How to design a tool for designers?

System-level feature-based modeling of cyber-physical systems

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Experience

INSTRUCTOR 2018 - Present
Sheridan College

RESEARCHER / INSTRUCTOR 2012 - 2017
Delft University of Technology

FACULTY MEMBER 2006 – 2012
Tabriz IA University

HEAD OF DEPARTMENT 2008 – 2011
Tabriz IA University

DESIGNER / PROJECT MANAGER 2004 – 2006
NAK design studio

DESIGNER / USER RESEARCHER 2000 – 2004
PARS ZARASA household design and industrial company

Education

PhD 2012 – 2017

Design Engineering department, IDE, TU Delft

- Topic: System-level feature-based modeling of Cyber-Physical Systems

MASTER's DEGREE 2003 - 2006

Art University of Tehran

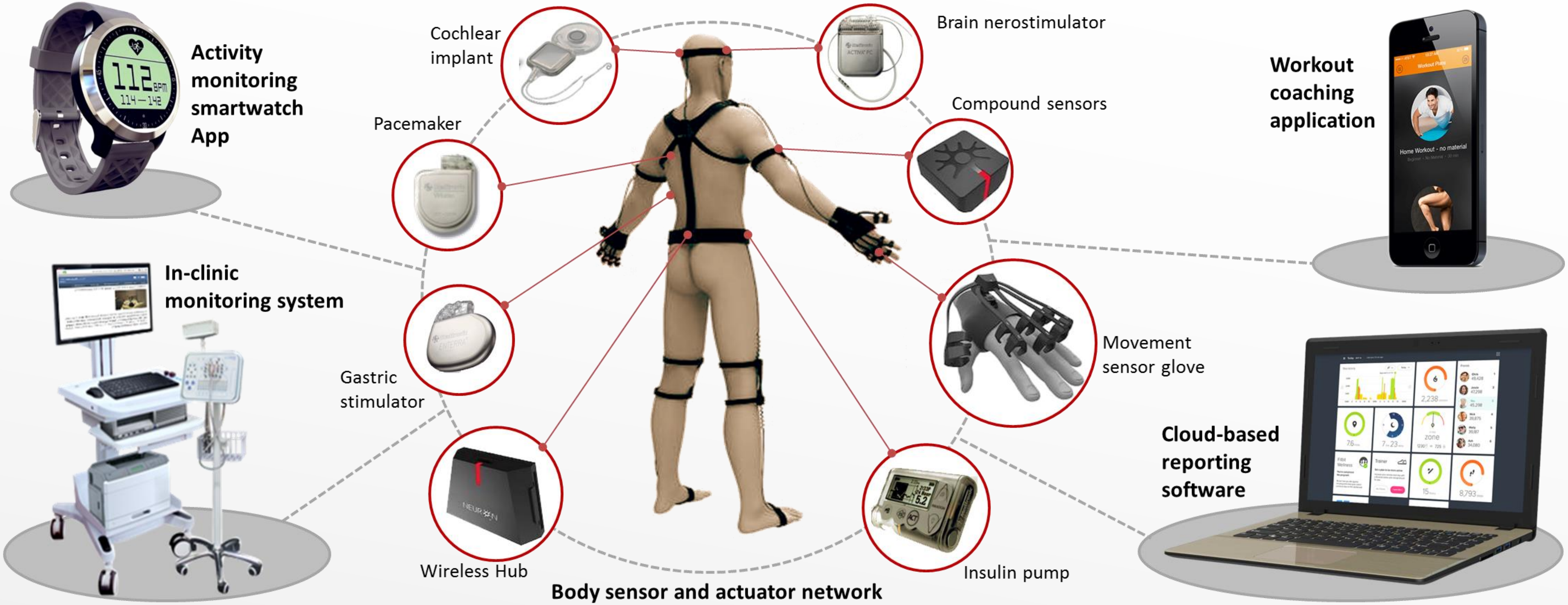
- Major: Industrial design engineering
- Summa cum laude

BACHELOR's DEGREE 1999 - 2003

Sahand University of Technology

- Major: Industrial design engineering
- Summa cum laude

Cyber-Physical System (CPS)



Characteristics of CPSs

Distributed integrity: distributed cooperative problem solving, in harmony with the techno-socio-economic environment

Openness: functional and structural openness (with blurred overall system boundaries)

Dynamicity: capability to dynamically change behaviors, and reconfigure internal structure

Source multiplicity: knowledge-intensive components are able to handle different information sources

Goal-oriented cooperation: components may operate according to different problem solving strategies while achieving the overall objective of the system

Autonomy: memorizing and learning from history in an unsupervised manner by smart agents

Proactivity: non-planned functional interactions, and acting proactively in emergent internal and external situations

Strategy variability, **Integrity,** **Heterogeneity,**

Real-time processing, **Situated reasoning,** **Reproductive intelligence**

Paradigmatic features	Ordinary systems	Low-end CPSs	High-end CPSs
System complexity	Ordinarily compound	Linearly complex	Non-linearly complex
Functional objectives	Providing means	Providing utilities	Providing services
Overall architecture	Closed system boundary	Extendable system boundary	Open system boundary
Construction topology	Predefined fix architecture	Predefined modifiable architecture	Runtime dynamically architected
Functional organization	Integrated structure	Distributed structure	Decentralized structure
Functional connectivity	Stand alone	Static networked	Dynamically networked
Operating principles	Execution and control	Sensing, computing and activating	Observing, reasoning, activating and motivating
Functional intelligence	Functionally determined	Functionally smart with limited awareness	Functionally autonomous and conscious
Readiness for operation	Condition activated	Alert in operation	Proactive in operation
Intelligent components	None or dedicated problem solvers	Individual agent-based reasoning	Cooperating agent swarm reasoning
System control	Manually controlled, Feedback controlled	Adaptive and self-adaptive control	Intelligent control according to goal driven operational scenarios
Placement in context	Largely independent of context	Context sensitive (situated) operation	Context driven operation
Adaptability	Partial external modifiability	Self-adapting capabilities	Self-evolving capabilities
Heterogeneity	Mono-disciplinary system	Multi-disciplinary system	Trans-disciplinary system

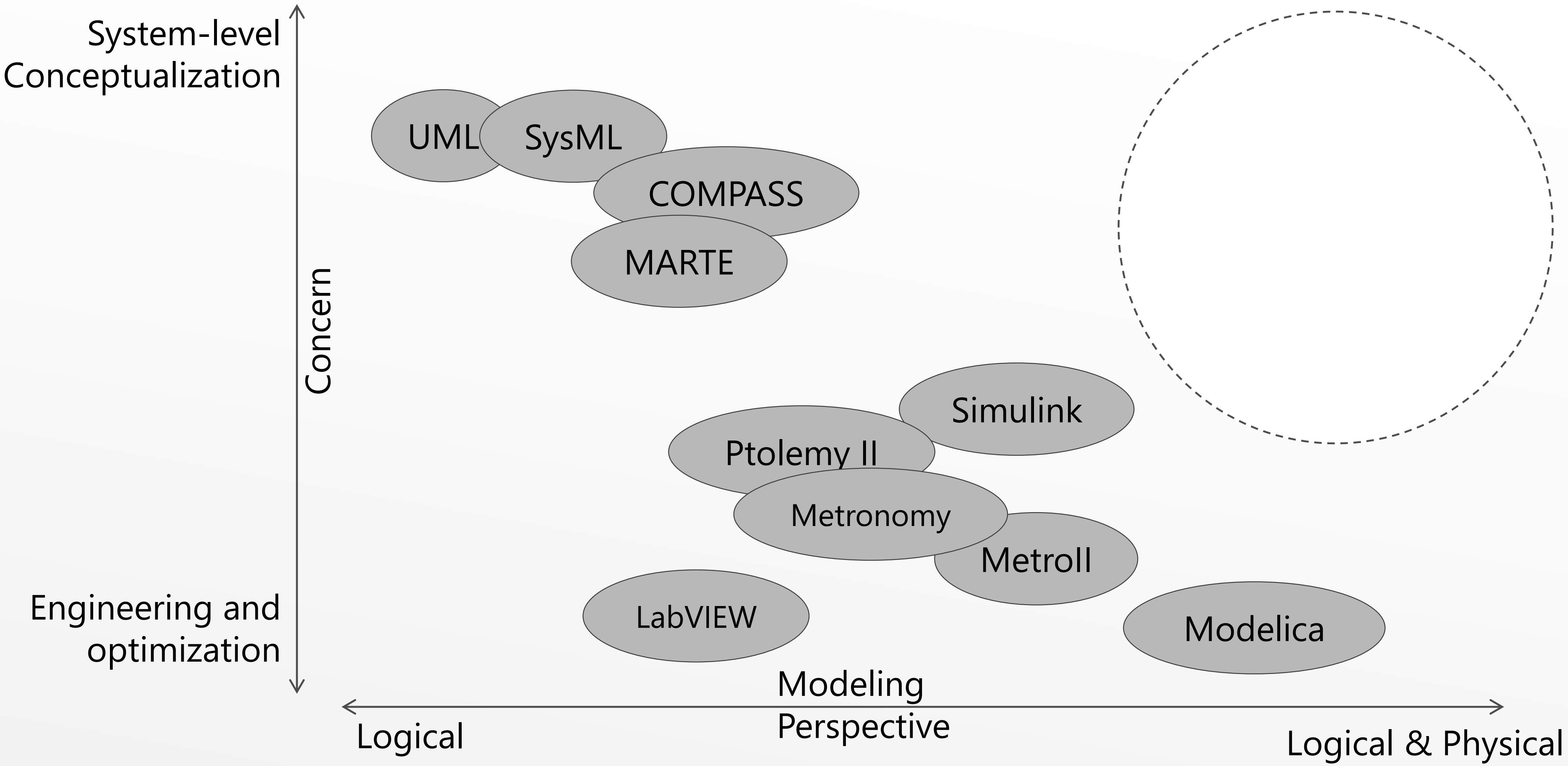
Shortcomings of the existing tools

- **Composability** concerns remained unsolved
- Are not suitable for **system-level design**
- Apply **too much simplification**
- Ignore **physical attributes**

Overview of the research

- **The research problem** — There is no suitable tool …
- **Initiating a solution** — A theoretical framework
- **Developing the idea** — Methodological fundamentals
- **Feasibility test** — Warehouses and procedures
- **Validation** — Benchmarking against other tools

Landscape of tools



Theoretical framework

Mereo-operandi theory

Architecture

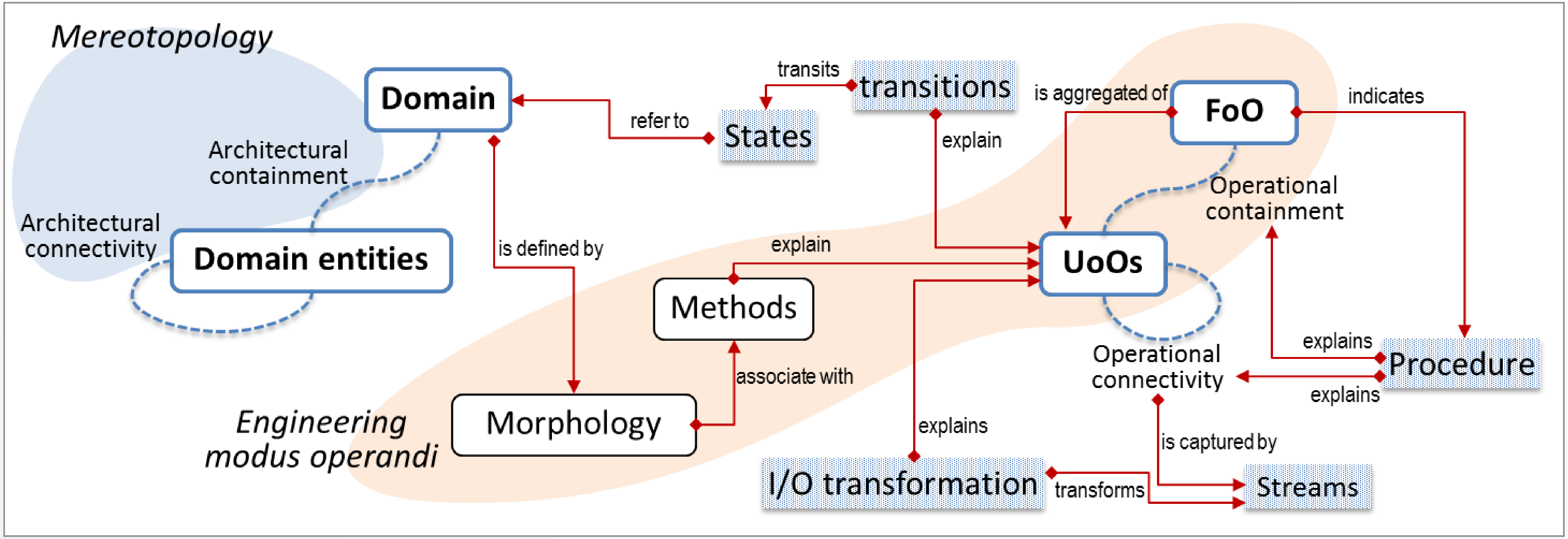
Mereotopology

Operations

Engineering modus operandi

Theoretical framework

Mereo-operandi theory

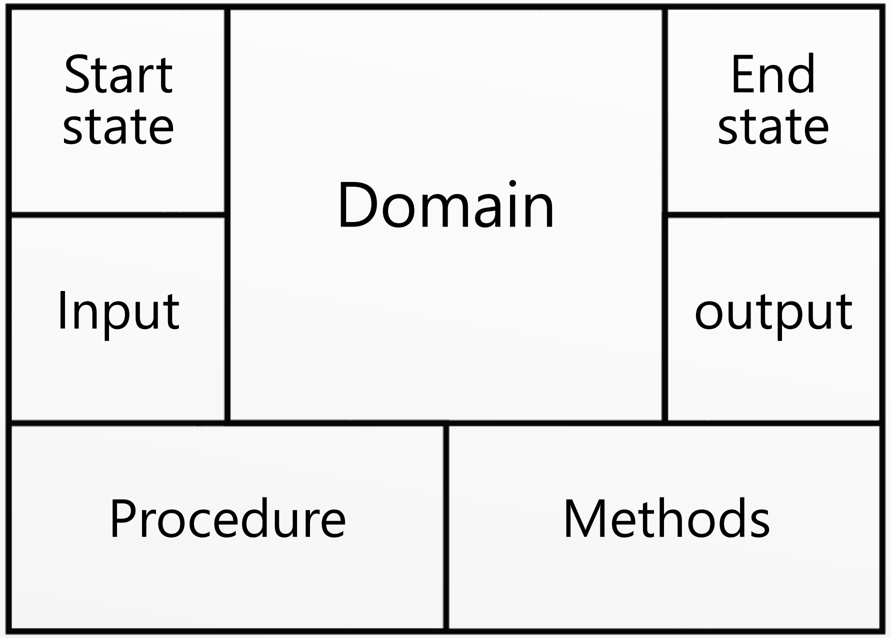


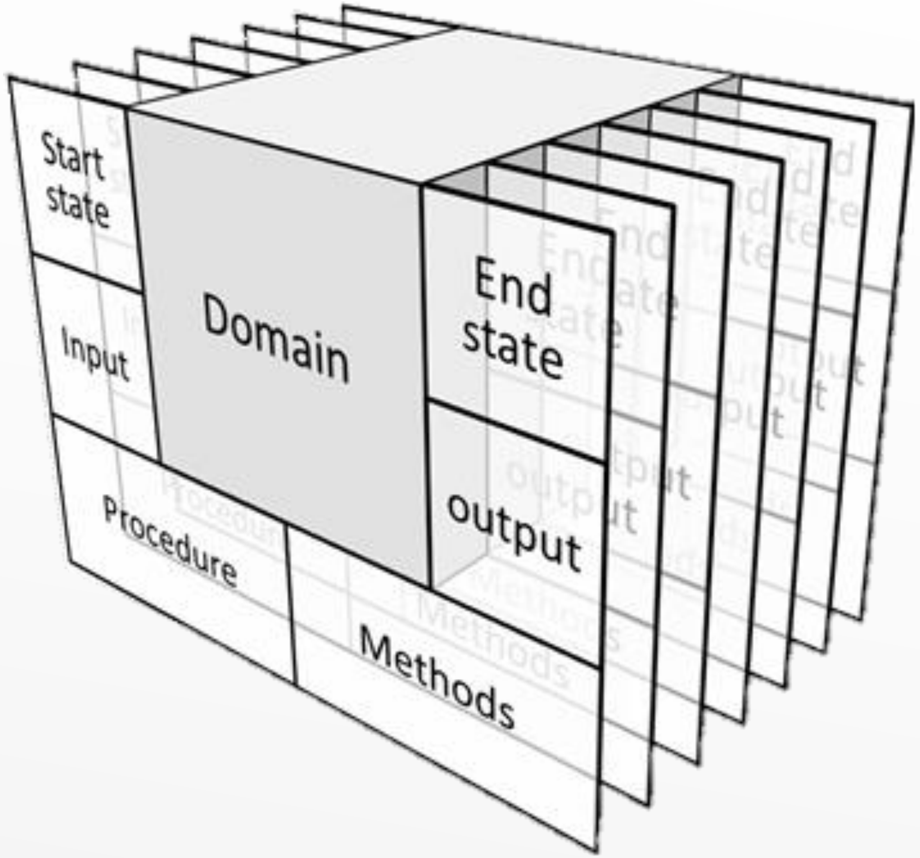
Theoretical framework

Mereo-operandi theory

1. System manifestation feature (SMF)
2. Operation and architecture concurrently and linked together
3. A uniform structure
4. Multi-granularity

System Manifestation Feature (SMF)

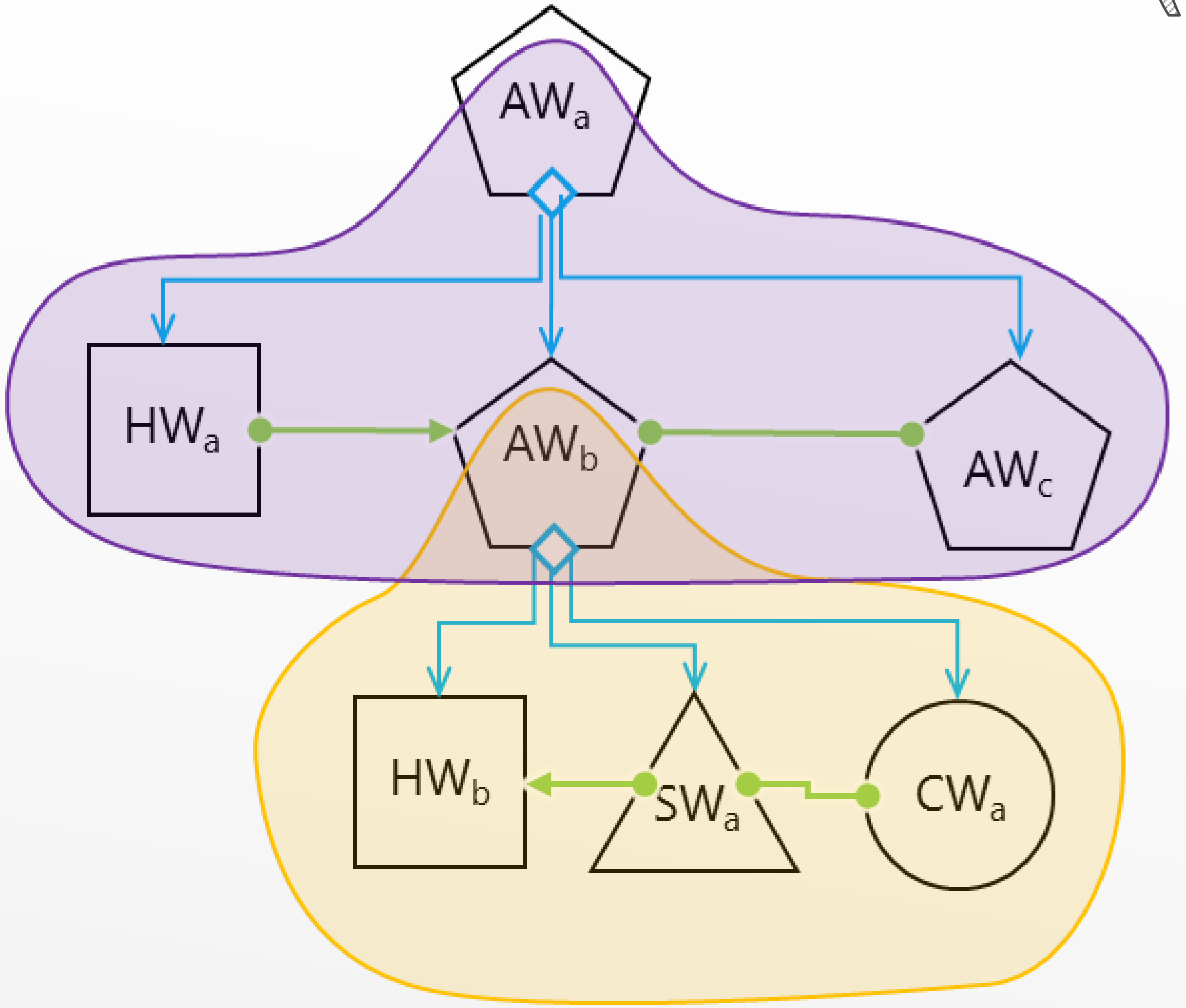




System Manifestation Feature (SMF)

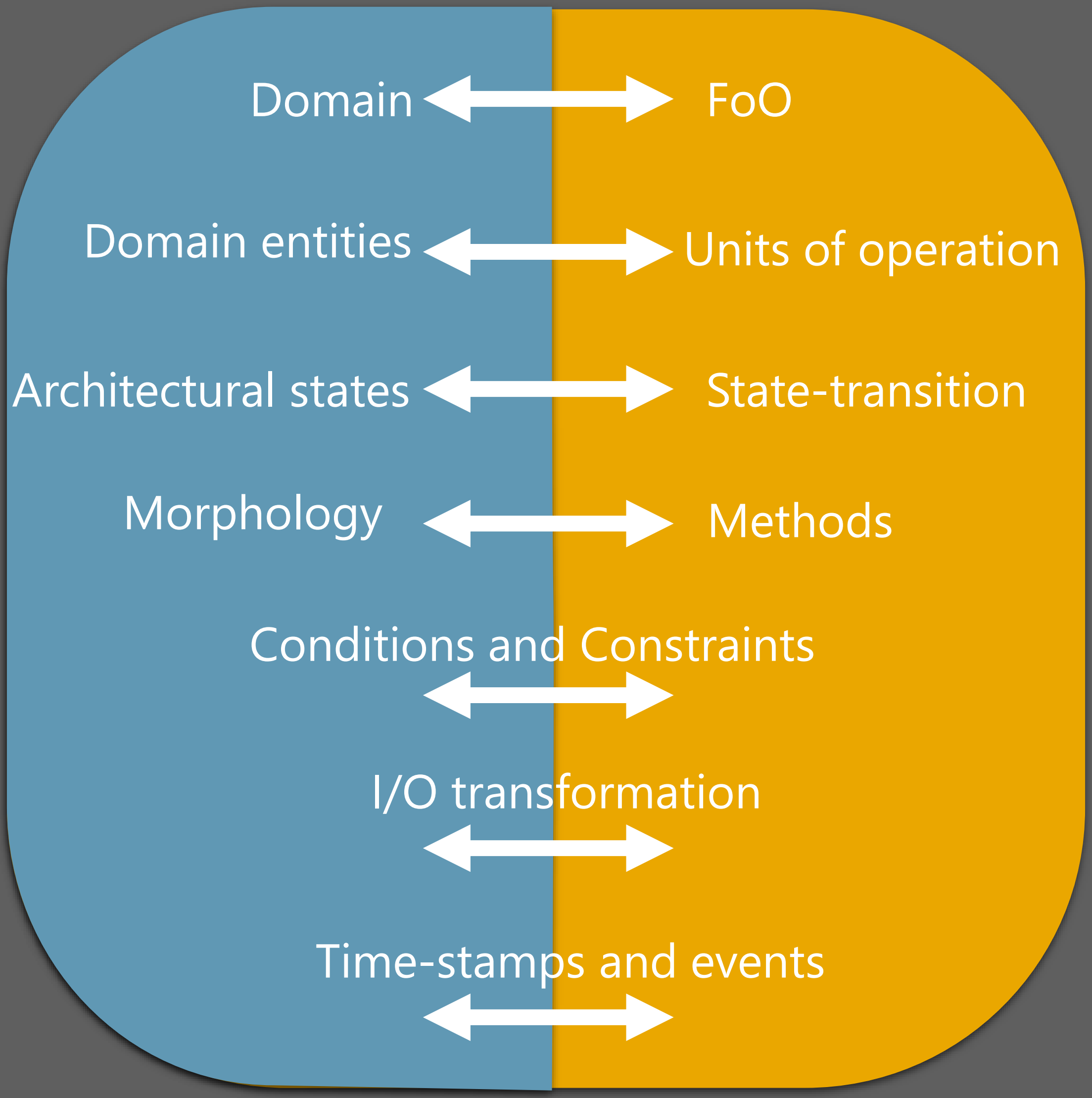
- A kind of system-level feature
- Reusable modeling entity
- Representing components (SW, HW, CW, AW) uniformly
- Captures both operation- and architecture- related info chunks, as well as their relations
- Supports multi-granularity
- Language independent
- Semantic-rich

System Manifestation Feature (SMF)



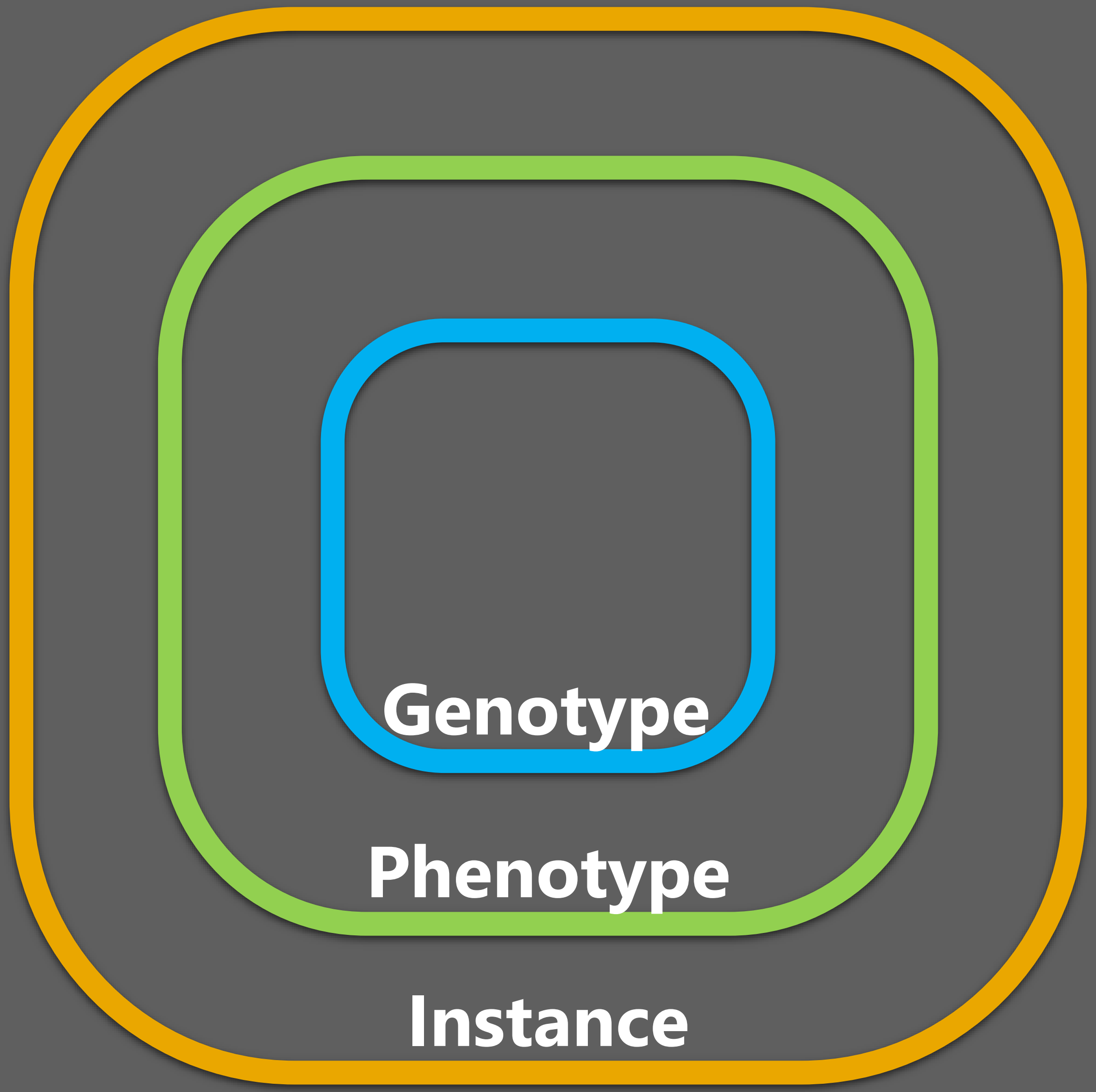
SMF

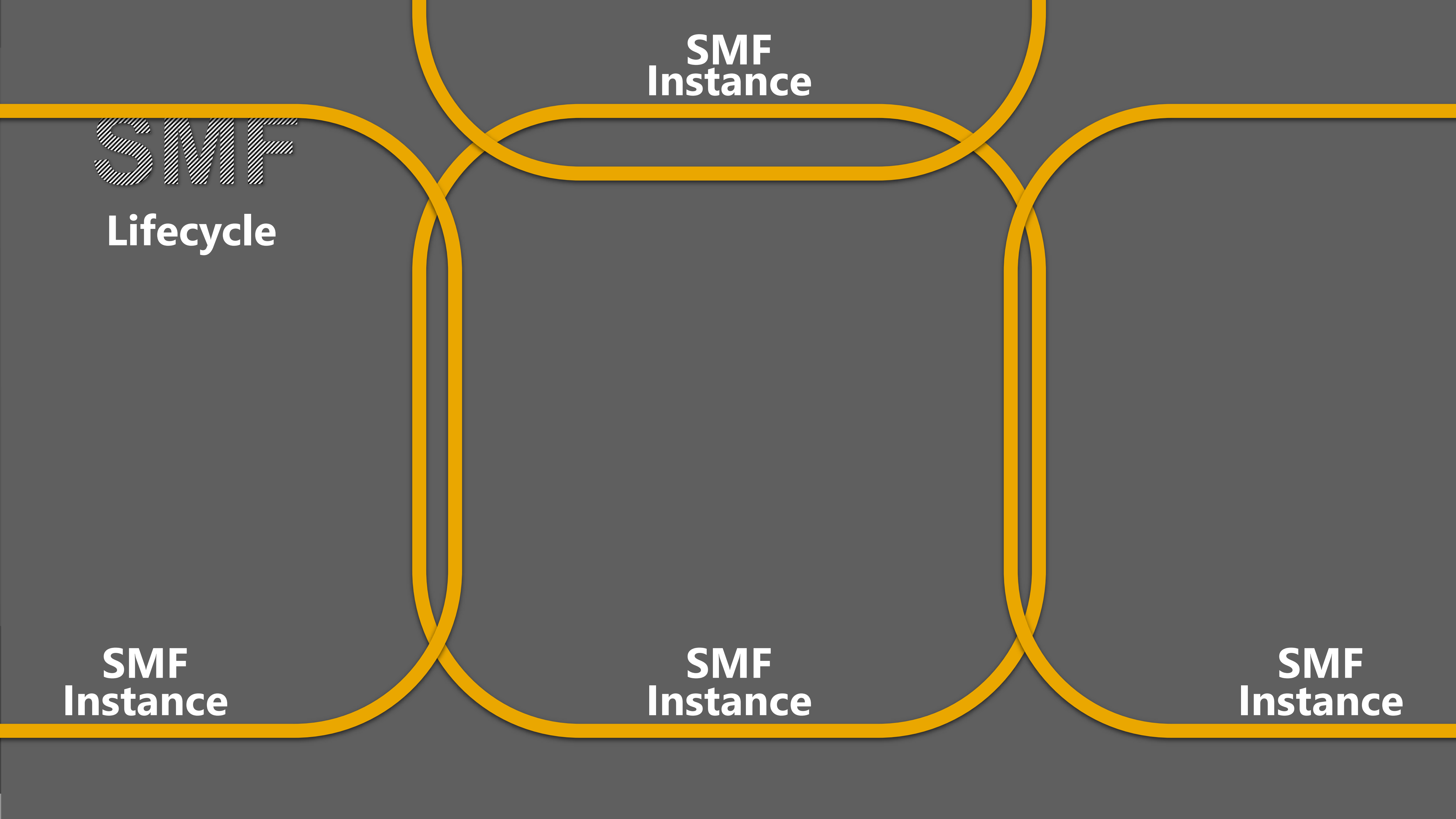
Architecture **Operation**



SMF

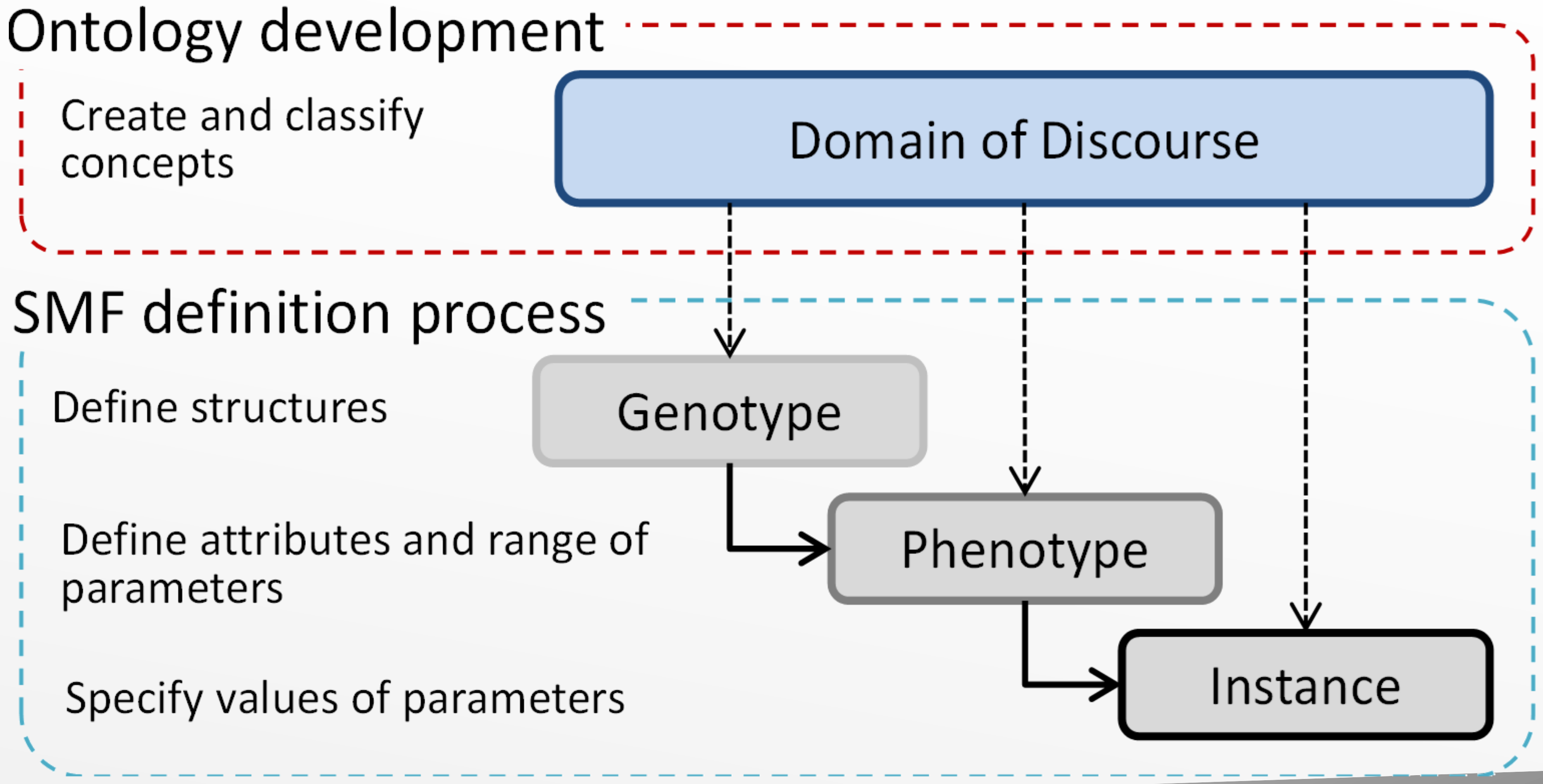
Lifecycle




SMF
Lifecycle
SMF Instance
SMF Instance
SMF Instance
SMF Instance

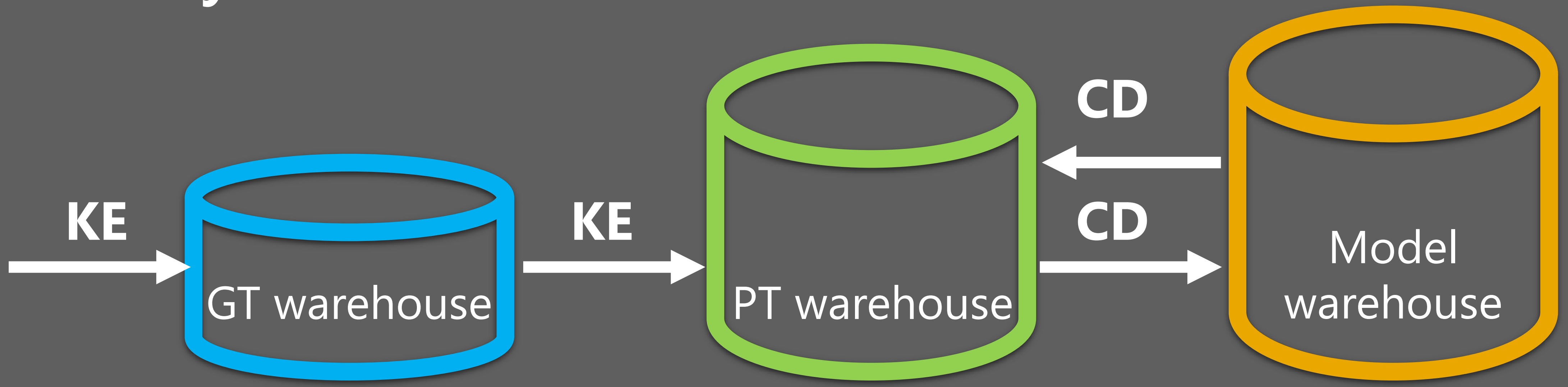
SMF

Lifecycle

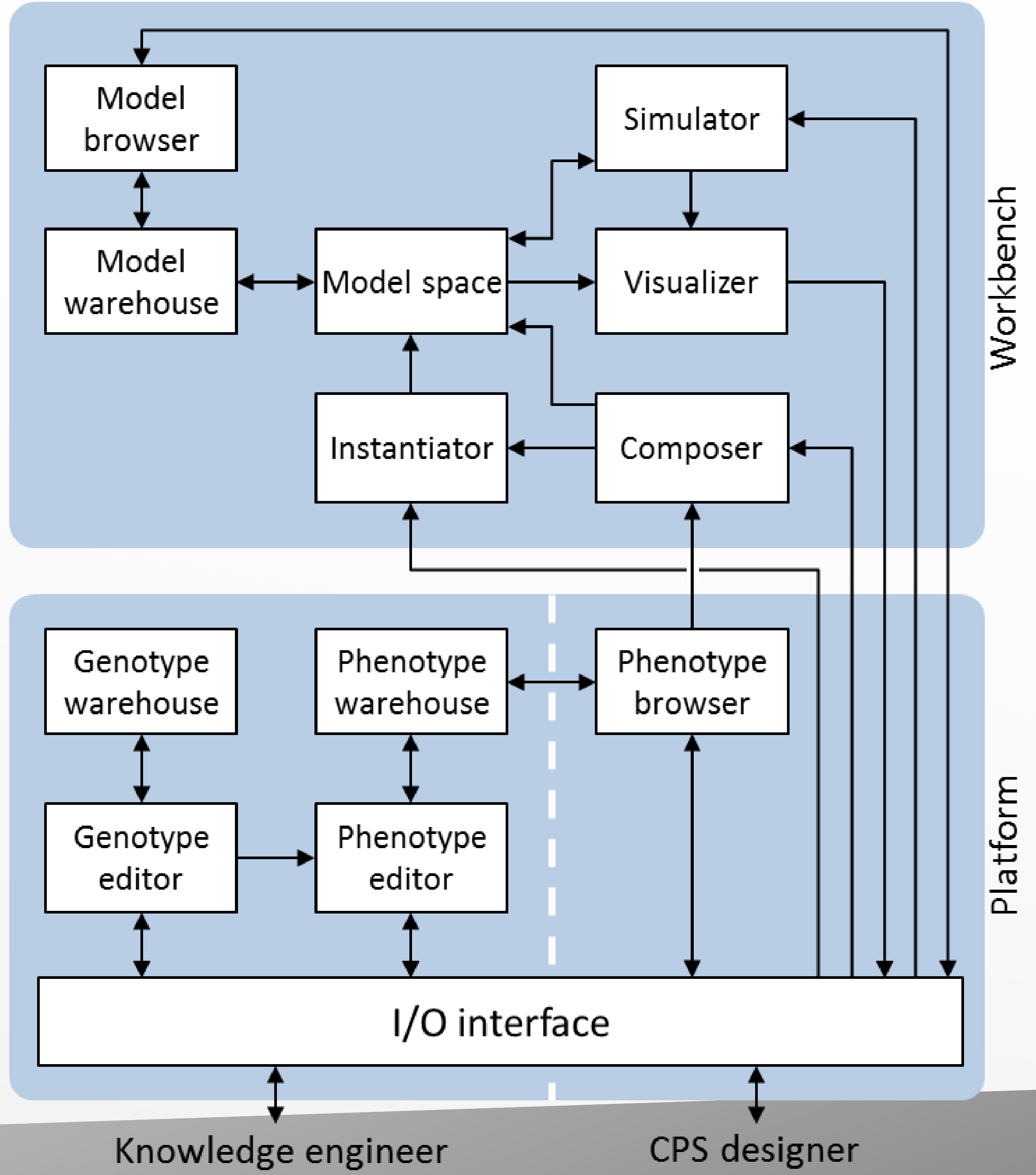


SMF

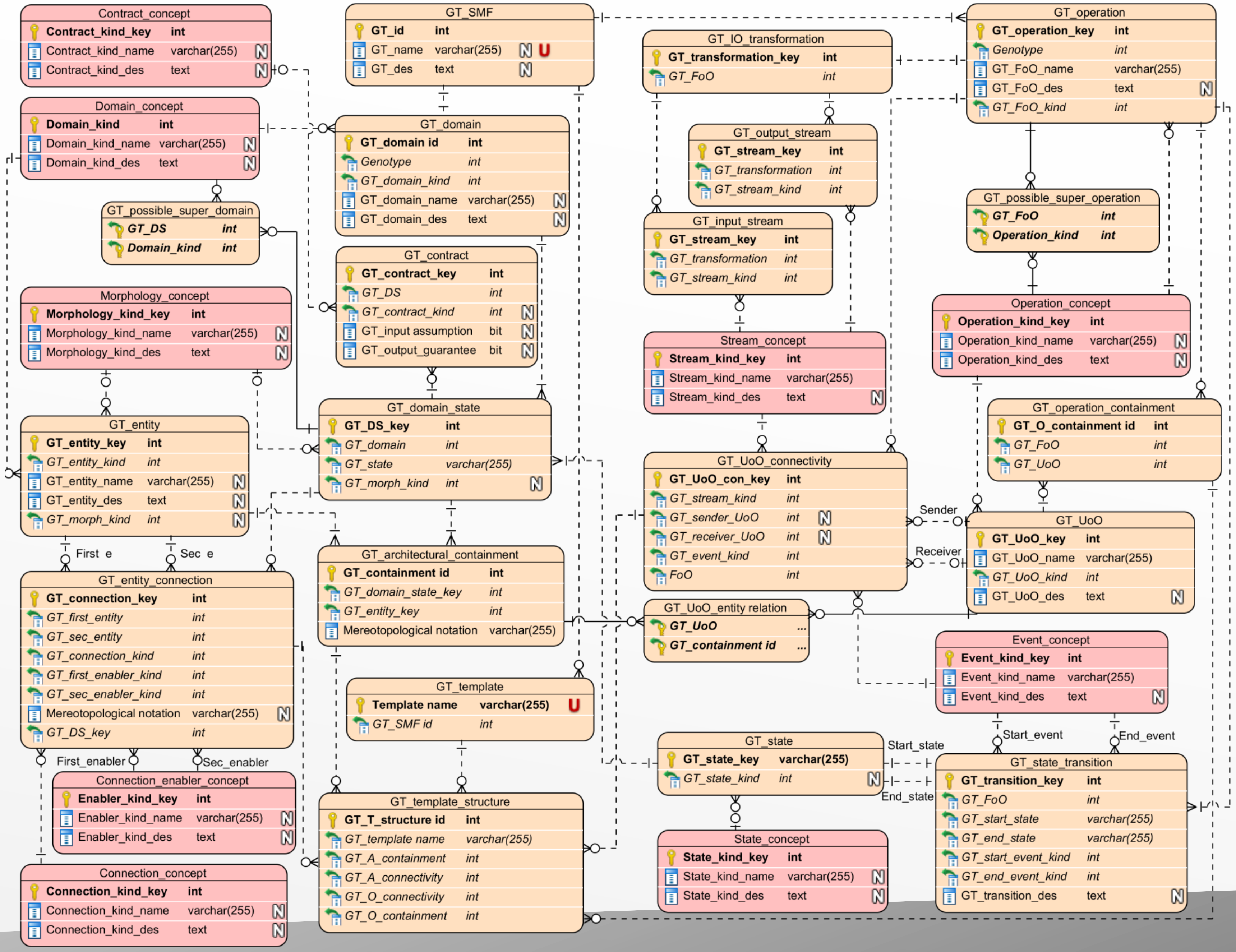
Lifecycle



SMF tool box


Model browser
Simulator
Model warehouse
Model space
Visualizer
Instantiator
Composer
Workbench
Genotype warehouse
Phenotype warehouse
Phenotype browser
Genotype editor
Phenotype editor
Platform
I/O interface
Knowledge engineer
CPS designer

GT database



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GT_DS int
Domain_kind int
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Sec_e
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Sec_enabler
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Receiver
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End_event
Start_state
End_state
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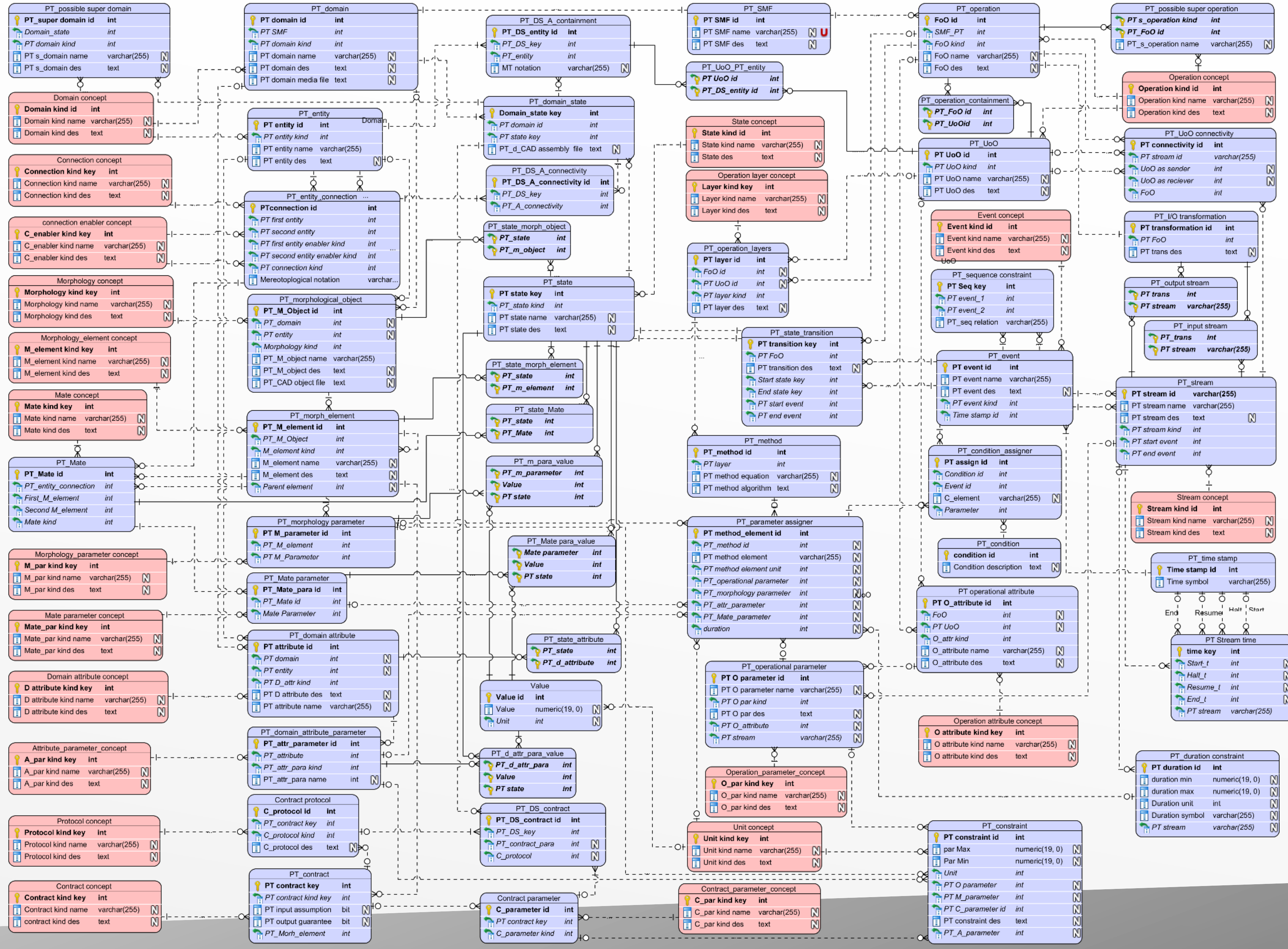
GT_end_event_kind int
GT_transition_des text

PT database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Domain kind name
Domain kind des
Connection concept
Connection kind key
Connection kind name
Connection kind des
connection enabler concept
C_enabler kind key
C_enabler kind name
C_enabler kind des
Morphology concept
Morphology kind key
Morphology kind name
Morphology kind des
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Mate concept
Mate kind key
Mate kind name
Mate kind des
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Second M_element
Mate kind
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Mate parameter concept
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D attribute kind name
D attribute kind des
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A_par kind des
Protocol concept
Protocol kind key
Protocol kind name
Protocol kind des
Contract concept
Contract kind key
Contract kind name
contract kind des
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PT SMF
PT domain kind
PT domain name
PT domain des
PT domain media file
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PT entity kind
PT entity name
PT entity des
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PT first entity
PT second entity
PT first entity enabler kind
PT second entity enabler kind
PT connection kind
Mereotoplogical notation
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PT_M_object des
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M_element des
Parent element
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PT M_Parameter
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PT layer des
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PT FoO
PT transition des
Start state key
End state key
PT start event
PT end event
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PT layer
PT method equation
PT method algorithm
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PT method element
PT_method element unit
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Time stamp id
Time symbol
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Resume
Halt
Start
PT Stream time
time key
Start_t
Half_t
Resume_t
End_t
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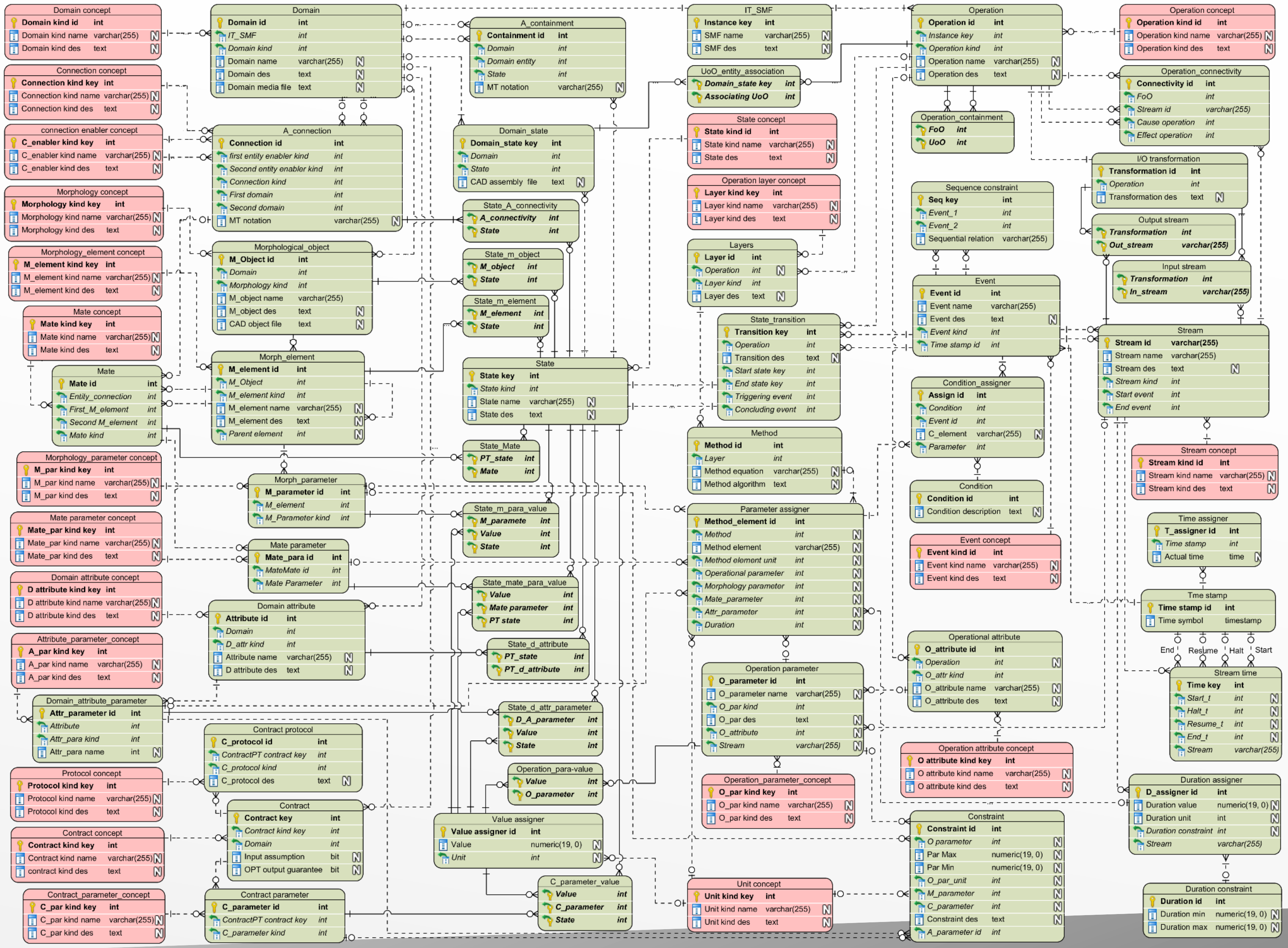
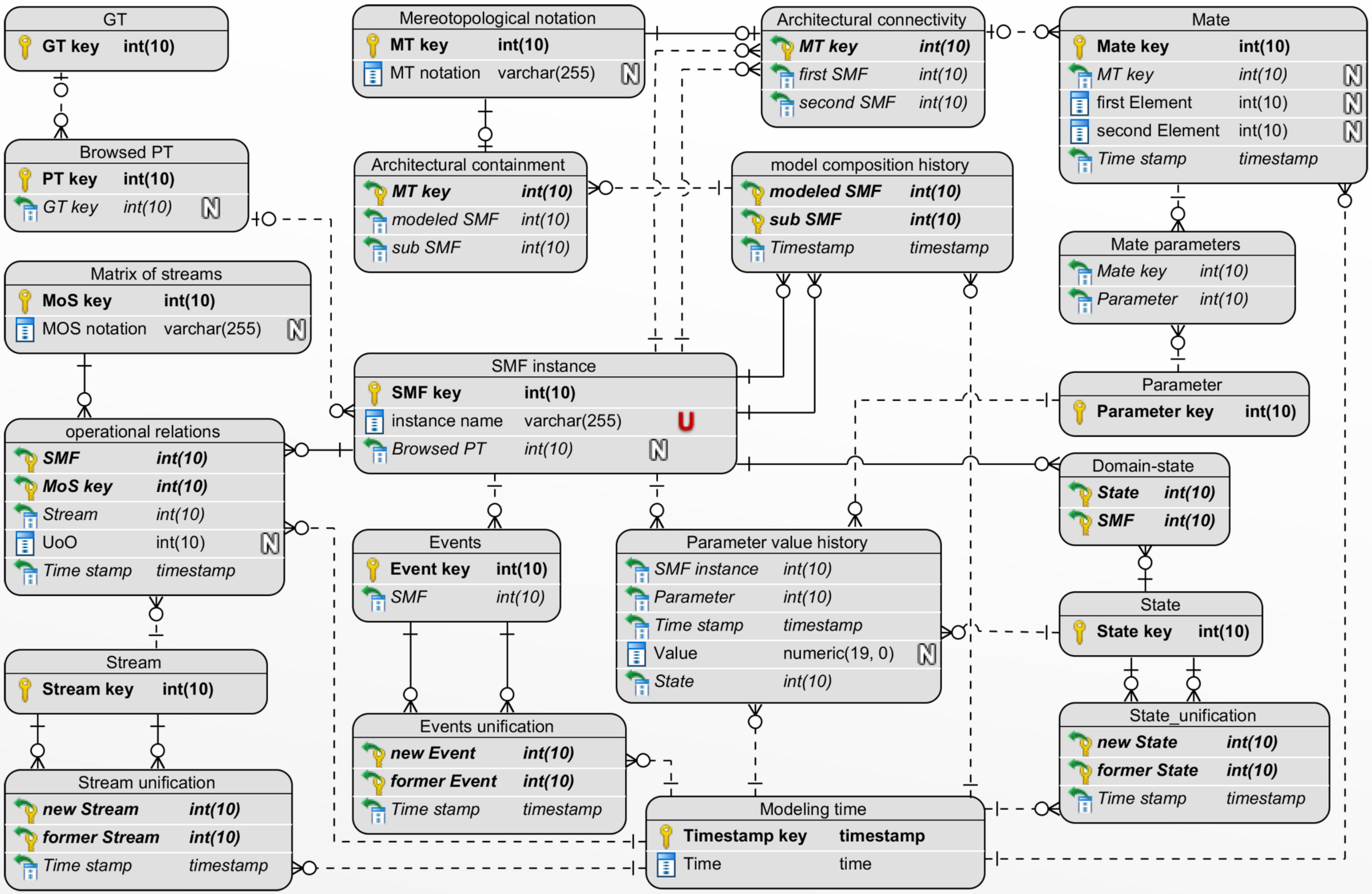
duration max
Duration unit
Duration symbol
PT stream

Model database



Meta-Model database



Affordances of SMF-TB

- Imposing strictly physical view
- Concurrent consideration of architecture and operation
- Uniform information structures for heterogeneous components
- Multi-level multi-granularity
- Multi-aspect coupling among SMFs
- Multi-stage model composition
- Multi-purpose system-level features
- Multiple application context
- Multi-component warehouses
- Active ontologies

Aspects of benchmarking

A1: Addressing heterogeneity of CPSs

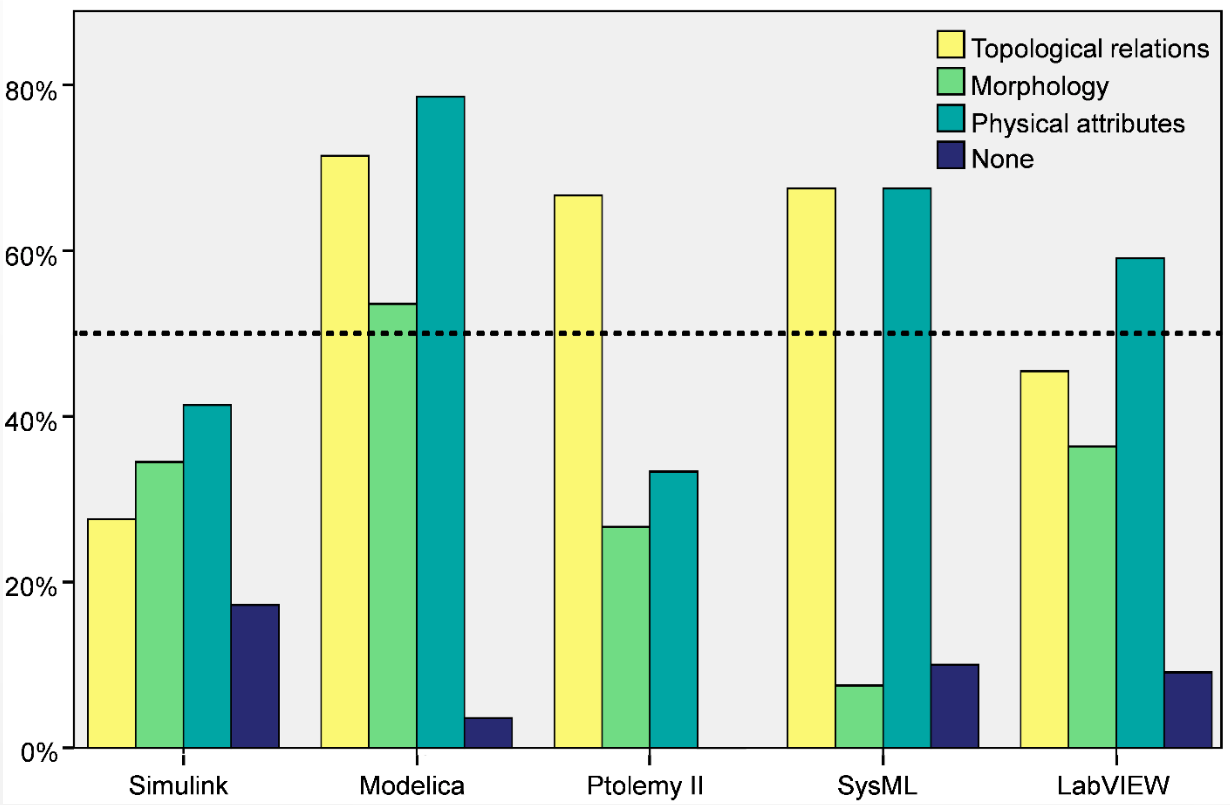
A2: Addressing integrity of CPSs:

A3: Addressing complexity of CPSs:

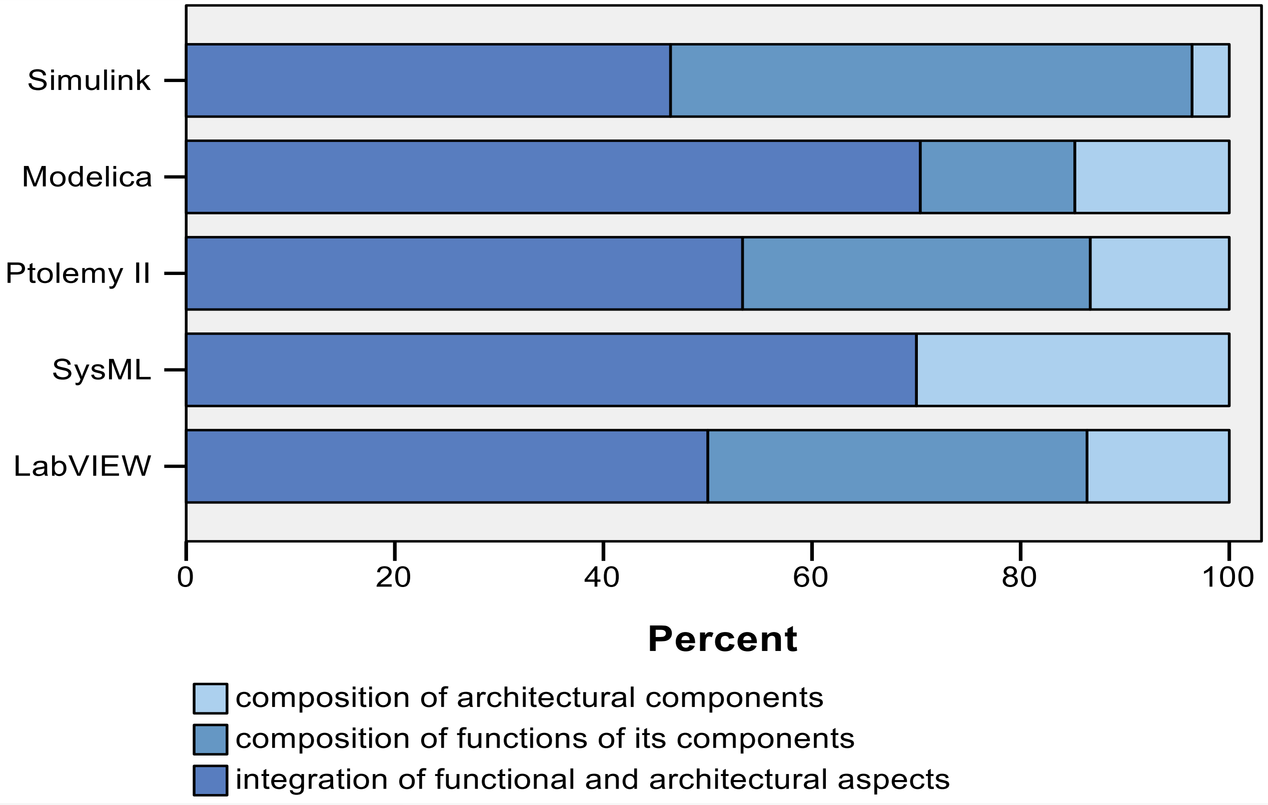
A4: Addressing information comprehensiveness:

A5: Addressing tool implementation:

Results

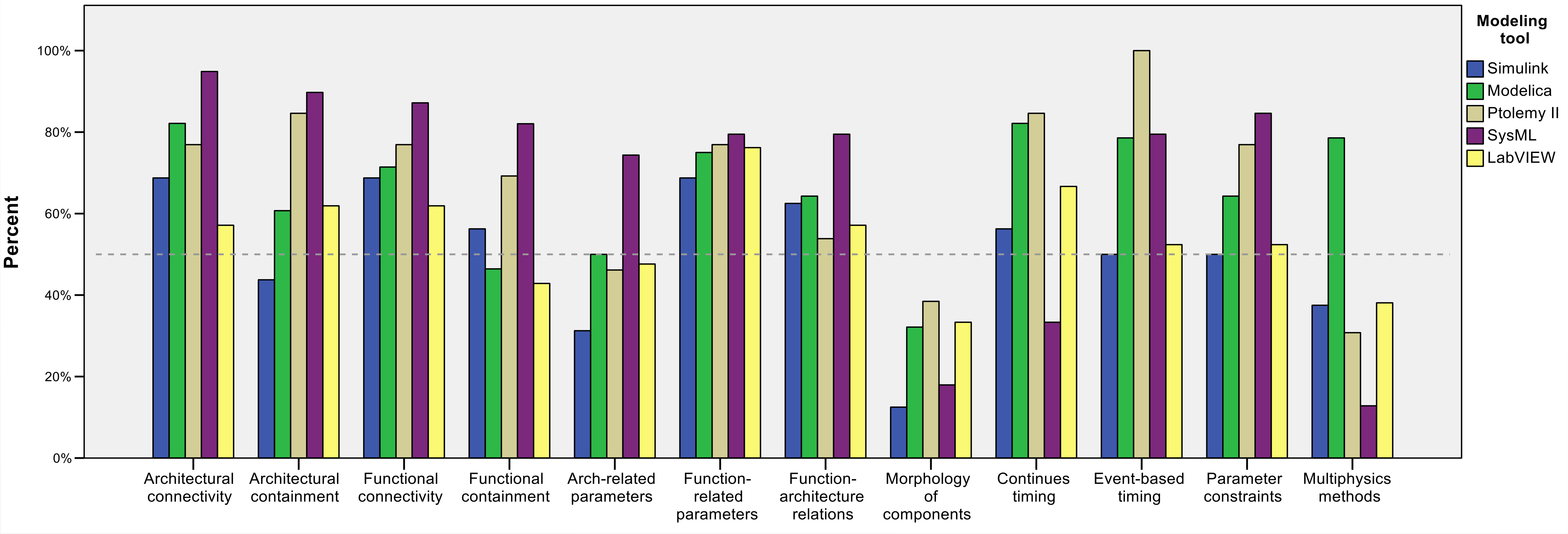


Topological relations
Morphology
Physical attributes
None
80%
60%
40%
20%
0%
Simulink
Modelica
Ptolemy II
SysML
LabVIEW



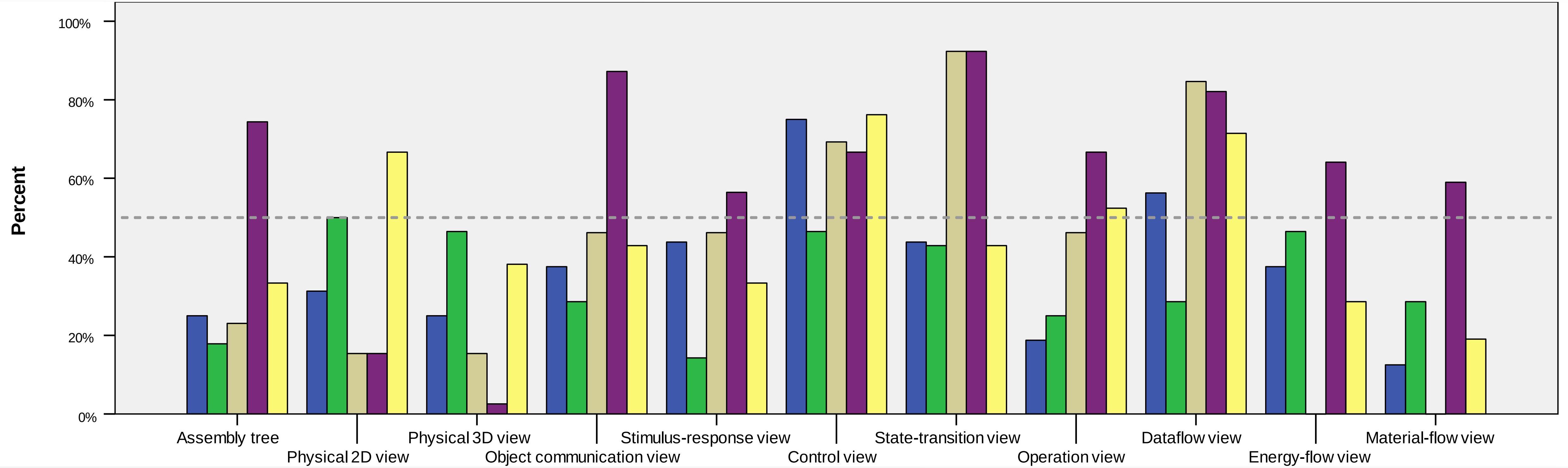
Simulink
Modelica
Ptolemy II
SysML
LabVIEW
0
20
40
60
80
100
Percent
composition of architectural components
composition of functions of its components
integration of functional and architectural aspects

Results



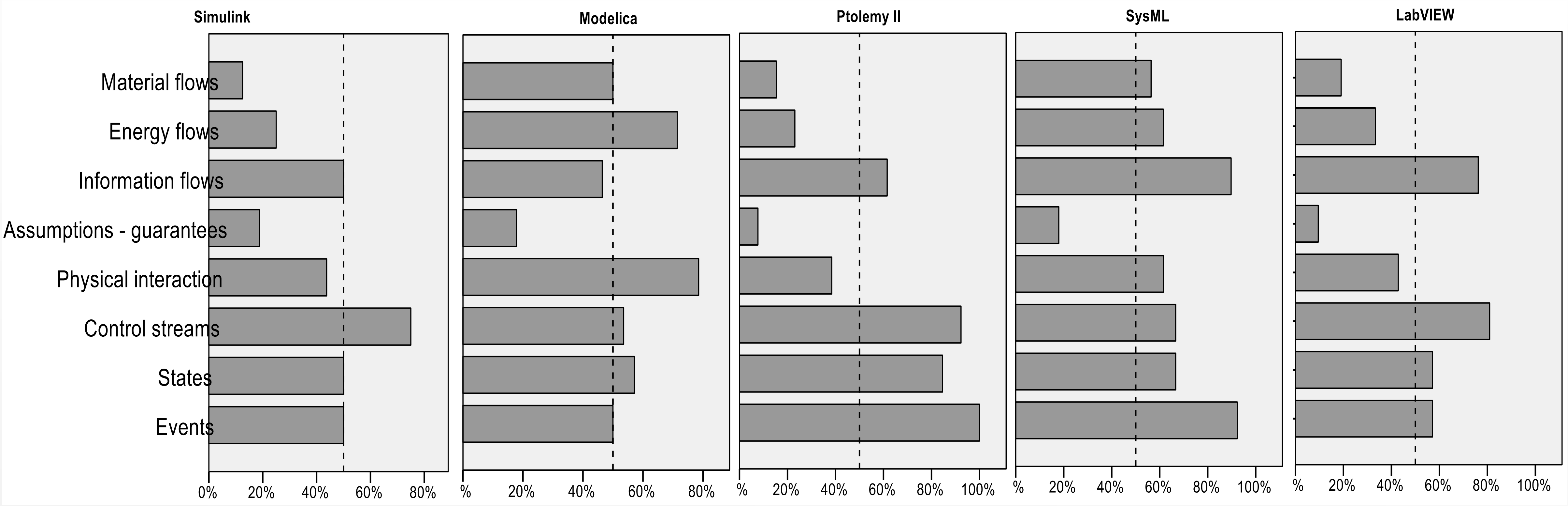
Modeling tool
Simulink
Modelica
Ptolemy II
SysML
LabVIEW
Percent
100%
80%
60%
40%
20%
0%
Architectural connectivity
Architectural containment
Functional connectivity
Functional containment
Arch-related parameters
Function-related parameters
Function-architecture relations
Morphology of components
Continues timing
Event-based timing
Parameter constraints
Multiphysics methods

Results



100%
80%
60%
40%
20%
0%
Percent
Assembly tree
Physical 2D view
Physical 3D view
Object communication view
Stimulus-response view
Control view
State-transition view
Operation view
Dataflow view
Energy-flow view
Material-flow view

Results



Simulink
Modelica
Ptolemy II
SysML
LabVIEW
Material flows
Energy flows
Information flows
Assumptions - guarantees
Physical interaction
Control streams
States
Events
0%
20%
40%
60%
80%
100%

Publications

- Pourtalebi, S., Horváth, I., & Opiyo, E. (2013). **Multi-aspect study of mass customization in the context of cyber-physical consumer durables**. In ASME 2013 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. American Society of Mechanical Engineers, pp. V004T05A006-V004T05A006.
- Pourtalebi, S., Horváth, I., & Opiyo, E. (2014). **New features imply new principles? deriving design principles for mass customization of cyber-physical consumer durables**. Proceedings of the TMCE, Budapest, Hungary, 95-108.
- Pourtalebi, S., Horváth, I., & Opiyo, E. Z. (2014a). **First steps towards a mereo-operandi theory for a system feature-based architecting of cyber-physical systems**. In GI-Jahrestagung, pp. 2001-2006.
- Pourtalebi, S., Horváth, I., & Opiyo, E. Z. (2014b). **New features imply new principles? Deriving design principles for mass customization of cyber-physical consumer durables**. In Proceedings of the 10th international symposium on tools and methods of competitive engineering TMCE 2014, Budapest, Hungary, May 19-23, 2014, Delft University of Technology.
- Horváth, I., & Pourtalebi, S. (2015). **Fundamentals of a mereo-operandi theory to support transdisciplinary modeling and co-design of cyber-physical systems**. In ASME 2015 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. American Society of Mechanical Engineers, pp. V01AT02A005-V01AT02A005.
- Pourtalebi, S., & Horváth, I. (2016a). **Towards a methodology of system manifestation features-based pre-embodiment design**. Journal of Engineering Design, 1-37.
- Pourtalebi, S., & Horváth, I. (2016b). **Information schema constructs for defining warehouse databases of genotypes and phenotypes of system manifestation features**. Frontiers of Information Technology & Electronic Engineering, vol. x, no. x, pp. x-x.
- Pourtalebi, S., & Horváth, I. (2017). **Information schema constructs for instantiation and composition of system manifestation features**. Frontiers of Information Technology & Electronic Engineering, vol. x, no. x, pp. x-x.
- Pourtalebi, S., & Horváth, I. (2018). **Benchmarking the conceptual framework of a system-level manifestation features-based toolbox**, (in preparation for journal publication), pp. x-x.