Bachelor Course Systems Engineering: Architectural Reasoning

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Abstract

This is a course for bachelor students in their second year of their engineering study. The focus is on architectural reasoning: an agile architecting approach. The students also get a more traditional course in systems engineering following the V-model.

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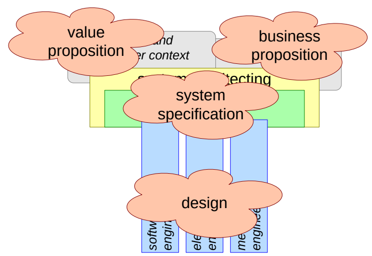
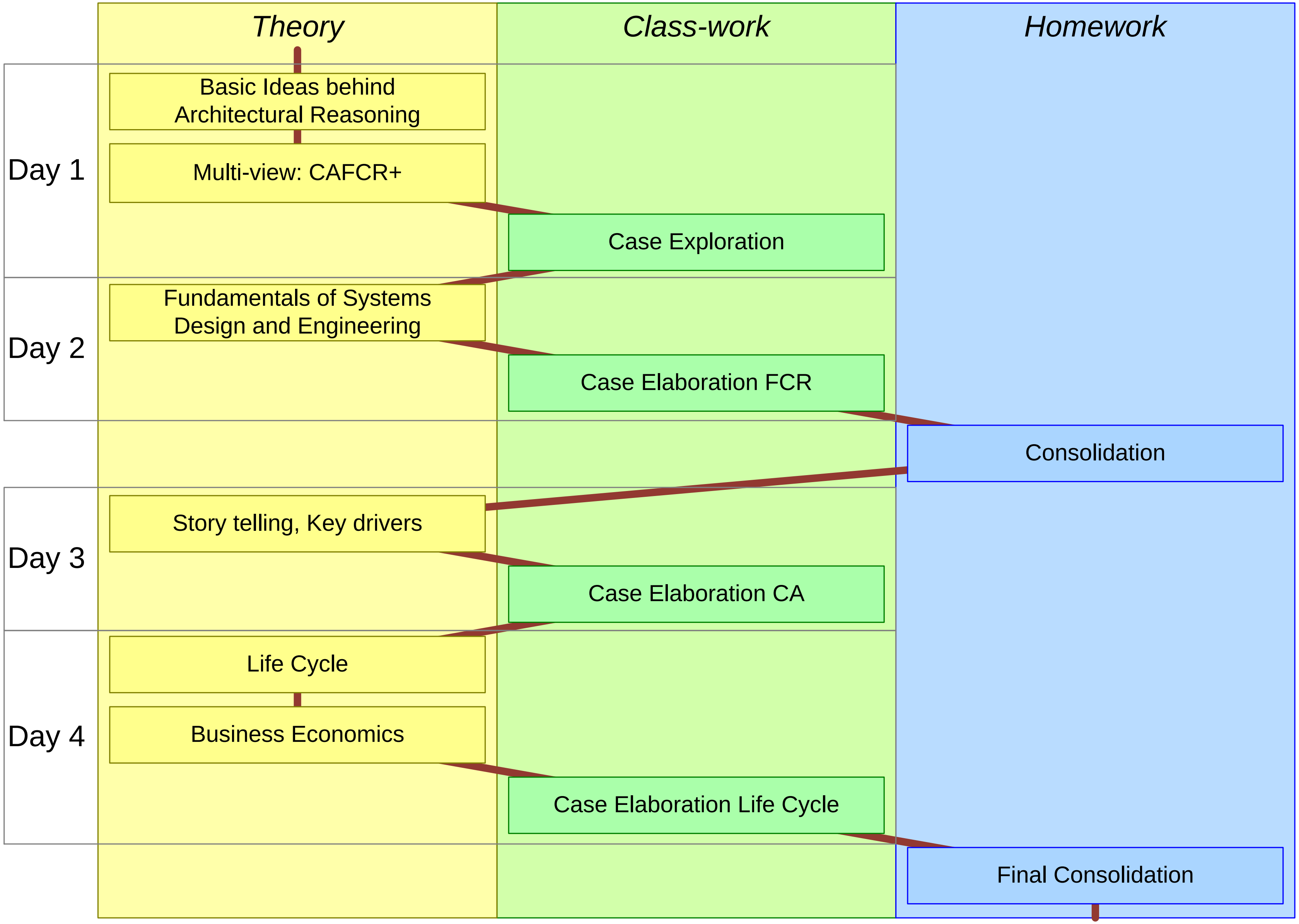


Course Program Architectural Reasoning



Objectives of Module Architectural Reasoning: Awareness

Make engineering students aware of:

- other disciplines
- “systems” design and engineering
- customers and life cycle as contexts of the system
- the impact of needs on design decisions

Objectives of Module Architectural Reasoning: Experience

Let engineering students apply and experience:

- multiple views
- visualizations
- simplification
- iteration
- quantification

See Homework Presentation

Bachelor Course Systems Engineering: Architectural Reasoning; Homework

http://www.gaudisite.nl/BachelorSEhomeworkSlides.pdf

Theory Block: The Basic Ideas behind Architectural Reasoning

We are going to stretch you!

from mono engineer

to systems engineer

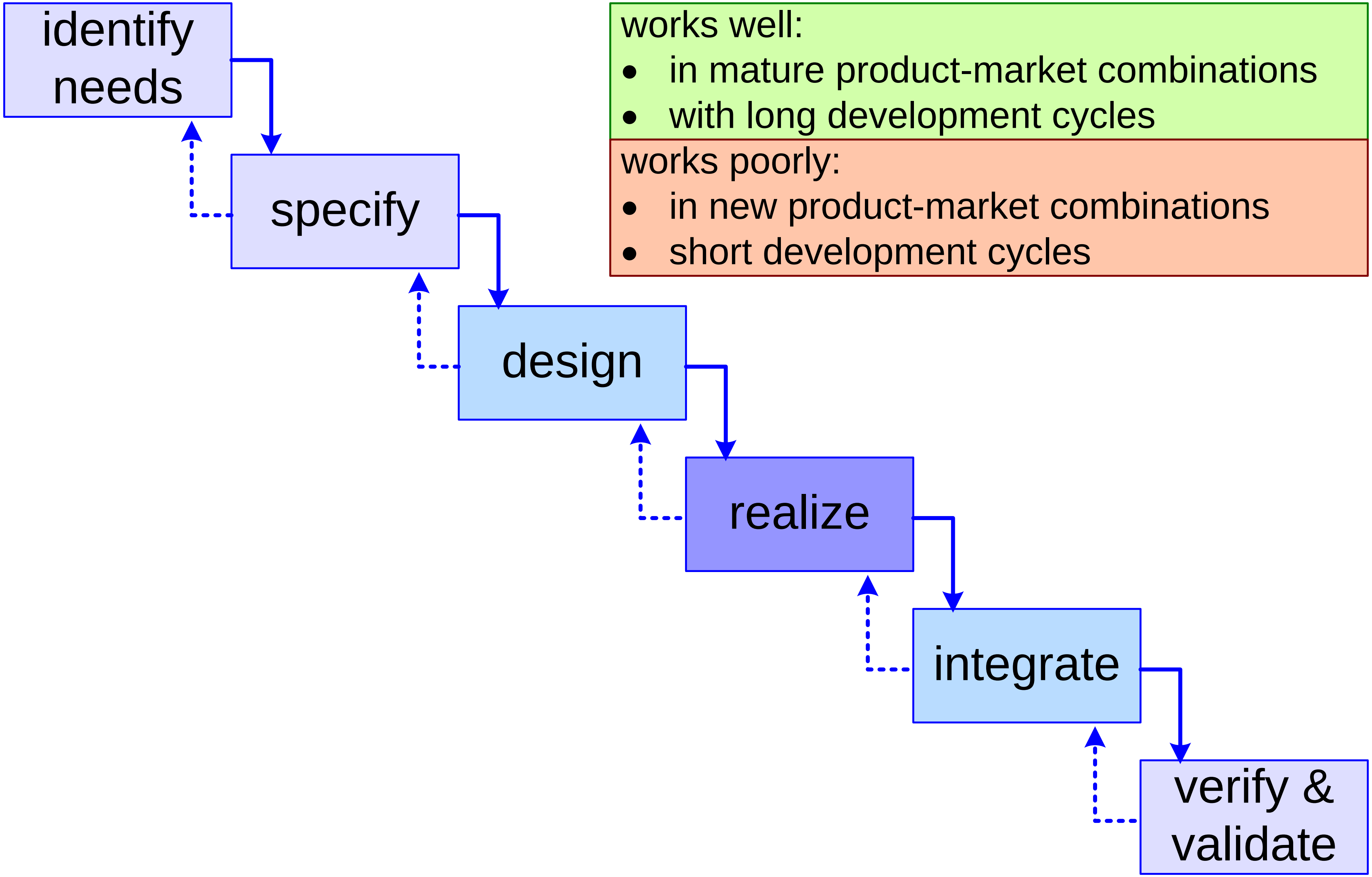
to architect

Why Chaotic?

Why so chaotic?

Why not follow
top-down SE process?

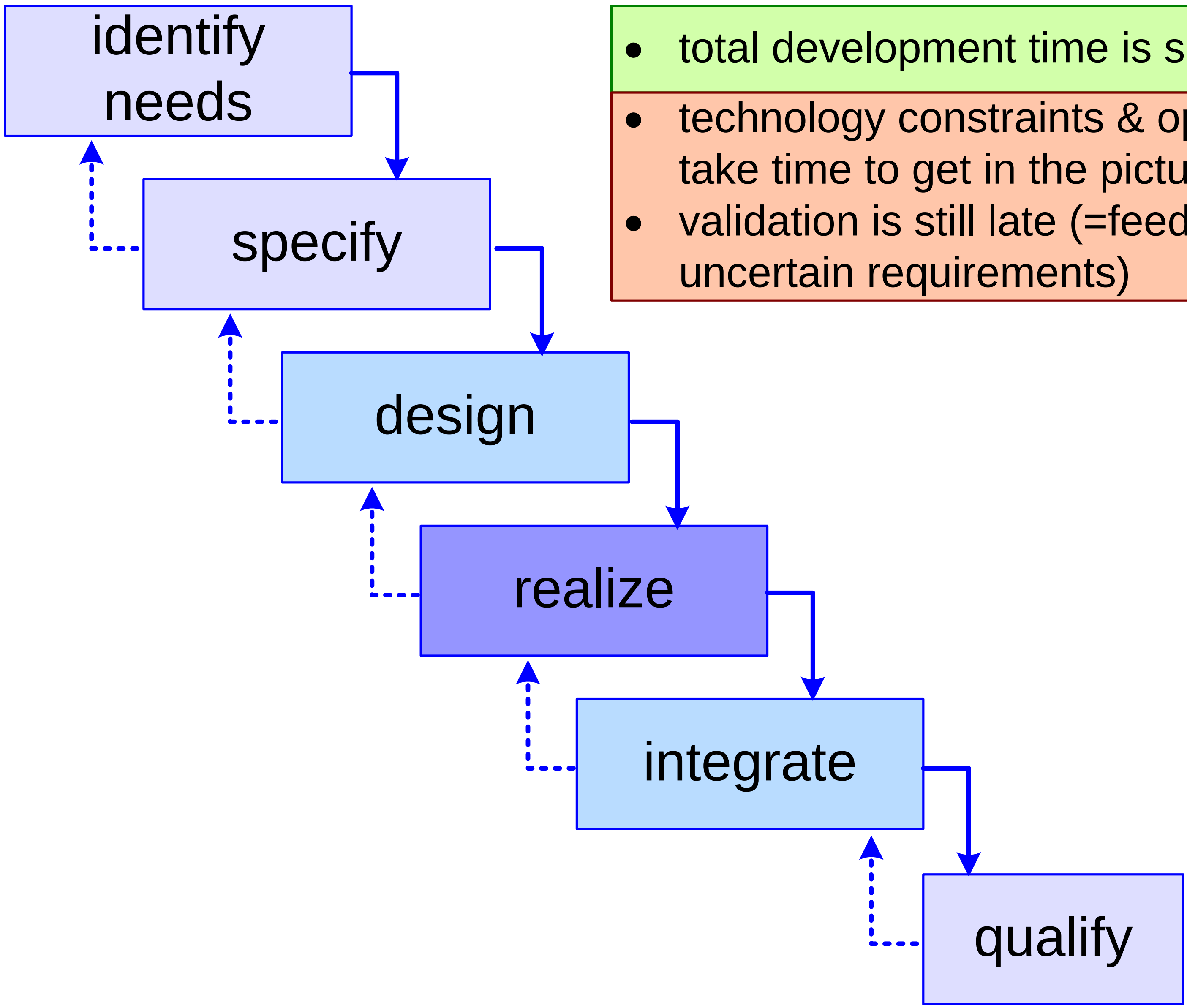
Waterfall model



works well:
- in mature product-market combinations
- with long development cycles

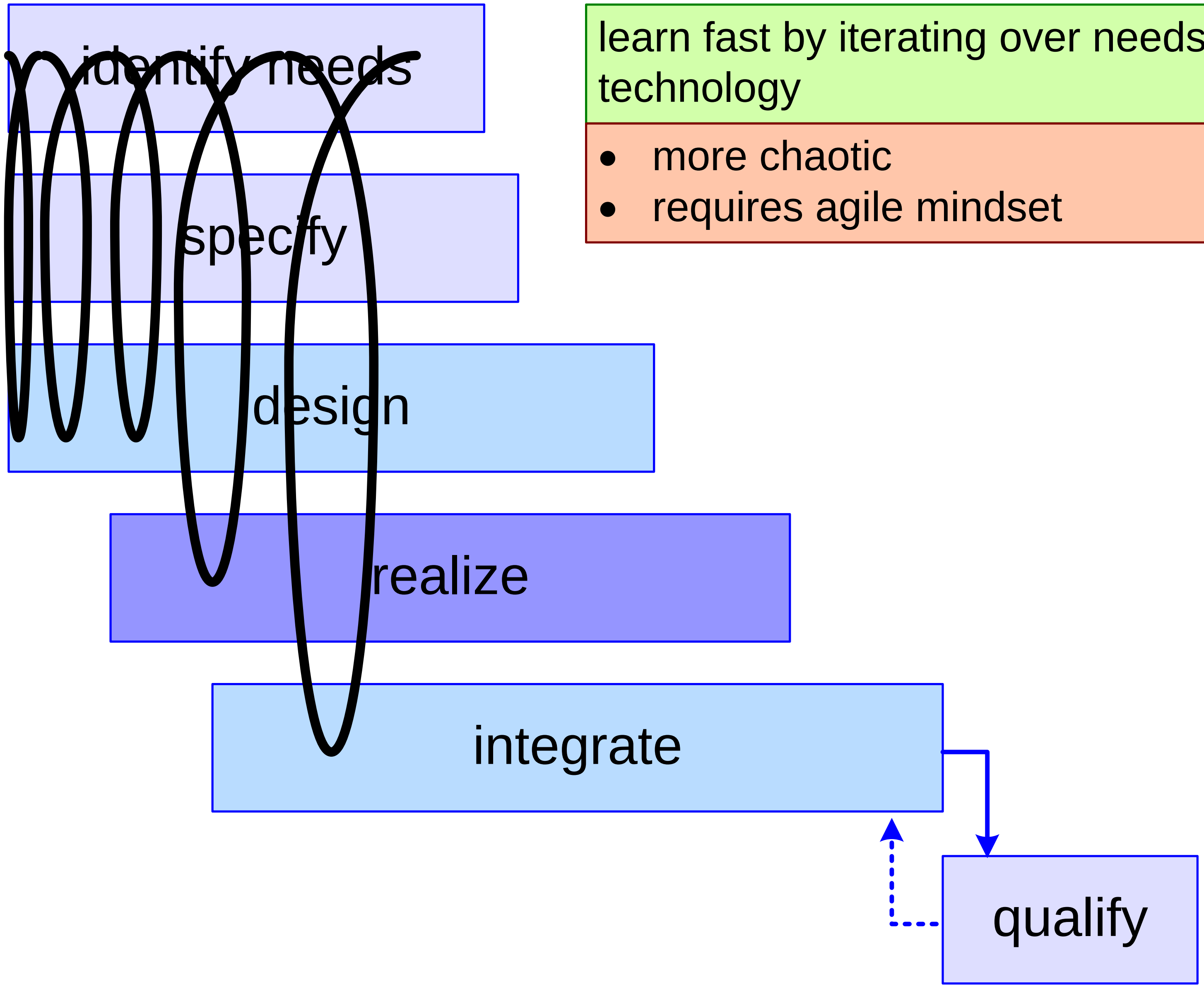
works poorly:
- in new product-market combinations
- short development cycles

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)

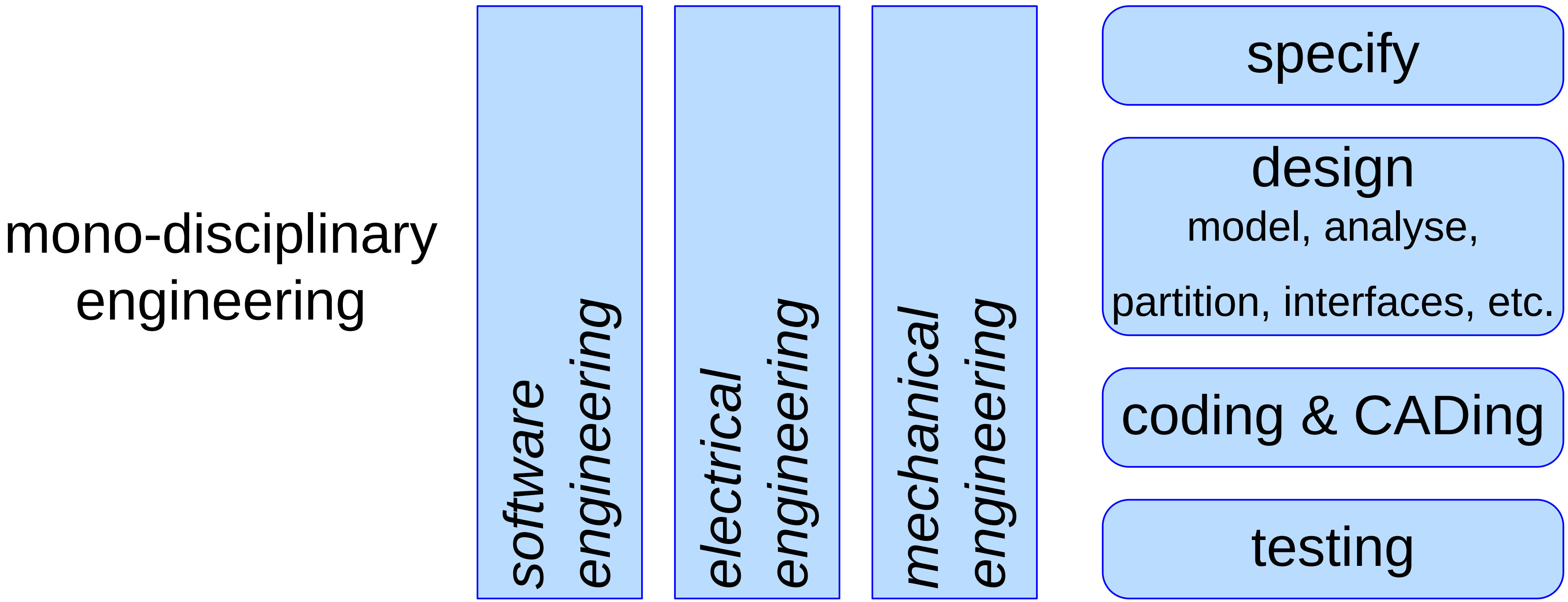
Iterative Approach



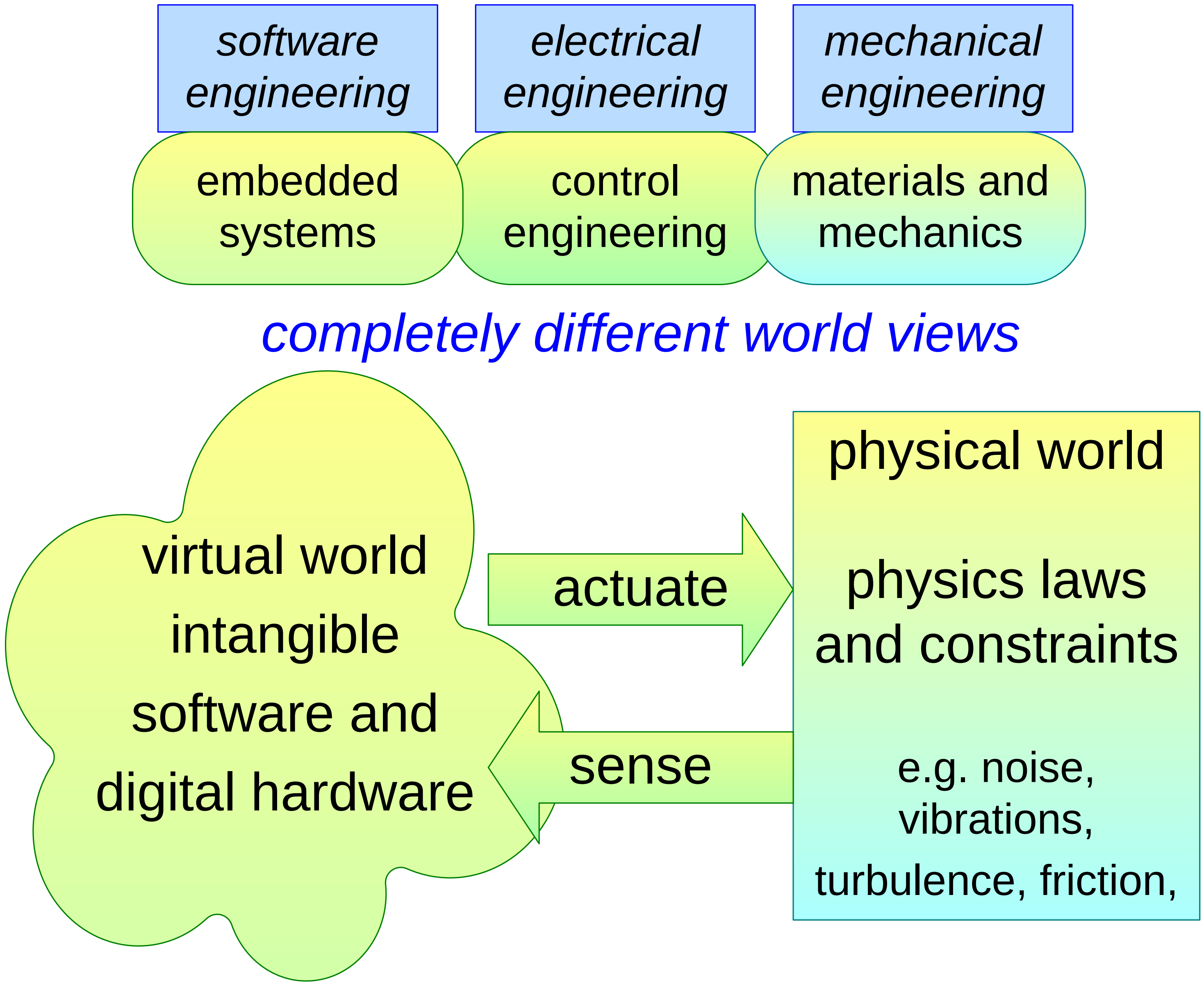
learn fast by iterating over needs and technology

- more chaotic
- requires agile mindset

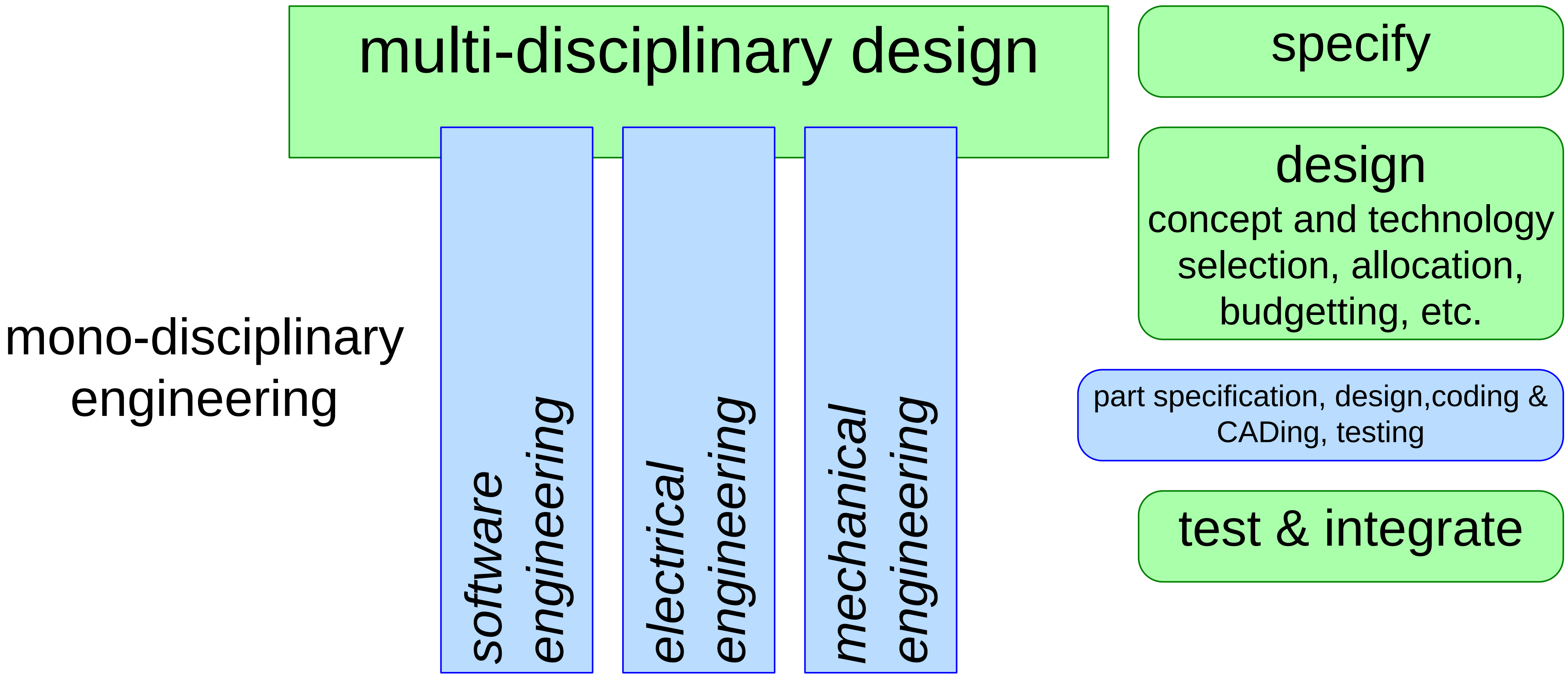
You study mono-disciplinary engineering



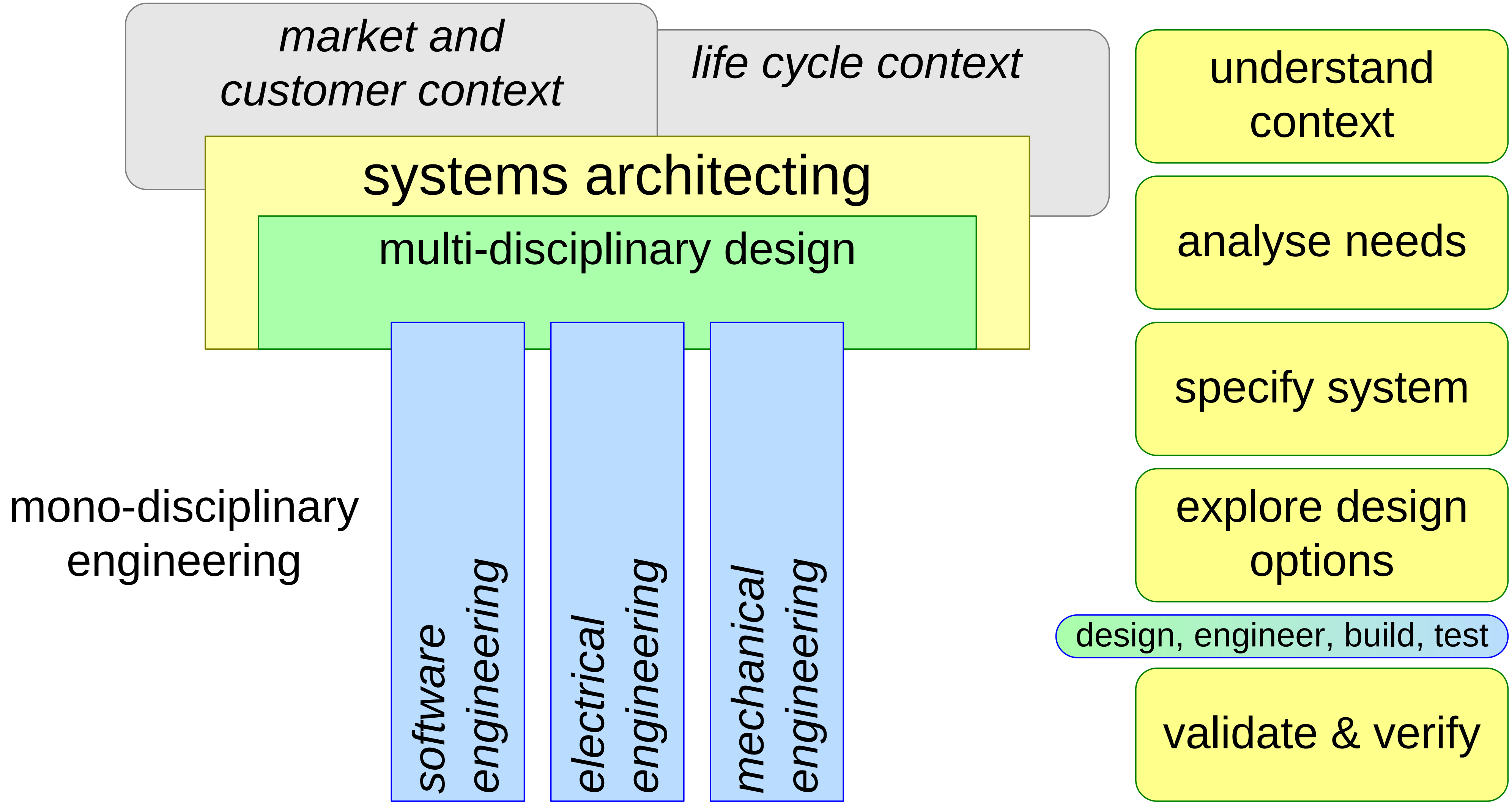
Huge differences in language and way of thinking



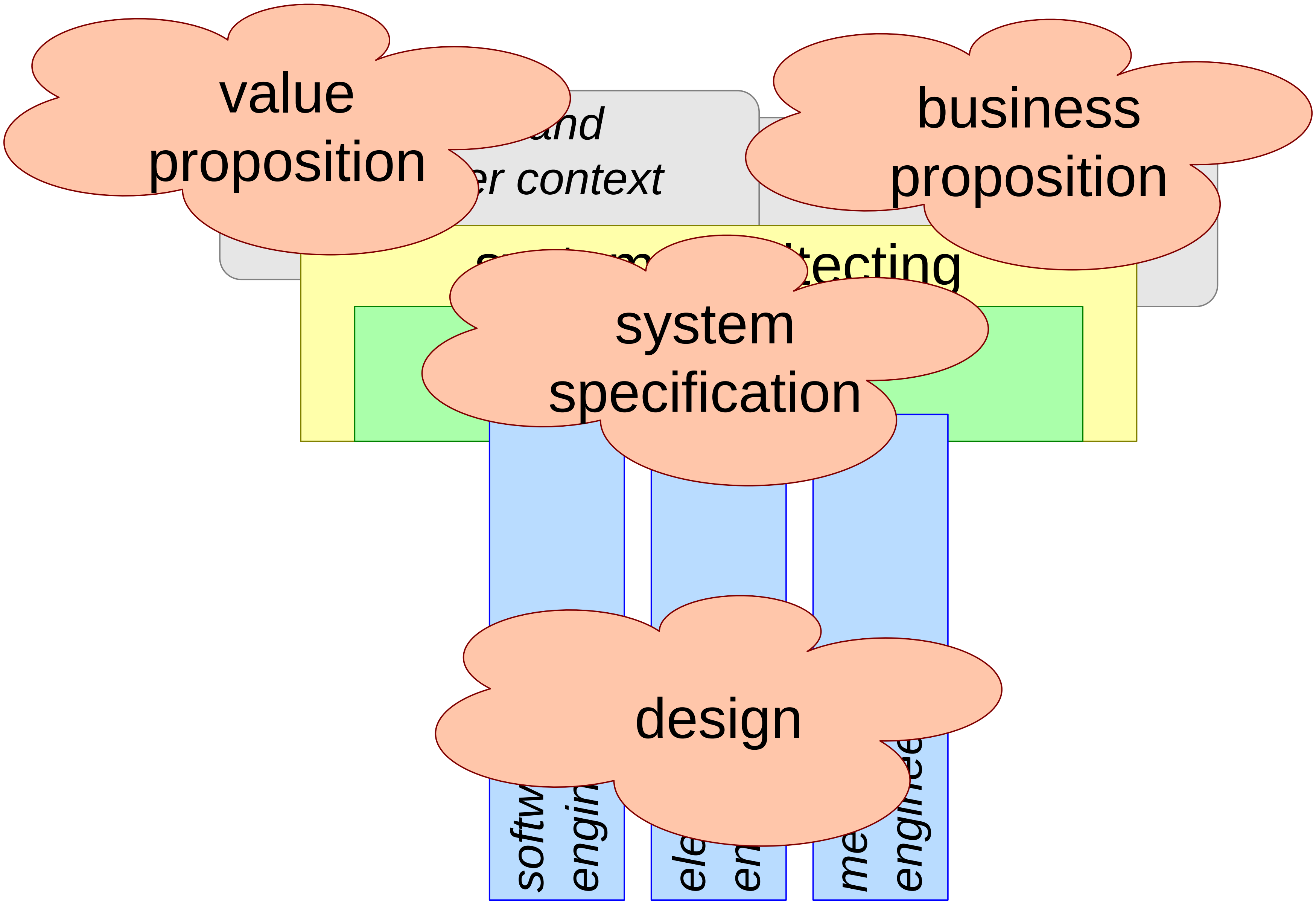
Multi-disciplinary design and engineering



Architecting: Fit-For-Purpose



Delivery at the end of this module



More specific deliveries

Value Proposition
Why does customer want to buy?
Why do users like to use the system?

- customer key drivers
- cost of ownership
- customer business analysis
- customer stakeholders and concerns
- story or scenario
- context diagram
- work flow or ConOps

Business Proposition
How do we earn money?
How do we run a healthy business?

- life cycle key drivers
- business model
- cash flow analysis
- life cycle stakeholders and concerns
- life cycle model
- supply chain
- organization chart
- plan

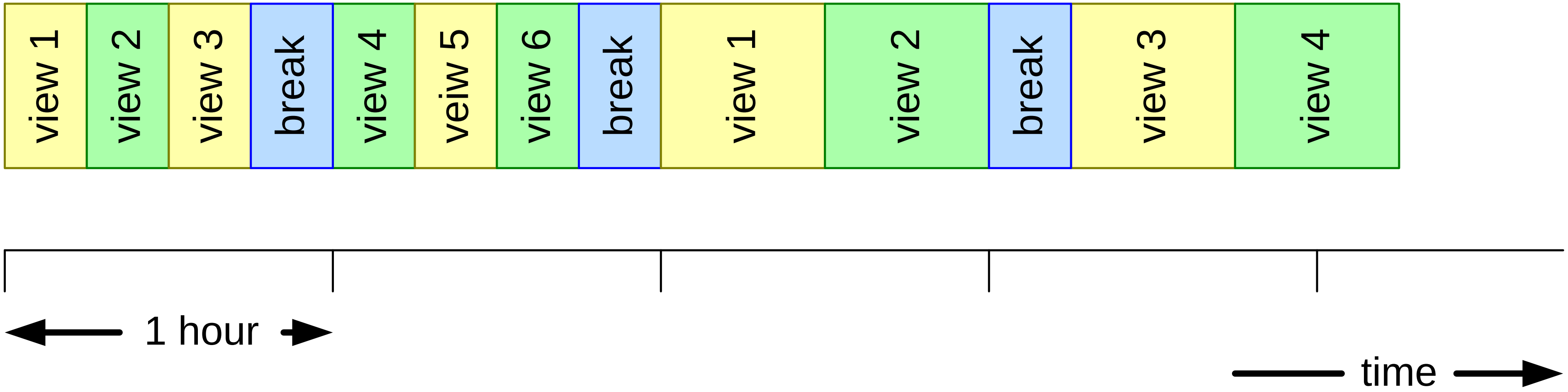
System Specification
What does customer get?
What is the system-of-interest that we deliver?

- functions
- qualities (e.g. quantified performance)
- interfaces
- constraints, standards, regulations

Design
How will we realize this specification?
How do we ensure performance, safety, robustness, etc.?

- partitioning and interfaces
- dynamic behavior, e.g. functional model
- performance budgets
- concept and technology selection
- make or buy, supplier selection

Time-boxing and Iteration



time-box

A time-box is a fixed amount of time allocated to perform one activity.

iteration

We iterate many times over different viewpoints. Every viewpoint is addressed multiple times with new insights from other viewpoints

Rationale behind Time-boxing and Iteration

Learn faster by “sampling” and seeing multiple perspectives

Identify the most relevant issues as early as possible

A time-box is always too short

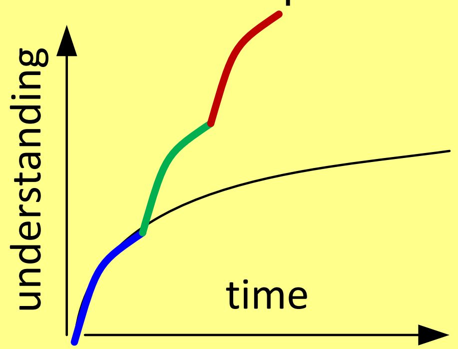
A specification, design, model, or analysis is never complete or finished

With many uncertainties and unknowns it does not make sense to be perfect

After some time progress slows down; it is more efficient to switch topic

Every view needs feedback from other views

Long time-boxes can waste lot of time



“wasting” a time-box is no problem when it is short and when you learn

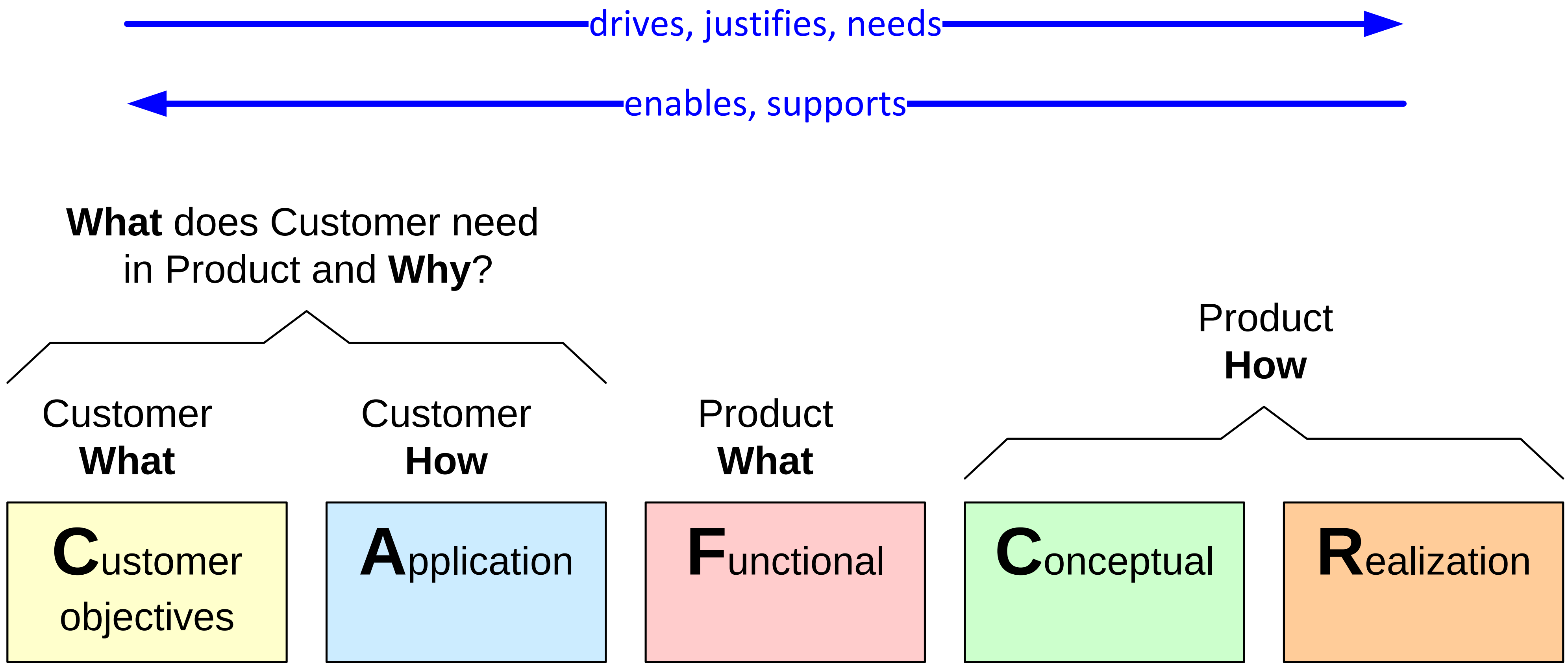
Theory Block: CAFCR

You need multiple views on a system

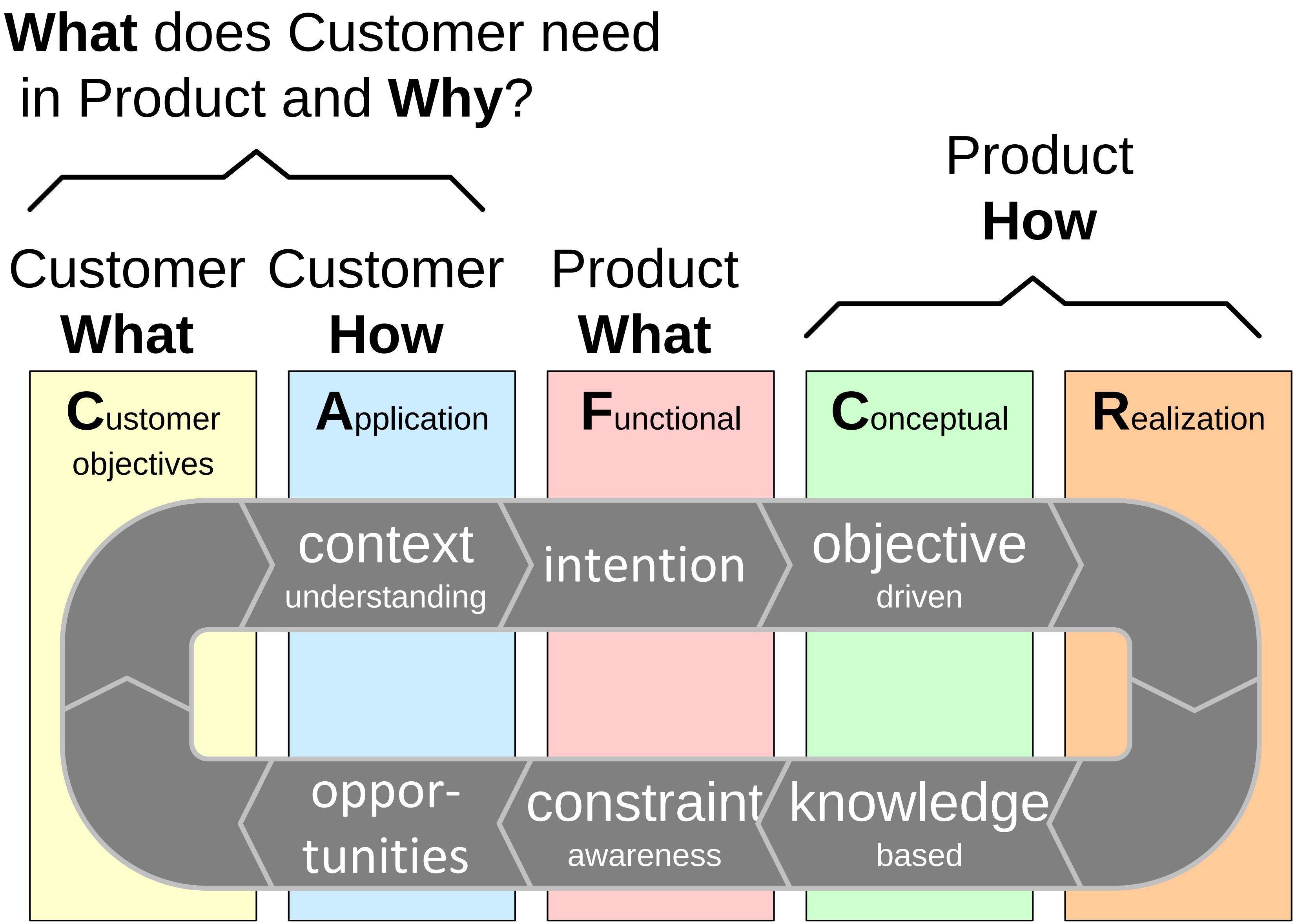
CAFCR defines 5 views

CAFCR+ adds one more view

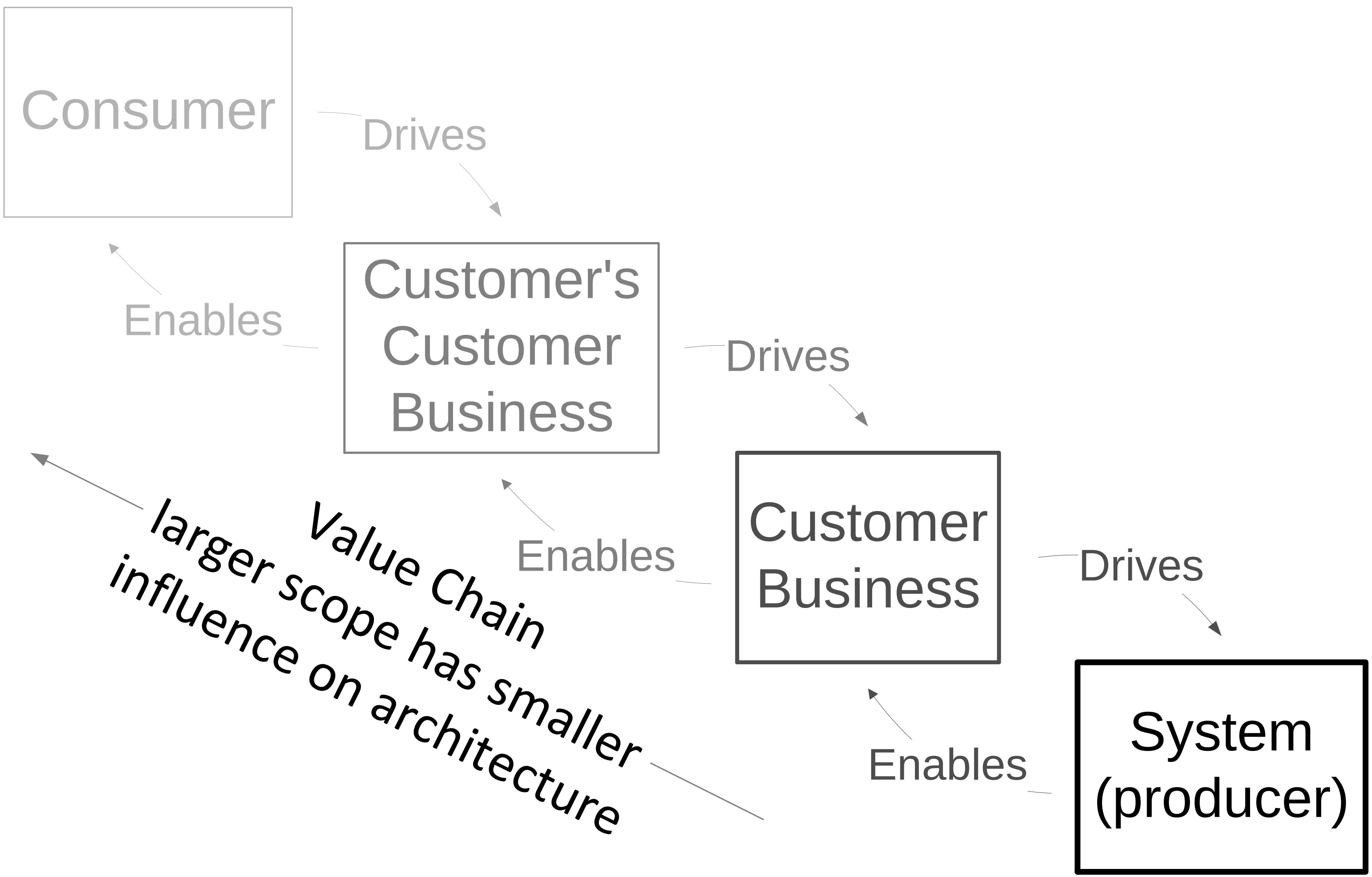
The “CAFCR” model



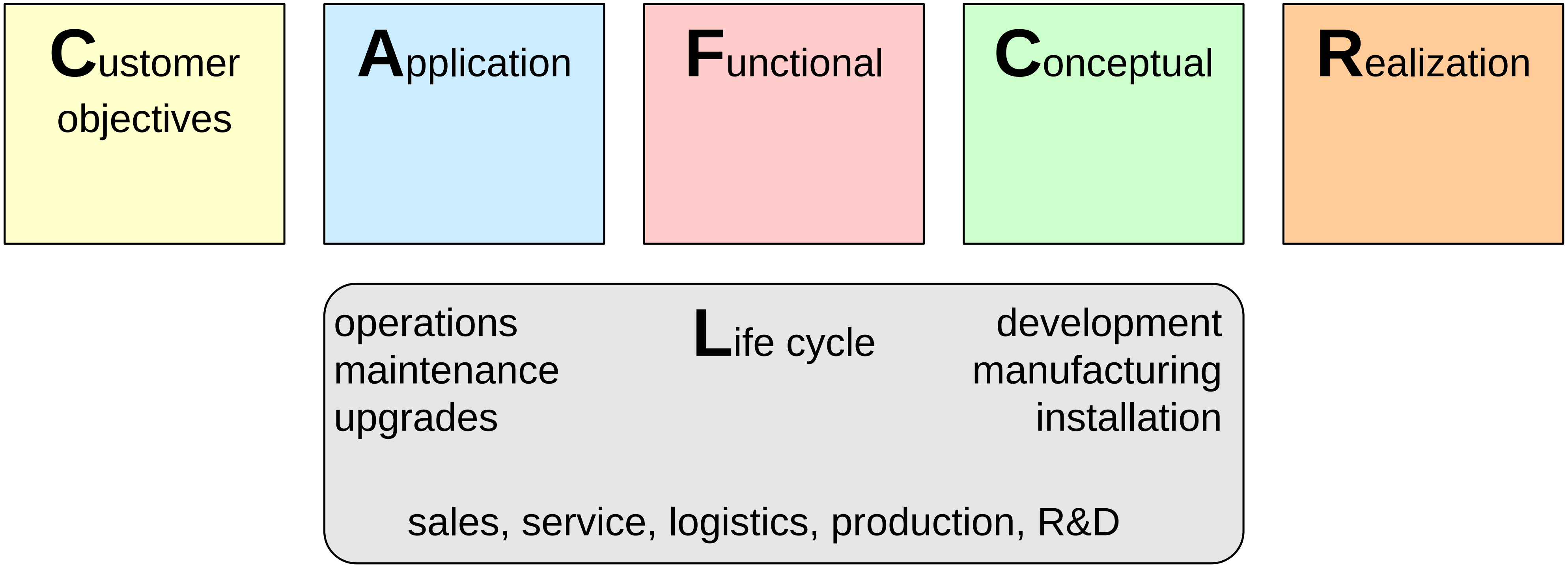
Integrating CAFCR



CAFCR can be applied recursively



CAFCR+ model; Life Cycle View



Stakeholders and Concerns

government
cost of care

financial dir.
cash flow
cost of op.

insurance
cost of care

administration
patient id
invoice

general practitioner
patient

ref. physician
diagnosis
treatment

radiologist
diagnosis
reimburstment

nurse
patient
ease of work

patient
comfort
health

inspection
quality

family
support

operator
ease of use

IT dep.
conformance
security

facility man.
space
service supp.

maintainer
accessibility
safety

cleaner
accessibility
safety

legend

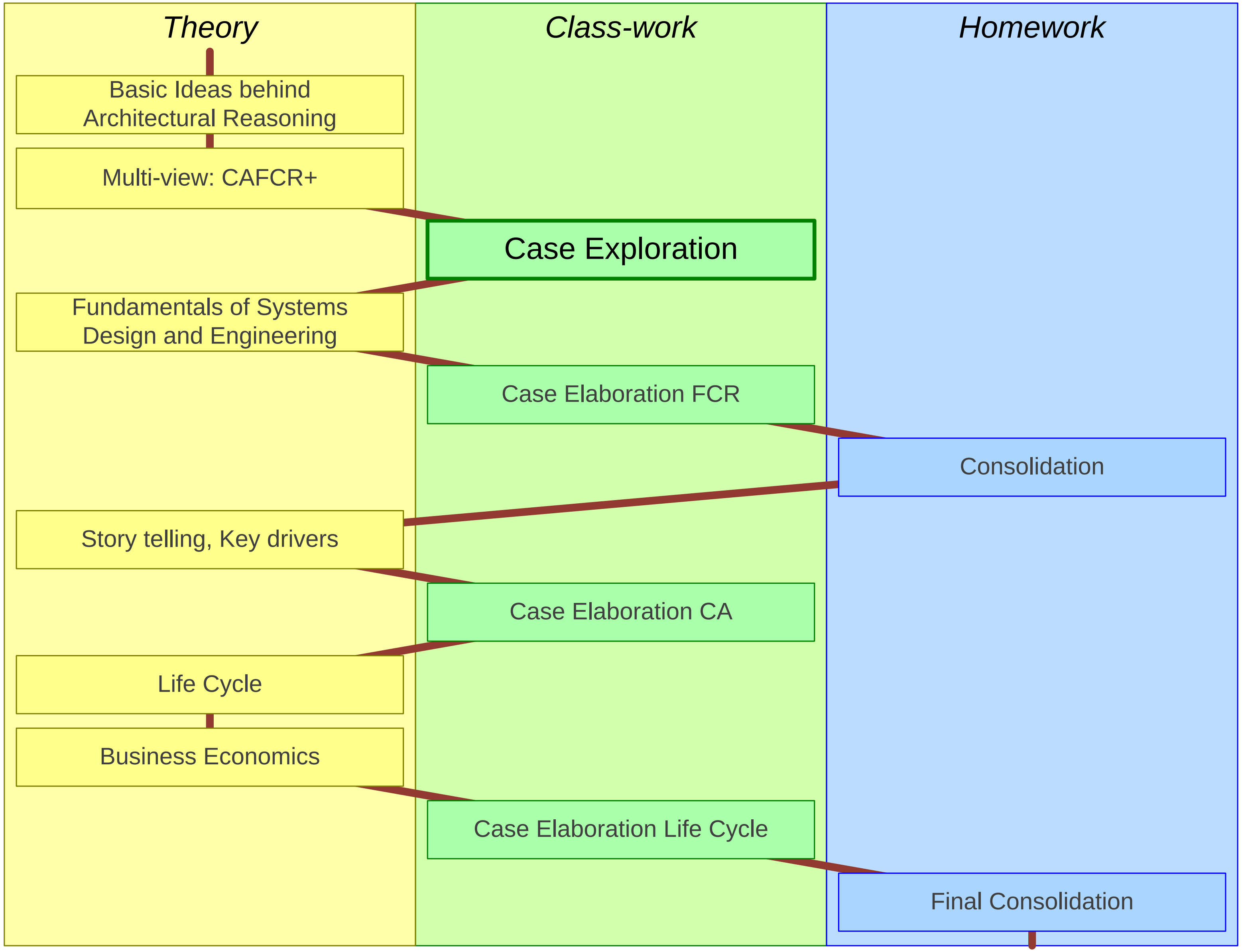
administrative

clinical

patient

support

Case Exploration



Classroom Work Instructions

Find an empty classroom and take the following with you:

- ~5 empty flipover sheets
- a set of 4 pens
- a block of yellow note stickers

Return leftovers to Gerrit's office (Krona 5370) or Jamal at the end of the 4 sessions.

email Gerrit.Muller and Jamal.Safi the room number at their USN email address, when you have found a (class)room.

Some recommendations

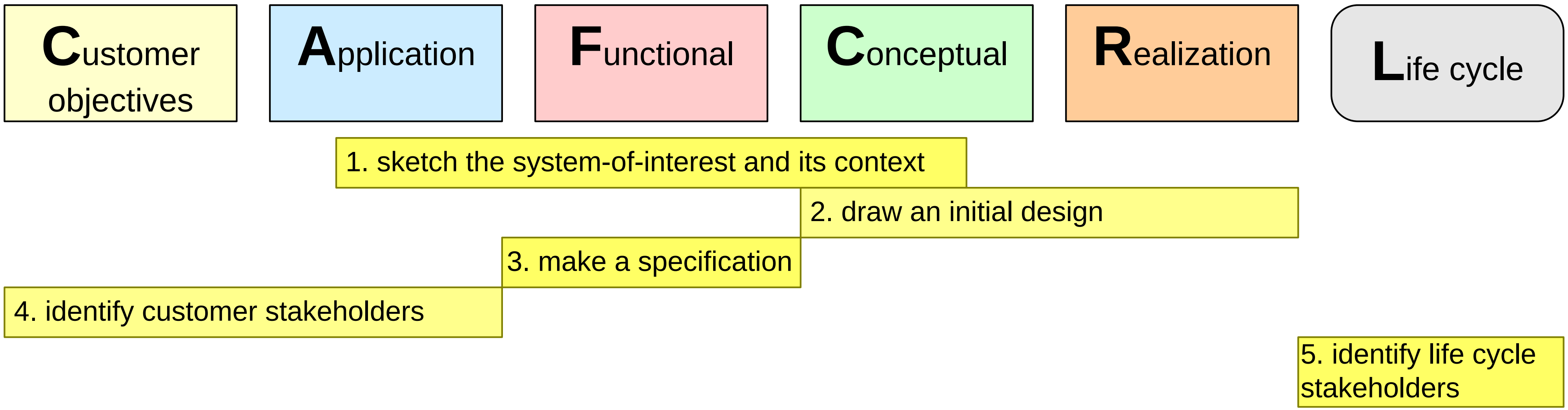
Do	Do **not**	Because
• start sketching/drawing as soon as possible	• write long texts .	• sketches stimulate sharing and discussion
• use shared large sheets of paper (e.g. flip-over)	• immediately capture electronic	• sharing and discussion help to explore faster
• number the flip-overs and add a title		• remembering the order gets challenging
• annotate (add notes) during discussions	• have nice but volatile discussions	• information and insight is quickly lost
• use yellow note stickers and flip-over markers	• write with pen or pencil	• stickers are easily (re)moved
• be open for ideas and surprises	• Do not stick to the first solution	• you hopefully discover a lot; increased insight will change problem and solution

Class-work Day 1: Exploration

Use **time-boxes** of **15 minutes** and perform the following steps:

- **Sketch** the **system-of-interest** and its immediate context
  - Annotate the sketch (e.g. main components, interfaces, functions, …)
- Draw an **initial design**
- Make a **specification** of the system-of-interest (view it as a blackbox)
  - What functionality, performance, interfaces, standards or regulations
- Identify the main **customer stakeholders** and their **concerns**
- Identify the main **life cycle stakeholders** and their **concerns**
- Review and make a plan to consolidate in a presentation

Class-work Day 1 mapped on CAFCR

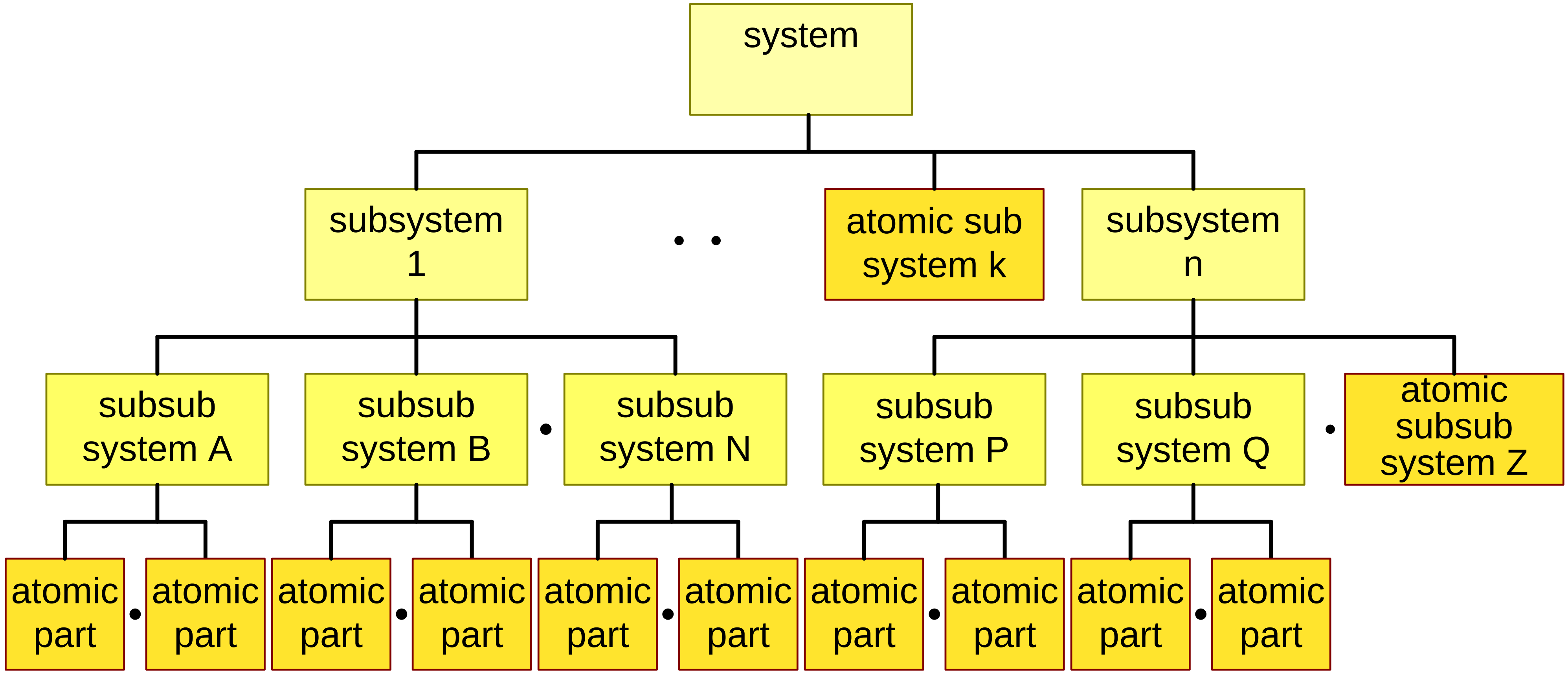


Theory Block: Fundamentals Systems Design and Engineering

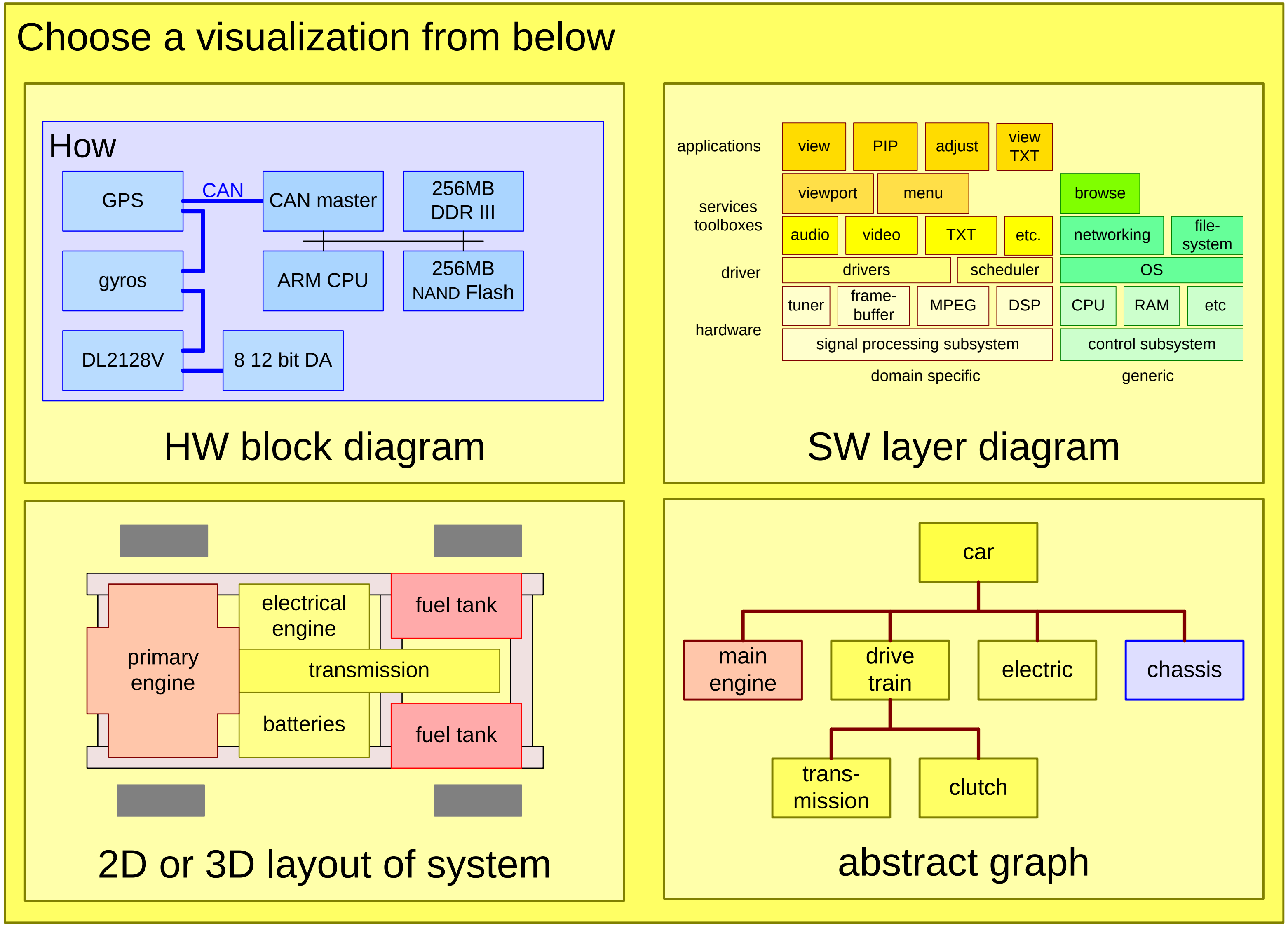
System Designers and Engineers

- Partition (decompose)
- Model Dynamic Behavior (functions)
- Quantify
- Allocate and budget
- Select concepts

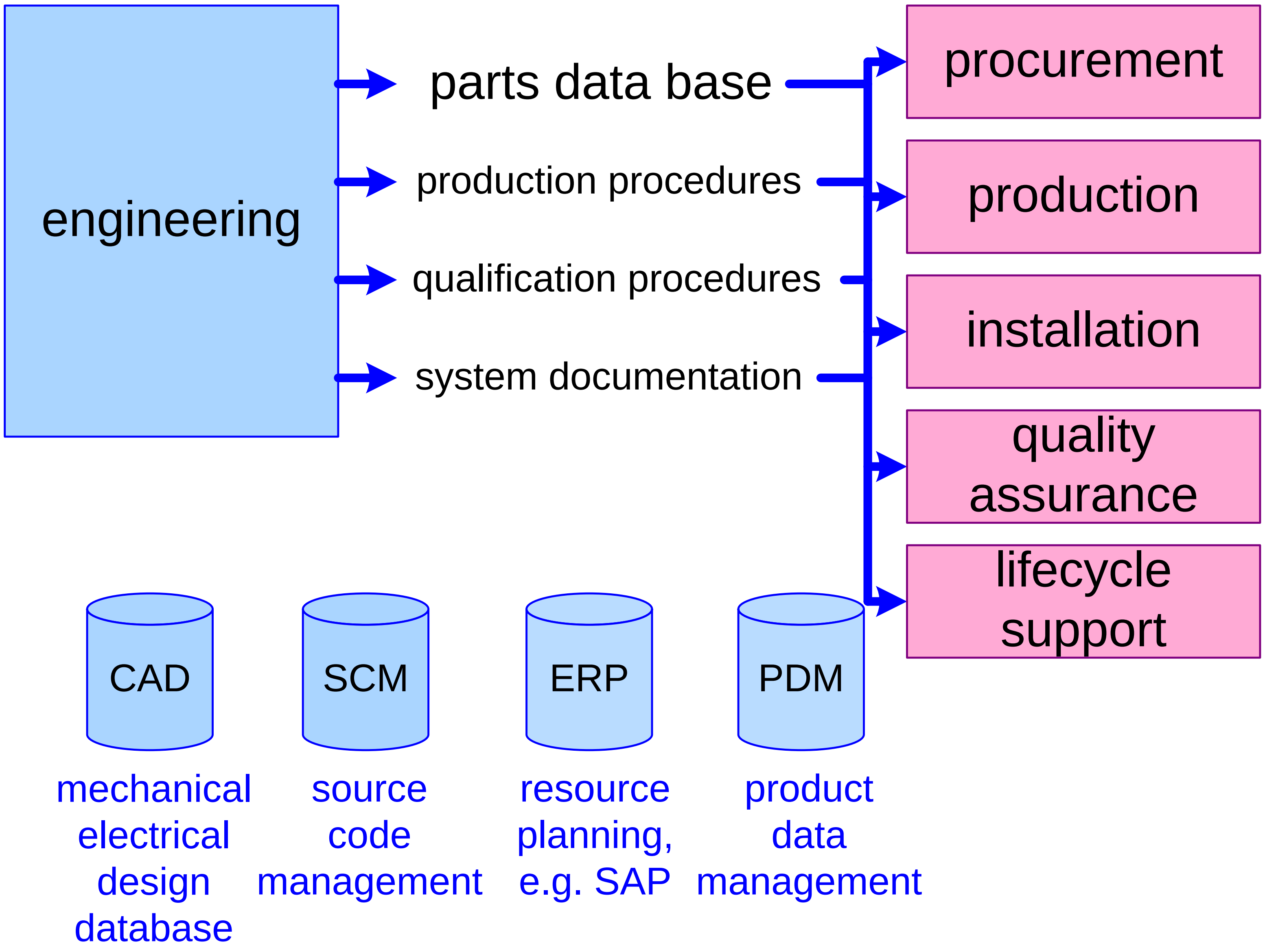
Partitioning is Applied Recursively



Possible Visualizations of Partitioning



Partitioning Dominates Many Processes



Theory of Partitioning

the part is cohesive

- functionality and technology belongs together

the coupling with other parts is minimal

- minimize interfaces

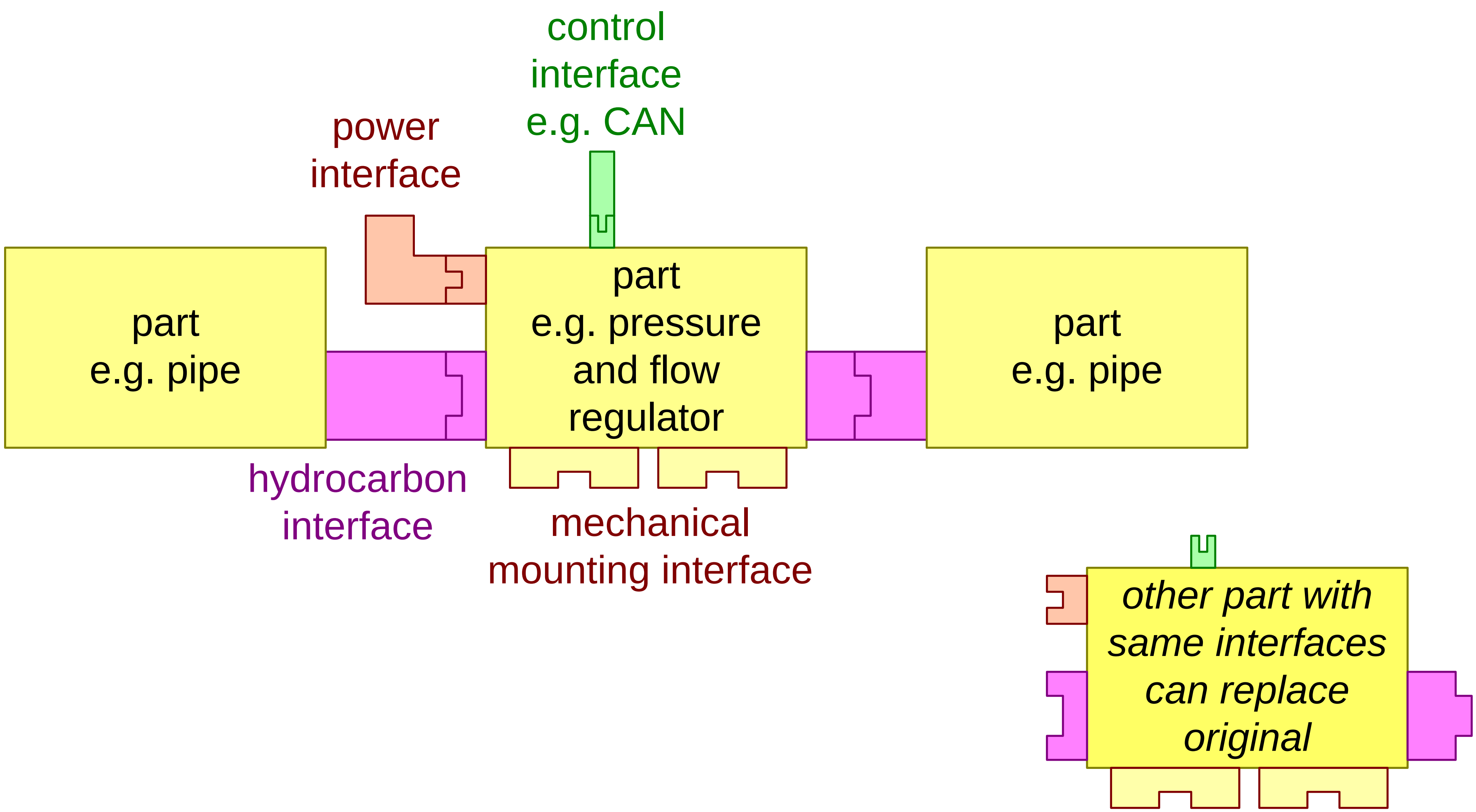
the part is selfsustained for production and qualification

- can be in conflict with cost or space requirements

clear ownership of part

- e.g. one department or supplier

Decoupling via Interfaces

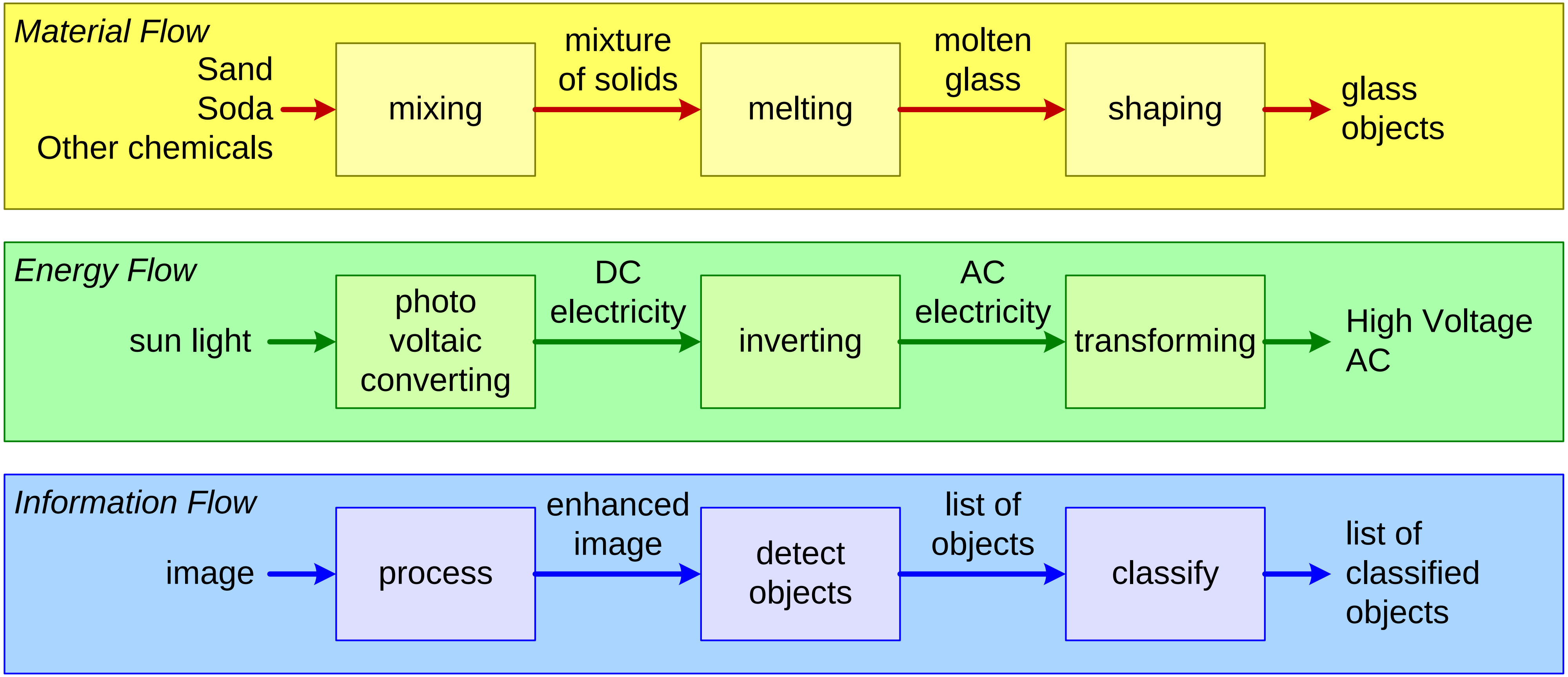


Interaction Results in Dynamic Behavior

Interaction between parts takes place via exchange of

- **M**aterial
- **E**nergy
- **I**nformation

Simple Examples of MEI Flows



Dynamic Behavior and Time

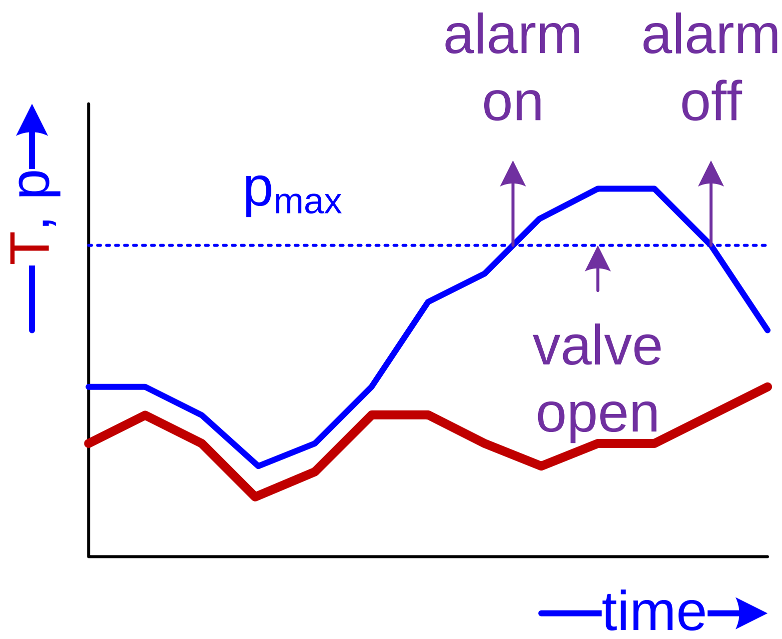
Interaction between parts can take place

- continuously

  for example, temperature or pressure variation due to continuous exchange of Material or Energy

- discrete (event based)

  for example, an alarm, command, or a fixed period control loop



Simple Examples of Dynamic Behavior

Every second:

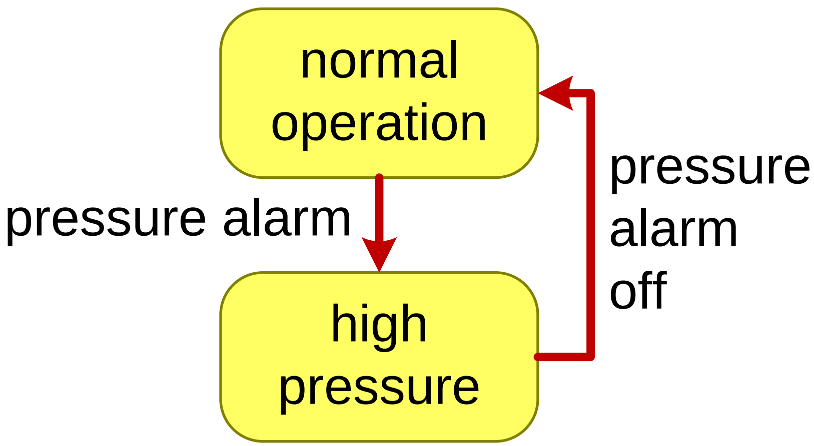
read **pressure**, **temperature**

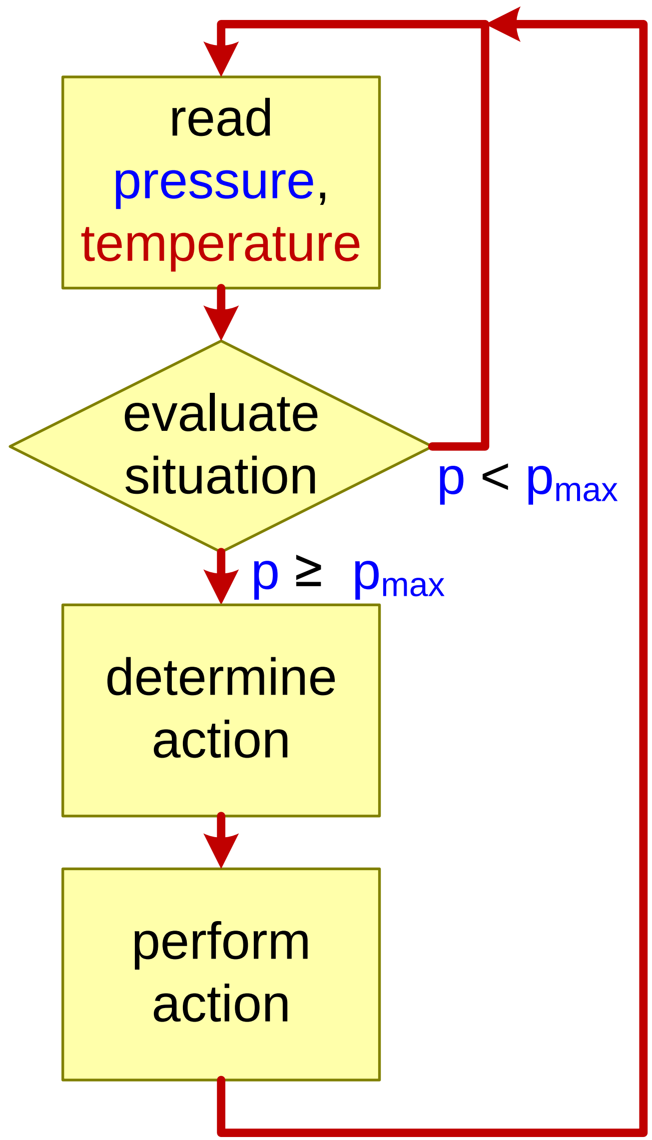
evaluate situation (e.g., $p < p_{max}$)

determine action

(e.g., lower pressure by opening valve)

perform action (e.g. **open valve**)





Quantification

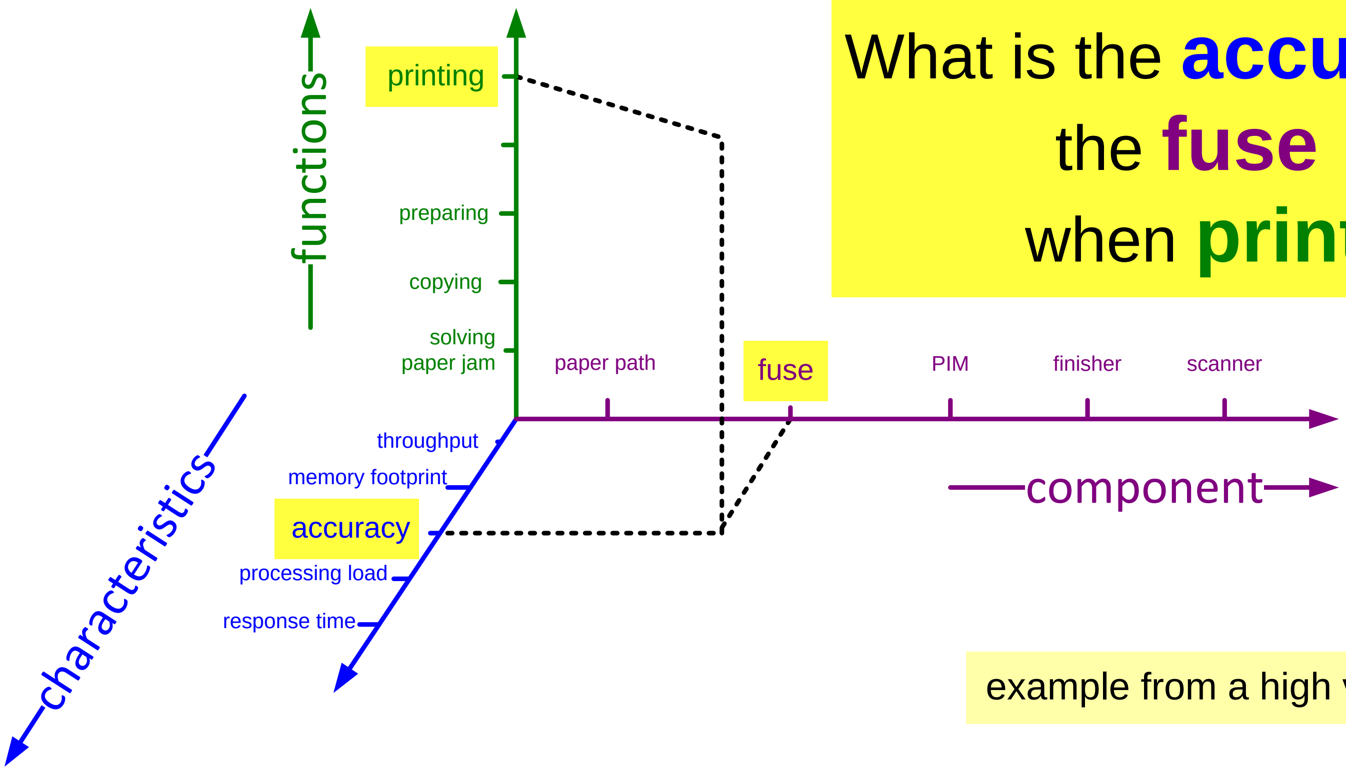
Size	2.4m * 0.7m * 1.3m
Weight	1450 Kg
Cost	30000 NoK
Reliability	MTBF 4000 hr
Throughput	3000 l/hr
Response time	0.1 s
Accuracy	+/- 0.1%

many characteristics of a system, function or part can be quantified

Note that quantities have a ***unit***

Question generator

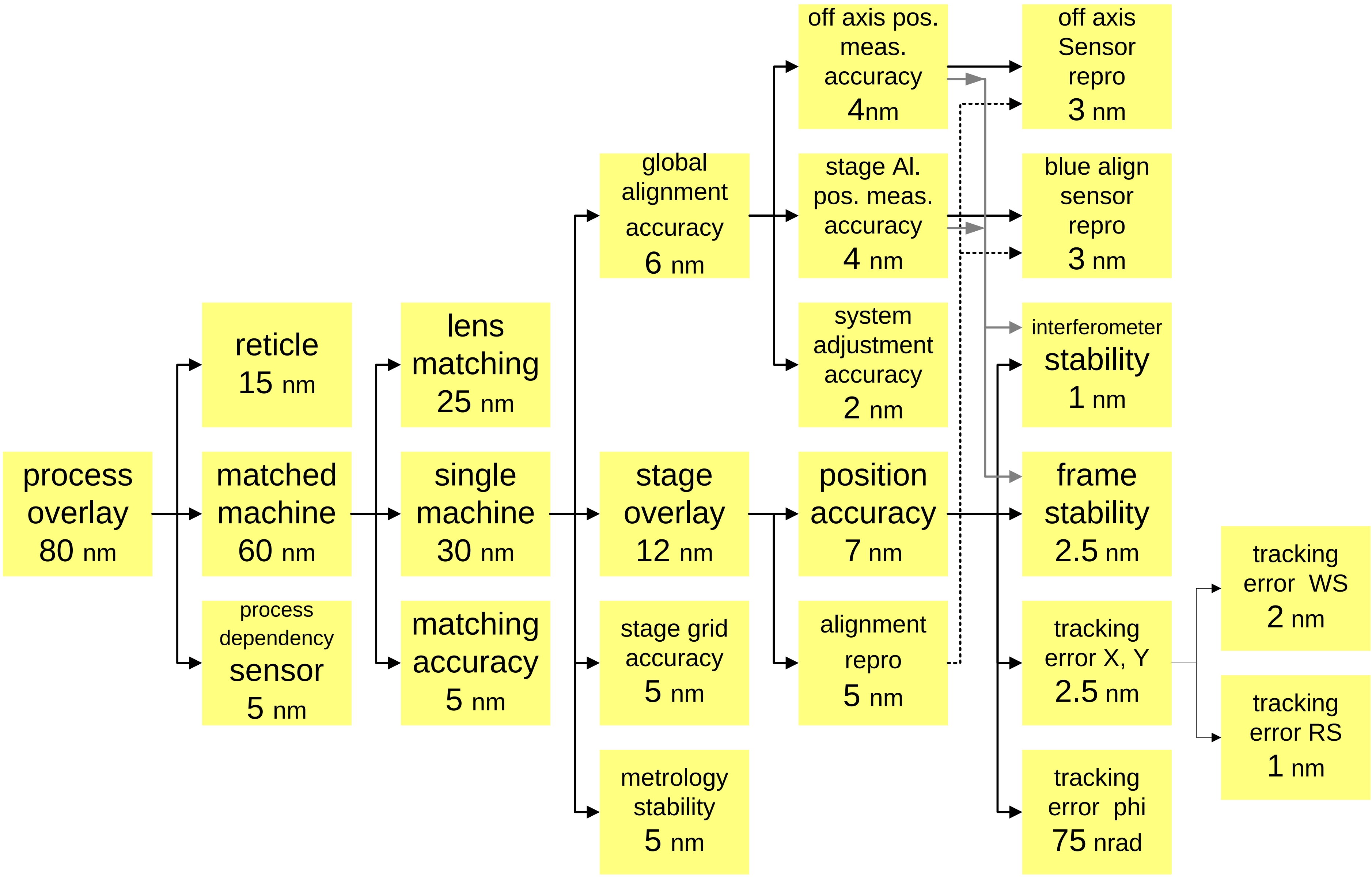
How about the **<characteristic>**
of the **<component>**
when performing **<function>**?



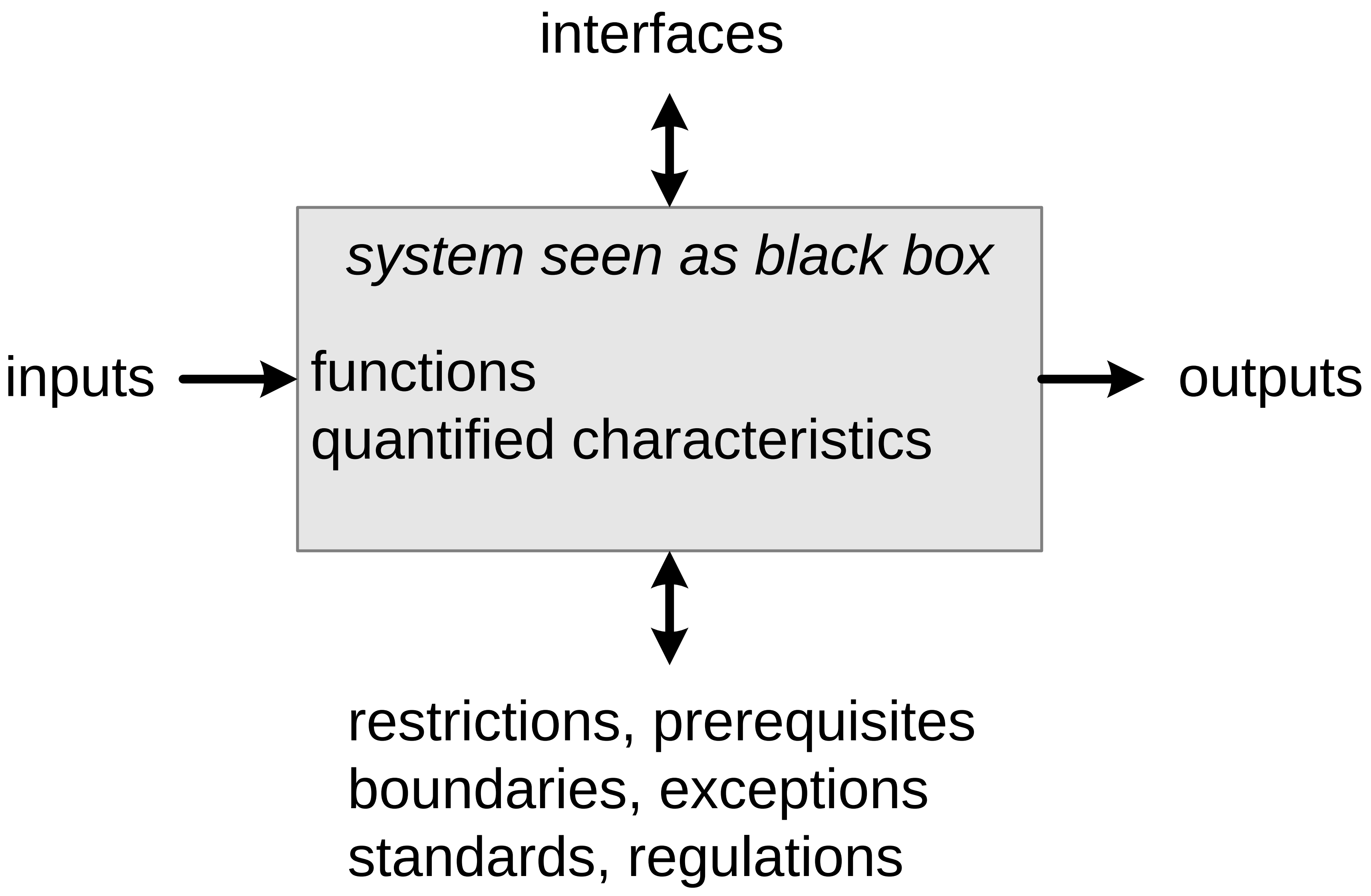
What is the **accuracy** of the **fuse** when **printing**

example from a high volume printer

Technical Budget



The System-of-interest as Black Box



Key Performance Parameters

Key Performance Parameters are **SMART**

the most important

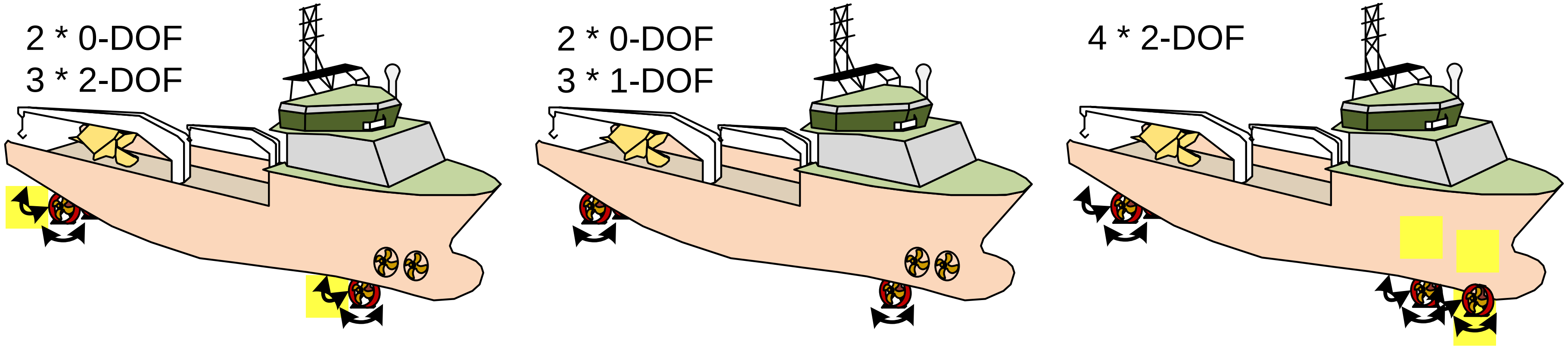
defined in use case:

the circumstances where the performance is valid

typical use with relevant (quantified!) context data

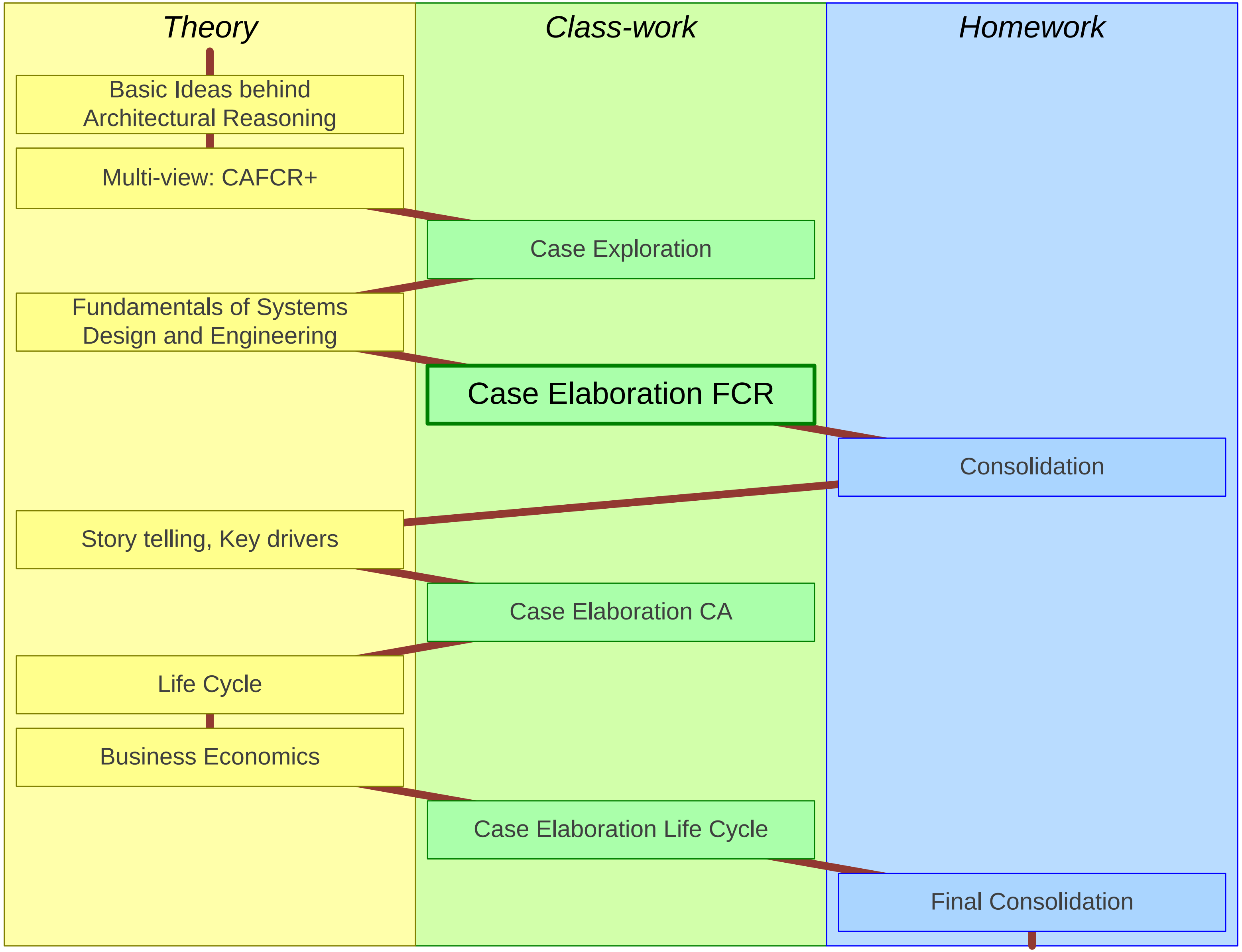
- **S**pecific quantified
- **M**easurable verifiable
- **A**chievable (Attainable, Action oriented, Acceptable, Agreed-upon, Accountable)
- **R**ealistic (Relevant, Result-Oriented)
- **T**ime-bounded (Timely , Tangible, Traceable)

Example of Pugh Matrix



Manoeuvrability	4	4	5
Energy consumption	5	3	5
Development Cost	3	4	2
Maturity (risk)	3	4	1
Purchasing Cost	3	4	3
Maintenance Cost	2	4	2

Case Elaboration FCR-views



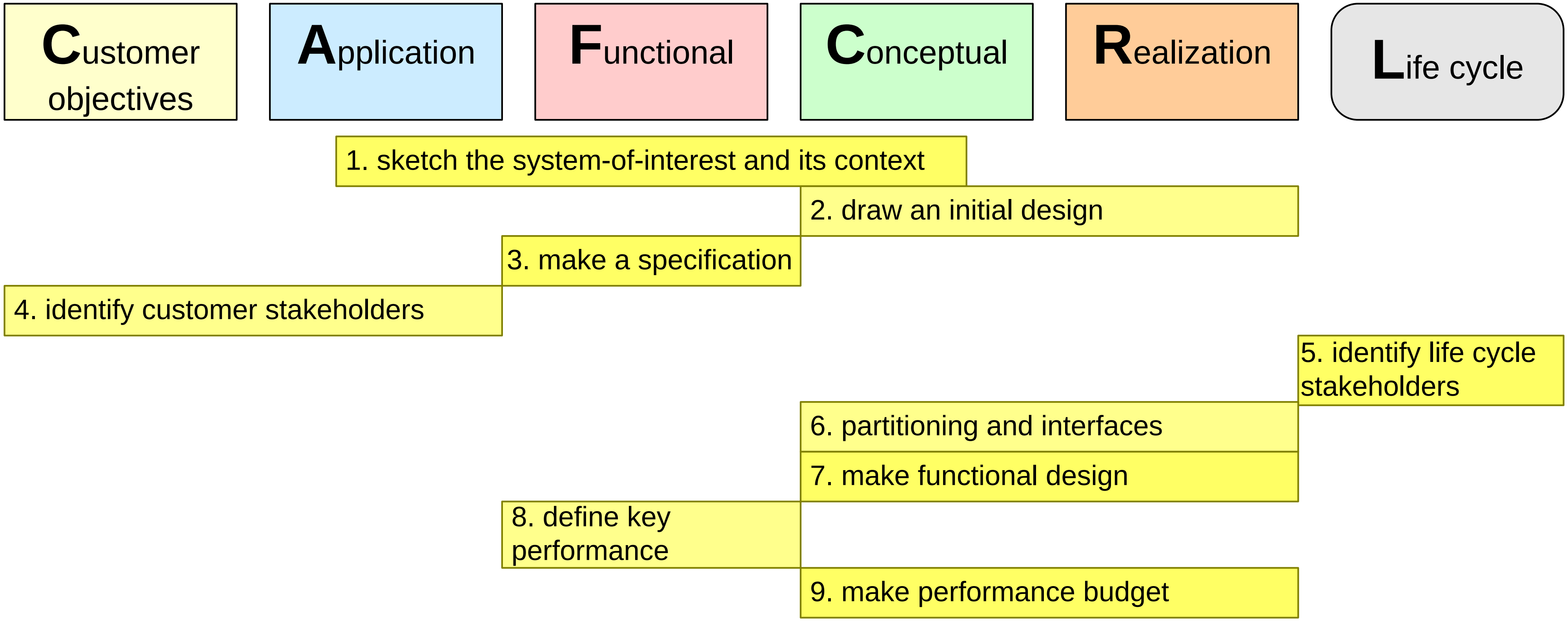
Class-work Day 2: Elaboration

Start second iteration by elaborating FCR views

Use time-boxes of about 30 minutes

- Decompose the system in subsystems, decompose one subsystem in subsubsystems.
  - Show the subsystems and interfaces in a block diagram
- Make a functional model of the internals of the system-of-interest
  - Use one or more diagrams to show the dynamic behavior
- Define 5..10 Key Performance Parameters of the system-of-interest
  - Define a use case to support the definition of KPPs
- Make a technical budget for one of the key performance parameters
- Review and make a plan to consolidate in a presentation

Class-work Day 2 mapped on CAFCR



Homework after Day 2

Transform your results in electronic form (e.g., PowerPoint or Visio)

Develop two alternative solutions/concepts

Compare the three solutions using a Pugh matrix

- define 5..10 criteria for comparison
- score the solutions on a scale from 1 (poor) to 5 (very good)
- recommend a solution with a rationale

Make a list of questions triggered by the first iteration

Search for facts to ease the next class-work

Submit as draft presentation via Canvas

Home work instructions

Homework instructions

presentation

filename: BSEAR team<your teamnumber/name> homework<number>

e.g. BSEAR team1 homework1.ppt

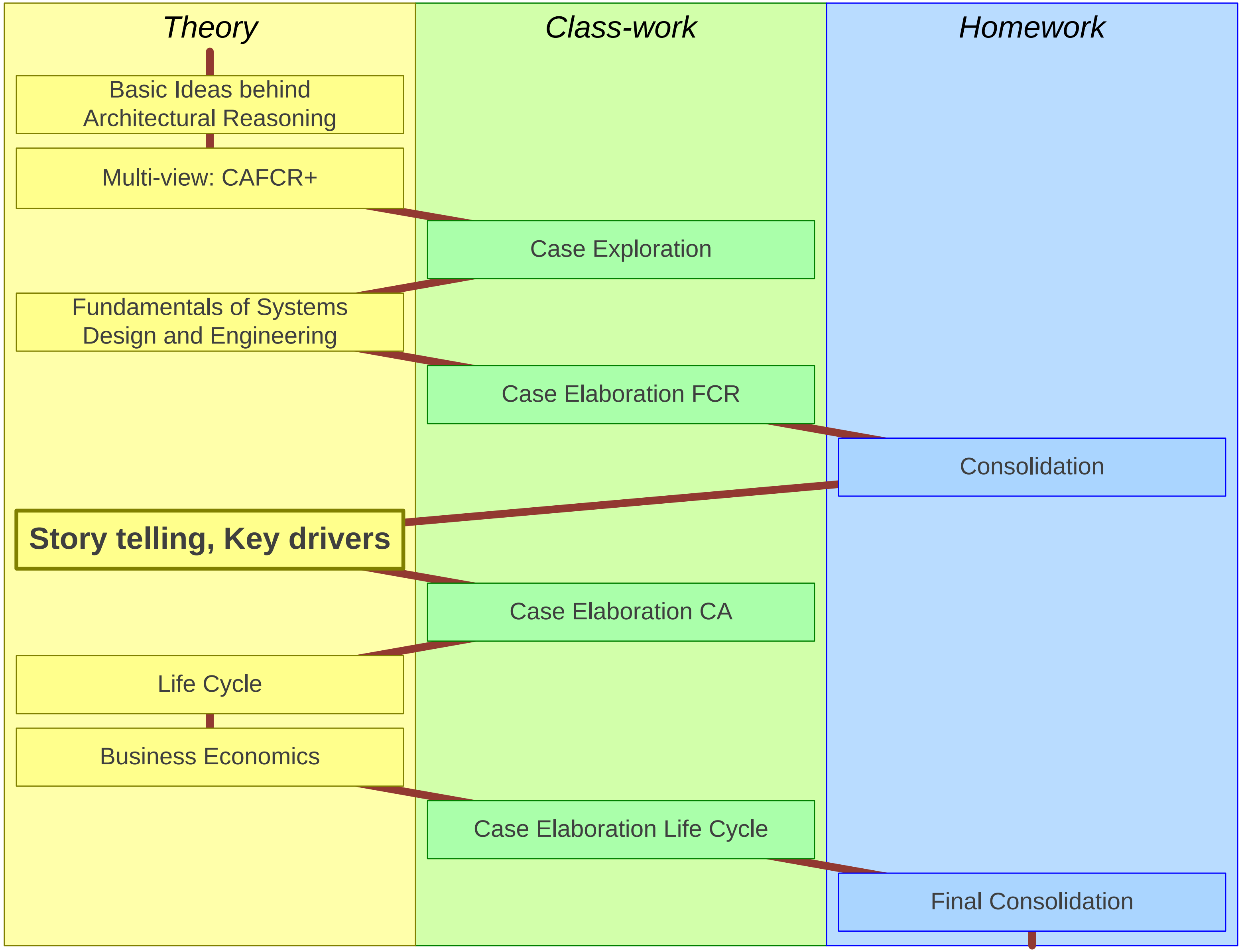
all team members on front page

upload homework to Canvas

Questions email to: <gerrit . muller @ gmail. com>

from/cc: <all email addresses of team members>

Story Telling and Key Drivers



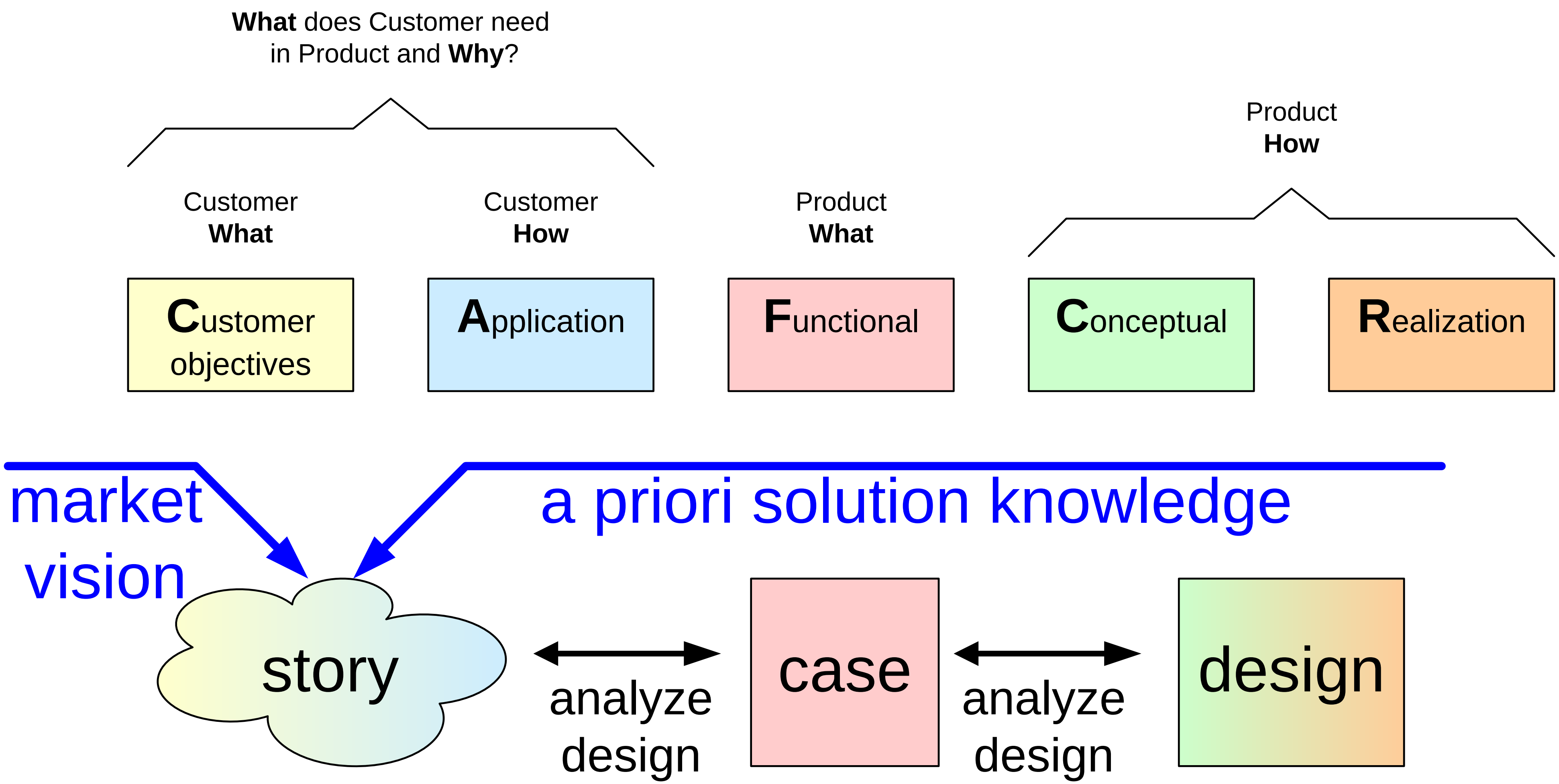
Theory Block: Understanding Customers

Story telling

Customer Key Driver Graph

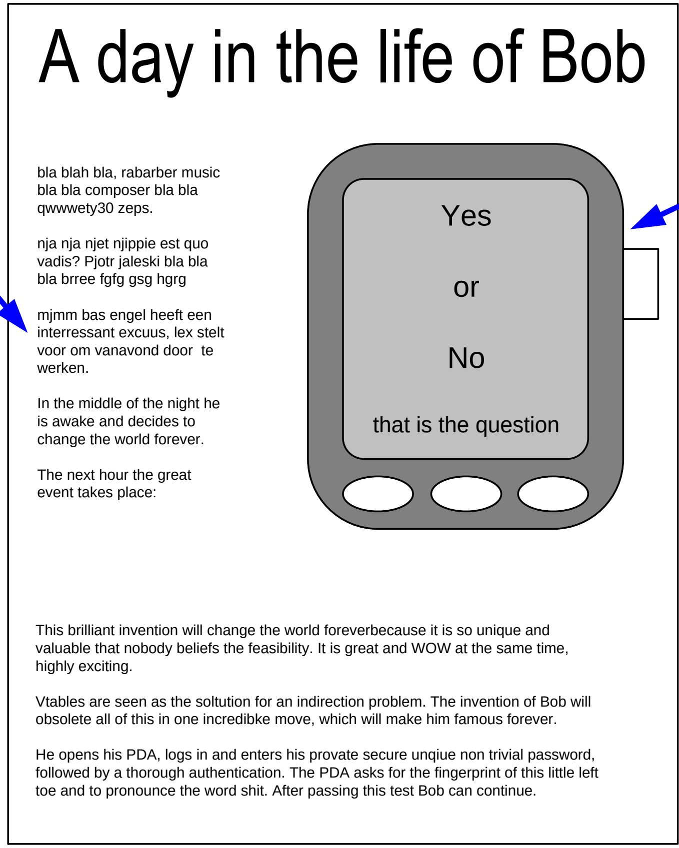
Context

From story to design



Example story layout

ca. half a page of plain English text



draft or sketch of some essential appliance

Points of attention

- purpose — What do you need to know for specification and design?
- scope — "umbrella" or specific event?
- viewpoint, stakeholders — Define your stakeholder and viewpoint f.i. user, maintainer, installer
- visualization — Sketches or cartoon. Helps to share and communicate ideas
- size (max 1 A4) — Can be read or told in few minutes
- recursive decomposition, refinement

Criteria for a good story

Customer objectives / **A**pplication	• accessible, understandable	"Do you see it in front of you?"
Customer objectives / **A**pplication	• valuable, appealing	attractive, important "Are customers queuing up for this?"
Conceptual / **R**ealization	• critical, challenging	"What is difficult in the realization?" "What do you learn w.r.t. the design?"
Application	• frequent, no exceptional niche	"Does it add significantly to the bottom line?"
Application / **F**unctional	• specific	names, ages, amounts, durations, titles, ...

Example of a story

Betty is a 70-year-old woman who lives in Eindhoven. Three years ago her husband passed away and since then she lives in a home for the elderly. Her 2 children, Angela and Robert, come and visit her every weekend, often with Betty's grandchildren Ashley and Christopher. As so many women of her age, Betty is reluctant to touch anything that has a technical appearance. She knows how to operate her television, but a VCR or even a DVD player is way to complex.

When Betty turned 60, she stopped working in a sewing studio. Her work in this noisy environment made her hard-of-hearing with a hearing-loss of 70dB around 2kHz. The rest of the frequency spectrum shows a loss of about 45dB. This is why she had problems understanding her grandchildren and why her children urged her to apply for hearing aids two years ago. Her technophobia (and her first hints or arthritis) inhibit her to change her hearing aids' batteries. Fortunately her children can do this every weekend.

This Wednesday Betty visits the weekly Bingo afternoon in the meetingplace of the old-folk's home. It's summer now and the tables are outside. With all those people there it's a lot of chatter and babble. Two years ago Betty would never go to the bingo: “I cannot hear a thing when everyone babbles and clatters with the coffee cups. How can I hear the winning numbers?!”. Now that she has her new digital hearing instruments, even in the bingo cacophony, she can understand everyone she looks at. Her social life has improved a lot and she even won the bingo a few times.

That same night, together with her friend Janet, she attends Mozart's opera The Magic Flute. Two years earlier this would have been one big low rumbly mess, but now she even hears the sparkling high piccolos. Her other friend Carol never joins their visits to the theaters. Carol also has hearing aids, however hers only “work well” in normal conversations. “When I hear music it's as if a butcher's knife cuts through my head. It's way too sharp!”. So Carol prefers to take her hearing aids out, missing most of the fun. Betty is so happy that her hearing instruments simply know where they are and adapt to their environment.

source: Roland Mathijssen
Embedded Systems Institute
Eindhoven

Value and Challenges in this story

Customer objectives
Application

Value proposition in this story:

quality of life:

- active participation in different social settings

usability for nontechnical elderly people:

- "intelligent" system is simple to use
- loading of batteries

Conceptual
Realization

Challenges in this story:

Intelligent hearing instrument

Battery life — at least 1 week

No buttons or other fancy user interface on the hearing instrument, other than a robust On/Off method

The user does not want a technical device but a solution for a problem

Instrument can be adapted to the hearing loss of the user

Directional sensitivity (to prevent the so-called cocktail party effect)

Recognition of sound environments and automatic adaptation (adaptive filtering)

source: Roland Mathijssen, Embedded Systems Institute, Eindhoven

Story: Workover Anno 2015

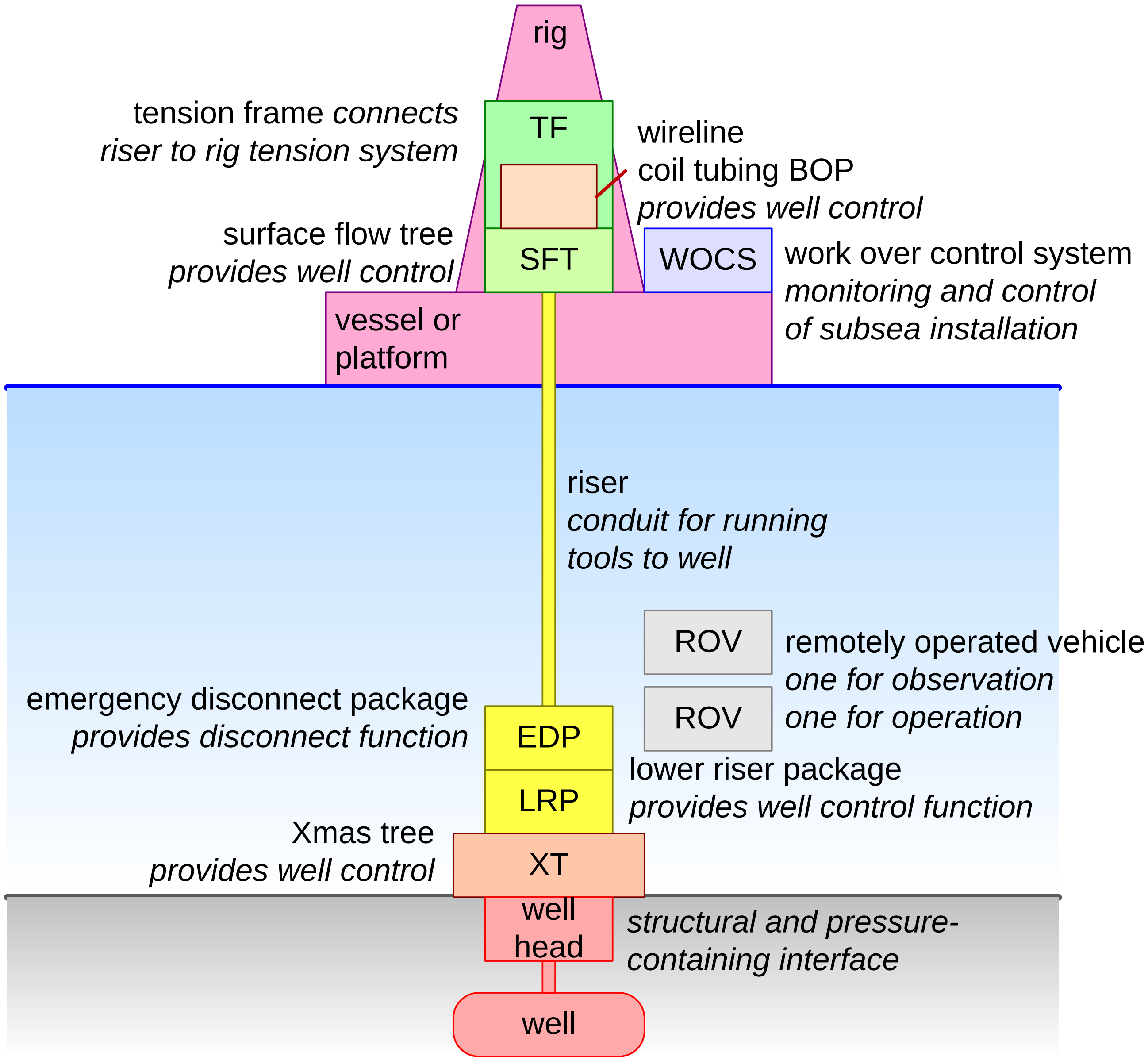
On September 4, Captain Frode Johansen was discussing the plans for the upcoming workover of South Gulfaks (see http://www.npd.no/en/Publications/Facts/Facts-2011/Chapter-10/Gullfaks-Sor-/) with his crew. Their vessel had been out of operation for recertification of the equipment much longer than anticipated, so there was a lot of pressure from Statoil on their schedule. Statoil sees diminishing production in several of the wells, so workover operations are urgent.

With the upcoming fall and winter storms, Frode hopes to finish the next three workover operations in a new record time. The equipment supplier had not only recertified all equipment, but also renovated parts of the riser system allowing for faster deployment and retrieval. The supplier tested and installed equipment in Horten. Tomorrow they will arrive in Sotra, their company support station. Here they will stock their fuel, food, coiled tubing, and other material.

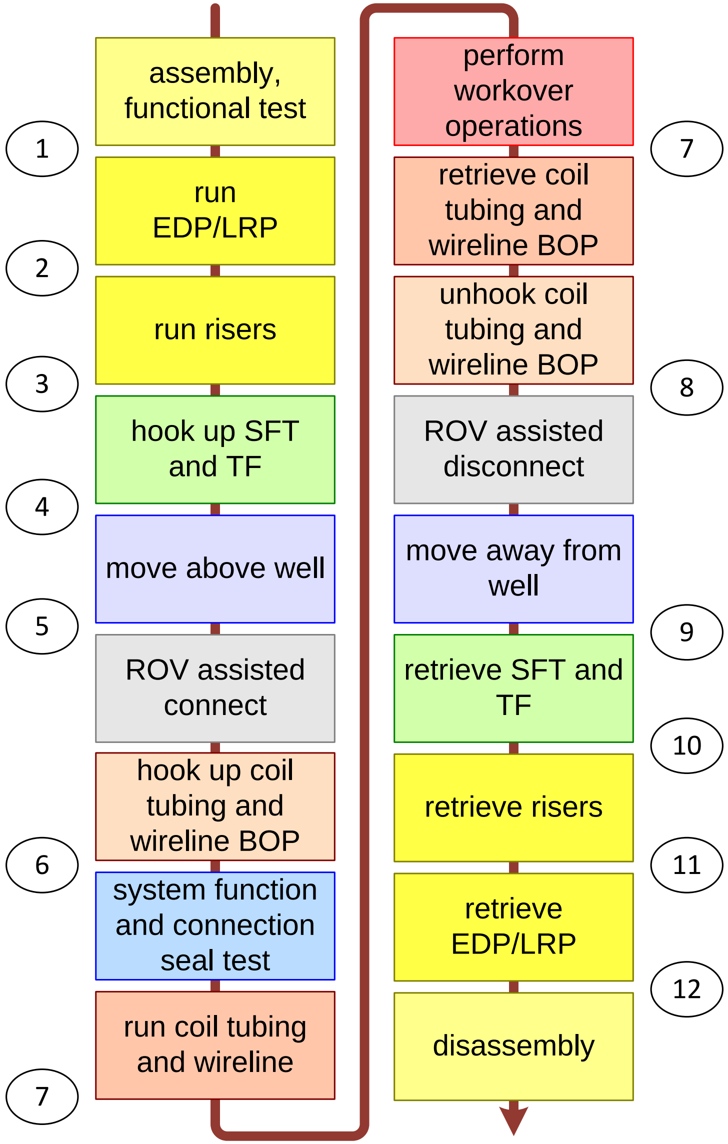
The weather forecast shows a depression close to Iceland that moves slowly in Norway's direction. If they can start deployment of the riser on September 7, then they probably finish the workover before the storm associated with the depression is too severe.

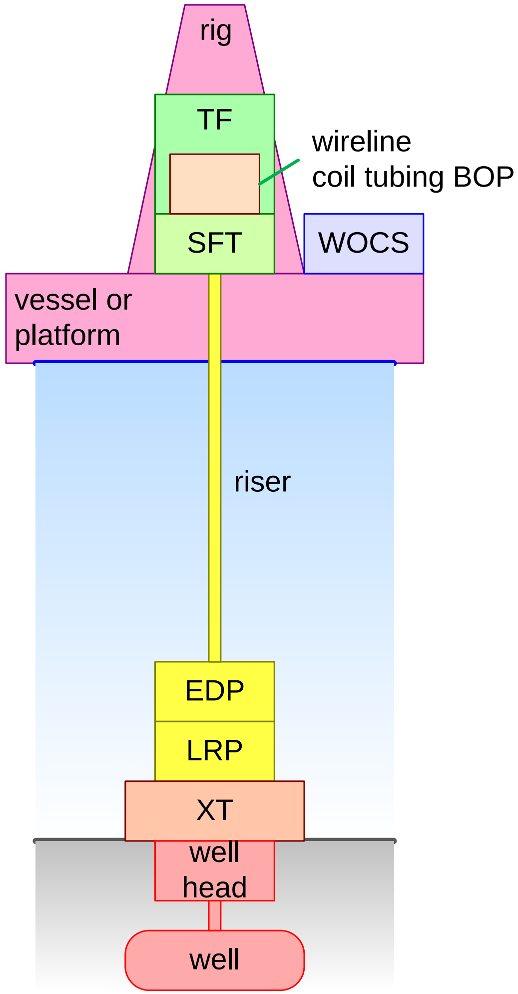
Since the schedule is so tight, the captain proposes to preassemble the riser system as far as possible while traveling. In addition, the accumulators can already be charged. The captain asks the foreman to make a schedule and to allocate tasks to the crew. Safety will be a key attention point, since working with such equipment with sea state 3 provides risks.

Annotated Physical Diagram of WorkOver System

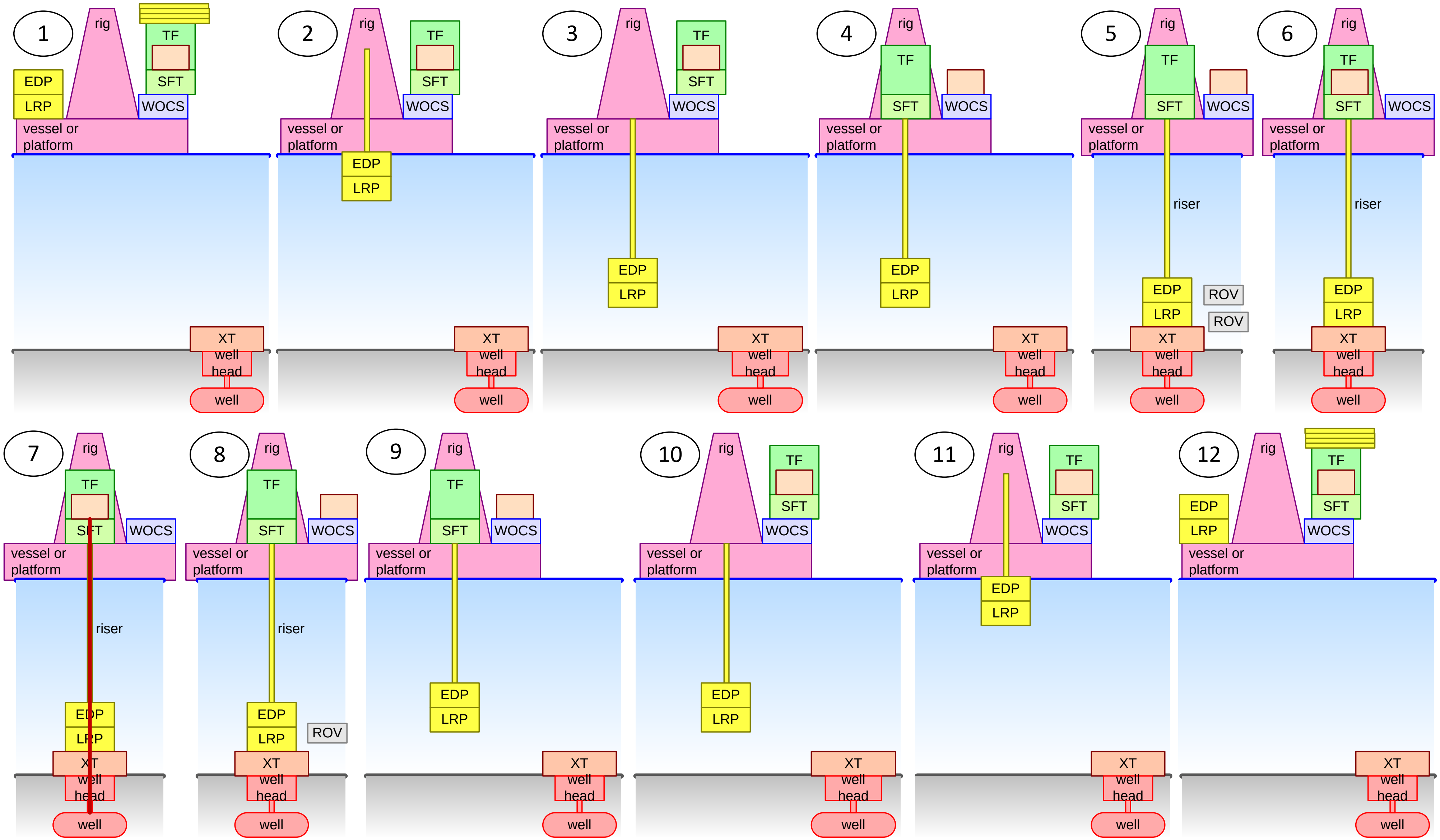


Typical Workover Operation





Typical Workover Operation as Cartoon



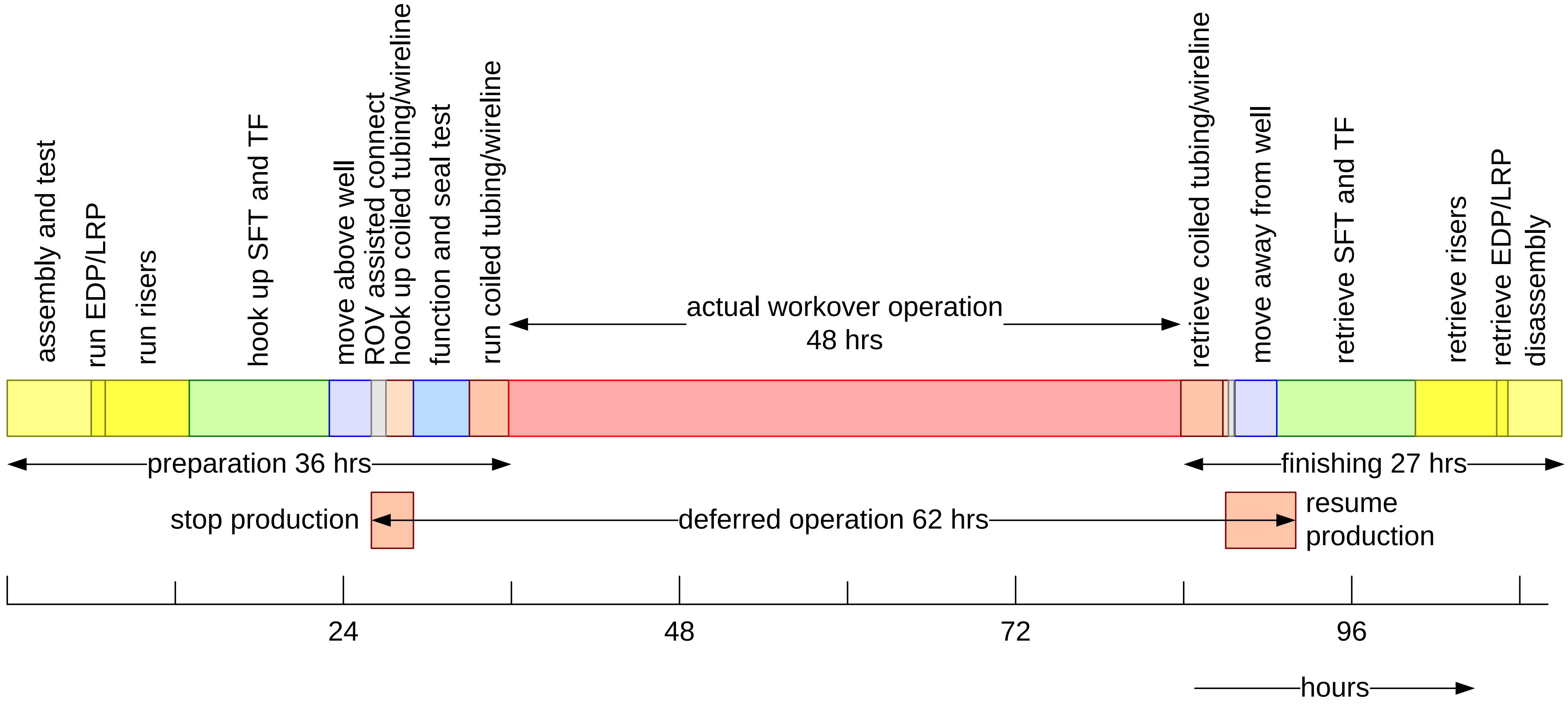
Typical Workover Operation on Timeline

assumptions:

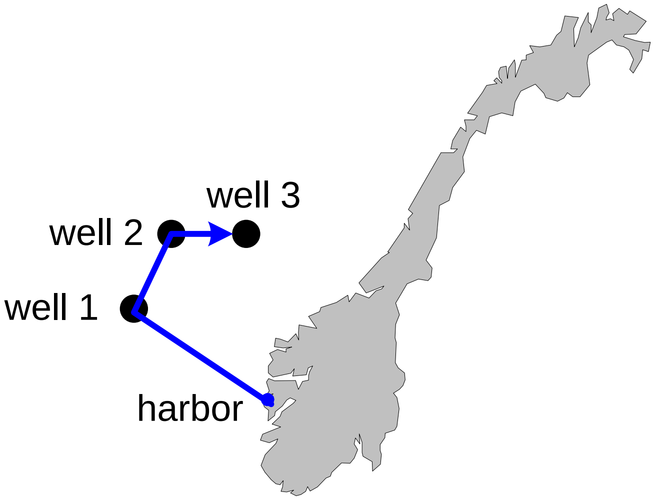
running and retrieving risers: 50m/hr

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

depth: 300m



Typical Workover Operation Context



zero order model

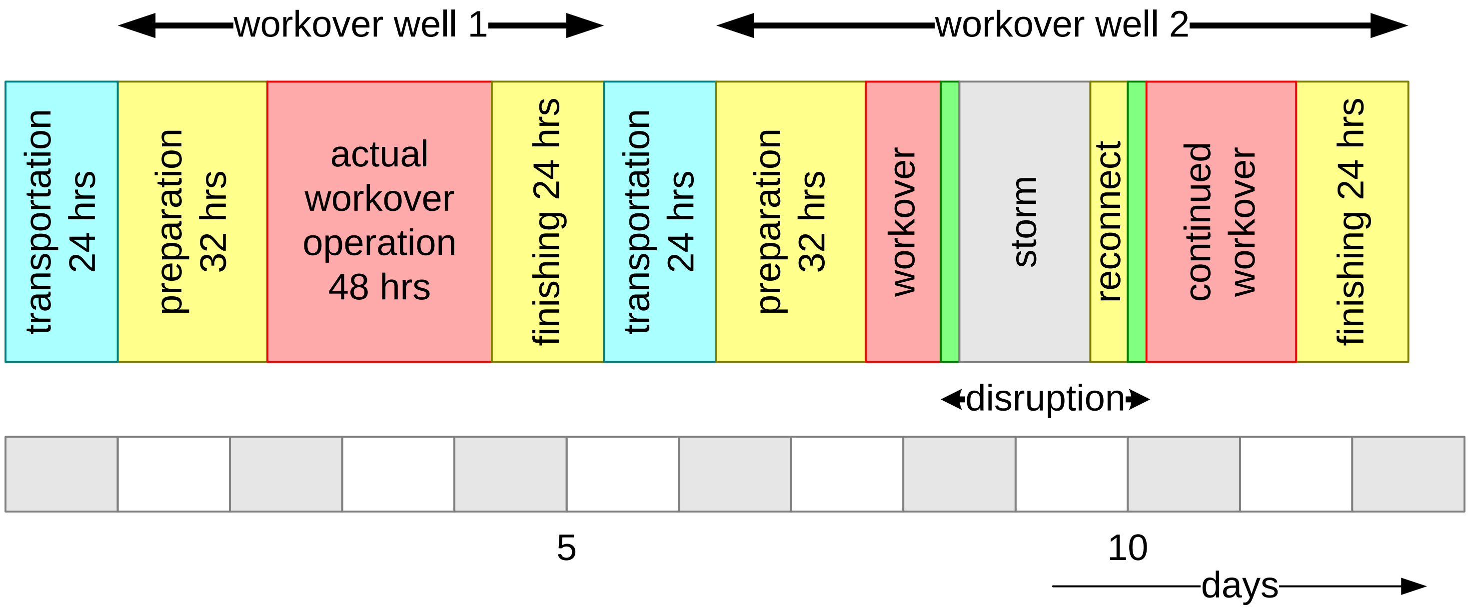
$t_{workover} =$

$t_{transportation} + t_{preparation} + t_{workover} +$
$t_{finishing}$

first order model

$t_{workover} =$

$t_{transportation} + t_{preparation} + t_{workover} +$
$t_{disruption} + t_{finishing}$



0-order Cost Model Workover Operation

workover cost per day	*assumed cost (MNoK)*
platform, rig	2
equipment	0.2
crew	0.1
total	2.3 MNoK/day

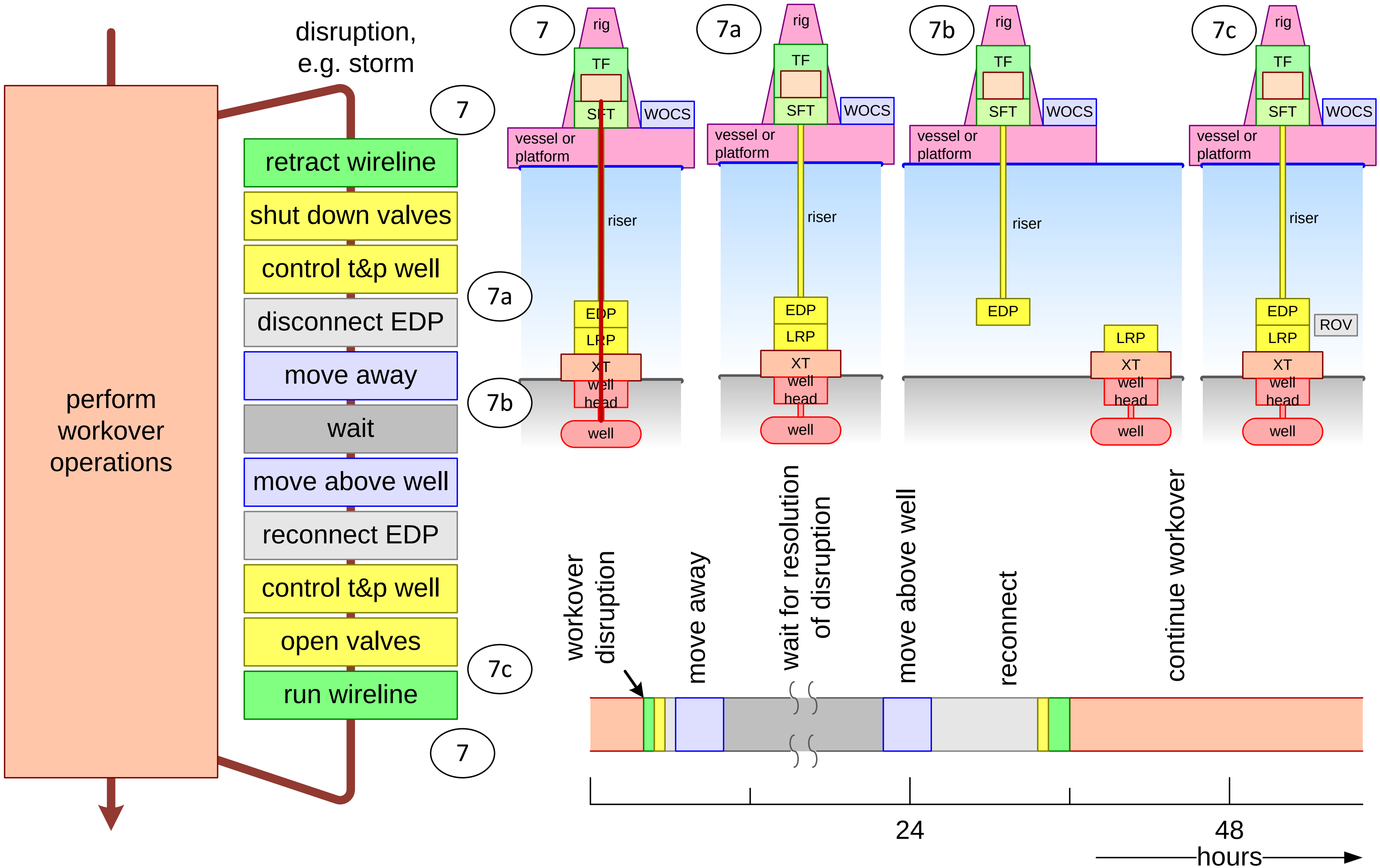
deferred operation per day	*assumed cost (MNoK)*
production delay	0.1
ongoing cost operation	0.2
total	0.3 MNoK/day

workover duration	*estimated duration (hours)*	*production loss*
transportation	24	
preparation	36	6
workover	48	48
finishing	27	8
total	135 (5.6 days)	62 (2.6 days)

$$cost = cost_{workover/day} * t_{workover} + cost_{deferred\ op./day} * t_{deferred\ op.}$$

$$\sim= 2.3 * 5.6 + 0.3 * 2.6 \sim= 14\ \text{MNoK / workover}$$

Disruption Workover Operation



First order Cost Model Workover Operation

workover cost per day	*assumed cost (MNoK)*
platform, rig	2
equipment	0.2
crew	0.1
total	2.3 MNoK/day

deferred operation per day	*assumed cost (MNoK)*
production delay	0.1
ongoing cost operation	0.2
total	0.3 MNoK/day

workover duration	*estimated duration (hours)*	*production loss*
workover 0-order	135 (5.6 days)	62 (2.6 days)
average disruption		
duration	72	
overhead	11	
disruption frequency	0.3	
1^{st} order disruption	83*0.3=	
correction	27	27
total	162 (6.7 days)	89 (3.7 days)

1^{st} order cost = $cost_{workover/day} * t_{workover} + cost_{deferred\ op./day} * t_{deferred\ op.}$

~= 2.3 * 6.7 + 0.3 * 3.7 ~= 16.5 MNoK / workover

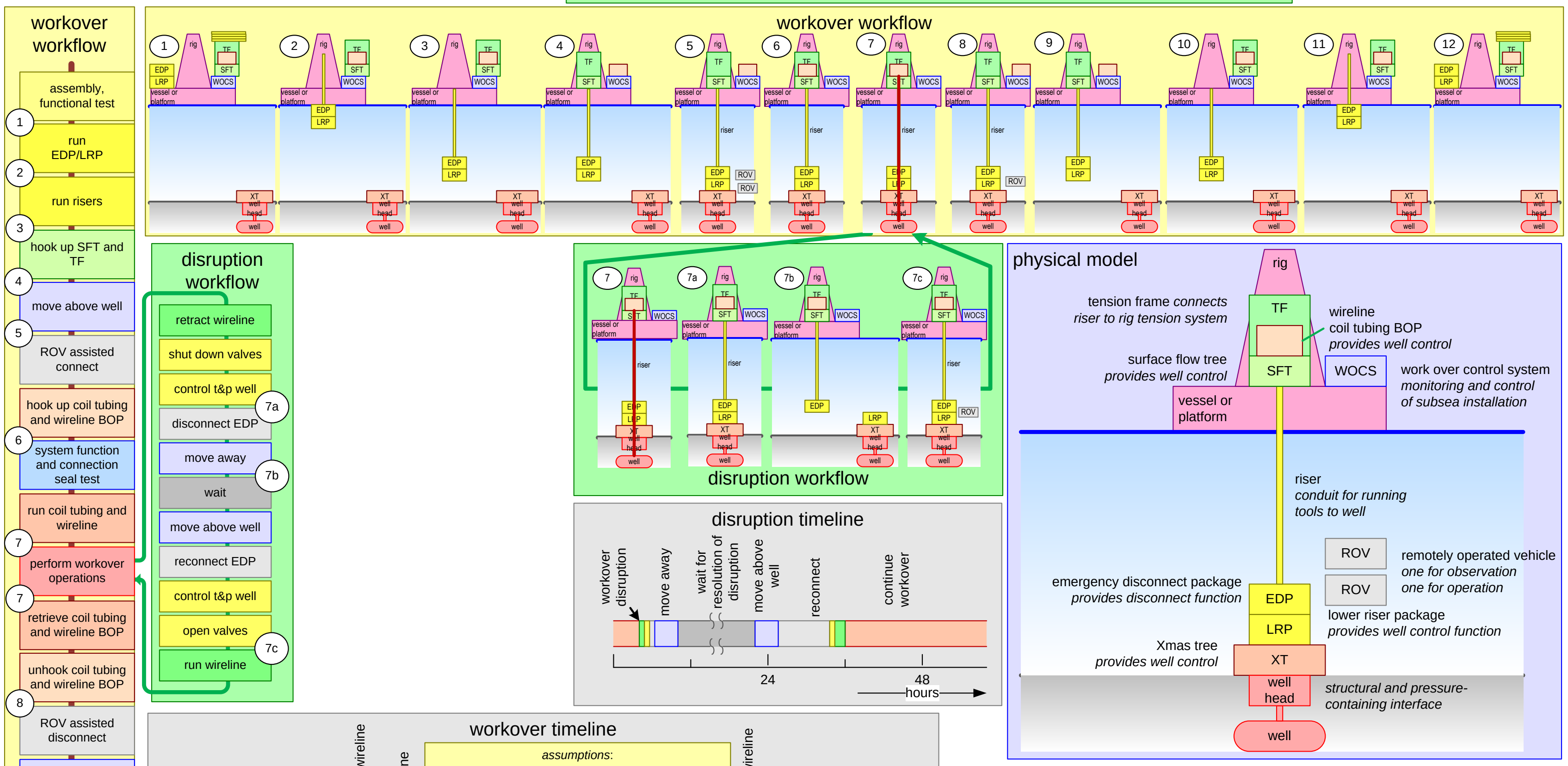
0-order cost ~= 14 MNoK ; disruption cost ~= 2.5 MNoK

Workover Example Summary

Workover operation; architecture overview

This A3 based on the work of SEMA participants: Martin Moberg[a], Tormod Strand[a], Vazgen Karlsen[f], and Damien Wee[f], and the master project paper by Dag Jostein Klever[f]. [a]Aker Solutions, [f]FMC Technologies

version 2.2 Gerrit Muller



0-order workover cost estimate

workover cost per day	assumed cost (MNoK)
platform, rig	2
equipment	0.2
crew	0.1
total	2.3 MNoK/day

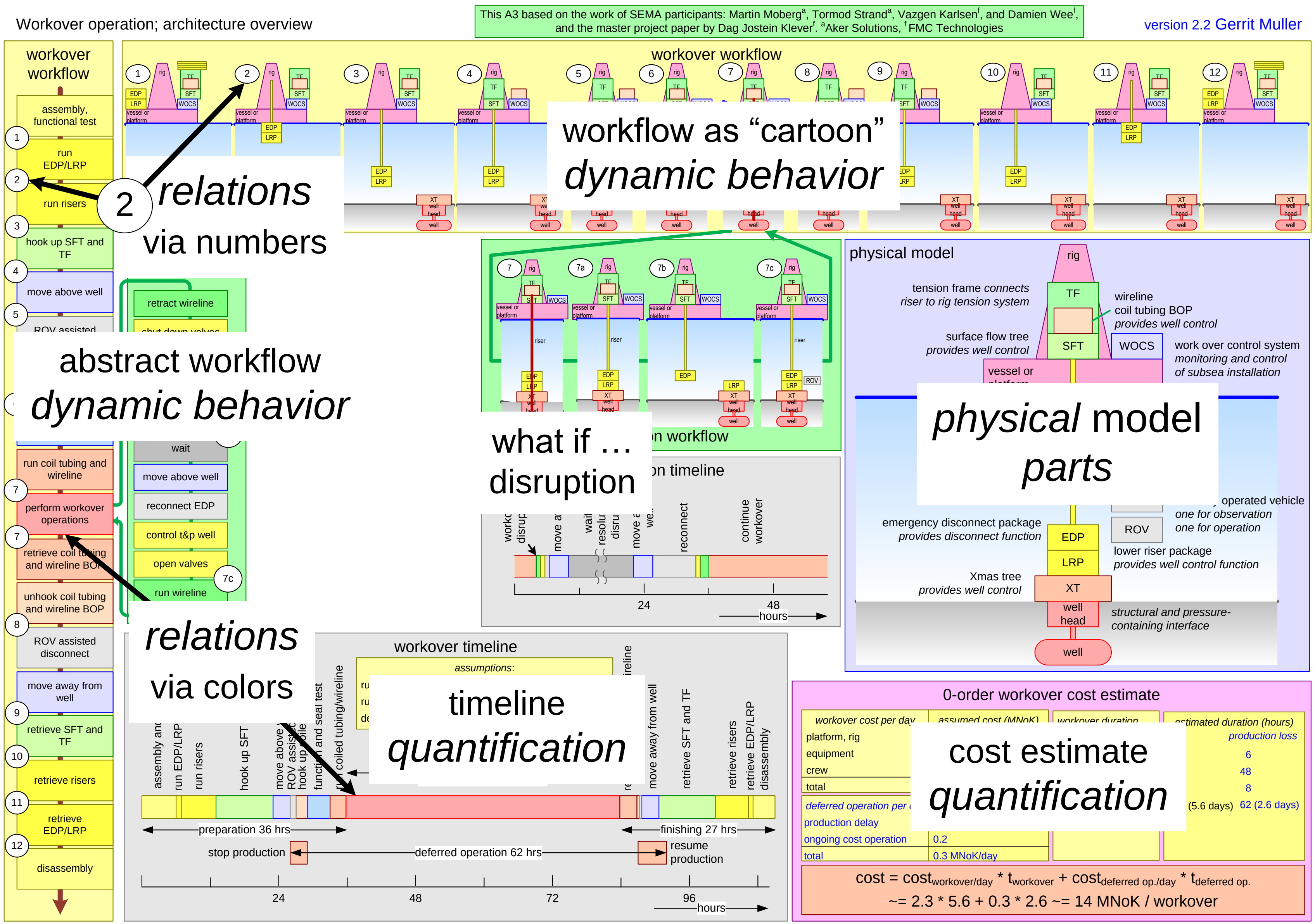
deferred operation per day	assumed cost (MNoK)
production delay	0.1
ongoing cost operation	0.2
total	0.3 MNoK/day

workover duration	estimated duration (hours)	production loss
transportation	24	
preparation	36	6
workover	48	48
finishing	27	8
total	135 (5.6 days)	62 (2.6 days)

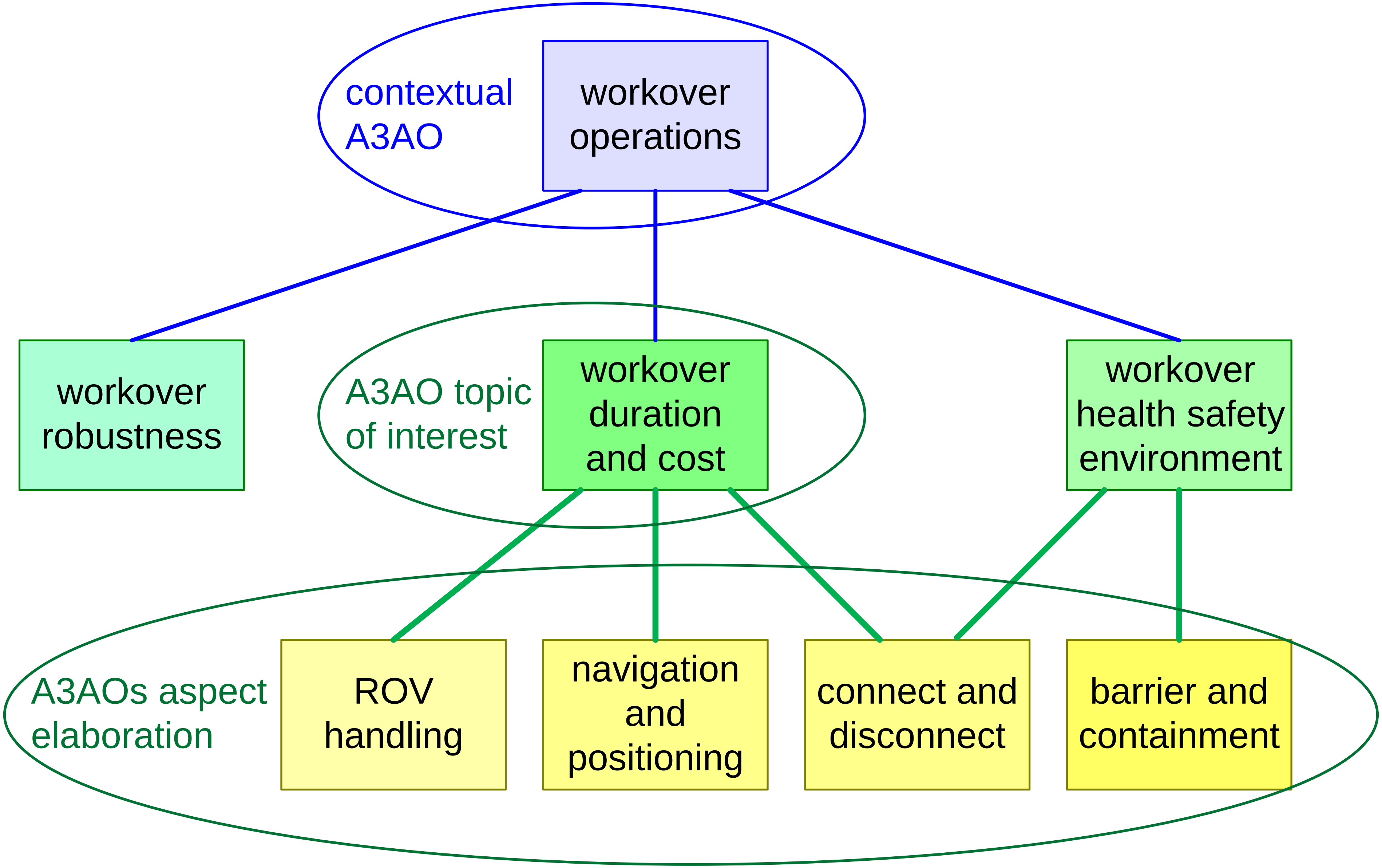
$$cost = cost_{workover/day} * t_{workover} + cost_{deferred\ op./day} * t_{deferred\ op.}$$

$$\approx 2.3 * 5.6 + 0.3 * 2.6 \approx 14\ MNoK / workover$$

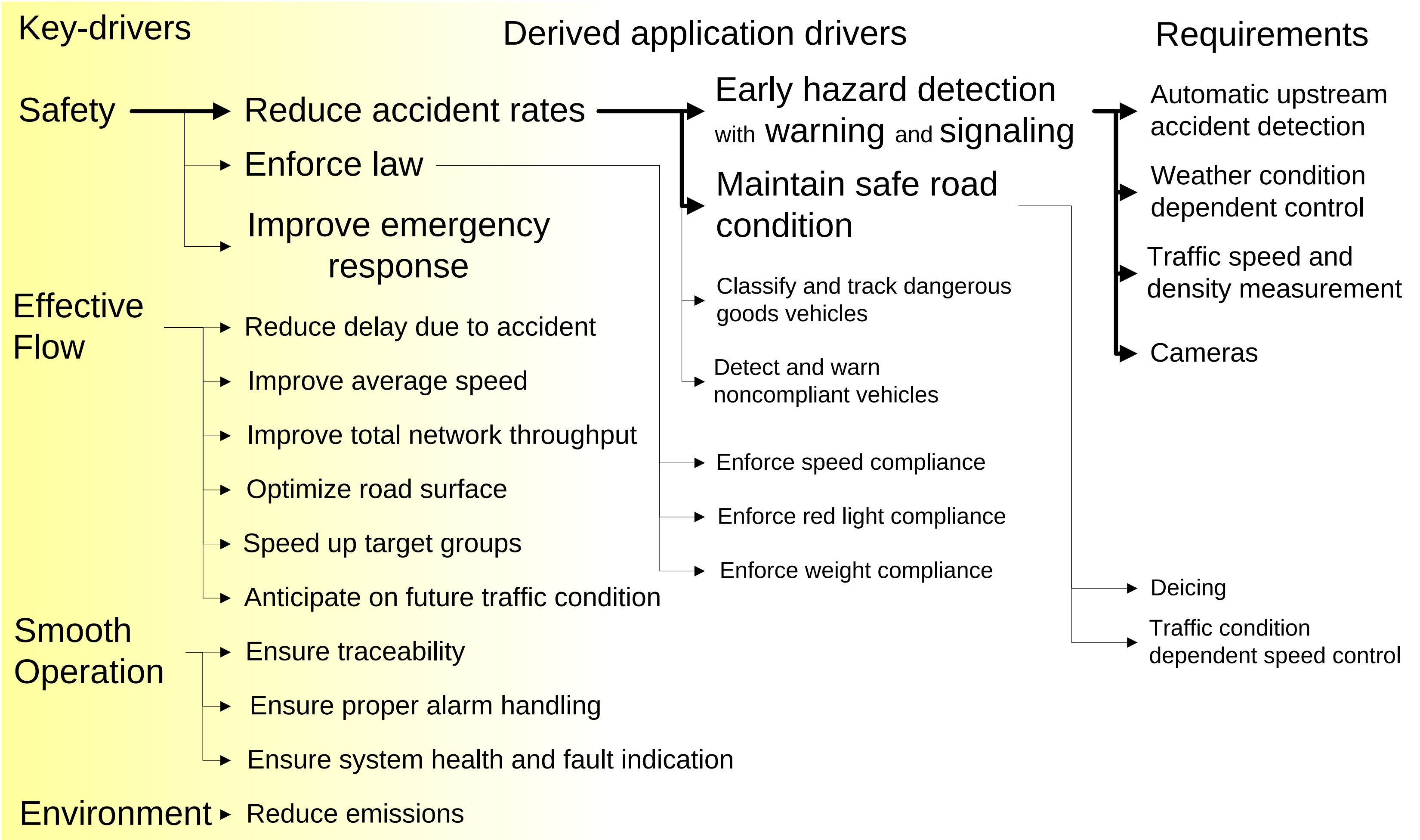
A3 Architecture Overview



Levels of A3s

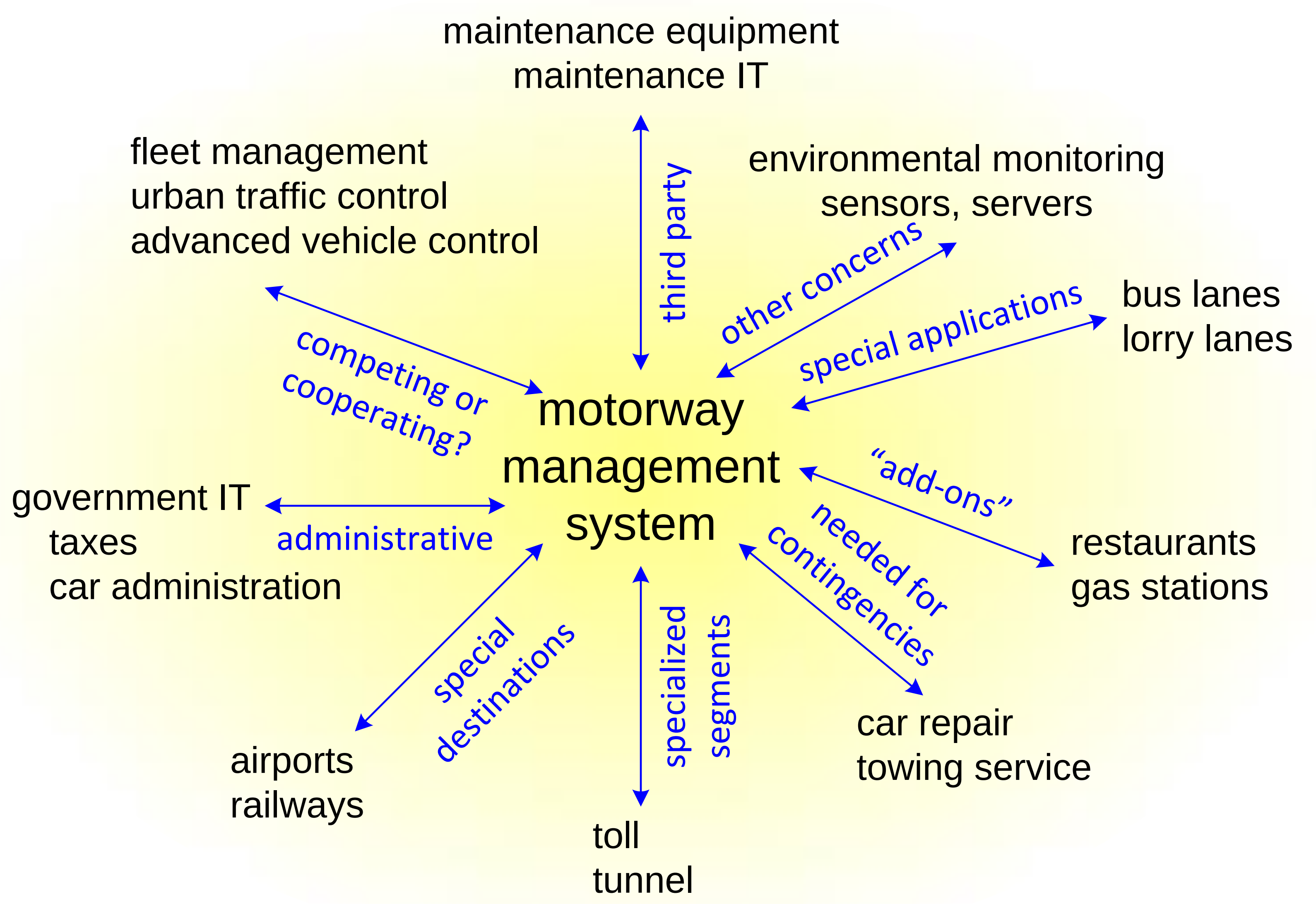


Example Graph for Motorway Management System

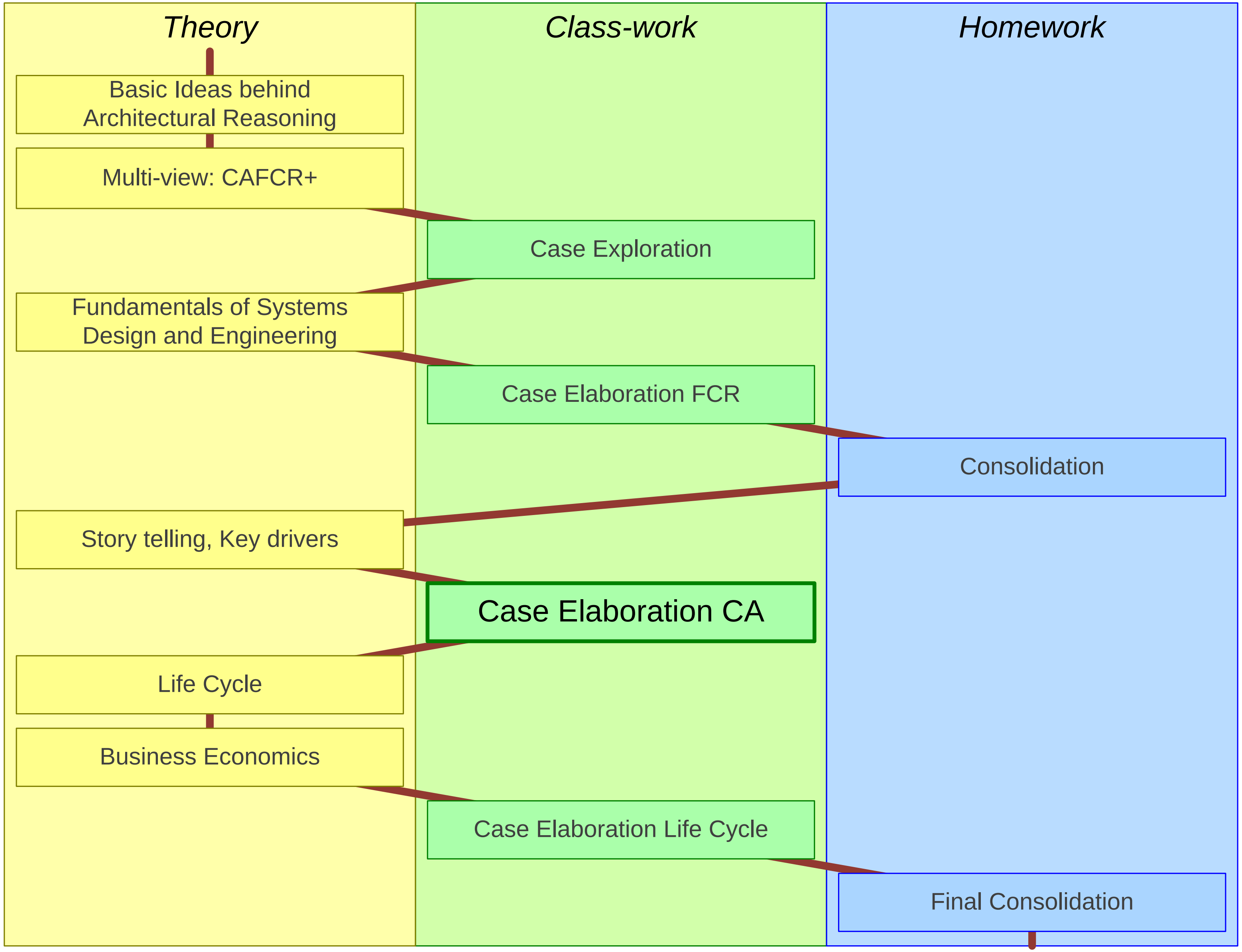


Note: the graph is only partially elaborated for application drivers and requirements

Example Context of Motorway Management System



Case Elaboration CA-views



Class-work Day 3: Elaboration CA-views

Continue second iteration by elaborating CA views

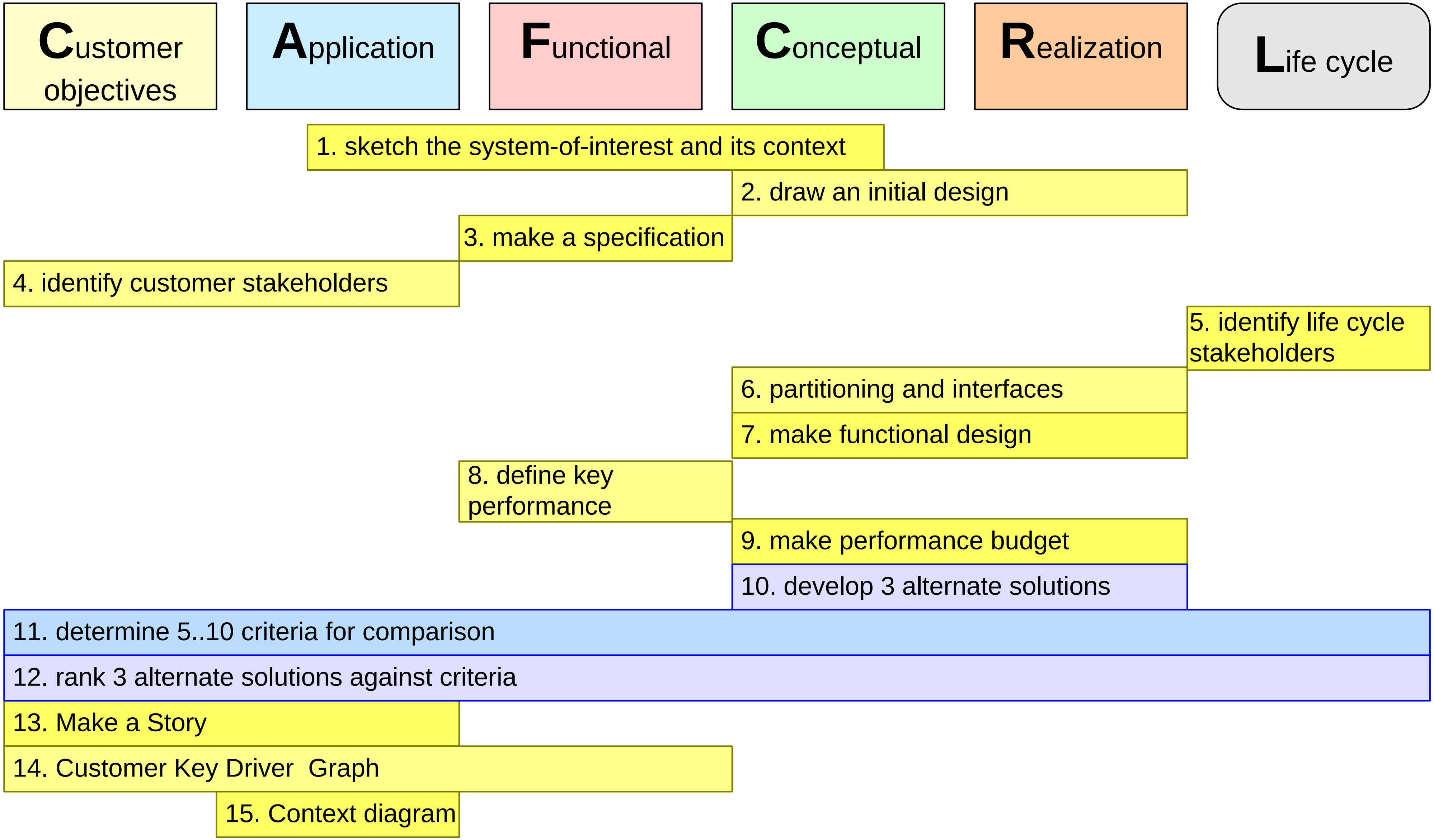
Use time-boxes of about 40 minutes

- Develop a story that helps you to understand the customer better and that facilitates analysis of specification and design
  - Verify your story against the story criteria
- Develop a customer key driver graph
  - Start with Key Performance Parameters and ask “why (is this needed)” repeatedly.

Use time-box of about 20 minutes for the remaining task

- Make a context diagram

Class-work Day 3 mapped on CAFCR



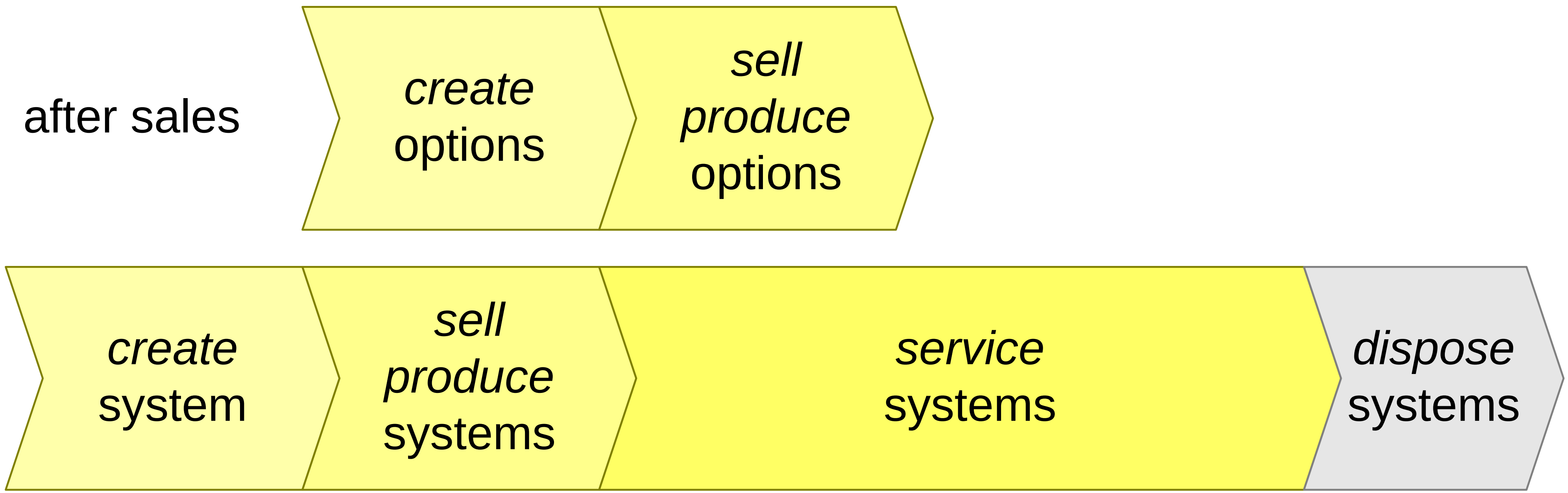
Theory Block: Life Cycle

Life Cycle

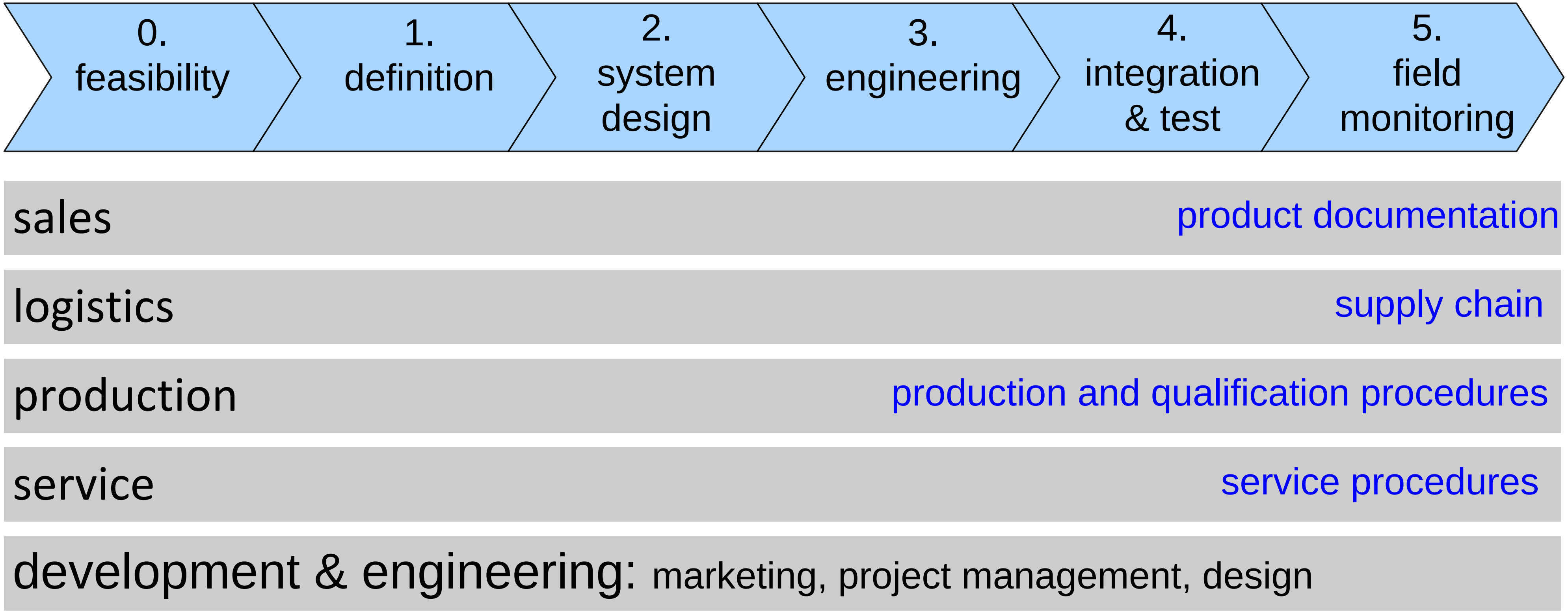
Conception and Development

From Deployment to Decommissioning and Disposal

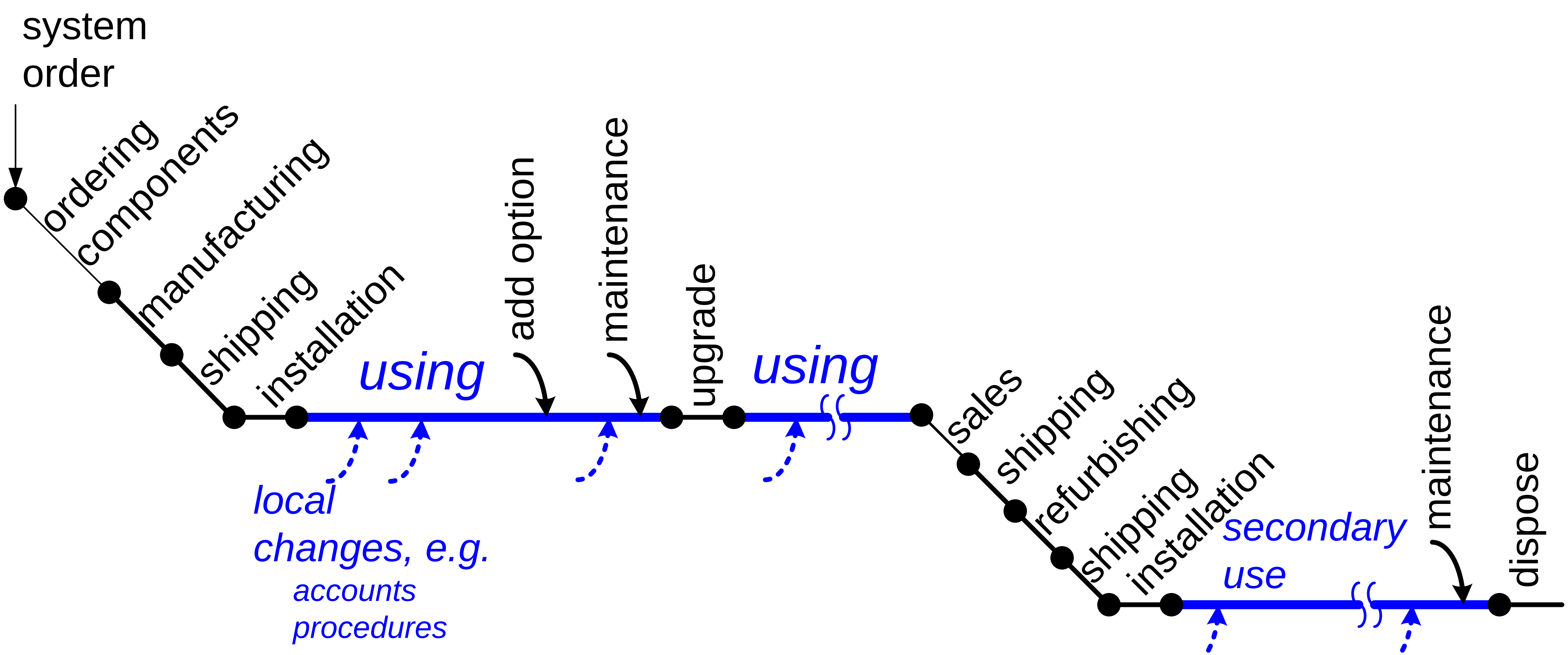
Product Life Cycle



System Development



Individual System Life Cycle



Theory Block: Business Economics

Simple Cash flow model

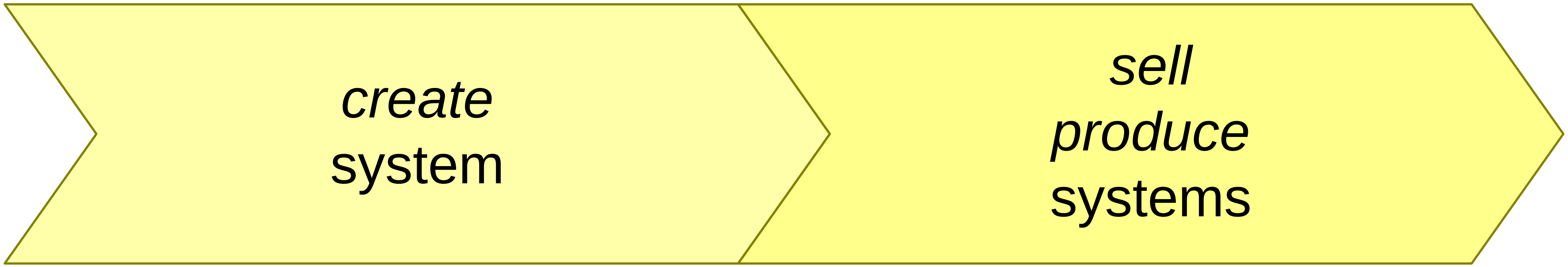
Business models

Cost of Ownership

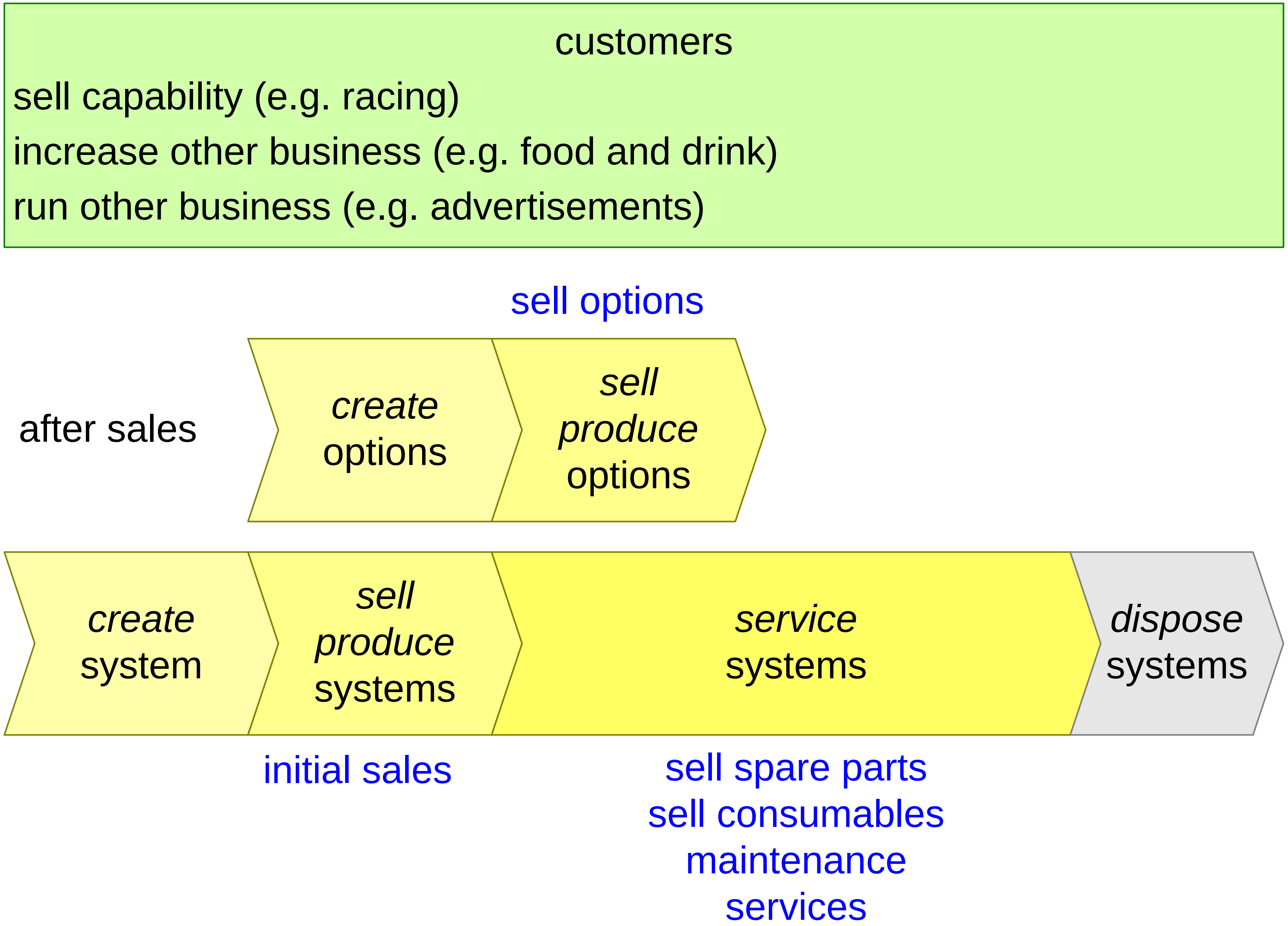
Expenses and Income

investment:
  development cost

expenses:
  purchase materials
  labour
income:
  system sales



Business Models



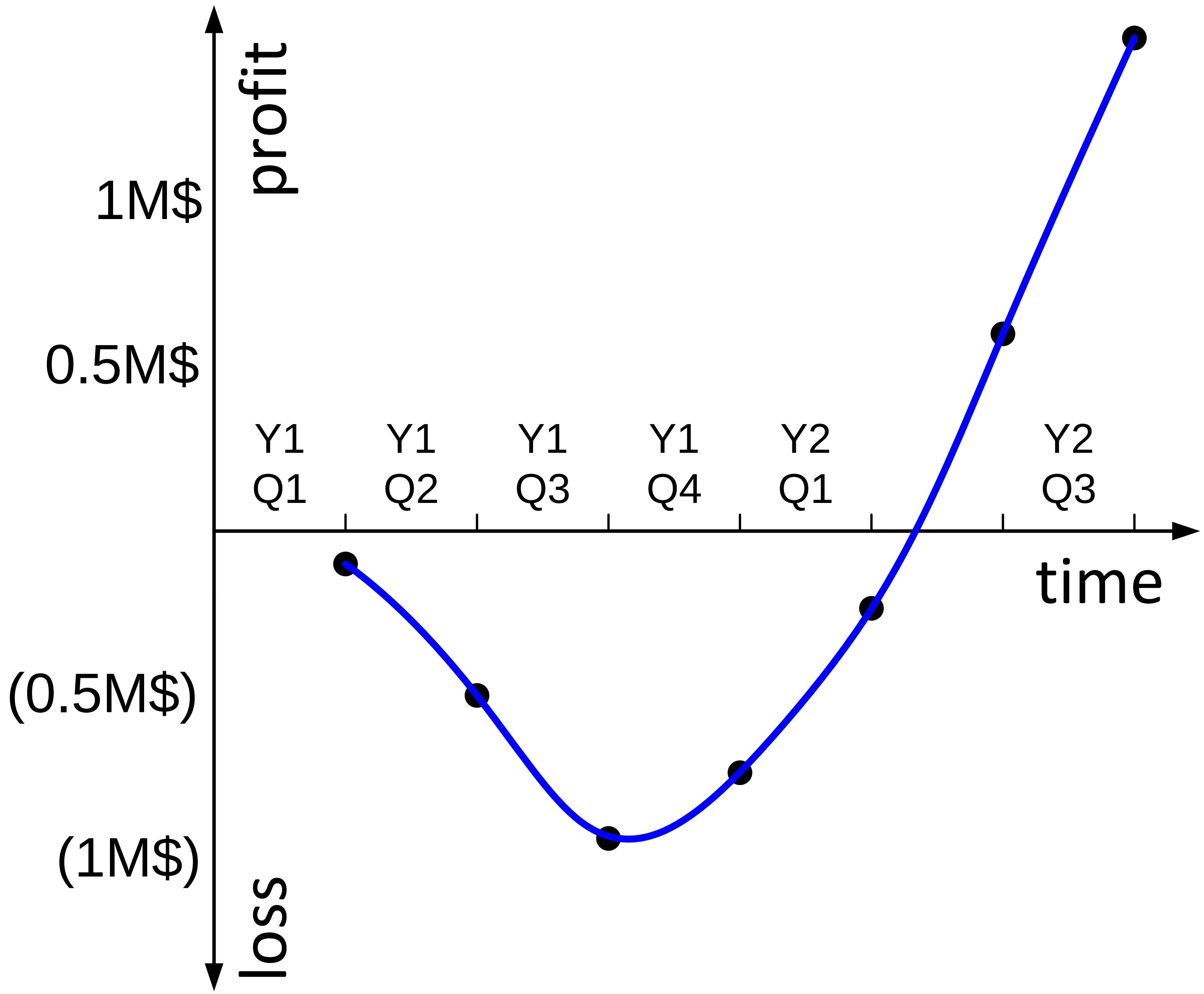
Example Cash Flow calculation

	Y1 Q1	Y1 Q2	Y1 Q3	Y1 Q4	Y2 Q1	Y2 Q2	Y2 Q3
investments	100k$	400k$	500k$	100k$	100k$	60k$	20k$
sales volume (units)	-	-	2	10	20	30	30
material & labour costs	-	-	40k$	200k$	400k$	600k$	600k$
income	-	-	100k$	500k$	1000k$	1500k$	1500k$
quarter profit (loss)	(100k$)	(400k$)	(440k$)	200k$	500k$	840k$	880k$
cumulative profit	(100k$)	(500k$)	(940k$)	(740k$)	(240k$)	600k$	1480k$

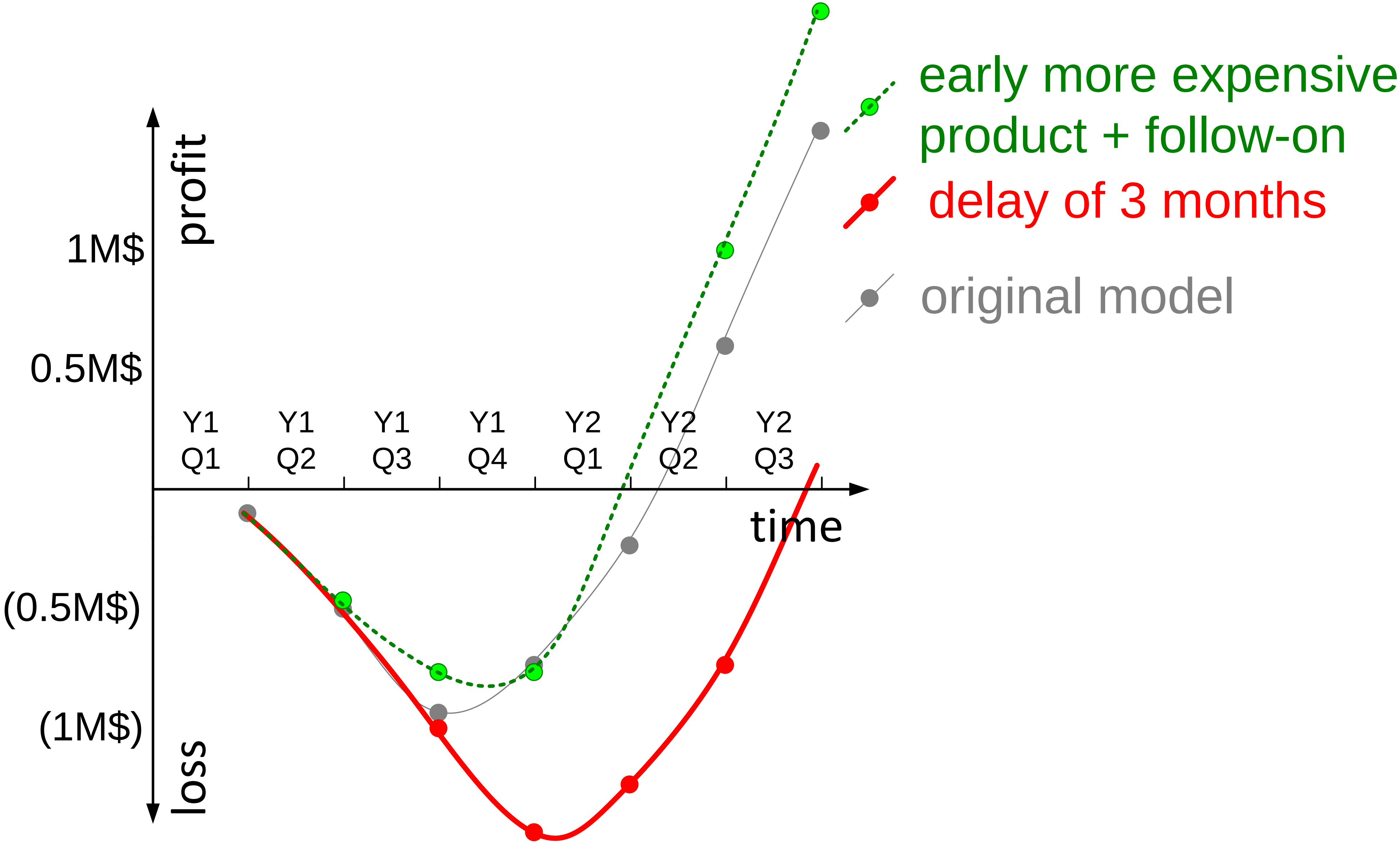
cost price / unit = 20k$
sales price / unit = 50k$

variable cost = sales volume * cost price / unit
income = sales volume * sales price / unit
quarter profit = income - (investments + variable costs)

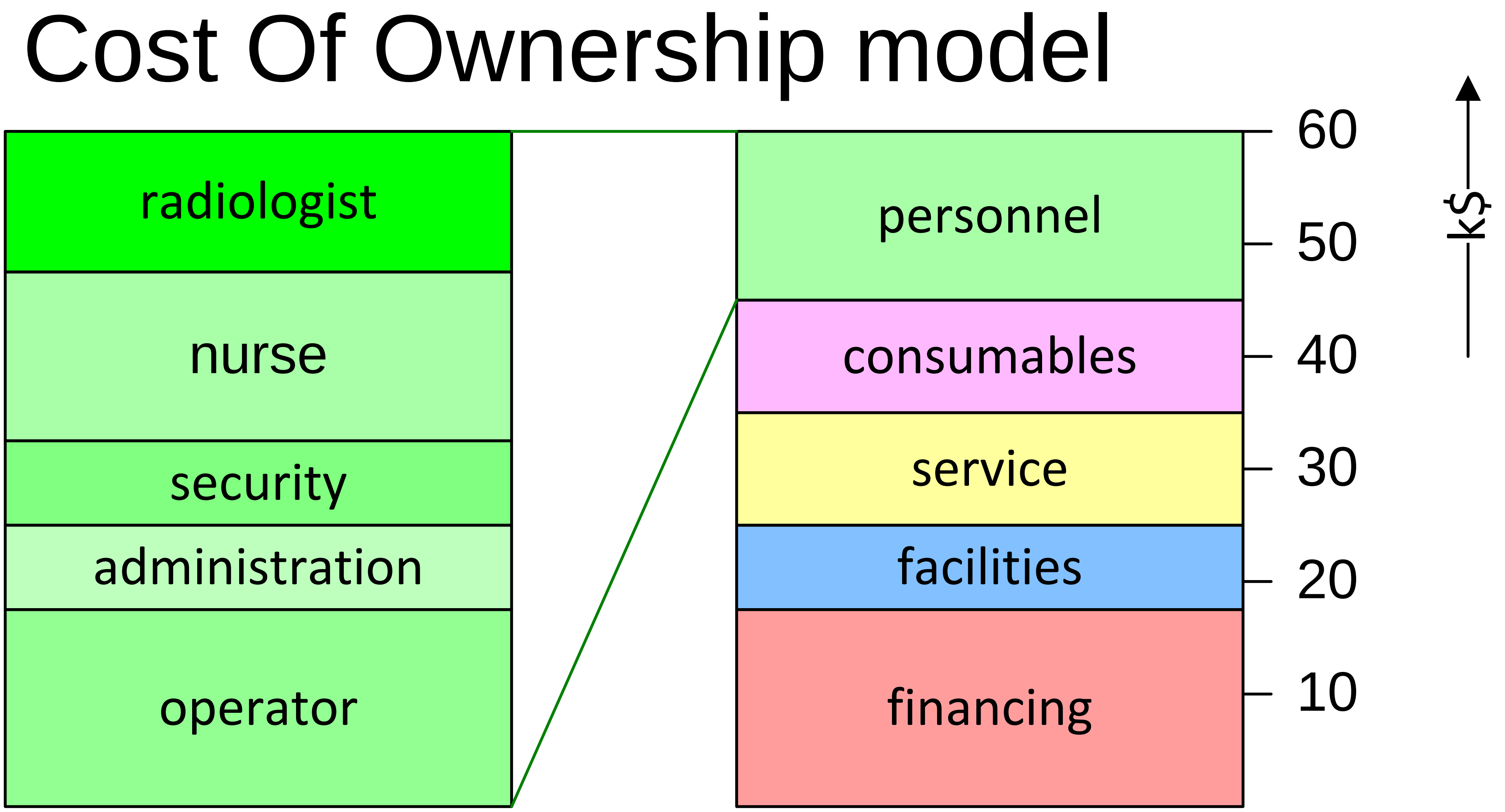
Cash Flow as Function of Time



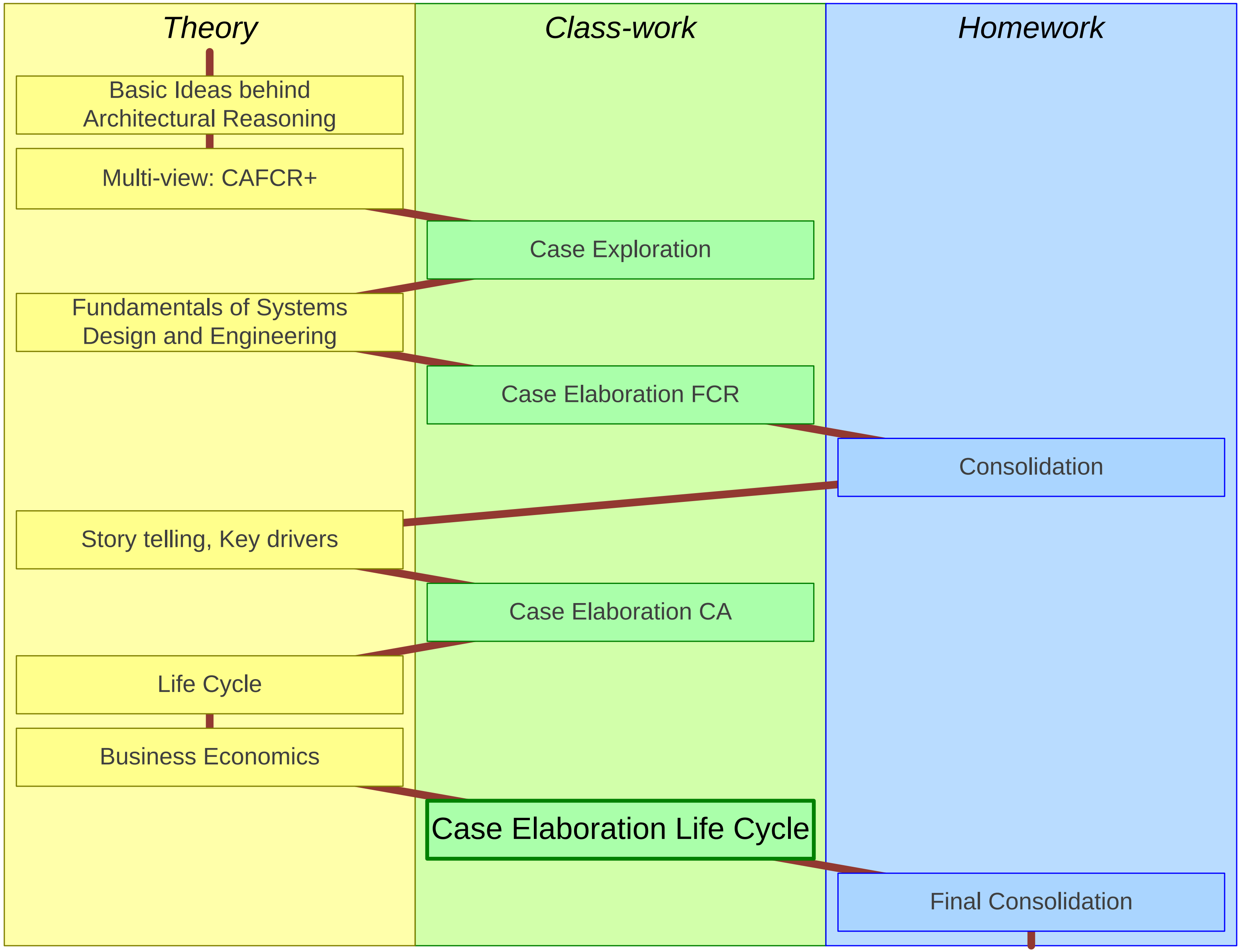
What If...?



early more expensive product + follow-on
delay of 3 months
original model
profit
loss
1M$
0.5M$
(0.5M$)
(1M$)
Y1 Q1
Y1 Q2
Y1 Q3
Y1 Q4
Y2 Q1
Y2 Q2
Y2 Q3
time


Cost Of Ownership model
radiologist
nurse
security
administration
operator
personnel
consumables
service
facilities
financing
60
50
40
30
20
10
k$

Case Elaboration Life Cycle-view



Class-work Day 4: Elaboration Life Cycle

Continue second iteration by elaborating life cycle view

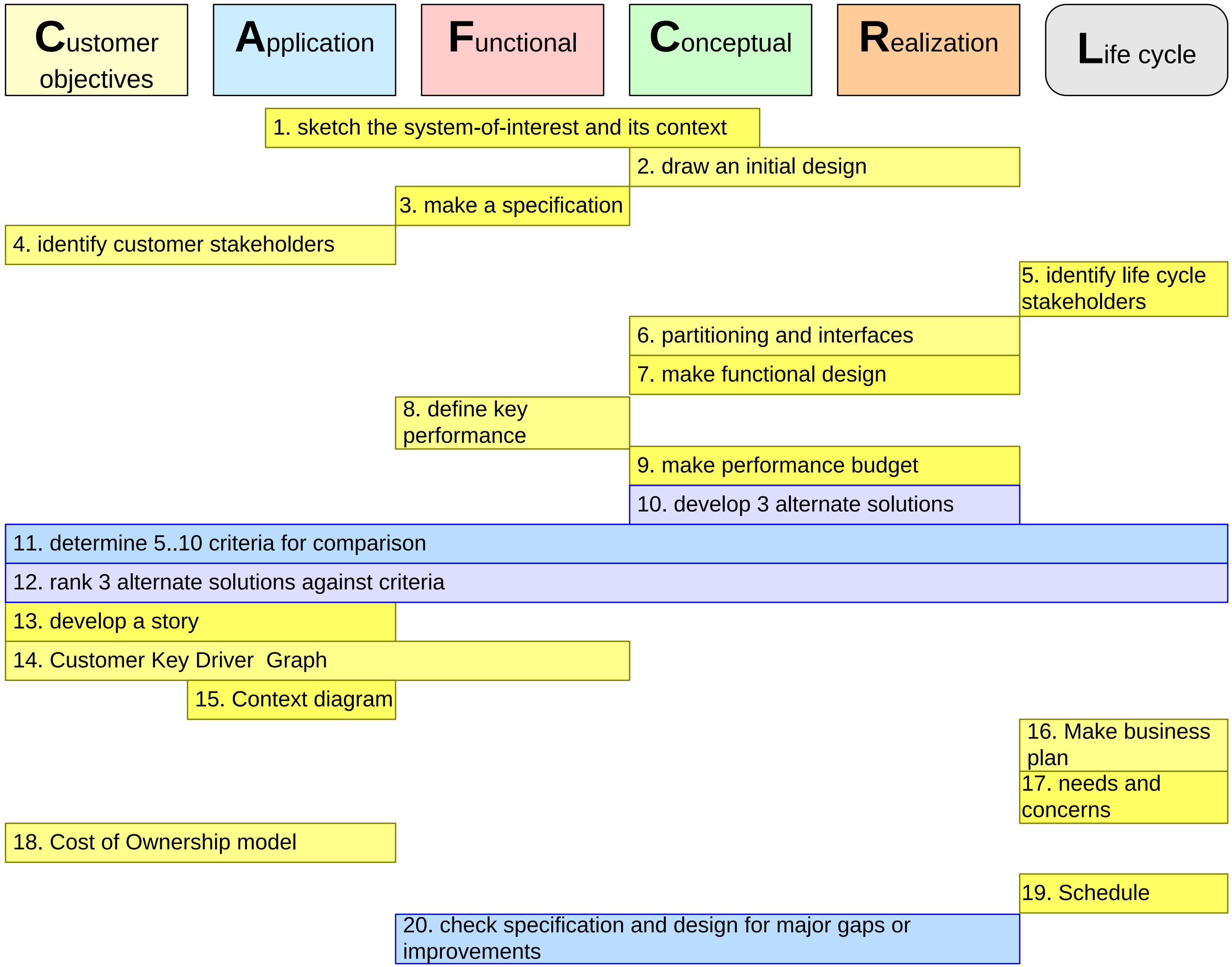
Use time-boxes of about 30 minutes

- Develop a business plan for your company
  - determine your role in the value chain
  - determine income, expenses, and investments
  - estimate cash flow as function of time
- Identify needs and concerns from life cycle stakeholders
  - determine life cycle key drivers and key performance parameters
- Make a Cost of ownership estimate for customers

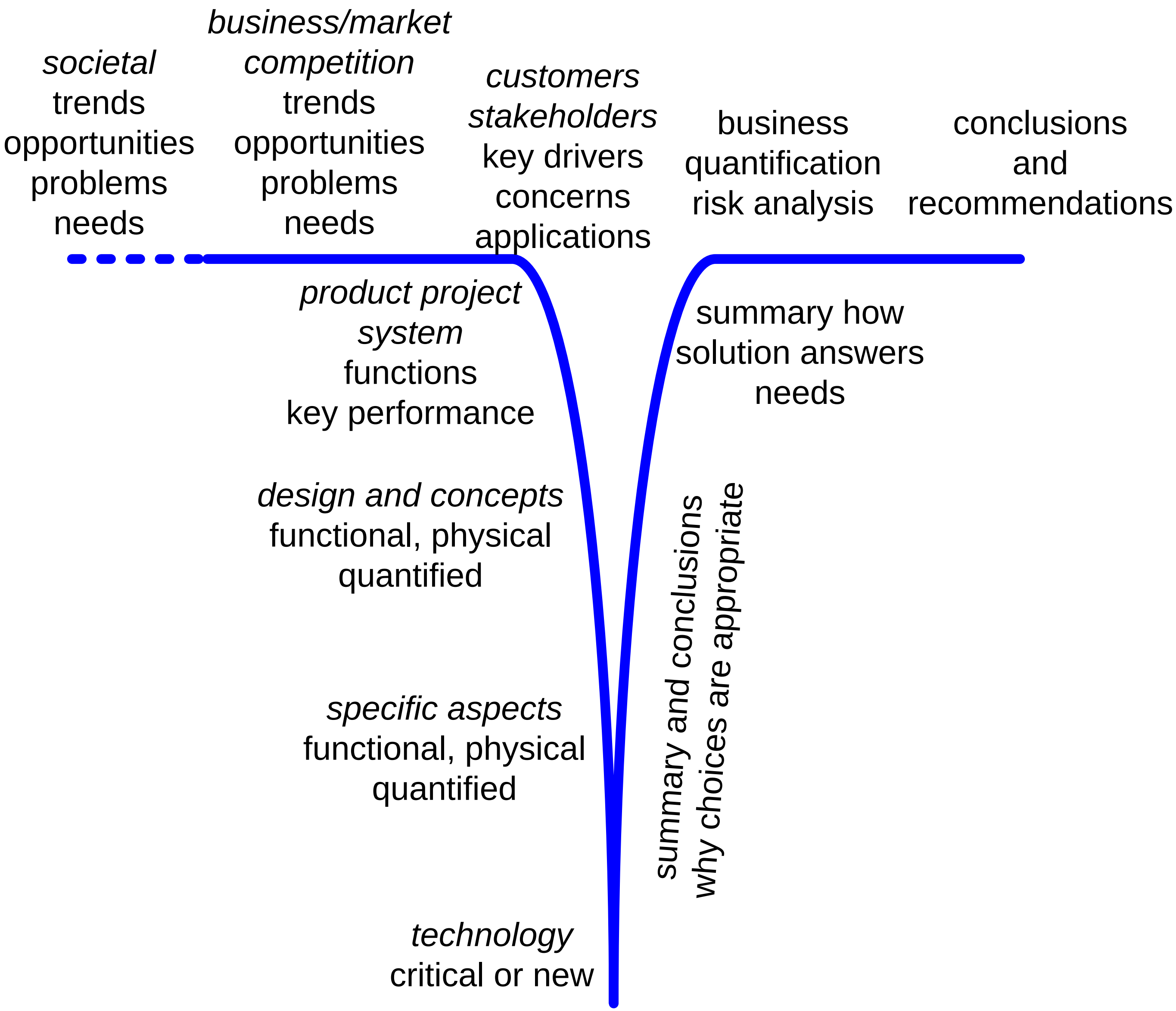
Use time-box of about 20 minutes for the remaining task

- Make a schedule for development and start of deployment

Class-work Day 4 mapped on CAFCR



T-shaped Presentation



Homework after Day 4

Check specification and design for major gaps or improvements

Transform your results in electronic form (e.g., PowerPoint or Visio)

Make a T-shaped presentation for your management, covering all 4 days; its main purpose is to make an initial go/no-go decision

Submit this presentation via Canvas

Write an individual reflection report, max 2 A4s:

- What are your main learning points?
- What aspects deserve most attention in next phase of your project? Explain why.

Submit this individual reflection report via Canvas

Summary Architectural Reasoning

Objective: Awareness

Make engineering students aware of:

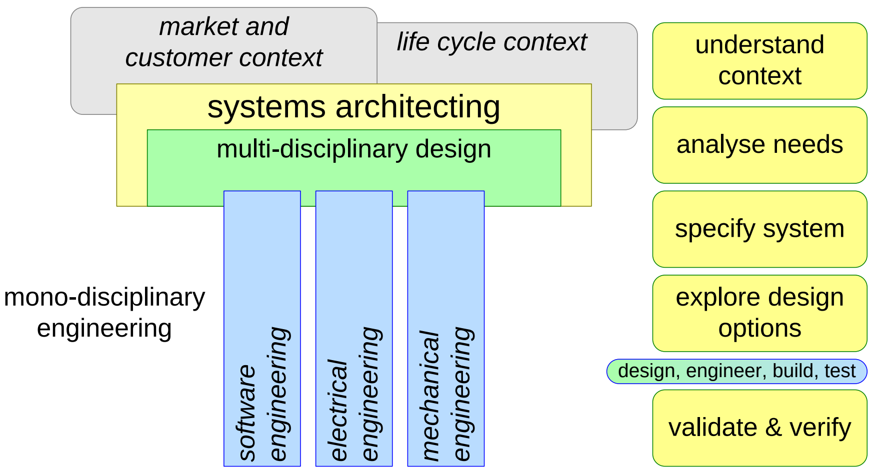
- other disciplines
- “systems” design and engineering
- customers and life cycle as contexts of the system
- the impact of needs on design decisions

Objective: Experience

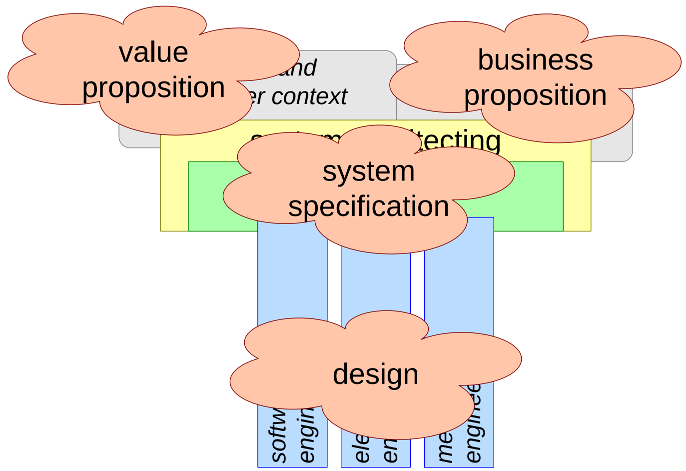
Let engineering students apply and experience:

- multiple views
- visualizations
- simplification
- iteration
- quantification

Stretch, Stretch, Stretch

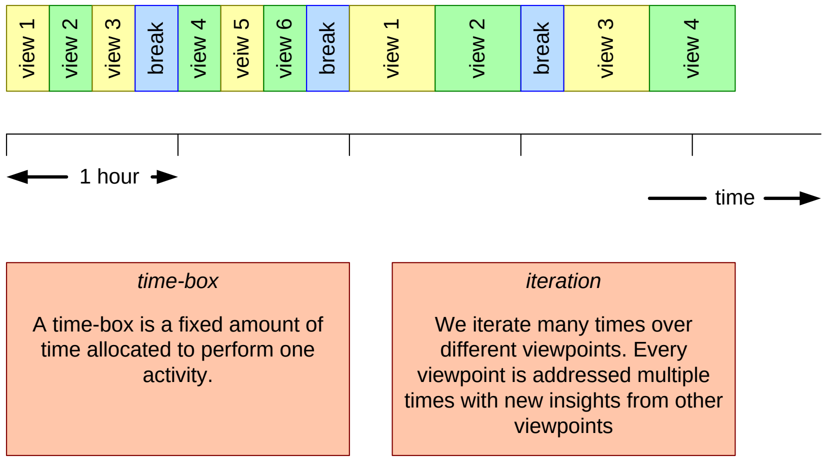


Main Deliveries

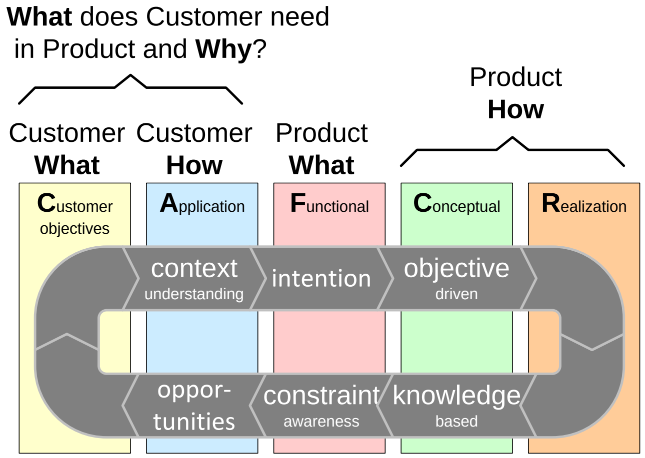


Summary CAFCR

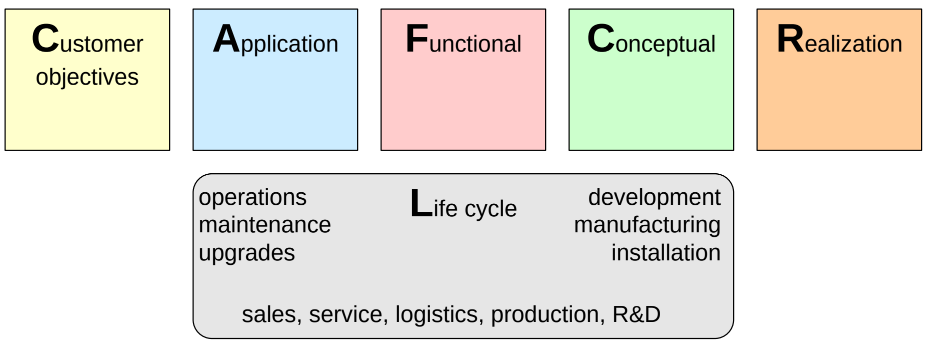
Time-boxing and Iteration



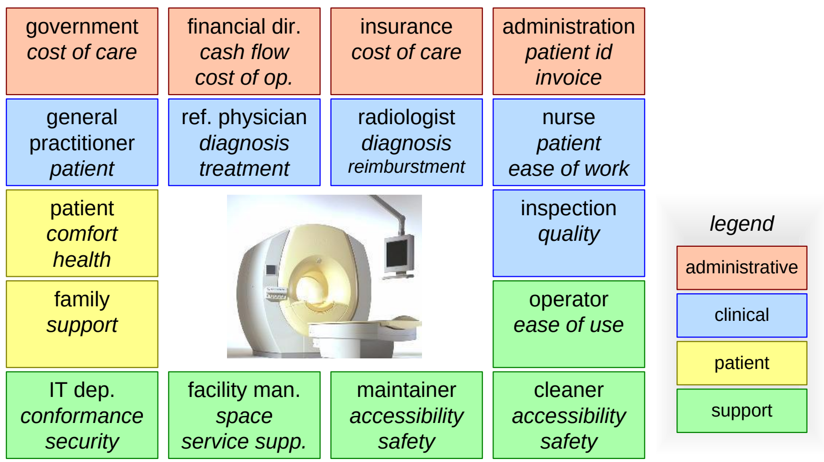
CAFCR views



CAFCR+

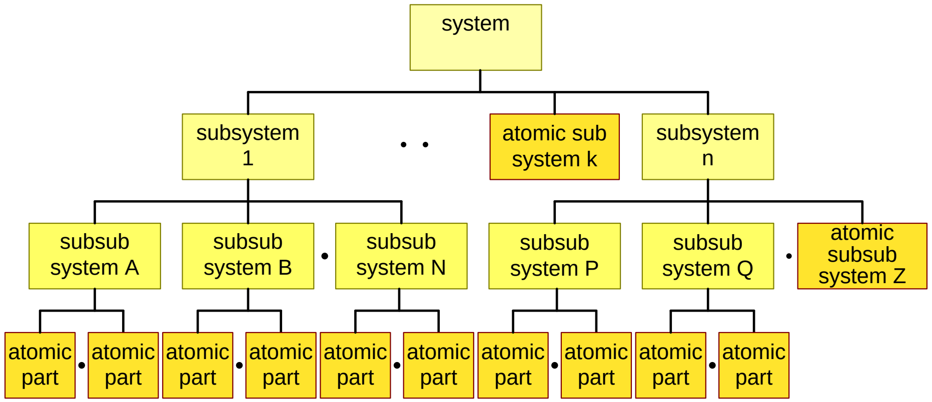


Stakeholders and Concerns

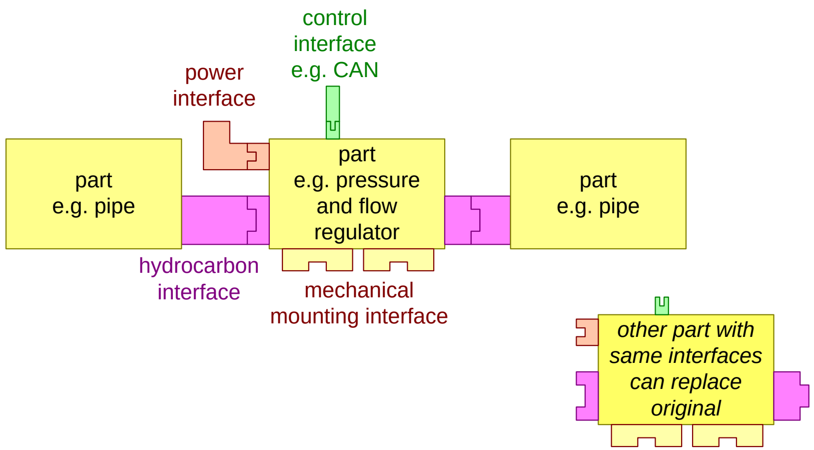


Summary Fundamentals Systems Engineering & Design

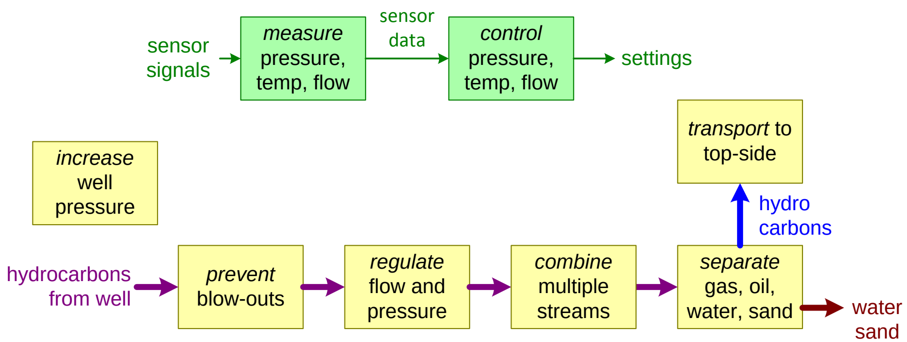
Partitioning



Interfaces



Functional Model



Key Performance Parameters

Key Performance Parameters are **SMART**

the most important

defined in use case:

the circumstances where the performance is valid

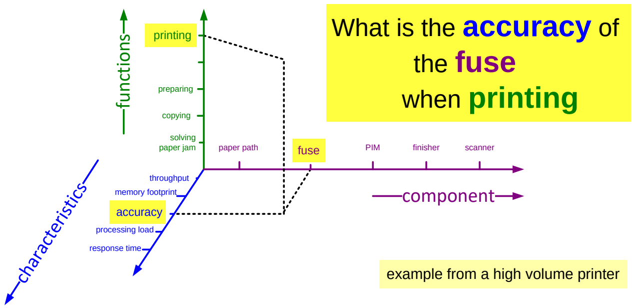
typical use with relevant (quantified!) context data

- **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)

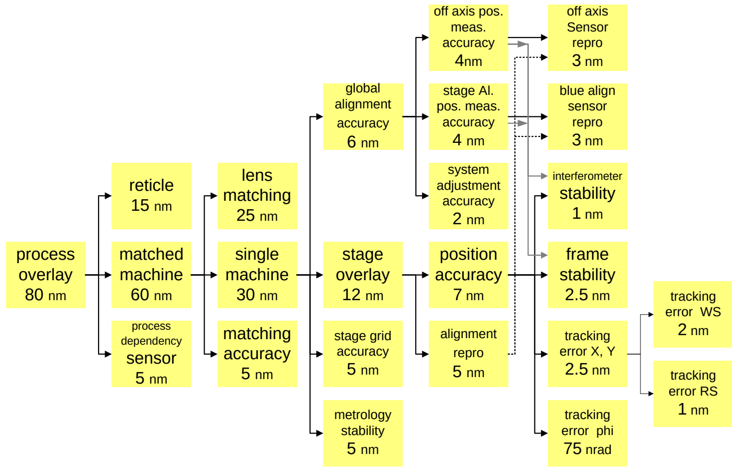
Summary Fundamentals Systems Engineering & Design (2)

Combining 3 Dimensions

How about the <characteristic>
of the <component>
when performing <function>?

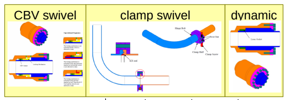


Technical Budget



Concept Selection

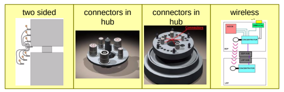
Swivel concept selection



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		4	100	4	100	4	100
internal							
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



Evaluation Criteria	Score	Concepts 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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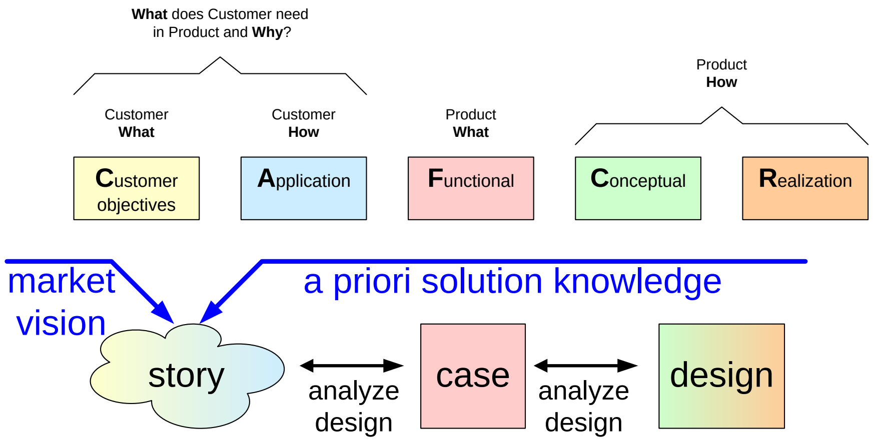
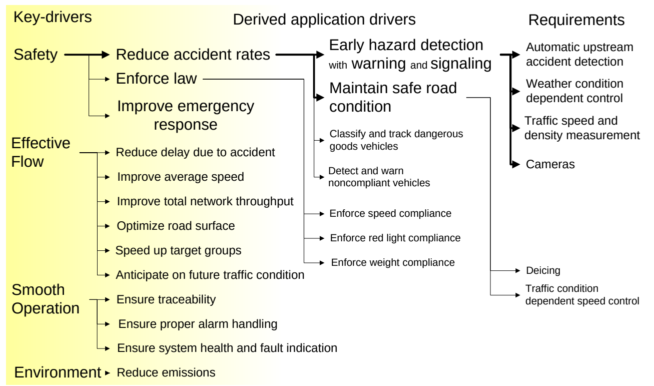
Summary Customer Understanding

Story Telling

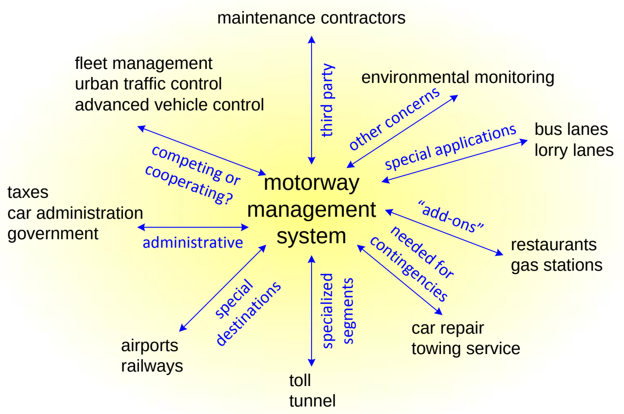


Key Driver Graph

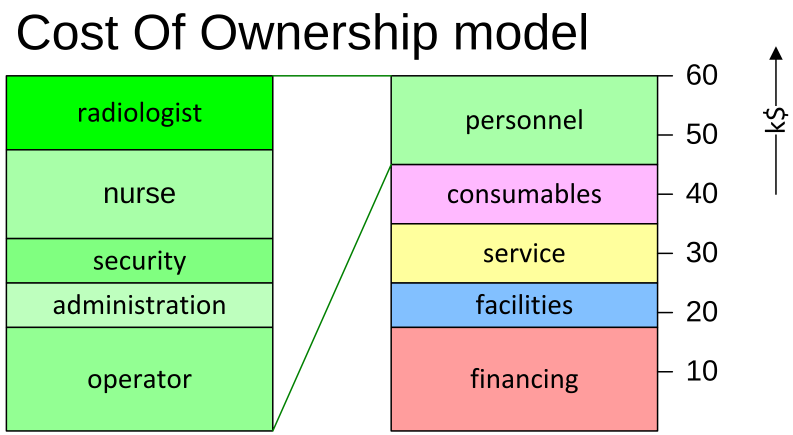


Note: the graph is only partially elaborated for application drivers and requirements

System Context

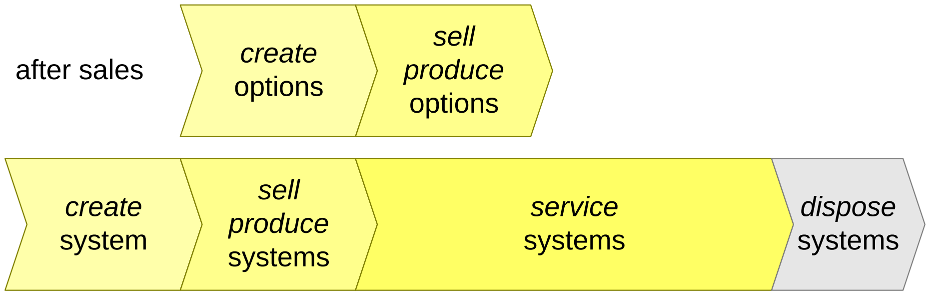


Cost of Ownership Model

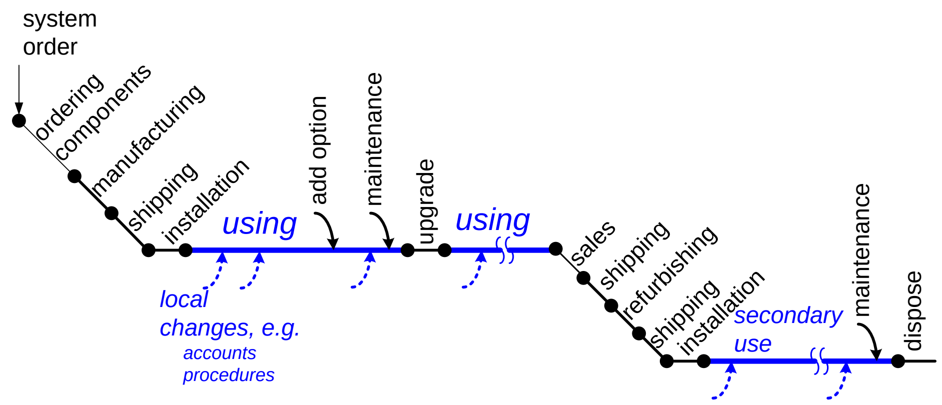


Summary Life Cycle and Business Economics

Product Life Cycle



System Life Cycle



Cash Flow

	Y1 Q1	Y1 Q2	Y1 Q3	Y1 Q4	Y2 Q1	Y2 Q2	Y2 Q3
investments	100k$	400k$	500k$	100k$	100k$	60k$	20k$
sales volume (units)	-	-	2	10	20	30	30
material & labour costs	-	-	40k$	200k$	400k$	600k$	600k$
income	-	-	100k$	500k$	1000k$	1500k$	1500k$
quarter profit (loss)	(100k$)	(400k$)	(440k$)	200k$	500k$	840k$	880k$
cumulative profit	(100k$)	(500k$)	(940k$)	(740k$)	(240k$)	600k$	1480k$

cost price / unit = 20k$
sales price / unit = 50k$

variable cost = sales volume * cost price / unit
income = sales volume * sales price / unit
quarter profit = income - (investments + variable costs)

Hockey Stick