Tutorial Software as Integrating Technology in Complex Systems

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Abstract

This tutorial describes the integrating value of software in complex systems. The extensive use of software technology to integrate other technologies has a significant impact on the product characteristics and on the product creation organization and process. This tutorial provides insight in the relation between software and the system, and it provides insight in the consequences for the product and the organization. Some recommendations are provided to cope with these consequences.

July 3, 2023
status: concept
version: 0.1

logo
TBD

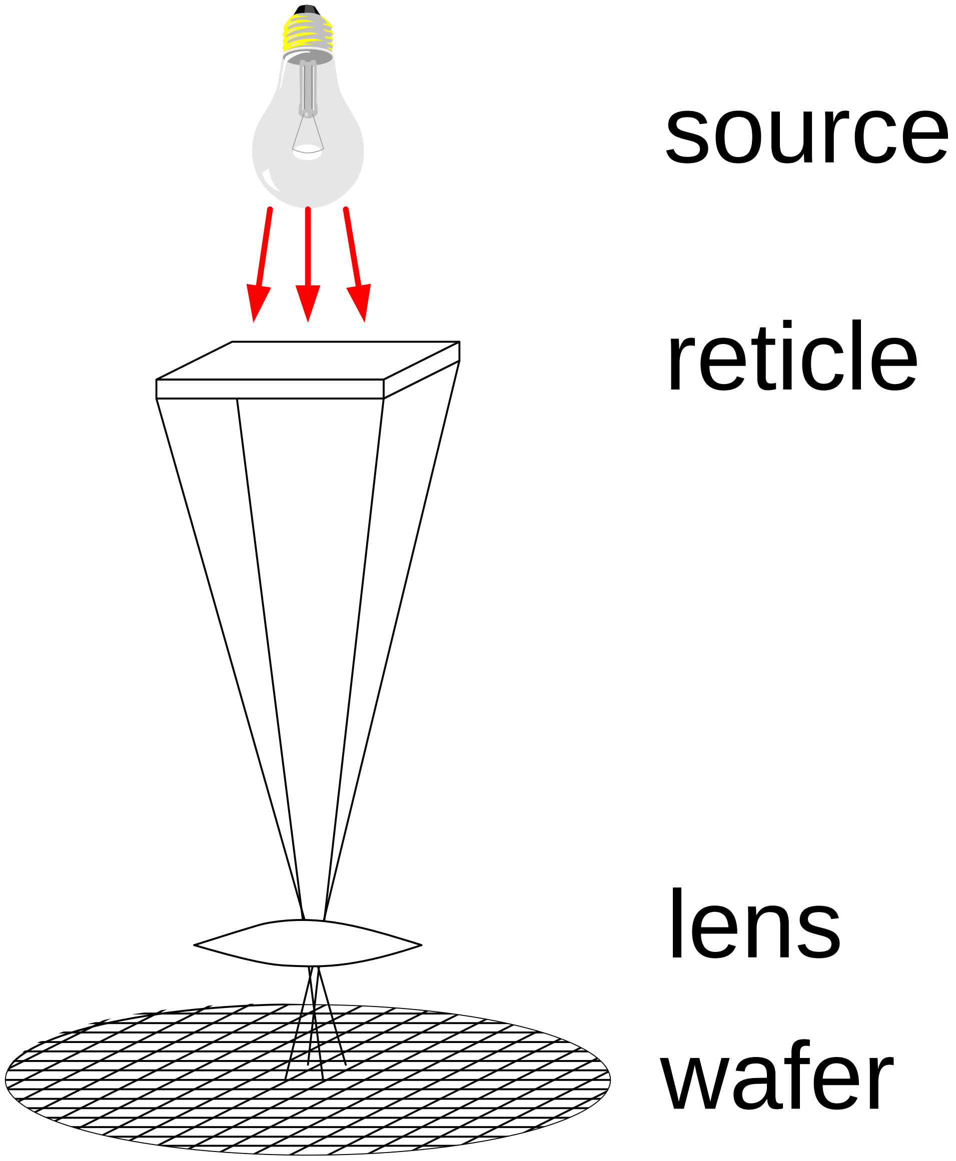
Program

- Case: the waferstepper and it’s context
- The role of software in general
- Levels of abstraction
- Software -> System Functionality and Qualities
- Requirements perspective
- Evolution and Growth
- Why do we always have problems with software?
- Conclusion

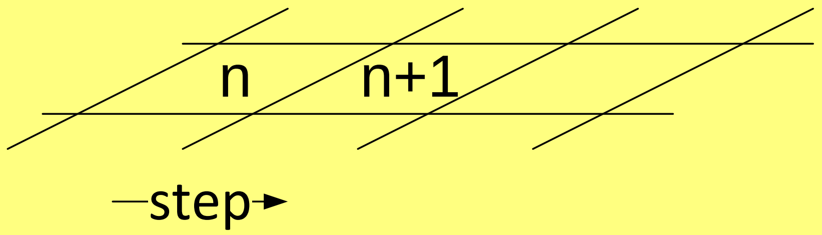
Twinscan AT1100

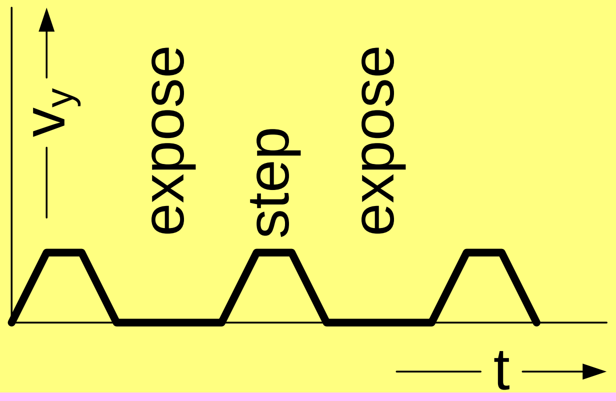
ASML
TWINSCAN
1100

What is a waferstepper

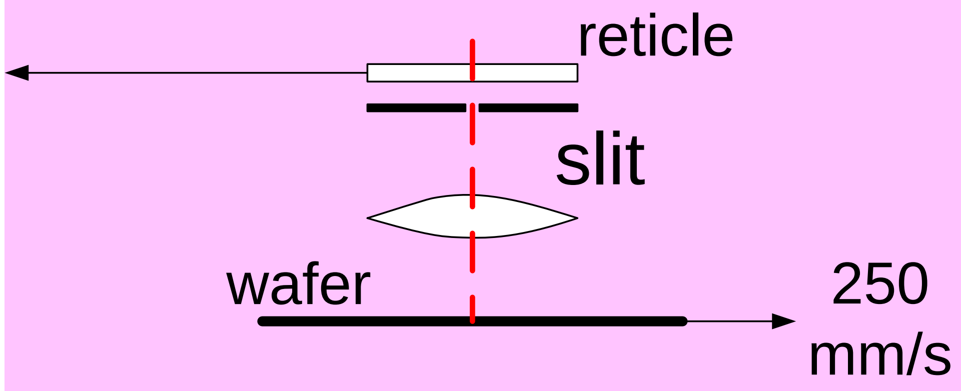


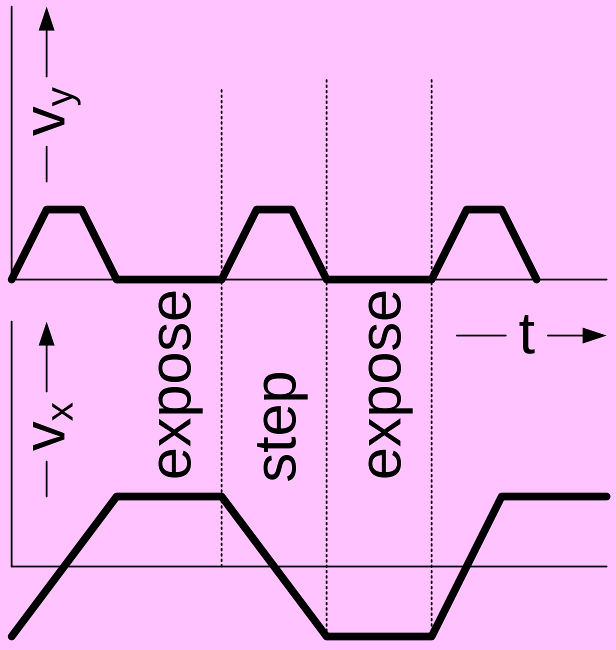
From stepping to scanning





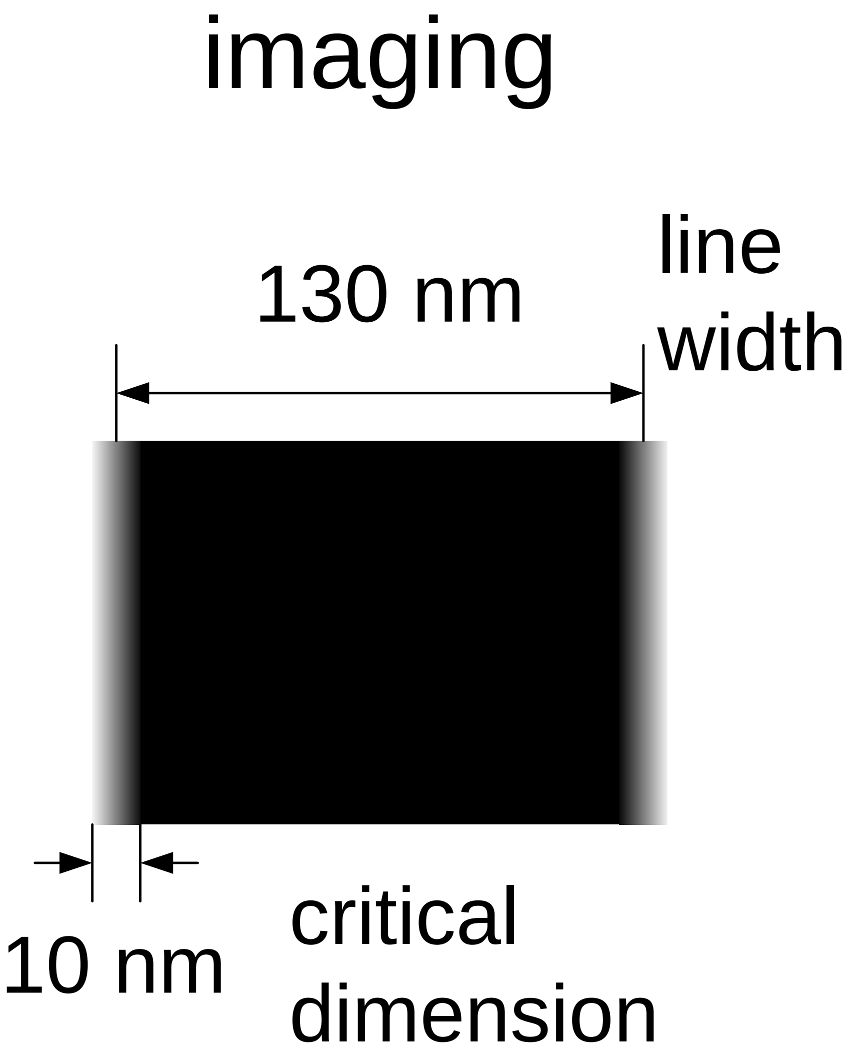
stepper: *static exposure of field*

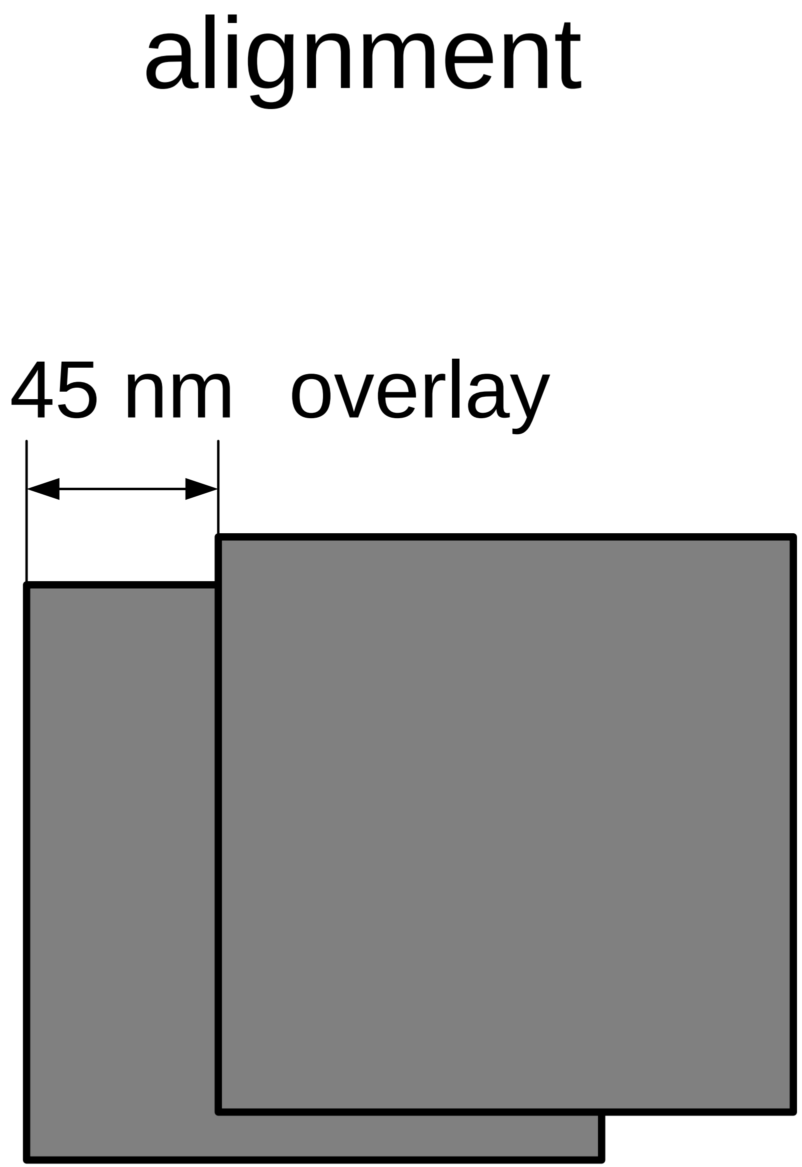




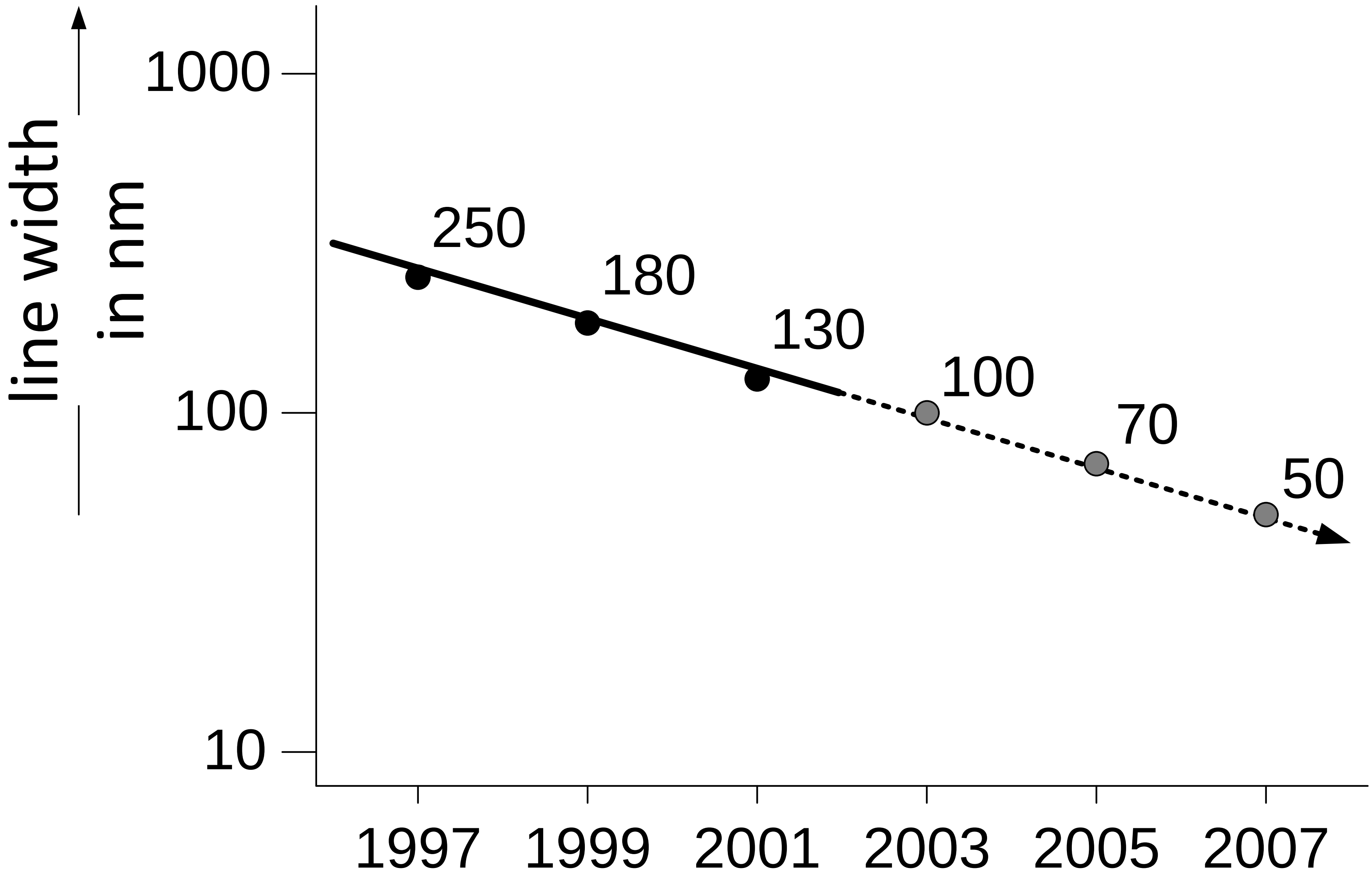
scanner: *dynamic exposure through slit*

Key specifications waferstepper

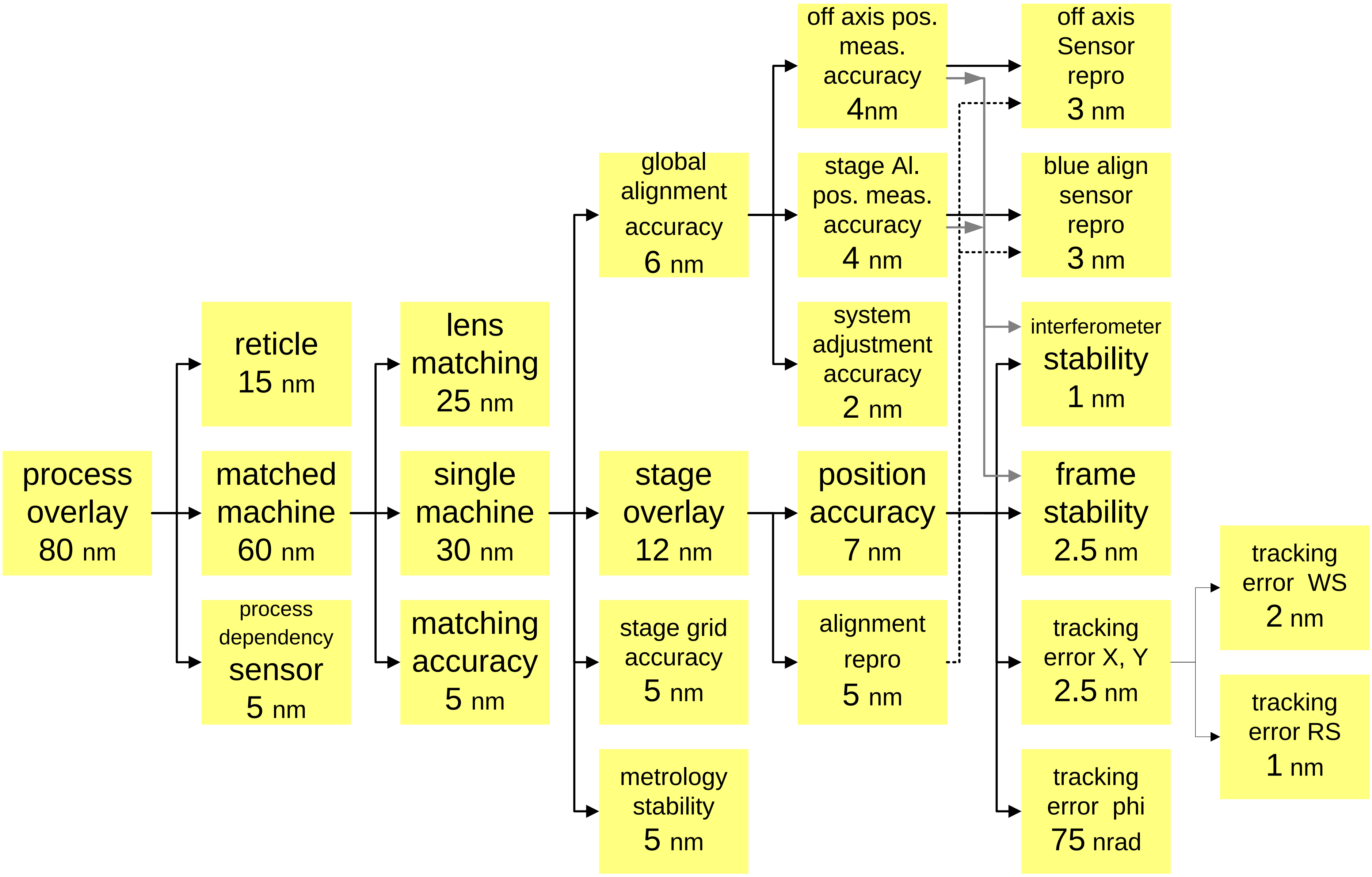




Moore's law

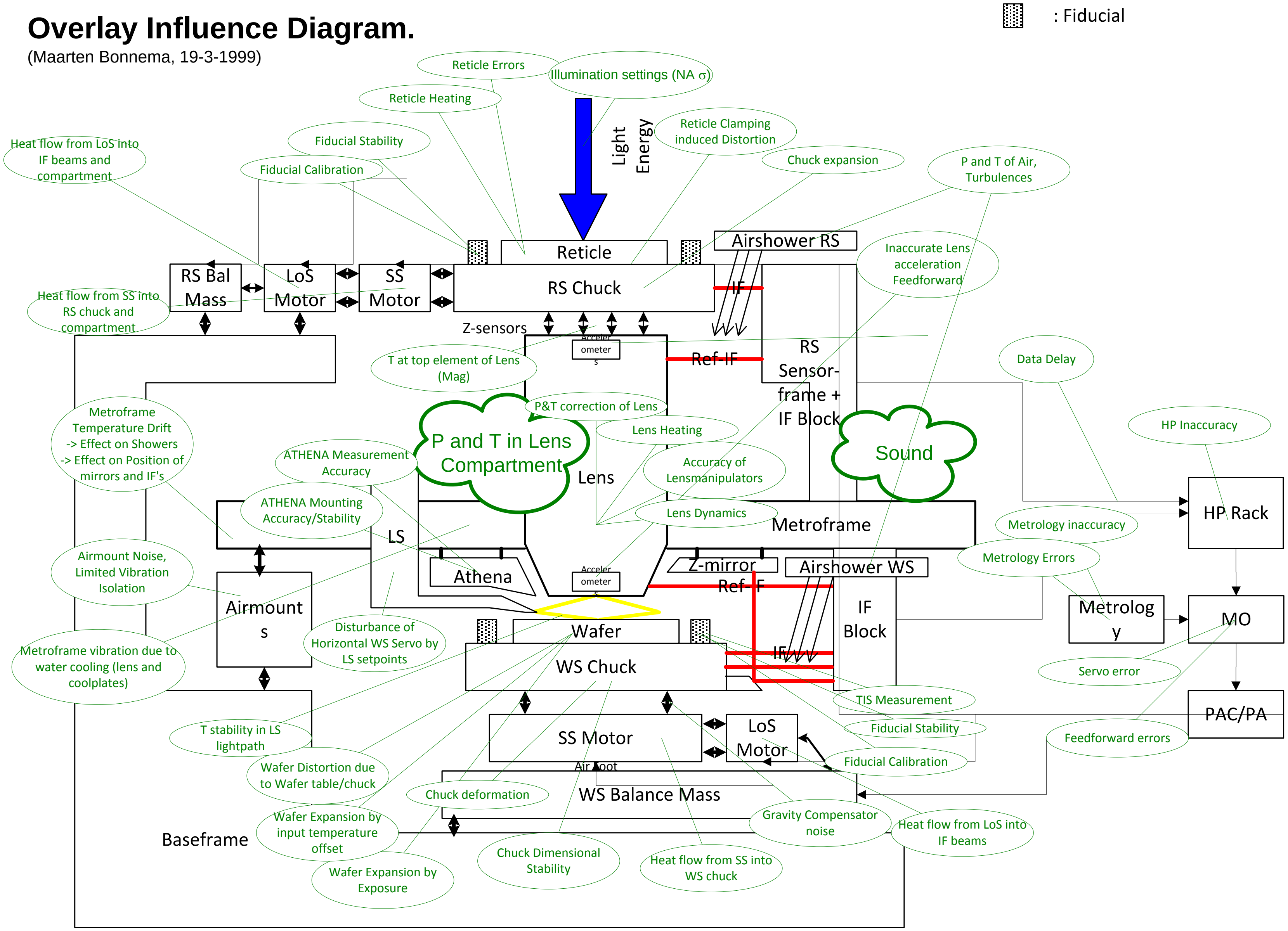

line width in nm
1000
100
10
250
180
130
100
70
50
1997
1999
2001
2003
2005
2007

Overlay budget (1999)



process overlay 80 nm
reticle 15 nm
matched machine 60 nm
process dependency sensor 5 nm
lens matching 25 nm
single machine 30 nm
matching accuracy 5 nm
global alignment accuracy 6 nm
stage overlay 12 nm
stage grid accuracy 5 nm
metrology stability 5 nm
off axis pos. meas. accuracy 4nm
stage Al. pos. meas. accuracy 4 nm
system adjustment accuracy 2 nm
position accuracy 7 nm
alignment repro 5 nm
off axis Sensor repro 3 nm
blue align sensor repro 3 nm
interferometer stability 1 nm
frame stability 2.5 nm
tracking error X, Y 2.5 nm
tracking error phi 75 nrad
tracking error WS 2 nm
tracking error RS 1 nm

Everything influences overlay


▨ : Fiducial
Reticle Errors
Illumination settings (NA σ)
Reticle Heating
Light Energy
Reticle Clamping induced Distortion
Fiducial Stability
Heat flow from LoS into IF beams and compartment
Fiducial Calibration
Chuck expansion
P and T of Air, Turbulences
Reticle
Airshower RS
Inaccurate Lens acceleration Feedforward
RS Bal Mass
LoS Motor
SS Motor
RS Chuck
IF
Heat flow from SS into RS chuck and compartment
Z-sensors
Acceler ometer s
Ref IF
RS Sensor-frame + IF Block
T at top element of Lens (Mag)
Data Delay
P&T correction of Lens
Metroframe Temperature Drift -> Effect on Showers -> Effect on Position of mirrors and IF's
Lens Heating
HP Inaccuracy
P and T in Lens Compartment
Sound
ATHENA Measurement Accuracy
Accuracy of Lensmanipulators
Lens
ATHENA Mounting Accuracy/Stability
Lens Dynamics
Metroframe
HP Rack
Metrology inaccuracy
LS
Airmount Noise, Limited Vibration Isolation
Metrology Errors
Athena
Z-mirror
Airshower WS
Acceler ometer
Ref-F
Airmount s
IF Block
Metrolog y
MO
Disturbance of Horizontal WS Servo by LS setpoints
Wafer
Metroframe vibration due to water cooling (lens and coolplates)
WS Chuck
IF
Servo error
TIS Measurement
PAC/PA
T stability in LS lightpath
SS Motor
LoS Motor
Fiducial Stability
Feedforward errors
Fiducial Calibration
Wafer Distortion due to Wafer table/chuck
Air foot
Chuck deformation
WS Balance Mass
Gravity Compensator noise
Heat flow from LoS into IF beams
Baseframe
Wafer Expansion by input temperature offset
Chuck Dimensional Stability
Heat flow from SS into WS chuck
Wafer Expansion by Exposure

Overlay Influence Diagram.

(Maarten Bonnema, 19-3-1999)

Exercise 1, 10 minutes

Make a 3 picture description (What, How, biggest challenge) of your own system.

Fab Context of Waferstepper

resists

devices

fab logistics

semiconductor design

fab automation

processing

tracks

SPC

wafer

reticule production

metrology

yield optimization

reticules

waferstepper

reticule logistics

matching

wafer logistics

operator

fab layout

maintenance

contamination

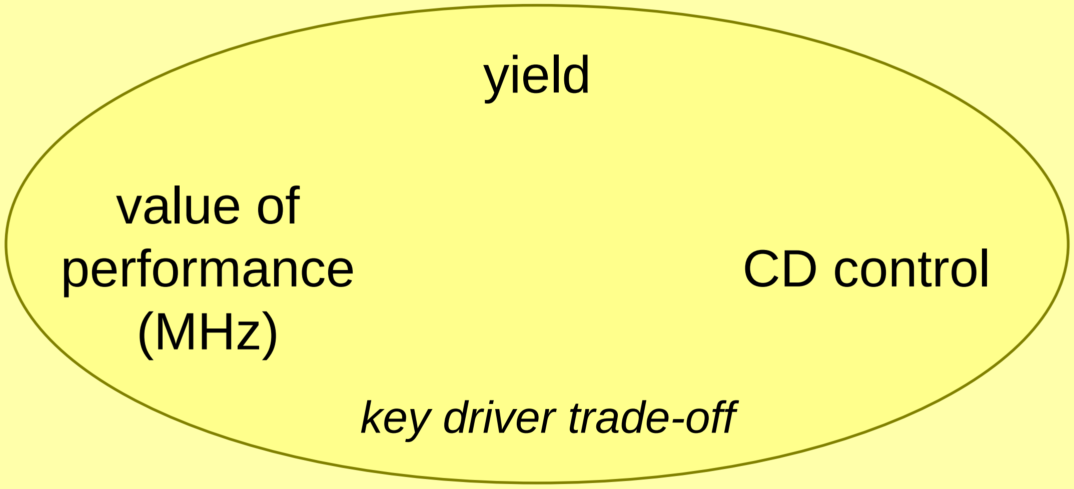
inspection and monitoring

utilization

fab cost model

fab infrastructure

Business Context

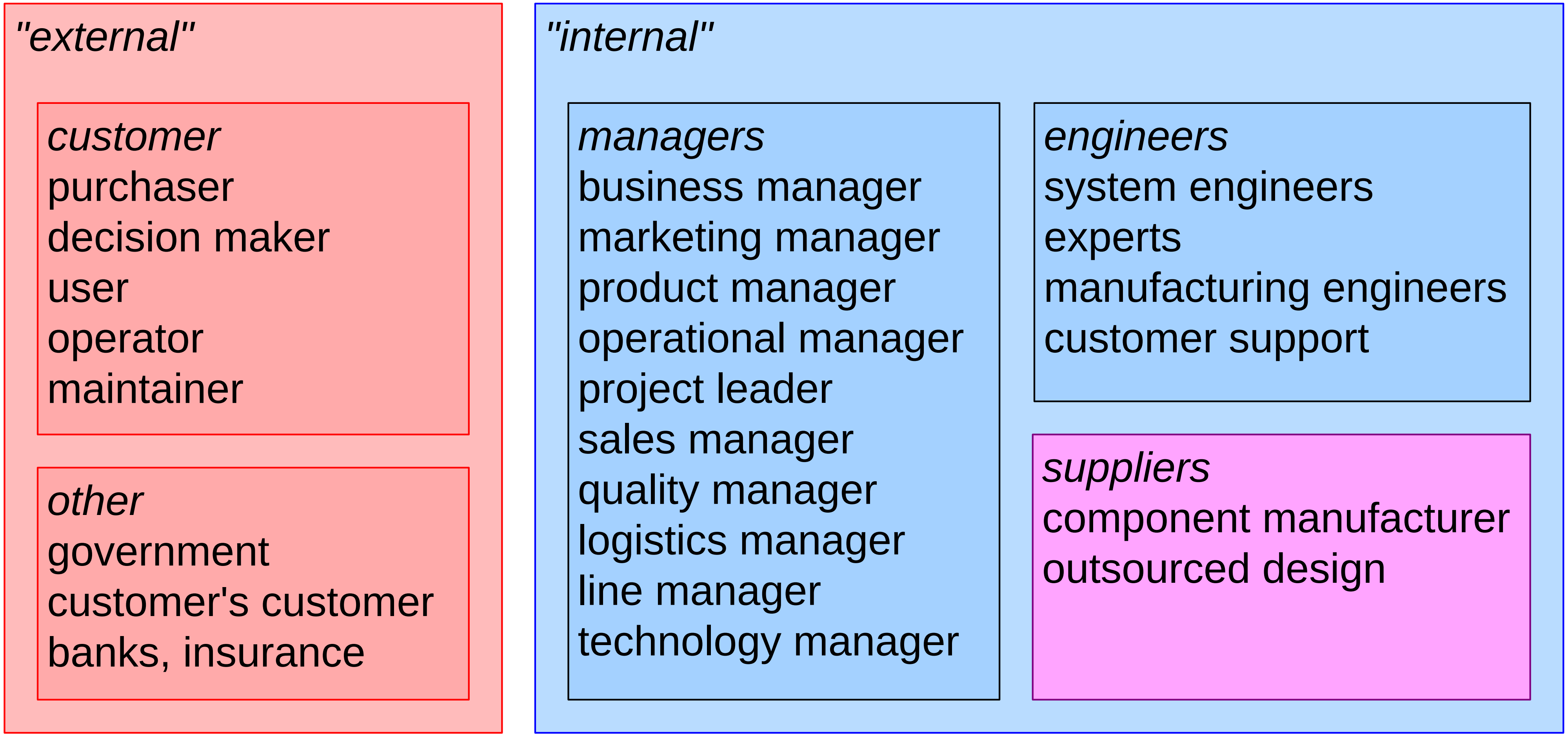


other players:
- equipments vendors
- system integrators
- lease companies
- fab designers
- consultants
- mask makers
- resist makers
- wafer makers
- OEM's: laser
- intimate partners: lens

business models of the customer:
- design houses
- foundries
- vertical integration

Limited number of customers;
Many systems per customer

Human Context: Stakeholders



"external"

customer
purchaser
decision maker
user
operator
maintainer

other
government
customer's customer
banks, insurance

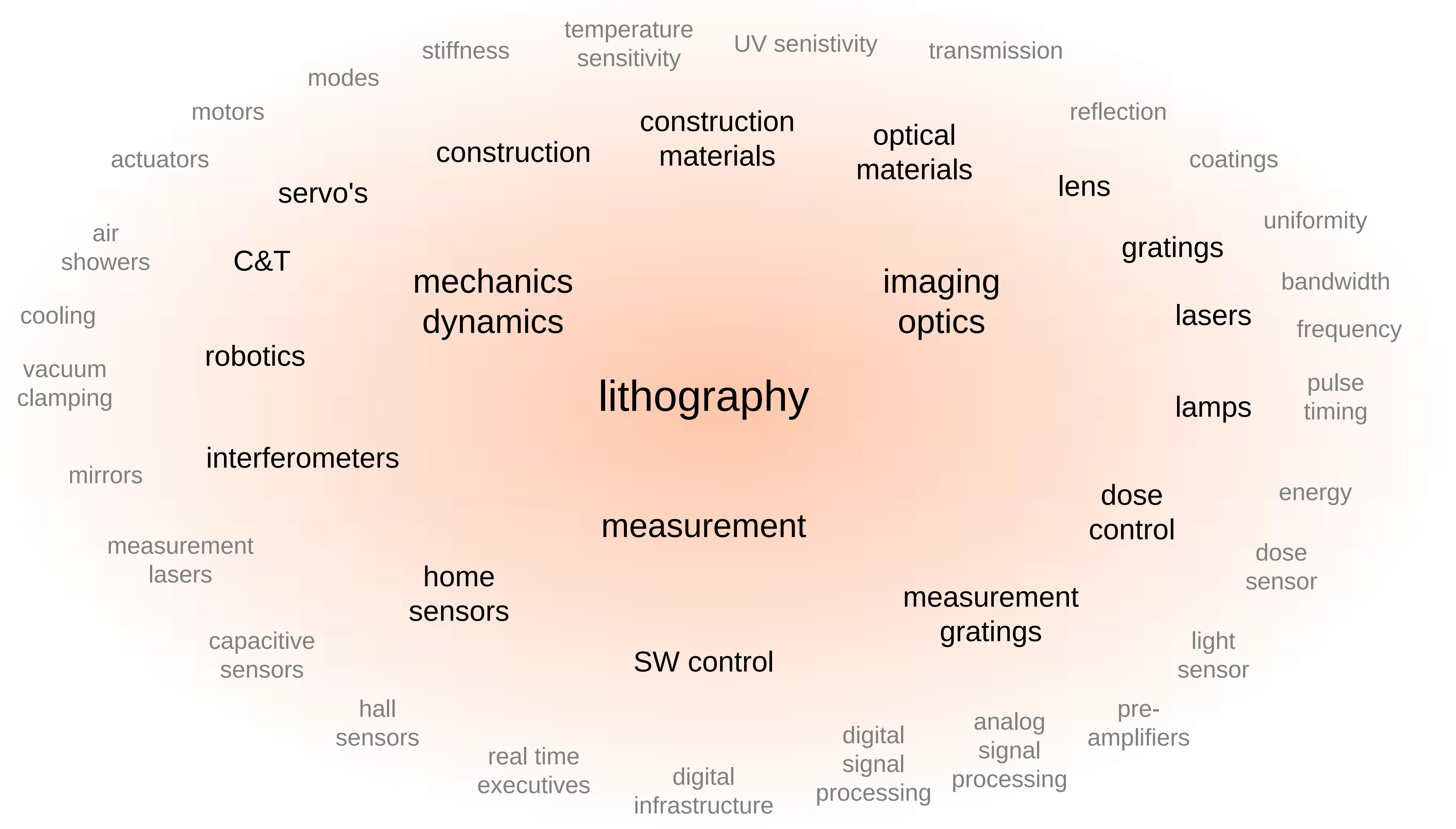
"internal"

managers
business manager
marketing manager
product manager
operational manager
project leader
sales manager
quality manager
logistics manager
line manager
technology manager

engineers
system engineers
experts
manufacturing engineers
customer support

suppliers
component manufacturer
outsourced design

Multitude of Disciplines



temperature sensitivity

stiffness

UV senistivity

transmission

modes

motors

reflection

construction materials

optical materials

construction

actuators

coatings

servo's

lens

uniformity

air showers

C&T

gratings

mechanics dynamics

imaging optics

bandwidth

cooling

lasers

frequency

robotics

vacuum clamping

lithography

pulse timing

lamps

mirrors

interferometers

dose control

energy

measurement

measurement lasers

dose sensor

home sensors

measurement gratings

capacitive sensors

SW control

light sensor

hall sensors

pre-amplifiers

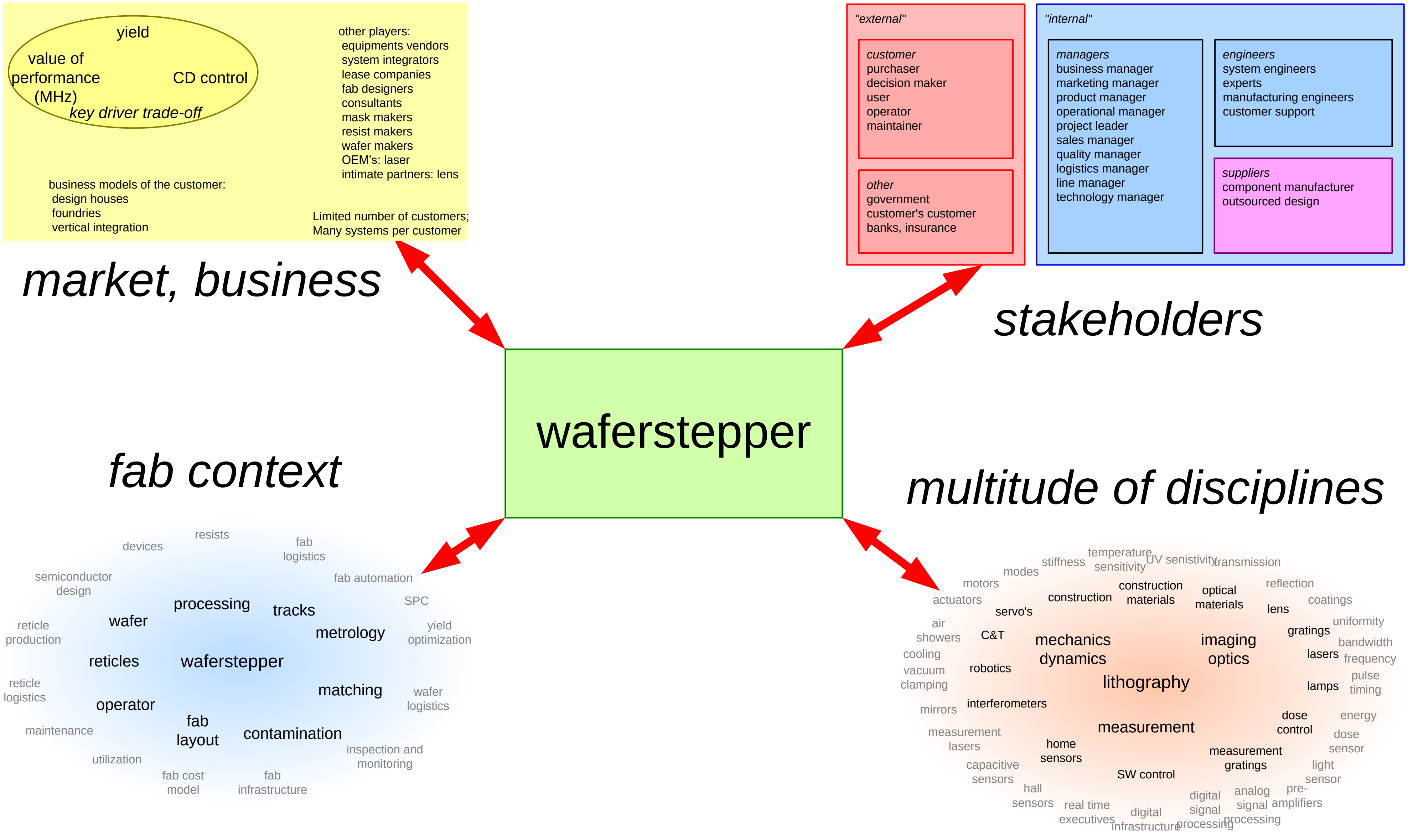
analog signal processing

digital signal processing

real time executives

digital infrastructure

Complexity of Waferstepper Context



yield
value of performance (MHz)
CD control
key driver trade-off

other players:
equipments vendors
system integrators
lease companies
fab designers
consultants
mask makers
resist makers
wafer makers
OEM's: laser
intimate partners: lens

business models of the customer:
design houses
foundries
vertical integration

Limited number of customers;
Many systems per customer

market, business

"external"

customer
purchaser
decision maker
user
operator
maintainer

other
government
customer's customer
banks, insurance

"internal"

managers
business manager
marketing manager
product manager
operational manager
project leader
sales manager
quality manager
logistics manager
line manager
technology manager

engineers
system engineers
experts
manufacturing engineers
customer support

suppliers
component manufacturer
outsourced design

stakeholders

waferstepper

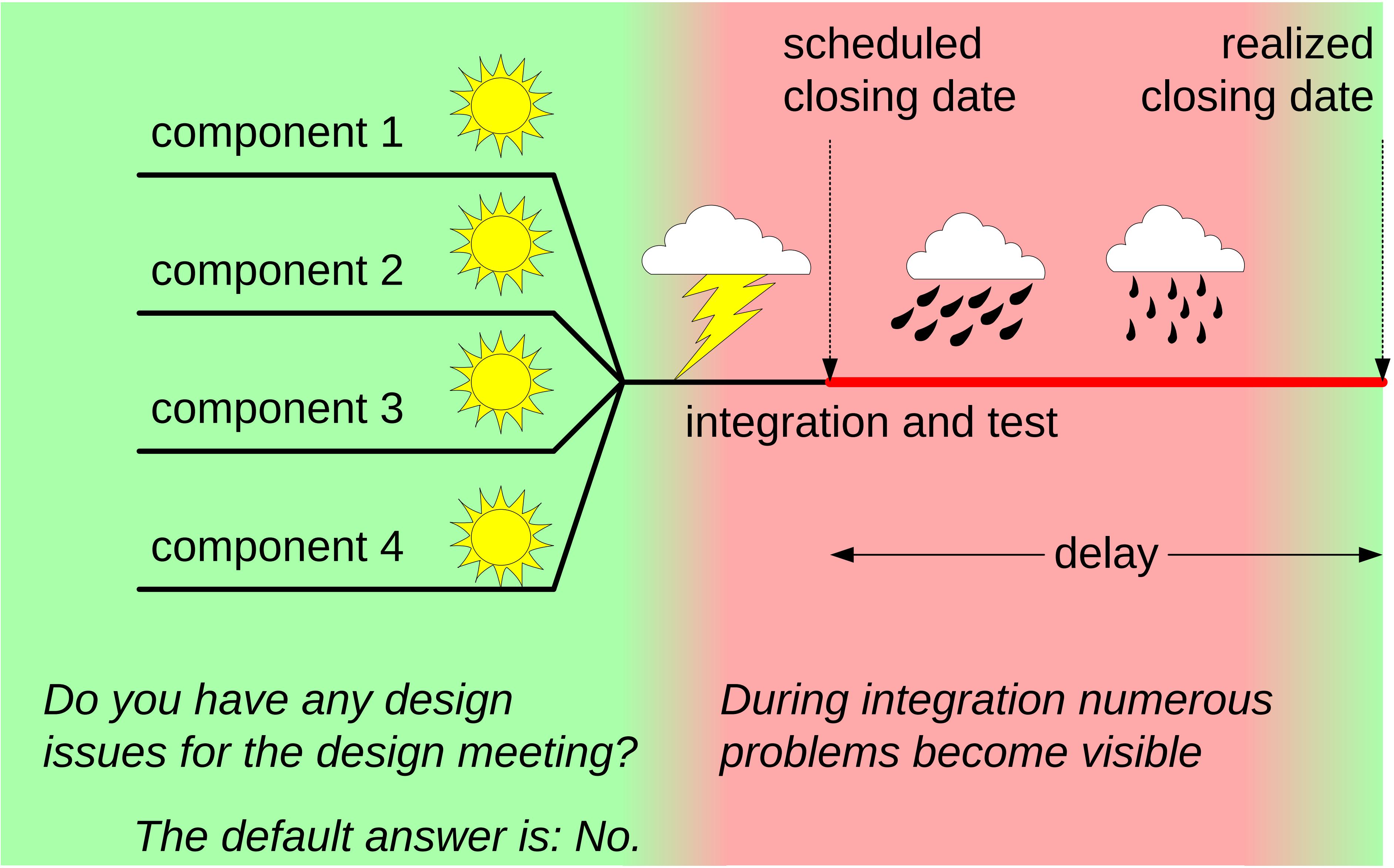
fab context

devices, resists, fab logistics, semiconductor design, fab automation, processing, tracks, SPC, wafer, reticle production, metrology, yield optimization, reticles, waferstepper, reticle logistics, matching, wafer logistics, operator, fab layout, contamination, maintenance, inspection and monitoring, utilization, fab cost model, fab infrastructure

multitude of disciplines

temperature sensitivity, stiffness, UV senistivity, transmission, modes, motors, construction, construction materials, optical materials, reflection, actuators, servo's, lens, coatings, air showers, C&T, mechanics dynamics, imaging optics, gratings, uniformity, bandwidth, cooling, lasers, frequency, vacuum clamping, robotics, lithography, lamps, pulse timing, mirrors, interferometers, dose control, energy, measurement lasers, measurement, dose sensor, home sensors, measurement gratings, capacitive sensors, SW control, light sensor, hall sensors, real time executives, digital infrastructure, digital signal processing, analog signal processing, pre-amplifiers

Symptom: Delays appear during Integration



Do you have any design issues for the design meeting?

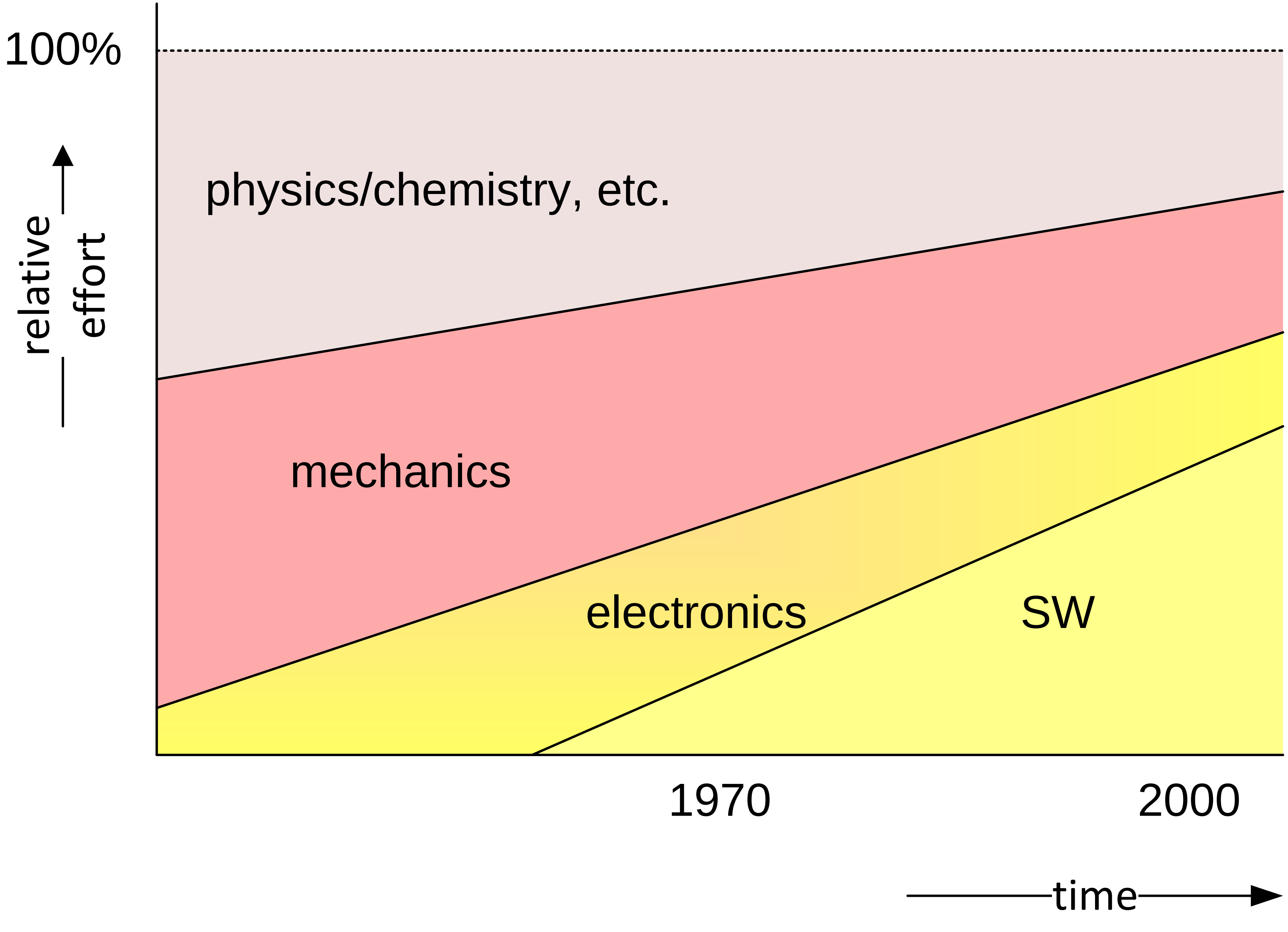
The default answer is: No.

During integration numerous problems become visible

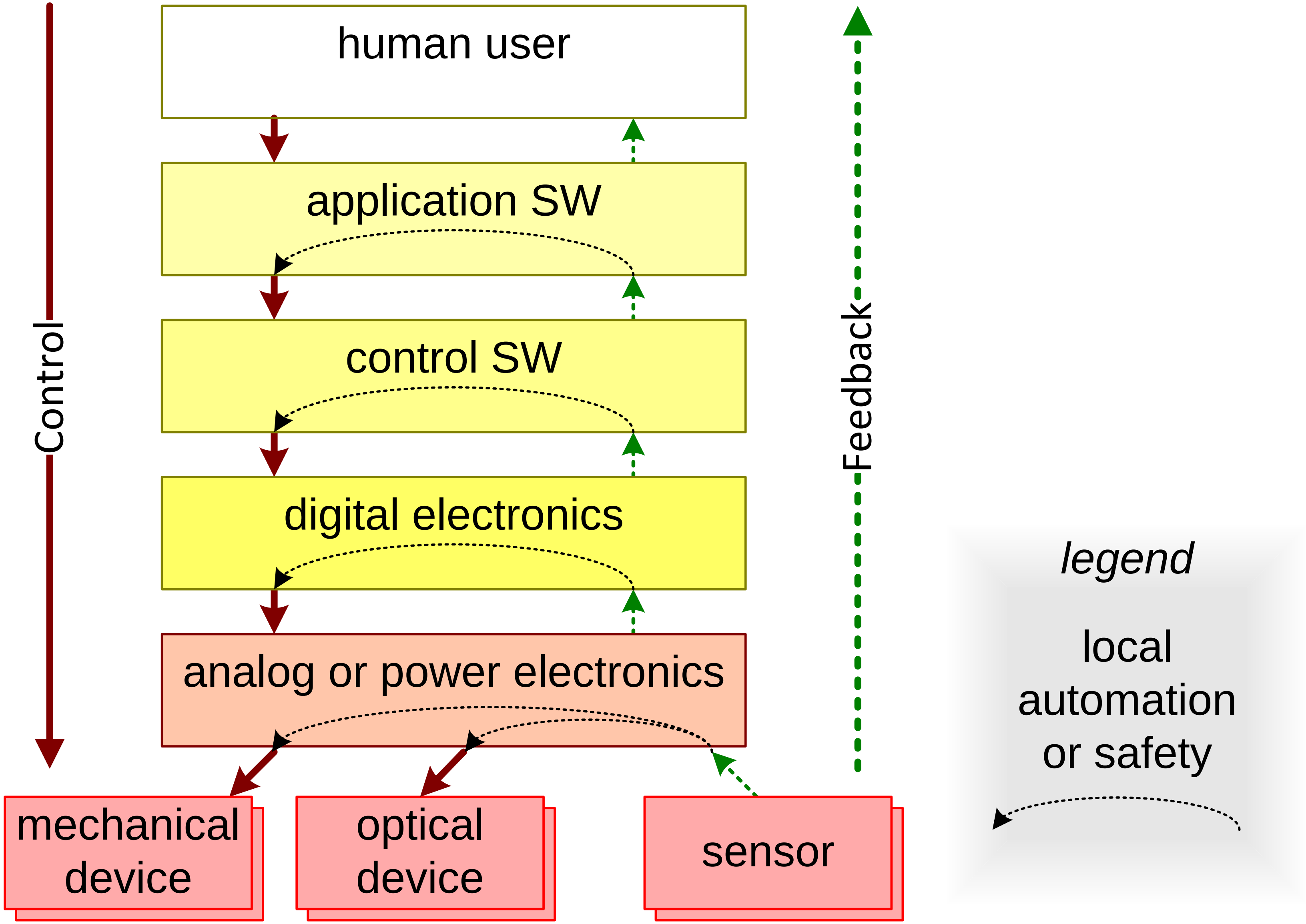
Exercise 2, 10 minutes

Make a 3 picture description (Application context, Value chain, technologies) of your own system.

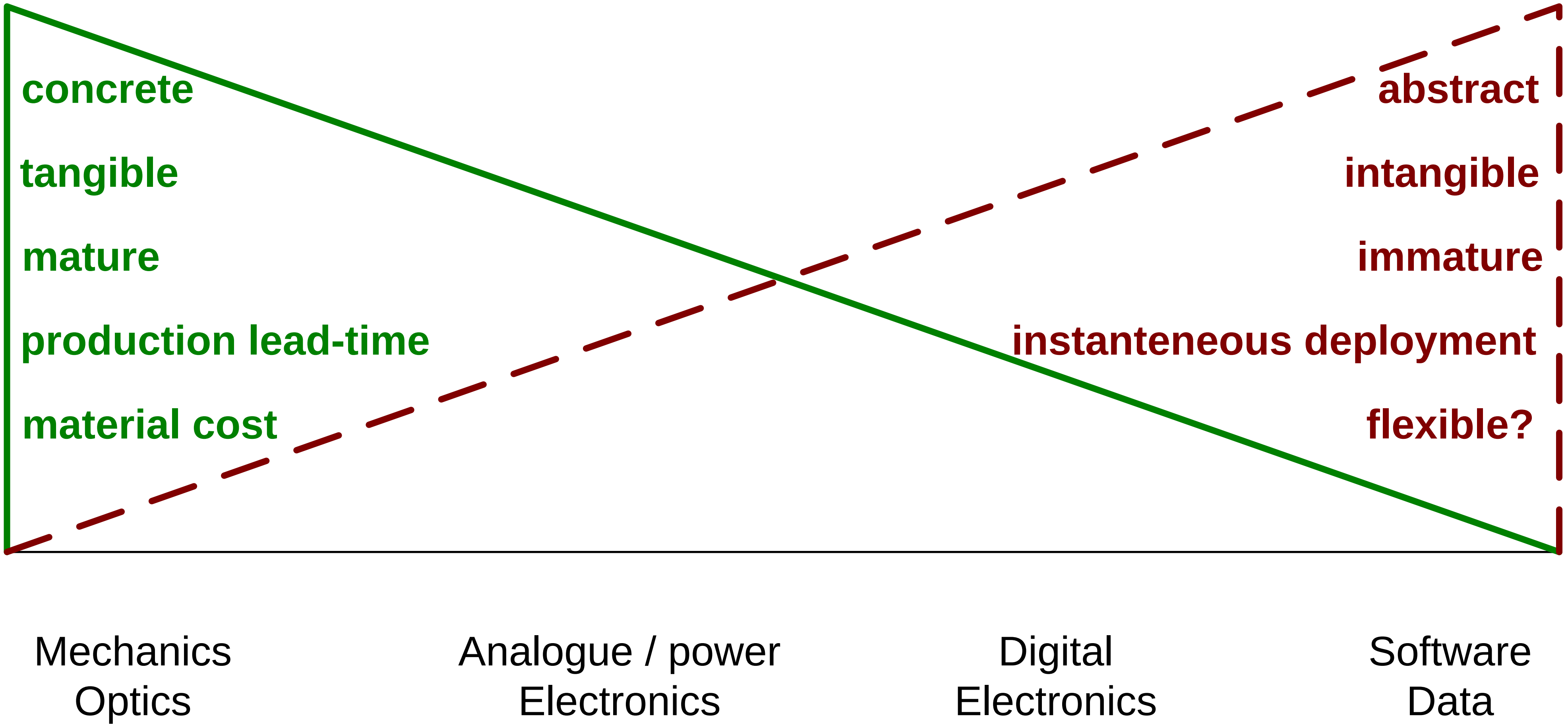
Relative Contribution of SW



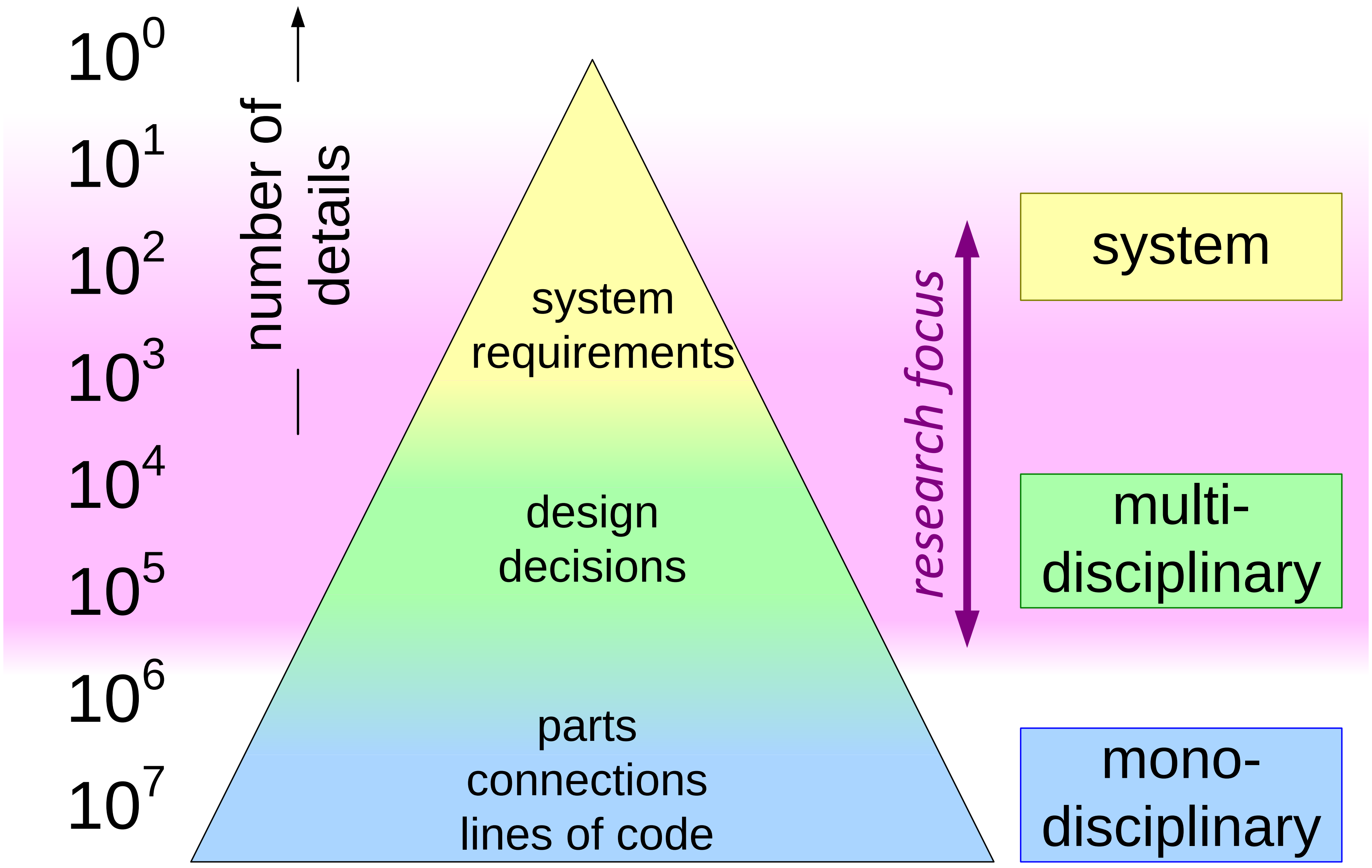
Control Hierarchy along Technology axis



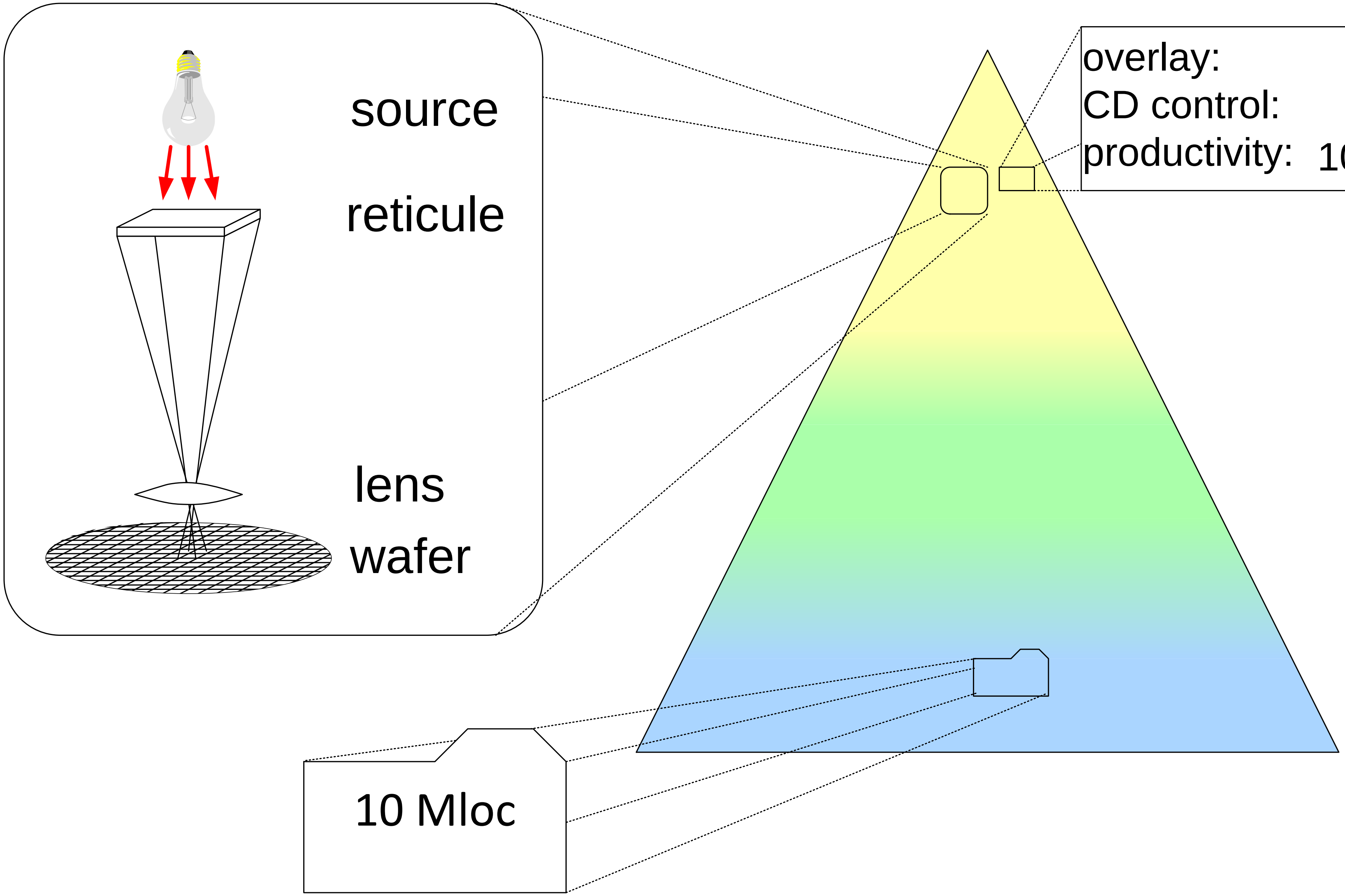
Characterization of disciplines



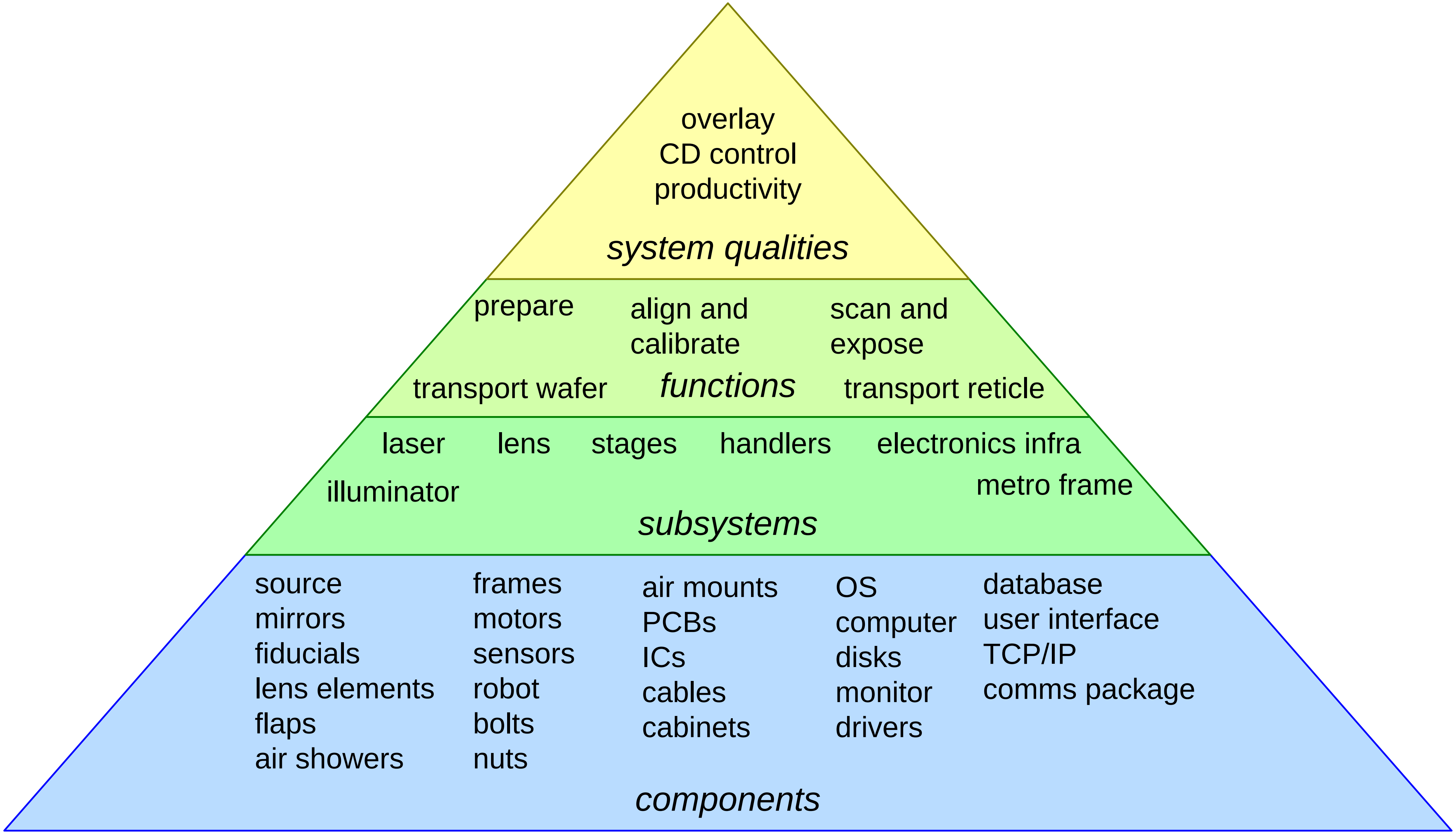
Exponential Pyramid, from requirement to bolts and nuts



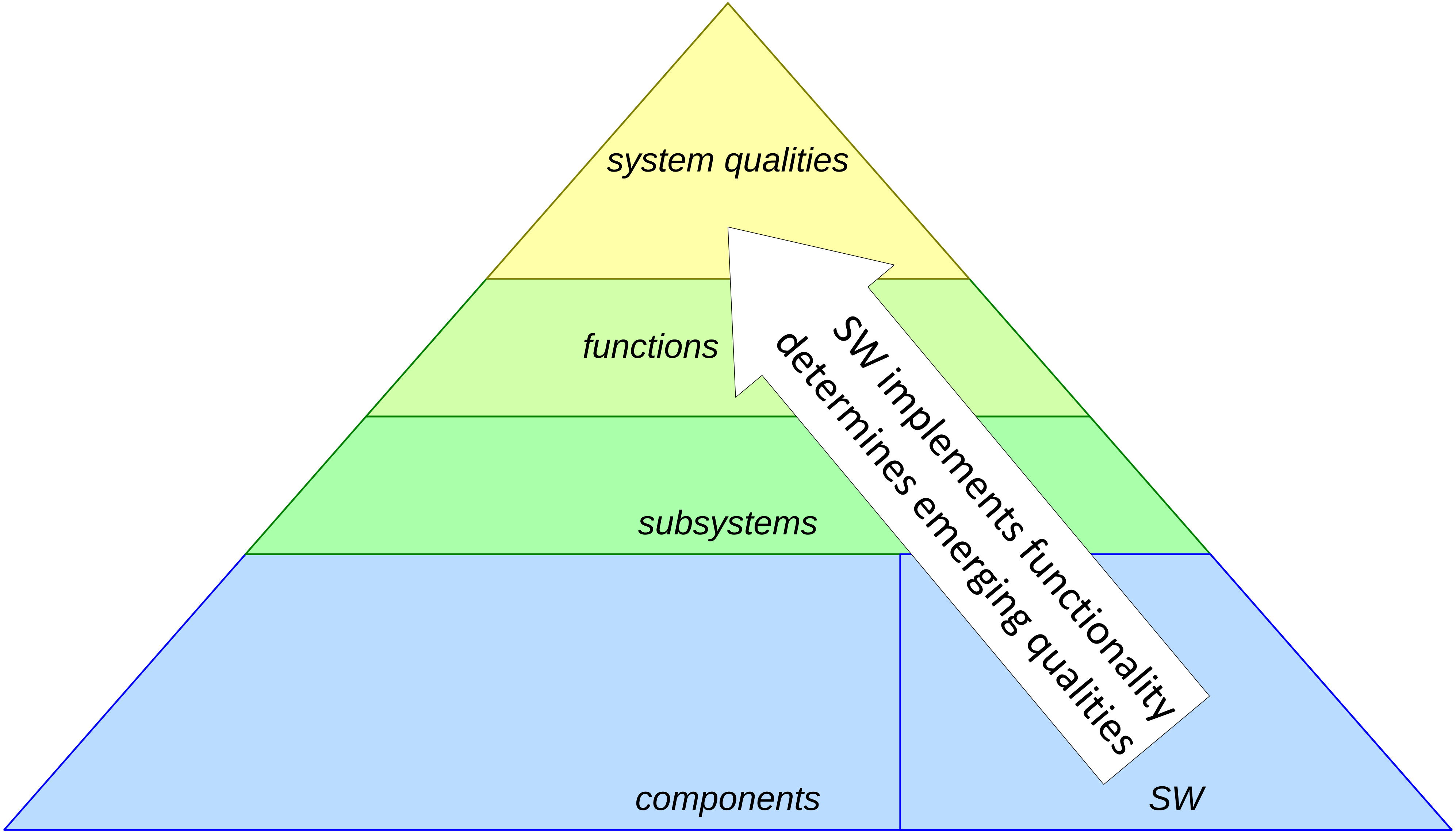
Waferstepper Example



From Components to System Qualities



Role of Software



Exercise 3, 10 minutes

Make a toplevel decomposition of the software in your system and estimate the amount of software of the constituting parts

System or Software?

When SW engineers demand "requirements",

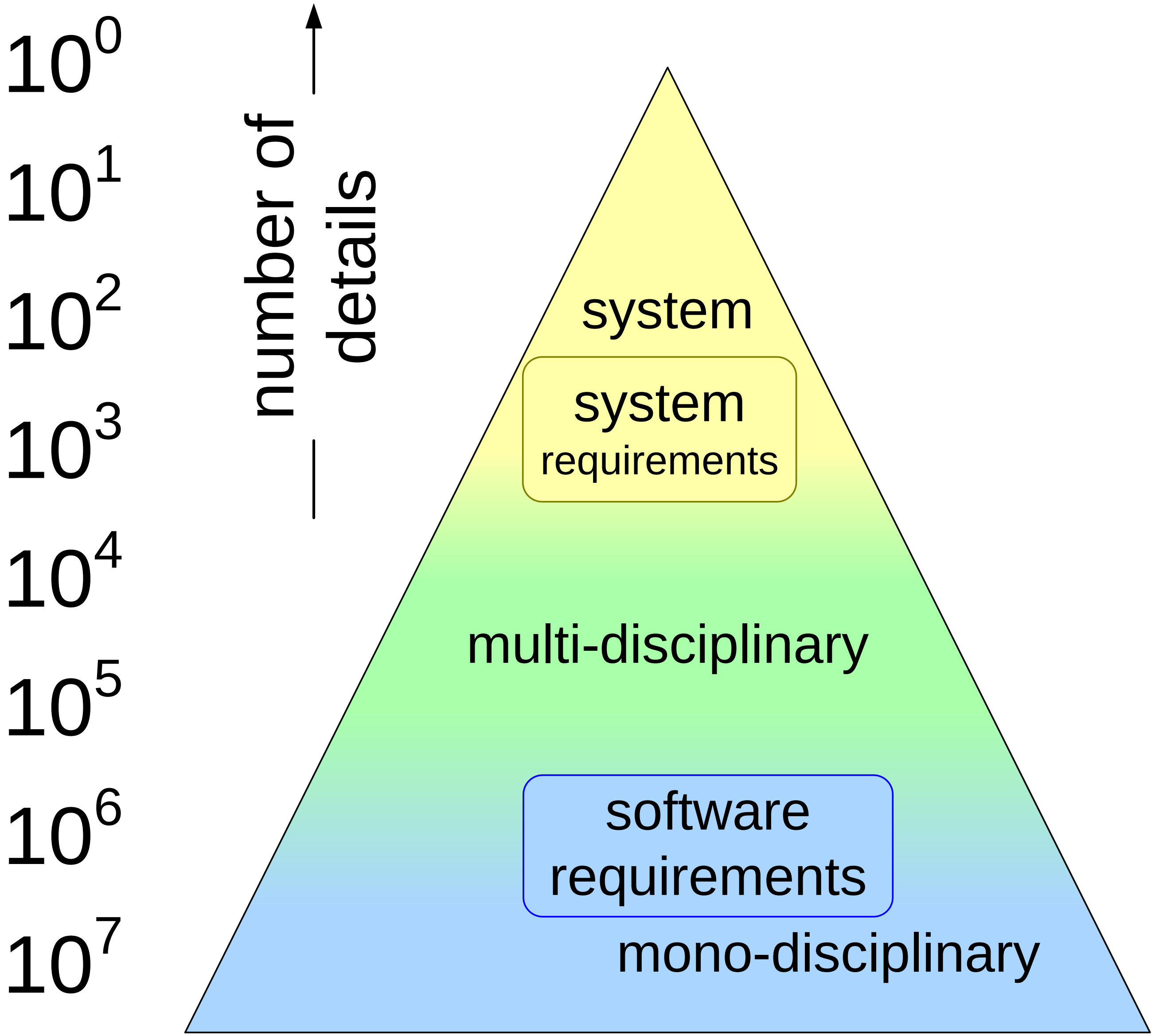
then they expect *frozen* inputs

to be used for

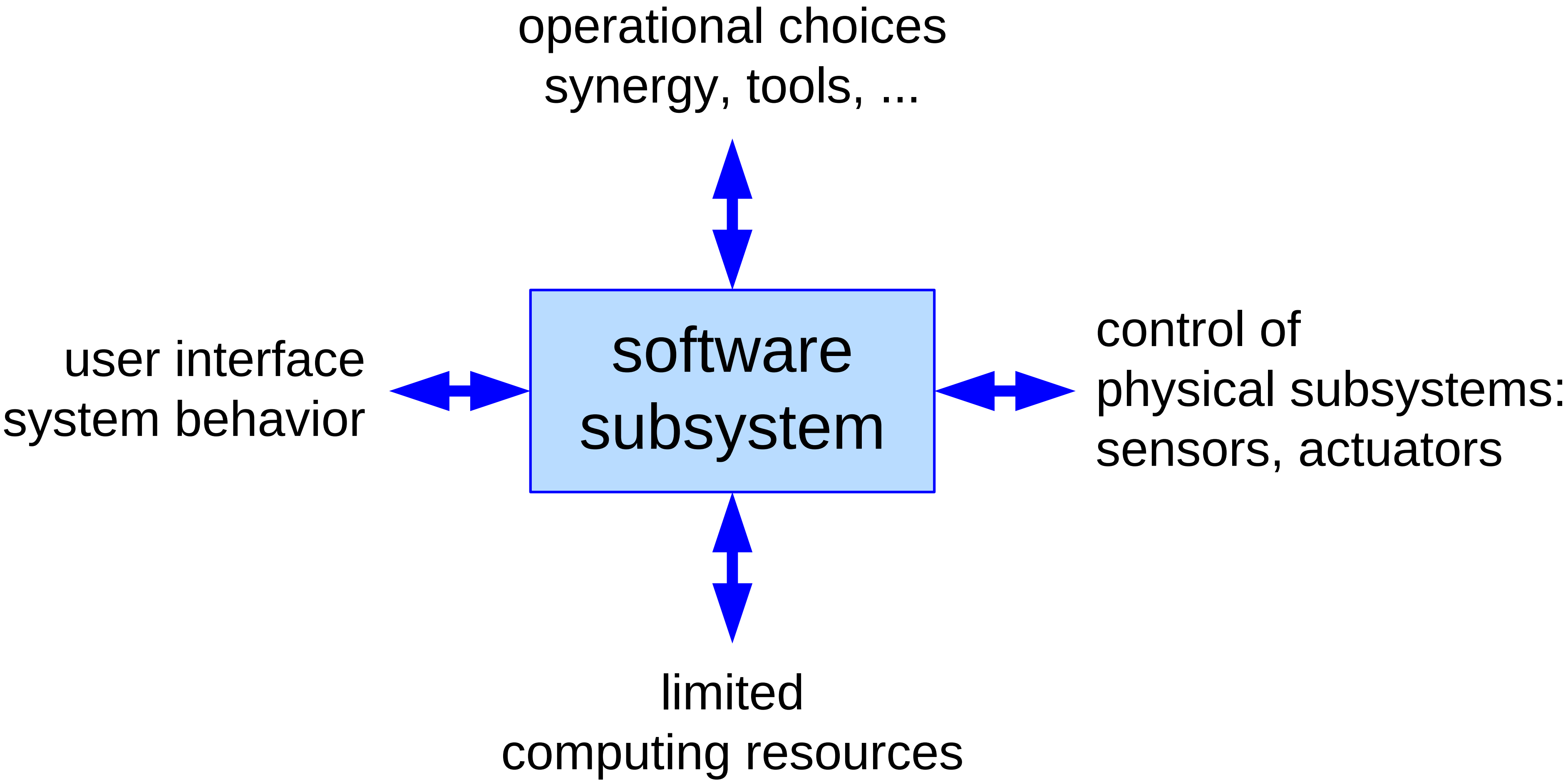
the design, implementation and validation

of the software

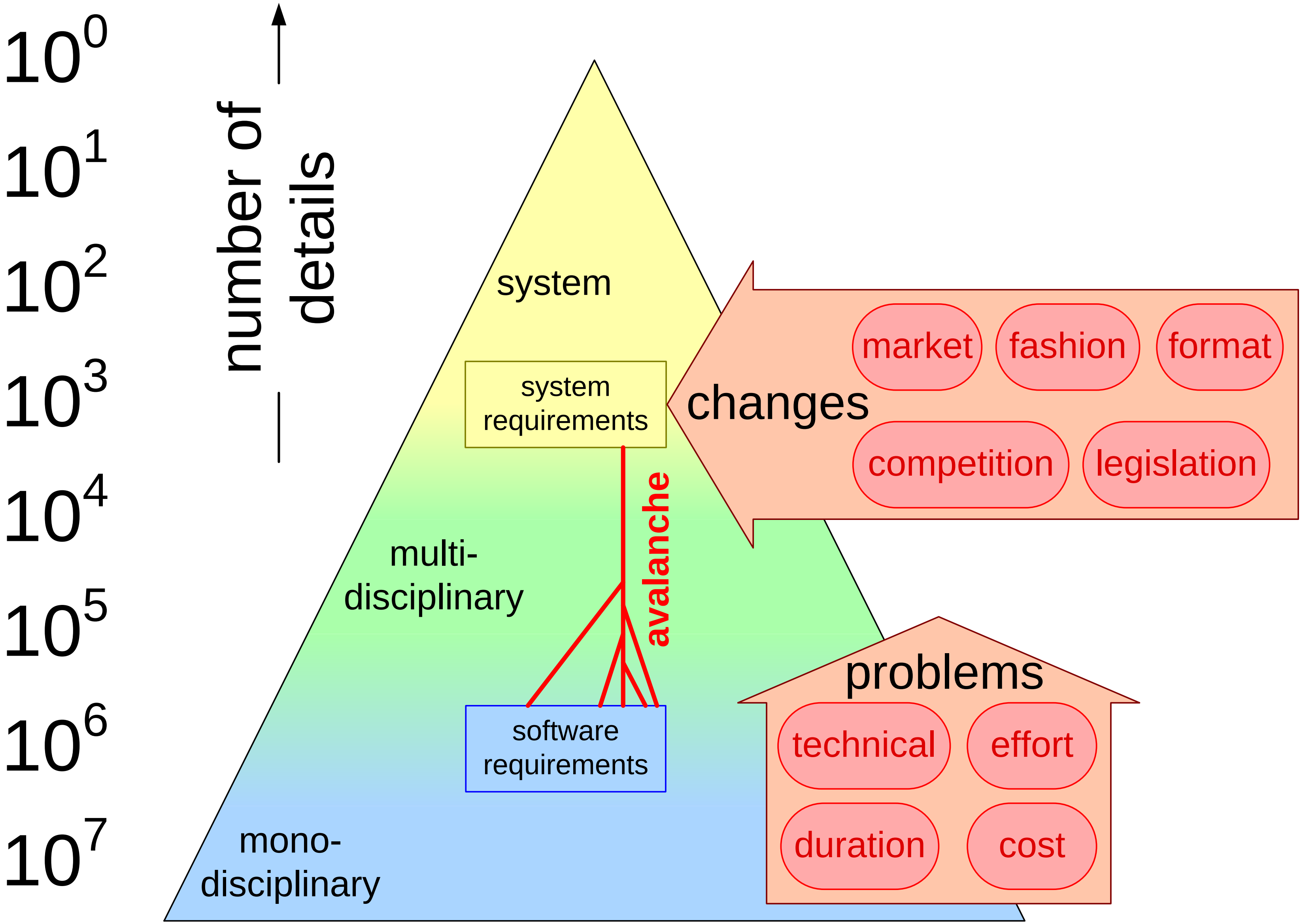
System vs Software Requirements



Why is the Software Requirement Specification so Large?



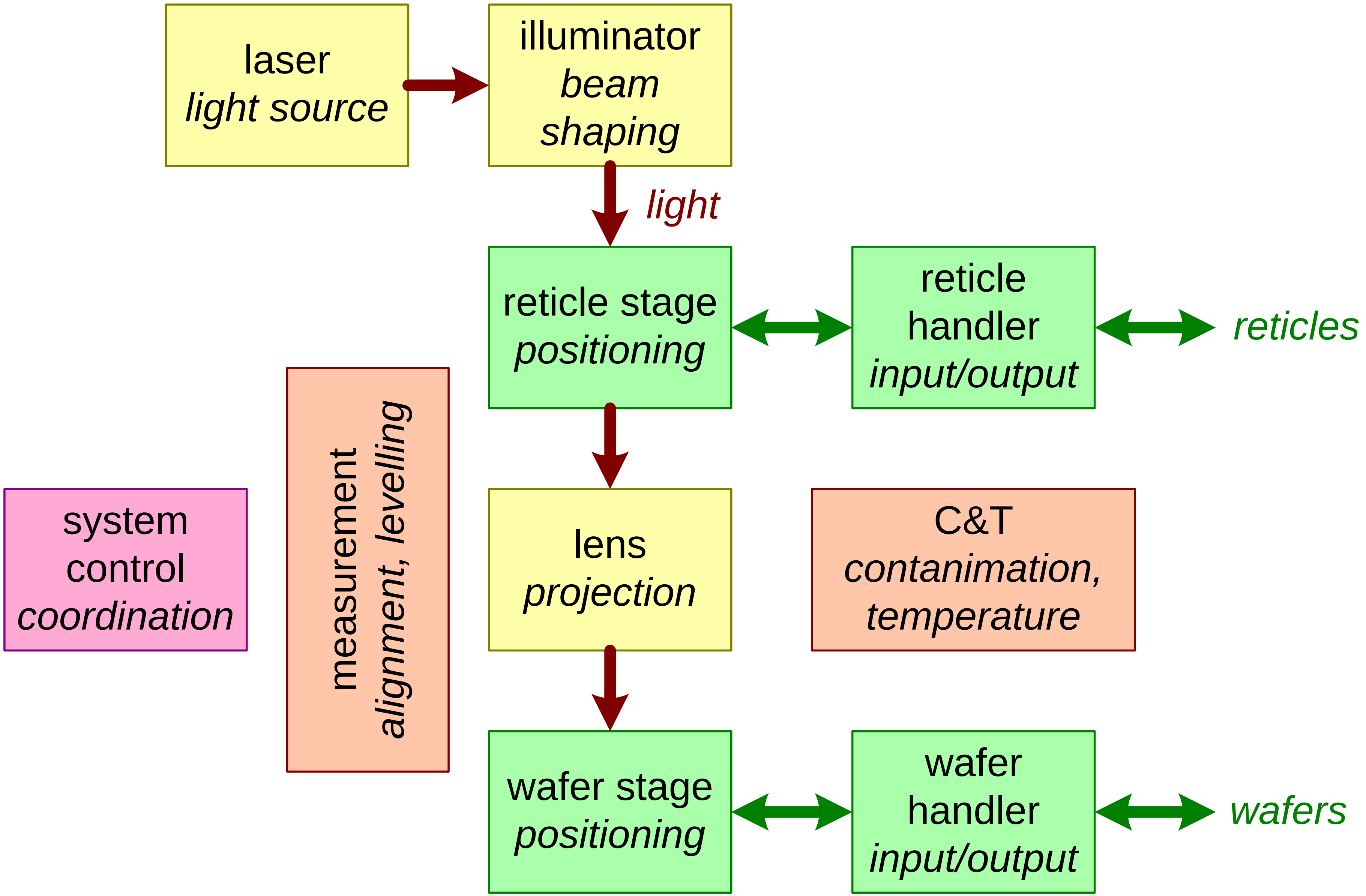
And why is it never up-to-date?



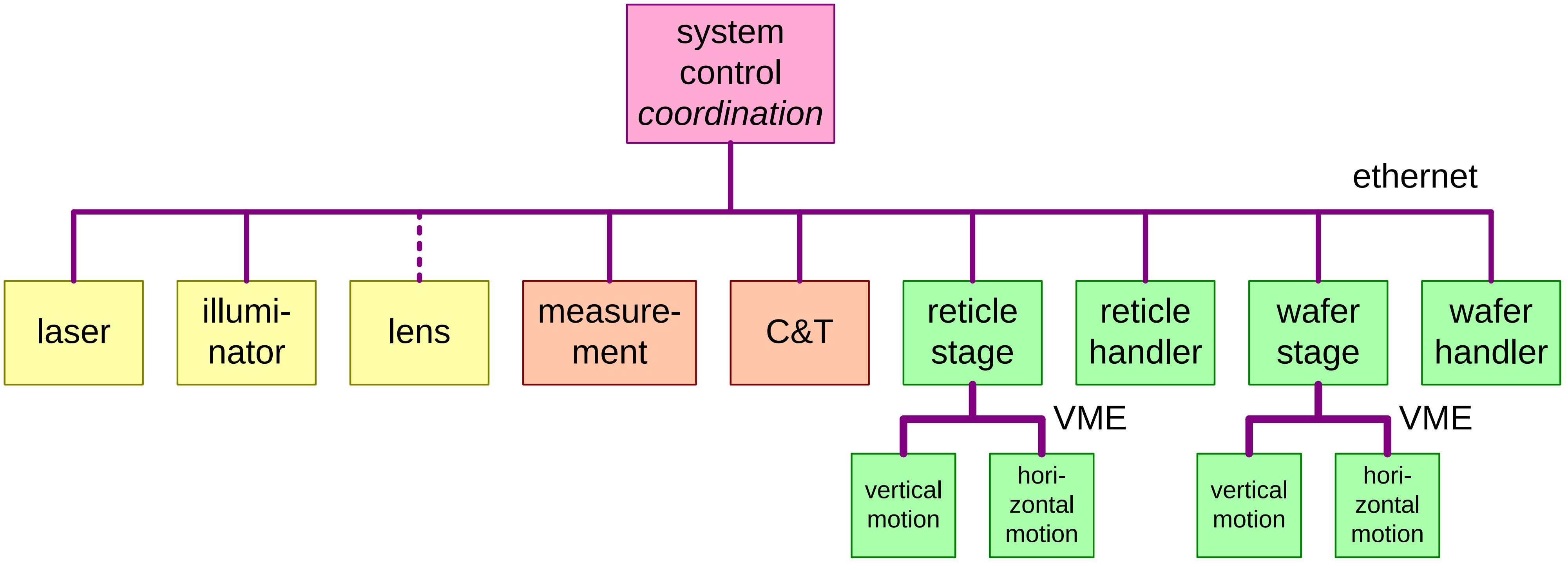
Exercise 4, 2 minutes

How many pages are in your Software Requirements Specification?

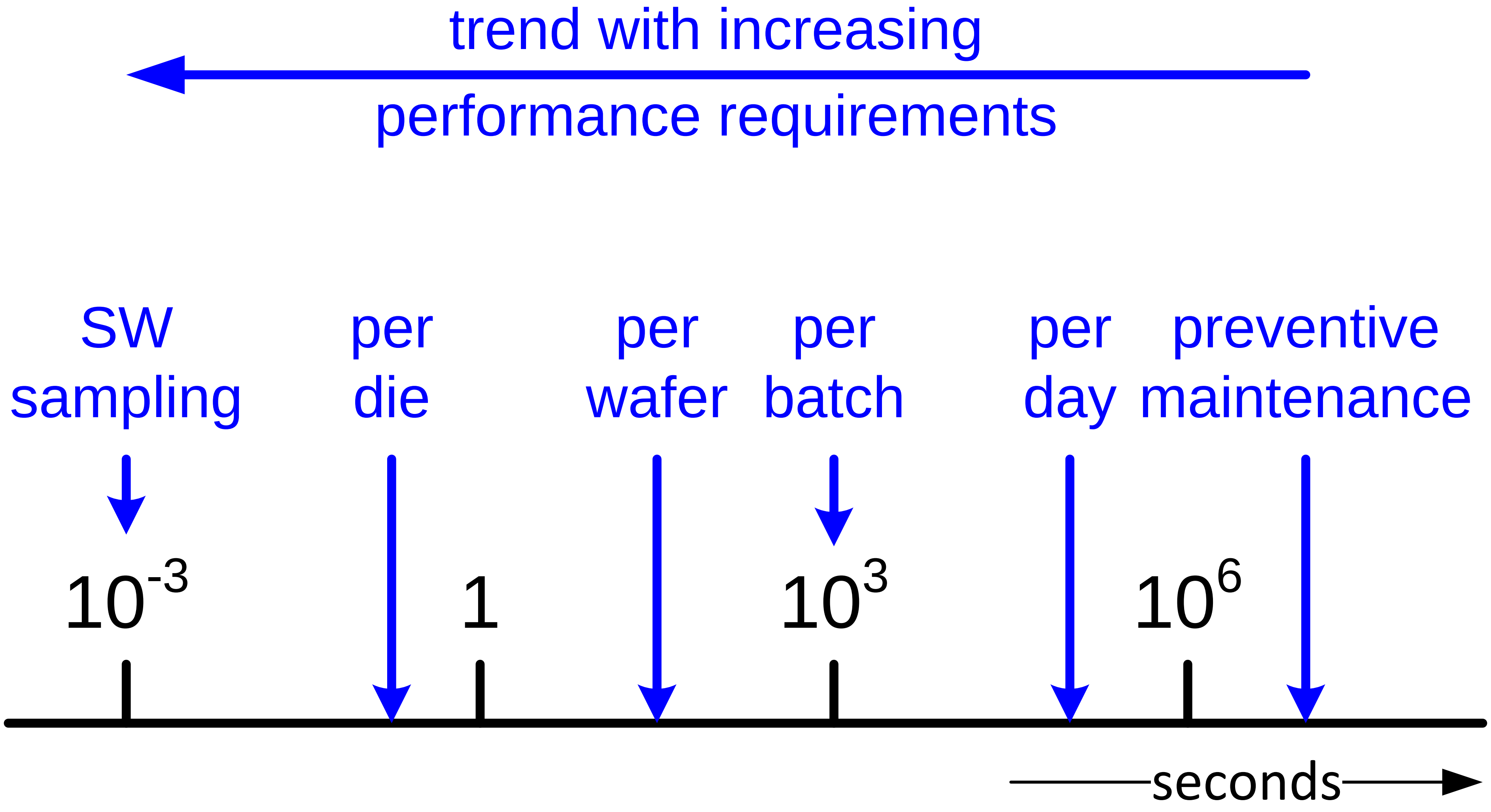
Block Diagram of a Waferstepper



Control Hierarchy of a Waferstepper



Frequency of Control Actions



trend with increasing performance requirements

SW sampling

per die

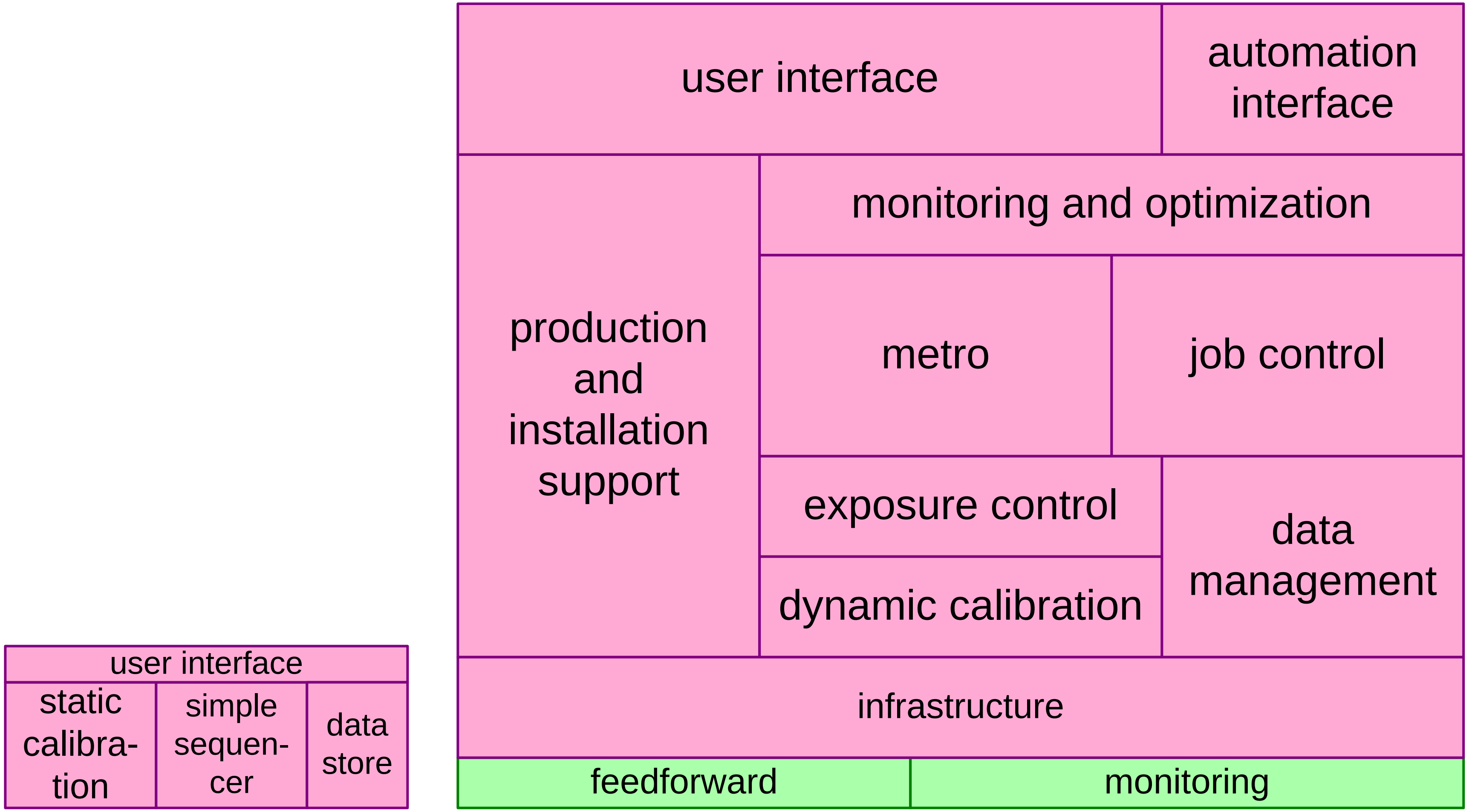
per wafer

per batch

per day

preventive maintenance

Evolution of System Control



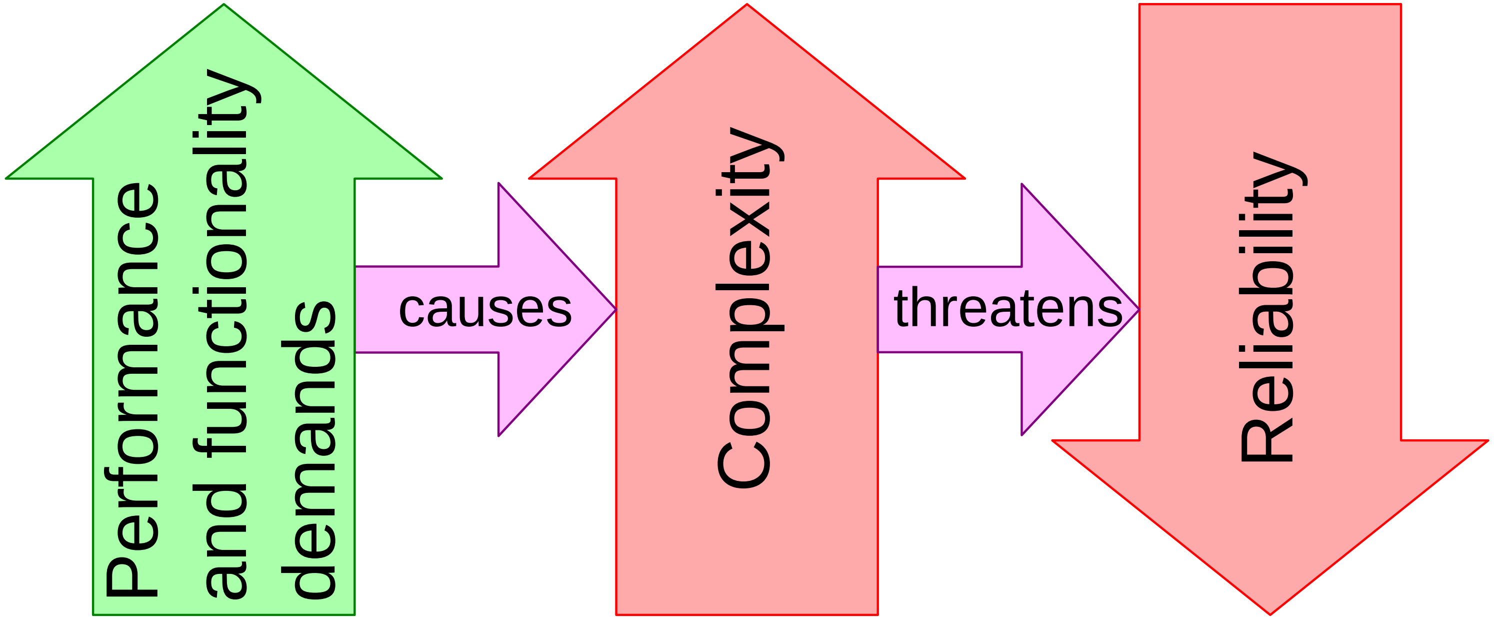
1990

150 kloc

2000

2000 kloc

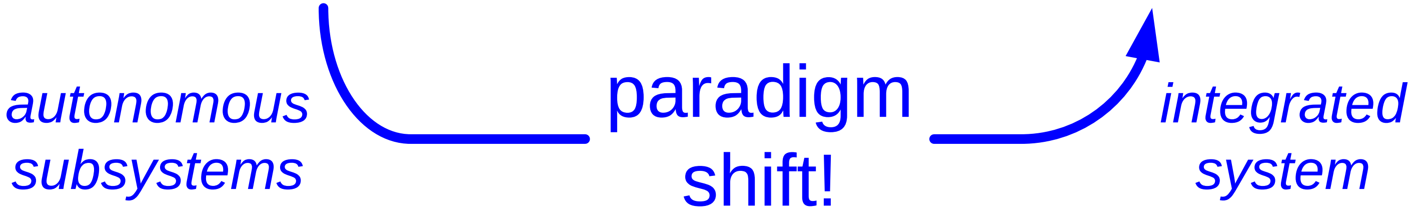
Consequences of Evolution



loss of overview (150kloc fits in 1 mind, 2Mloc not)

(more than?) exponential increase of coupling

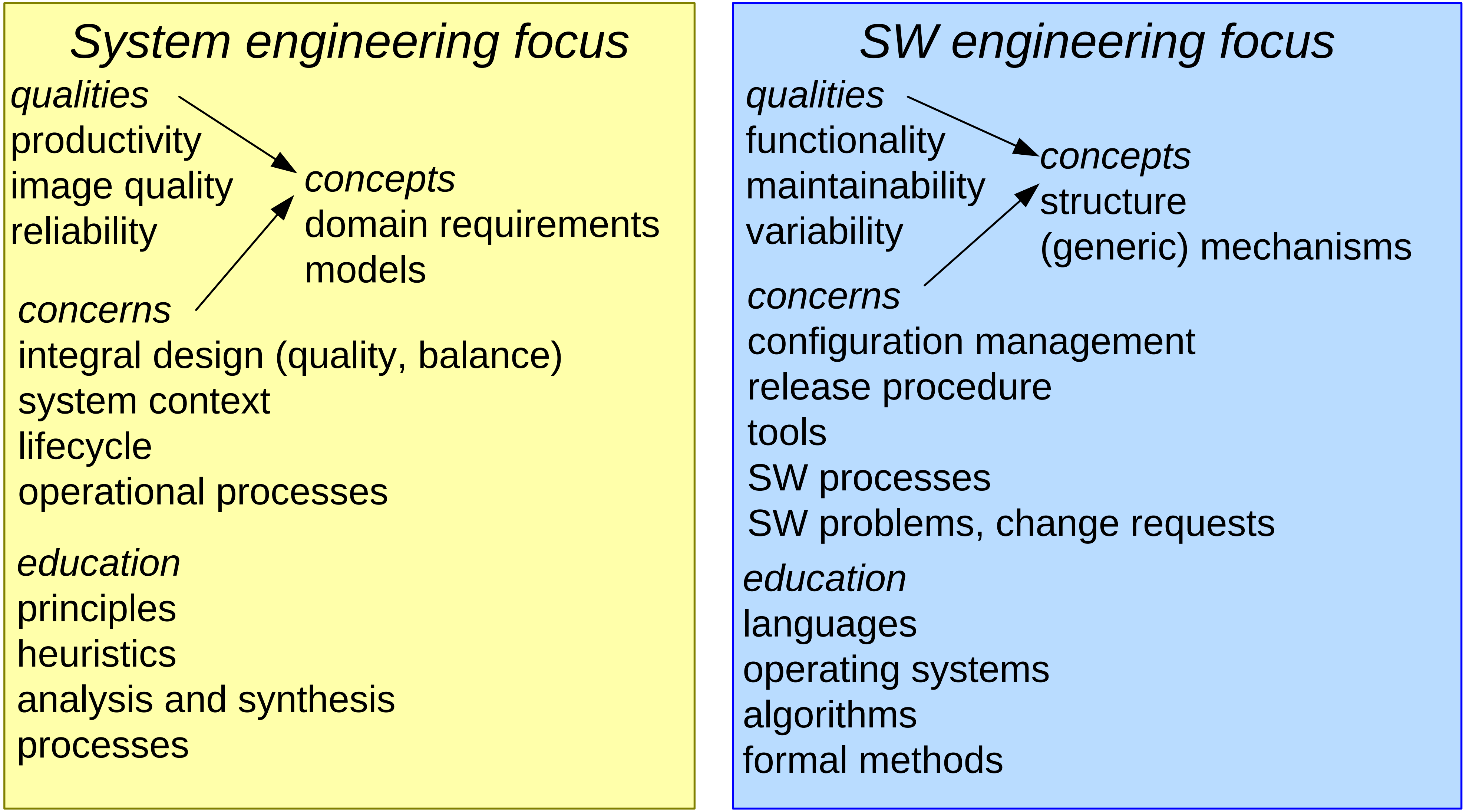
1:1 relation HW:SW becomes n:m relation



Exercise 5, 10 minutes

Visualize the (SW) evolution of your system. What is your current phase?

Different Focus of Software and System



System engineering focus

qualities
productivity
image quality
reliability

concepts
domain requirements
models

concerns
integral design (quality, balance)
system context
lifecycle
operational processes

education
principles
heuristics
analysis and synthesis
processes

SW engineering focus

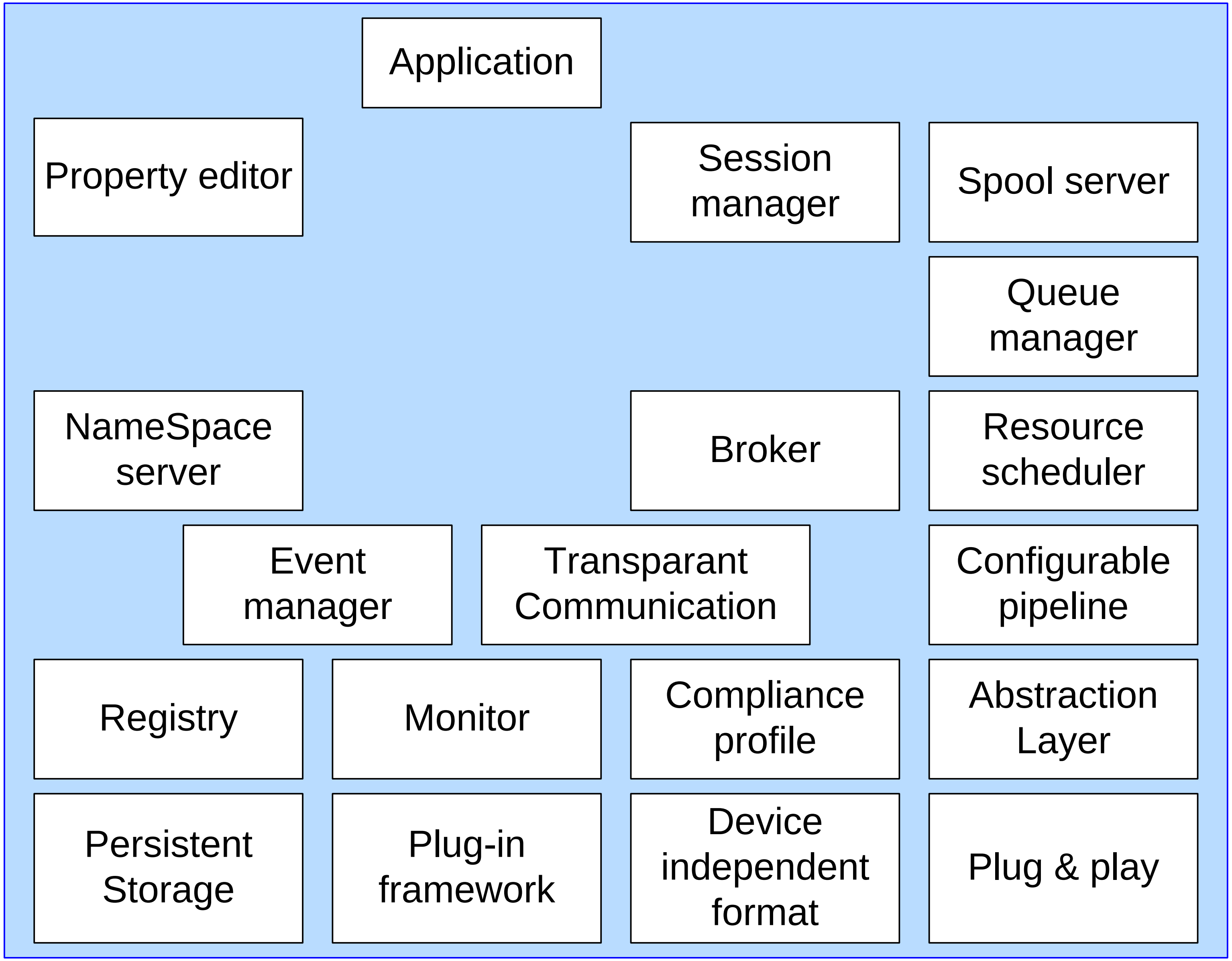
qualities
functionality
maintainability
variability

concepts
structure
(generic) mechanisms

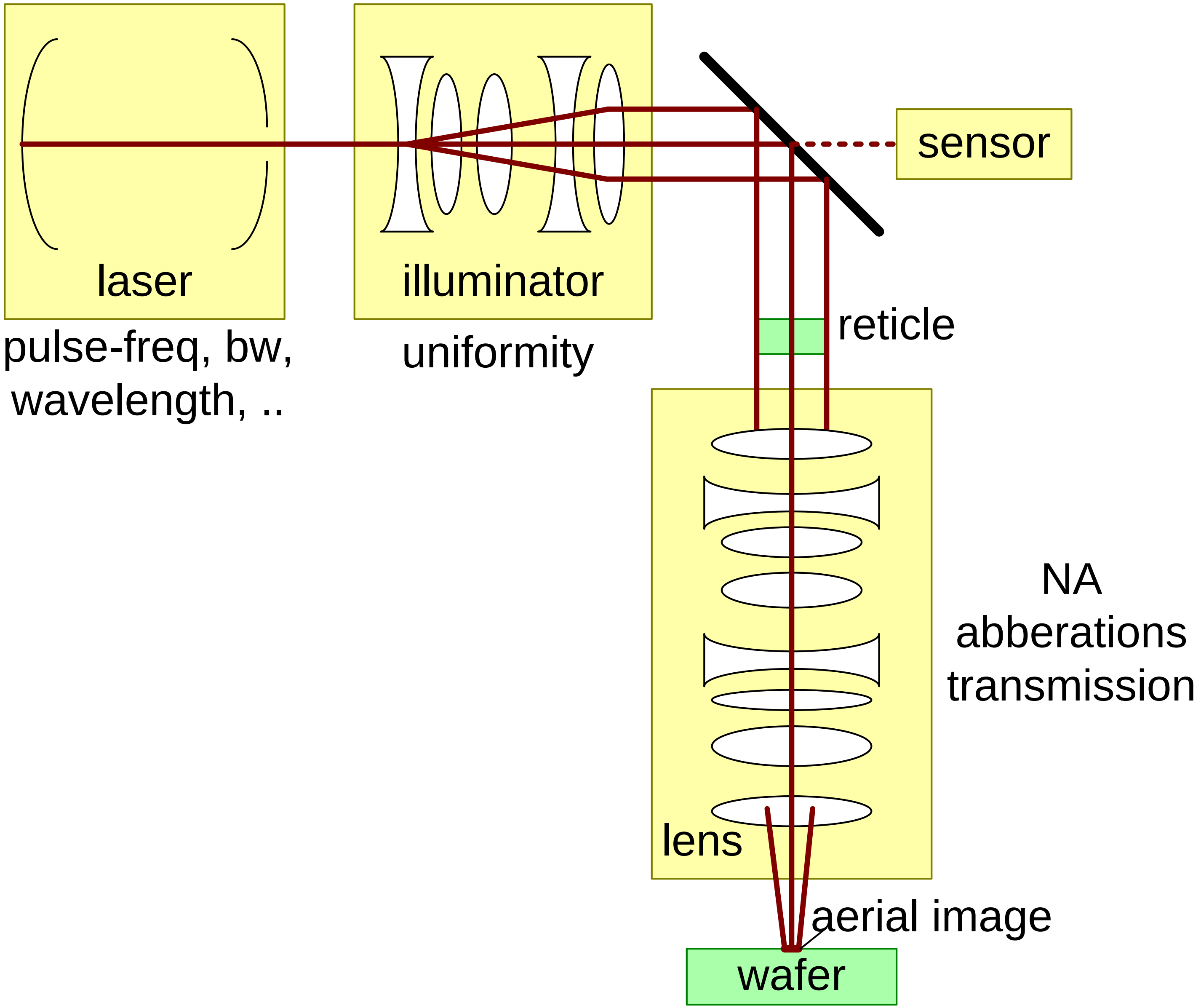
concerns
configuration management
release procedure
tools
SW processes
SW problems, change requests

education
languages
operating systems
algorithms
formal methods

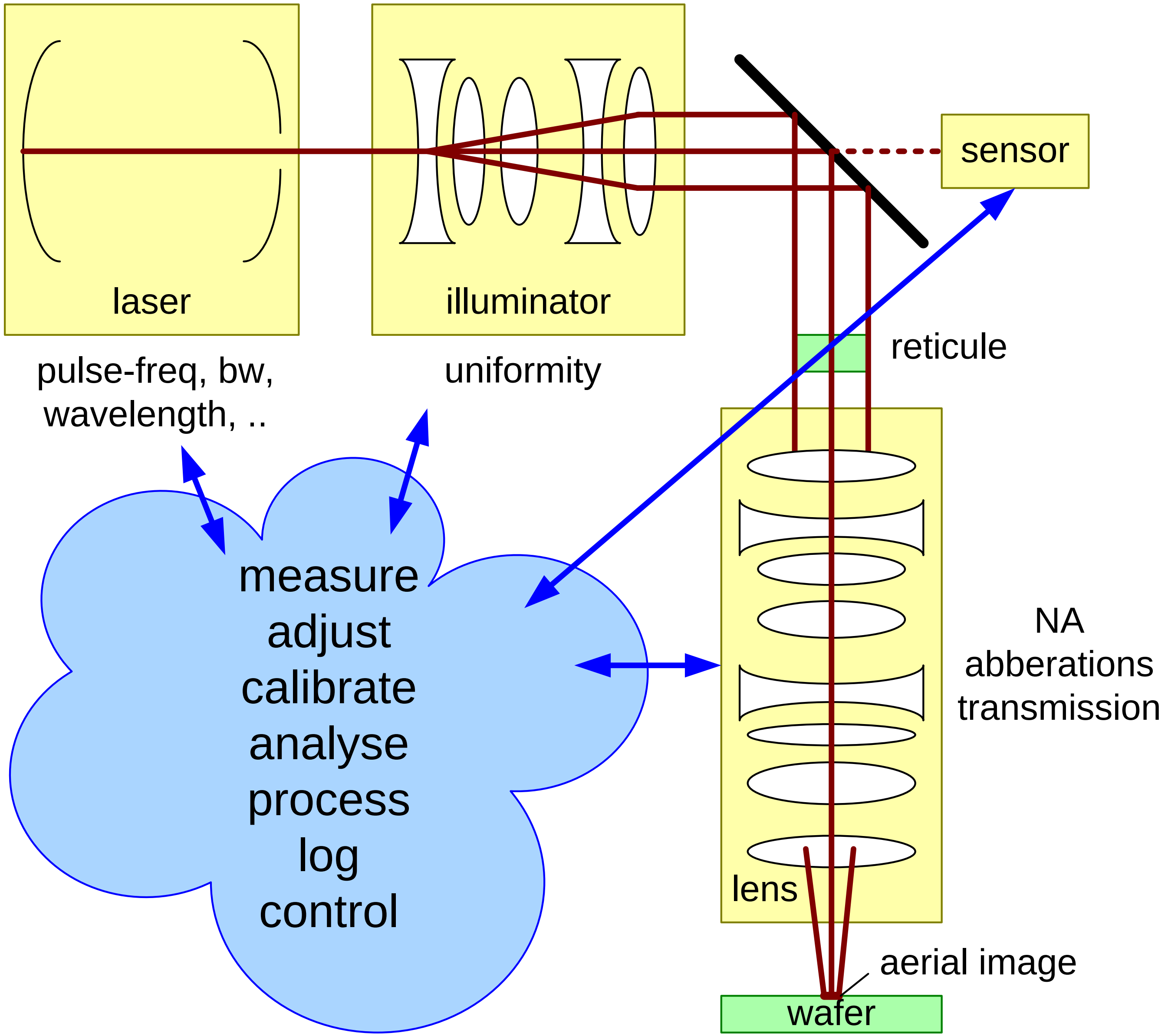
Caricature of a SW Architecture



Caricature of Physics Systems View



Relation SW and Physics



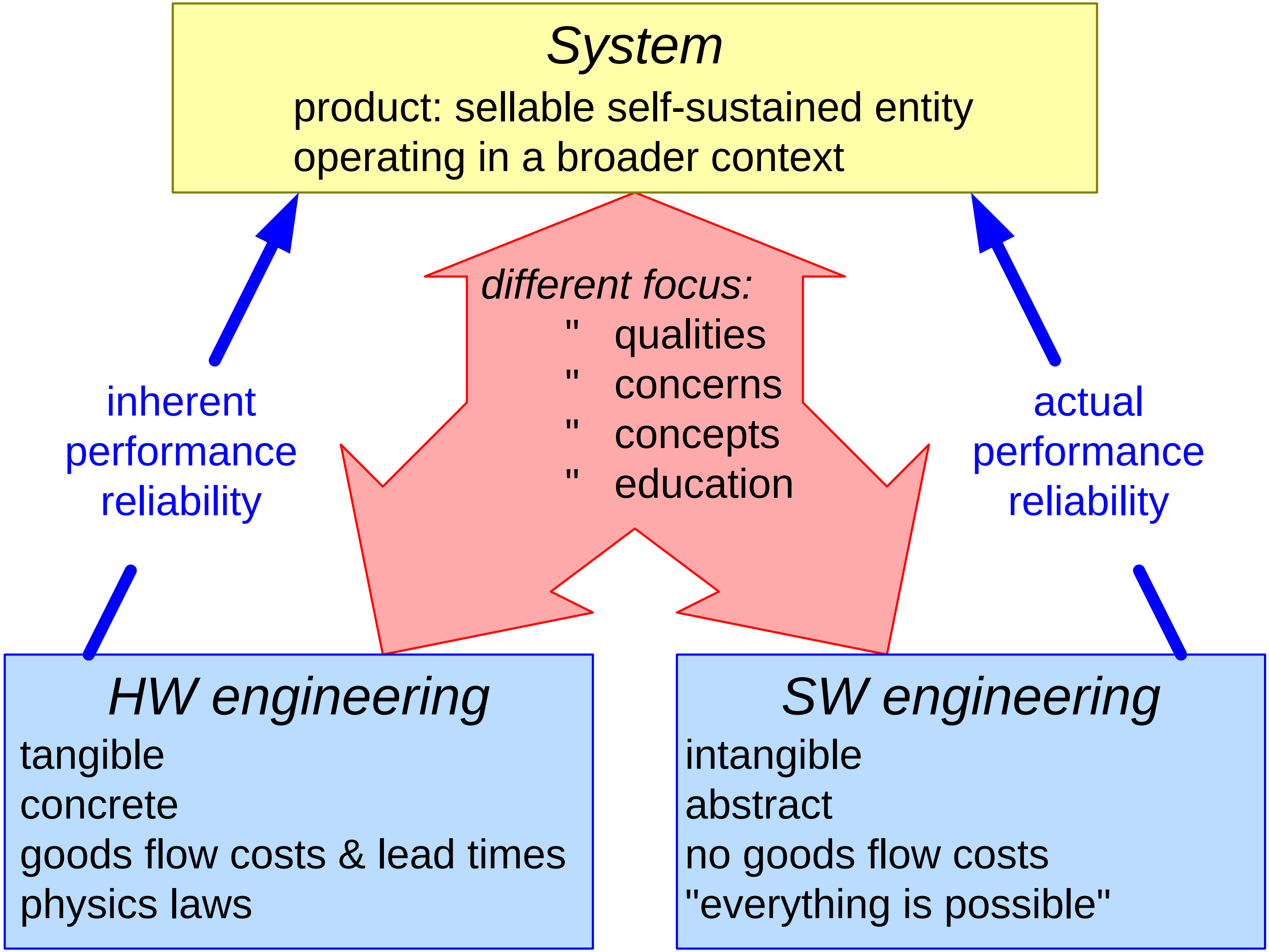
Symptoms of too isolated SW efforts

symptoms	*counter measures*
SW people are clustered together	colocation per function, subsystem or quality
SW is alpha tested before system integration	continuous system integration
SW team uses own specification and design process	higher level processes are shared
SW specification is in SW jargon or formalism	interaction between SW, HW and system engineers

Exercise 6, 5 minutes

What is the degree of integration or isolation of SW in your organization?

Different Mindsets and Characteristics



System

product: sellable self-sustained entity
operating in a broader context

different focus:

- qualities
- concerns
- concepts
- education

inherent performance reliability

actual performance reliability

HW engineering

tangible
concrete
goods flow costs & lead times
physics laws

SW engineering

intangible
abstract
no goods flow costs
"everything is possible"