Bachelor Course System Design

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

Abstract

The bachelor Course System Design is a course for third year students Mechanical Engineering at Buskerud University College. The course material is based on the MOSAD course *Multi-Objective System Architecting and Design*. However, more and shorter exercises are added, and common cases are used thorughout the course.
The course addresses multi-disciplinary design with multiple views, time boxing, iteration, CAFCR model, capturing customer understanding and life cycle aspects.

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status: preliminary draft
version: 0.1

logo
TBD

Information Bachelor Course System Design

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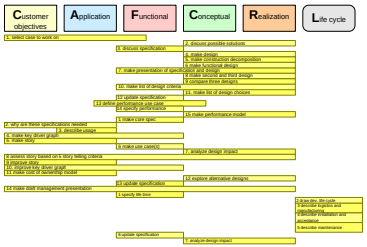
Abstract

The bachelor Course System Design is a course for third year students Mechanical Engineering at Buskerud University College. This document provides the program and exercises.



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status: draft
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Program

Step 1, 2 half days

Multi-view system design based on CAFCR method;

Iteration and time boxing;

Functional, Conceptual and Realization view

- Functional decomposition, construction decomposition modelling

Step 2, 2 half days

Customer objectives and application view

Story telling

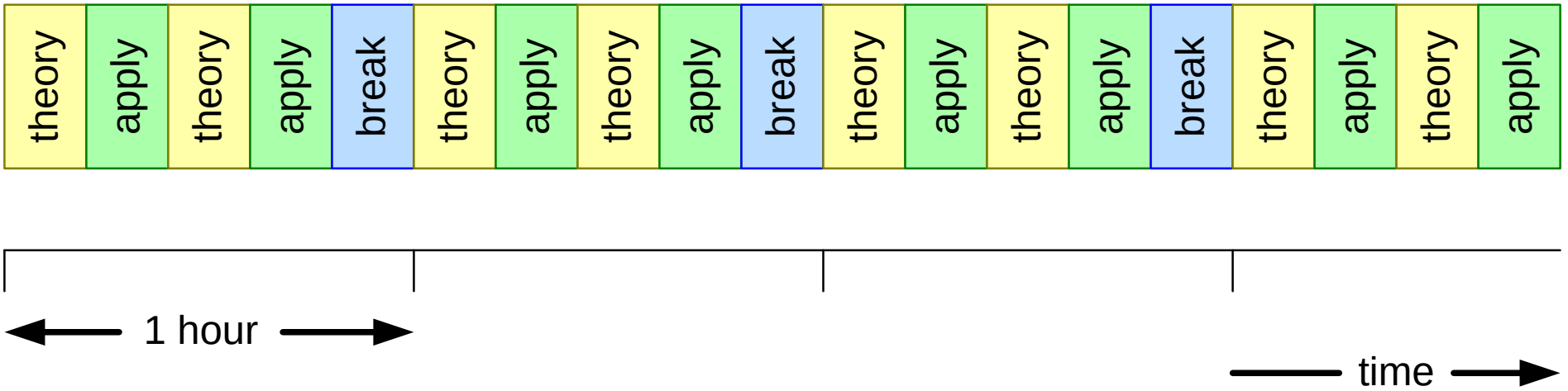
Use cases and scenarios

Step 3, half day (optional)

Life Cycle view

- product creation process, manufacturing and logistics, life cycle model

Didactic Model



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

Example Case: Tree Cutting Robot

Tree Cutting Robot

background:

Less young people are willing to work in the wild and mountainous areas in Norway, Canada, or USA to cut trees for wood production.

product:

Robot that supports the cutting and processing of trees so that less people are needed

Example Case: Explorer Inaccessible Spaces

Explorer Inaccessible Spaces

background:

When renovating houses and buildings the builder needs to know the construction and the position of infrastructure

product:

Robot that is flexible and remotely operated that can explore inaccessible spaces in houses and buildings

Examples of cases

apple, tomato, or strawberry plucking robot

apple, tomato, or strawberry sorting robot

tree cutting robot

spinach or lettuce harvesting robot

robot that removes or kills lices, wasps, or mosquitos

communication device for elderly people (80+ years old)

automated loader for Electric Vehicle

robot to help builders to look in inaccessible places

robot to install cables in tunnels

device to assist elderly people (80+ years) with washing, clothing, eating, drinking, getting in and out bed

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@usn.no>

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

Home work step 1

The homework for step 2 is to consolidate the work of the first step.
Make a presentation of specification and design, including a list of highlights and risks.
Note that this presentation is intended for the management team of your company.

Home work Step 2

The homework for step 3 is to consolidate the work of the second step.
Make a presentation of customer context and product specification, including a list of conclusions and consequences for the design.
Note that this presentation is intended for the management team of your company.

Short introduction to basic “CAFCR” model

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Abstract

The basic “CAFCR” reference model is described, which is used to describe a system in relation to its context. The main stakeholder in the context is the customer. The question “Who is the customer?” is addressed.

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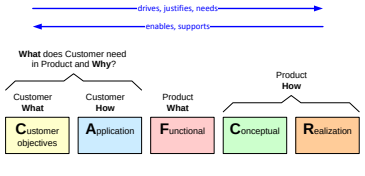
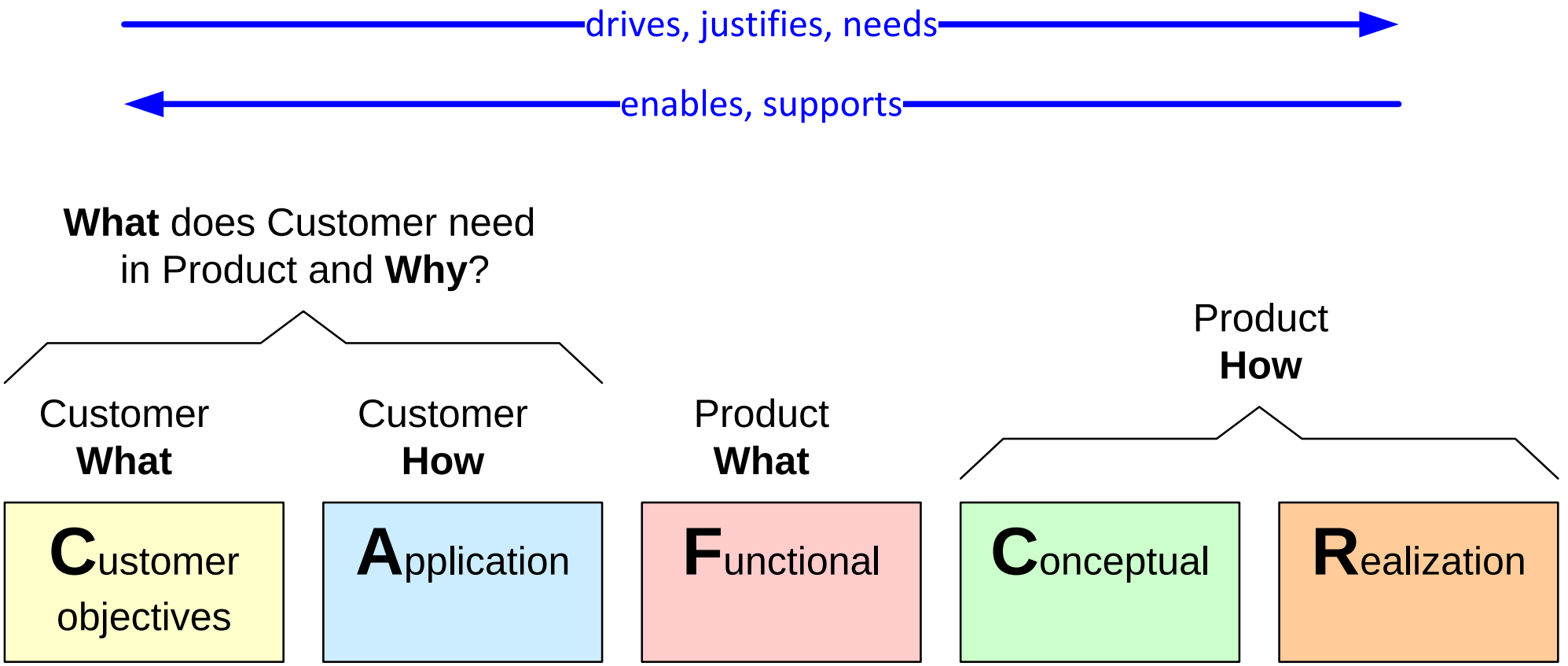
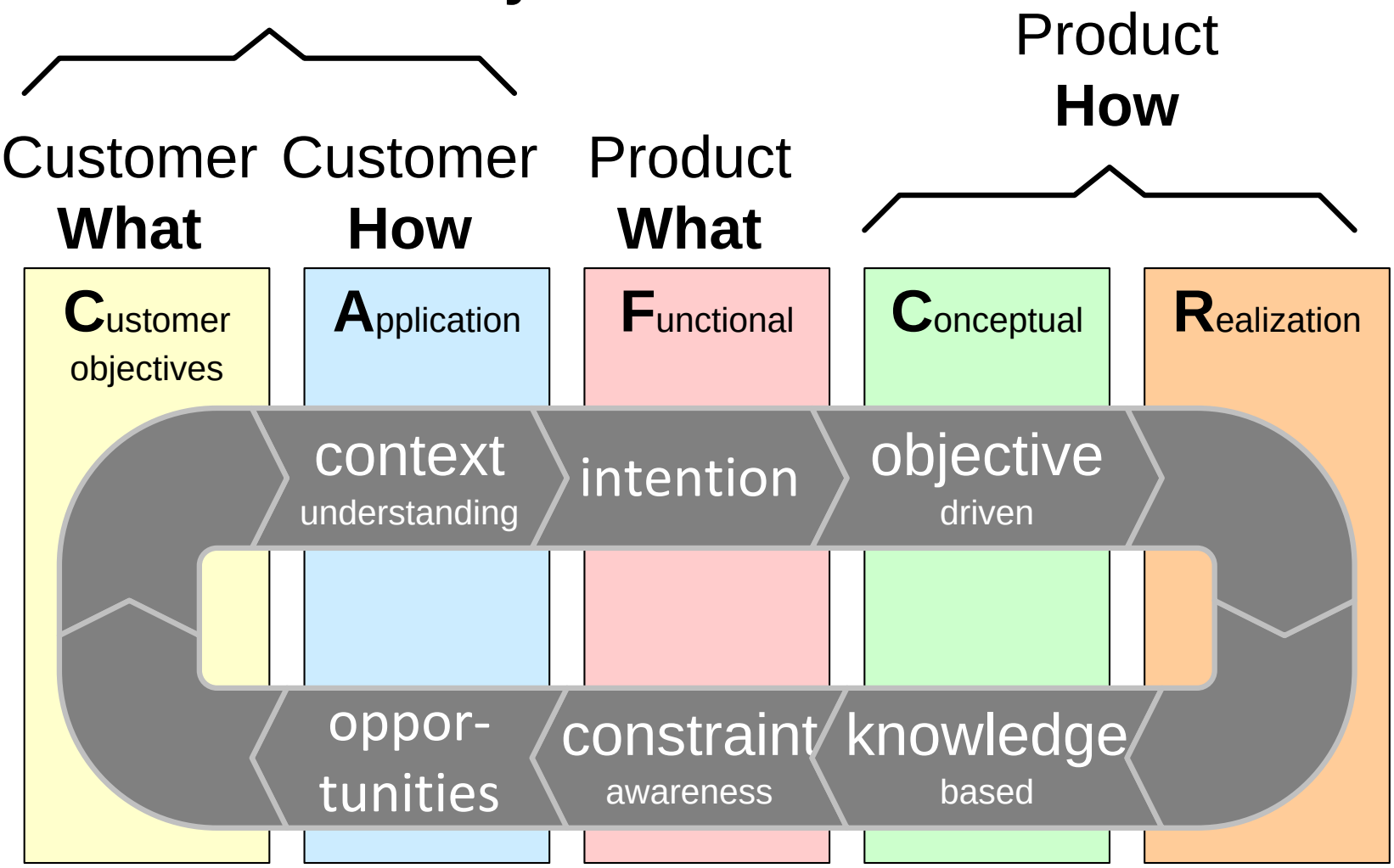


The “CAFCR” model

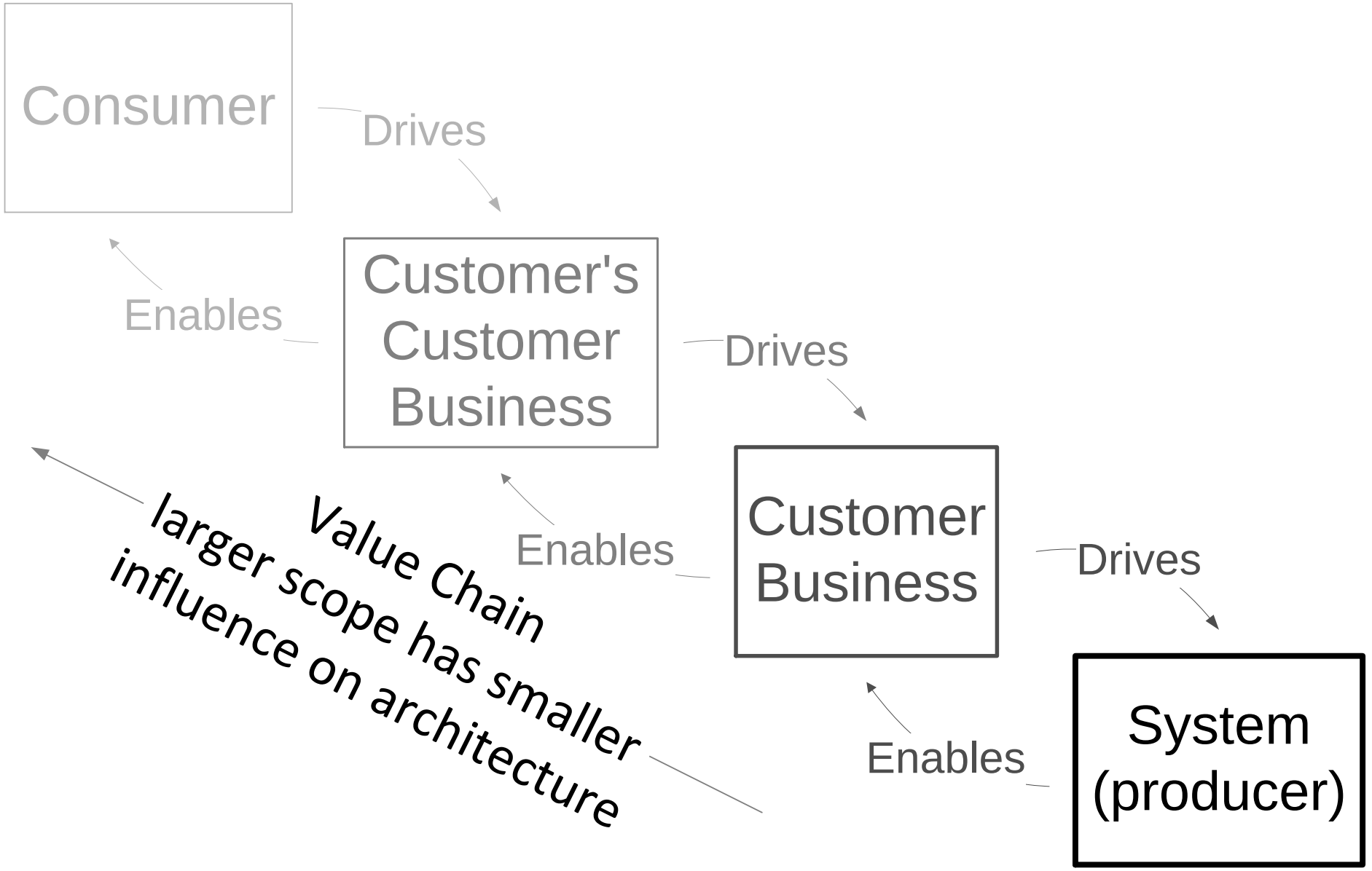


Integrating CAFCR

What does Customer need in Product and **Why**?



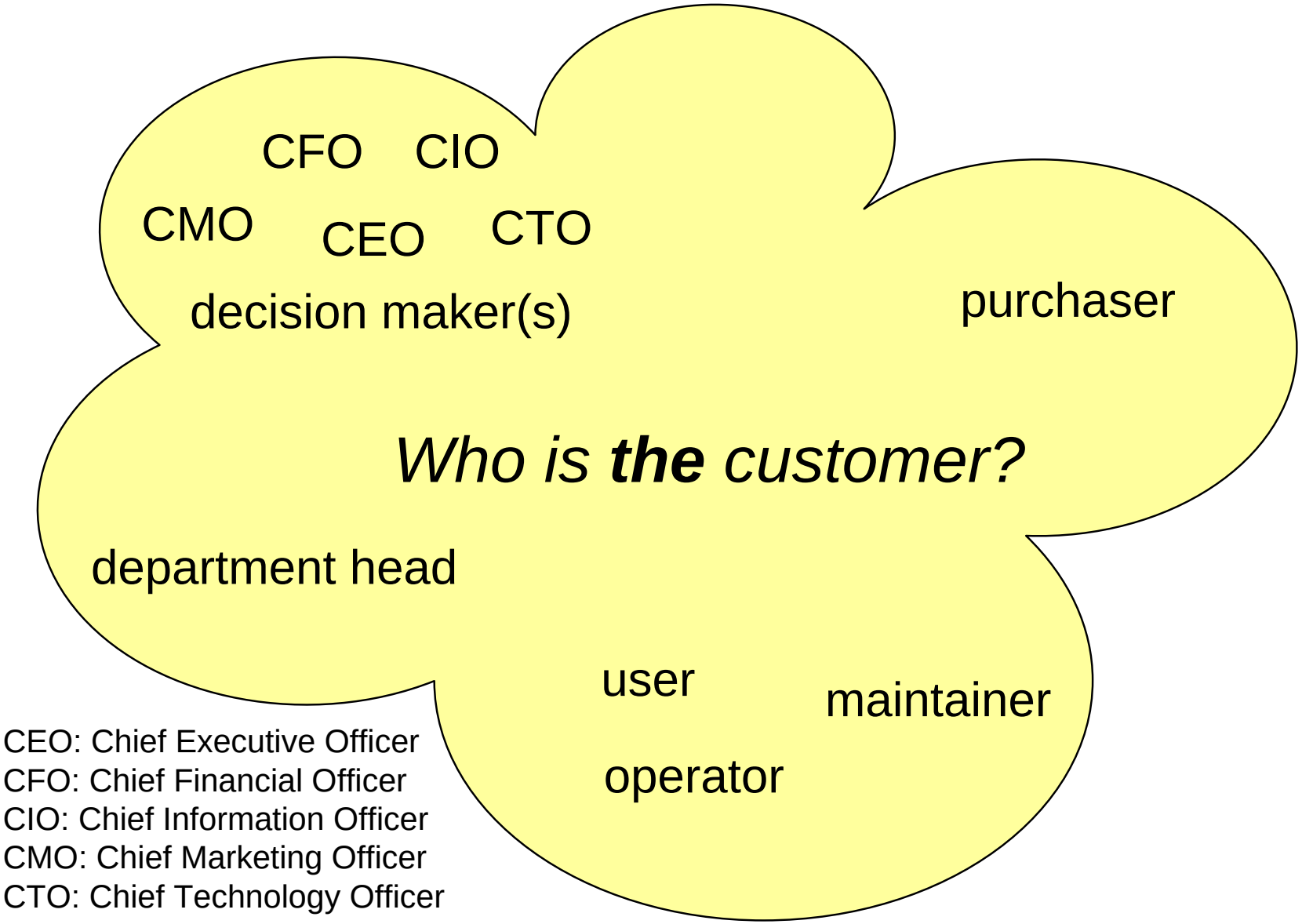
CAFCR can be applied recursively



Market segmentation

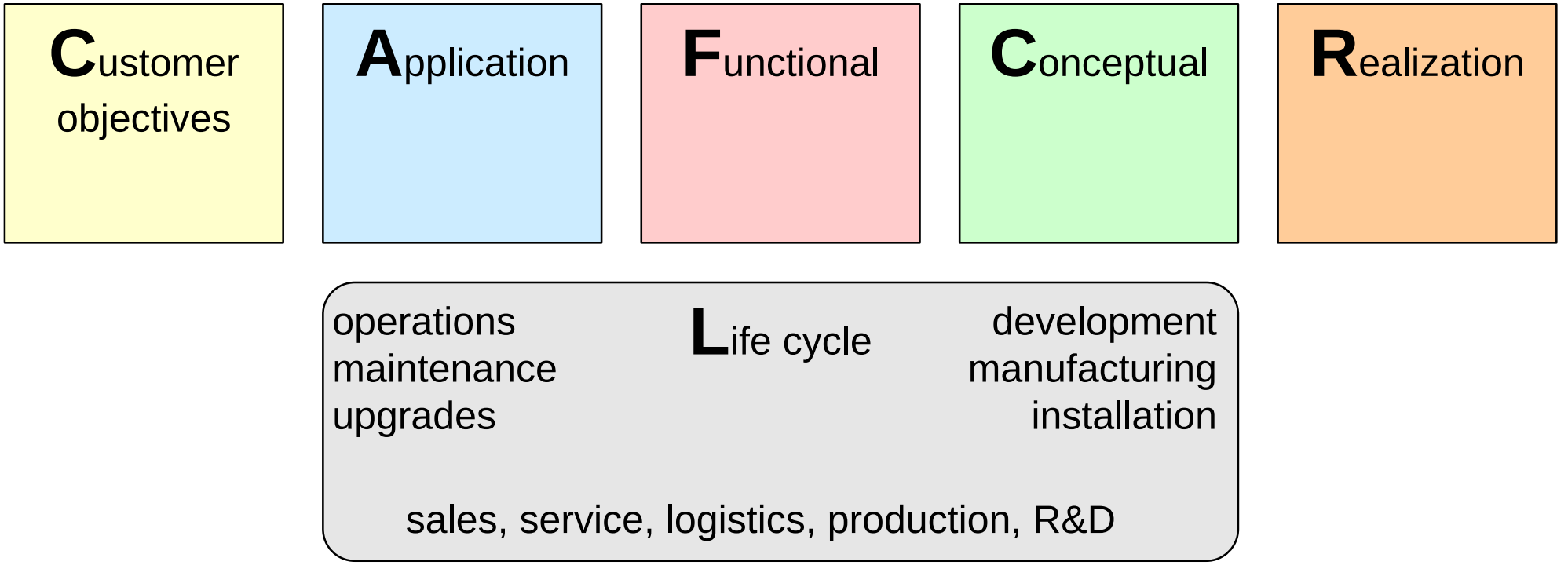
segmentation axis	examples
geographical	USA, UK, Germany, Japan, China
business model	profit, non profit
economics	high end versus cost constrained
consumers	youth, elderly
outlet	retailer, provider, OEM, consumer direct

Example of a small buying organization

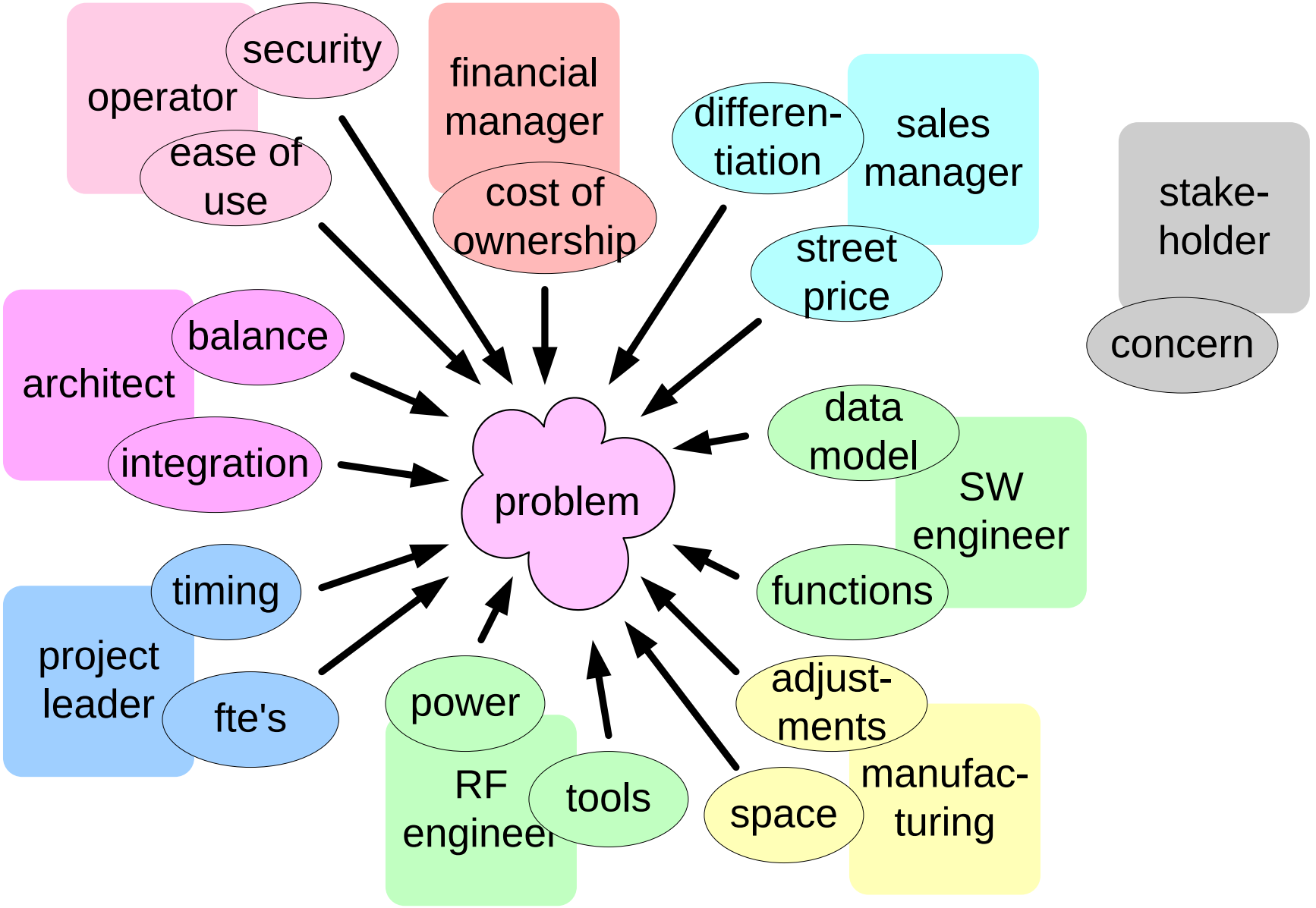


CEO: Chief Executive Officer
CFO: Chief Financial Officer
CIO: Chief Information Officer
CMO: Chief Marketing Officer
CTO: Chief Technology Officer

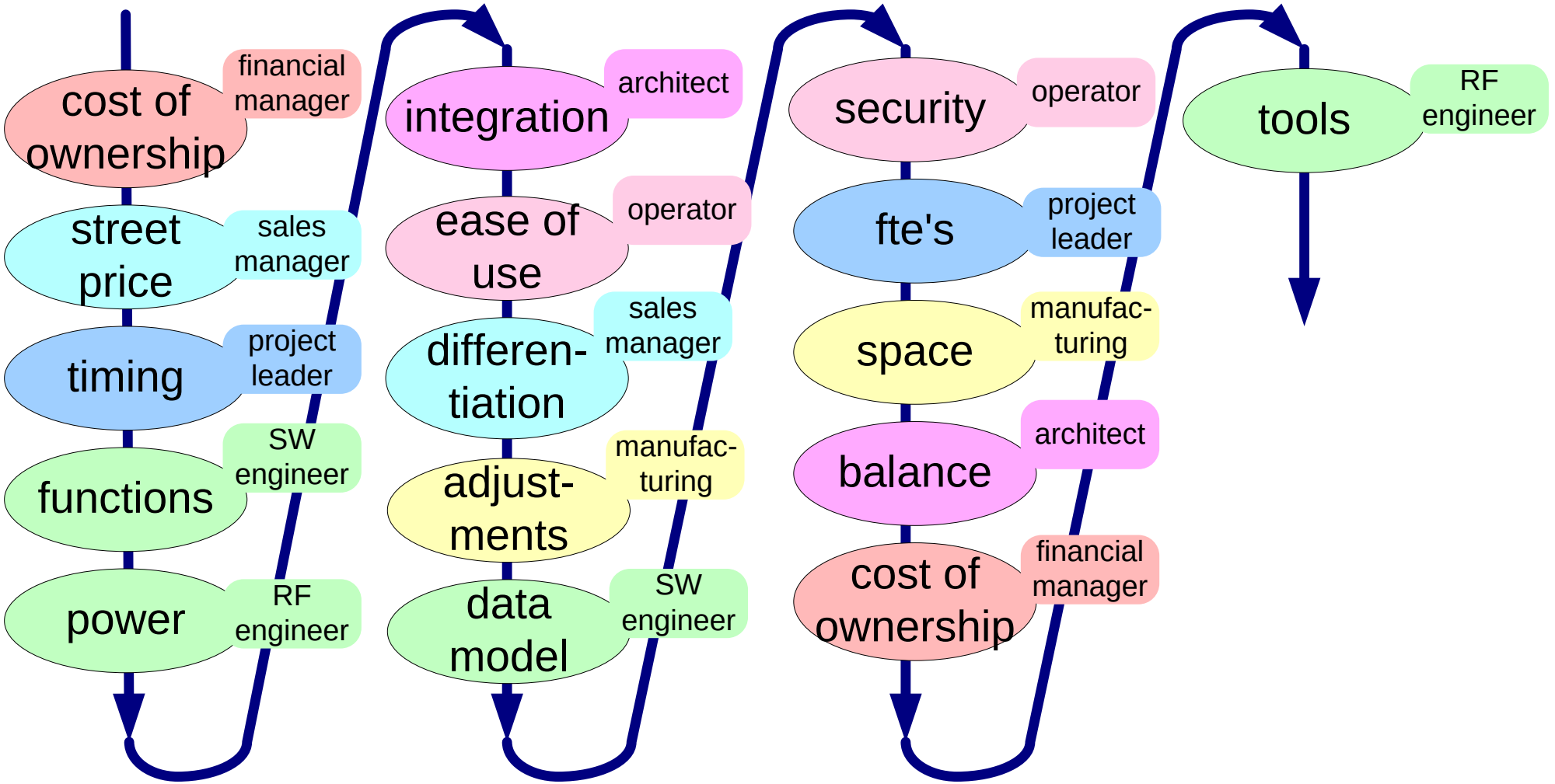
CAFCR+ model; Life Cycle View



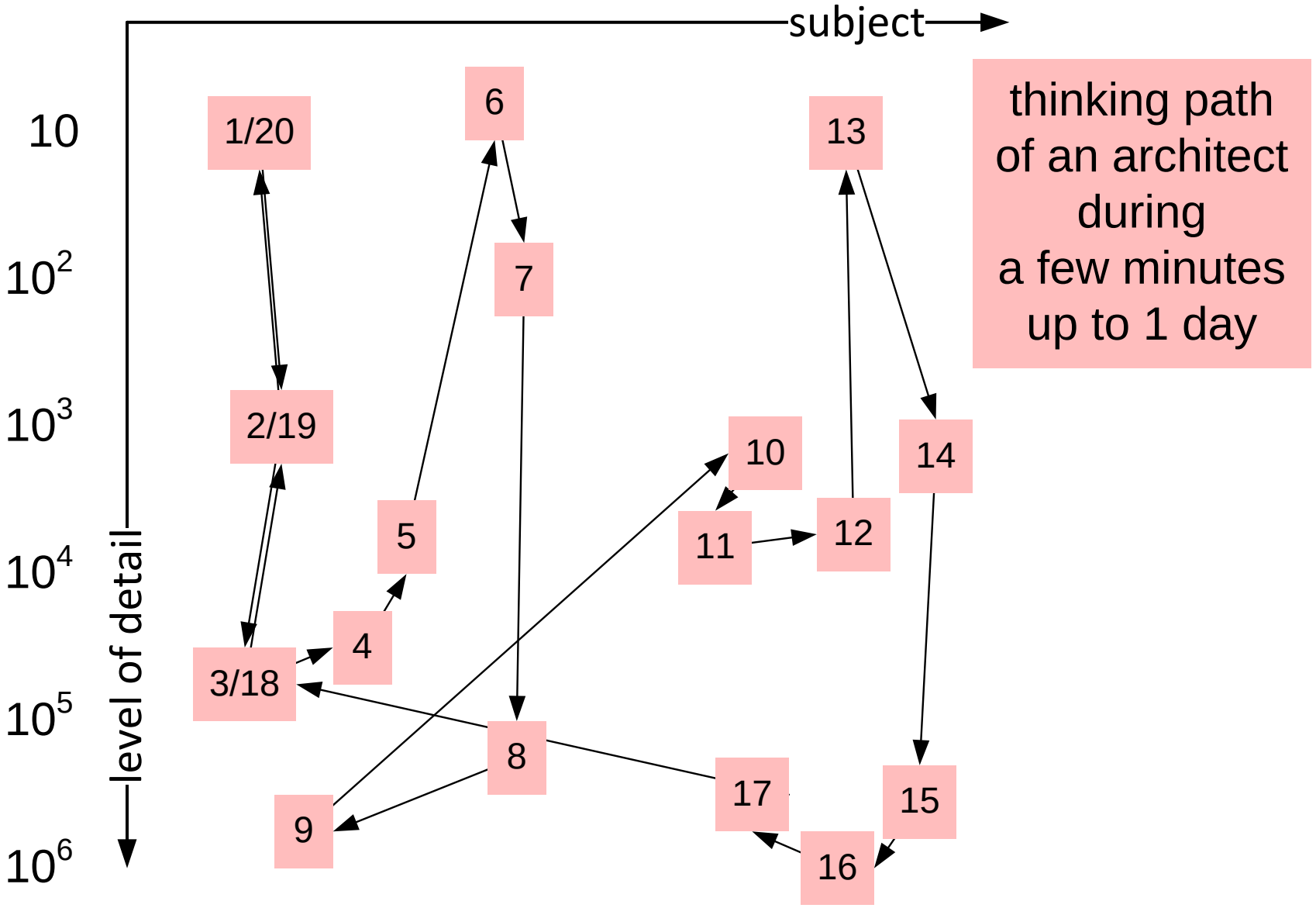
Many viewpoints



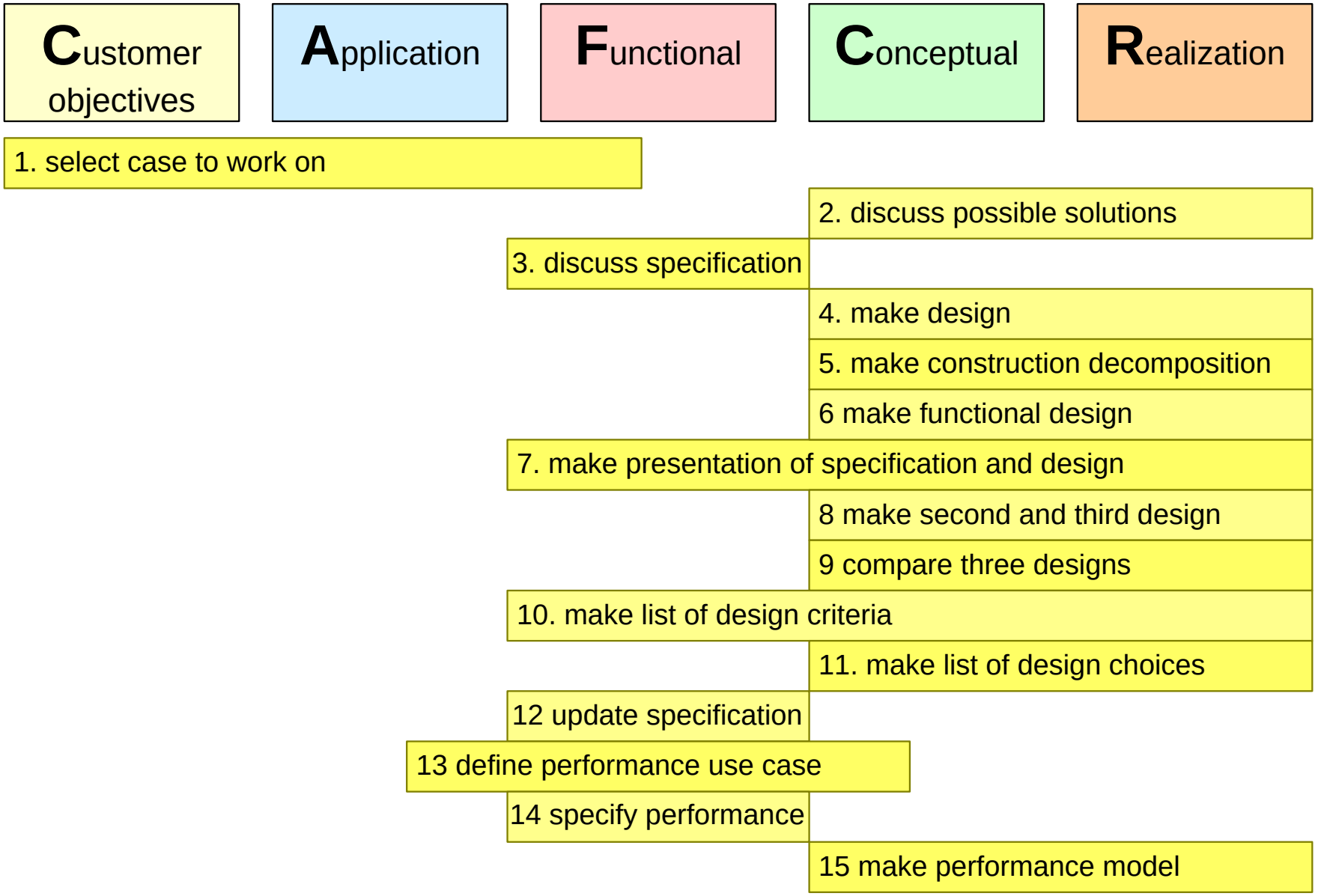
Viewpoint Hopping



The seemingly random exploration path



Exercises Step 1



Step 1, Exercise 1

select the case to work on

Discuss the available cases briefly.

Do you understand what the system is and what the challenges are to design it?

Note: you will be working on this system for the remainder of the course!

All groups are asked what case they have chosen.

Step 1, Exercise 2

discuss possible solutions

Make sketch or sketches of the solution that you have in mind

Note that you will be working with this solution for the remainder of the course. Pick a feasible and good solution. You may change the solution later, but radical changes are painful

Two groups will present their solution briefly (about 1 minute per group)

Step 1, Exercise 3

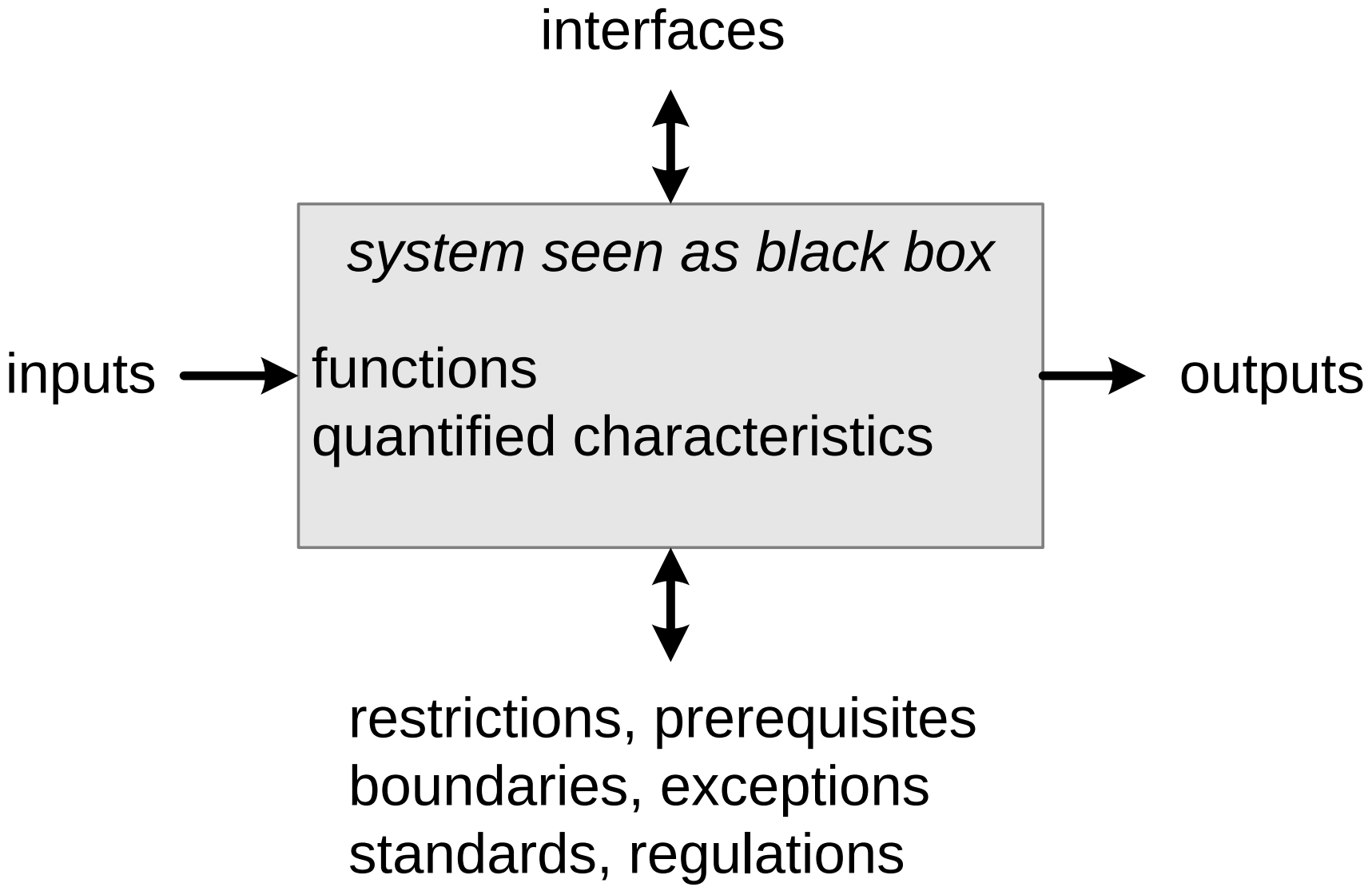
discuss system specification

What functions, performance, and interfaces are required?

Describe what the system must do as "black box", avoid to prescribe how to do this; see next slide.

Two groups will present their solution briefly (about 1 minute per group)

System as Black Box



Step 1, Exercise 4

make design

Make diagrams that explain how the system will work, how are the main functions performed?

Two groups will present their design briefly (about 1 minute per group)

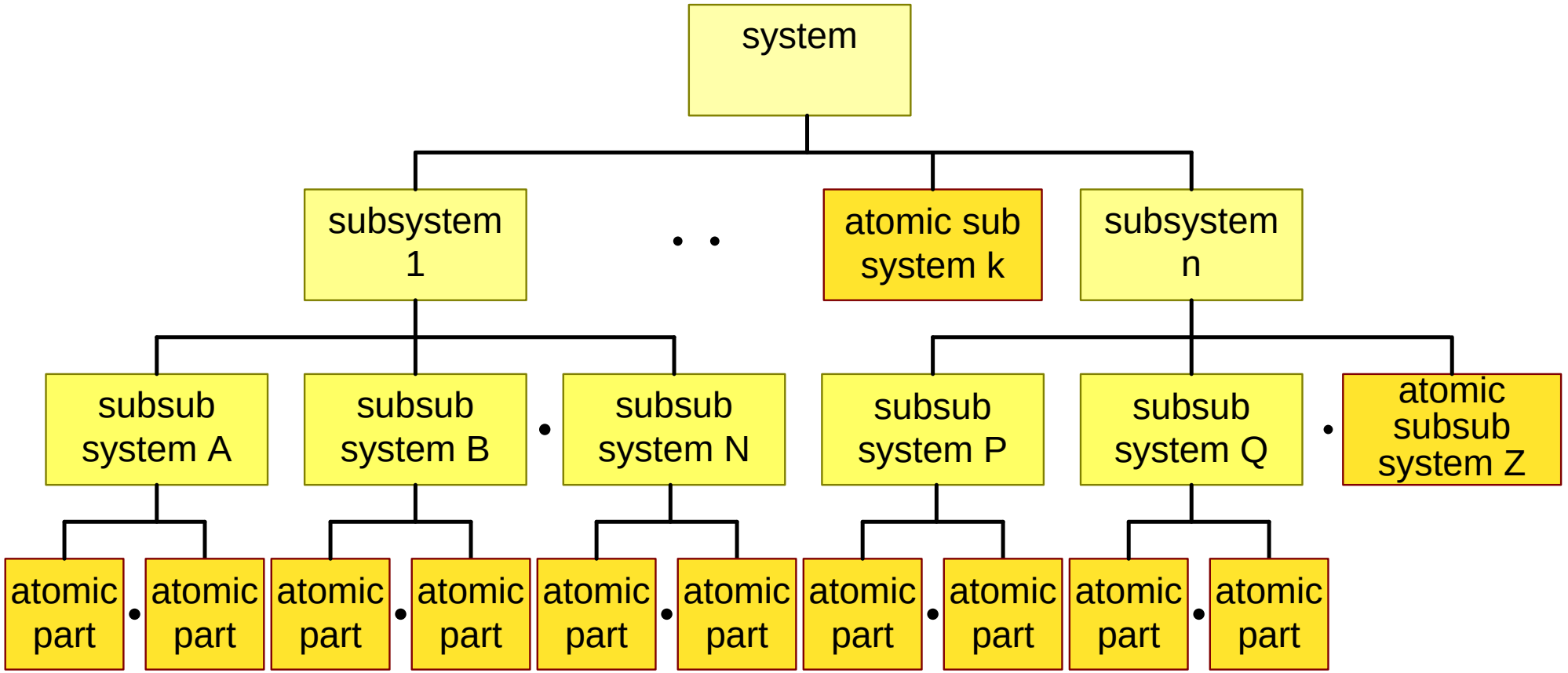
Step 1, Exercise 5

make construction decomposition

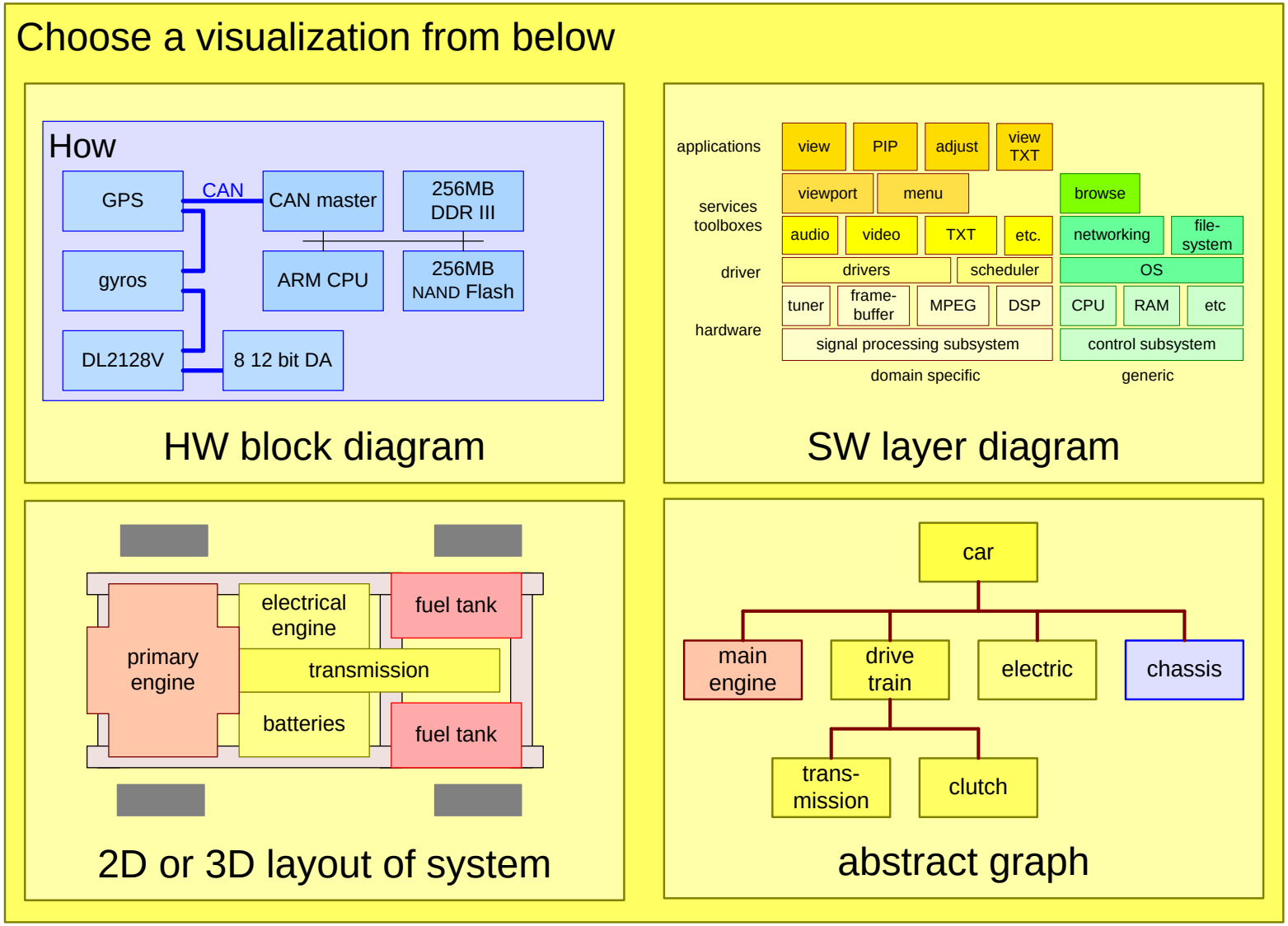
Decompose the system in subsystems, decompose one subsystem in subsubsystems.

Two groups will present their decomposition briefly (about 1 minute per group)

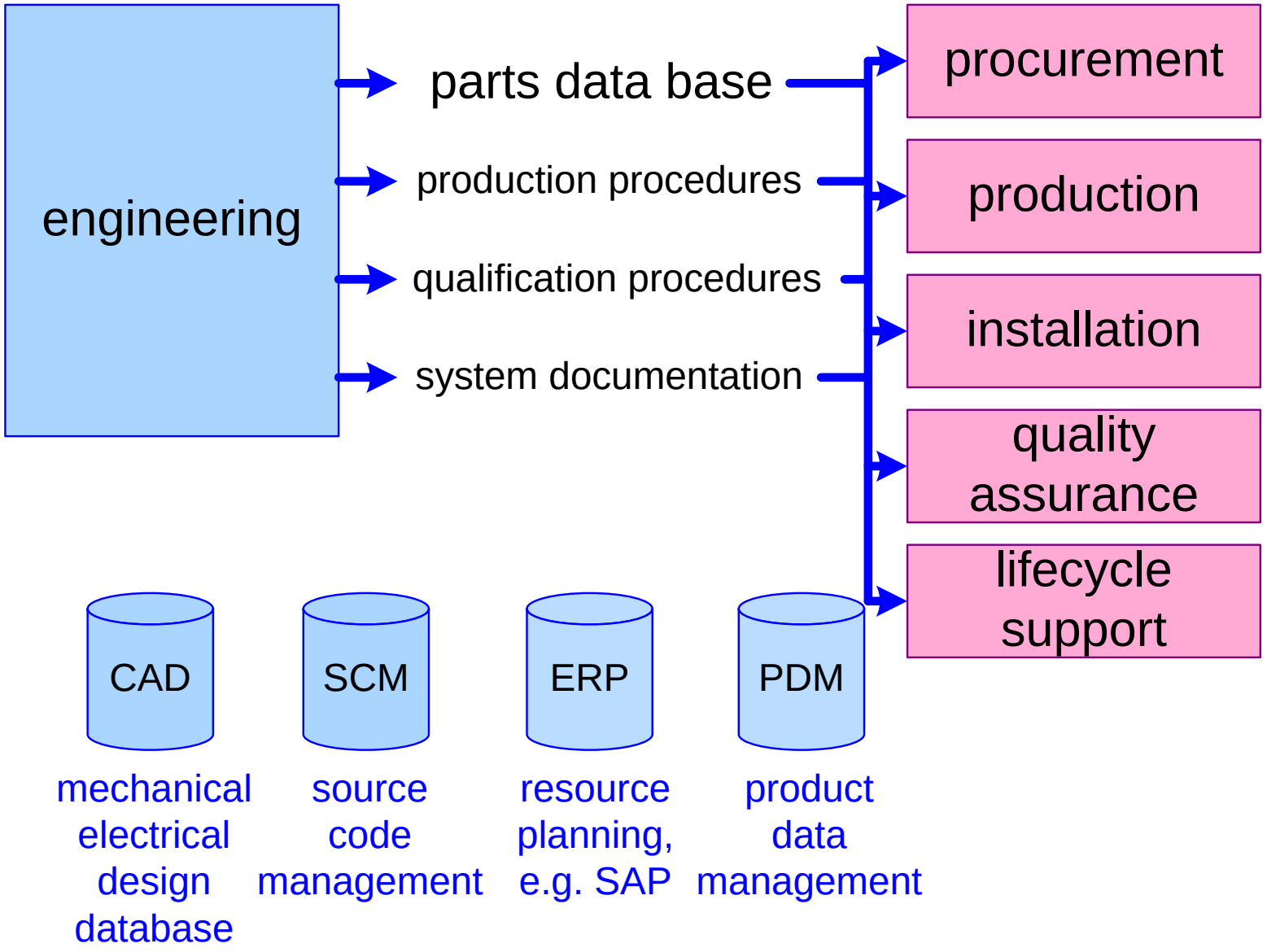
Partitioning is Applied Recursively



Visualizations of Construction Decomposition



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

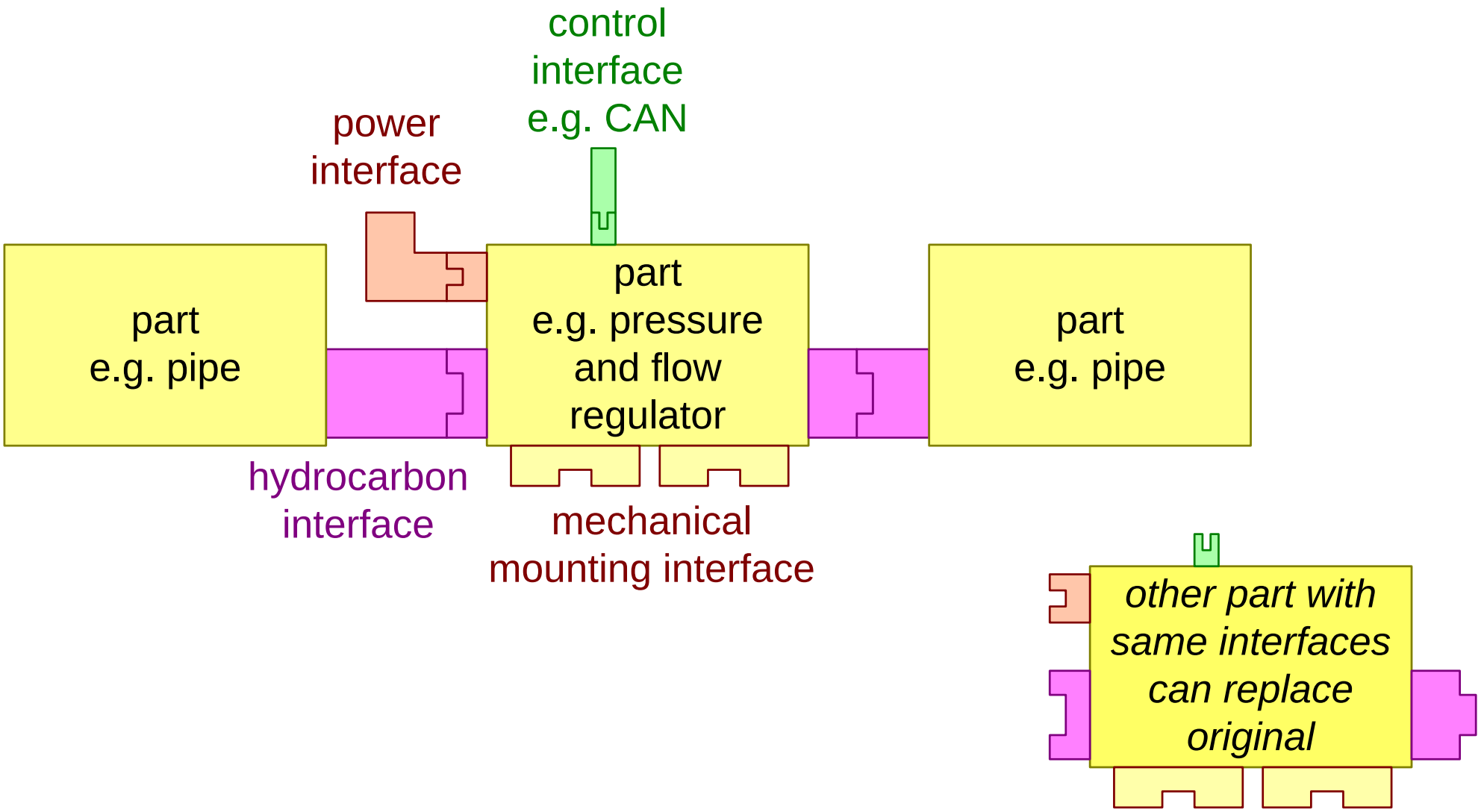
the part is selfsustained for production and qualification

can be in conflict with cost or space requirements

clear ownership of part

e.g. one department or supplier

Decoupling via Interfaces



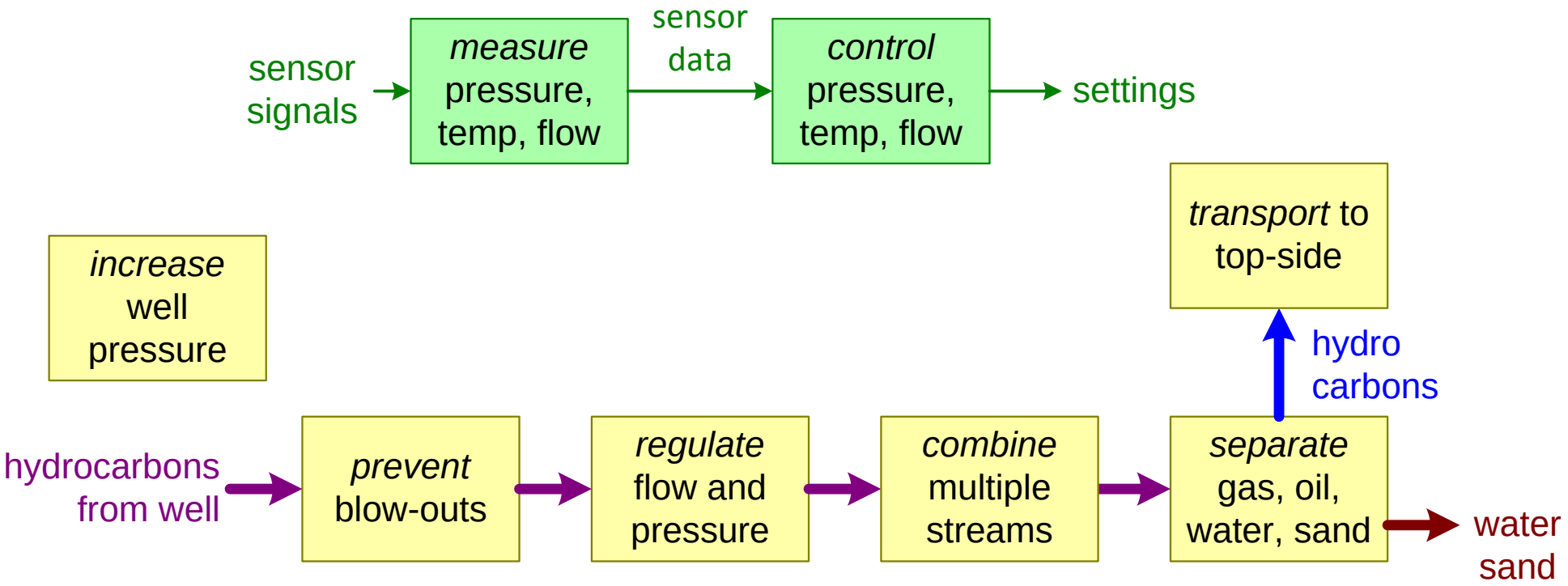
Step 1, Exercise 6

make functional design

Make a functional design of the system. A functional design explains how the system works.

Two groups will present their design briefly (about 1 minute per group)

Simplistic Functional SubSea Example



Functional Decomposition

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)
- information (e.g. measurements)
- control

At lower level one part ~= one function

- pump pumps, compressor compresses, controller controls

At higher level functions are complex interplay of physical parts

- e.g. regulating constant flow, pressure and temperature

Step 1, Exercise 7

make presentation of specification and design

Make a presentation of your specification and design for your management. Purpose is to inform them about the current status.

Management expects a top-down presentation.

Two groups will present their presentation briefly (about 3 minutes per group)

Step 1, Exercise 8

make a second and third design

Make two other designs that are based on different concepts

for example:

- hydraulic control i.s.o. electrical
- driving i.s.o. of walking
- sawing i.s.o. of cutting

Two groups will present their alternate designs briefly (about 2 minutes per group)

Step 1, Exercise 9

compare the designs

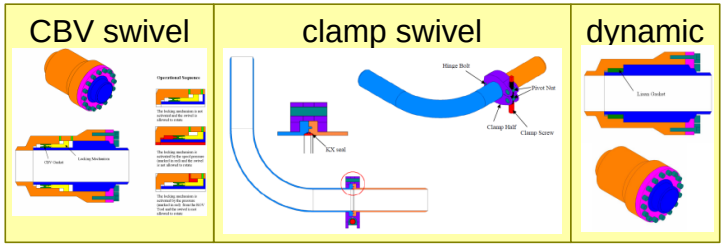
What design is better?

Why is that design better?

Two groups will present their comparisons briefly (about 2 minutes per group)

Concept Selection by Pugh Matrix

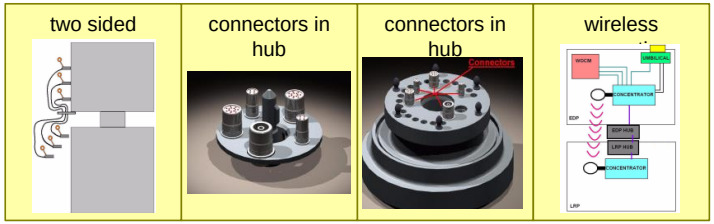
Swivel concept selection



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		2	50	5	125	2	50
external		4	100	4	100	4	100
Temperature range							
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

Step 1, Exercise 10

define the criteria for comparison of alternate designs

Make a list of 4 to 8 criteria to compare the design.

Fill the evaluation matrix

Two groups will present their criteria briefly (about 1 minute per group)

Step 1, Exercise 11

make a list of design choices

In your initial design you have made many implicit design choices

For example:

- how to move
- what energy source
- what control mechanism

Make a list of 5 to 10 choices

Two groups will present their choices briefly (about 1 minute per group)

Step 1, Exercise 12

update the specification

What functions, interfaces, or performances figures should be changed or added?

Two groups will present their specification and the changes briefly (about 1 minute per group)

Step 1, Exercise 13

make a performance use case

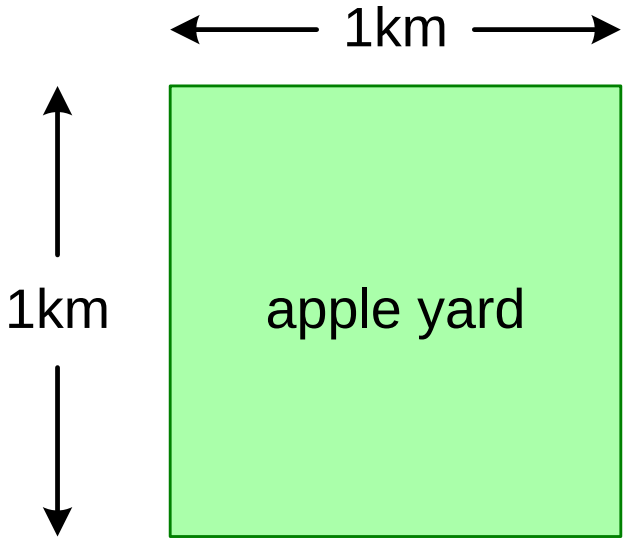
Define specific circumstances to define the system performance

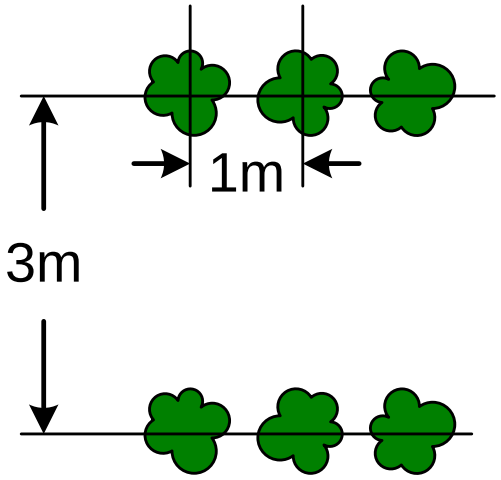
For example, for the tree cutting robot define the wood area, tree density, and type of trees

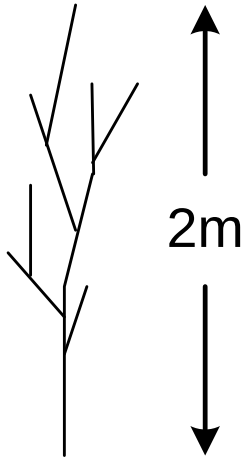
Start with making a sketch of the circumstances, then add quantifications.

Two groups will present their use case briefly (about 1 minute per group)

Example for apple plucking robot







12 m branches
~7 apples/m

yard size	tree density	apples/tree
10^6 m^2	1 tree / 3 m^2	~84 apples/tree

$$\text{nr apples} = 10^6 * 1/3 * 84 = 28 * 10^6$$

Step 1, Exercise 14

refine performance specification

Use the performance use case to refine the performance specification

For example, throughput, range limitations of objects, storage capacity

Two groups will present their performance specifications briefly (about 1 minute per group)

Step 1, Exercise 15

make a performance model

describe functional flow

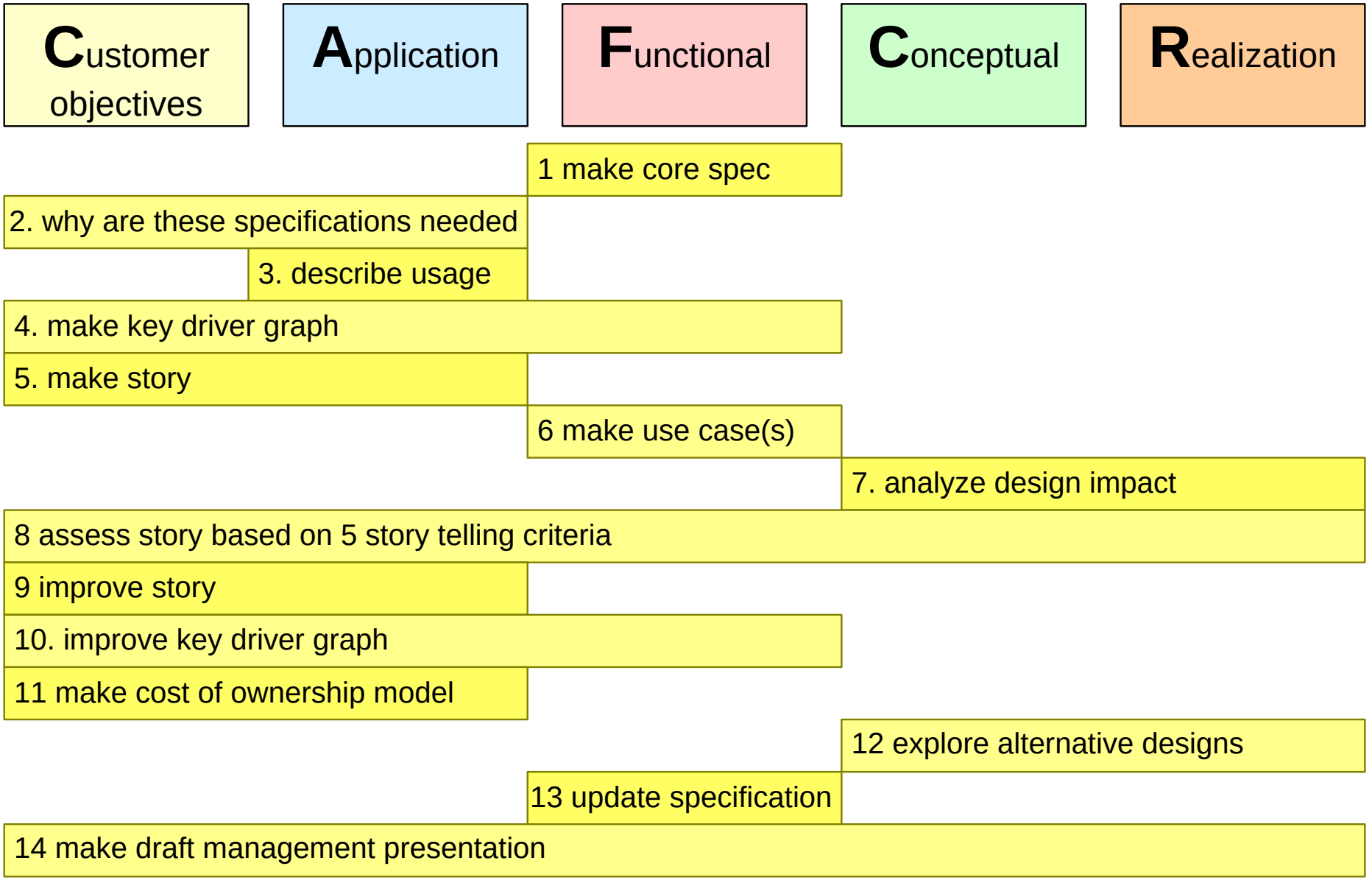
e.g. look for tree, move to tree, place gripper, move saw to tree, cut, move tree

estimate time per step based on current design

calculate system performance

Two groups will present their performance model briefly (about 2 minutes per group)

Exercises Step 2



Step 2, Exercise 1

make core specification

Make a list of 4 to 8 Key Performance Parameters (KPM).

Quantify each KPM

Two groups will present their KPMs briefly (about 1 minute per group)

Step 2, Exercise 2

Why is the core specification as is?

Why will the current core specification be attractive and useful for your potential customers?

Two groups will present their justifications briefly (about 1 minute per group)

Step 2, Exercise 3

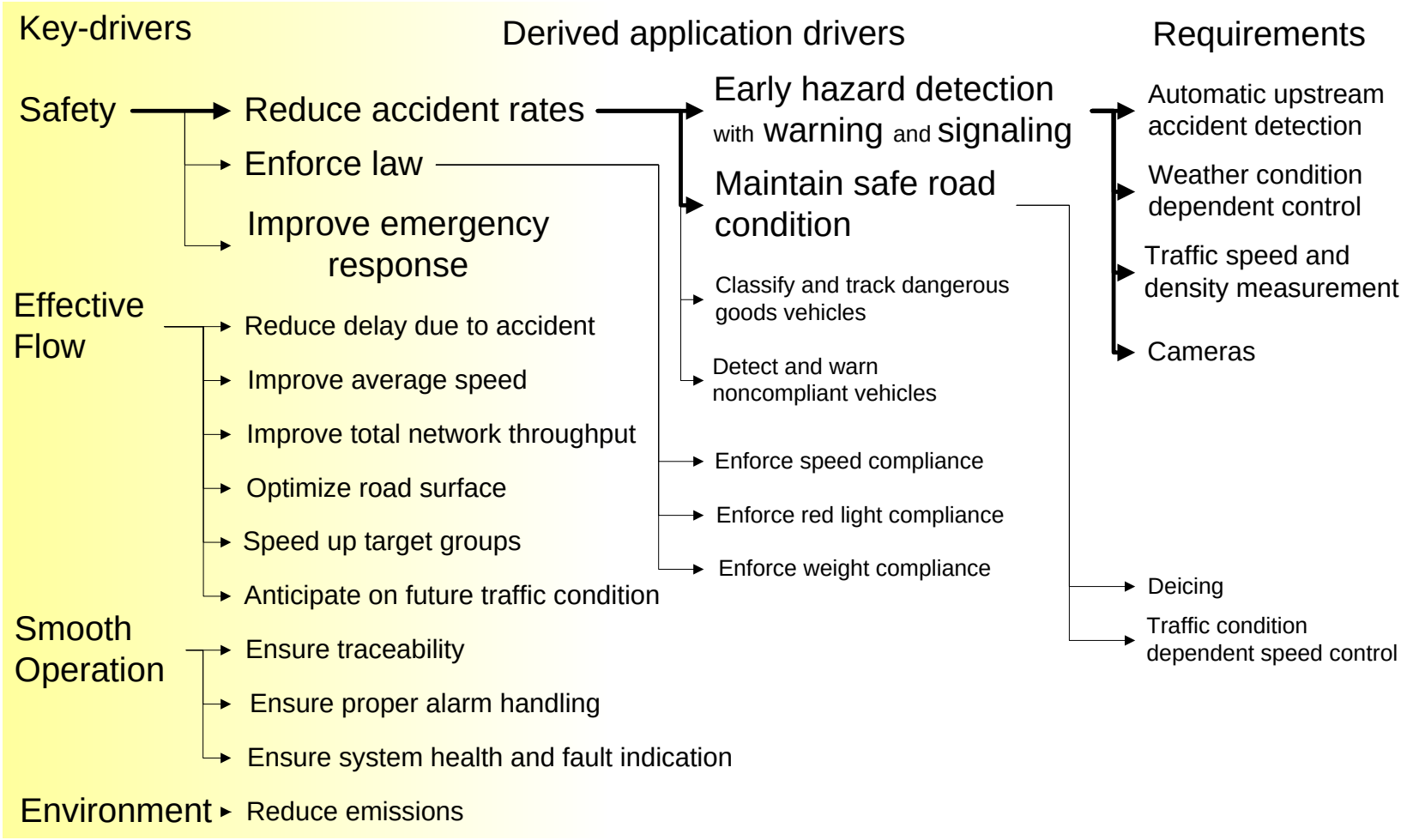
describe usage

How will your customer use your system?

Make sketches of the use and annotate them

Two groups will present their usage briefly (about 2 minutes per group)

Example Graph for Motorway Management System



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

Step 2, Exercise 4

determine customer key drivers

Start with the core specification

Ask for each KPM several times "why does the customer need this"

Identify 3 to 6 customer key drivers

Two groups will present their key drivers briefly (about 1 minute per group)

Story How To

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

A story is an easily accessible story or narrative to make an application live. A good story is highly specific and articulated entirely in the problem domain: the native world of the users. An important function of a story is to enable specific (*quantified, relevant, explicit*) discussions.

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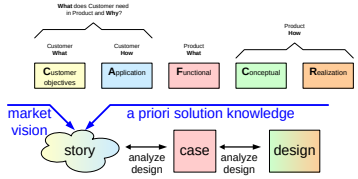
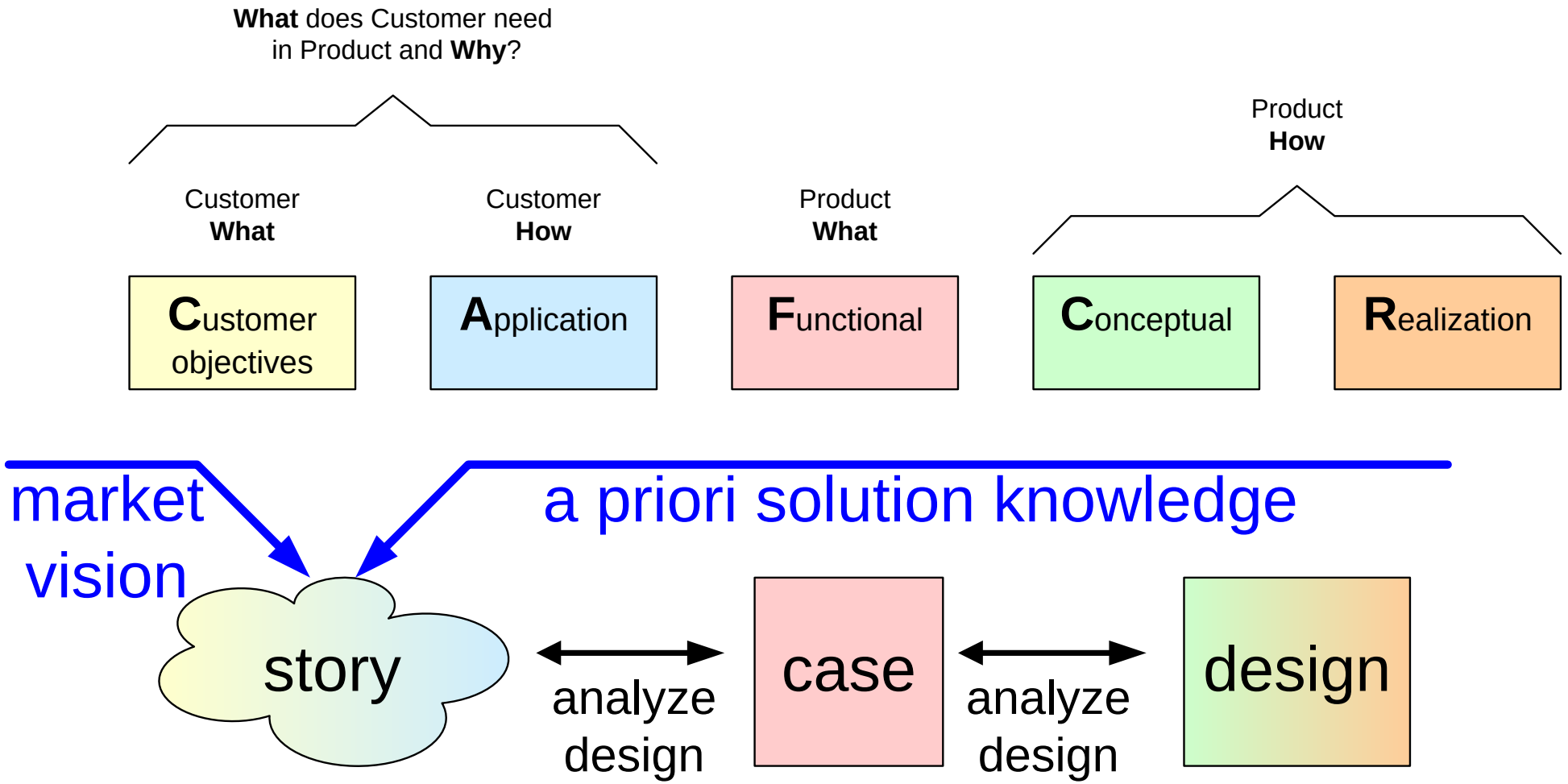
status: concept
version: 1.2

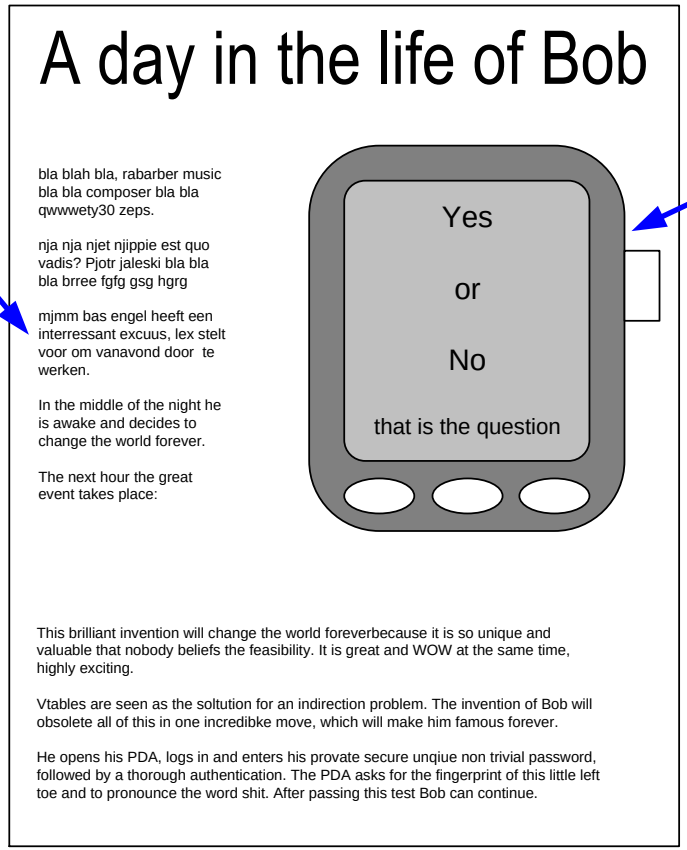


From story to design



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 / Application
  - accessible, understandable

    "Do you see it in front of you?"

- Customer objectives / Application
  - valuable, appealing

    attractive, important

    "Are customers queuing up for this?"

- Conceptual / Realization
  - 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 / Functional
  - 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

Step 2, Exercise 5

make a story

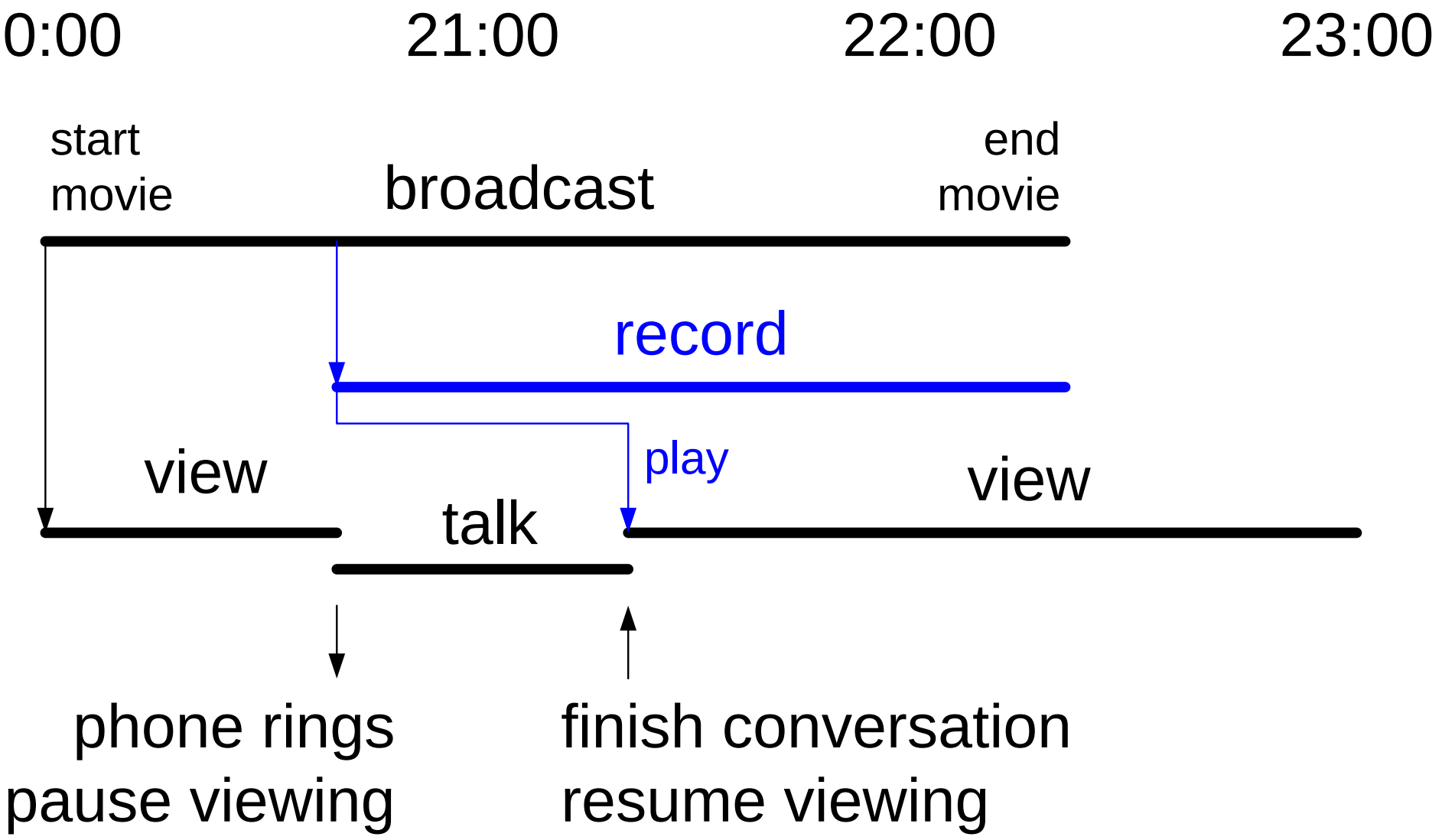
Make a story with sketches and text or as cartoon.

Keep the 5 criteria in mind

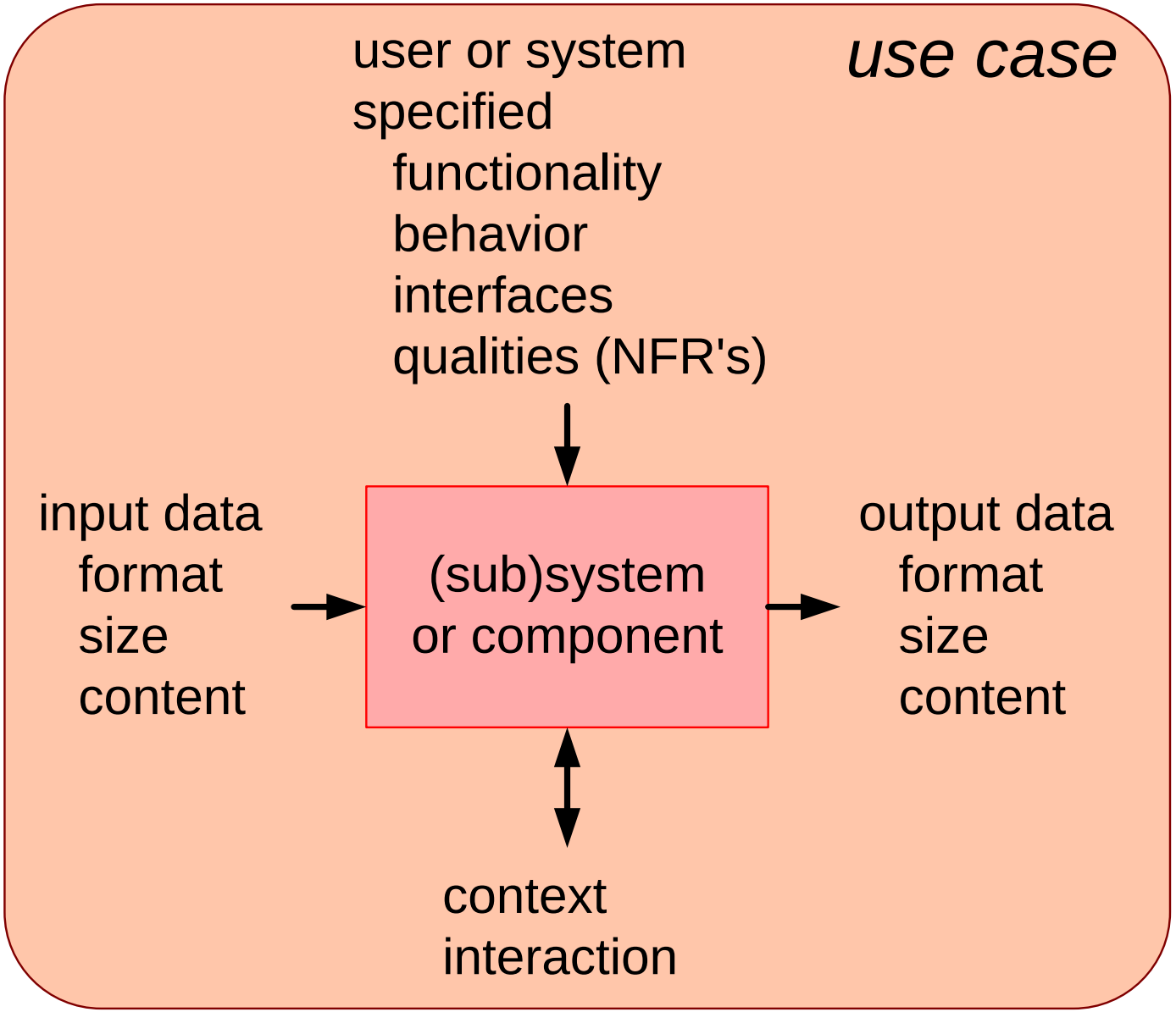
Focus on customer experience; technical solutions are implicit

Two groups will present their story briefly (about 3 minutes per group)

Example Time Shift recording



Content of a Use Case



Step 2, Exercise 6

make use case

Identify main functions, interfaces, and performance figures in the story

Two groups will present their use case briefly (about 1 minute per group)

Step 2, Exercise 7

revisit design and determine impact of last exercises

Previous exercises probably will have triggered new insights.

What should change in your design to improve it and adapt to the new insights?

Two groups will present their design impact briefly (about 1 minute per group)

Step 2, Exercise 8

assess the story

Use the 5 criteria:

- accessible, understandable
- valuable, appealing
- critical, challenging
- frequent, no exceptional niche
- specific

Two groups will present their assessment briefly (about 1 minute per group)

Step 2, Exercise 9

improve the story

Use the previous assesment with 5 criteria.

Possible improvements:

- add more personal data, e.g. emotions, feelings, perceptions
- add more circumstances, e.g. rain, snow, mountains, swamps, insects, dirt
- clarify user value; for example, compare old and new
- remove too exceptional events or too funny sidelines
- add more quantifications

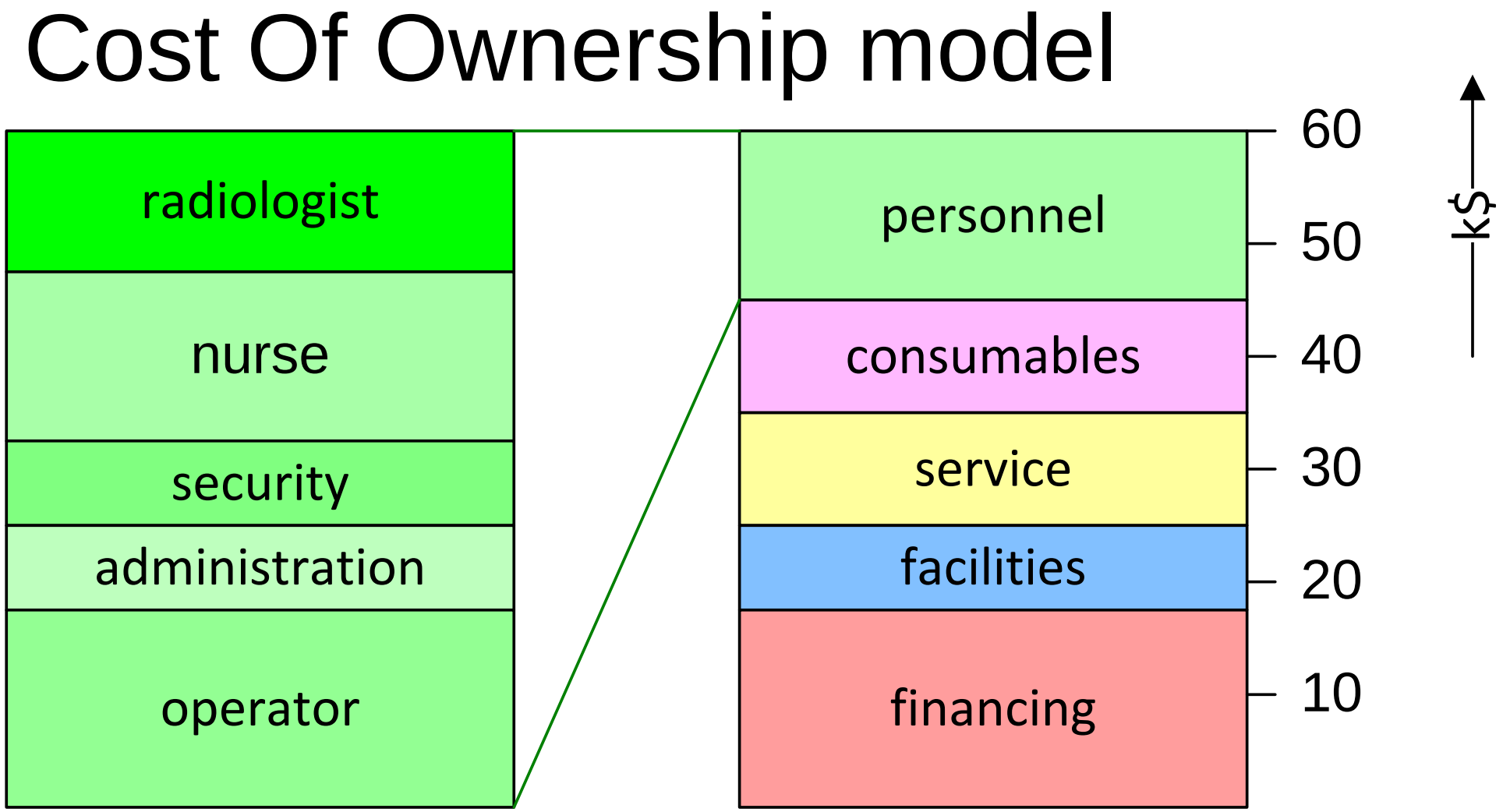
Two groups will present their story briefly (about 2 minutes per group)

Step 2, Exercise 10

improve key drivers

Use the new insights from story telling and use cases to rethink the key drivers.

Two groups will present their key drivers and the changes briefly (about 1 minute per group)


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

Step 2, Exercise 11

make a Cost of Ownership (CoO) model

Determine all the costs that the customer makes to own and operate the system.

Make a coarse estimate of these costs

Two groups will present their CoO model briefly (about 2 minutes per group)

Step 2, Exercise 12

explore alternate designs

Use insights in usage circumstances, performance needs, and customer key drivers to revisit the design

Challenge your own design choices

Explore alternate design choices

Two groups will present their alternate designs briefly (about 2 minutes per group)

Step 2, Exercise 13

update the specification

What functions, interfaces, or performances figures should be changed or added?

Two groups will present their specification and the changes briefly (about 1 minute per group)

Step 2, Exercise 14

make draft presentation for management

Make a presentation of all CAFCR views for your management. Purpose is to inform them about the current status.

Management expects a top-down presentation.

Management expects summary/conclusion/recommendation; e.g. we recommend this design because it satisfies these customer and business needs

Two groups will present their presentation briefly (about 3 minutes per group)

The Product Creation Process

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Abstract

The Product Creation Process is described in its context. A phased model for Product Creation is shown. Many organizations use a phased model as blueprint for the way of working. The operational organization of the product creation process is discussed, especially the role of the operational leader.

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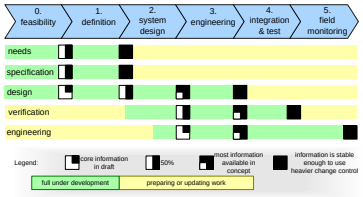
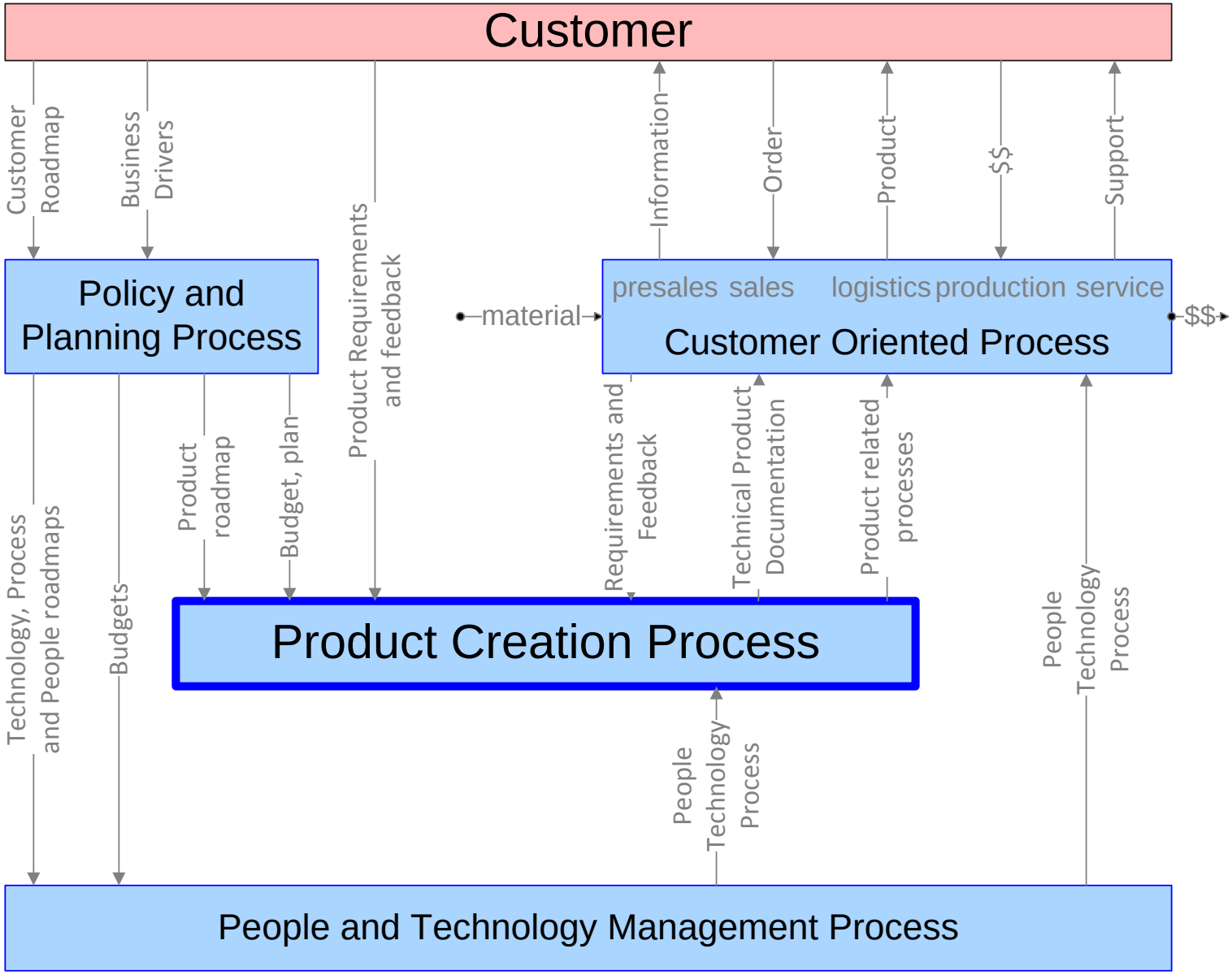
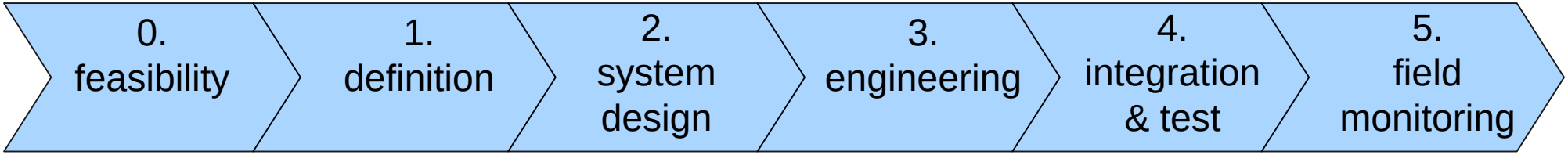
status: concept
version: 2.2



The Product Creation Process in Business Context



Phasing of the PCP at Business Level



sales

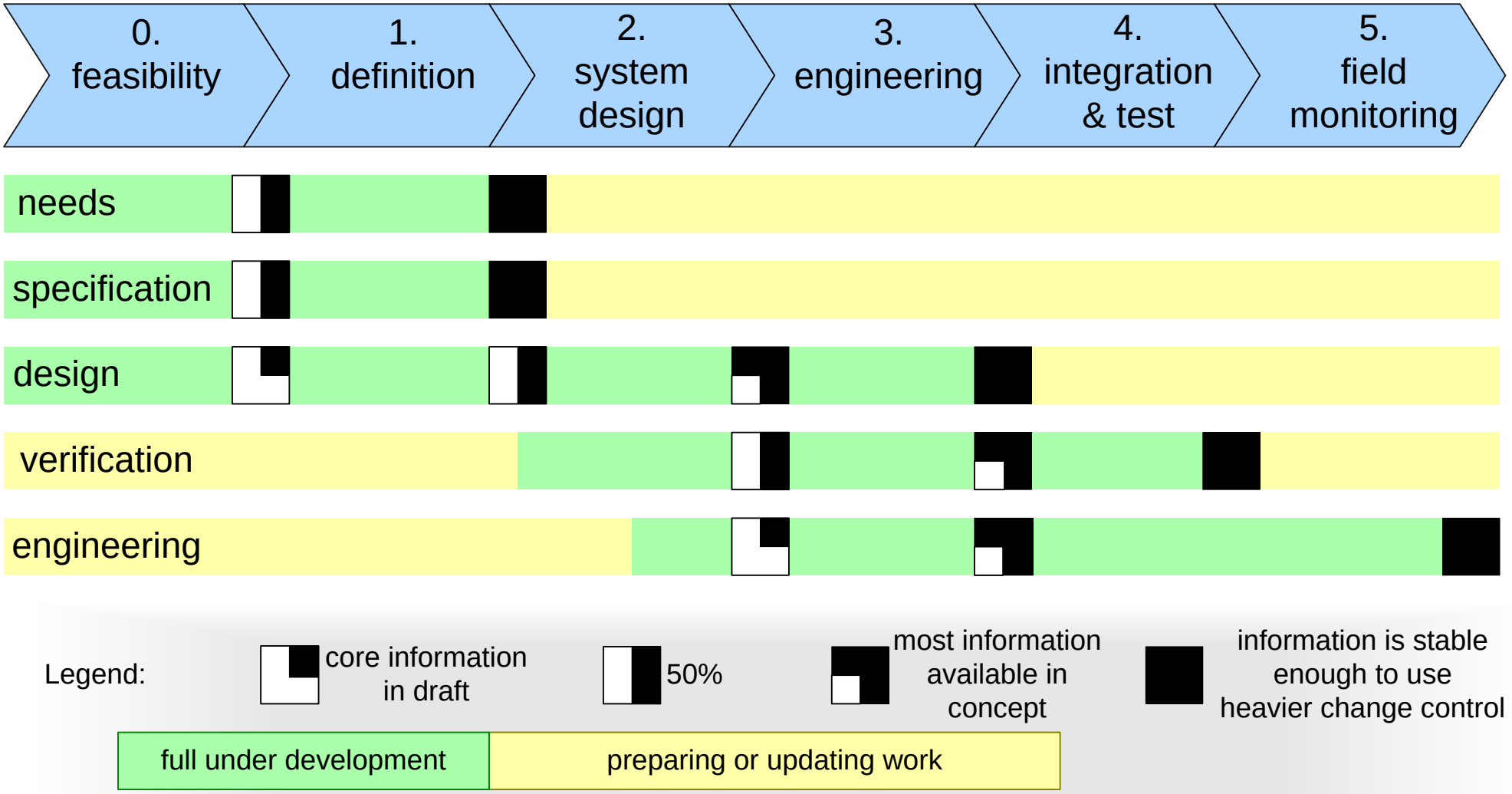
logistics

production

service

development & engineering: marketing, project management, design

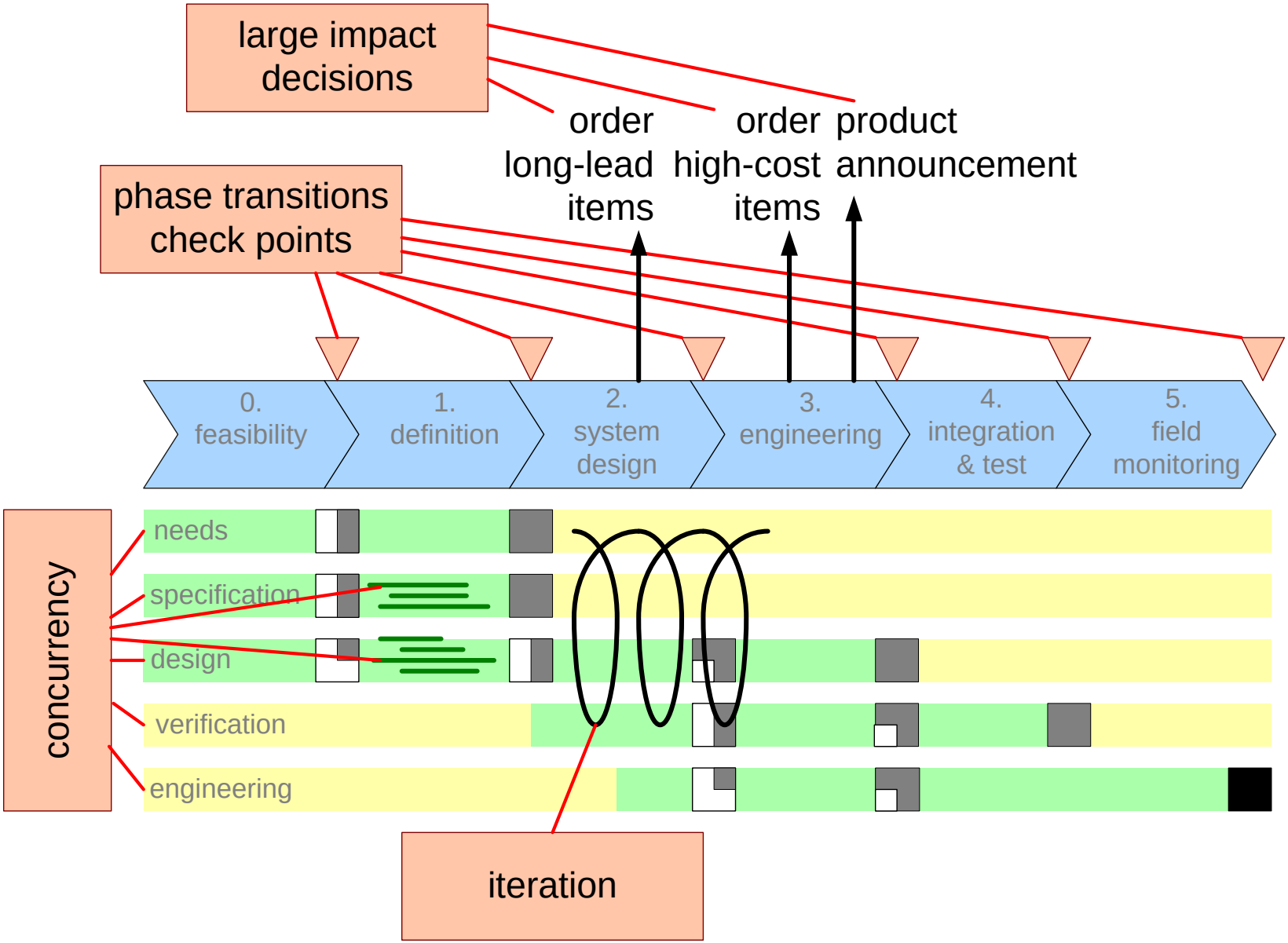
Phasing the Design Control Process



Advantages and Disadvantages of a Phased Process

benefits	*disadvantages*
blueprint: how to work	following blueprint blindly
reuse of experience	too bureaucratic
employees know *what* and *when*	transitions treated black and white
reference for management	

Characteristics of a Phase Model



Decisions and Phase Transitions

Define a minimal set of *large-impact* decisions.

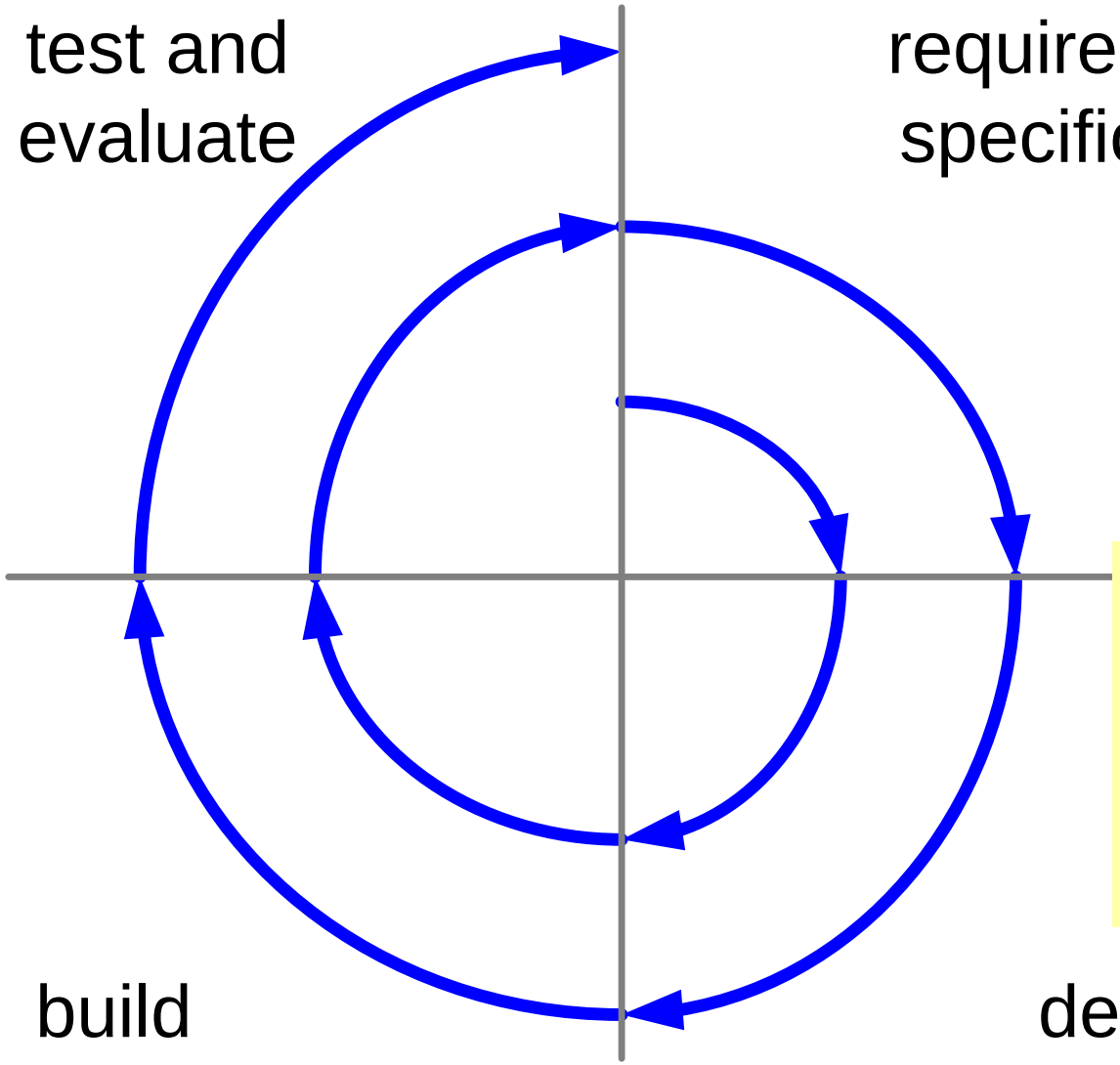
Define the mandatory and supporting information required for the decision.

Schedule a decision after the appropriate phase transition.

Decide explicitly.

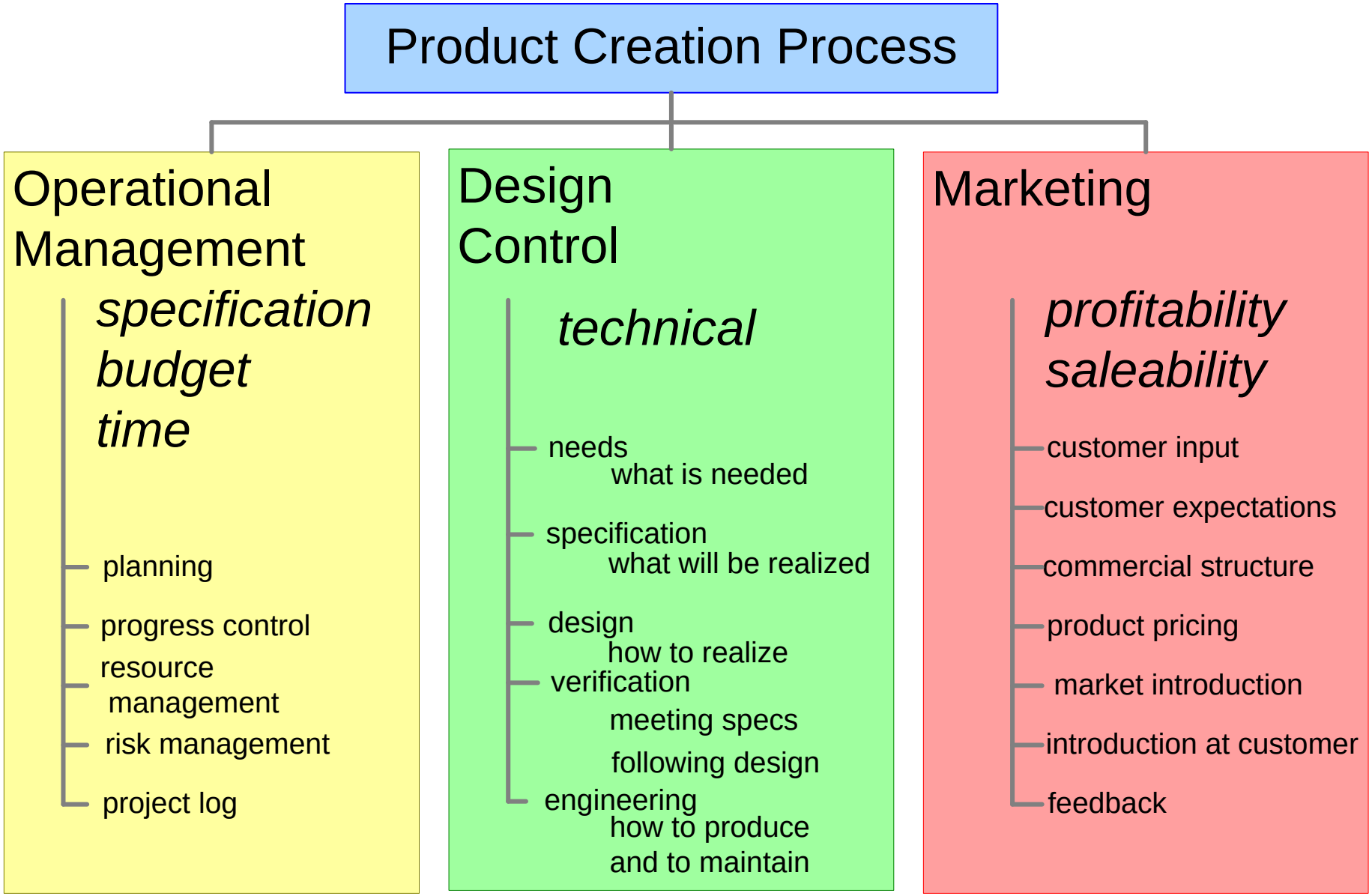
Communicate the decision clearly and widely.

Evolutionary PCP model

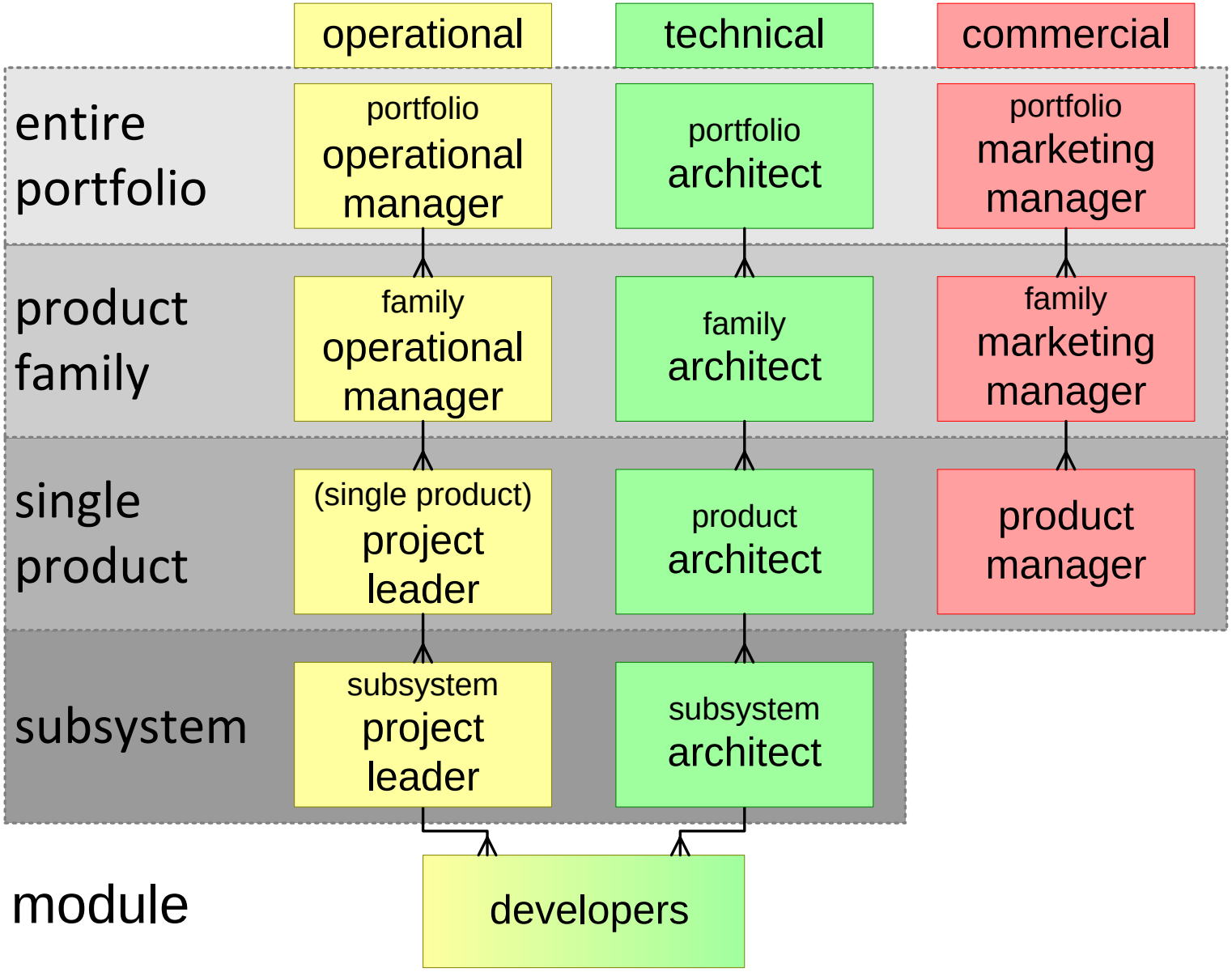


2% of budget (EVO)
2 weeks (XP)
up to 2 months
per cyclus

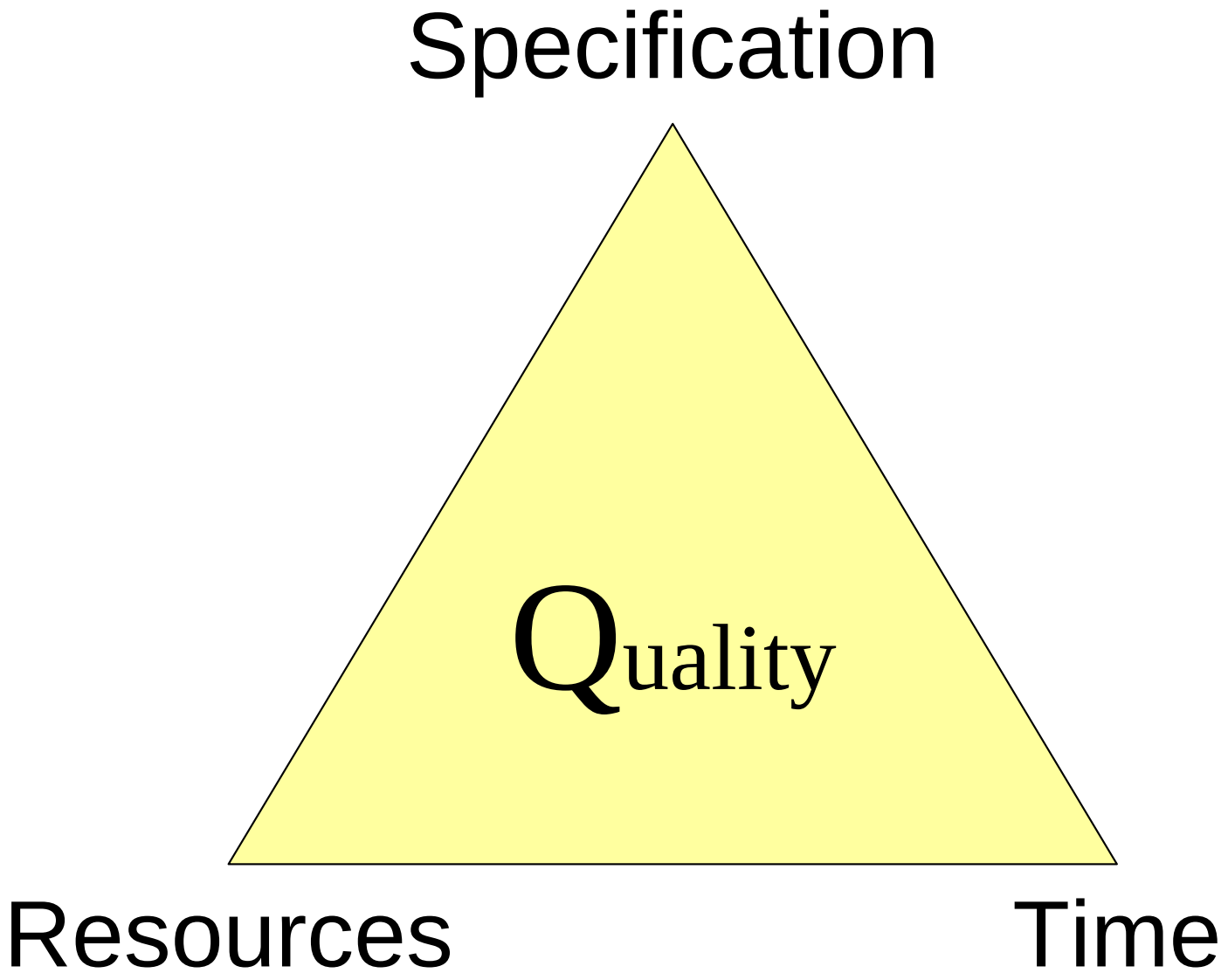
Decomposition of the Product Creation Process



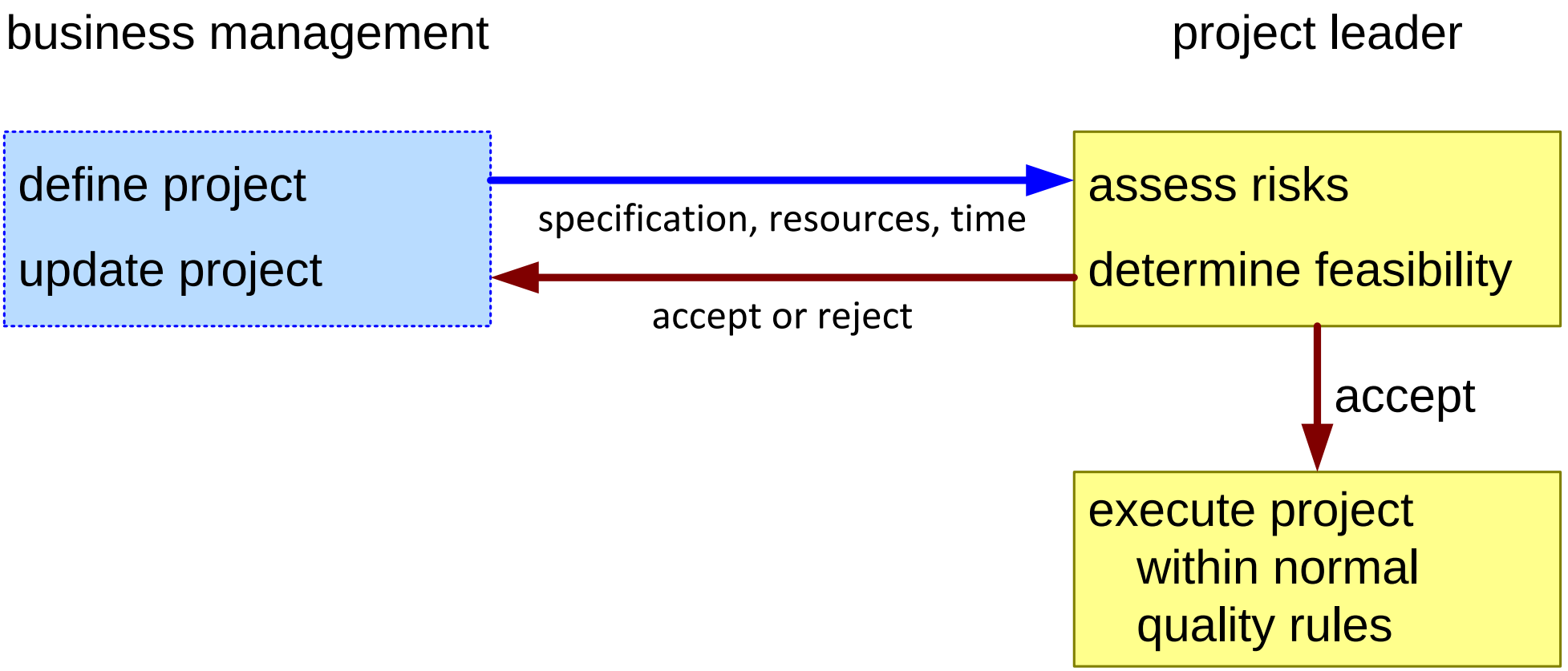
Operational Organization of the PCP



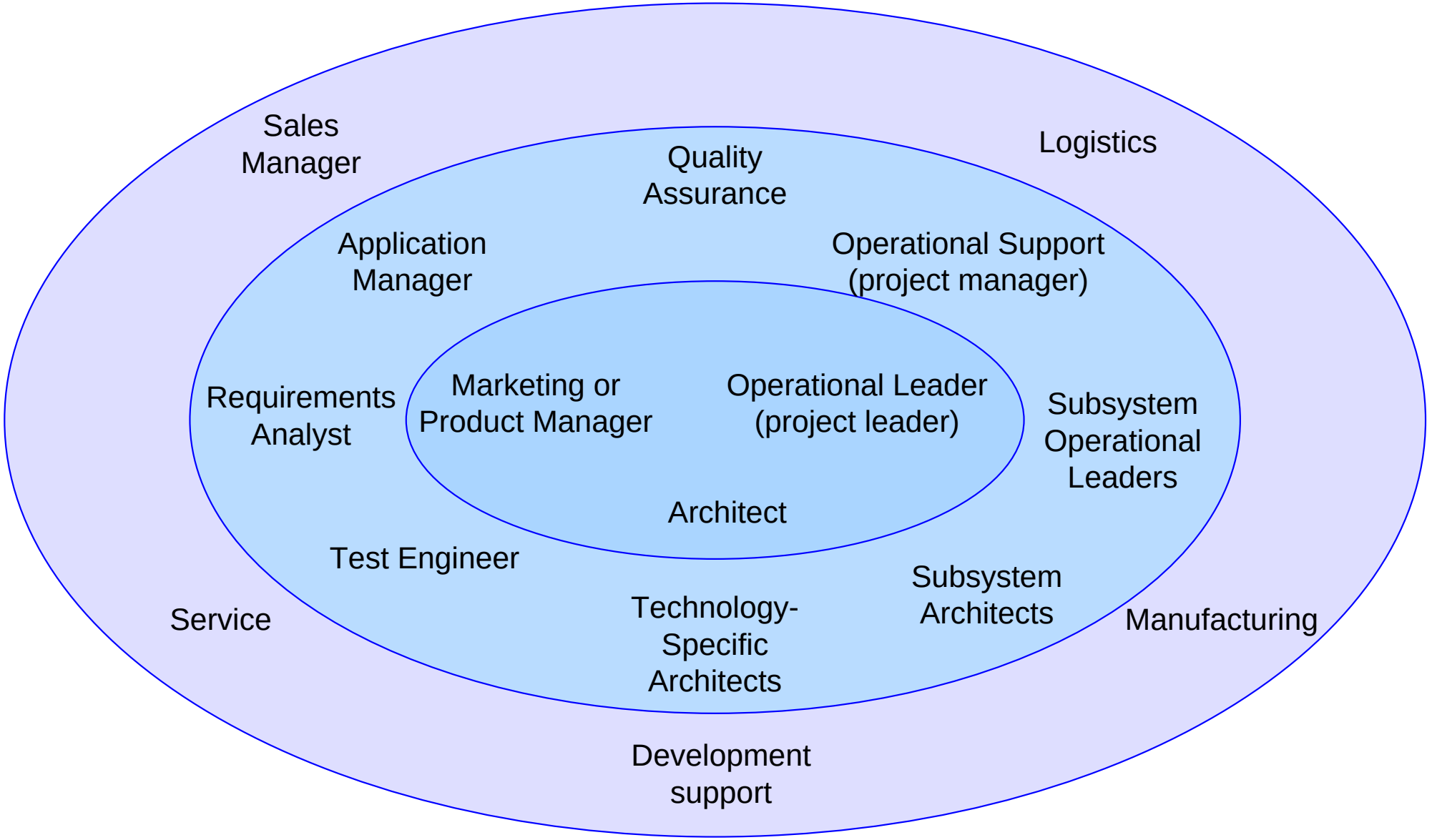
Prime Responsibilities of the Operational Leader



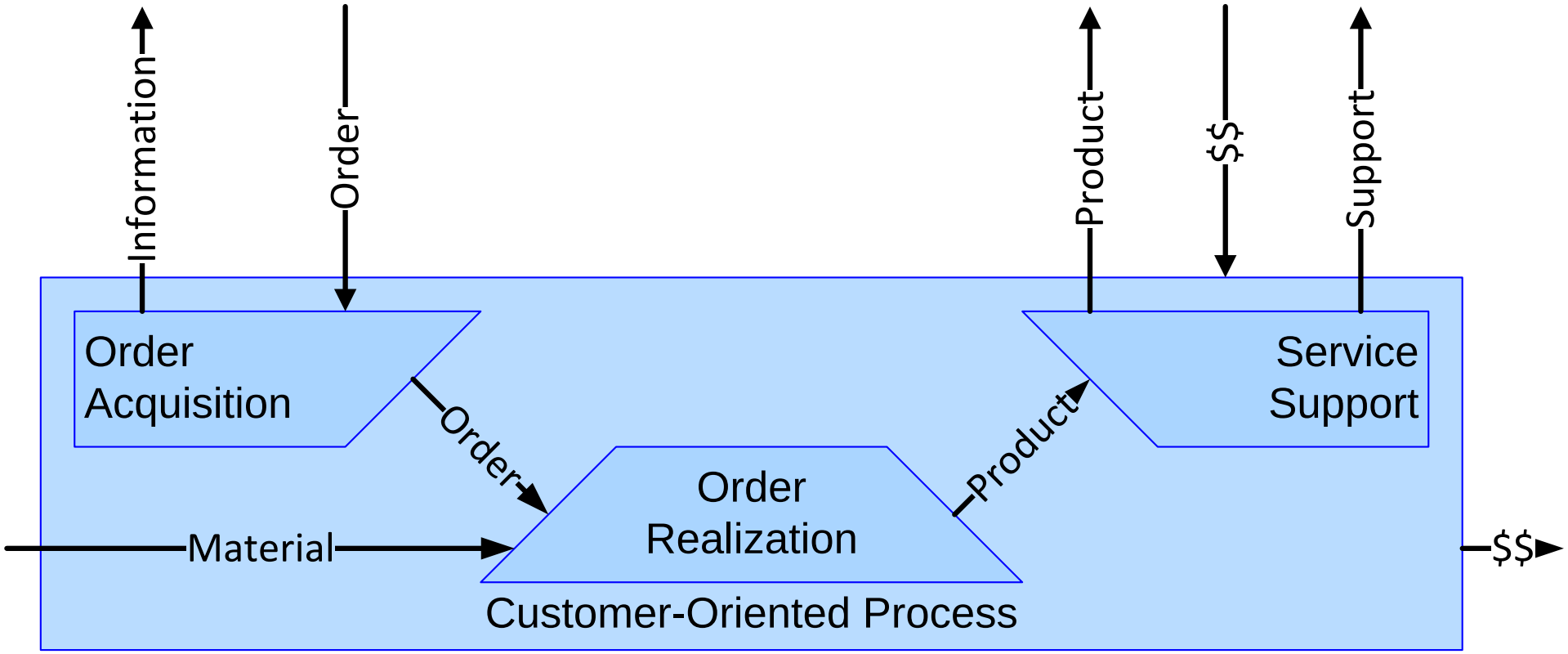
The Rules of the Operational Game



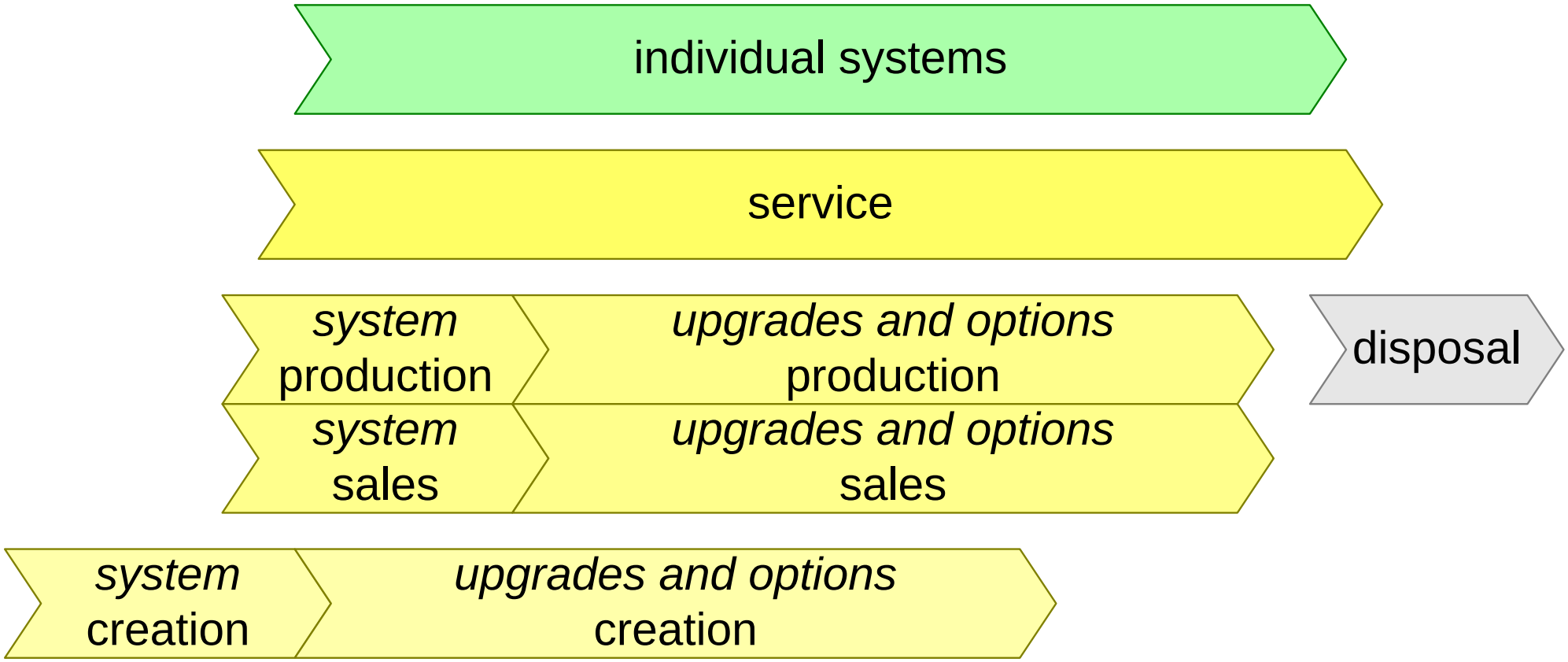
Operational Teams



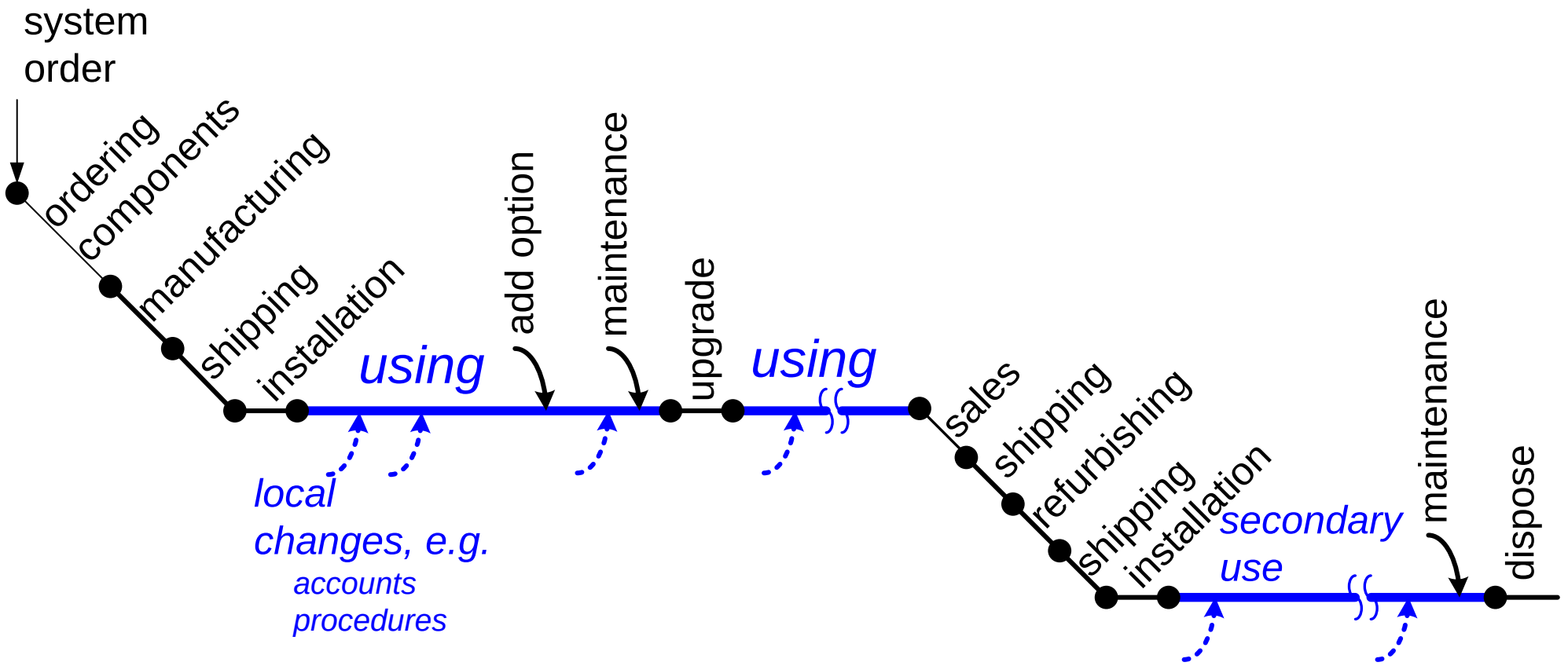
Customer Oriented Process



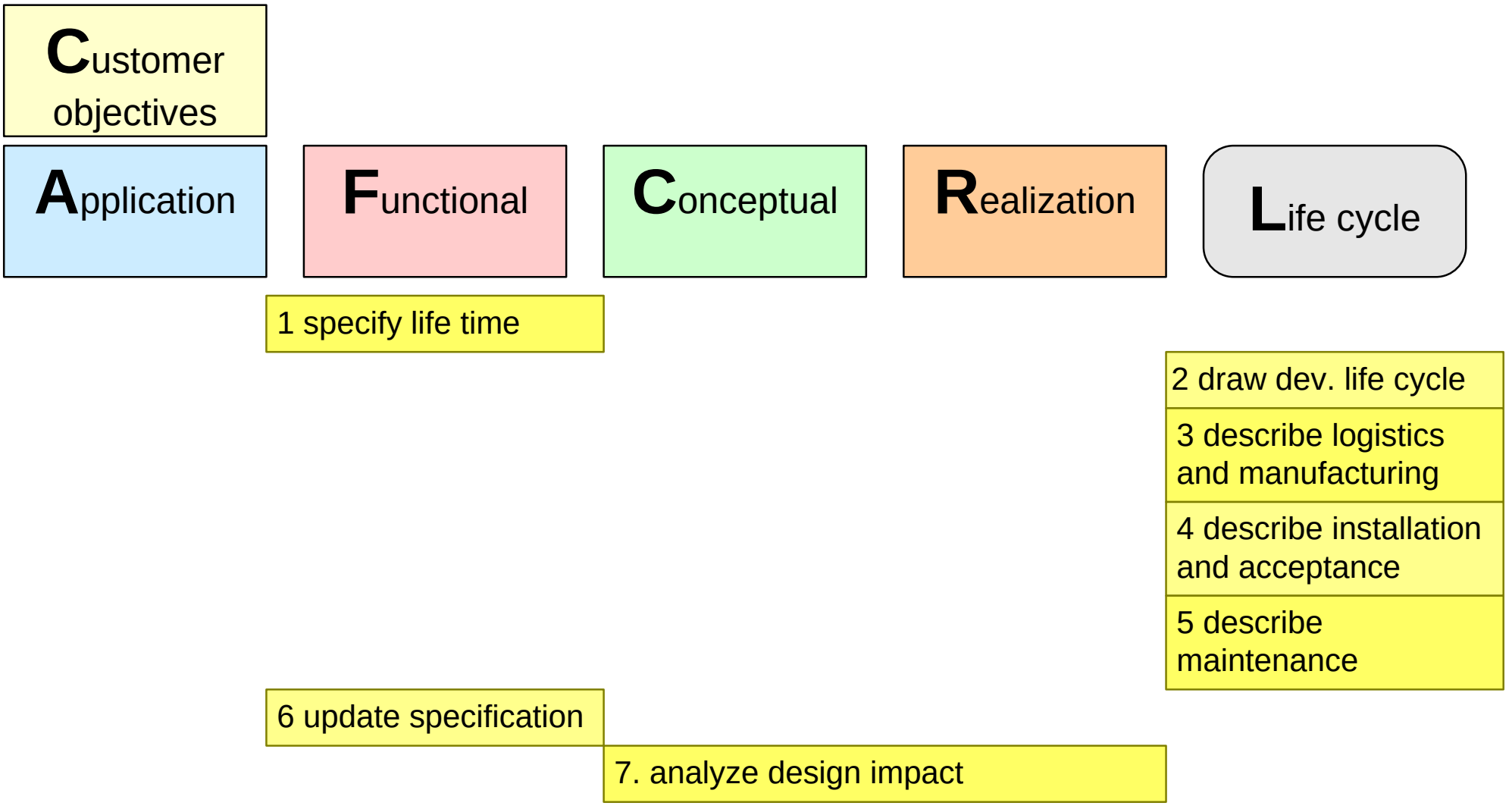
Product Related Life Cycles



System Life Cycle



Exercises Step 3



Step 3, Exercise 1

specify system life time

How long can the system be used by your customer?

How long will you offer support?

We will make a quick inventory of all life times.

Step 3, Exercise 2

draw development life cycle

What are the phases in the development life cycle?

What is the duration of each phase?

What are the main stakeholders per phase?

Two teams will briefly present their development life cycle (about 2 minutes per team)

Step 3, Exercise 3

describe logistics and manufacturing

How do you organize your logistics and manufacturing?

What is outsourced, what does your company do?

Two teams will briefly present their logistics and manufacturing (about 2 minutes per team)

Step 3, Exercise 4

describe installation and acceptance test

How is the system installed?

What is the acceptance procedure?

Two teams will briefly present their installation and acceptance (about 2 minutes per team)

Step 3, Exercise 5

describe maintenance

How is the system maintained?

What preventive maintenance is done?

How are field problems solved?

Two teams will briefly present their installation and acceptance (about 2 minutes per team)

Step 3, Exercise 6

update the specification

What functions, interfaces, or performances figures should be changed or added?

Two groups will present their specification and the changes briefly (about 1 minute per group)

Step 3, Exercise 7

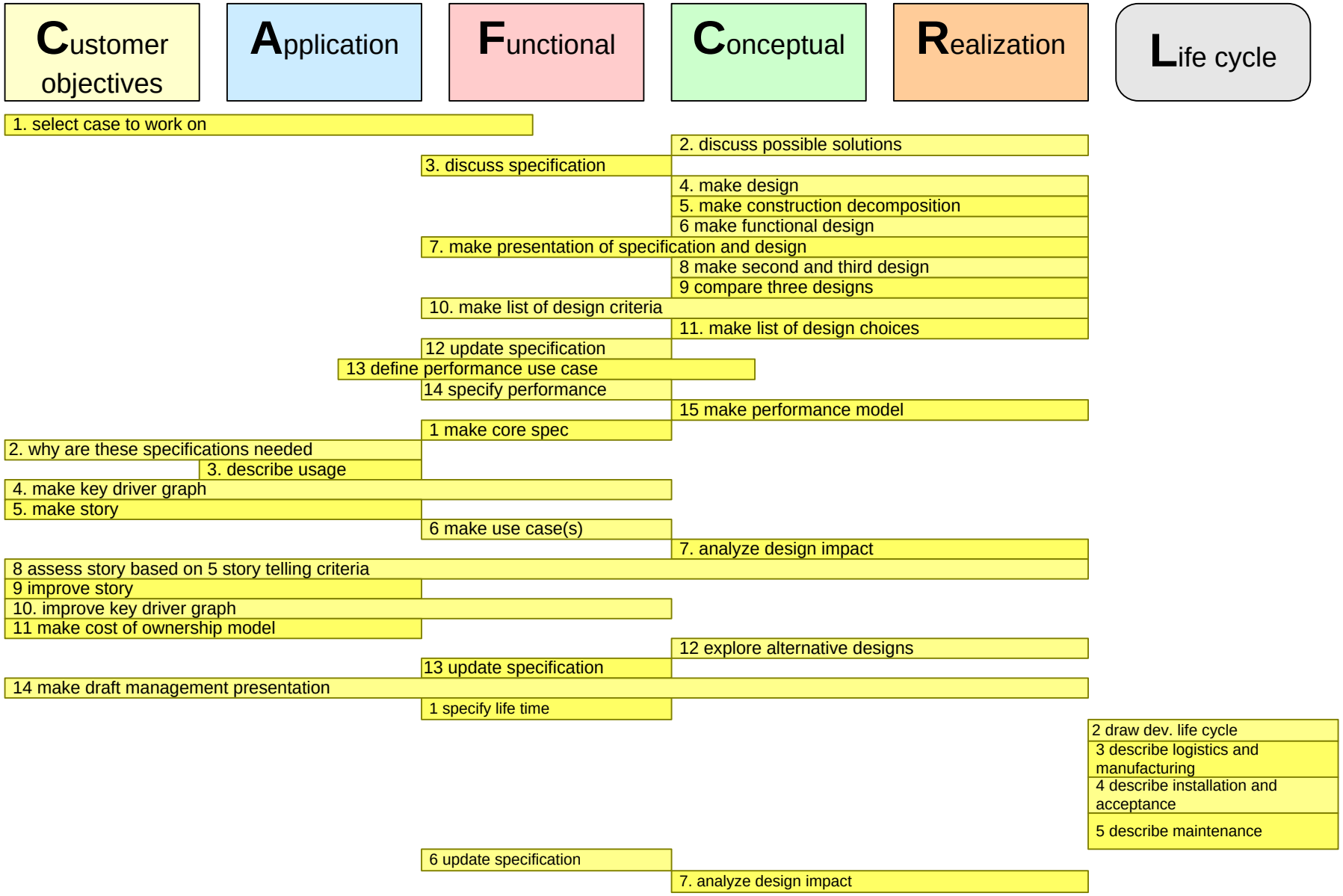
revisit design and determine impact of last exercises

Previous exercises probably will have triggered new insights.

What should change in your design to improve it and adapt to the new insights?

Two groups will present their design impact briefly (about 1 minute per group)

Summary


Customer objectives
Application
Functional
Conceptual
Realization
Life cycle
1. select case to work on
2. discuss possible solutions
3. discuss specification
4. make design
5. make construction decomposition
6 make functional design
7. make presentation of specification and design
8 make second and third design
9 compare three designs
10. make list of design criteria
11. make list of design choices
12 update specification
13 define performance use case
14 specify performance
15 make performance model
1 make core spec
2. why are these specifications needed
3. describe usage
4. make key driver graph
5. make story
6 make use case(s)
7. analyze design impact
8 assess story based on 5 story telling criteria
9 improve story
10. improve key driver graph
11 make cost of ownership model
12 explore alternative designs
13 update specification
14 make draft management presentation
1 specify life time
2 draw dev. life cycle
3 describe logistics and manufacturing
4 describe installation and acceptance
5 describe maintenance
6 update specification
7. analyze design impact

What we did not do...

Customer objectives

competition
other customers
value chain
future trends

Application

system context
stakeholders
productivity
lay-out
legislation

Functional

worst cases
exceptions
standards
reliability
price

Conceptual

start up
integration
safety
multiple decompositions

Realization

budgets
analysis
granularity
measurements

Life cycle

life cycle business
upgrades
extensions
services

production design
logistics flow
cycle time
configuration management

supply chain
make or buy
outsourcing
co-design