GPDIS 2024 MBSE Workshop

On MBSE, V-model, digital thread, digital twin and all that with design languages

Graph-based Design Languages and Design Cockpit 43®

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workshop concept (1 of 2)

theory and methodology analysis

- (no) digital consistency of models
- (no) digital continuity of processes
- (no) digital interoperability of software tools

graph-based design languages

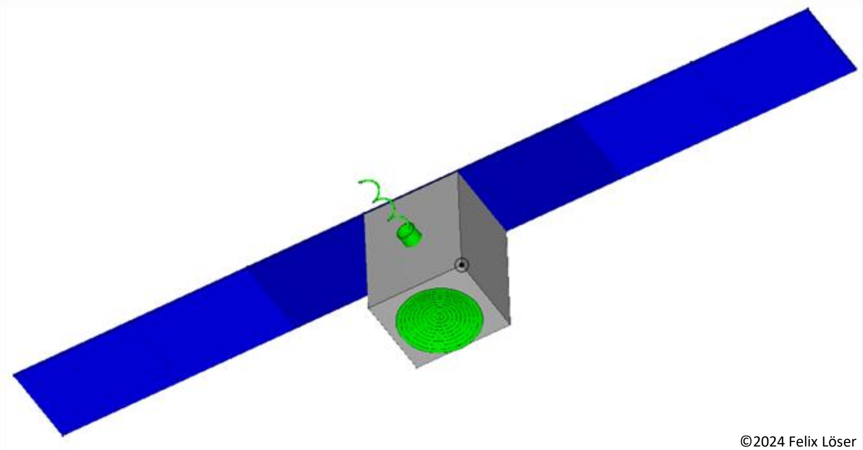
- vocabulary (object-oriented analysis) for
- ontologies (class diagrams)
- model-transformations (M2M, M2T) for rules
- programs (activity diagrams)
- design graph (knowledge graph)
- model generation (DSLs)
- requirements formalization, mapping, tracing

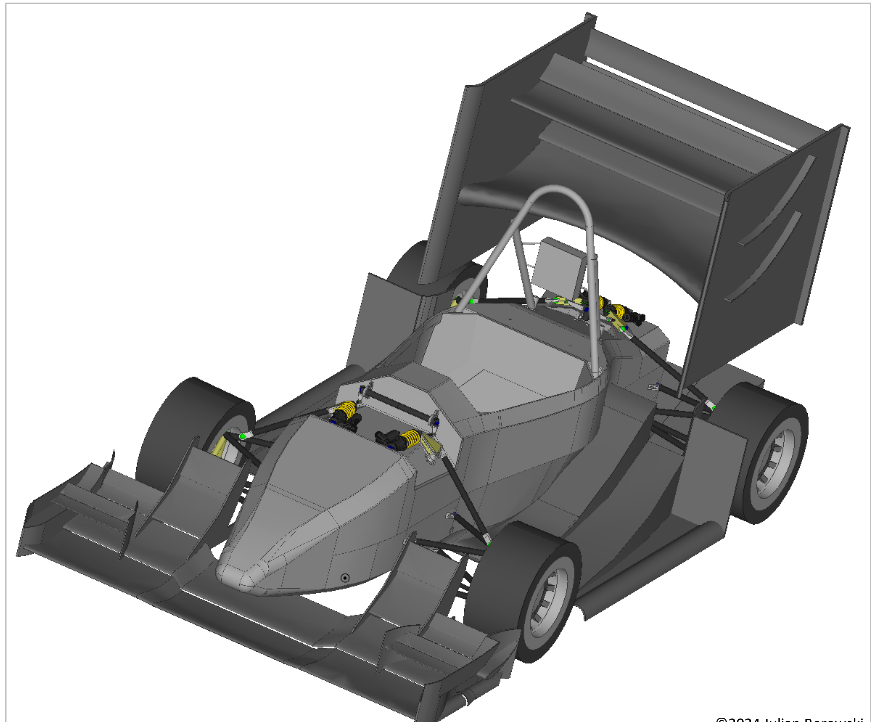
application and use cases

- SMAD book (Space mission analysis and design, by Wertz et al. 1996), 1000 pages
- FORMULA student 2023 (requirements document), 131 pages

open discussion rounds

- digital twin, knowledge graphs, …
- digital thread, OEM-supplier cooperation, …





workshop concept (2 of 2)

tentative schedule (duration 2 hours)

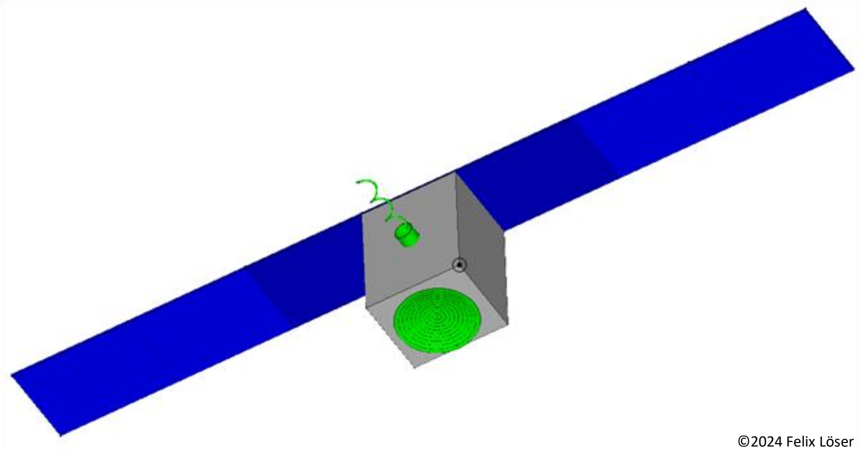
00:00 introduction to modeling using graph-based design languages (20 mins)
by Stephan Rudolph, University of Stuttgart, Germany

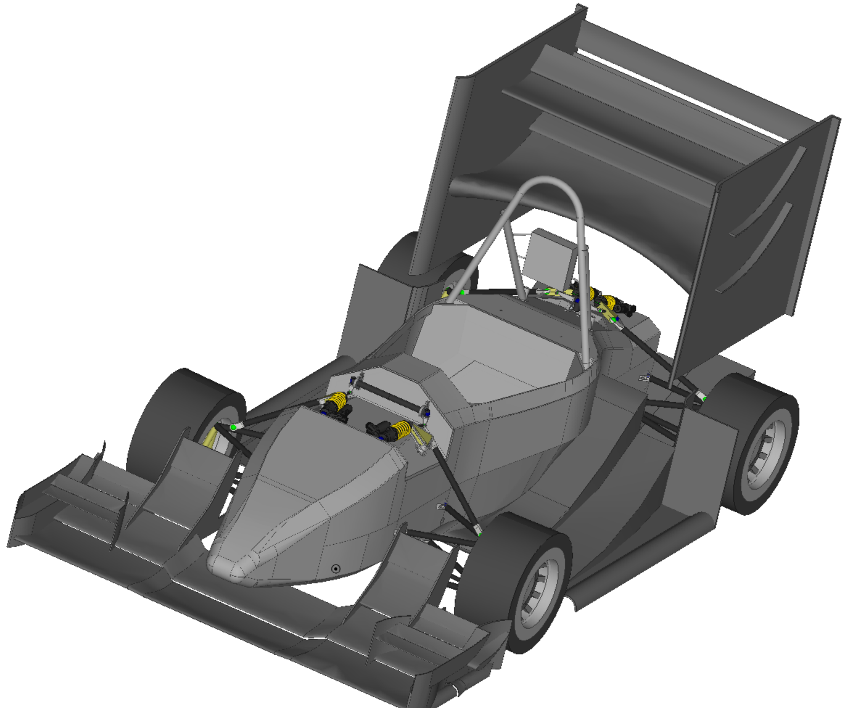
00:20 “live” modeling and simulation session of FIRE-SAT (45 mins)
power subsystem using graph-based design languages.
Content is based on the chapter 11.4 (about 3 pages,
with about 90 sentences) of the SMAD-Book (Space
Mission Analysis and Design, by Wertz et al, 1996)

01:05 digital twin modeling, generation and simulation (40 mins)
of a FORMULA Student racing car using graph-based design languages,
Detailed analysis of 5 subsystems: electrical energy system, spring and
damper, suspension system, brake system, aerodynamics, …

01:45 scientific summary of workshop topics (15 mins)
from the graph-based modeling perspective

02:00 end

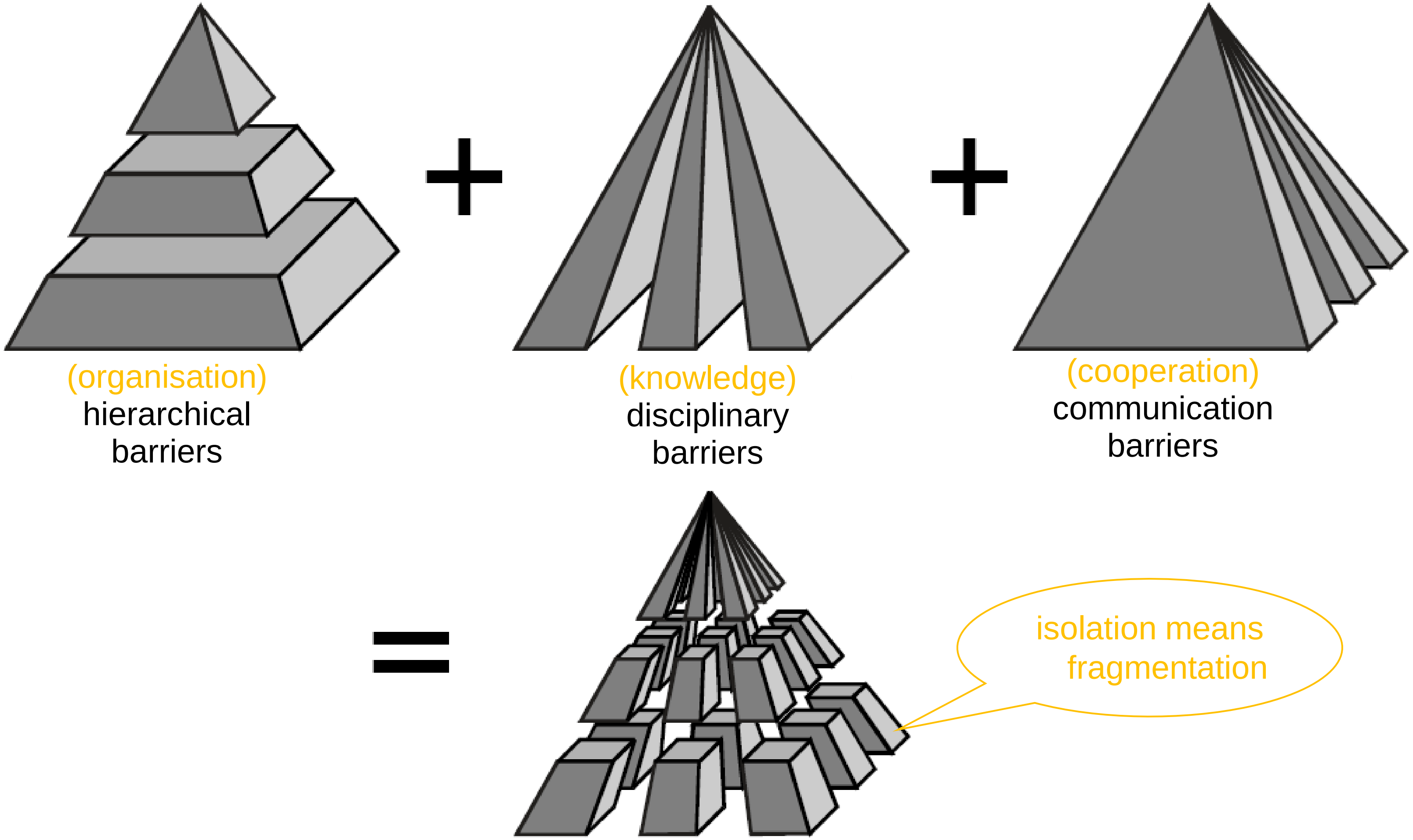




digitalization means

digital consistency (of data), digital continuity (of processes) and digital interoperability (of tools) along the PLC

origin knowledge islands and data lakes



fragmented data (i.e. data lakes)
and knowledge islands

…. adapted from
Probst et al. (1997)

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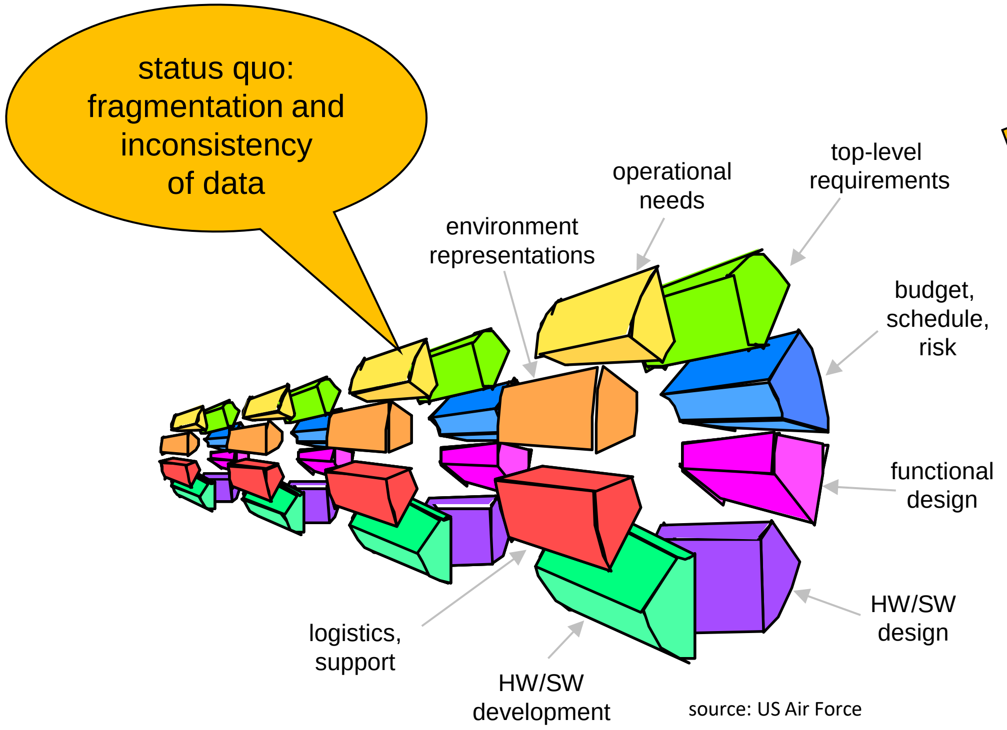
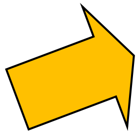
handling knowledge islands and data lakes

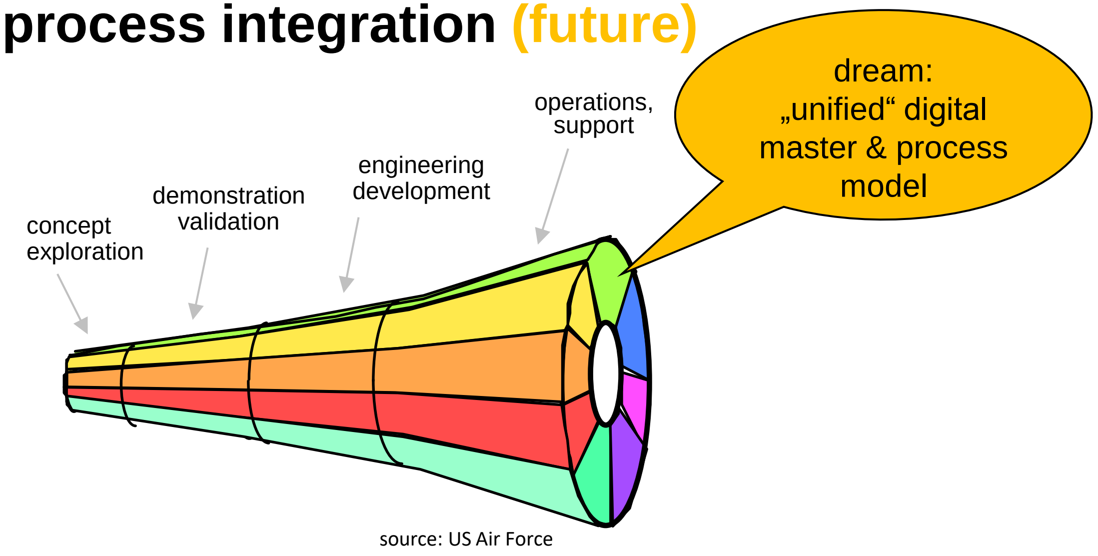
data fragmentation (today)

- limited data consistency
- limited tool interoperability
- limited scope, scalability
- ….





process integration (future)

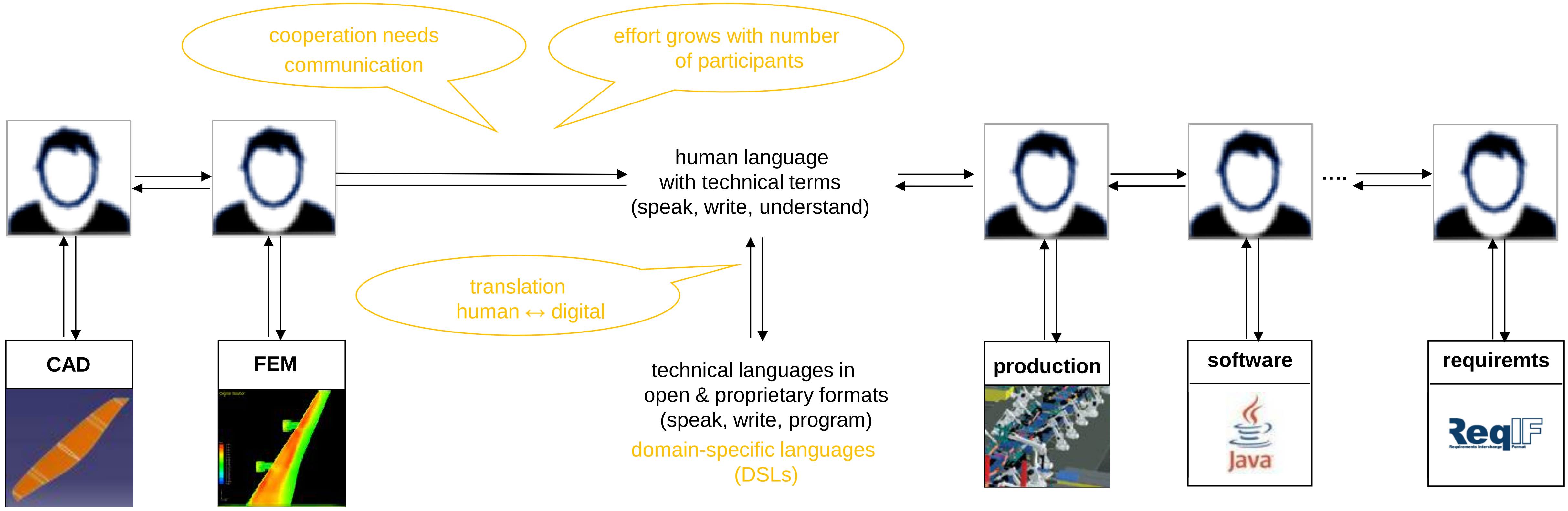


engineering dream (future)

– collaborative/concurrent handling across different disciplines/distributed sites
– snapshots of system status across engineering/business/information domains
– complete, integrated view of system
– integrate major standard engineering tools
CAD (CATIA V5/V6, …), MBS (ADAMS, …), FEM (ABAQUS, …), …
CFD (STAR-CCM+, …), thermal analysis (SINDA-G,…), controls (MATLAB), …
– understanding/processing by human and machine

handling knowledge islands and data lakes

static view
(process loops missing)



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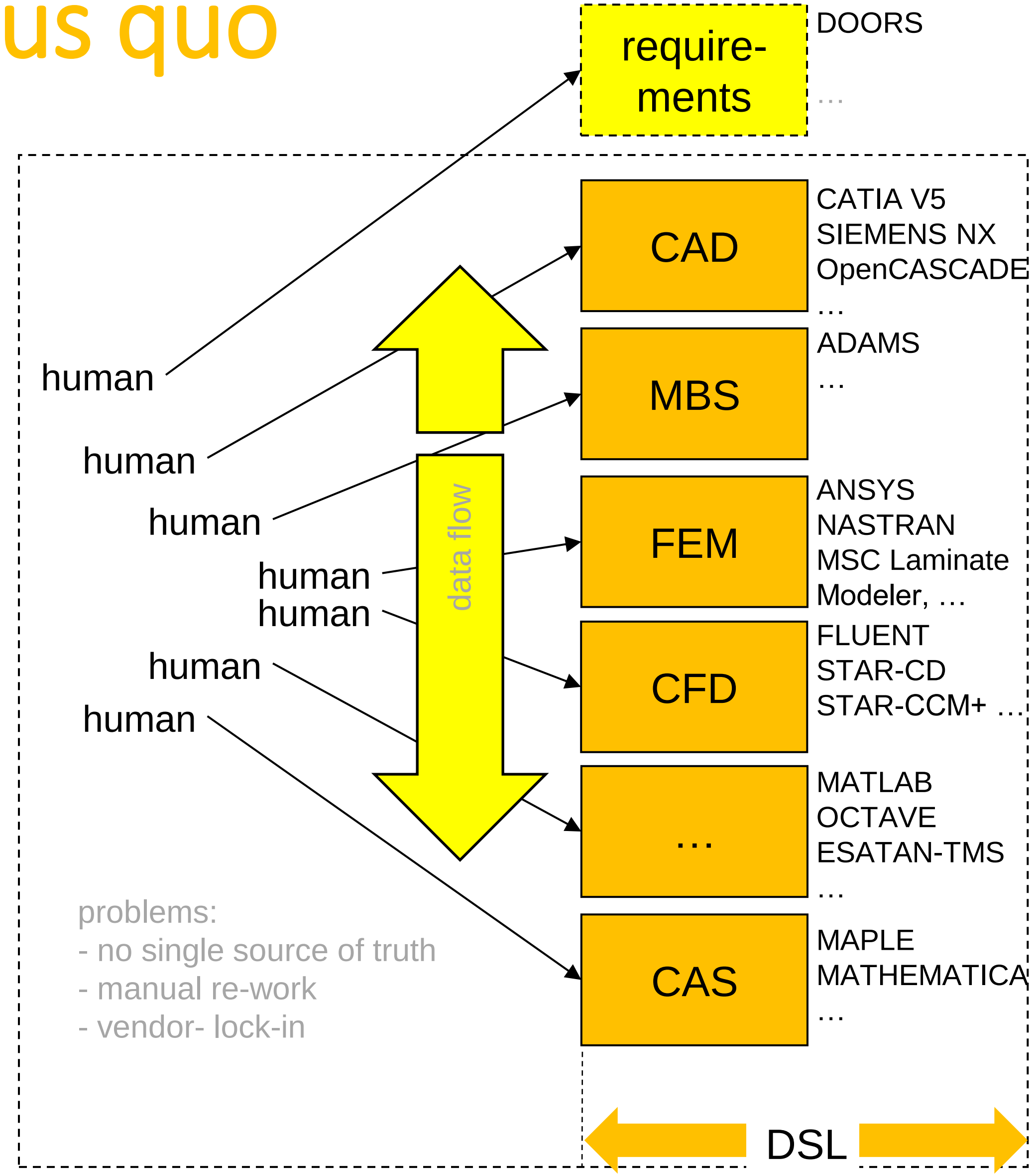
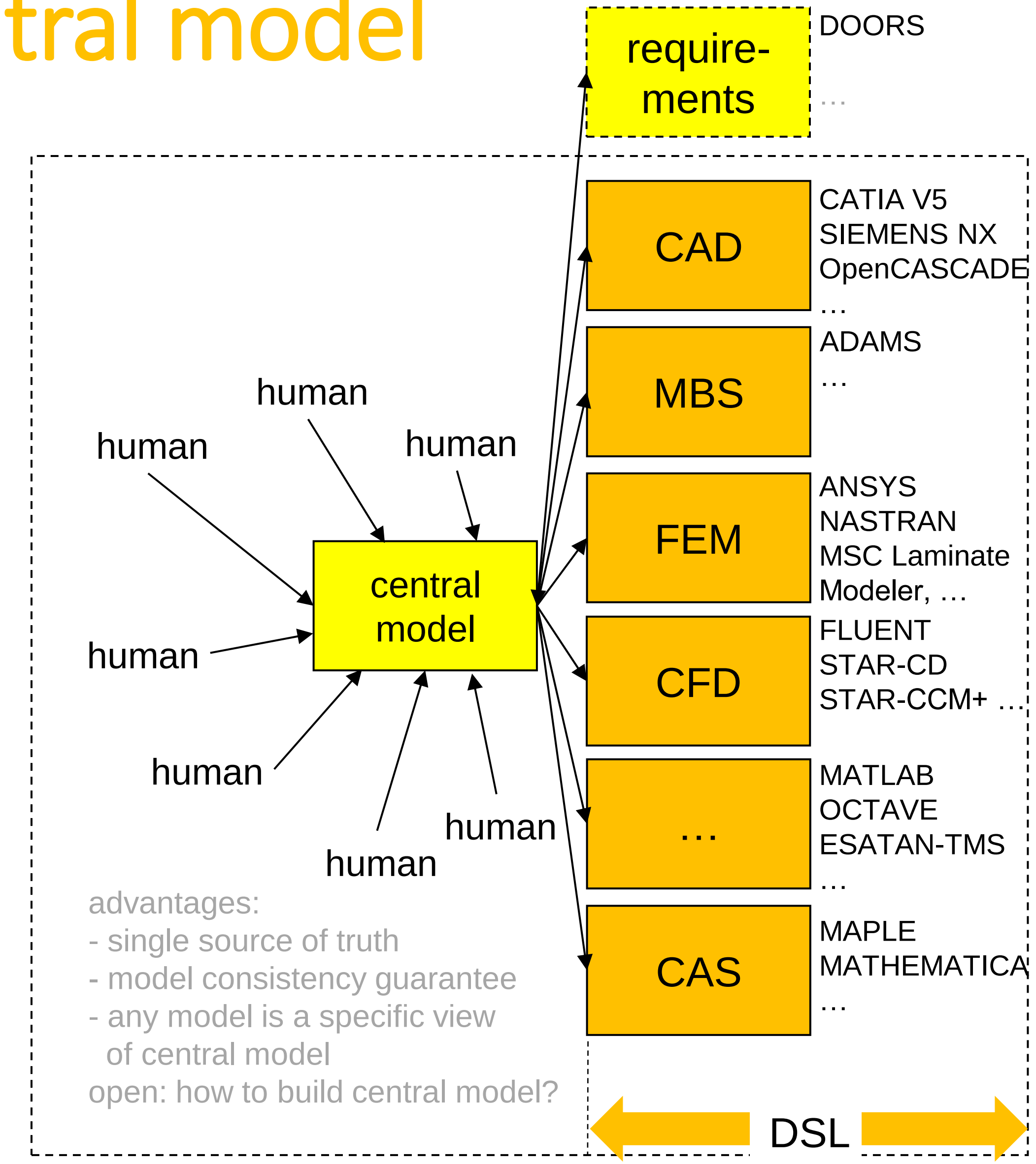
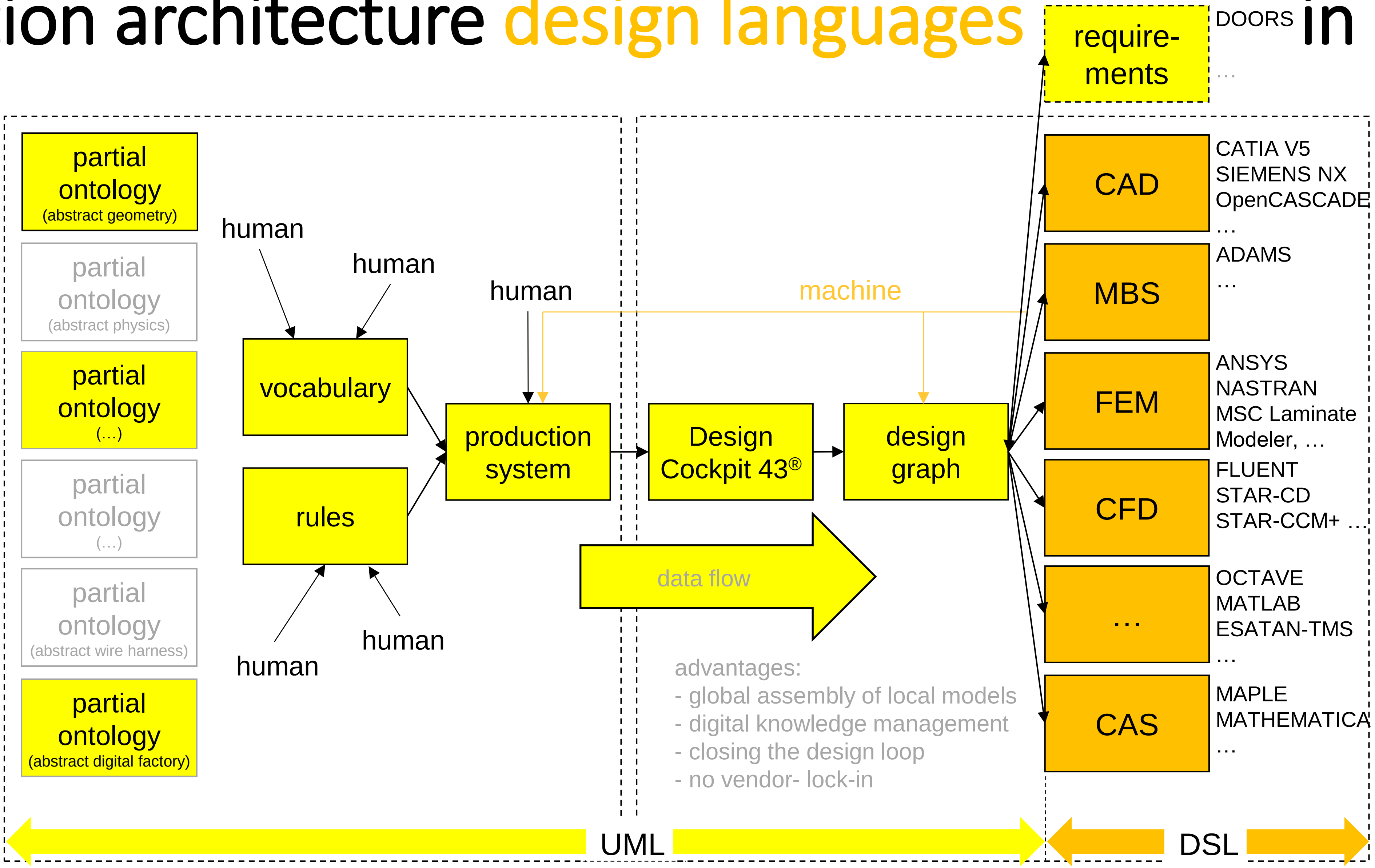
information architecture status quo



information architecture central model

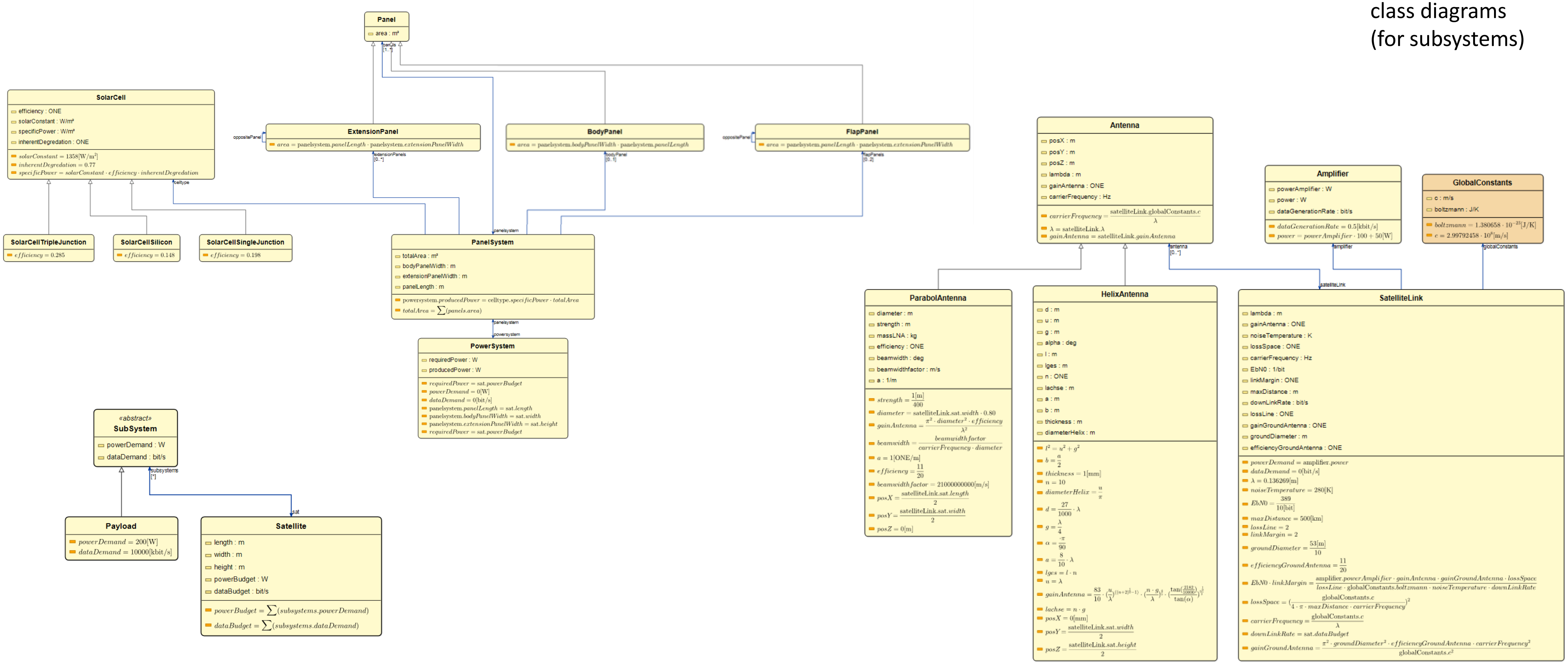


information architecture design languages in DC43®

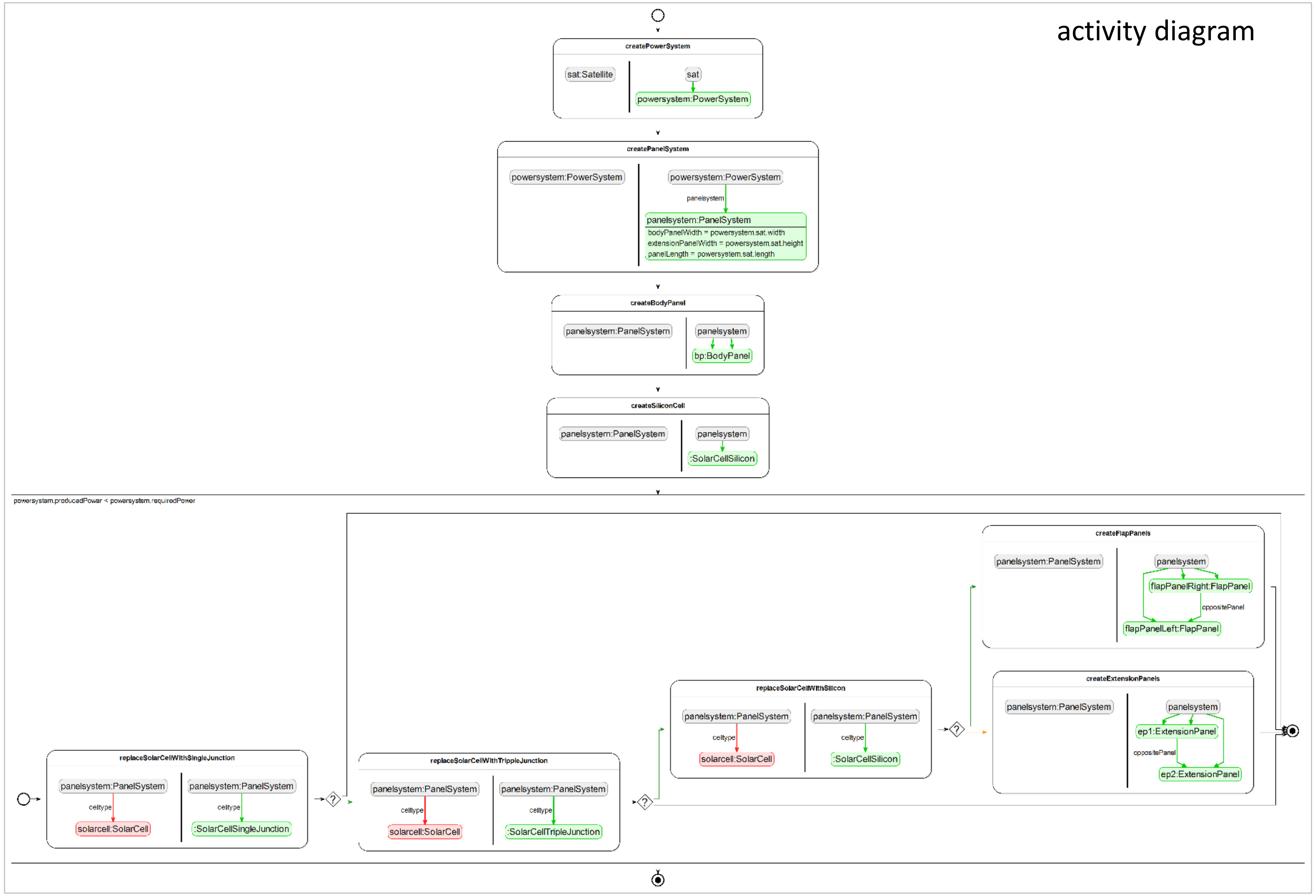


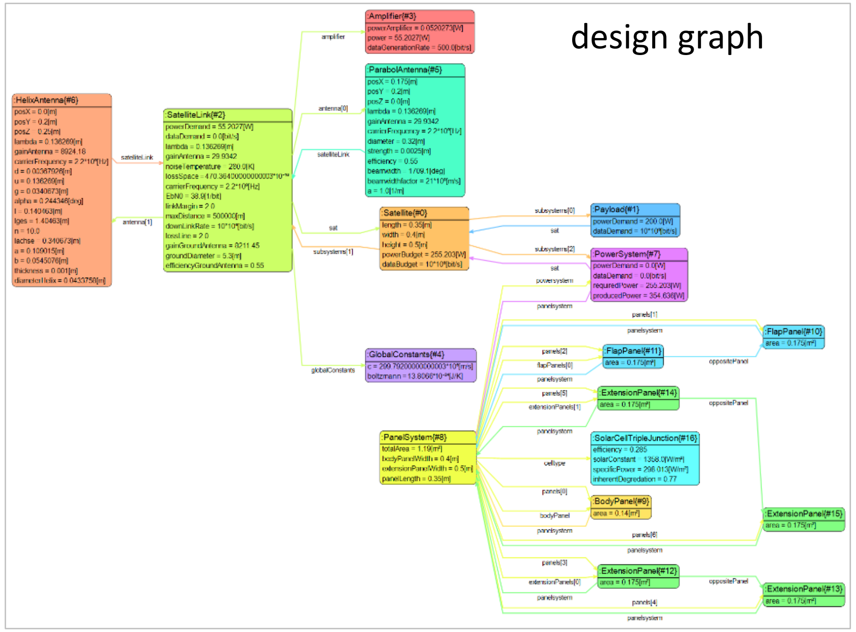
diagrams design languages in DC43®

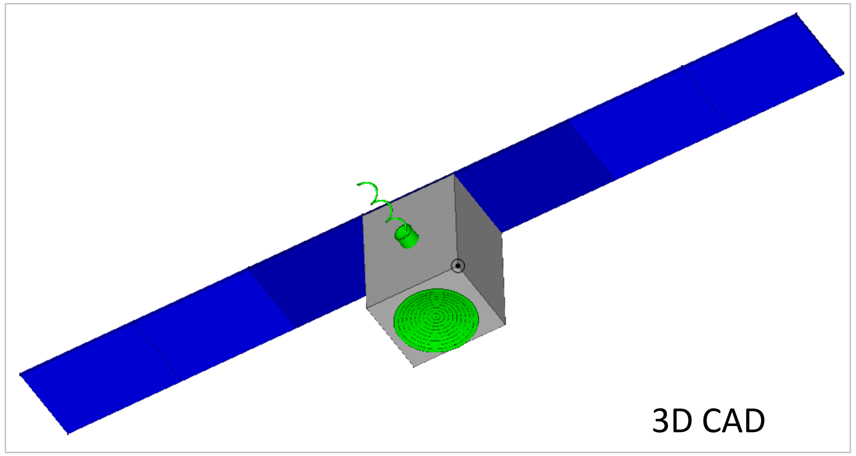
class diagrams
(for subsystems)



diagrams design languages in DC43®

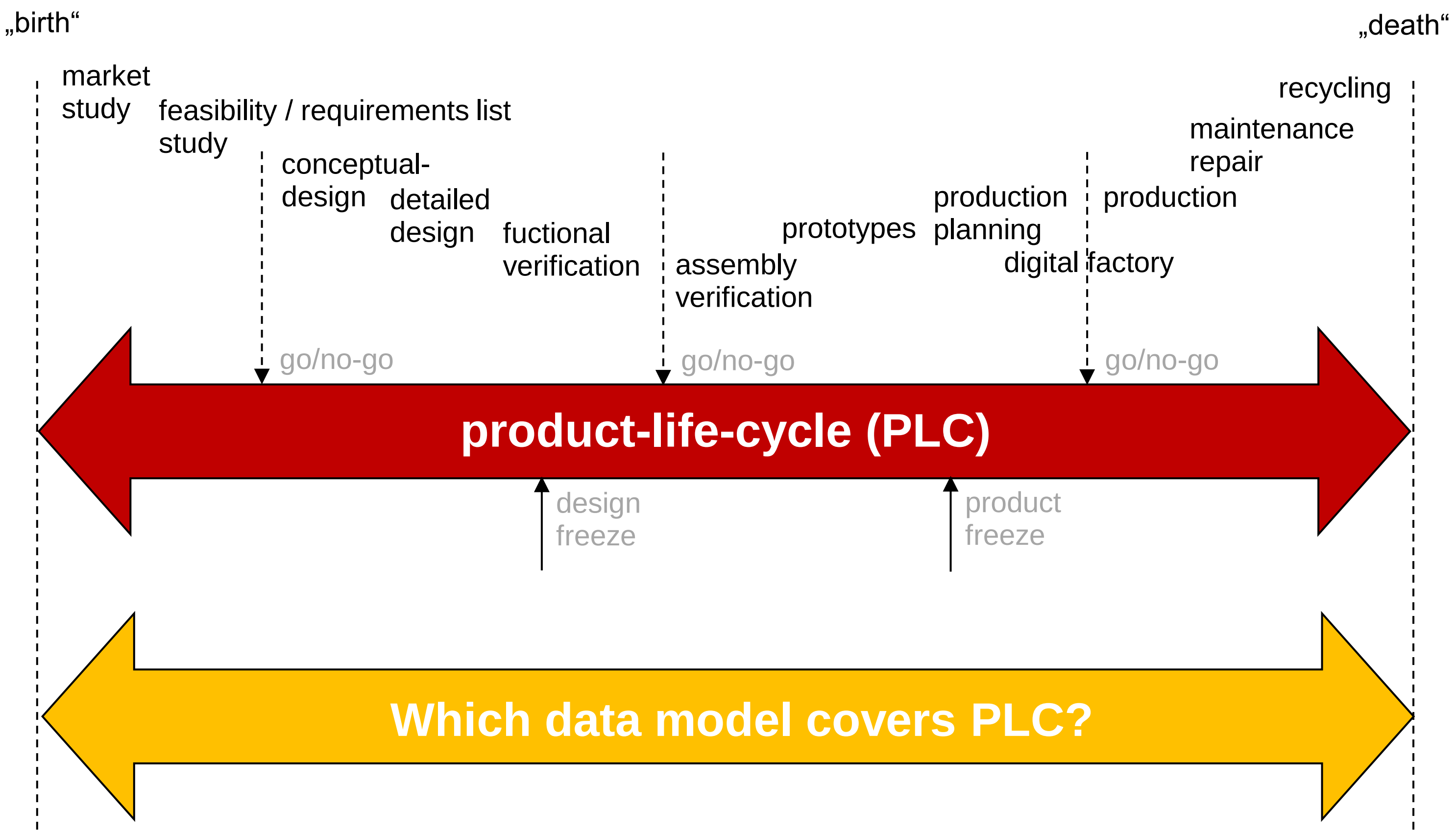






introduction to
domain modeling (with class diagrams),
design rules (with model-to-model transformations),
model generation (with activity diagrams)
in a language compiler (the Design Cockpit 43®)
by Felix Löser

digitalization problem along PLC

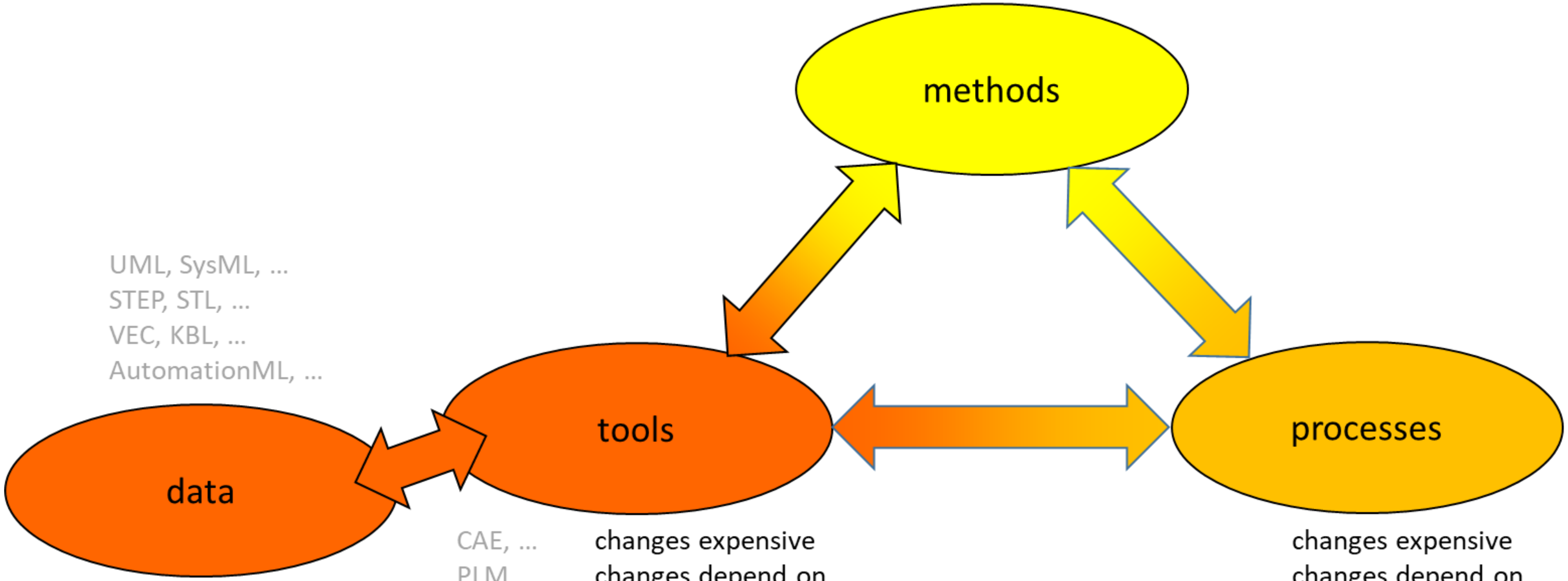


problem emergence digitalization

Pahl&Beitz, …
MBSE, …
AGILE, …

changes expensive
changes depend on
- implementation (processes)
- means (tools)

UML, SysML, …
STEP, STL, …
VEC, KBL, …
AutomationML, …



data translation
- coding (syntax)
- meaning (semantics)

CAE, …
PLM,
CAM, …
ERP, …

changes expensive
changes depend on
- knowledge (methods)
- sequence (processes)

changes expensive
changes depend on
- knowledge (methods)
- means (tools)

car design process (48 months)
aircraft design process (7 years)

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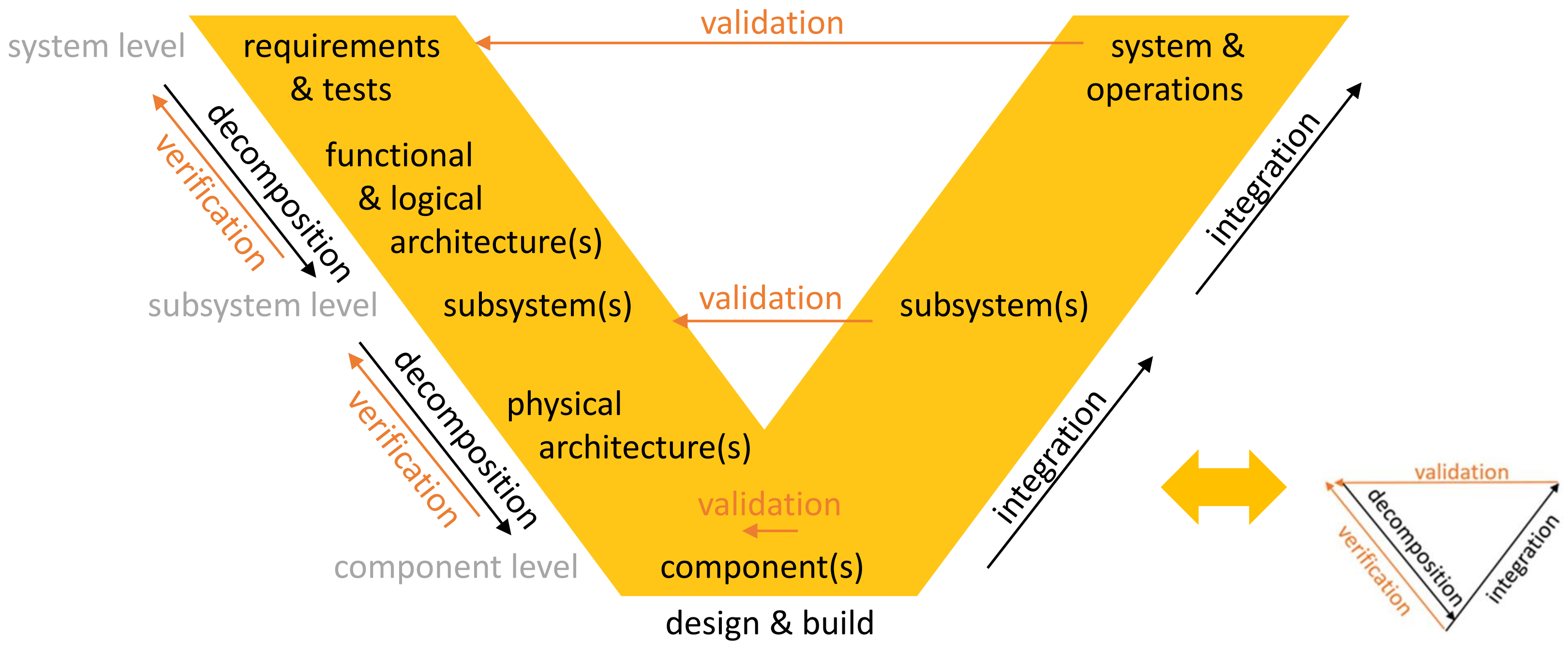
V-Model of model-based systems engineering (MBSE)



use-case 1

design scenario
in the FIRE-SAT satellite design
(University of Stuttgart, IILS mbH)
by Felix Löser

design languages in UML (Unified Modeling Language)

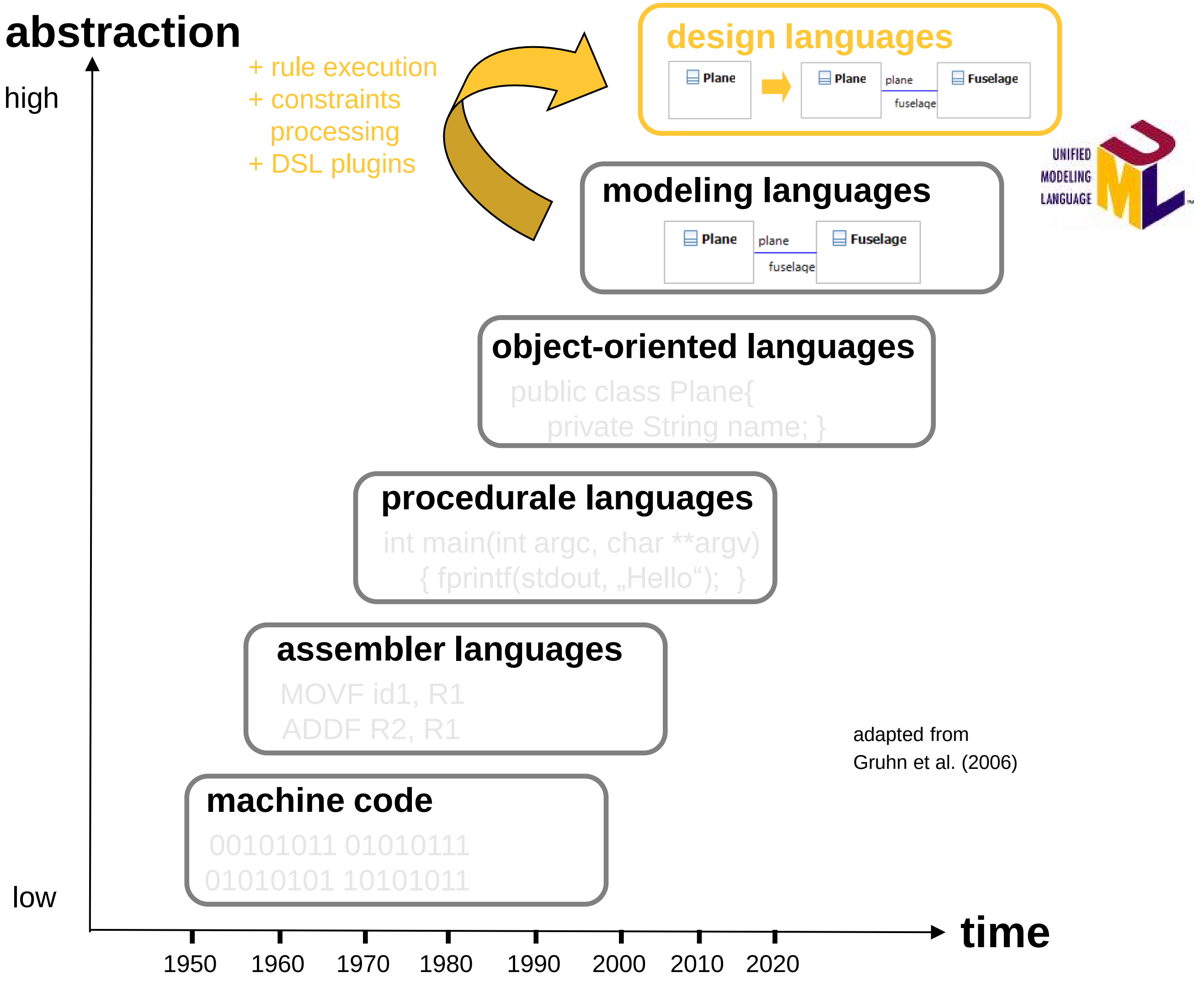
international, vendor-independent
format and development tools

productivity, quality
und security by
- code expansion
- code re-use
- code generation

with capability of
- abstraction
- hierarchization
- modularization
- visualization

of information

design of
complex
SW/HW-systems



adapted from
Gruhn et al. (2006)

machine-executable MBSE V-model in DC43®

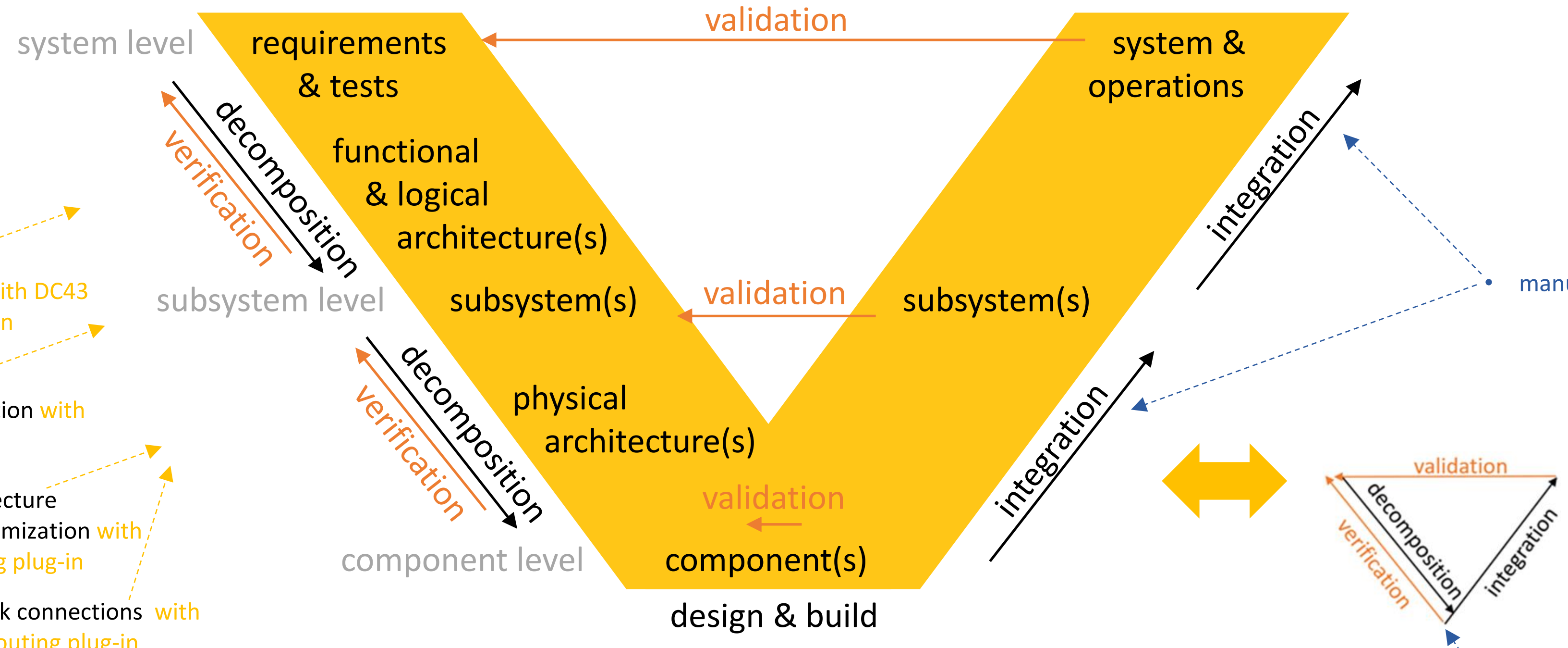
machine-executable V-Model
for design optimization in DC43 using
plug-ins with (artificial) intelligence

functional architecture
design and optimization with DC43
artificial intelligence plug-in

logical architecture
design and optimization with
DC43 FTA plug-in

physical architecture
design and optimization with
DC43 packaging plug-in

network connections with
DC43 routing plug-in
DC43 piping plug-in



machine-executable architecture trades

- functional architecture level
  - seamless variation from all electrical aircraft to all hydraulic aircraft (and anything inbetween)
  - artificial intelligence techniques for design solution generation
- logical architecture level
  - automated analysis and evaluation of alternative network topologies (ring, star, tree, daisy chain, …)
  - automated fault-tree analysis for network topology optimization
- physical architecture level
  - automated packaging for optimal placement under side-constraints
  - automated analysis and evaluation of equipment changes
  - automated design trades weight over cost
  - automated generation of all kinds of user-defined data/documents: BOM, costs, reports, …
- manufacturing and assembly
  - automated assembly sequence generation and ranking
  - automated collision („clashes“) detection and avoidance
  - digital factory layout optimization

notice: different plug-ins have different maturity level (TRLs), IILS mbH offers full end-to-end services

- (re-)occuring design patterns in design loops show the huge potential of design automation
- (re-)using design knowledge in form of design patterns and algorithms is fostered in DC43

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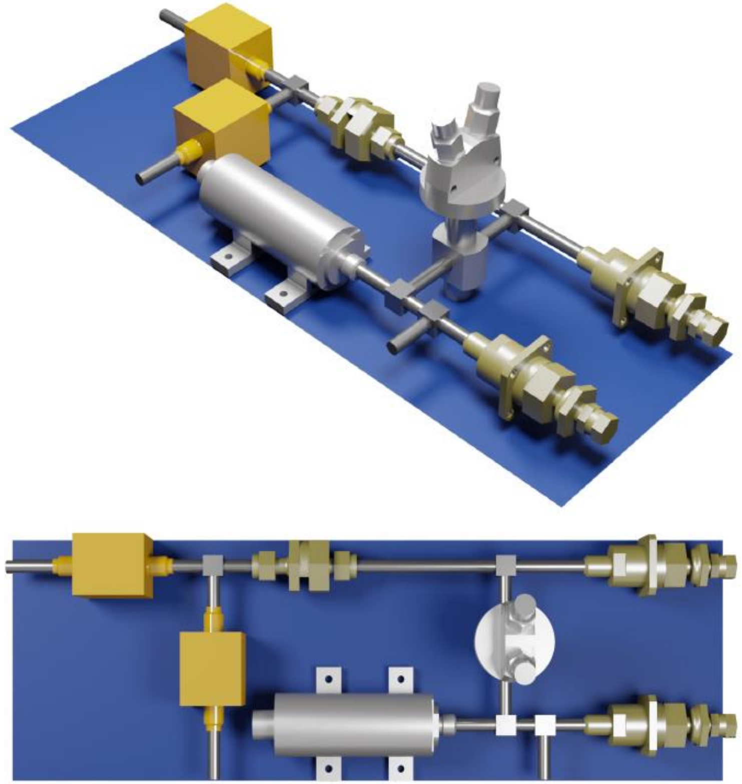
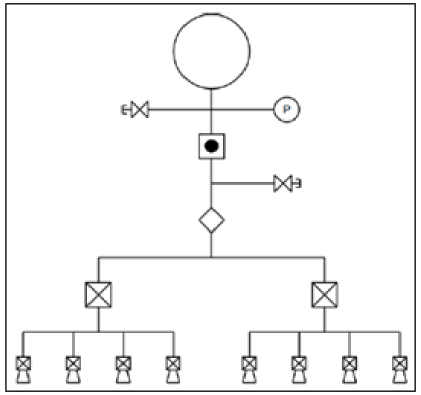
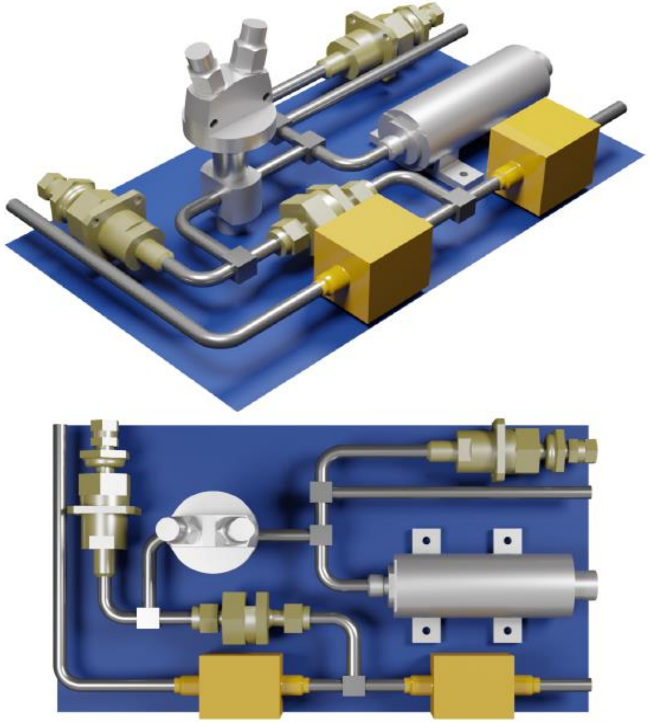
Design Cockpit 43® Packaging Plug-In





packaging algorithm
maps logical architecture

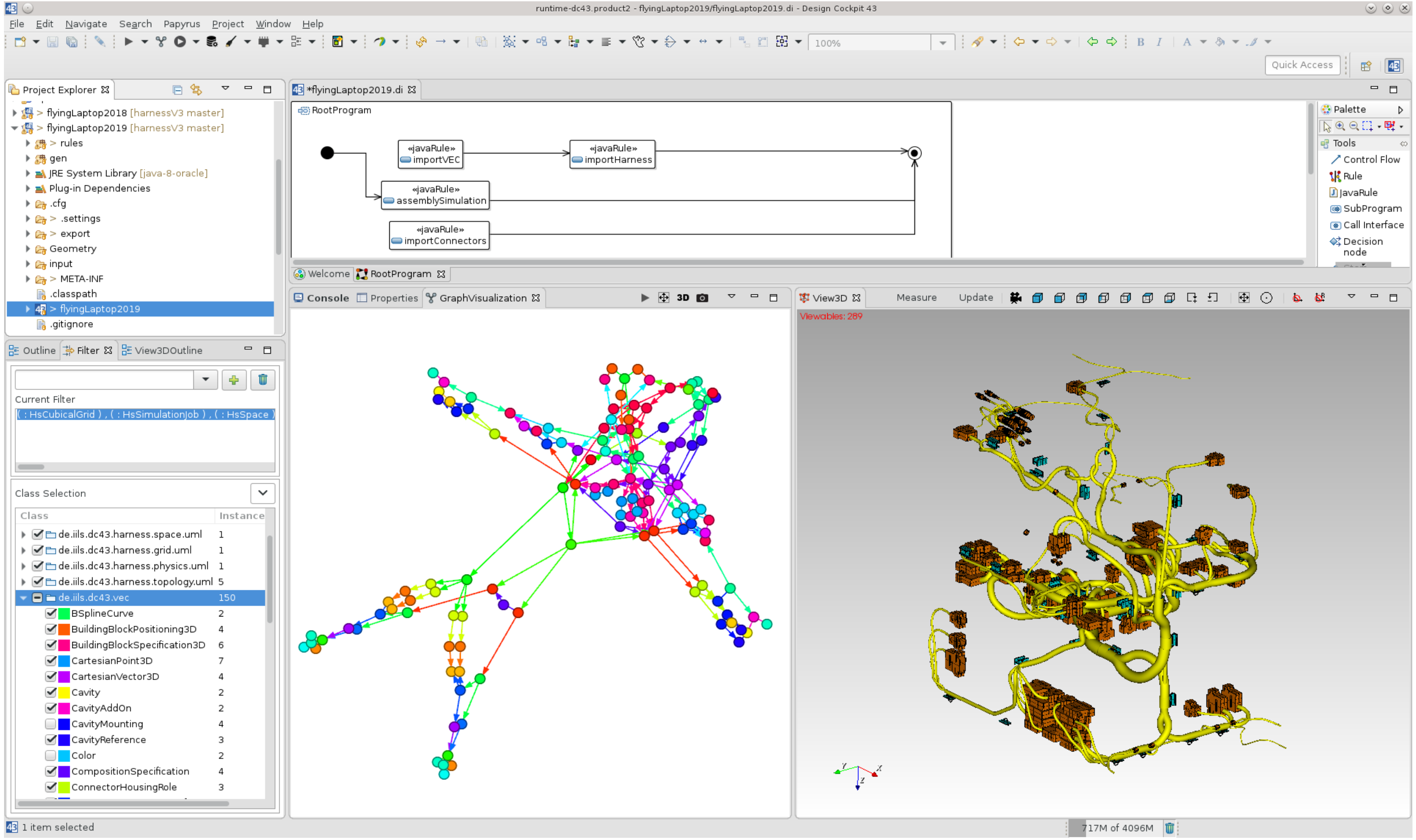
to physical architecture
w/o side-constraints



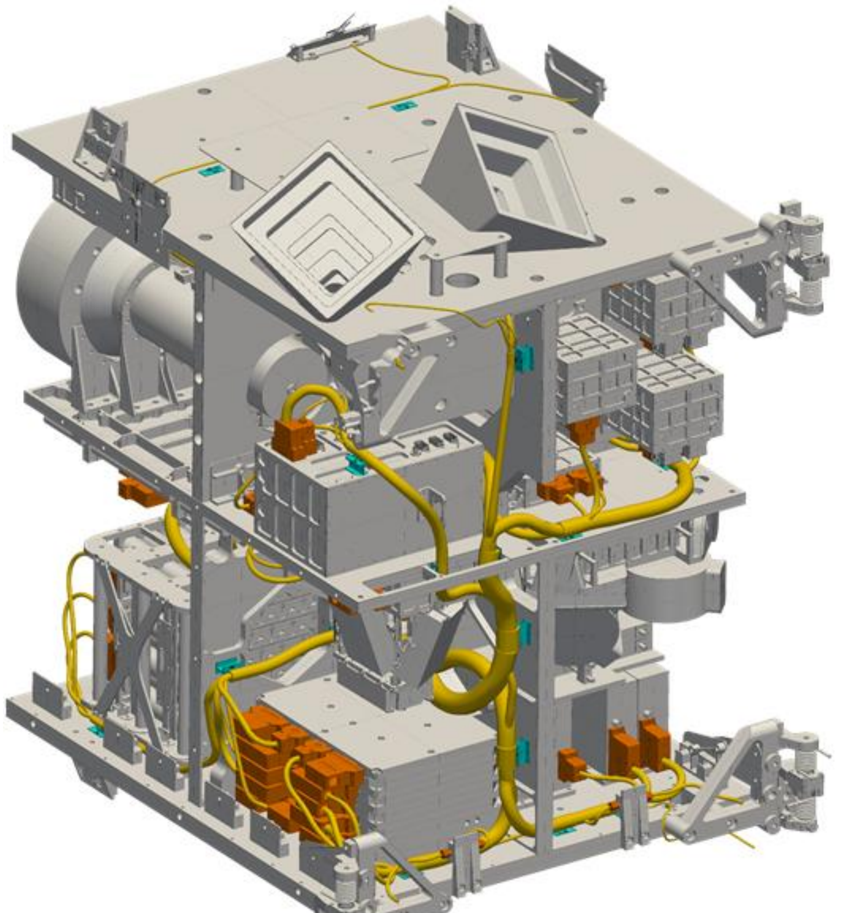
automatically generated packaging in DC43®
(bendings forbidden, area 457 cm^2)

automatically generated packaging in DC43®
(bendings allowed, area 361 cm^2)
22% space savings by 6 bends

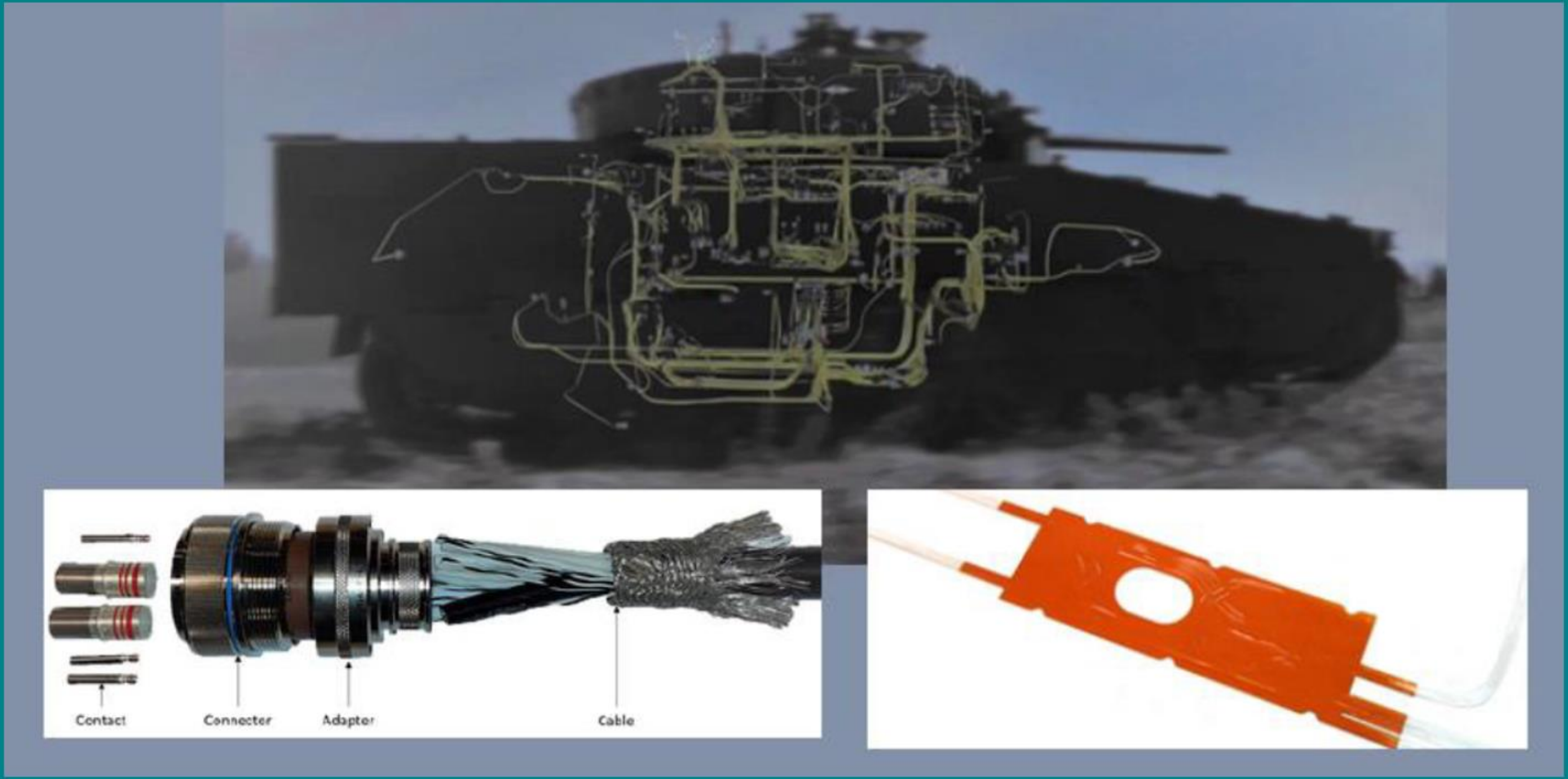
Design Cockpit 43® Routing-Plug-In



© 2018 by IILS mbH. Design Compiler 43® with Routing-Plugin (Harness shown was automatically generated in approx. 15 mins on PC with i5@3,2GHz, 32GB RAM)



CAD model courtesy © 2018 by IRS
(Institute for Space Systems, University of Stuttgart)
with integrated wire harness generated automatically in DC43® Routing-Plugin



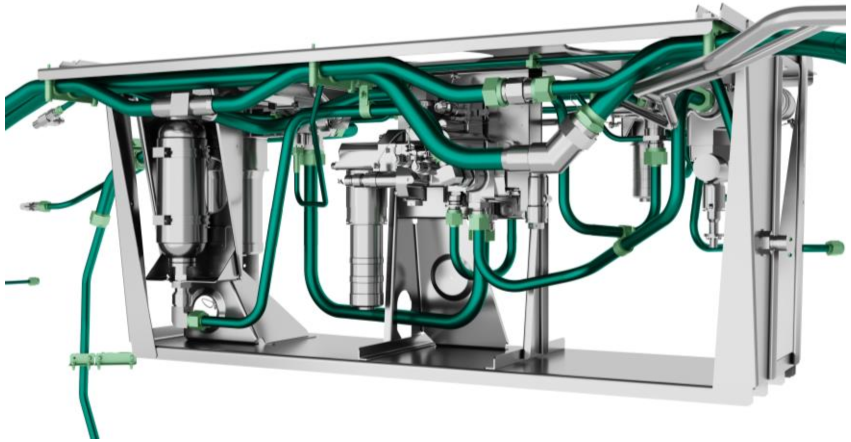
FORTIFIER project contributed to the ISO 10203/AP 242 EWIS team at PDES

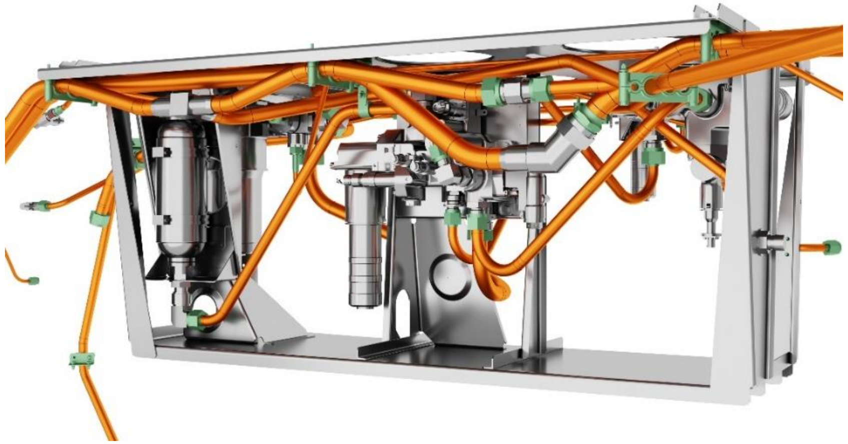
slide courtesy of
©2024 by Kjell Bengtsson (Jotne, vice president)
kjell.bengtsson@jotne.com

FORTIFIER project partners

- IILS mbH, Germany www.iils.de
- Lead: University of Stuttgart, Germany www.uni-stuttgart.de
- T&G elektro, Norway www.tgelektro.com
- Lead: Jotne, Norway www.jotne.com

Design Cockpit 43® Piping-Plug-In

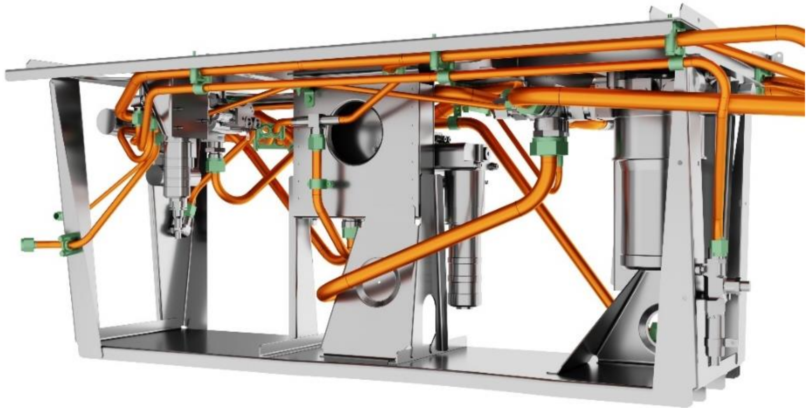




Neumaier, M.; Kranemann, S.; Kazmeier, B.; Rudolph, S.:
Automated Piping in an Airbus A320 Landing Gear Bay Using Graph-Based Design Languages.
Aerospace 2022, 9, 140.
https://doi.org/10.3390/aerospace9030140

Physical Wing Architecture Optimization System
https://cordis.europa.eu/project/id/865044

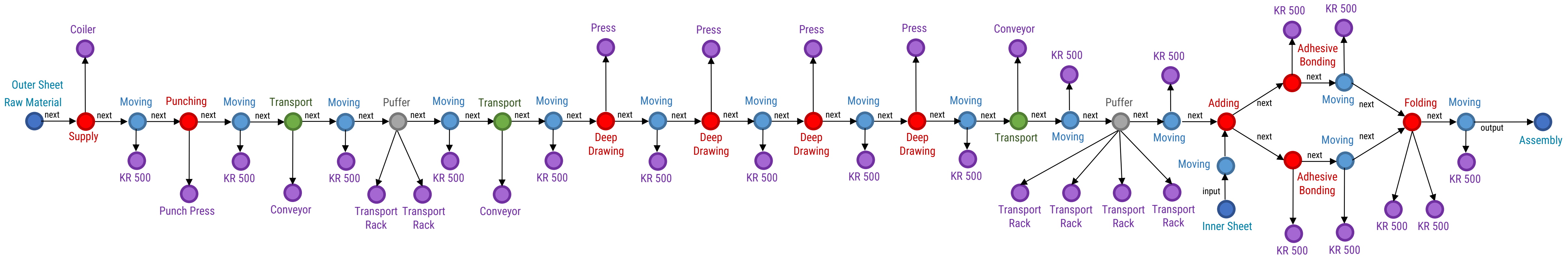
DC43® extensions (planned for 2023/2024)
- real-time pressure drop prognosis using pre-trained neural networks
- off-line automated full 3D fluid flow simulation for pressure drop validation
- inclusion of artificial intelligence techniques to learn from experience (e.g. simulation)



manually designed series solution AIRBUS A320
(pipe lengths 22.6 [m], 107 bends)

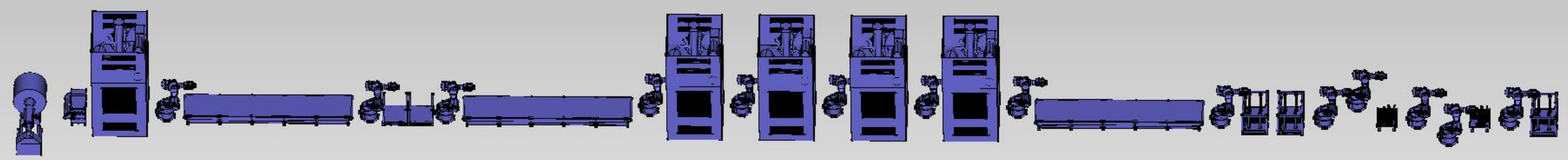
DC43® automatically generated solution
(pipes lengths 20.414 [m], 95 bends)
10% length and weight savings with 12 bends less

Design Cockpit 43® Digital Factory-Plug-In



Digitale Fabrik im Design Compiler 43®

- Berechnung des Layouts, Durchsatz der Transferlinie
- Generierung der Digitalen Fabriksimulation
- VR-fähig in HTC VIVE



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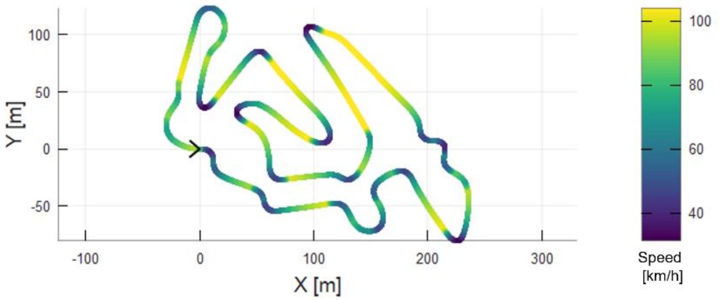
use-case 2

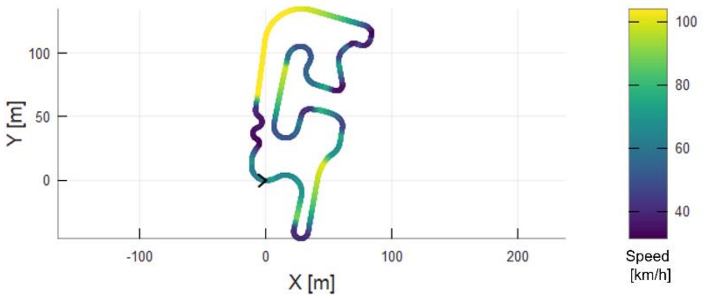
digital twin generation of
FORMULA student racing car at RWU
(Ravensburg-Weingarten University, IILS mbH)
by Julian Borowski

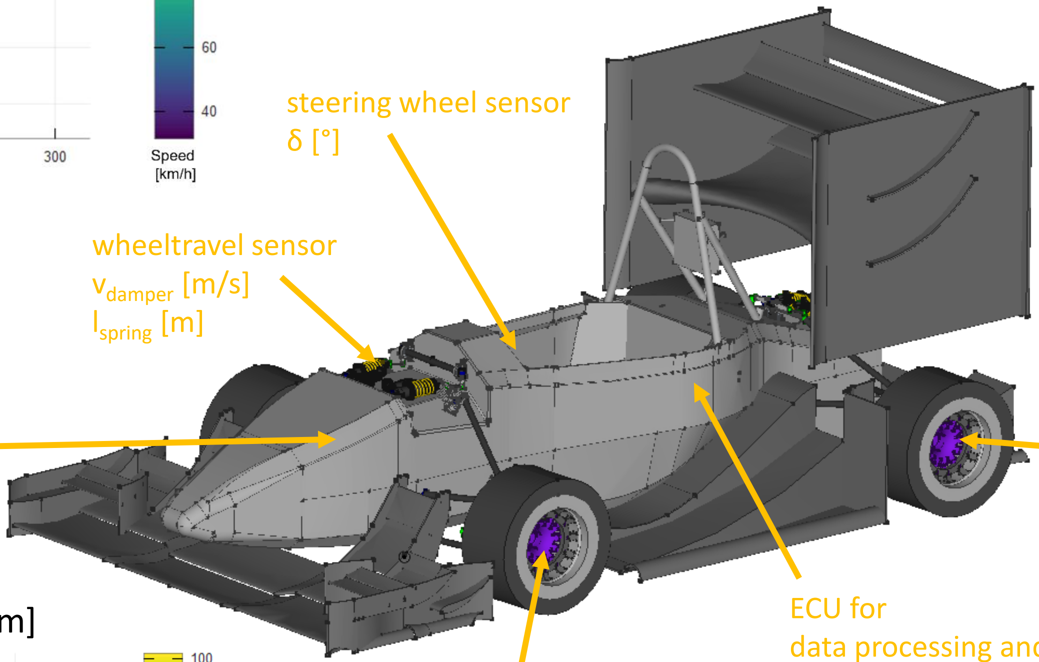
Formula Student RWU generation in Design Cockpit 43®

FS Germany track, length 1424 [m]

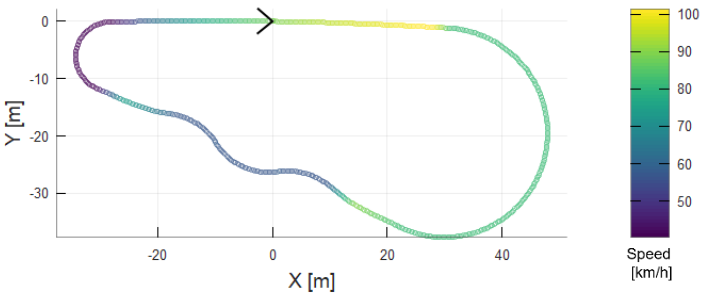


FS Hungary track, length 632 [m]

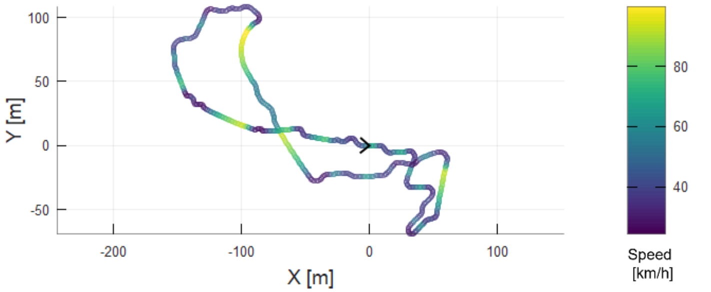




RWU test track, length 200 [m]



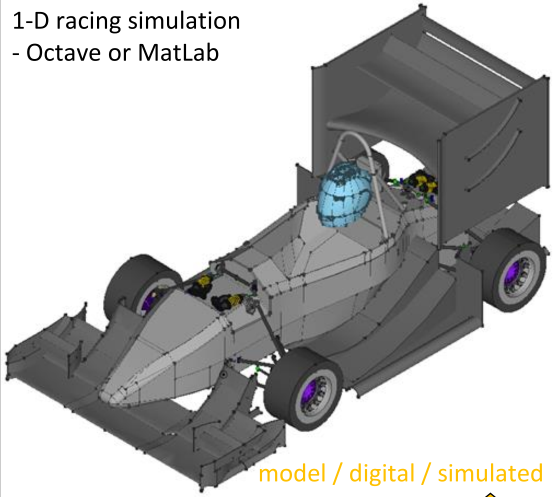
FS Spain track, length 771 [m]



each racing track requires individual modifications
- suspension
  - tire pressure
  - ...
- aerodynamics
  - angle of attack (primary for rear spoilers)
- - ...

Formula Student RWU generation in Design Cockpit 43®

1-D racing simulation
- Octave or MatLab



model / digital / simulated

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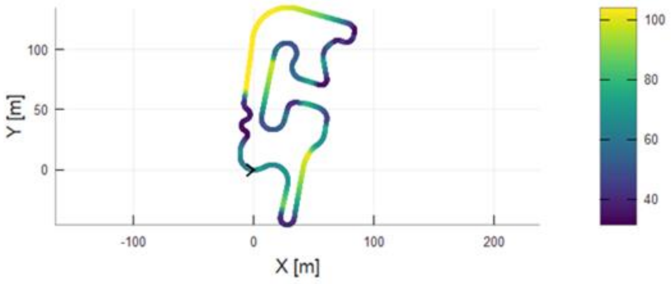
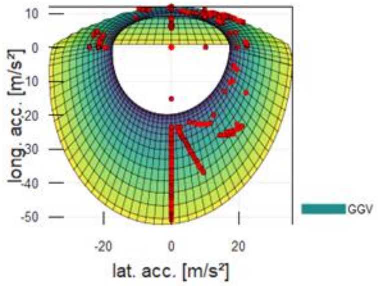
Digital Twin

©2023 RWU

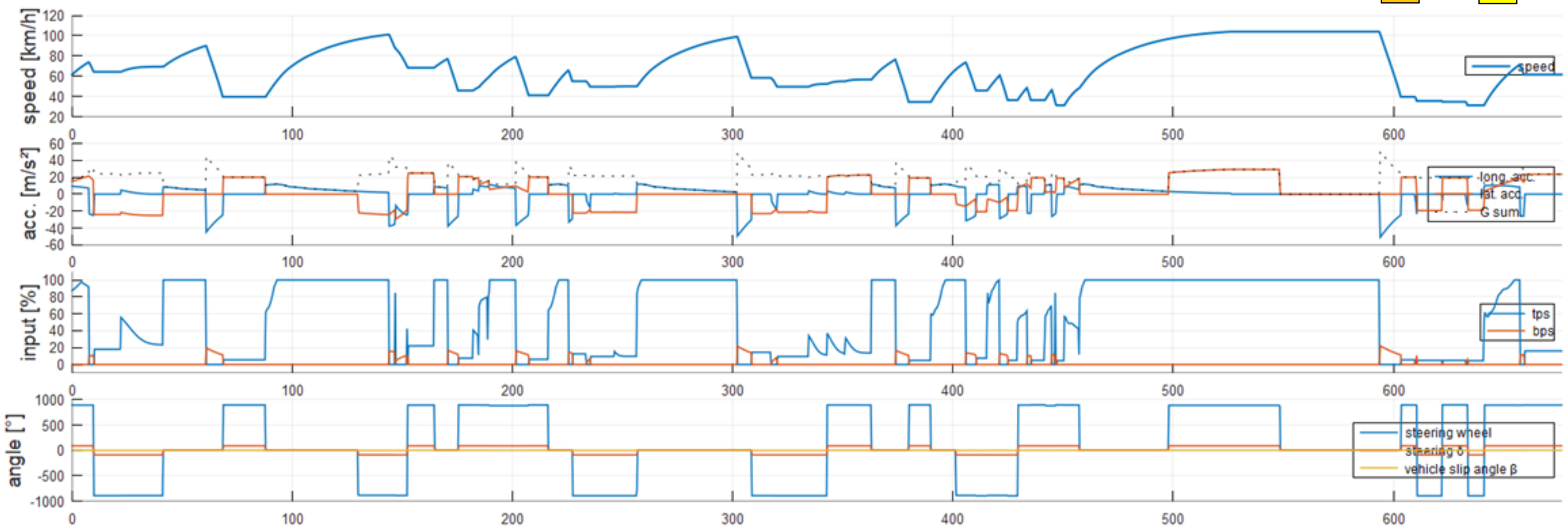


car design (loops)
- topology
- parameters

results
interpretation
- modifications



closing the design loop
- classic: optimization
- smart: artificial intelligence
(another talk, another time)



FS Germany Hockenheim
car design (loops)
- sensitivity analysis
- parameter study

	mass [kg]	cl*A [m²]	cd*A [m²]	CoG [mm]	time [s]	delta [s]
Base	232	5.0	2.0	284.6	69.91	0.00
friction +10%	232	5.0	2.0	284.6	67.47	-2.44
mass -10%	209	5.0	2.0	284.6	67.62	-2.29
cl*A +10%	232	5.5	2.0	284.6	69.02	-0.89
CoG -10%	232	5.0	2.0	262.3	69.60	-0.31
Torque +10%	232	5.0	2.0	284.6	69.60	-0.31
cd*A -10%	232	5.0	1.8	284.6	69.63	-0.28

Formula Student RWU generation in Design Cockpit 43®

©2023 RWU

One-Day Racing-Car (system model)
→ 5526 instances (nodes) and 5258 associations (links)
→ 236 symbolic equations, MBS, FEM, CFD, Thermal simulations
→ 3min 51s runtime
(model transformations, model generation, simulations)

brake disc (subsystem)
→ 43 instances (nodes) and 27 associations (links)
→ 87 symbolic equations, FEM and Thermal simulation
→ 13s runtime
(model transformations, model generation, simulations)

effort to use Design Cockpit 43® (DC43® upfront invest)		**yearly effort Formula Student Team RWU**
→ design languages 19.973 klocs (20 projects, 127 classes, 162 rules)	↔	manually CAD, MBS, CFD, Thermal, BOM, …
→ re-usable, machine-executable specification	↔	manual re-use of know-how from previous years (via students)
→ human programming 1,5 man years	↔	55 students during 1 year

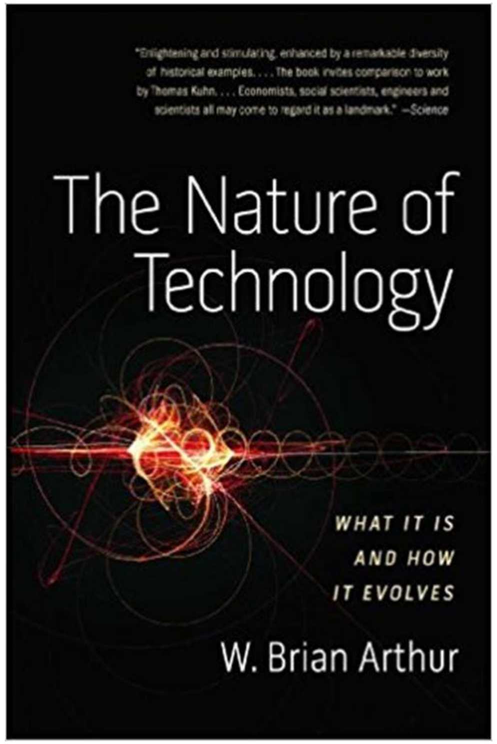
scientific summary

"On MBSE, V-model, digital thread, digital twin and all that with design languages"

philosophical justification

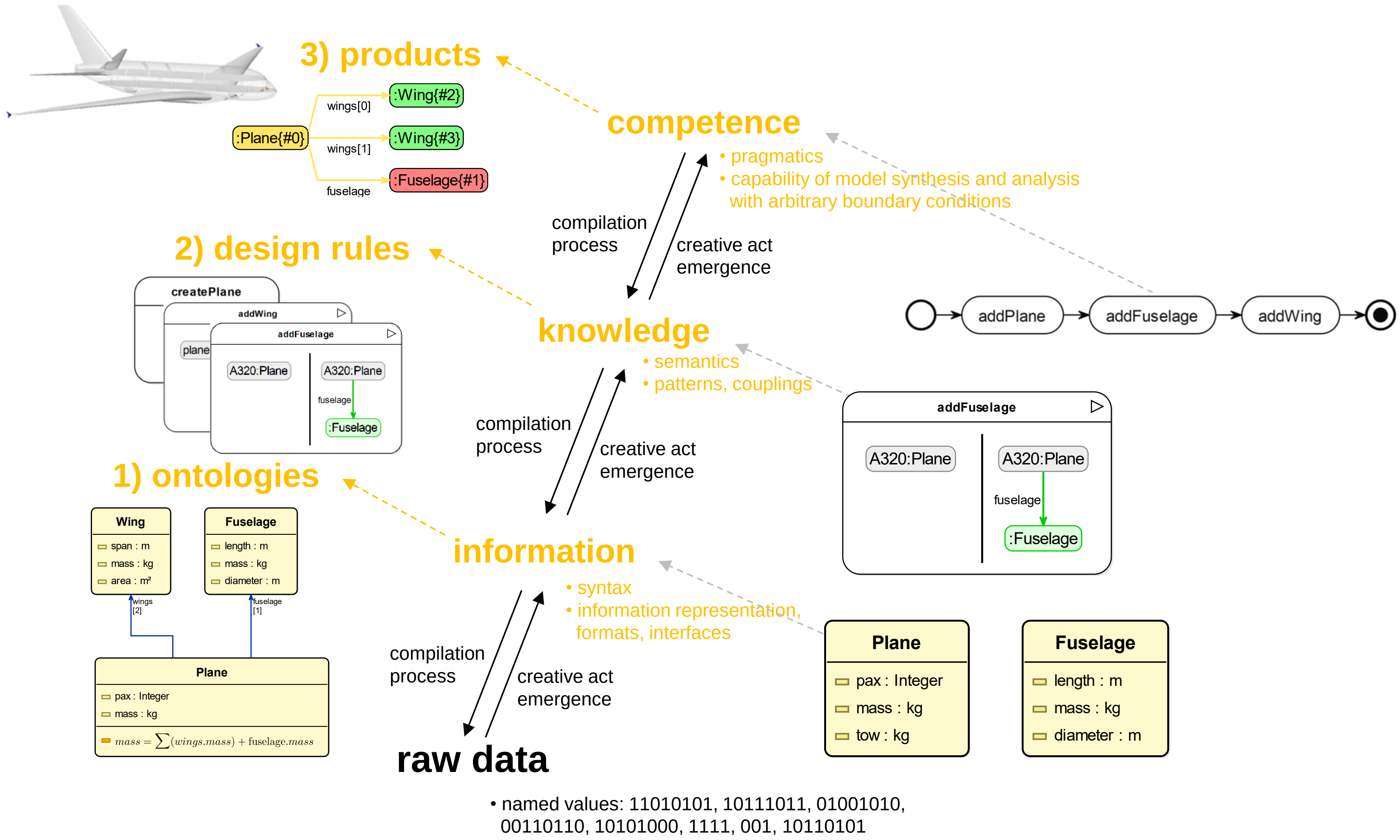
The philosopher William Brian Arthur postulated in his book[1] "The nature of Technology" (2009) in chapter 5.2 entitled "Design as an Expression Within a Language":

- A new device or method is put together from the available components – the available vocabulary – of a domain. In this sense a domain forms a language; and a new technological artifact constructed from components of the domain is an utterance in the domain's language.
- And it means that the key activity in technology – engineering design – is a form of composition. It is an expression within a language (or several).

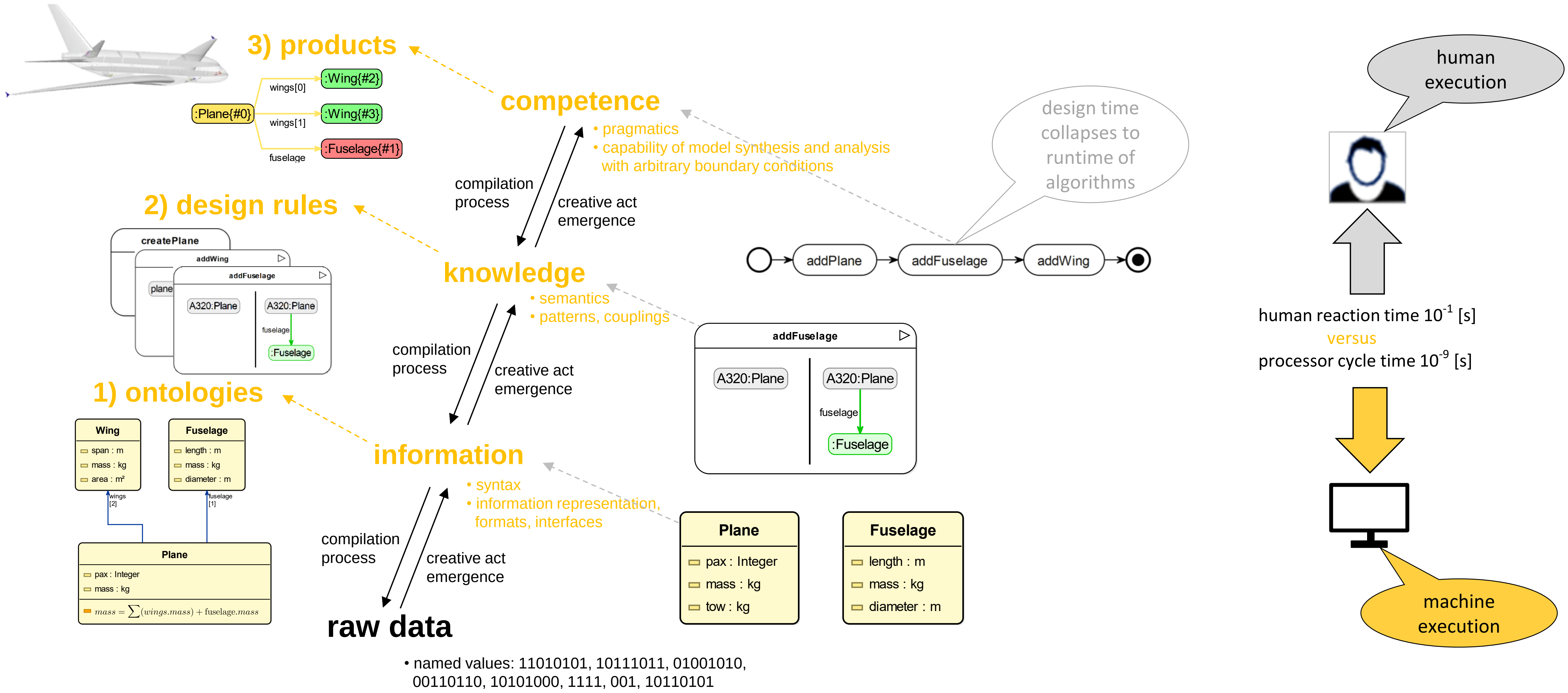


[1]Arthur, W.B.: The Nature of Technology – What It Is and How It Evolves. New York, Free Press, 2009.

design language investment



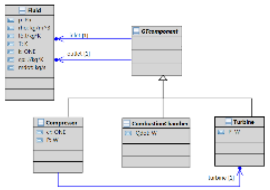
design language return on investment (1 of 3)

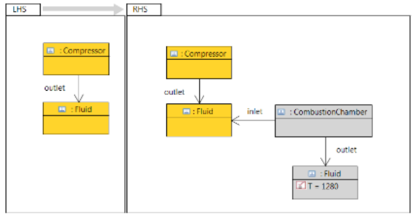


design language return on investment (2 of 3)

- knowledge representation
  the expressive power of engineering design
  - ontology representation/formulae
  - processes/activities
  - AI methods

  …



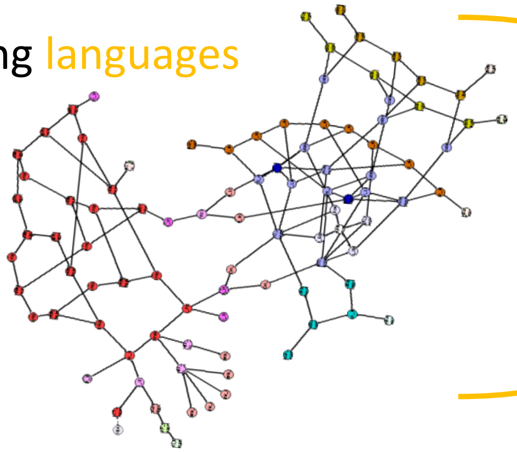


design languages
digital knowledge representation

with

- compilation of formal programming languages
  in computer science which can be
  - translated/compiled
  - traced/validated/verified
  - DoE exploration

  …



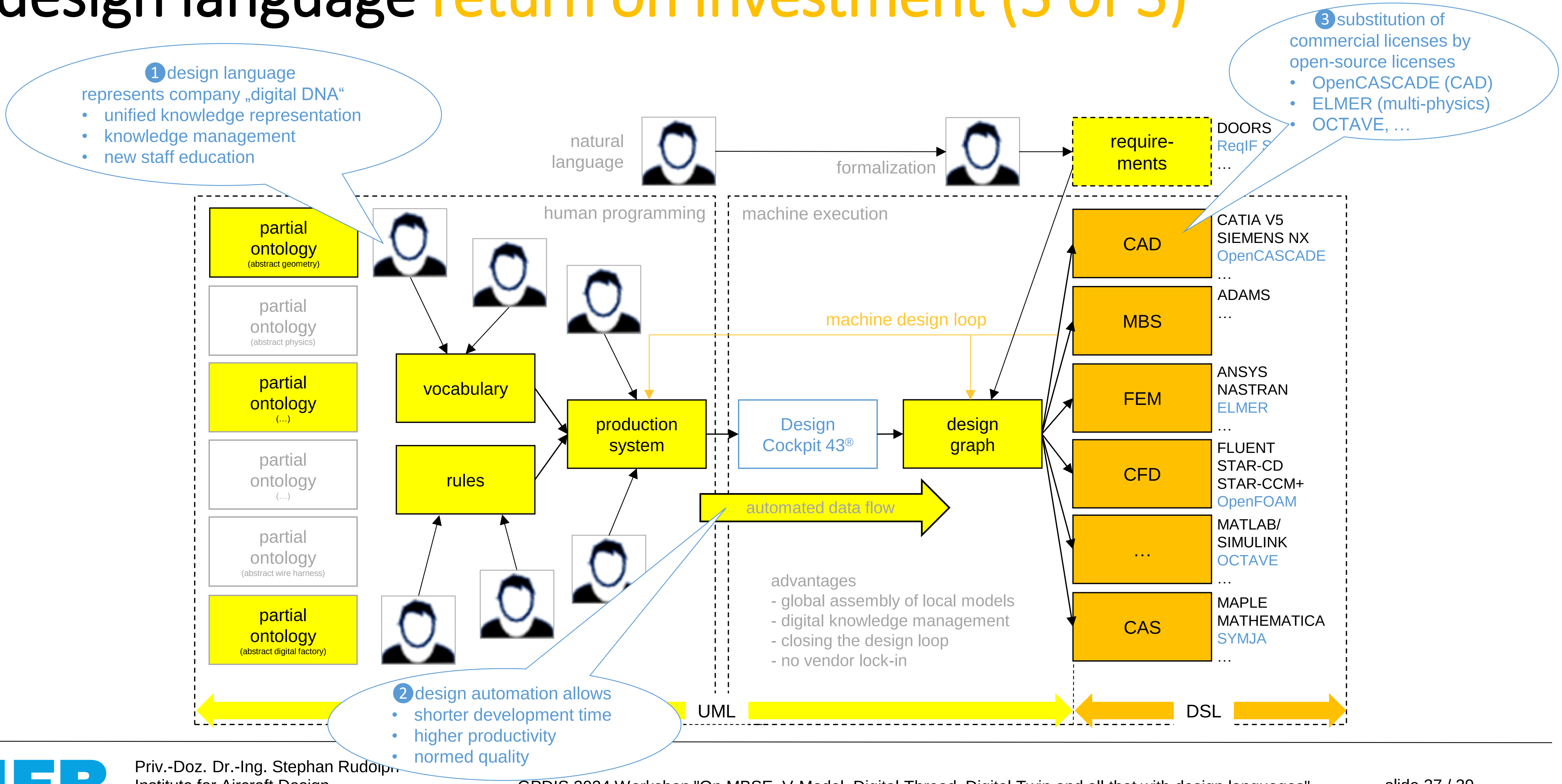
design compiler
compilation and processing engine

KPIs time savings
cost savings
quality gains

artificial intelligence enhanced design and process automation
„Industry 4.0“

10^X variants
design exploration

design language return on investment (3 of 3)



workshop take home messages and prognosis

- future data formats are graph-based
  - from a design language perspective knowledge graphs are design graphs
  - role of data formats and data standards is overtaken by ontologies
    (because ontologies are the knowledge graph/design graphs meta-models)
  - future PDM systems are graph-based (because knowledge graphs/design graphs are the future) and not relational databases (because classical PDM systems store disciplinary models without their couplings)

- design language compiler platforms (such as Design Cockpit 43® or, for short DC43®) offer
  - digital consistency (of data), digital continuity (of processes) and digital interoperability (of tools) along PLC
  - boost productivity by process-based automation (design time collapses to the runtime of the algorithms)
  - while models are dead and need interpretation, encoded design processes can be automatically re-executed
  - processes (and not models) generate value, encoded design processes are part of knowledge management
  - design languages constitute the “digital DNA” i.e. the digital assets and intellectual property of a company

- open discussion round
  - digital twin, knowledge graphs, digital thread, OEM-supplier cooperation, …

contact and references

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