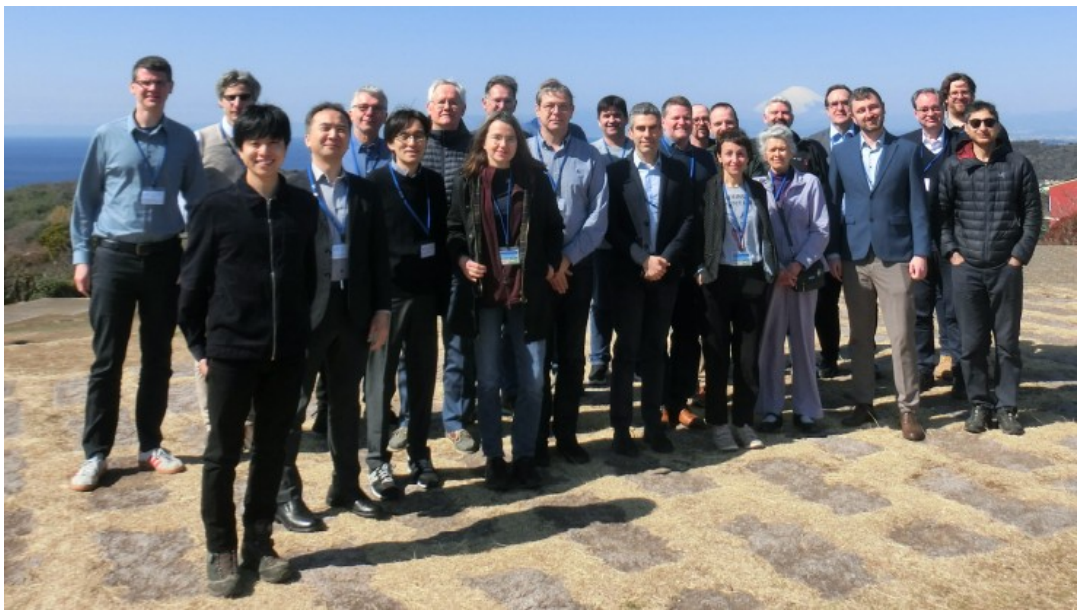
Relating (Multi-Paradigm) Modelling Concepts

Joachim Denil and Hans Vangheluwe



Tuesday 25 March 2025

NII 湘南会議 SHONAN MEETING

Universiteit Antwerpen

University of Antwerp
Cosys-lab | Co-Design of Cyber Physical Systems

Ansymo
Antwerp Systems & Software Modelling
University of Antwerp

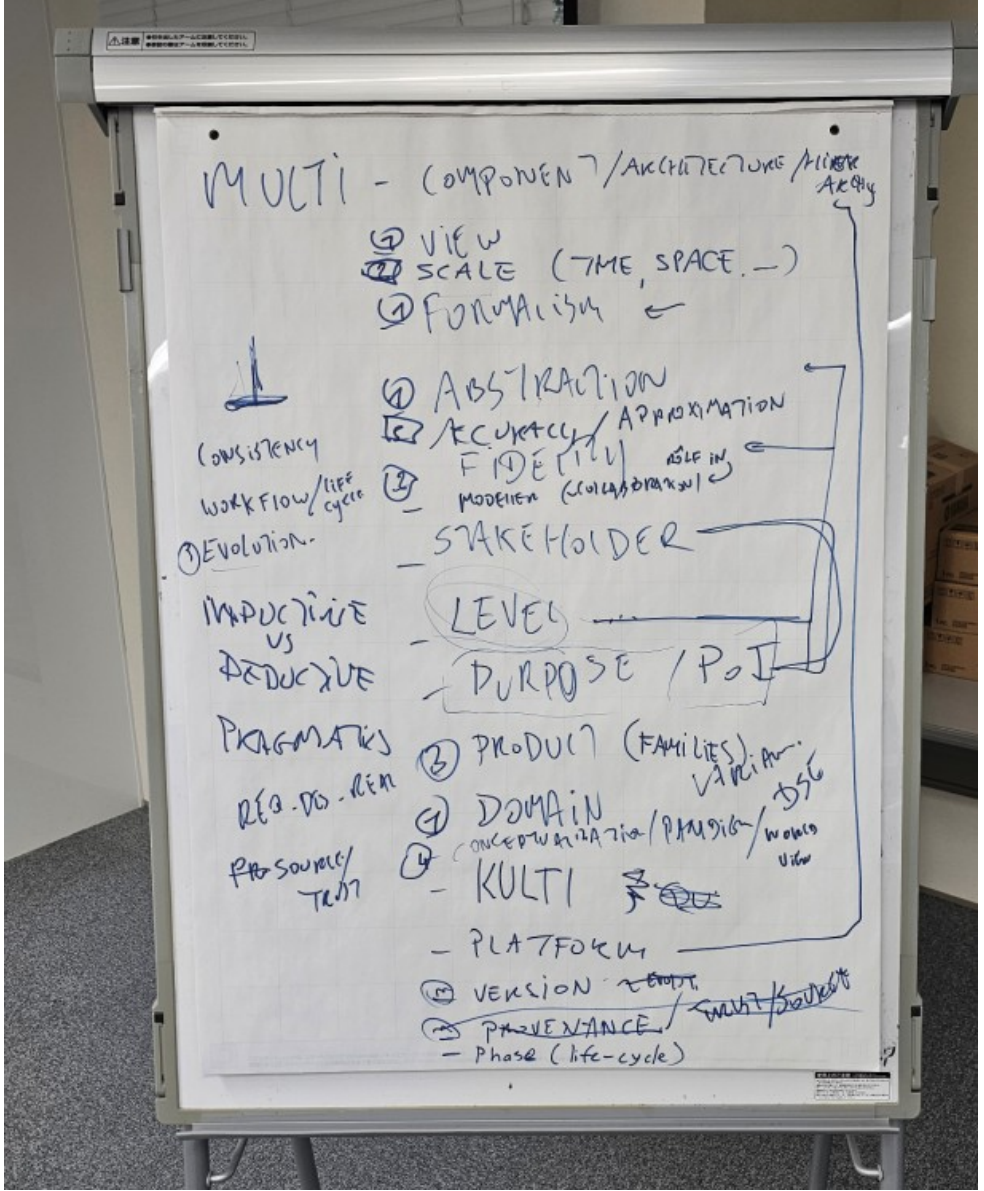
Nexor
Cyber-Physical Systems
University of Antwerp

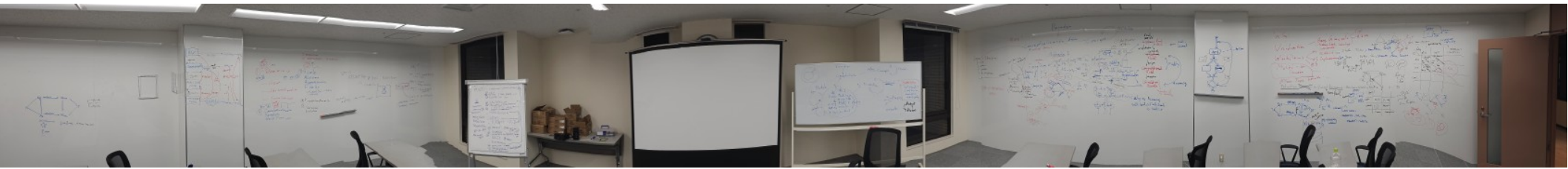
FLANDERS MAKE
MANUFACTURING INNOVATION NETWORK

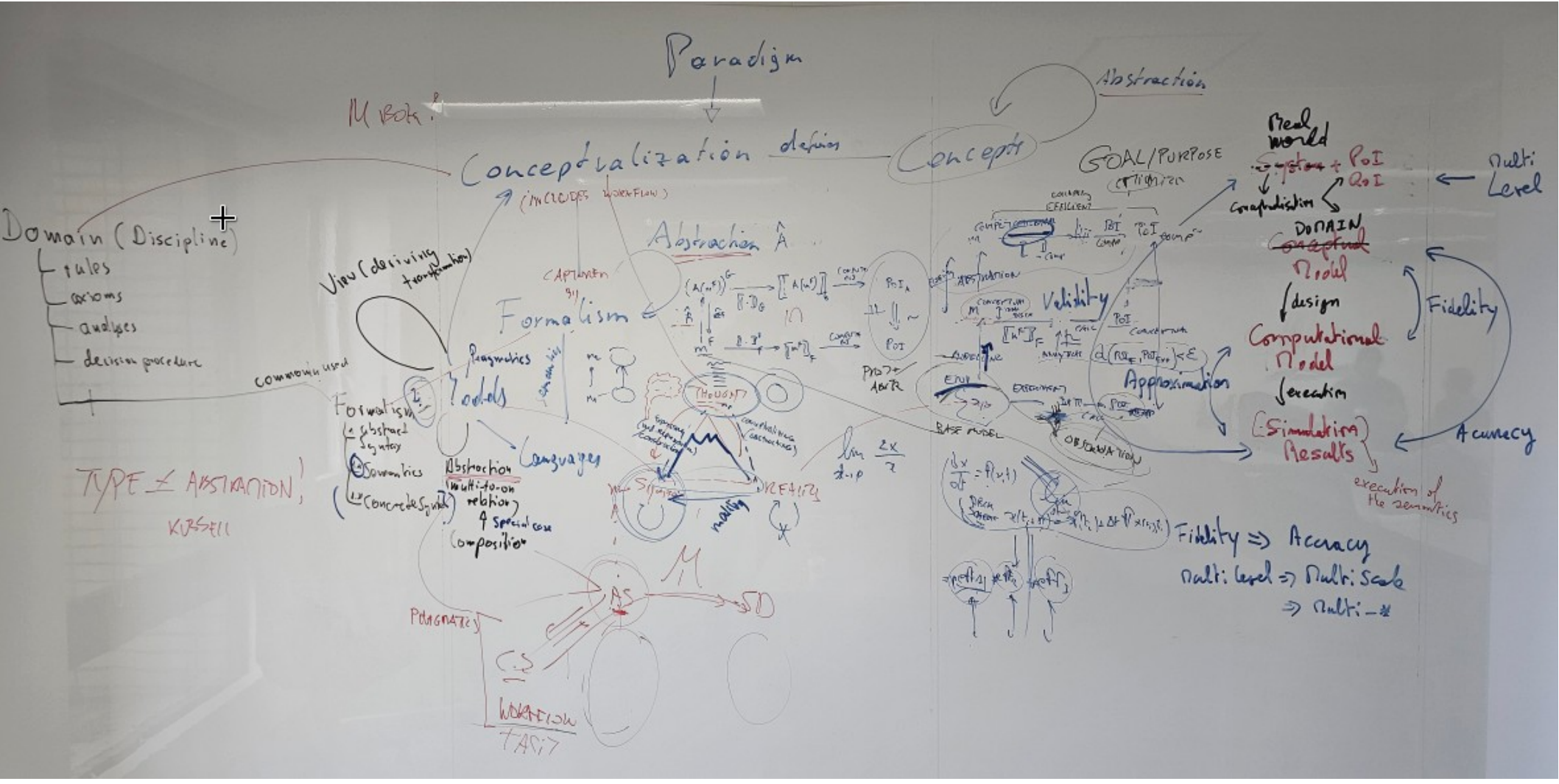
MPM4CPS

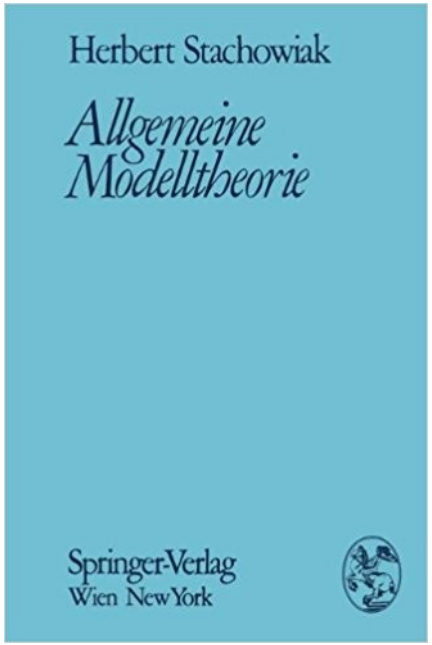
cost

Multi-*
==
Ambitious






Paradigm
Abstraction
Conceptualization
Concepts
Domain (Discipline)
rules
axioms
analyses
decision procedure
View (deriving transformation)
Formalism
Models
Languages
Abstraction
TYPE ≠ ABSTRACTION
KURSELL
GOAL/PURPOSE
Real World
PoI
QoI
Multi Level
DOMAIN
Model
design
Computational Model
execution
Simulation Results
Fidelity
Accuracy
Validity
Approximation
execution of the semantics
Fidelity ⇒ Accuracy
multi level ⇒ multi scale
⇒ multi-*

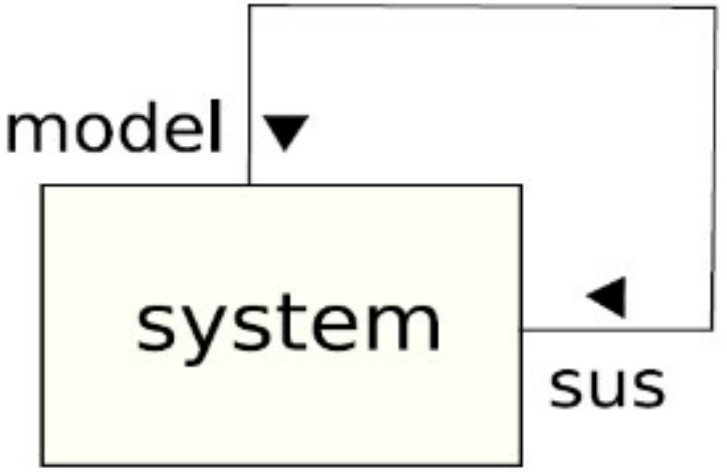


1973

“Model” Features

mapping feature	A model is based on an original.[4]
reduction feature	A model only reflects a (relevant) selection of an original’s properties.
pragmatic feature	A model needs to be usable in place of an original with respect to some purpose.

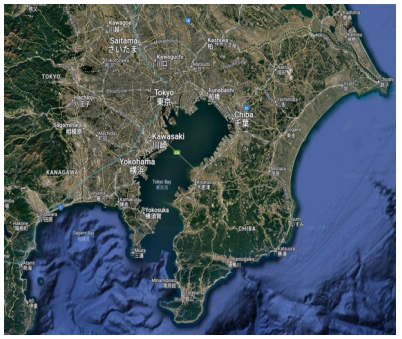
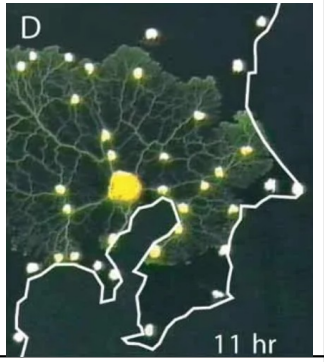
Marvin L. Minsky



To an observer B, an object A* is a model of an object A to the extent that B can use A* to answer questions that interest him about A.

Matter, Mind and Models

System under Study (SuS) vs. Model

	Real-World Model	**Virtual** Model
Real-World SuS	 	
Virtual SuS		

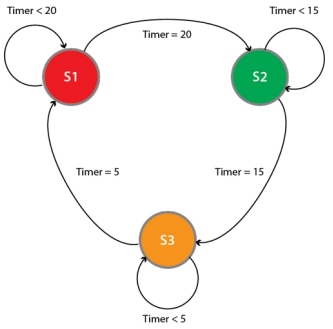
System under Study (SuS) vs. Model

	Real-World Model	**Virtual** Model
Real-World SuS	 	
Virtual SuS		

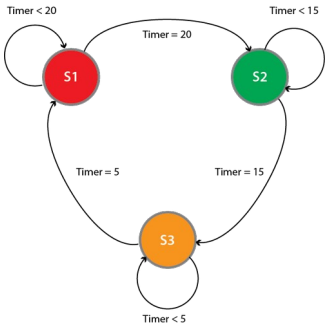
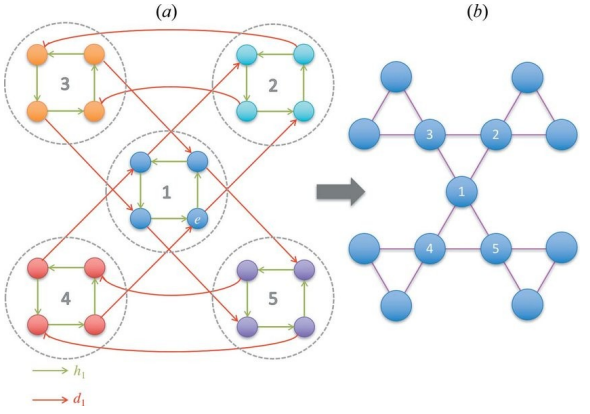
System under Study (SuS) vs. Model

	Real-World Model	**Virtual** Model
Real-World SuS	 	
Virtual SuS	$\frac{dx}{dt} = \alpha x - \beta xy,$ $\frac{dy}{dt} = -\gamma y + \delta xy,$ 	

System under Study (SuS) vs. Model

	Real-World Model	**Virtual** Model
Real-World SuS	 	 
Virtual SuS	$\frac{dx}{dt} = \alpha x - \beta xy,$ $\frac{dy}{dt} = -\gamma y + \delta xy,$ 	

System under Study (SuS) vs. Model

	Real-World Model	**Virtual** Model
Real-World SuS	 	 
Virtual SuS	$\frac{dx}{dt} = \alpha x - \beta xy,$ $\frac{dy}{dt} = -\gamma y + \delta xy,$ 	

Triangle of Reference, Semiotic Triangle

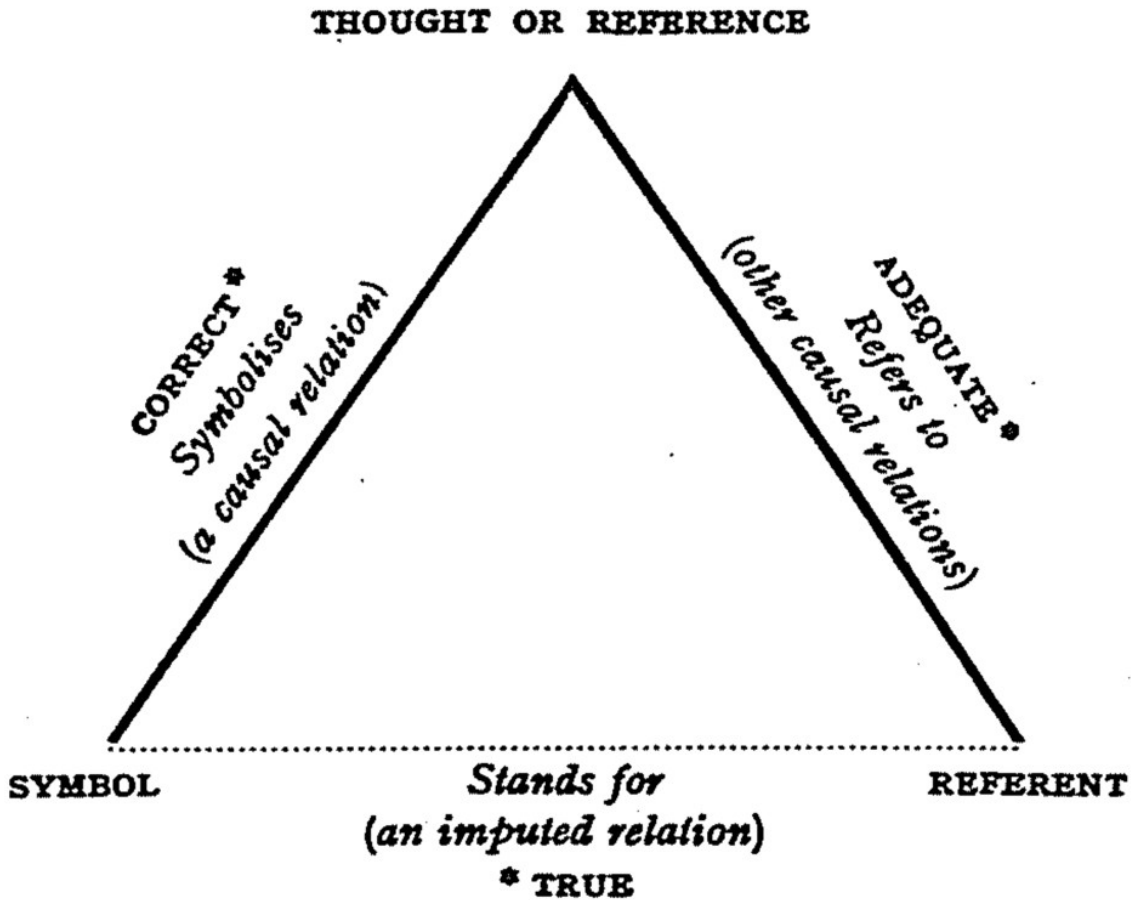
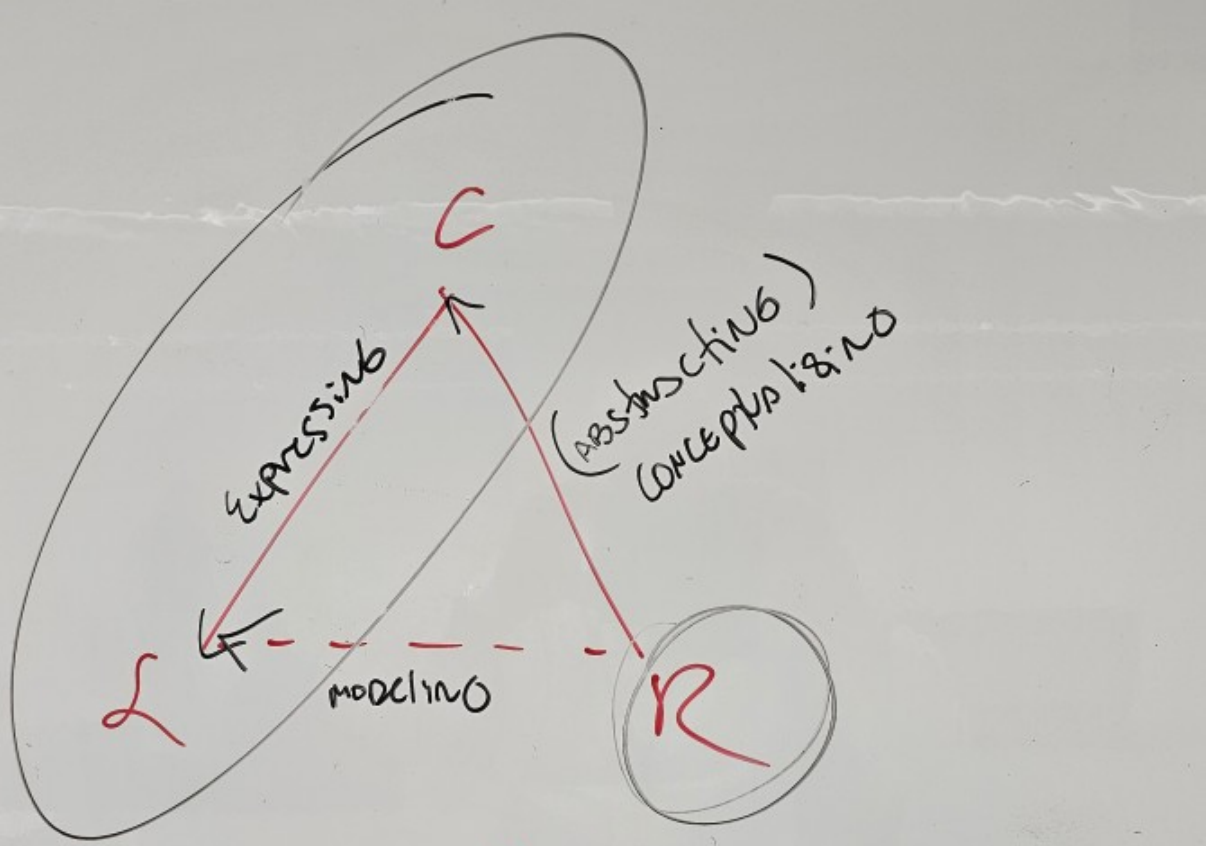
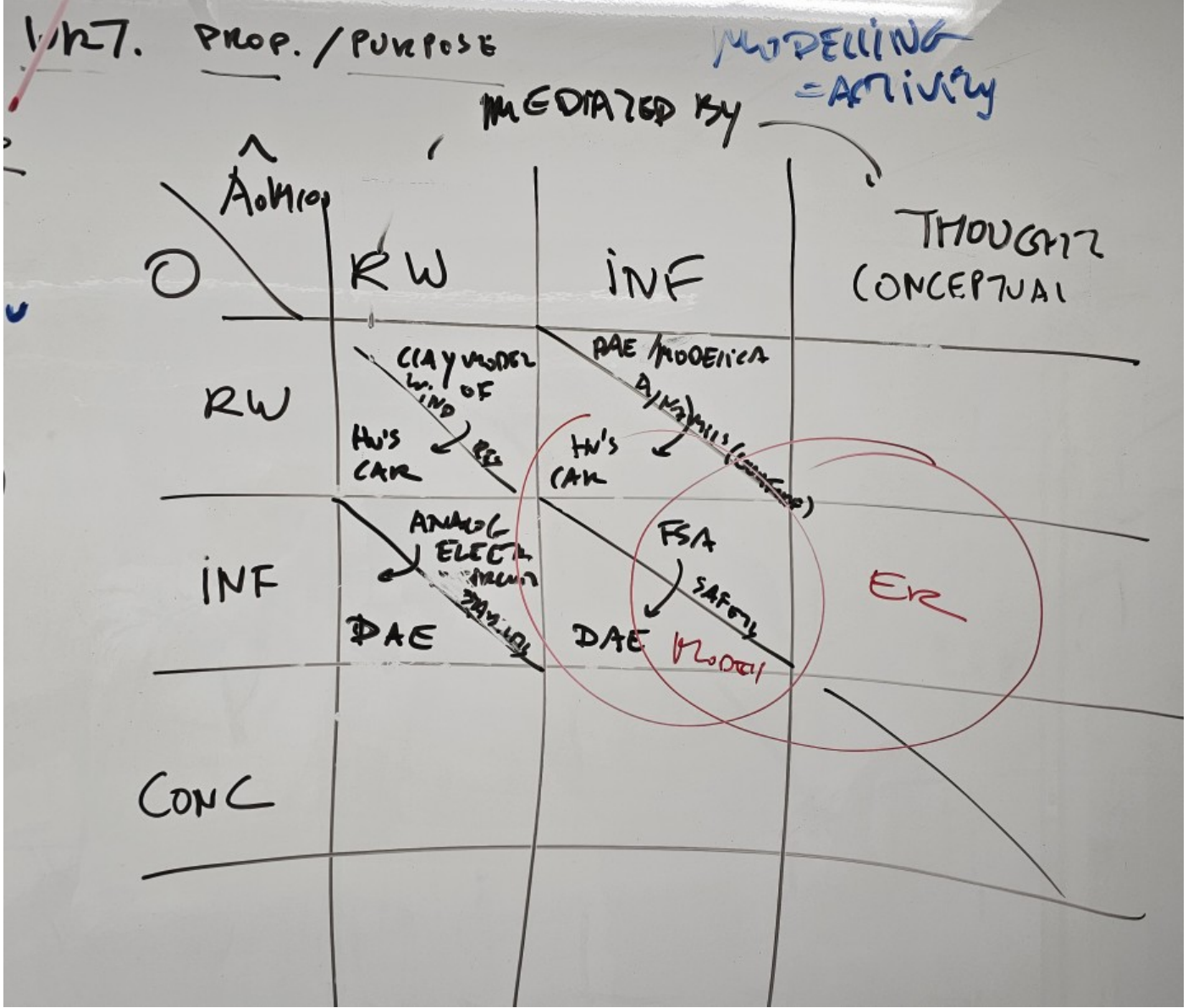


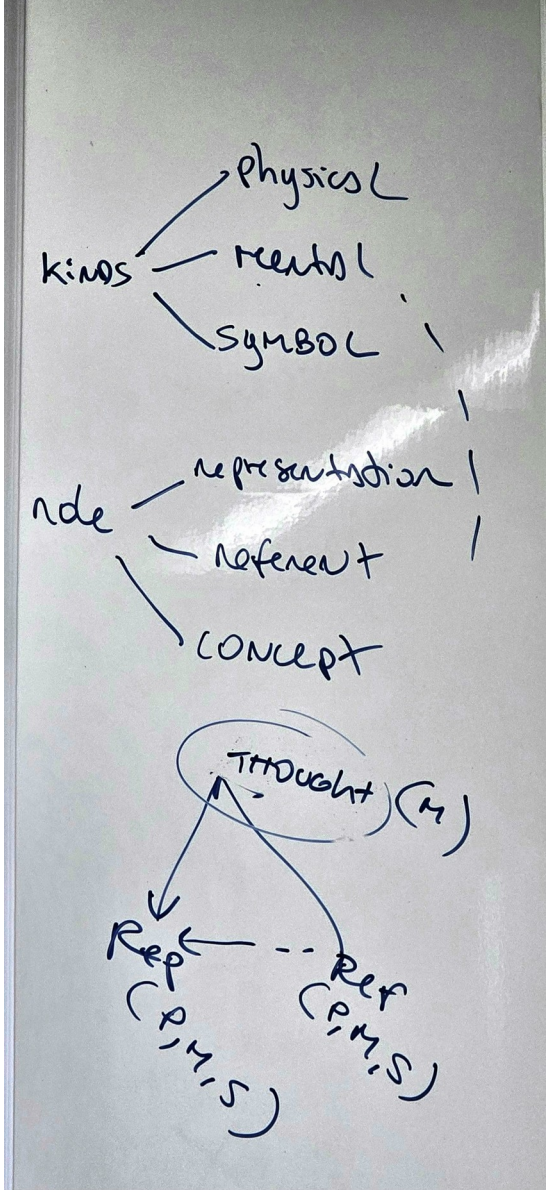
Figure taken from page 11, The Meaning of Meaning: A Study of the Influence of Language upon Thought and of the Science of Symbolism, 1923, was co-authored by C. K. Ogden and I. A. Richards, Magdalene College, University of Cambridge



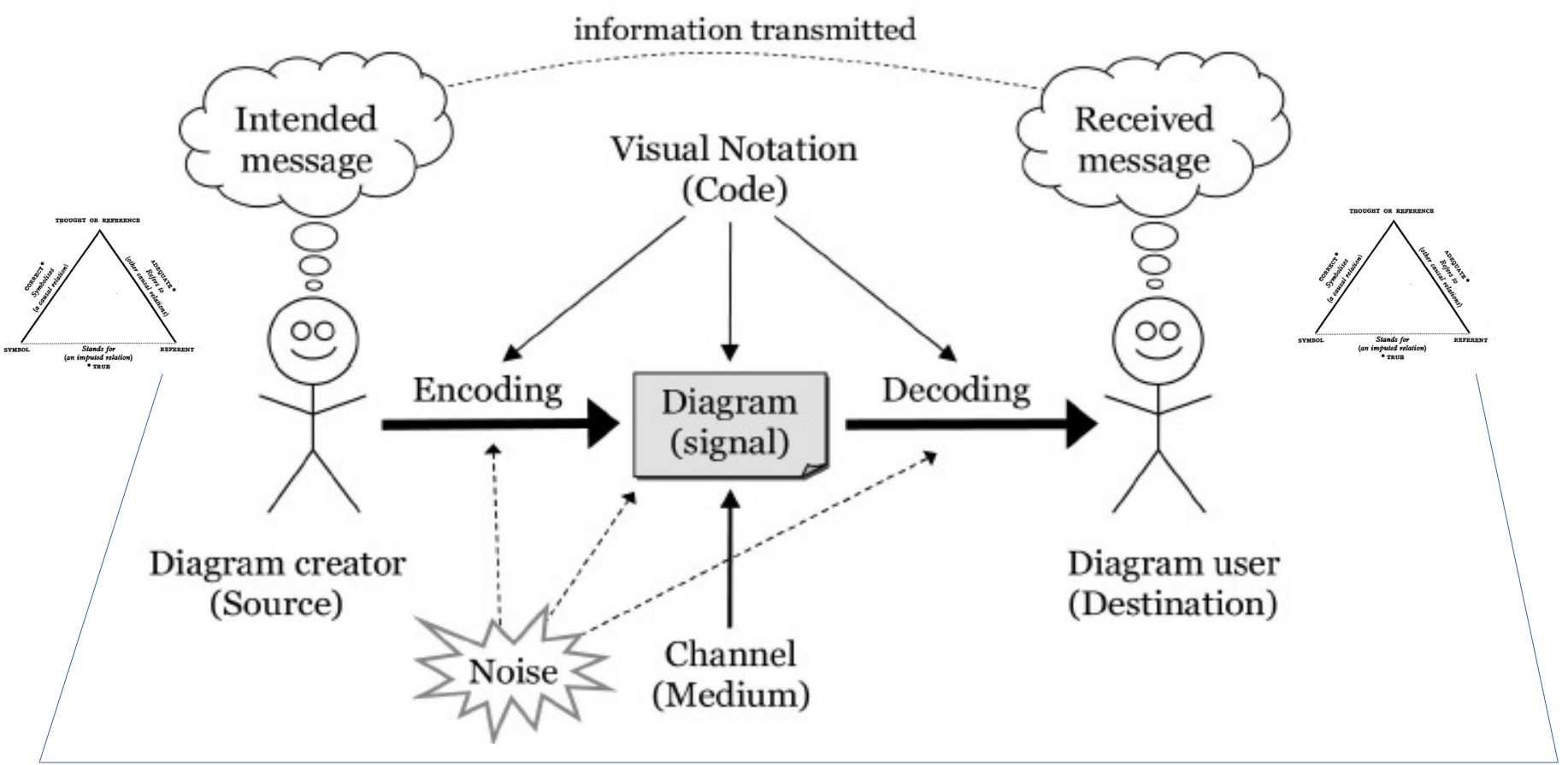
Modeling = conceptualizing ; Expressing (including representing in language)


PROP. / PURPOSE
MODELLING = ACTIVITY
MEDIATED BY
THOUGHT
CONCEPTUAL
RW
INF
CONC
DAE
FSA
SAFETY
ER

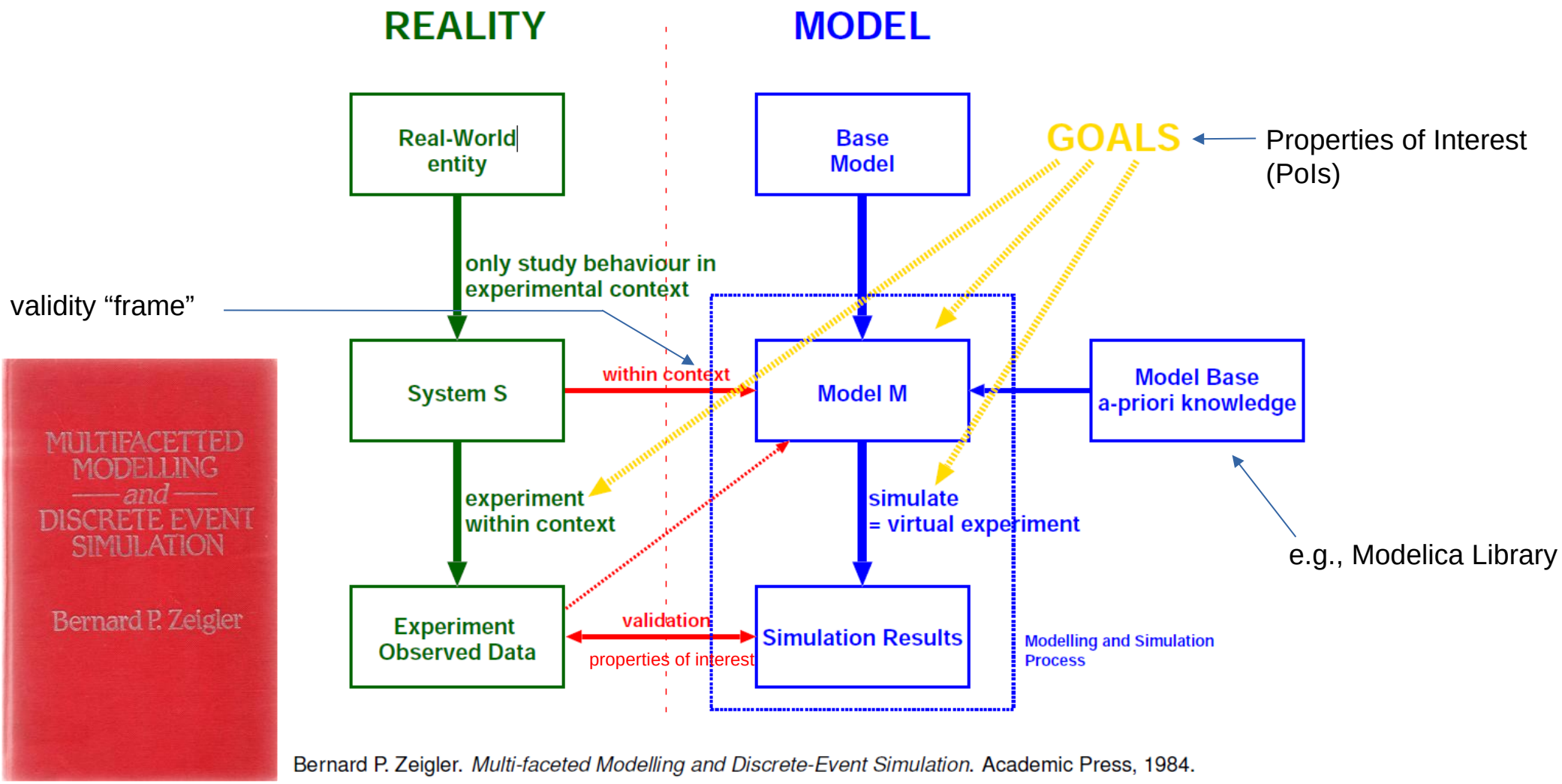

Physical
kinds
mental
SYMBOL
representation
referent
CONCEPT
THOUGHT


Physical
kinds
mental
symbol
representation
nde
referent
concept
THOUGHT
(M)
Rep
(P,M,S)
Ref
(P,M,S)

Moody “Physics of Notation”: communication theory

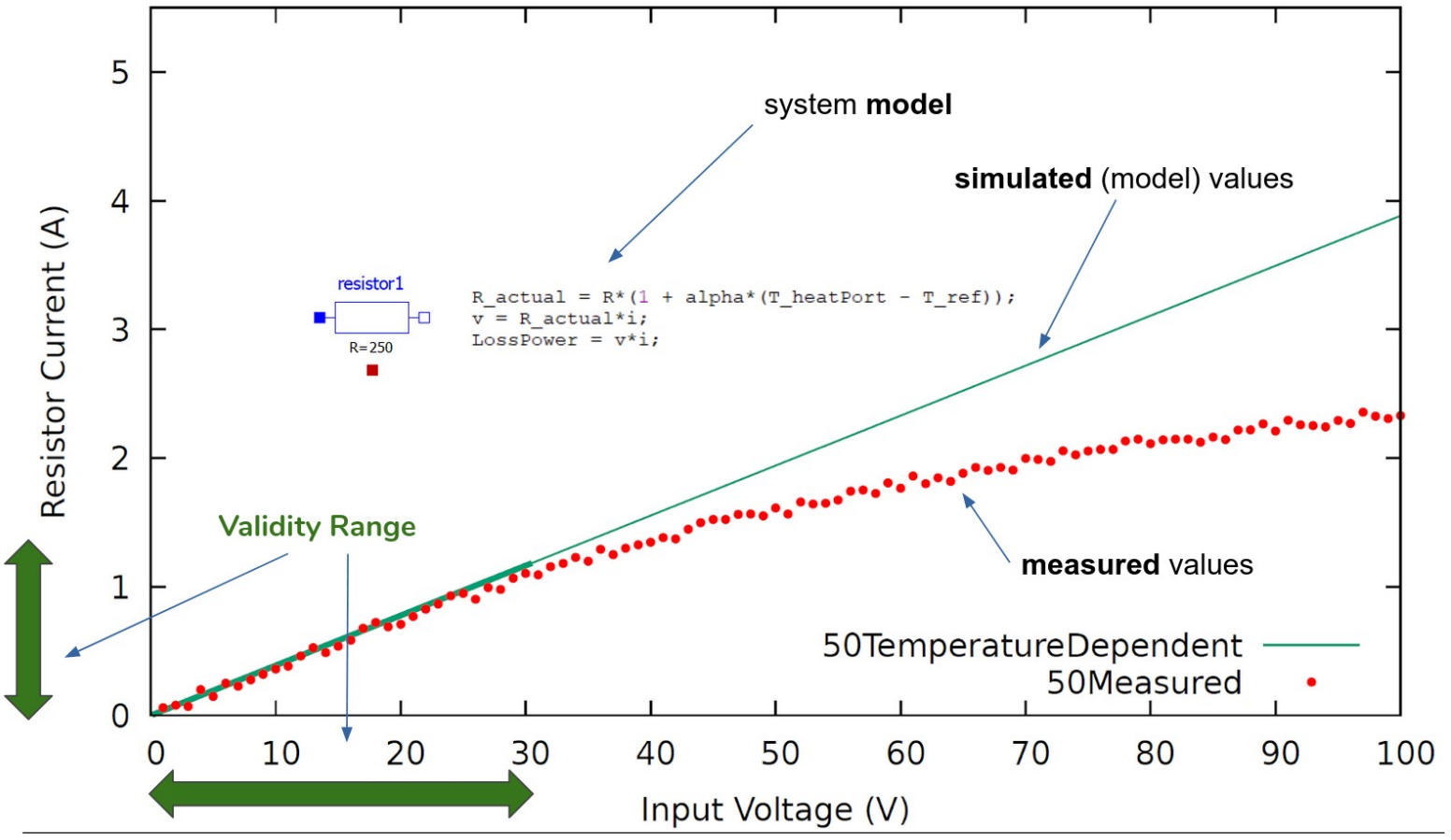


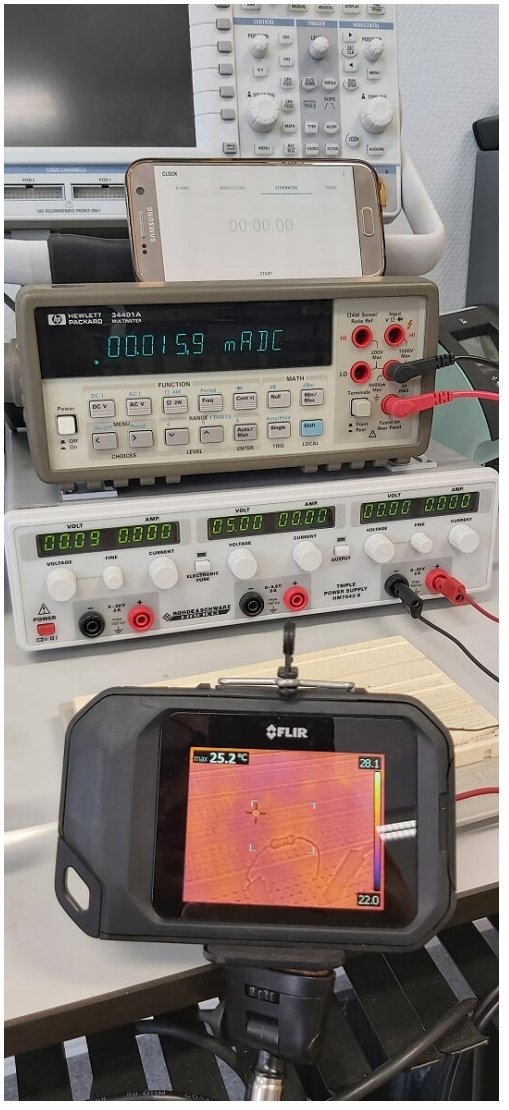
purpose of modelling: substitutability (engineering), explainability (science)



Bernard P. Zeigler. *Multi-faceted Modelling and Discrete-Event Simulation.* Academic Press, 1984.

A Resistor Model's Validity Range





https://msdl.uantwerpen.be/cloud/public/fcfc42

Abstract (In)Validity Frame

The (possibly infinite) **Set of Experiments *e*** for which the **Distance *d*** between the obtained (computed) **Properties of Interest PoI** from ***e*** carried out in the **REAL** world and ***e*** carried out in the **VIRTUAL** world is (larger)smaller than a **treshold *Tr***.

$$AVF_{\mu_n} \cup AIF_{\mu_n} = \mathbb{U}_{\mu_n}$$

$$AVF_{\mu_n} \cap AIF_{\mu_n} = \varnothing$$

Thanks to Rhys Goldstein for the notion of abstract frame

AUTODESK.

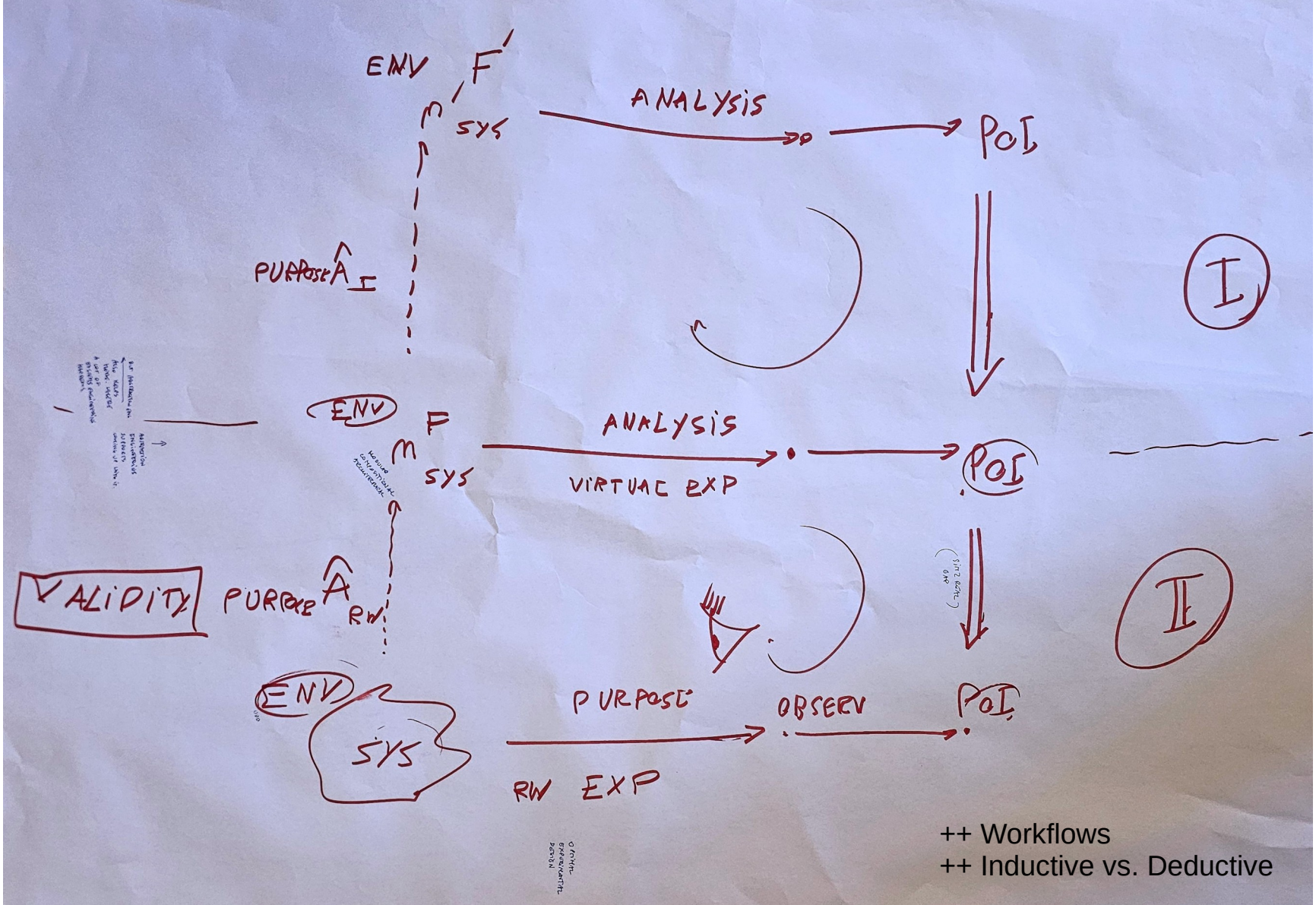
Concrete (In)Validity Frame

- Concrete Validity Frame (CVF)
  The finite set of **performed experiments** in which a model is valid

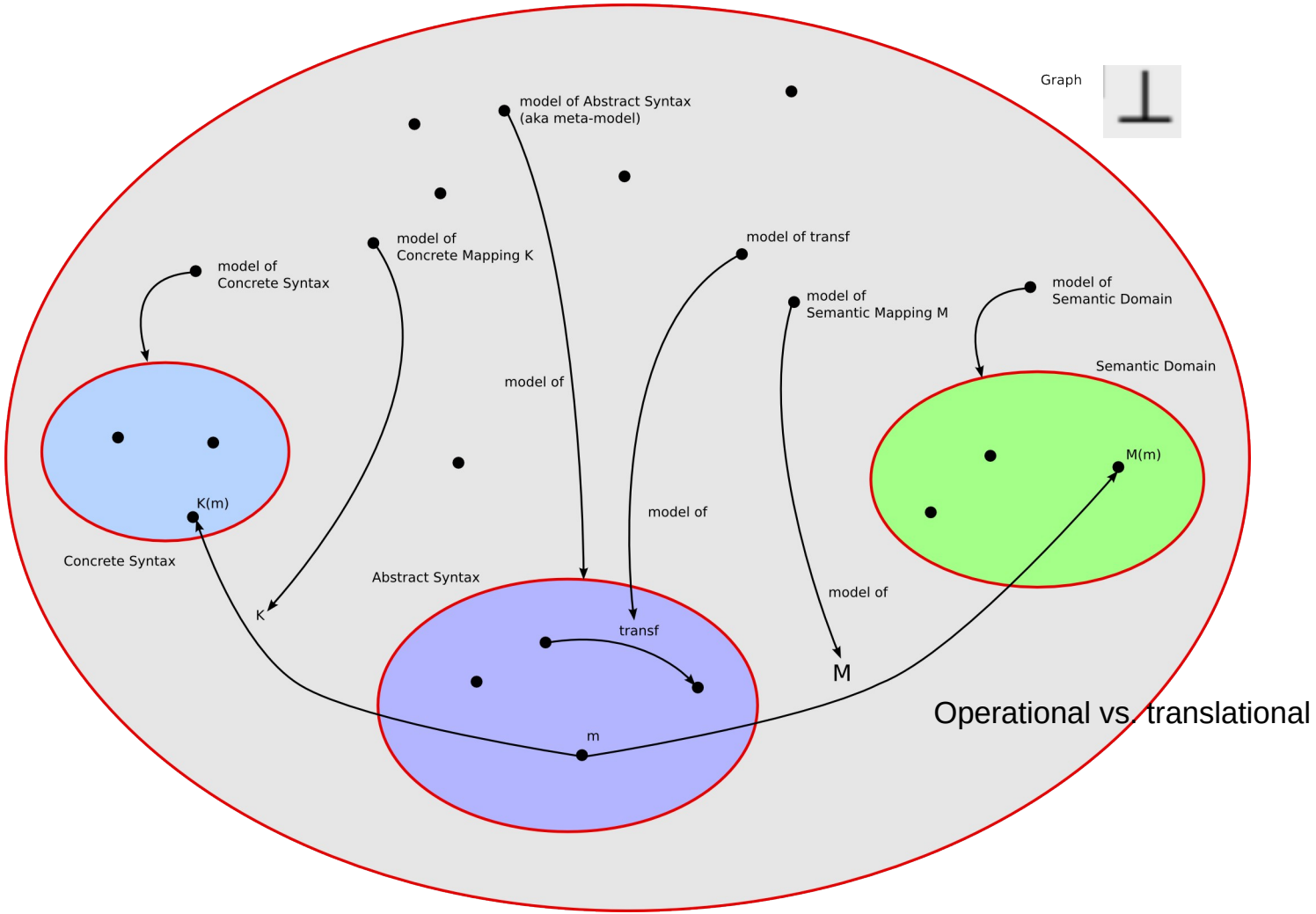
- Concrete Invalidity Frame (CIF)
  The finite set of **performed experiments** in which a model is invalid

$$CVF_{\mu_n} \cap CIF_{\mu_n} = \emptyset$$

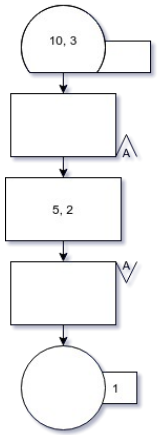
Rakshit Mittal, Raheleh Eslampanah, Lucas Lima, Hans Vangheluwe and Dominique Blouin.
Towards an Ontological Framework for Validity Frames. In the 20th MoDeVVa workshop at MoDELS 2023.

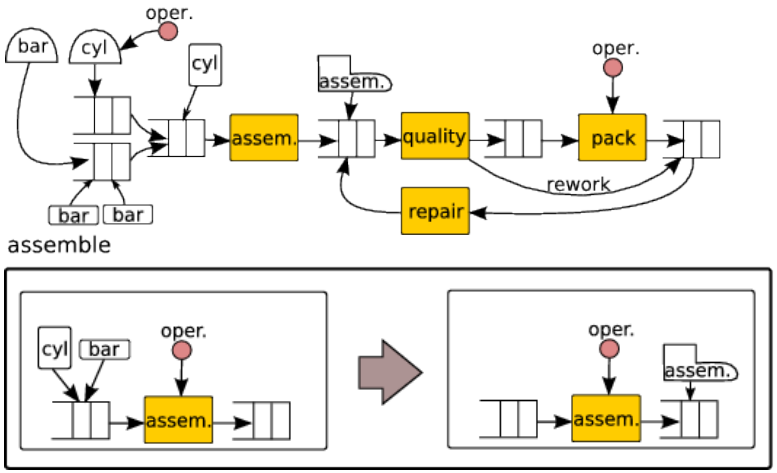

ENV
F
SYS
ANALYSIS
PoI
PURPOSE
I
ENV
F
SYS
ANALYSIS
VIRTUAL EXP
PoI
II
VALIDITY
PURPOSE
ENV
SYS
PURPOSE
OBSERV
PoI
RW EXP
++ Workflows
++ Inductive vs. Deductive

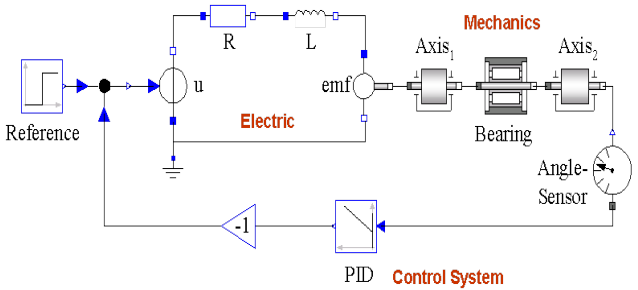
Explicit Modelling of Modelling Languages/Formalisms (++ debugging)

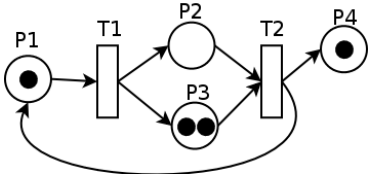


Using the most appropriate formalism(s)









1. for $\{0 \le z \le z_f - \sigma\}$:

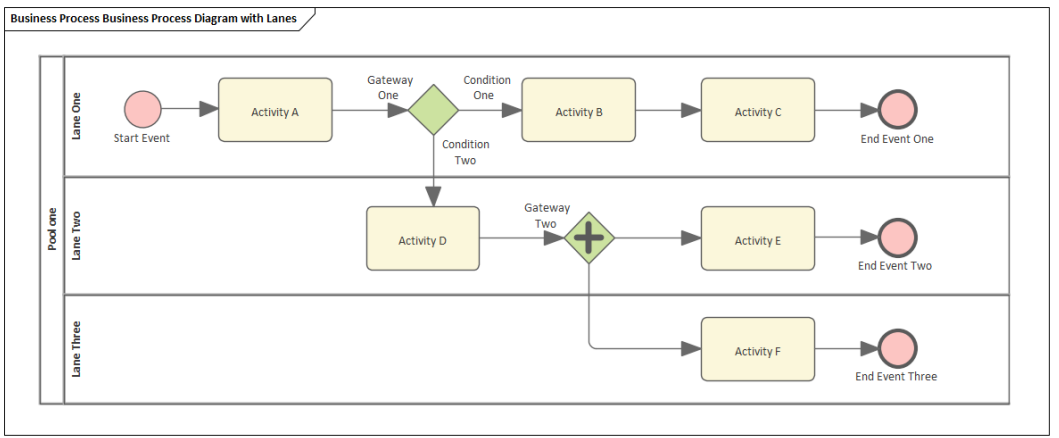
$$\frac{\partial X(z,t)}{\partial t} = -\left[(1 - nX(z,t))\, v_0\, e^{-nX(z,t)} + \frac{Q_u(t)}{A}\right]\frac{\partial X(z,t)}{\partial z} + D_0 \frac{\partial^2 X(z,t)}{\partial z^2};$$

2. for $\{z_f - \sigma < z < z_f + \sigma\}$:

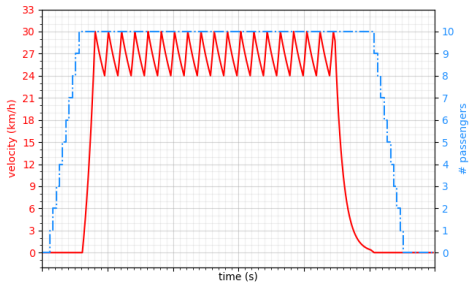
$$\frac{\partial X(z,t)}{\partial t} = -\left[(1 - nX(z,t))\, v_0\, e^{-nX(z,t)} + \frac{Q_u(t)}{A}\right]\frac{\partial X(z,t)}{\partial z} + X_f(t)\frac{Q_f(t)}{A}\frac{1}{2\sigma} + D_0 \frac{\partial^2 X(z,t)}{\partial z^2};$$

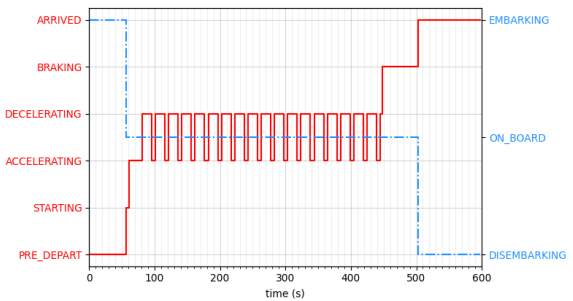
3. for $\{z_f + \sigma \le z \le L\}$:

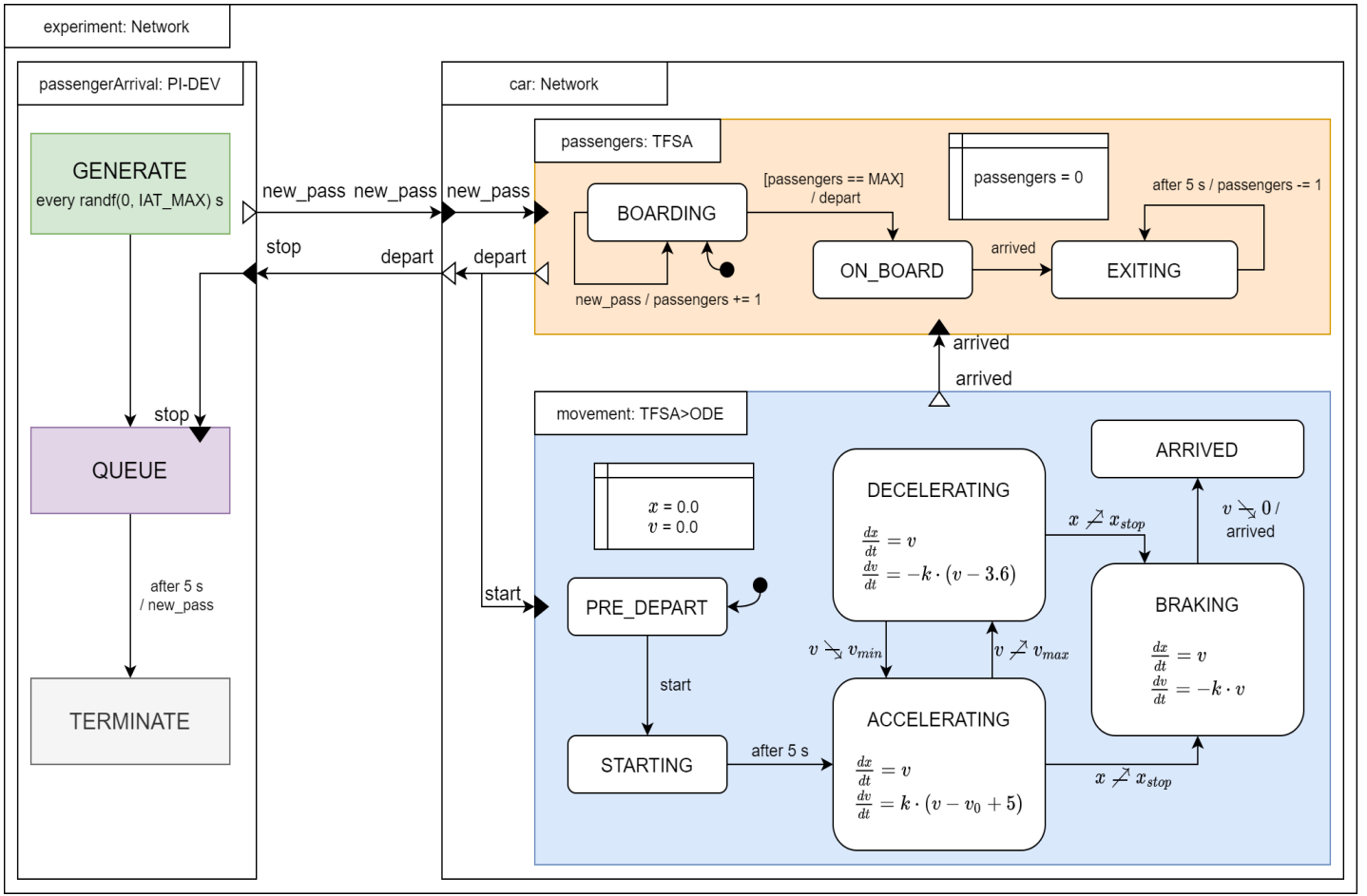
$$\frac{\partial X(z,t)}{\partial t} = -\left[(1 - nX(z,t))\, v_0\, e^{-nX(z,t)} + \frac{Q_u(t)}{A}\right]\frac{\partial X(z,t)}{\partial z} + D_0 \frac{\partial^2 X(z,t)}{\partial z^2}.$$



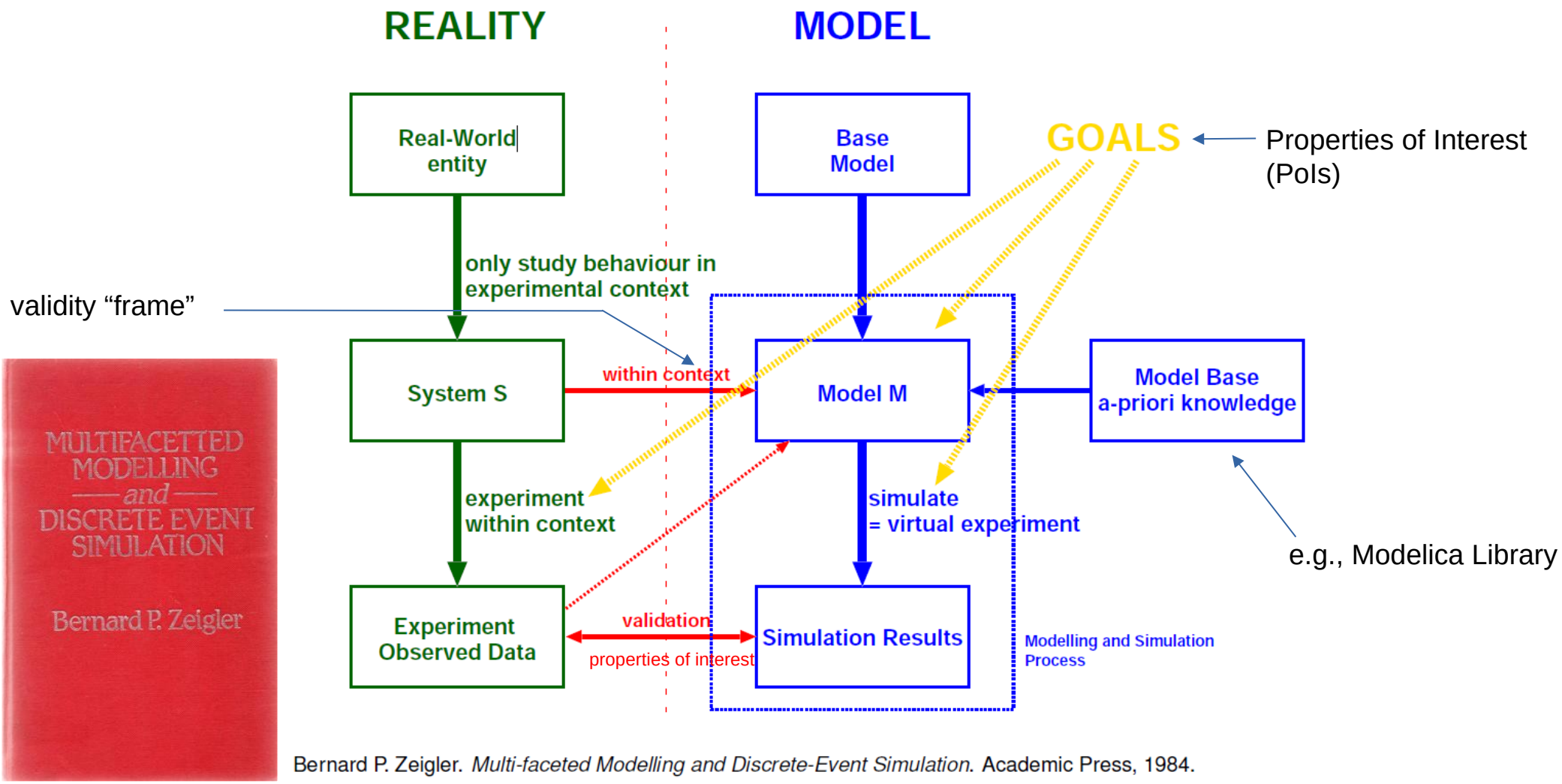

Morgantown
Personal Rapid Transit


velocity (km/h)
passengers
time (s)


ARRIVED
BRAKING
DECELERATING
ACCELERATING
STARTING
PRE_DEPART
EMBARKING
ON_BOARD
DISEMBARKING
time (s)


experiment: Network
passengerArrival: PI-DEV
GENERATE
every randf(0, IAT_MAX) s
QUEUE
after 5 s
/ new_pass
TERMINATE
new_pass new_pass
new_pass
stop
depart
depart
stop
car: Network
passengers: TFSA
BOARDING
[passengers == MAX]
/ depart
passengers = 0
after 5 s / passengers -= 1
ON_BOARD
arrived
EXITING
new_pass / passengers += 1
arrived
arrived
movement: TFSA>ODE
x = 0.0
v = 0.0
start
PRE_DEPART
start
STARTING
after 5 s
DECELERATING
$\frac{dx}{dt} = v$
$\frac{dv}{dt} = -k \cdot (v - 3.6)$
$v \searrow v_{min}$
ACCELERATING
$\frac{dx}{dt} = v$
$\frac{dv}{dt} = k \cdot (v - v_0 + 5)$
$v \nearrow v_{max}$
$x \nearrow x_{stop}$
ARRIVED
$v \searrow 0$ /
arrived
BRAKING
$\frac{dx}{dt} = v$
$\frac{dv}{dt} = -k \cdot v$
$x \nearrow x_{stop}$

purpose of modelling: substitutability (engineering), explainability (science)



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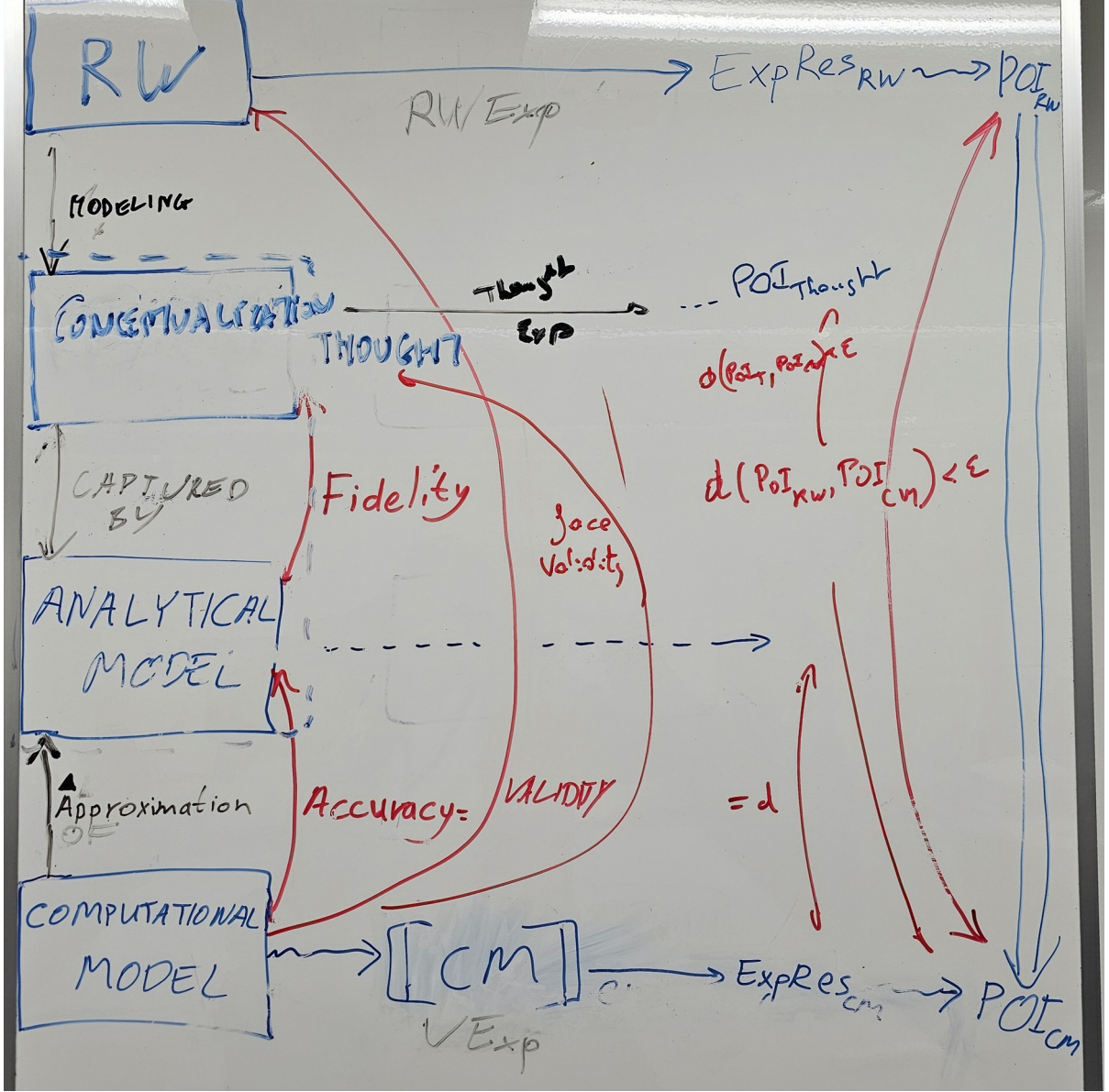
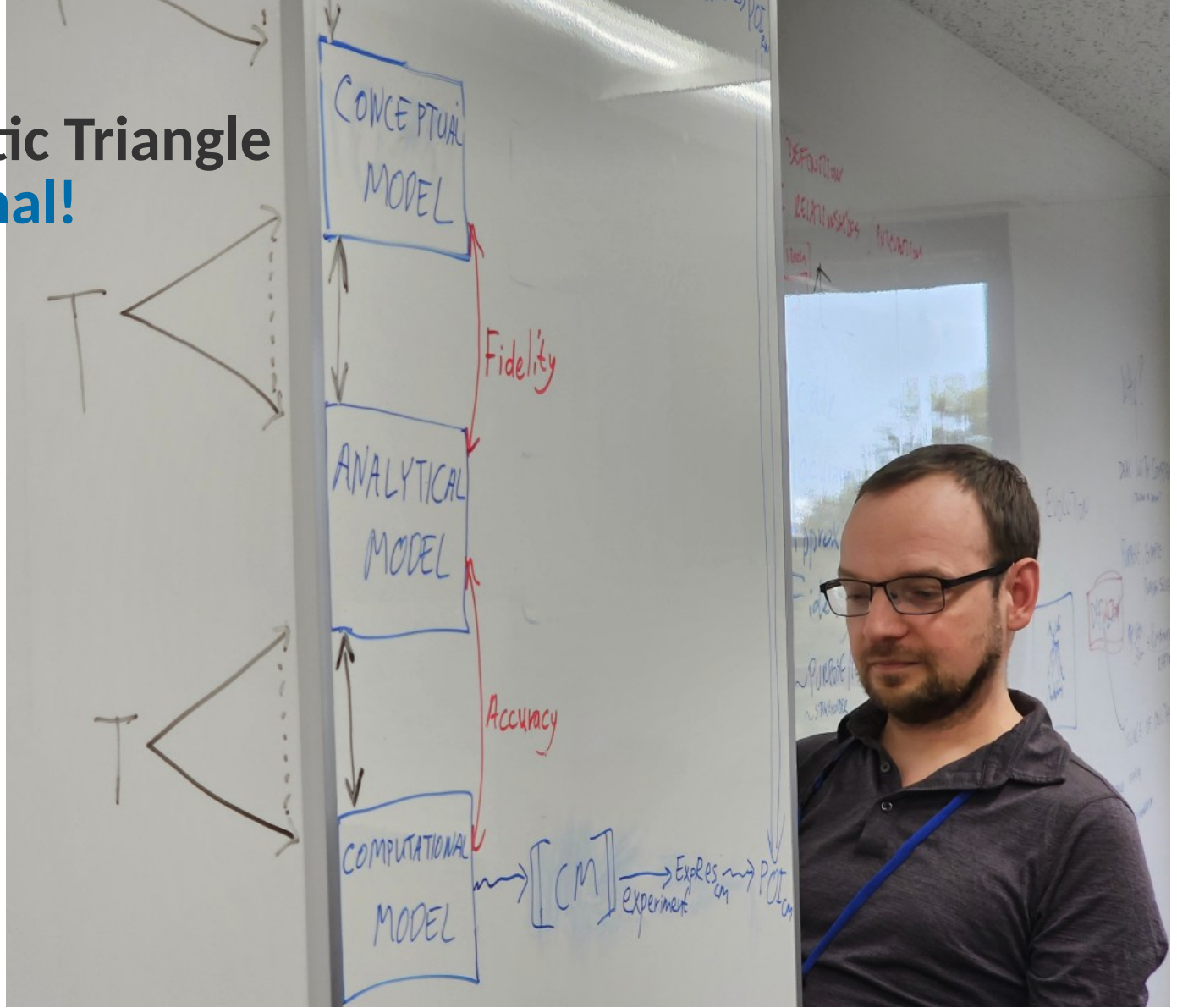
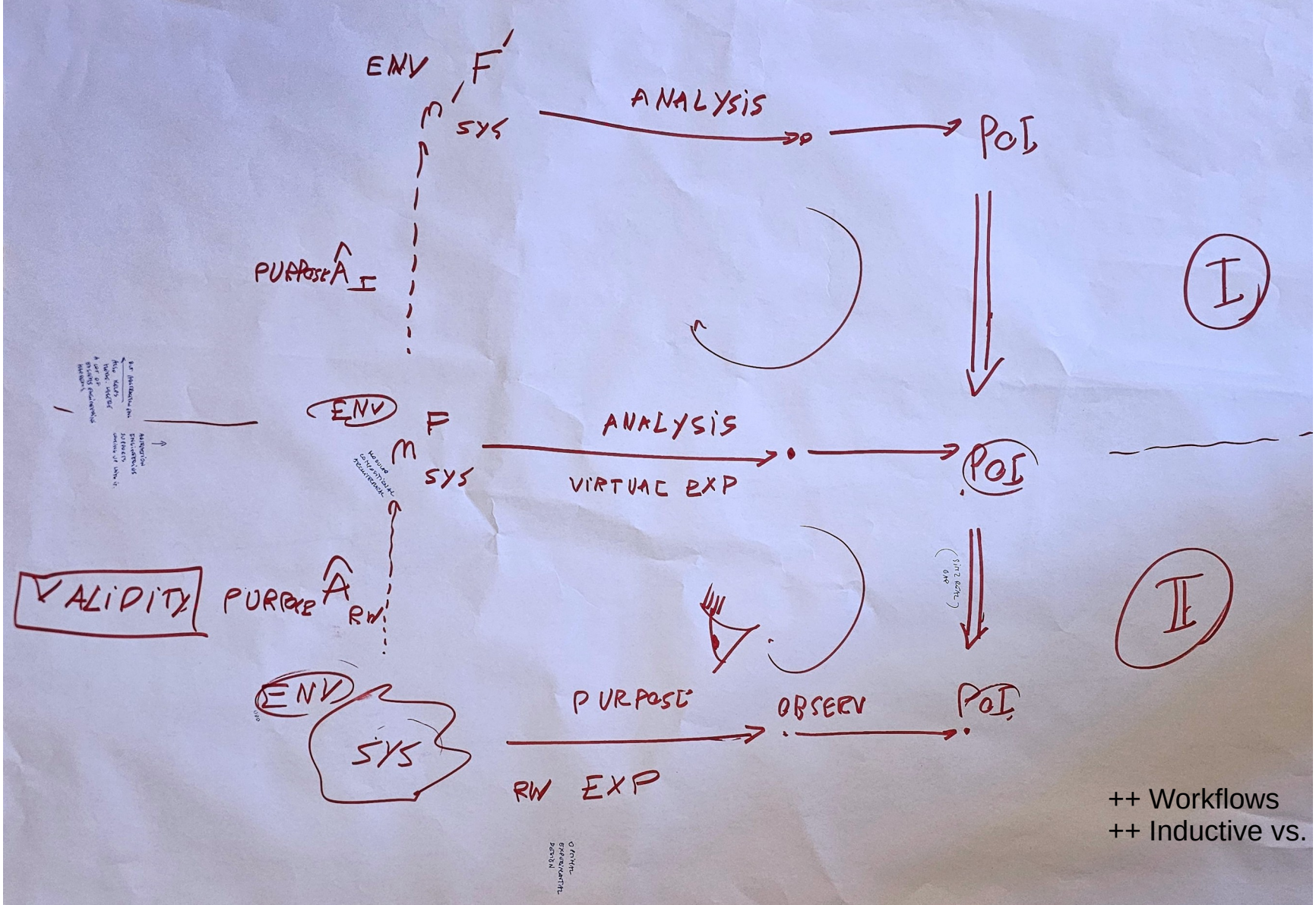

RW
RW Exp
ExpRes RW
POI RW
MODELING
CONCEPTUALIZATION
THOUGHT
Thought Exp
POI Thought
d(POI, POI) < ε
CAPTURED BY
Fidelity
Face Validity
d(POI RW, POI CM) < ε
ANALYTICAL MODEL
Approximation
Accuracy=
VALIDITY
= d
COMPUTATIONAL MODEL
[[CM]]
VExp
ExpRes CM
POI CM

The Semiotic Triangle is orthogonal!

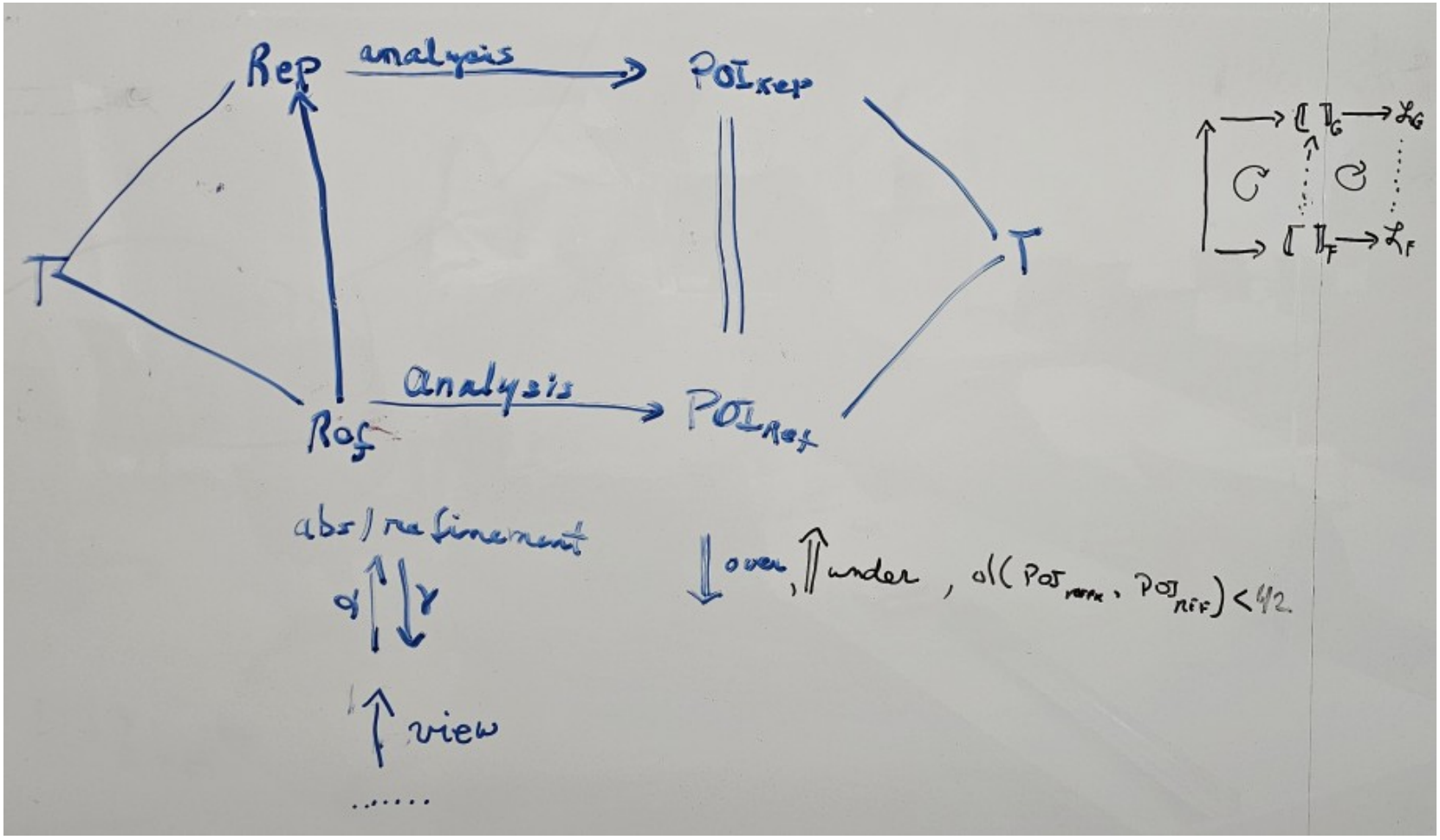


Abstraction Â is orthogonal!

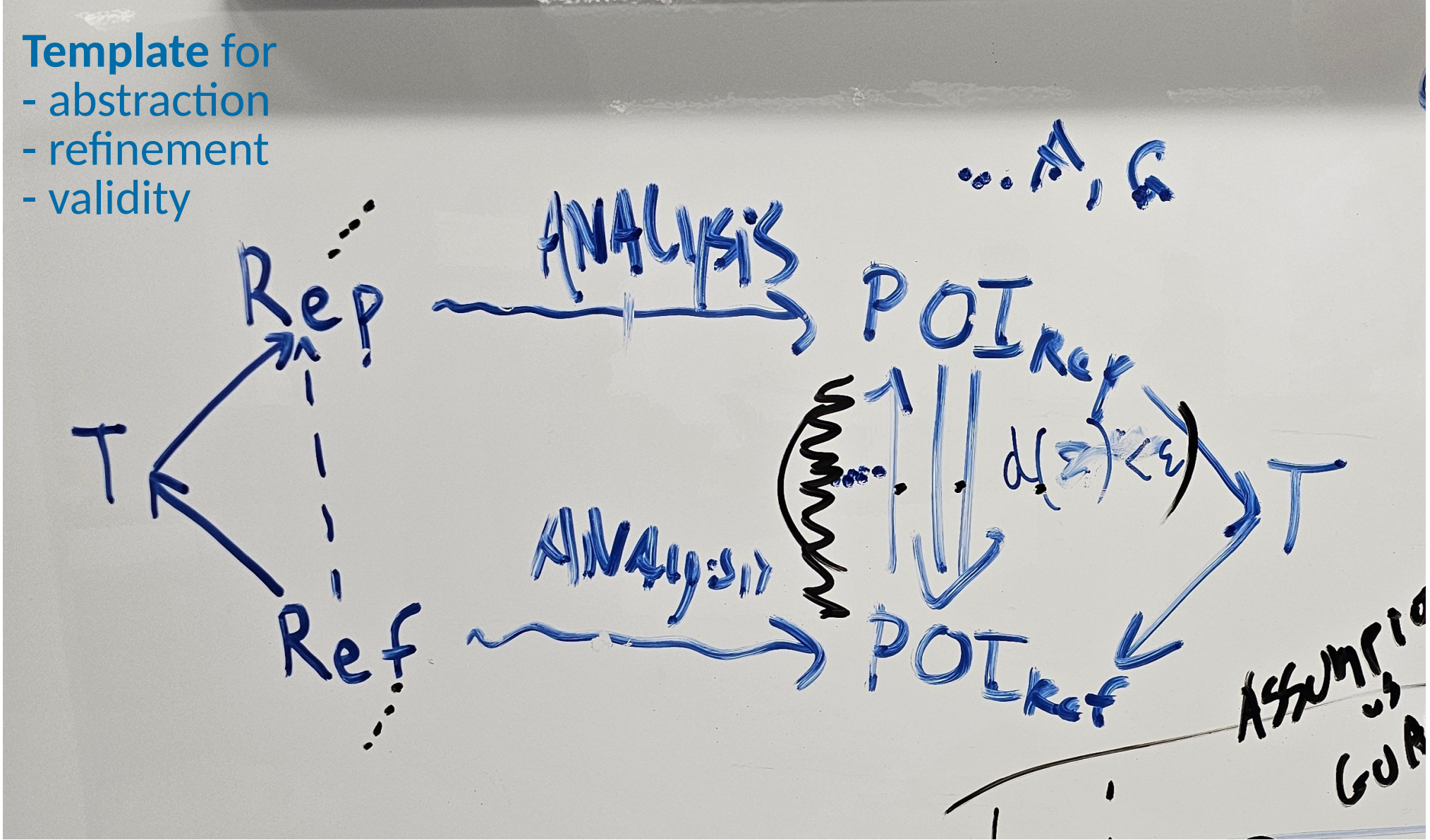


++ Workflows
++ Inductive vs. Deductive

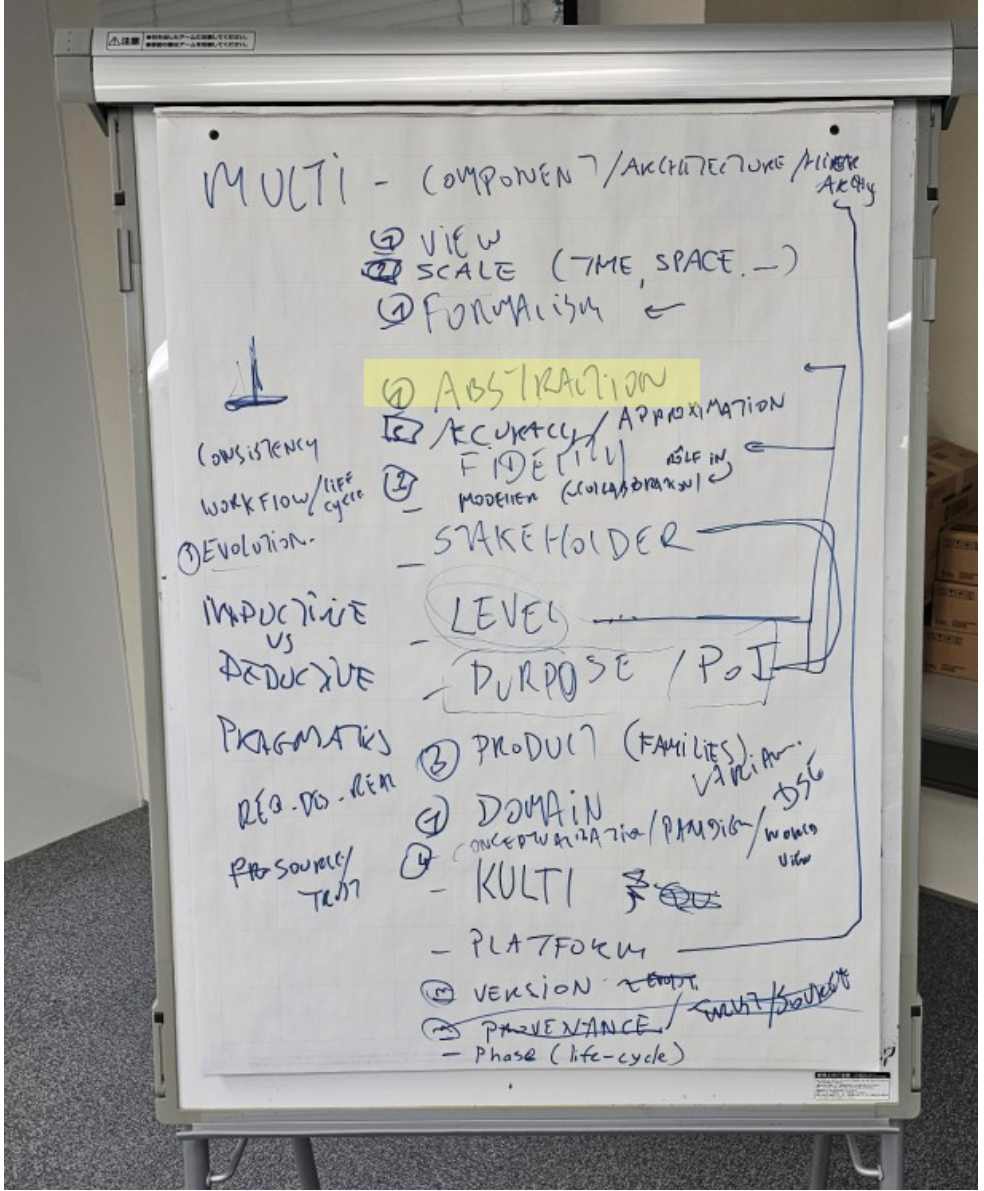
Template for
- abstraction
- refinement
- validity

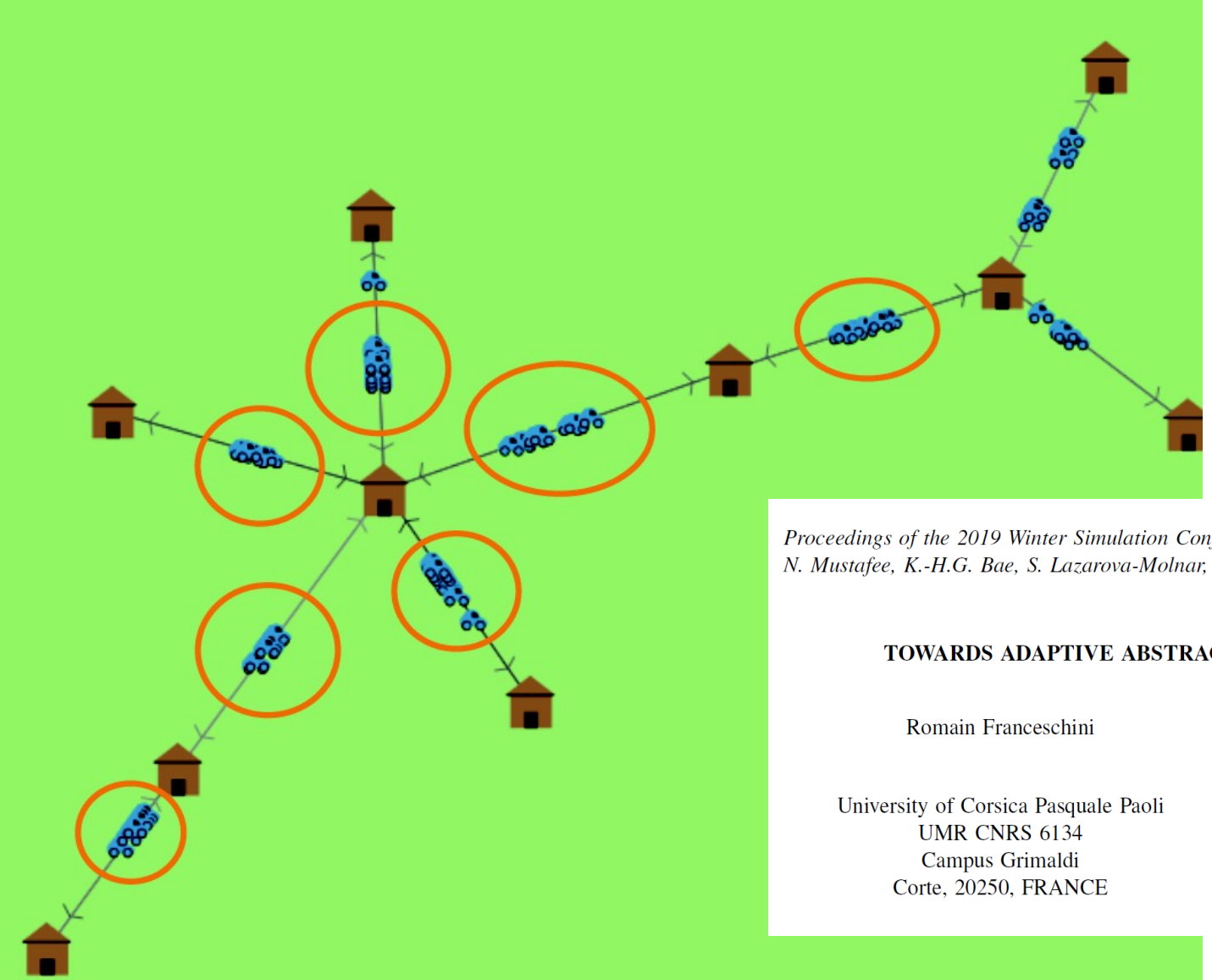


Template for
- abstraction
- refinement
- validity



Multi-*


MULTI - COMPONENT / ARCHITECTURE / MIDDLE AGE
① VIEW
② SCALE (TIME, SPACE, —)
③ FORMALISM
④ ABSTRACTION
⑤ ACCURACY / APPROXIMATION
⑥ FIDELITY
MODELLER
CONSISTENCY
WORKFLOW / LIFE CYCLE
⑦ EVOLUTION.
STAKEHOLDER
LEVEL
PURPOSE / POI
INDUCTIVE
VS
DEDUCTIVE
PRAGMATICS
⑧ PRODUCT (FAMILIES)
⑨ DOMAIN
⑩ KULTI
PLATFORM
⑪ VERSION
⑫ PROVENANCE
— Phase (life-cycle)



Abstraction

- For performance (scale-ability)
- For **insight**

Proceedings of the 2019 Winter Simulation Conference
N. Mustafee, K.-H.G. Bae, S. Lazarova-Molnar, M. Rabe, C. Szabo, P. Haas, and Y.-J. Son, eds.

TOWARDS ADAPTIVE ABSTRACTION IN AGENT BASED SIMULATION

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Simon Van Mierlo
Hans Vangheluwe

Department of Mathematics and Computer Science
University of Antwerp - Flanders Make
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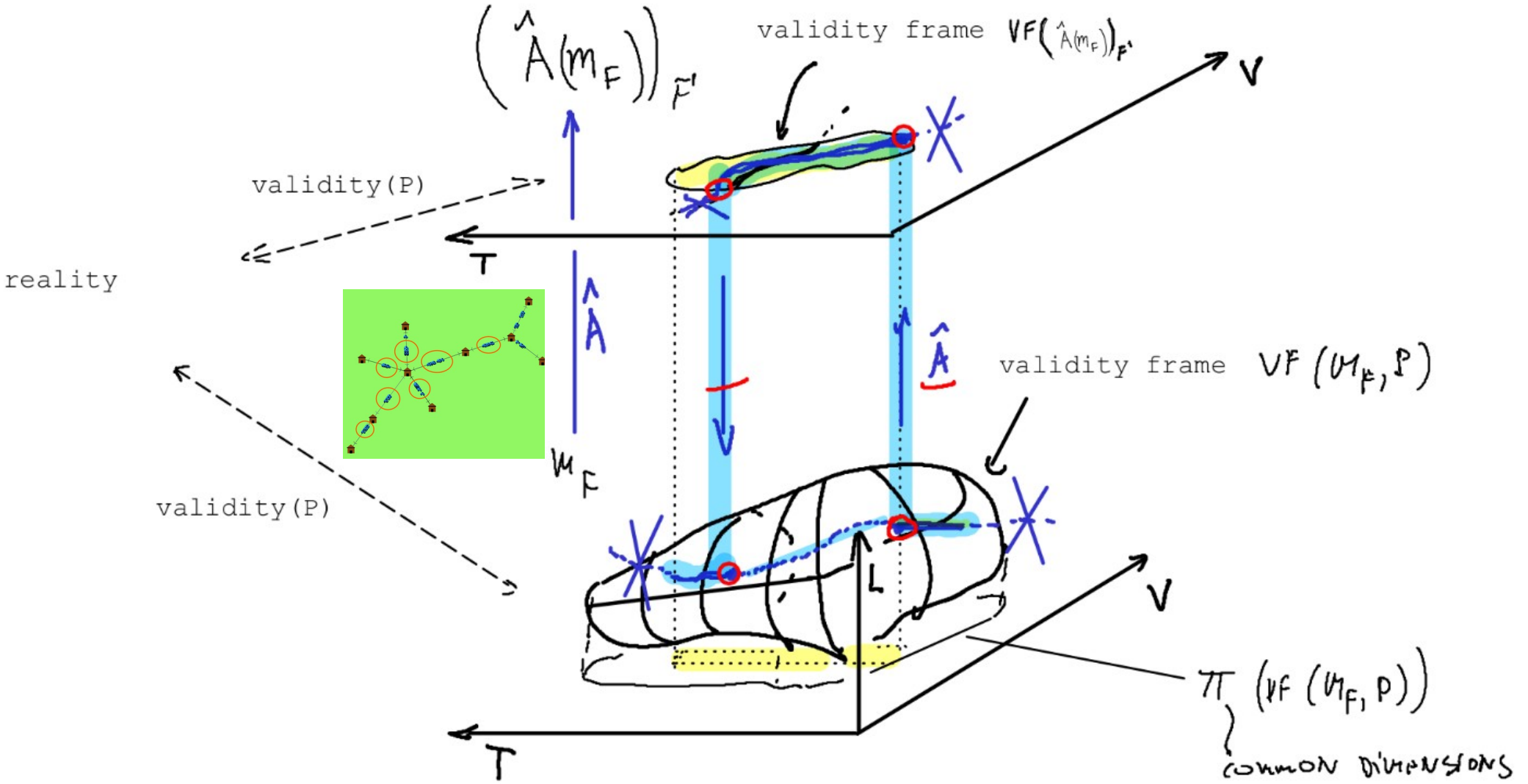
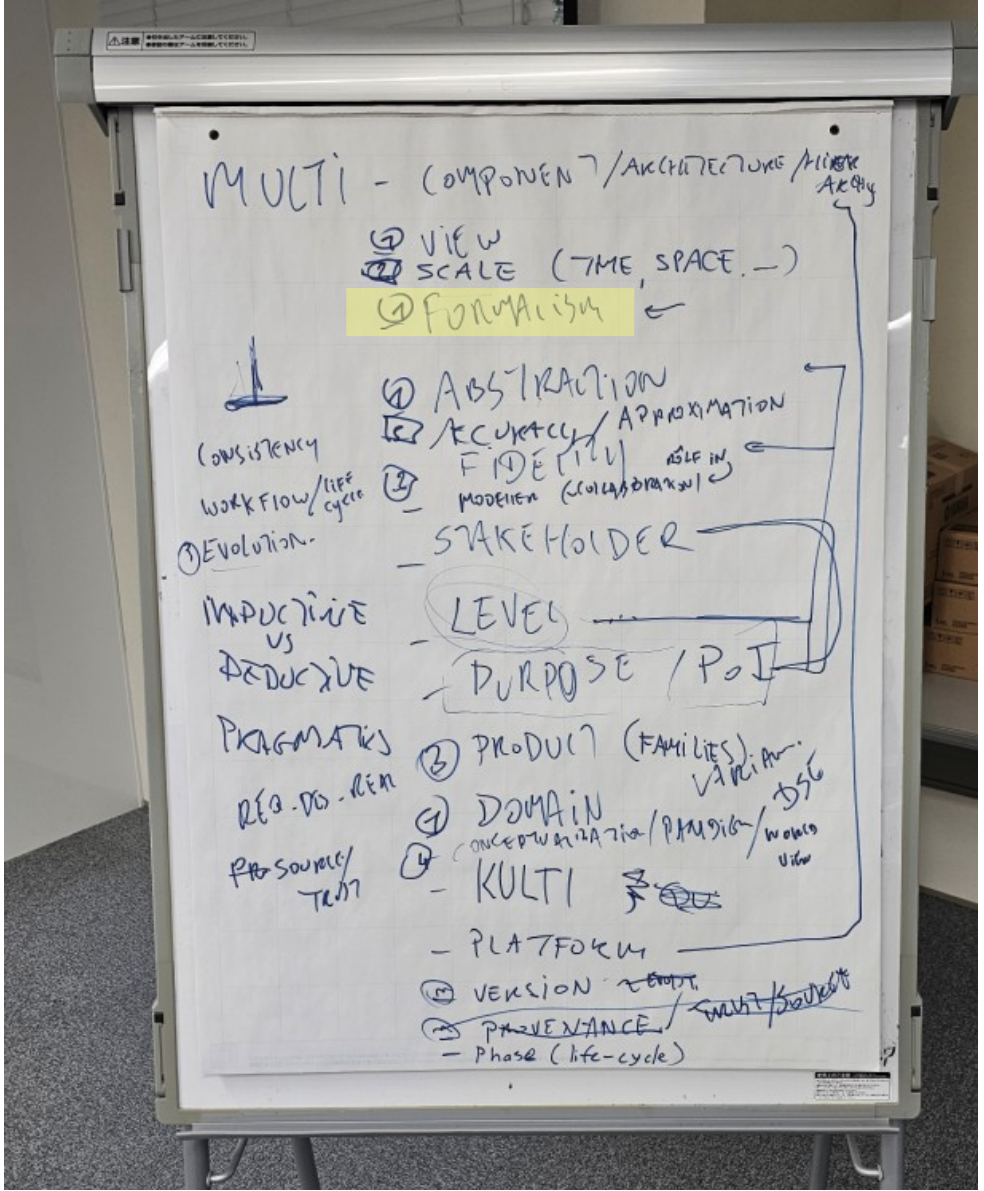
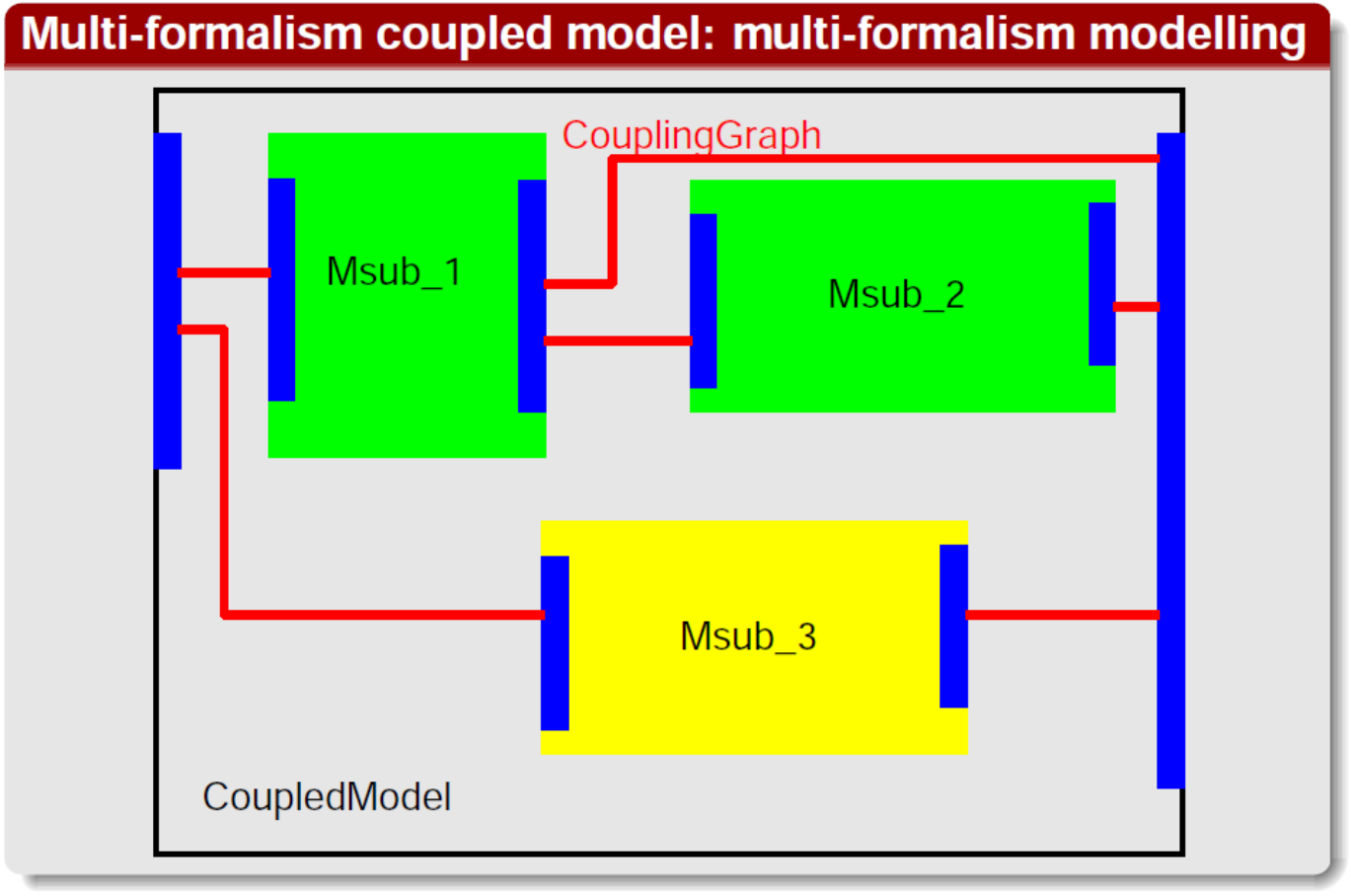
properties P

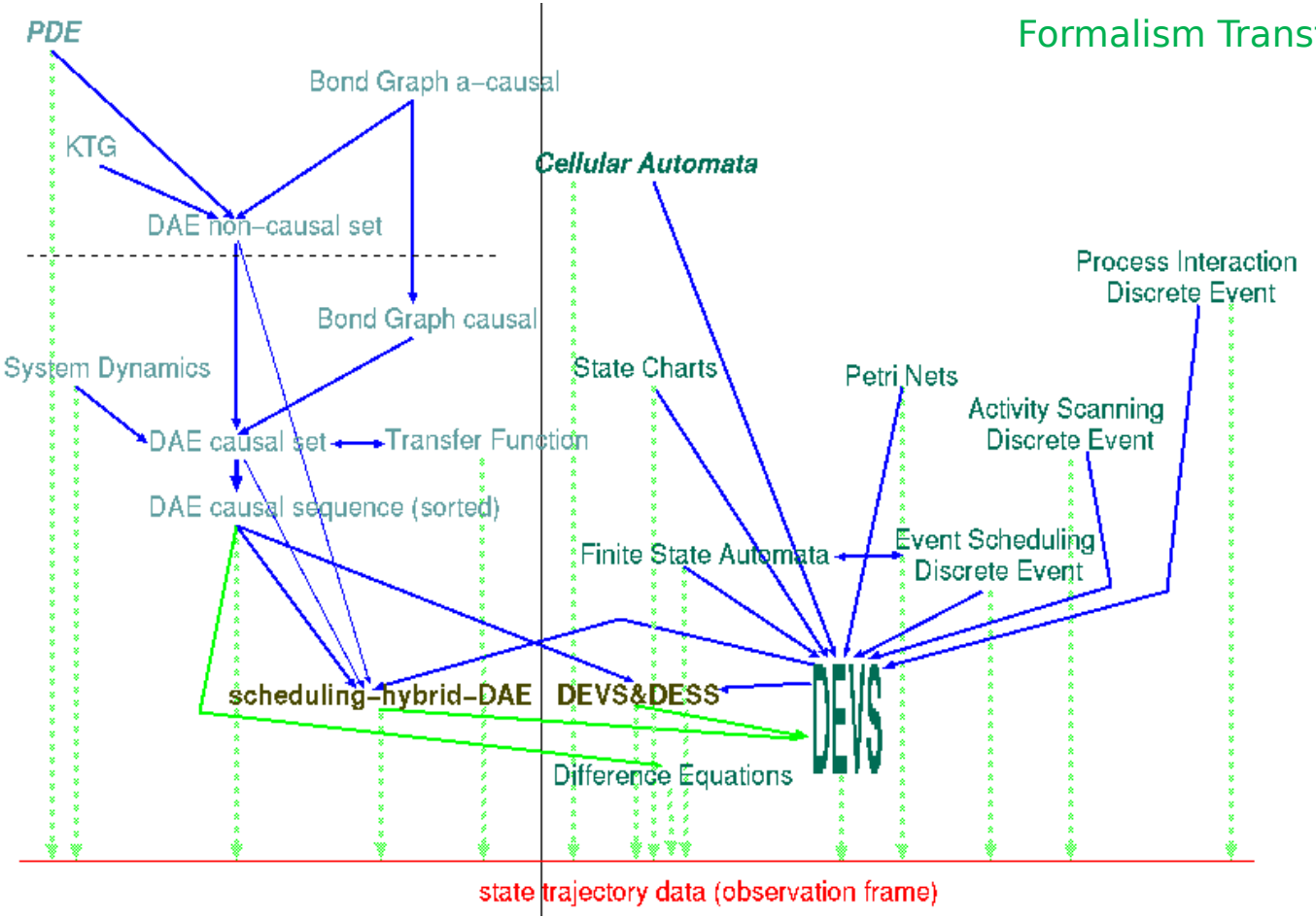



MULTI - COMPONENT / ARCHITECTURE / MIXED ARCHY
① VIEW
② SCALE (TIME, SPACE, —)
③ FORMALISM
① ABSTRACTION
② ACCURACY / APPROXIMATION
③ FIDELITY
MODELLER (COLLABORATION)
CONSISTENCY
WORKFLOW / LIFE CYCLE
④ EVOLUTION.
- STAKEHOLDER
- LEVEL
- PURPOSE / POV
INDUCTIVE
VS
DEDUCTIVE
PRAGMATICS
REQ. DO. DEM
RESOURCE / TRUST
② PRODUCT (FAMILIES)
③ DOMAIN
④ CONCEPTUALIZATION / PARADIGM / DSL
WORLD VIEW
- KULTI
- PLATFORM
⑤ VERSION
⑥ PROVENANCE
- Phase (life-cycle)

Bran Selić: “fragmentation problem”



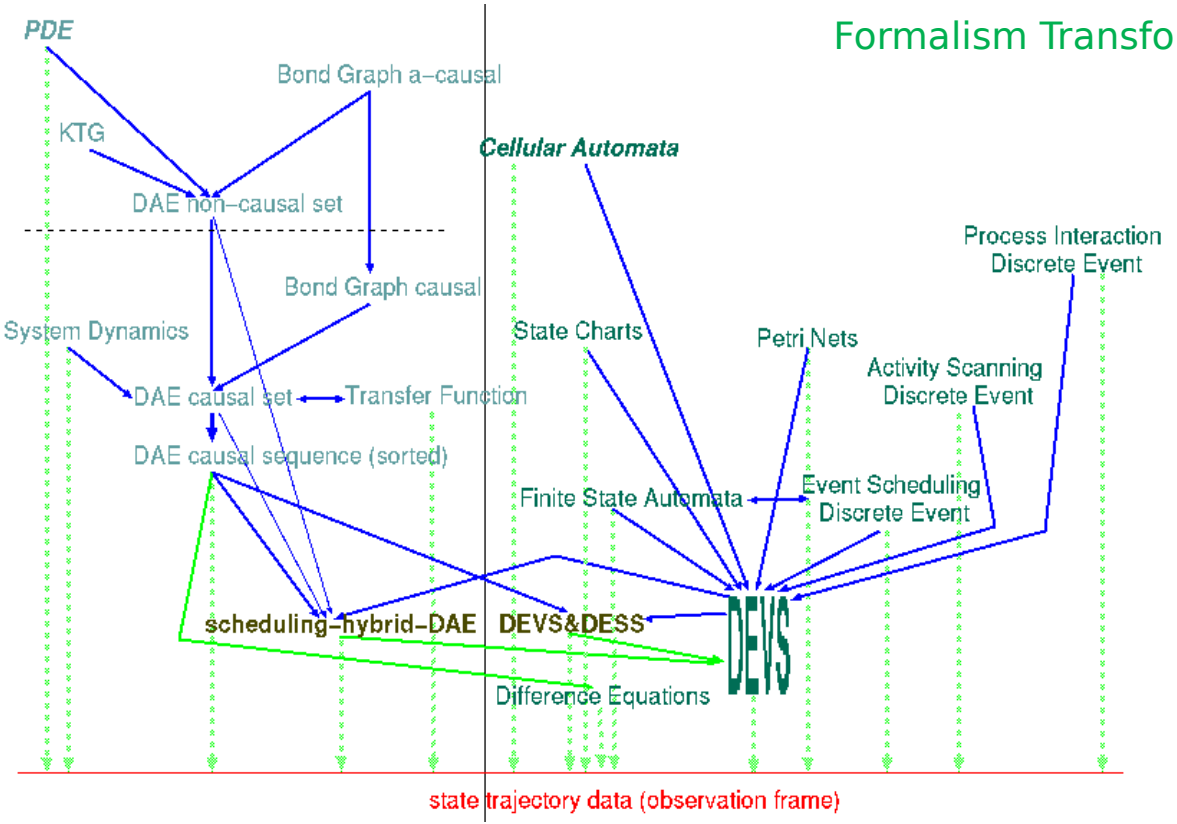
Formalism Transformation Graph (FTG)

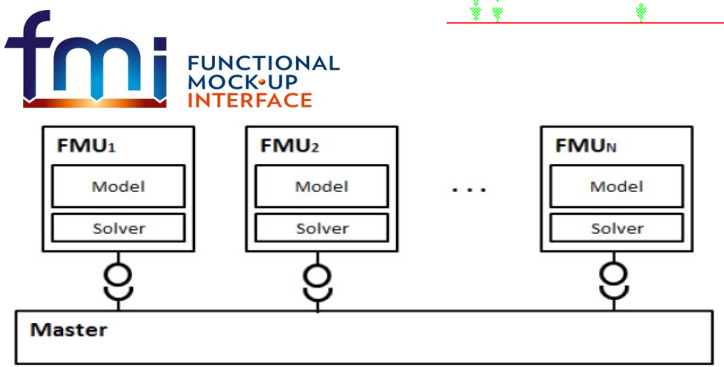


Caveat: proving semantics/property preservation of a single transformation (denoted by a blue arrow) may take at least one PhD thesis!

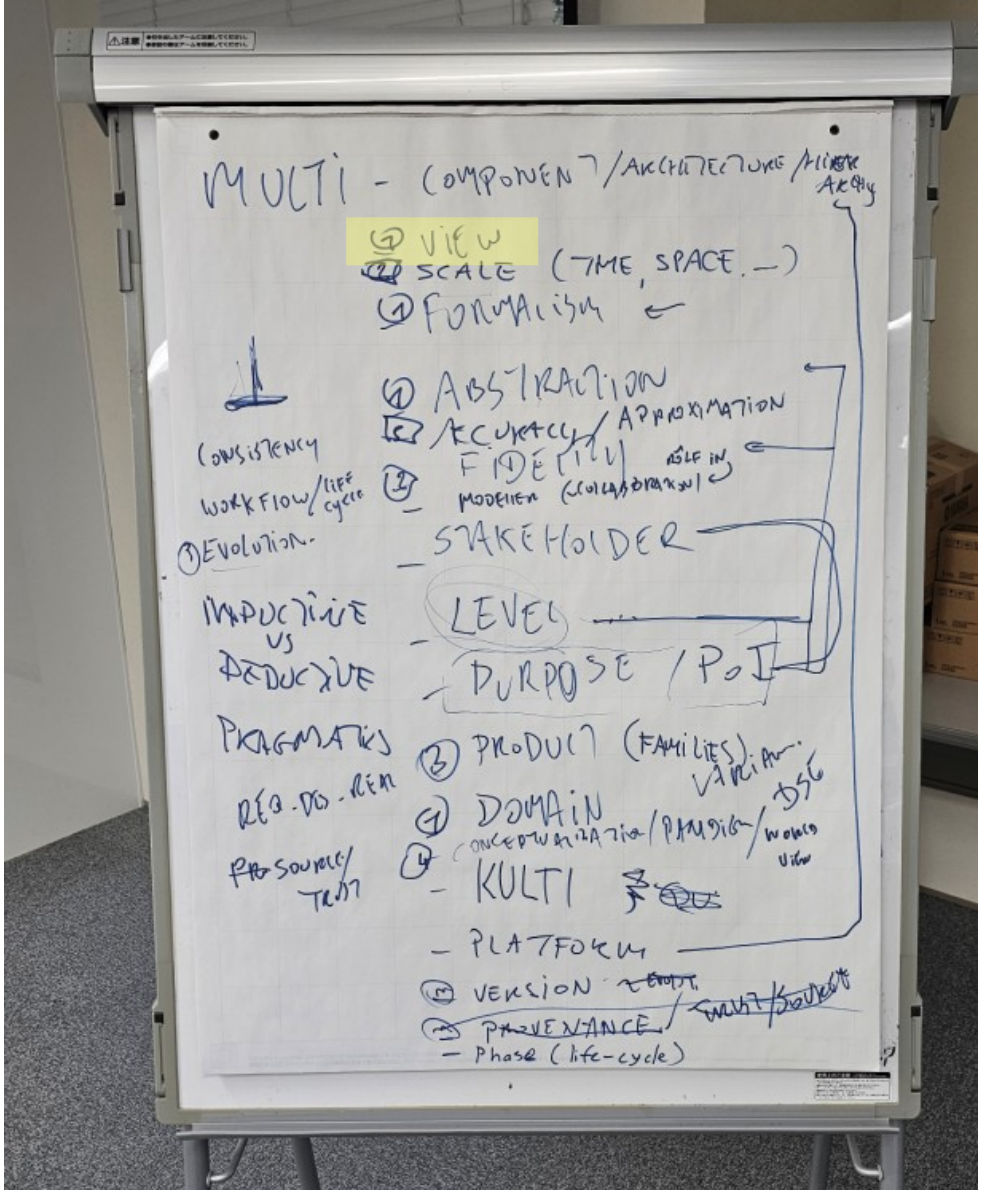
Hans Vangheluwe and Ghislain C. Vansteenkiste. A multi-paradigm modeling and simulation methodology: Formalisms and languages. In European Simulation Symposium (ESS) , pages 168 – 172. Society for Computer Simulation International (SCS), October 1996. Genoa, Italy.

Formalism Transformation Graph (FTG) co-simulation



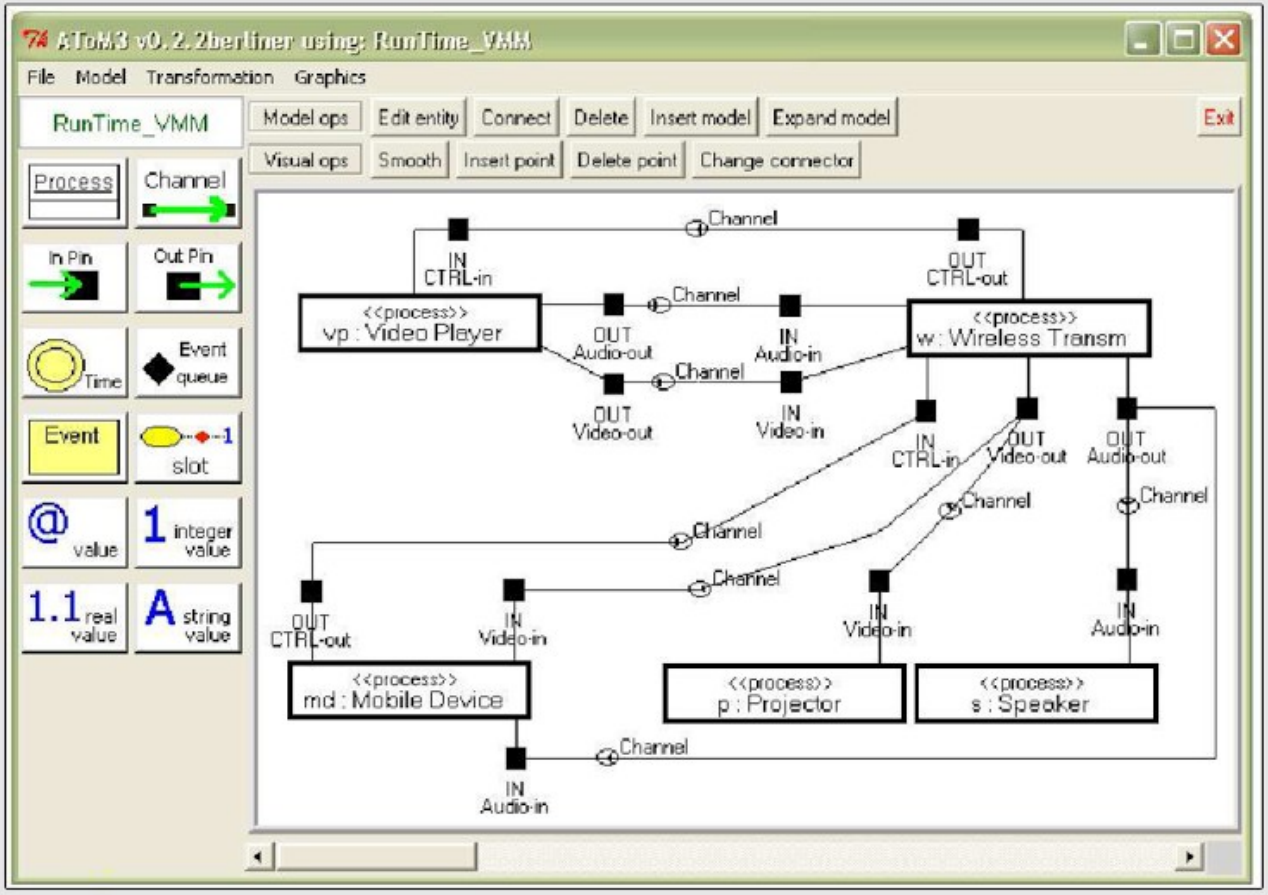


Cláudio Gomes, Casper Thule, David Broman, Peter Gorm Larsen, and Hans Vangheluwe.
Co-simulation: A survey. ACM Computing Surveys (CSUR) , 51(3):49:1-49:33, 2018.


MULTI - COMPONENT / ARCHITECTURE / Aliases
① VIEW
② SCALE (TIME, SPACE, —)
③ FORMALISM
① ABSTRACTION
② ACCURACY / APPROXIMATION
③ FIDELITY
MODELLER
STAKEHOLDER
LEVEL
PURPOSE / POV
③ PRODUCT (FAMILIES)
④ DOMAIN
⑤ KULTI
PLATFORM
⑥ VERSION
⑦ PROVENANCE
Phase (life-cycle)
CONSISTENCY
WORKFLOW / LIFE CYCLE
③ EVOLUTION.
INDUCTIVE
VS
DEDUCTIVE
PRAGMATICS
REQ. DO. REM
RESOURCE / TRUST

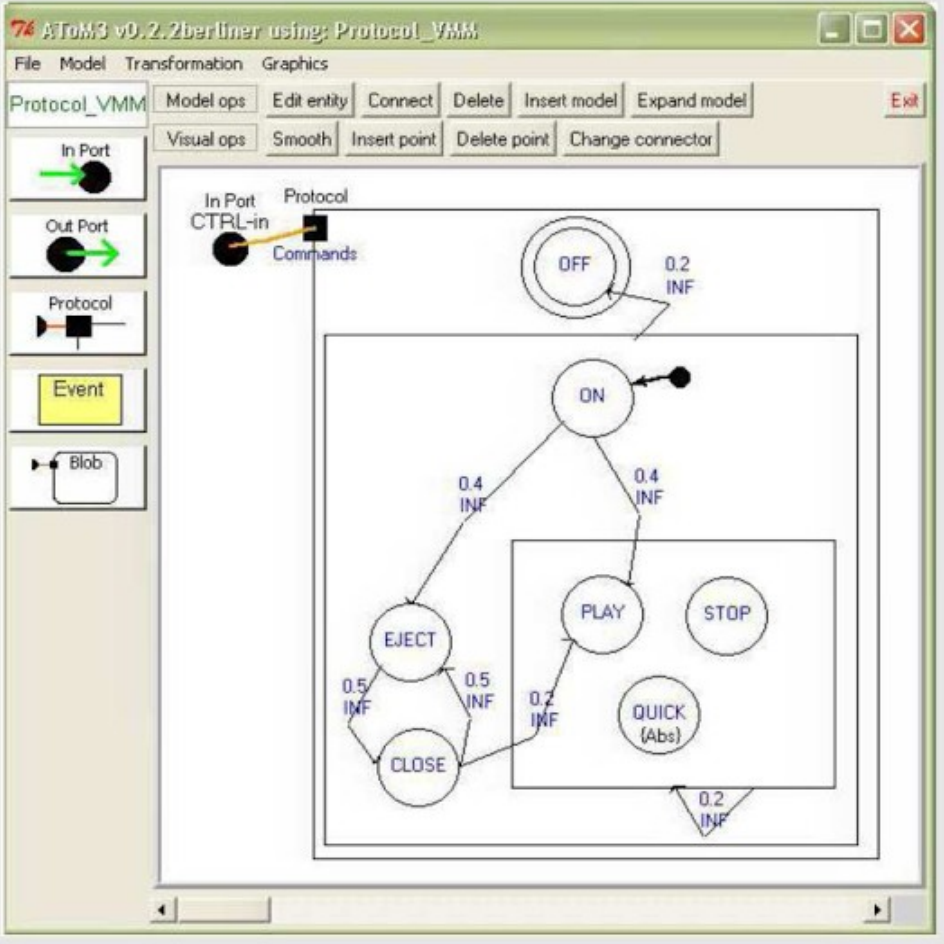
Wireless Home Entertainment System

Multiple (consistent !) Views (in ≠ Formalisms)



E. Guerra, P. Diaz and J. de Lara, A formal approach to the generation of visual language environments supporting multiple views. 2005 IEEE Symposium on Visual Languages and Human-Centric Computing (VL/HCC'05), Dallas, TX, USA, 2005, pp. 284-286, doi: 10.1109/VLHCC.2005.6.

View: Protocol Statechart



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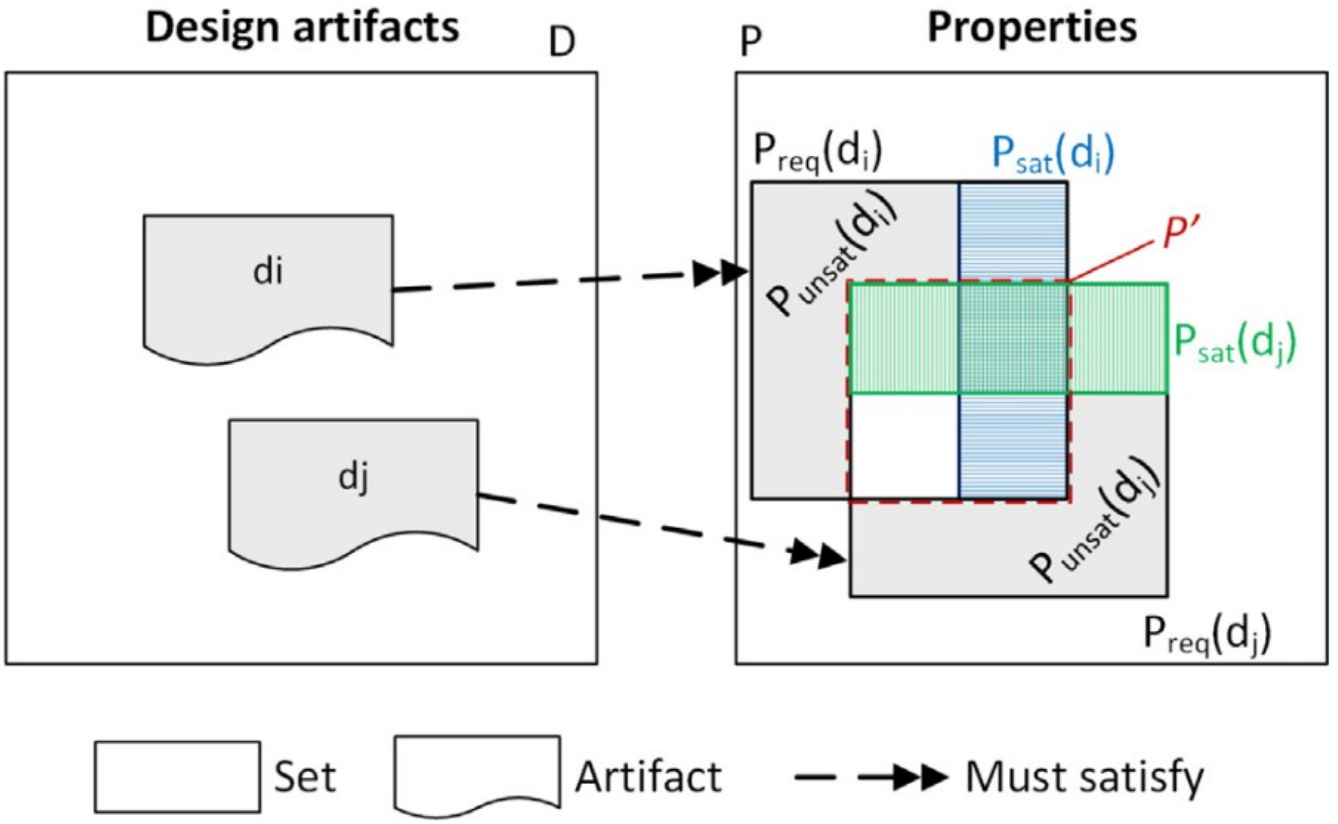
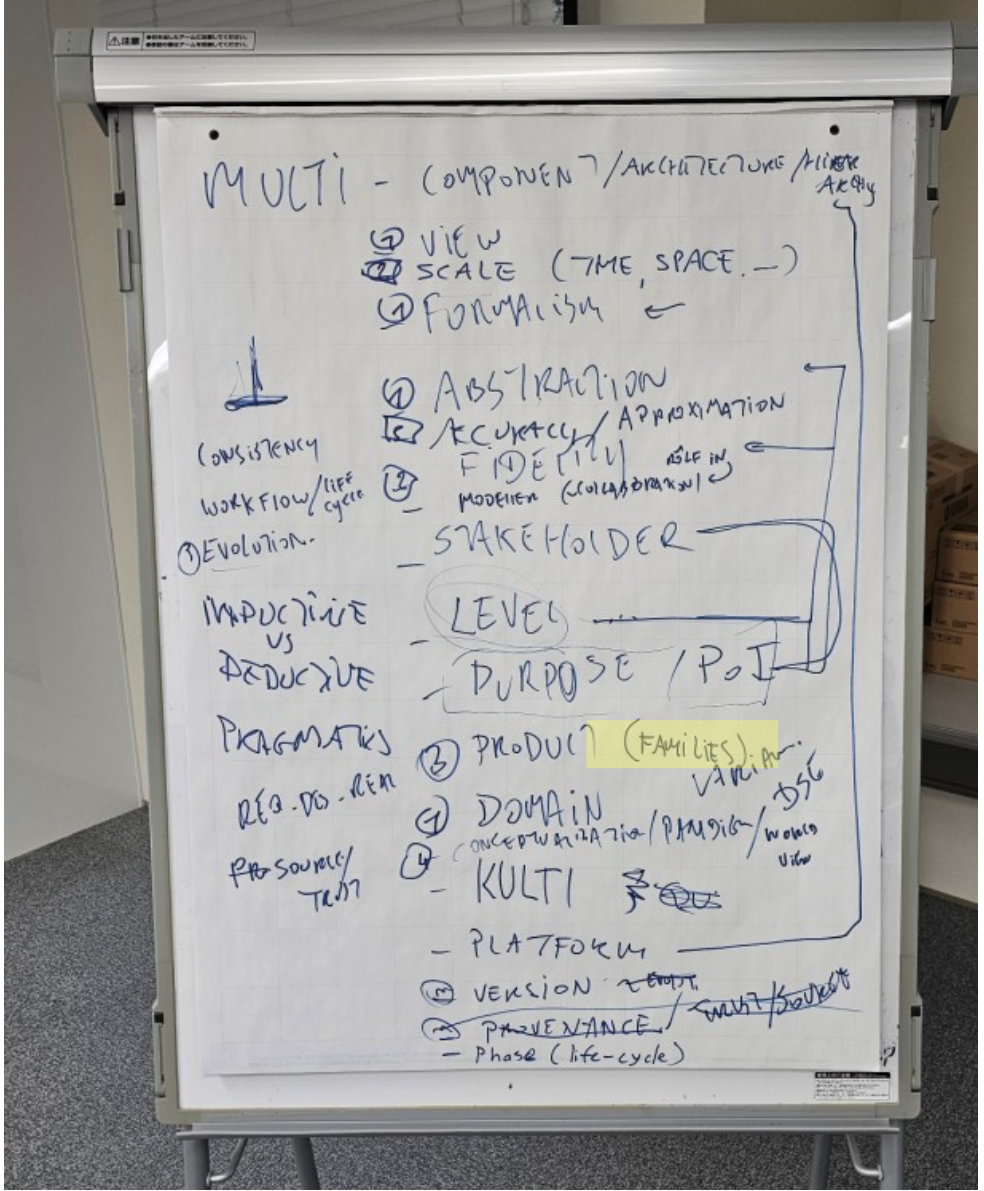
Model consistency as a heuristic for eventual correctness

Istvan David [a,*], Hans Vangheluwe [b,c], Eugene Syriani [a]




MULTI - COMPONENT / ARCHITECTURE / MIXED ARCHY
① VIEW
② SCALE (TIME, SPACE, —)
③ FORMALISM
① ABSTRACTION
② ACCURACY / APPROXIMATION
③ FIDELITY
MODELLER (COLLABORATION)
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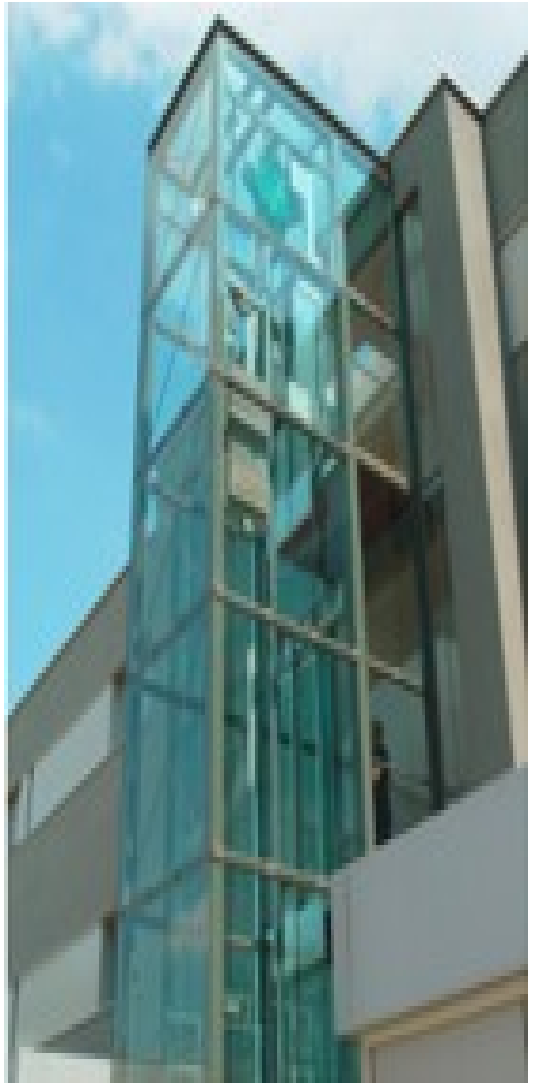
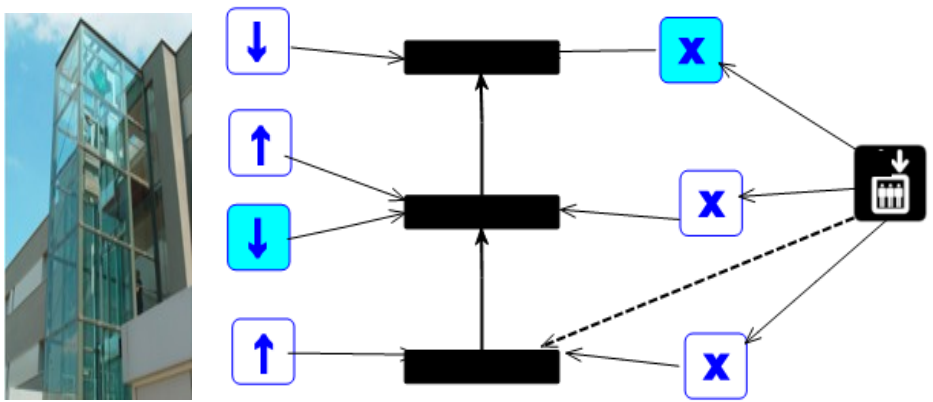
— PLATFORM
⑤ VERSION
⑥ PROVENANCE
— Phase (life-cycle)



Designing Requirements/Property Languages

Design ⊨ Property

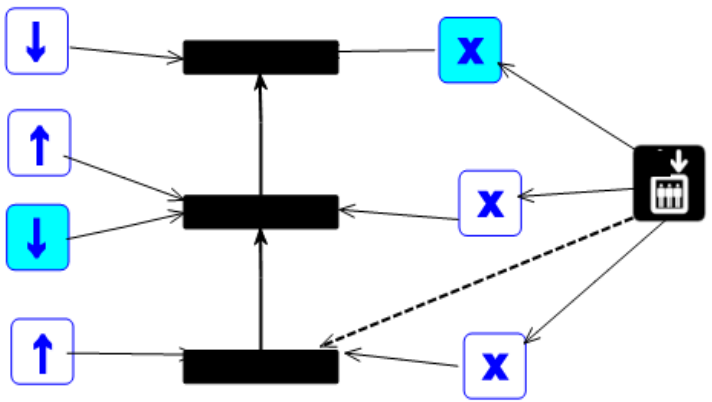


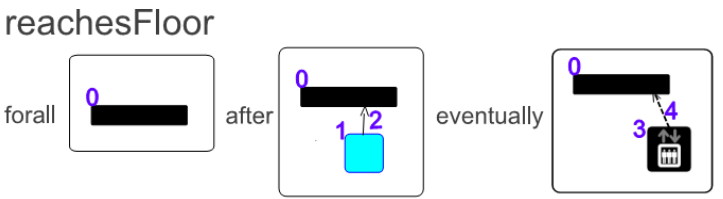
$$\Box(((go0 \wedge up0) \vee \Diamond(floor0 \vee idle)) \rightarrow ((\neg(floor0) \vee \neg(floor0 \vee idle))\mathcal{U}((floor0 \vee idle) \wedge (((floor0) \vee \neg(floor0 \vee idle))\mathcal{U}((floor0 \vee idle) \wedge ((\neg(floor0) \vee \neg(floor0 \vee idle))\mathcal{U}((floor0 \vee idle) \wedge (((floor0) \vee \neg(floor0 \vee idle))\mathcal{U}((floor0 \vee idle) \wedge (\neg(floor0)\mathcal{U}(floor0 \vee idle))))))))))) \vee \Box(((go1 \wedge up1 \wedge down1) \vee \Diamond(floor1 \vee idle)) \rightarrow ((\neg(floor1) \vee \neg(floor1 \vee idle))\mathcal{U}((floor1 \vee idle) \wedge (((floor1) \vee \neg(floor1 \vee idle))\mathcal{U}((floor1 \vee idle) \wedge ((\neg(floor1) \vee \neg(floor1 \vee idle))\mathcal{U}((floor1 \vee idle) \wedge (((floor1) \vee \neg(floor1 \vee idle))\mathcal{U}((floor1 \vee idle) \wedge (\neg(floor1)\mathcal{U}(floor1 \vee idle))))))))))) \vee \Box(((go2 \wedge down2) \vee \Diamond(floor2 \vee idle)) \rightarrow ((\neg(floor2) \vee \neg(floor2 \vee idle))\mathcal{U}((floor2 \vee idle) \wedge (((floor2) \vee \neg(floor2 \vee idle))\mathcal{U}((floor2 \vee idle) \wedge ((\neg(floor2) \vee \neg(floor2 \vee idle))\mathcal{U}((floor2 \vee idle) \wedge (((floor2) \vee \neg(floor2 \vee idle))\mathcal{U}((floor2 \vee idle) \wedge (\neg(floor2)\mathcal{U}(floor2 \vee idle))))))))))$$

B. Meyers, R. Deshayes, L. Lucio, E. Syriani, H. Vangheluwe, and M. Wimmer. ProMoBox: A Framework for Generating Domain-Specic Property Languages. In Software Language Engineering (SLE), Vasteras, Sweden, LNCS vol. 8706, pp. 1- 20. Springer. September 2014.

Designing Requirements/Property Languages

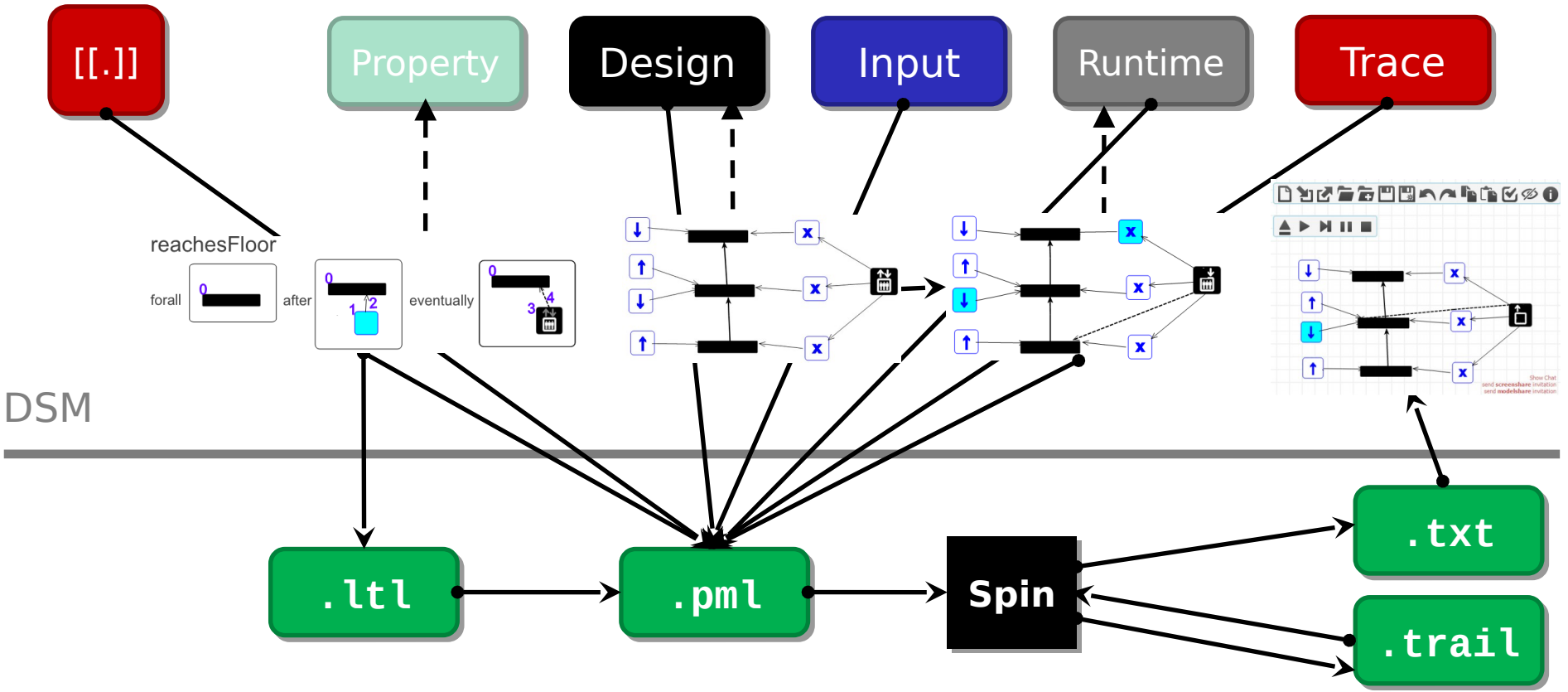
Design ⊨ Property





B. Meyers, R. Deshayes, L. Lucio, E. Syriani, H. Vangheluwe, and M. Wimmer. ProMoBox: A Framework for Generating Domain-Specic Property Languages. In Software Language Engineering (SLE), Vasteras, Sweden, LNCS vol. 8706, pp. 1- 20. Springer. September 2014.

Designing DS Requirements/Property Languages



B. Meyers, H. Vangheluwe, J. Denil and R. Salay, "A Framework for Temporal Verification Support in Domain-Specific Modelling,"
in IEEE Transactions on Software Engineering. doi:10.1109/TSE.2018.2859946

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