# TECHNISCHE UNIVERSITÄT MÜNCHEN

## Software Engineering in Industrial Practice (SEIP)

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# Software Engineering Workflow

**PRODUCT FOCUS** — Business & Deliverables

ENVISION · CONFIGURE · RELEASE · ROLLOUT

WHY?
**PRD** PRODUCT MANAGEMENT

**DOMAIN FOCUS** — Problem & Solution

IDEATE · EXPLORE · SPECIFY · UNDERSTAND

WHAT?
**BIZ** BUSINESS

**PROJECT FOCUS** — Communication & Orchestration

INITIATE · DEFINE · PLAN · STEER

WHEN?
**PRJ** PROJECT MANAGEMENT

DESIGN · IMPLEMENT · BUILD · VERIFY

HOW?
**DEV** DEVELOPMENT

ADAPT (meta)

DEPLOY · INTEGRATE · OPERATE · MONITOR

WHERE?
**OPS** OPERATIONS

**TECHNOLOGY FOCUS** — Software & Systems

(A) Automatable

**ITERATIVE APPROACH:** The three main and two auxiliary workflow cycles express a fully iterative engineering approach.

**FULL-CYCLE SCOPE:** The scope of the full main-cycle workflow usually is based on business-value-adding user scenarios.

**PEOPLE INCLINATIONS:** The five workflow cycles intentionally loosely align with the usual inclinations, which express the different types of involved people.

**EMPHASIS AND SEQUENCING:** The workflow step colors represent the usual workflow emphasis. Workflow steps are executed in sequence but may be skipped if dispensable.

**INTERLINKED CYCLES:** The three main cycles are inter-linked and can cycle through their steps at different speeds $S(x)$: $S(BIZ) \geq S(DEV) \geq S(OPS)$

**DISCIPLINE RESPONSIBILITY:** Each workflow step has one or more disciplines which are responsible for continuously performing the step in practice.

*focus & steps*

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The Workflow Model describes the work segregation in Software Engineering. In the **Workflow**, three main and two auxiliary workflow cycles express the iterative approach. The full main-cycle workflow is usually based on business-value-adding user scenarios.

The three main cycles are interlinked and can cycle through their steps at different speeds, $S(x)$, with $S(BIZ)$ greater then or equal to $S(DEV)$, which in turn is greater then or equal to $S(OPS)$. Because the cycles with earlier steps should not slow down the cycles with later steps.

The step colors represent workflow emphasis. Workflow steps are executed in sequence but may be skipped if dispensable.

The ten discipline areas of Software Engineering express the different roles of the involved people. The five inclinations express the different types of the involved people. Hence, the Workflow consists of exactly five cycles.

## Questions

❓ What does the Workflow-Model of Software Engineering describe?

# Software Engineering Steps

## PRODUCT MANAGEMENT — PRD

**ENVISION** — PRD · UXP

**Envision Solution:**
We envision the solution functionality and quality from the business and user perspectives.

**CONFIGURE** — PRD · VER

**Configure Version:**
We configure versions of the solution from versioned artifacts and their feature-sets.

**RELEASE** — PRD · ASM · DOC

**Release Version:**
We create and release a distinct version of the solution.

**ROLLOUT** — CHG · TRN

**Rollout Version:**
We adequately inform, involve and train the users and operators of the solution.

## BUSINESS EFFORTS — BIZ

**UNDERSTAND** — REQ · UXP · PRD

**Understand Problem:**
We empathically understand the problem and requirements of the users.

**IDEATE** — UXP · REQ

**Ideate Solution:**
We find an adequate solution for the problem and the requirements of the users.

**EXPLORE** — UXP · UID · SWA · DEV

**Explore Ideas:**
We prototype, explore, and assess ideas, approaches and technologies for the solution.

**SPECIFY** — DOM · UID

**Specify Solution:**
We rigorously and completely specify the functionality and quality of the solution.

## DEVELOPMENT EFFORTS — DEV

**DESIGN** — SWA · SYA

**Design Architecture:**
We design how to implement the solution in an orthogonal, adequate and sustainable way.

**IMPLEMENT** — DEV · DOC · REF · REV

**Implement Solution:**
We implement the solution outside-in, from coarse to fine aspects.

**BUILD** — ASM · VER

**Build Artifacts:**
We build and package the solution from versioned artifacts.

**VERIFY** — TST · REV

**Verify Solution:**
We rigorously, but adequately, review and test the functional and non-functional aspects of the solution.

## OPERATIONS EFFORTS — OPS

**DEPLOY** — DPL · OPS · SYA

**Deploy Artifacts:**
We ship and deploy the solution releases and their updates in an automated and repeatable way.

**INTEGRATE** — DPL · OPS · SYA

**Integrate Environment:**
We integrate the solution with its target environment.

**OPERATE** — OPS

**Operate Solution:**
We ensure that our infrastructures and the solution can be operated in a resilient and secure manner.

**MONITOR** — OPS · TST

**Monitor Solution:**
We continuously monitor our infrastructures and the solution under run-time.

## PROJECT MANAGEMENT — PRJ

**INITIATE** — PRJ · COA

**Initiate Project:**
We initially setup the project on the contract and resource level.

**DEFINE** — PRJ · PRD

**Define Constraints:**
We define the constraints of the project on the time, cost, and scope level.

**PLAN** — PRJ · PRD

**Plan Tasks:**
We continuously plan the next iterations, their steps and their tasks in the project.

**STEER** — PRJ

**Steer People:**
We rigorously and continuously balance time, cost and scope to react on changes and still fulfilling the constraints.

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Software Engineering, on an operational level, can be alternatively understood through 20 distinct **Steps** which are continuously performed within the **Software Engineering Workflow**. Each Step belongs to one primarily responsible Discipline and zero or more secondarily responsible Disciplines.

Workflow Steps are the adequate concept to understand which activities have to be performed in each iteration of a **Software Engineering Process**.

## Questions

❓ Which concept allows one to best understand which activities have be performed in a Software Engineering Process?

# Software Engineering Process

**1. WORKFLOW CYCLES**
The workflow has five cycles which continuously iterate through their steps. Workflow steps are executed in each cycle in sequence, but may be skipped if dispensable in a particular iteration of the process. The length of an iteration is arbitrary, but can be e.g. about 1/3 of a Scrum sprint.

**2. WORKFLOW STEPS:**
The workflow steps describe a logical activity which has to be performed. Each step relates to one or more discipline areas and their corresponding disciplines, which express the operative responsibilities for each workflow step. In each discipline individual roles act.

**3. WORKFLOW ROLES:**
The workflow roles are held by individual persons. Each role is primarily responsible for a particular workflow step. In addition, each role can be secondarily responsible for other workflow steps or at least actively support those steps.

**4. PROJECT SCHEDULE:**
To create a particular project execution schedule, the five cycles, their iterations and their steps have to be mapped onto a timeline. The cycles are mapped onto (horizontal) timeline tracks, the iterations are mapped onto (vertical) timeline phases, and the steps are mapped onto timeline activities.

**5. PROCESS FLOWS (THE CRUX):**
The activities across the cycles can (and should) be linked into individual (diagonal) waterfall-like flows, although the execution schedule, from the perspective of the cycles, is fully iterative. There are multiple such flows in parallel and they are usually highly interleaved on the project timeline in order to maximally utilize the team.
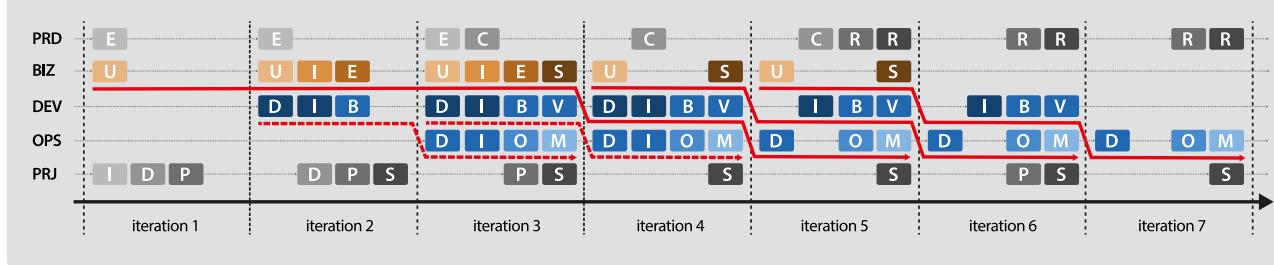
**6. PROCESS ADAPTION:**
In the meta-step ADAPT, the process is adapted by choosing which workflow steps are required for the next iteration. The major input for this decision is the current solution state and the feedback on it by the customer.



Legend:
- ■ responsible (primarily)
- ■ responsible (secondarily)
- + supporting



*roles & tasks*

The workflow has five main cycles, which continuously iterate through their steps. Workflow steps are executed in each cycle in sequence but may be skipped if dispensable.

The workflow steps are annotated with discipline areas to express operative responsibilities. In each area, multiple roles act.
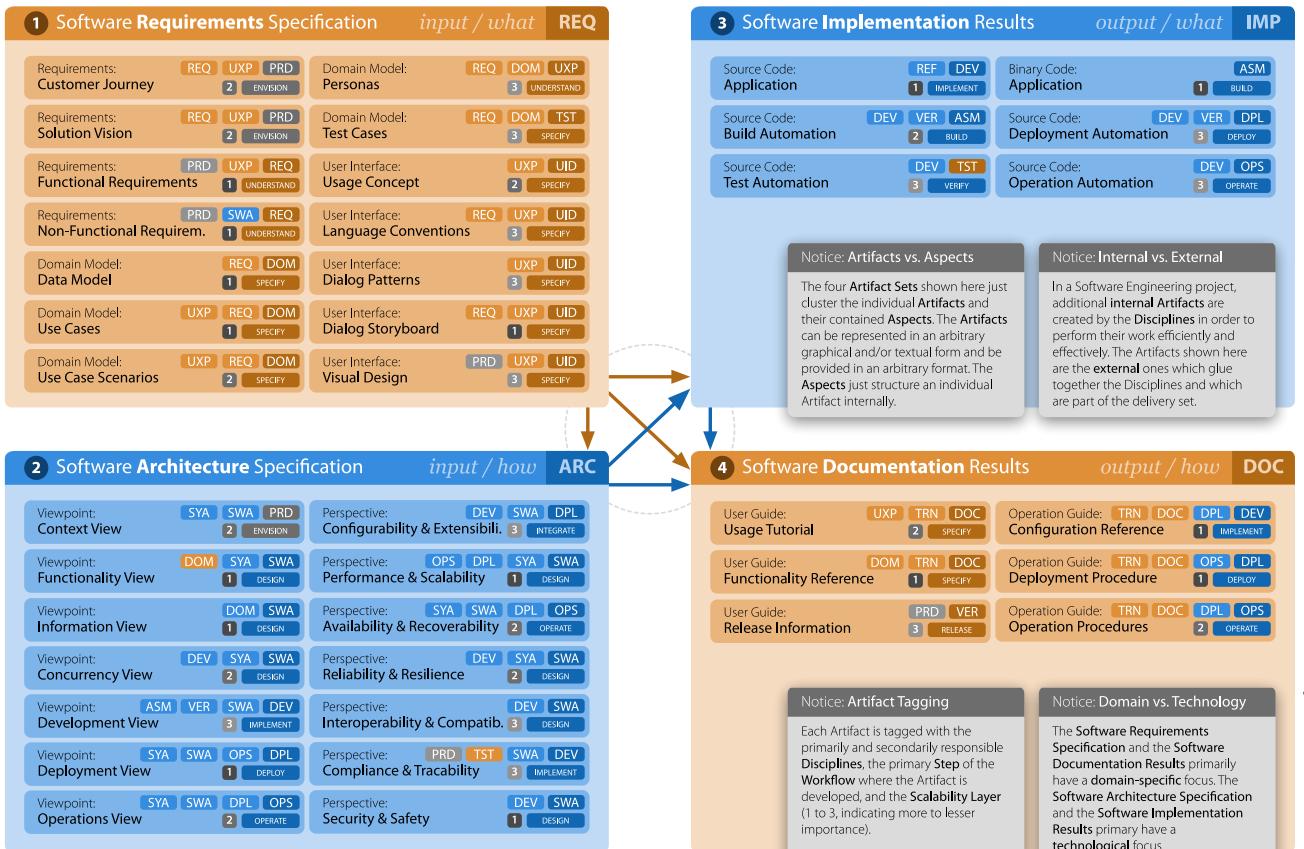
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To create a particular project execution schedule, the five cycles, their iterations, and their steps have to be mapped onto a timeline. The cycles are mapped onto (horizontal) timeline tracks, and the iterations are mapped onto (vertical) timeline phases, and the steps are mapped onto timeline activities.

The activities across the cycles can (and should) be linked into individual (diagonal) waterfall-like flows, although the execution schedule, from the perspective of the cycles, is fully iterative. There are multiple such flows in parallel, and they are usually highly interleaved on the project timeline in order to maximally utilize the team.

## Questions

❓ How can maximum utilization of the team be achieved in Software Engineering, despite a division of labor?

# Software Engineering Artifacts

**1** Software **Requirements** Specification — *input / what* — **REQ**

| | | |
|---|---|---|
| Requirements: Customer Journey — REQ UXP PRD — 2 ENVISION | Domain Model: Personas — REQ DOM UXP — 3 UNDERSTAND | |
| Requirements: Solution Vision — REQ UXP PRD — 2 ENVISION | Domain Model: Test Cases — REQ DOM TST — 3 SPECIFY | |
| Requirements: Functional Requirements — PRD UXP REQ — 1 UNDERSTAND | User Interface: Usage Concept — UXP UID — 2 SPECIFY | |
| Requirements: Non-Functional Requirem. — PRD SWA REQ — 1 UNDERSTAND | User Interface: Language Conventions — REQ UXP UID — 3 SPECIFY | |
| Domain Model: Data Model — REQ DOM — 1 SPECIFY | User Interface: Dialog Patterns — UXP UID — 3 SPECIFY | |
| Domain Model: Use Cases — UXP REQ DOM — 1 SPECIFY | User Interface: Dialog Storyboard — REQ UXP UID — 1 SPECIFY | |
| Domain Model: Use Case Scenarios — UXP REQ DOM — 2 SPECIFY | User Interface: Visual Design — PRD UXP UID — 3 SPECIFY | |

**3** Software **Implementation** Results — *output / what* — **IMP**

| | |
|---|---|
| Source Code: Application — REF DEV — 1 IMPLEMENT | Binary Code: Application — ASM — 1 BUILD |
| Source Code: Build Automation — DEV VER ASM — 2 BUILD | Source Code: Deployment Automation — DEV VER DPL — 1 DEPLOY |
| Source Code: Test Automation — DEV TST — 3 VERIFY | Source Code: Operation Automation — DEV OPS — 3 OPERATE |

**Notice: Artifacts vs. Aspects**

The four **Artifact Sets** shown here just cluster the individual **Artifacts** and their contained **Aspects**. The **Artifacts** can be represented in an arbitrary graphical and/or textual form and be provided in an arbitrary format. The **Aspects** just structure an individual Artifact internally.

**Notice: Internal vs. External**

In a Software Engineering project, additional **internal Artifacts** are created by the **Disciplines** in order to perform their work efficiently and effectively. The Artifacts shown here are the **external** ones which glue together the Disciplines and which are part of the delivery set.

**2** Software **Architecture** Specification — *input / how* — **ARC**

| | | |
|---|---|---|
| Viewpoint: Context View — SYA SWA PRD — 2 ENVISION | Perspective: Configurability & Extensibili. — DEV SWA DPL — 3 INTEGRATE | |
| Viewpoint: Functionality View — DOM SYA SWA — 1 DESIGN | Perspective: Performance & Scalability — OPS DPL SYA SWA — 1 DESIGN | |
| Viewpoint: Information View — DOM SWA — 1 DESIGN | Perspective: Availability & Recoverability — SYA SWA DPL OPS — 2 OPERATE | |
| Viewpoint: Concurrency View — DEV SYA SWA — 2 DESIGN | Perspective: Reliability & Resilience — DEV SYA SWA — 2 DESIGN | |
| Viewpoint: Development View — ASM VER SWA DEV — 3 IMPLEMENT | Perspective: Interoperability & Compatib. — DEV SWA — 3 DESIGN | |
| Viewpoint: Deployment View — SYA SWA OPS DPL — 1 DEPLOY | Perspective: Compliance & Tracability — PRD TST SWA DEV — 3 IMPLEMENT | |
| Viewpoint: Operations View — SYA SWA DPL OPS — 2 OPERATE | Perspective: Security & Safety — DEV SWA — 1 DESIGN | |

**4** Software **Documentation** Results — *output / how* — **DOC**

| | |
|---|---|
| User Guide: Usage Tutorial — UXP TRN DOC — 2 SPECIFY | Operation Guide: Configuration Reference — TRN DOC DPL DEV — 1 IMPLEMENT |
| User Guide: Functionality Reference — DOM TRN DOC — 1 SPECIFY | Operation Guide: Deployment Procedure — TRN DOC OPS DPL — 1 DEPLOY |
| User Guide: Release Information — PRD VER — 3 RELEASE | Operation Guide: Operation Procedures — TRN DOC DPL OPS — 2 OPERATE |

**Notice: Artifact Tagging**

Each Artifact is tagged with the primarily and secondarily responsible **Disciplines**, the primary **Step** of the **Workflow** where the Artifact is developed, and the **Scalability Layer** (1 to 3, indicating more to lesser importance).

**Notice: Domain vs. Technology**

The **Software Requirements Specification** and the **Software Documentation Results** primarily have a **domain-specific** focus. The **Software Architecture Specification** and the **Software Implementation Results** primary have a **technological** focus.

*artifacts & deliverables*

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Each **Artifact** is tagged with the primary and secondary responsible **Disciplines**, the primary **Step** of the Workflow where the Artifact is developed, and the Scalability Layer (1 to 3, indicating more to lesser importance).

The **Software Requirements Specification** and the **Software Documentation Results** primarily have a **domain-specific** focus. The **Software Architecture Specification** and the **Software Implementation Results** primarily have a **technological** focus.

## Questions

**?** What focus has the **Software Requirements Specification**?

# Software Engineering Efforts

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Software **products** follow a **life-cycle** of seven temporal, non-equally sized **phases**. Software Engineering **disciplines** individually focus their **efforts** on those phases and their efforts either bottom-up depend on the domain-specific **scope** or top-down do not depend on it. The amount of required **human resources** differs between those phases, too. Effort **estimations** have to take disciplines, their phase focus, their domain-specific scope dependency, and the human resource **staffing curve** into account.

| | | | | DEVELOPMENT | | | | MAINTENANCE | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **Inception** | **Elaboration** | **Construction** | **Transition** | **Production** | **Retirement** | **Termination** |
| | | | | Initial project setup by defining the goal and establishing all necessary resources. | Scope is roughly specified, architecture is defined and walking skeleton is crafted. | Product step by step and in full detail is specified, implemented, tested and deployed. | Final product version is officially rolled out through final deployment and user training. | Product is regularly bug-fixed and dependency upgraded, and updated in production. | Product is bug-fixed only and updated in production on demand only. | Product termination by archiving all sources and data and destroying all infrastructures. |
| AN | REQ | Requirements | ↗ | | | | Temporal Phase | Human Resource Staffing Curve | | |
| | DOM | Domain Modeling | ↗ | | | | Effort Focus | | | |
| EX | UXP | User Experience | ↗ | | | | Effort Focus Primary Peak | | | |
| | UID | User Interface Design | ↗ | | | | | | | |
| AR | SWA | Software Architecture | ↘ | | | | | | | |
| | SYA | System Architecture | ↘ | | | | | | | |
| DV | DEV | Software Development | ↗ | | | | | | | |
| | REF | Software Refactoring | ↗ | | | | | | | |
| CF | VER | Software Versioning | ↘ | | | | | | | |
| | ASM | Software Assembly | ↘ | | | | | | | |
| DL | DPL | Software Deployment | ↘ | | | | | | | |
| | OPS | System Operations | ↘ | 40% Top-Down Non-Scope-Dependent Effort | | | | | | |
| AC | REV | Software Review | ↗ | 60% Bottom-Up Scope-Dependent Effort | | | | | | |
| | TST | Software Testing | ↗ | | | | | | | |
| CP | DOC | Usage Documentation | ↗ | | | | | | | |
| | TRN | User Training | ↗ | | | | | | | |
| MG | PRD | Product Management | ↗ | | | | | | | |
| | PRJ | Project Management | ↗ | | | | | | | |
| AD | COA | Project Coaching | ↘ | | | | | | | |
| | CHG | Change Management | ↘ | | | | | | | |

*phases & efforts*

Software products follow a **life-cycle** of seven temporal, non-equally sized **phases**. Software Engineering **disciplines** individually focus their **efforts** on those phases, and their efforts either bottom-up depend on the domain-specific scope, or their efforts top-down do not depend on it. The amount of required **human resources** differs between those phases, too.
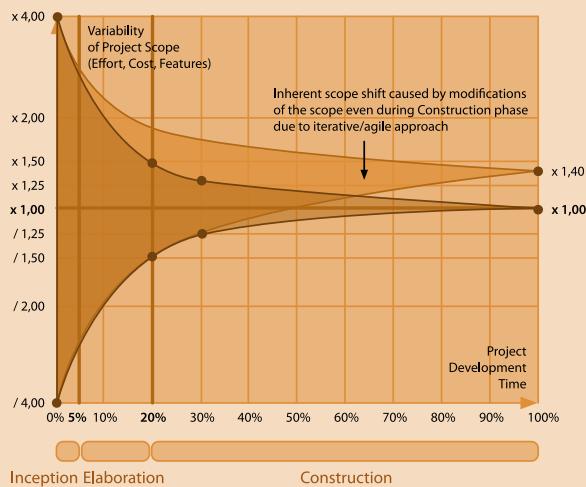
**Effort estimations** have to take into account disciplines, their phase focus, their domain-specific scope dependency, and the human resource staffing curve.

Furthermore, the seven sequential phases, especially, do not conflict with agile process models: agile time **periods** (named "sprints" in Scrum) merely subdivide the individual phases.

## Questions

❷ What is the Software Engineering **Phase** called, which has the greatest personnel requirements and in which primarily the functionalities are realized?

# Uncertainty & Elaboration

## Cone of Uncertainty

Variability of Project Scope (Effort, Cost, Features)

x 4,00

x 2,00

Inherent scope shift caused by modifications of the scope even during Construction phase due to iterative/agile approach

x 1,50
x 1,25
**x 1,00**
/ 1,25
/ 1,50

x 1,40

x 1,00

/ 2,00

/ 4,00

0% 5% 10%   **20%**   30%   40%   50%   60%   70%   80%   90%   100%

Project Development Time

Inception   Elaboration     Construction

The *Cone of Uncertainty* (*Steve McConnell*, 2006) tells how the variability of the project scope (measured in Effort, Cost or Features) in Software Development changes over time. Initially, it usually is within the range of +/- 400% of the final scope.

The early development phases Inception and Elaboration especially have to ensure that within the first 20% of the project, the variability is reduced noticeably to just +/- 50%. During the initial iterations of the Construction phase within the first 30% of the project, the variability usually can be further reduced to about +/- 25%.

For iterative/agile approaches, experience showed that during the Construction phase inherently the final scope further shifts by about + 40% due to the just step-by-step learned required details of the required solution. This especially has to be taken into account for estimations.
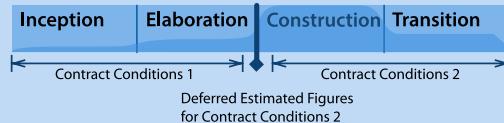
## Essential Elaboration Phase

**Walking Skeleton:**

The *Walking Skeleton* (or *Technical Breakthrough*) is the design and implementation of the bare technical foundation of an application, still *without* any domain-specific functionalities. It is made during the Elaboration phase with the primary purpose to establish a stable integration of all technical aspects (libraries, frameworks, build procedures, etc) onto which the domain-specific functionalities later can be successively put onto.

**Agile Fixed-Price Contracts:**

| Inception | Elaboration | Construction | Transition |
|---|---|---|---|

Contract Conditions 1       Contract Conditions 2

Deferred Estimated Figures for Contract Conditions 2

The *Agile Fixed-Price* is an agile variant of a fixed-price contract, *not* a fixed-price project with an agile development process.

There are two important inherent aspects:
First, the contract contains two types of conditions: one (usually *Time & Material* but fixed duration based) for the Inception and Elaboration phases in order to make experiences and to gather necessary figures, and one (usually Fixed-User-Story and/or Fixed-Price based) for the Construction and Transition phases based on deferred estimated figures, gathered in the Elaboration phase.
Second, the Fixed-Price aspect of the contract is actually based on an amount of User-Stories (resulting in costs by multiplying them with either an average hourly rate of an engineer or individual rates based on engineer job levels), which the customer can 1:1 *exchange* during the project for different deliverables.

The crux of an Agile Fixed-Price contract is: first, during the Inception and Elaboration phases the supplier can shrink the *Cone of Uncertainty* and this way its risks dramatically, and second, during the Construction and Transition phases the customer still remains flexible in scope.

*uncertainty & elaboration*

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The **Cone of Uncertainty** tells how the variability of the project scope (measured in Effort, Cost or Features) in Software Development changes over time. The early development phases Inception and Elaboration especially have to ensure that the variability is reduced noticeably.

For iterative/agile approaches, experience showed that during the Construction phase, inherently, the final scope further shifts due to the just step-by-step learned, required details of the required solution.

The Elaboration phase is especially important for the creation of the **Walking Skeleton**, where all the technical integrations of libraries, frameworks, build procedures, etc., are done without already implementing any domain-specific functionalities.

Because of the **Cone of Uncertainty**, **Agile Fixed-Price** project contracts usually differentiate between the early phases Inception and Elaboration and the main phases Construction and Transition. The contract conditions of the latter usually depend on figures that can only be seriously estimated at the end of the Elaboration phase.

## Questions

❓ What is especially developed in the project phase "Elaboration"?

# Effort Estimations

*uncertainty & efforts*

## Estimation & Variability

**Three-Point Estimation and Estimation Variability Classes:**

$e = (b + 4 \times m + w) / 6$    expected effort (weighted average)
$s = (w - b) / 6$    standard deviation (effort variation)

**b**: best-case (optimistic)
**m**: most-likely (realistic)
**w**: worst-case (pessimistic)

Insane Variability: +/- 10%
Very Good Variability: +/- 15%
Good Variability: +/- 20%
Acceptable Variability: +/- 25%
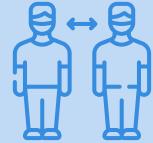
## Conversion & Normalization

**1. Ask Estimater:**
*"How many Person-Days do you need when you can focus on this task?"*

**2. Convert from Estimator to Performer:**
(see also CAP model, http://cap-model.com)

| | | Performer | | | | |
|---|---|---|---|---|---|---|
| Non-Linear Effort Reduction | | 0% | 10% | 25% | 45% | 80% |
| | | Novice | Practitioner | Master | Expert | Guru |
| Estimator | Novice | 1,00 | 0,90 | 0,75 | 0,55 | 0,20 |
| | Practitioner | 1,11 | 1,00 | 0,83 | 0,61 | 0,22 |
| | Master | 1,33 | 1,20 | 1,00 | 0,73 | 0,27 |
| | Expert | 1,82 | 1,64 | 1,36 | 1,00 | 0,36 |
| | Guru | 5,00 | 4,50 | 3,75 | 2,75 | 1,00 |
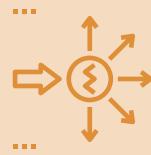
## Sizes & Variability

**Estimation Sizes and Estimation Variability:**

| T-Shirt-Size (Logically) | XXS | XS | S | M | L | XL | XXL | XXXL |
|---|---|---|---|---|---|---|---|---|
| Fibonacci-Size (PD or SP) | 0,50 | 1 | 2 | 3 | 5 | 8 | 13 | 21 |
| Size Variability (-) | 0,25 | 0,25 | 0,50 | 0,50 | 1,00 | 1,50 | 2,50 | 4,00 |
| Size Variability (+) | 0,25 | 0,50 | 0,50 | 1,00 | 1,50 | 2,50 | 4,00 | 8,00 |

Notice: Estimations can be done in *Person-Days (PD)* or *Story-Points (SP)*. In both cases, keep in mind to use something like the *Fibonacci* numbers which increase in a non-linear fashion and express the increasing variability with the increasing total amount of estimated effort.
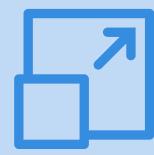
## Risk Mitigation & Upscaling

**3. Adjust for Reality:**
Estimator Optimism: **+30%**
Performer Meetings: **+20%**

**4. Adjust for Uncertainty:**

| Domain | Inception | Elaboration | Construction |
|---|---|---|---|
| unknown | 30% | 40% | 20% |
| partially known | 15% | 20% | 10% |
| fully known | 0% | 0% | 0% |

| Technology | Inception | Elaboration | Construction |
|---|---|---|---|
| unknown | 20% | 60% | 10% |
| partially known | 10% | 30% | 5% |
| fully known | 0% | 0% | 0% |

| Process | Inception | Elaboration | Construction |
|---|---|---|---|
| unknown | 60% | 40% | 20% |
| partially known | 30% | 20% | 5% |
| fully known | 0% | 0% | 0% |

| People | Inception | Elaboration | Construction |
|---|---|---|---|
| unknown | 60% | 40% | 0% |
| partially known | 30% | 20% | 0% |
| fully known | 0% | 0% | 0% |

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Effort Estimations are usually based on a **Three-Point Estimation** where a weighted average of "best case", "most likely" and "worst case" are used. A good estimation variability in practice is about +/- 20%.

For **Expert Estimations**, a fixed scale of estimation sizes are usually used in practice, which is based on the **Fibonacci** sequence of numbers, to take into account the fact that higher estimated efforts also have higher estimation variability.
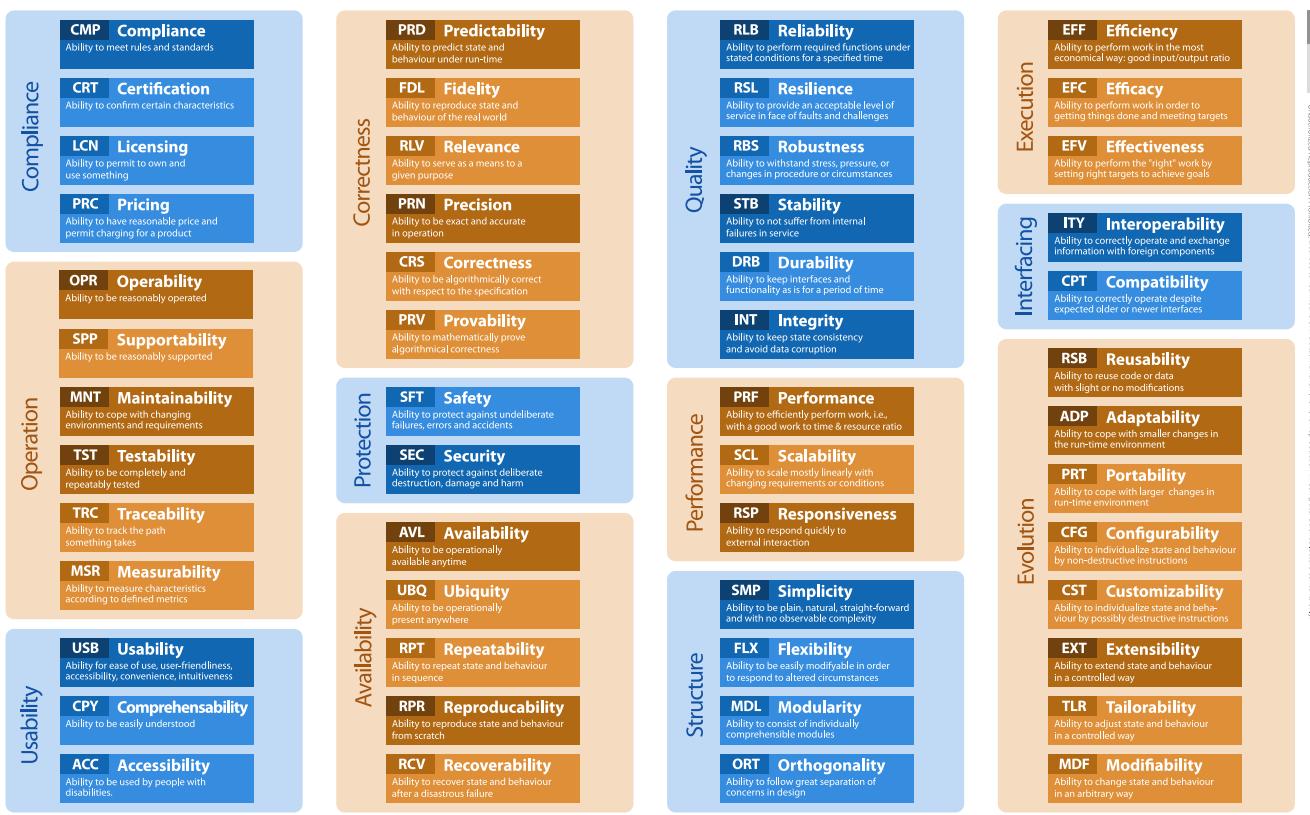
Additionally, one usually has to post-adjust the estimation of experts to further take into account the different skill and experience levels between the task estimator and the subsequent task performer, the usual human optimism of the estimator and the practical meeting and inevitable communication distractions of the performer.

In case of uncertainty because of entirely unknown or at least just partially known aspects Domain, Technology, Process and People, the total estimated efforts of the usual project phases have to be additionally upscaled.

## Questions

❓ What variability does a **good** Estimation have?

# Requirements Basics

ARCHITECTURE FUNDAMENTALS

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## Requirements Specification

A binding document that specifies the requirements for a solution, by focusing on the WHAT and WHY of the solution — and *not* giving instructions for the HOW.

The documented set of requirements has to be: correct, unambiguous, complete, consistent, ranked, verifiable, modifiable, and traceable.

## Requirement Classes

### FR   Functional (Shall Do)

A condition or capability that a solution must have to provide its service in terms of its behaviour and information. Think: Functionality.

### NFR   Non-Functional (Shall Be)

A condition, property or quality that a solution must have to satisfy a contract, standard, or other formally imposed obligation. Think: Constraints and "*-ilities".

## Requirement Interdependencies

### POS   Positive (Backing)

One requirement supports the other (e.g. for NFRs: Maintainability and Comprehensibility usually support Adaptability, Portability, Modifiability, etc., and Scalability usually supports Availability, etc.)

### NEG   Negative (Trade-Off)

One requirement interferes with the other (e.g. for NFRs: Security usually interferes with Efficiency, Usability, Performance, etc., and Orthogonality can interfere with Usability)

## Requirement Characteristics

### S   Specific
The requirement is precise, unambiguous, and clear on what should be done.

### M   Measurable
The requirement can be verified when it has been achieved by use of a particular test.

### A   Achievable
The requirement is achievable given existing circumstances and feasible and viable solutions.

### R   Relevant
The requirement is relevant to the goals of the context.

### T   Time-Bound
The requirement can be achieved within a reasonable time frame.

## Requirement Life-Time

### E   Enduring
The requirement lasts forever, as it is derived from core activities and organisational structures.

### V   Volatile
The requirement can be temporary, as it might change over time.

## Requirement Expression

[<req-id>] <req-name>:
<subject/actor>
**SHALL**
<result/action/condition>
**BECAUSE**
<rationale>

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The **Requirements Specification** is a binding document in which primarily the WHAT and WHY of the solution is specified, however not the concrete technical HOW. The set of requirements must be correct, unambiguous, complete, consistent, prioritized, verifiable, changeable and traceable.

There are two types of requirements: **Functional Requirement** ("Shall Do", functionality) and **Non-Functional Requirements** ("Shall Be", Conditions, in English often expressed with words ending in "-ility"). The architect primarily takes care of the latter.

Requirements can also be reciprocally positive (backing) or negative (trade-off). The architect also primarily takes care of the latter.

Requirements should be "SMART": **Specific**, **Measurable**, **Achieveable**, **Relevant** and **Time-Bound**.

In addition, requirements are either **Enduring** (fixed) or **Volatile** (unstable). The architect should pay attention to the latter.

## Questions

❓ What kind of **requirements** should the architect primarily keep in mind and should be explicitly addressed by him in the solution finding?

# Non-Functional Requirements

**ARCHITECTURE FUNDAMENTALS**

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## Compliance

### Compliance
**CMP Compliance** — Ability to meet rules and standards

**CRT Certification** — Ability to confirm certain characteristics

**LCN Licensing** — Ability to permit to own and use something

**PRC Pricing** — Ability to have reasonable price and permit charging for a product

### Operation
**OPR Operability** — Ability to be reasonably operated

**SPP Supportability** — Ability to be reasonably supported

**MNT Maintainability** — Ability to cope with changing environments and requirements

**TST Testability** — Ability to be completely and repeatably tested

**TRC Traceability** — Ability to track the path something takes

**MSR Measurability** — Ability to measure characteristics according to defined metrics

### Usability
**USB Usability** — Ability for ease of use, user-friendliness, accessibility, convenience, intuitiveness

**CPY Comprehensability** — Ability to be easily understood

**ACC Accessibility** — Ability to be used by people with disabilities.

## Correctness

### Correctness
**PRD Predictability** — Ability to predict state and behaviour under run-time

**FDL Fidelity** — Ability to reproduce state and behaviour of the real world

**RLV Relevance** — Ability to serve as a means to a given purpose

**PRN Precision** — Ability to be exact and accurate in operation

**CRS Correctness** — Ability to be algorithmically correct with respect to the specification

**PRV Provability** — Ability to mathematically prove algorithmical correctness

### Protection
**SFT Safety** — Ability to protect against undeliberate failures, errors and accidents

**SEC Security** — Ability to protect against deliberate destruction, damage and harm

### Availability
**AVL Availability** — Ability to be operationally available anytime

**UBQ Ubiquity** — Ability to be operationally present anywhere

**RPT Repeatability** — Ability to repeat state and behaviour in sequence

**RPR Reproducability** — Ability to reproduce state and behaviour from scratch

**RCV Recoverability** — Ability to recover state and behaviour after a disastrous failure

## Quality

### Quality
**RLB Reliability** — Ability to perform required functions under stated conditions for a specified time

**RSL Resilience** — Ability to provide an acceptable level of service in face of faults and challenges

**RBS Robustness** — Ability to withstand stress, pressure, or changes in procedure or circumstances

**STB Stability** — Ability to not suffer from internal failures in service

**DRB Durability** — Ability to keep interfaces and functionality as is for a period of time

**INT Integrity** — Ability to keep state consistency and avoid data corruption

### Performance
**PRF Performance** — Ability to efficiently perform work, i.e., with a good work to time & resource ratio

**SCL Scalability** — Ability to scale mostly linearly with changing requirements or conditions

**RSP Responsiveness** — Ability to respond quickly to external interaction

### Structure
**SMP Simplicity** — Ability to be plain, natural, straight-forward and with no observable complexity

**FLX Flexibility** — Ability to be easily modifyable in order to respond to altered circumstances

**MDL Modularity** — Ability to consist of individually comprehensible modules

**ORT Orthogonality** — Ability to follow great separation of concerns in design

## Execution

### Execution
**EFF Efficiency** — Ability to perform work in the most economical way: good input/output ratio

**EFC Efficacy** — Ability to perform work in order to getting things done and meeting targets

**EFV Effectiveness** — Ability to perform the "right" work by setting right targets to achieve goals

### Interfacing
**ITY Interoperability** — Ability to correctly operate and exchange information with foreign components

**CPT Compatibility** — Ability to correctly operate despite expected older or newer interfaces

### Evolution
**RSB Reusability** — Ability to reuse code or data with slight or no modifications

**ADP Adaptability** — Ability to cope with smaller changes in the run-time environment

**PRT Portability** — Ability to cope with larger changes in run-time environment

**CFG Configurability** — Ability to individualize state and behaviour by non-destructive instructions

**CST Customizability** — Ability to individualize state and behaviour by possibly destructive instructions

**EXT Extensibility** — Ability to extend state and behaviour in a controlled way

**TLR Tailorability** — Ability to adjust state and behaviour in a controlled way

**MDF Modifiability** — Ability to change state and behaviour in an arbitrary way

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There are potentially many **Non-Functional Requirements**. For any solution, one must therefore first determine the actual quantity of such Requirements. This quantity must be minimized by the Architect!

For every contractually stipulated Requirement, one should take into account that it is clearly defined since there are great similarities between Requirements and the differences are sometimes very subtle.

A few of the Non-Functional Requirements that almost always have to be considered in practice are **Maintainability**, **Usability**, **Security**, **Availability**, **Reliability**, **Performance**, **Responsiveness** and **Adaptability**.

## Questions

❓ Name 3 in practice frequently considered **Non-Functional Requirements**!