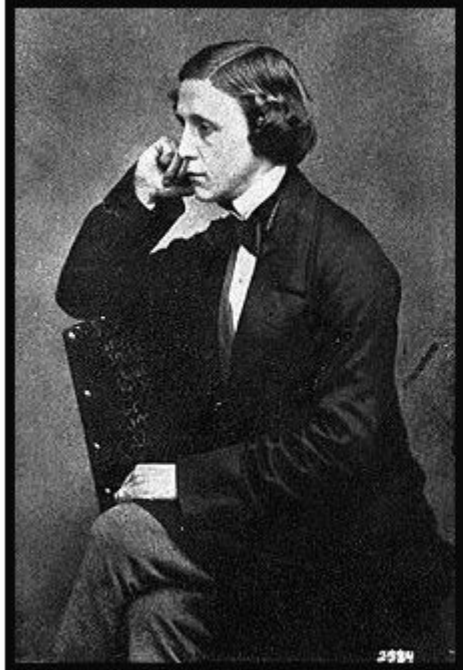
Modelling of Software Intensive Systems (MoSIS)
”dealing with complexity”

http://msdl.uantwerpen.be/people/hv/teaching/MoSIS/

Hans Vangheluwe

https://www.uantwerp.be/en/staff/hans-vangheluwe/

Universiteit Antwerpen | Ansymo Antwerp Systems & Software Modelling University of Antwerp | Nexor Cyber-Physical Systems University of Antwerp | FLANDERS MAKE MANUFACTURING INNOVATION NETWORK | McGill | MPM4CPS | cost



The time has come,' the walrus said, 'to talk of many things: of shoes and ships - and sealing wax - of cabbages and kings.

(Lewis Carroll)

izquotes.com

Complexity!
causes?

Causes of Complexity?

in **Engineering** vs. in Science

Complex vs. Complicated

- large number of components (in an “architecture”)
- multiple concerns/views/stakeholders → consistency?

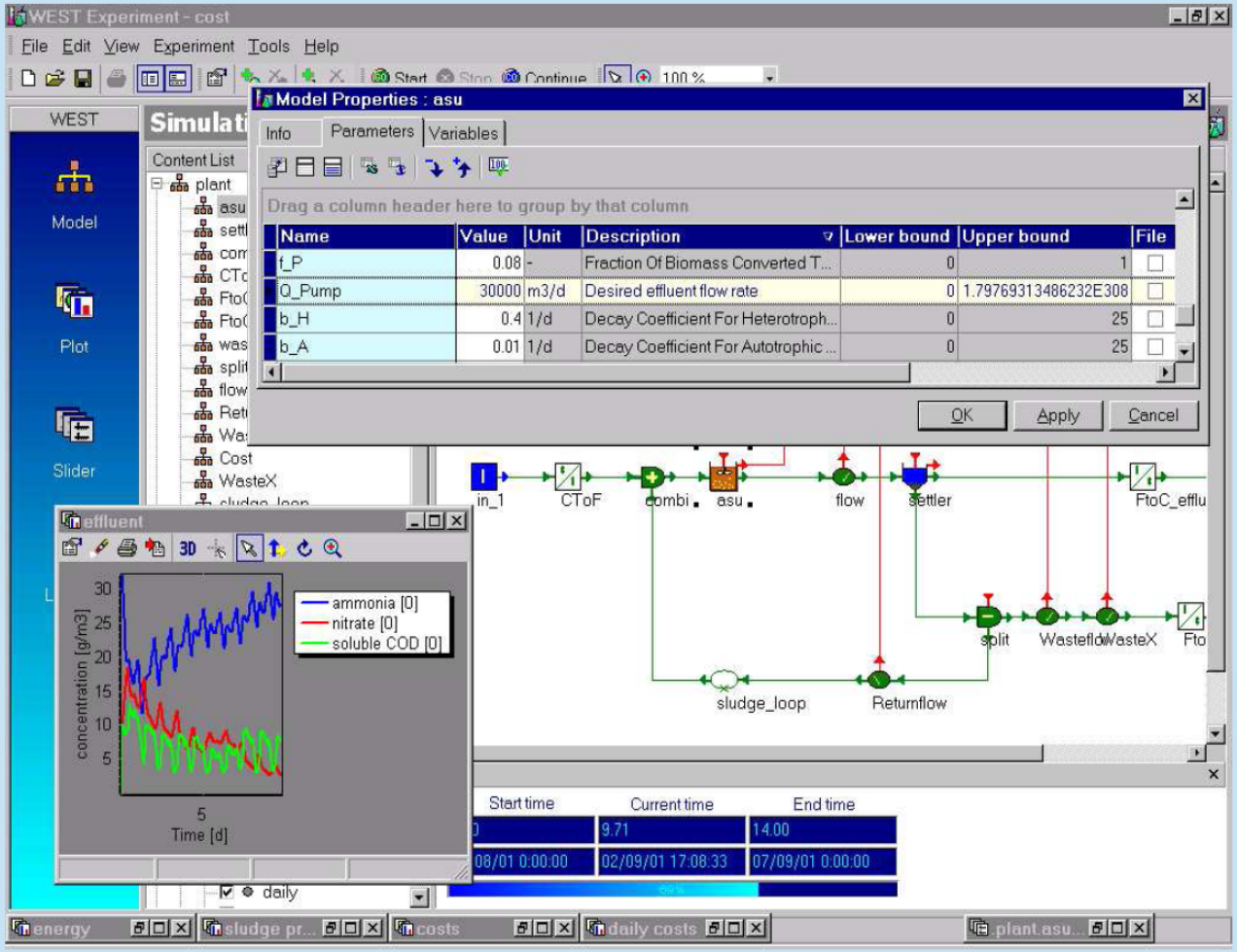
- heterogeneity of components / views
    - different formalisms
    - different abstractions

- emergent behaviour

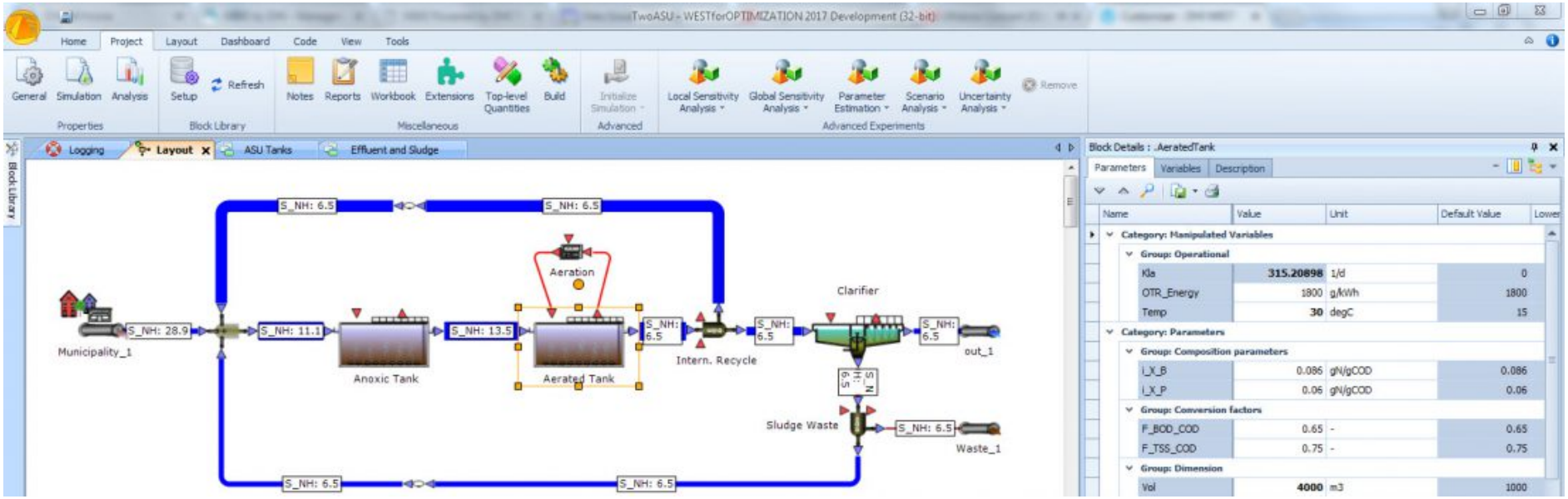
- engineering:
    - long requirements → design path
    - insufficient understanding of requirements, system under study, …
    - difficulty in collaboration
    - modelling languages and tools may introduce “accidental complexity”

Std
ILS APP
TERR ON ND
AUTO BRK
ENGINE
UP
DOWN

DS(V)M Environment



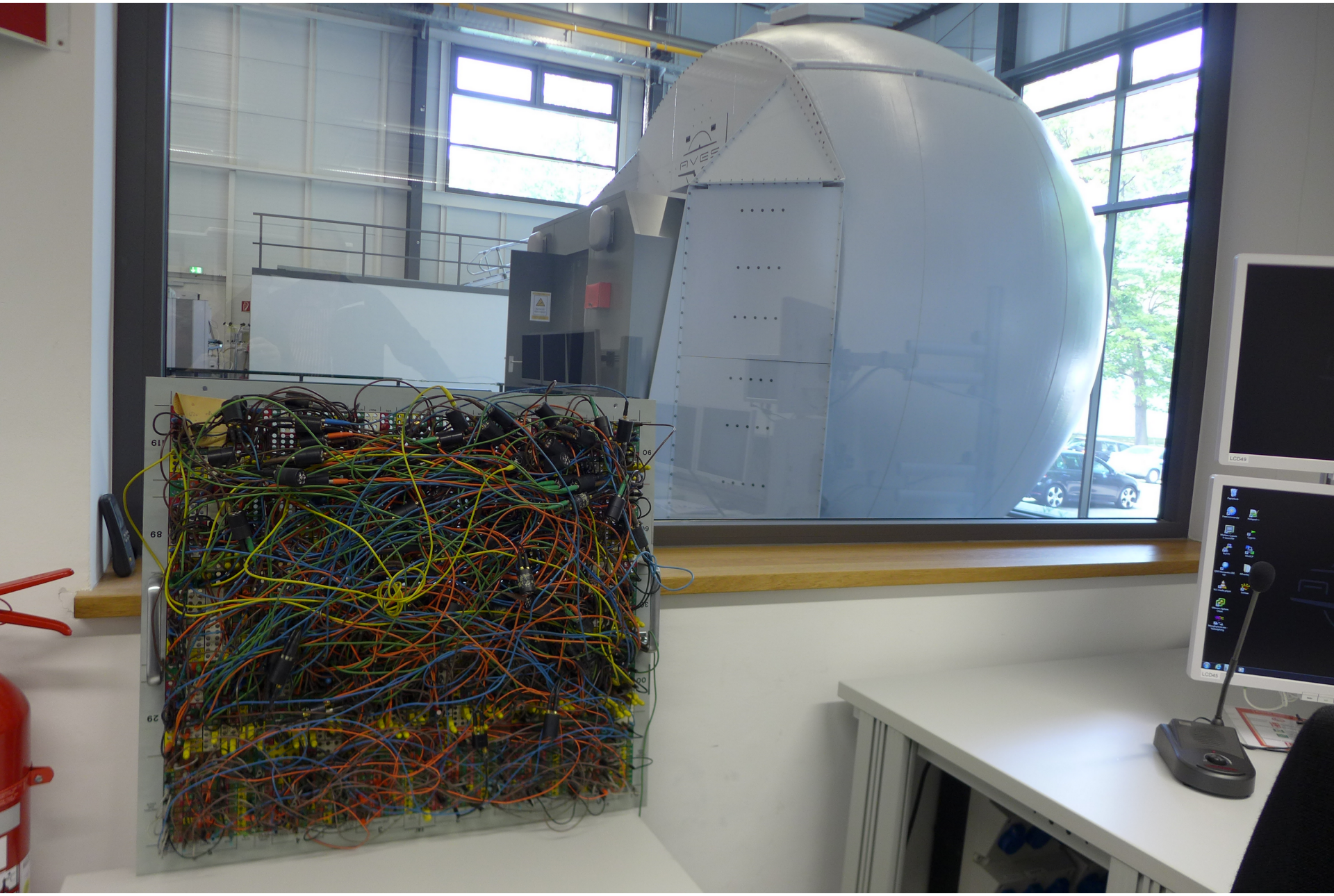
WEST: modelling biological wastewater treatment.
Henk Vanhooren, Jurgen Meirlaen, Youri Amerlinck, Filip Claeys, Hans Vangheluwe and Peter A.Vanrolleghem.
Journal of Hydroinformatics 5 (2003) 27-50

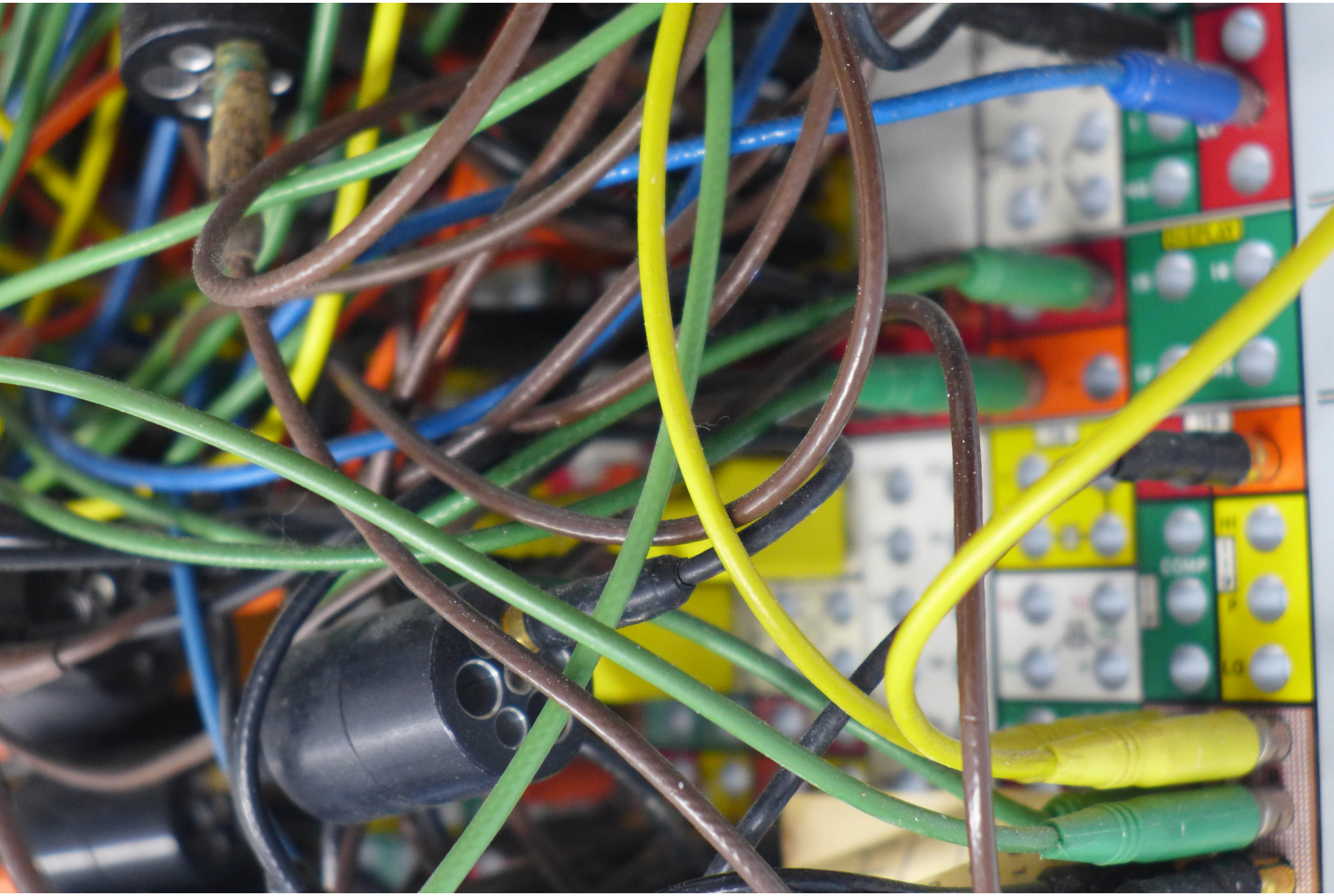


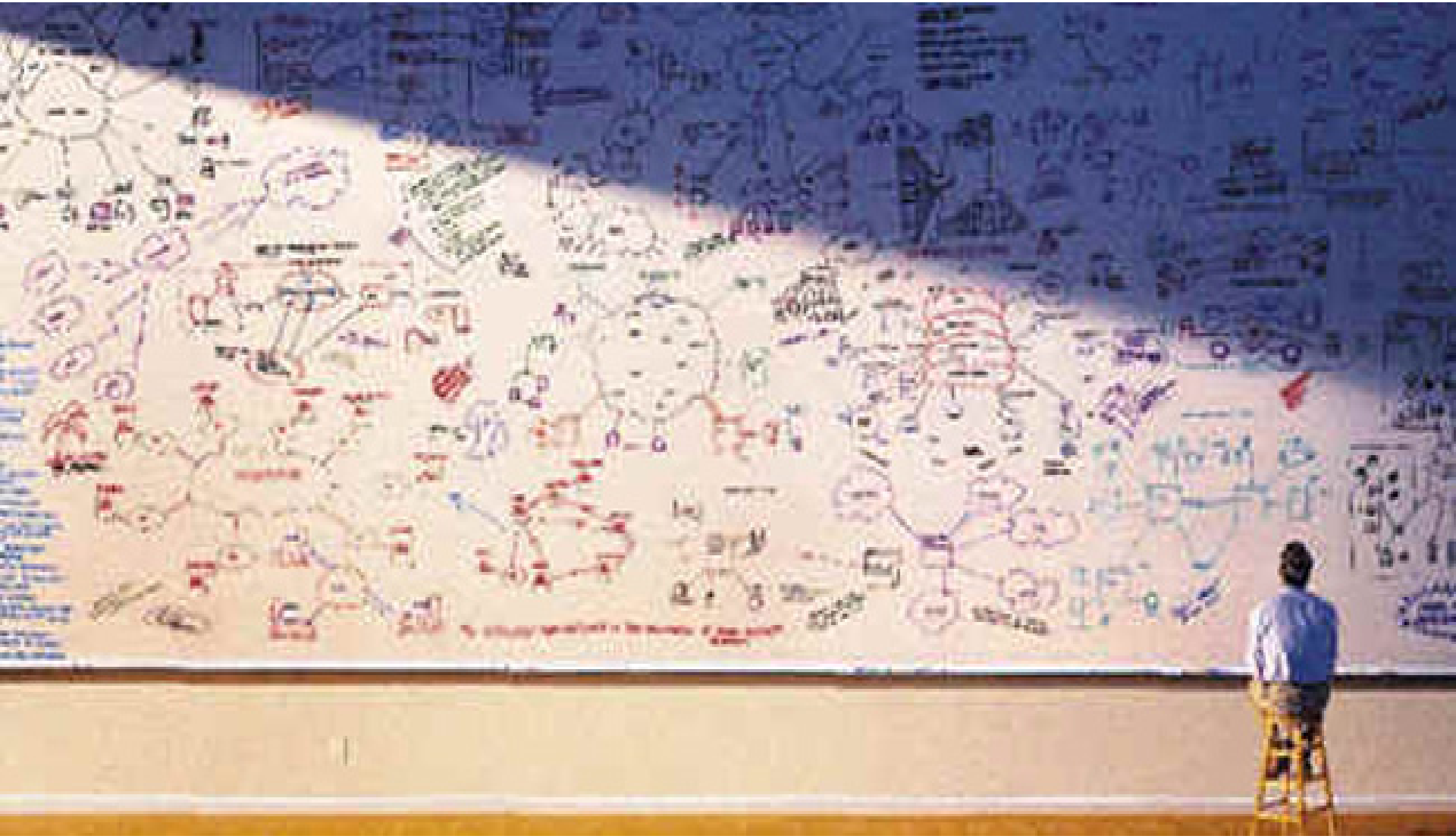
http://www.mikebydhi.com/products/west

Std
ILS APP
TERR ON ND
AUTO BRK
ENGINE
UP
DOWN

DLR
RHEINMETALL
DEFENCE




COMP



How to deal with **Complexity?**

(in engineered systems)

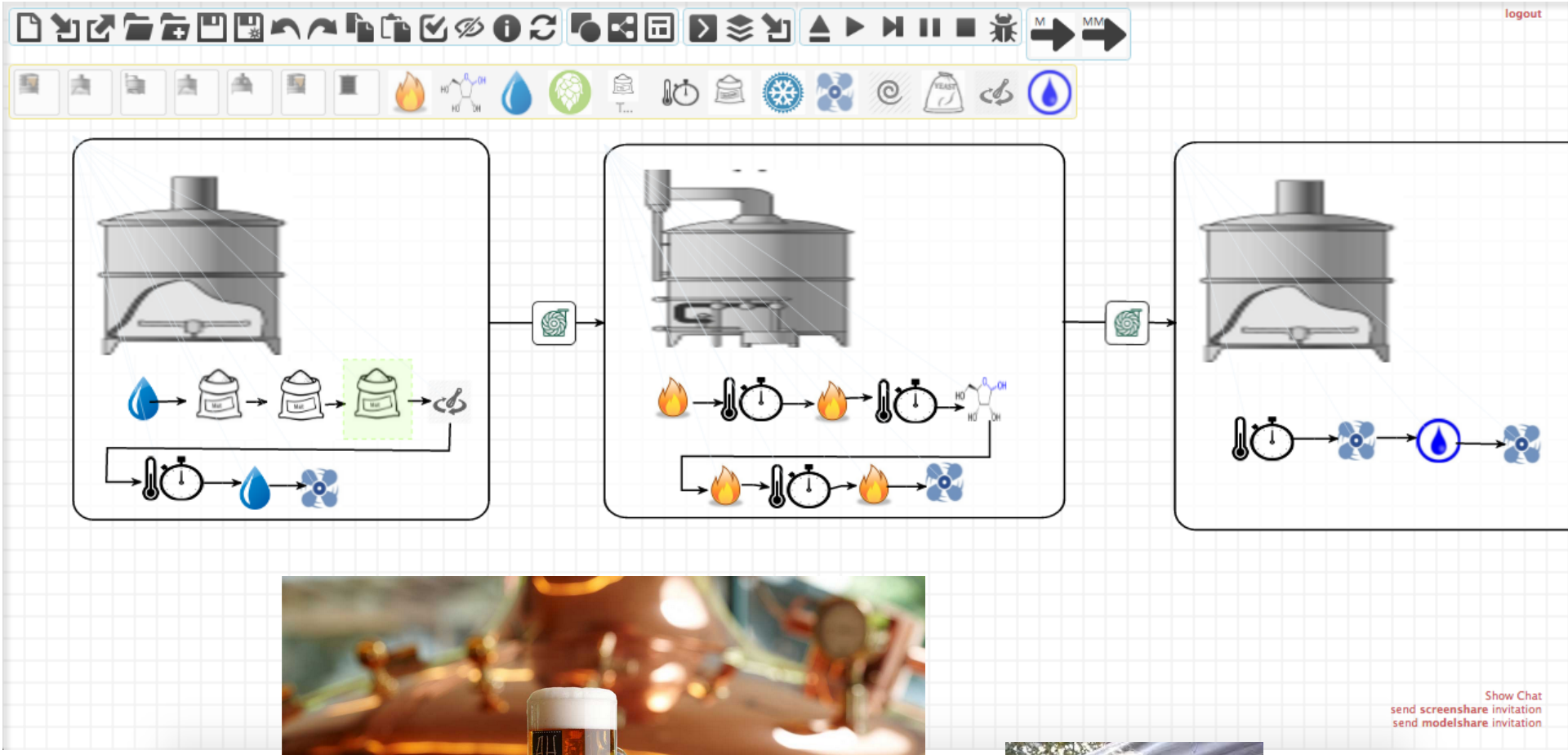
at the most appropriate level(s) of abstraction
using the most appropriate formalism(s)
explicitly modelling workflows

DSM TP 2014
Theory and Practice

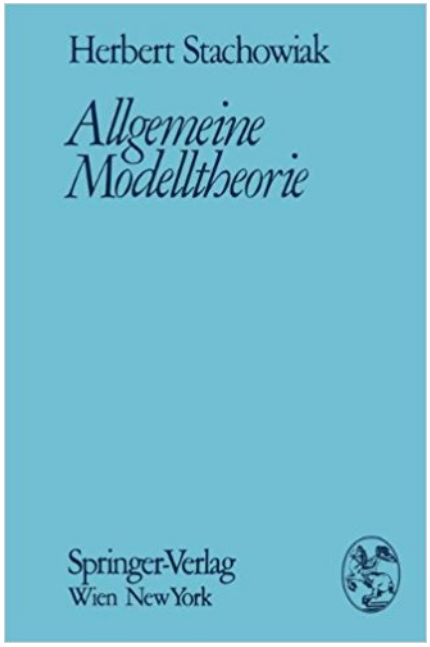
5th International Summer School
on Domain Specific Modeling

Antwerp, Belgium
25 - 29 August

Thomas Kühne



Joachim Denil



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.

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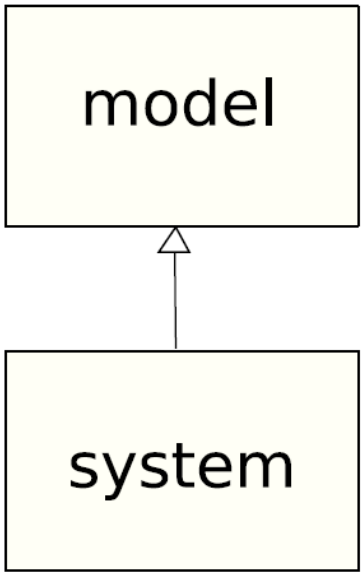
Mannequin comes from the French word mannequin, which had acquired the meaning "an artist's jointed model", which in turn came from the Flemish word manneken, meaning "little man, figurine".

The American Heritage Dictionary of the English Language. Houghton Mifflin Company. 2004.

Jean Bézivin

Everything is a model !

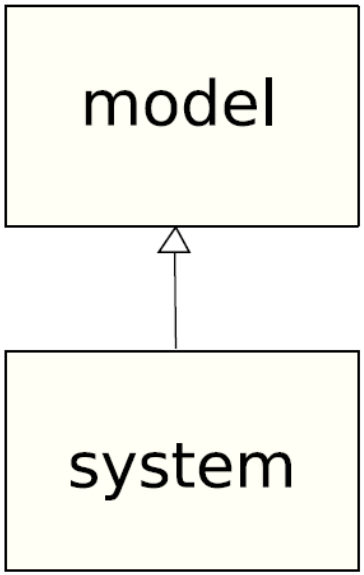


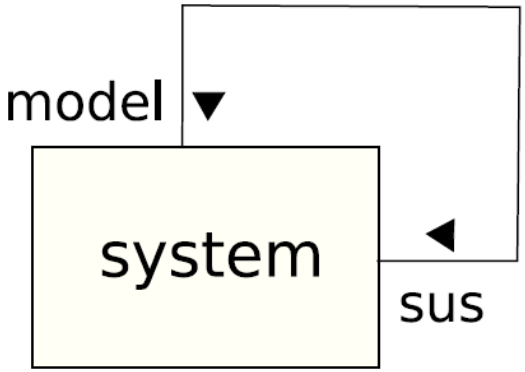
Jean Bézivin

Everything is a model !

Jean-Marie Favre

Nothing is a model !





Jean Bézivin

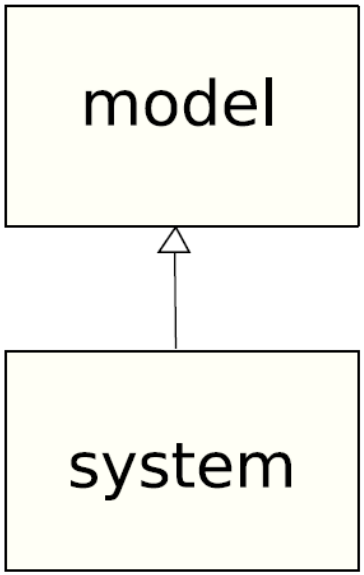
Everything is a model !

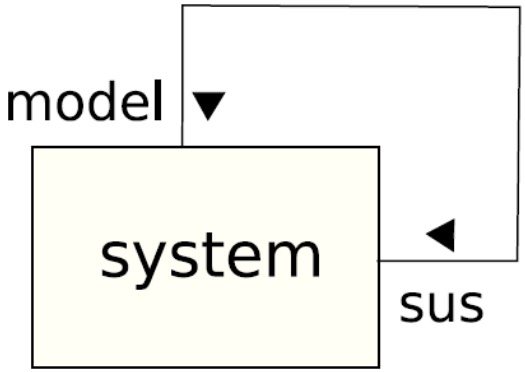
Jean-Marie Favre

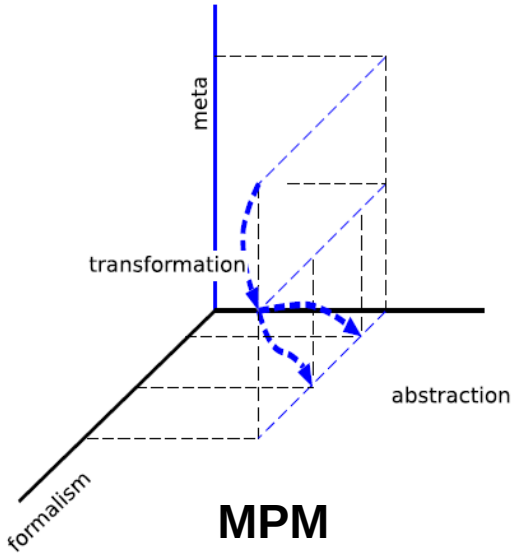
Nothing is a model !

Hans Vangheluwe

Model everything !







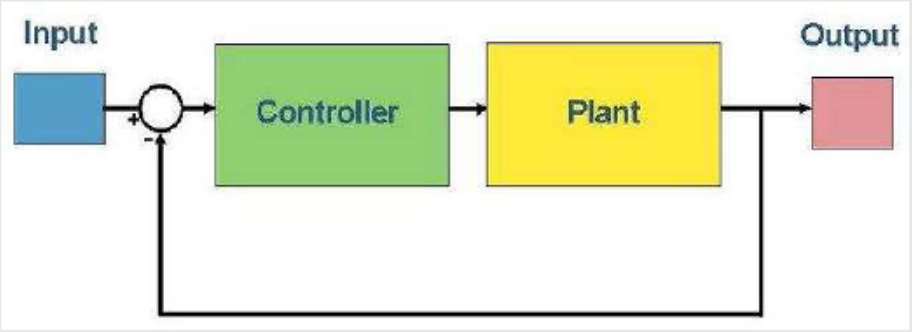
“System”

System Boundaries

- **System** to be built/studied
- **Environment** with which the system interacts

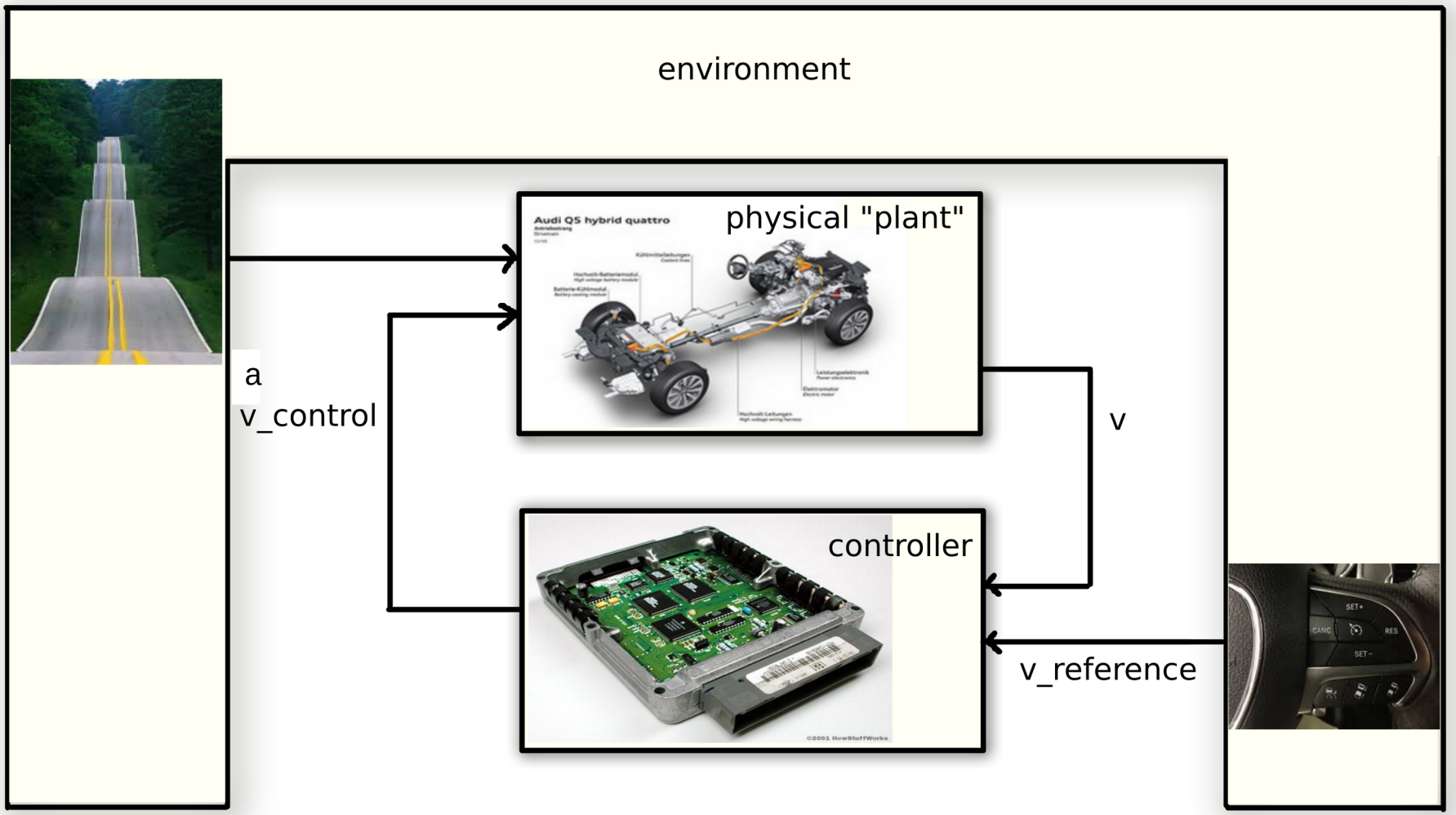
“System”

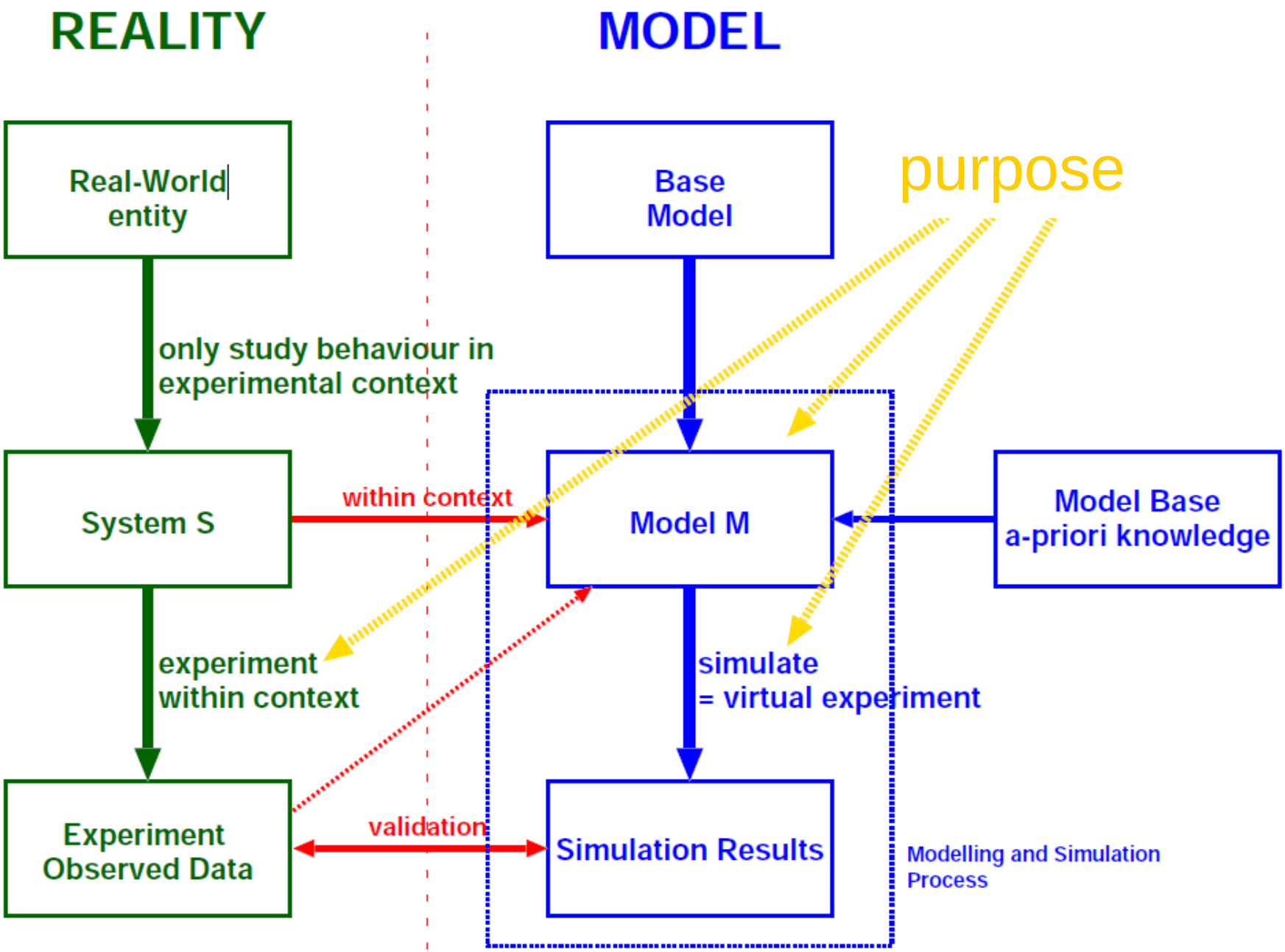
System vs. “Plant”



“Plant”?!

system = environment / “plant” / controller

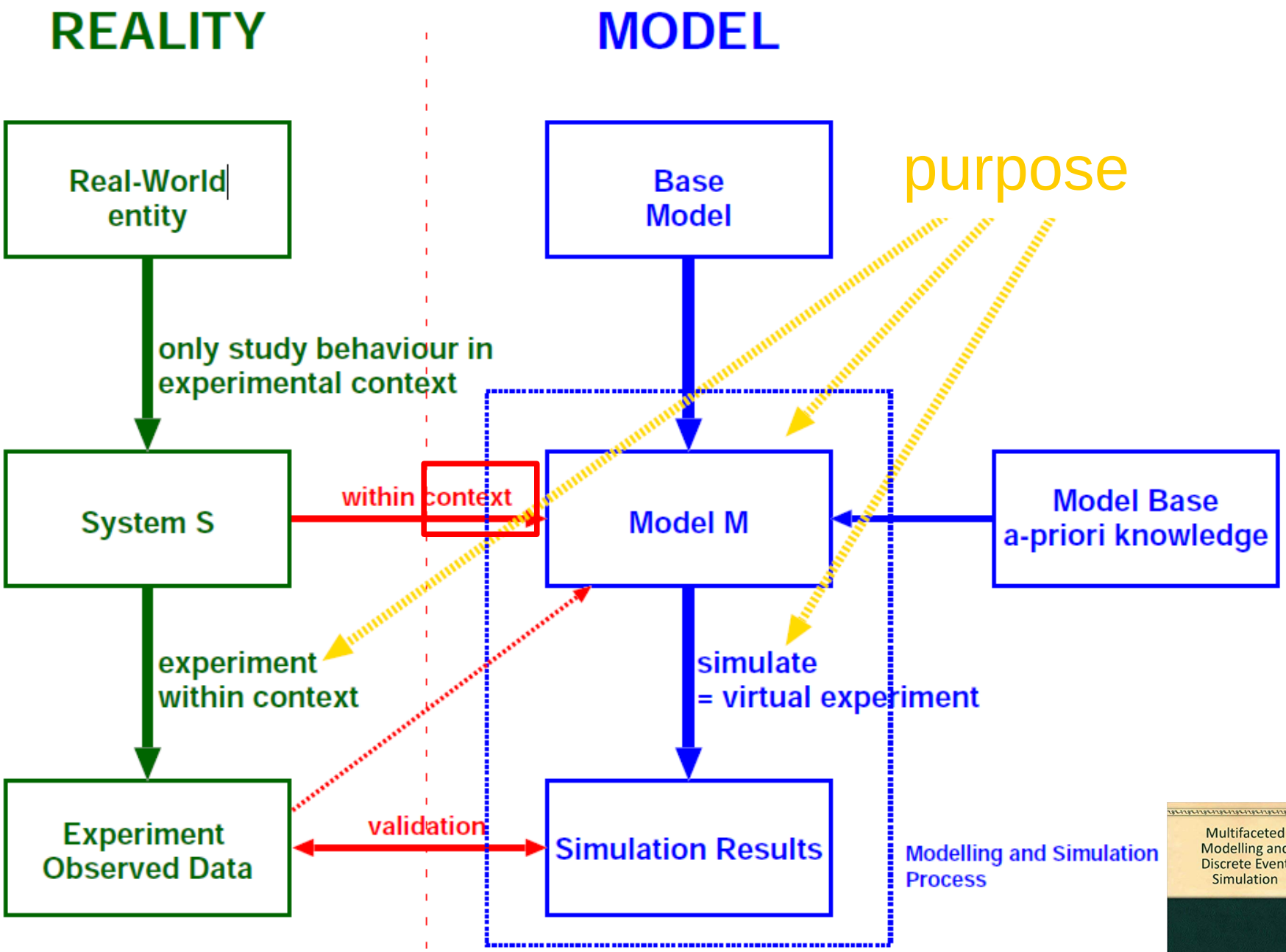


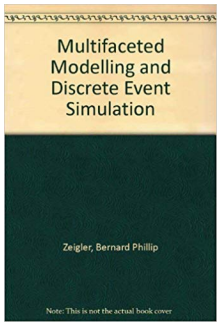


Bernard P. Zeigler. *Multi-faceted Modelling and Discrete-Event Simulation*. Academic Press, 1984.

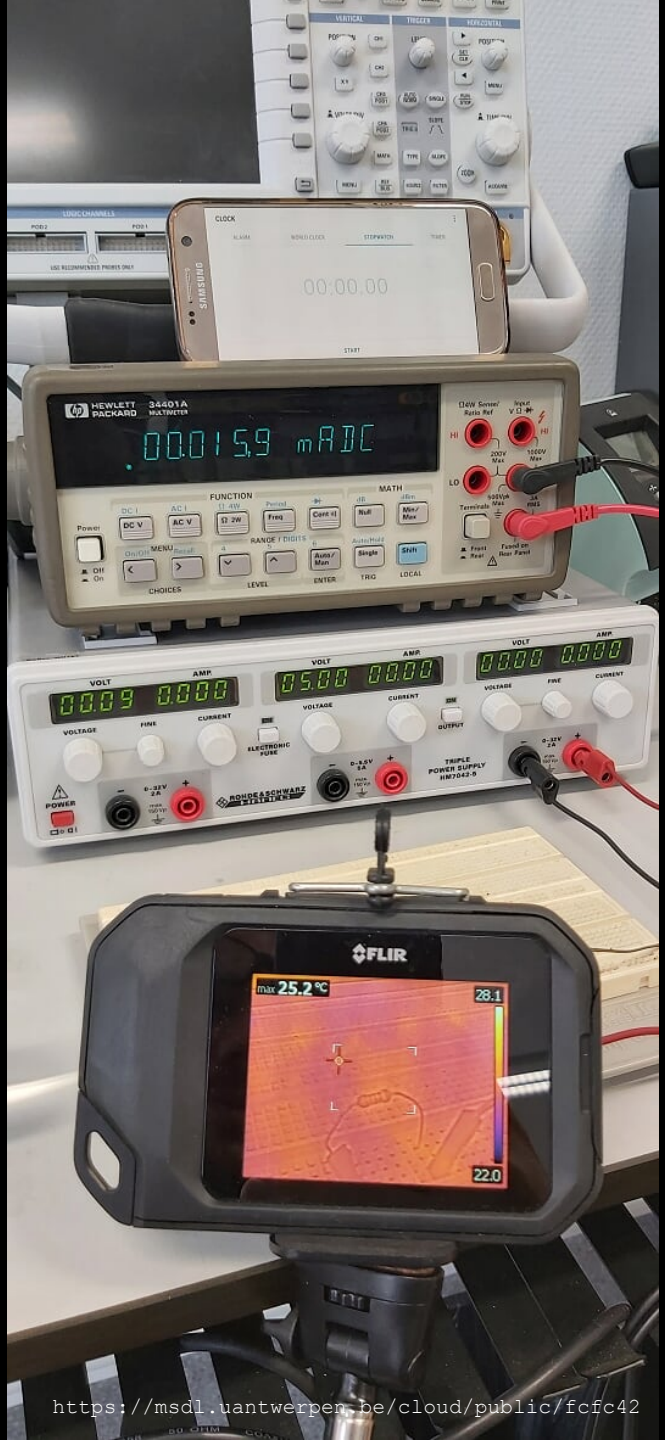
model must be “fit for purpose”

drives choice of:
level of abstraction, formalism, notation, ….



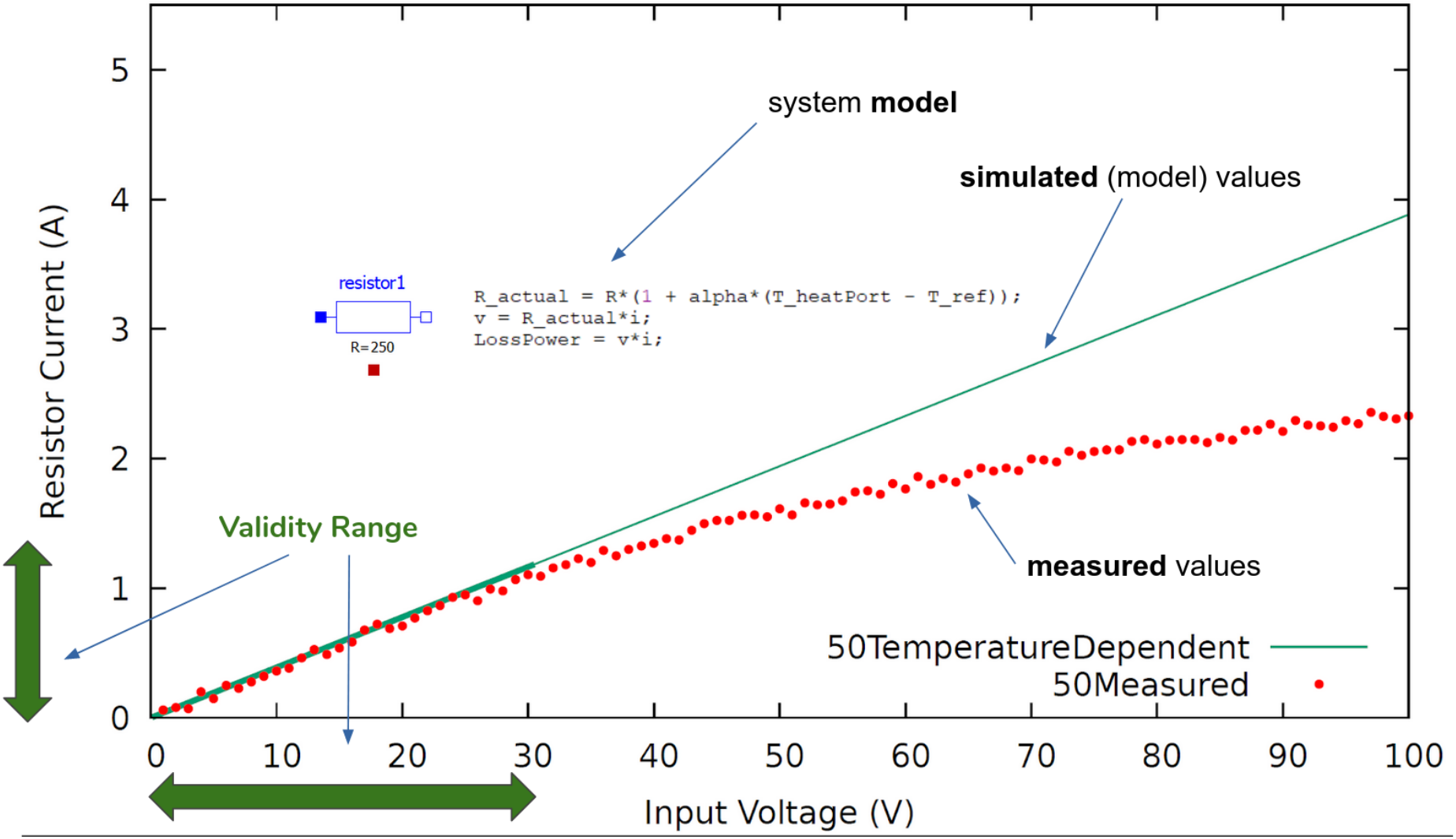


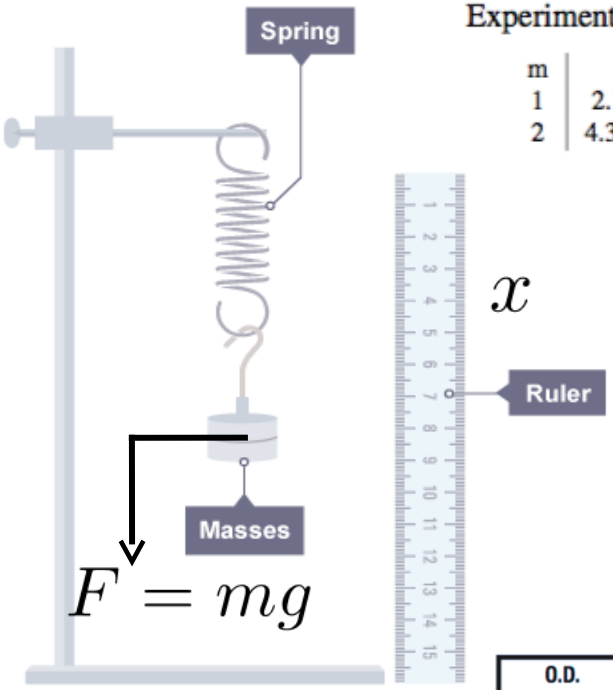
Bernard P. Zeigler. *Multi-faceted Modelling and Discrete-Event Simulation.* Academic Press, 1984.



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

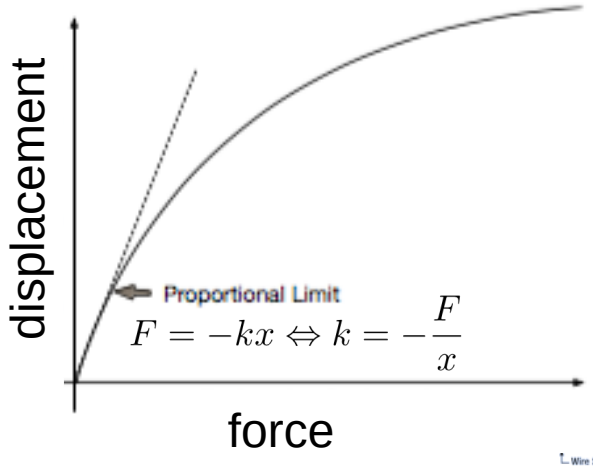
Model Validity … Context?





Experimental spring results, with mass m in kg and displacement x (± 0.0001) in cm

m	x	m	x	m	x	m	x	m	x
1	2.100	3	6.3749	5	10.4915	7	14.6081	9	19.0012
2	4.3166	4	8.4332	6	12.5489	8	16.7774		



O.D. Inches	O.D. mm	CENTURY STOCK NUMBER	FREE LENGTH Inches	FREE LENGTH mm	I.D. Inches	I.D. mm	RATE Lbs./In.	RATE N/mm	SUGG. MAX. DEFL. Inches	SUGG. MAX. DEFL. mm	SUGG. MAX. LOAD Lbs.	SUGG. MAX. LOAD N	SOLID LENGTH Inches	SOLID LENGTH mm	WIRE DIA. Inches	WIRE DIA. mm	TOTAL COILS	MAT'L	ENDS	FNSH
0.036	.91	10075	.59	15.1	.022	.6	2.6	.46	.15	3.8	.39	1.7	.35	8.9	0.007	0.2	49.0	SST	C	N
0.036	.91	JJ-7	.63	15.9	.024	.6	1.6	.28	.16	4.1	.25	1.1	.25	6.2	0.006	0.2	40.0	SST	C	N
0.040	1.02	2924	.66	16.8	.020	.5	11	2.0	.13	3.2	1.4	6.4	.50	12.6	0.010	0.3	48.5	MW	C	N
0.040	1.02	10778	.69	17.5	.028	.7	1.0	.17	.35	8.9	.35	1.6	.30	7.7	0.006	0.2	49.5	MW	C	N
0.054	1.37	RR-6	.25	6.4	.036	.9	6.2	1.1	.09	2.2	.56	2.5	.16	4.1	0.009	0.2	16.5	SST	C	N
0.054	1.37	10619	.72	18.3	.038	1.0	1.6	.29	.37	9.3	.60	2.7	.32	8.1	0.008	0.2	39.0	MW	C	N
0.057	1.45	70000	.13	3.3	.045	1.1	3.7	.66	.07	1.7	.25	1.1	.04	1.0	0.006	0.2	5.75	MW	C	N
0.057	1.45	70000S	.13	3.3	.045	1.1	3.3	.57	.05	1.3	.17	.74	.04	1.0	0.006	0.2	5.75	SST	C	N
0.057	1.45	70009	.13	3.3	.043	1.1	6.9	1.2	.06	1.5	.40	1.8	.05	1.2	0.007	0.2	6.00	MW	C	N
0.057	1.45	70009S	.13	3.3	.043	1.1	6.0	1.1	.04	1.1	.26	1.2	.05	1.2	0.007	0.2	6.00	SST	C	N
0.057	1.45	70018	.13	3.3	.041	1.0	12	2.1	.05	1.2	.57	2.5	.06	1.4	0.008	0.2	6.13	MW	C	N
0.057	1.45	70018S	.13	3.3	.041	1.0	11	1.8	.03	.88	.37	1.6	.06	1.4	0.008	0.2	6.13	SST	C	N
0.057	1.45	70001	.19	4.8	.045	1.1	2.3	.40	.11	2.8	.25	1.1	.06	1.4	0.006	0.2	8.13	MW	C	N
0.057	1.45	70001S	.19	4.8	.045	1.1	2.0	.35	.08	2.1	.17	.74	.06	1.4	0.006	0.2	8.13	SST	C	N
0.057	1.45	70010	.19	4.8	.043	1.1	4.0	.70	.10	2.5	.40	1.8	.07	1.8	0.007	0.2	8.88	MW	C	N
0.057	1.45	70010S	.19	4.8	.043	1.1	3.5	.61	.07	1.9	.26	1.2	.07	1.8	0.007	0.2	8.88	SST	C	N
0.057	1.45	70019	.19	4.8	.041	1.0	7.4	1.3	.08	2.0	.57	2.5	.08	2.0	0.008	0.2	8.75	MW	C	N
0.057	1.45	70019S	.19	4.8	.041	1.0	6.4	1.1	.06	1.4	.37	1.6	.08	2.0	0.008	0.2	8.75	SST	C	N
0.057	1.45	70002	.25	6.4	.045	1.1	1.7	.30	.15	3.8	.25	1.1	.07	1.7	0.006	0.2	10.3	MW	C	N
0.057	1.45	70002S	.25	6.4	.045	1.1	1.5	.26	.11	2.8	.17	.74	.07	1.7	0.006	0.2	10.3	SST	C	N
0.057	1.45	70011	.25	6.4	.043	1.1	3.1	.54	.13	3.3	.40	1.8	.08	2.1	0.007	0.2	11.0	MW	C	N
0.057	1.45	70011S	.25	6.4	.043	1.1	2.7	.47	.10	2.5	.26	1.2	.08	2.1	0.007	0.2	11.0	SST	C	N
0.057	1.45	70020	.25	6.4	.041	1.0	5.3	.92	.11	2.8	.57	2.5	.10	2.5	0.008	0.2	11.5	MW	C	N
0.057	1.45	70020S	.25	6.4	.041	1.0	4.6	.80	.08	2.0	.37	1.6	.10	2.5	0.008	0.2	11.5	SST	C	N
0.057	1.45	70003	.31	7.9	.045	1.1	1.4	.24	.19	4.7	.25	1.1	.08	2.0	0.006	0.2	12.4	MW	C	N
0.057	1.45	70003S	.31	7.9	.045	1.1	1.2	.21	.14	3.6	.17	.74	.08	2.0	0.006	0.2	12.4	SST	C	N
0.057	1.45	70012	.31	7.9	.043	1.1	2.4	.42	.17	4.2	.40	1.8	.10	2.6	0.007	0.2	13.5	MW	C	N
0.057	1.45	70012S	.31	7.9	.043	1.1	2.1	.37	.12	3.2	.26	1.2	.10	2.6	0.007	0.2	13.5	SST	C	N
0.057	1.45	70021	.31	7.9	.041	1.0	4.1	.72	.14	3.6	.57	2.5	.12	3.1	0.008	0.2	14.3	MW	C	N
0.057	1.45	70021S	.31	7.9	.041	1.0	3.6	.63	.10	2.6	.37	1.6	.12	3.1	0.008	0.2	14.3	SST	C	N

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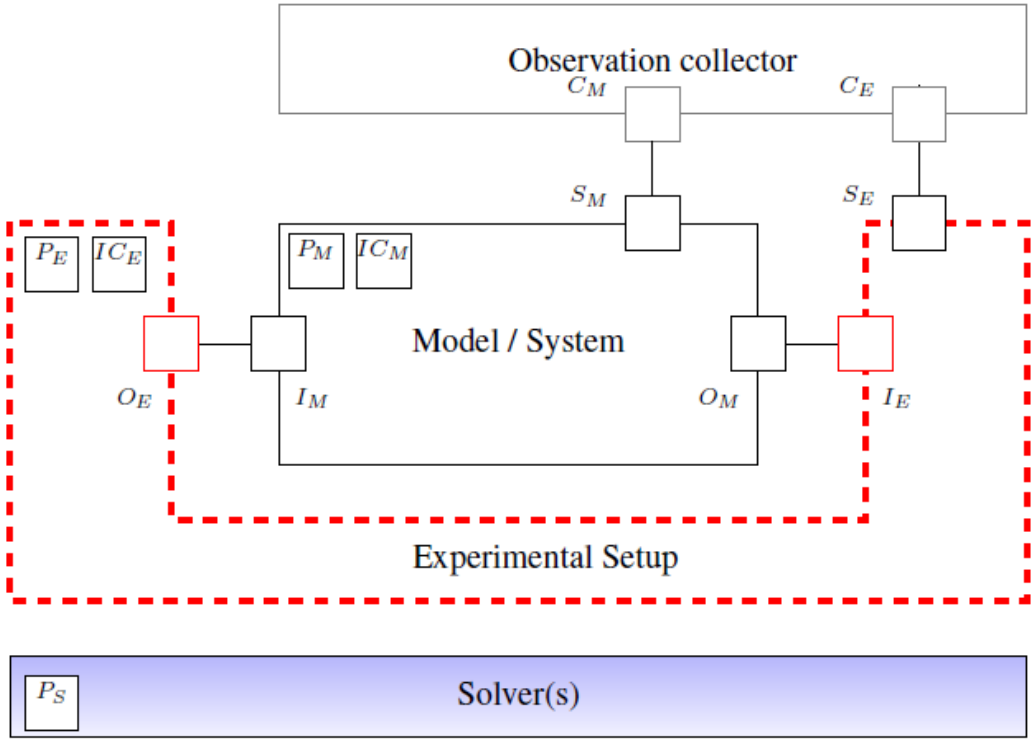
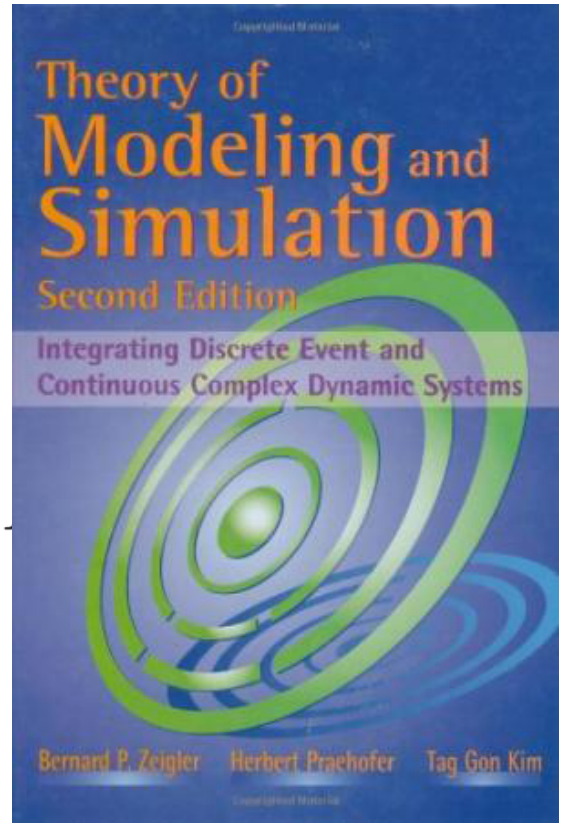
Experimental/Validity **“Frame”**





Denil, J., Klikovits, S., Mosterman, P. J., Vallecillo, A., & Vangheluwe, H. (2017).
The experiment model and validity frame in M&S.
In *Proceedings of the Symposium on Theory of Modeling & Simulation* (Vol. 49).

Vanherpen, K., Denil, J., De Meulenaere, P., & Vangheluwe, H. (2016).
Ontological Reasoning as an Enabler of Contract-Based Co-design.
In C. Berger, M. R. Mousavi, & R. Wisniewski (Eds.), *Cyber Physical Systems. Design, Modeling, and Evaluation: 6th International Workshop, CyPhy 2016, Pittsburgh, PA, USA, October 6, 2016, Revised Selected Papers* (pp. 101–115). Cham: Springer International Publishing.
http://doi.org/10.1007/978-3-319-51738-4_8

What vs. How

Requirements ("What?")

- Detached or Semi-detached
- Style (classical, modern, . . .)
- Number of Floors
- Number of rooms of different types (bedrooms, bathrooms, . . .)
- Garage, Storage, . . .
- Cellar
- . . .

Design ("How?")

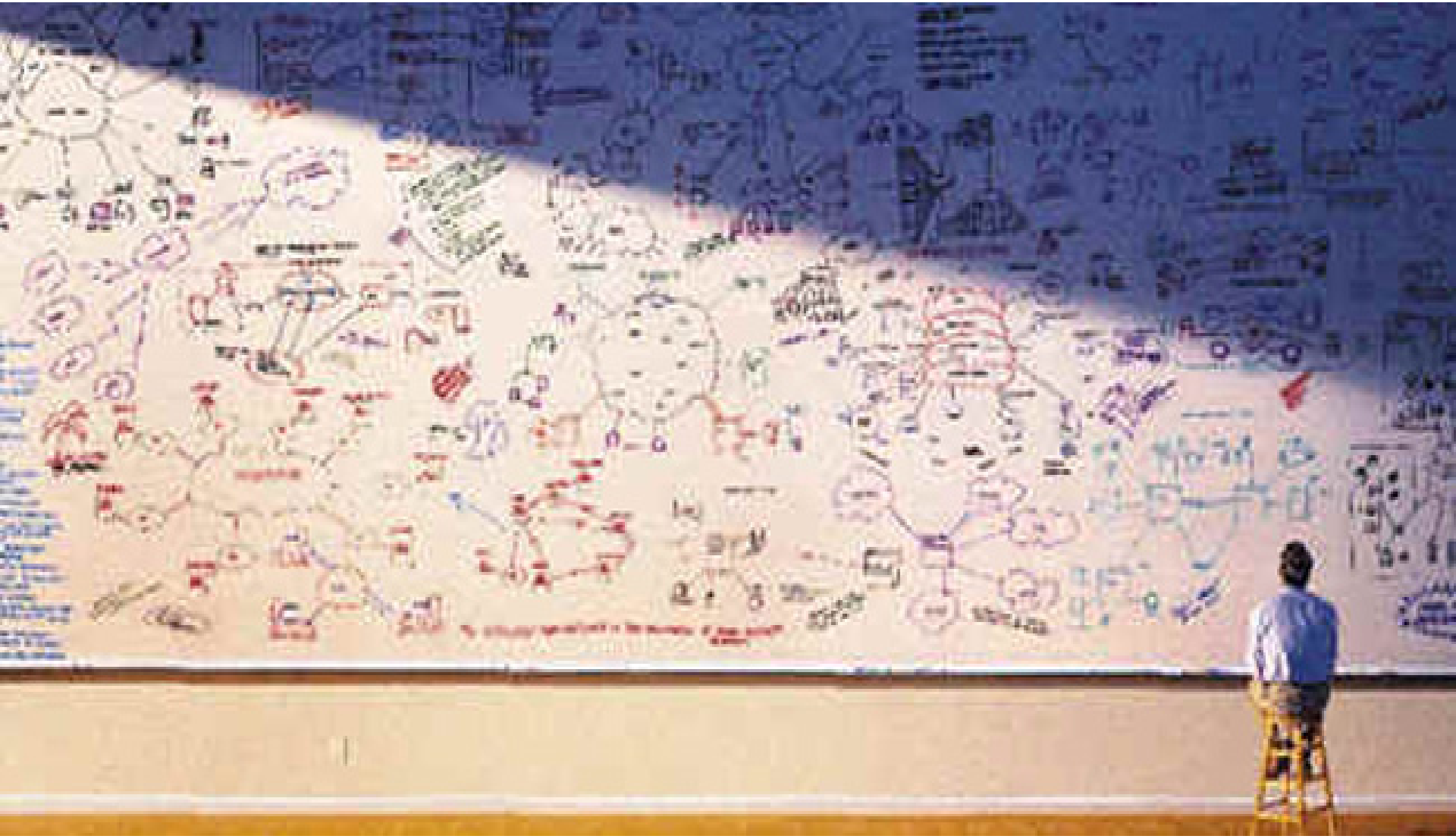
note: product family

requirements
(i.e., a set of properties)

– *satisfied by* →

design

(may in turn serve as requirements ...)



How to deal with **Complexity?**

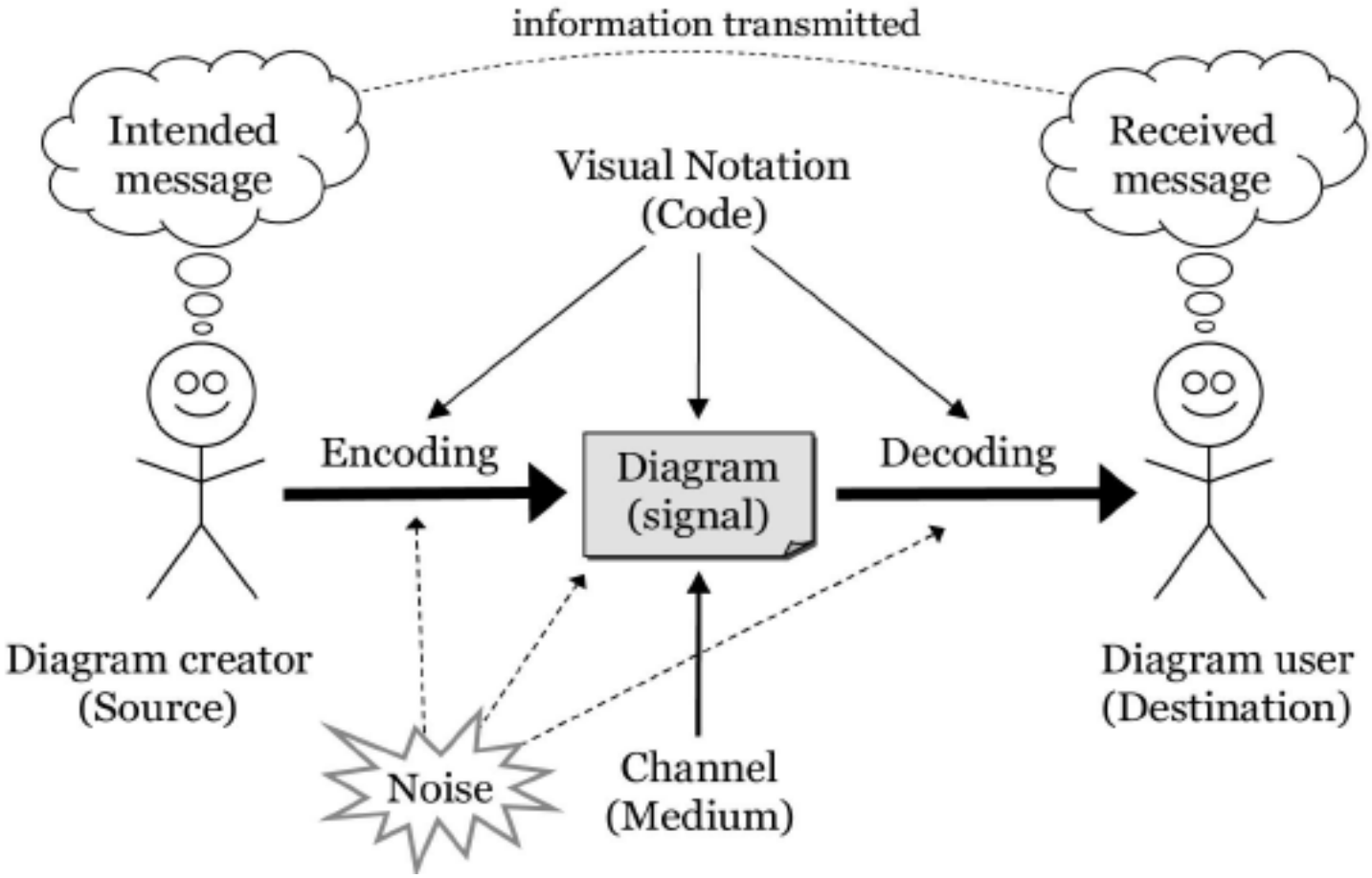
(in engineered systems)

IEEE TRANSACTIONS ON SOFTWARE ENGINEERING, VOL. 35, NO. 5, NOVEMBER-DECEMBER 2009

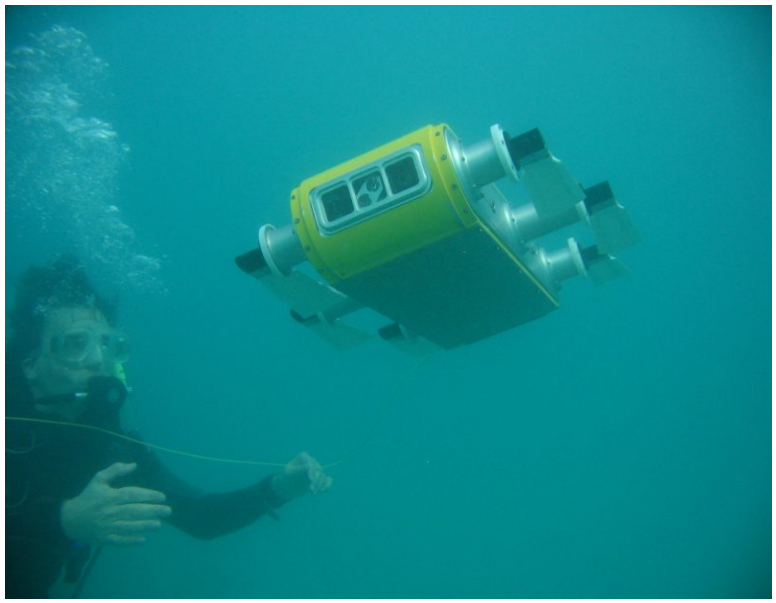
The “Physics” of Notations: Towards a Scientific Basis for Constructing Visual Notations in Software Engineering

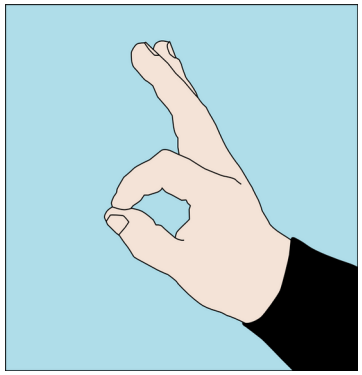
Daniel L. Moody, *Member, IEEE*

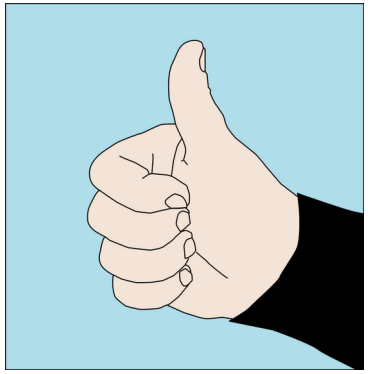
Communication Theory

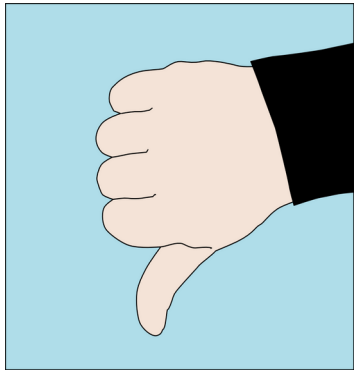


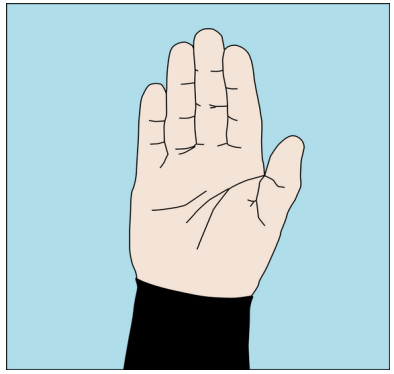
Perceptual Discriminability





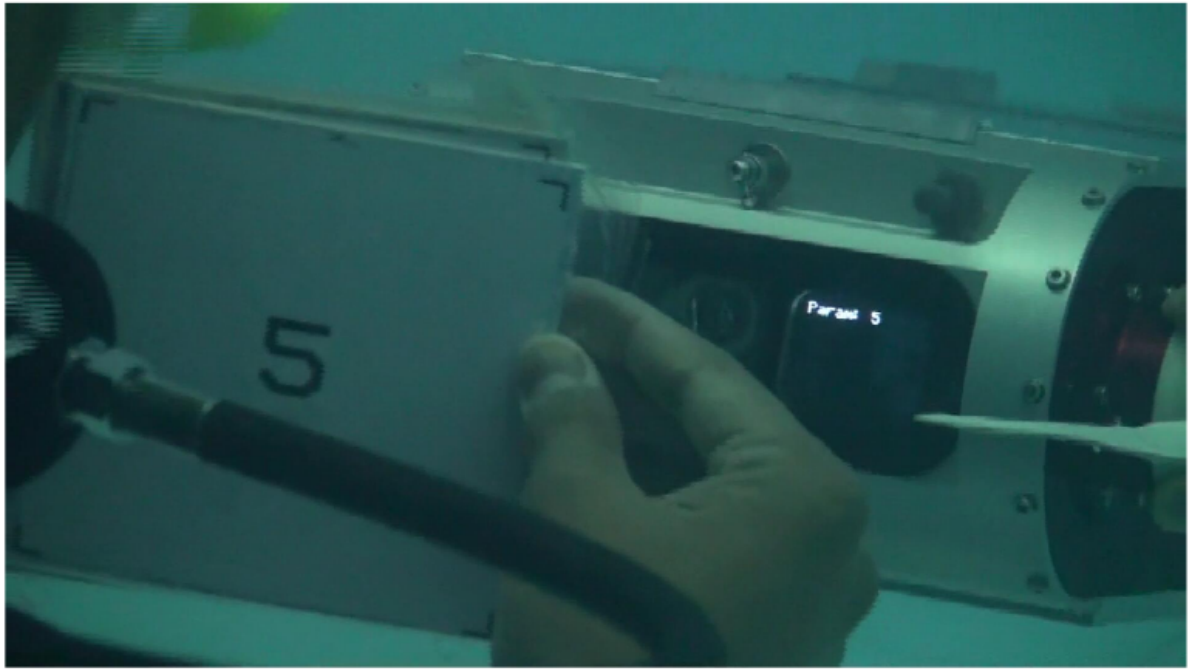






(a) Divers programming Aqua2 during pool trials.

(b) A diver programming Aqua2 during an HRI trial held at a lake in central Québec.



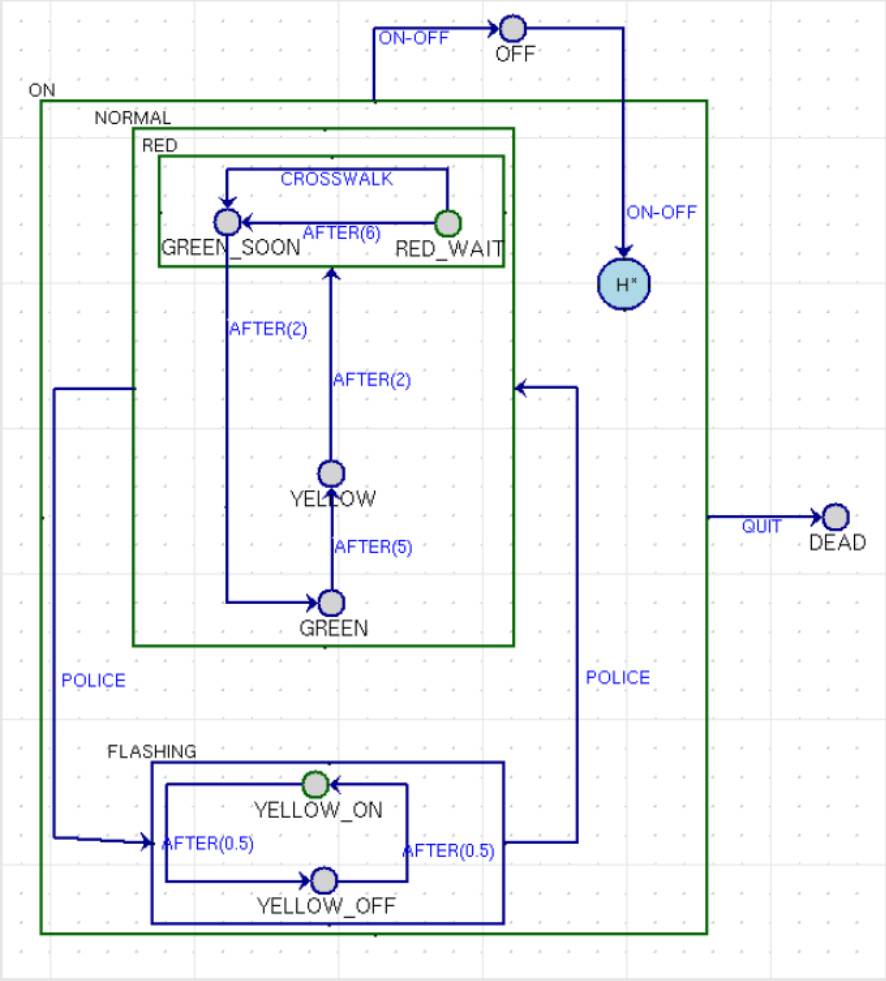
(c) Example of command acknowledgement given on the LED screen of the Aqua2 robot during field trials.

Junaed Sattar, Gregory Dudek. Reducing Uncertainty in Human-Robot Interaction: A Cost Analysis Approach. ISER 2010: 81-95.

Semantic Transparency: semantically perverse symbols

depends on context/user/. ..

Most Appropriate Formalism

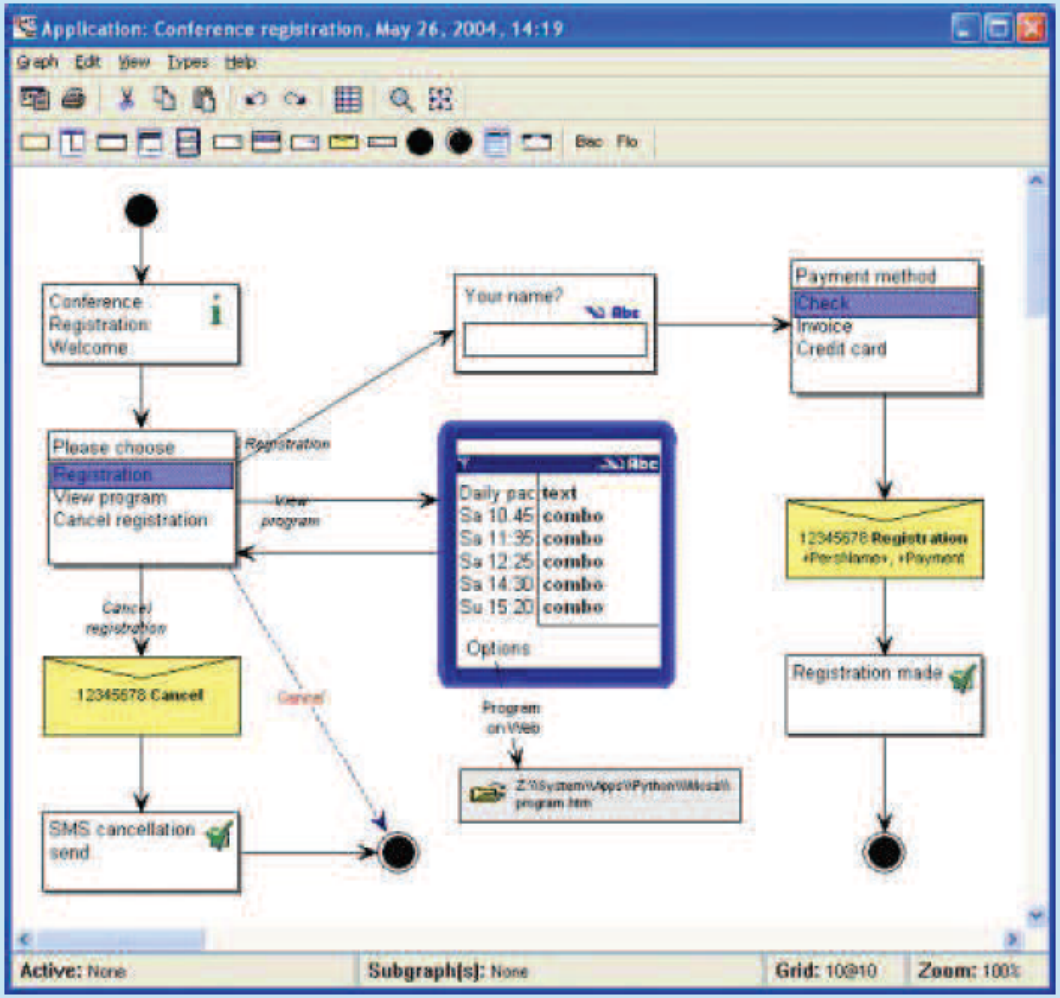


DS(V)M Example in Software Domain
smart phones, the application

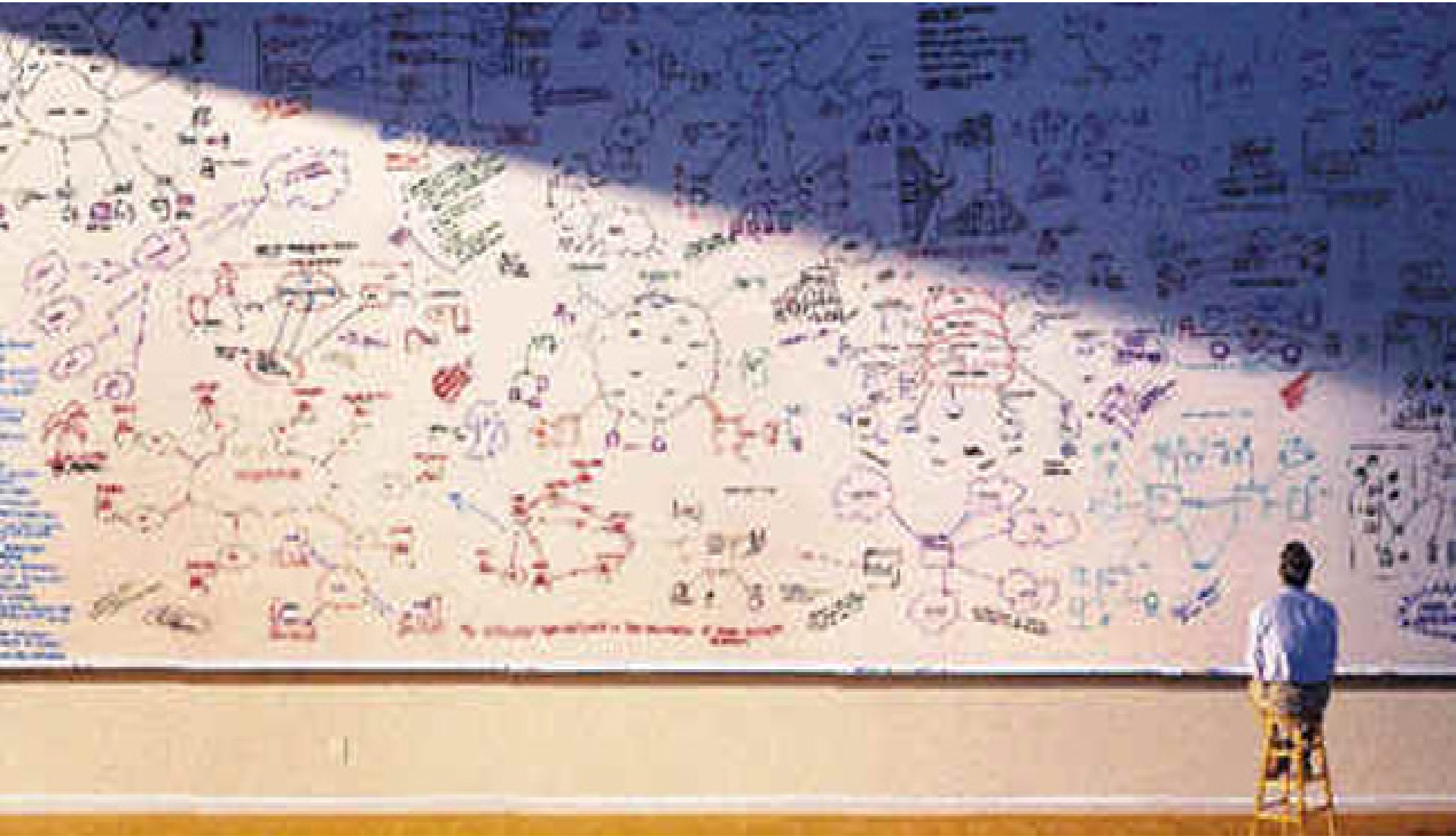
MetaEdit+ (www.metacase.com)

Use “most appropriate” (for purpose/user/...) Formalism
Minimize “accidental complexity”

DS(V)M Example: smart phones, the Domain-Specific model



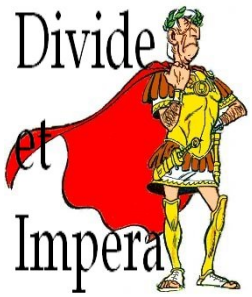
Frederick P. Brooks, Jr. No Silver Bullet: Essence and Accidents of Software Engineering

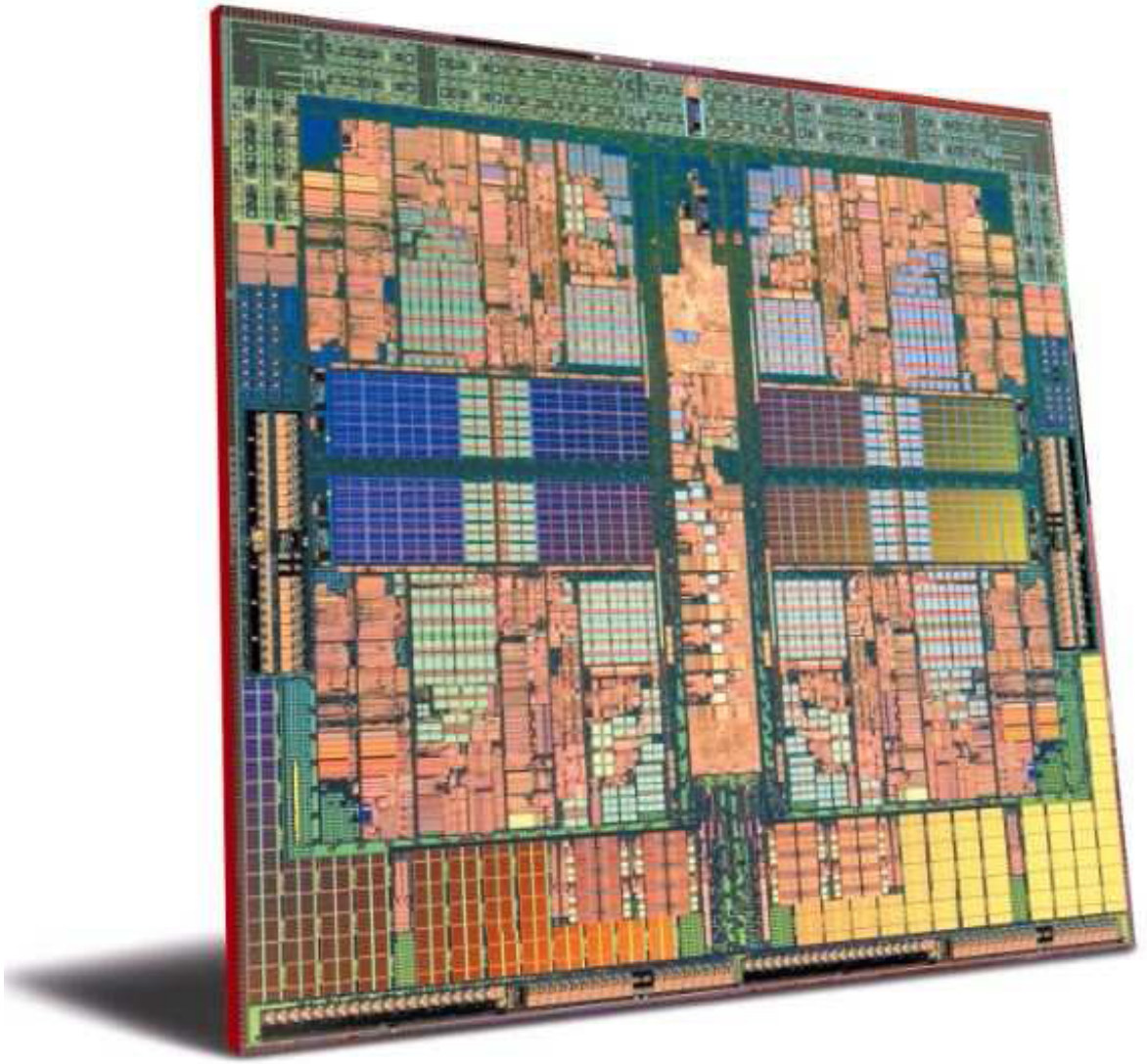


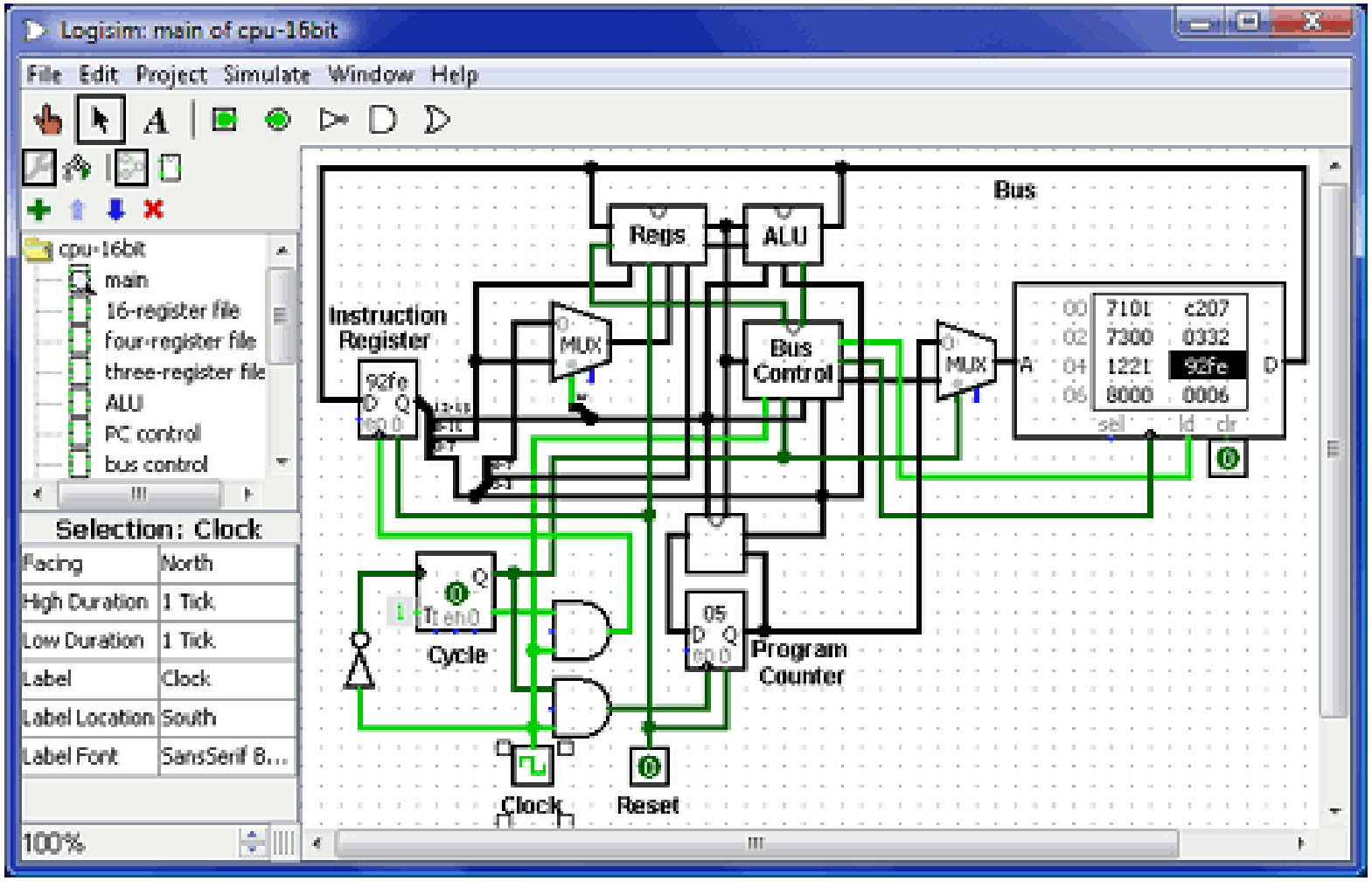
How to deal with **Complexity?**

(in engineered systems)

“architectural” (hierarchical) **(de-)composition**



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File Edit Project Simulate Window Help
cpu-16bit
main
16-register file
four-register file
three-register file
ALU
PC control
bus control
Selection: Clock
Facing North
High Duration 1 Tick
Low Duration 1 Tick
Label Clock
Label Location South
Label Font SansSerif 8...
100%
Bus
Regs
ALU
Instruction Register
92fe
MUX
Bus Control
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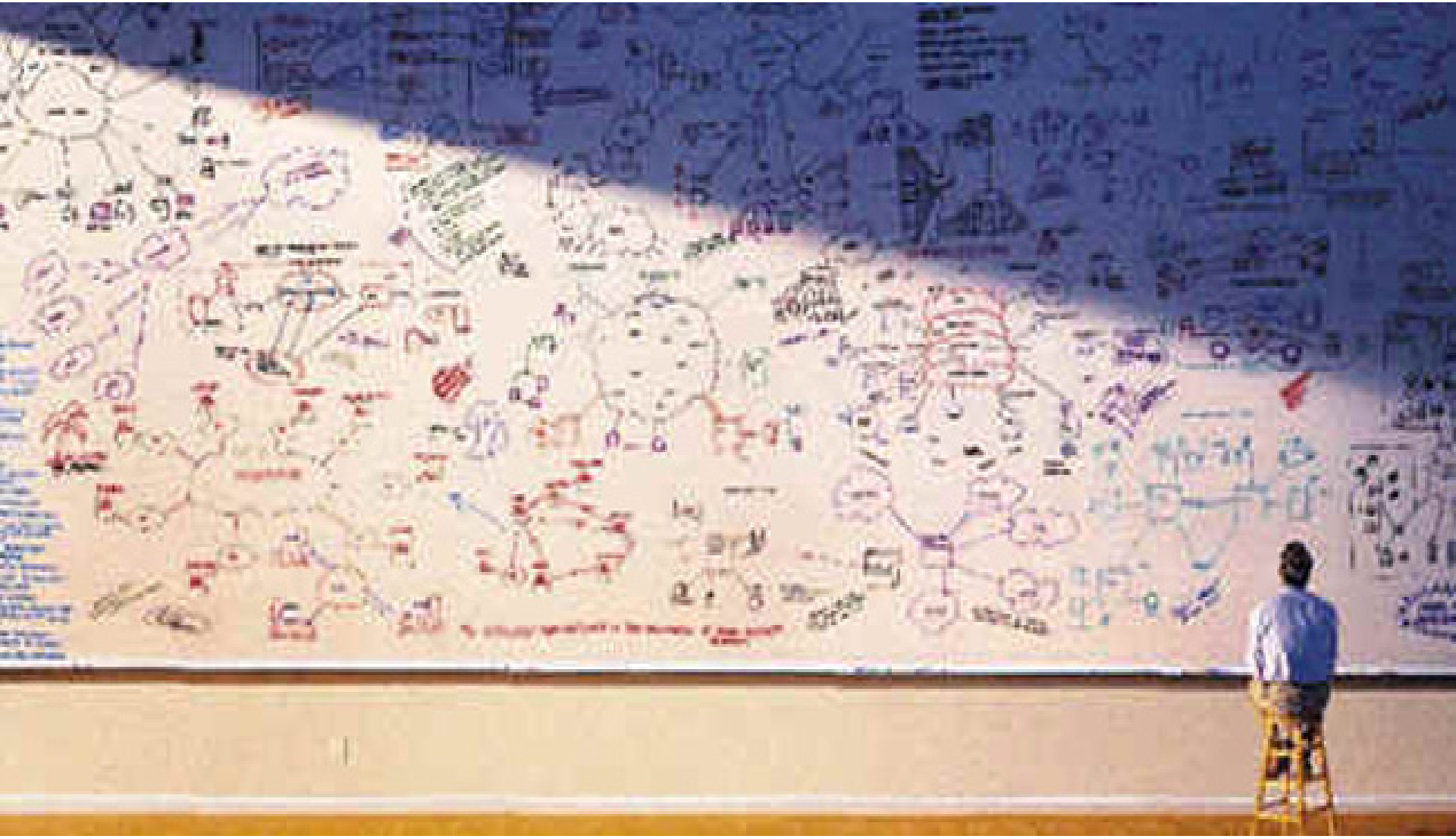
sel ld clr
Cycle
05
Program Counter
Clock
Reset



How to deal with **Complexity?**

(in engineered systems)

USA TODAY Home News Travel Money Sports Life Tech

Nation Inside News ▼ Car

VW recalls 790,000 vehicles because of brake lights

Updated 2/26/2007 3:45 PM ET

E-mail | Print | RSS

Enlarge Volkswagen

2001-2007 New Beetles are part of the recall. An earlier recall for the same issue affected 1998-2002 Beetles.

WASHINGTON (AP) — Volkswagen of America said Monday it would recall 790,000 vehicles because of problems with the brake light switch.

The recall involves several vehicles: 1999-2006 model years of the Golf and GTI, 2001-2005 Jettas, 2001-2007 New Beetles and the 2004 R32. It expands upon a recall announced last year of some Jettas and New Beetles because of the same defect.

Volkswagen told the National Highway Traffic Safety Administration that the brake light switches in the vehicles could malfunction if they were imp

The automaker said the ligh function, which would fail to proper braking signal and p

In some vehicles with auton light could work in tandem v the vehicle and require towing, said VW spokesman Keith Price.

> " … a faulty brake light could work in tandem with the shift interlock to immobilize the vehicle and require towing"

Last year, VW recalled 362,000 Jetta and New Beetle sedans because of similar problems with the brake lights. That recall affected Jettas from the 1999-2002 model years and New Beetles from the 1998-2002 model years.

Price said the latest recall is an extension of the previous one because the company "found that there was a broader pool of vehicles that had the defective part."

He said owners of 2001-2002 Jettas and New Beetles who already had the repairs completed following last year's recall would not need to return for a second time.

VW dealers will install the newly designed brake light switch free of charge. The recall is expected to begin in late April and owners may contact VW with questions at 800-822-8987.

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http://usatoday30.usatoday.com/news/nation/2007-02-26-volkswagen-recall_x.htm

unexpected interactions
(only “emerge” when doing **full system** evaluation)

USA TODAY Home News Travel Money Sports Life Tech

Nation Inside News ▼ Car

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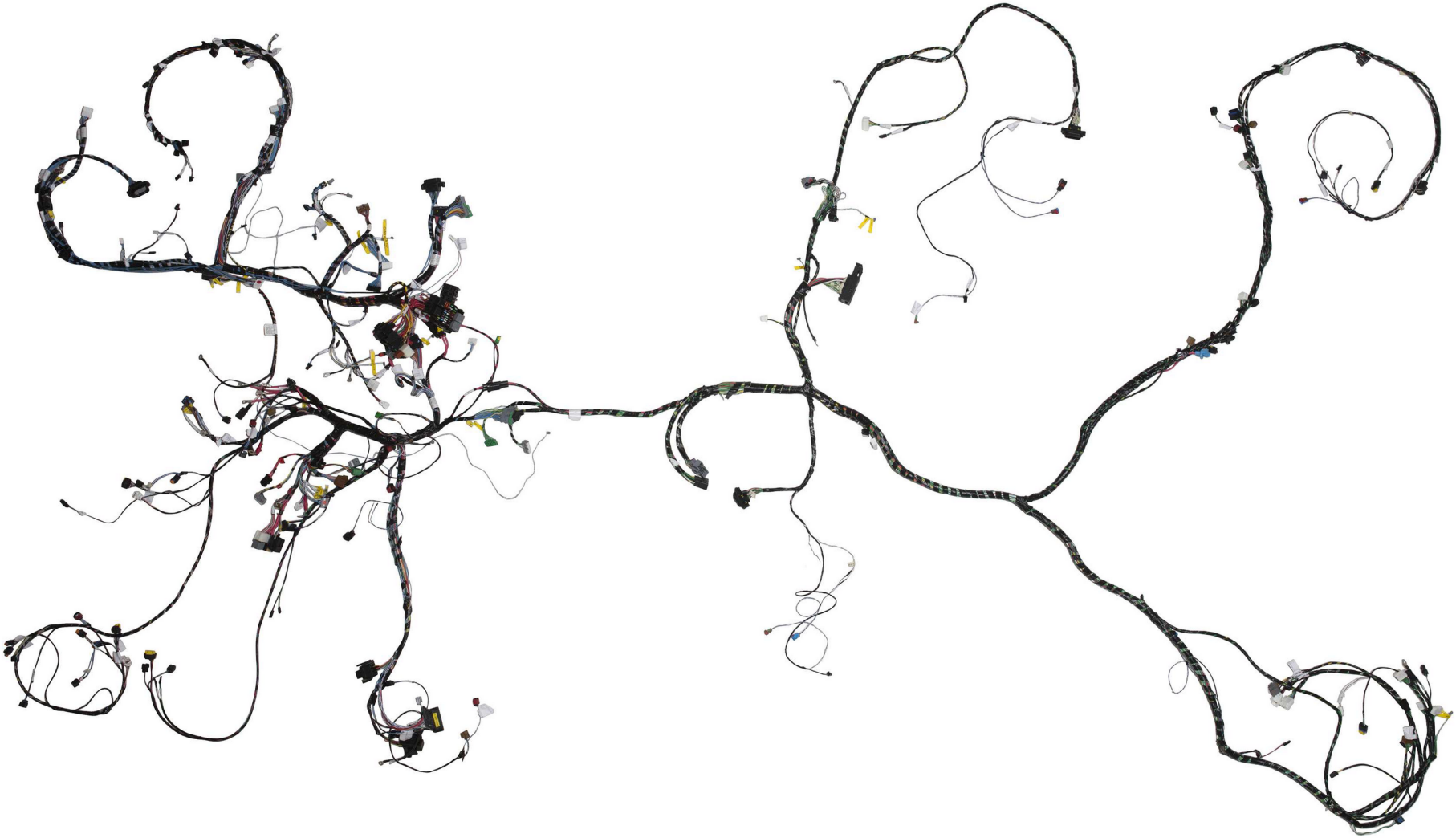
http://usatoday30.usatoday.com/news/nation/2007-02-26-volkswagen-recall_x.htm

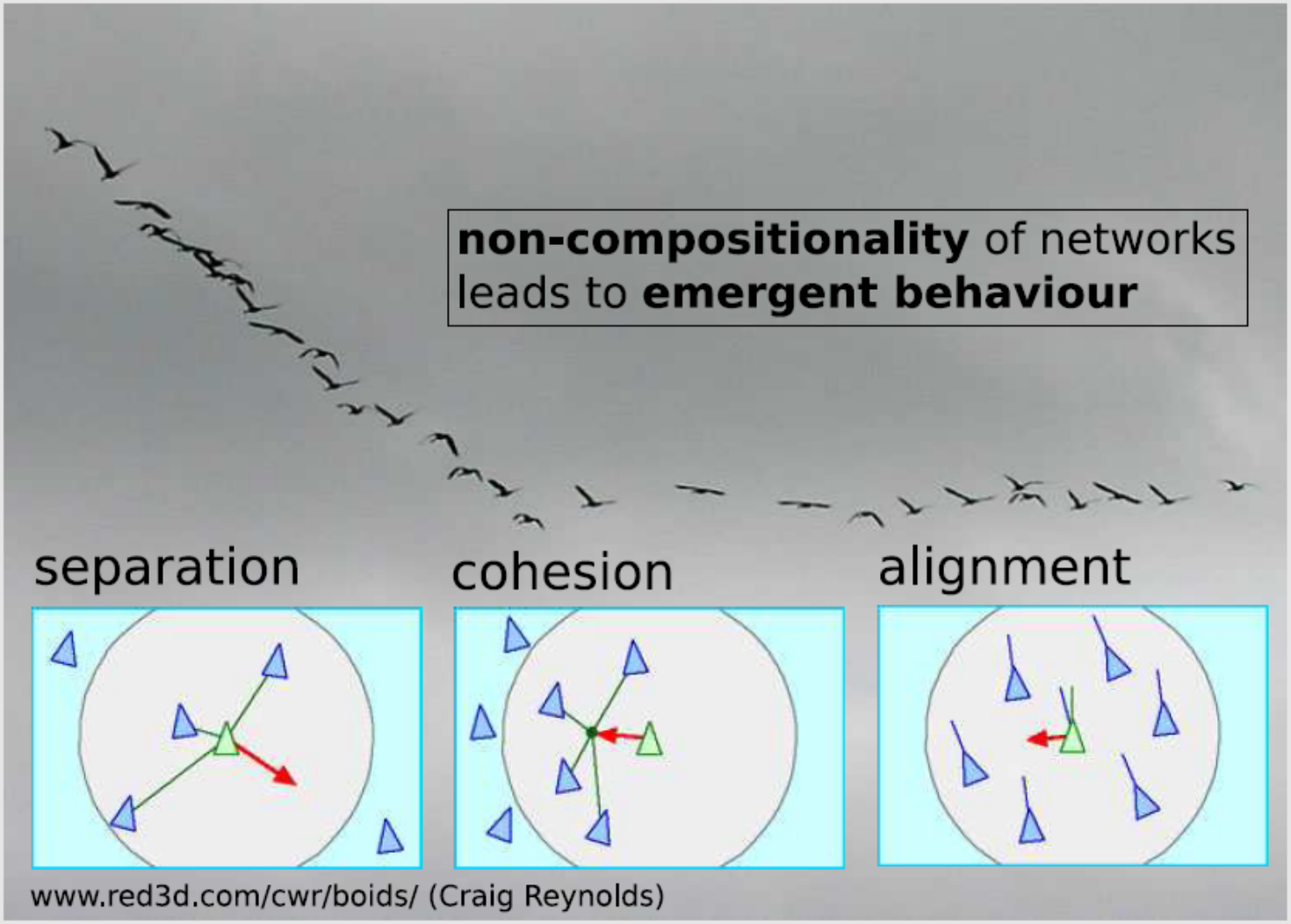


CAN

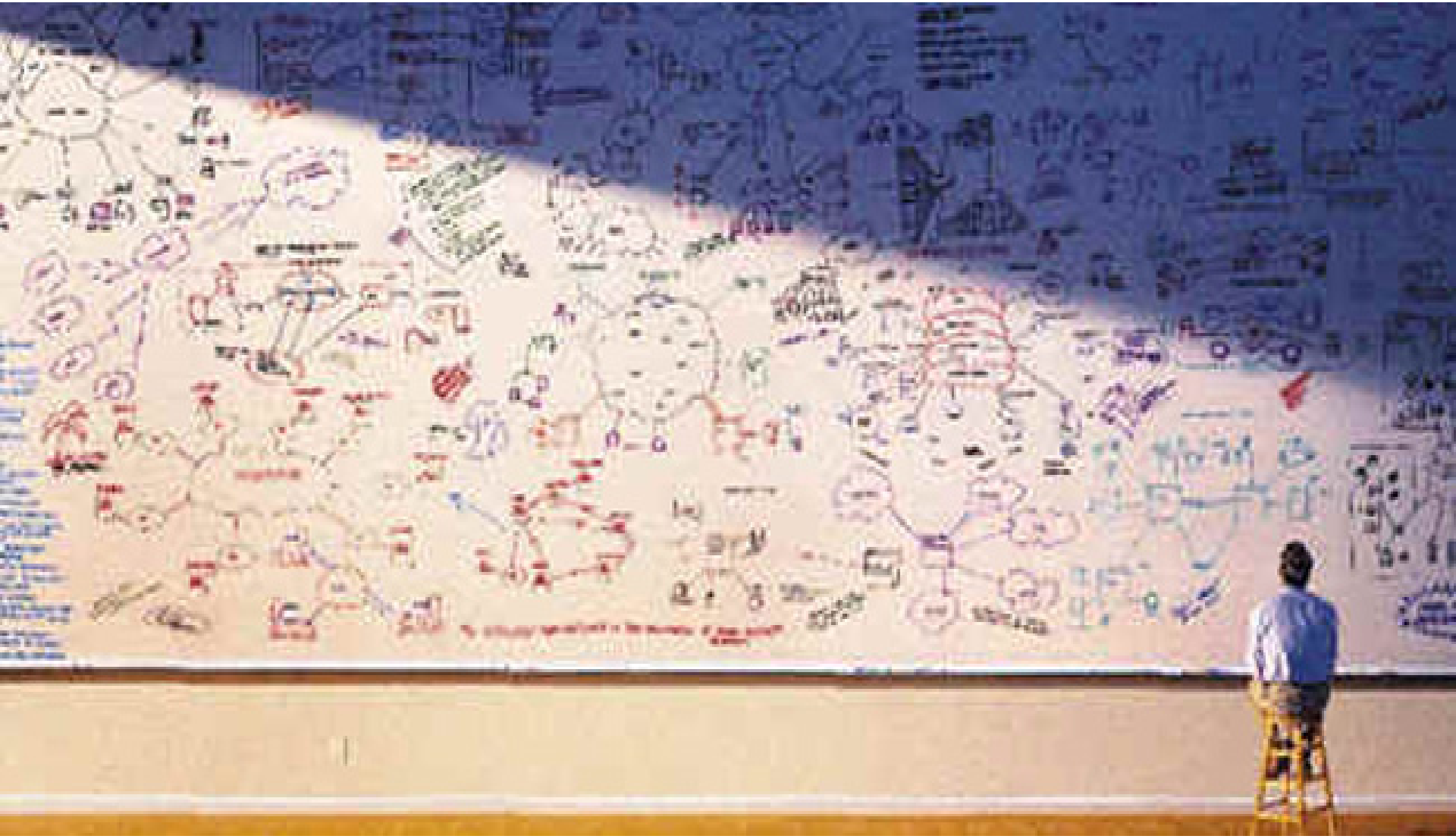
Cause of Complexity: constrained resources unanticipated interactions

VW Phaeton: “wiring harness” length > 2km, copper weight > 30kg

Non-compositional/Emergent Behaviour



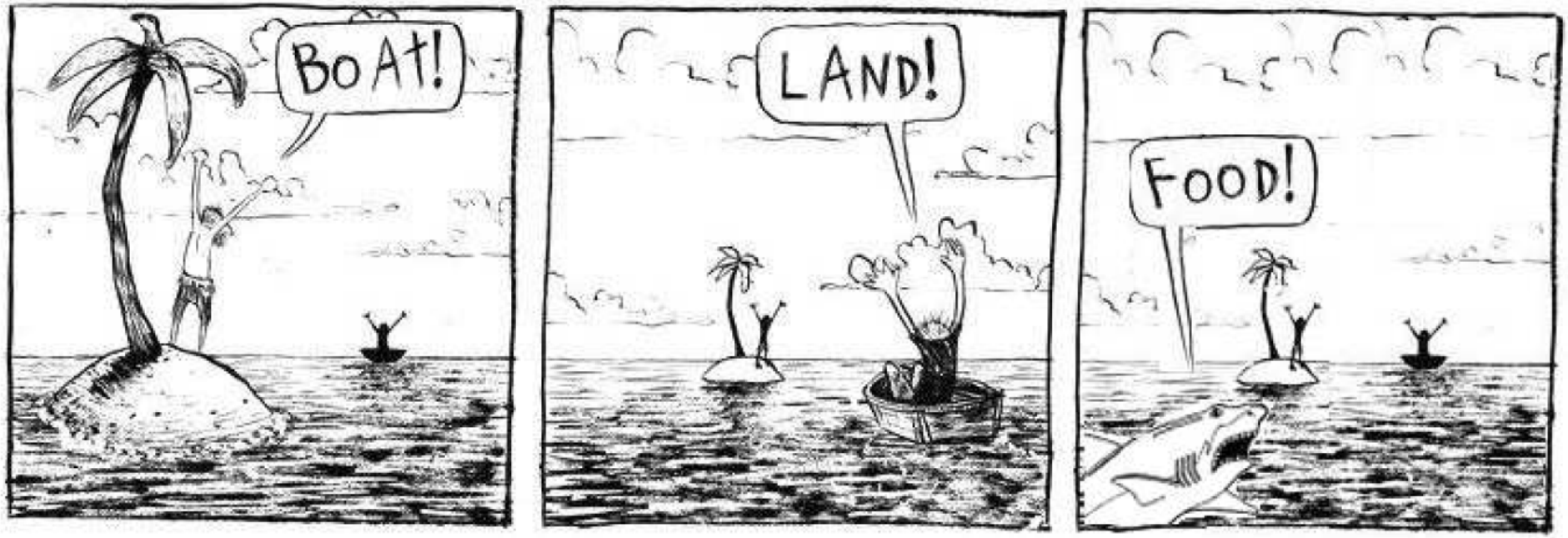
may use to reason (for a while) about abstraction “flock”



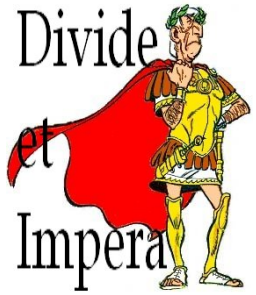
How to deal with **Complexity?**

(in engineered systems)

multiple viewpoints

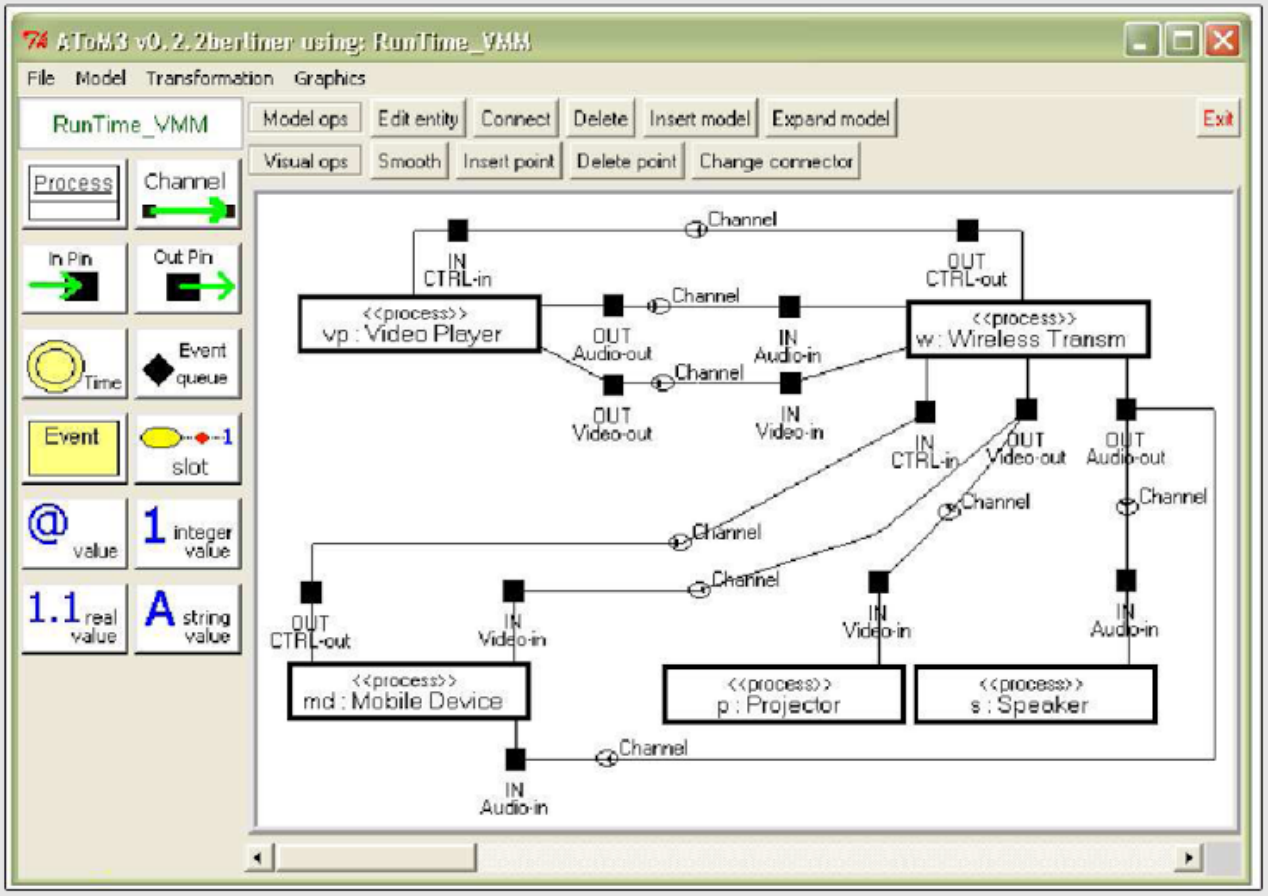


multiple viewpoints

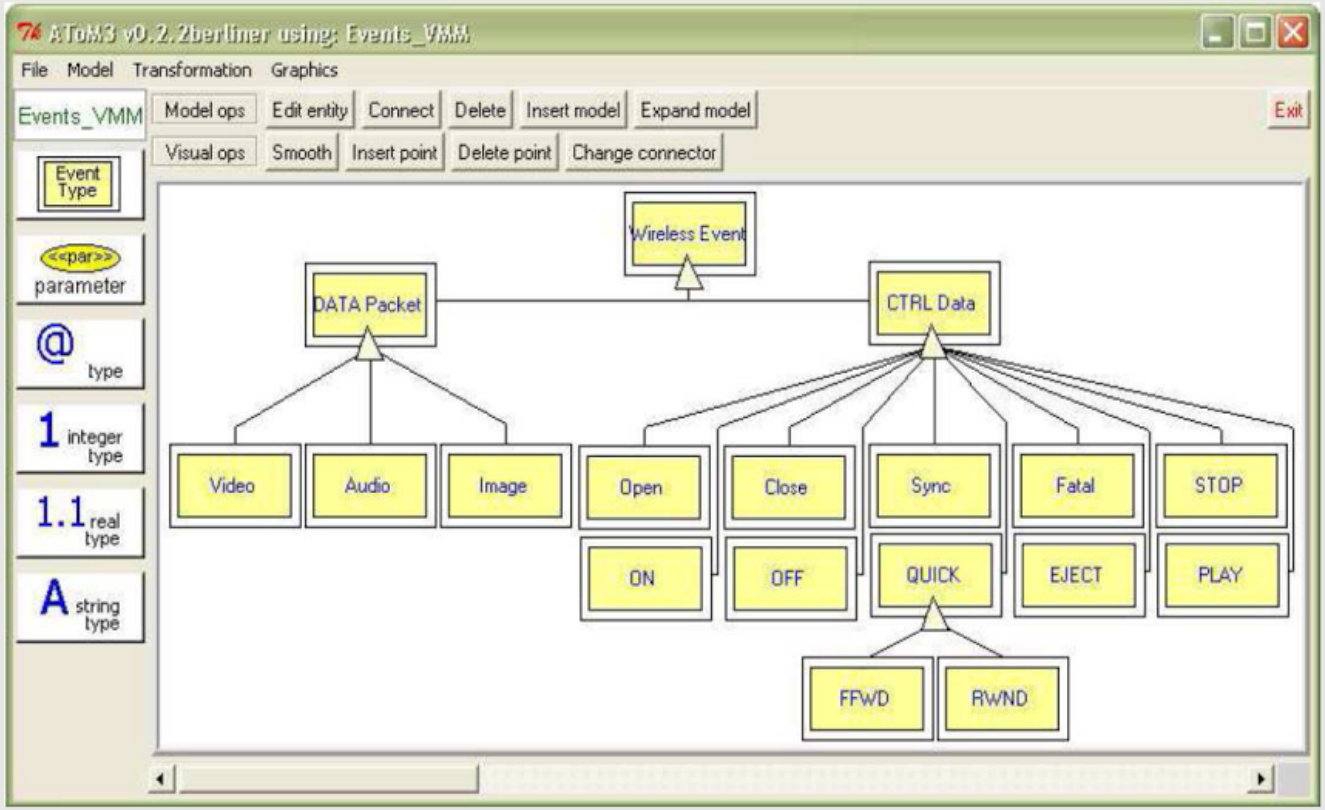


Wireless Home Entertainment System

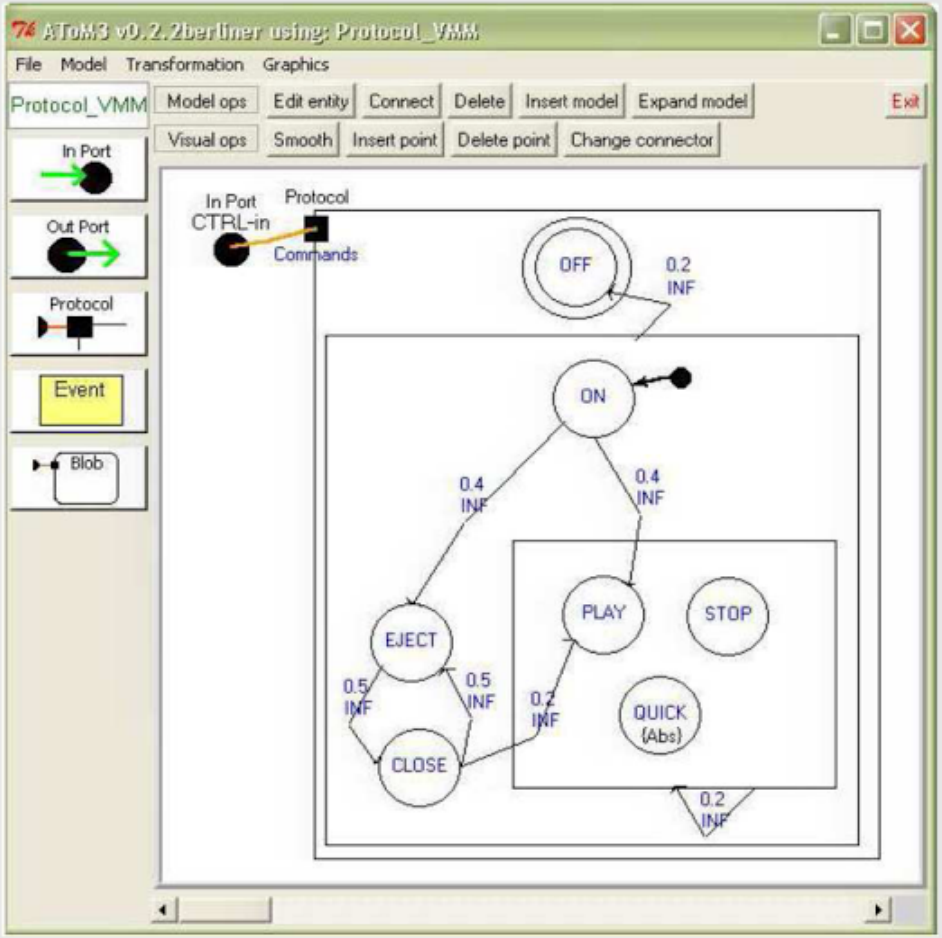
Multiple (consistent !) Views (in $\neq$ Formalisms)

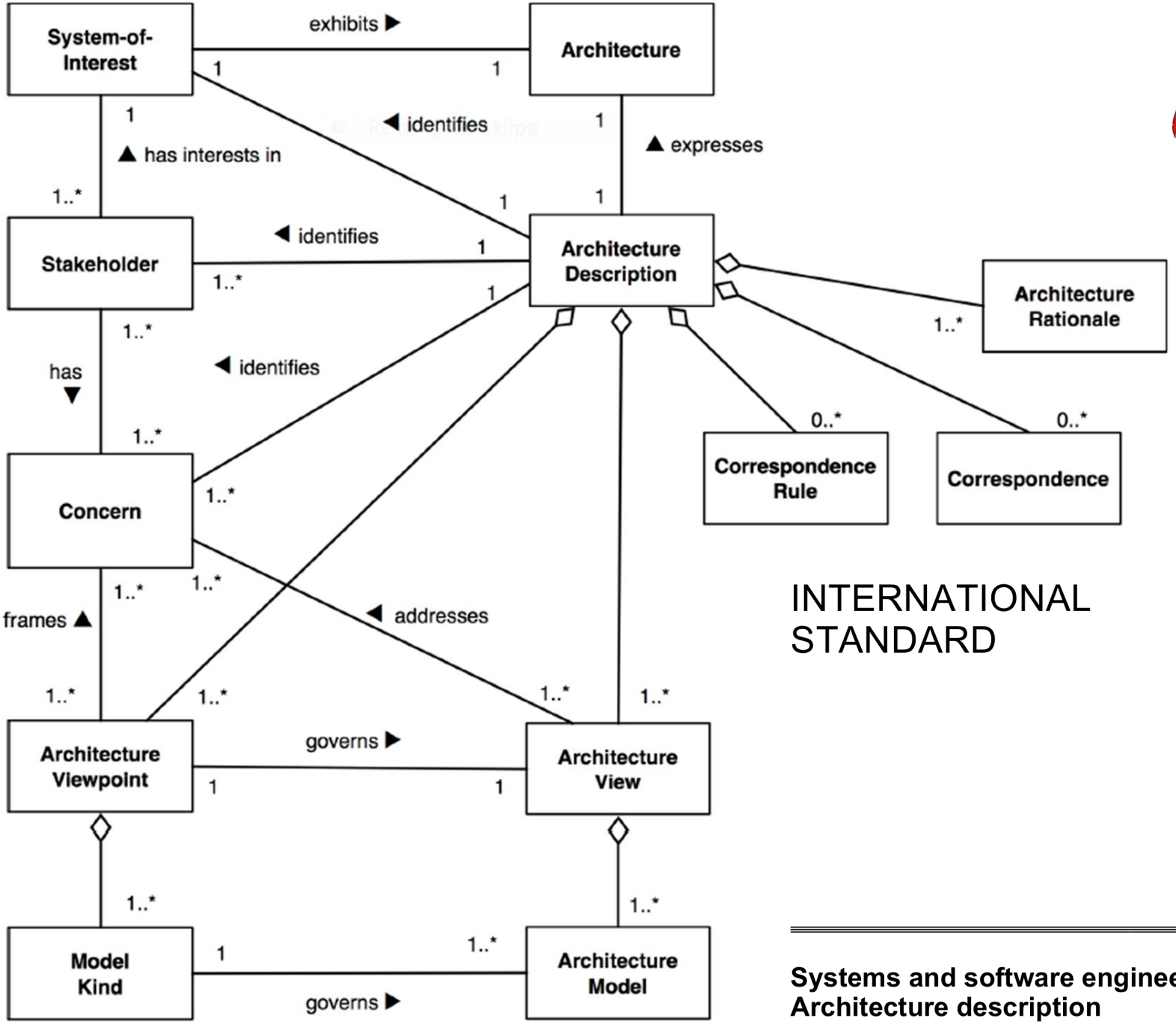


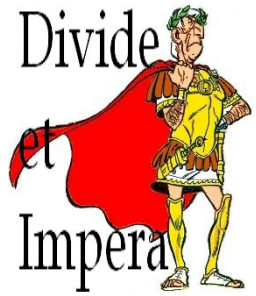
View: Events Diagram



View: Protocol Statechart







INTERNATIONAL STANDARD

ISO/IEC/ IEEE 42010

First edition
2011-12-01

Systems and software engineering — Architecture description

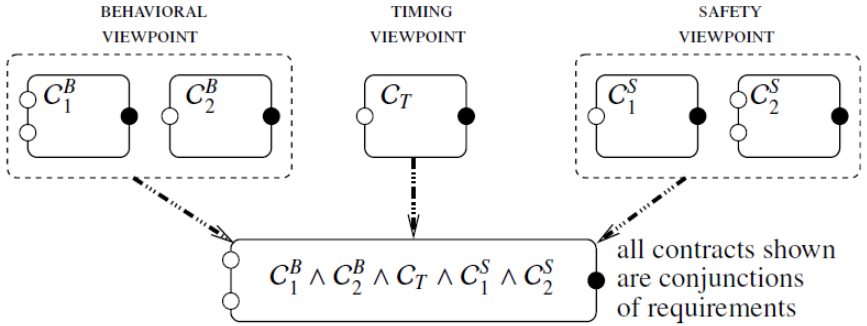
Contracts for Systems Design: Theory

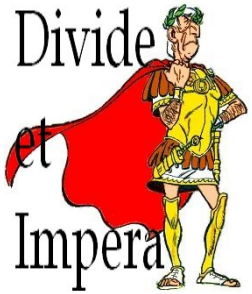
Albert Benveniste , Benoît Caillaud, Dejan Nickovic
Roberto Passerone, Jean-Baptiste Raclet
Philipp Reinkemeier, Alberto Sangiovanni-Vincentelli
Werner Damm, Tom Henzinger, Kim G. Larsen

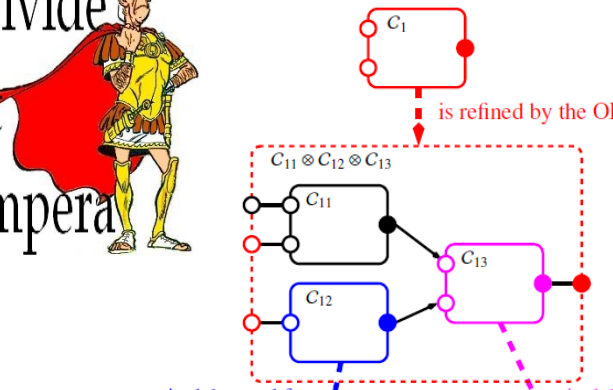
RESEARCH REPORT
N° 8759
July 2015
Project-Teams Hycomes

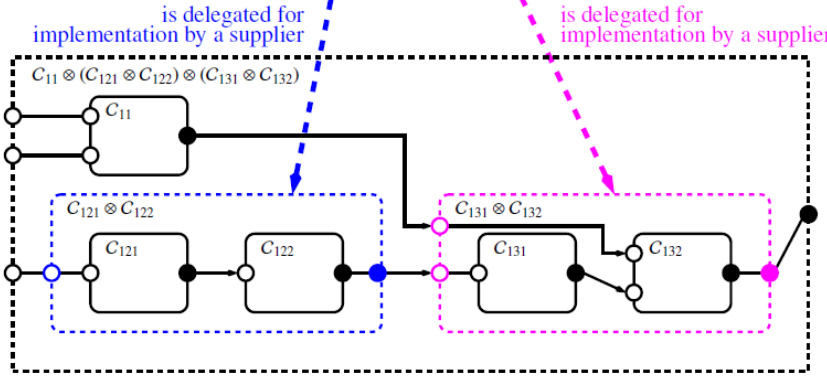
ISSN 0249-6399 ISRN INRIA/RR--8759--FR+ENG

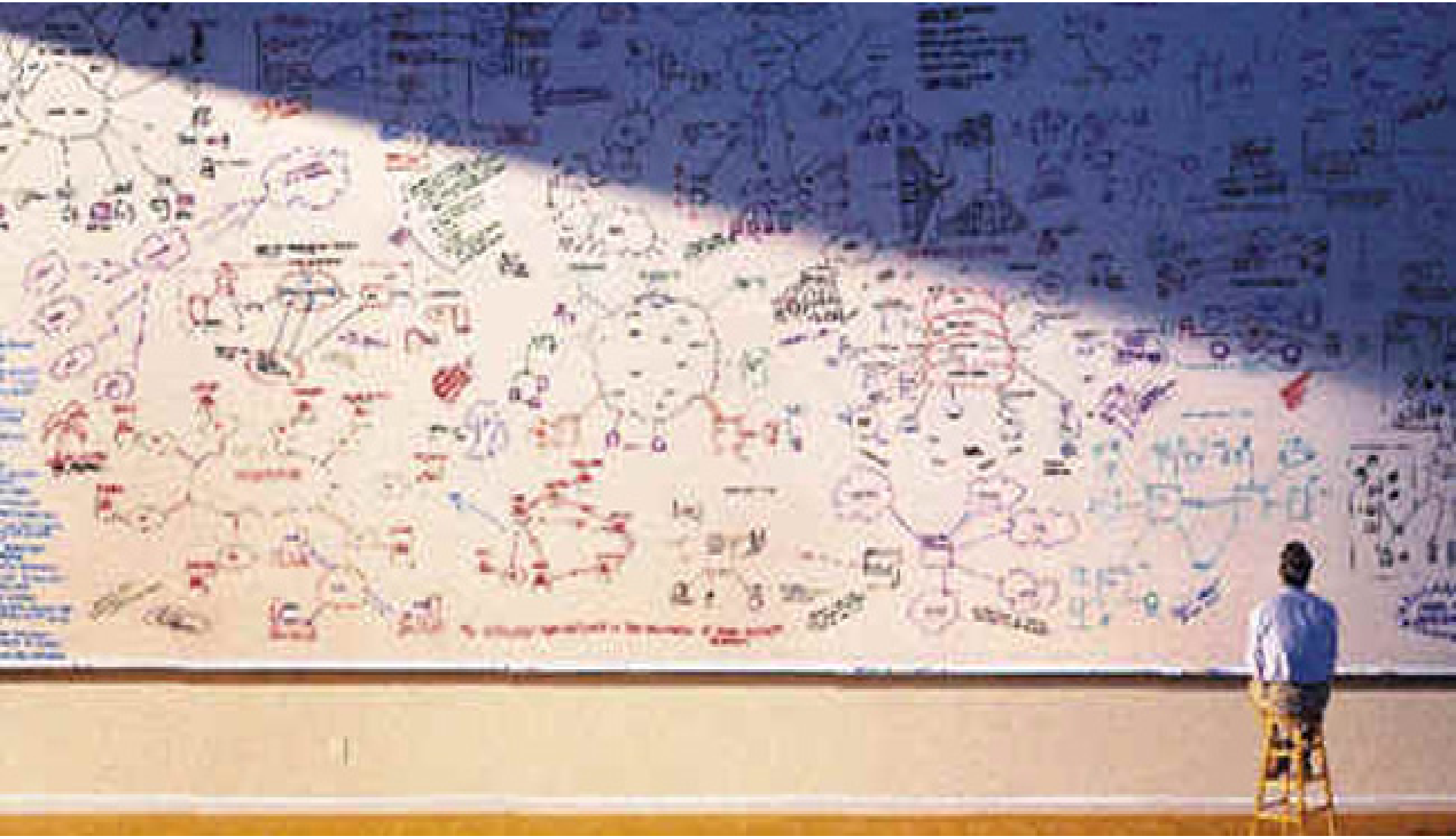
guarantees offered by the component
assumptions on its possible context







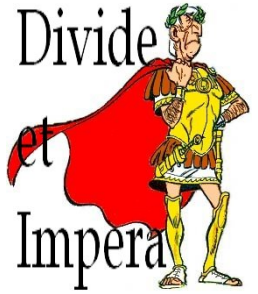




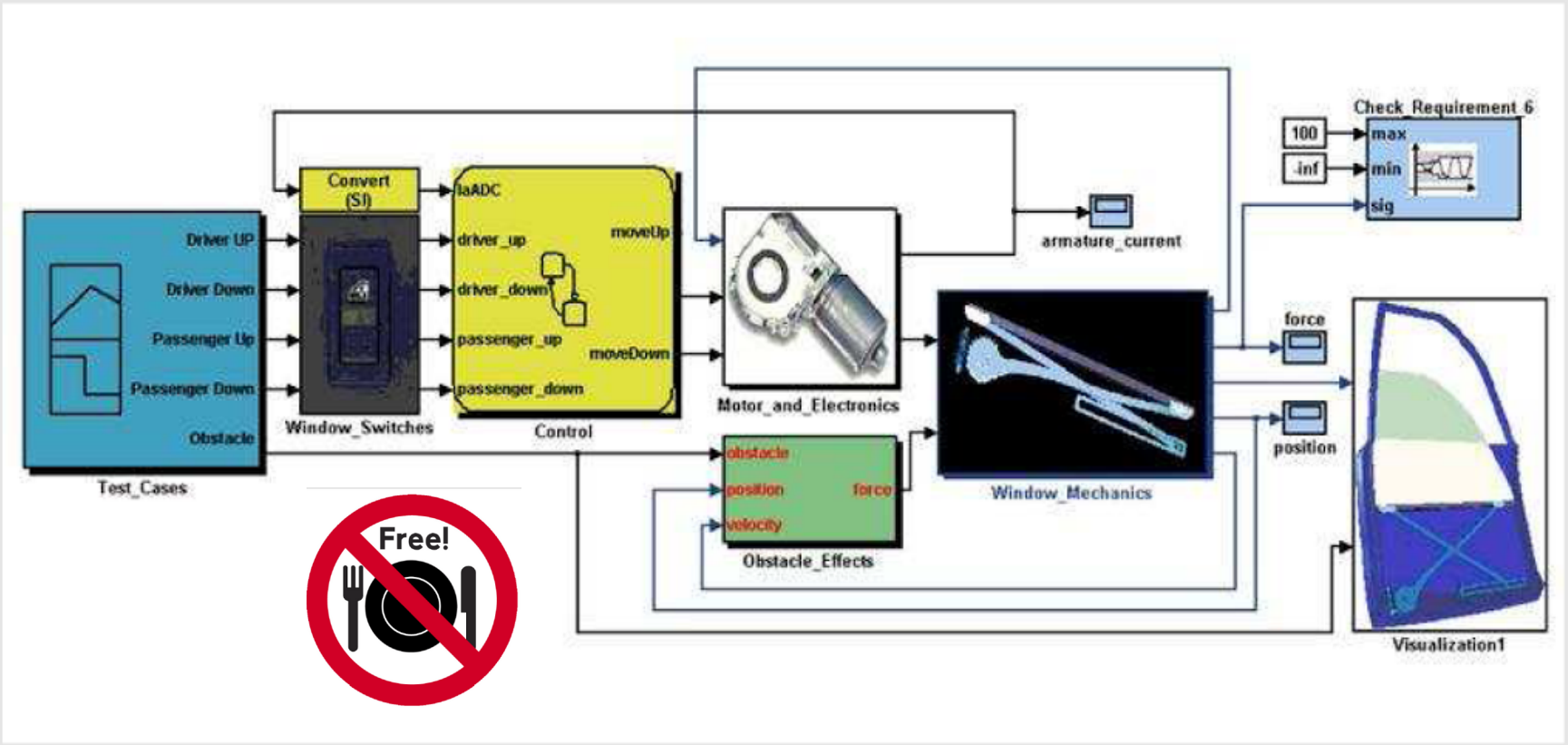
How to deal with **Complexity?**

(in engineered systems)

Most Appropriate Formalism(**s**)



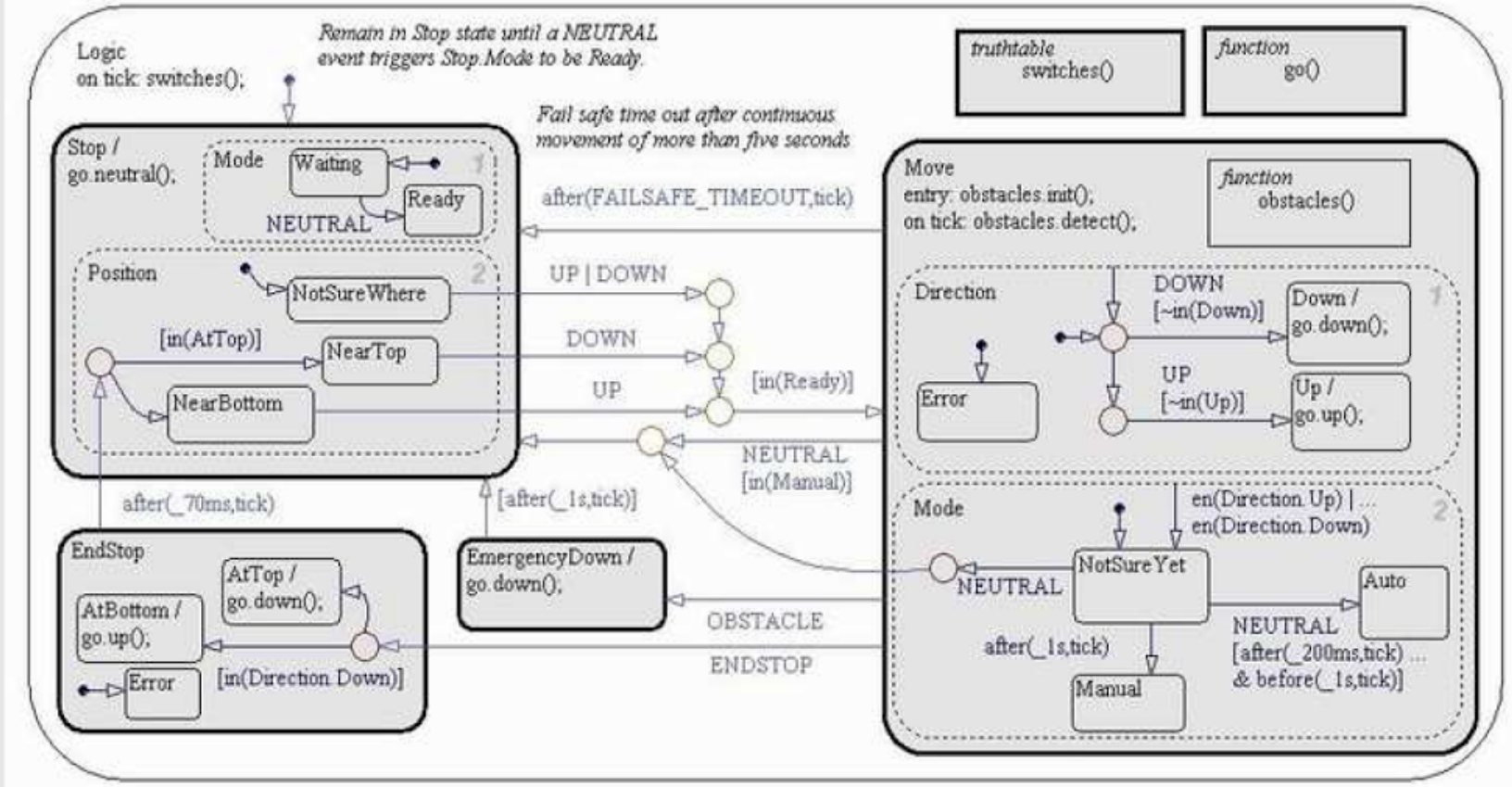
Components in Different Formalisms



www.mathworks.com/products/demos/simulink/PowerWindow/html/PowerWindow1.html

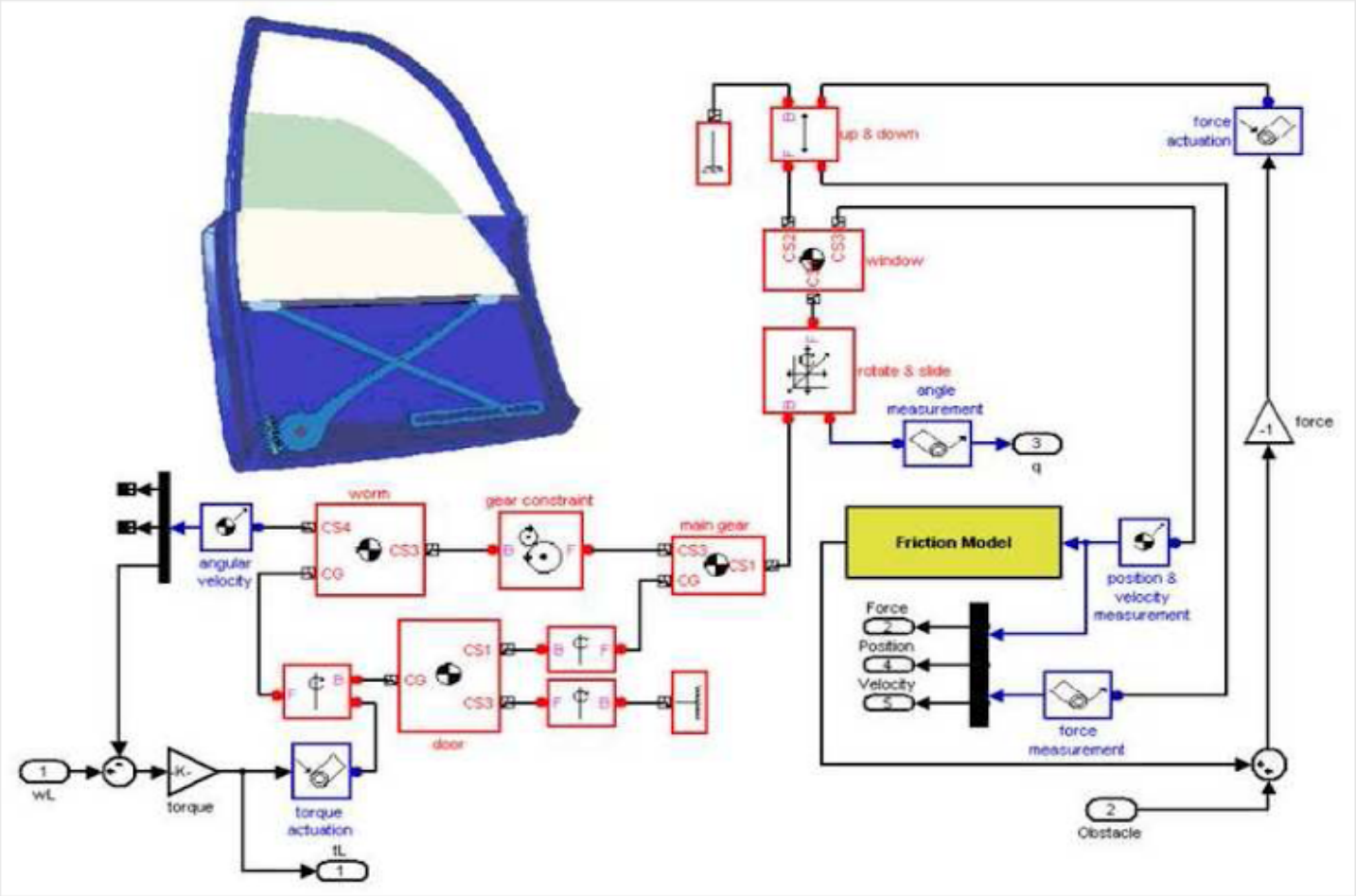
Most Appropriate Formalism(**s**)

Controller, using Statechart(StateFlow) formalism

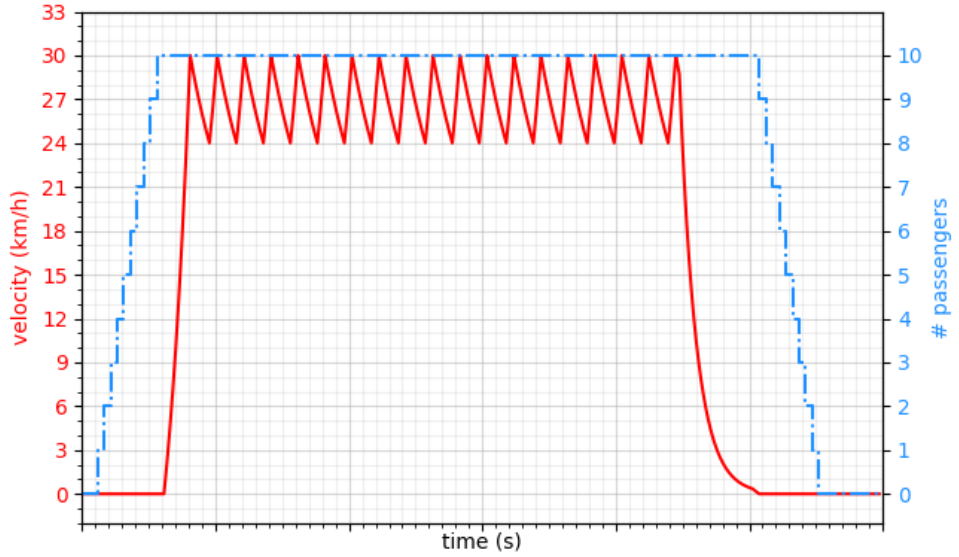


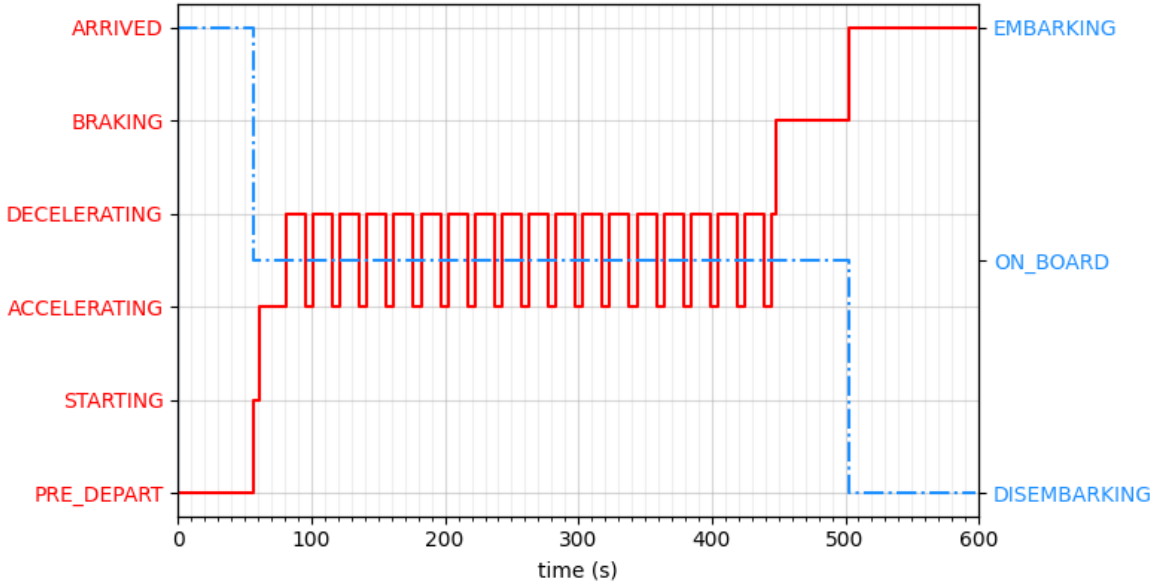
Most Appropriate Formalism(**s**)

Mechanics subsystem

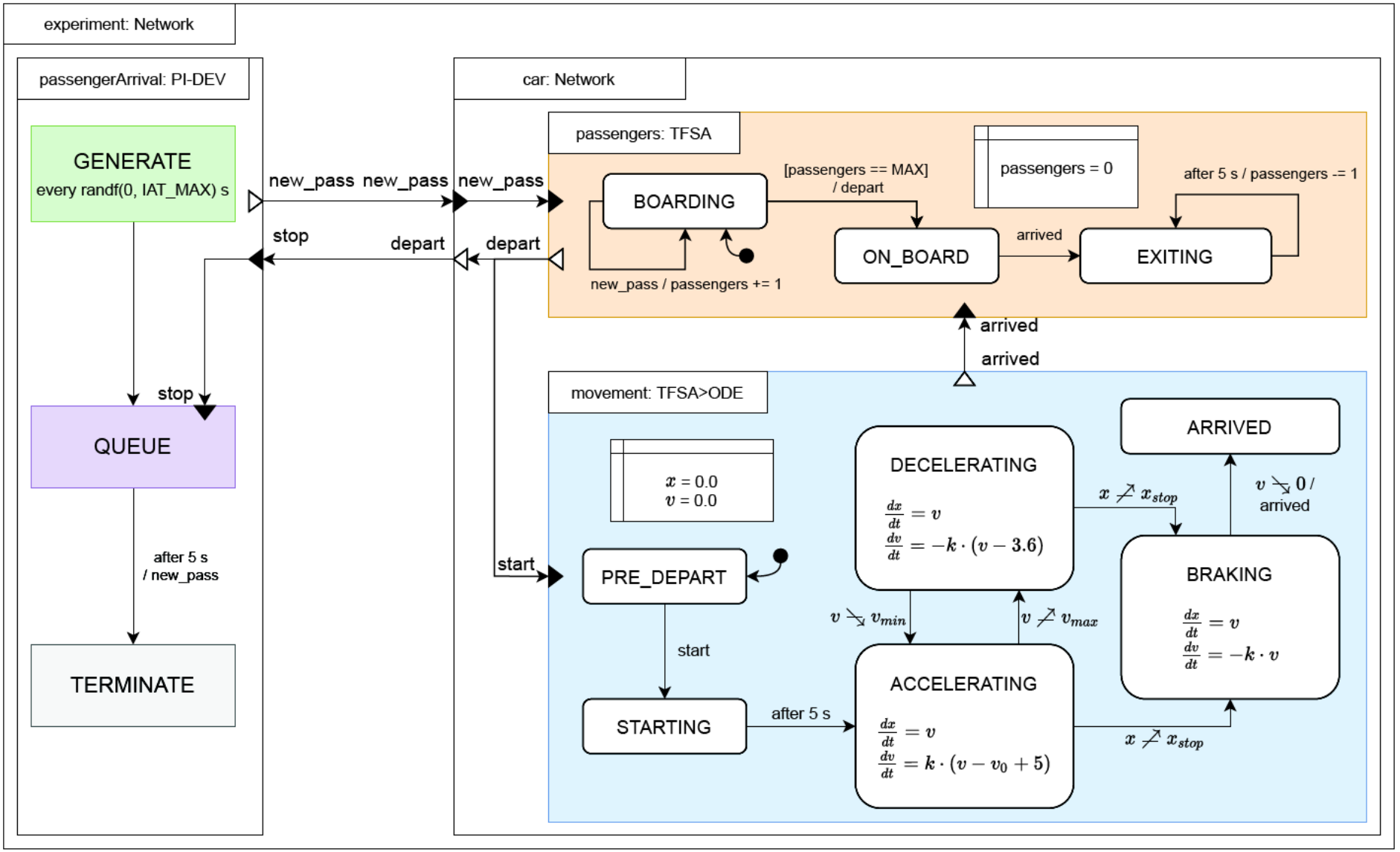


Morgantown
Personal Rapid Transit

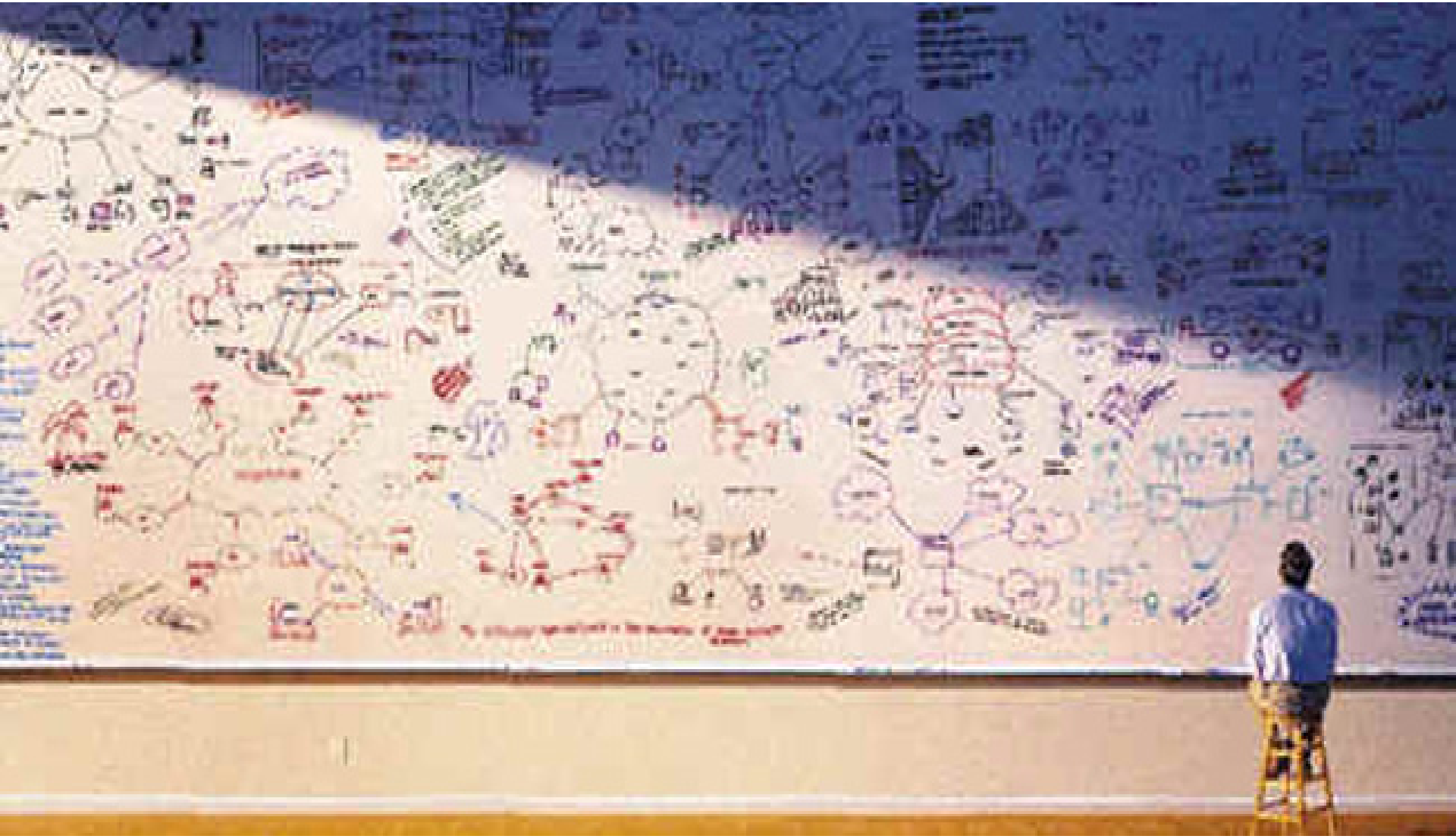

velocity (km/h)
passengers
time (s)
0
3
6
9
12
15
18
21
24
27
30
33
0
1
2
3
4
5
6
7
8
9
10
0
100
200
300
400
500
600


ARRIVED
BRAKING
DECELERATING
ACCELERATING
STARTING
PRE_DEPART
EMBARKING
ON_BOARD
DISEMBARKING
time (s)
0
100
200
300
400
500
600

“hybrid” modelling language



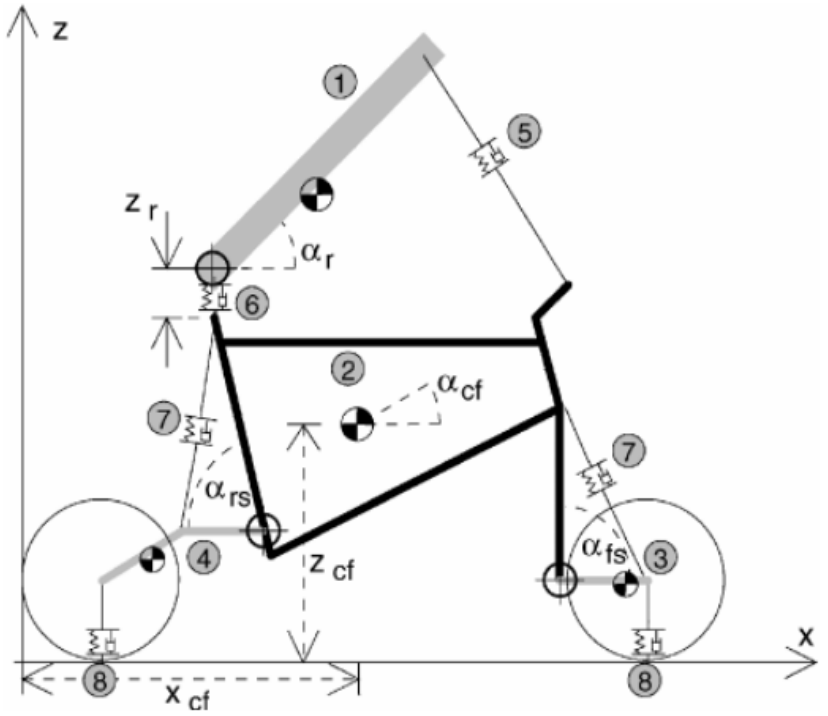
Universiteit Antwerpen
Ansymo Antwerp Systems & Software Modelling University of Antwerp
Nexor Cyber-Physical Systems University of Antwerp
FLANDERS MAKE MANUFACTURING INNOVATION NETWORK
McGill
MPM4CPS
cost



How to deal with **Complexity?**

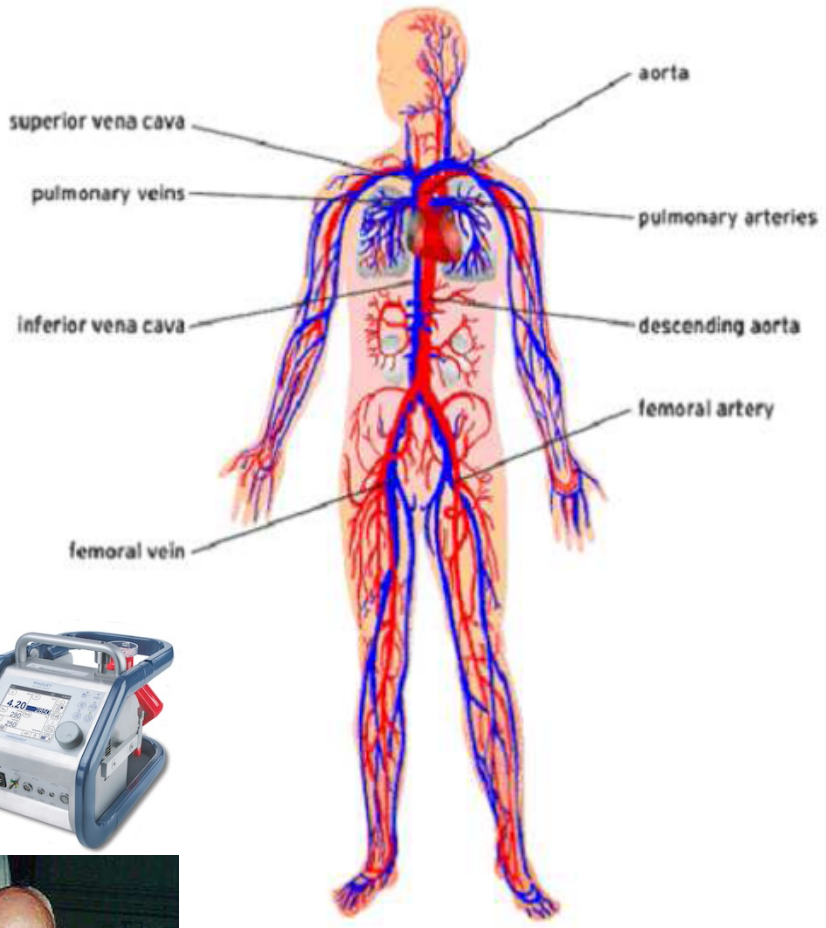
(in engineered systems)

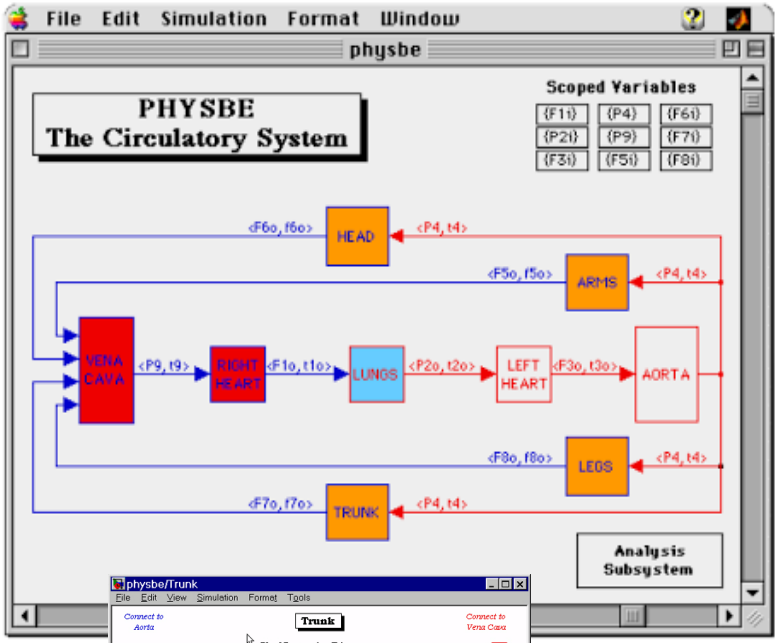
Different abstractions
(same or different formalisms)

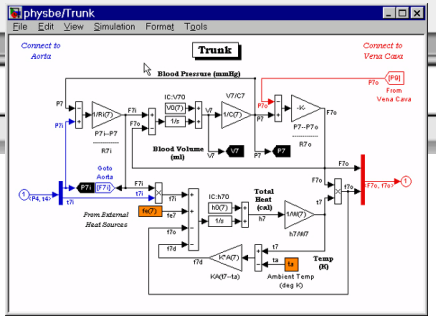


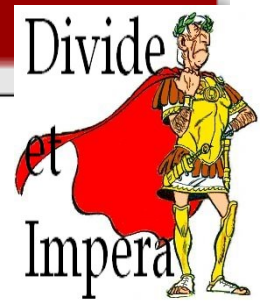
Distributed param. Lumped param.

Different Abstraction Levels – properties preserved









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McLeod J. PHYSBE ... a physiological simulation benchmark experiment SIMULATION vol 7 no 6 December **1966** pp 324-329

Mathematical and Computer Modelling of Dynamical Systems, 2013
Vol. 19, No. 3, 238–249, http://dx.doi.org/10.1080/13873954.2012.727187

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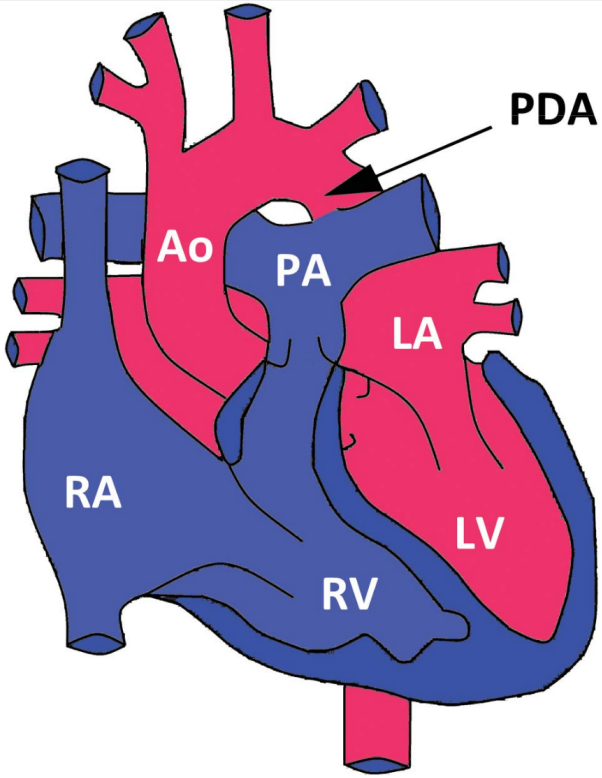
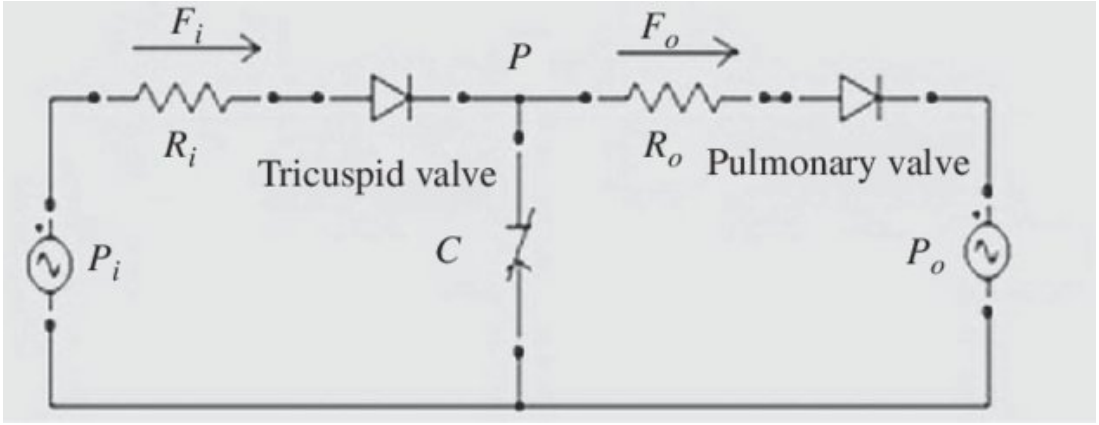
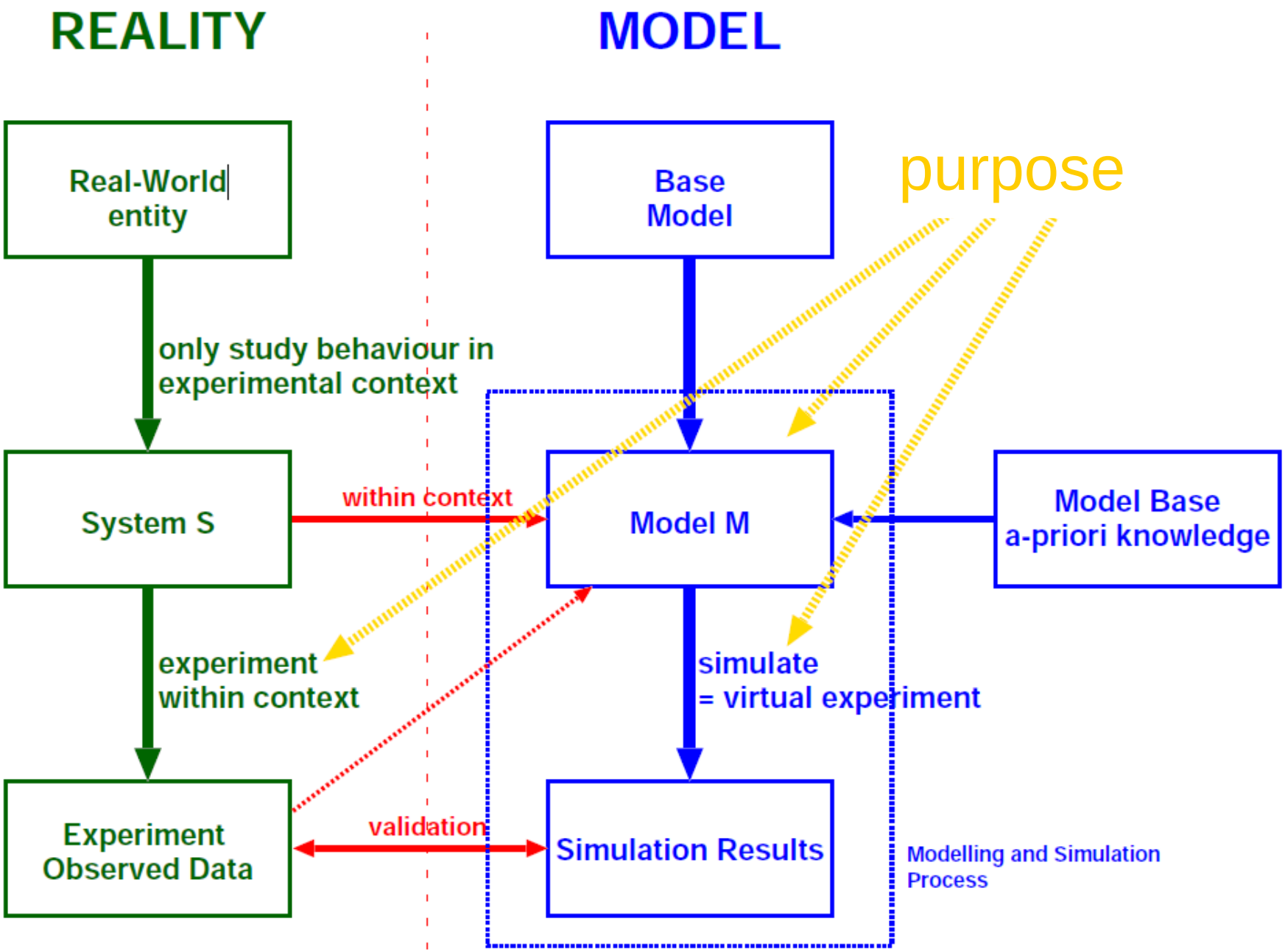
Mathematical modelling of the patent ductus arteriosus (PDA)

Mohamad Amin Bakhshali, Mahsa Mafi and Sabalan Daneshvar*

Biomedical Engineering Department, Electrical Engineering Faculty, Sahand University of Technology, Tabriz, Iran







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

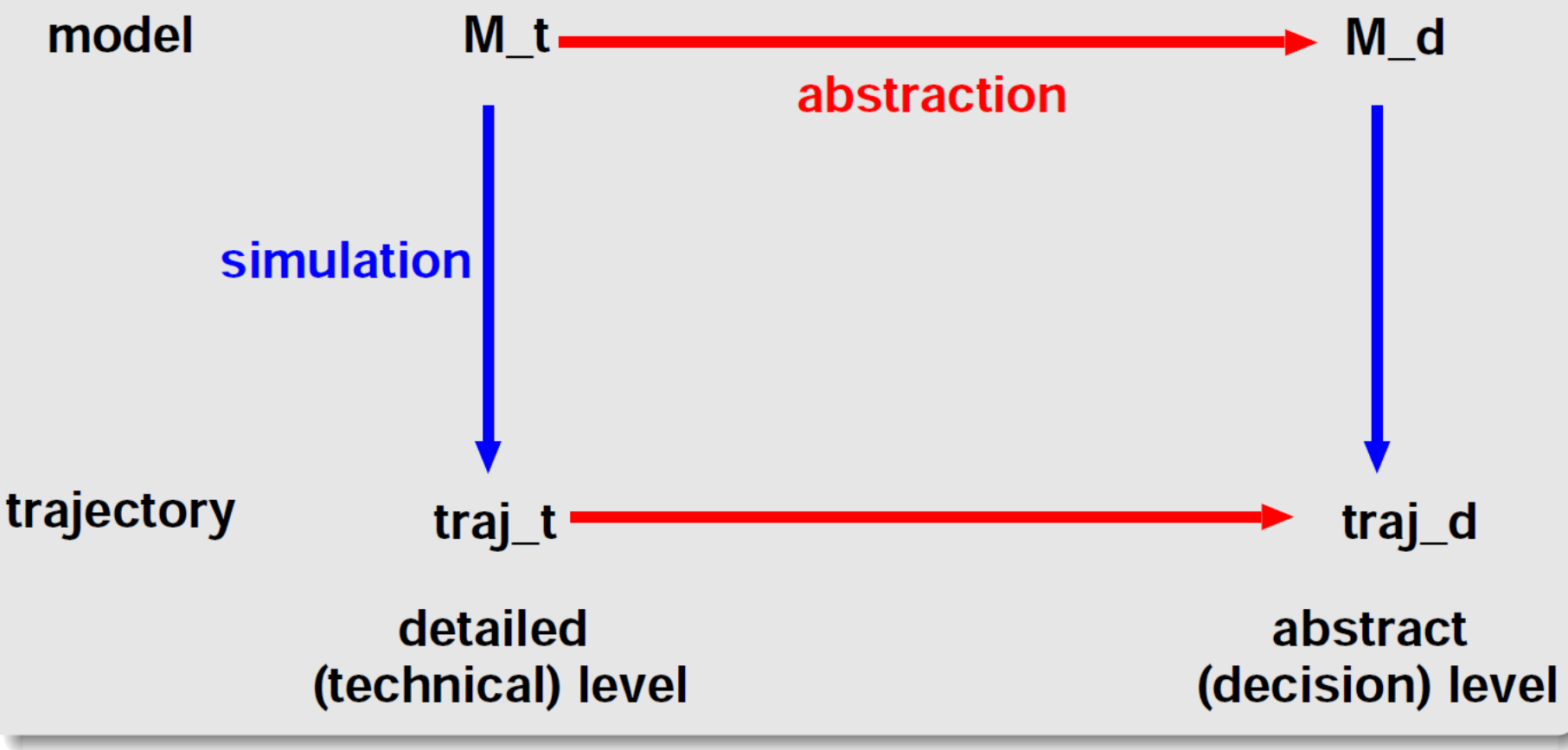
Abstraction Relationship

foundation: the *information* contained in a model M.
Different *questions* (properties) $P = I(M)$ which can be asked concerning the model.
These questions either result in true or false.

Abstraction and its opposite, *refinement* are *relative to a non-empty set of questions* (properties) P.

- If M_1 is an *abstraction* of M_2 with respect to P, for all $p \in P$: $M_1 \models p \Rightarrow M_2 \models p$. This is written $M_1 \sqsupseteq_P M_2$.
- M_1 is said to be a *refinement* of M_2 iff M_2 is an *abstraction* of M_1. This is written $M_1 \sqsubseteq_P M_2$.

Levels of Abstraction/Views: Morphism

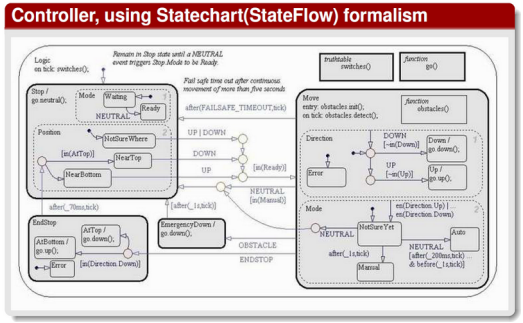


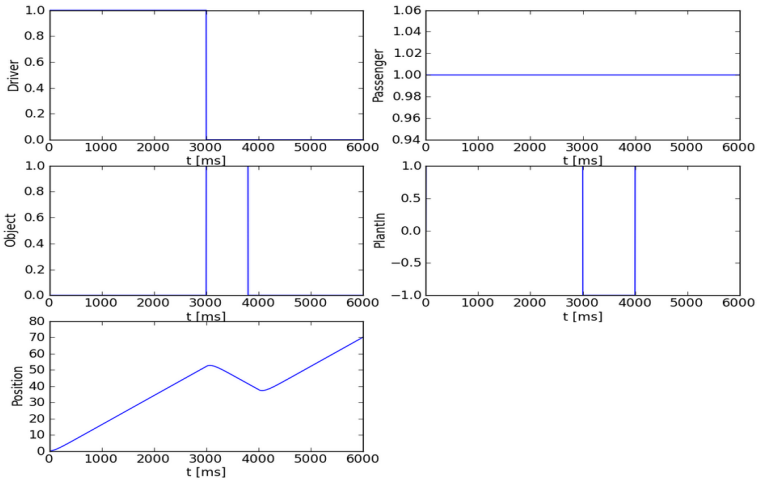
Caveat: **“Leaky” Abstractions** (and **approximations**)

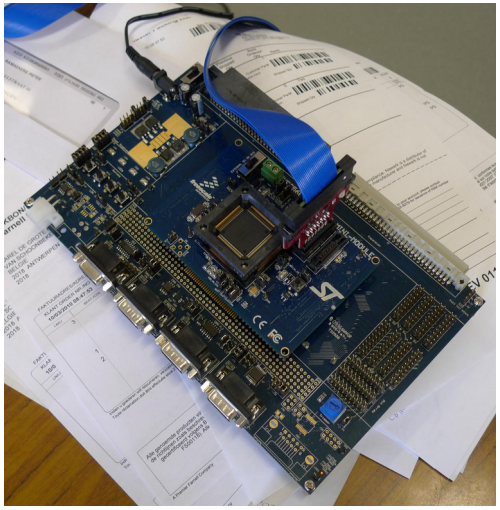
“All non-trivial abstractions, to some degree, are leaky.”

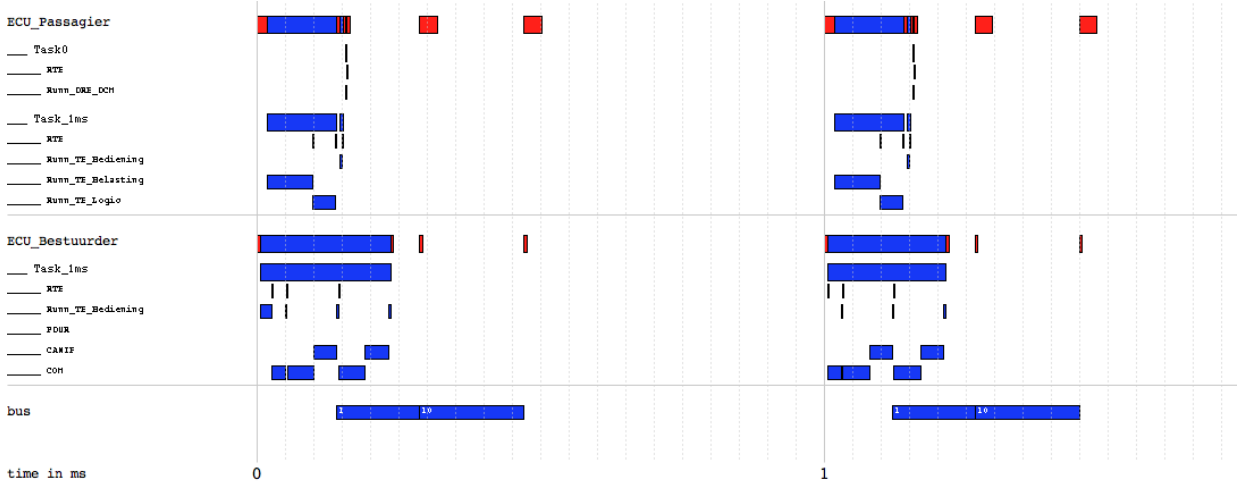
Joel Spolsky
http://www.joelonsoftware.com/articles/LeakyAbstractions.html

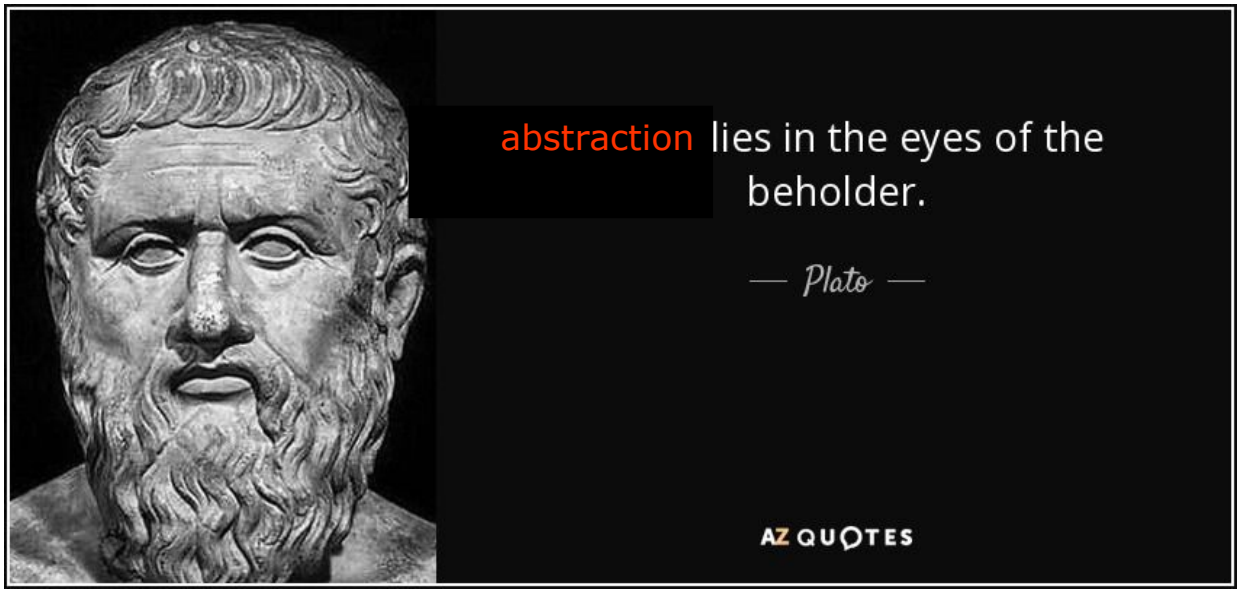
Caveat: **“Leaky” Abstractions** (and **approximations**)

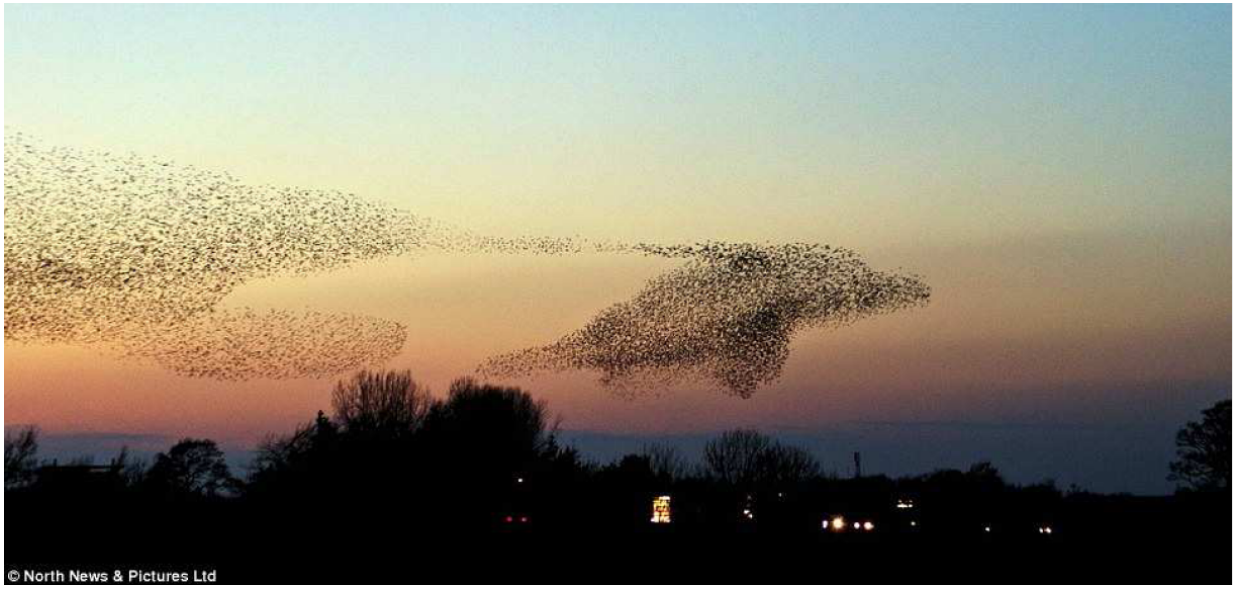









abstraction lies in the eyes of the beholder.
— Plato —
AZ QUOTES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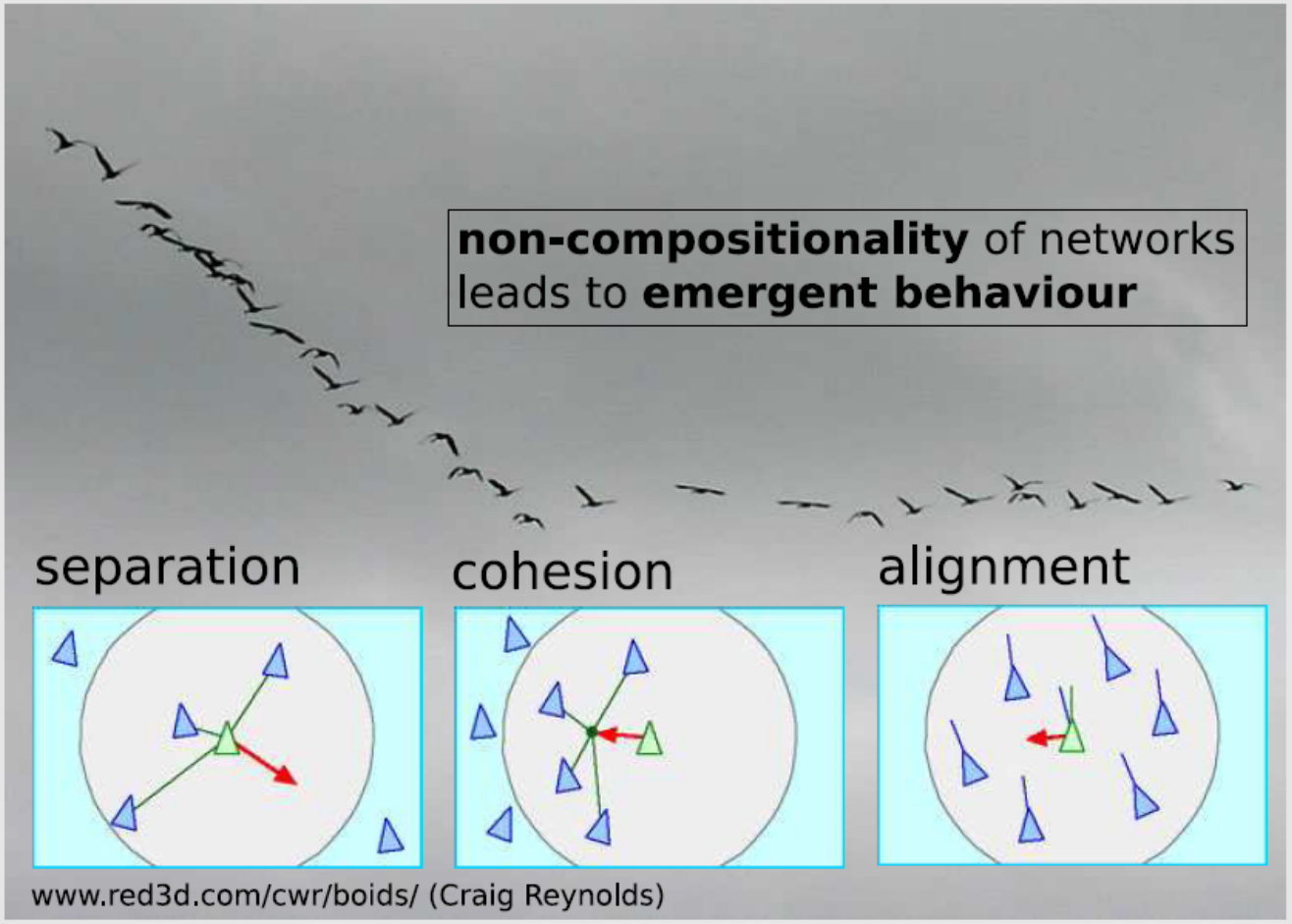
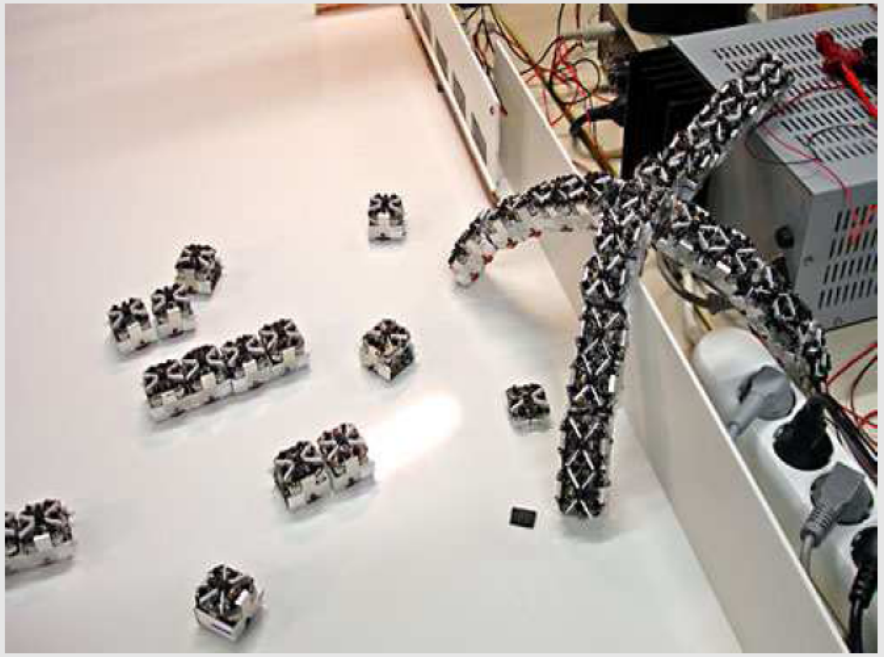
abstraction depends on the **properties** of interest!

Non-compositional/Emergent Behaviour

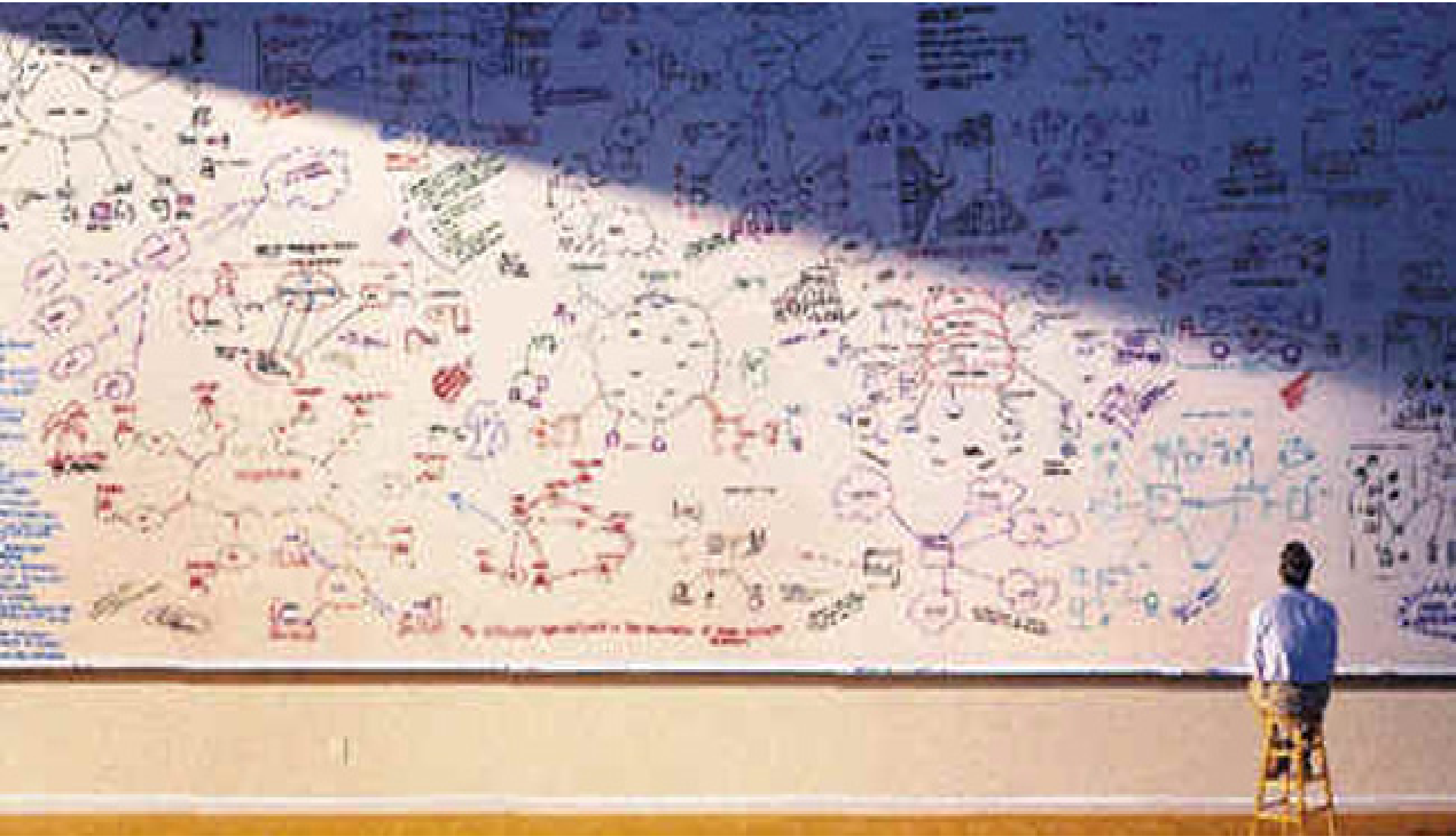


may use to reason (for a while) about abstraction “flock”

Engineered Emergent Behaviour

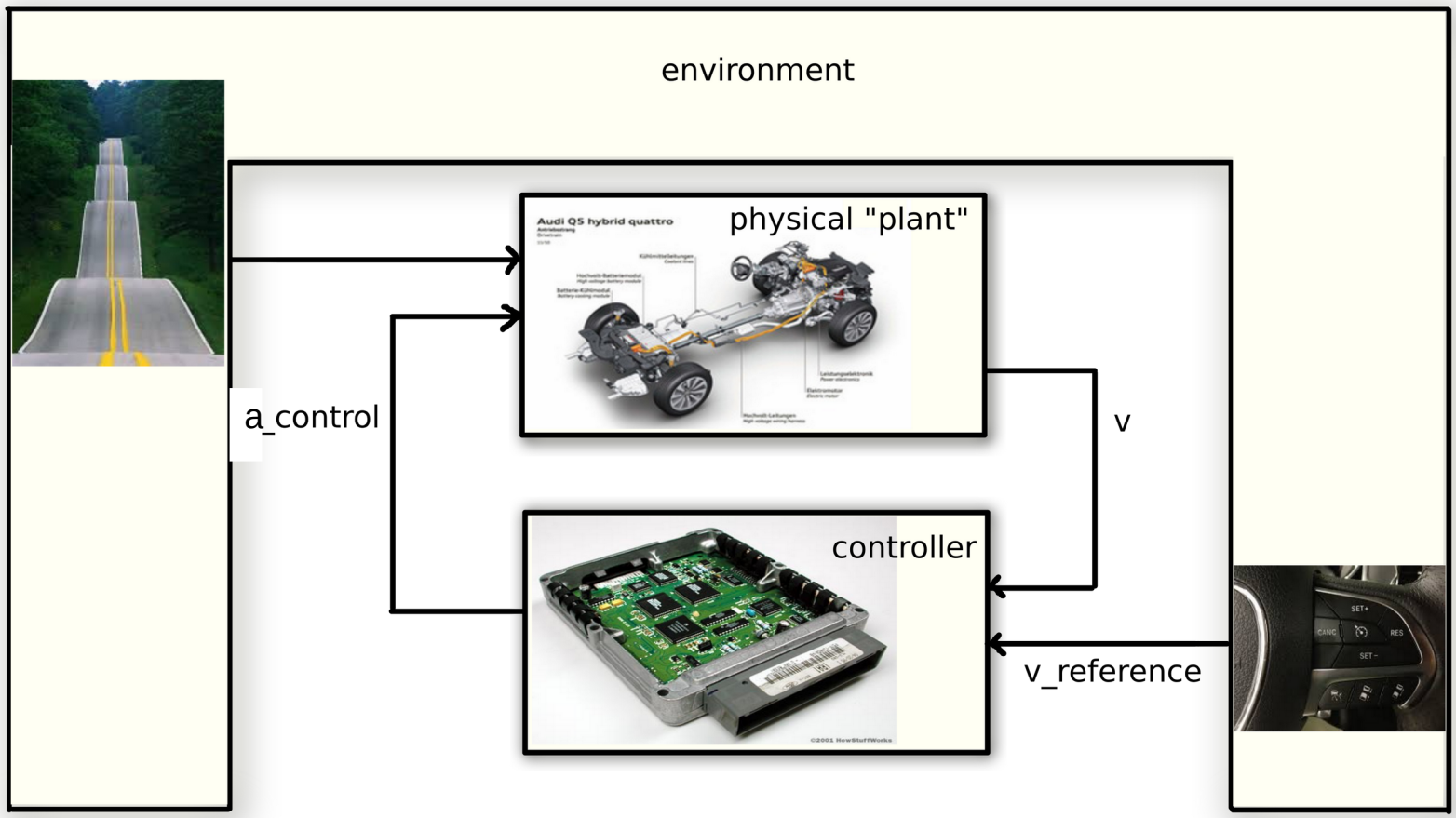


Robert Bogue. *Swarm intelligence and robotics.* Industrial Robot: An International Journal. 35(6):488 - 495, 2008.

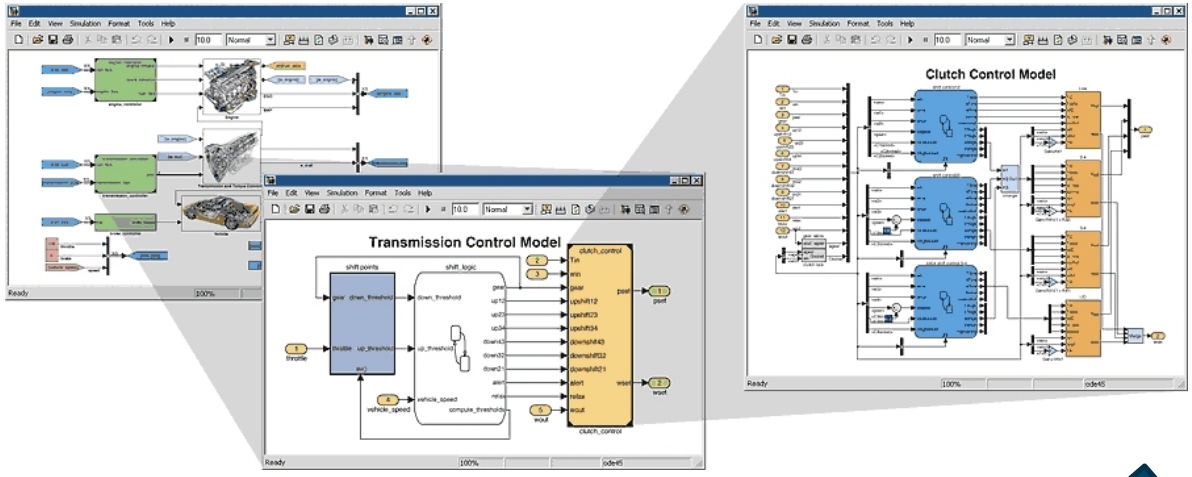


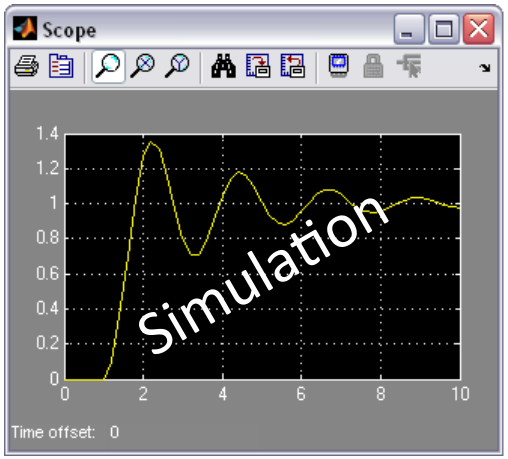
How to deal with **Complexity?**

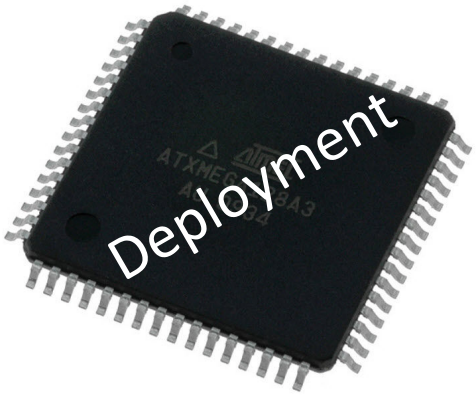
(in engineered systems)


environment
physical "plant"
Audi Q5 hybrid quattro
a_control
v
controller
v_reference

Model-Based System Design



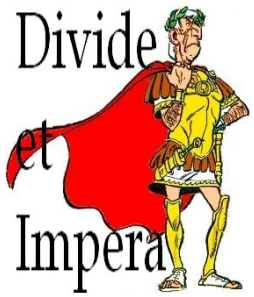




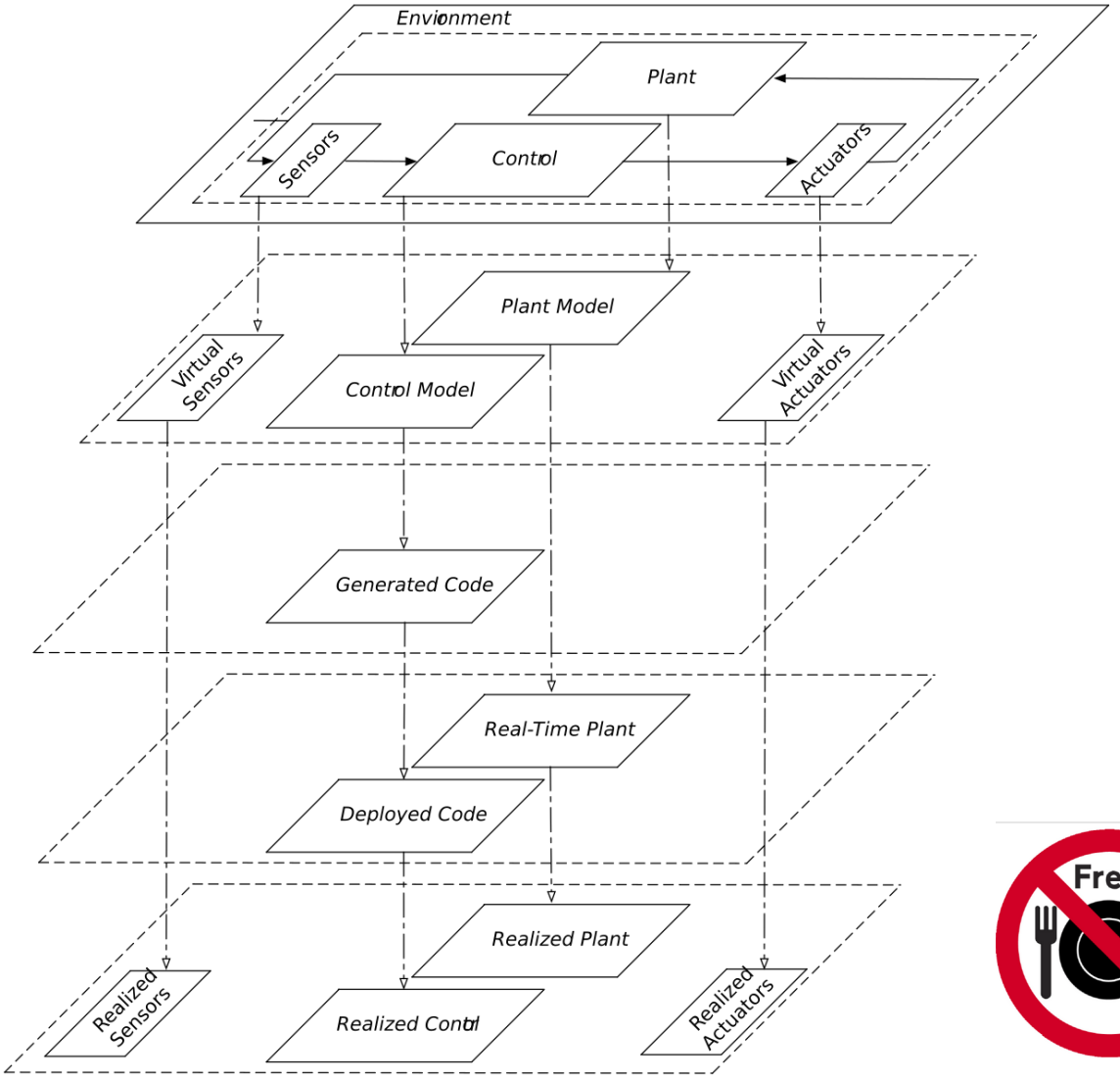
MiL, HiL, SiL, ...

XiL: X = Model, Software, Processor, Hardware

CoSys-Lab
Constrained Systems Lab
University of Antwerp



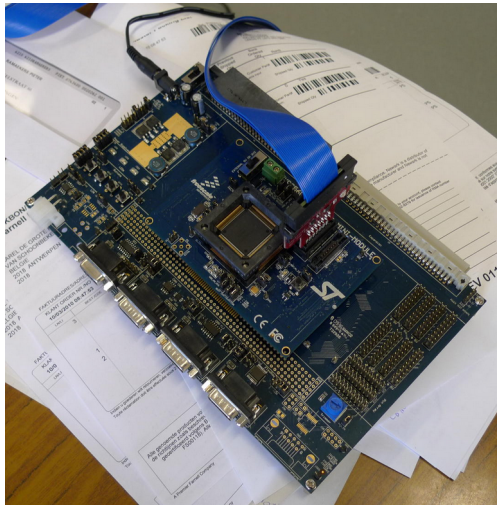
Requirements
Architectural Design
Model Design
MiL
Virtual System Design
SiL
Real-Time System Design
PiL and HiL
Real System Design
Integration Test



vertical consistency!

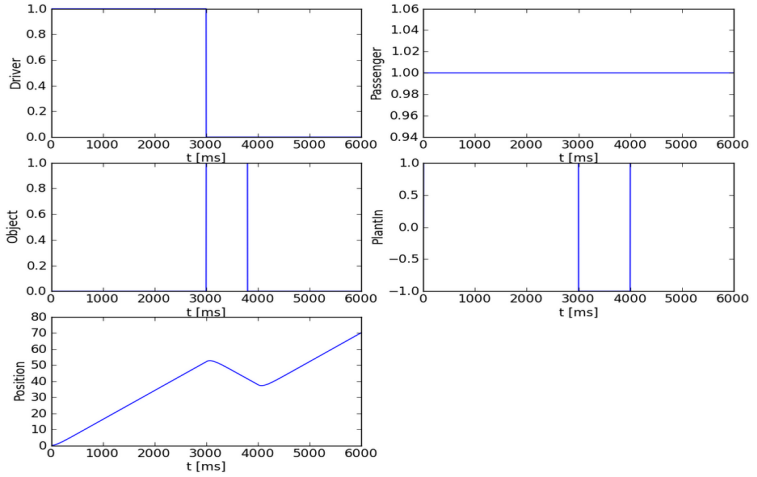
Ken Vanherpen. A contract-based approach for multi-viewpoint consistency in the concurrent design of cyber-physical systems. PhD thesis University of Antwerp. 2018.

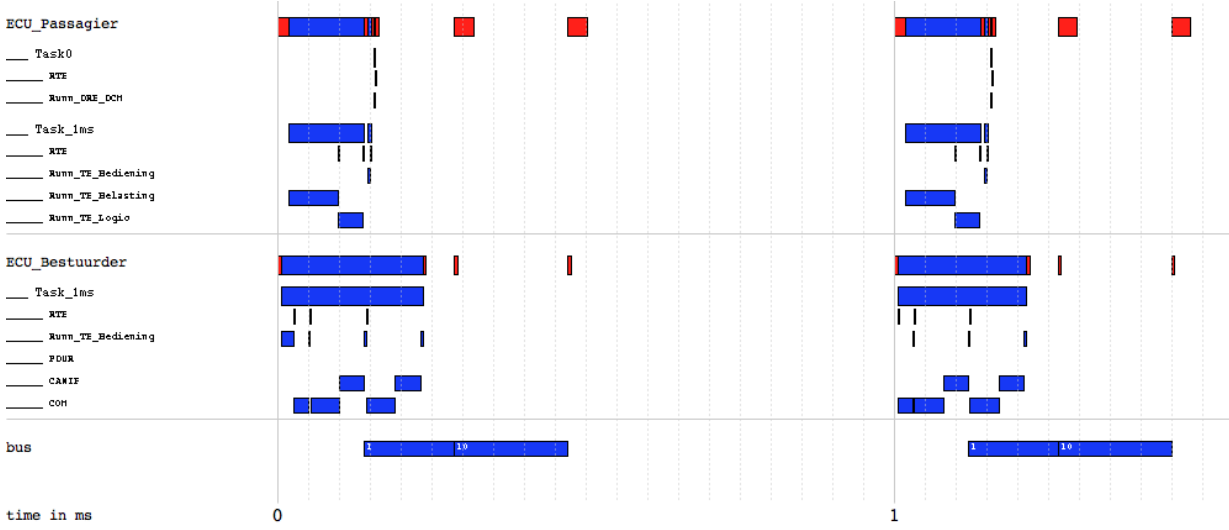
Deployment and Resource-Optimized Execution



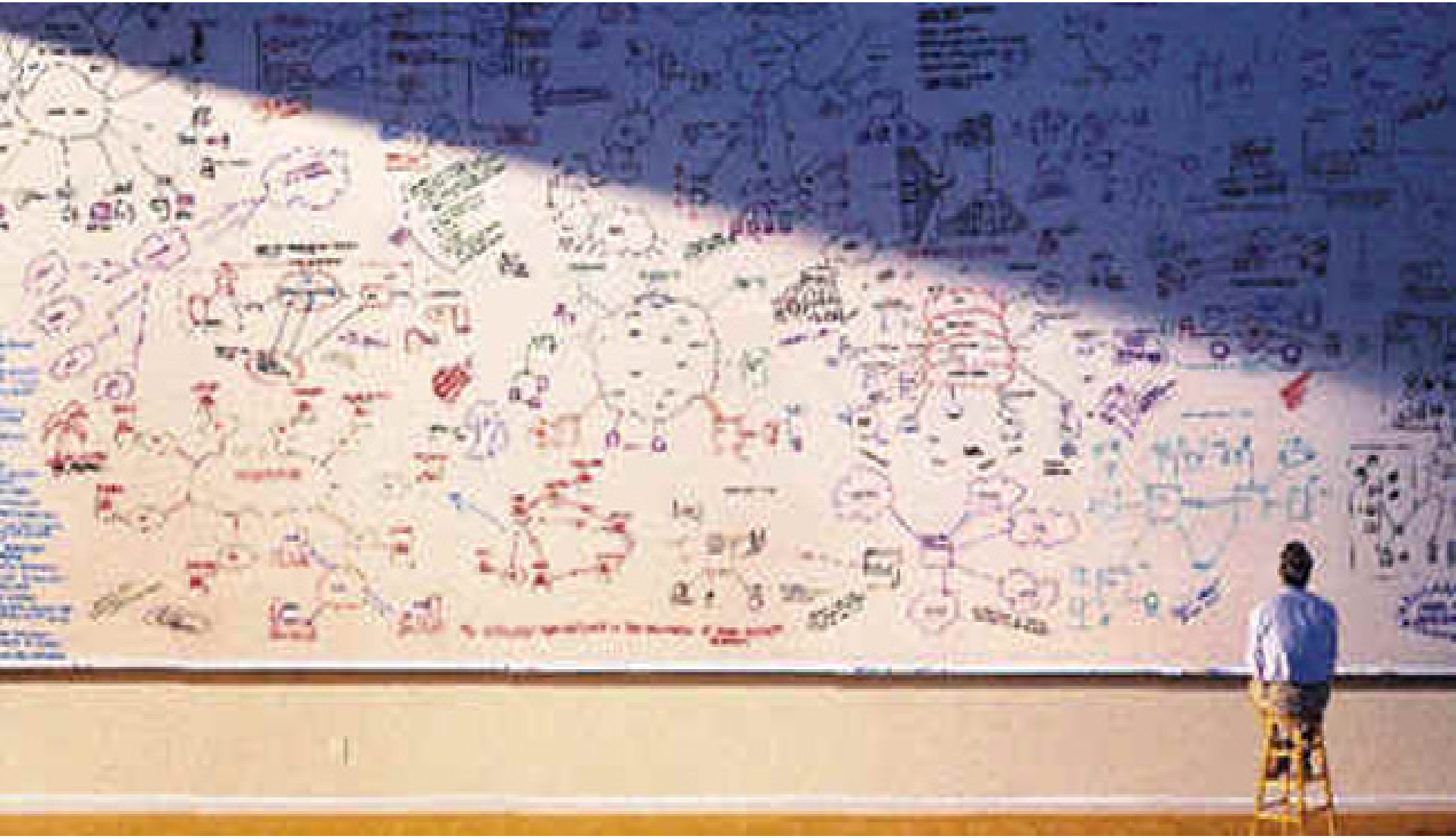
Joachim Denil, Paul De Meulenaere, Serge Demeyer, and Hans Vangheluwe. DEVS for AUTOSAR-based system deployment modeling and simulation. SIMULATION: Transactions of the Society for Modeling and Simulation International , 93(6):489 – 513, 2017.

Deployment/Design-Space Exploration (trsf. To MILP, trsf. based)





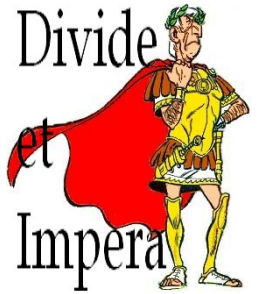
Joachim Denil, Hans Vangheluwe, Pieter Ramaekers, Paul De Meulenaere, and Serge Demeyer. DEVS for AUTOSAR platform modelling. In Spring Simulation Multiconference , pages 67 - 74. Society for Computer Simulation International (SCS), April 2011. Boston, MA, USA.



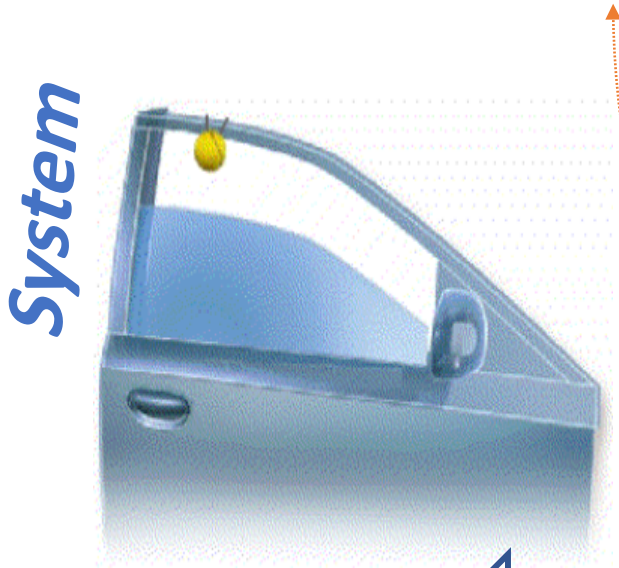
How to deal with **Complexity?**

(in engineered systems)

Multi-Disciplinary Teams

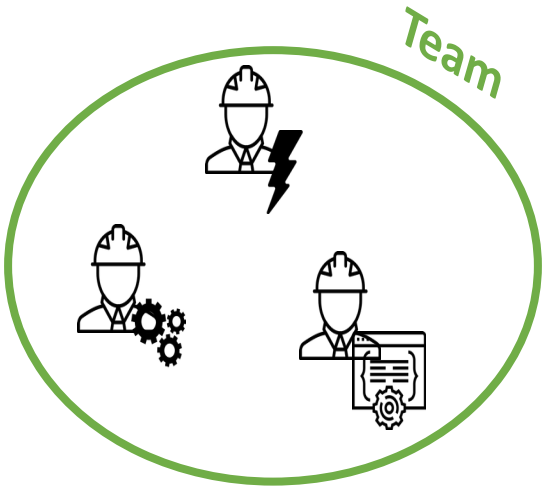


System properties: **safety**, **correctness**, (cost) **optimal**, …



needs to satisfy

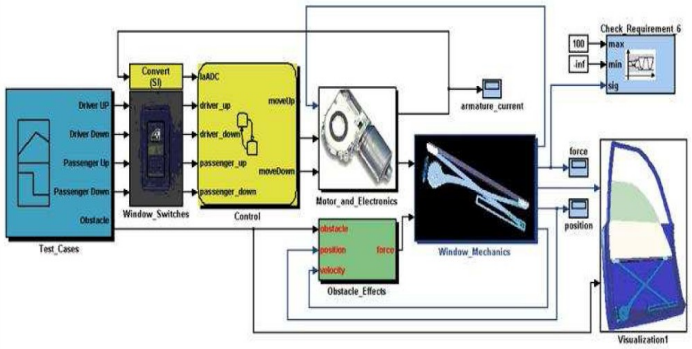
DESIGN

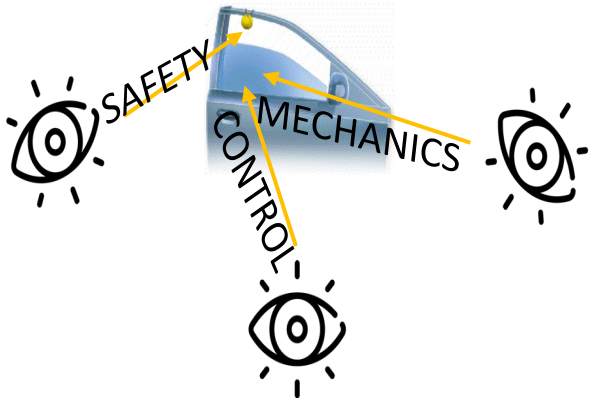


Architectural

Decomposition

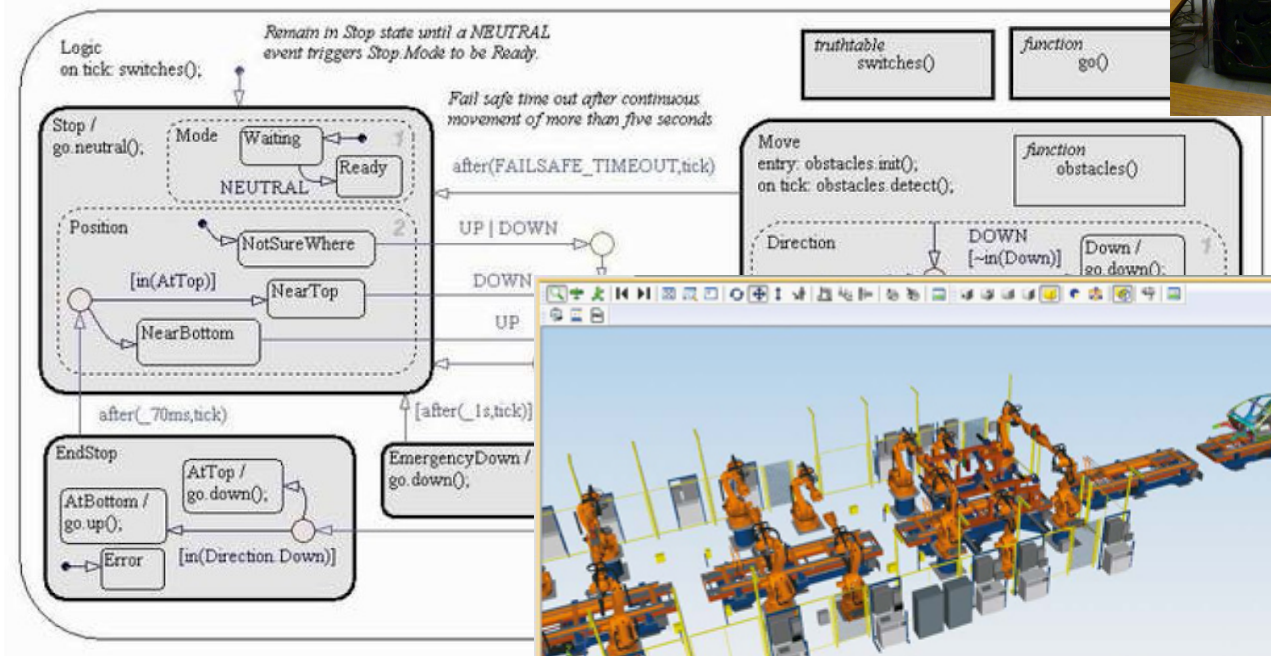
Viewpoint



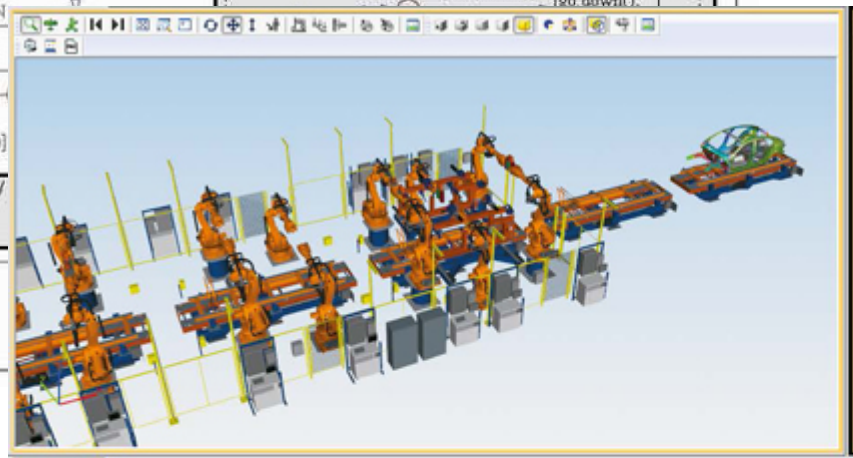


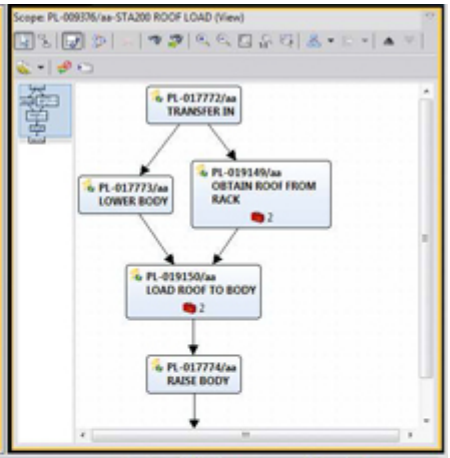
method/tool support exists for “downstream” activities

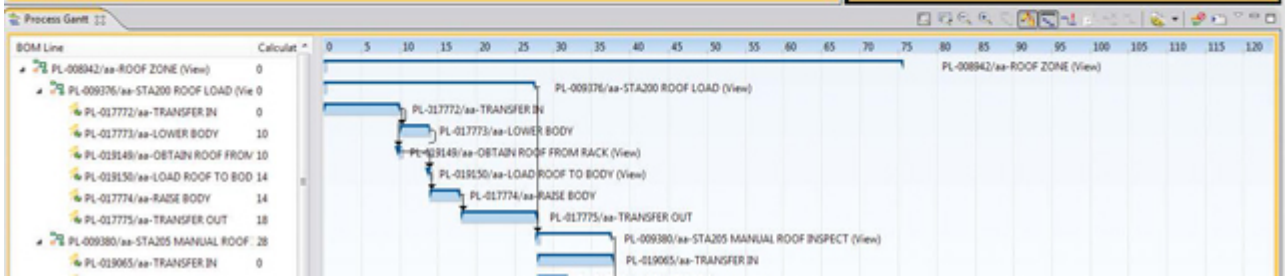
Modelling/Simulation/Verification/Synthesis/… Tools



PLM Tools







John Fitzgerald · Peter Gorm Larsen
Marcel Verhoef *Editors*

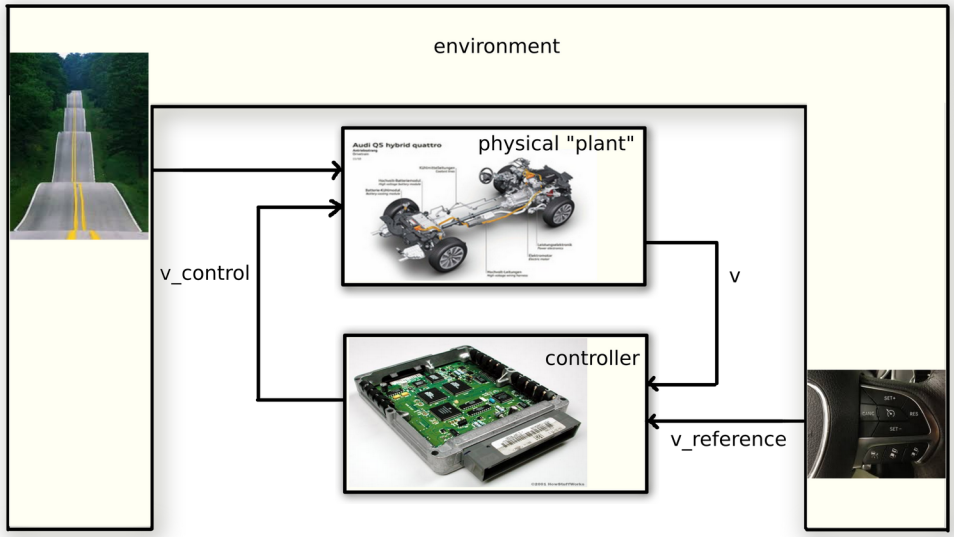
Collaborative Design for Embedded Systems

Co-modelling and Co-simulation

Springer

http://www.destecs.org
(Design Support and Tooling for Embedded Control Software)

- CT first
- DE first
- contract first



http://crescendotool.org/
DE: Overture (VDM) + CT: 20Sim (Bond Graph)

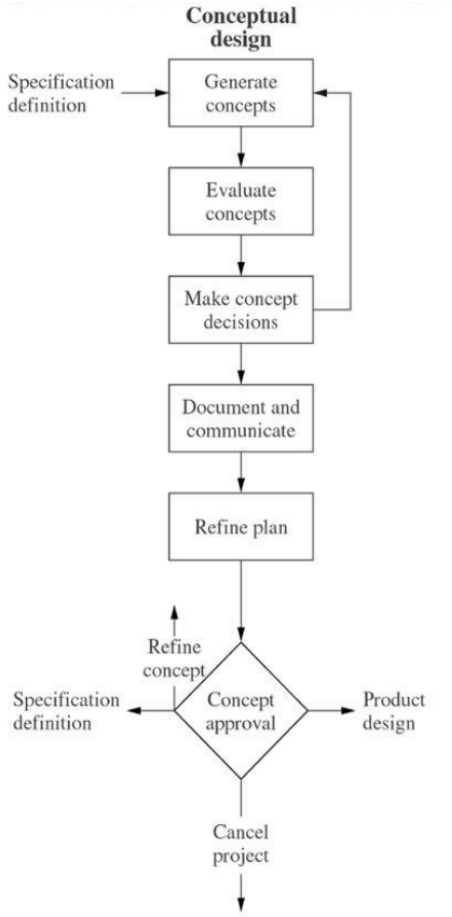
http://into-cps.org

Integrated Tool Chain
for Model-based Design
of Cyber-Physical Systems

INTO-CPS

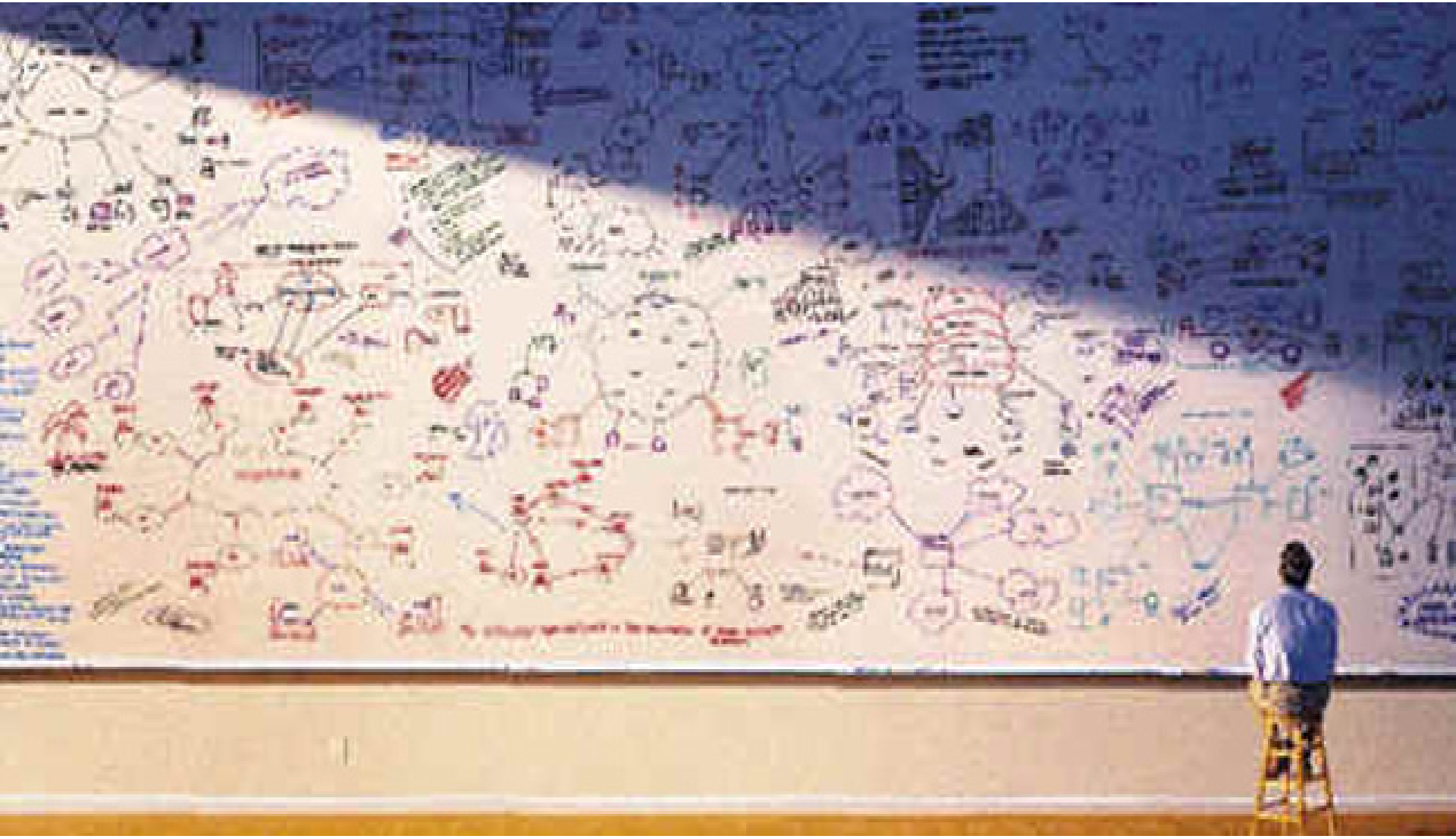
DE: Overture (VDM) + CT: Modelica /FMI

What about Agile “early stage” **Ideation** (aka “sketching”)?



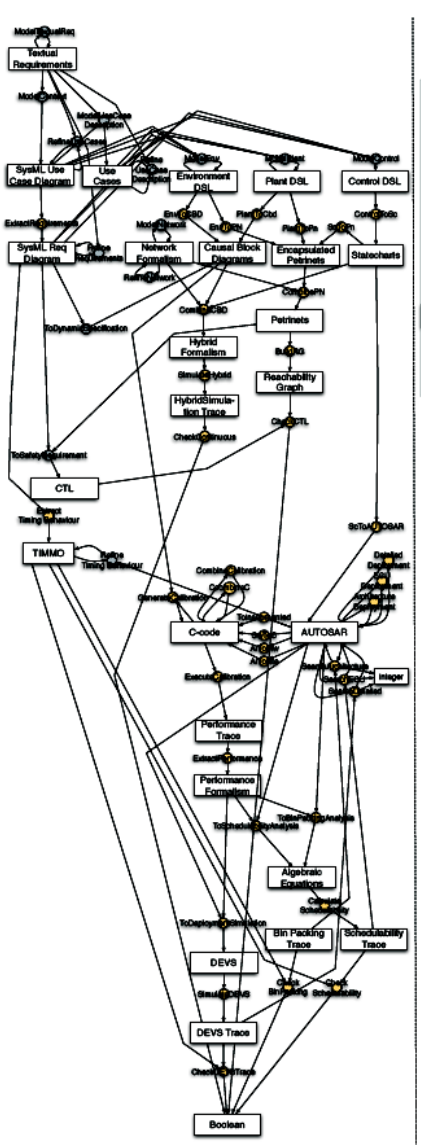
Requires developing **common understanding/modelling languages** together
Tool support? Modelling Language Engineering: **a posteriori typing**?

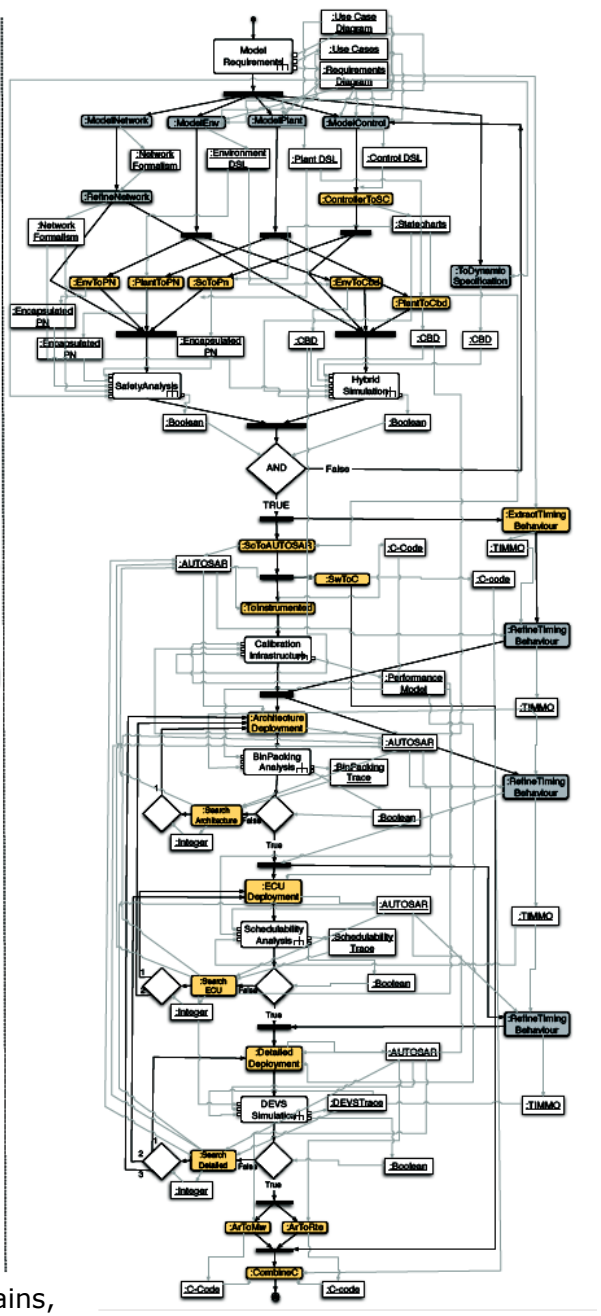
Juan de Lara and Esther Guerra. A Posteriori Typing for Model-Driven Engineering: Concepts, Analysis, and Applications. ACM Trans. Softw. Eng. Methodol. 25(4): 31:1-31:60 (2017A Posteriori Typing for Model-Driven Engineering: Concepts, Analysis, and Applications. ACM Trans. Softw. Eng. Methodol. 25(4): 31:1-31:60 (2017).



How to deal with **Complexity?**

(in engineered systems)



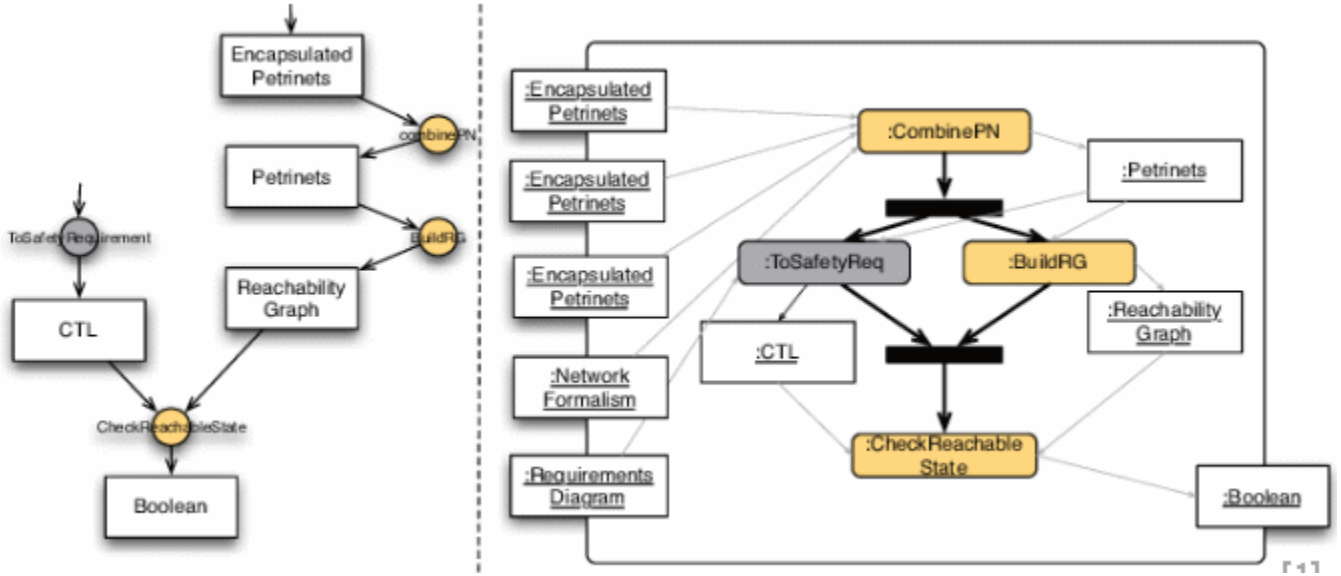


28 different modelling formalisms

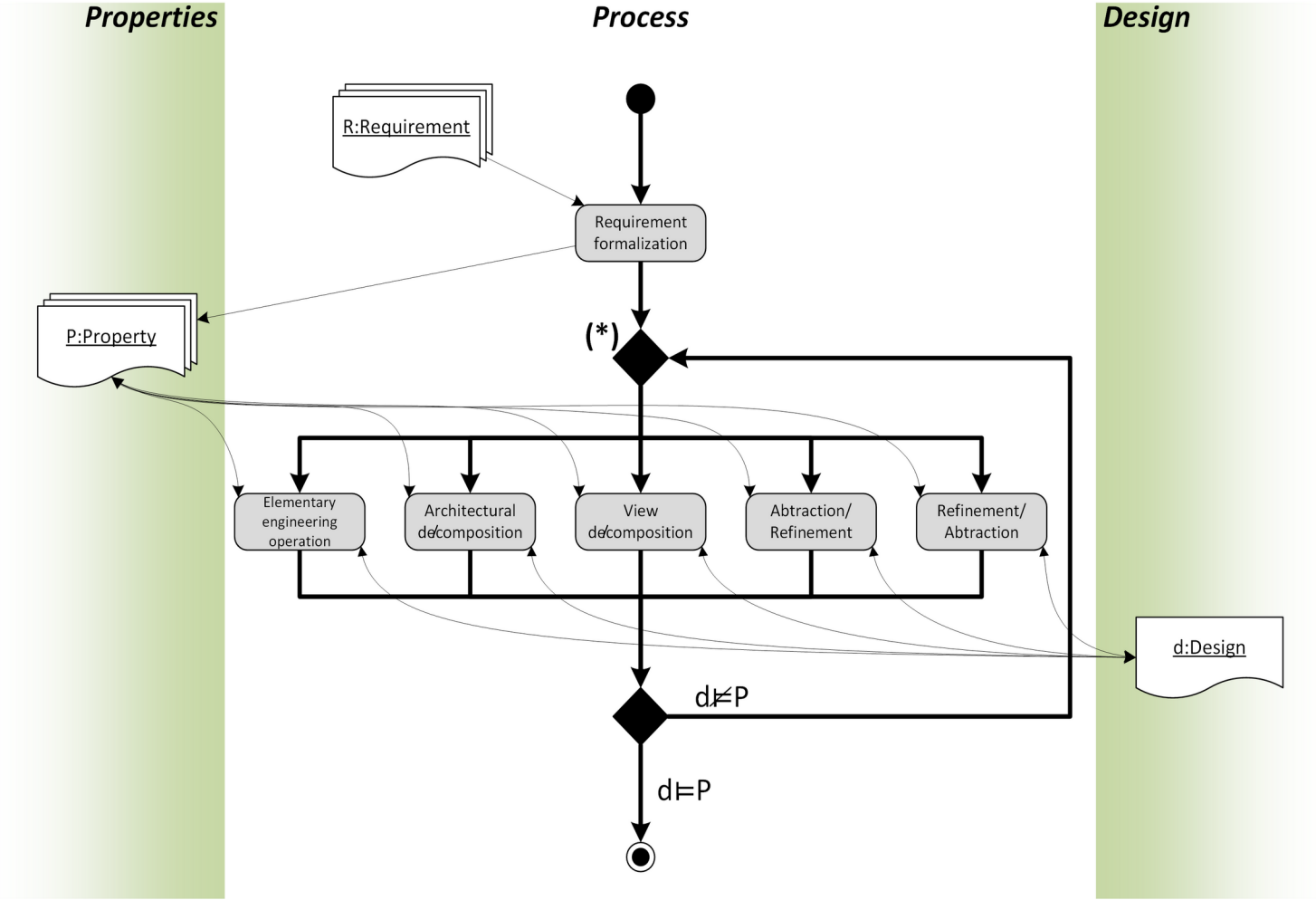
50 transformations

FTG+PM (Process Model)

FTG+PM: An Integrated Framework for Investigating Model Transformation Chains, Levi Lúcio, Sadaf Mustafiz, Joachim Denil, Hans Vangheluwe, Maris Jukss. Proceedings of the System Design Languages Forum (SDL) 2013, Montreal, Quebec. Lecture Notes in Computer Science (LNCS), Volume 7916, pp 182-202, 2013.


Encapsulated Petrinets
combinePN
Petrinets
BuildRG
ToSafetyRequirement
Reachability Graph
CTL
CheckReachableState
Boolean
:Encapsulated Petrinets
:Encapsulated Petrinets
:Encapsulated Petrinets
:Network Formalism
:Requirements Diagram
:CombinePN
:Petrinets
:ToSafetyReq
:BuildRG
:Reachability Graph
:CTL
:CheckReachable State
:Boolean

Recursive workflow: from Properties to Design



Causes of Complexity …

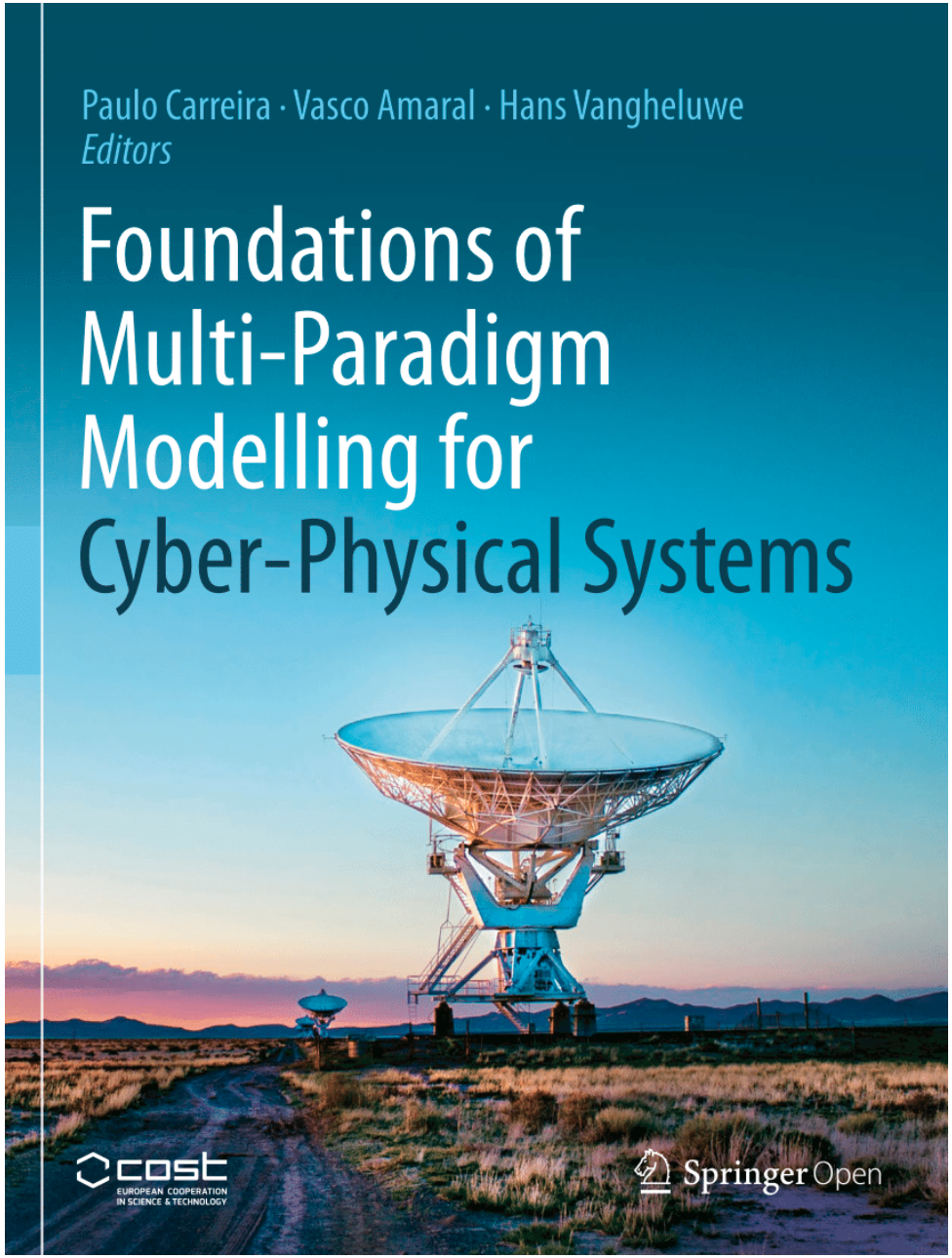
and how to deal with them

- large number of components (in an “architecture”)
- multiple concerns/views/stakeholders → consistency?

- heterogeneity of components / views
    - different formalisms
    - different abstractions

- emergent behaviour

- engineering:
    - long requirements → design → realization path (complex workflow)
    - insufficient understanding of requirements, system under study, …
    - difficulty in collaboration
    - modelling languages and tools may introduce “accidental complexity”



Carreira P., Amaral V., Vangheluwe H. (eds)
Foundations of Multi-Paradigm Modelling for Cyber-Physical Systems. Springer.

https://doi.org/10.1007/978-3-030-43946-0_2