Systems Engineering Fundamentals Course

by *Gerrit Muller*
University of South-Eastern Norway-NISE

Abstract

This course touches all fundamentals of Systems Engineering. Topics are programs, projects, strategy and operation, stakeholders and concerns, needs elicitation and requirements management, concept selection, architecting and design, supply chain, risk management, systems integration, verification and validation, deployment, and life cycle.

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Systems Engineering Fundamentals Course Overview

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Abstract

Course overview of the course Systems Engineering Fundamentals.

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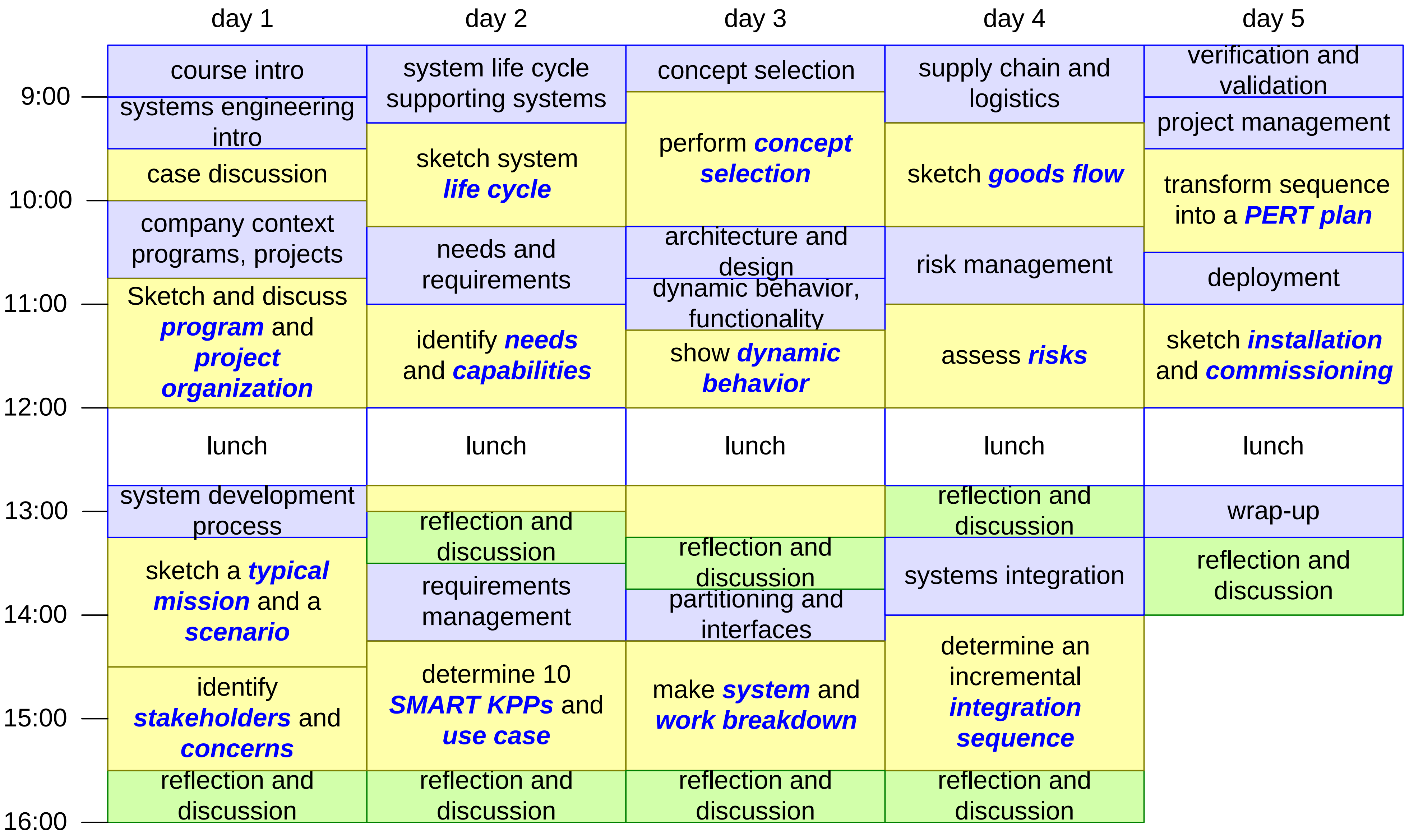
Single page Course Overview



day 1	course intro	systems engineering intro	case discussion	company context programs, projects	Sketch and discuss ***program*** and ***project organization***	lunch	system development process	sketch a ***typical mission*** and a ***scenario***	identify ***stakeholders*** and ***concerns***	reflection and discussion
day 2	system life cycle supporting systems	sketch system ***life cycle***	needs and requirements	identify ***needs*** and ***capabilities***	lunch	reflection and discussion	requirements management	determine 10 ***SMART KPPs*** and ***use case***	reflection and discussion	
day 3	concept selection	perform ***concept selection***	architecture and design	dynamic behavior, functionality	show ***dynamic behavior***	lunch	reflection and discussion	partitioning and interfaces	make ***system*** and ***work breakdown***	reflection and discussion
day 4	supply chain and logistics	sketch ***goods flow***	risk management	assess ***risks***	lunch	reflection and discussion	systems integration	determine an incremental ***integration sequence***	reflection and discussion	
day 5	verification and validation	project management	transform sequence into a ***PERT plan***	deployment	sketch ***installation*** and ***commissioning***	lunch	wrap-up	reflection and discussion		

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SEFOVschedule

Systems Engineering Fundamentals; Course Material

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Abstract

Listing the course material for the course Systems Engineering Fundamentals.

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Introduction

core

Systems Engineering Fundamentals Introduction

http://gaudisite.nl/info/SEFintroduction.info.html

optional

Course Overview

core

Systems Engineering Fundamentals Course Overview

http://gaudisite.nl/info/SEFoverview.info.html

optional

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SEFMAoverview

Assignments

core

Systems Engineering Fundamentals Assignments

http://gaudisite.nl/info/SEFassignments.info.html

optional

Programs, Projects, Process, Organization

core

Project Systems Engineering Introduction; Phasing, Process, Organization

http://gaudisite.nl/info/ProjectSEintroPPO.info.html

Module System Architecture Context

https://gaudisite.nl/ModuleSystemArchitectureContextPaper.pdf

Products, Projects, and Services; similarities and differences in architecting

https://gaudisite.nl/ProductsProjectsServicesPaper.pdf

optional

System Engineering Management Plan (SEMP) DOES ONE SIZE FIT ALL?

Zonnenshain, A., Malotaux, N., Honour, E., Kasser, J., Urio, U., Shabtay, M., INCOSE 2009

Systems Engineering Management Plan (SEMP) Technical Content

https://www.nasa.gov/consortium/SystemsEngineeringManagementPlanTechnicalContent

Life Cycle

core

Systems Engineering Fundamentals Life Cycle

http://gaudisite.nl/info/SEFlifeCycle.info.html

Modeling and Analysis: Life Cycle Models

https://gaudisite.nl/MAlifeCyclePaper.pdf

optional

SEBoK Life Cycle models

https://www.sebokwiki.org/wiki/Life_Cycle_Models

Needs and Requirements

core

Systems Engineering Fundamentals Needs Elicitation

http://gaudisite.nl/info/SEFneeds.info.html

optional

SEBoK Stakeholder Needs and Requirements

https://www.sebokwiki.org/wiki/Stakeholder_Needs_and_Requirements

Requirements Management

core

Systems Engineering Fundamentals Requirements Management

http://gaudisite.nl/info/SEFrequirements.info.html

Fundamentals of Requirements Engineering

https://gaudisite.nl/FundamentalsOfRequirementsPaper.pdf

optional

Concept Selection

core

Concept Selection, Set Based Design and Late Decision Making

https://gaudisite.nl/SEFconceptSelectionSlides.pdf

optional

Concept Selection - Applying Pugh Matrices in the Subsea Processing Domain by Linda Lønmo and Gerrit Muller; INCOSE 2014 in Las Vegas

https://gaudisite.nl/INCOSE2014_Lonmo_Muller_ConceptSelection.pdf

Researching the application of Pugh Matrix in the sub-sea equipment industry by Gerrit Muller, Dag Jostein Klever, Halvard H. Bjørnsen, and Michael Pennotti; CSER 2011 in Los Angeles

https://gaudisite.nl/CSER2011_MullerEtAl_ResearchingPughMatrix.pdf

Visualizing Dynamic Behavior

core

Visualizing Dynamic Behavior

http://gaudisite.nl/info/VisualizingDynamicBehavior.info.html

optional

Creating an A3 Architecture Overview; a Case Study in SubSea Systems by Gerrit Muller, Damien Wee, and Martin Moberg; INCOSE 2015 in Seattle, WA, USA

http://gaudisite.nl/INCOSE2015_MullerEtAl_SubseaOverviewA3.pdf

Supply Chain and Logistics

core

Systems Engineering Fundamentals Supply Chain and Logistics

https://gaudisite.nl/SEFsupplyChainSlides.pdf

optional

Build to order https://en.wikipedia.org/wiki/Build_to_order

P-D Ratios https://oldleandude.com/2015/05/27/p-d-ratios/

Risk Management

core

Systems Engineering Fundamentals Risk Management

https://gaudisite.nl/SEFriskManagementSlides.pdf

optional

Failure Mode and Effects Analysis

https://en.wikipedia.org/wiki/Failure_mode_and_effects_analysis

Readiness Levels

core

Course Systems Integration; Readiness Levels

http://www.gaudisite.nl/info/MSIreadinessLevels.info.html

optional

From TRL to SRL: The Concept of Systems Readiness Levels

CSER 2006, Brian Sauser et al.

Technology Readiness Levels

https://en.wikipedia.org/wiki/Technology_readiness_level

Systems Integration Process and Positioning

core

Mastering Systems Integration; Process and Positioning

http://gaudisite.nl/info/MSIprocessAndPositioning.info.html

optional

SESA /SARCH Module 01, System Architecture Context

http://gaudisite.nl/info/ModuleSystemArchitectureContext.info.html

Project Management and Systems Integration

core

Course Systems Integration; Project Management

http://gaudisite.nl/info/MSIprojectManagement.info.html

optional

Combating Uncertainty in the Workflow of Systems Engineering Projects

INCOSE 2013, Barry Papke and Rick Dove

Verification and Validation Terminology

core

Course Systems Integration; Terminology

http://www.gaudisite.nl/info/MSIterminology.info.html

optional

Understanding Objective Evidence: (What It Is and What It Definitely Is Not),

by Denise Dion

http://www.eduquest.net/Advisories/EduQuest%20Advisory_ObjectiveEvidence.pdf

List of Cognitive Biases, Wikipedia:

https://en.wikipedia.org/wiki/List_of_cognitive_biases

Systems Engineering Fundamentals Assignments

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Abstract

All assignments of the course Systems Engineering Fundamentals.

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Case

Propose a Non-Lethal Urban Crowd Controller

Discuss the Case

Sketch the **system-of-interest**

Sketch some of the **environment** the system will be operating in

Sketch some of the **system internals**

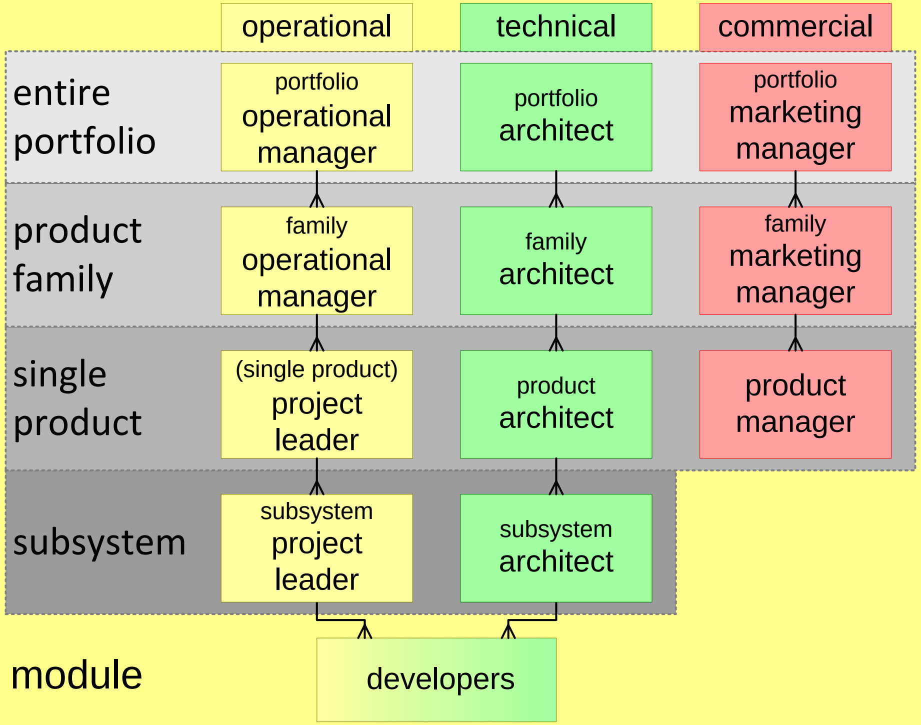
Draw the **system boundary**

Map the Operational Organization

Make a map with names of individuals in the **operational organization** of one project and its context

Identify the **relationships** of the **project core team**:

- **geographical**
- **organizational**
- **psychological**



	operational	technical	commercial
entire portfolio	portfolio operational manager	portfolio architect	portfolio marketing manager
product family	family operational manager	family architect	family marketing manager
single product	(single product) project leader	product architect	product manager
subsystem	subsystem project leader	subsystem architect	
module	developers		

Sketch Mission and Scenario

Sketch

a ***typical mission***

and a specific ***scenario.***

The scenario needs to be highly specific:

- numbers (how much, how far, how accurate)
- names (where, who)
- circumstances (when, where)
- actions (what, how)

Identify Stakeholders and Concerns

Brainstorm ***stakeholders***

Brainstorm for each stakeholder the ***concerns***

Elaborate concerns in 5 to 10 words, make them more specific

Use the **mission** and **scenario** for inspiration

Sketch the System Life Cycle

Sketch the system ***life cycle***

from idea until decommissioning and recycling.

Identify **stakeholders** per phase or activity

Identify Needs and Capabilities

Identify ***stakeholder needs***

in terms of ***capabilities.***

Capabilities typically are ***functions***

with ***quantifiable characteristics***

Use the mission, scenario, and stakeholder analysis for inspiration

Determine Key Performance Parameters and Use Case

Determine 5 to 10 ***Key Performance Parameters*** (KPP) of the System

Quantify these KPPs

Define the KPPs roughly, using a ***Use Case***

Perform a Concept Selection

Make a **decision matrix** for one of the **concept selections**.

- define at least 3 concepts
- define 7 to 10 criteria for selection
- score the concepts against the criteria, for example using a scale from 1 to 5: 1 = very poor, 5 = very good
- recommend a concept with a rationale

	concept 1 ○	concept 2 □	concept 3 △
criterion 1	1	3	5
criterion n	4	4	2
			best, because ...

Show Dynamic Behavior

Model the Dynamic Behavior of the System.

Focus on the Dynamic Behavior that relates to the KPP.

Visualize the Dynamic Behavior with various sketches, diagrams, or graphs (see Visualizing Dynamic Behavior for inspiration).

Make a System and Work Breakdown

Make a ***system breakdown***

in subsystems and subsubsystems

and a ***work breakdown structure***

to assist in organizing the project

Sketch the Goods Flow

sketch the ***goods flow***

from (sub) ***suppliers***

via ***assembly*** and ***test***

to ***customer site***,

deployment,

and ***maintenance***

Assess Risks

Assess ***risks***

- ***feasibility*** of achieving ***KPPs***
- ***fitness for purpose*** in customer context
- ***integration configurations*** and ***testware***
- ***supplier*** and ***logistics*** status
- ***technology readiness***
- ***development*** and ***resource*** status

Determine ***probability*** and ***severity*** per risk

Determine an Incremental Integration Sequence

Determine an incremental ***integration sequence*** to build confidence in the KPP ASAP.

Strive for about 6 main increments.

Reason starting at the end result and then backward in time.

For each increment determine its prerequisites in terms of parts, interfaces, functions, and performance levels.

Transform Sequence into a PERT Plan

Transform the integration sequence and the planning from the other perspectives into a ***PERT-plan***.

A PERT-plan focuses on ***activities*** and their mutual ***relations***; the logic of the plan. Time and resources are secondary information.

Sketch an Installation and Commissioning

Sketch an ***installation***

and ***commissioning***

Systems Engineering Fundamentals Introduction

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Abstract

This presentation introduces the ideas behind the course Systems Engineering Fundamentals.

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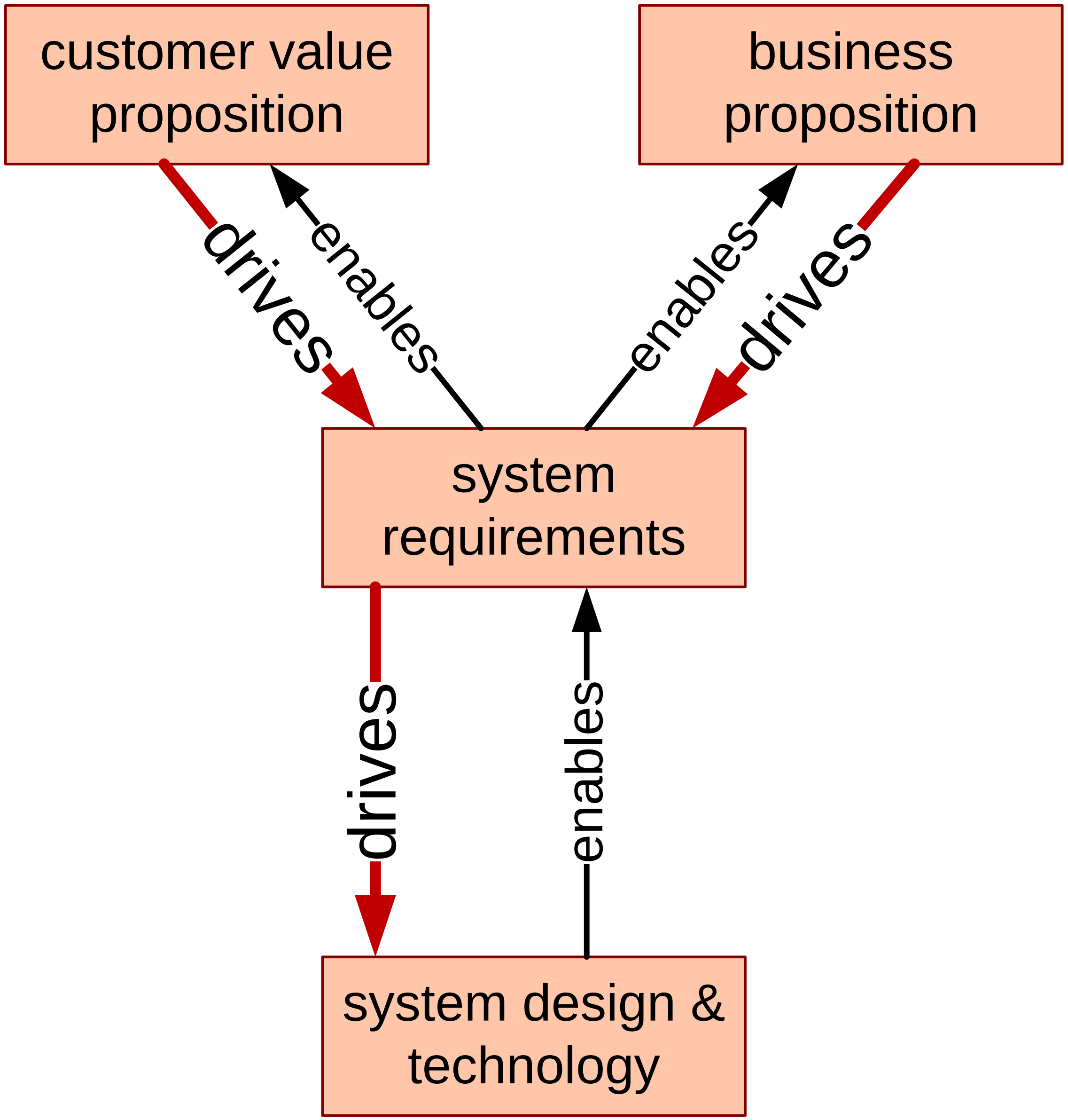
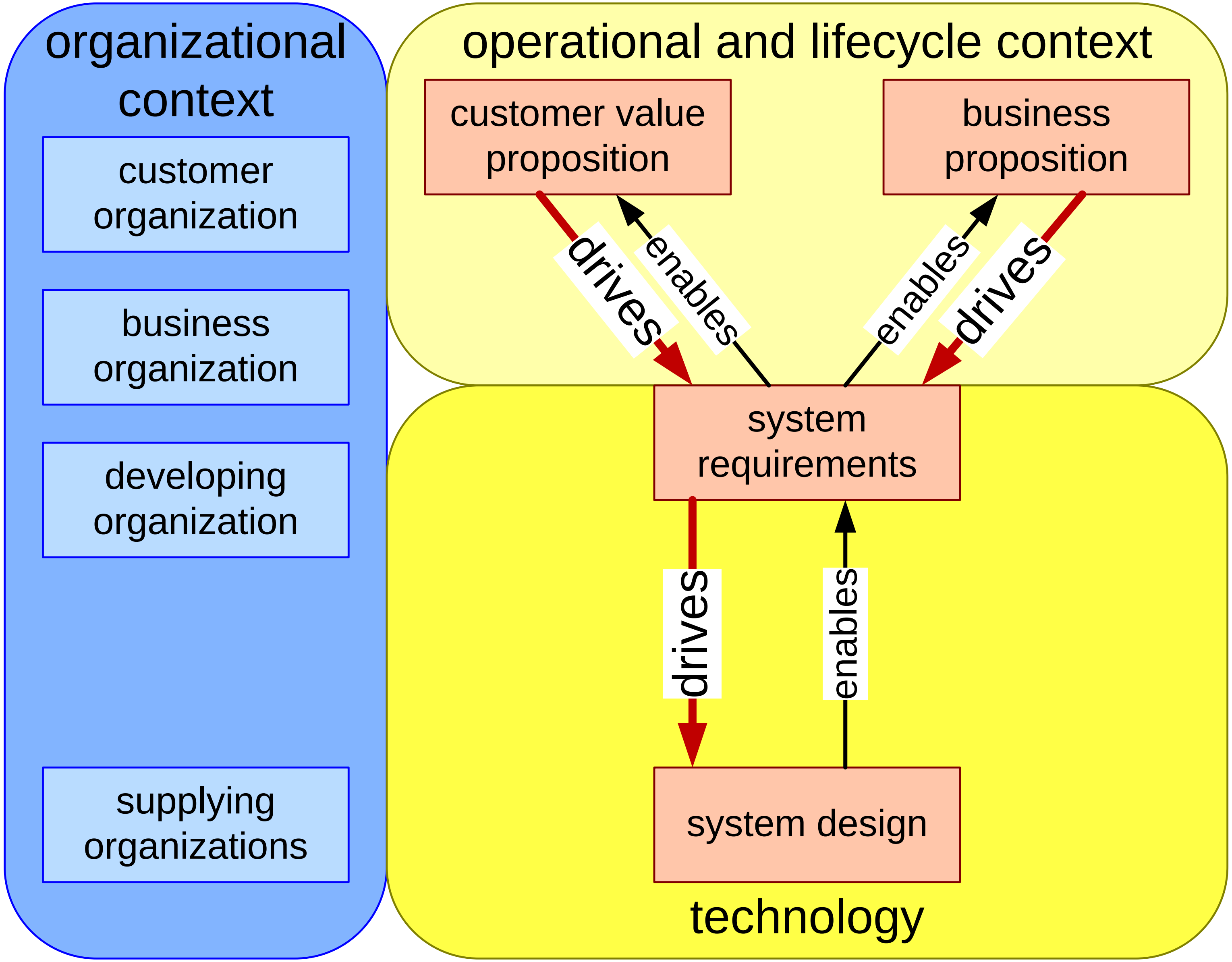
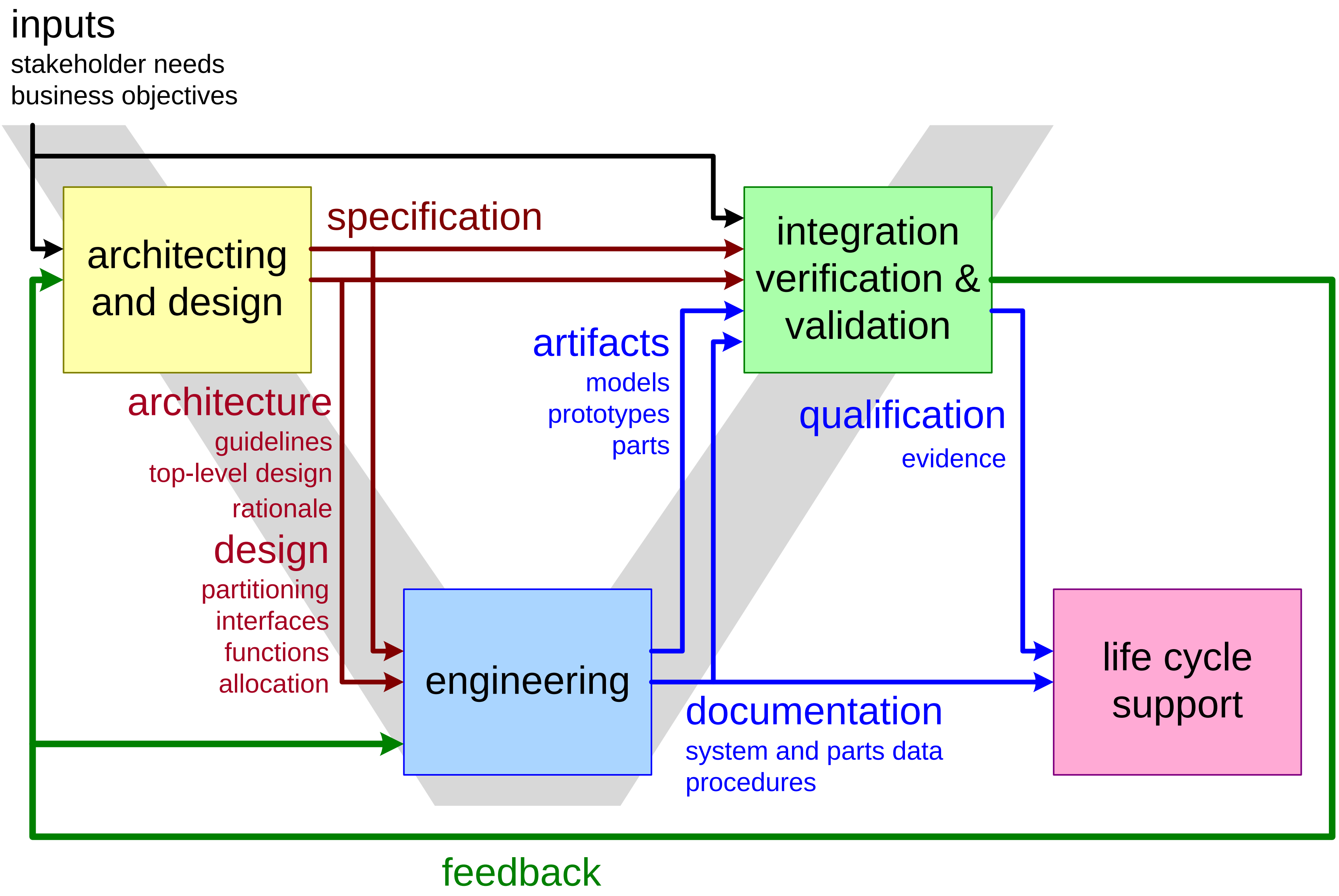
Architecture Top View



Architecting Playing Field



Simplified Systems Engineering Model



inputs
stakeholder needs
business objectives

architecting and design

specification

integration verification & validation

artifacts
models
prototypes
parts

qualification
evidence

architecture
guidelines
top-level design
rationale

design
partitioning
interfaces
functions
allocation

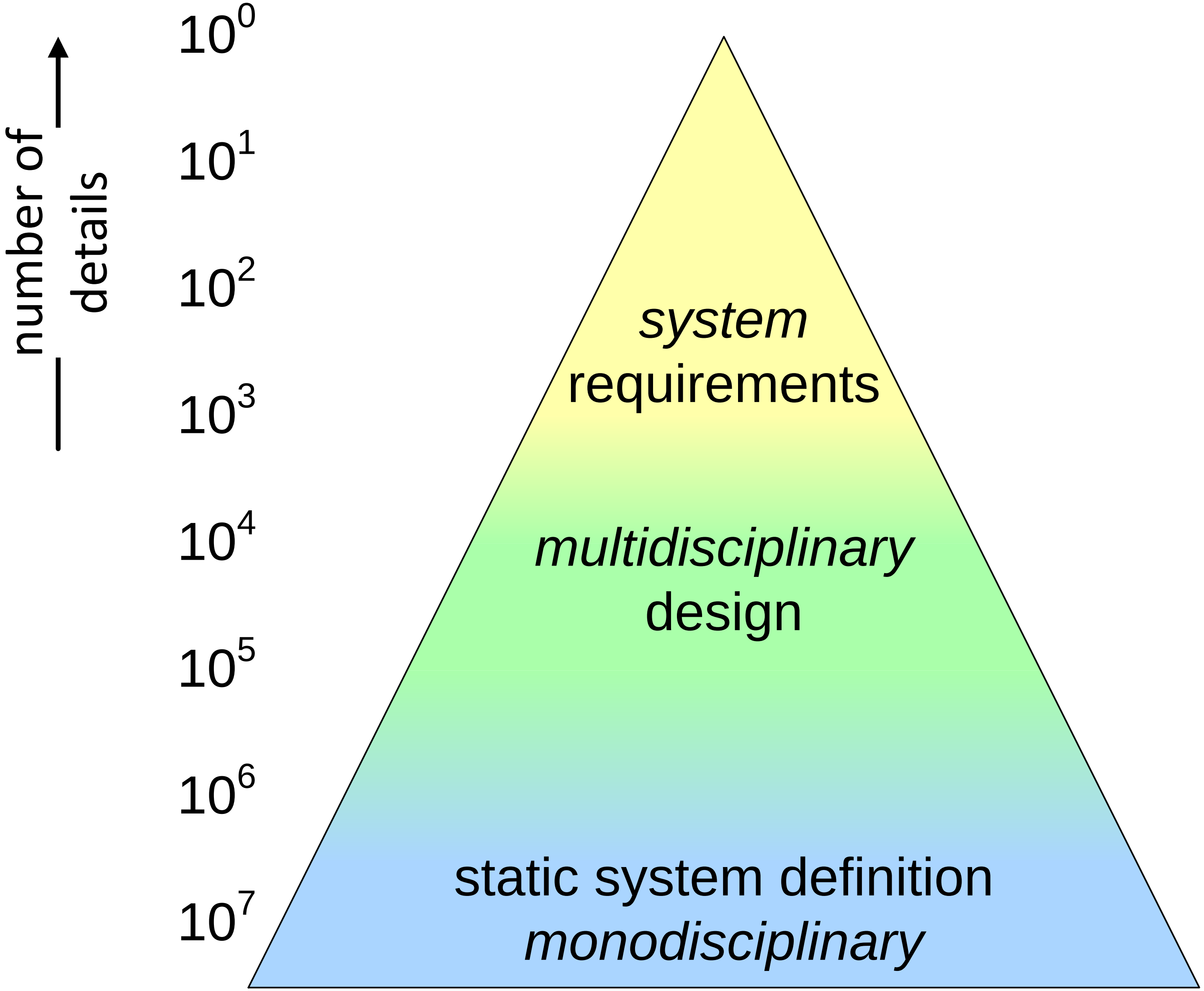
engineering

life cycle support

documentation
system and parts data
procedures

feedback

Level of Abstraction Single System



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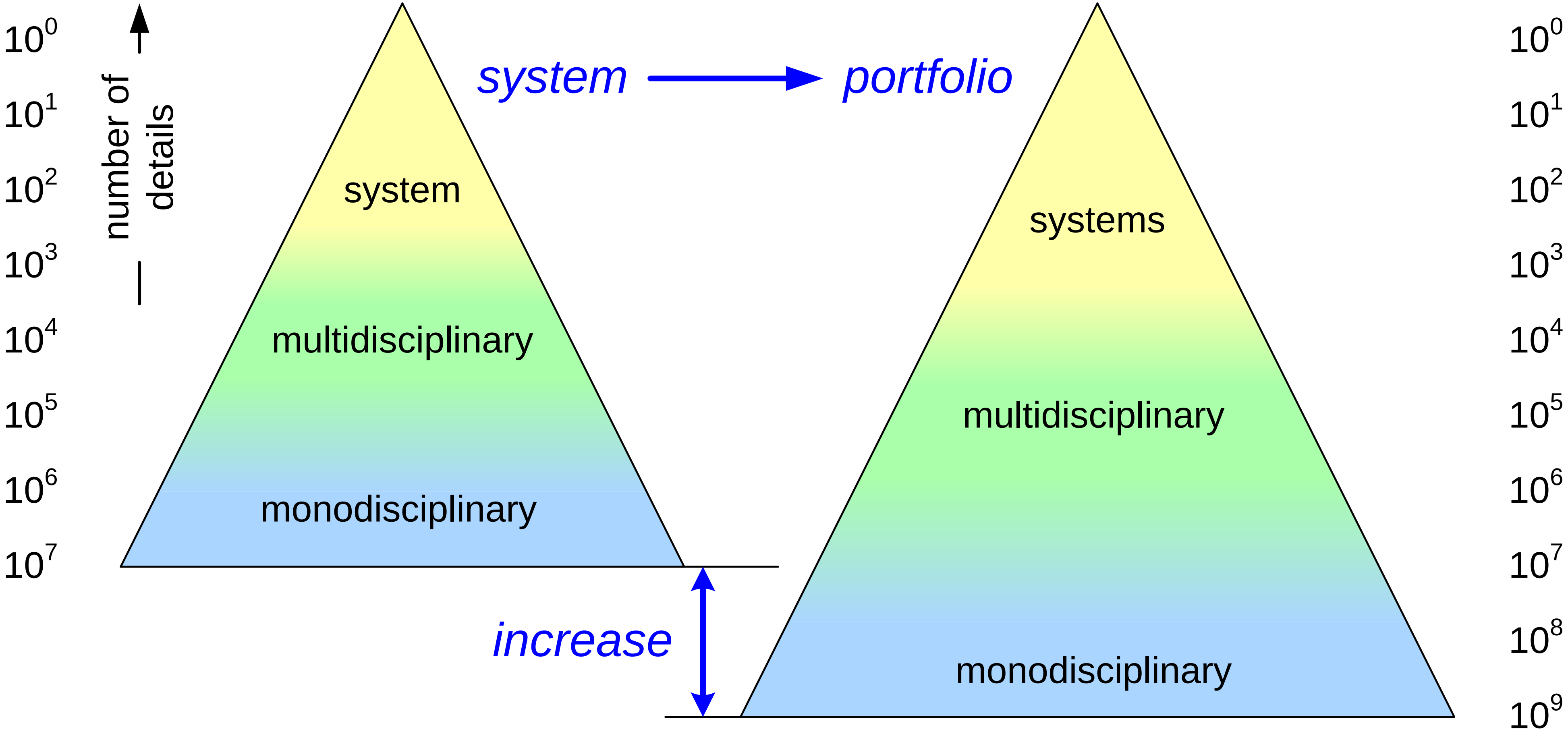
RAPpyramid

From system to Product Family or Portfolio



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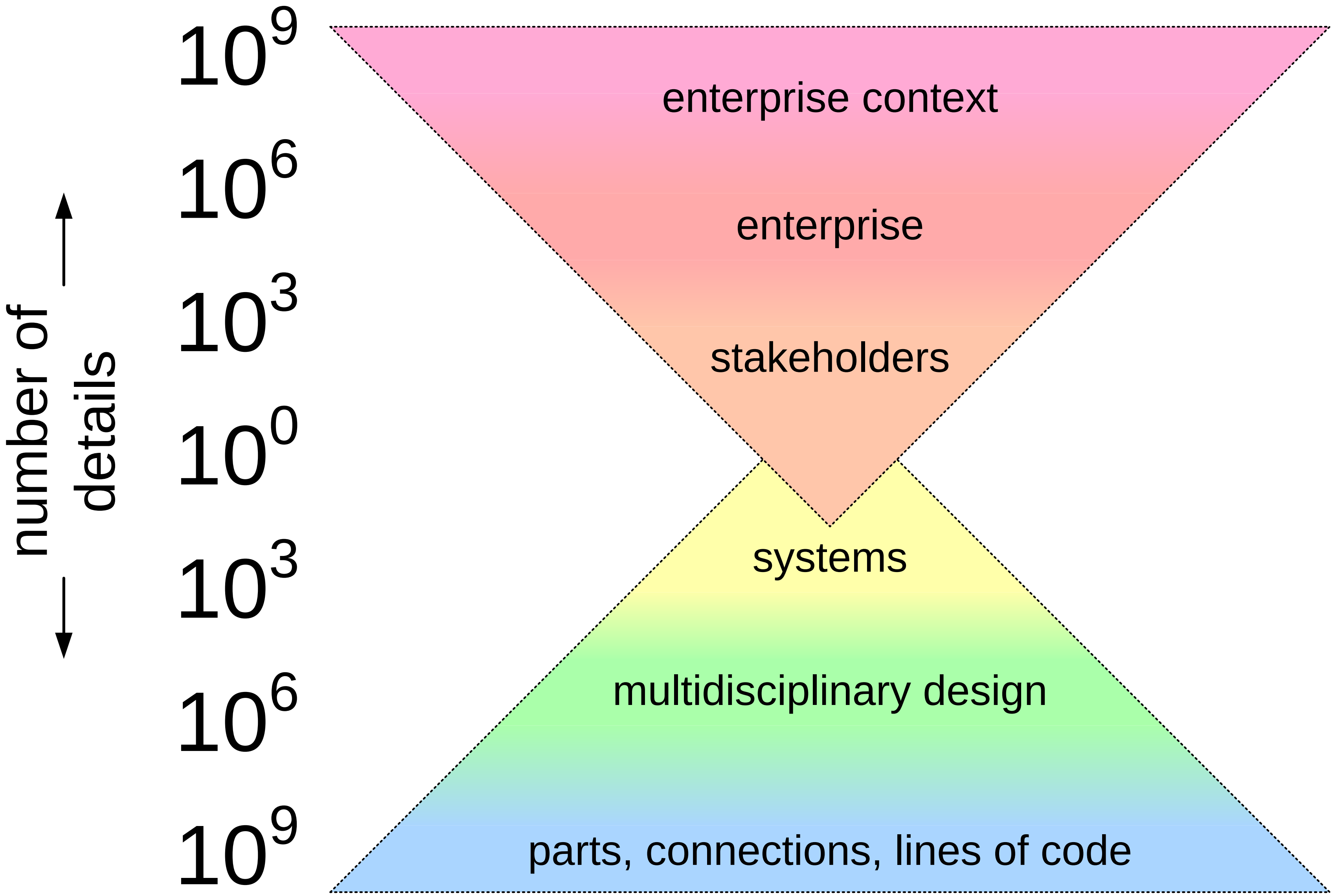
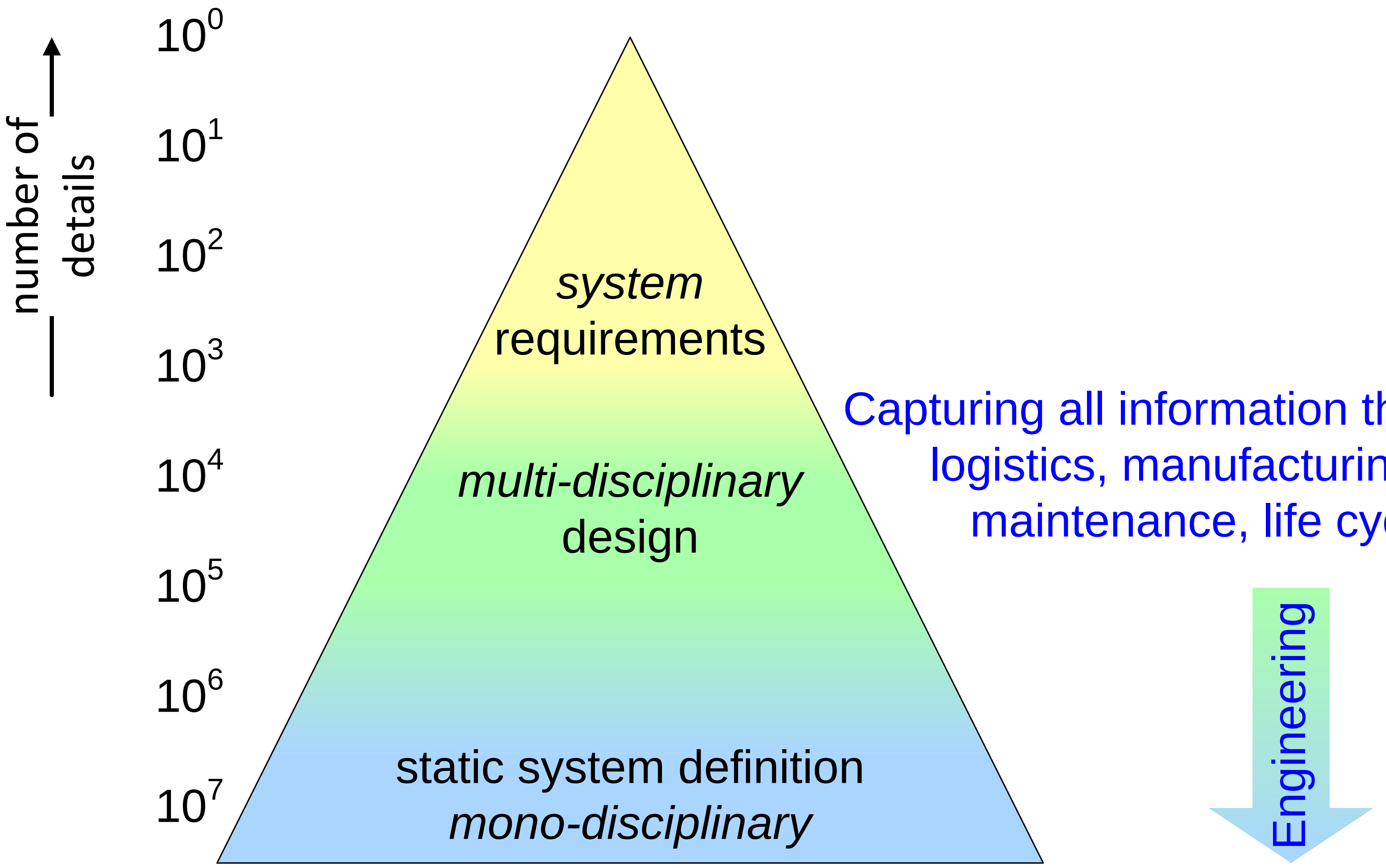
DRALpyramidGrowth

Product Family in Context

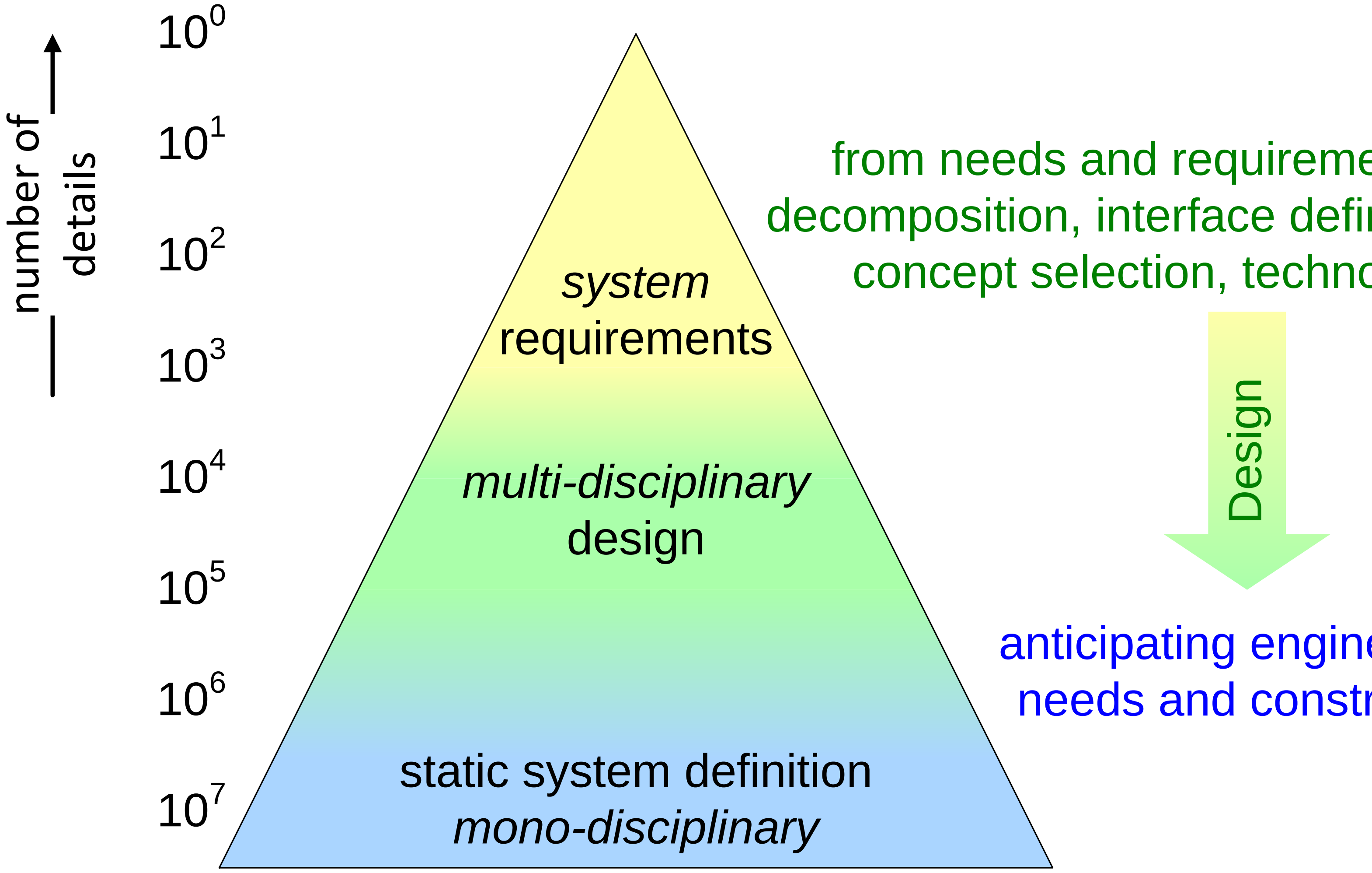


Engineering



Capturing all information that is required for: logistics, manufacturing, legislation, maintenance, life cycle support,

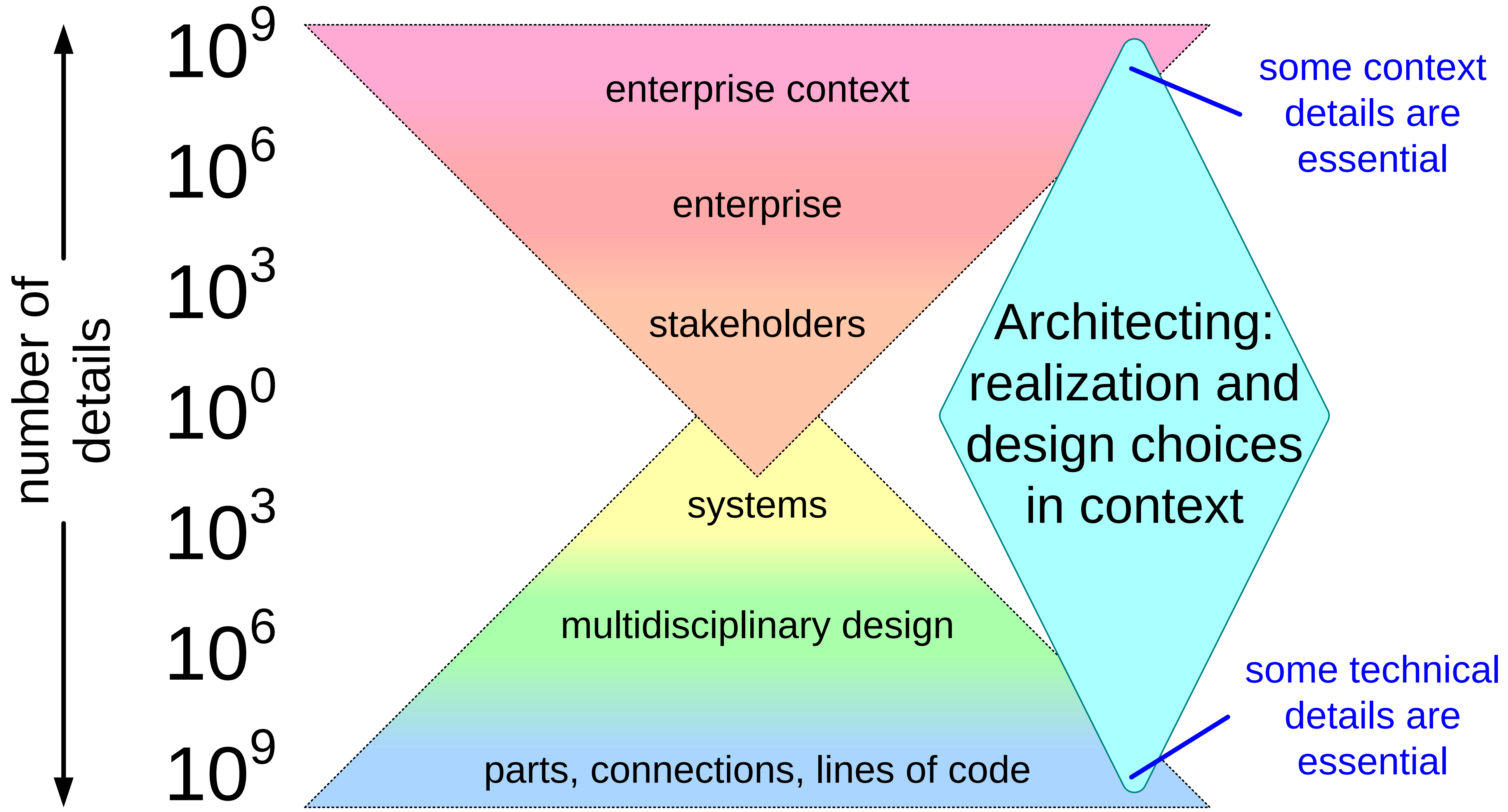
Design



from needs and requirements to design:
decomposition, interface definition, allocation,
concept selection, technology choices

anticipating engineering
needs and constraints

Architecting



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LAWFdiabolo

Project Systems Engineering Introduction; Phasing, Process, Organization

by *Gerrit Muller* University of South-Eastern Norway-NISE
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Abstract

The fundamental concepts and approach to project oriented Systems Engineering are explained. We look at project phasing, phase transition, processes, and organization.

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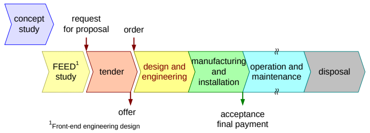
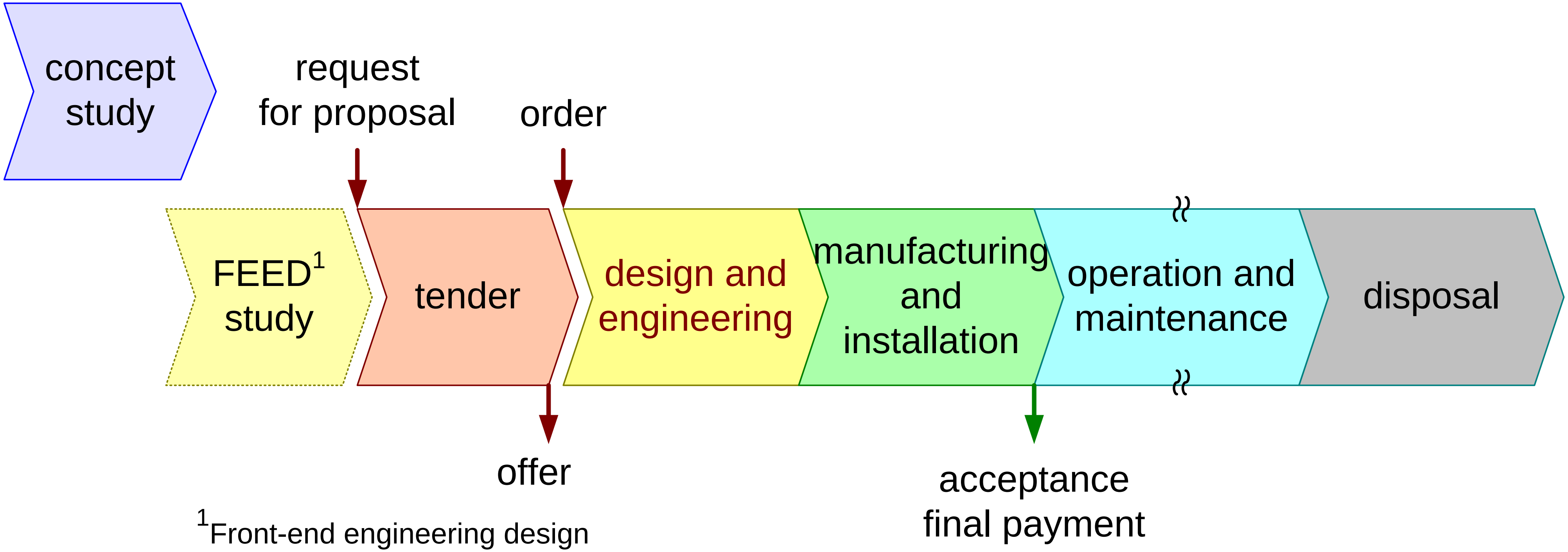
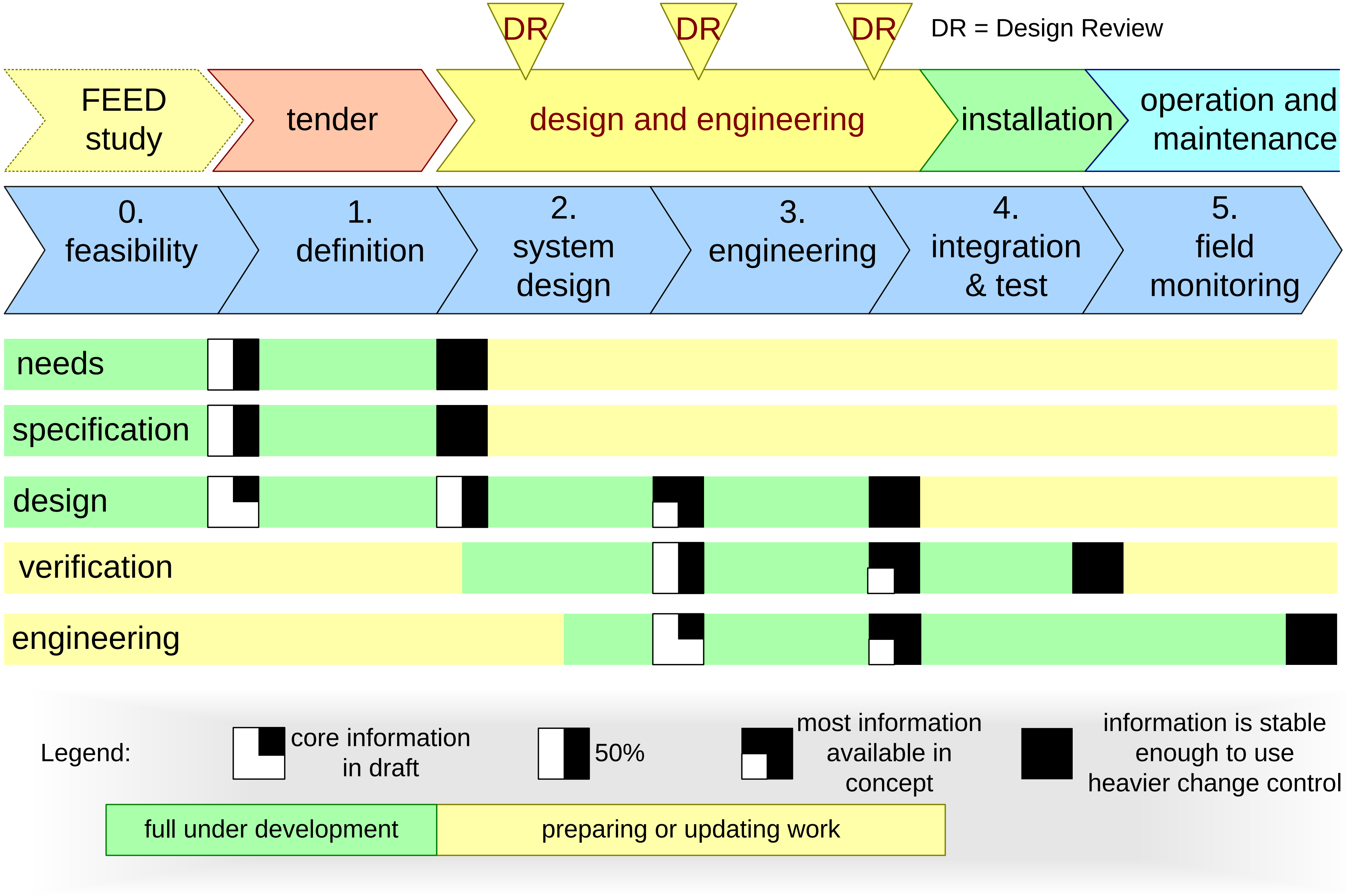


Project Life Cycle



[1] Front-end engineering design

Phased Project Approach



DR DR DR DR = Design Review

FEED study

tender

design and engineering

installation

operation and maintenance

0. feasibility

1. definition

2. system design

3. engineering

4. integration & test

5. field monitoring

needs

specification

design

verification

engineering

Legend:

core information in draft

50%

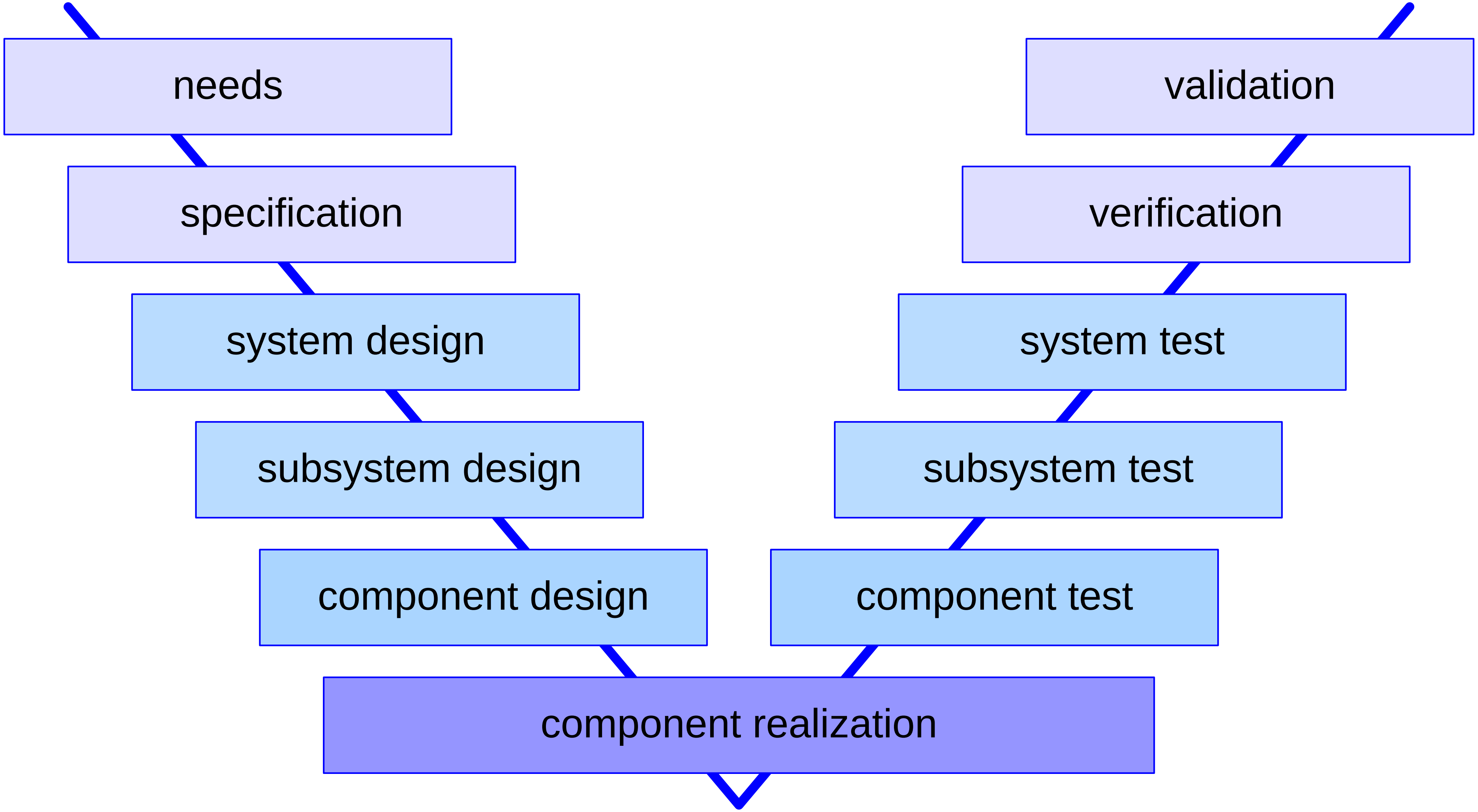
most information available in concept

information is stable enough to use heavier change control

full under development

preparing or updating work

V-Model



needs

specification

system design

subsystem design

component design

component realization

component test

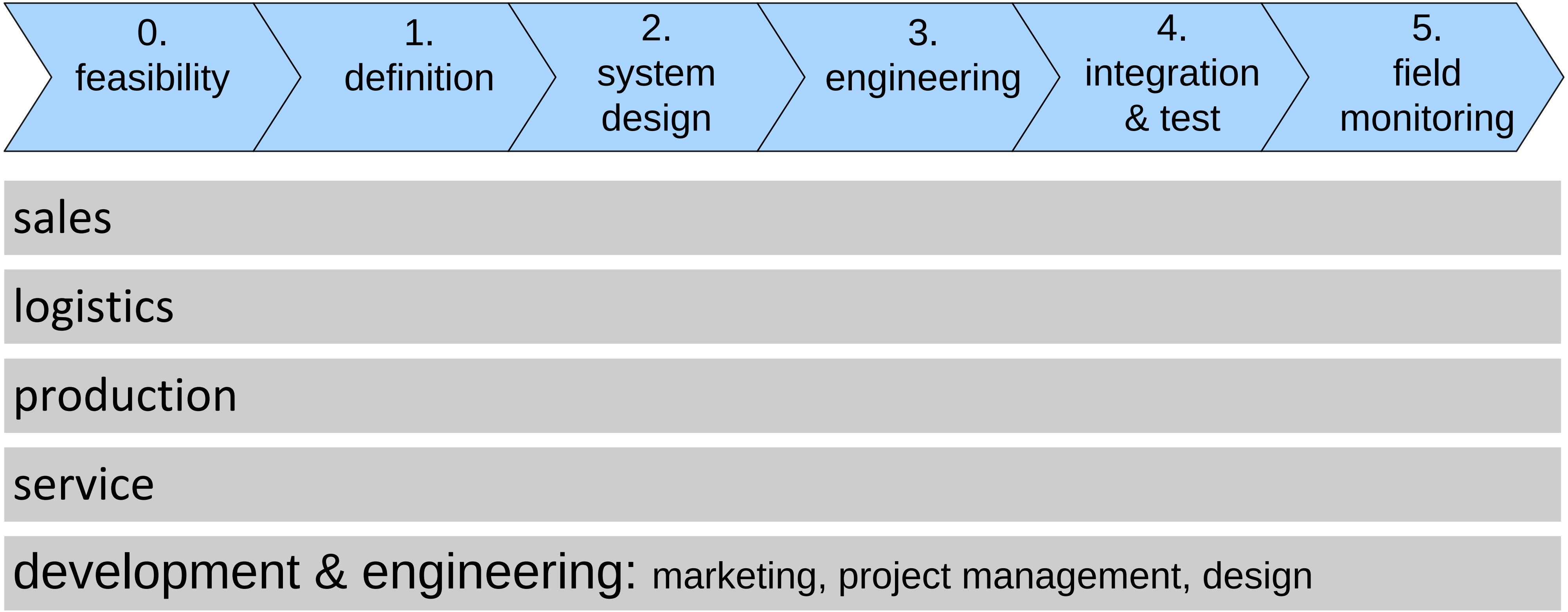
subsystem test

system test

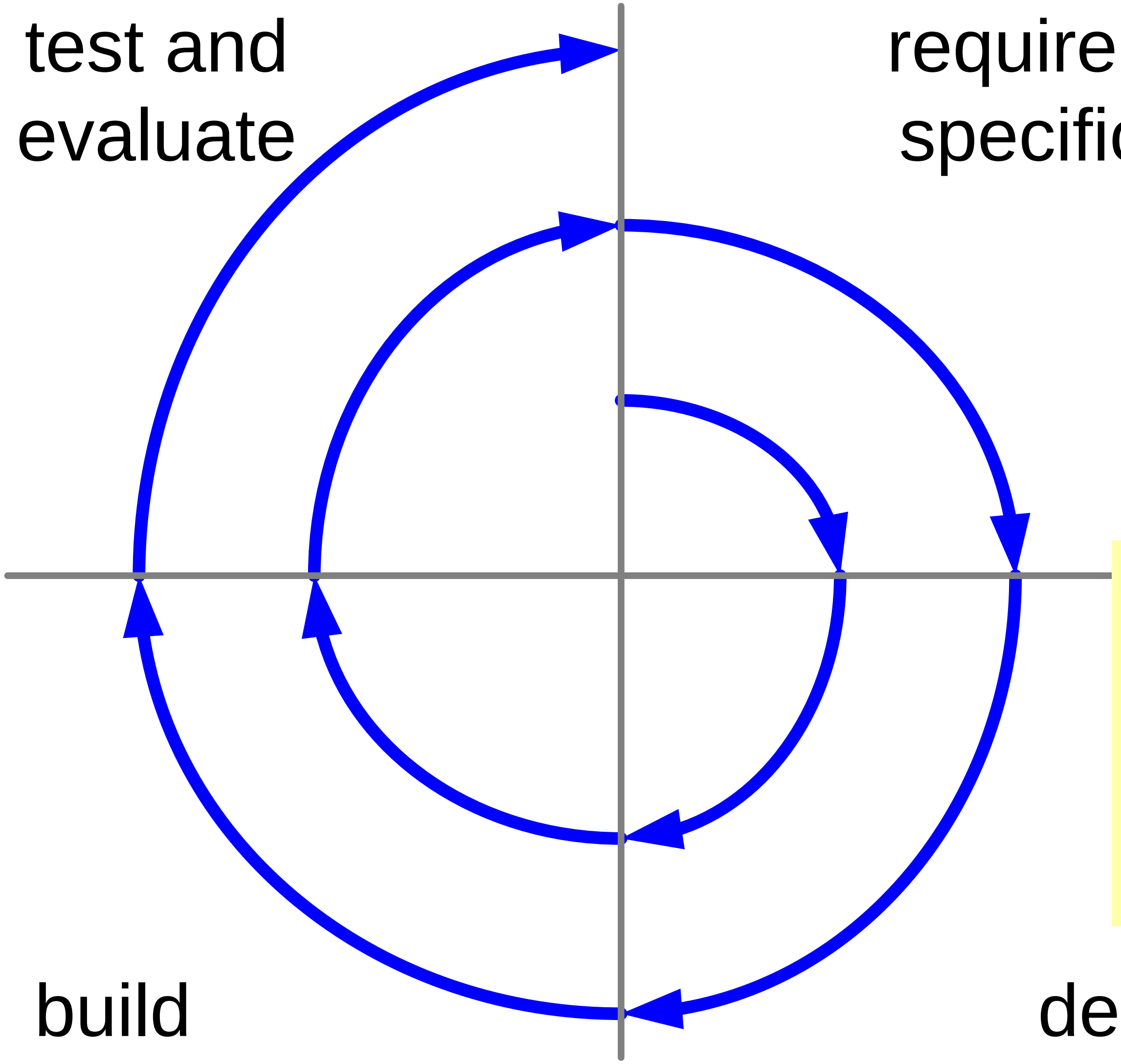
verification

validation

All Business Functions Participate

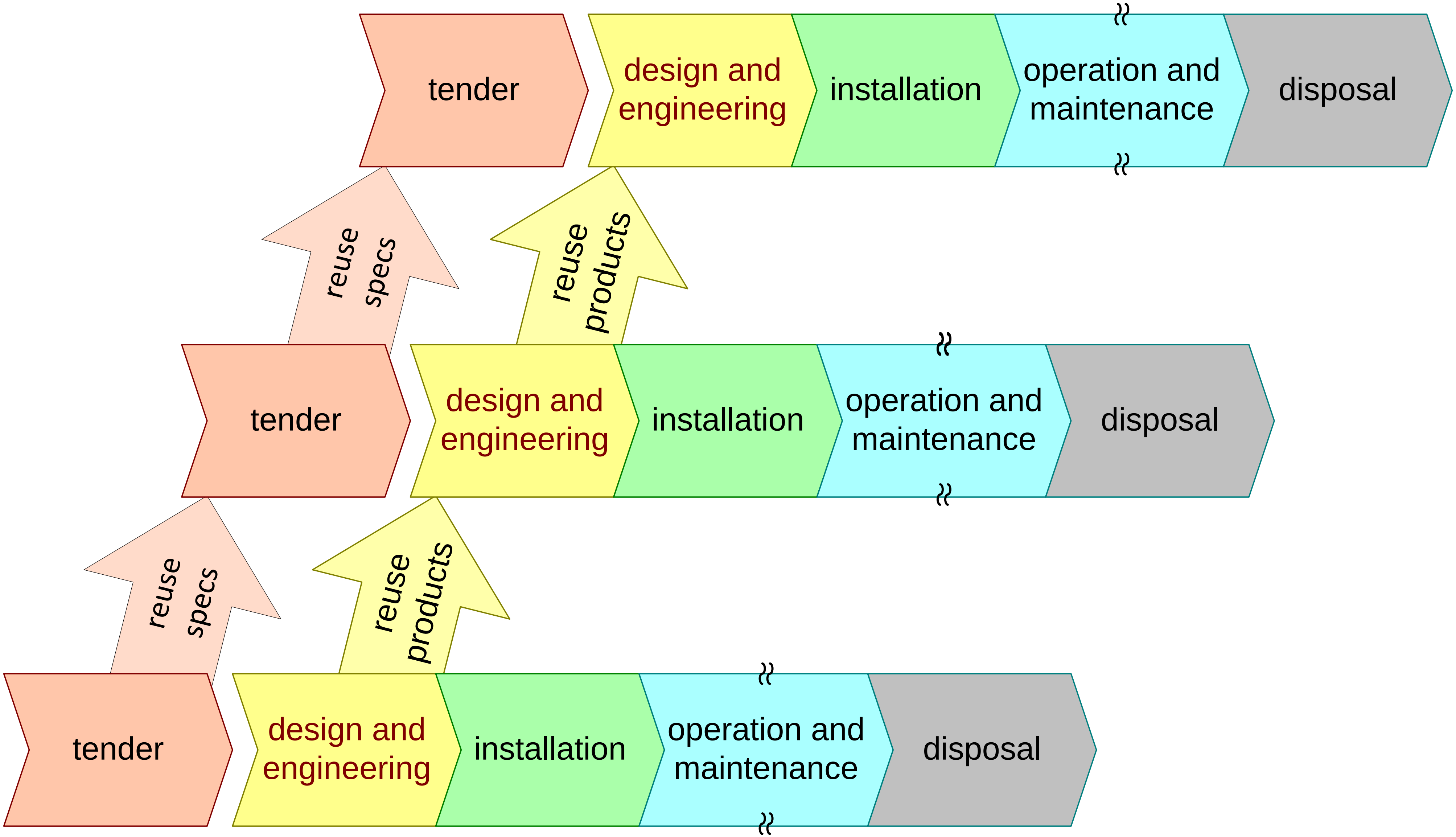


Evolutionary PCP model

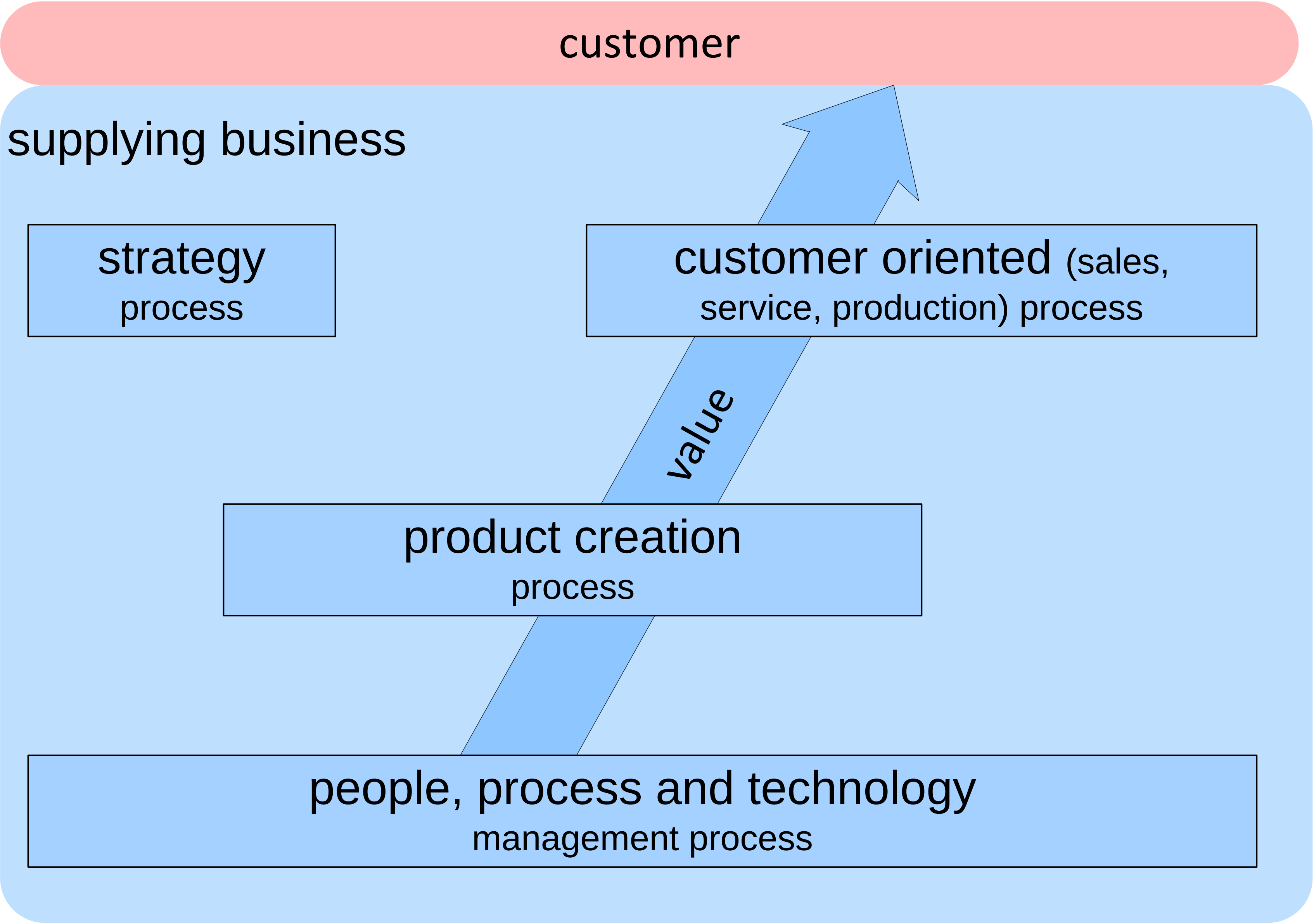


2% of budget (EVO)
2 weeks (XP)
up to 2 months
per cyclus

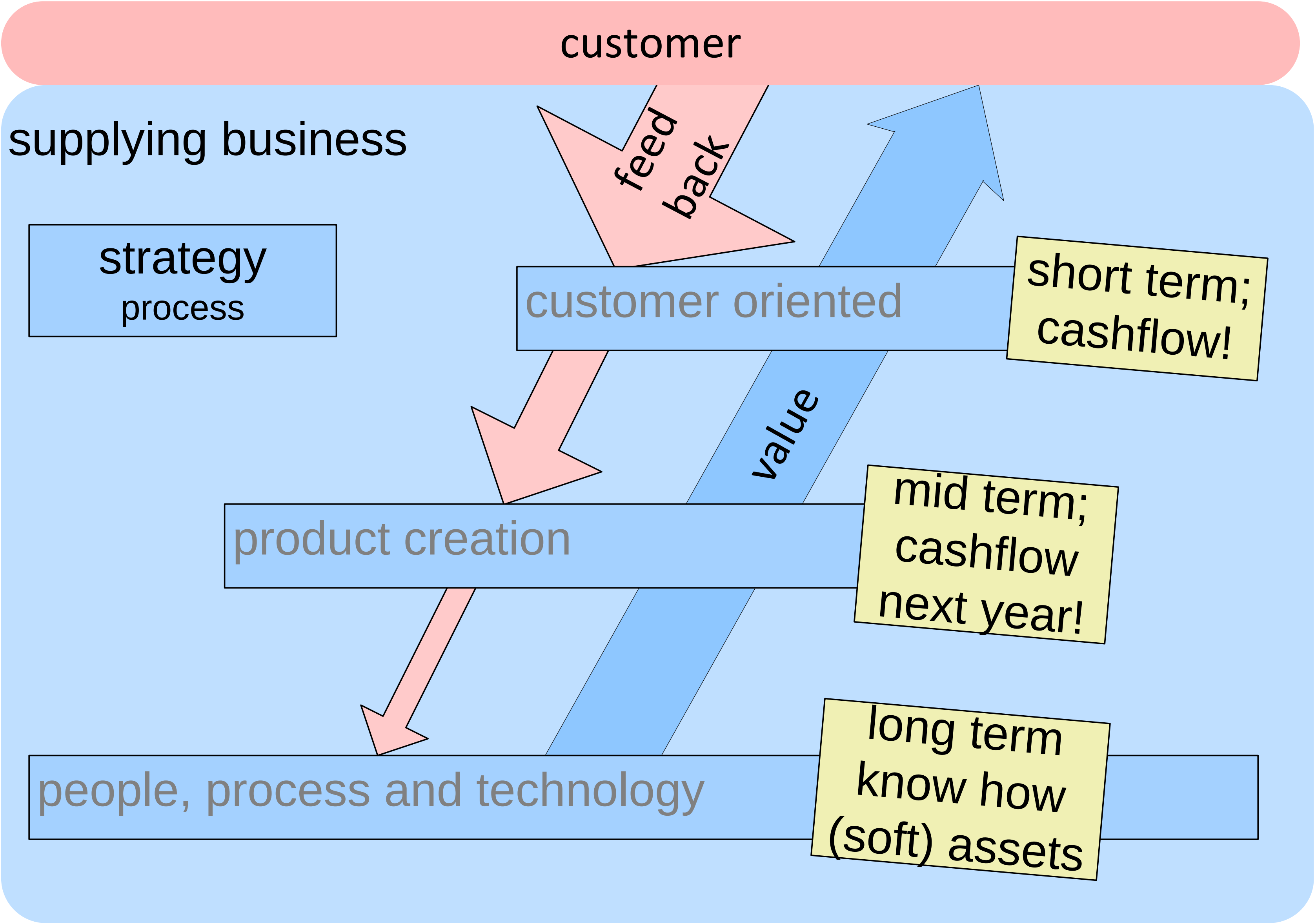
Reuse and Products



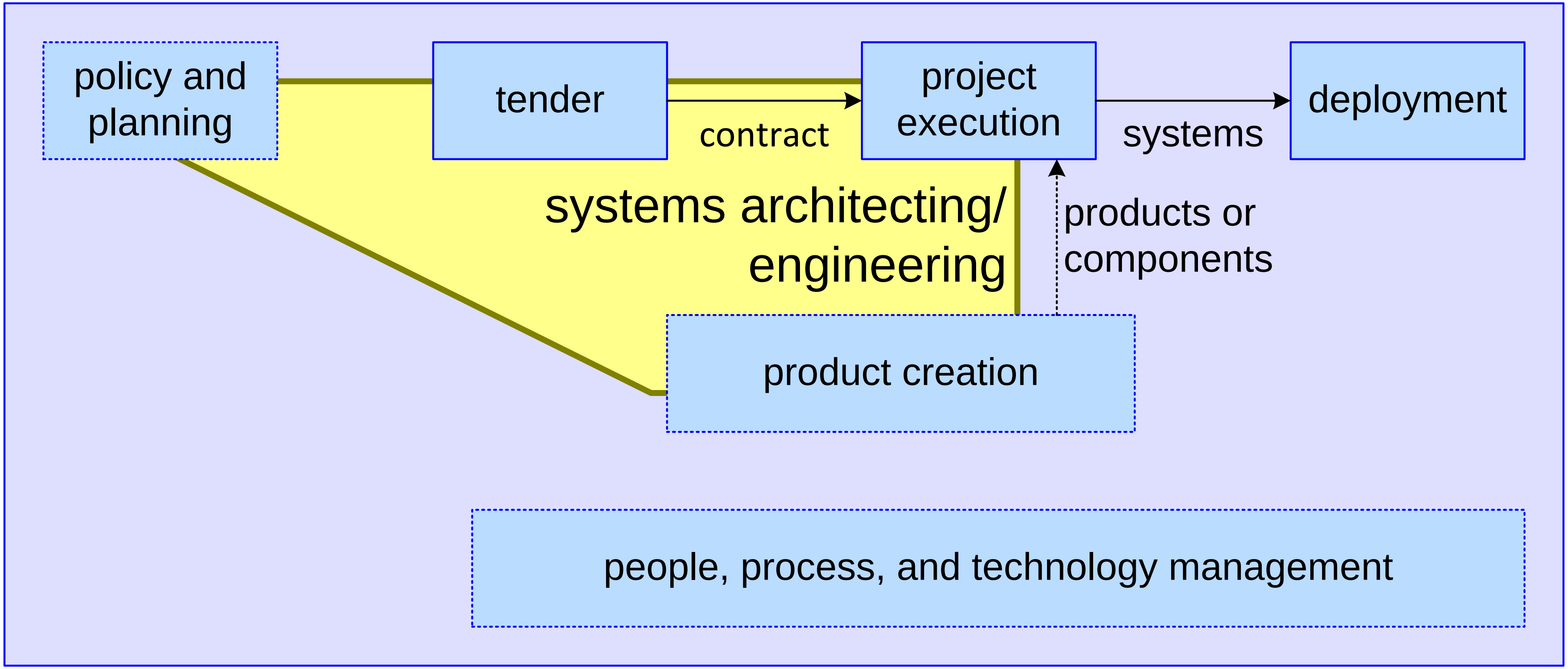
Simplified Process View



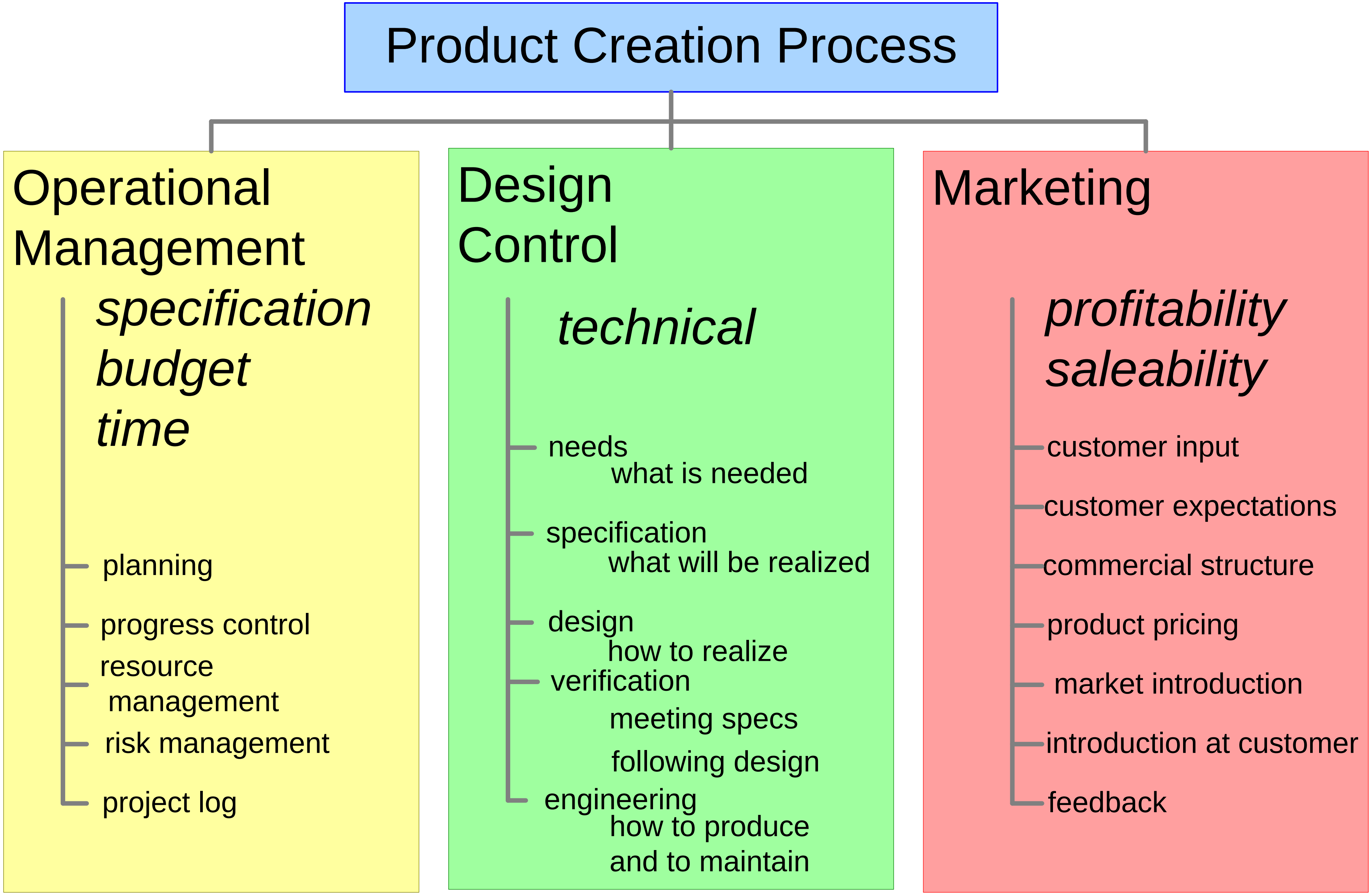
Simplified Process; Money and Feedback



Simplified process diagram for project business



Decomposition of the Product Creation Process



Product Creation Process

Operational Management

specification
budget
time

- planning
- progress control
- resource management
- risk management
- project log

Design Control

technical

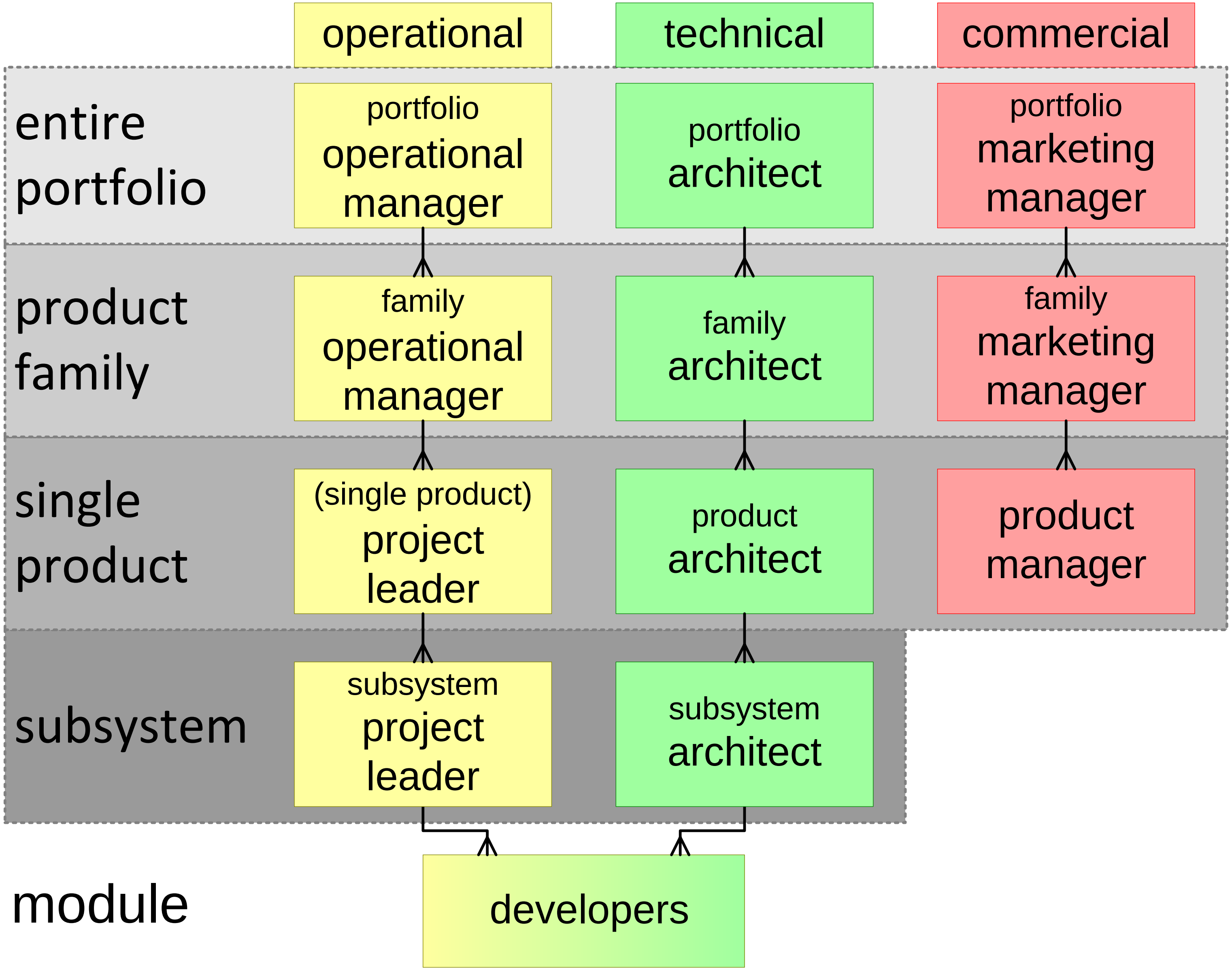
- needs
  what is needed
- specification
  what will be realized
- design
  how to realize
- verification
  meeting specs
  following design
- engineering
  how to produce
  and to maintain

Marketing

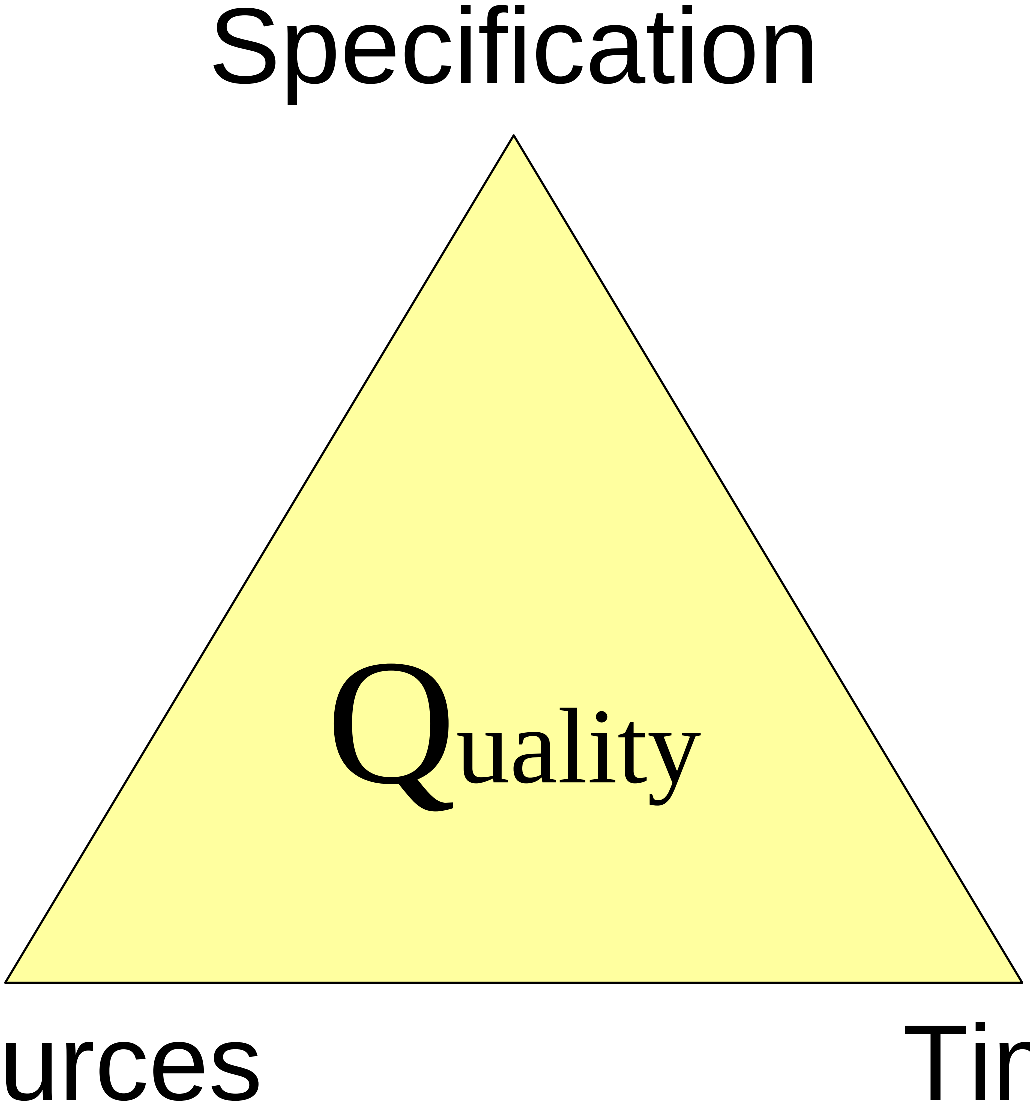
profitability
saleability

- customer input
- customer expectations
- commercial structure
- product pricing
- market introduction
- introduction at customer
- feedback

Operational Organization of the PCP



Prime Responsibilities of the Operational Leader



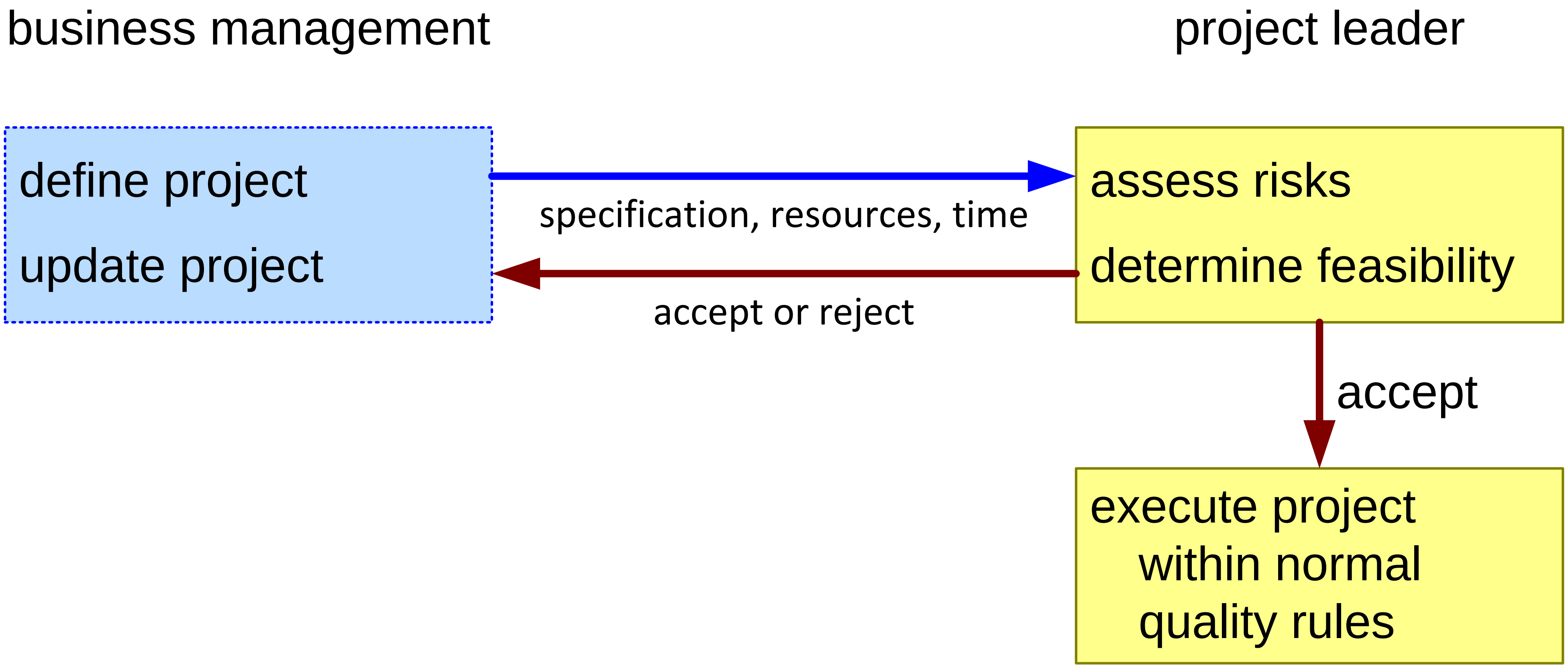
Specification

Quality

Resources

Time

The Rules of the Operational Game



business management

project leader

define project

update project

specification, resources, time

accept or reject

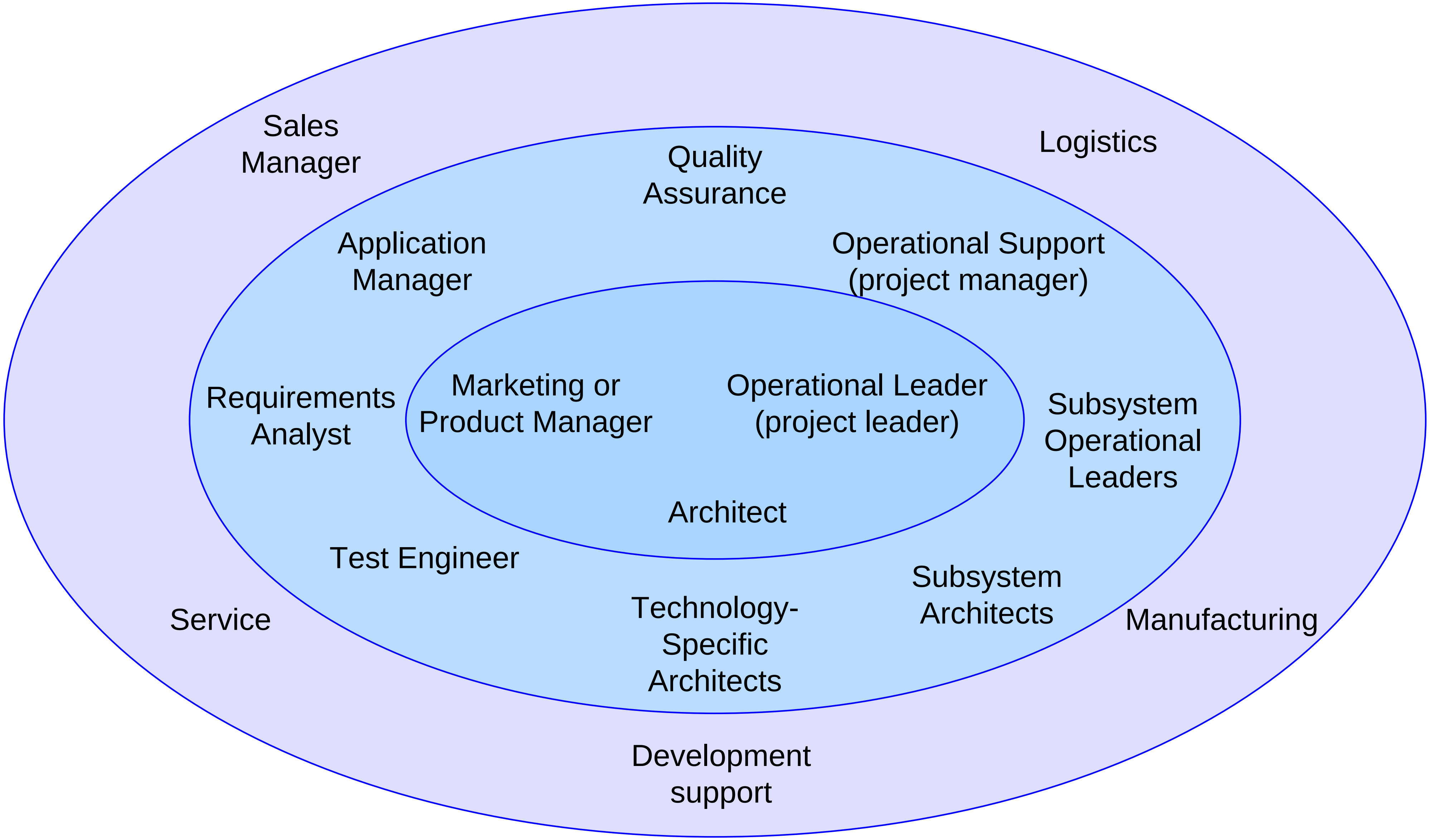
assess risks

determine feasibility

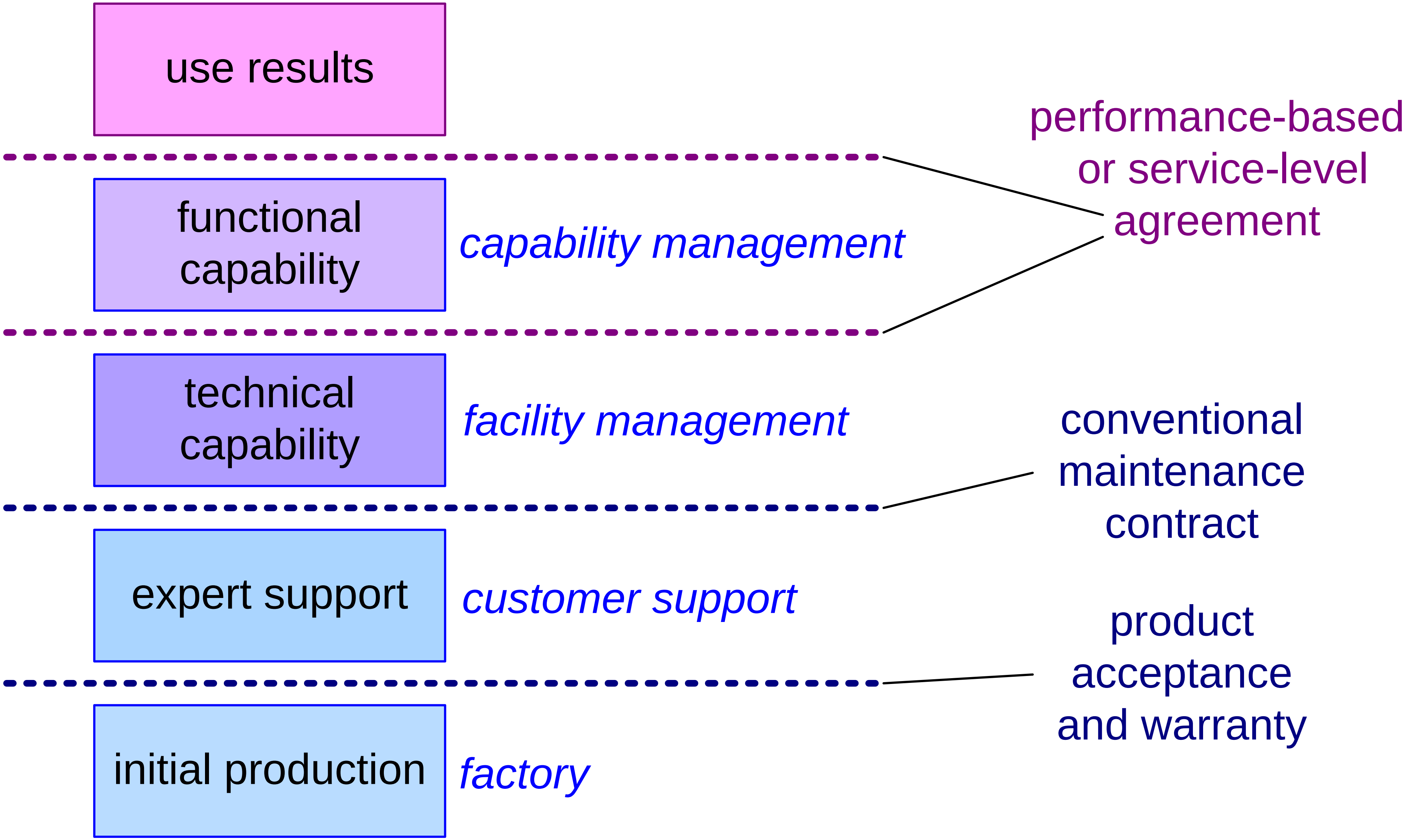
accept

execute project
within normal
quality rules

Operational Teams



What Service Level to Deliver?



use results

functional capability

technical capability

expert support

initial production

capability management

facility management

customer support

factory

performance-based or service-level agreement

conventional maintenance contract

product acceptance and warranty

Systems Engineering Management Plan (SEMP)

How the project will perform the systems engineering process:

- main events and activities
- roles and responsibilities
- work products
- procedures and standards

Bridge between project management and engineering (NASA 2016)

Mastering Systems Integration; Early Validation

by *Gerrit Muller*   TNO-ESI, University of South-Eastern Norway]
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Abstract

The core principle of systems integration is early validation; are the assumptions of the needs, specifications and design decisions valid? it is better to fail early, then to hit faulty assumptions, unknowns, or uncertainties late in development.

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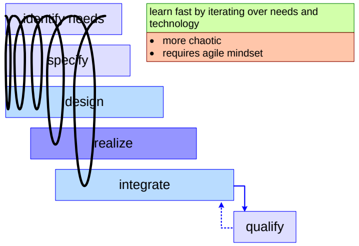
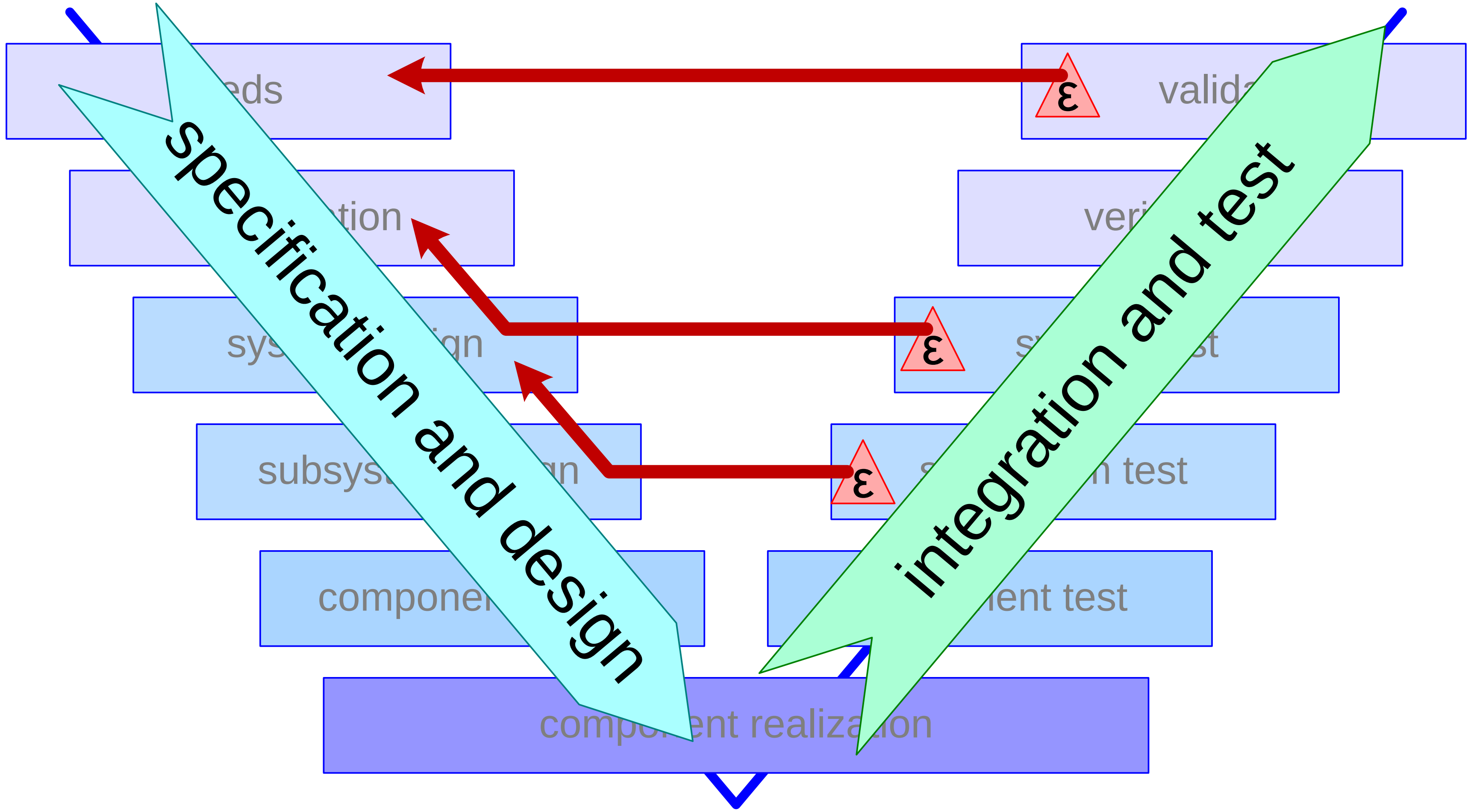
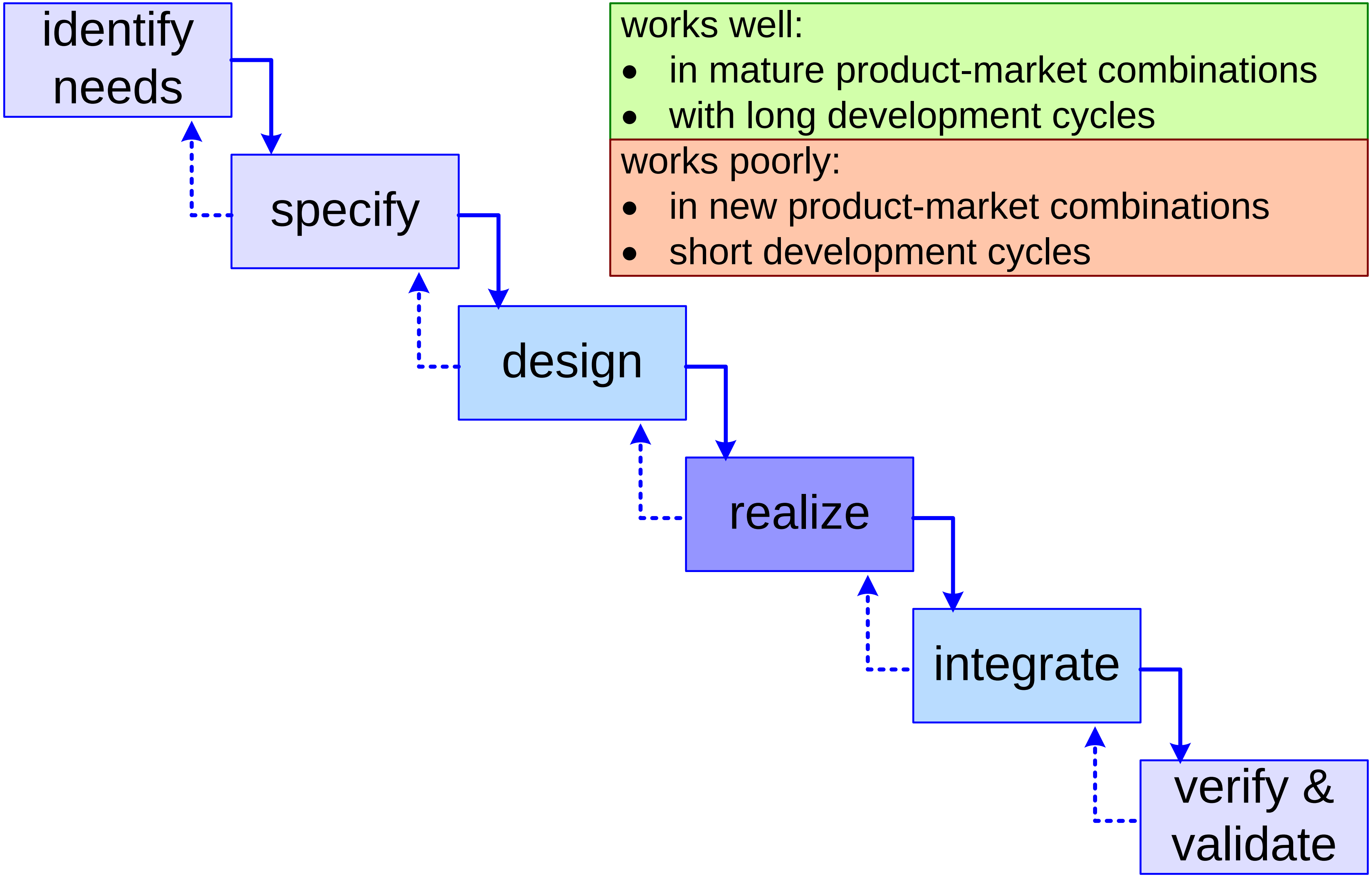


Most Problems are Found Late

failures found during integration and test can be traced back to ***unknowns***, ***unforeseens***, and ***wrong assumptions***



Waterfall model



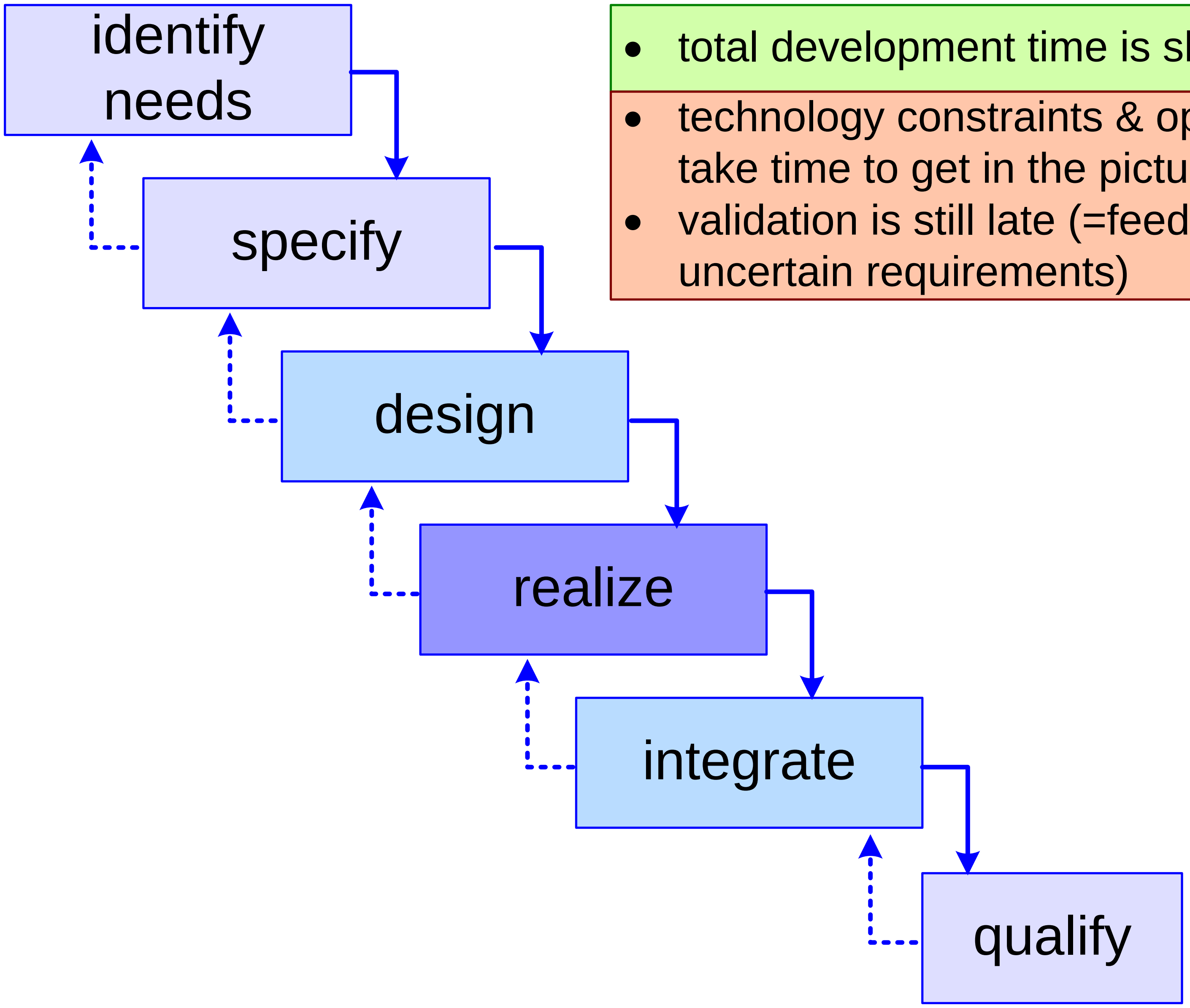
works well:

- in mature product-market combinations
- with long development cycles

works poorly:

- in new product-market combinations
- short development cycles

Concurrent Engineering



- total development time is shorter

- technology constraints & opportunities take time to get in the picture
- validation is still late (=feedback on uncertain requirements)

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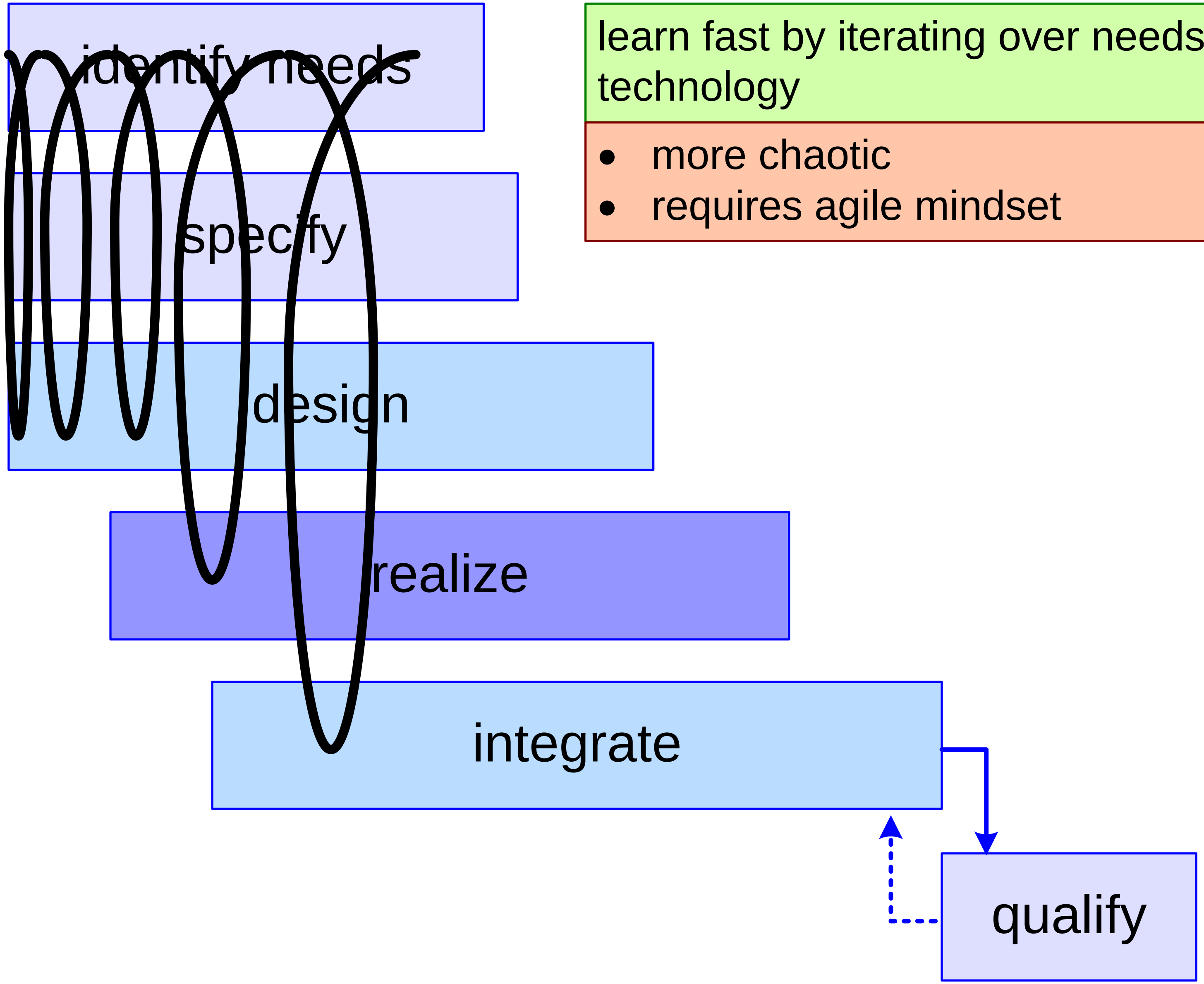
BSEARconcurrentEngineering

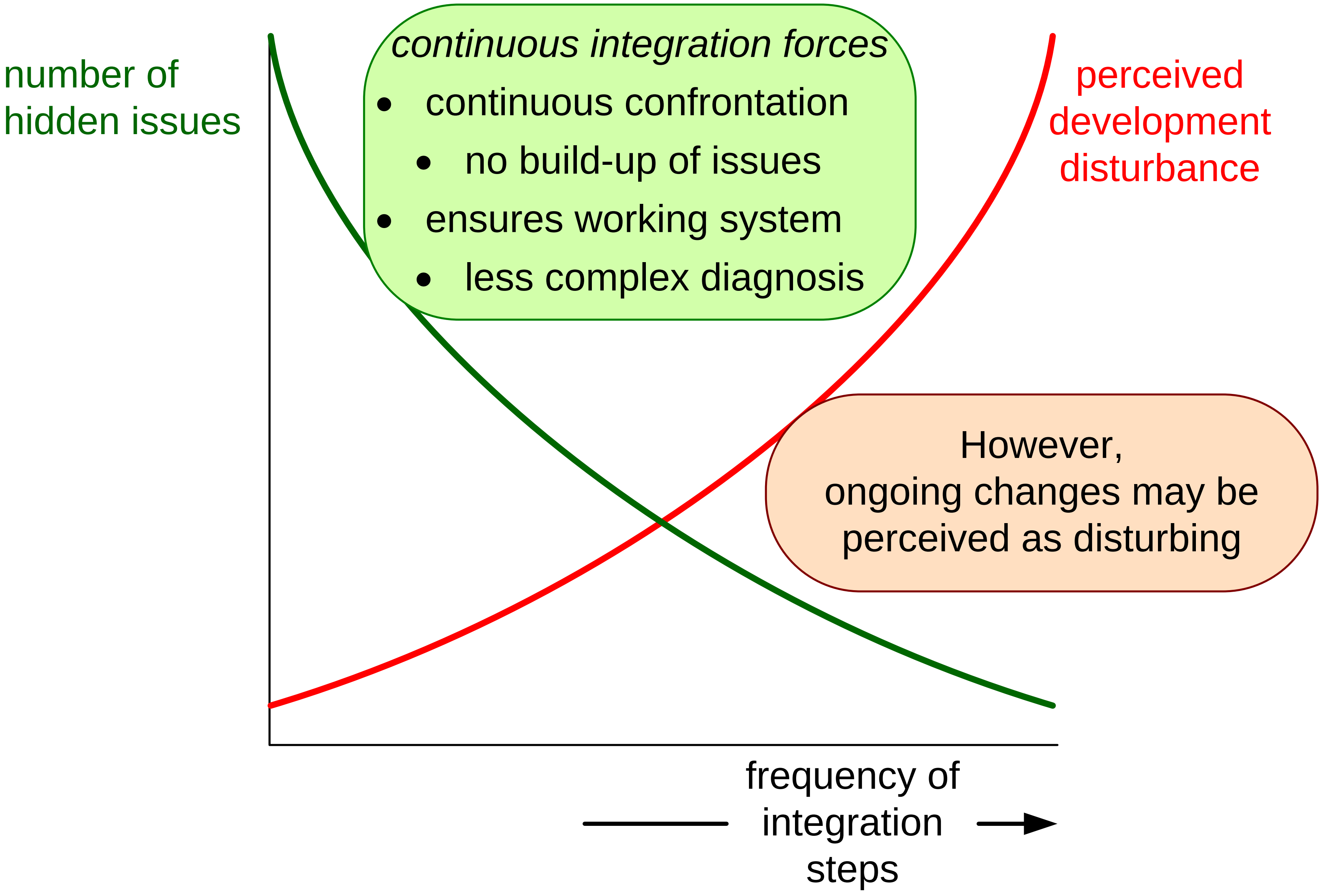
Iterative Approach



learn fast by iterating over needs and technology

- more chaotic
- requires agile mindset

Continuous Integration

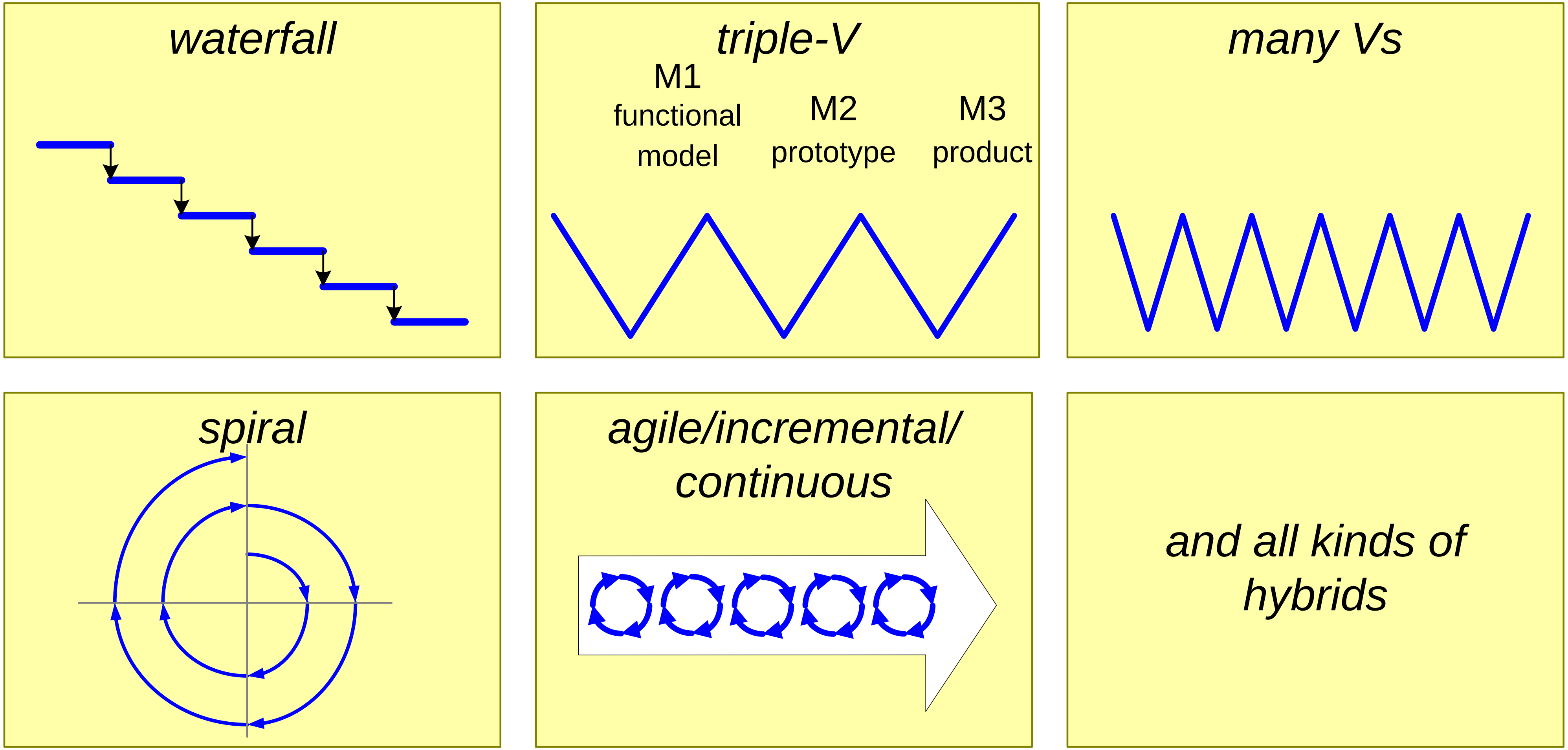


continuous integration forces

- continuous confrontation
  - no build-up of issues
- ensures working system
  - less complex diagnosis

However,
ongoing changes may be
perceived as disturbing

Development Processes From Waterfall to Agile



waterfall

triple-V

M1
functional
model

M2
prototype

M3
product

many Vs

spiral

agile/incremental/ continuous

and all kinds of hybrids

Systems Engineering Fundamentals Life Cycle

by *Gerrit Muller* University of South-Eastern Norway-NISE
e-mail: `gaudisite@gmail.com`
`www.gaudisite.nl`

Abstract

Products and enterprises evolve over time. This presentation explores the impact of these changes on the system and on the business by making (small and simple) models of life cycle aspects.

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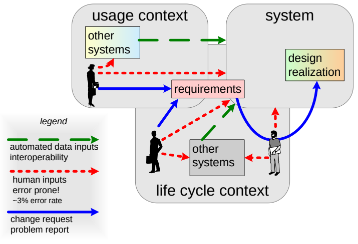
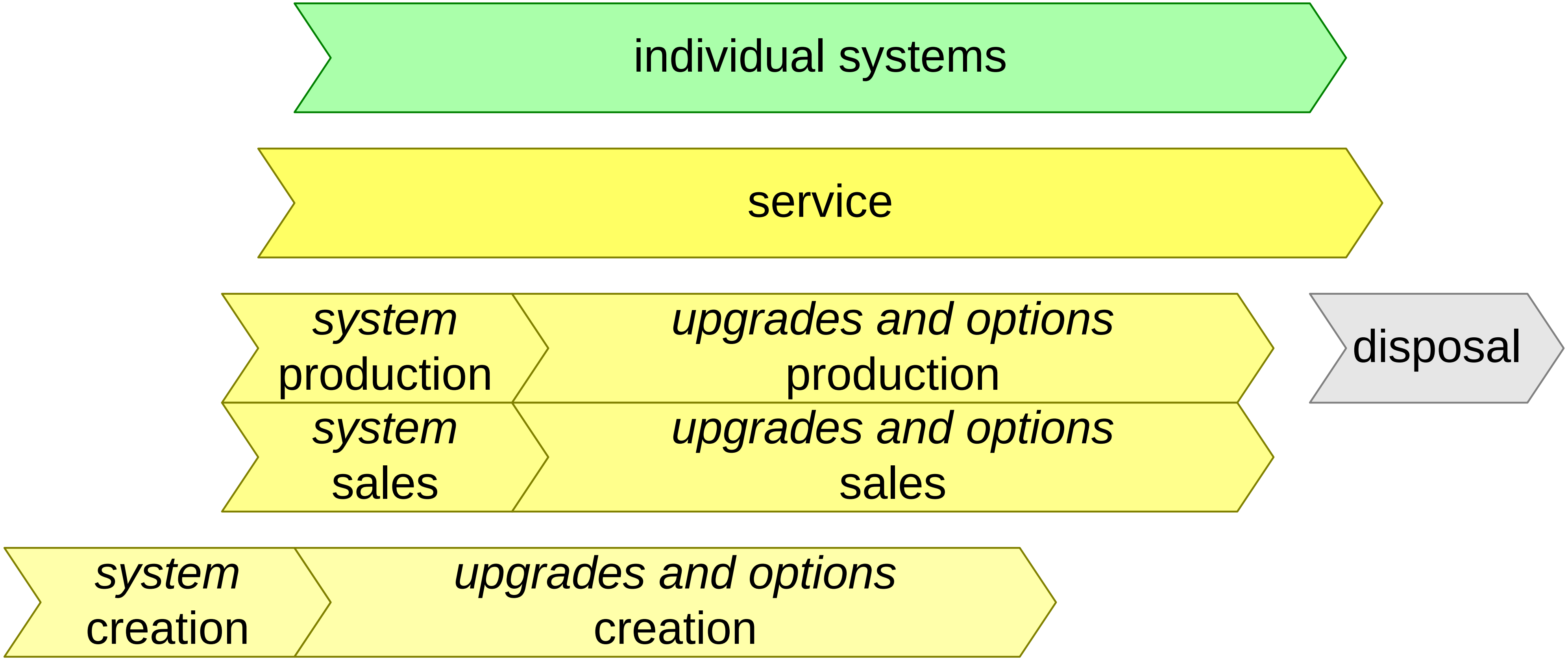


Product Related Life Cycles



individual systems

service

system production

upgrades and options production

disposal

system sales

upgrades and options sales

system creation

upgrades and options creation

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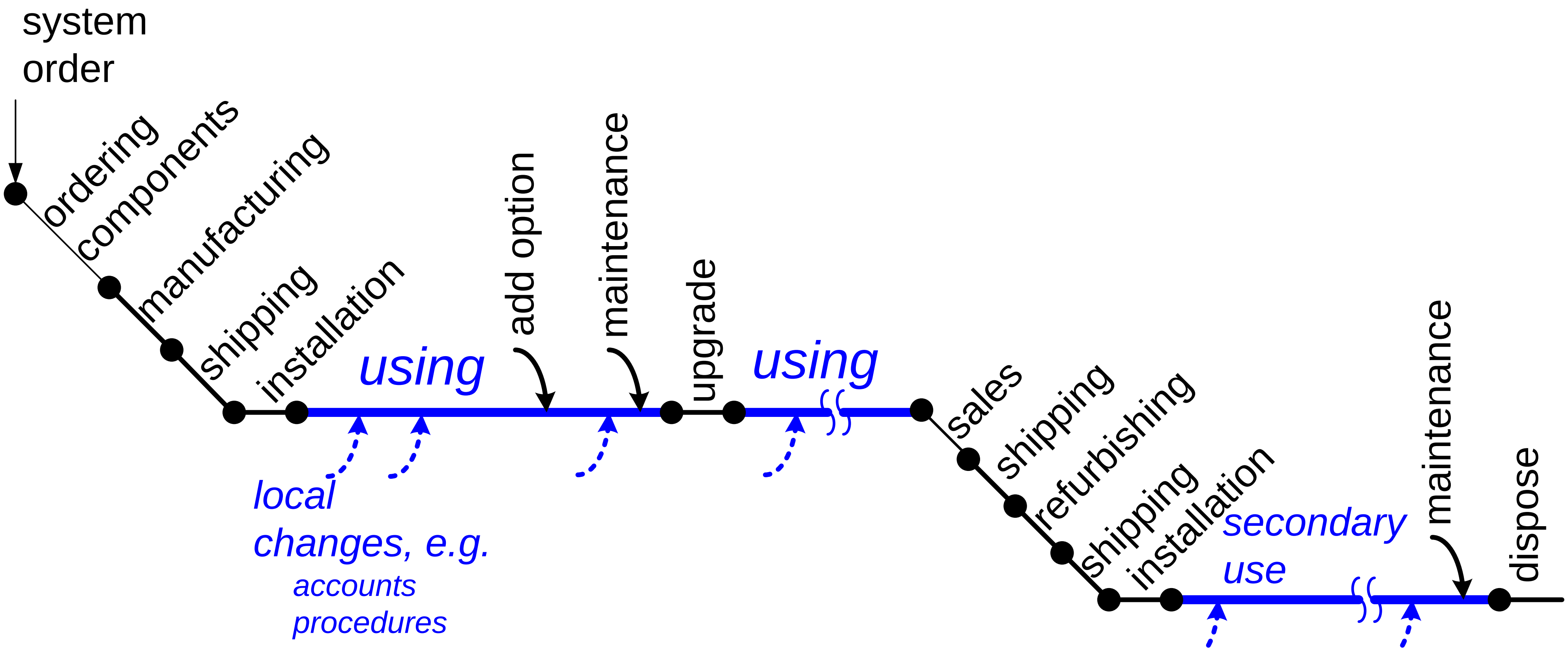
November 18, 2023
MALCproductLifeCycle

System Life Cycle



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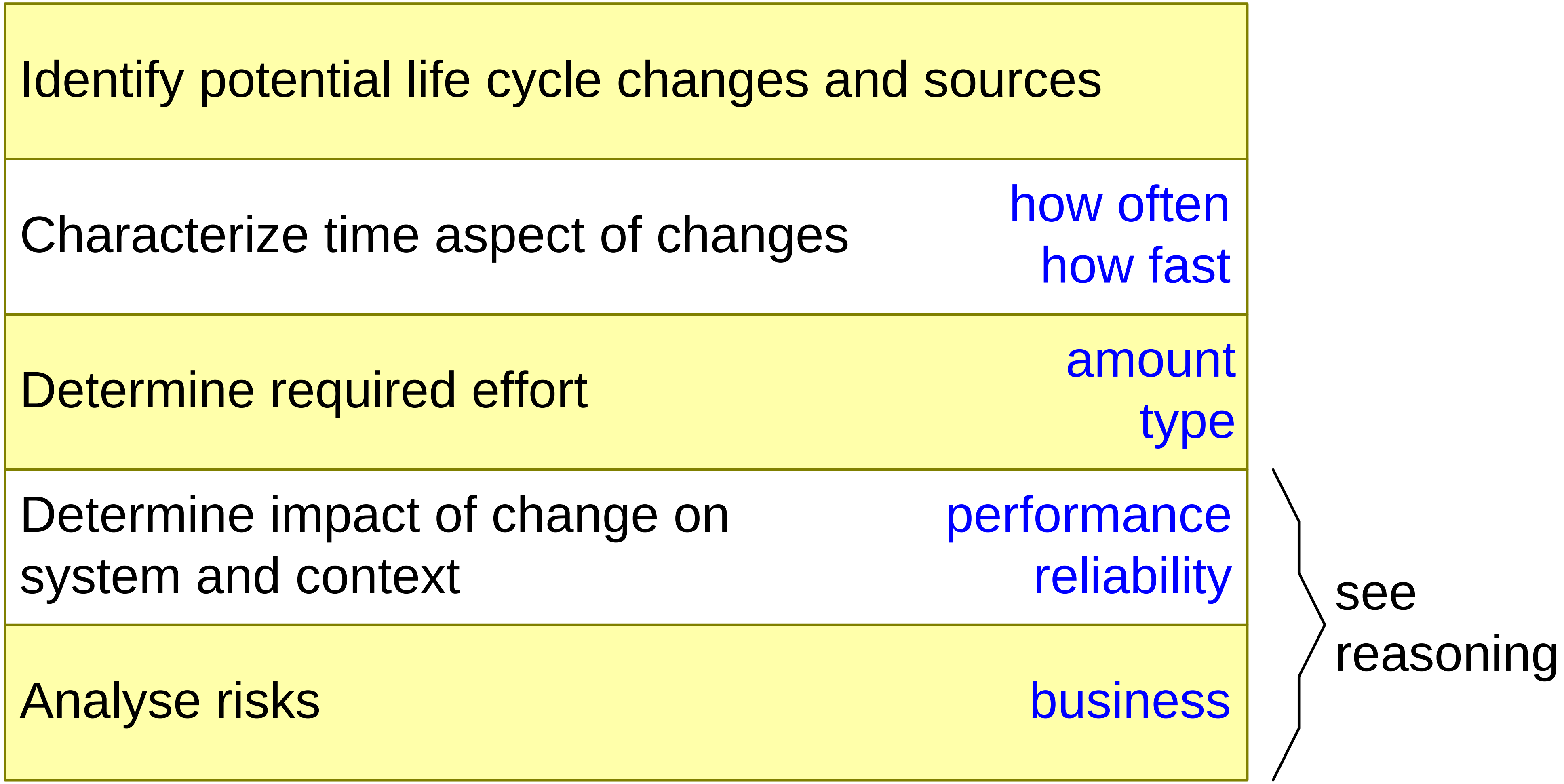
MALCsystemLifeCycle

Approach to Life Cycle Modeling



Identify potential life cycle changes and sources

Characterize time aspect of changes — how often, how fast

Determine required effort — amount, type

Determine impact of change on system and context — performance, reliability

Analyse risks — business

see reasoning

Systems Engineering Fundamentals Needs Elicitation

by *Gerrit Muller* University of South-Eastern Norway-NISE
e-mail: `gaudisite@gmail.com`
`www.gaudisite.nl`

Abstract

This presentation uses the TRIZ 9 Windows diagram as framework to think about needs elicitation.

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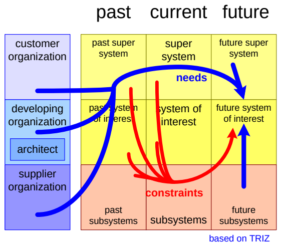
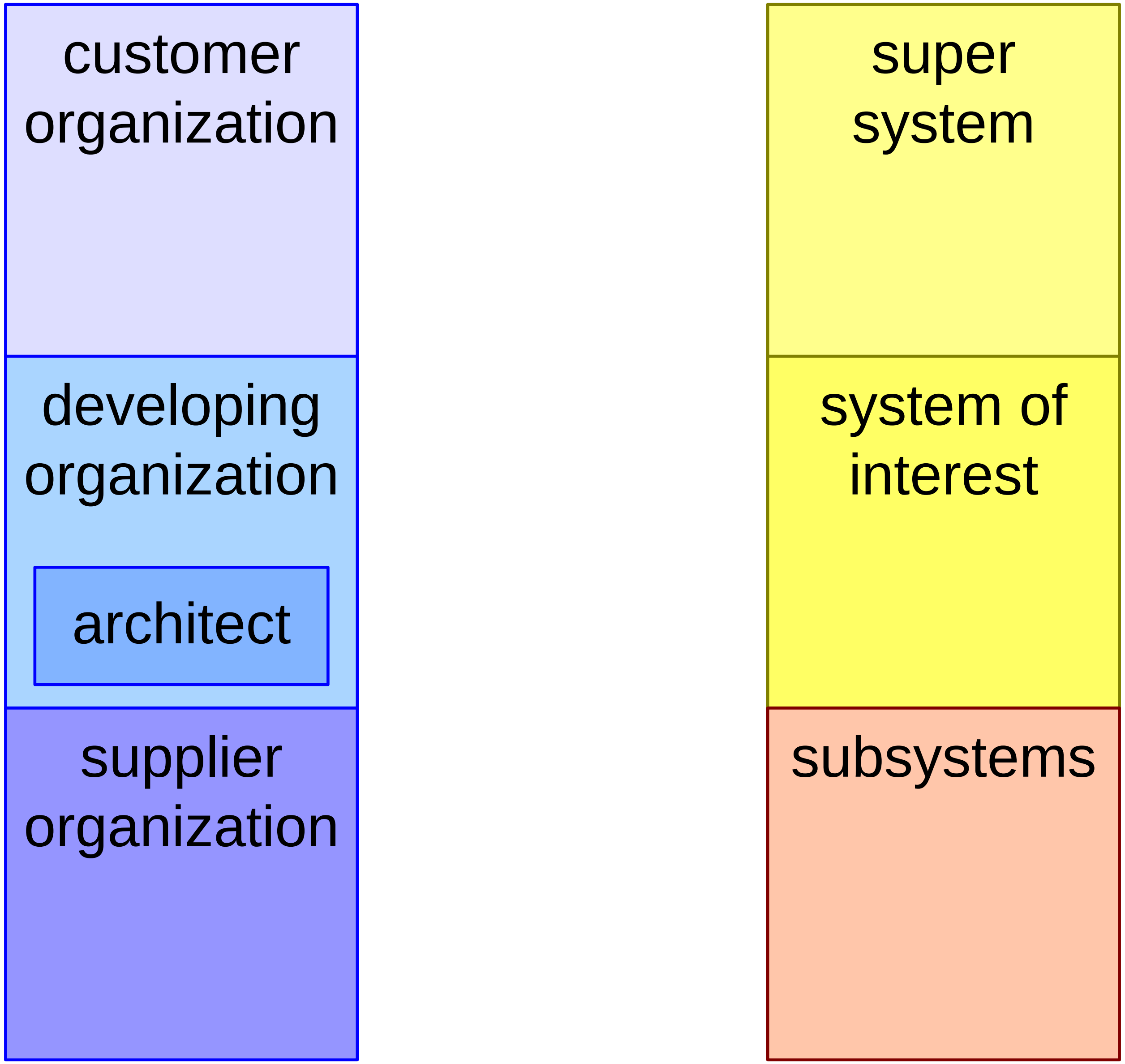


Our Primary Interest

Context, Zoom-out and Zoom-in



customer organization

developing organization

architect

supplier organization

super system

system of interest

subsystems

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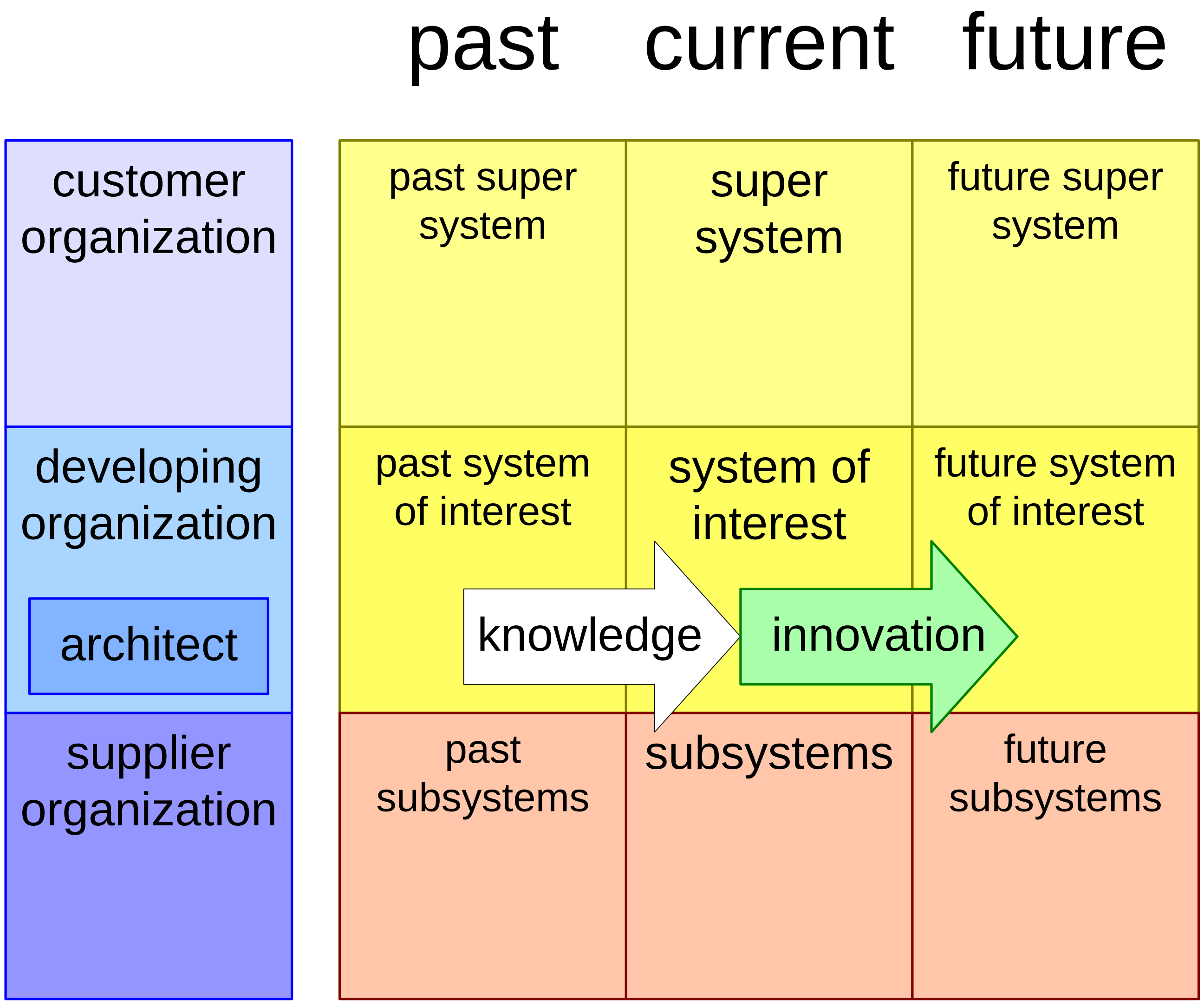
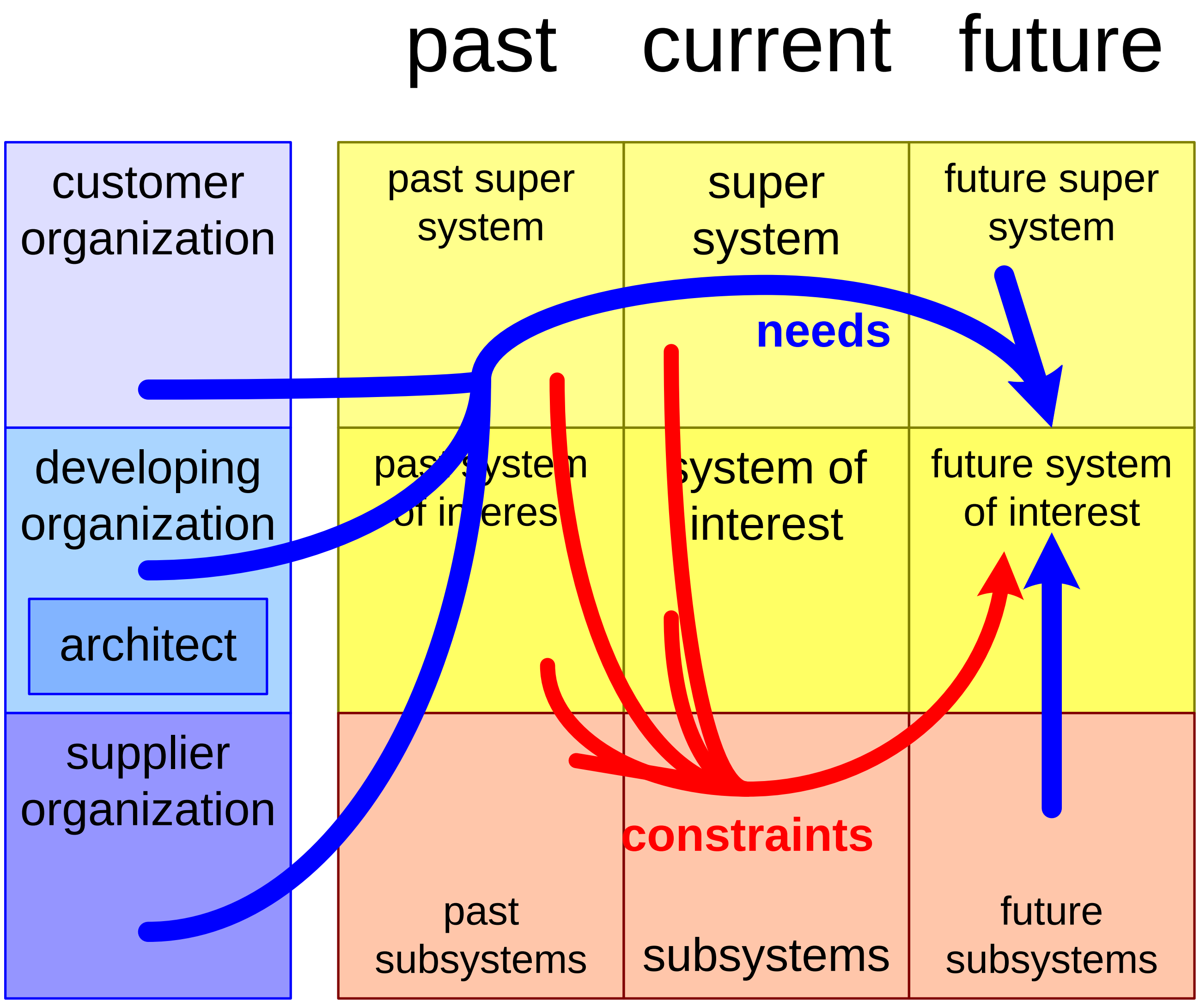
November 18, 2023
SEMABsuperSubEntities

Adding the Time Dimension



based on TRIZ

Sources of Needs and Constraints



based on TRIZ

version: 0
November 18, 2023
SEFNEtriz

Systems Engineering Fundamentals Requirements Management

by *Gerrit Muller* University of South-Eastern Norway-NISE
e-mail: `gaudisite@gmail.com`
`www.gaudisite.nl`

Abstract

Requirements engineering is one of the systems engineering pillars. In this document we discuss the fundamentals of systems engineering, such as the transformation of needs into specification. Needs and requirements prescribe *what* rather than *how*.

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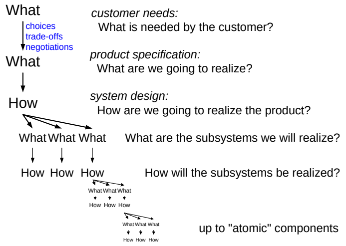


Definition of “Requirement”

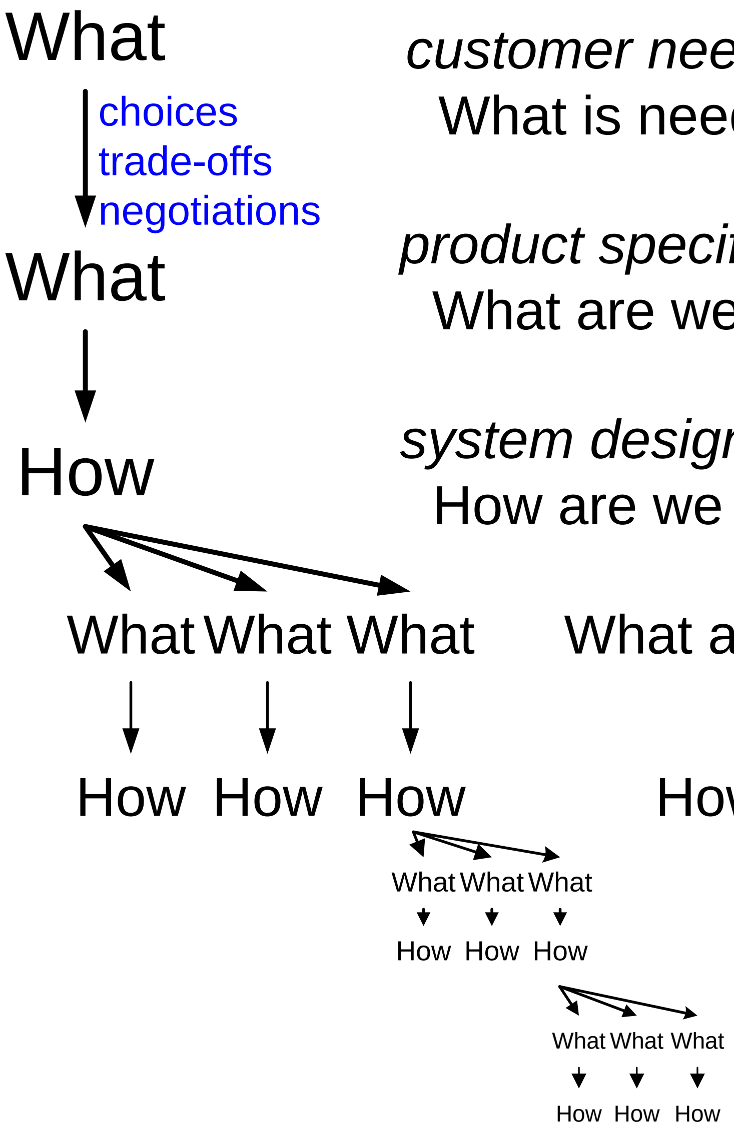
Requirements describing the needs of the customer: ***Customer Needs***

Requirements describing the characteristics of the final resulting system (product): ***System (Product) Specification***

The ***requirements management process*** recursively applies this definition for every level of decomposition.

Requirements describing the needs of the company itself over the life cycle: ***Life Cycle Needs***

Flow of Requirements



What

choices
trade-offs
negotiations

What

How

What What What

How How How

What What What

How How How

What What What

How How How

customer needs:
What is needed by the customer?

product specification:
What are we going to realize?

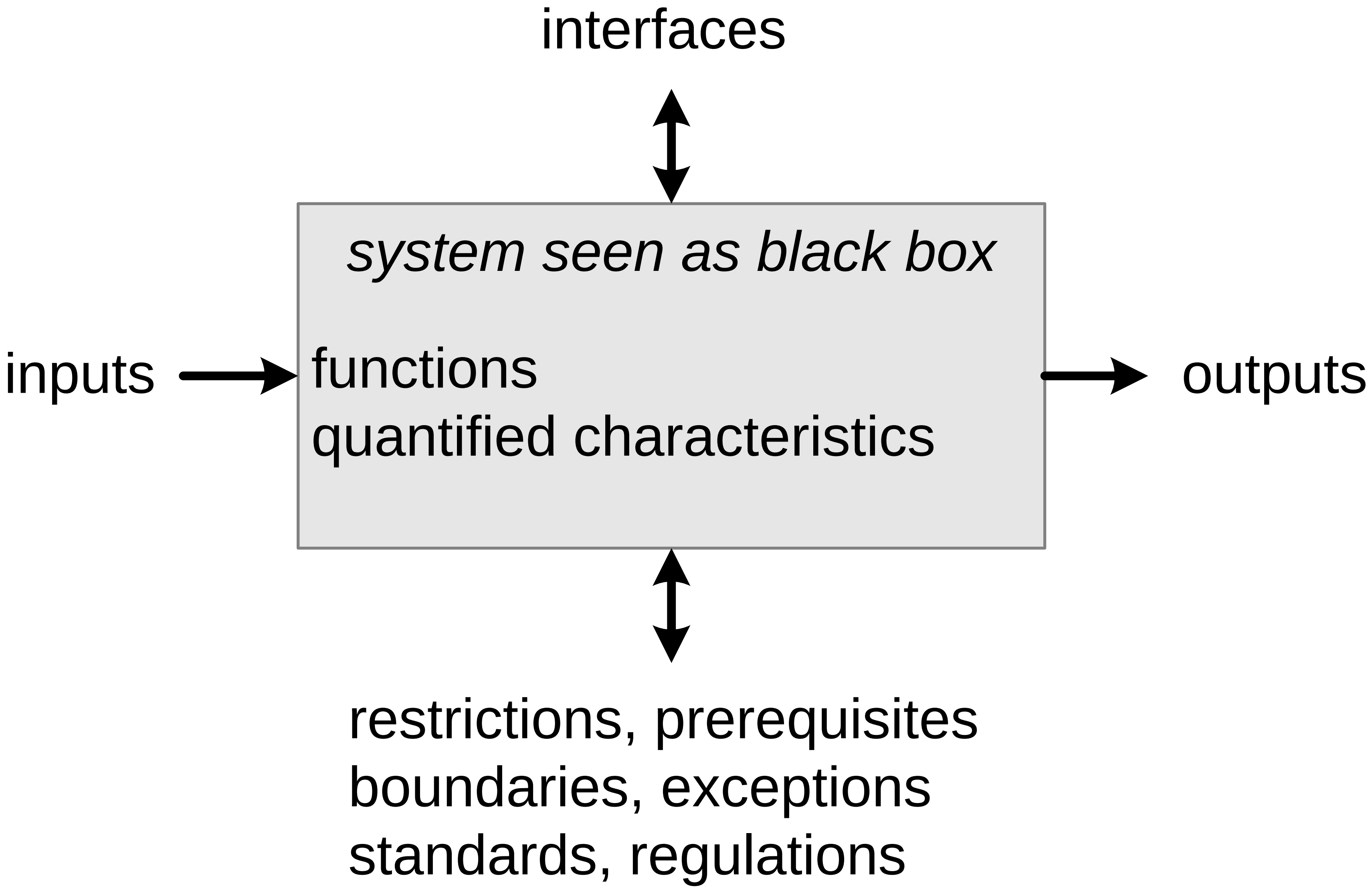
system design:
How are we going to realize the product?

What are the subsystems we will realize?

How will the subsystems be realized?

up to "atomic" components

System as a Black Box



interfaces

system seen as black box

inputs

functions
quantified characteristics

outputs

restrictions, prerequisites
boundaries, exceptions
standards, regulations

Good Requirements are “SMART”

- **S**pecific quantified
- **M**easurable verifiable
- **A**chievable (Attainable, Action oriented, Acceptable, Agreed-upon, Accountable)
- **R**ealistic (Relevant, Result-Oriented)
- **T**ime-bounded (Timely , Tangible, Traceable)

Specific Requirements have Specific Circumstances

Typical Use Case

- What is the user typically doing with the system in the system context
- Quantify the operation and context in this typical case

Other Use Cases

- Operational variants
- Boundary behavior
- Exceptional cases

these use cases >> SysML use cases

Concept Selection, Set Based Design and Late Decision Making

by *Gerrit Muller* University of South-Eastern Norway-NISE
e-mail: `gaudisite@gmail.com`
`www.gaudisite.nl`

Abstract

We discuss a systems design approach where several design options are maintained concurrently. In LEAN Product Development this is called set-based design. Concentioanl systems engineering also promotes the concurrent evaluation of multiple concepts, the so-called concept selection. Finally, LEAN product development advocates to keep options open as long as feasible; the so-called late decision making.

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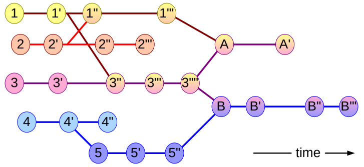
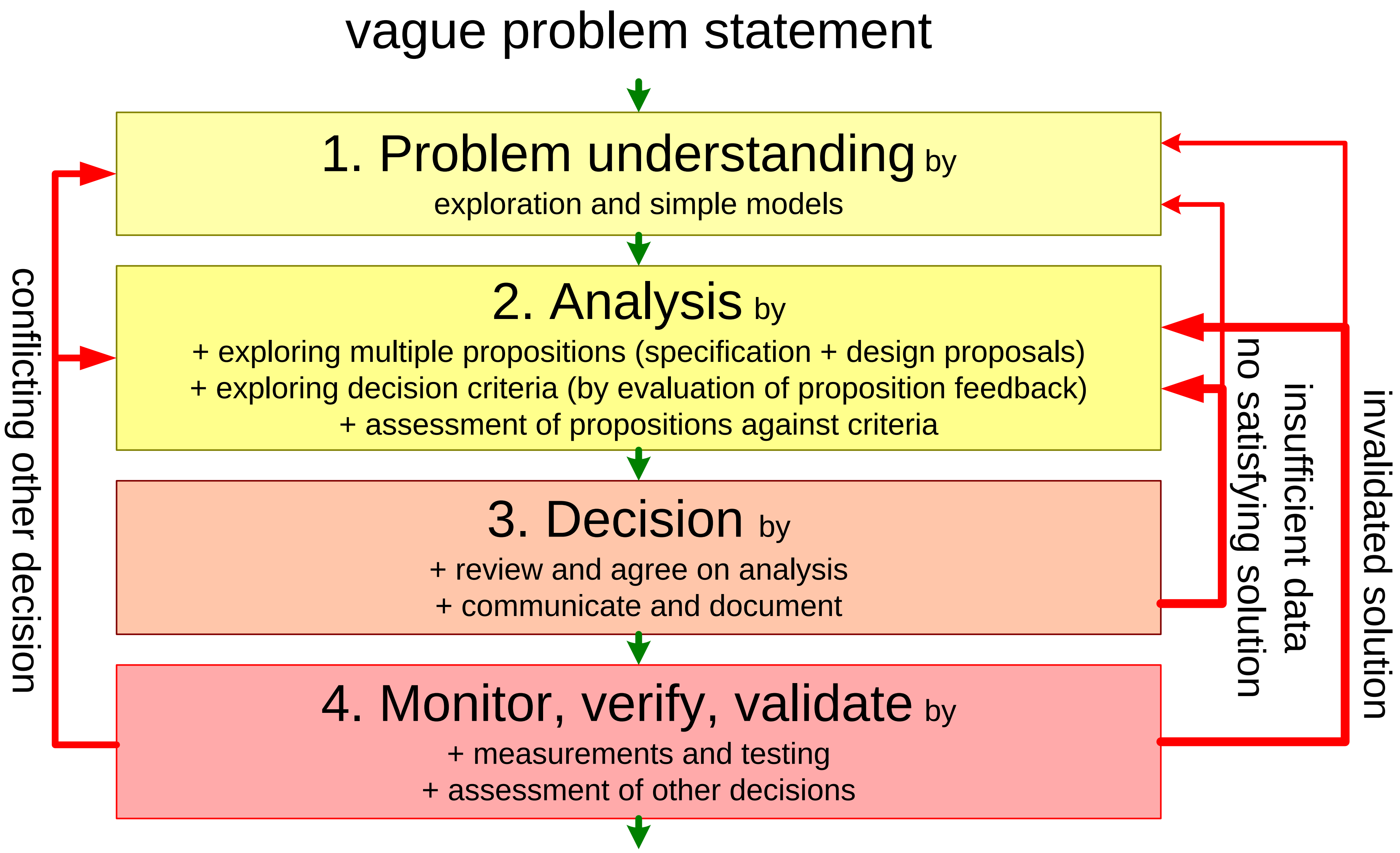


Problem Solving Approach



vague problem statement

1. Problem understanding by
exploration and simple models

2. Analysis by
+ exploring multiple propositions (specification + design proposals)
+ exploring decision criteria (by evaluation of proposition feedback)
+ assessment of propositions against criteria

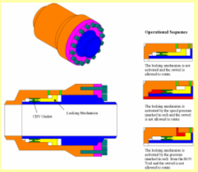
3. Decision by
+ review and agree on analysis
+ communicate and document

4. Monitor, verify, validate by
+ measurements and testing
+ assessment of other decisions

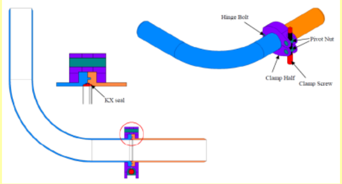
Examples of Pugh Matrix Application

Swivel concept selection

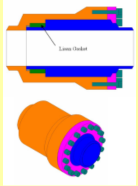
CBV swivel



clamp swivel



dynamic

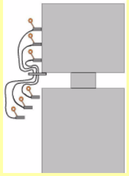


evaluation criteria	weight	CBV		clamp		dynamic	
Maturity	10						
Development level		5	50	2	20	2	50
Cost	20						
Hardware cost		4	80	2	40	5	100
Development cost		5	100	2	40	2	40
Design robustness	25						
Design life							
swivel cycles		5	125	3	75	3	75
pressure cycles		5	125	4	100	5	125
Pressure range							
internal		4	100	4	100	4	100
external		2	50	5	125	2	50
Temperature range		4	100	4	100	4	100
Installation	20						
Initial installatio/retrieval		2	40	3	60	4	80
Connection/disconnection		2	40	4	80	5	100
Operation	25						
Swivel resistance		1	25	4	100	5	125
Spool Length Short		1	25	4	100	5	125
Spool Length Long		3	75	5	125	5	125
Hub loads		2	50	4	100	5	125
Σ points			985		1165		1290

from master paper Halvard Bjørnsen, 2009

EDP-LRP connection

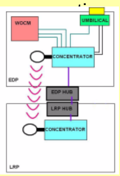
two sided



connectors in hub

connectors in hub

wireless



		Concepts			
Evaluation Criteria	Score	1	2	3	4
Time to connect					
Need for ROV		-	+	+	+
Design		-	+	+	+
Robustness					
Connector design		-	S	S	+
Number of parts		-	-	+	+
Handle roll-off		+	-	S	+
Influence other		+	S	-	S
Redundancy					
Design		+	-	-	S
Interchangeability		+	-	-	-
Cost					
HW cost		-	-	-	-
Manufacturing cost		S	S	-	S
Engineering cost		+	-	S	-
Service cost		-	+	+	+
Maturity		-	-	S	+
	Σ-	7	7	5	3
	ΣS	1	3	4	3
	Σ+	5	3	4	7
	Pos.	3	4	2	1

from master paper Dag Jostein Klever, 2009

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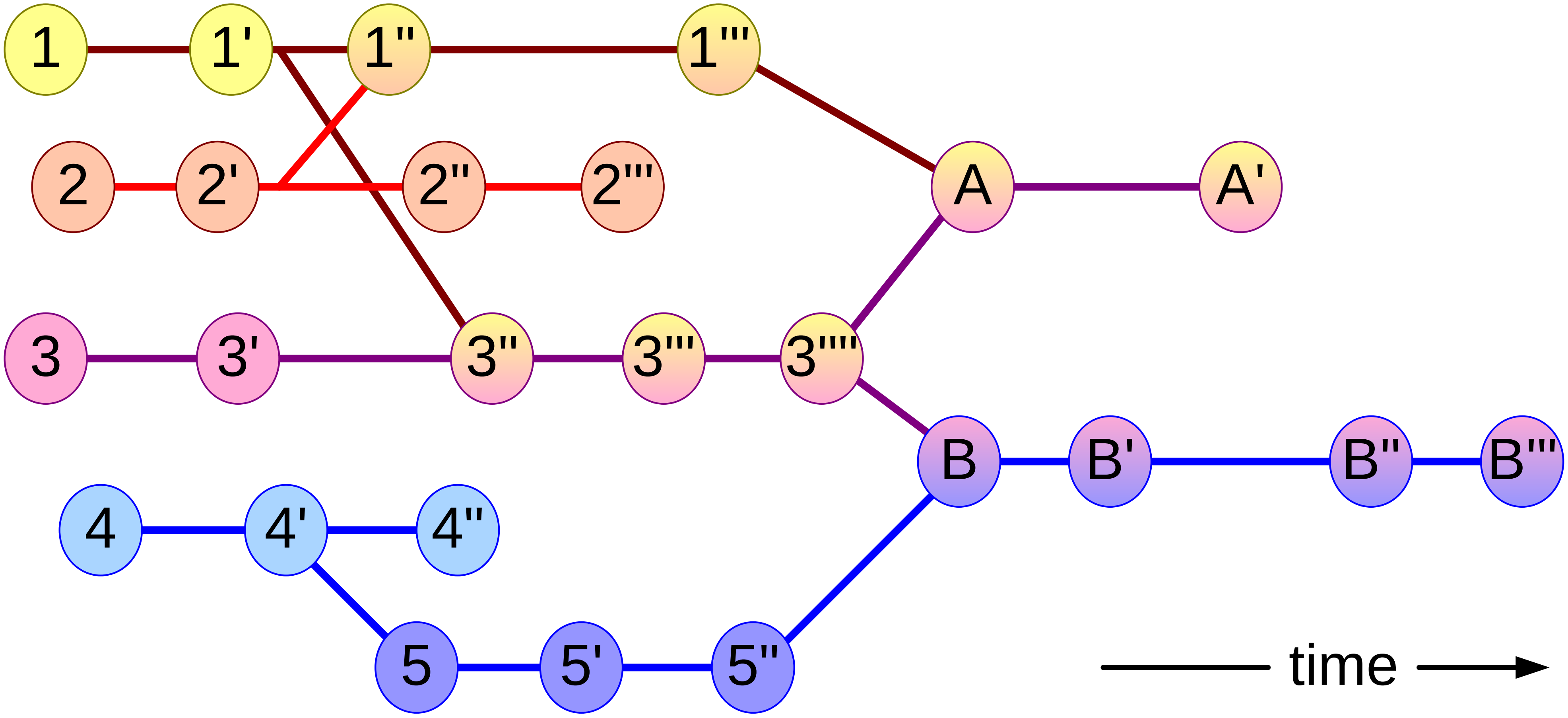
CSSBpughExamples

Evolution of Design Options



Conclusions

Evolving multiple concepts increases insight and understanding (LEAN product development: set-based design, SE: Pugh matrix)

Articulation of criteria sharpens evaluation

The discussion about the Pugh matrix is more valuable than final bottomline summation

Delaying decisions may help to keep options (Lean Product Development: late decision making, finance: real options)

Systems Engineering Fundamentals Architecture and Design

by *Gerrit Muller* University of South-Eastern Norway-NISE
e-mail: `gaudisite@gmail.com`
`www.gaudisite.nl`

Abstract

This presentation explains the fundamentals behind Architecture and Design, such as conceptual and functional design, partitioning, interfaces, and allocation.

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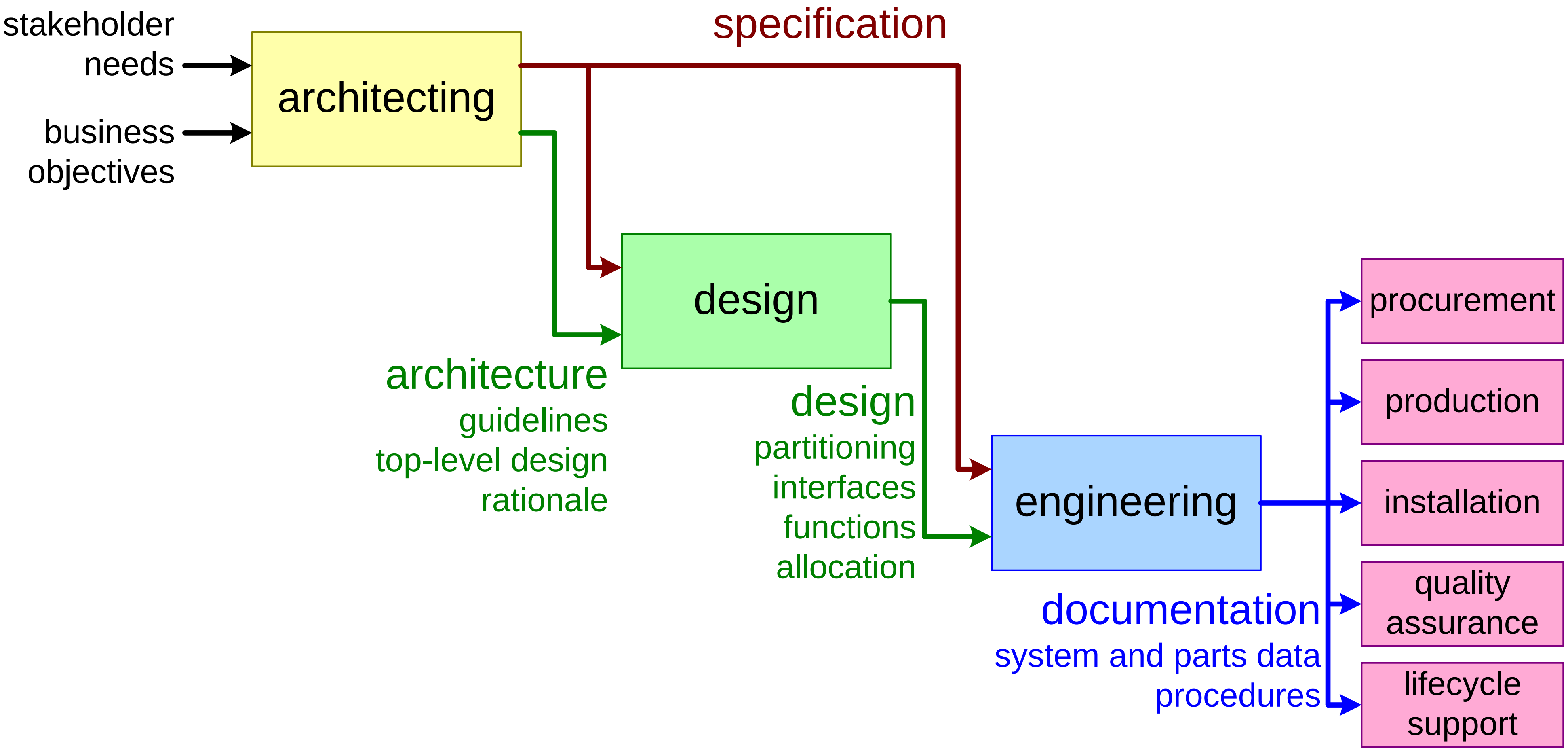
logo
TBD

Architecture and Design

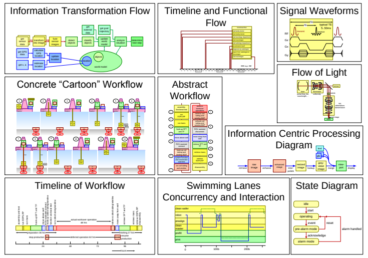


Visualizing Dynamic Behavior

by *Gerrit Muller* TNO-ESI, University of South-Eastern Norway]
e-mail: `gaudisite@gmail.com`
`www.gaudisite.nl`

Abstract

Dynamic behavior manifests itself in many ways. Architects need multiple complementary visualizations to capture dynamic behavior effectively. Examples are capturing information, material, or energy flow, state, time, interaction, or communication.



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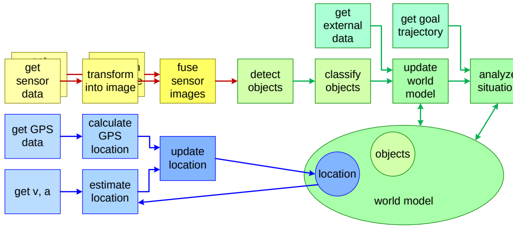
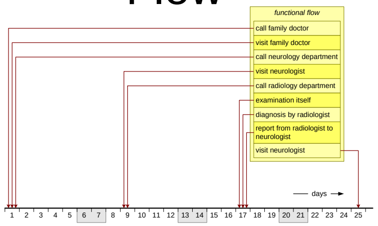
Overview of Visualizations of Dynamic Behavior

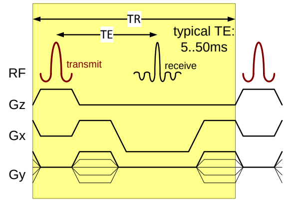
Information Transformation Flow



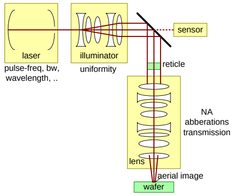
Timeline and Functional Flow



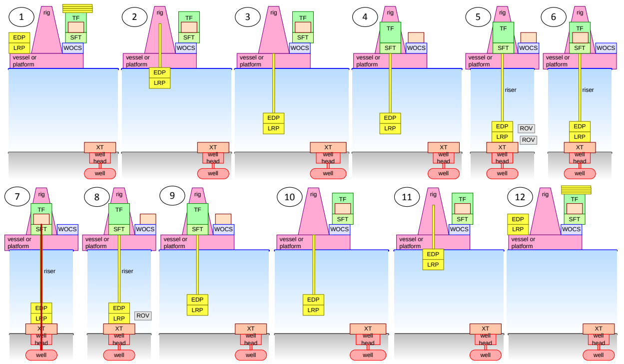
Signal Waveforms



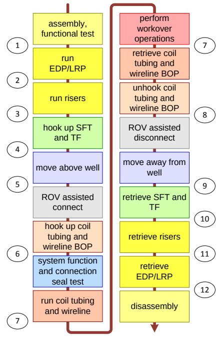
Flow of Light



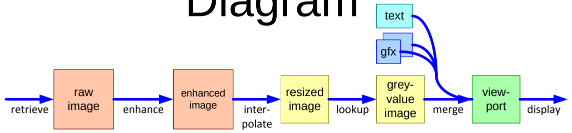
Concrete “Cartoon” Workflow



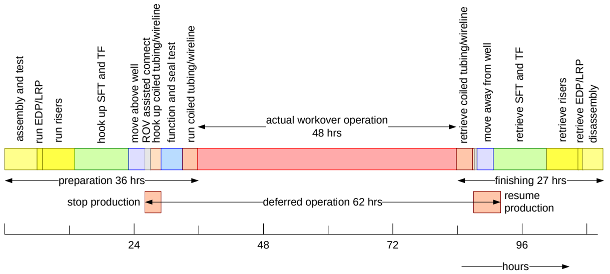
Abstract Workflow



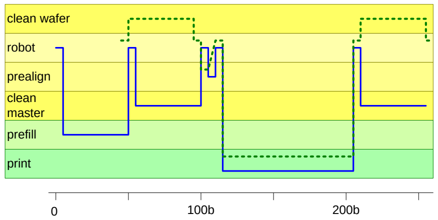
Information Centric Processing Diagram



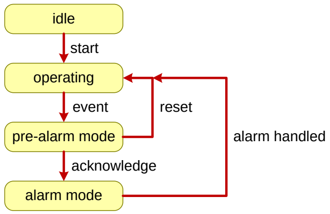
Timeline of Workflow



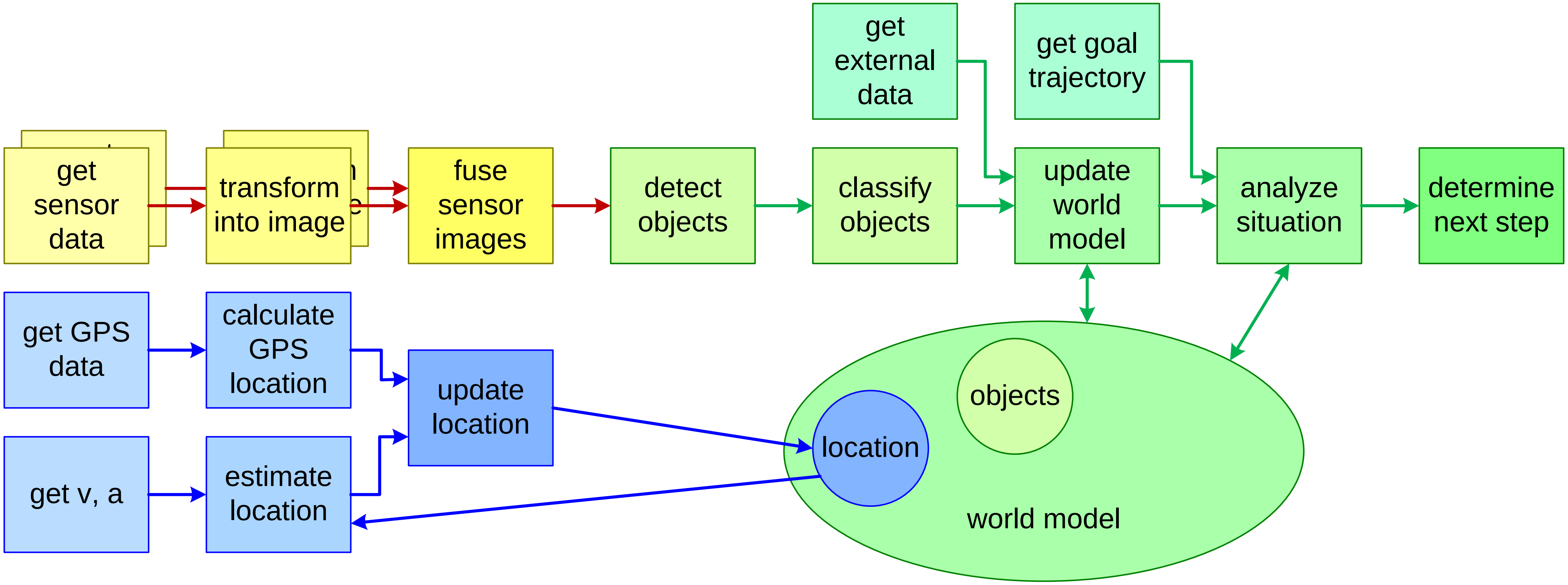
Swimming Lanes Concurrency and Interaction



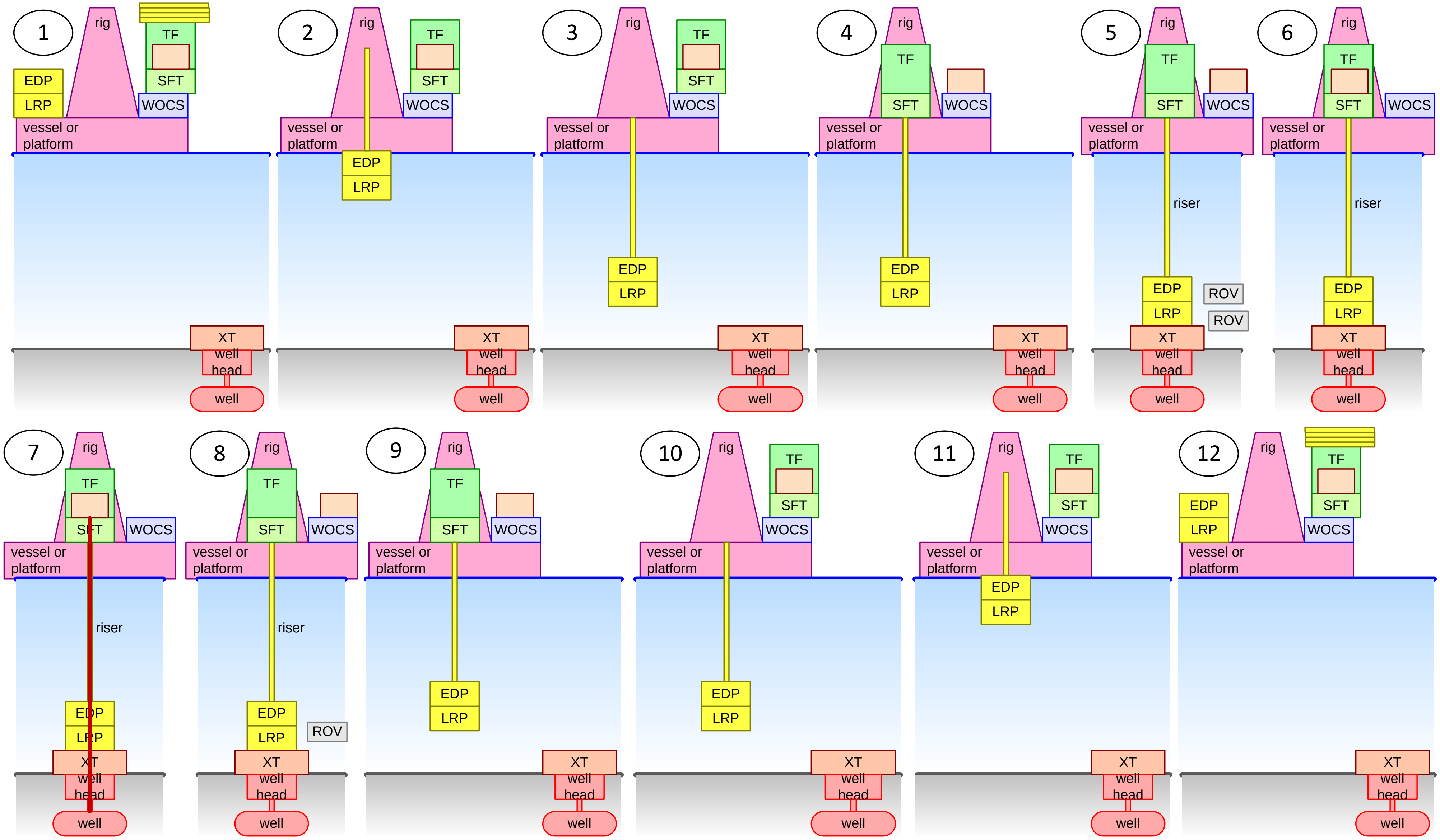
State Diagram



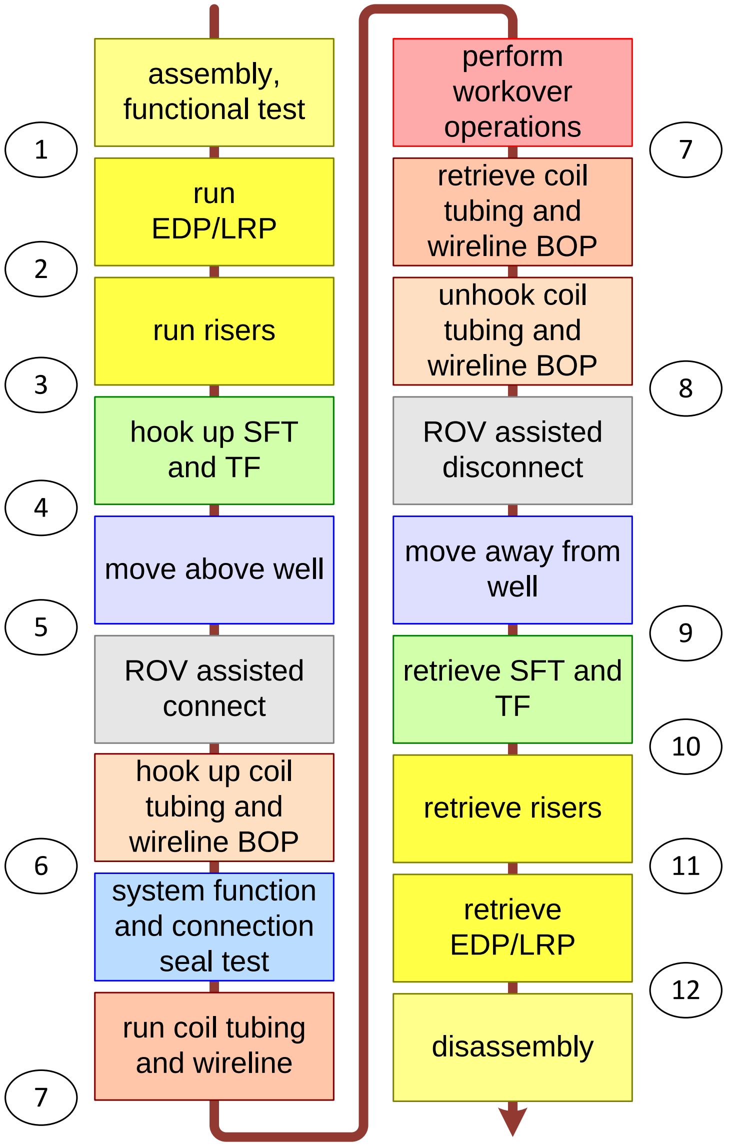
Example Functional Model of Information Flow

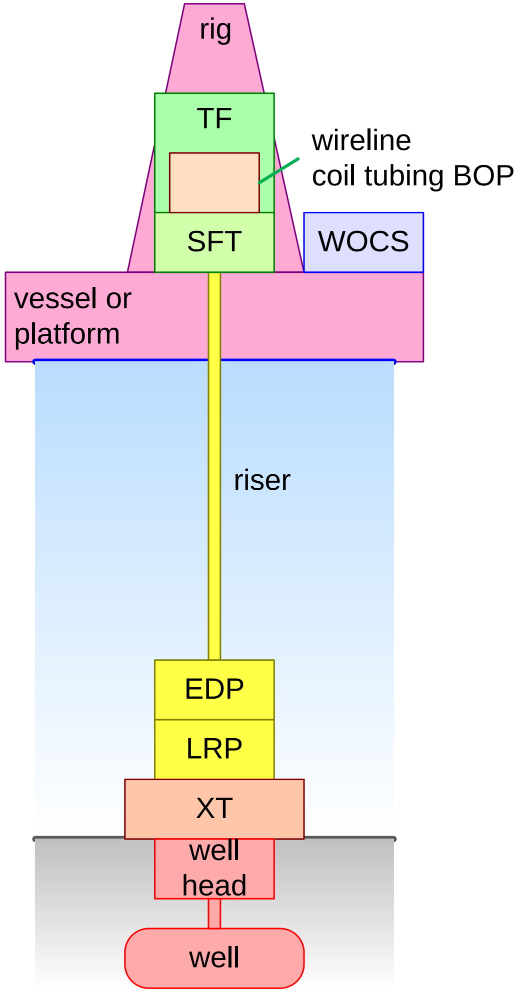


”Cartoon” Workflow



Workflow as Functional Model





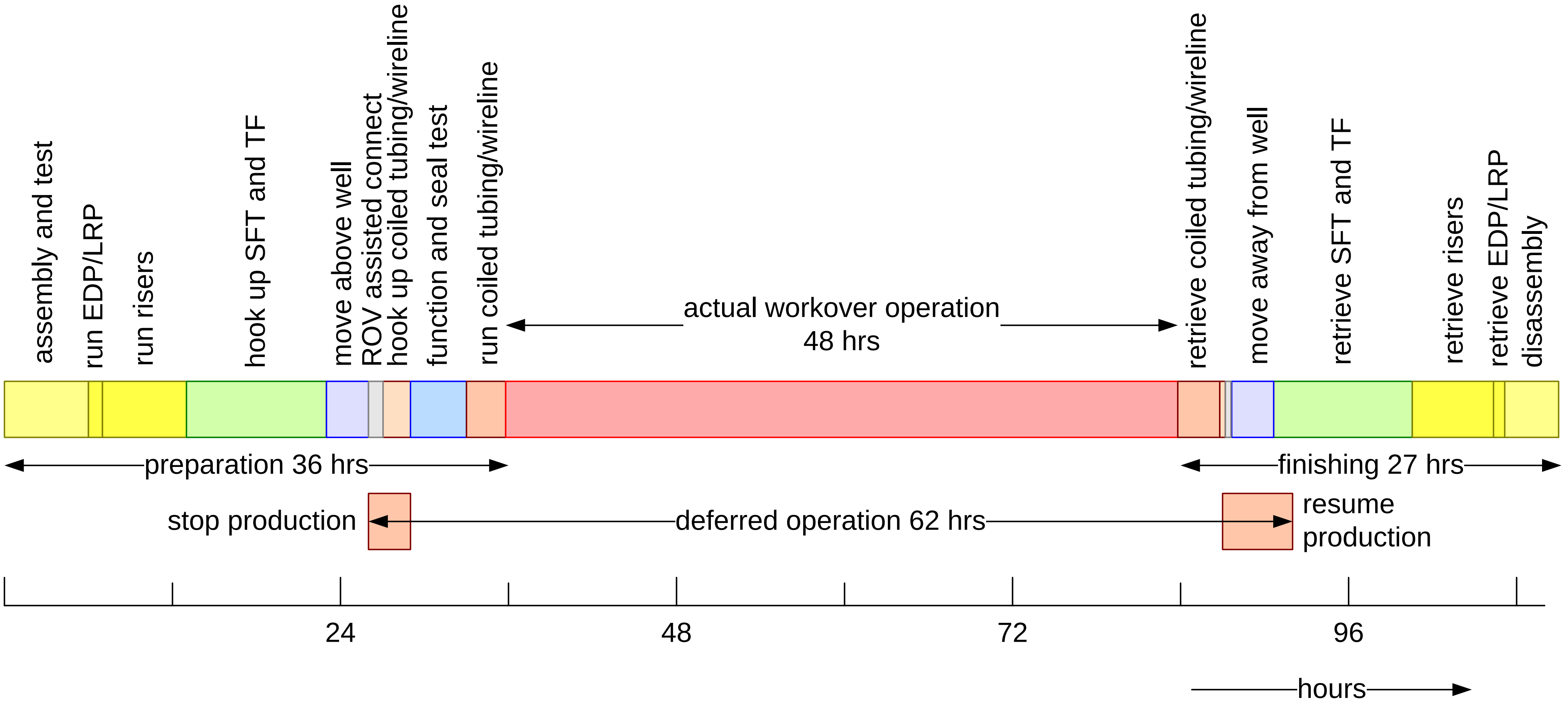
Workflow as Timeline

assumptions:

running and retrieving risers: 50m/hr

running and retrieving coiled tubing/wireline: 100m/hr

depth: 300m



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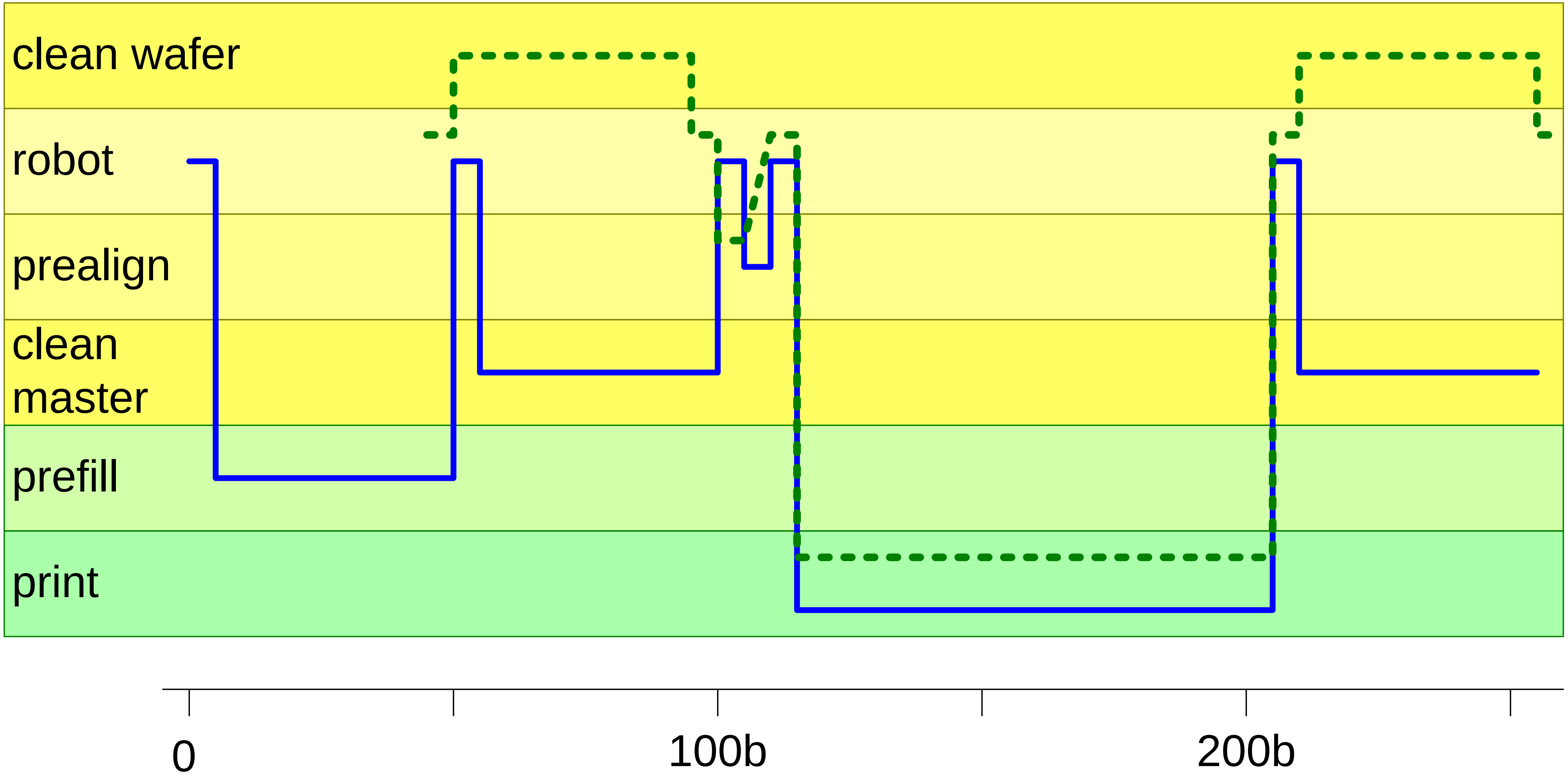
SSMEtypicalWorkoverOperationTimeline

Swimming Lane Example



version: 0
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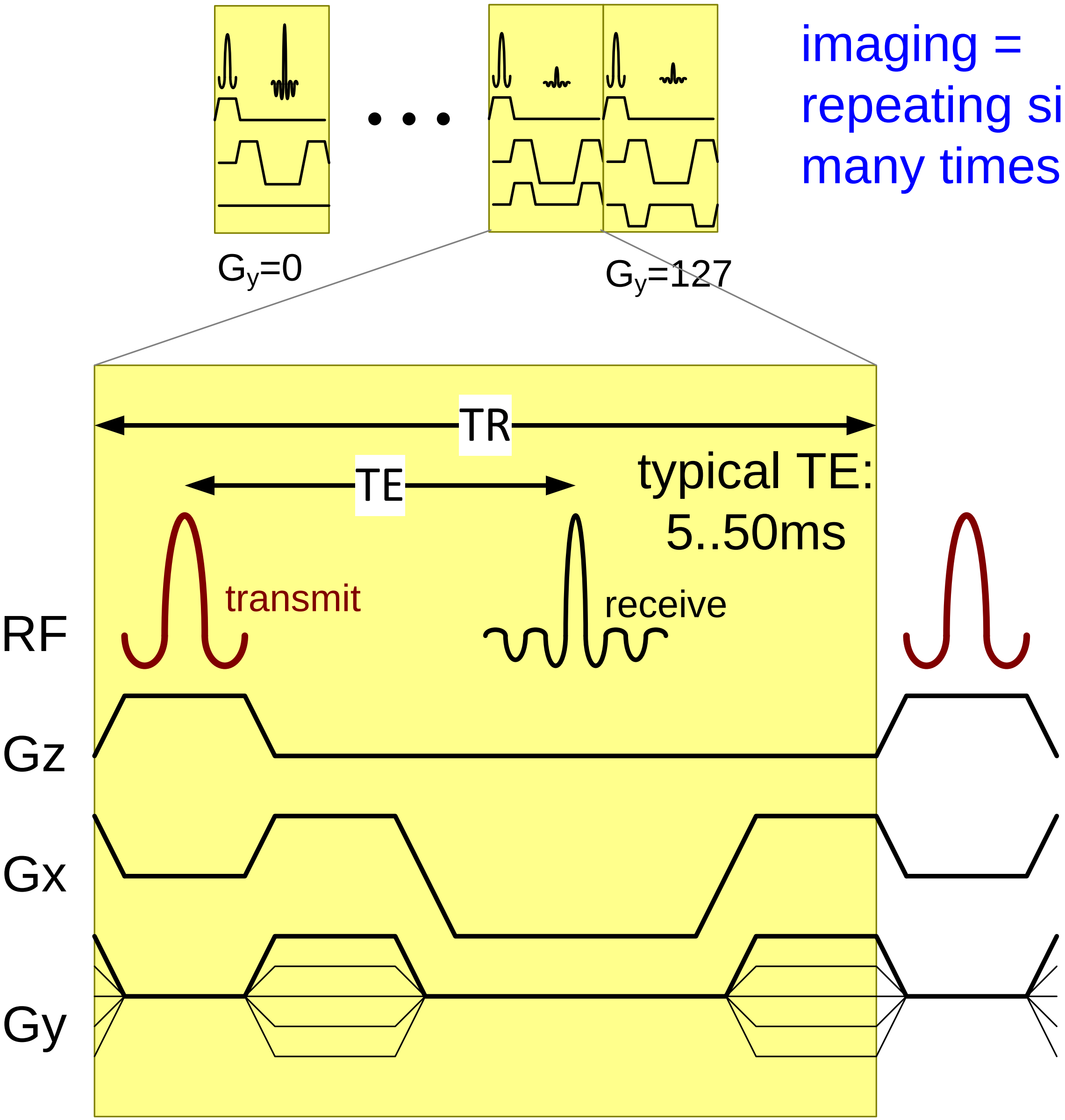
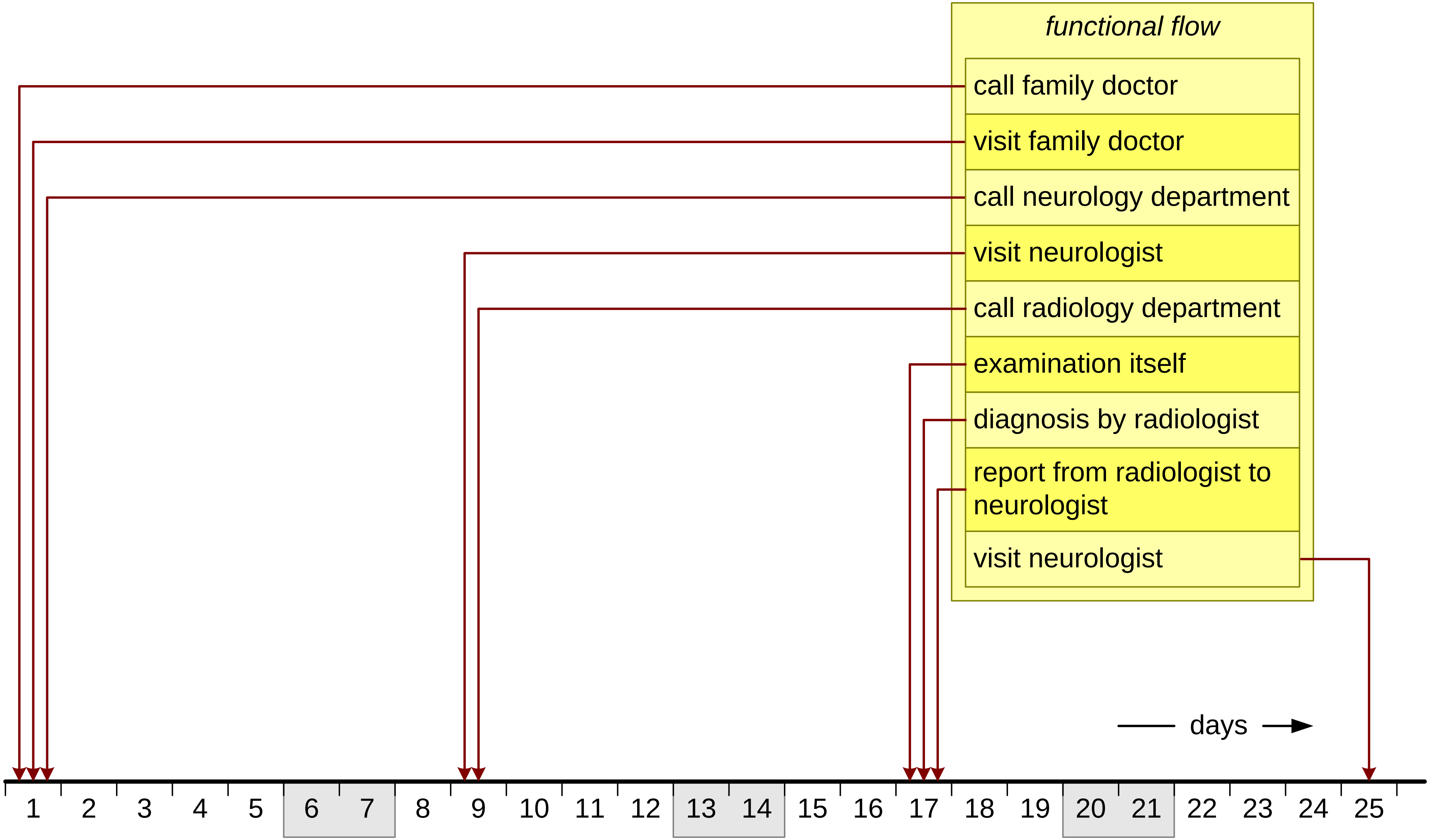
REPLIcellTimeLineSimplified

Example Signal Waveforms



imaging =
repeating similar pattern
many times

Example Time Line with Functional Model



functional flow

- call family doctor
- visit family doctor
- call neurology department
- visit neurologist
- call radiology department
- examination itself
- diagnosis by radiologist
- report from radiologist to neurologist
- visit neurologist

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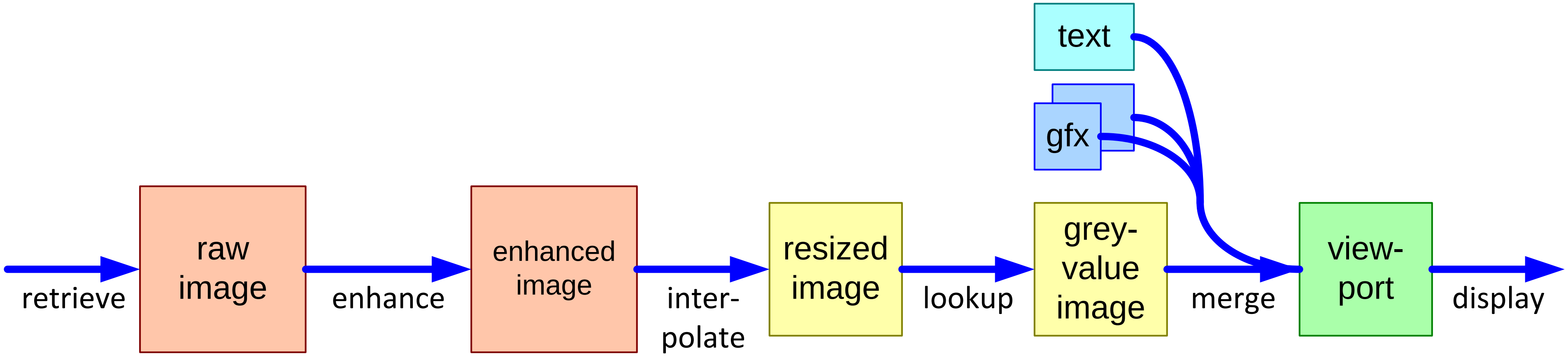
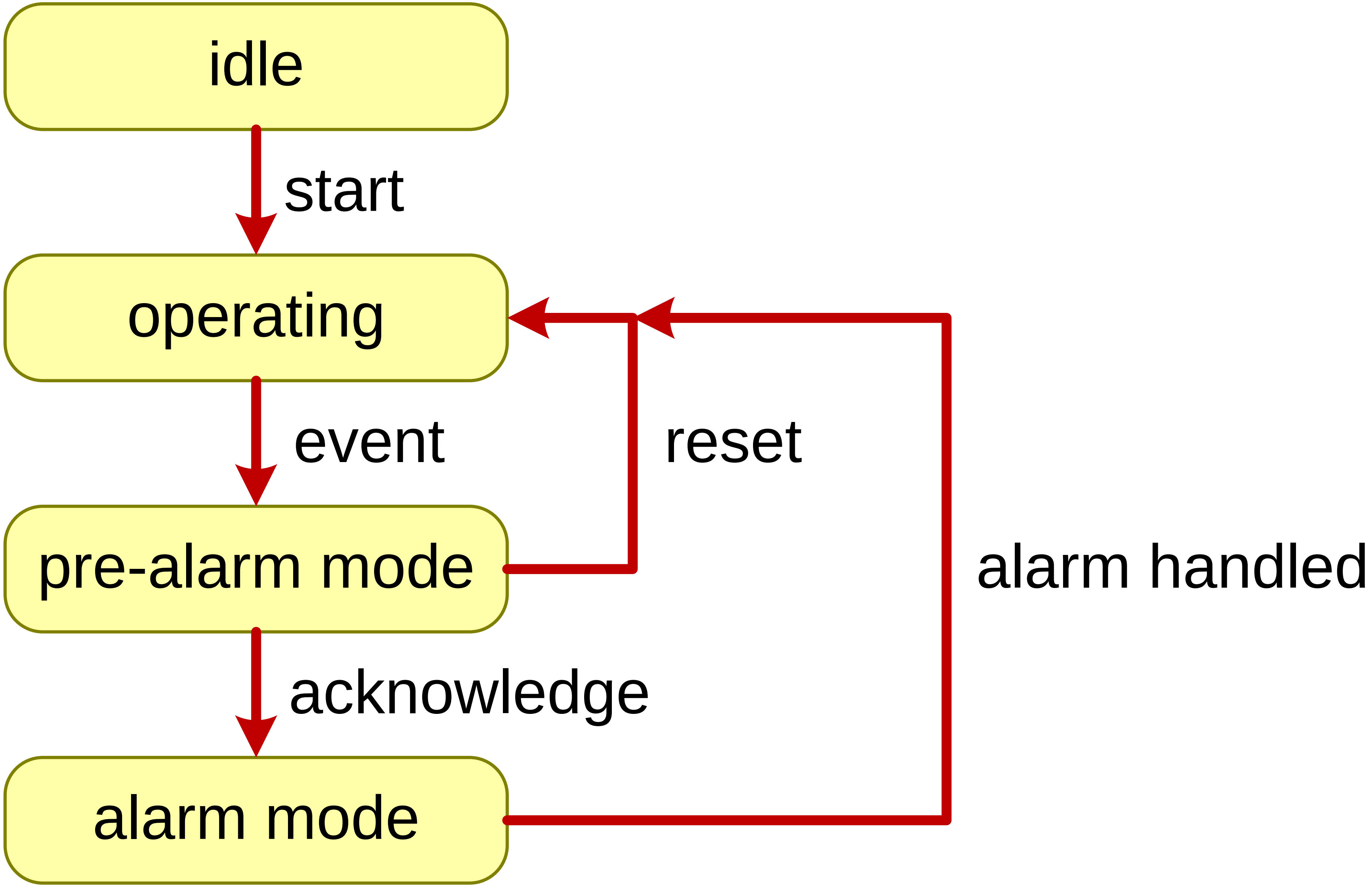
MRendToEndTimeLine

Information Centric Processing Diagram



Example State Diagram


idle

start

operating

event

reset

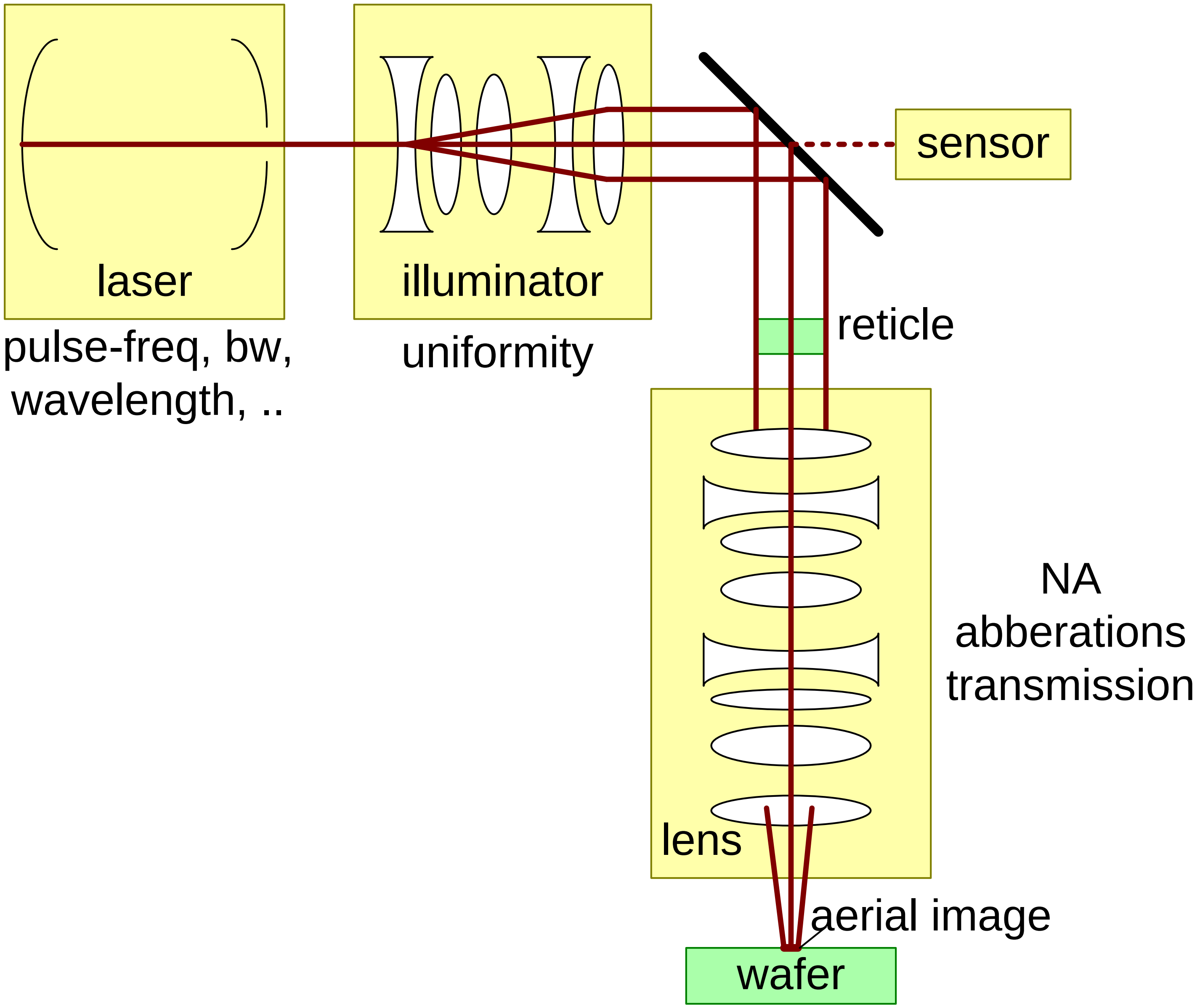
pre-alarm mode

alarm handled

acknowledge

alarm mode

Flow of Light (Physics)



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TSAITphysicsView

Dynamic Behavior is Multi-Dimensional

How does the system work and operate?

Functions describe *what* rather than *how.*

Functions are *verbs*.

Input-Process-Output paradigm.

Multiple kinds of flows:

- physical (e.g. hydrocarbons, goods, energy)
- information (e.g. measurements, signals)
- control

Time, events, cause and effect

Concurrency, synchronization, communication

multi-dimensional information and dynamic behavior

Systems Engineering Fundamentals Partitioning and Interfaces

by *Gerrit Muller* University of South-Eastern Norway-NISE
e-mail: `gaudisite@gmail.com`
`www.gaudisite.nl`

Abstract

The presentation explains fundamental concepts of and approach to system partitioning .

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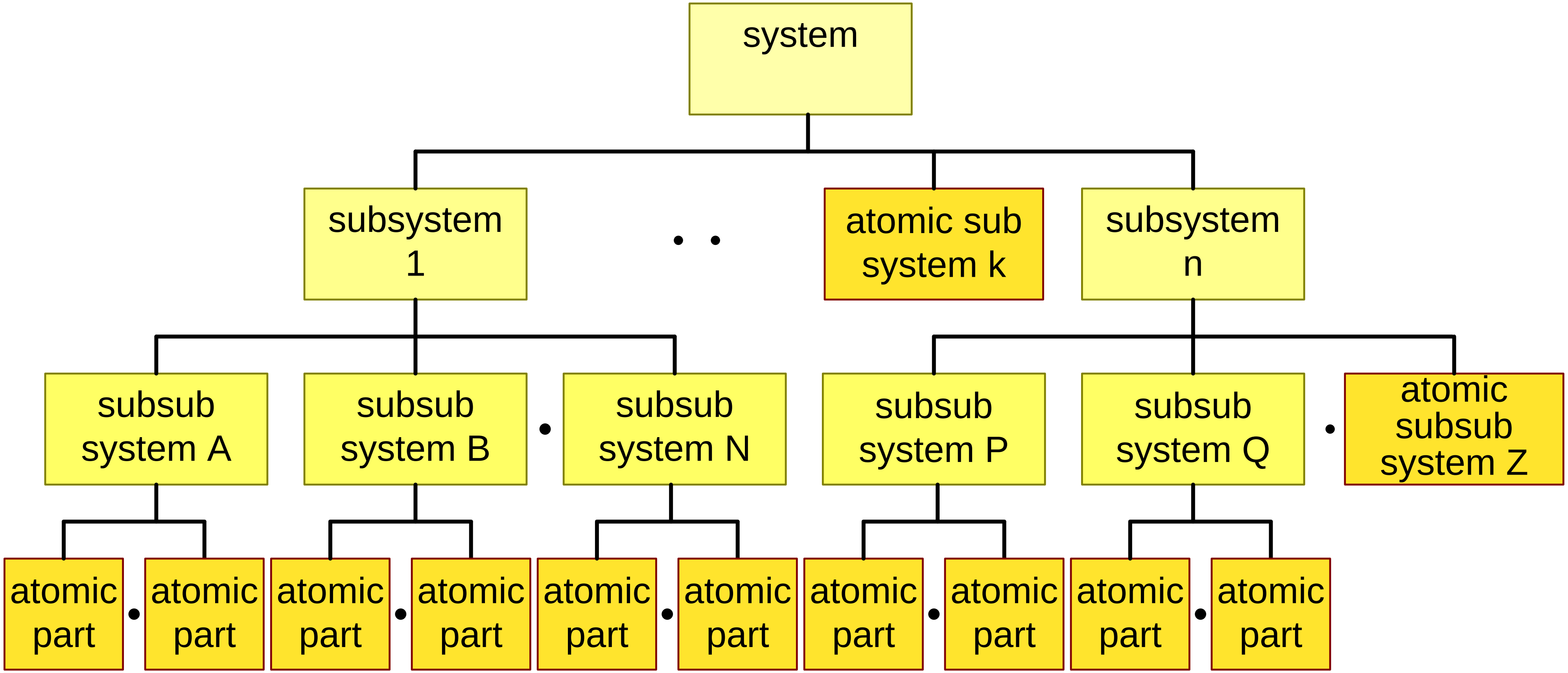
version: 0

logo
TBD

Partitioning is Applied Recursively



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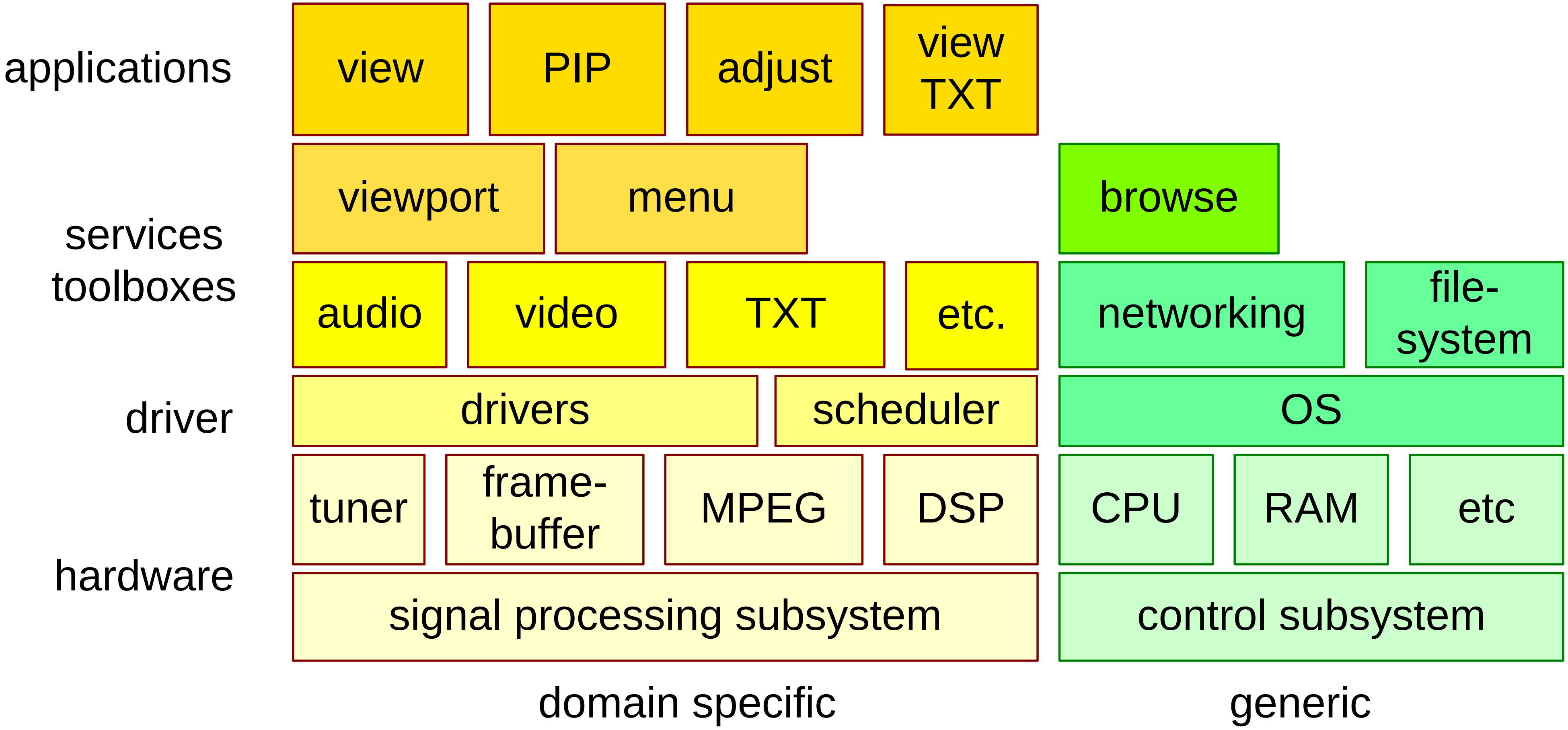
November 18, 2023
SPFrecursion

Software plus Hardware Decomposition


applications

services toolboxes

driver

hardware

view

PIP

adjust

view TXT

viewport

menu

browse

audio

video

TXT

etc.

networking

file-system

drivers

scheduler

OS

tuner

frame-buffer

MPEG

DSP

CPU

RAM

etc

signal processing subsystem

control subsystem

domain specific

generic

Guidelines for Partitioning

the part is cohesive

functionality and technology belongs together

the coupling with other parts is minimal

minimize interfaces

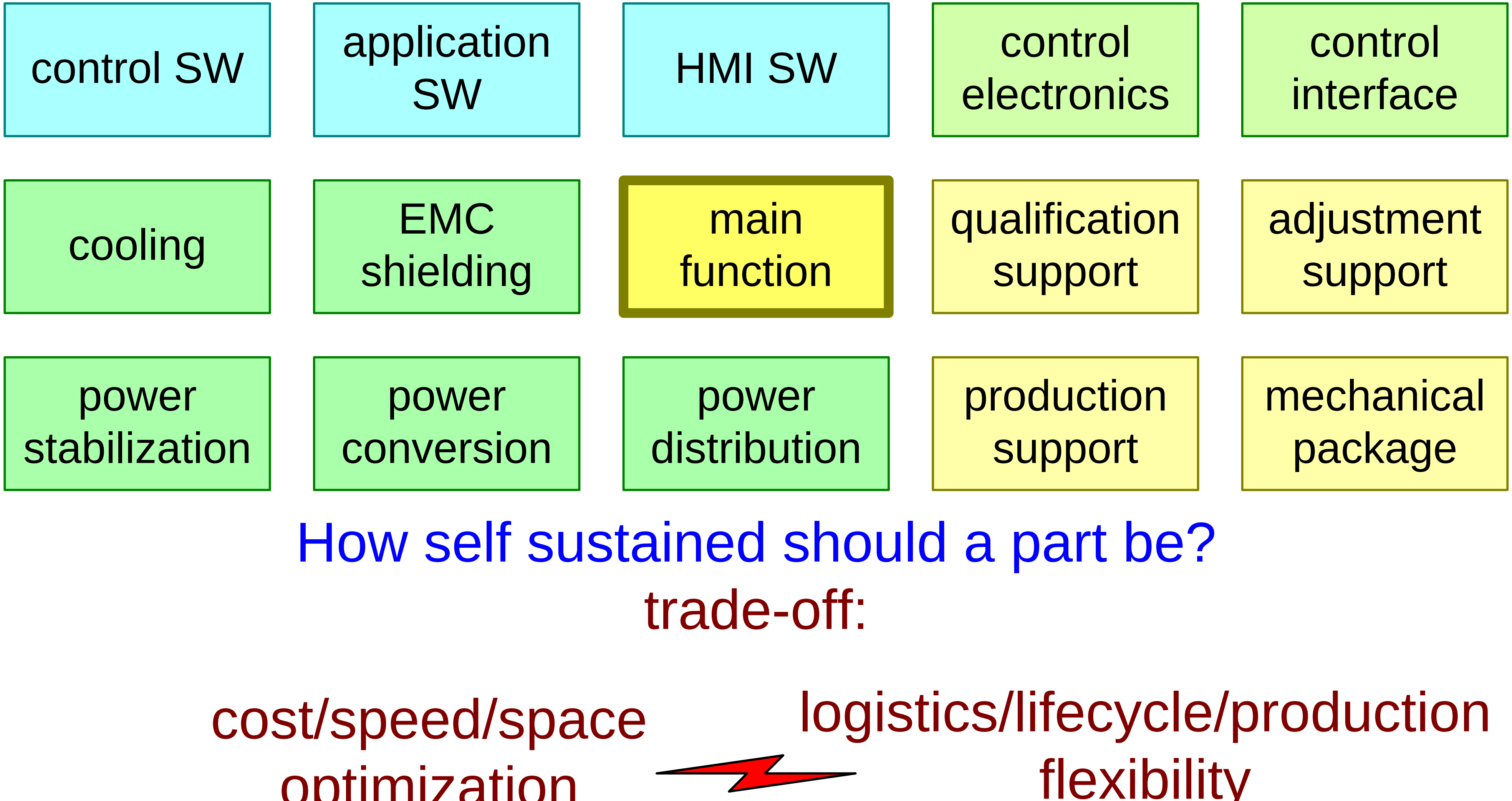
the part is selfsustained for production and qualification

can be in conflict with cost or space requirements

clear ownership of part

e.g. one department or supplier

How much self-sustained?



control SW

application SW

HMI SW

control electronics

control interface

cooling

EMC shielding

main function

qualification support

adjustment support

power stabilization

power conversion

power distribution

production support

mechanical package

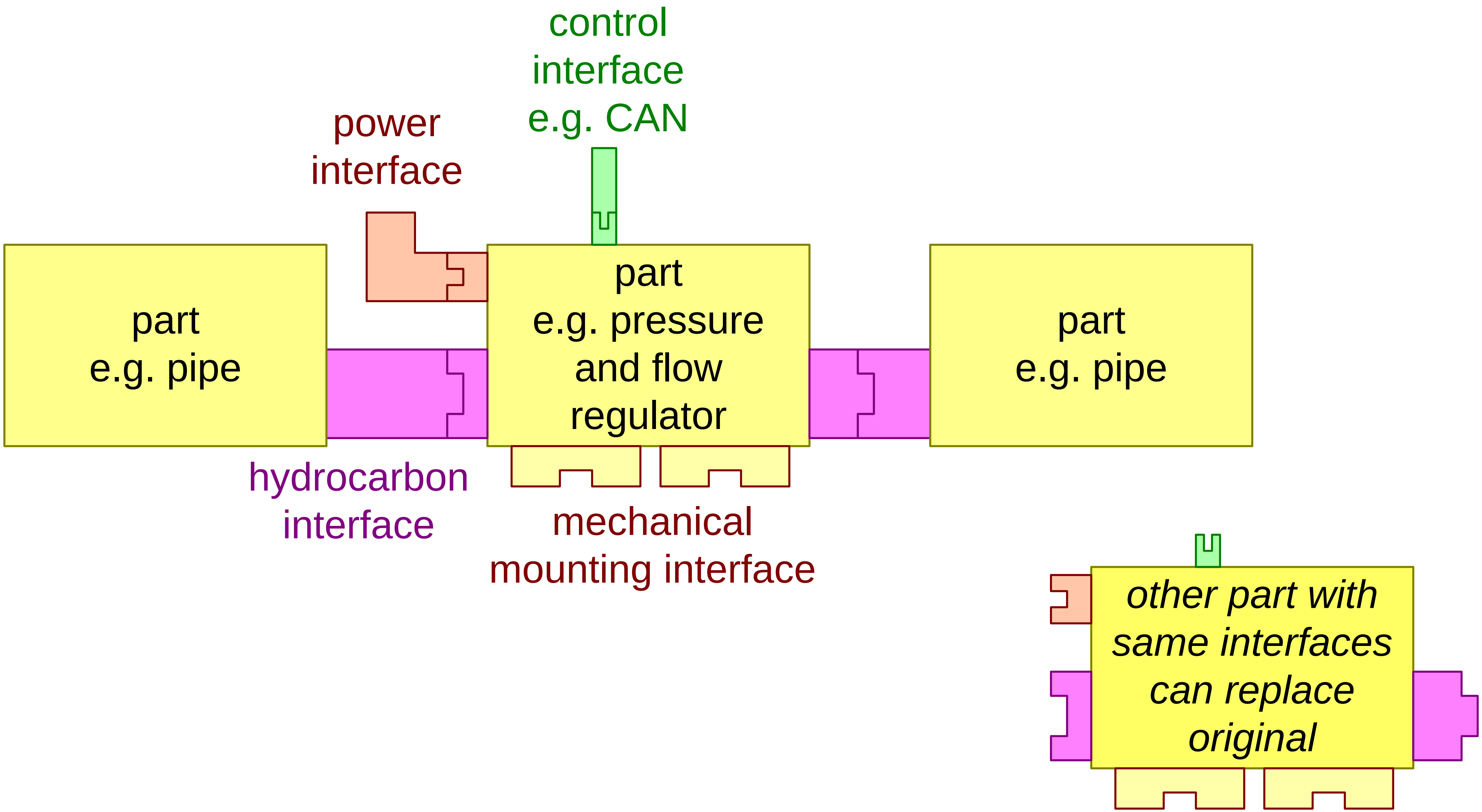
How self sustained should a part be?

trade-off:

cost/speed/space optimization

logistics/lifecycle/production flexibility clarity

Decoupling via Interfaces



The Ideal Modularity

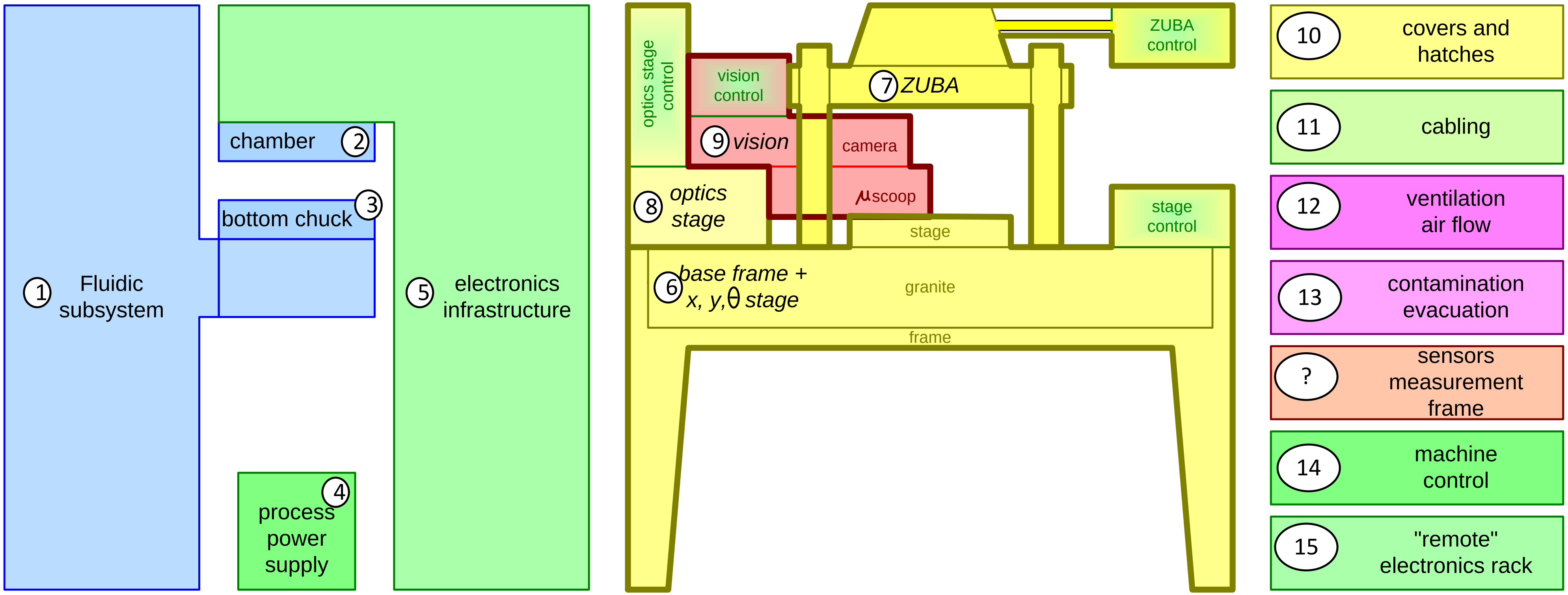
System is composed

by using standard interfaces

limited catalogue of variants (e.g. cost performance points)

version: 0
November 18, 2023
SPFmodularityGame

Example Physical Decomposition and Visualization

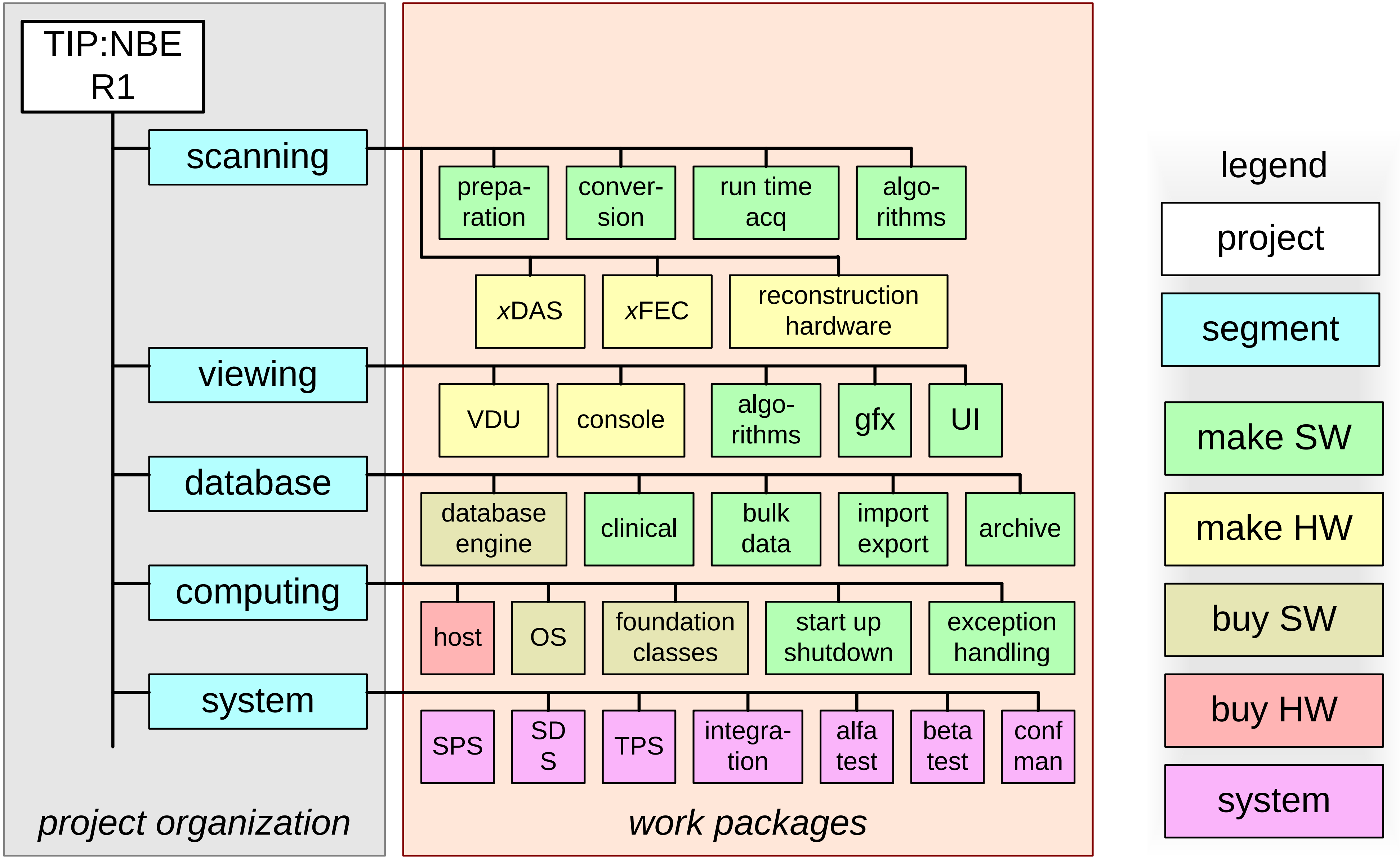


back side view

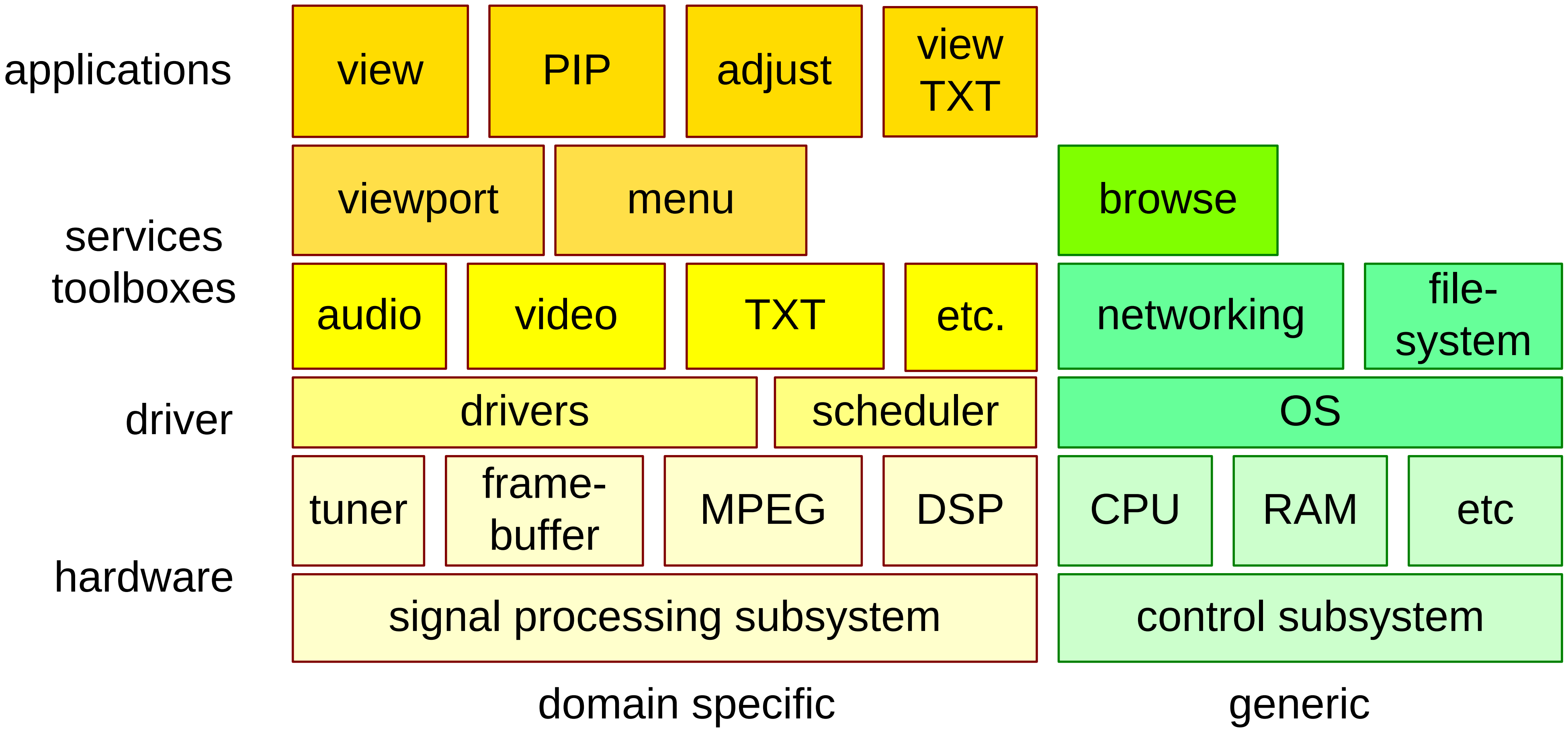
front side view

integrating

Example Work Breakdown Structure



Example SW plus HW Decomposition



version: 0
November 18, 2023
CVconstructionDecomposition

Systems Engineering Fundamentals Supply Chain and Logistics

by *Gerrit Muller* University of South-Eastern Norway-NISE
e-mail: `gaudisite@gmail.com`
`www.gaudisite.nl`

Abstract

The supply chain dominates the economic viability of systems. Developing a system and its business requires the design of the supply chain.

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version: 0

logo
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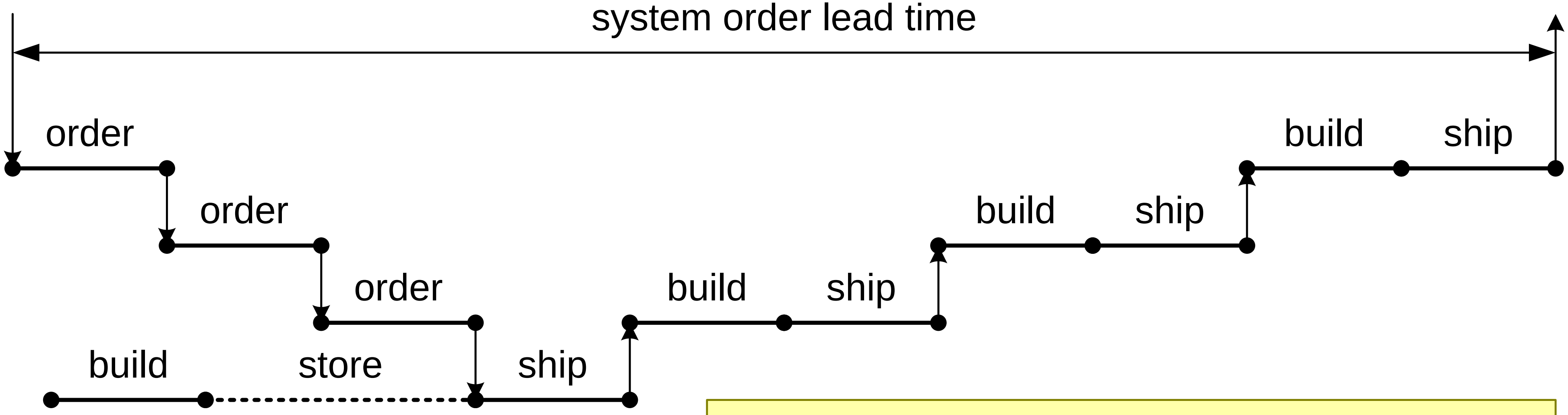
System Order Lead Time



for all systems, subsystems, modules, components, ...

Considerations for Designing the Supply Chain

- **Flow** of goods; stock = cost
- Produce Delivery Ratio < 1
  - Facilitate **demand-driven** goods flow.
  - Forecasting causes stocks and risks of obsolescence or underrun)
- **Risk** management
  - supplier dependency (2nd supplier policy)
- Production and service **life time**
- **Traceability** of configurations and versions

Systems Engineering Fundamentals Risk Management

by *Gerrit Muller* University of South-Eastern Norway-NISE
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`www.gaudisite.nl`

Abstract

Systems Engineering offers many methods and techniques to detect and mitigate risks. This presentaion touches upon methods like Failure Mode Effect Analysis, Hazard Analysis, etc. addressing related concerns such as reliability, safety, and security.

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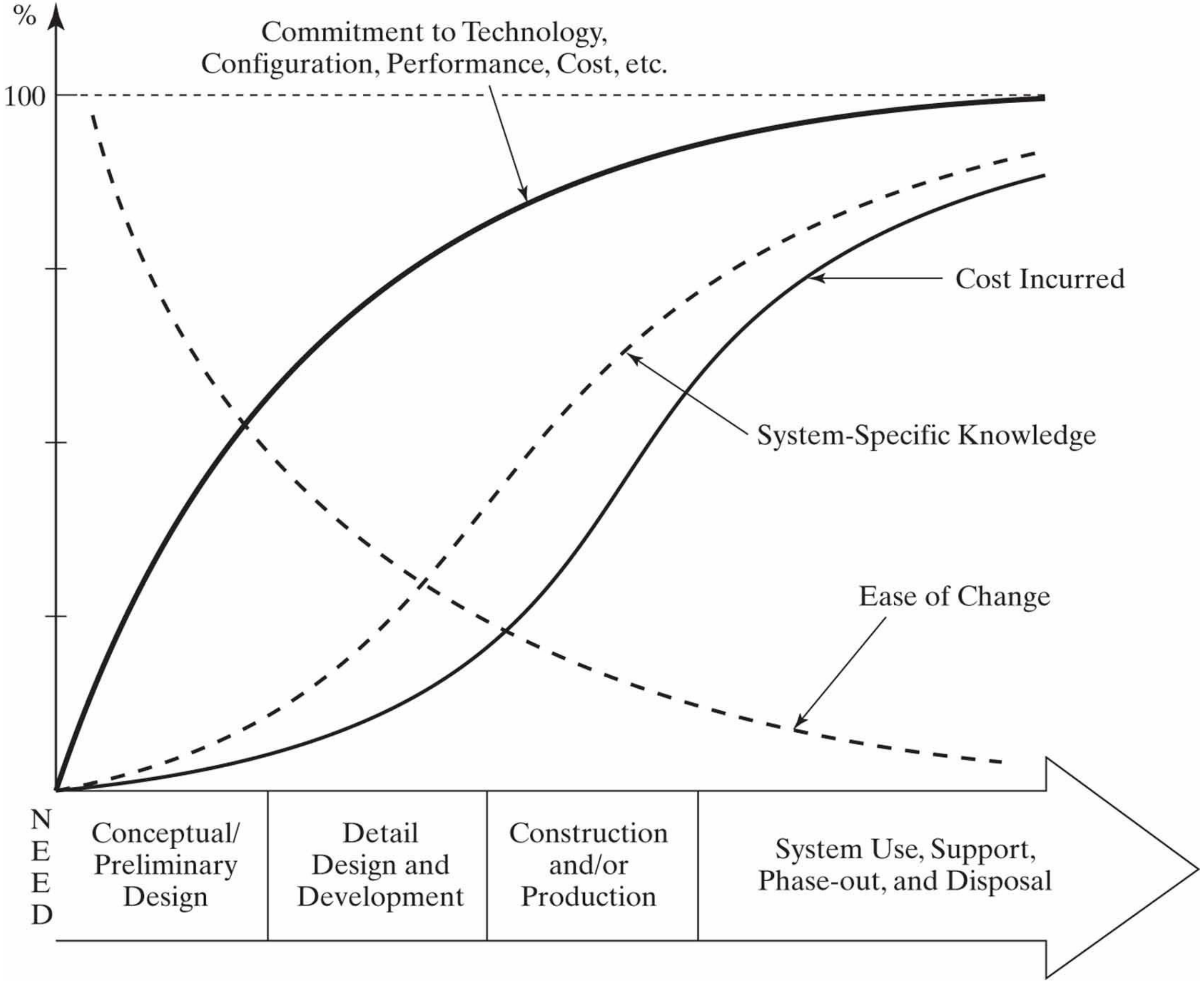
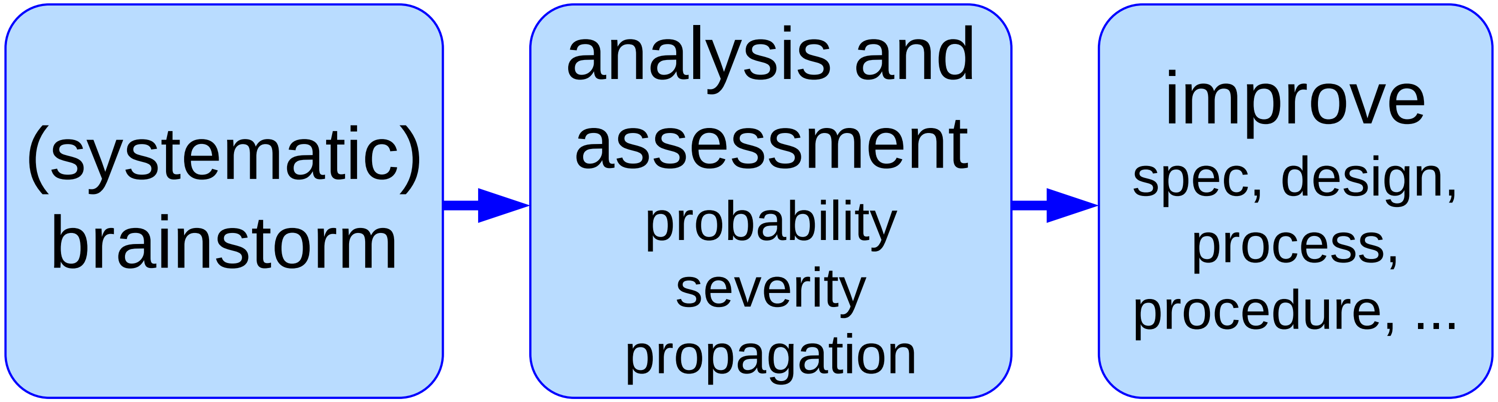
TBD

Life-cycle Commitment, Knowledge, and Incurred Cost

Systems Engineering and Analysis, Fifth Edition
Benjamin S. Blanchard • Wolter J. Fabrycky
Copyright ©2011, ©2006, ©1998 by Pearson Education, Inc.
Upper Saddle River, New Jersey 07458



FMEA-like Analysis Techniques



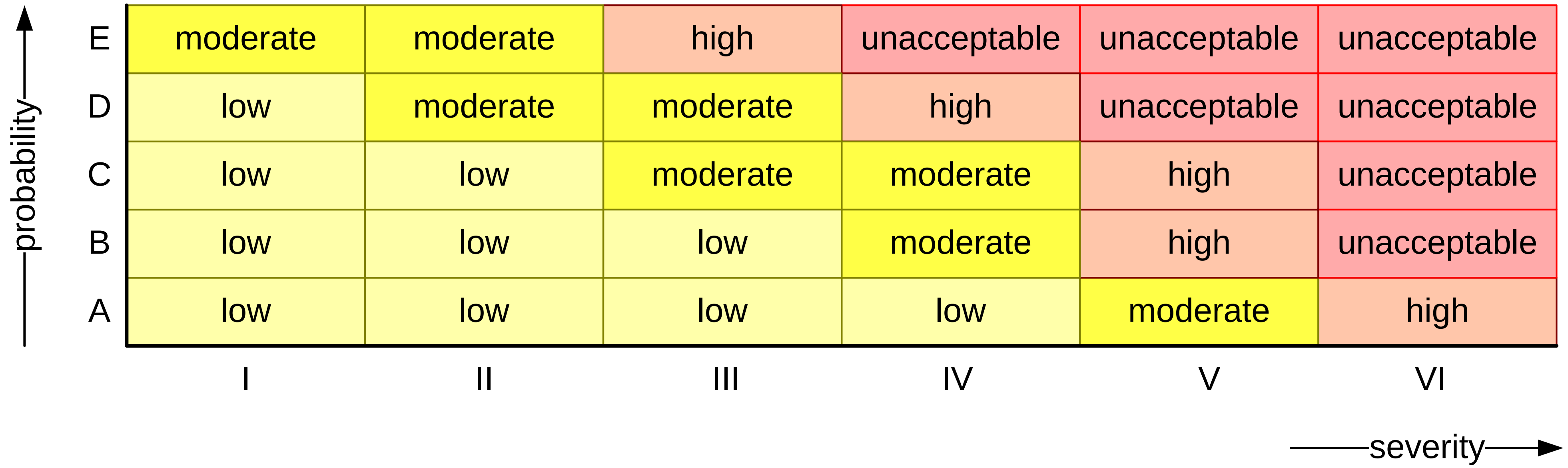
(systematic) brainstorm

analysis and assessment
probability
severity
propagation

improve
spec, design, process, procedure, ...

safety hazard analysis	potential hazards	damage	measures
reliability FMEA	failure modes exceptional cases	effects	measures
security	vulnerability risks	consequences	measures
maintainability	change cases	impact, effort, time	decisions
performance	worst cases	system behavior	decisions

Severity-Probability Classification Matrix



E	moderate	moderate	high	unacceptable	unacceptable	unacceptable
D	low	moderate	moderate	high	unacceptable	unacceptable
C	low	low	moderate	moderate	high	unacceptable
B	low	low	low	moderate	high	unacceptable
A	low	low	low	low	moderate	high
	I	II	III	IV	V	VI

based on https://en.wikipedia.org/wiki/Failure_mode_and_effects_analysis

version: 0
November 18, 2023
SEFRMmatrix

Mastering Systems Integration; Readiness Levels

by *Gerrit Muller* TNO-ESI, University of South-Eastern Norway]
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Abstract

Readiness level models offer a yardstick to assess the status of specific project aspects. Examples are technology readiness and integration readiness.

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logo
TBD

Technology Readiness Levels

TRL 9	actual system proven in operational environment
TRL 8	system complete and qualified
TRL 7	system prototype demonstration in operational environment
TRL 6	technology demonstrated in relevant environment
TRL 5	technology validated in relevant environment
TRL 4	technology validated in lab
TRL 3	experimental proof of concept
TRL 2	technology concept formulated
TRL 1	basic principles observed

after: https://serkanbolat.com/2014/11/03/technology-readiness-level-trl-math-for-innovative-smes/

Integration Readiness Levels

TRL 7	The integration of technologies has been ***verified and validated*** with sufficient detail to be actionable.
TRL 6	The integrating technologies can ***accept, translate, and structure information*** for its intended application.
TRL 5	There is sufficient ***control*** between technologies necessary to establish, manage, and terminate the integration.
TRL 4	There is sufficient detail in the ***quality and assurance*** of the integration between technologies.
TRL 3	There is ***compatibility*** (i.e. common language) between technologies to orderly and efficiently integrate and interact.
TRL 2	There is some level of specificity to characterize the ***interaction*** (i.e. ability to influence) between technologies through their interface.
TRL 1	An ***interface*** (i.e. physical connection) between technologies has been identified with sufficient detail to allow characterization of the relationship.

from: From TRL to SRL: The Concept of Systems Readiness Levels, CSER2006, by Sauser et al.

Mastering Systems Integration; Process and Positioning

by *Gerrit Muller*　TNO-ESI, University of South-Eastern Norway]
e-mail: `gaudisite@gmail.com`
`www.gaudisite.nl`

Abstract

This lesson positions systems integration as process in the development processes.

Distribution

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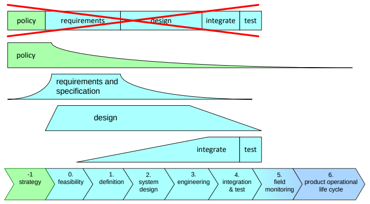
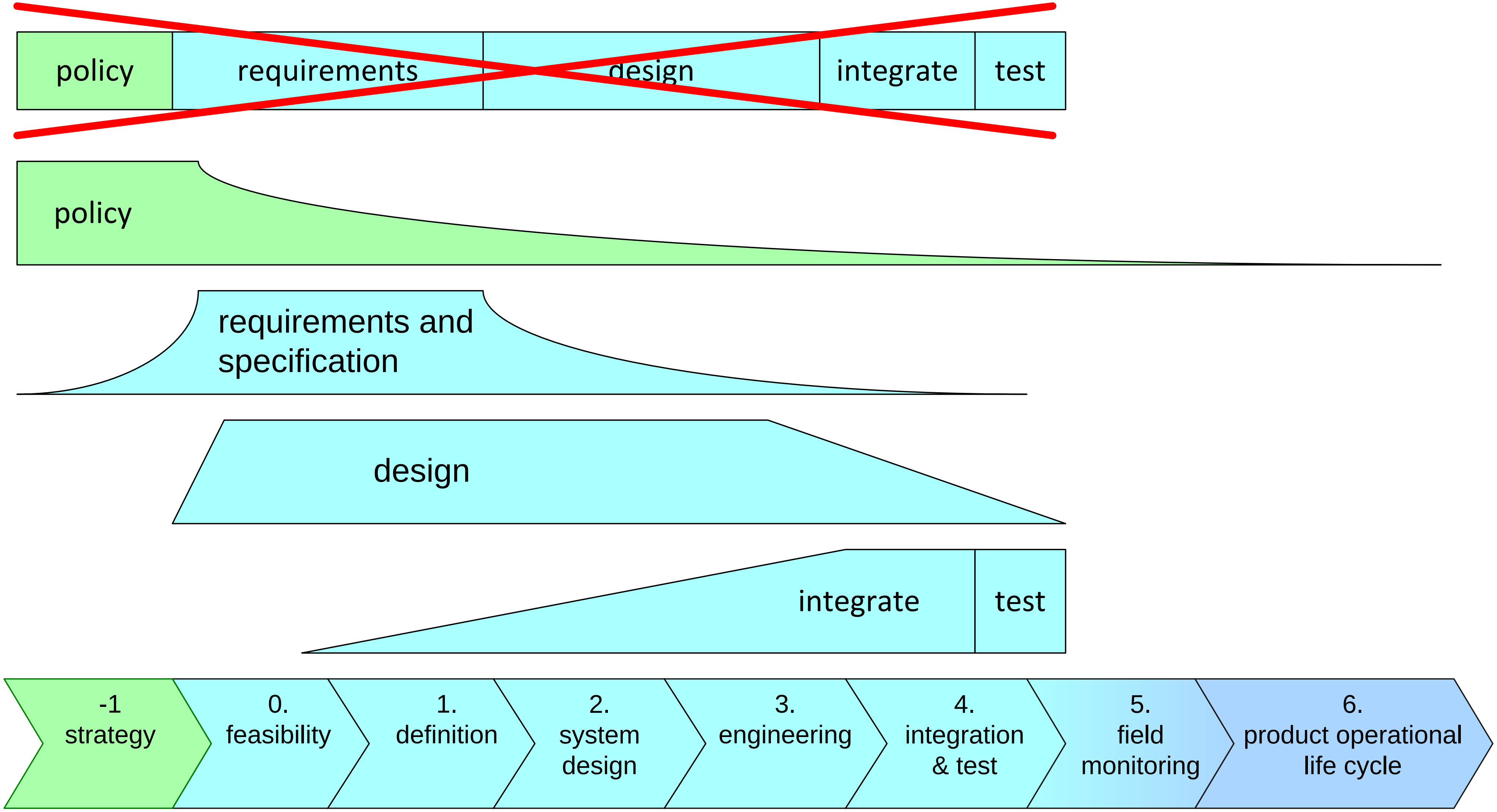
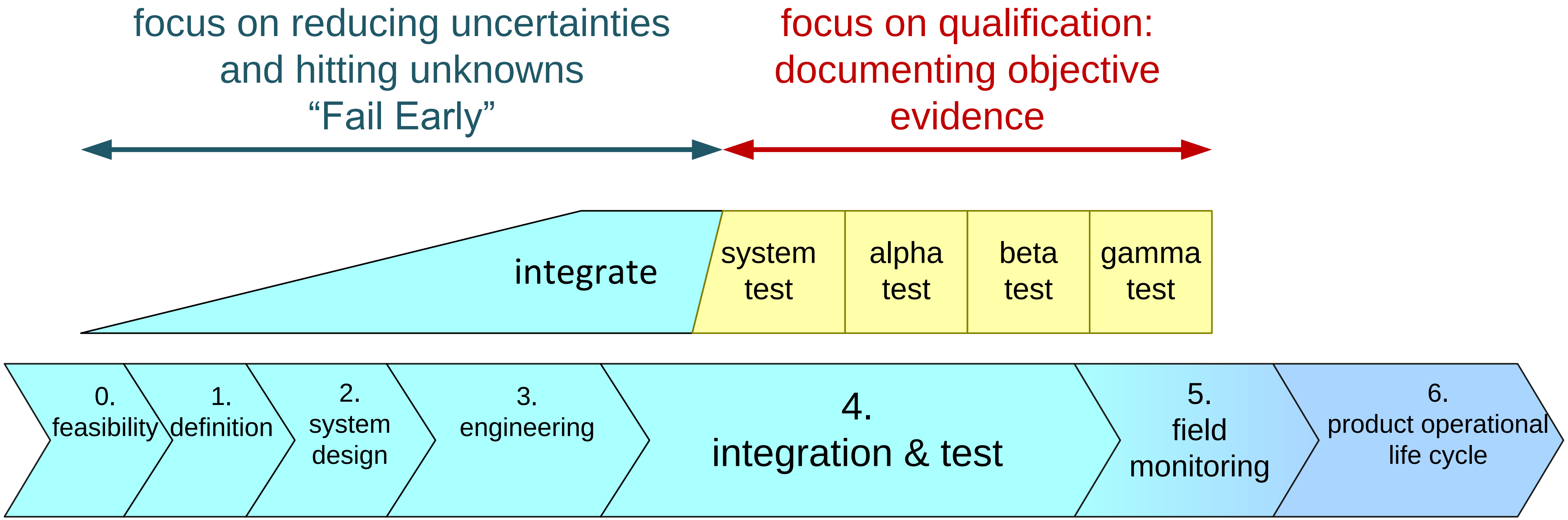
version: 0.3



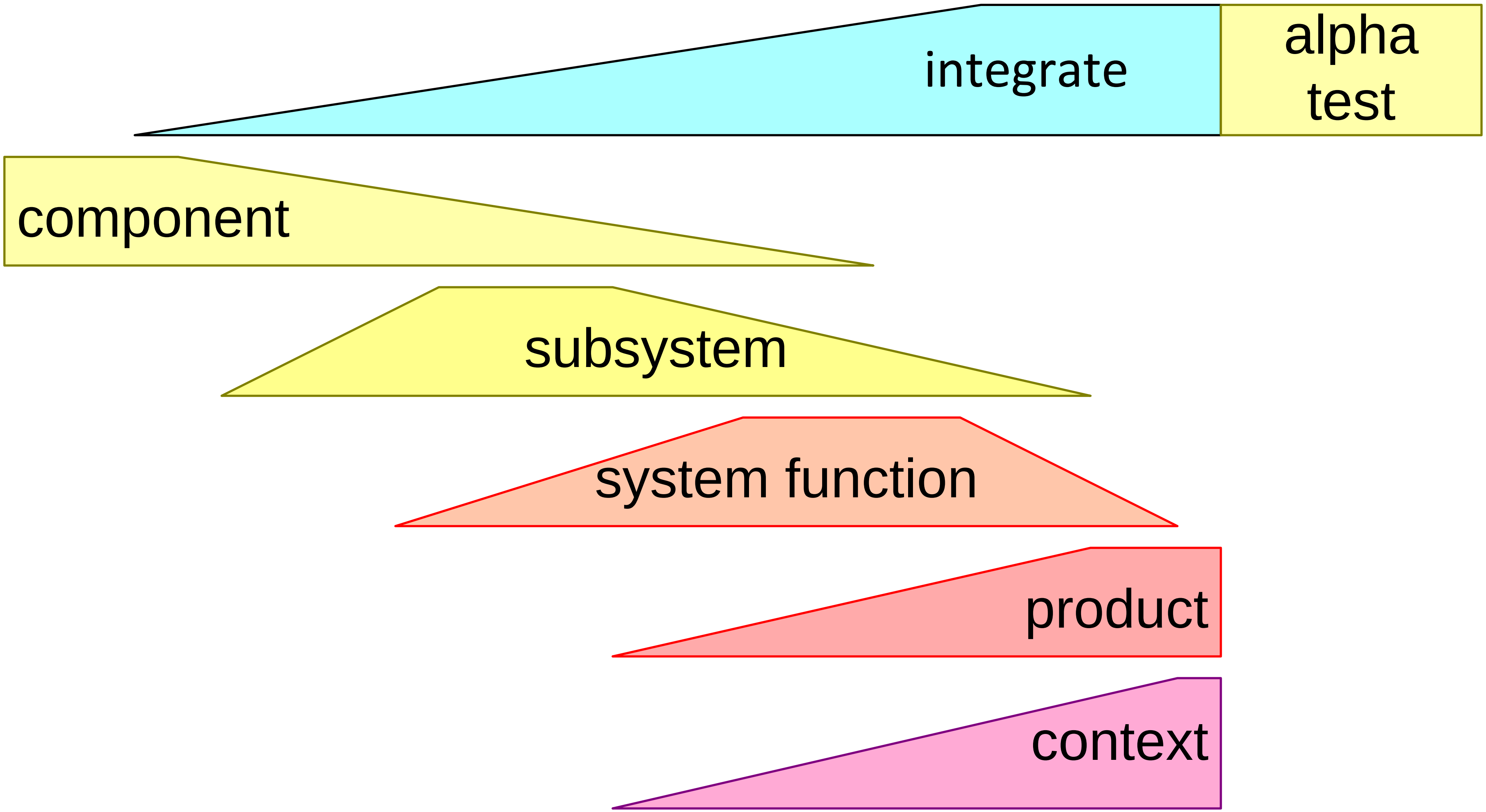
Typical Concurrent Product Creation Process



Zooming in on Integration and Tests



Integration Takes Place in a Bottom-up Fashion



version: 0.3
November 18, 2023
SINTlevels

Mastering Systems Integration; Integration Strategy

by *Gerrit Muller*   TNO-ESI, University of South-Eastern Norway]
e-mail: `gaudisite@gmail.com`
`www.gaudisite.nl`

Abstract

This presentations discusses the strategy for integration. The strategy is transformed into an approach to determine an integration sequence based on Key Performance Parameters and potential risks to achieve them.

Distribution

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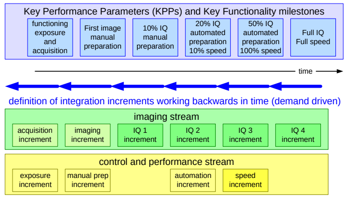
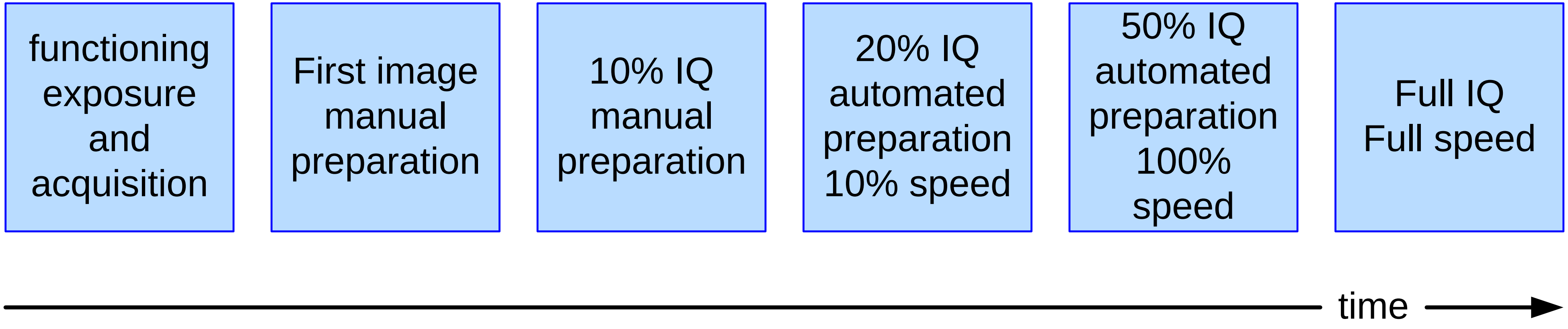
status: preliminary draft
version: 0.5



Integration Strategy

- Get Key Performance Parameters functioning ASAP
- Work on highest risks ASAP
- Use a pacing process (regular visible results)
    - with regular milestones
    - and increments in functionality and performance
- Merge constraints from test configurations, suppliers, resources, etc.

Pacing Milestones



functioning exposure and acquisition

First image manual preparation

10% IQ manual preparation

20% IQ automated preparation 10% speed

50% IQ automated preparation 100% speed

Full IQ Full speed

time

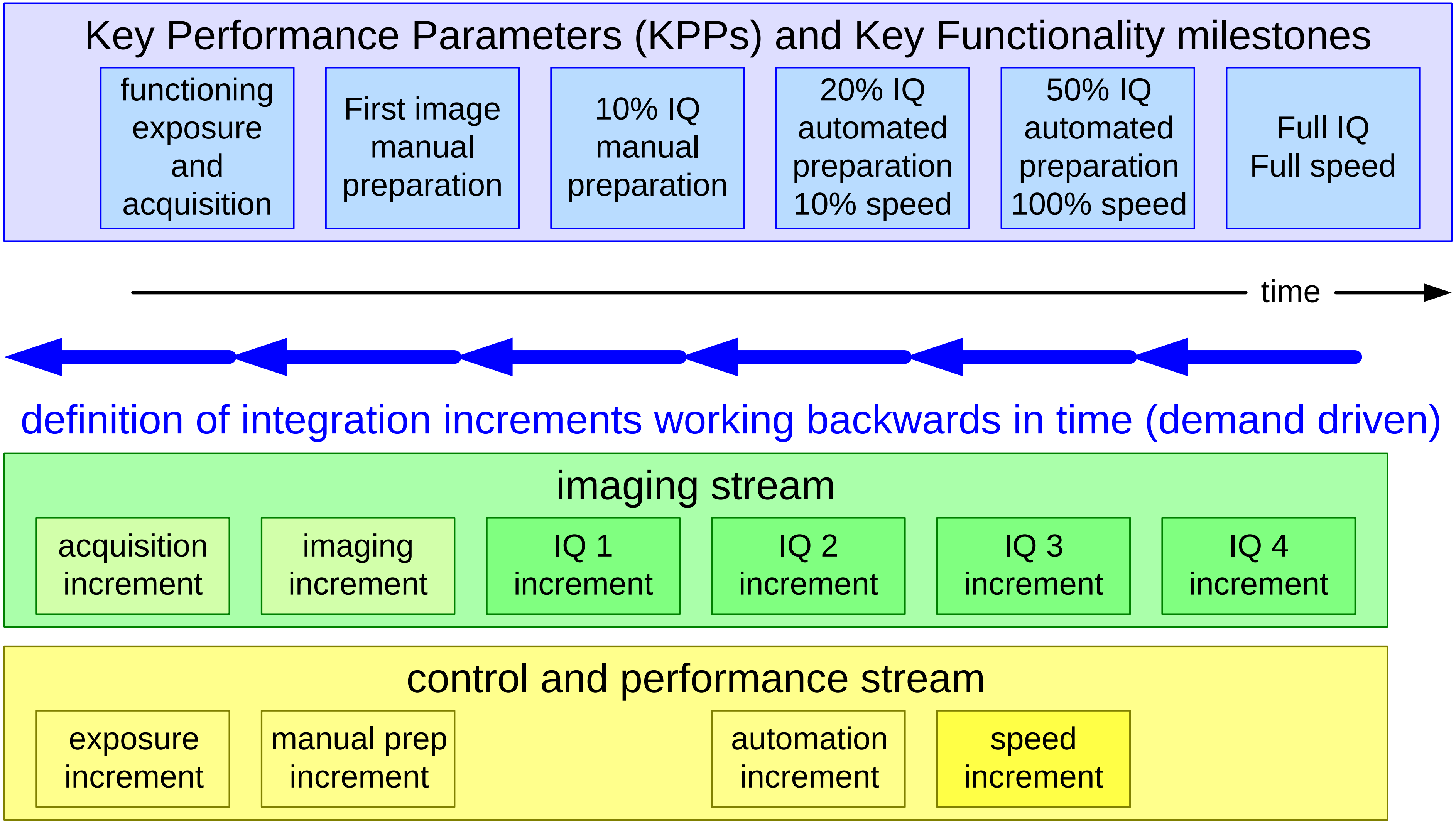
pacing:

maximum 6 month between milestones

depending on technology and domain

version: 0.5
November 18, 2023
MSIPMpacingMilestones

Defining an Integration Sequence in Increments



Key Performance Parameters (KPPs) and Key Functionality milestones

functioning exposure and acquisition

First image manual preparation

10% IQ manual preparation

20% IQ automated preparation 10% speed

50% IQ automated preparation 100% speed

Full IQ Full speed

time

definition of integration increments working backwards in time (demand driven)

imaging stream

acquisition increment

imaging increment

IQ 1 increment

IQ 2 increment

IQ 3 increment

IQ 4 increment

control and performance stream

exposure increment

manual prep increment

automation increment

speed increment

Stepwise Integration Approach

1	Determine most critical system performance parameters.
2	Identify subsystems and functions involved in these parameters.
3	Work towards integration configurations along these chains of subsystems and functions.
4	Show system performance parameter as early as possible; start with showing "typical" system performance.
5	Show "worst-case" and "boundary" system performance.
6	Rework manual integration tests in steps into automated regression tests.
7	Monitor regression results with human-driven analysis.
8	Integrate the chains: show system performance of different parameters simultaneously on the same system.

Mastering Systems Integration; Project Management

by *Gerrit Muller* TNO-ESI, University of South-Eastern Norway]
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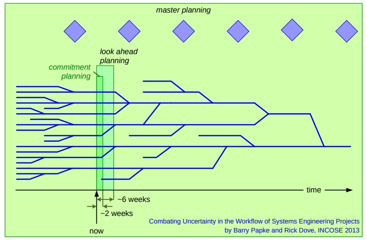
`www.gaudisite.nl`

Abstract

Systems Integration requires specific project management. The challenge for project managers is to plan ahead, knowing that the integration plan will need continuous adaptations.

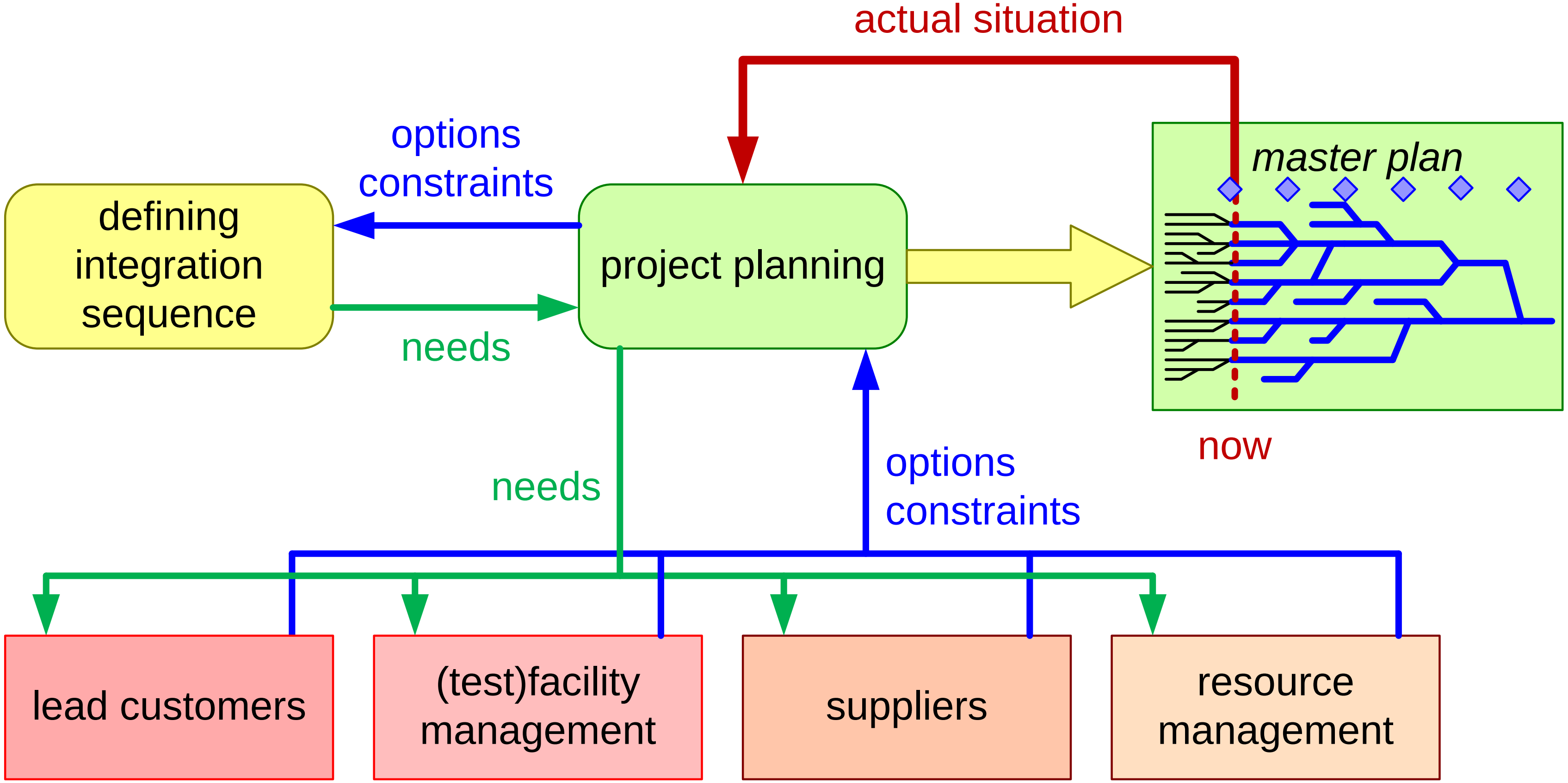
Distribution

November 18, 2023
status: preliminary draft
version: 0.6

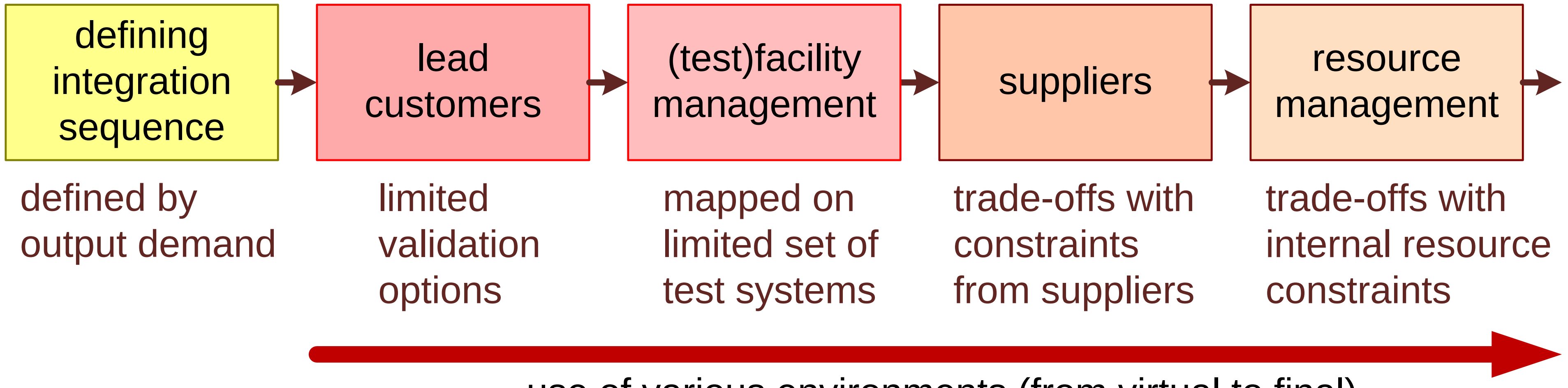


Combating Uncertainty in the Workflow of Systems Engineering Projects
by Barry Papke and Rick Dove, INCOSE 2013

Integration Planning



Demand Driven, Fitting Constraints



defining integration sequence

lead customers

(test)facility management

suppliers

resource management

defined by output demand

limited validation options

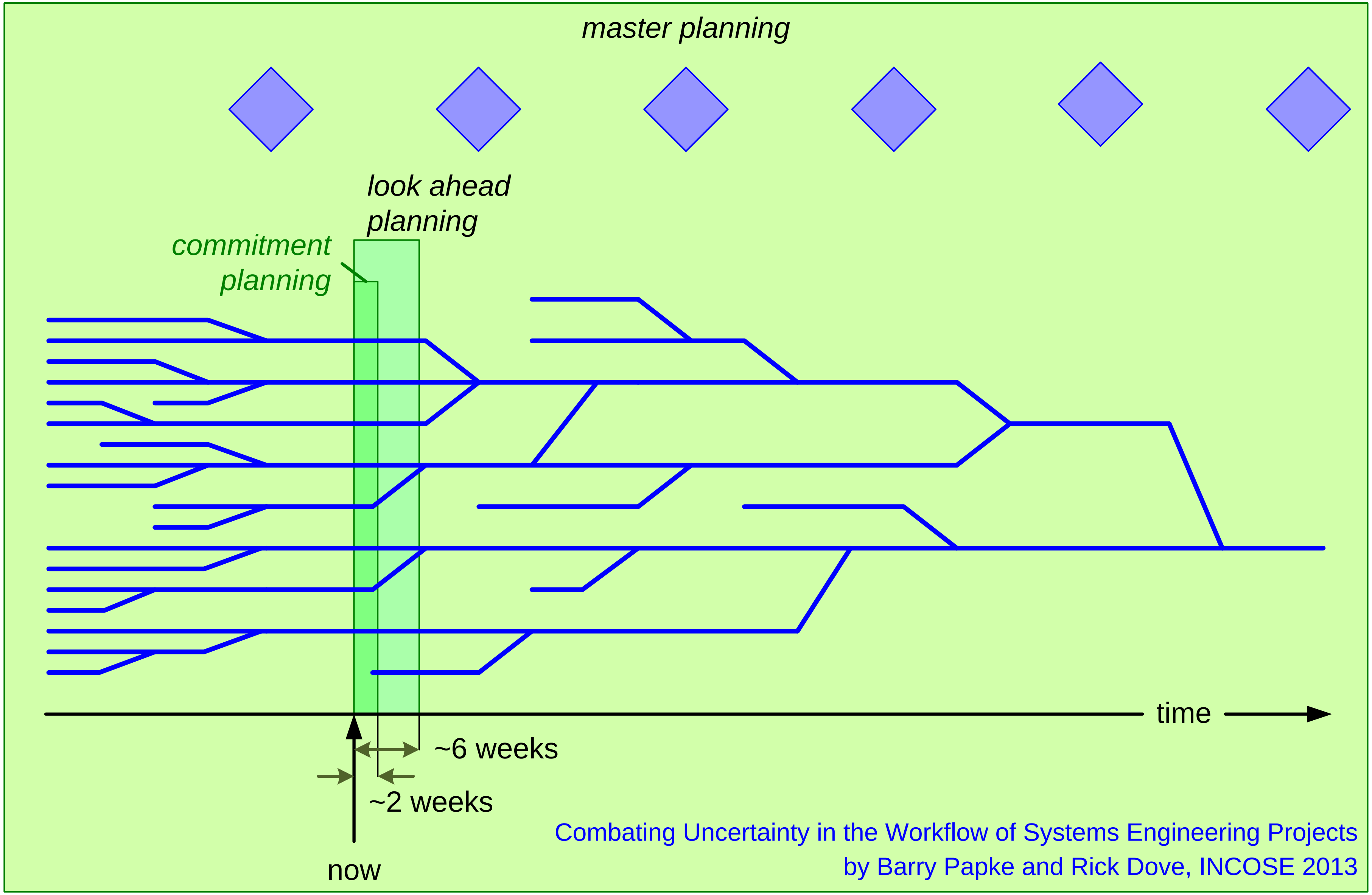
mapped on limited set of test systems

trade-offs with constraints from suppliers

trade-offs with internal resource constraints

use of various environments (from virtual to final)
reordering of integration sequence

Last Planner; Look Ahead!



Combating Uncertainty in the Workflow of Systems Engineering Projects
by Barry Papke and Rick Dove, INCOSE 2013

Mastering Systems Integration; Terminology

by *Gerrit Muller*   TNO-ESI, University of South-Eastern Norway]
e-mail: `gaudisite@gmail.com`
`www.gaudisite.nl`

Abstract

This presentation defines terms, which are used in relation to systems integration, such as validation, verification, qualification, evidence, approval process, certification, and acceptance.

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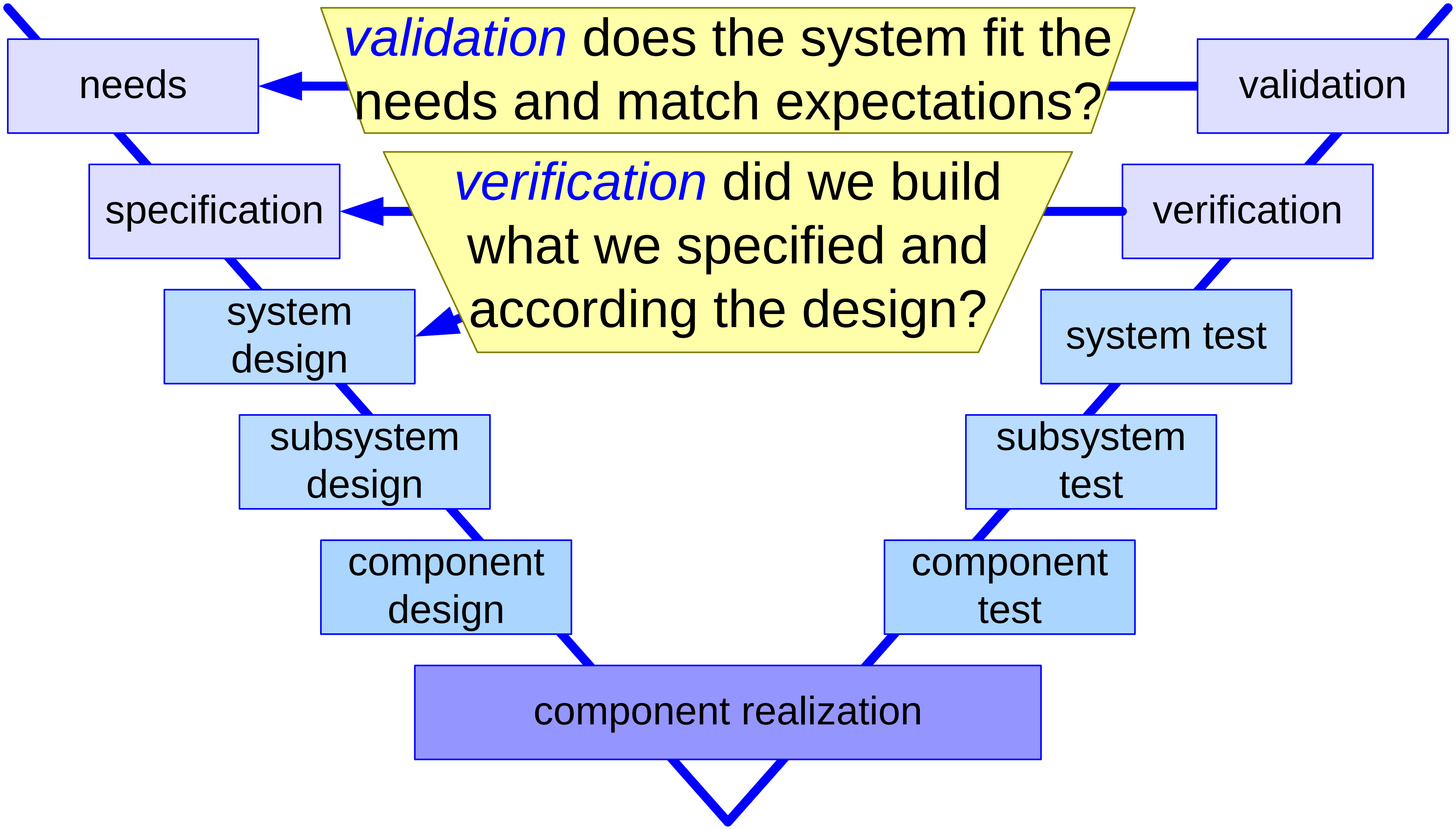
version: 0

logo
TBD

Validation and Verification in the V-model



validation does the system fit the needs and match expectations?

verification did we build what we specified and according the design?

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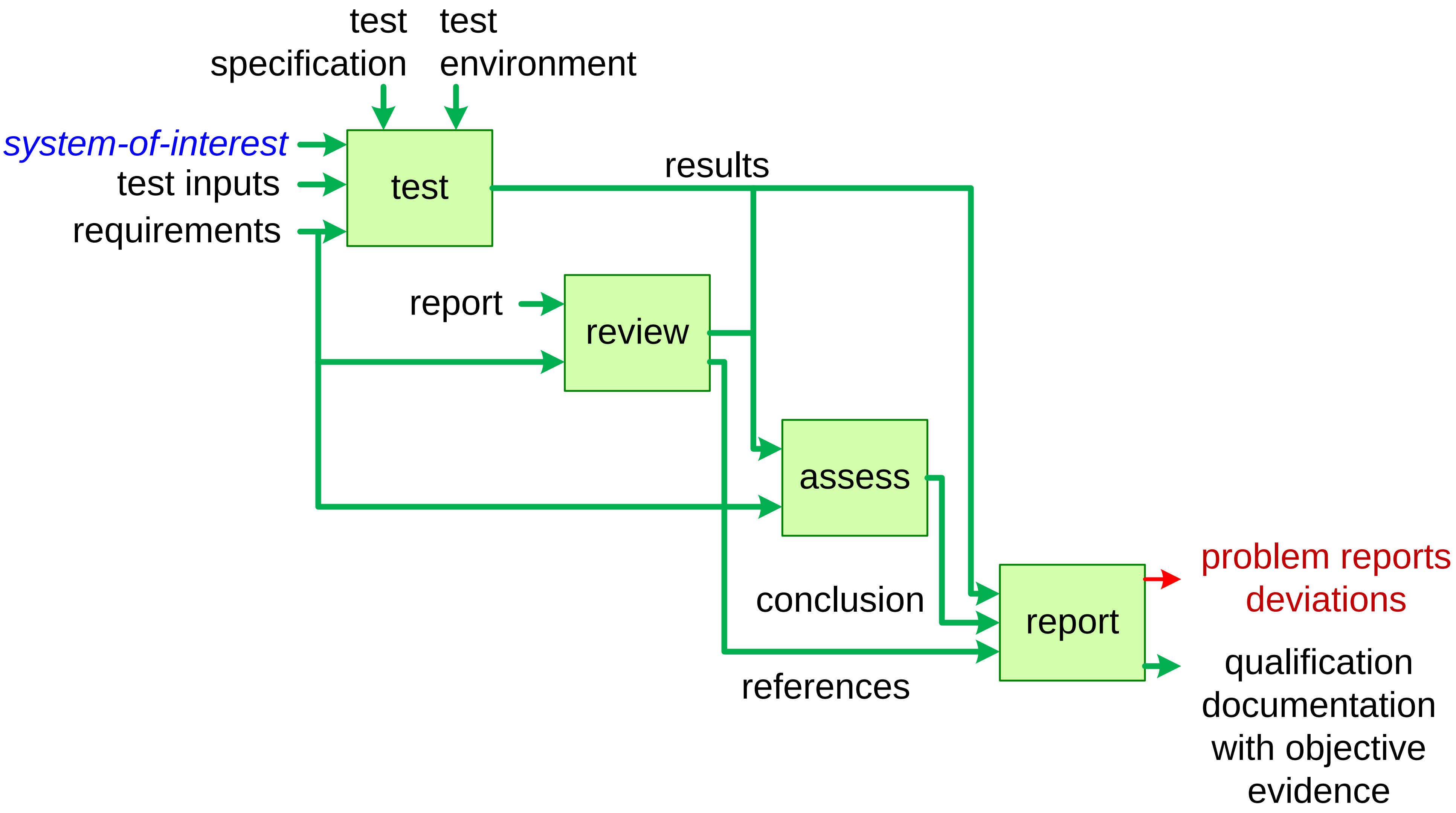
VVTvModel

Functional Model of Verification



test specification

test environment

system-of-interest

test inputs

requirements

test

results

report

review

assess

conclusion

references

report

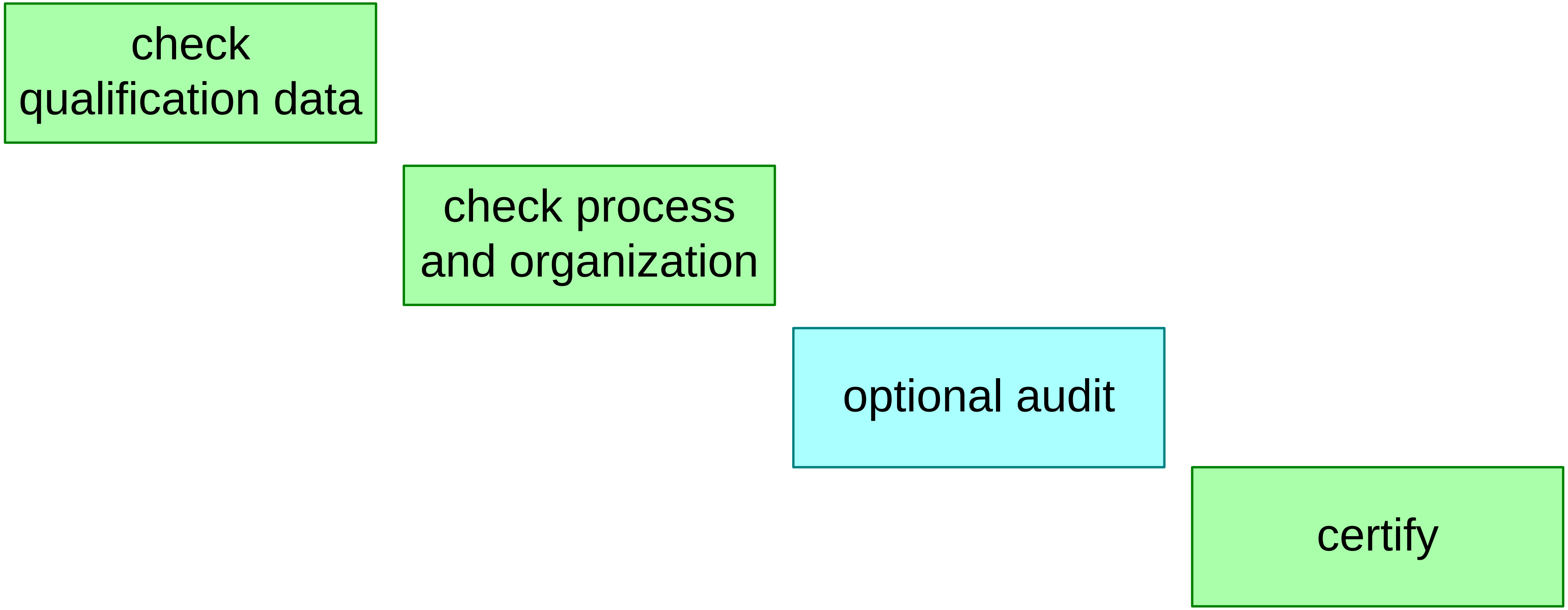
problem reports deviations

qualification documentation with objective evidence

Certification

Certification: an independent agency (e.g. DNV-GL) certifies the quality of the system-of-interest, technology, or process

Self-certification: the company has been accredited by the agency to do the certification themselves.



check qualification data

check process and organization

optional audit

certify

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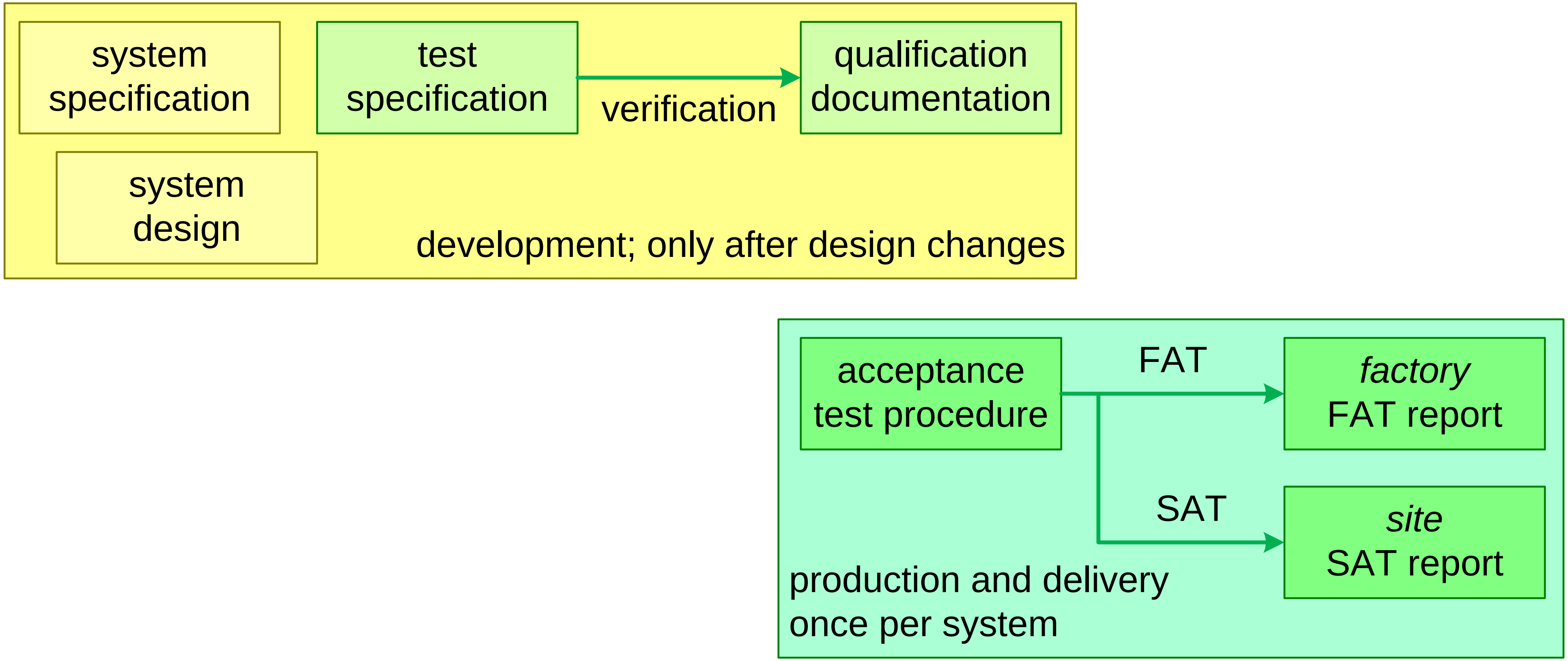
November 18, 2023
VVTcertification

Development and (repeated) Production



version: 0
November 18, 2023
VVTproduction

Objective Evidence

From a business perspective: Objective evidence is “information based on facts that can be proved through analysis, measurement, observation, and other such means of research.”

From a legal perspective: Objective evidence is “real evidence, also known as demonstrative or objective evidence; this is naturally the most direct evidence.”

From a scientific perspective: “To be termed scientific, a method of inquiry must be based on gathering observable, empirical, and measurable evidence subject to specific principles of reasoning. A scientific method consists of the collection of data through observation and experimentation, and the formulation and testing of hypotheses.”

From a list of Plain English definitions related to the ISO 9000, 9001 and 9004: Objective evidence is “data that show or prove that something exists or is true. Objective evidence can be collected by performing observations, measurements, tests, or by using any other suitable method.”

from: Understanding Objective Evidence: (What ItIs and What It Definitely Is Not),
by Denise Dion http://www.eduquest.net/Advisories/EduQuest%20Advisory_ObjectiveEvidence.pdf

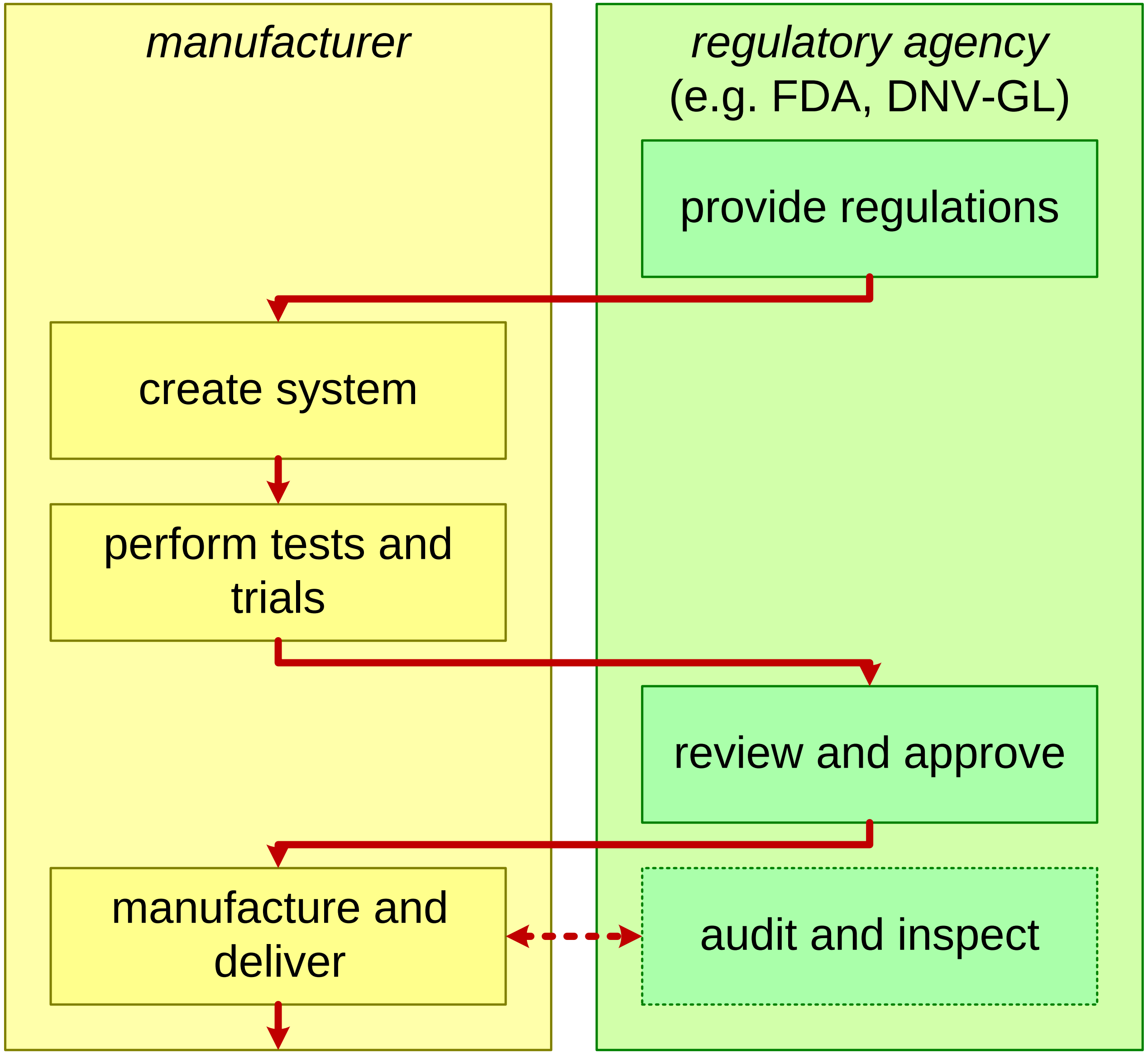
FDA Requirements for Objective Evidence

FDA is a science-based law enforcement agency and, therefore, requires answers that are scientifically and legally supported. FDA expects your objective data to answer the following questions:

- **Scientific** – Can the data be ***evaluated by independent observers*** to reach the same conclusions?
- **Scientific** – Are the data documented in a manner that ***allows re-creation of the data*** or the events described?
- **Scientific** – Does the documented evidence provide ***sufficient data*** to prove what happened, when, by whom, how, and why?
- **Legal** – Was the documentation ***completed concurrently*** with the tasks?
- **Legal** – Is the documentation ***attributable*** (directly traceable to a person)?
- **Legal** – Have the data and associated documentation been maintained in a manner that ***provides traceable evidence*** of changes, deletions, additions, substitutions, or alterations?
- **Legal** – Are the data and associated documentation maintained in a manner that ***protects and secures*** them from changes, deletions, additions, substitutions, or alterations?

from: Understanding Objective Evidence: (What It Is and What It Definitely Is Not),
by Denise Dion http://www.eduquest.net/Advisories/EduQuest%20Advisory_ObjectiveEvidence.pdf

Regulatory Approval Process



manufacturer

regulatory agency
(e.g. FDA, DNV-GL)

provide regulations

create system

perform tests and trials

review and approve

manufacture and deliver

audit and inspect

version: 0
November 18, 2023
MSITMapprovalProcess

Systems Engineering Deployment and Commissioning

by *Gerrit Muller* University of South-Eastern Norway-NISE
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`www.gaudisite.nl`

Abstract

Deployment covers all steps from receiving shipped components to getting the system live and operating the system in its operational context.

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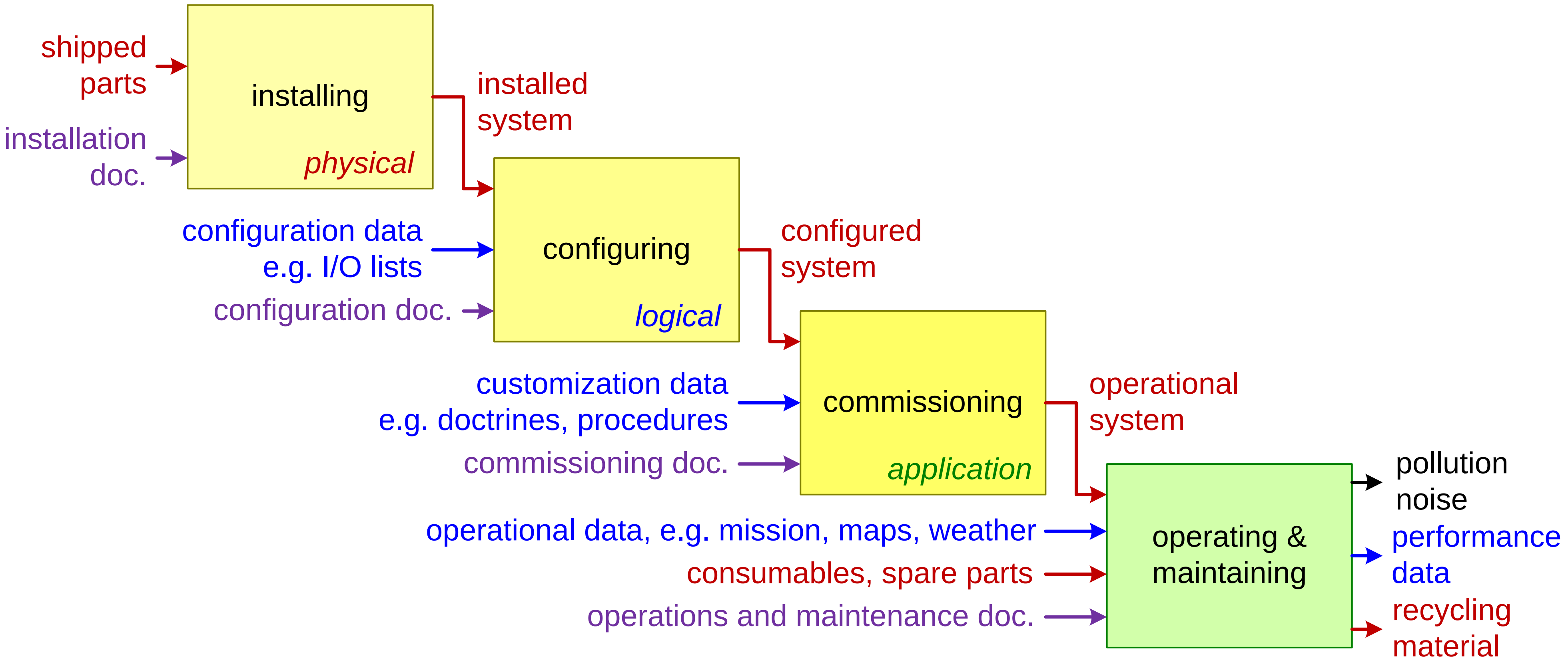
status: planned
version: 0

logo
TBD

Deployment Workflow



shipped parts

installation doc.

installing

physical

installed system

configuration data e.g. I/O lists

configuration doc.

configuring

logical

configured system

customization data e.g. doctrines, procedures

commissioning doc.

commissioning

application

operational system

operational data, e.g. mission, maps, weather

consumables, spare parts

operations and maintenance doc.

operating & maintaining

pollution noise

performance data

recycling material

version: 0
November 18, 2023
SEFDCworkflow