OHB System AG
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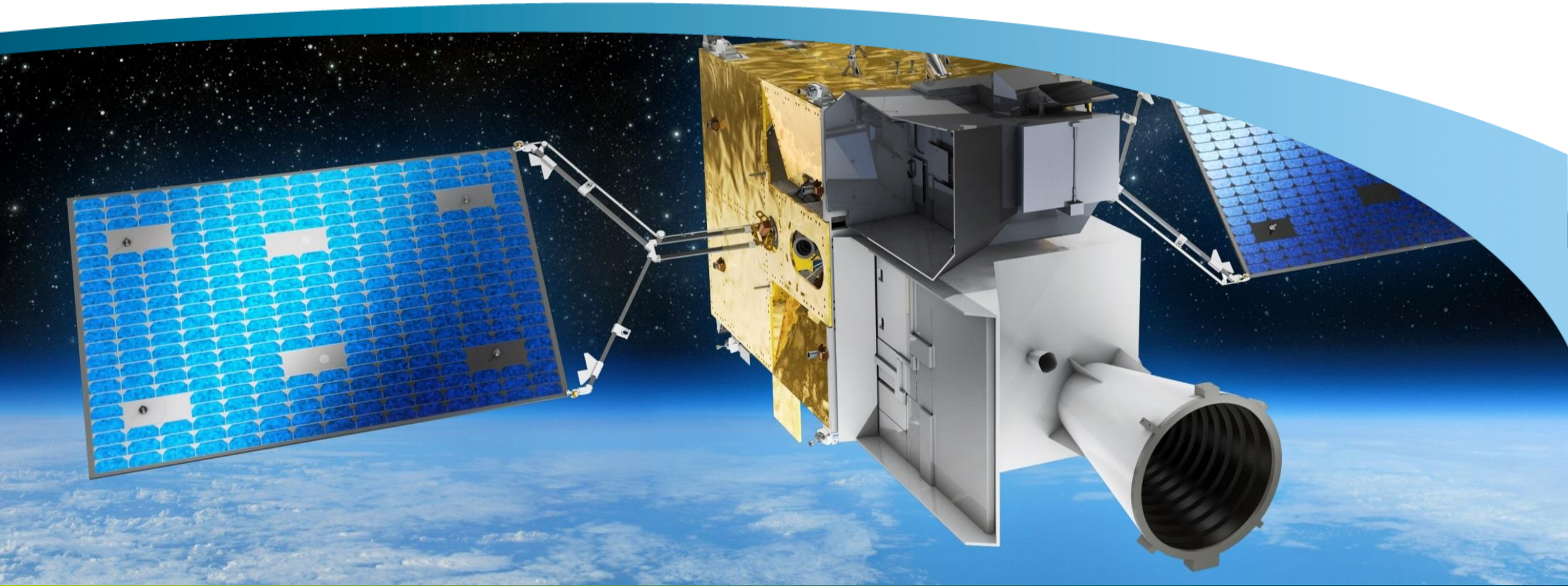
18.10.2016, ADCSS



SPACE SYSTEMS

Rationale, recent projects and future options for Model based Developments

We. Create. Space.

Agenda

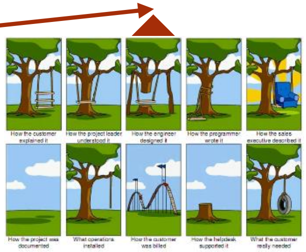
- Why (not) Model based Engineering/Development
- Application of Model Based Approaches – Recent Projects
- Studies and Long–Term Options

Why Model based Engineering

- Very brief development life cycle

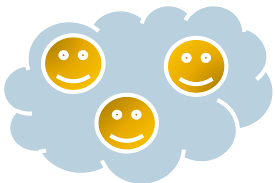
Reality

Intention



Gap:
The wrong system has been built

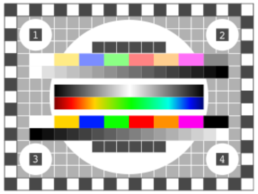
Goal:
Minimize gap



Discussion
(reveal, listen, understand …)

Natural Language Requirements

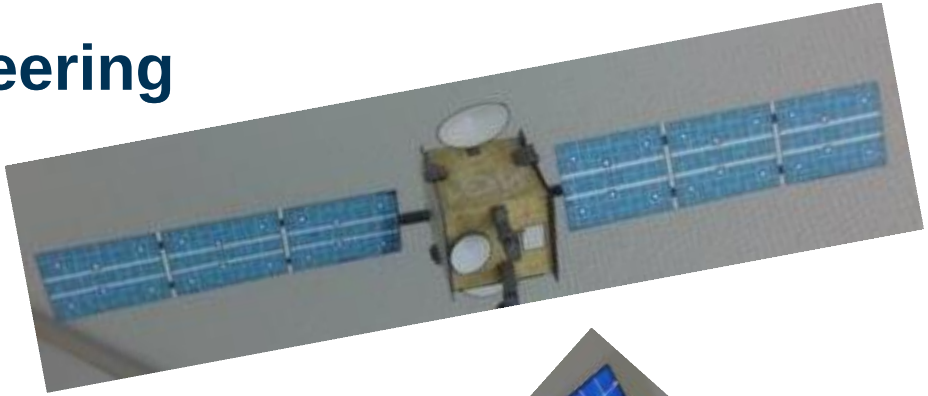
Implementation



Test,
& Verification

What we need here is:
An efficient objective alignment in the various steps of the life-cycle to support communication.

What is Model based Engineering



- This objective language is modelling
  (→ Model centric engineering)

  - Ensure a common/understanding
  - A model is a virtual representation of something
    - Interdisciplinary
    - Usually sufficiently complex
    - Contains interdependent parts

  - Example (entry) languages to : UML, SysML …

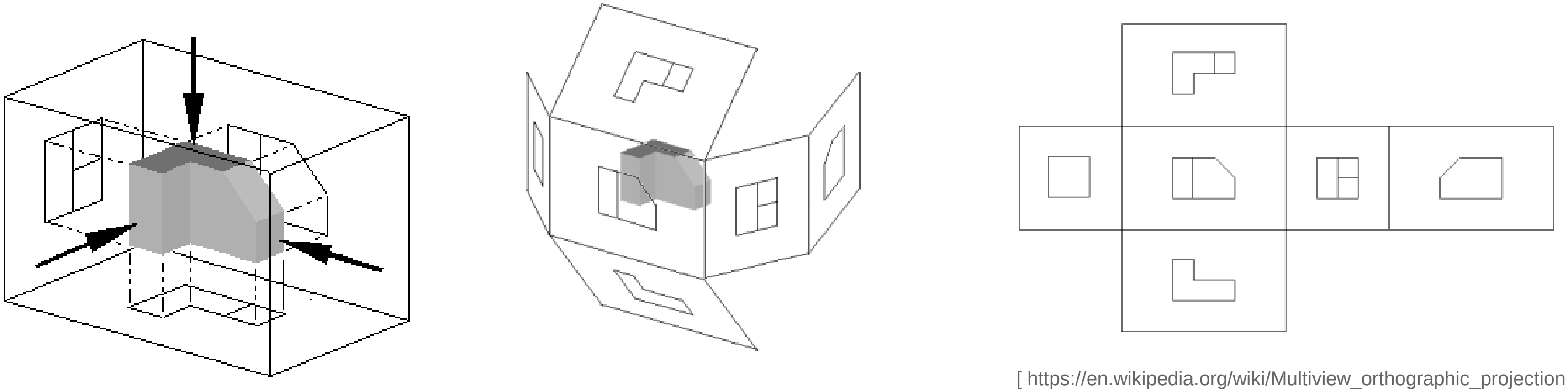
  - Different views on the same model supported
    - A view has a limited scope and purpose
    - Allows different specialists to work in their domain
    - Gather information to ease analyses and documentation

What is Model based Engineering

- Model

A **conceptual model** is a representation of a system, made of the composition of concepts which are used to help people know, understand, or simulate a subject the model represents. [Wikipedia]

- Different views of the same model



[https://en.wikipedia.org/wiki/Multiview_orthographic_projection]

So … it‘s more than just drawing UML figures

Benefits of Model based Engineering

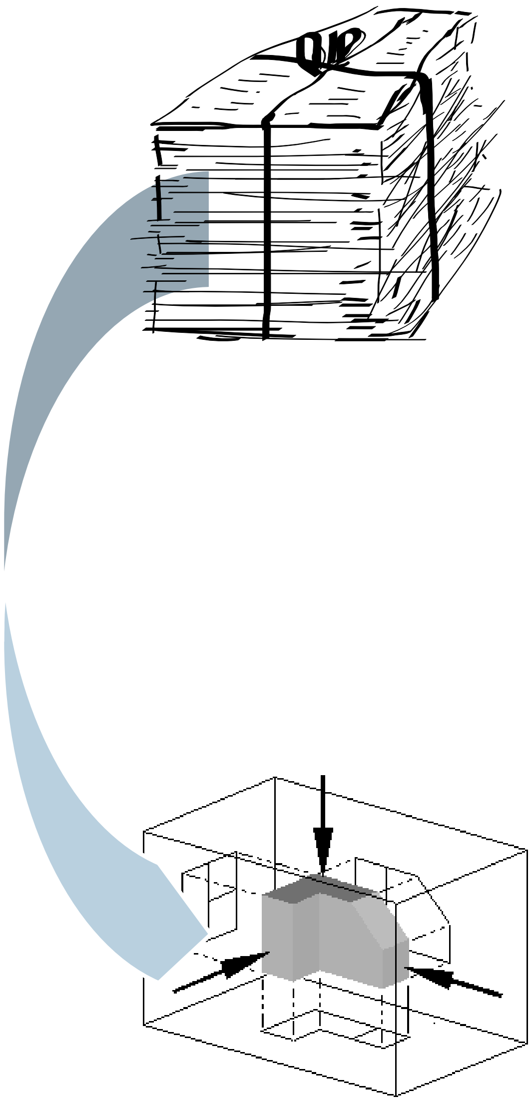
- The model is objective and has well-defined semantics
  - The model is machine-readable
  - Benefits:

    → Consistent representation of the (desired) system

    → (Parts of) the implementation can be generated

    → Checks and Analyses can be carried out on the model

    → …

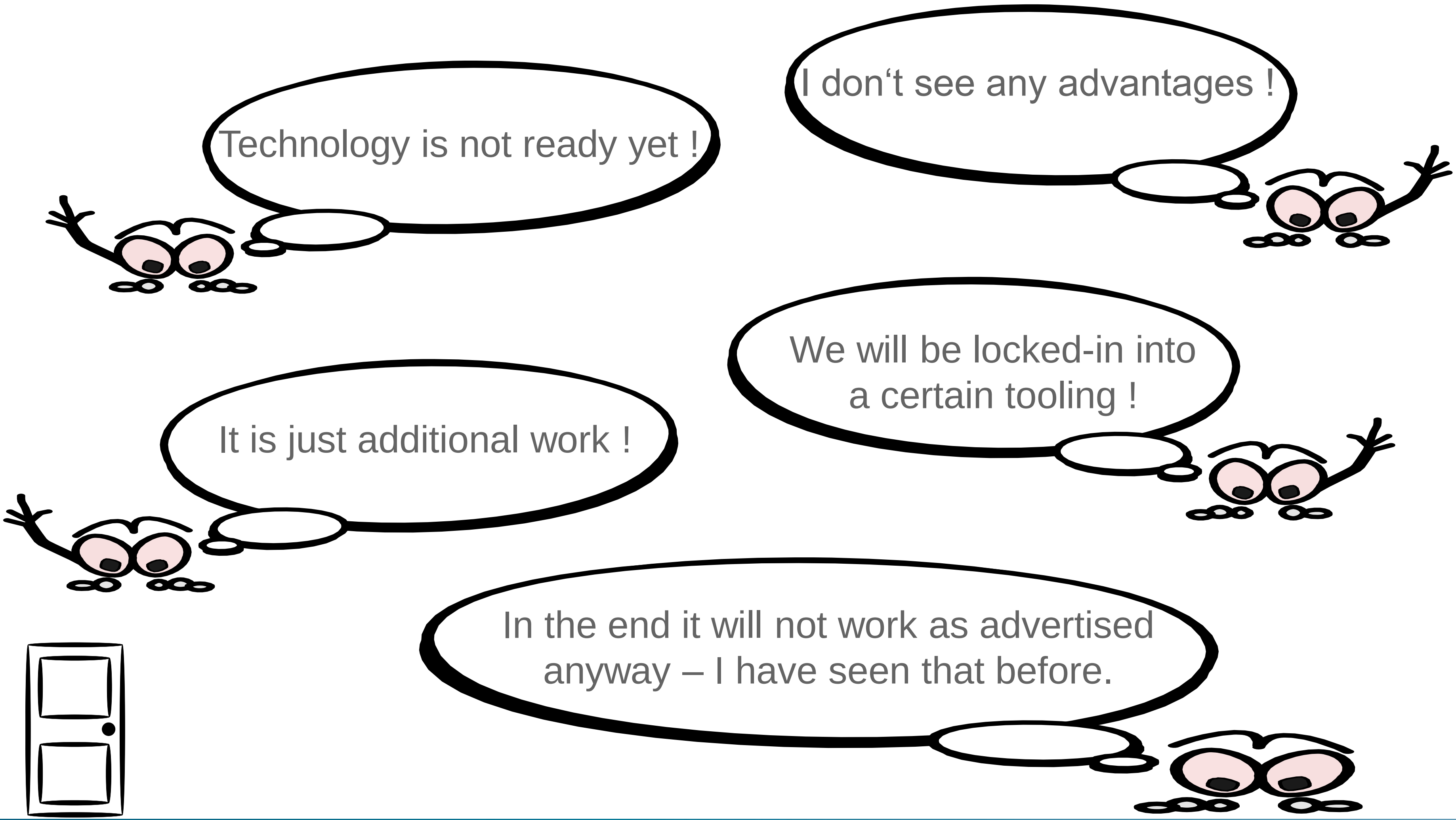


- Document based Engineering → Model based Engineering
- Diagram-centric → Model-centric "thinking"

… Where is, will and might it be useful …

- Mechanical, Thermal, Structure (MTS) Design
  - CAD tools → fully applied, virtually self-evident
  - Analyses → corrective actions → model validation
- AOCS (Algorithms are exercised on a modeled environment)
- Word Processor (Office suites …)
- …
- System Engineering (SysML …)
- Requirements Engineering
- Software
- FDIR
- Operational and Test Procedures
- Different versions for analysis/evaluation or product line variability
- …

… Real-Life Hesitance / Counter-Arguments



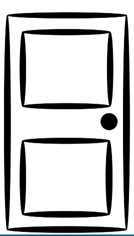
Motivations to apply model based approaches

New technology/tooling has evolved and we want to investigate it – it's model based

There is a issue which is worth analysis – define a mathematical model

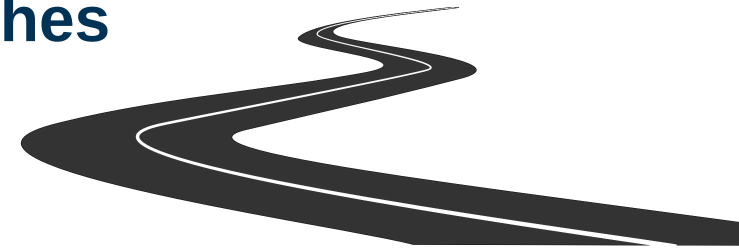
"… model based …"

In my project I have a specific challenge to master – the solution we came up with involves a model



We have learned from previous projects and want to significantly improve – so we need a solid foundation

Application of Model Based Approaches



- AOCS Algorithms and Environmental Models
- Mechanical, Thermal, Structure, Harness …
- Concurrent Engineering Facility

Avionics:

- Model Based Software Development using IBM Rhapsody in C
- Electronic Datasheets (EDS) as part of the Satellite Reference Database (SRDB)
- Valispace (Collaborative System Engineering Tool)
- Hardware/Software Codesign
- Schedulability Analysis of Flight Software

Observation:

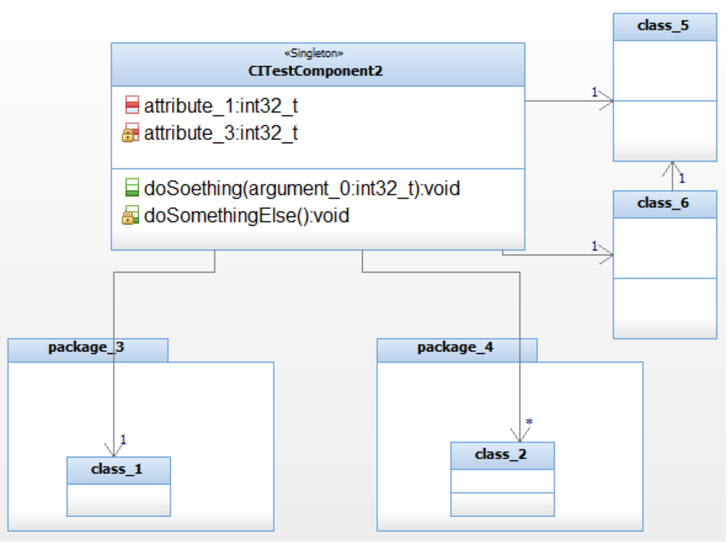
Mainly the supporters and motivators are with software background.

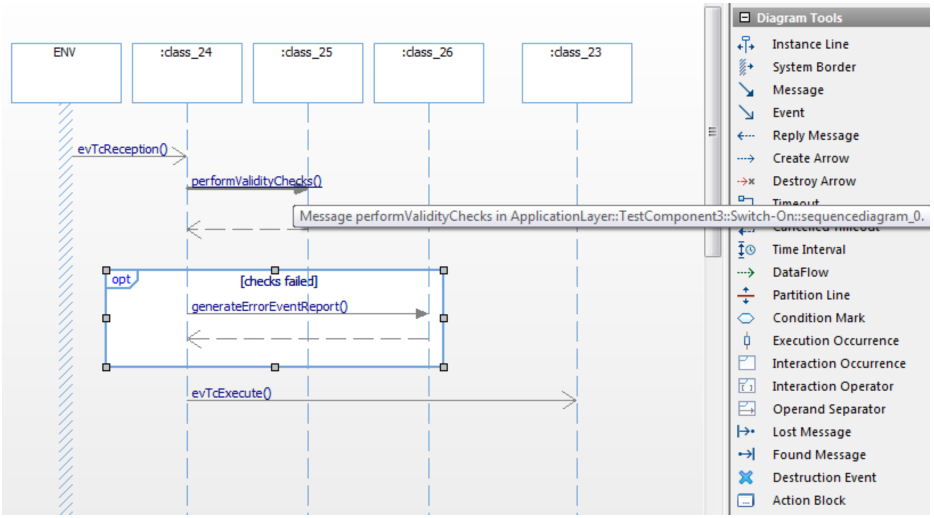
IBM Rhapsody in C

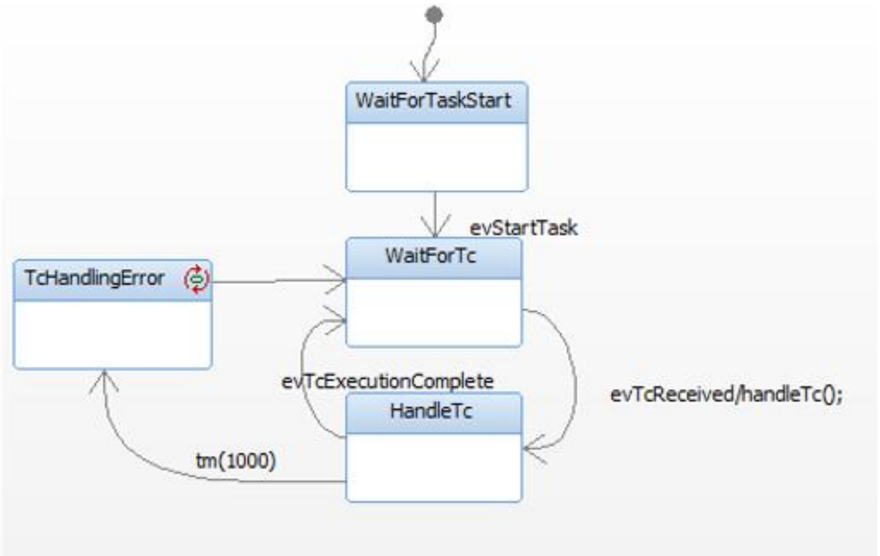
- Small GEO, Galileo, MTG

  (Approach for a common future Platform Software)

- Structural code is generated from component diagrams, state charts, sequence diagrams …
- Linking with natural language requirements in DOORS







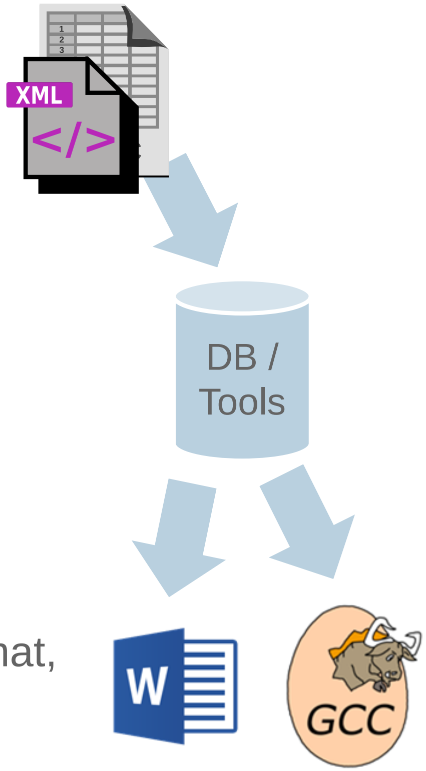
From practical experience - model based software development

- Entry Language UML / SysML
  - … is too limited
    - Need for additional domain specific elements (Attributes accessible (r/w) by ground, PUS compliant interface …)
  - … is too generic
    - An enforced restriction to established design pattern would mitigate impl. errors

  → Need to raise the abstraction level within the (space-)domain

- The “scope” of such tools is too limited to model the entire thing
  - Usually the C-level implementation is in-lined into the model
    → Functional implementation is not part of the model
  - The Exterior is not covered (avionics hardware)
    - Entire System and the deployment of the software within
    - Device Interfaces → EDS
    - …

EDS – Electronic Datasheets

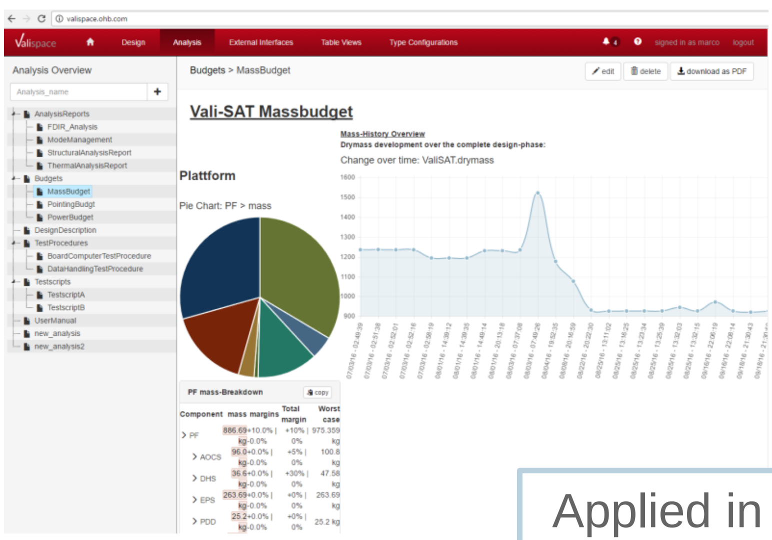


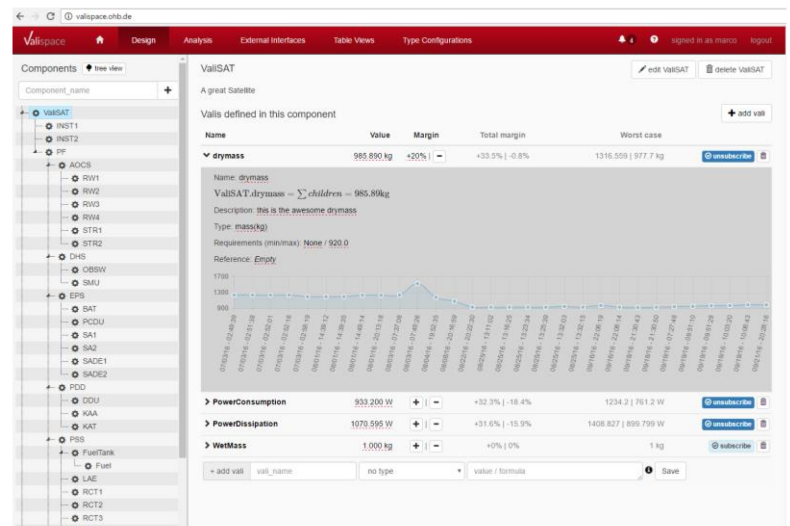
- Proprietary Approaches:
  - Based on Excel sheets
  - Based on XML
  - … reuse by different projects (to some extend)
- The issues are:
  - No Standard established
  - Supplier usually do not (correctly) provide data in the required format, resulting in additional work for the implementers
  - No elaborated model based tooling
    - Limited set of checks

    →even though it is a model we can't all the potential benefit from it

Model based Systems Engineering

- Browser based, collaborative COTS Tool for Phases A-E
- Maintains Engineering Data and Budgets
- Reports history, trends, requirement compliance
- Integrates with Word/Excel/Matlab/etc. via REST



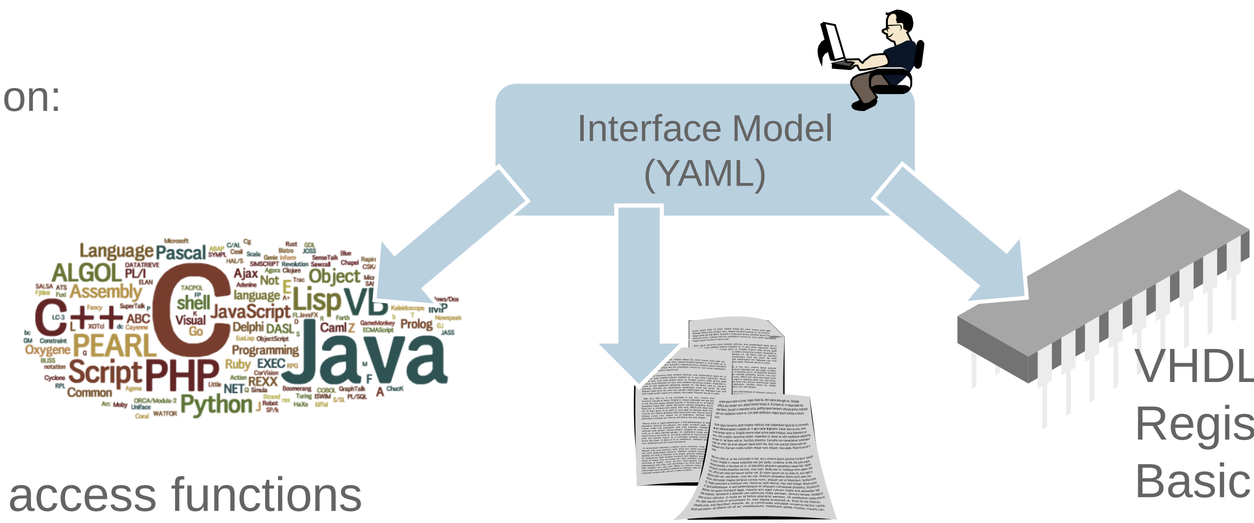


Applied in Pre-development Study – planned for C/D

Hardware/Software Codesign

- Problem:
  - Iterative Design Process between HW and SW → late design decisions
  - Precise Interface Definition needs to be communicated

- Solution:



Software access functions
Software emulation of hardware
(incl. failure injection)

Documentation
(HW/SW ICD)

VHDL interface
Register sets
Basic functionality
(reset, trigger …)

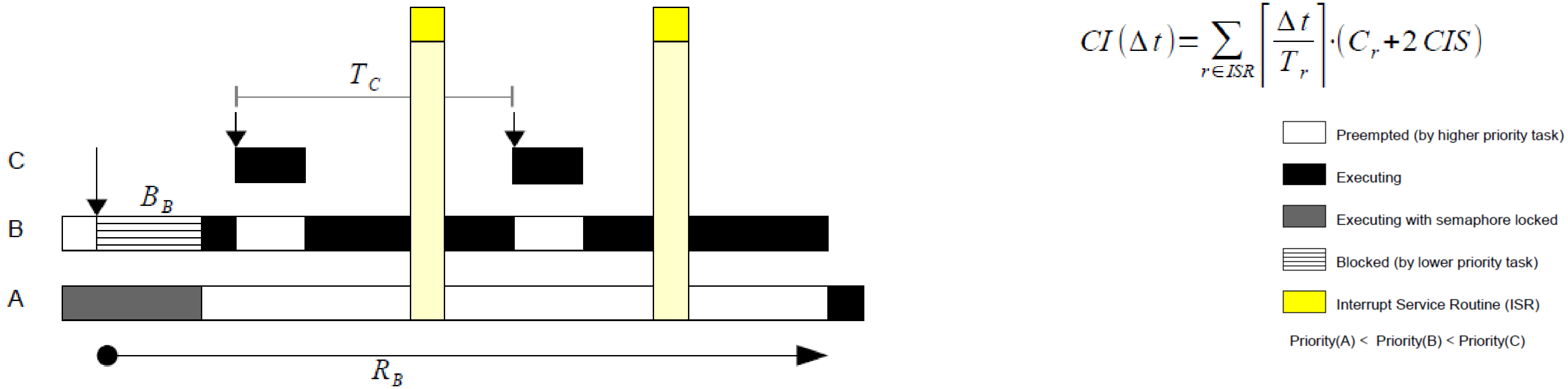
Full utilization in software and hardware development process.

Schedulability Analysis of Flight Software

- Computational Model of the Software
  - – a specific (mathematical) view of the model for timing analysis

$$R_i = CS + B_i + C_i + \sum_{j \in hp(i)} \left\lceil \frac{R_i}{T_j} \right\rceil \cdot (C_j + 2\,CS) + CI(R_i)$$

$$CI(\Delta t) = \sum_{r \in ISR} \left\lceil \frac{\Delta t}{T_r} \right\rceil \cdot (C_r + 2\,CIS)$$



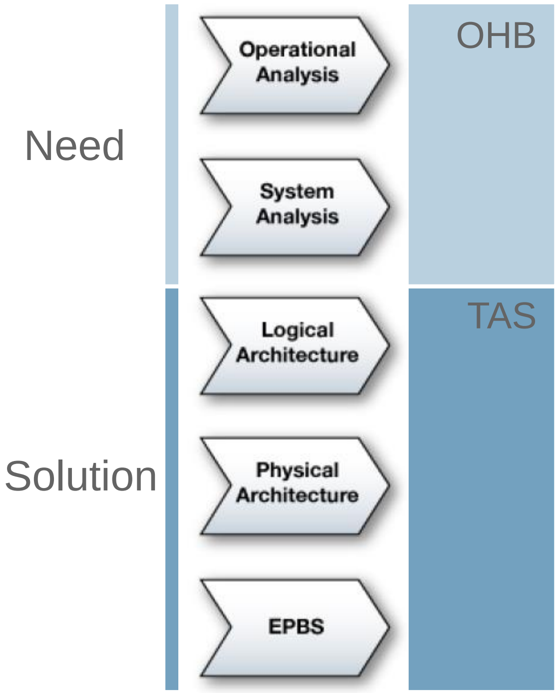
Full utilization in various commercial projects.

Ongoing Studies and Long-Term Options

- Capella in e.deorbit study (Systems-Engineering)
  - Functional Breakdown of the Mission
  - Model of Ground Segment
- Autonomous FDIR
- Model based Autonomy
- Extend the model to cover the C language

Capella used in e.deorbit study – Functional Breakdown of the Mission

- Capella implements the ARCADIA method: “Architecture Analysis and Design”



Functional Architecture described with Capella
(1) Functional breakdown of the system
(1) Functional dependencies and sequences
(2) Operational sequence diagrams
(2) Block/system diagrams
Consistency of the model checked
Derivation of functional system requirements from model

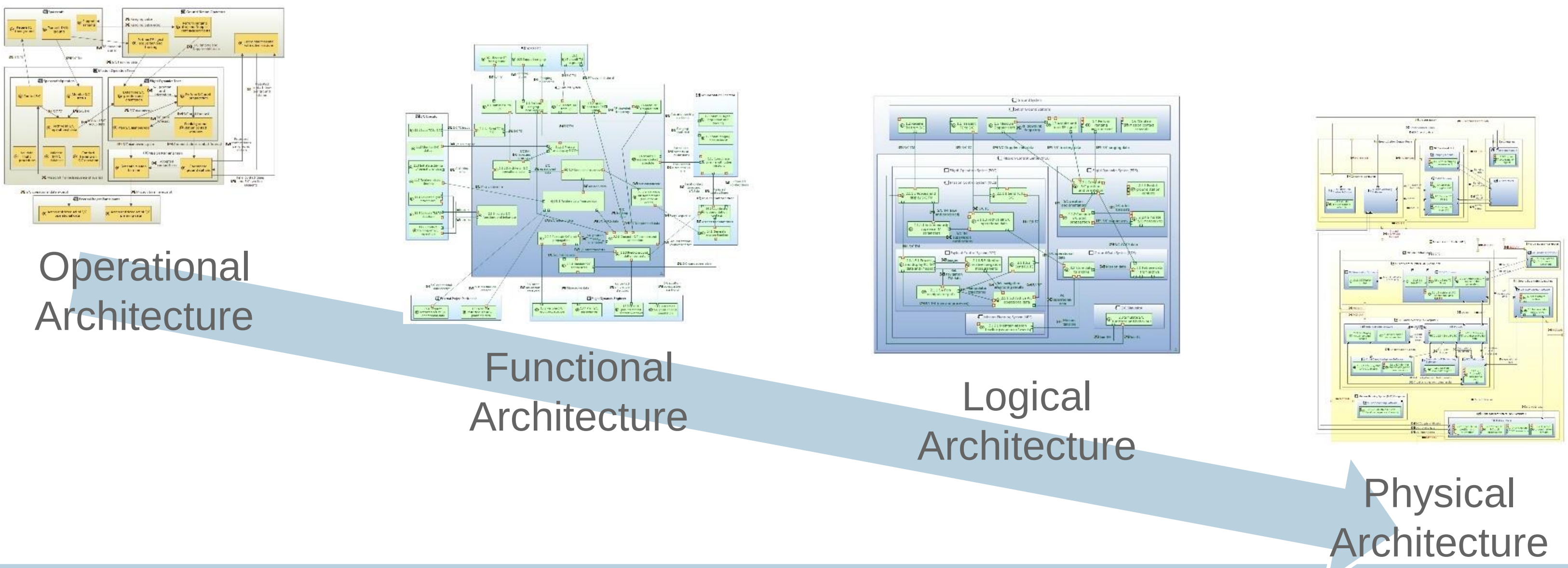
Further Refinement done by TAS
… model physical structures
… link with S/W development

Presented at SECESA, 10/2016

Capella used in e.deorbit study – Model of Ground Segment

Capella implements the Arcadia Method for model based architectural design

- Successive engineering phases by model transformations



→ Main Issues: Technical realization of tool

- Entering a model is time-consuming (proper arrangement of boxes and lines)
- Diagrams become convoluted rather quickly (when details are added)
- Modelling rules need to be obeyed (limited automatic guidance)

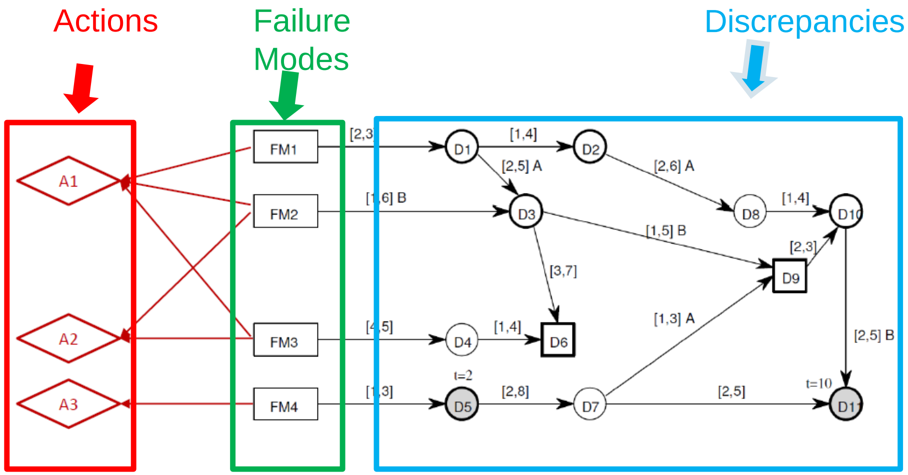
Autonomous FDIR

- (Extended) Time Failure Propagation Graph proposed as methodology for FDIR modeling
  - Model the dynamic behavior of a system when a failure has taken place
  - Formal mathematical model

  - Labeled directed graph
  - Nodes: failure modes (fault causes) and discrepancies (anomalous conditions)
  - Edges: model propagation of failures, annotated with condition and timing

- Extensions
  - Recovery actions
  - Sustainability time limit
  - Observability

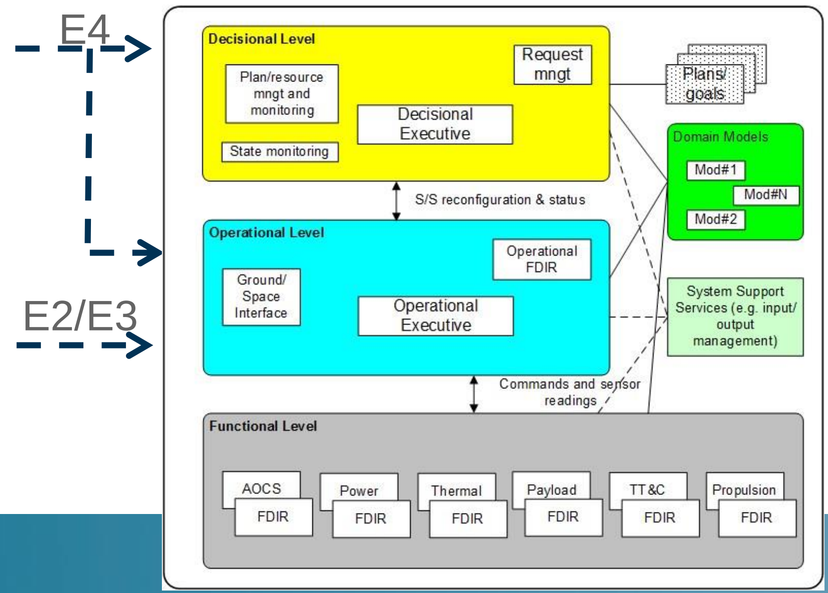
- Applications
  - Documentation and Analysis
  - Assist Development
  - Support Operations



Model based Autonomy – Study

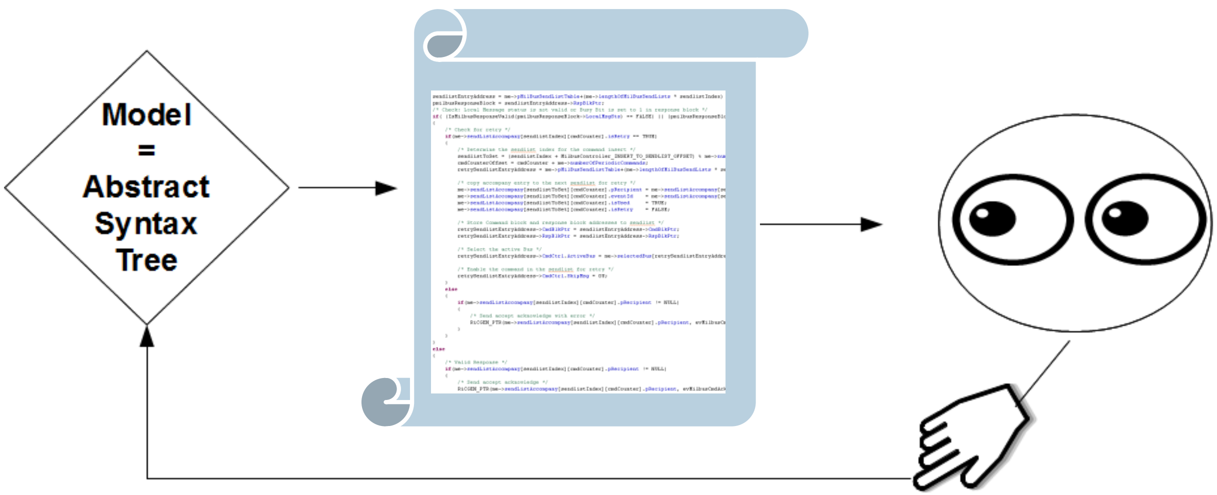
- Spacecraft autonomy: migration of functionality from the ground segment to the flight segment
- Different levels of spacecraft autonomy (ECSS-E-ST-70-11C – Space Segment Operability) based on factors such as mission types, mission objectives, operational concepts
  - Level E1: Flight Control Procedure (ground based)
  - Level E2: Mission Timeline
  - Level E3: OBCP
  - Level E4: Execution of goal oriented mission operations onboard

- Reconfiguration (decisional level) modelled via a Markov Decision Process (MDP) framework (→ mathematical model)
- MDP based approach for spacecraft autonomy at operational level



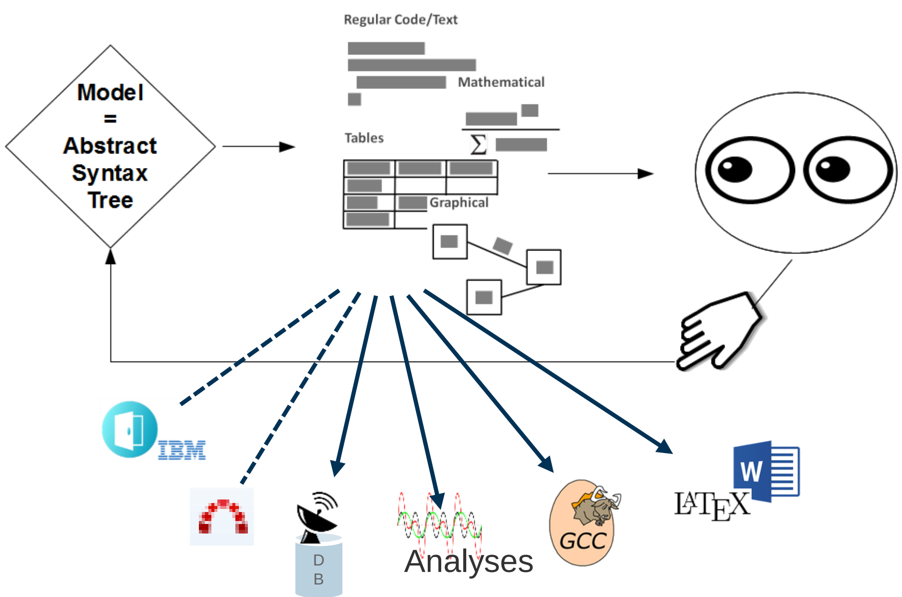
Extend the model to cover the C language

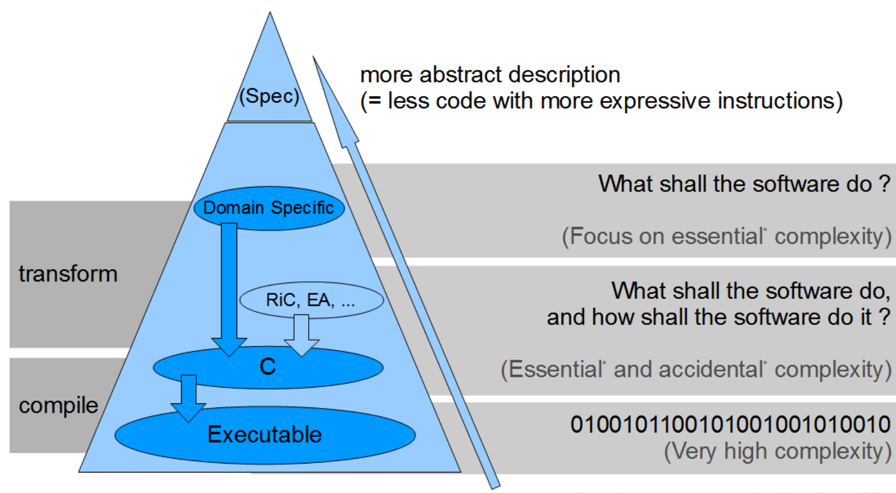
- From Lessons Learned in model based flight software development:
  - The C-level implementation is in-lined into the model → technically unrelated
  - Domain specific abstractions are missing
- Solution
  - C Language is implemented with a model based technology
    → A Domain Specific Language that looks like C and behaves like C
  - Blur the border between modeling and implementation **(Model == S/W Implementation)**



Extend the model to cover the C language

- Augment the C language with domain specific extensions
- Raise level of abstraction, respecting domain specific needs (Flight-, Simulator-, Ground- S/W)





* Essential and accidental complexity as identified by Frederick P. Brooks in 1986, „No Silver Bullet – Essence and Accidents of Software Engineering“

Summary and Vision

- There are a lot of model based activities ongoing with different approaches and intentions.

  → We need to integrate the various approaches for even better results.

- We see a strong tendency towards **model based** and **(domain) specific** tooling
  - Increasing Complexity is mitigated by
    - Shifting domain specific knowledge into the tooling
    - Specific and limited views on the model
  - Models enable
    - Single source paradigm (up-to-date documentation, configuration …)
    - Formal checks (verification, plausibility …)

- In most cases the technology (engaged) is not yet capable to deliver all the advantages that theoretically can be drawn from model based approaches.

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Thank you !

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