Testing Challenges

for Cyber Physical Systems

Jan Tretmans

TNO - ESI – Embedded Systems Innovation at TNO
Radboud University Nijmegen
Högskolan i Halmstad
jan.tretmans@tno.nl

Cyber-Physical Systems

Semiconductor manufacturing equipmen

Agricultural robots

Software is brain of system

- software controls, connects, monitors almost any aspect of CPS system behaviour
- majority of innovation is in software

Software determines

quality and reliability

of Cyber-Physical System

- often > 50 % of system defects are software bugs

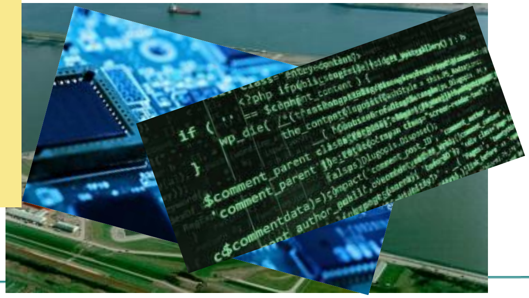
Traffic management

Robotized warehousing

Combat management systems

Industrial printers

Automotive



Dike

TNO – ESI : Applied Research at a Glance

Synopsis

- ❑ Foundation ESI started in 2002
- ❑ ESI acquired by TNO per January 2013
- ❑ ~60 staff members, many with extensive industrial experience
- ❑ 7 Part-time Professors
- ❑ Working at industry locations

Focus

Managing complexity
of high-tech systems

through

- system architecting,
- system reasoning and
- model-driven engineering

delivering

- methodologies validated in cutting-edge industrial practice

Partners

ASML
ThermoFisher SCIENTIFIC
PHILIPS
itec
VANDERLANDE
Canon
THALES
TNO
UNIVERSITY OF AMSTERDAM
TU Delft Delft University of Technology
Radboud University Nijmegen
UNIVERSITY OF TWENTE.
TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY
Capgemini engineering

Testing Challenges for Cyber-Physical Systems

Testing Trends & Challenges

- Complexity
- Variability
- Multi-Disciplinarity
- Evolution
- Building Blocks
- Connectivity
- Non-Functionals
- New Paradigms
- Environment
- Going Up
- Agile

Testing Trends & Challenges

- Size & Complexity
- Variability
- Multi-Disciplinarity
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Size & Complexity

Completely testing ‘ + ’ for 32-bit Int

- $2^{32} * 2^{32} = 10^{19}$ test cases
- 1 nsec / test = 585 years of testing

Car

- 100,000,000 LoC
- 40,000 parts
- 4,000 manufactured components

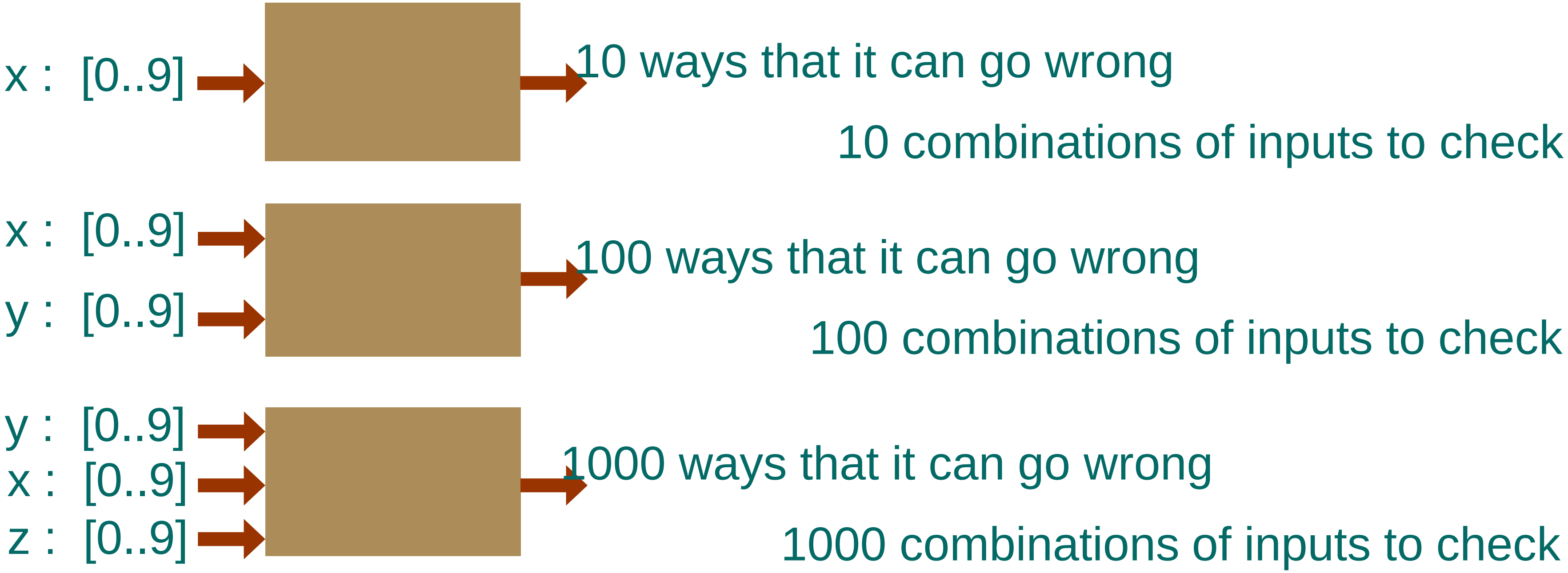
Machine with 300 parameters

- $2^{300} = 10^{90}$ different configurations
- #atoms on earth $= 10^{50}$, #atoms in known universe $= 10^{80}$

Size & Complexity

Testing effort grows exponentially with system size

Testing cannot keep pace with development



x : [0..9]

10 ways that it can go wrong

10 combinations of inputs to check

x : [0..9]

y : [0..9]

100 ways that it can go wrong

100 combinations of inputs to check

y : [0..9]

x : [0..9]

z : [0..9]

1000 ways that it can go wrong

1000 combinations of inputs to check

Size & Complexity

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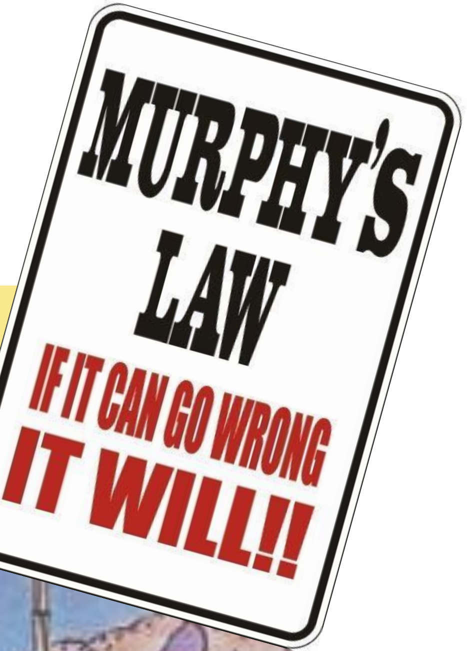

→ combinatorial explosion of required testing effort

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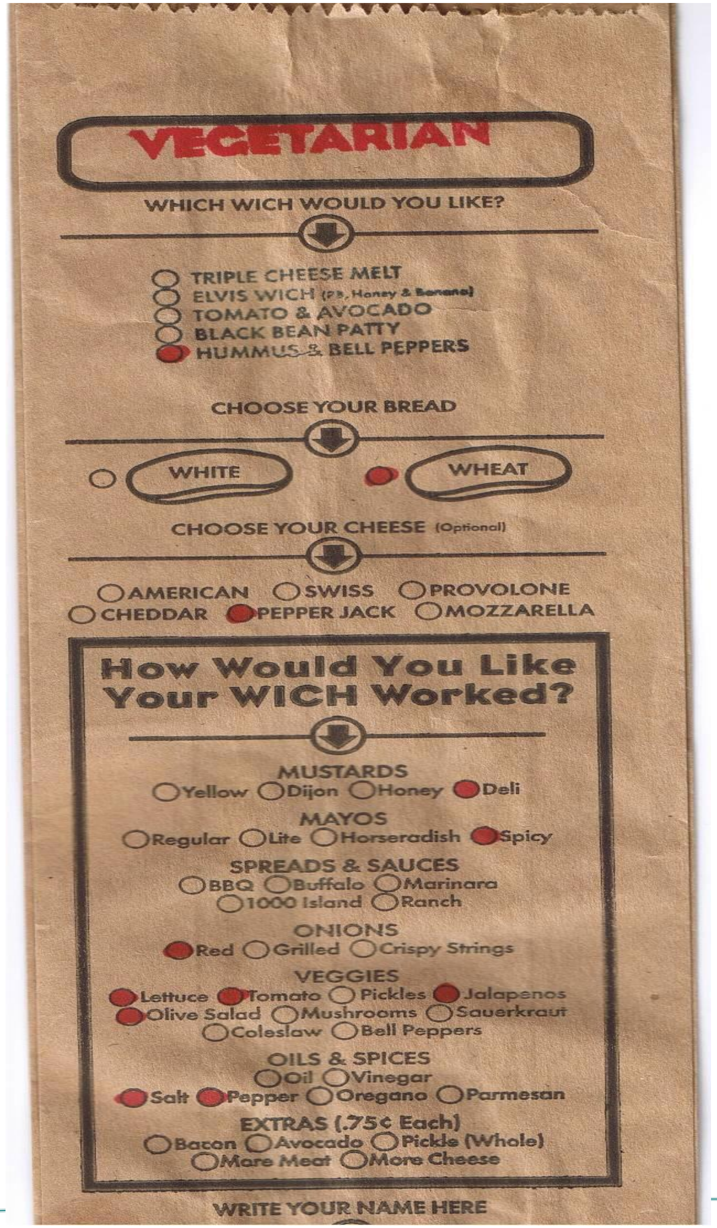
Variability & Product Lines

or: How to Select your Sandwich



VEGETARIAN

WHICH WICH WOULD YOU LIKE?

○ TRIPLE CHEESE MELT
○ ELVIS WICH (PB, Honey & Banana)
○ TOMATO & AVOCADO
○ BLACK BEAN PATTY
● HUMMUS & BELL PEPPERS

CHOOSE YOUR BREAD

○ WHITE ● WHEAT

CHOOSE YOUR CHEESE (Optional)

○ AMERICAN ○ SWISS ○ PROVOLONE
○ CHEDDAR ● PEPPER JACK ○ MOZZARELLA

How Would You Like Your WICH Worked?

MUSTARDS
○ Yellow ○ Dijon ○ Honey ● Deli

MAYOS
○ Regular ○ Lite ○ Horseradish ● Spicy

SPREADS & SAUCES
○ BBQ ○ Buffalo ○ Marinara
○ 1000 Island ○ Ranch

ONIONS
● Red ○ Grilled ○ Crispy Strings

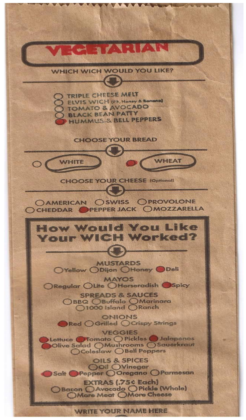
VEGGIES
● Lettuce ● Tomato ○ Pickles ● Jalapenos
● Olive Salad ○ Mushrooms ○ Sauerkraut
○ Coleslaw ○ Bell Peppers

OILS & SPICES
○ Oil ○ Vinegar
● Salt ● Pepper ○ Oregano ○ Parmesan

EXTRAS (.75¢ Each)
○ Bacon ○ Avocado ○ Pickle (Whole)
○ More Meat ○ More Cheese

WRITE YOUR NAME HERE

Variability



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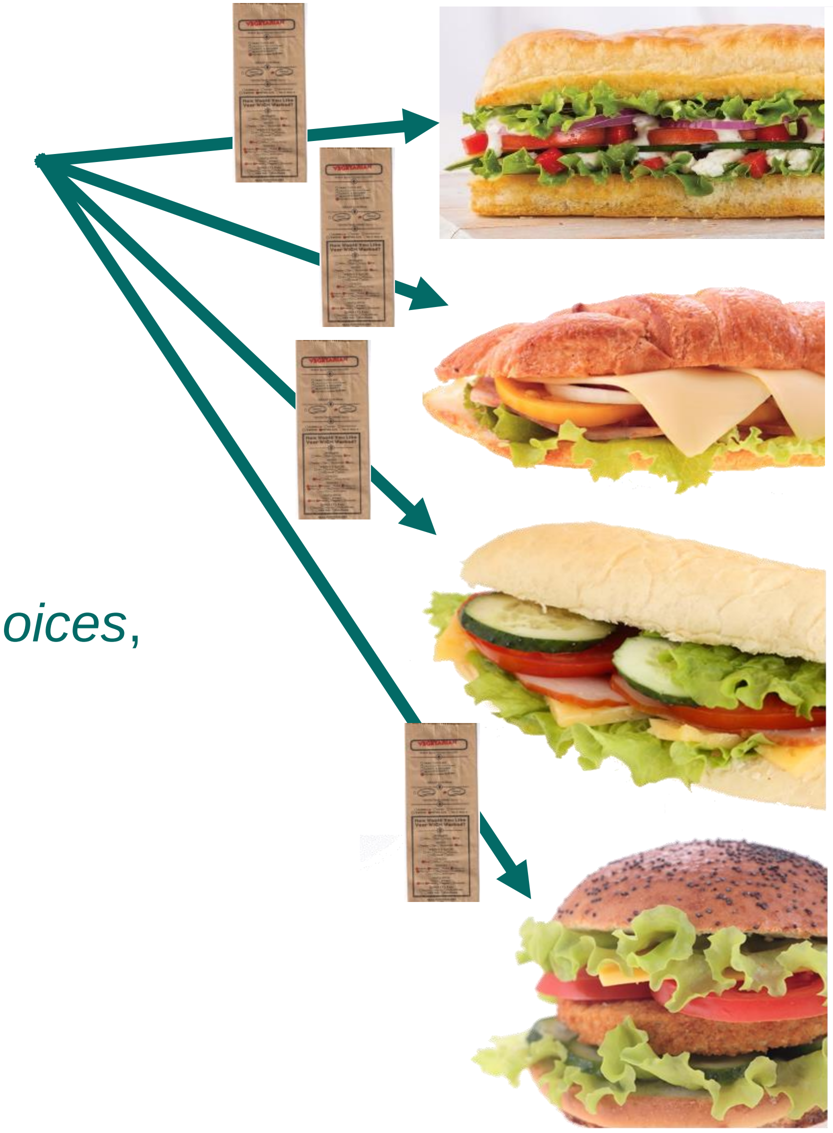
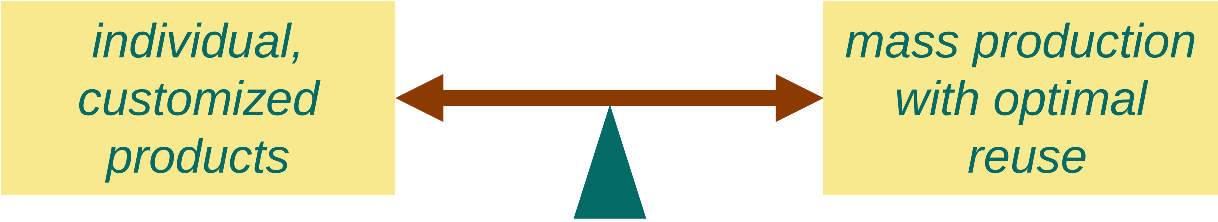


- Highly configurable sandwich*: exponential number of choices*, **a different sandwich for everybody on the planet!**
- Not all combinations make sense: *dependencies*
- **How to taste / test all of them?**
- Sandwich product line = family of sandwiches
- Also for high-tech systems
  Linux, cars, . . .

Variability Engineering



individual, customized products

mass production with optimal reuse

- Customization & reuse by developing families of 'similar' products

  → identify variation points

  → instantiate to different configurations = products

- *Aim*: instantiate as late as possible,
  to perform design, analysis, …, on the product family
  and not on each individual product

- *But*: testing is always on an individual product
  → **how to select configurations for testing ?**

Testing Trends & Challenges

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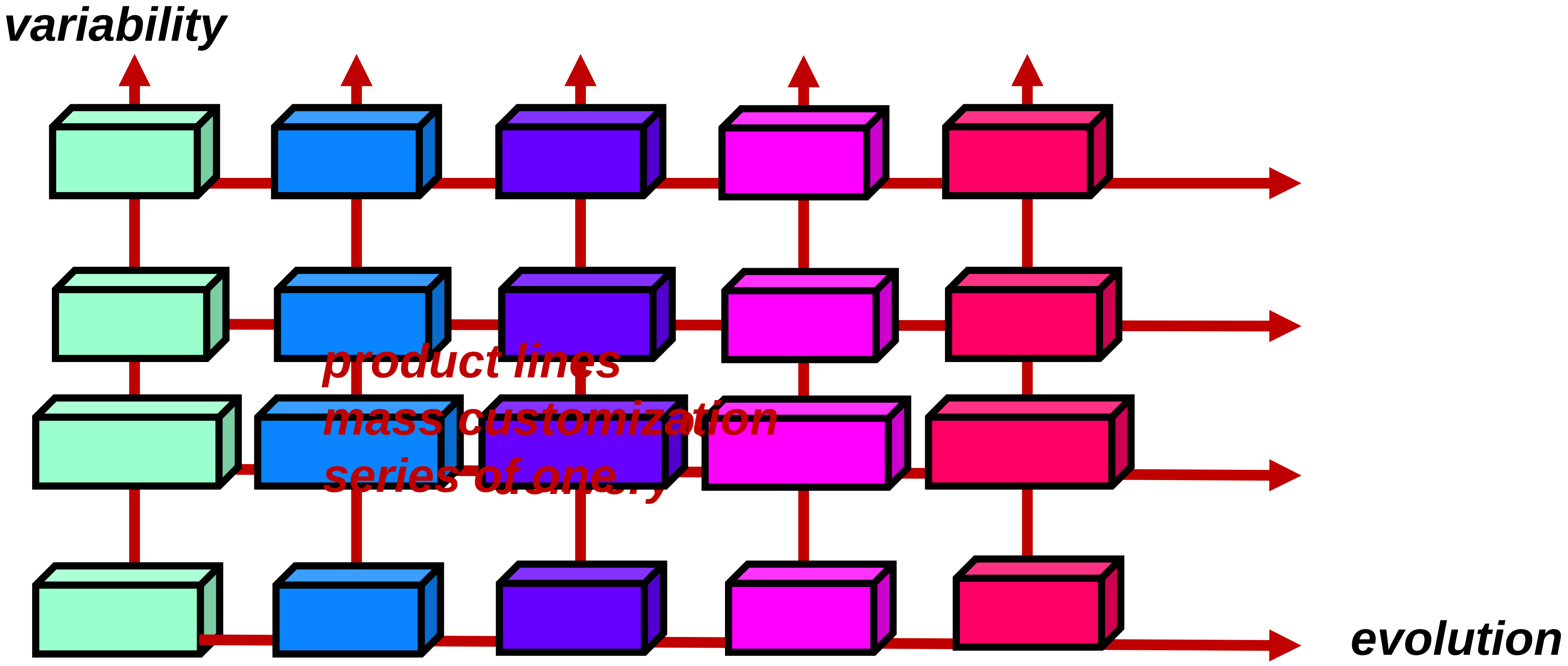
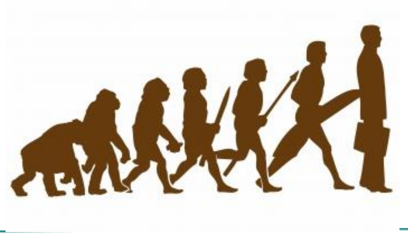
- Agile

Evolution : Change over Time

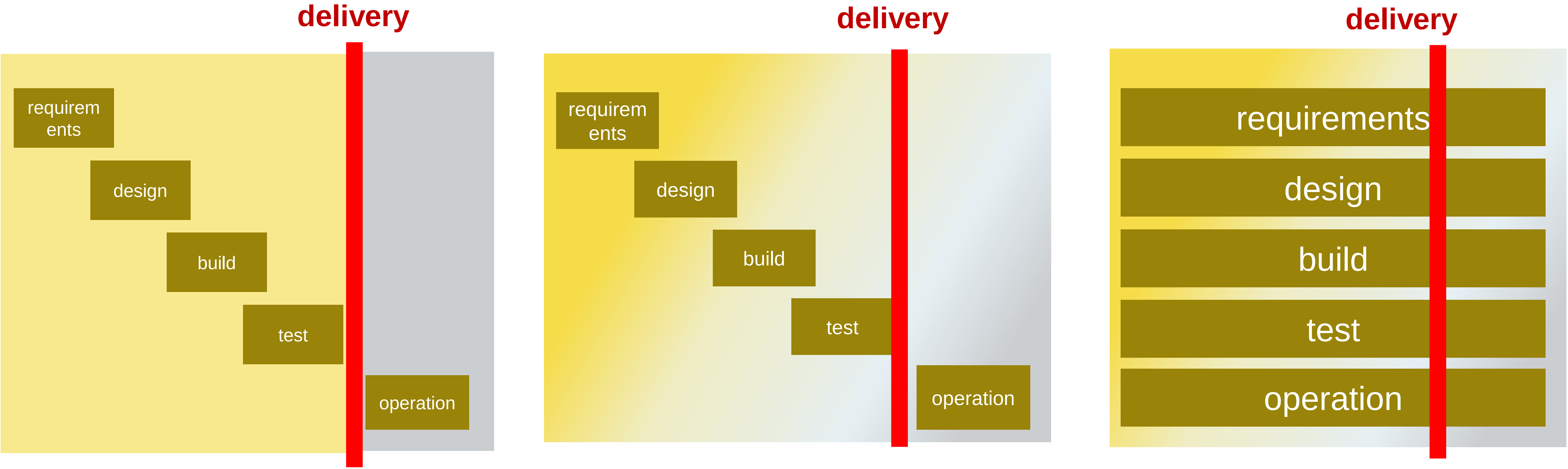
- system never comes alone: *variability*
- systems continuously change: *evolution*

yet another source of
Test Explosion

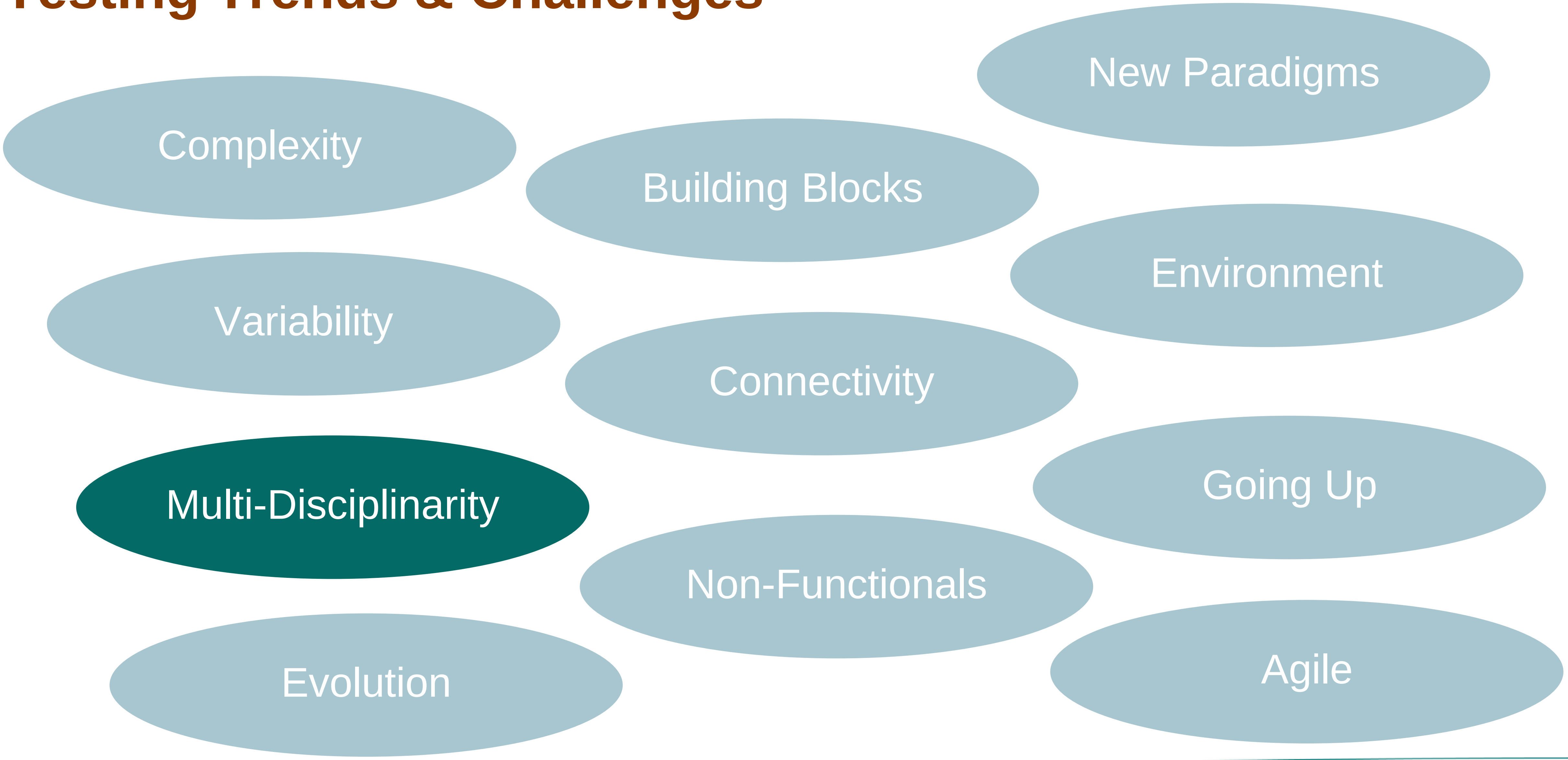




Evolution, Change : Fading Boundaries



Testing Trends & Challenges



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Cyber-Physical Systems

Semiconductor manufacturing equipment

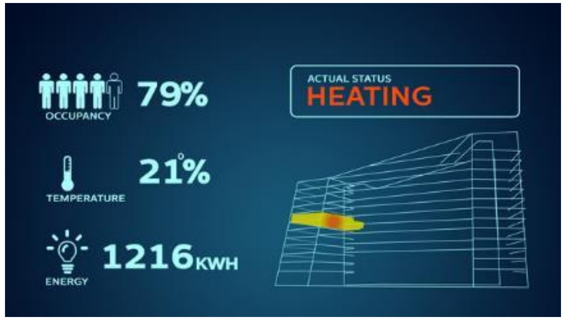
Medical systems

Food processing

Agricultural robots

Traffic management

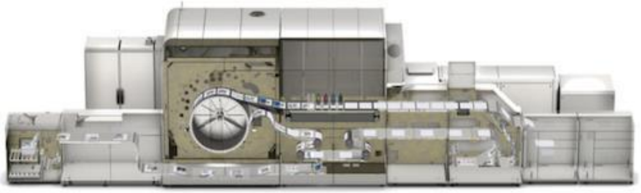
Electron microscopes



Building control

Robotized warehousing

Combat management systems



Industrial printers

Automotive

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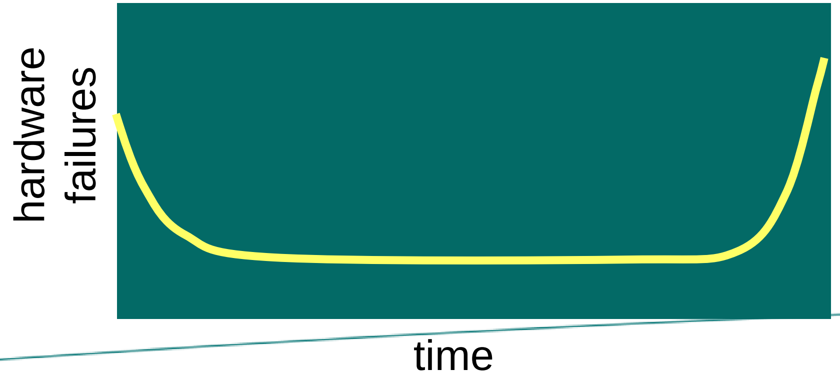
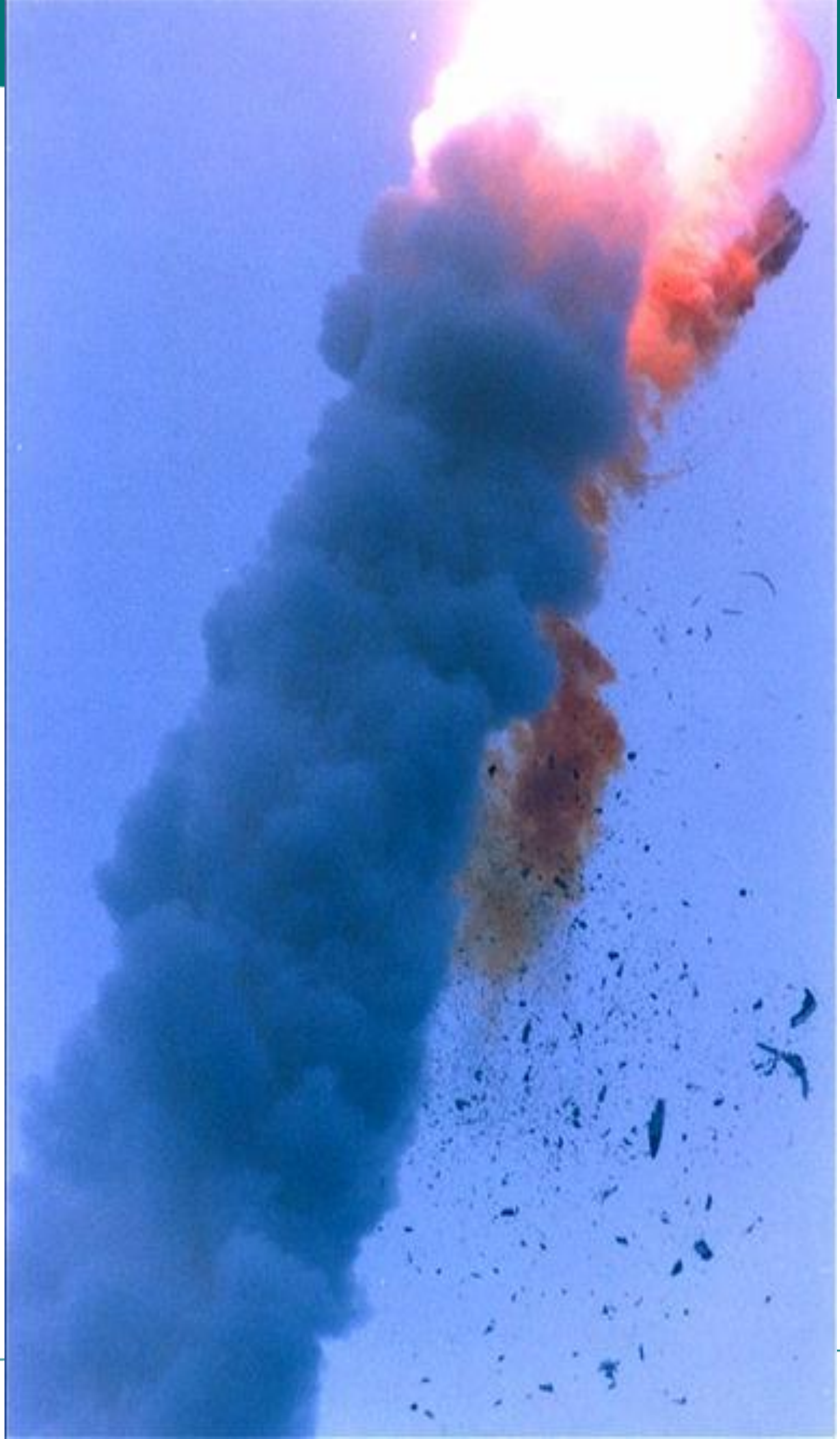
Software is Different

Software is different from hardware :

- non-continuous
- any bug is a design error
- adopting redundancy is useless
- no wear and tear
- no MTBF
- what is software reliability?





Multi-disciplinarity

- Cyber-Physical Systems
- Combination of physics/mechanics/electronics … with computer/software
- Requires various expertises
- Testing such combinations requires

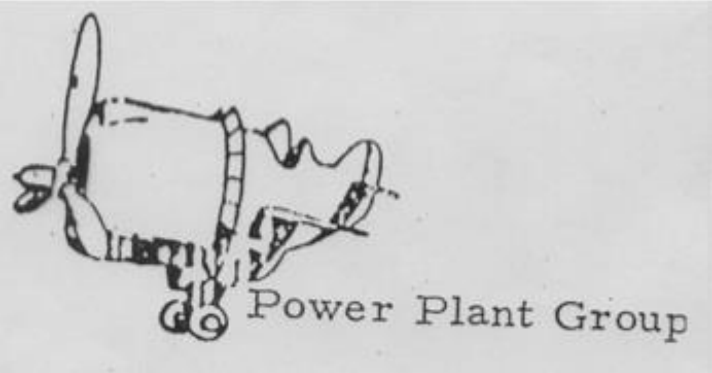
  stubs, simulations, virtualization, digital twin

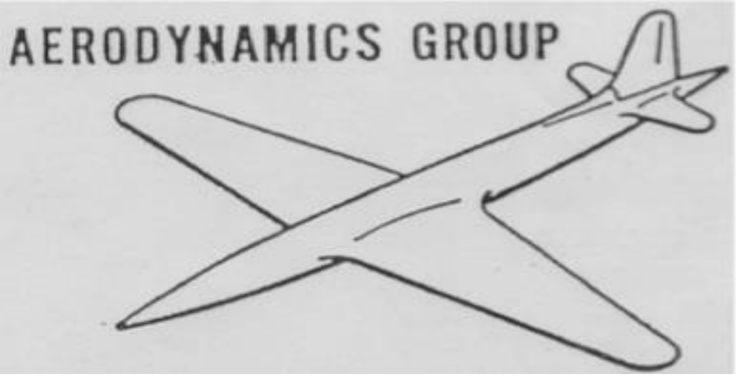
Multi-disciplinarity

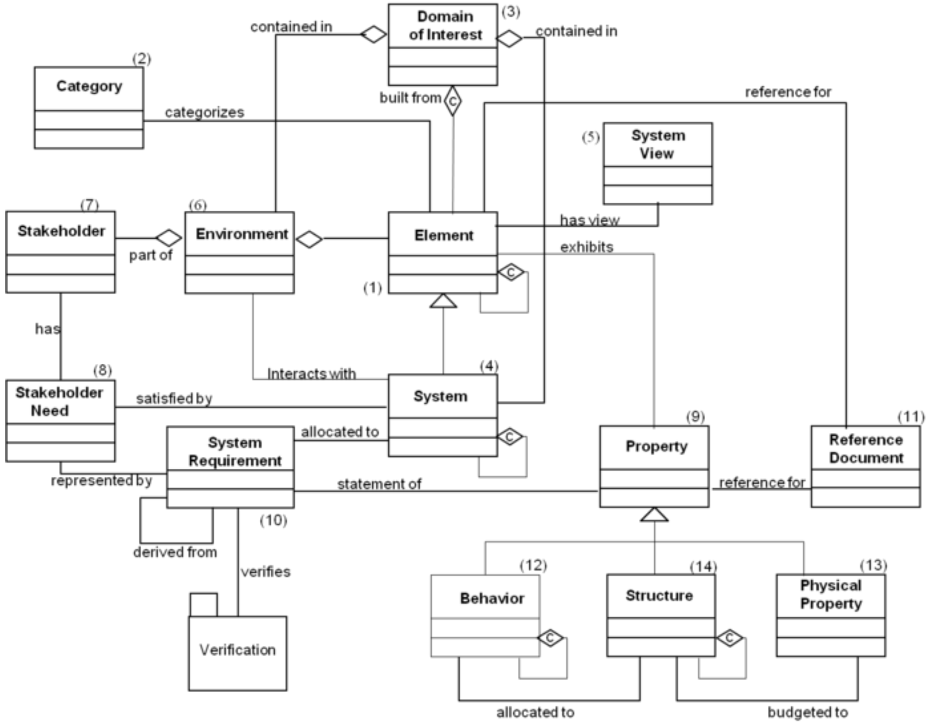
- **Virtualization**
  - models to simulate/emulate physical and environment in t
  - intelligent stub, in-the-loop testing
  - because real system is: expensive, infeasible, dangerous, too slow, too fast, cannot produce error scenarios, …

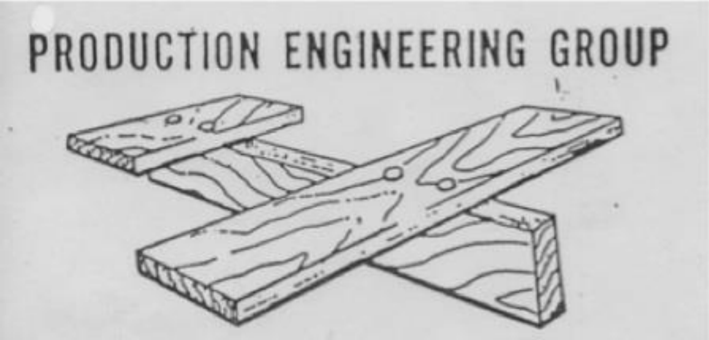
- **Modeling**
  - system ←→ physical part ←→ software ←→ environment
  - models for virtualization ←→ models for testing

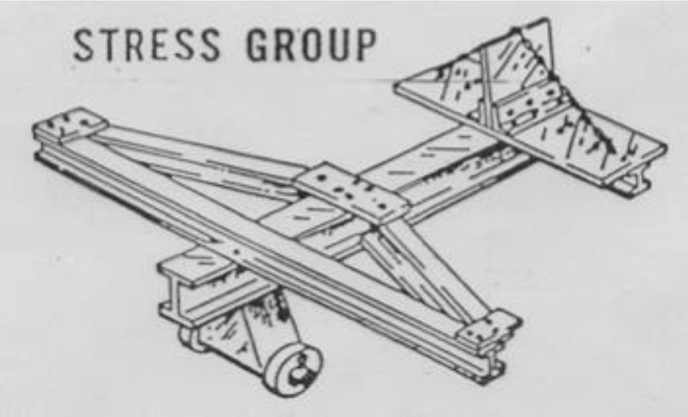
Multi-disciplinarity : Different Views on Systems





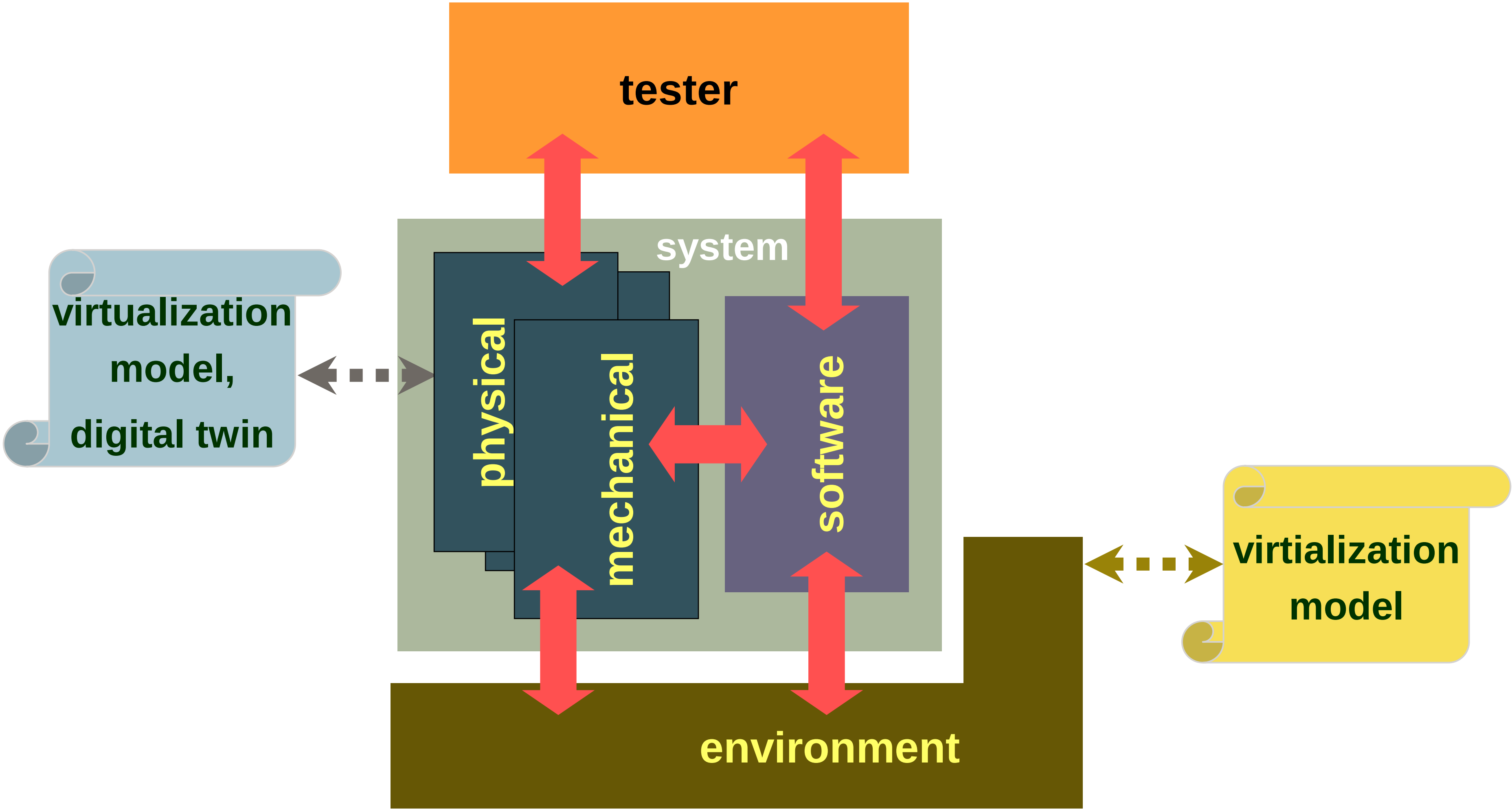






software group

Models for Multi-disciplinary Testing



Testing Trends & Challenges

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- Multi-Disciplinarity
- Evolution
- **Building Blocks**
- Connectivity
- Non-Functionals
- New Paradigms
- Environment
- Going Up
- Agile

Building Blocks : Components

Compon

legacy
open source
ON & OFF SHORE
Off The Shelf
CHINA
BHUTAN
NEPAL
PAKISTAN
New Delhi
INDIA
BANGLADESH
BURMA
Bay of Bengal
Arabian Sea
SRI LANKA
INDONESIA

TO REUSE, OR NOT TO REUSE

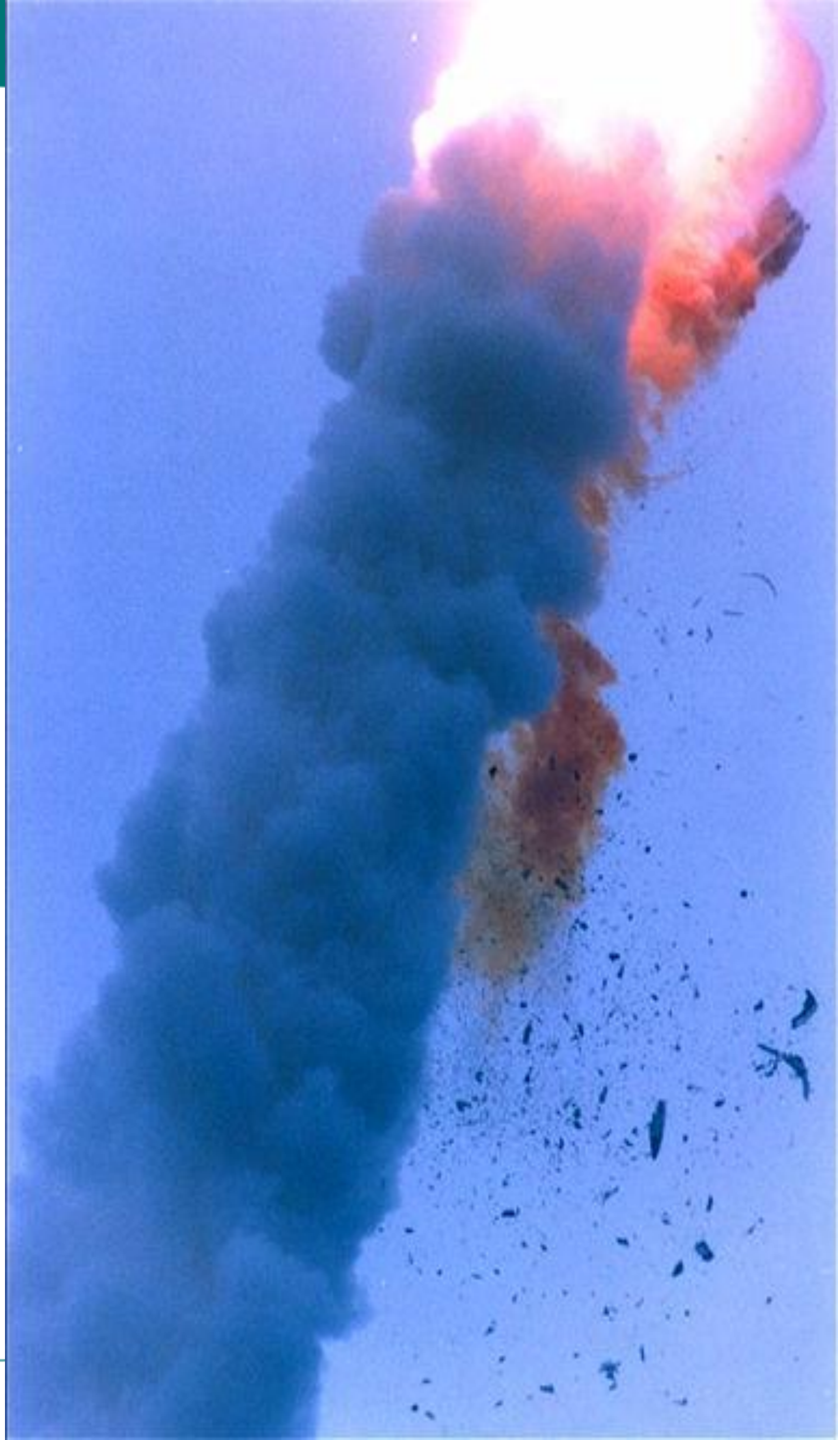
IN PARTICULAR,
IN TIMES OF CONTINOUS CHANGES

- reuse
- platform
- integration challenges
- dependencies
- when to test
- where to diagnose, repair

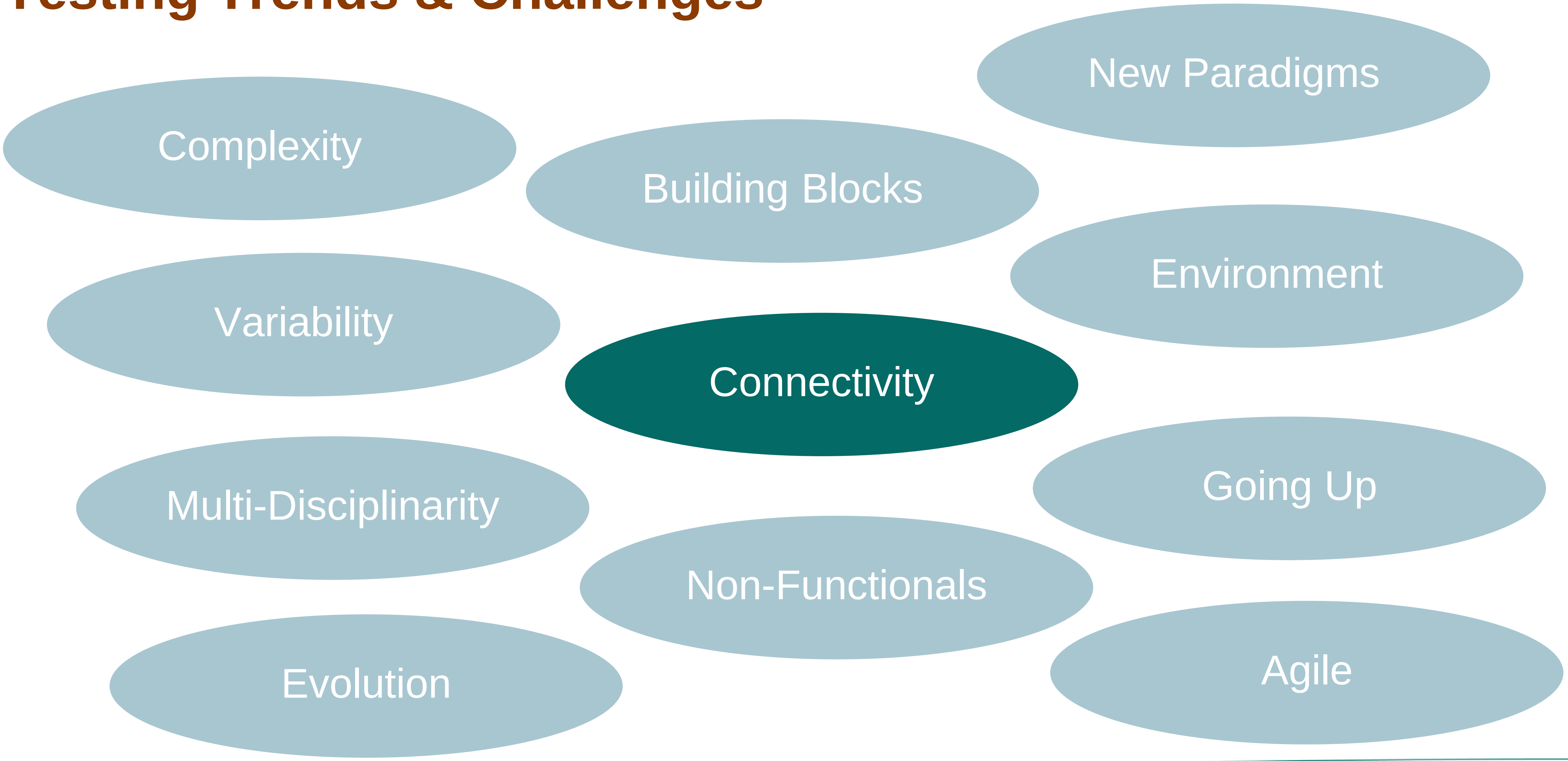
Components and Failures

Ariane V rocket
- Design defects in control software

- Design
  - Exception handler assumed hardware errors only
  - Reuse of Ariane IV component in Ariane V without proper system testing
- Error
  - Software exception
- Failure
  - Mis-interpretation of diagnostic information



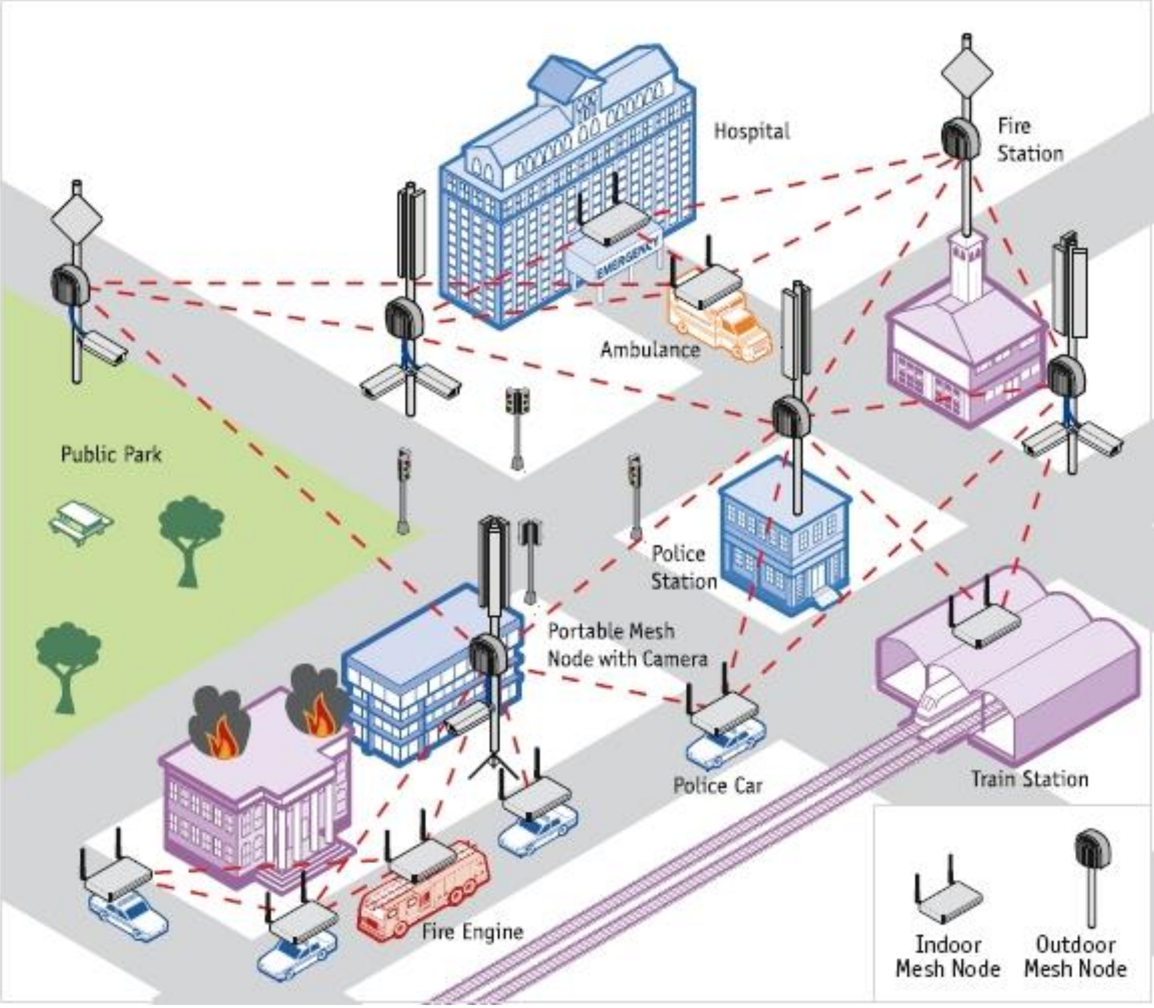
Testing Trends & Challenges



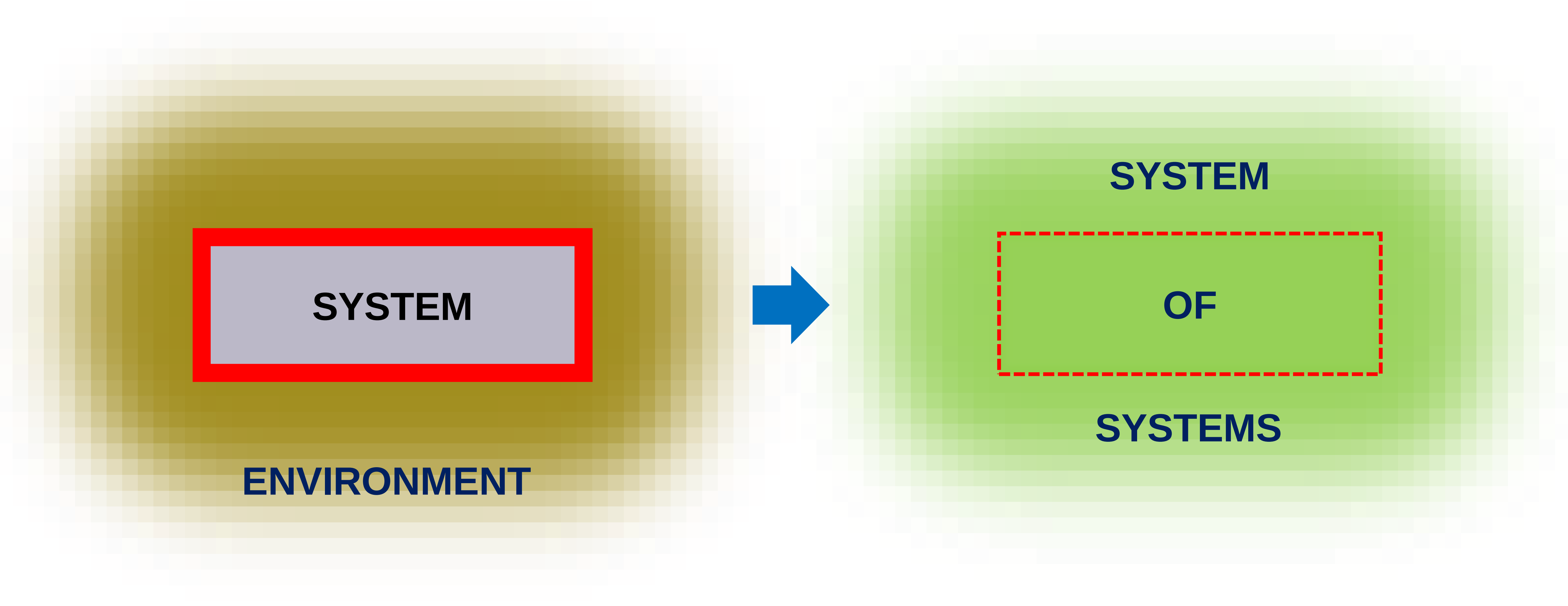
- New Paradigms
- Complexity
- Building Blocks
- Environment
- Variability
- Connectivity
- Going Up
- Multi-Disciplinarity
- Non-Functionals
- Agile
- Evolution

Connectivity

- Blurring boundaries of systems
  → everything connected
- Systems-Of-Systems
  - Dynamically connected systems
  - Not under own control
- Software is glue
  - with internal and external world
- Testing:
  - what is SUT ?
- Virtualization
  - which systems are available for testing ?
  - which systems must be virtualized?
- Dynamics
  - run-time testing and integration



Fading Boundaries



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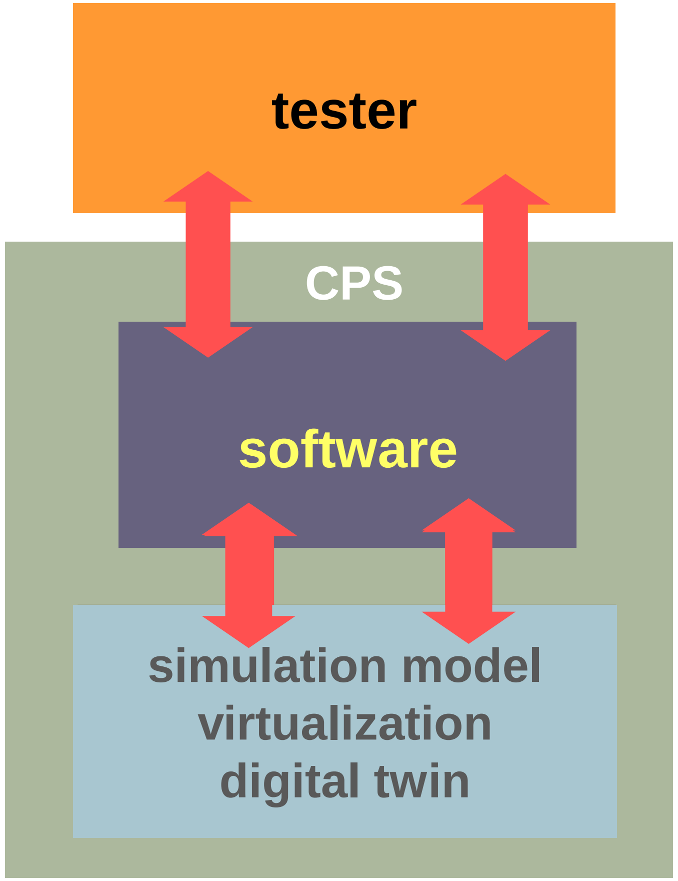
Environment



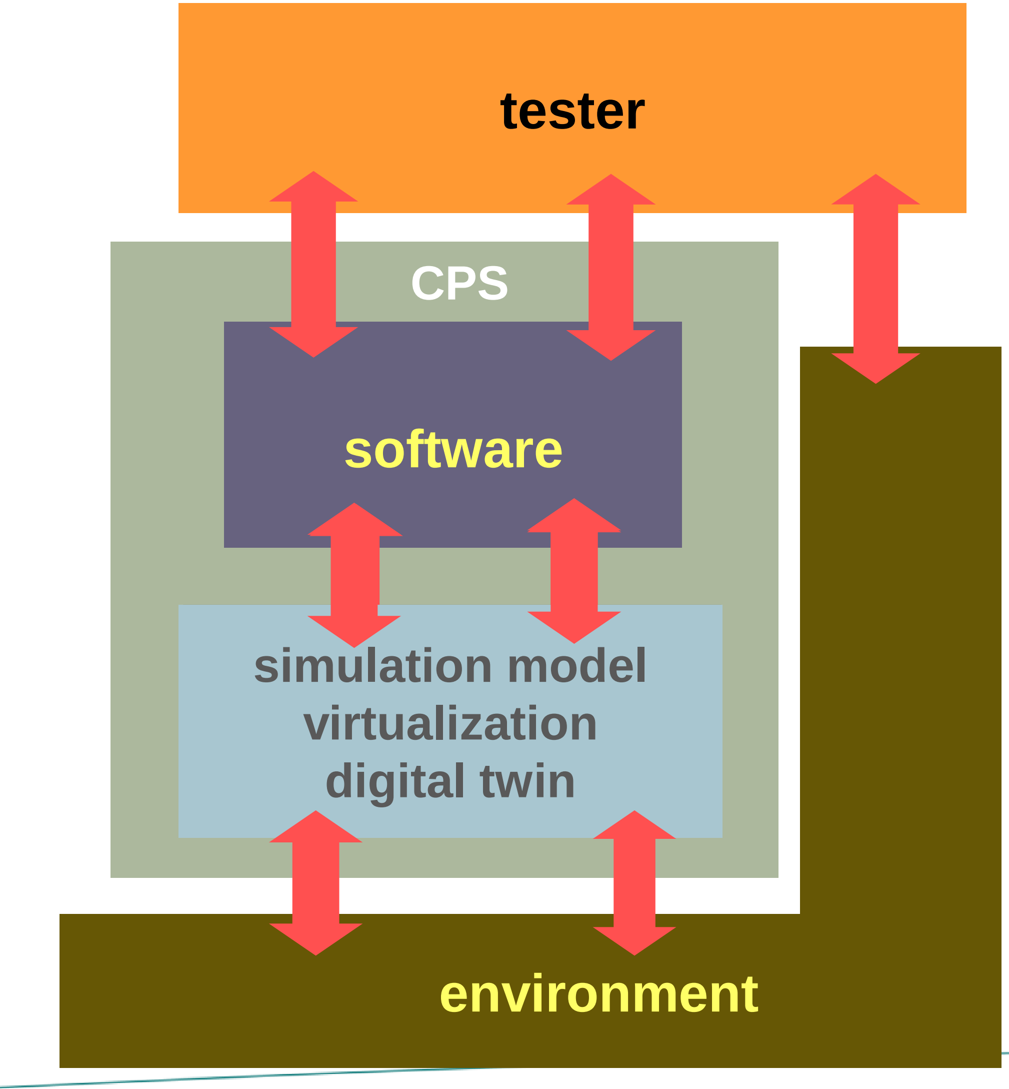
tester

CPS

software

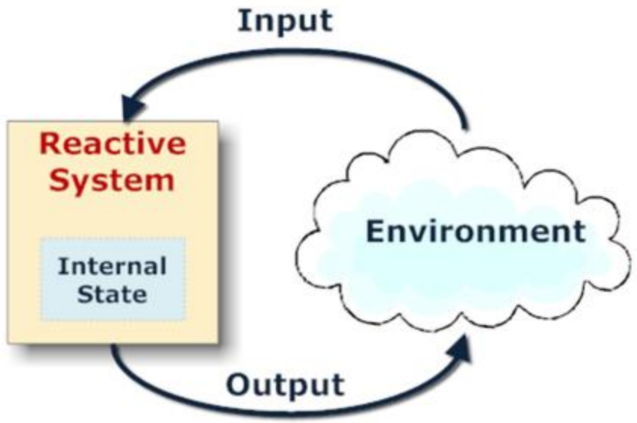
simulation model
virtualization
digital twin

Environment



Environment

functional



state-based

autonomous

calculation : *I* → *O*

tests over *I*

reactive: *I, S* → *O, S'*

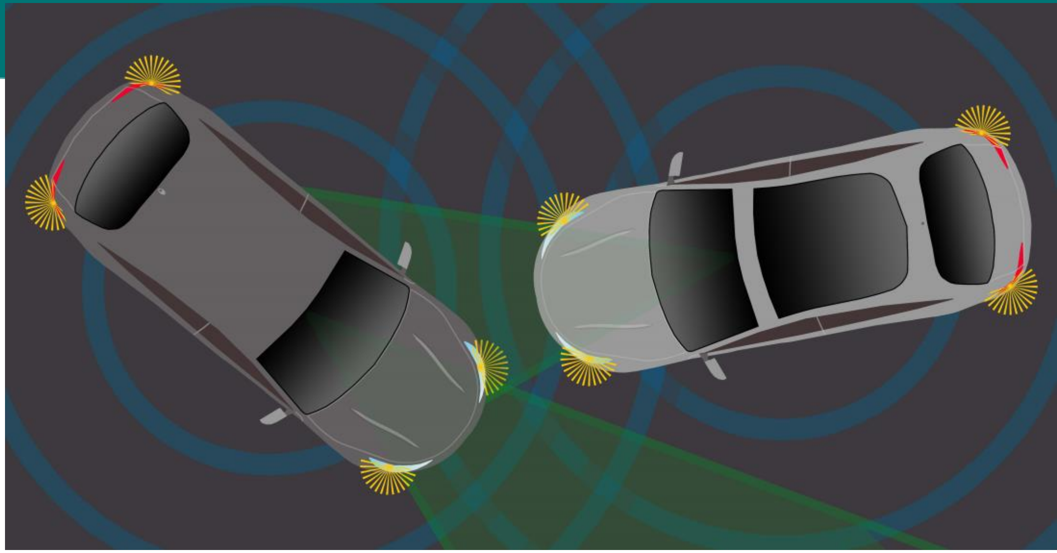
tests over *I, S*

proactive : *I, S, E* → *O, S', E'*

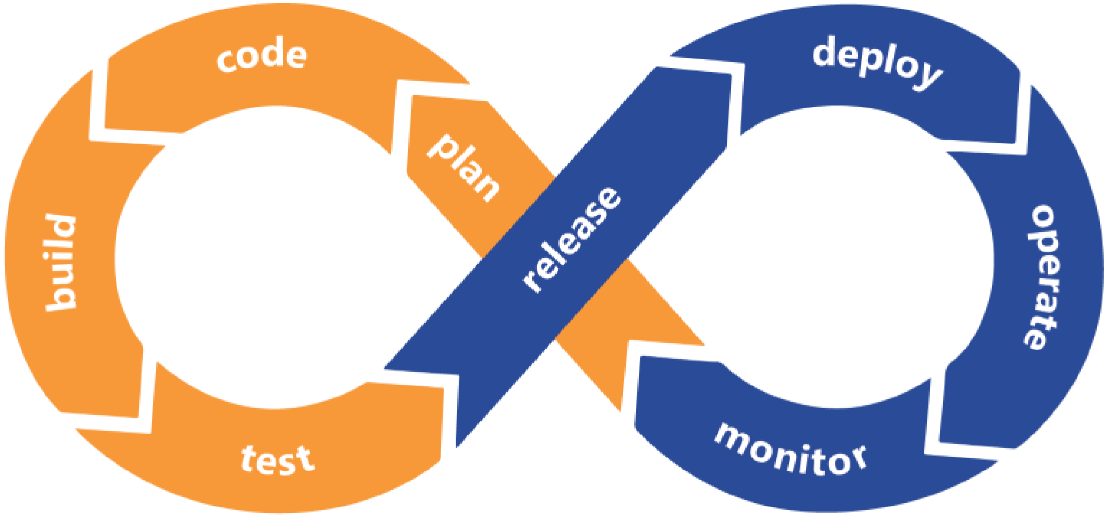
tests over *I, S, E*

for *safety*, *trustworthiness*, *dependability*,
the **environment** must be taken into account

Environment

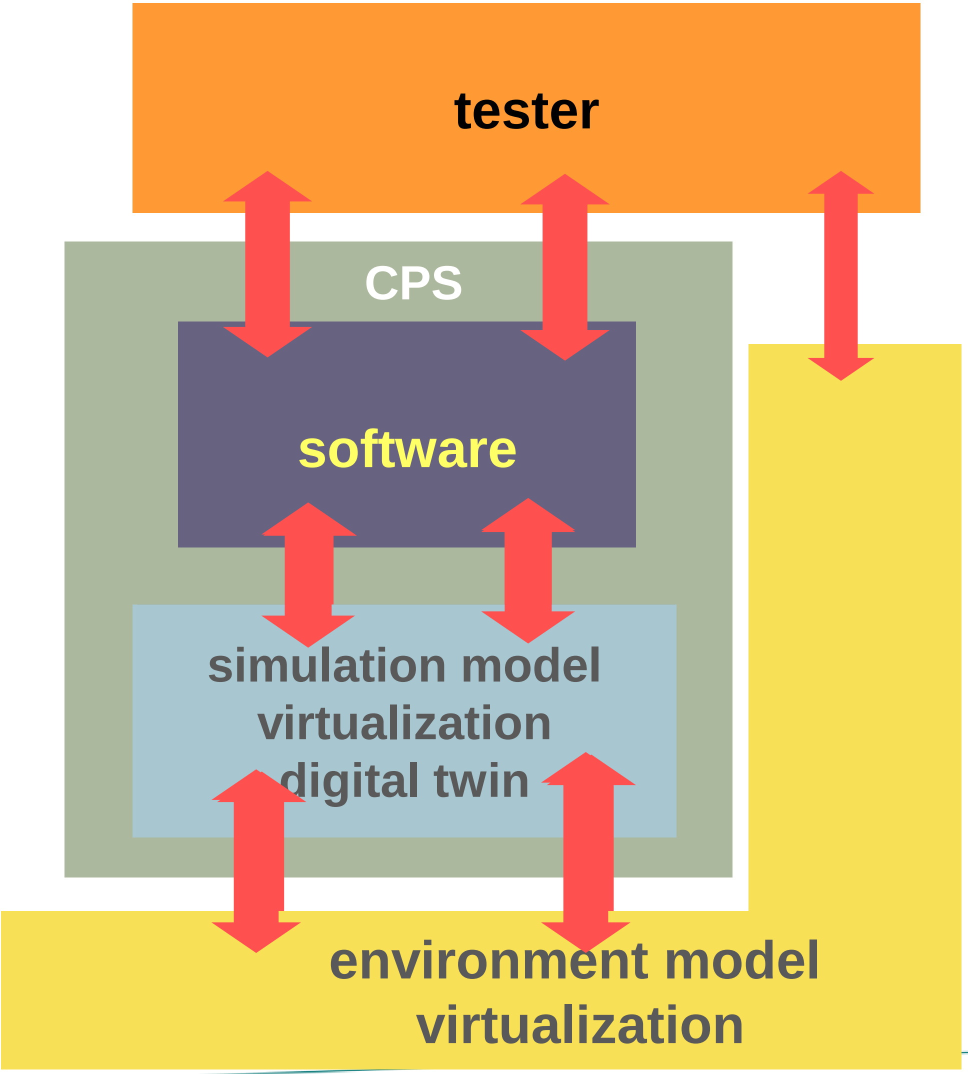


- Autonomous
  → take part in environment
- Safety of autonomous cars
  → test in all possible environments
- Environment
  → not, or limited, under (test) control
- Environment
  → can change
  → new testing ?



Testing everything before release is an illusion
→ continue quality control after release

Environment



Testing Trends & Challenges

New Paradigms

Complexity

Building Blocks

Environment

Variability

Connectivity

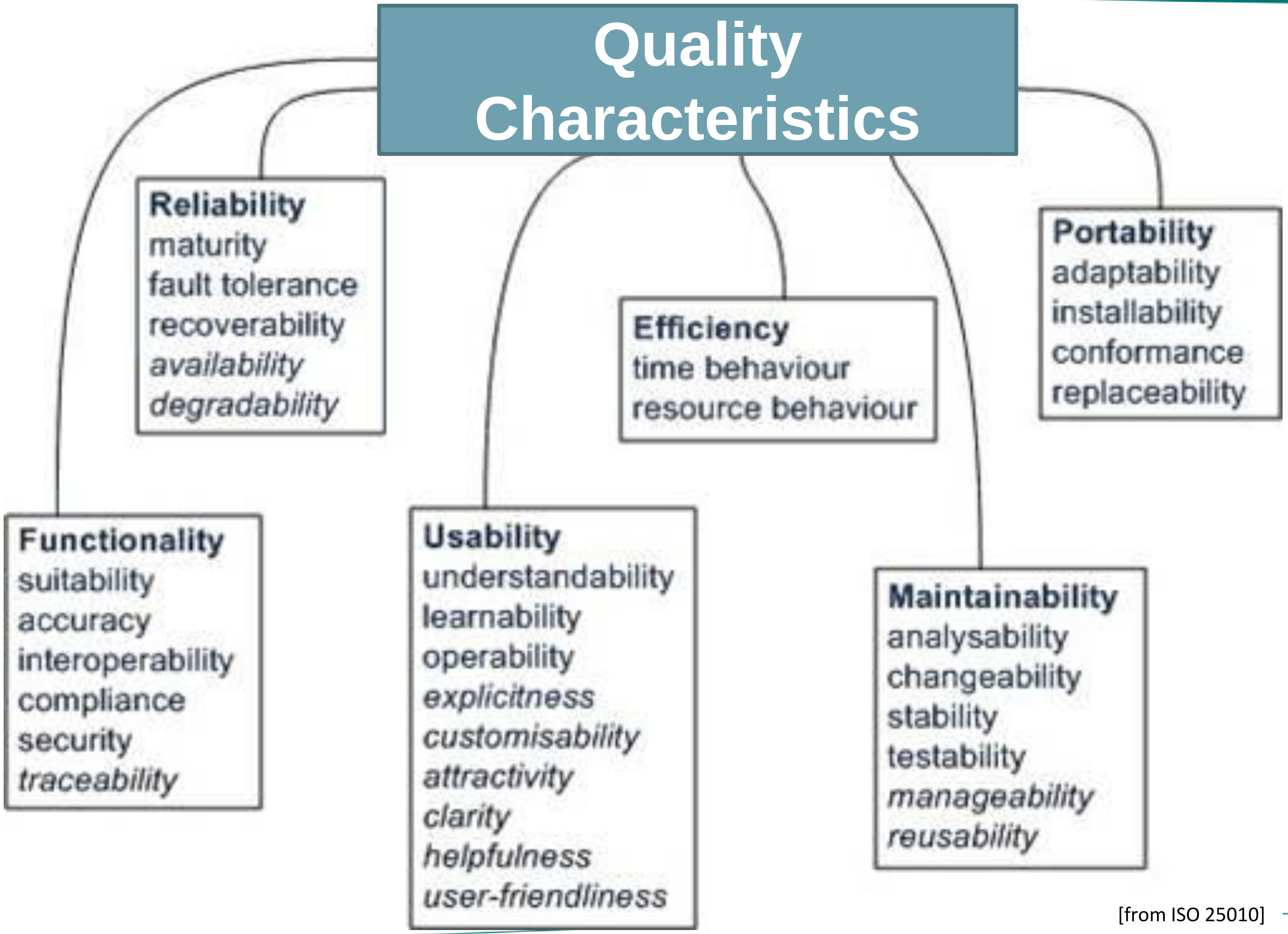
Going Up

Multi-Disciplinarity

Non-Functionals

Agile

Evolution



Quality Characteristics

Reliability
maturity
fault tolerance
recoverability
availability
degradability

Efficiency
time behaviour
resource behaviour

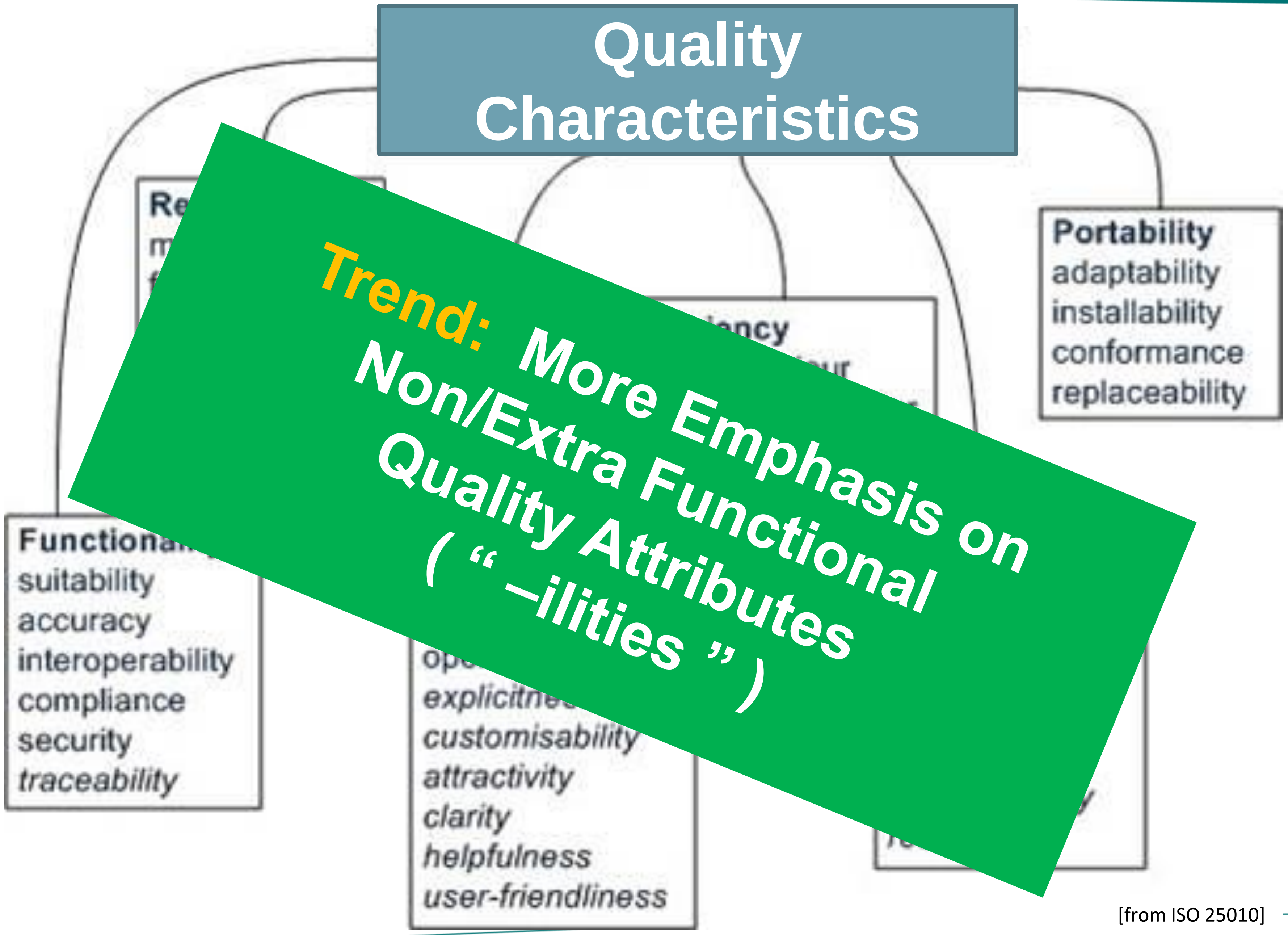
Portability
adaptability
installability
conformance
replaceability

Functionality
suitability
accuracy
interoperability
compliance
security
traceability

Usability
understandability
learnability
operability
explicitness
customisability
attractivity
clarity
helpfulness
user-friendliness

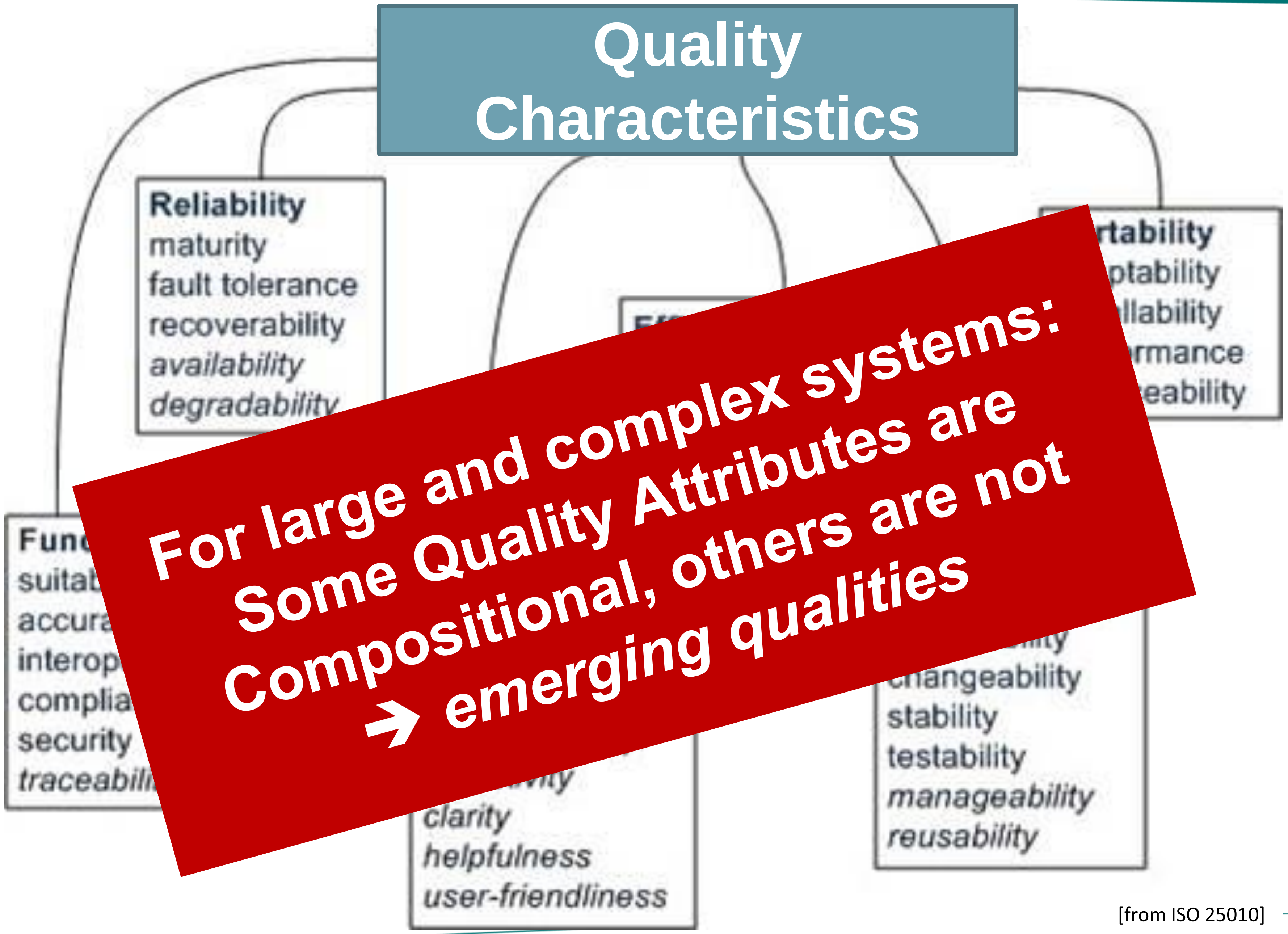
Maintainability
analysability
changeability
stability
testability
manageability
reusability

[from ISO 25010]



Trend: More Emphasis on Non/Extra Functional Quality Attributes (“ –ilities ”)

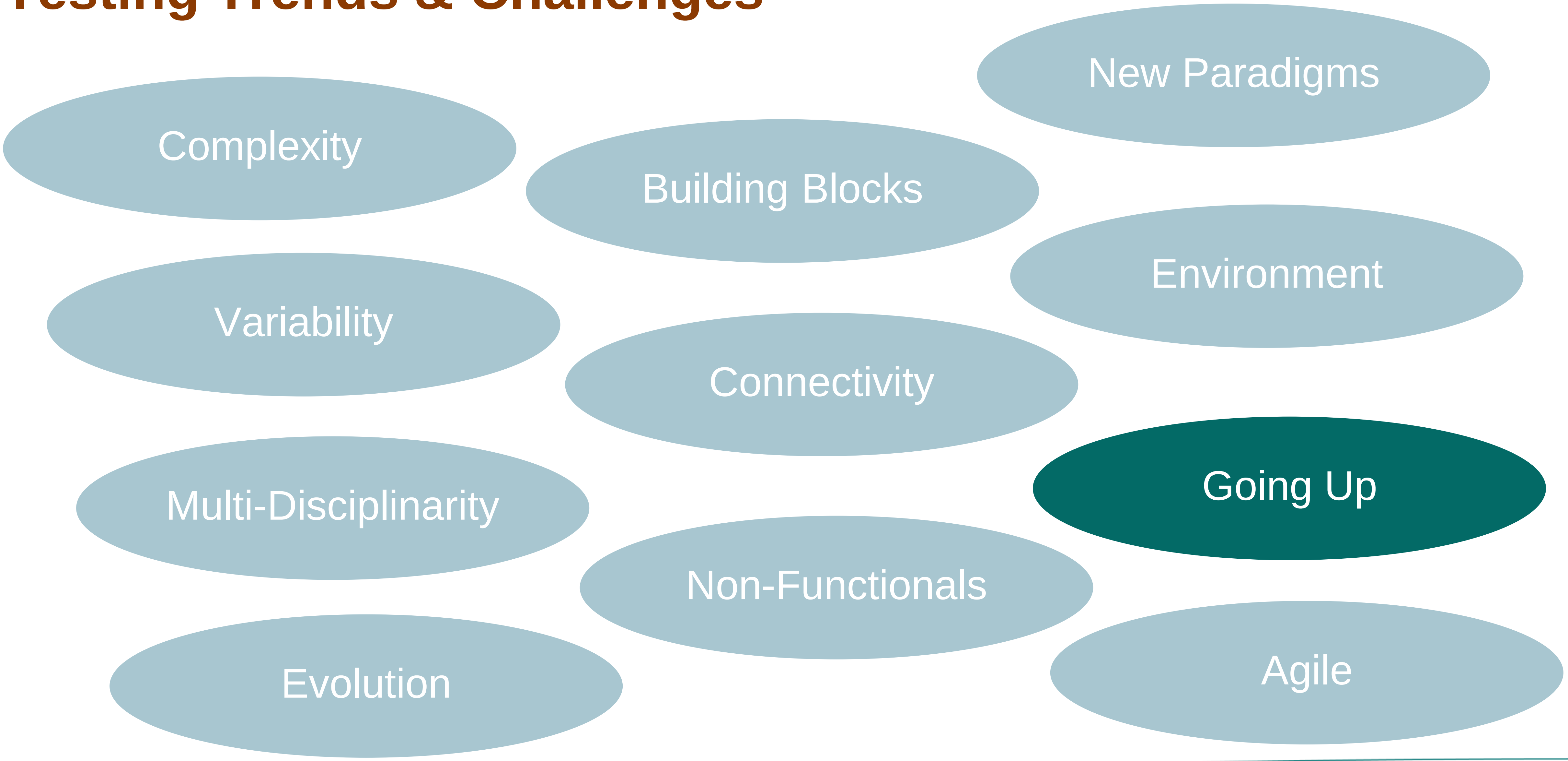
[from ISO 25010]



For large and complex systems: Some Quality Attributes are Compositional, others are not → emerging qualities

[from ISO 25010]

Testing Trends & Challenges



Complexity

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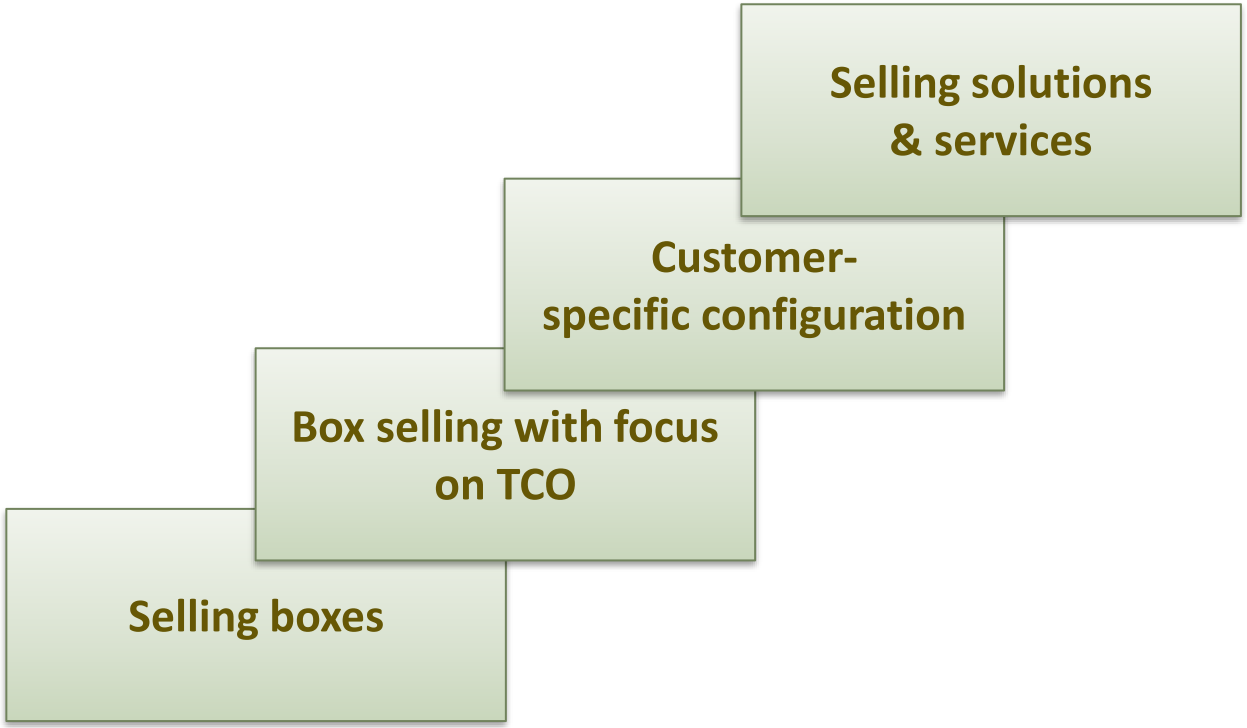
Going Up

- In the Value Chain
  - new business models
  - testing quality-of-service

- In the Test Pyramid
  - everybody does unit tests
  - bugs are on the higher levels

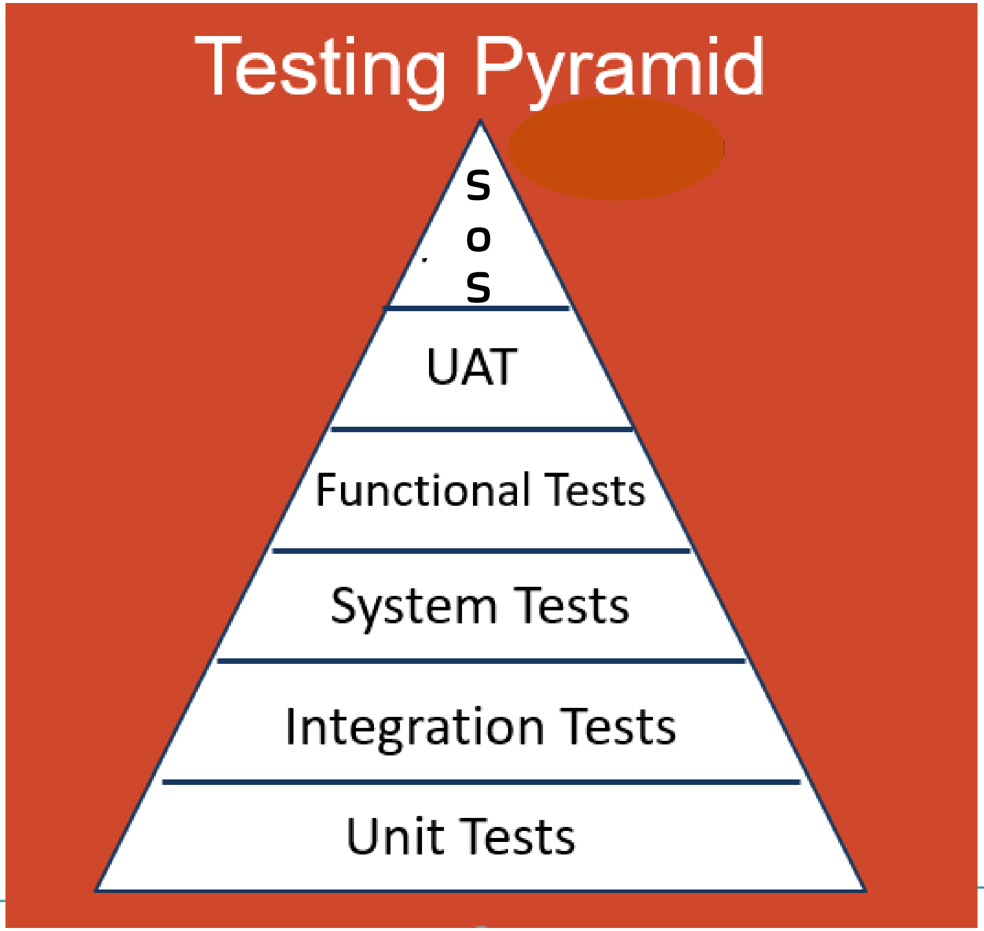


Selling solutions & services

Customer-specific configuration

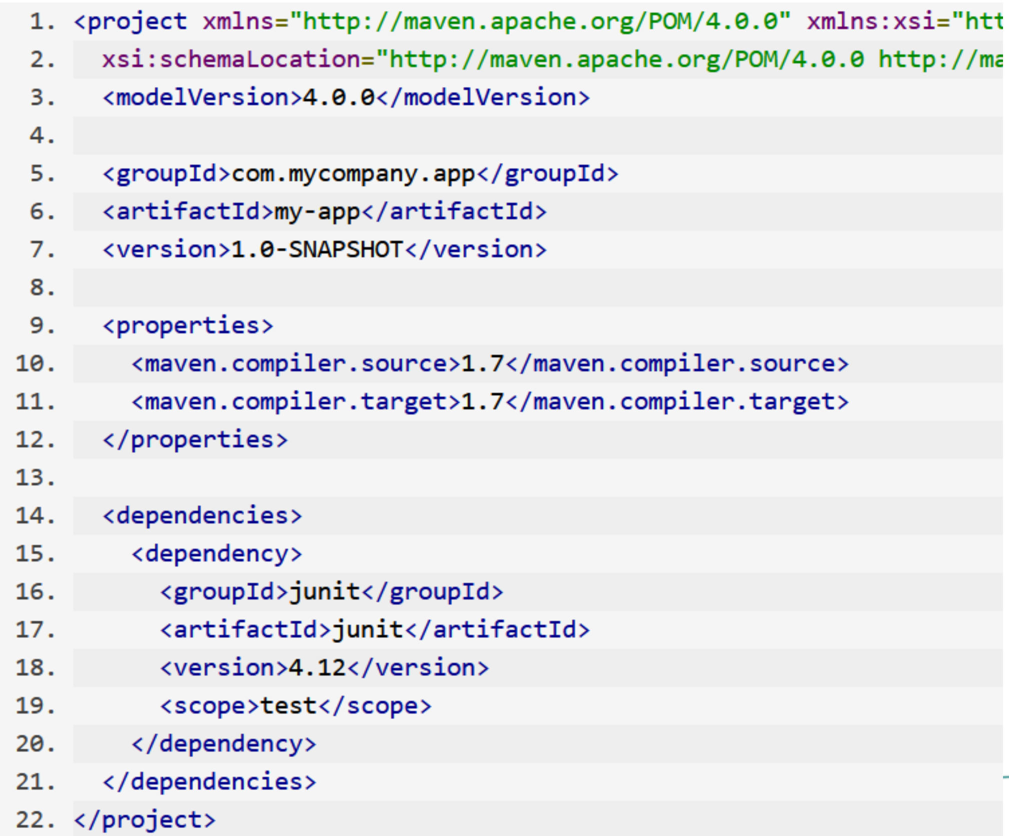
Box selling with focus on TCO

Selling boxes



Going Up

- In Coding
  - from software to meta-software: build tools, build scripts, configuration setting, . . .



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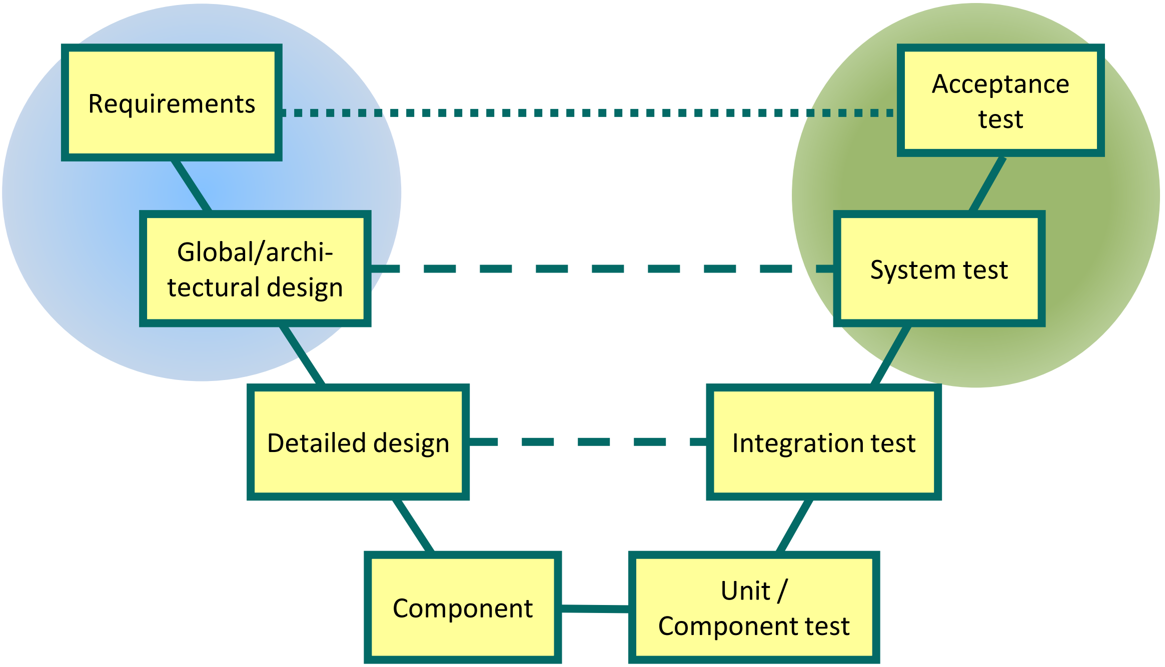
  <modelVersion>4.0.0</modelVersion>

  <groupId>com.mycompany.app</groupId>
  <artifactId>my-app</artifactId>
  <version>1.0-SNAPSHOT</version>

  <properties>
    <maven.compiler.source>1.7</maven.compiler.source>
    <maven.compiler.target>1.7</maven.compiler.target>
  </properties>

  <dependencies>
    <dependency>
      <groupId>junit</groupId>
      <artifactId>junit</artifactId>
      <version>4.12</version>
      <scope>test</scope>
    </dependency>
  </dependencies>
</project>
```

- In the V-Model
  - requirements, design, system test
  - detailed design, coding, unit tests outsourced

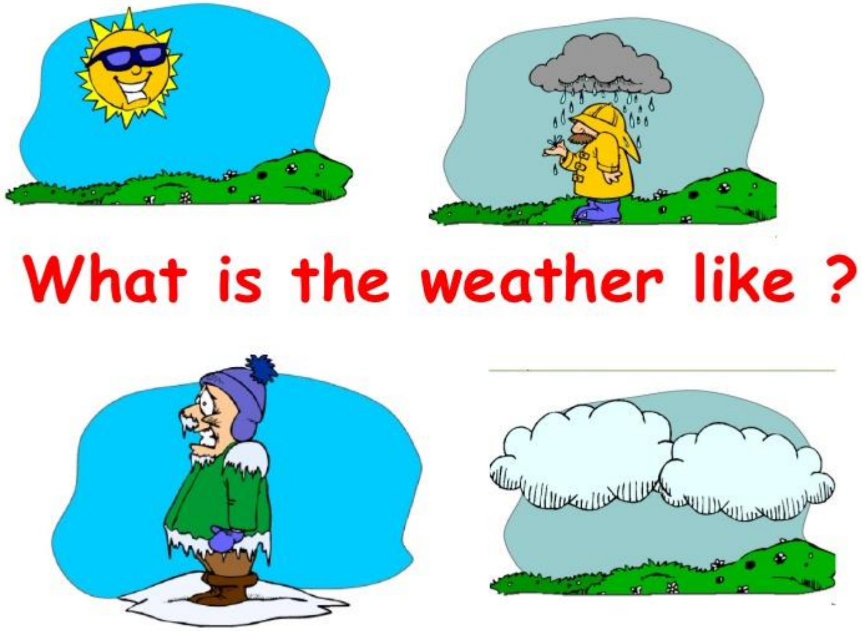


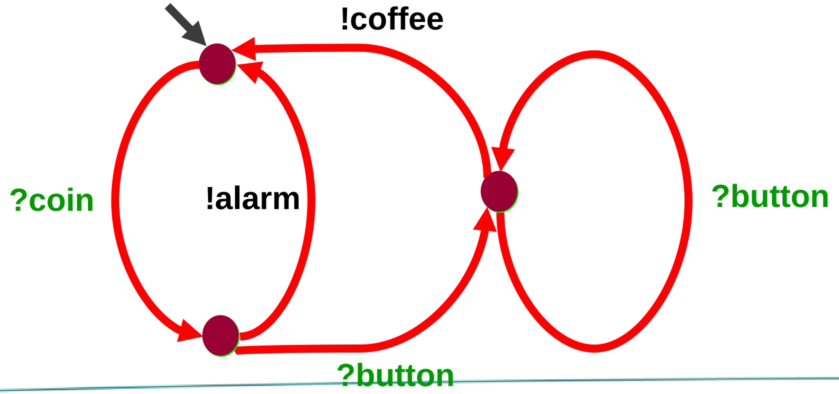
Going Up Consequence : Uncertainty & Non-Determinism

- Sometimes you don’t know …..
  - testing a search engine, weather forecast, …
  - systems-of-systems, big data, ...
- Sometimes you don’t want to know …..
  - no details
  - abstraction
  - particular view

Uncertainty of test outcomes & oracles

- **non-determinism**
- **probabilities**

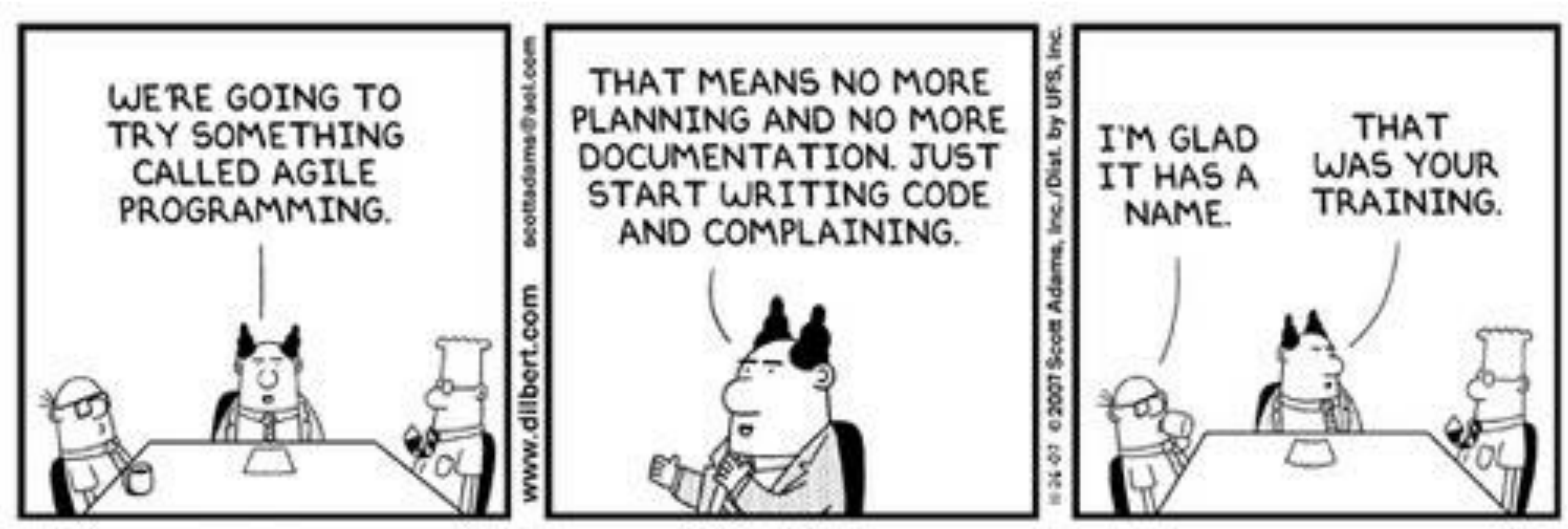




Testing Trends & Challenges

- Complexity
- Variability
- Multi-Disciplinarity
- Evolution
- Building Blocks
- Connectivity
- Non-Functionals
- New Paradigms
- Environment
- Going Up
- Agile

Agile ?


WE'RE GOING TO TRY SOMETHING CALLED AGILE PROGRAMMING.
www.dilbert.com scottadams@aol.com
THAT MEANS NO MORE PLANNING AND NO MORE DOCUMENTATION. JUST START WRITING CODE AND COMPLAINING.
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I'M GLAD IT HAS A NAME.
THAT WAS YOUR TRAINING.

Agile

- Agile → test automation
  - test execution automation
  - test fast and often

→ Large repositories of scripted tests

- the night is too short
- traceability to requirements ?
- maintainability ?
- pesticide paradox : *how to increase variation in tests ?*

Agile - fallacy of complete specification:

We finally have the guts to admit that we don't know precisely what the system should do when we start coding.

Testing Trends & Challenges

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New Paradigms and Technologies

- Cloud
- Self-adaptive systems
- AI, Machine Learning
- Quantum Computing
- Ethics, sustainability, …
- ......

Testing Trends & Challenges

New Paradigms

Complexity

Building Blocks

Environment

Variability

Connectivity

Multi-Disciplinarity

Non-Functionals

Evolution

Internships and Master Theses in Testing CPS

Semiconductor manufacturing equipment

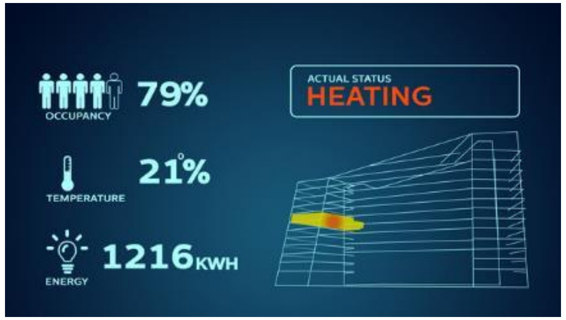
Medical systems

Food processing

Agricultural robots

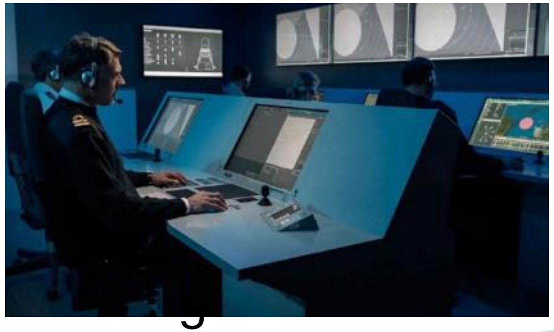
Traffic management

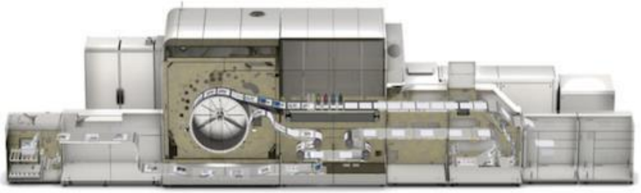
Electron microscopes



Building control

Robotized warehousing


Combat management systems


Industrial printers

Automotive

Dike