

A method for quantitative evaluation of functional chains supported by a Capella add-on

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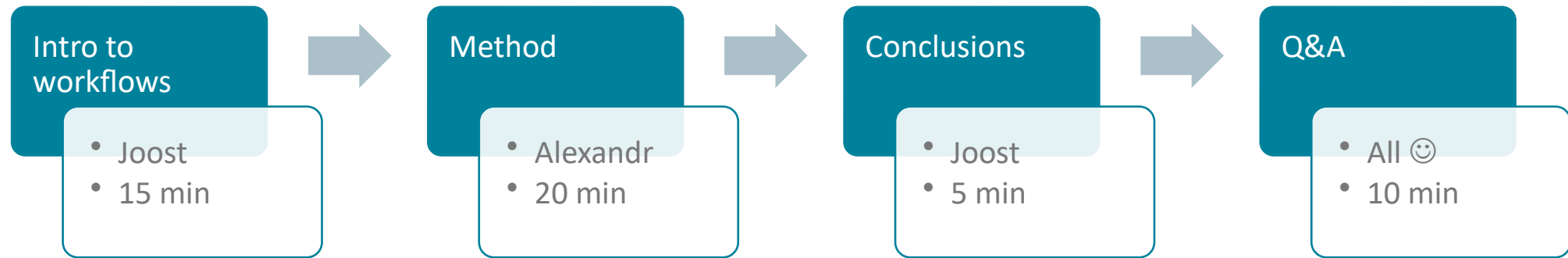
Jamie McCormack

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Outline



Introduction to workflows

(Joost, 15 min)



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thermo scientific | applied biosystems | invitrogen | fisher scientific | unity lab services | patheon | PPD

\$40B
revenue

110,000
employees

\$1,4B
invested in R&D

5,700
R&D scientists and engineers

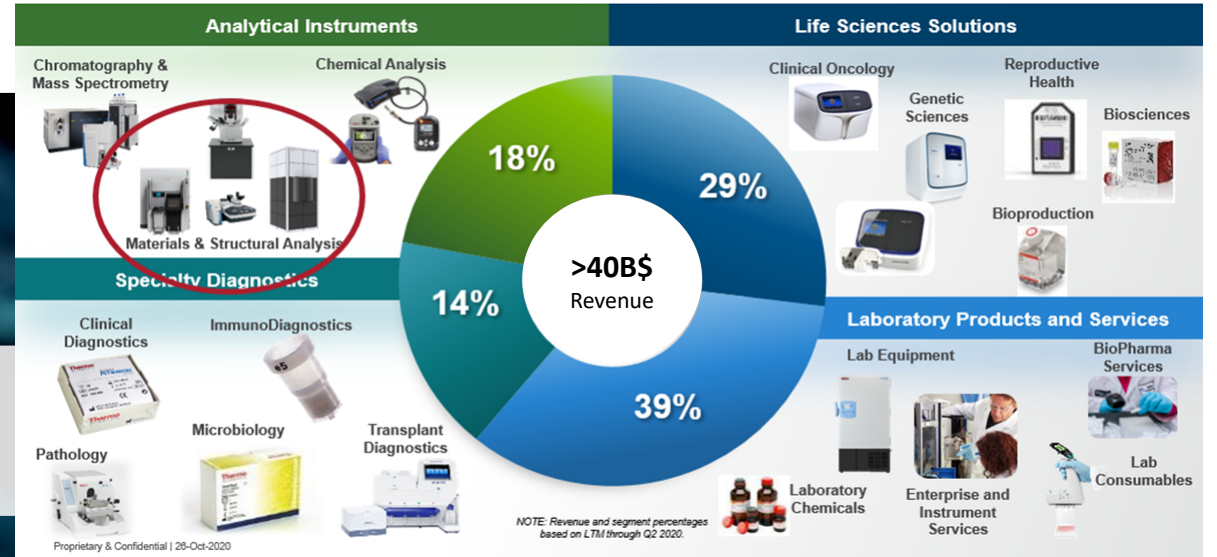
Industry-leading scale

- Unparalleled commercial reach
- Unique customer access
- Extensive global footprint

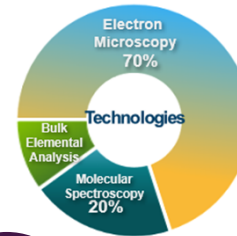
Unmatched depth of capabilities

- Leading innovative technologies
- Deep applications expertise
- Premier productivity partner
- Comprehensive services offering

Powered by our Practical Process Improvement (PPI) Business System

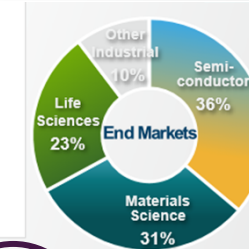


➤ Material and Structural Analysis



Global Footprint

- 5,000+ employees globally
- 750+ R&D engineers including 300+ software engineers
- Main operations and R&D sites:
 - Czech Republic (Brno)
 - Netherlands (Eindhoven)
 - USA (Madison WI; Hillsboro OR)



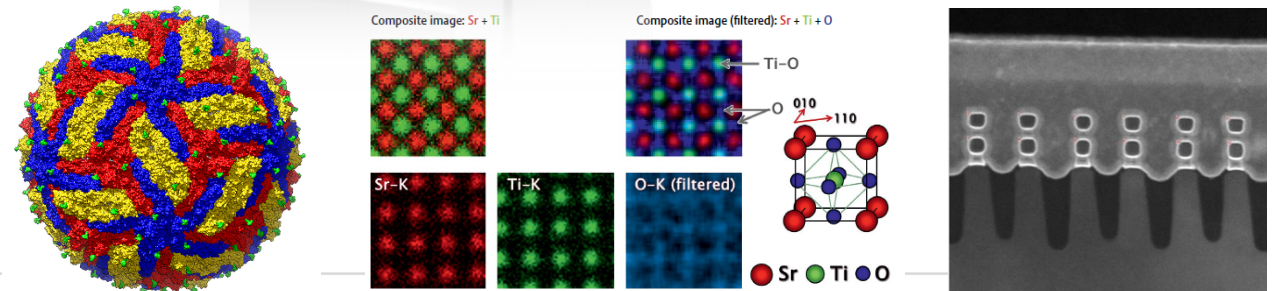
System Scope

Transmission Electron Microscope

- Dimensions: 1.6m x 1.6m x 3.0-4.3m
- Weight: > 1600kg
- Resolution: 50pm
- Cost: 1M\$ – 15M\$

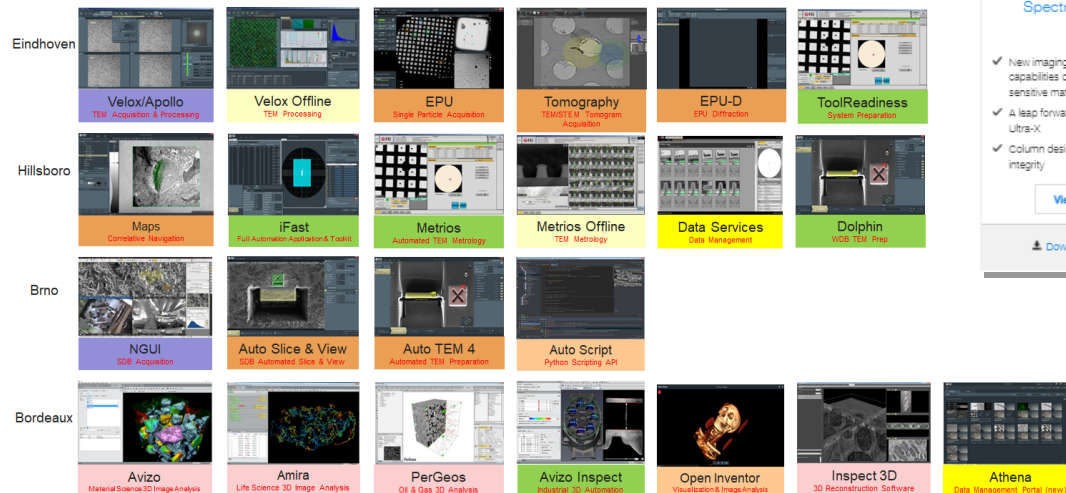
Applications

- **Life Sciences**
 - Virus and cell structure research
- **Material Sciences**
 - Chemical and material investigations
- **Semiconductor**
 - Process analysis / control



Background

- 15 active commercial TEM products
- More than 20 customer-facing applications
- More than 400 Modules
- 1 TEM Server Software Stack
- 1000+ active configurations
- Distributed Development



Krios Rx Cryo-TEM

- Industry leading productivity & ease of use
- Fixed 300 kV voltage for SPA
- Pharma-dedicated service path for guaranteed reliability

[View product](#)

[Download datasheet](#)

Glacios Cryo-TEM

- Flexible Accelerating Voltage 80-200 kV
- Industry-leading Autoloader for cryogenic sample manipulation
- Small footprint
- Enhanced ease-of-use

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[Download datasheet](#)

Talos Arctic TEM

- Increased data acquisition speed
- High data with robotic sample handling & automated loading
- Unattended platform operation and automated data acquisition
- Low cost of ownership with remote diagnostics and preventive service

[View product](#)

[Download datasheet](#)

Metrios AX TEM

- Automation options to support quality, consistency, metrology, and reduced OPEX
- Leverages machine learning for superior autofunctions and feature recognition
- Workflows for both in-situ and ex-situ lamella preparation

[View product](#)

[Download datasheet](#)

Spectra Ultra TEM

- New imaging and spectroscopy capabilities on the most beam sensitive materials
- A leap forward in EDS detection: Ultra-X
- Column designed to maintain integrity

[View product](#)

[Download datasheet](#)

Themis ET

- Precise control and km sample temperature
- Improved sample stab and assisted sample d x, y, and z axes
- Advancing high-quality movie acquisition func

[View product](#)

[Download datasheet](#)

Talos F200S TEM

- Precise chemical composition data
- High-performance imaging and precise compositional analysis for dynamic microscopy
- Features Velox Software for fast and easy acquisition and analysis of multimodal data

[View product](#)

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Talos F200X TEM

- High resolution throughput in STEM imaging and chemical analysis
- Add application-specific in situ sample holders for dynamic experiments
- Features Velox Software for fast and easy acquisition and analysis of multimodal data

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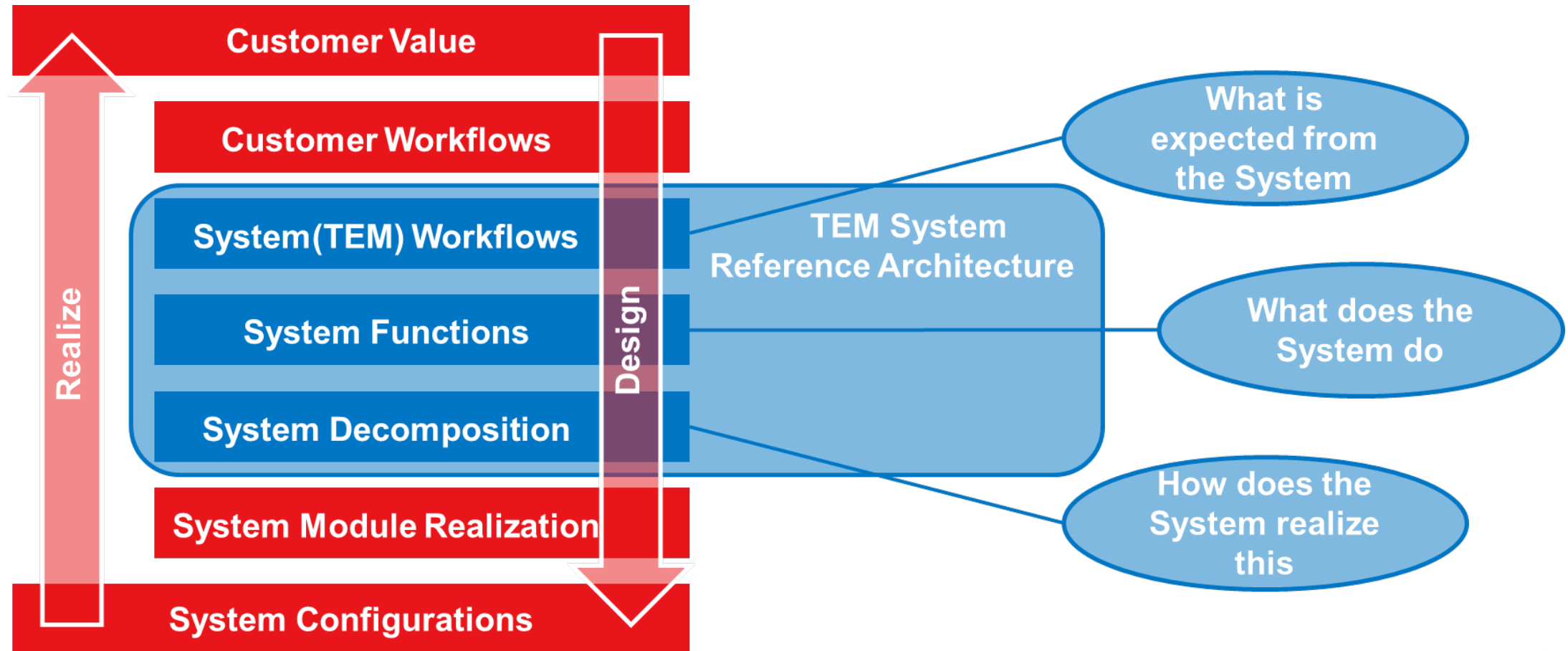
Talos F200C TEM

- Flexible EDS analysis reveals chemical information
- High-contrast, high-quality TEM and STEM imaging
- Ceta 16 Mpixel CMOS camera provides large field of view and high read-out speed

[View product](#)

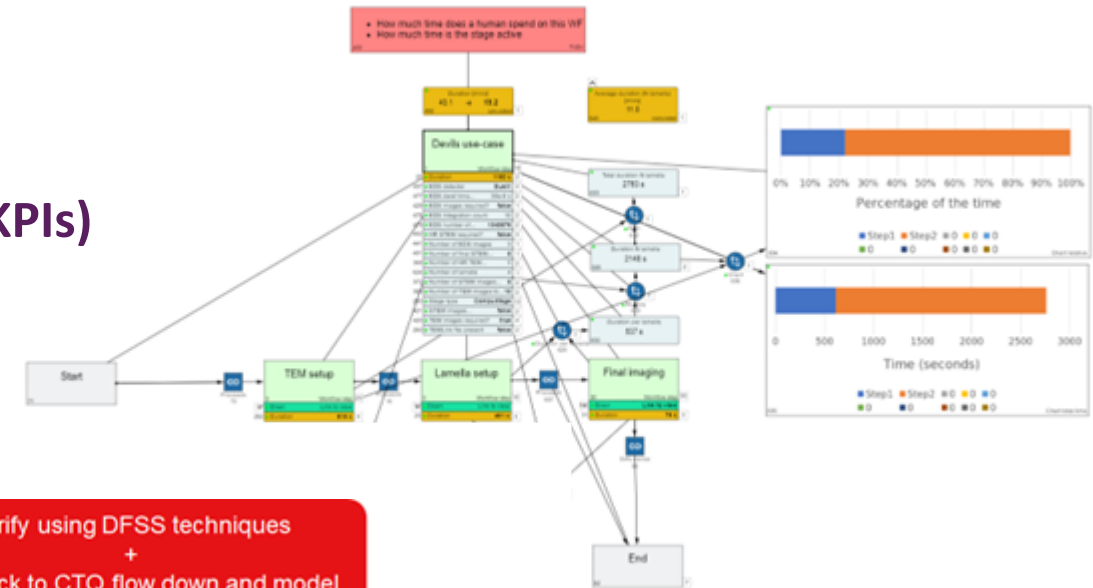
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Reference Architecture Overview



Workflow Analysis

- Identify Customer Value
- Identify Critical To Quality (CTQ) Parameters (KPIs)
- Allocate CTQ Parameters to Features



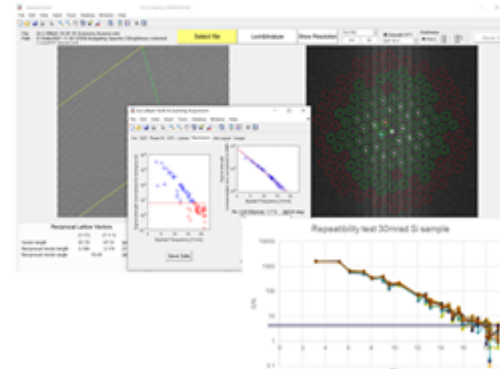
Start with CTQ Flow down
From Customer needs via
System CTQs to module CTQs



Build transfer function model by
combining domain specific models to
do impact analysis and tolerancing



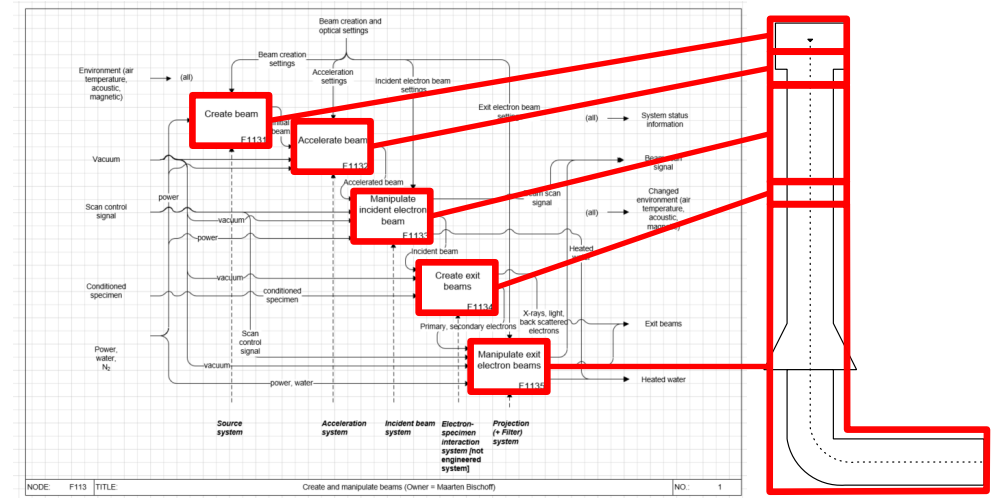
Verify using DFSS techniques
+
feedback to CTQ flow down and model



Functional Decomposition / System Decomposition

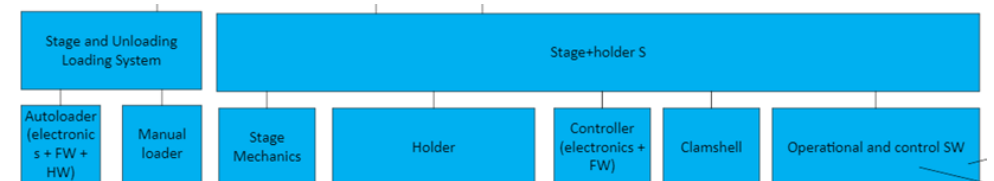
➤ Decompose System into Functions

- Decompose CTQ parameters
- Cover hardware and software



➤ Decompose System into Modules

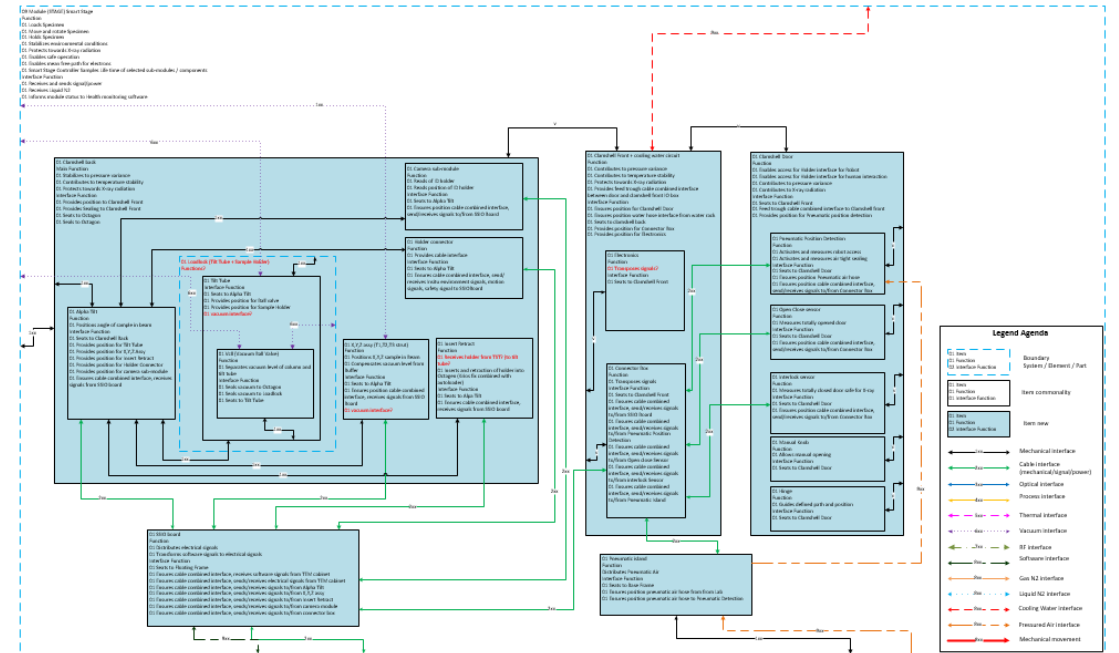
- Allocate Functions to Modules and Owners (Hardware and Software)
- Logical grouping of functions
- Define transfer functions for Modules (based on Function CTQ Parameters)



Logical Architecture / Compatibility

- **Identify interfaces between Modules**
 - Critical for compatibility
 - Used for risk management (FMEA)
 - Component naming aligned though Taxonomy

- **Define technical compatibility**
 - Map Module compatibility to Systems
 - Include Non-Standard Requests
 - Include Backward Compatibility



Module	System	Interface	Compatibility	Notes
Module 1	System A	Mechanical Interface	Yes	
Module 1	System B	Mechanical Interface	No	Non-standard request
Module 2	System A	Thermal Interface	Yes	
Module 2	System B	Thermal Interface	No	Non-standard request
Module 3	System A	Optical Interface	Yes	
Module 3	System B	Optical Interface	No	Non-standard request
Module 4	System A	Software Interface	Yes	
Module 4	System B	Software Interface	No	Non-standard request
Module 5	System A	Gas Inlet Interface	Yes	
Module 5	System B	Gas Inlet Interface	No	Non-standard request
Module 6	System A	Liquid Inlet Interface	Yes	
Module 6	System B	Liquid Inlet Interface	No	Non-standard request
Module 7	System A	Cooling Water Interface	Yes	
Module 7	System B	Cooling Water Interface	No	Non-standard request
Module 8	System A	Pressured Air Interface	Yes	
Module 8	System B	Pressured Air Interface	No	Non-standard request
Module 9	System A	Mechanical Movement	Yes	
Module 9	System B	Mechanical Movement	No	Non-standard request

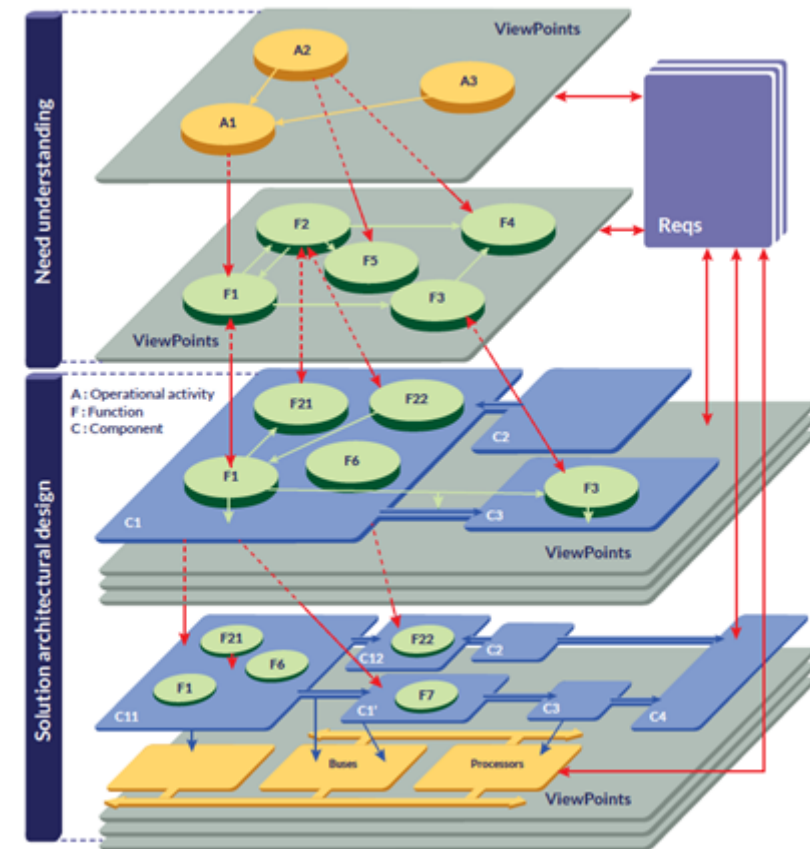
MBSE – Evolving Reference Architecture

➤ Tool to support Reference Architecture

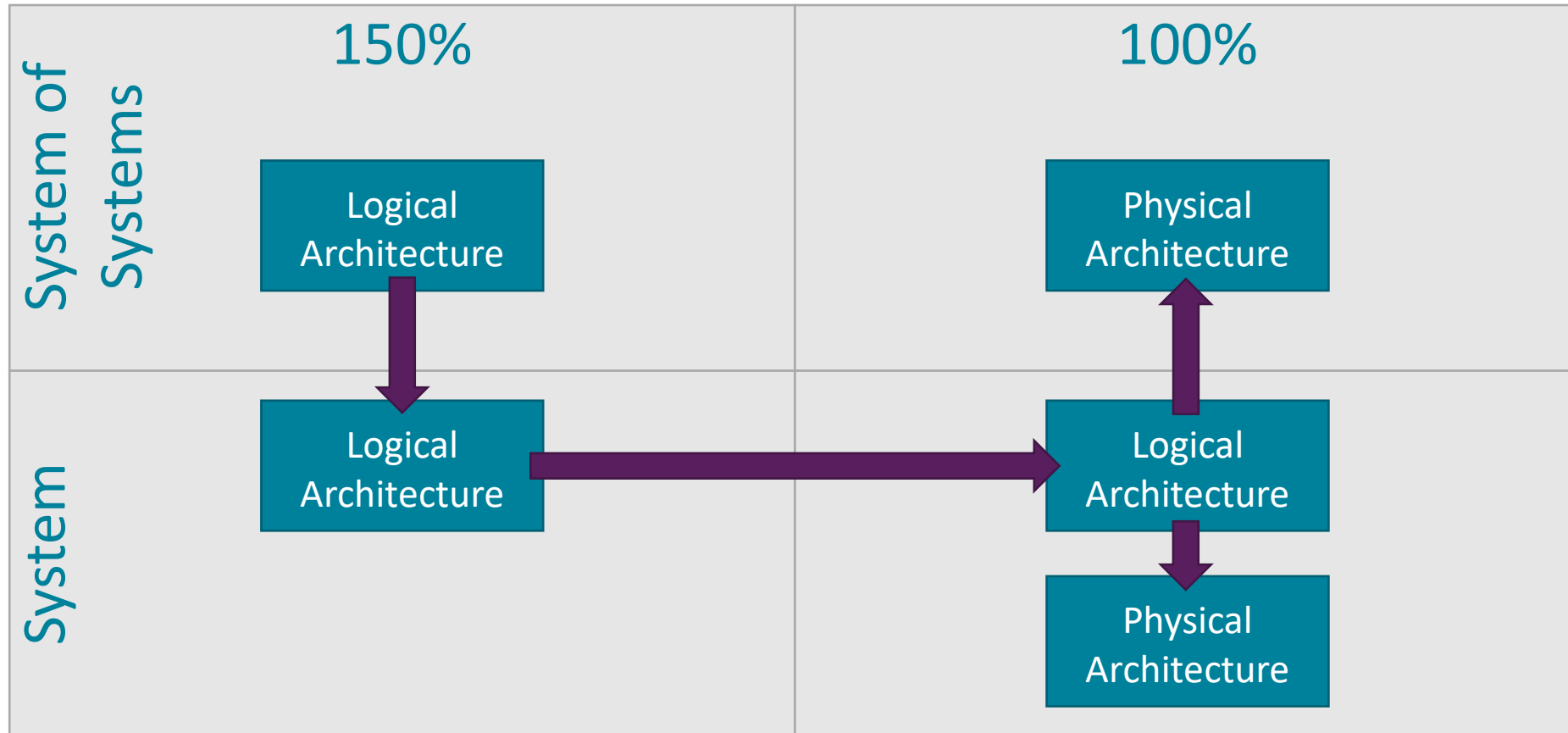
- Guarantee consistency
- Ease maintainability
- Increase automation opportunities

➤ Process to ensure maintainability

- System-of-Systems approach
- Separate models for System versions



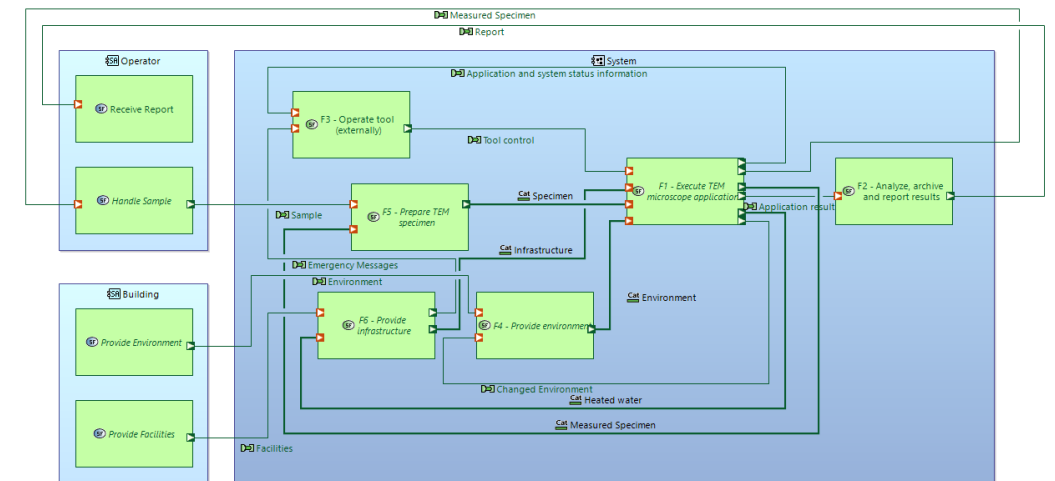
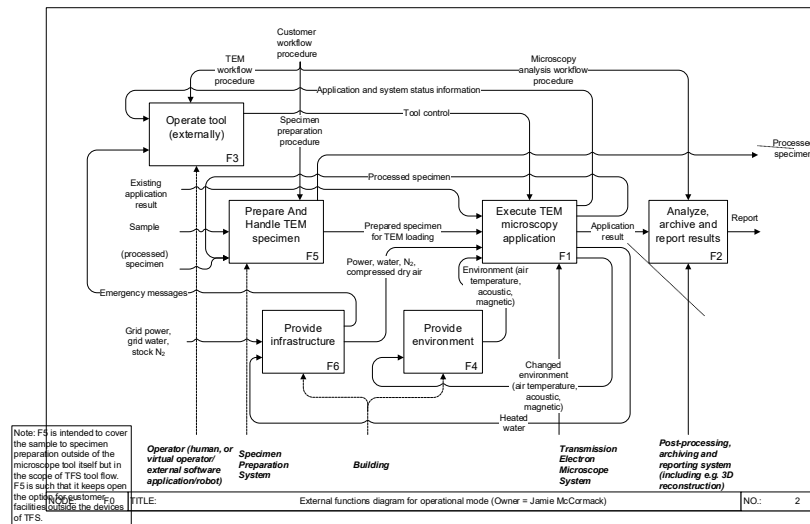
MBSE – Modeling Structure



MBSE – Transition

➤ Transfer Reference Architecture to Capella

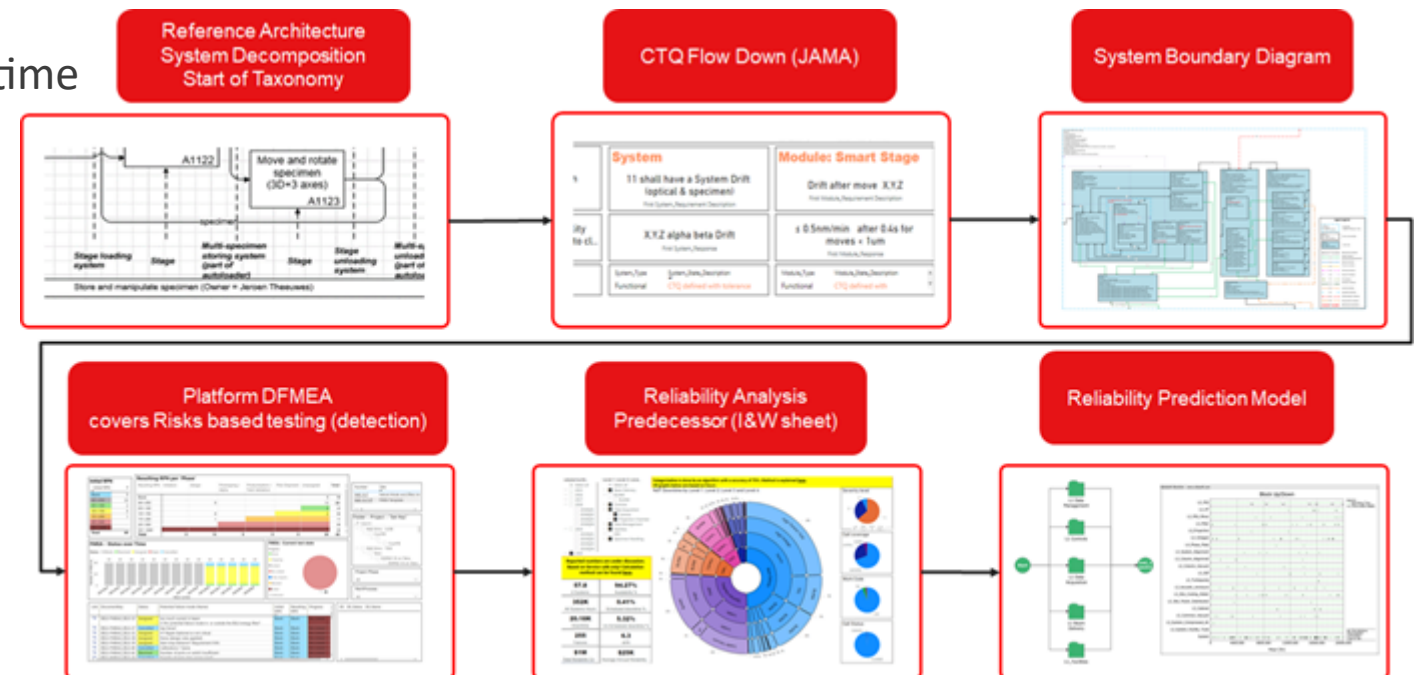
- Functional Decomposition
- System Decomposition
- Interface Specifications



MBSE – Maximizing Benefits

➤ CTQ / KPI Calculation

- Attribute model with CTQ parameters
- Extract performance based on configuration
- Reliability prediction model
- Define Customer Value at design time



Method for quantitative evaluations of functional chains

(Alexandr, 20 min)

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ESI

An initiative of industry, academia and TNO

ESI 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

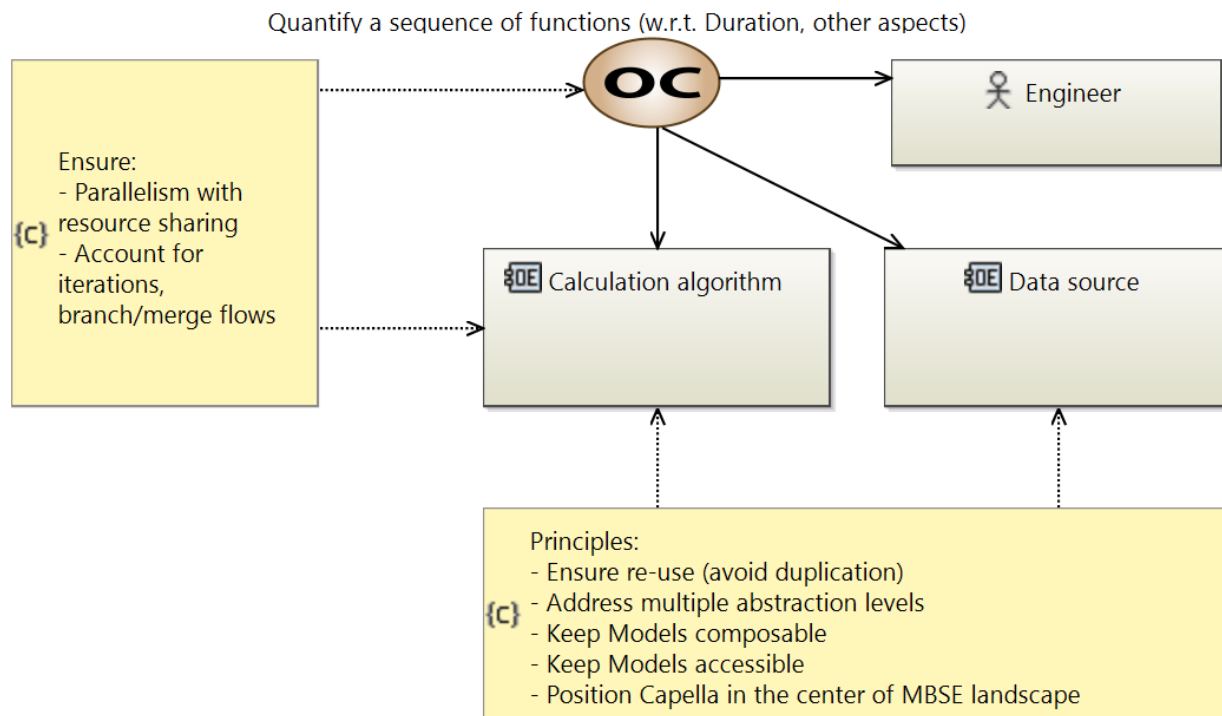
- methodologies validated in cutting-edge industrial practice

Partners



Capgemini engineering

What do we want to achieve?



Conclusion: we need simulation

Approach: Simulate functional chains in Capella

- **Why:** Natural fit to 'precedes' relation, Iteration/OR/AND nodes
- **To do:** Specify meaning of nodes, add properties

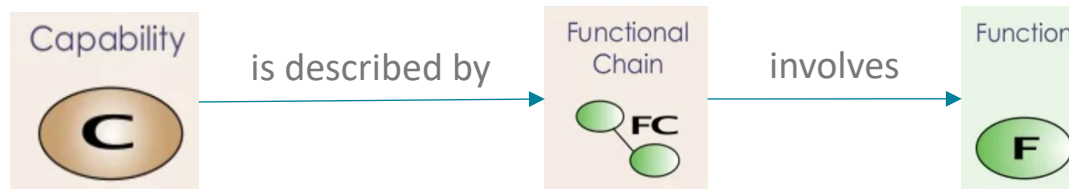
Intro to Functional Chains

Functional Chain: a specific path among all possible paths (using certain Functions and Functional Exchanges).

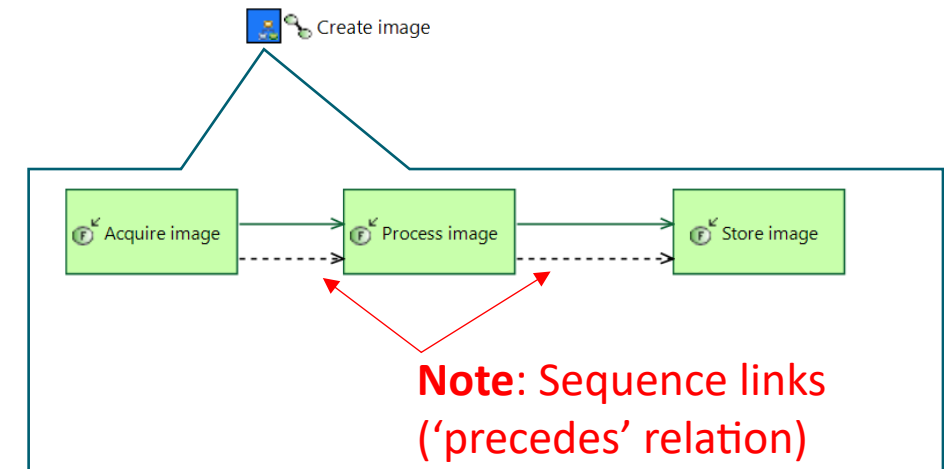
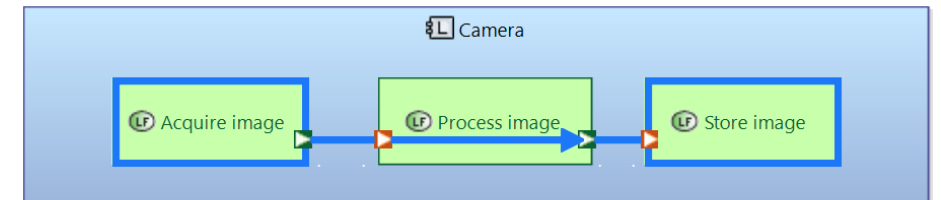
Systems Architecture Modeling with the Arcadia Method

Pascal Roques

A Practical Guide to Capella



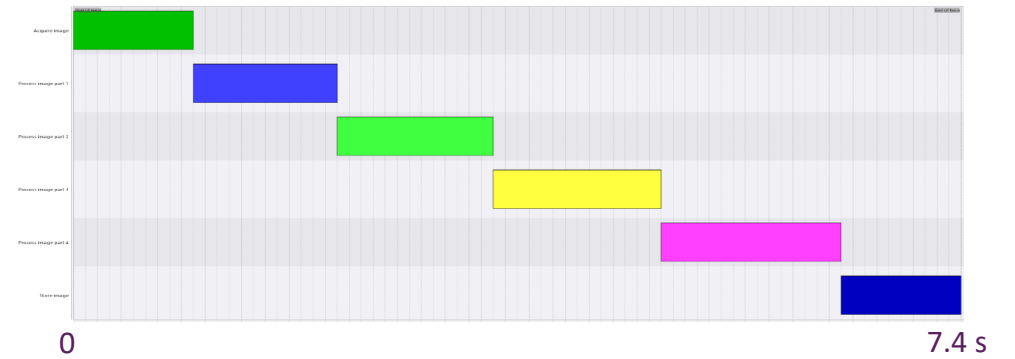
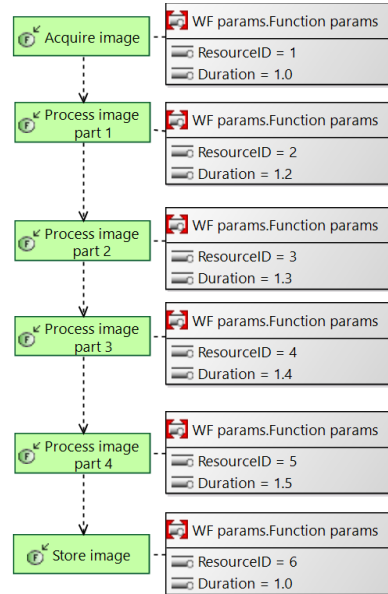
Example of a functional chain:



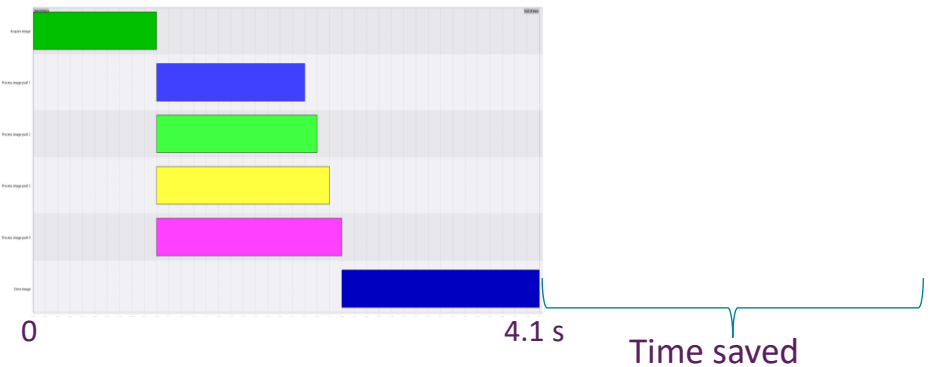
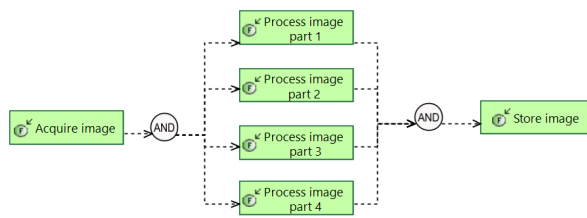
A method in a nutshell

End goal: To get quantified results of functional chains, for instance:

1



2



A method in a nutshell

Steps:

1. Create a 'simulatable' functional chain (with specific property values)
2. Export and run the chain
3. Visualize result

Used constructs:

The screenshot shows two palettes. The 'Involvements' palette has 'Function' circled. The 'Sequencing' palette has 'AND', 'OR', 'IT', and 'Sequence Link' circled.

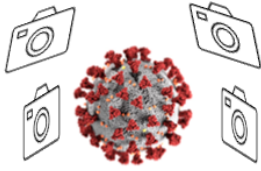
Extra parameters:

Function params		Control Node params	
Duration	1.0 s	Repetitions	10
ResourceID	Comp1	Description	
Description			

Overall architecture:



Functional chain (incl. property values)
+ rule checker

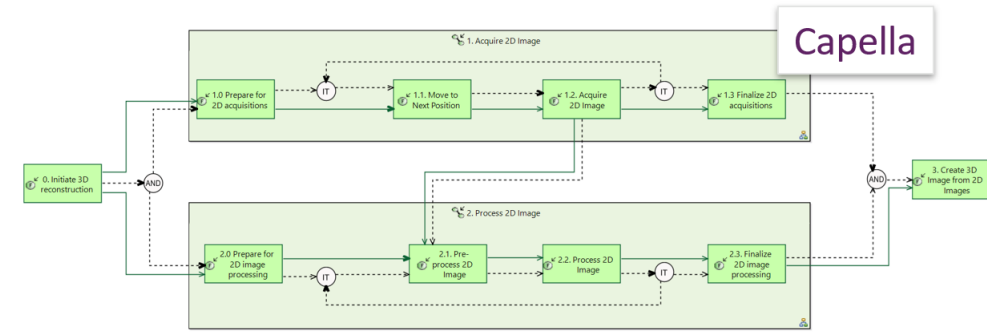


Demo: construct a 3D model out of 2D images

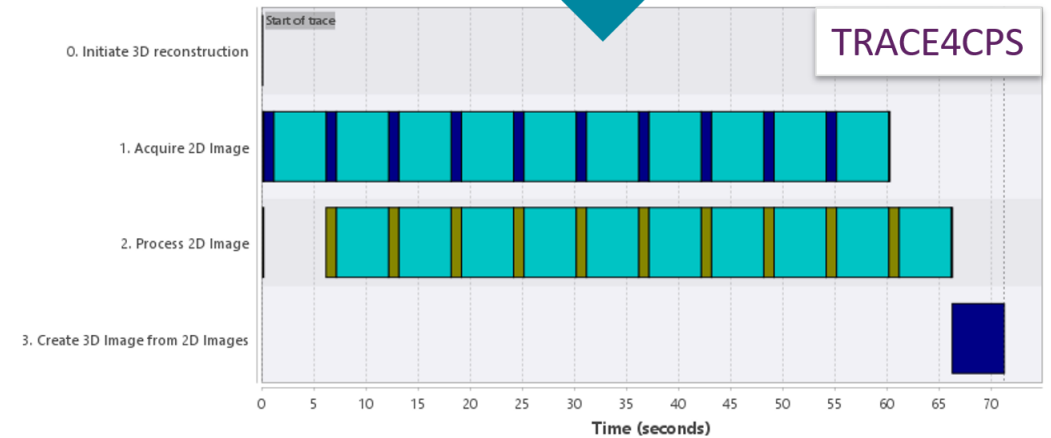
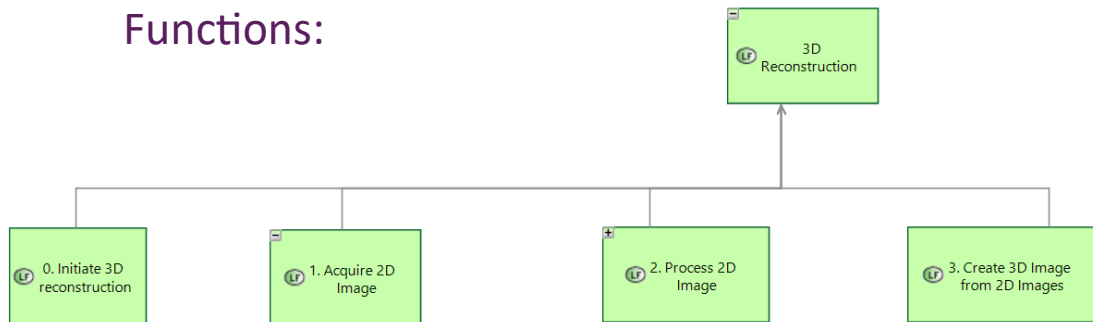
Highlights:

- A library of functional chains
- Generated graph

Overview:



Functions:



Behind the scenes

Formalized model

Workflow (element) – Graph structure (2/4)

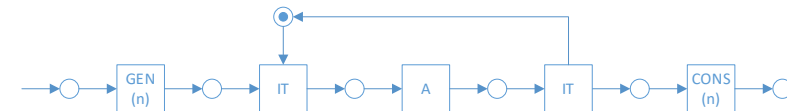
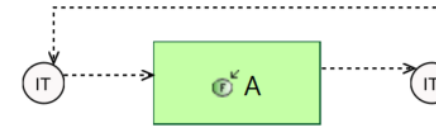
A workflow (element) $G = (N_f \cup N_c, A)$ satisfies following conditions

- N contains exactly one *START* node, i.e. a node $n \in N$ with type $t_n = START$ (or $t_n = START\&END$)
- N contains exactly one *END* node, i.e. a node $n \in N$ with type $t_n = END$ (or $t_n = START\&END$)
- The *START* node has no predecessor nodes, i.e. no incoming arcs
- The *END* node has no successor nodes, i.e. no outgoing arcs
- *INTERMEDIATE* nodes have at least one incoming and at least one outgoing arc
- Every node $n \in N$ lies on a path from the *START* node to the *END* node

Property values definition (PVMT add-on)

WF params		
Function params		
> Scope	[SYSTEM, LOGICAL, PHY...	
> Duration	floatProperty	0.0 s
Range [0.0 - 1.0E30]		
ResourceID	stringProperty	
Description	stringProperty	
Sequence Link params		
> Scope	[SYSTEM, LOGICAL, PHY...	
> Weight	floatProperty	0.0
Range [0.0 - 100.0]		
Control Node params		
> Scope	[SYSTEM, LOGICAL, PHY...	
> Repetitions	integerProperty	1
Range [1 - 1000000000]		
Description	stringProperty	

Transformations from a functional chain via Petri-net formalism to a simulation

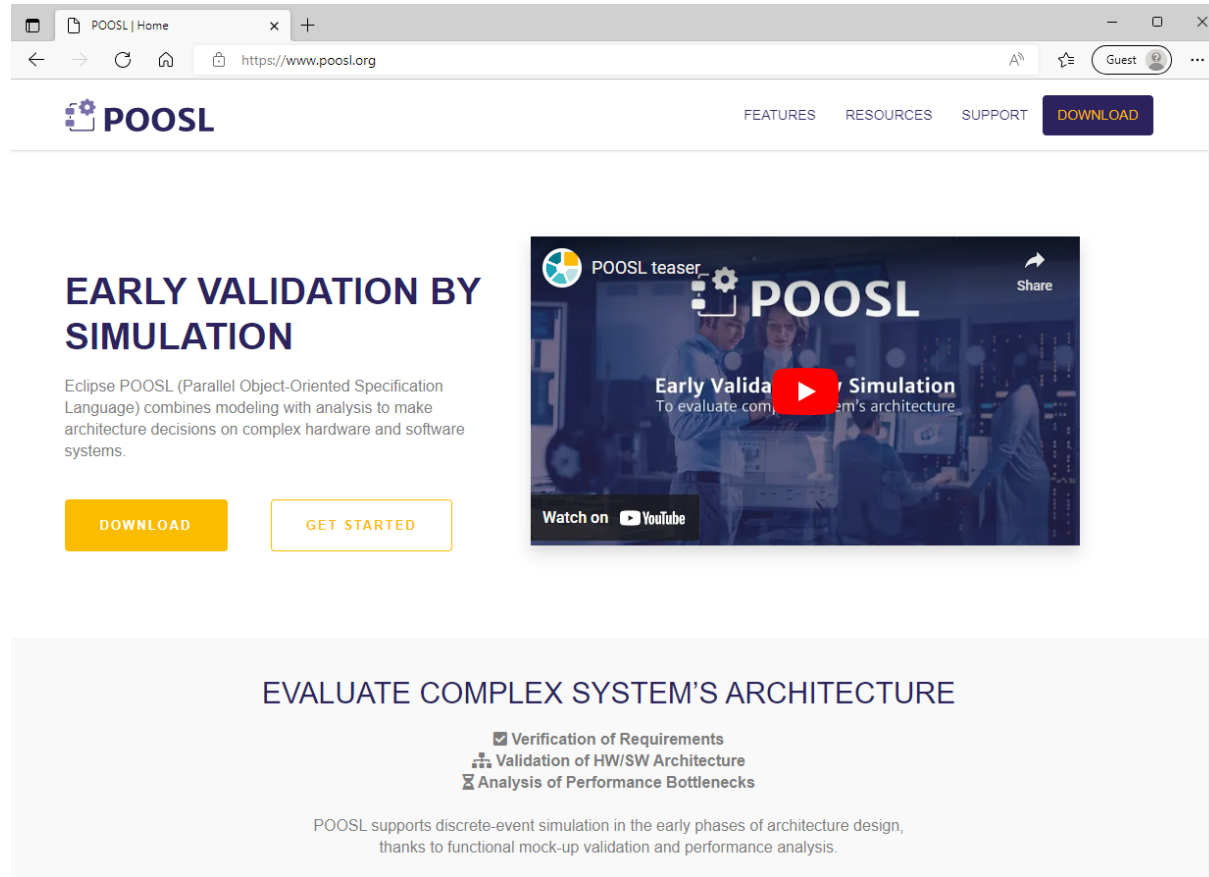


```

t6 : Transition(number := 4,
prePlaceChanges := new(Array) resize(2)
  putAt(1, new(PlaceChange) setPlace(1) setChange(1))
  putAt(2, new(PlaceChange) setPlace(1) setChange(1)),
duration := 0.0,
postPlaceChanges := new(Array) resize(1)
  putAt(1, new(PlaceChange) setPlace(1) setChange(1)),
resourcenames := new(Array) resize(1) putAt(1, "UNKNOWN"),
name := "T56",
level := 1,
levelnames := new(Array) resize(1) putAt(1, "N"),
logsize := false)
  
```

POOSL

<https://www.poosl.org/>



POOSL | Home

https://www.poosl.org

POOSL

FEATURES RESOURCES SUPPORT DOWNLOAD

EARLY VALIDATION BY SIMULATION

Eclipse POOSL (Parallel Object-Oriented Specification Language) combines modeling with analysis to make architecture decisions on complex hardware and software systems.

DOWNLOAD GET STARTED

POOSL teaser

POOSL

Share

Early Validation by Simulation

To evaluate complex system's architecture

Watch on YouTube

EVALUATE COMPLEX SYSTEM'S ARCHITECTURE

- ✓ Verification of Requirements
- ✚ Validation of HW/SW Architecture
- ⌘ Analysis of Performance Bottlenecks

POOSL supports discrete-event simulation in the early phases of architecture design, thanks to functional mock-up validation and performance analysis.

Functionality highlights:

- simulation of parallel processes,
- well-defined semantics


TRACE4CPS

<https://www.eclipse.org/trace4cps/>

Eclipse TRACE4CPS™
Version V0.1

Eclipse TRACE4CPS™ is a **customizable, domain-independent and source-independent Gantt chart viewer** with mathematically-founded analysis support. Eclipse TRACE4CPS™ supports the visualization of activities on resources as a function of time (Gantt charts), as well as the visualization of continuous signals. Eclipse TRACE4CPS™ also supports several analysis techniques to identify bottlenecks, check formally-specified (performance) properties, and analyze resource usage. A key feature of Eclipse TRACE4CPS™ is the ability to configure the identification, selection and visualization of such information to match any specific application domain.

The Eclipse TRACE4CPS™ project is currently in the [Incubation Phase](#).

 ECLIPSE
INCUBATION

Visualization and analysis of concurrent system activities

Eclipse TRACE4CPS™ helps us to understand complicated behavior over time for all kinds of systems through its domain-independent capabilities for visualizing and analyzing concurrent activities that are encoded in execution traces. Eclipse TRACE4CPS™ supports claims on resources, events, dependencies, and continuous signals.

[Figure 1](#) shows a typical Eclipse TRACE4CPS™ Gantt chart of an application that iteratively executes activities A-G. The claims model executions of these system activities and are shown as colored rectangles with a start and end time. Data

Functionality highlights:

- critical path analysis,
- customization of visualization using user-defined attributes (grouping, coloring, filtering)

Experiences

We've validate the approach through interviews and an industrial case with:

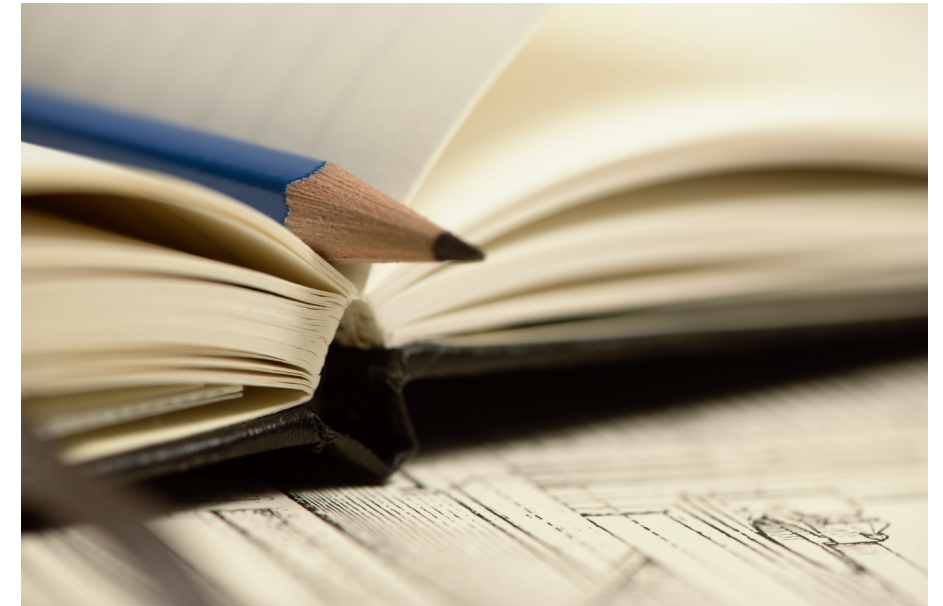
- 12 Functional chains
- 4 levels of nesting
- 3 levels of functions + set of re-usables functions
- ~35 functions (most used 2+ times)

It's **easy** to:

- explain the model to other stakeholders due to clear traceability
- quickly explore new options
- relate to Arcadia constructs (Functions, Functional chains, Components)

It's **good to remember** that:

- complexity can grow quickly, e.g.,
 - adding extra information
 - when re-using a sub-FC several times in the higher-level FC
 - potential links between Arcadia layers (e.g., to Configuration Items)
- modelers should agree on and carefully follow a modeling convention
- as with any toolchain, one shall pay attention to versioning and exceptions
- there is an entry bar to such a project: Arcadia and Capella knowledge, programming skills



Work in progress

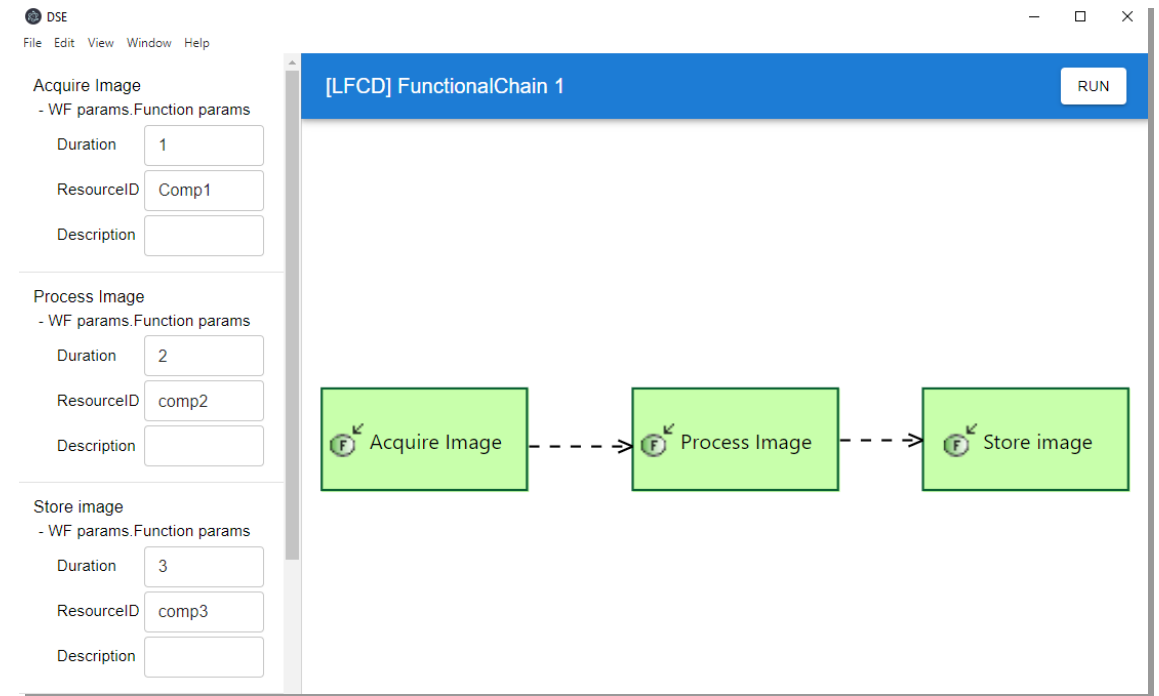


Design Space Exploration

- The user can vary timing parameters
 - min-max durations
 - iteration numbers
 - weights of conditional arcs
- Allocate functions to resources
- Defining duration as a function of involved components

Quantifying other properties (e.g., cost, reliability)

- Specifying parameters
- Exporting components for analysis using other techniques



Early example

Summary

We created a way to simulate Functional Chains with steps:

1. Create a 'simulatable' Functional chain
2. Export and run the chain in POOSL
3. Visualize result (TRACE4CPS)

To note:

- We'll write a generic report
- We consider releasing the code, subject to discussions:
 - On licensing
 - Vision of project stakeholders

Some leads:

- *Interested about MBSE and high-tech industry?*
Check ESI report 'MBSE in the high-tech equipment industry'
<https://esi.nl/news/blogs/mbse-tno-report-2022>
- *Interested in POOSL-TRACE4CPS native integration?*
Check TRANSACT project (<https://transact-ecsel.eu/>).

Conclusions

(Joost, 5 min)



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Conclusions – Solution Space

- **Proof of Concept delivered**
 - Simulation of Workflows
 - Capella Integration

- **Systems Engineering Goal**
 - Prevention of double recording of Information
 - Customer Value Maximization through design space exploration

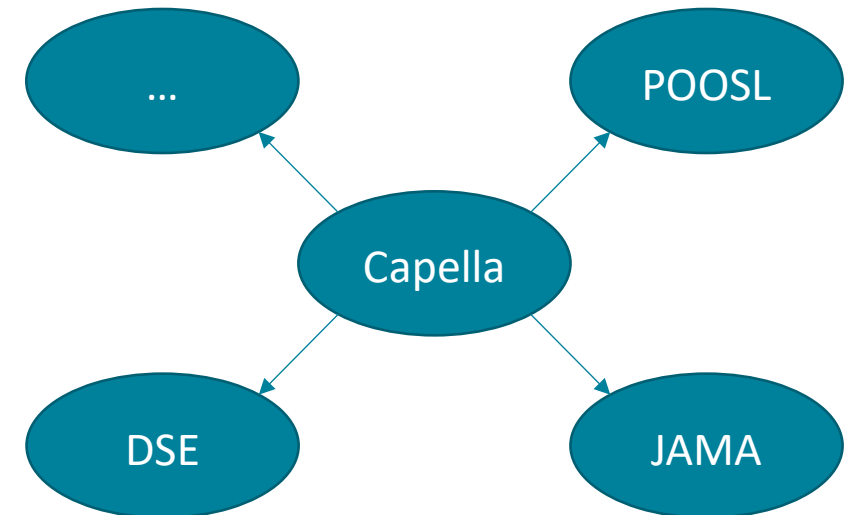
Conclusions & Next Steps

➤ Collaboration with ESI

- Short develop-review cycles
- Regular checks on the deliverables and goals
- Applying scientific methods in industry on specific cases

➤ Next Steps

- Capella Model as authoritative source of truth
- Tools that use Capella Model as input



Q&A (10 min)



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Your questions and thoughts?

Your experience on:

1. Quantitative analysis of any Capella diagram, not just functional chains
2. Simulation/analysis of functional chains in general

