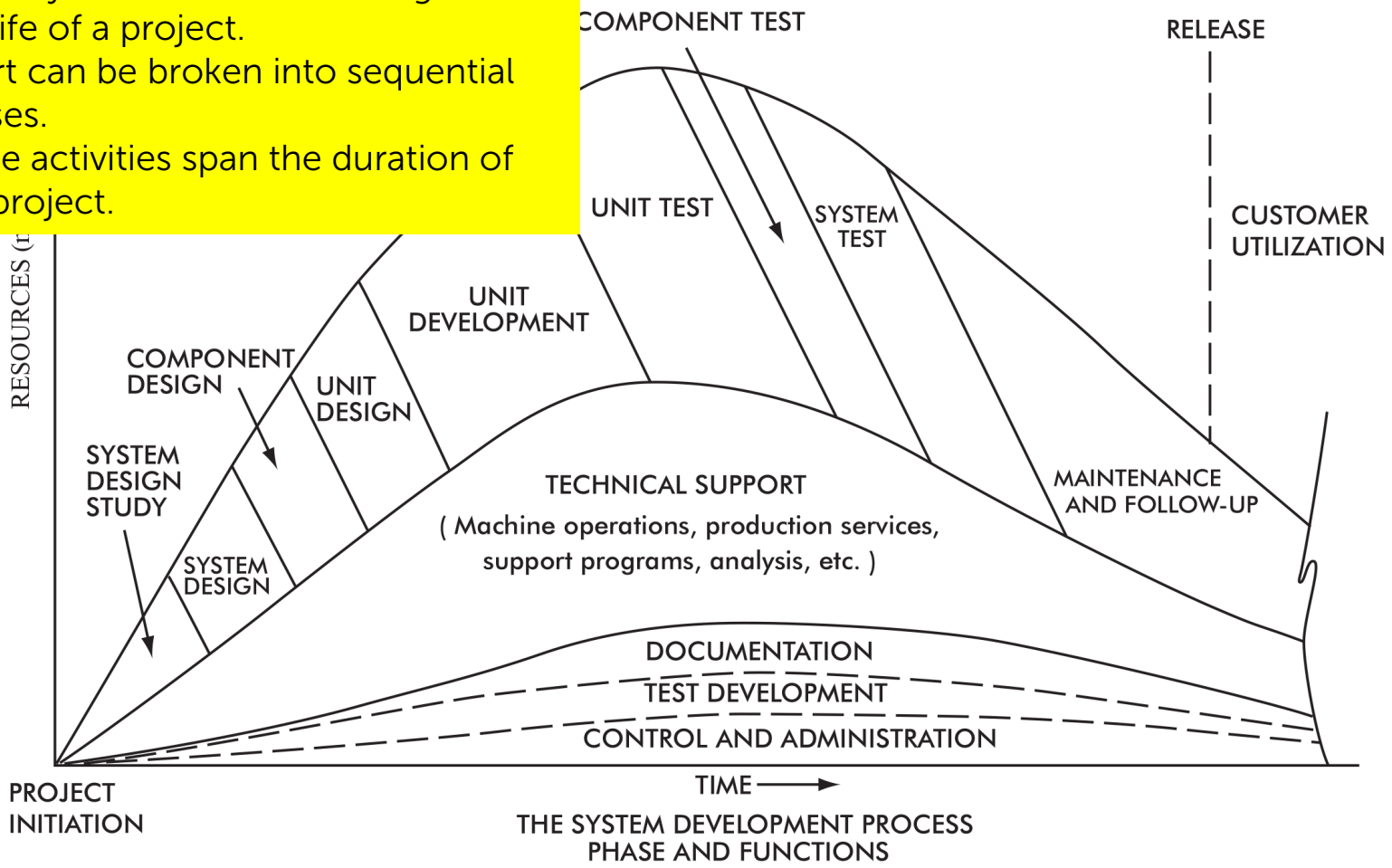
Companies in the US spend over $250 billion each year on IT application development of approximately 175,000 projects. The average cost of a development project for a large company is $2.3 million; for a medium company, it is $1.3 million; and for a small company, it is $434,000. A great many of these projects will fail. Software development projects are in chaos, and we can no longer imitate the three monkeys -- hear no failures, see no failures, speak no failures.
The Standish Group research reveals that a staggering 31.1 per cent of projects will be cancelled before they ever get completed; 52.7 per cent of projects will cost 189 per cent of their original estimates. The cost of these failures and overruns is just the tip of the proverbial iceberg. The lost opportunity costs are not measurable, but could easily be in trillions of dollars. One just has to look to the City of Denver to realise the extent of this problem. The failure to produce reliable software to handle baggage at the new Denver airport is costing the city $1.1 million per day.
Risk is always a factor when pushing the technology envelope, but many of these projects were as mundane as a driver's licence database, a new accounting package, or an order entry system.

Software Engineering: context

- "Software Engineering" as a term was invented in the late 1960s
  - From 1945 to early 1960s, major cost was computing hardware
  - That started to change in the early 1960s
  - Programming environments, languages, and tools were focused on the computer, not the programmer
- By 1967/68 many experts declared a "software crisis". They saw the following:
  - Inability to hire enough trained programmers
  - Cost & budget overruns
  - Buggy software resulting in property damage or theft
  - Software defects leading to injury or even death
- Another view: Programmers were struggling to write code that would be correct, useable, and on time
- Proposal in 1968: To develop and apply principles to the development of software in a manner similar to established engineering disciplines.

Software development effort

1. Intensity of effort varies throughout the life of a project.
2. Effort can be broken into sequential phases.
3. Some activities span the duration of the project.



From NATO report (1968)

Software engineering: definition

- No one definition encompasses all uses of the term
  - Thousands of researchers
  - Tens of thousands of research papers + books
  - Many tools
  - Many disagreements over what problems are most important...
- Wikipedia's definition can work for our purposes:
  - "The application of a systematic, disciplined, quantifiable approach to the design, development, operation, and maintenance of software, and the study of these approaches; that is, the application of engineering to software."

45+ years of research

- Since 1968 there have been many advances in software engineering
  - New programming languages
  - Advances in computing hardware
  - Developments in operating systems, networking
  - New computer-based tools supporting software-system construction
  - Much more besides
- As a result:
  - We are now able to develop, deploy and maintain very complex software systems
  - We are better able to manage the construction of such systems
  - We can collaborate on such work while geographically distributed
  - We very often use the computer itself to support the coordination task (e.g., Subversion)

Some areas in software engineering

System Engineering

Requirements Engineering

Analysis Modelling

Design Engineering

Component-Level Design

Architecture Design

User Interface Design

Software Metrics

Software Testing Strategies

Formal Methods

Software Evolution

Re-engineering

Reverse Engineering

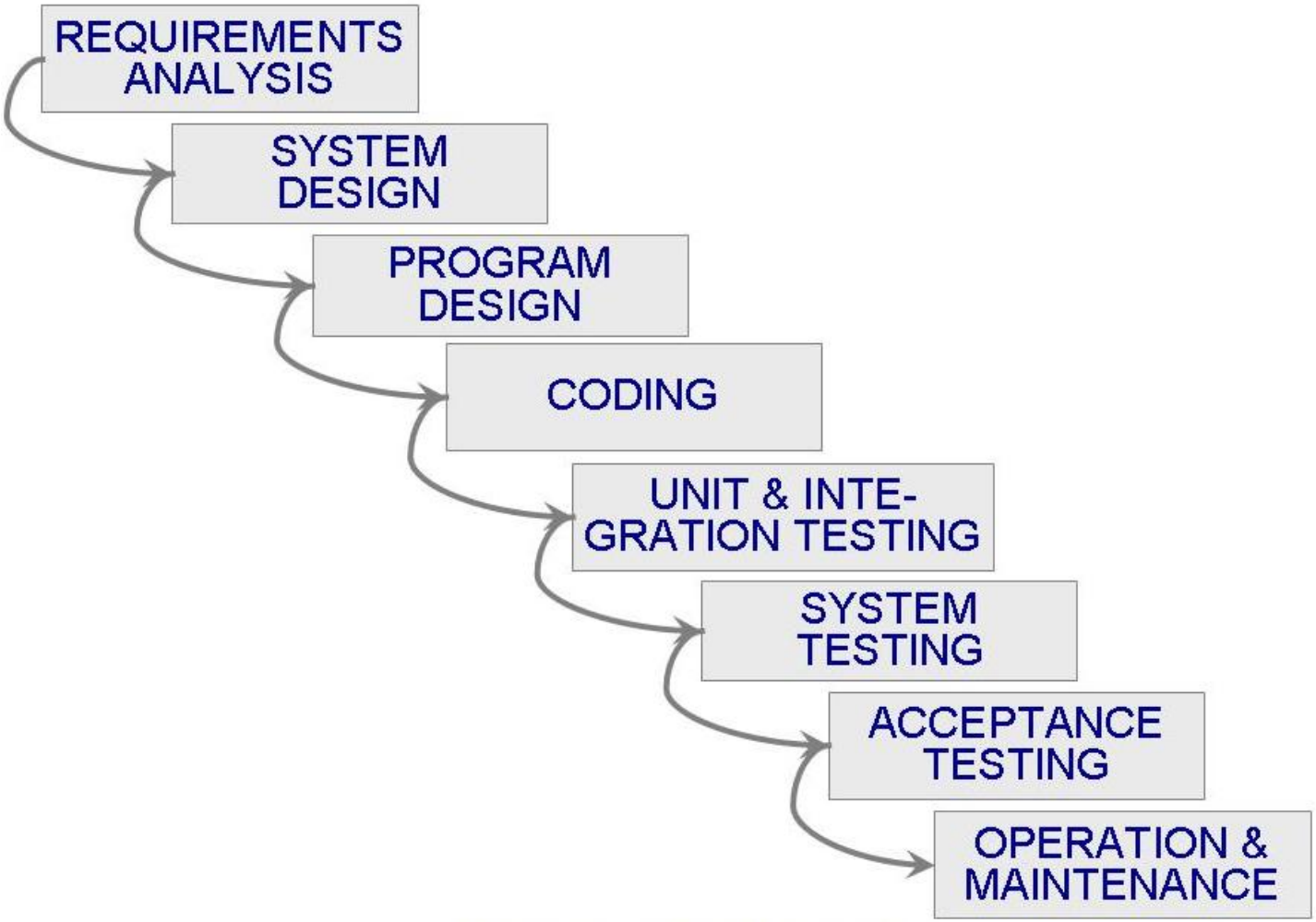
Changing nature of software

- The variety of software systems makes it challenging to describe one single best approach to designing and building software systems
- There are several broad categories of software
  - **System** software
  - **Application** software
  - **Engineering/scientific** software
  - **Embedded** software
  - **Product-line** software
  - **Web applications**
  - **Artificial intelligence (AI)** software, including machine learning
- New challenges in development continue to arise:
  - Open source
  - Ubiquitous computing
  - Cloud computing

Software Process

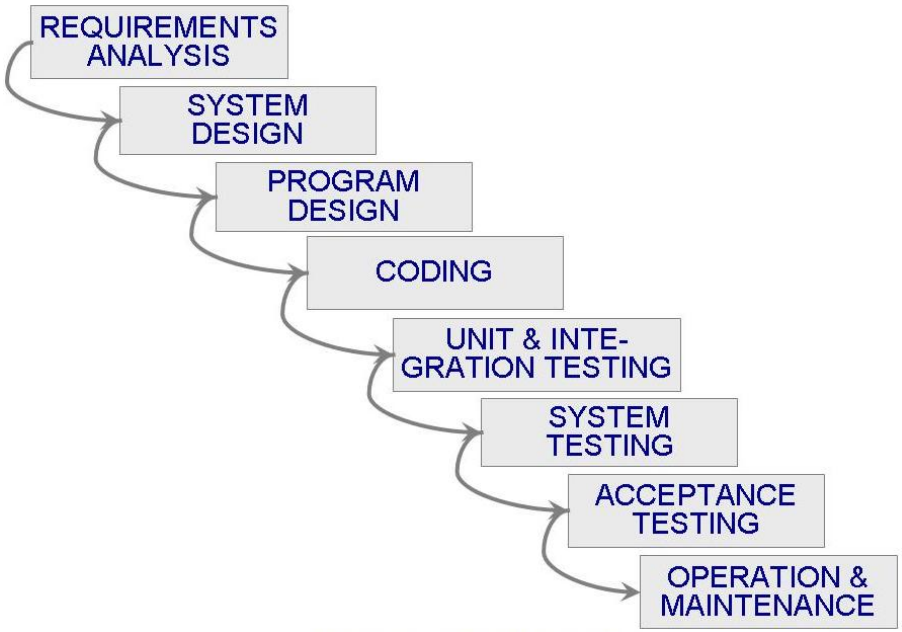
- **Process**
  - A **series of steps** involving **activities**, **constraints**, and **resources** that produce an **intended output** of some kind
  - Involves a **set of tools and techniques**
- Processes are considered important for several reasons:
  - They impose consistency and structure on a set of activities
  - They also guide us to **understand**, **control**, **examine**, and improve the activities
  - Ultimately this enables us to **capture** our experiences and pass them along to future projects

Example process: Waterfall model



Characteristics of a process model

- Prescribes all major process **activities**
- Uses resources, subject to set of constraints (such as a **schedule**)
- Produces **intermediate** and **final products**
- May be composed of **subprocesses** with hierarchy or links
- Each process activity has **entry and exit criteria**
- Activities are organized in **sequence**, so timing is clear
- Each process has **guiding principles**, including **goals of each activity**
- **Constraints** may apply to an activity, resource or product



Why bother modeling a process?

- Phrased differently:
  - "Why don't we stop navel gazing and start writing the darn software right away? We're all pretty smart programmers!"
- Reasons to model a process:
  - To form a **common understanding** amongst team members.
  - To find **inconsistencies, redundancies, omissions** within the process.
  - To **find and evaluate appropriate activities** for reaching process goals.
  - To **tailor a general process** for a particular situation in which it will be used.

An aside: Kinds of coders

- Gandalf
- The Martyr
- Fanboy
- Heavy Metal
- Ninja
- Theoretician
- **Code Cowboy**
- Paratrooper
- Mediocre Man / Mediocre Woman
- Evangelist

- **Cowboy Coders** are programmers who write code according to their own rules. They may be very good at writing code, but [the code] doesn't generally follow the standards, processes, policies, or anything else derived from the group. Cowboy Coders work well alone, or in the old-style CaveProgrammer environment, but they rarely, if ever, work well in a team. Often times, they are a burr in the saddle that keeps the team from getting positive work done.

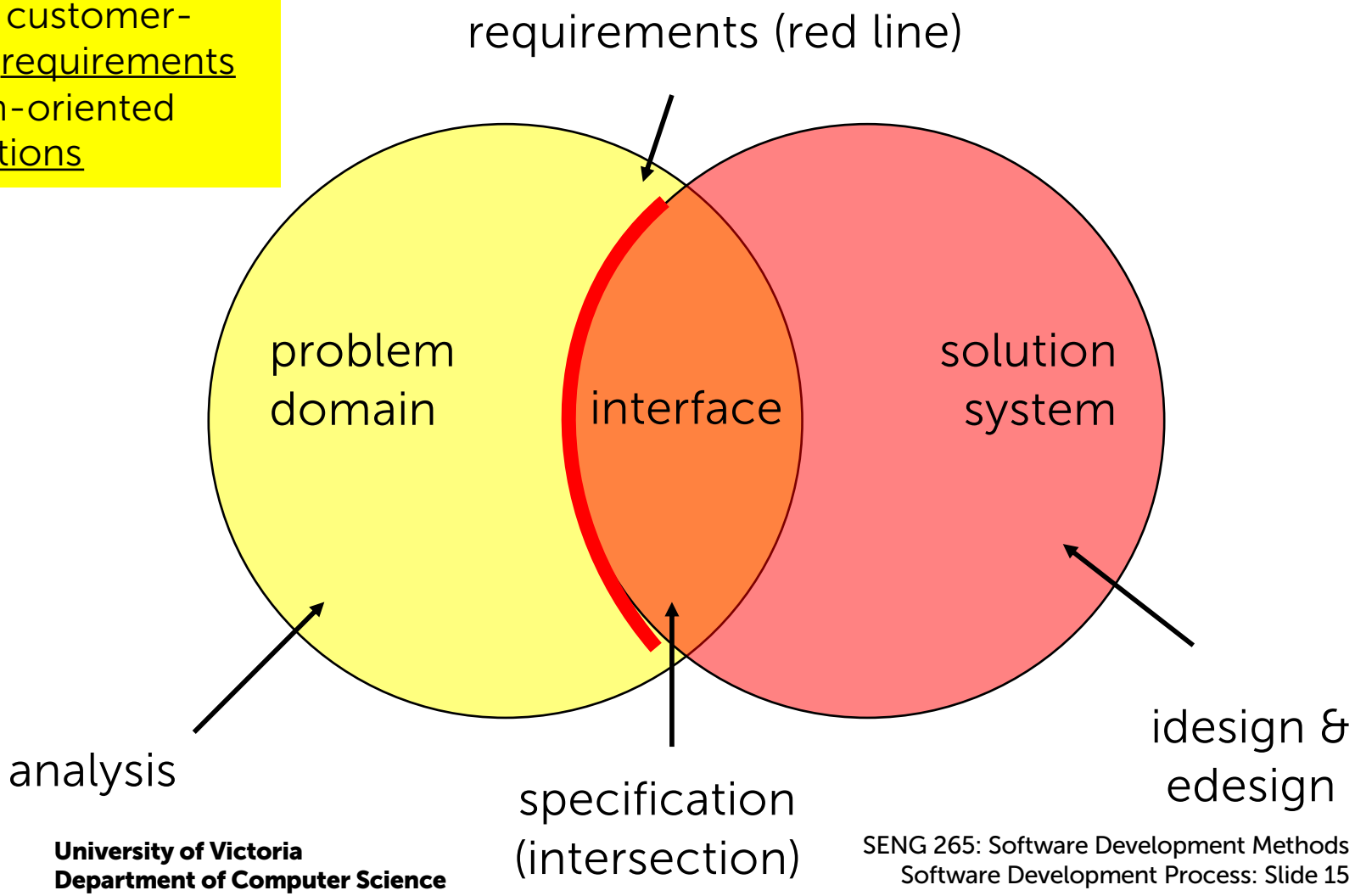
https://tek.io/2K7GjVv

Software life cycle

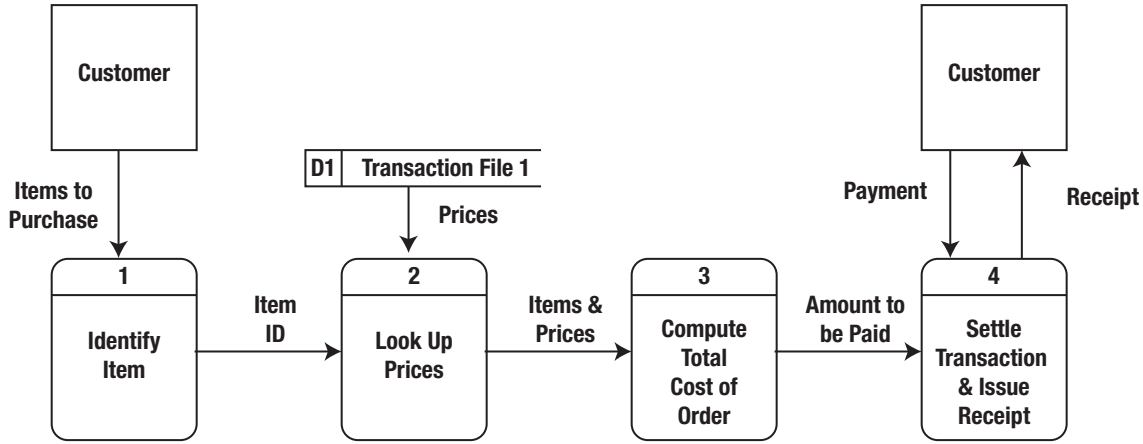
- Sometimes a **software development process** is also referred to as a **software lifecycle**
- The lifecycle involves some variant and arrangement of these seven phases:
  1. **Requirements** analysis and system **specification**
  2. **System design** (i.e., architecture)
  3. **Program design** (i.e., detailed / procedural)
  4. **Writing** the program (i.e., coding, implementation)
  5. **Testing** (unit testing, integration testing, system testing, acceptance testing)
  6. **System delivery** (i.e., deployment)
  7. **Maintenance**

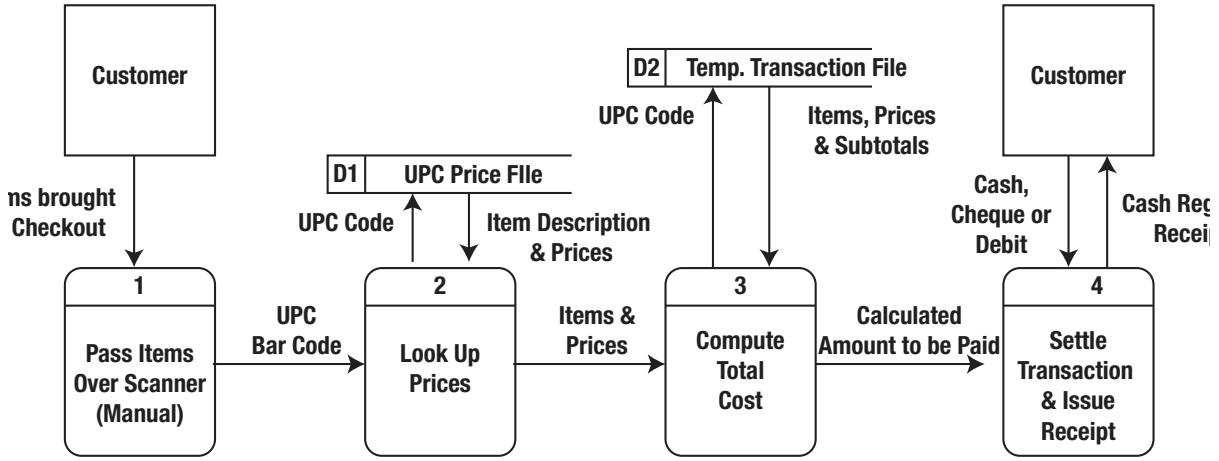
1. Requirements & Specification

Note the relationship between customer-oriented requirements and team-oriented specifications



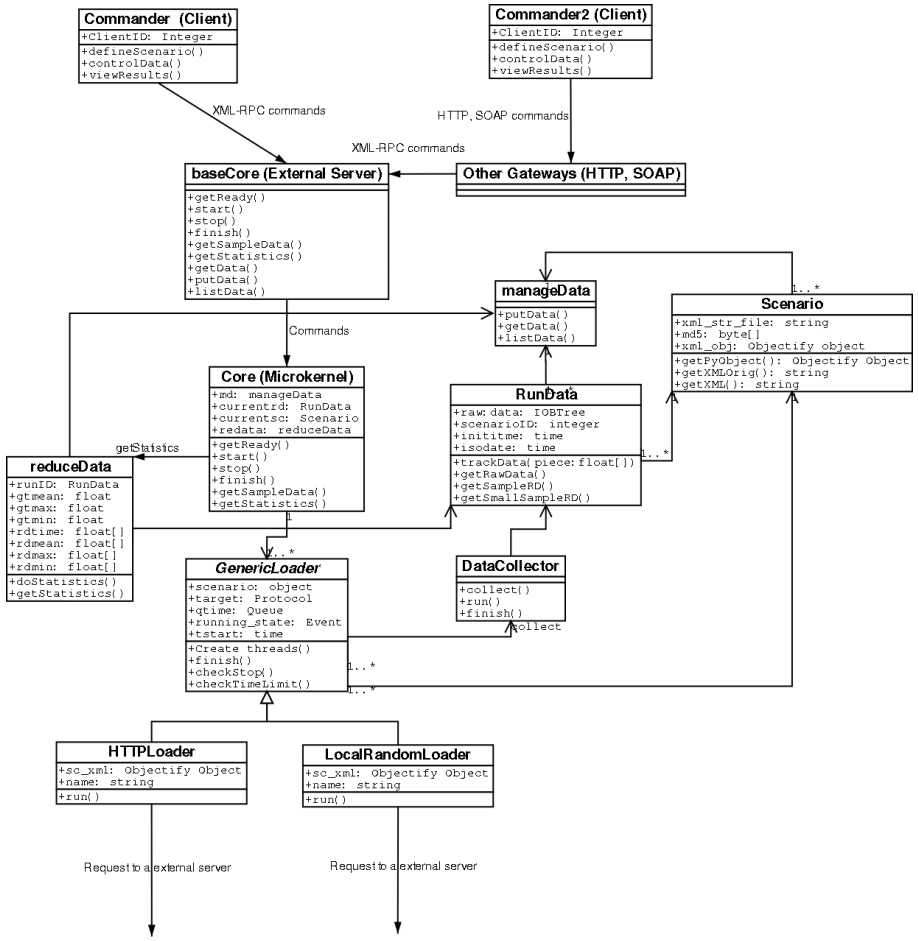
2. System Design

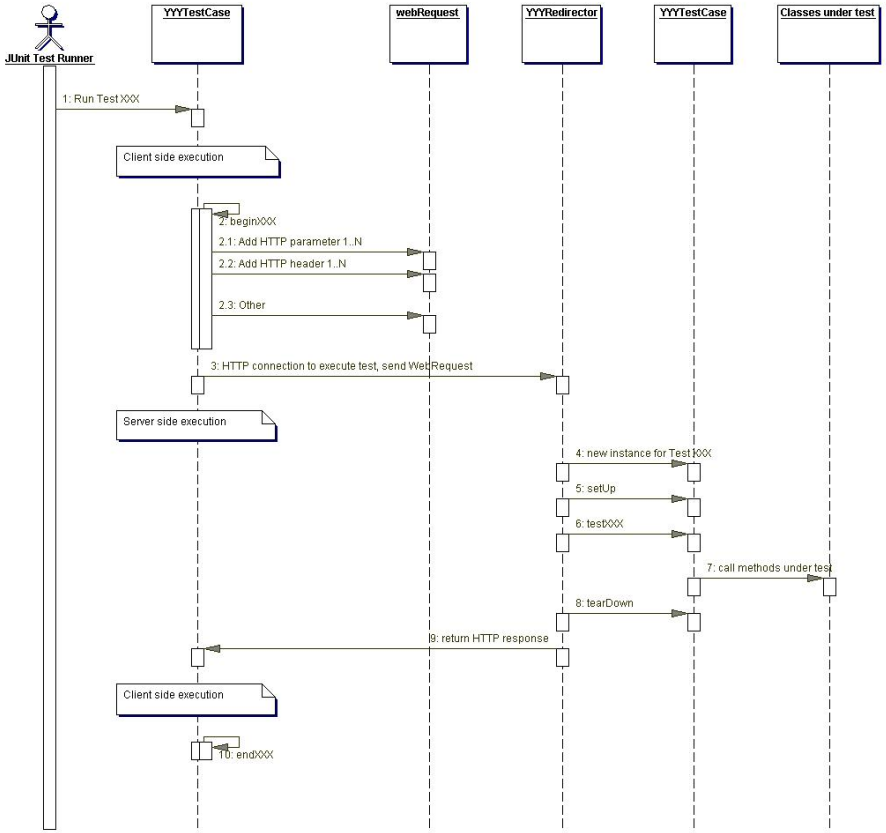




Dataflow diagrams (Logical vs. Physical)

3. Program Design

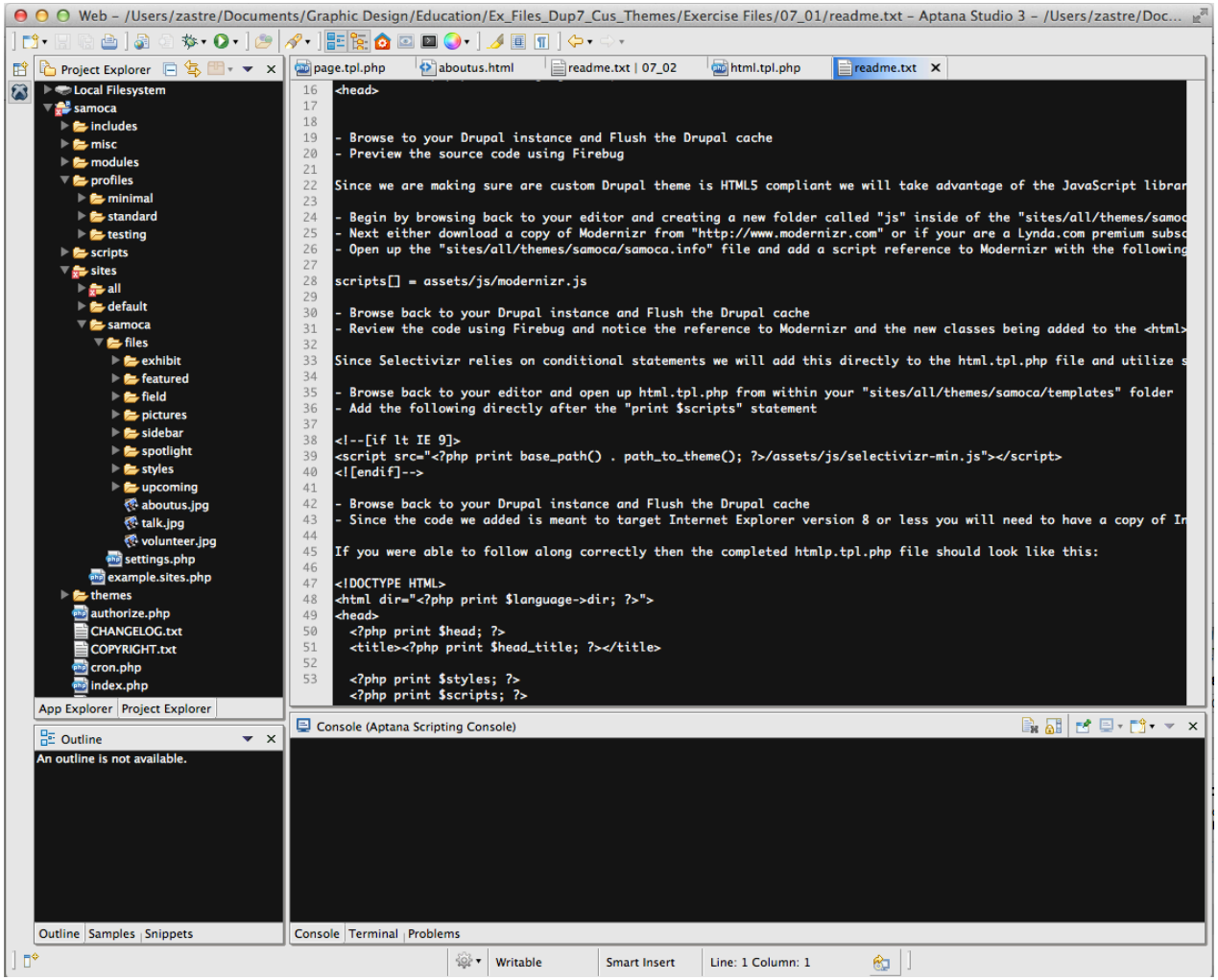




Class diagram example: static properties

Sequence diagram example: dynamic behavior

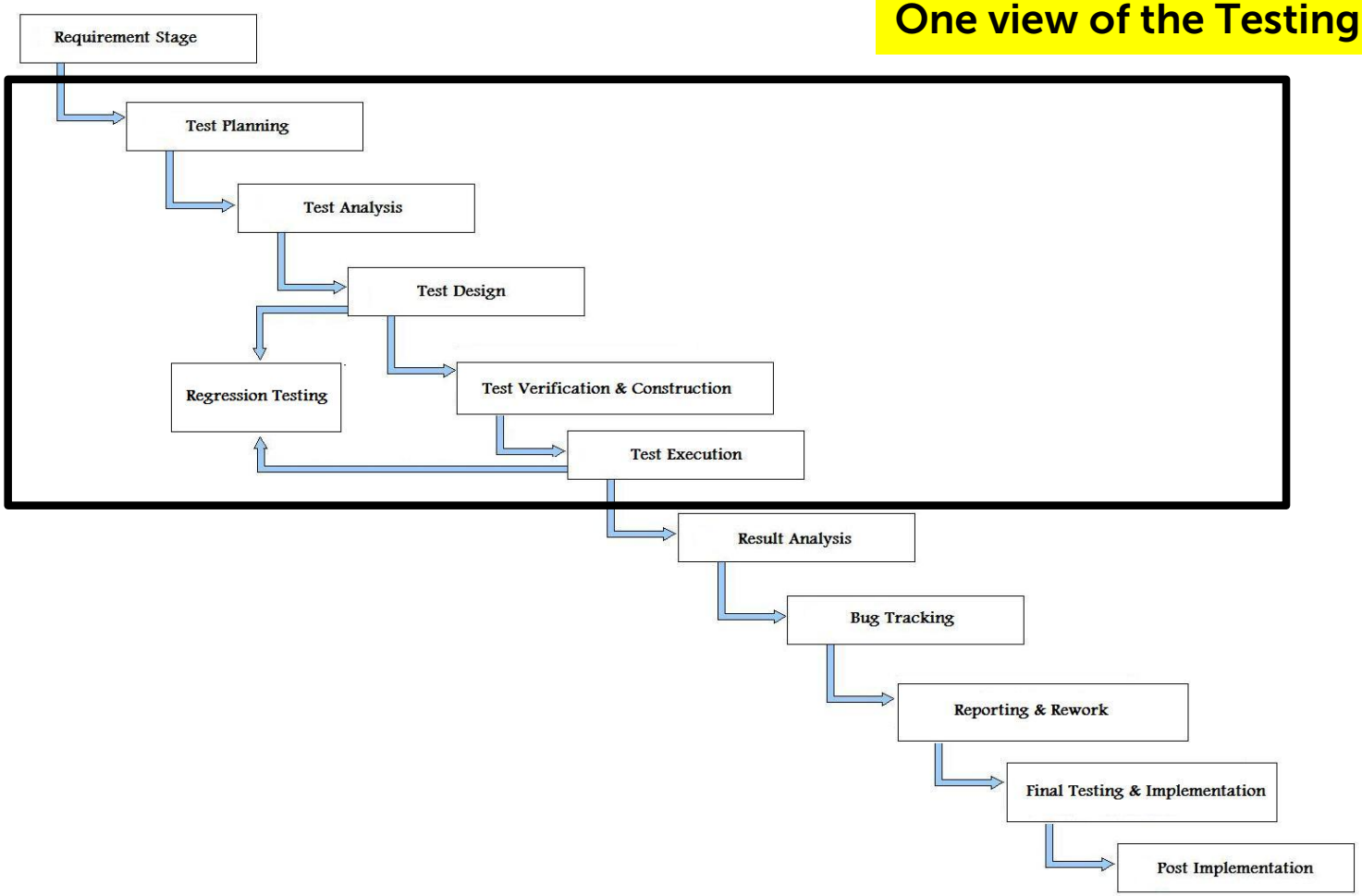
4. Writing the code



Screenshot of Aptana Studio 3

5. Testing

One view of the Testing sub-cycle



6. Deployment; 7. Maintenance

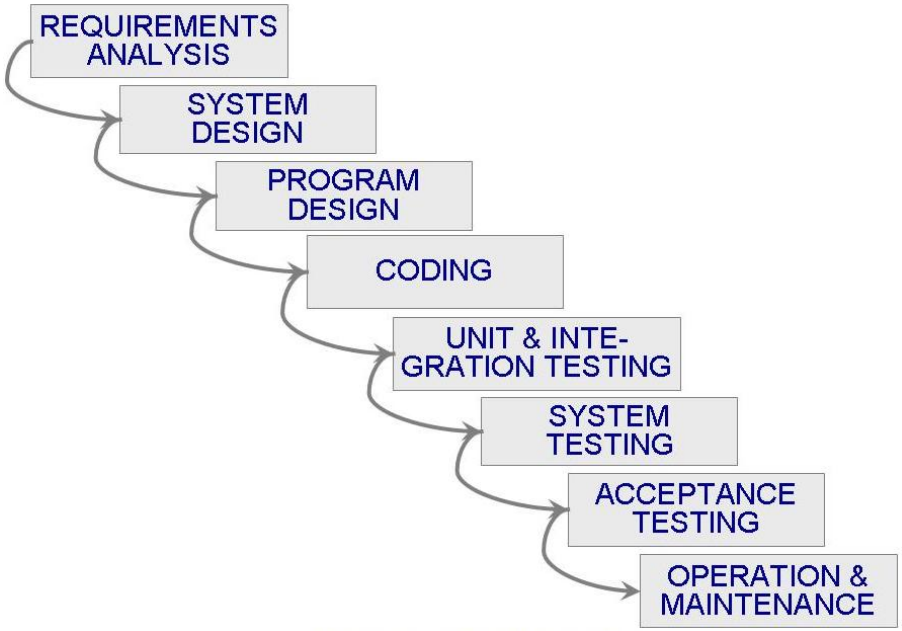
- Deployment:
  - May also involve testing system using client data, mockup of client's environment
  - Usually includes acceptance testing
  - Three actions: delivery, support, feedback
- Maintenance:
  - Fixing problems
  - Adding new functionality, extending existing functionality
  - Least glamorous but perhaps most important phase
  - (Iceberg model of visualizing effort!)
  - May also include software re-engineering (i.e., a rebuilding activity)

Some software process models

A. Waterfall model
B. V model
C. Prototyping model
D. Operational specification
E. Transformational model
F. Phased development: increments and iterations
G. Spiral model
H. Agile methods

A. Waterfall model

- Pure form of the waterfall model indicates a one-way flow of information
  - Data and details never move upstream
  - Model assumes that once system design is done, this phase of the process is not revisited again
- However, this is not an accurate reflection of actual development
  - Models are sometimes distinguished between being **prescriptive** and **descriptive**
  - Waterfall is meant to be prescriptive…
  - … yet it has not worked well in practice!

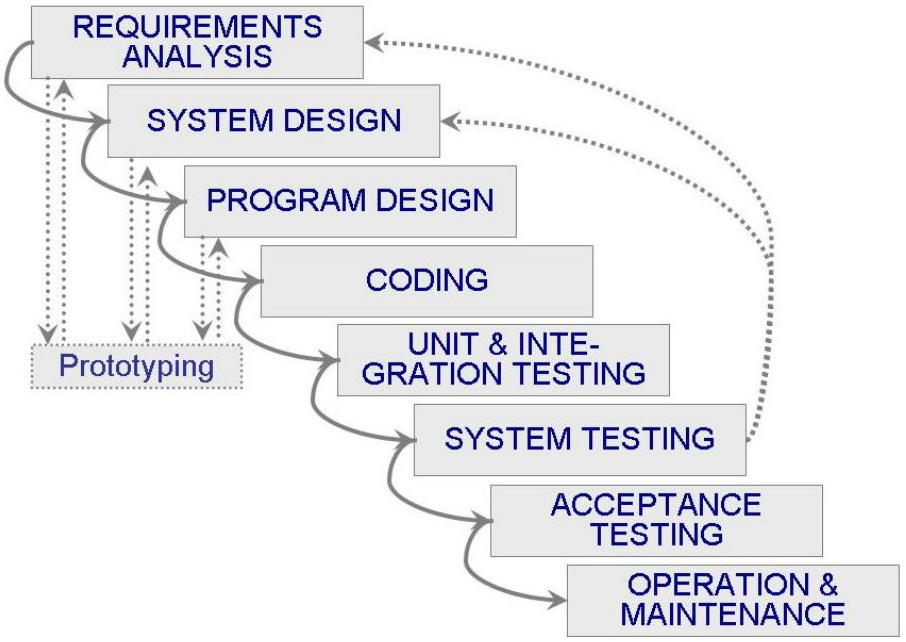


A. Waterfall model

- Provides no guidance how to handle changes to products and activities during development
  - Example: assumes requirements can be frozen, and that they are not ever modified when the customer sees a version of the system
- Views software development as a **manufacturing process** rather than as a **creative process**
- There are no iterative activities that lead to creating a final product
- Long wait before a final product
- (U.S. DoD story)

A. Modified Waterfall model

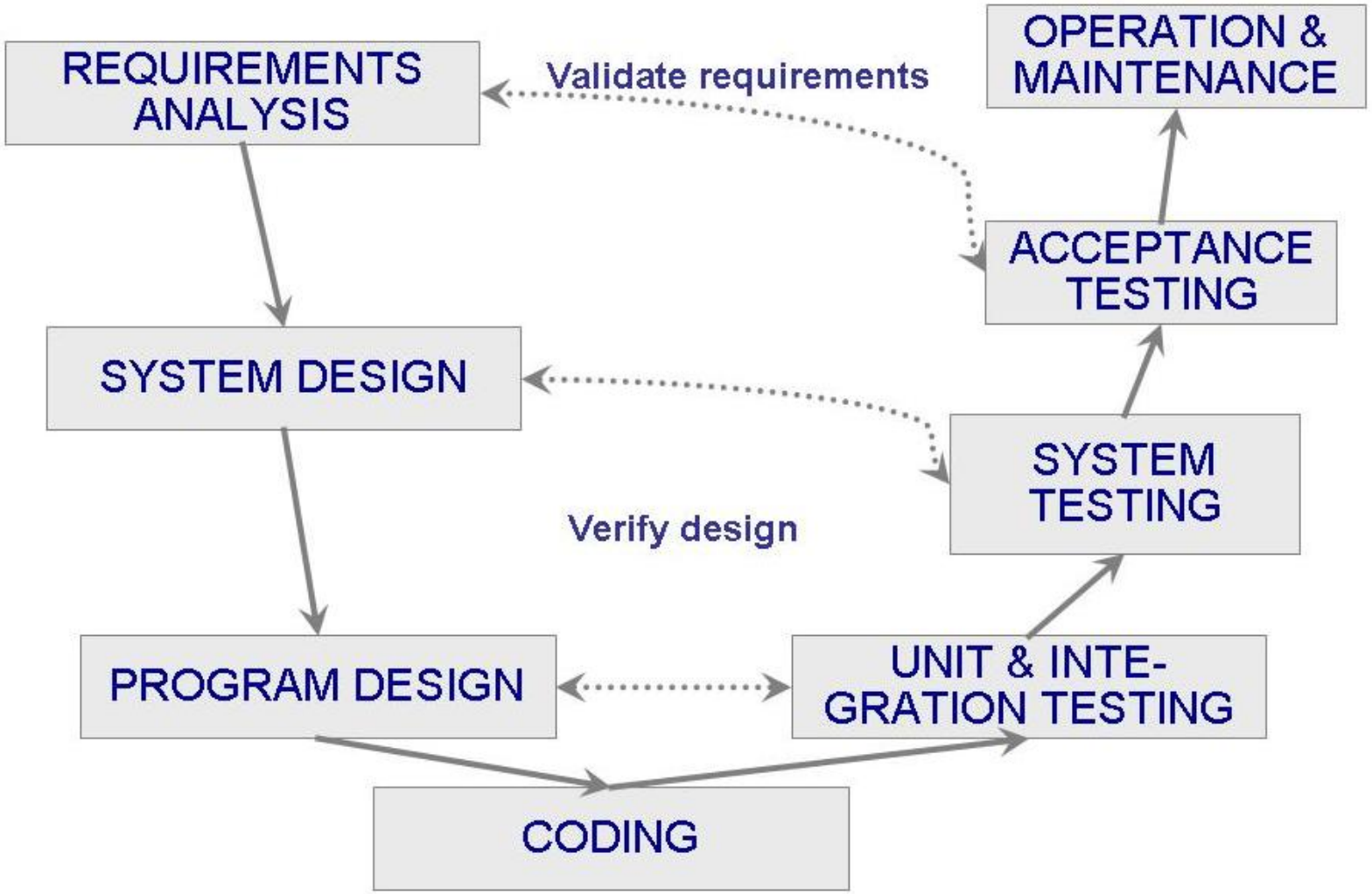
- Includes a prototyping element
- A **prototype** is a **partially developed product**
- Prototyping helps:
  - Developers **assess alternative design strategies** (design prototype)
  - **Users understand what the system will be like** (e.g., user interface prototype)
- Prototyping is useful for verification and validation
- The prototype is usually thrown away (i.e., prototype helps answer questions)



B. V Model

- Another variant of the waterfall model
- Uses **unit testing** to verify **procedural design**
- Uses **integration testing** to verify **architectural (system) design**
- Uses **acceptance testing** to validate the **requirements**
- If problems are found during verification and validation, the activities on the left side of a "V" diagram can be re-executed before testing on the right side is re-enacted

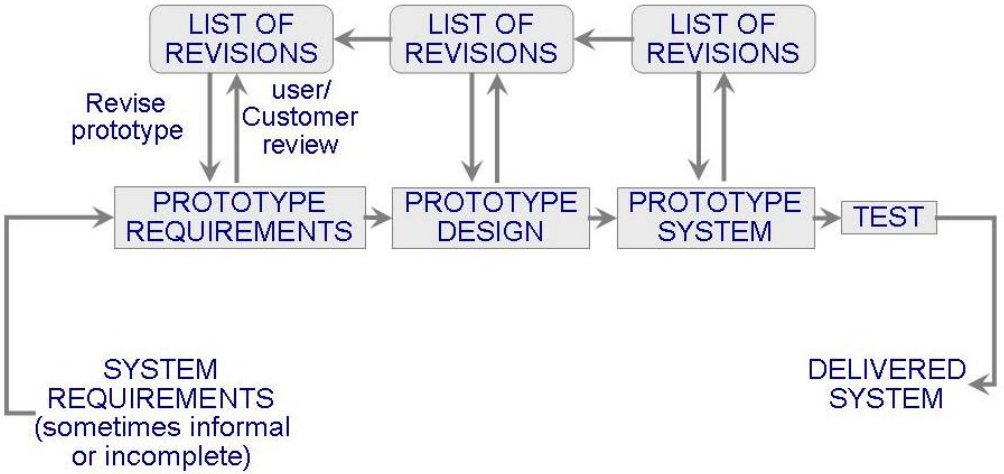
B. V Model


REQUIREMENTS ANALYSIS
Validate requirements
OPERATION & MAINTENANCE
ACCEPTANCE TESTING
SYSTEM DESIGN
SYSTEM TESTING
Verify design
PROGRAM DESIGN
UNIT & INTE-GRATION TESTING
CODING

B. V Model

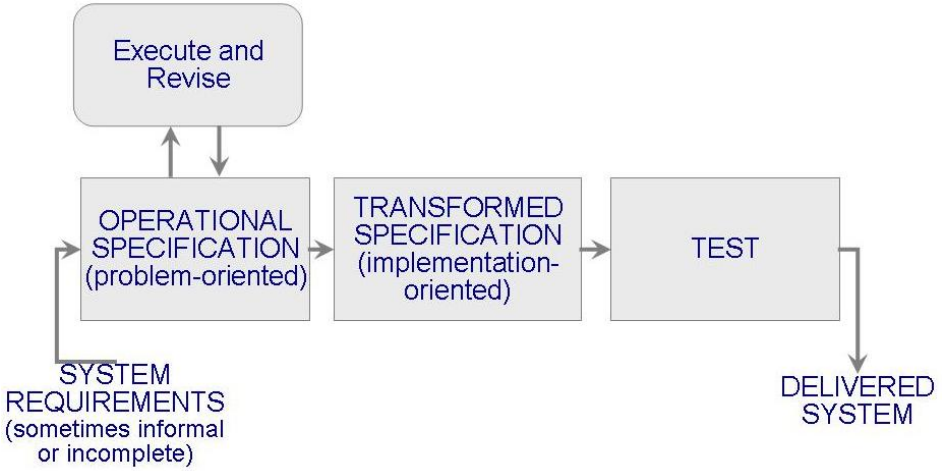
- The model makes more explicit the actual iteration present in software development
- Model was publicized/popularized through its adoption in the early 1990s by the German Ministry of Defense
  - Therefore many defense-industry participants use such a model as it is often a requirement in the tendering process
  - It has its opponents in the agile methods camp (but more about agile methods later)

C. Prototyping model



- Allows repeated investigation of the requirements or design
- Reduces risk and uncertainty in development as customer is able to verify each prototype
- If prototype is not thrown away after each iteration of the cycle, then this approach is something known as **tracer bullets**

D. Operational Specification model



- Requirements/specifications are expressed in some executable format (i.e., a specification language)
  - A flavour of this is also sometimes called "algebraic specification"
- The requirements are executed (either via a tool or by hand examination) and their implication evaluated early in the development process
- Aspects of functionality and design are – in effect – merged in this approach (unlike Waterfall where design and functionality are kept in separate phases).

Example operational specification

Air-traffic control

SECTOR

sort Sector
imports INTEGER, BOOLEAN

Enter - adds an aircraft to the sector if safety conditions are satisfed
Leave - removes an aircraft from the sector
Move - moves an aircraft from one height to another if safe to do so
Lookup - Finds the height of an aircraft in the sector

Create - creates an empty sector
Put - adds an aircraft to a sector with no constraint checks
In-space - checks if an aircraft is already in a sector
Occupied - checks if a specified height is available

Example operational specification

Air-traffic control

Enter (Sector, Call-sign, Height) → Sector
Leave (Sector, Call-sign) → Sector
Move (Sector, Call-sign, Height) → Sector
Lookup (Sector, Call-sign) → Height

Create → Sector
Put (Sector, Call-sign, Height) → Sector
In-space (Sector, Call-sign) → Boolean
Occupied (Sector, Height) → Boolean

Enter (S, CS, H) =
    if In-space (S, CS) **then** S **exception** (Aircraft already in sector)
    elsif Occupied (S, H) **then** S **exception** (Height conflict)
    else Put (S, CS, H)

Leave (Create, CS) = Create **exception** (Aircraft not in sector)
Leave (Put (S, CS1, H1), CS) =
    if CS = CS1 **then** S **else** Put (Leave (S, CS), CS1, H1)

Move (S, CS, H) =
    if S = Create **then** Create **exception** (No aircraft in sector)
    elsif **not** In-space (S, CS) **then** S **exception** (Aircraft not in sector)
    elsif Occupied (S, H) **then** S **exception** (Height conflict)
    else Put (Leave (S, CS), CS, H)

-- NO-HEIGHT is a constant indicating that a valid height cannot be returned

Lookup (Create, CS) = NO-HEIGHT **exception** (Aircraft not in sector)
Lookup (Put (S, CS1, H1), CS) =
    if CS = CS1 **then** H1 **else** Lookup (S, CS)

Occupied (Create, H) = false
Occupied (Put (S, CS1, H1), H) =
    if (H1 > H **and** H1 - H ≤ 300) **or** (H > H1 **and** H - H1 ≤ 300) **then** true
    else Occupied (S, H)

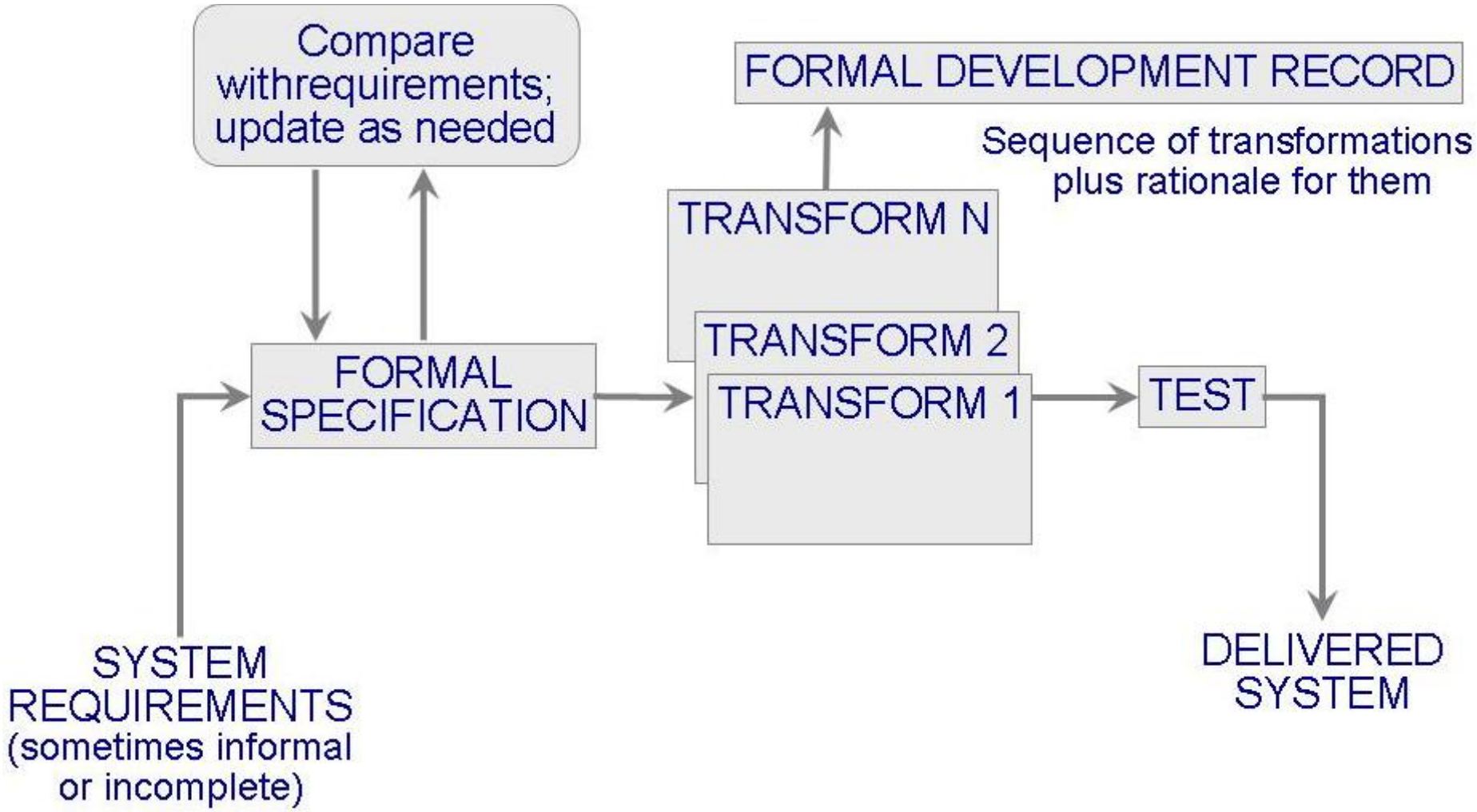
In-space (Create, CS) = false
In-space (Put (S, CS1, H1), CS) =
    if CS = CS1 **then** true **else** In-space (S, CS)

Air-traffic control

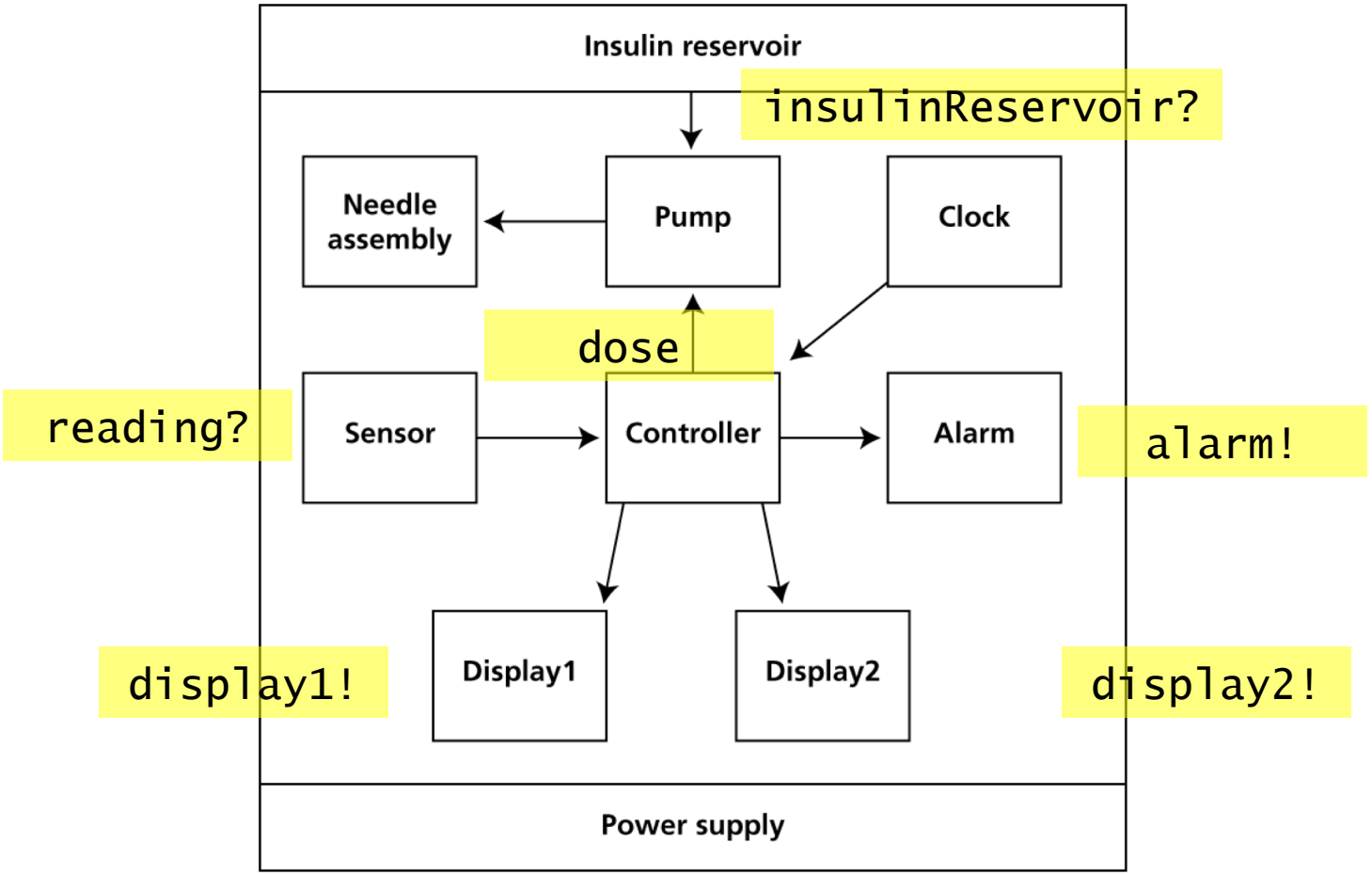
E. Transformational model

- Fewer major development steps
- Applies a series of transformations to change a specification into a deliverable system
  - Change data representation
  - Select algorithms
  - Optimize
  - Compile
- Relies on using a specific **formalism**
- Sometimes this model is referred to as **formal specification**
  - These permit specific transformations to be applied to equations in the formal specification

E. Transformational model



Example: Insulin pump



Example: Insulin pump schema

Insulin_pump

reading?: $\mathbb{N}$
dose, cumulative_dose: $\mathbb{N}$
r0, r1, r2: $\mathbb{N}$ // last three readings
capacity: $\mathbb{N}$
alarm!: {off, on}
pump!: $\mathbb{N}$
display1!, display2!: STRING

$dose \leq capacity \land dose \leq 5 \land cumulative\_dose \leq 50$
$capacity \geq 40 \Rightarrow display! = \text{“ ”}$
$capacity \leq 39 \land capacity \geq 10 \Rightarrow display! = \text{“Insulin low”}$
$capacity \leq 9 \Rightarrow alarm! = on \land display! = \text{“Insulin very low”}$
$r2 = reading?$

DOSAGE schema

DOSAGE

ΔInsulin_Pump

$$
\begin{aligned}
&(\\
&\quad \text{dose} = 0 \ \wedge \\
&\quad (\\
&\qquad ((\ r1 \geq r0\ ) \wedge (\ r2 = r1\ )) \vee \\
&\qquad ((\ r1 > r0\ ) \wedge (\ r2 \leq r1\ )) \vee \\
&\qquad ((\ r1 < r0\ ) \wedge ((r1-r2) > (r0-r1))) \\
&\quad) \vee \\
&\quad \text{dose} = 4 \ \wedge \\
&\quad (\\
&\qquad ((\ r1 \leq r0\ ) \wedge (\ r2 = r1\ )) \vee \\
&\qquad ((\ r1 < r0\ ) \wedge ((r1-r2) \leq (r0-r1))) \\
&\quad) \vee \\
&\quad \text{dose} = (r2 - r1) * 4 \ \wedge \\
&\quad (\\
&\qquad ((\ r1 \leq r0\ ) \wedge (\ r2 > r1\ )) \vee \\
&\qquad ((\ r1 > r0\ ) \wedge ((r1-r2) \geq (r1-r0))) \\
&\quad) \\
&) \\
&\\
&\text{capacity}' = \text{capacity} - \text{dose} \\
&\text{cumulative\_dose}' = \text{cumlative\_dose} + \text{dose} \\
&r0' = r1 \wedge r1' = r2
\end{aligned}
$$

University of Victoria
Department of Computer Science

Output schemas

DISPLAY

ΔInsulin_Pump

---

display2!′ = Nat_to_string(dose) ∧
(reading? < 3 ⇒ display1!′ = “Sugar low” ∨
reading? > 30 ⇒ display1!′ = “Sugar high” ∨
reading? ≥ 3 ∧ reading? ≤ 30 ⇒ display1!′ = “OK”)

ALARM

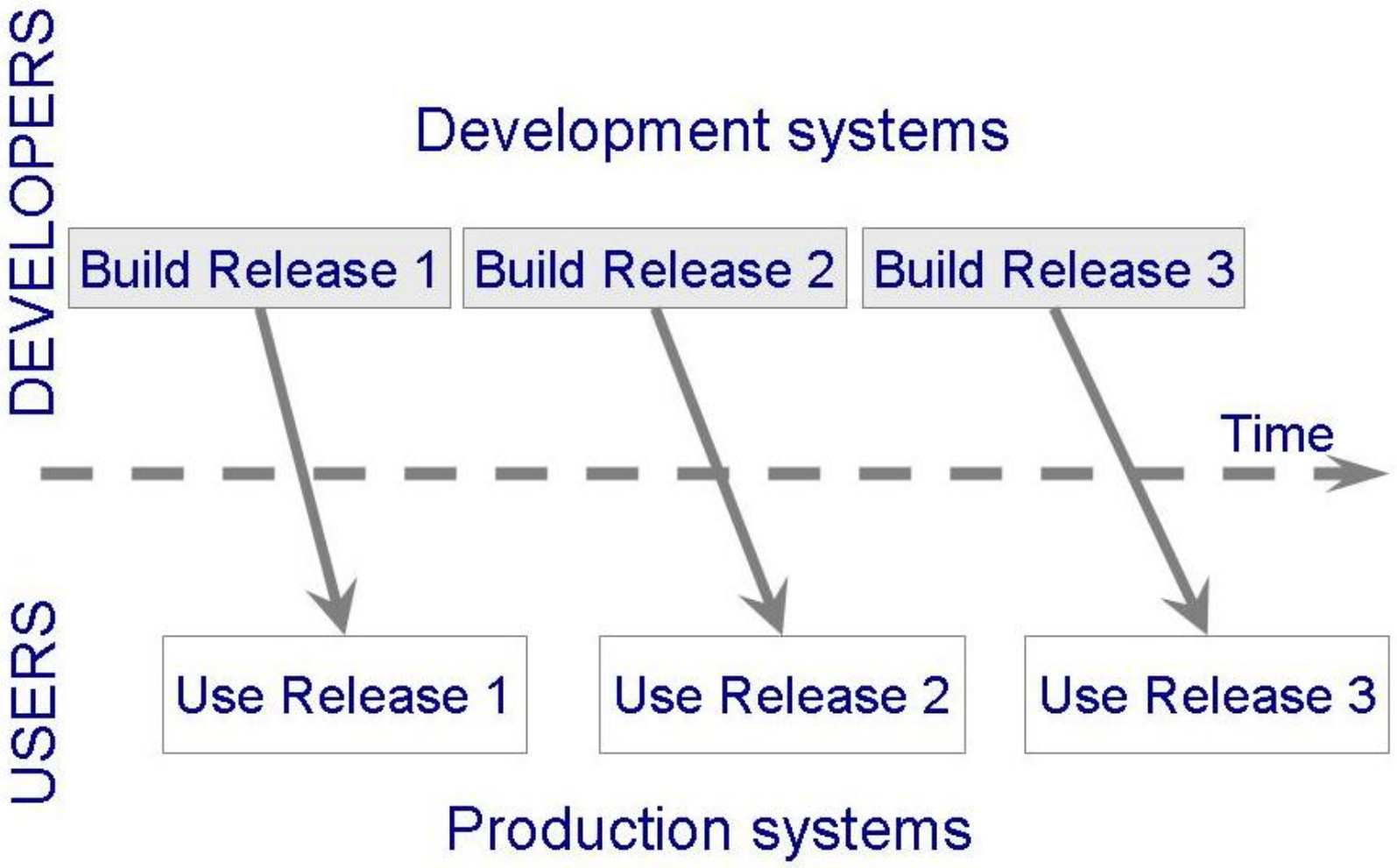
ΔInsulin_Pump

(reading? < 3 ∨ reading? > 30) ⇒ alarm!′ = on ∨
(reading? ≥ 3 ∧ reading? ≤ 30) ⇒ alarm!′ = off

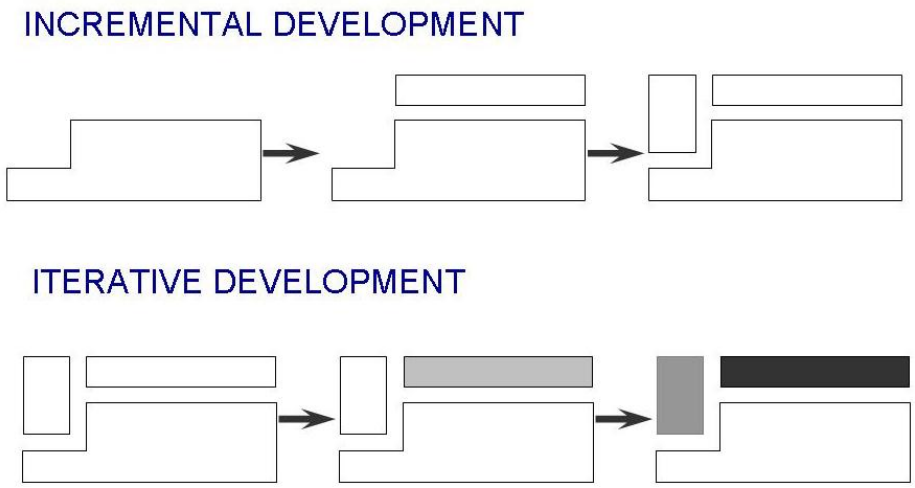
F. Incremental & Iterative

- Shorter cycle time
- System delivered in pieces
  - Enables customers to have some functionality while the rest is being developed
- Allows two systems to function in parallel
  - The production system (release n): currently being used
  - The development system (release n+1): the next version
- Has been used for over 50 years

F. Incremental & Iterative



F. Incremental vs. Iterative...



- **Incremental development**: Starts with **small functional subsystem** and **adds** functionality with each new release
- **Iterative development**: Starts with **full system albeit having minimal functionality**, then **changes** functionality of each subsystem with each new release

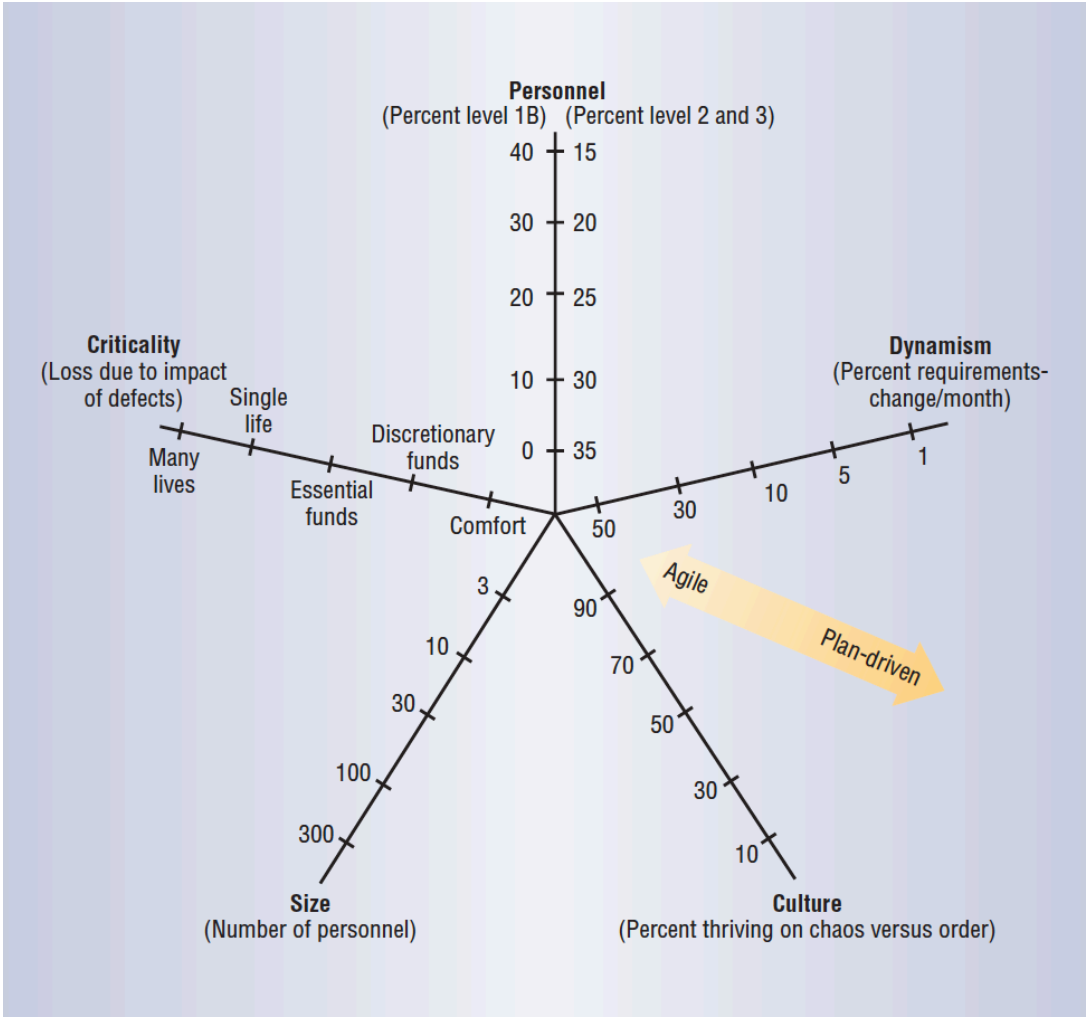
F. Incremental & Iterative

- This phased development is desirable for several reasons
  - Training can begin early, even though some functions are missing
  - Markets can be created early for functionality that has never before been offered
  - Frequent releases allow developers to fix unanticipated problems globally and quickly
  - The development team can focus on different areas of expertise with different releases

G. Spiral Model

- Suggested by Barry Boehm in the late 1980s
- Combines **development activities** with **risk management** to minimize and help control risks present in software-development projects
- The model is presented as a spiral in which each iteration is represented by a circuit around four major activities
  - Plan
  - Determine goals, alternatives, and constraints
  - Evaluate alternatives and risks
  - Develop and test
- What do we mean by **risk** in the context of software development?

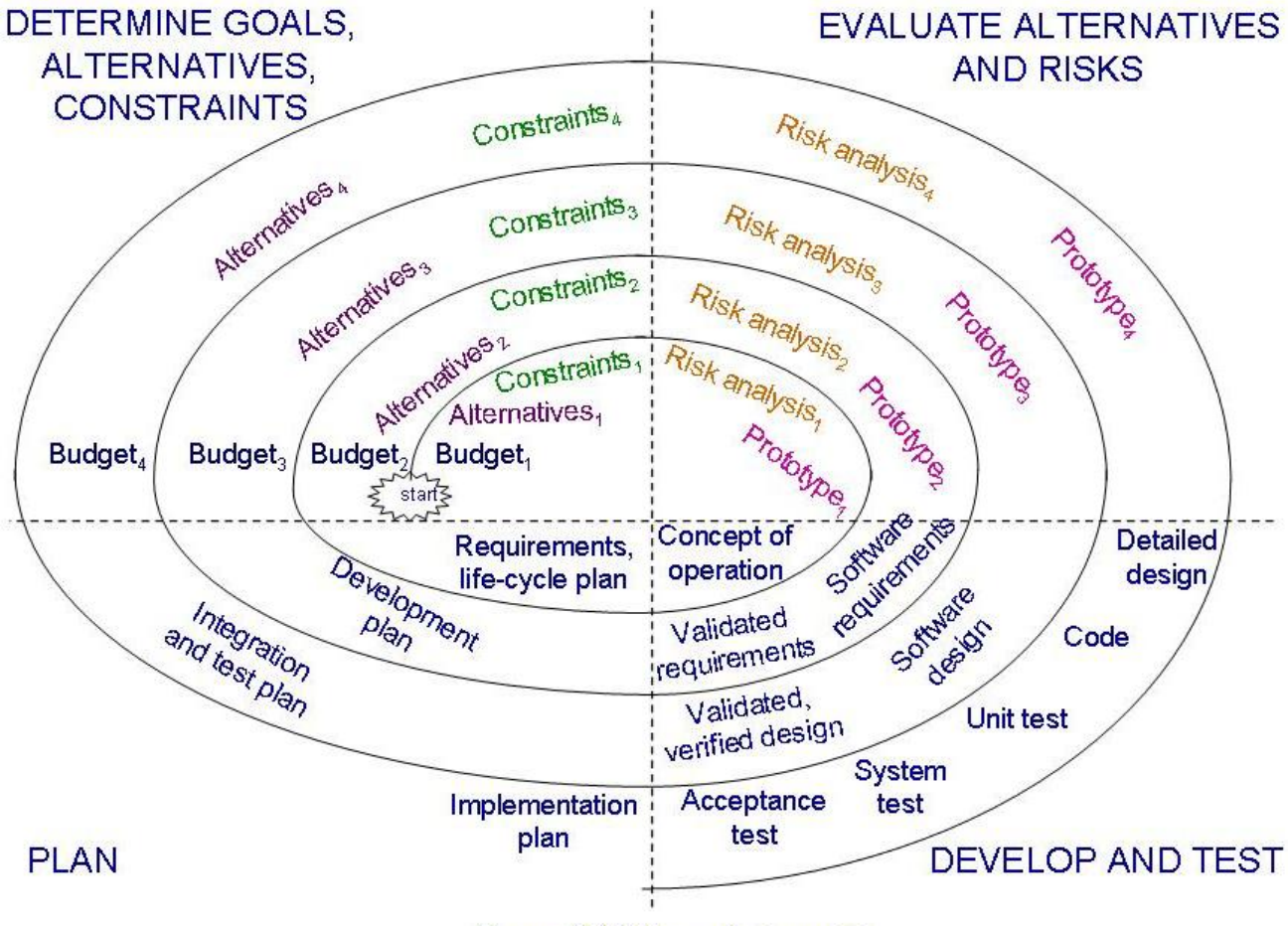
(An aside about development risks)



Cockburn's Three levels of Software Understanding (revised by Boehm)

- 3: Able to revise a method, breaking its rules to fit an unprecedented new situation
- 2: Able to tailor a new method to fit a previously-seen situation.
- 1A, 1B: With training, able to perform some discretionary or procedural steps (or both)
- -1: May have technical skills, but unable or unwilling to collaborate or follow shared methods.

G. Spiral model



H. Agile methods

- Emphasis on flexibility in producing software quickly and capably
- **Agile Manifesto**
  - Value individuals and interactions over process and tools
  - Prefer to invest time in producing working software rather than in producing comprehensive documentation
  - Focus on customer collaboration rather than contract negotiation
  - Concentrate on responding to change rather than on creating a plan and then following it regardless of what happens

H. Agile methods

- **Extreme programming** (XP) is one flavour of Agile methods
- **Crystal**: a collection of approaches based on the notion that every project needs a unique set of policies and conventions
- **Scrum**: Seven- to 30-day iterations; multiple self-organizing teams; daily “scrum” coordination
- **Adaptive software development** (ASD): repeating series of "speculate", "colloborate" and "learn" cycles.

H. Agile methods

- Emphasis on **four characteristics of agility**
  - **Communication**: Continual interchange between customers and developers
  - **Simplicity**: Select the simplest design or implementation
  - **Courage**: Commitment to delivering functionality early and often
  - **Feedback**: Loops built into the various activities during the development process

H. Agile methods

- The planning game: customer defines value
- Small releases
- Shared metaphors: common vision, common names
- Simple design
- Writing tests first
- Refactoring
- Pair programming
- Collective ownership
- Continuous integration: small increments
- Sustainable pace: 40 hours/week
- On-site customer
- Coding standards

H. Agile methods: concerns

- Extreme programming's practices are interdependent
  - A vulnerability if one of them is modified
- Requirements expressed as a set of test cases must be passed by the software
  - System passes the tests but a "test-passing system" is not what the customer is paying for
- Refactoring is an issue
  - Difficult to rework a system without degrading its architecture

Summary

- Process development involves activities, resources, and product
- Process model includes organizational, functional, behavioral, and other perspectives
- A process model is useful for guiding team behavior, coordination, and collaboration

Colophon

- Some slides based on Pfleeger & Atlee, "Software Engineering: Theory and Practice" © 2006 Prentice Hall
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