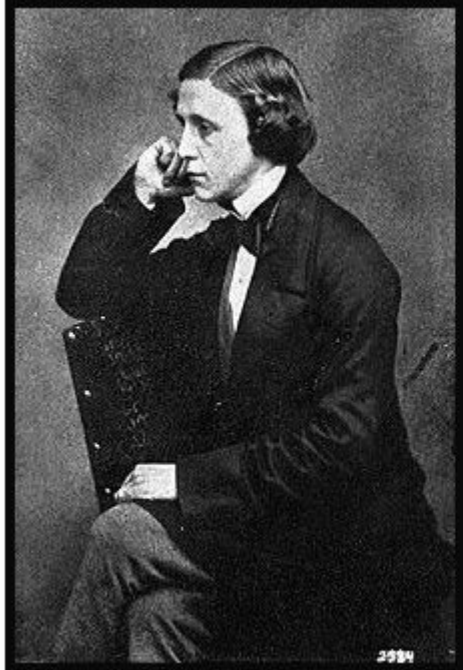
Modelling of Software Intensive Systems (MoSIS)
”dealing with complexity”

http://msdl.cs.mcgill.ca/people/hv/teaching/MoSIS/

Hans Vangheluwe

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



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
- heterogeneity
- emergent behaviour
- multiple concerns/views/stakeholders → consistency?
- engineering: long requirements → design path
- insufficient understanding of requirements, system under study, …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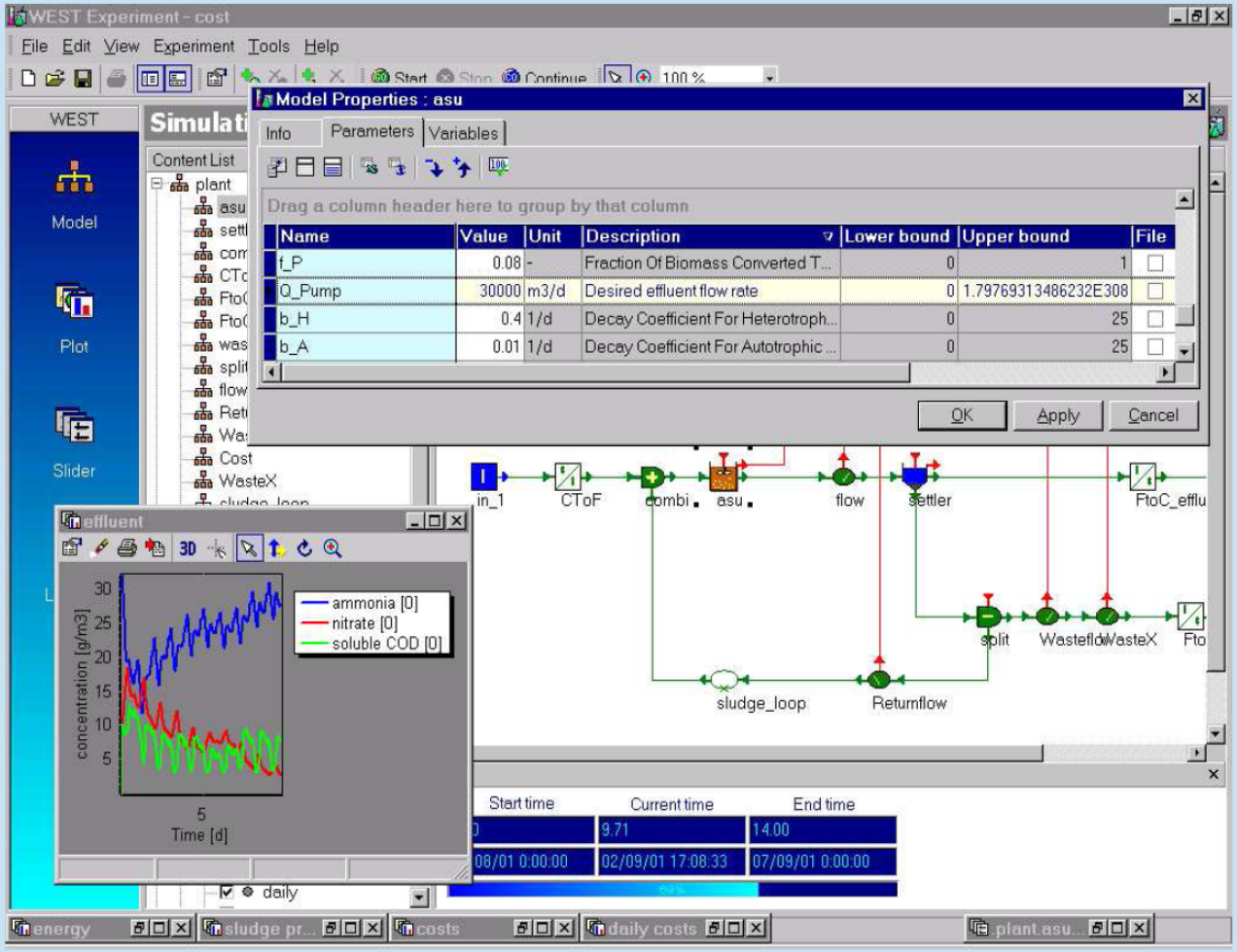
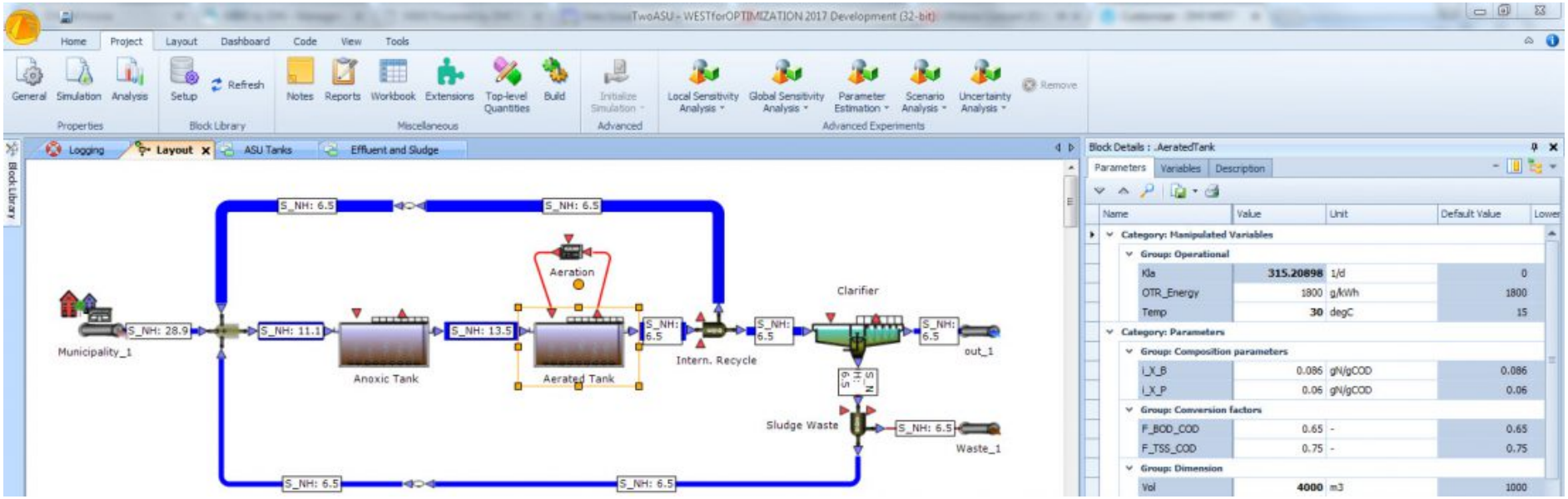
DS(V)M Environment



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

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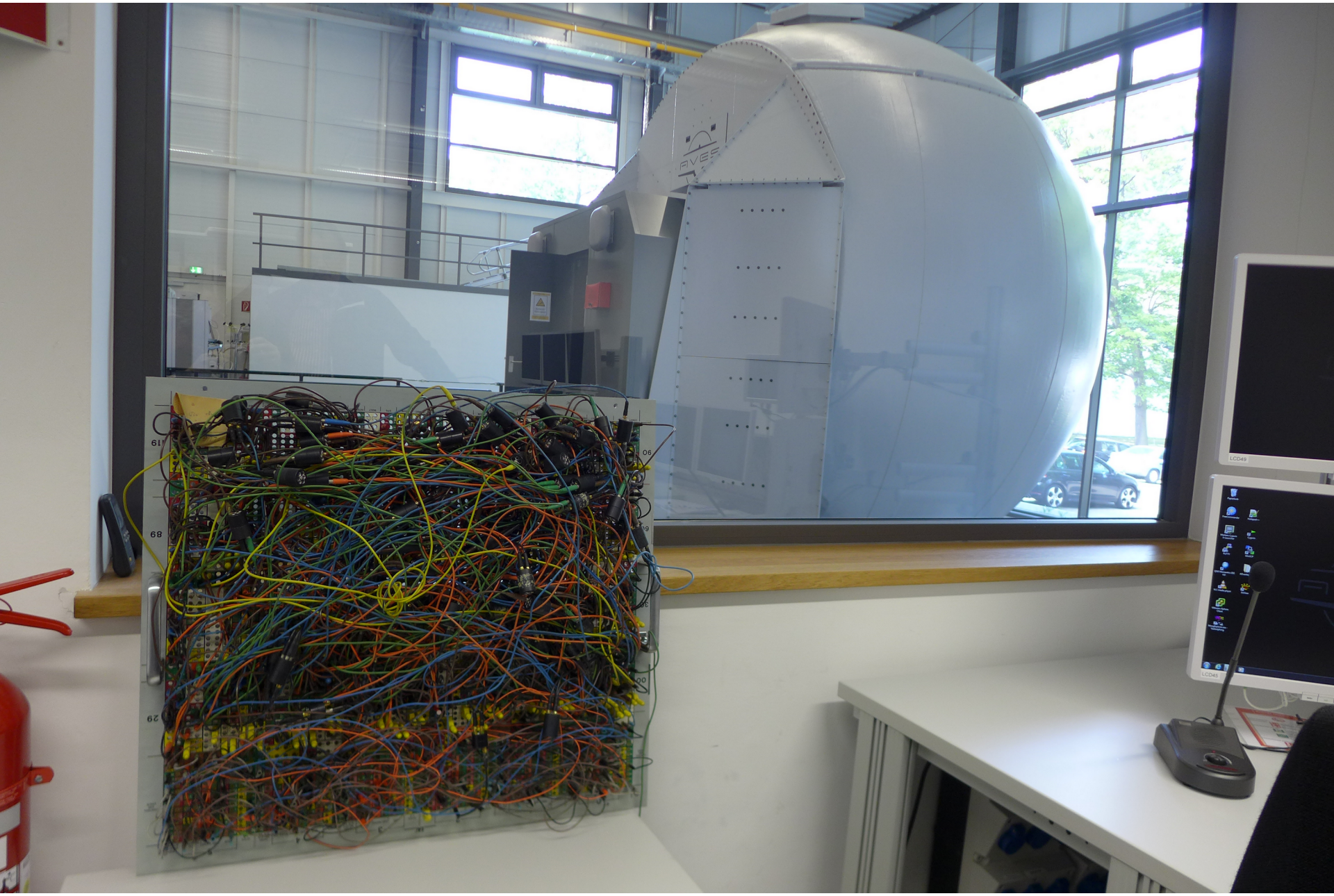
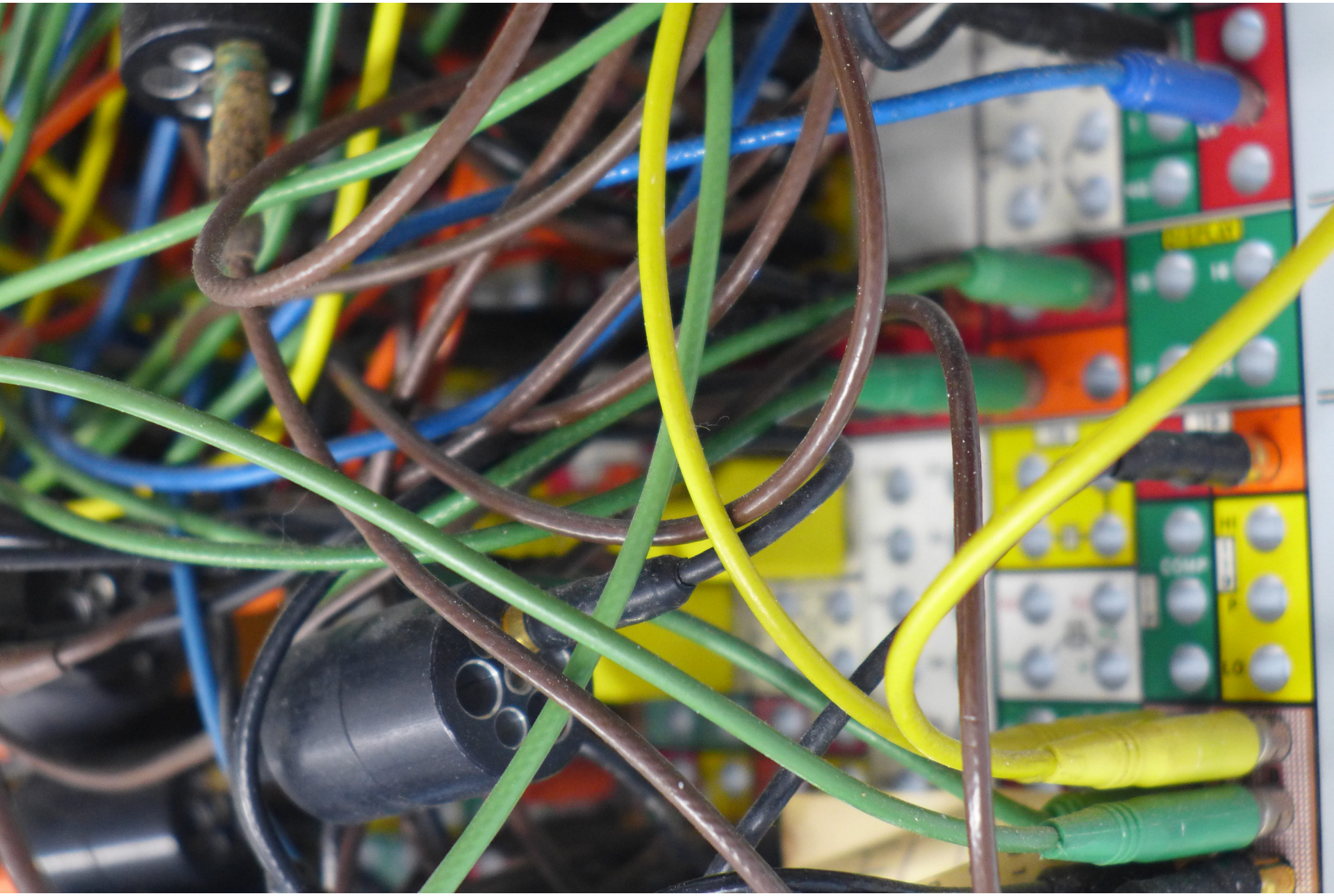
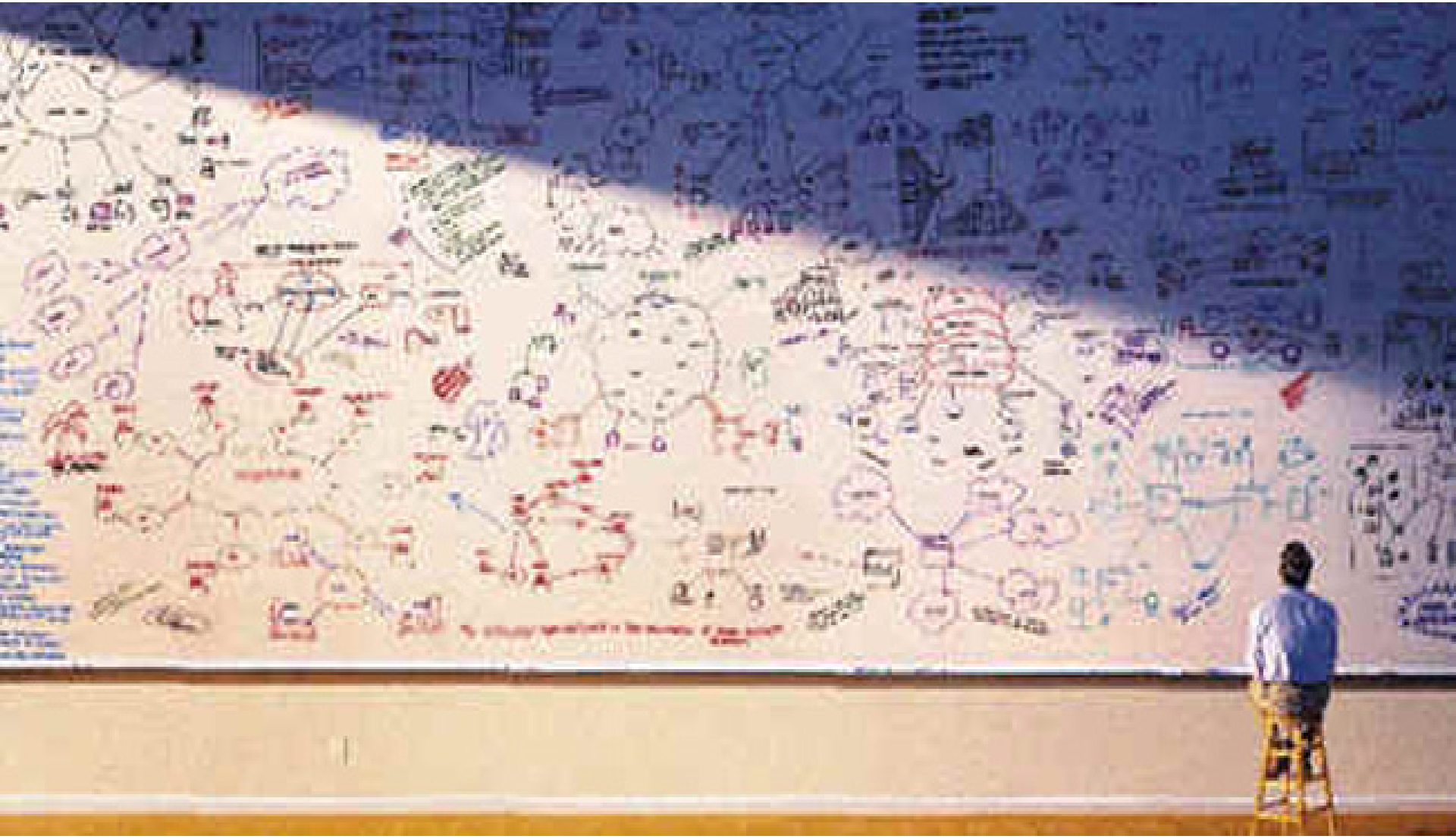






How to deal with **Complexity?**

(in engineered systems)

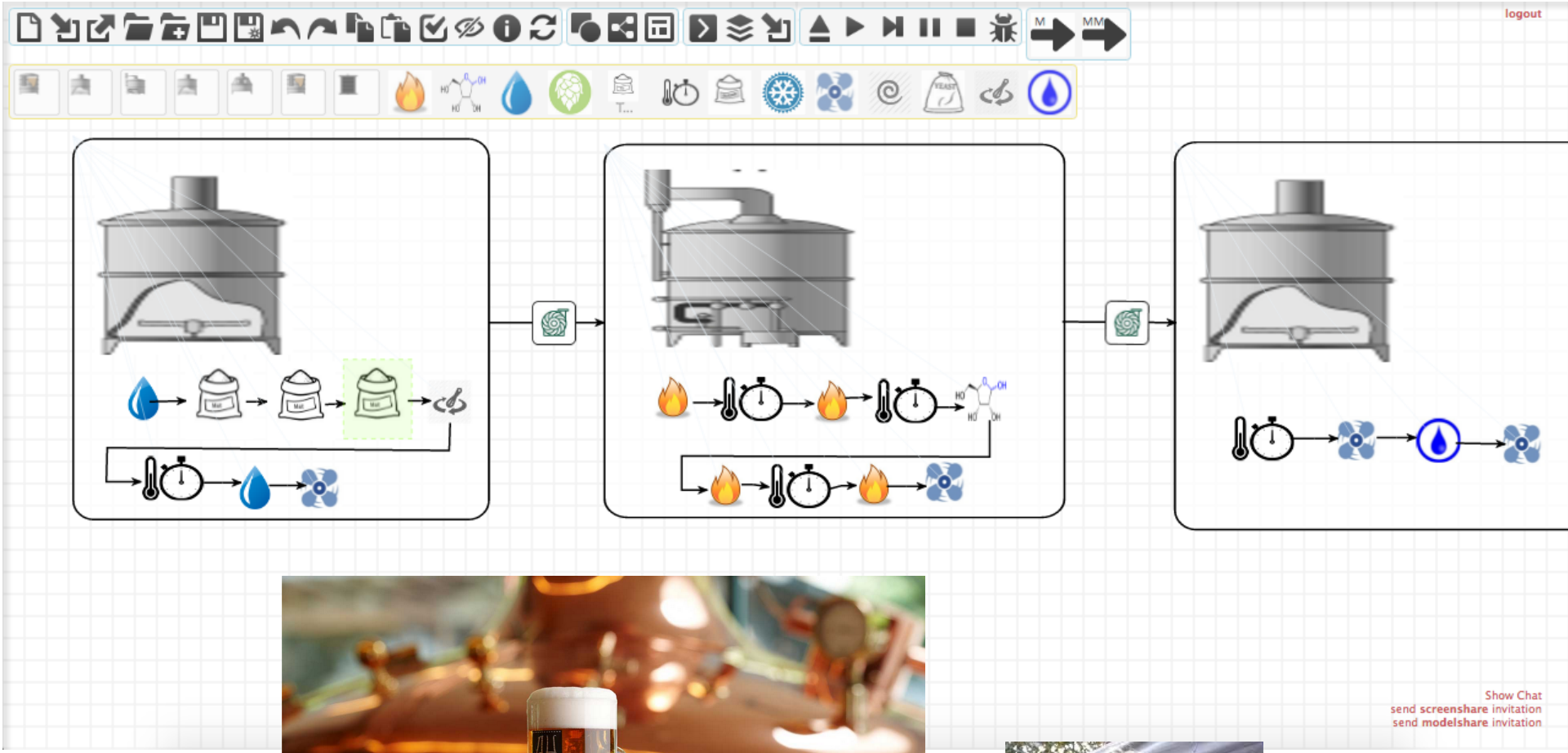
at the most appropriate level(s) of abstraction
using the most appropriate formalism(s)
explicitly modelling workflows

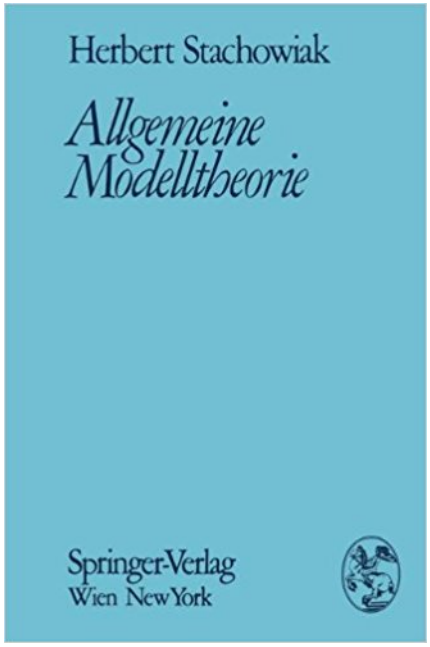
DSM TP 2014
Theory and Practice

5th International Summer School
on Domain Specific Modeling

Antwerp, Belgium
25 - 29 August

Thomas Kühne


logout
Show Chat
send screenshare invitation
send modelshare invitation



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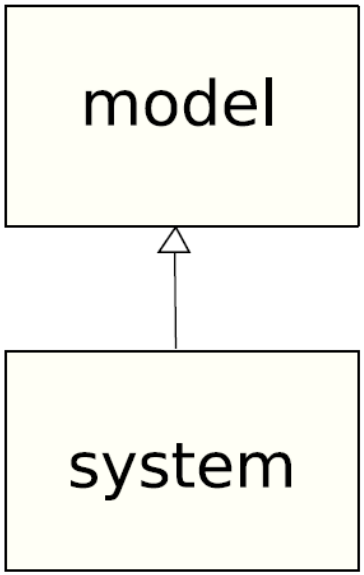
Mannequin comes from the French word mannequin, which had acquired the meaning "an artist's jointed model", which in turn came from the Flemish word manneken, meaning "little man, figurine".

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

Jean Bézivin

Everything is a model !

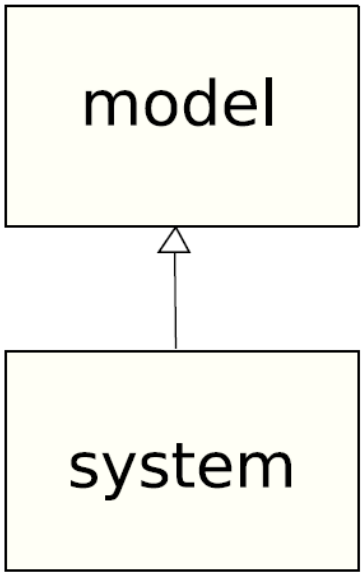


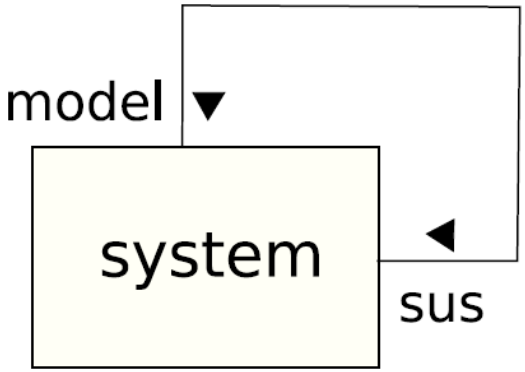
Jean Bézivin

Everything is a model !

Jean-Marie Favre

Nothing is a model !





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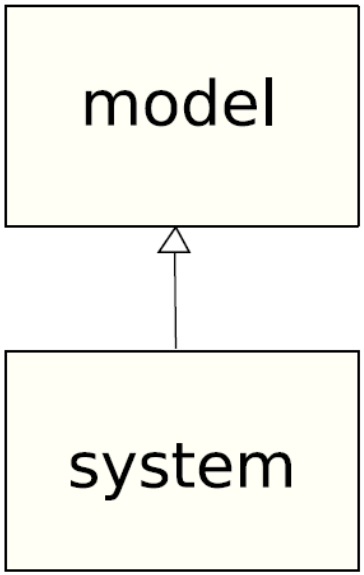
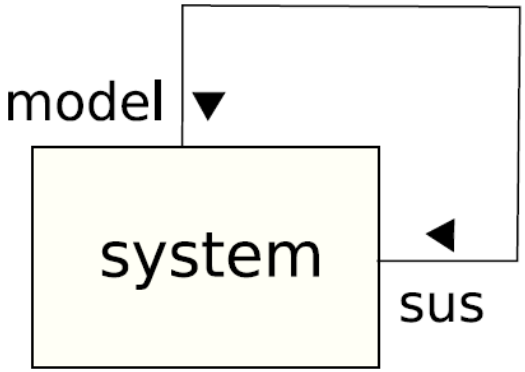
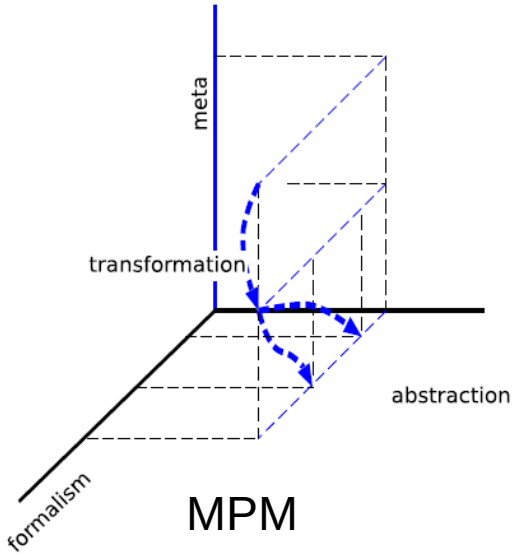
Hans Vangheluwe

Model everything !





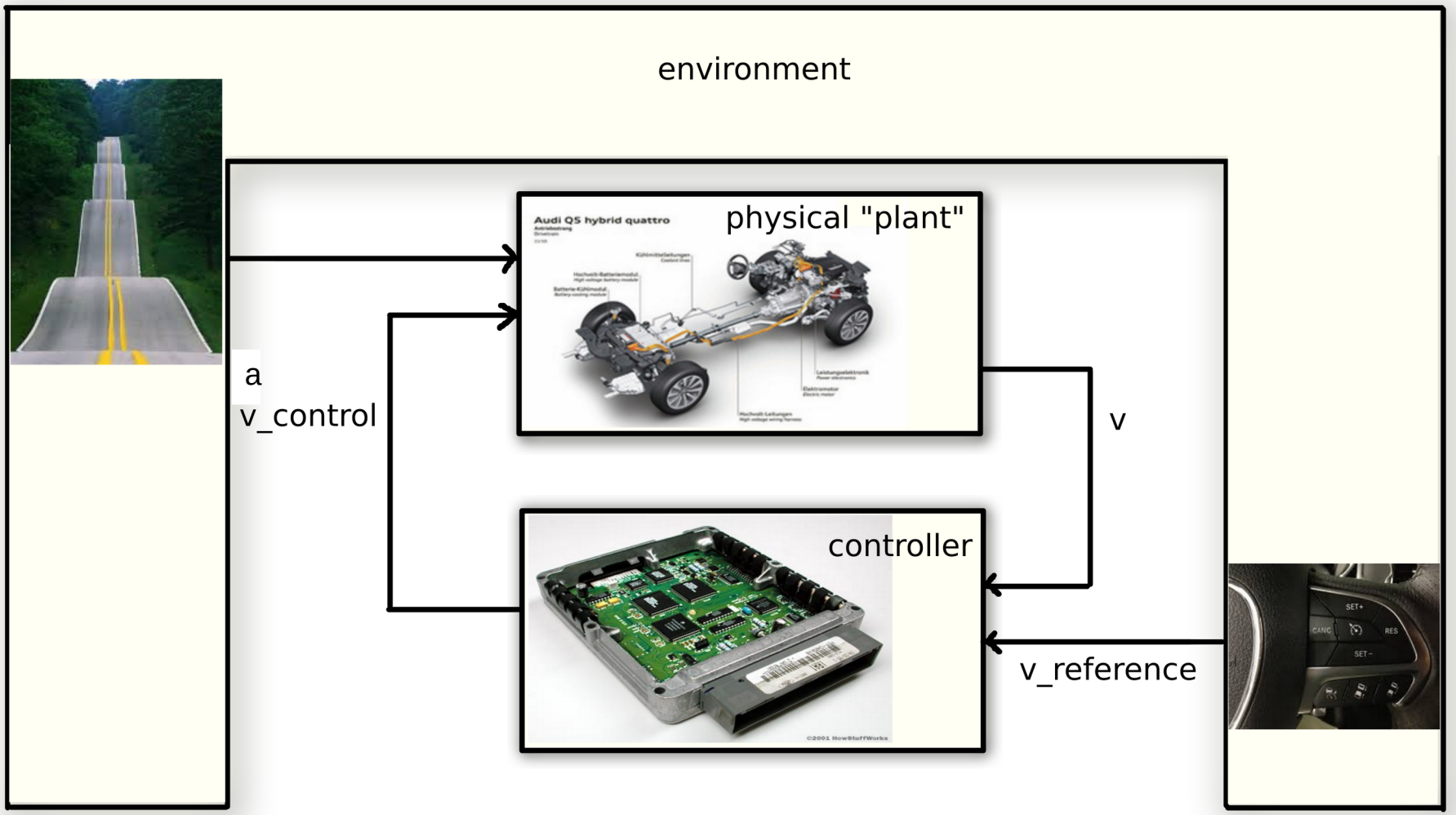


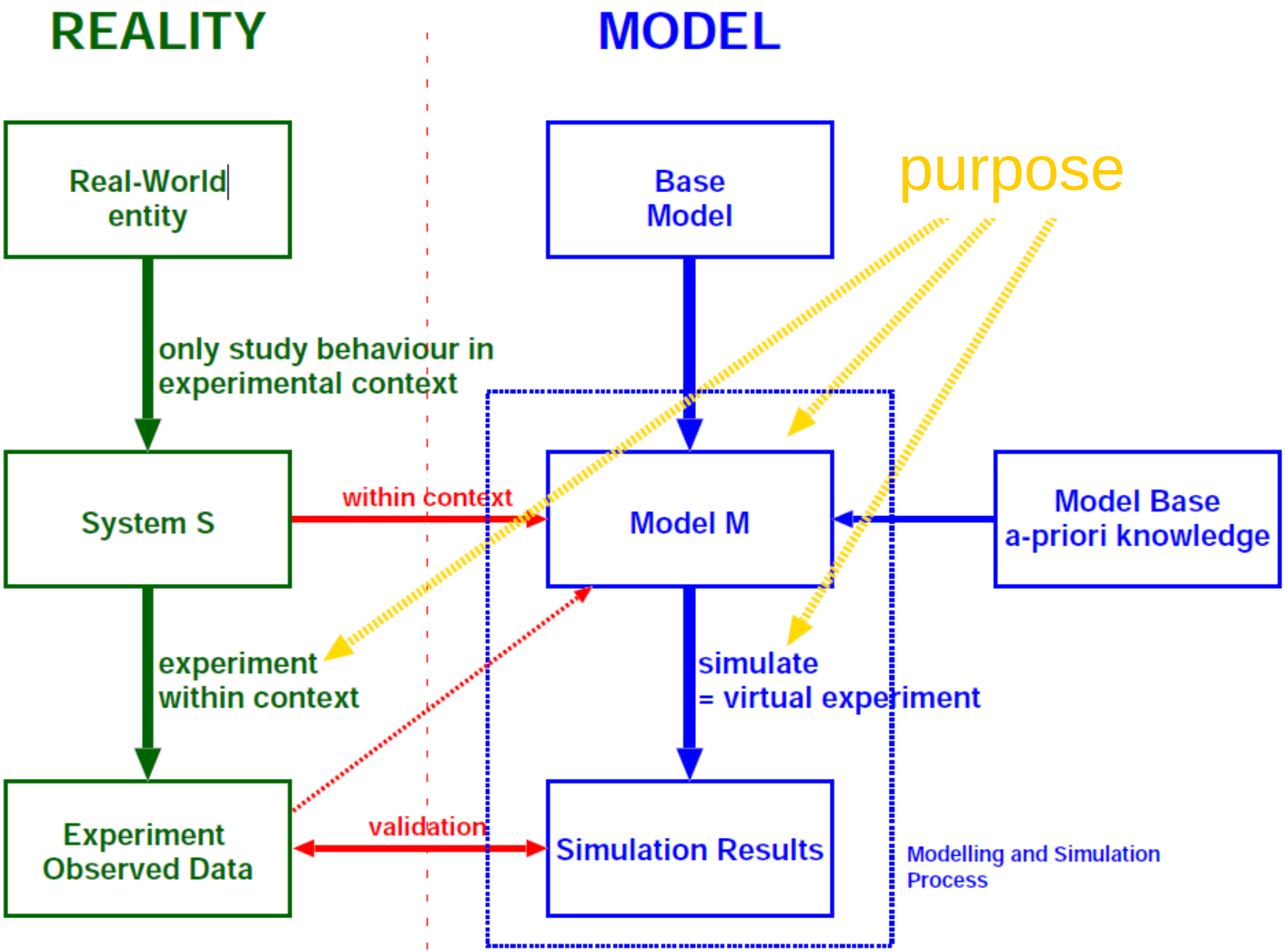
“System”

System Boundaries

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

system = environment / “plant” / controller

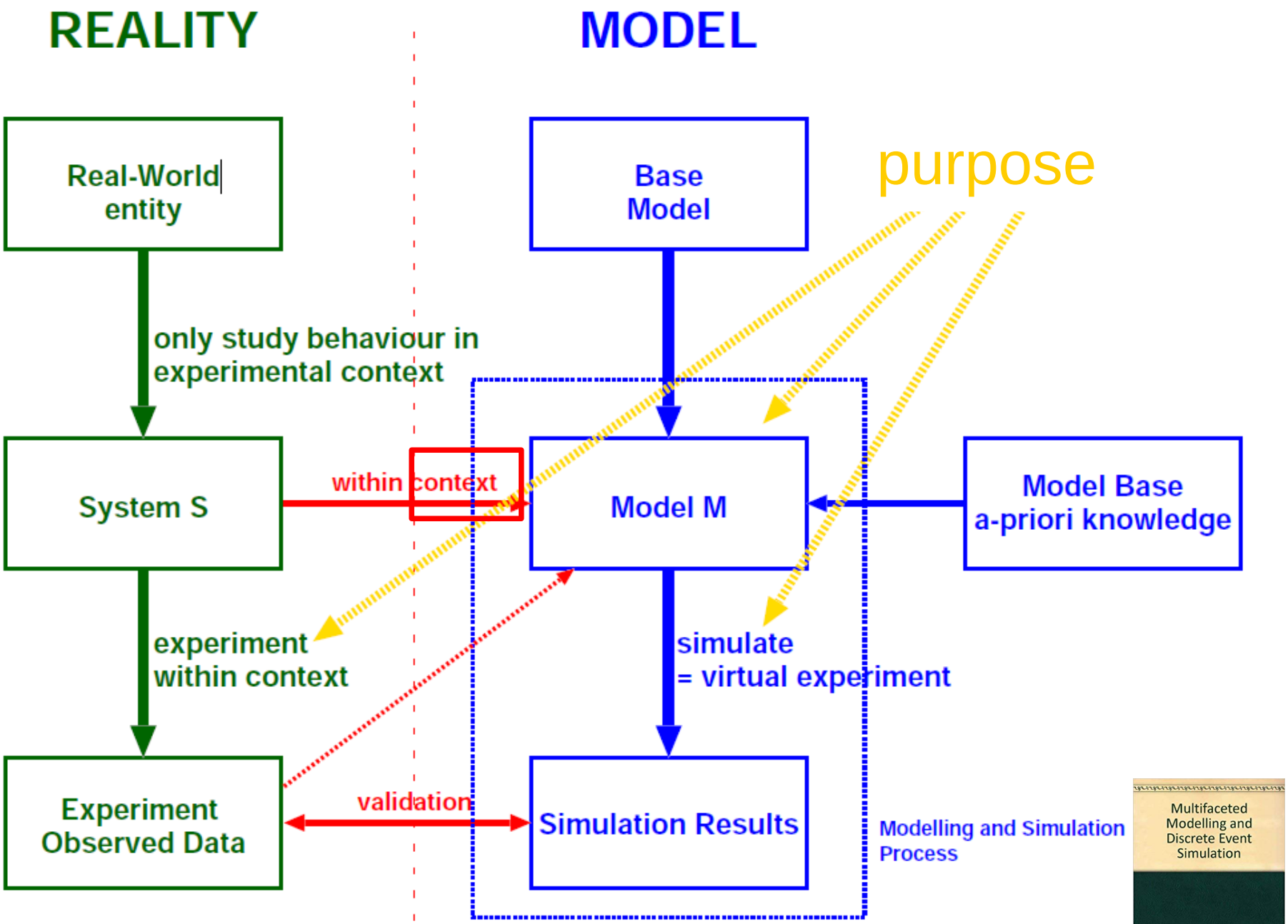




Bernard P. Zeigler. *Multi-faceted Modelling and Discrete-Event Simulation*. Academic Press, 1984.

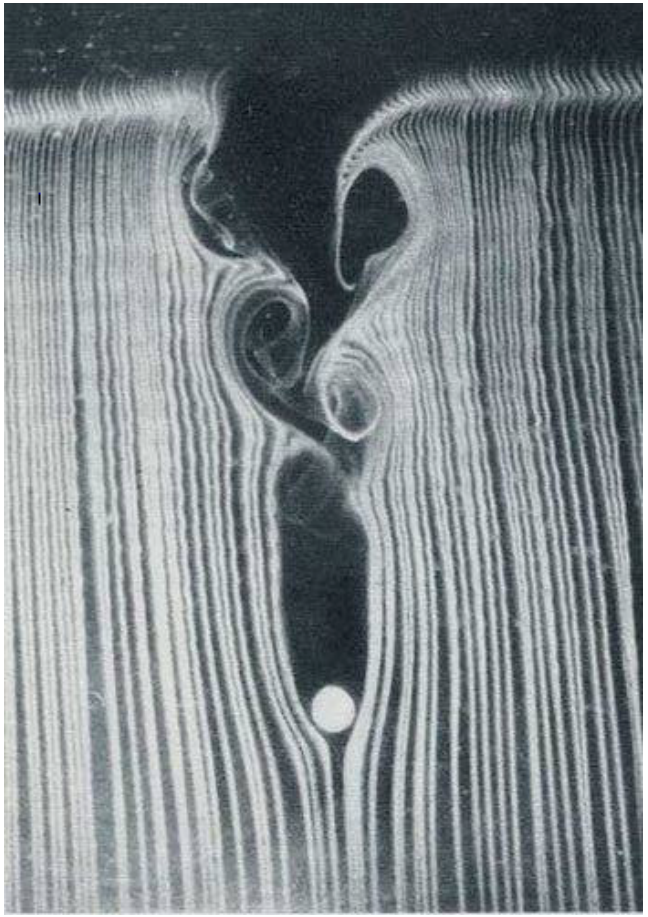
model must be “fit for purpose”

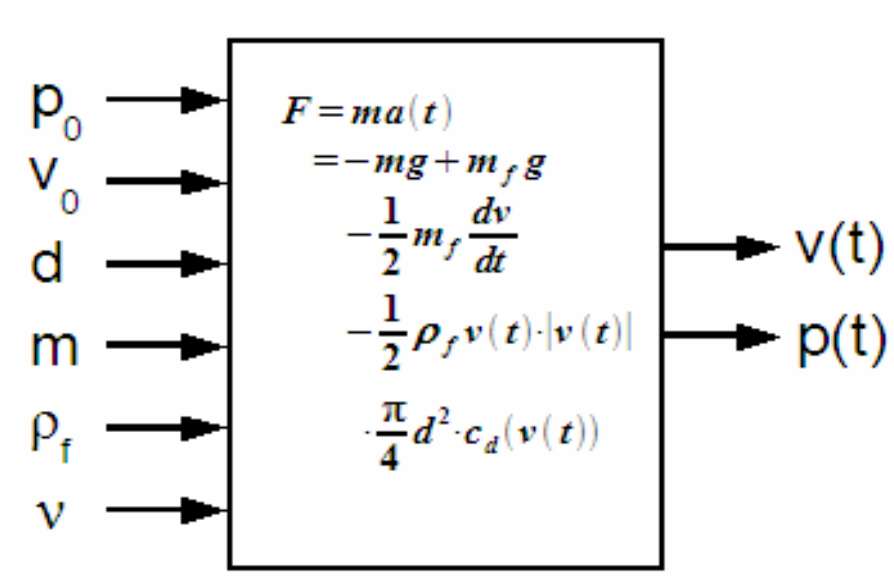
drives choice of:
level of abstraction, formalism, notation, ….



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

Model Validity … Context?





Spiegel, M., Reynolds, P. F., & Brogan, D. C.
A Case Study of Model Context for Simulation Composability and Reusability.
In *Proceedings of the Winter Simulation Conference, 2005.* (Vol. 2005, pp. 437–444). IEEE.
http://doi.org/10.1109/WSC.2005.1574279

1. Invariant Constraints

1a Sphere Attributes

1. Sphere Property - The body is a sphere and it remains spherical.
2. Smooth Property - The body is smooth and it remains smooth.
3. Impermeable Property - The body is completely impermeable.
4. Initial Velocity - The body has an initial velocity of v_0 that has no horizontal component of motion.
5. Angular Velocity - The body has no initial angular velocity.
6. Constant Mass - The mass of the body remains constant over time. The body does not experience ablation or accretion.
7. Constant Diameter - The diameter of the body remains constant over time.
8. Distribution of Mass - The body has a centrally symmetric mass distribution that remains constant over time.
9. Uncertainty Principle - The diameter of the body is much greater than the Plank length.
10. Brownian Motion - The mass and diameter of the body are large enough such that Brownian motion of the fluid has negligible impact on the body.
11. General Relativity - The mass of the body is low enough to ignore the gravitational curvature of space-time.

Implicit Assumptions!

1c Earth Attributes

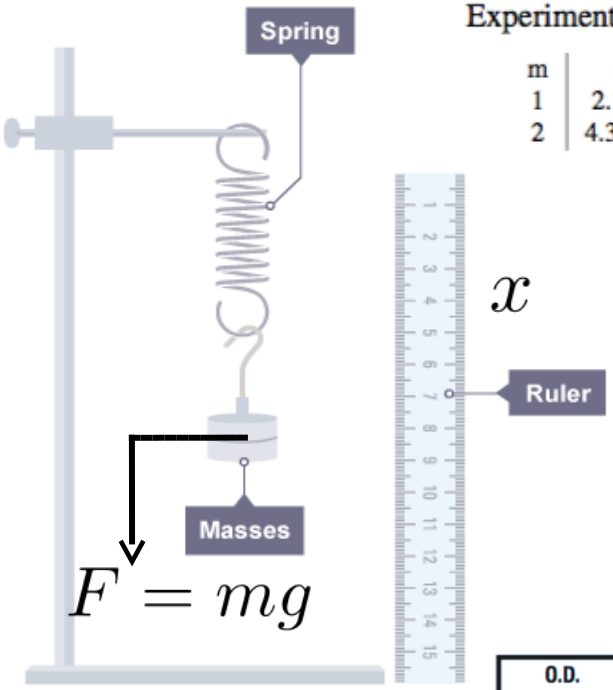
18. Flat Terrain - The ground does not have terrain and remains flat for all $t > 0$.
19. Coriolis Effect - The Earth is not rotating. We ignore the Coriolis effect.

2. Dynamic Constraints

20. Mach Speed - The velocity of the body is sufficiently less than the speed of sound for that medium.
21. Special Relativity - The velocity of the body is sufficiently less than the speed of light for that medium.
22. Reynolds Number - The Reynolds number remains between 10^{-2} and 10^{7} for all $t > 0$. The Reynolds number is a function of velocity.

3. Inter-Object Constraints

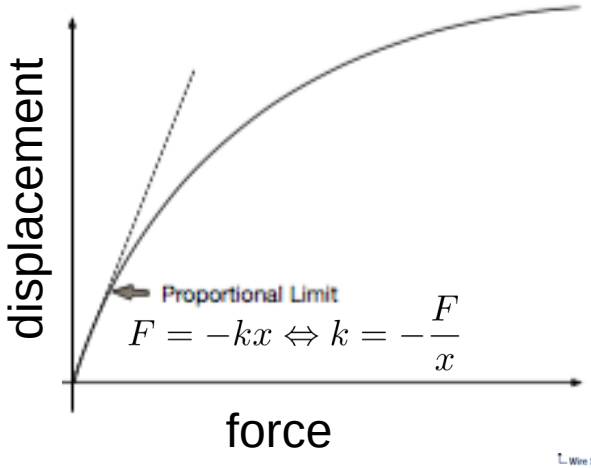
23. Sphere/Fluid Interaction - The body and the fluid interact only through buoyancy and drag. For example, the body cannot dissolve in the fluid, nor can the body transfer heat to the fluid.
24. Sphere/Earth Interaction - The body and the earth interact only through the gravitational force.
25. Fluid/Earth Interaction - The fluid and the earth do not interact.
26. Closed System - The Earth, sphere, and fluid do not interact with any other objects.
27. Simple Gravity - Gravity is a constant downward force of 9.8 m/s^2.
28. One-Sided Gravity - The mass of the body is much less than the mass of the Earth. The Earth is not affected by the gravitational pull of the body.
29. Inelastic Collision - The collision between the sphere and the ground is perfectly inelastic.



x

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		

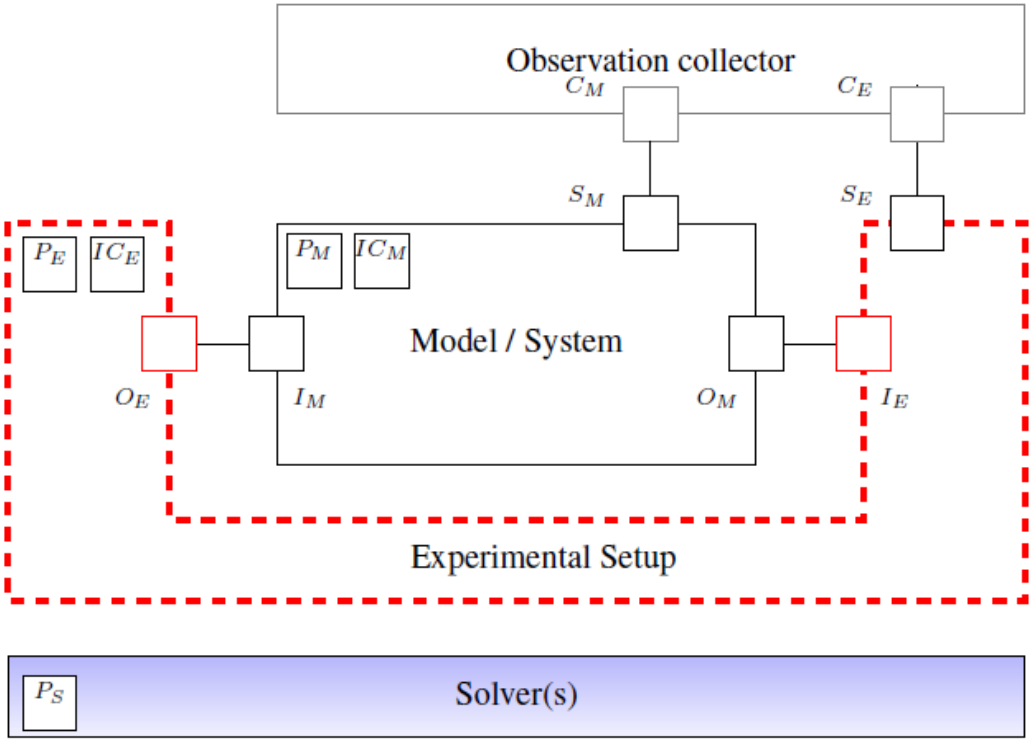


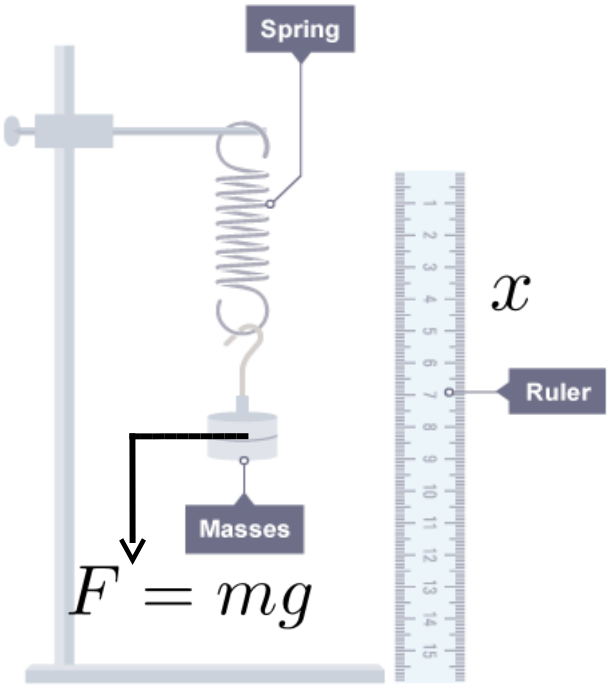
Wire Size

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

www.centuryspring.com

Validity **“Frame”** ~ reproducibility





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?")

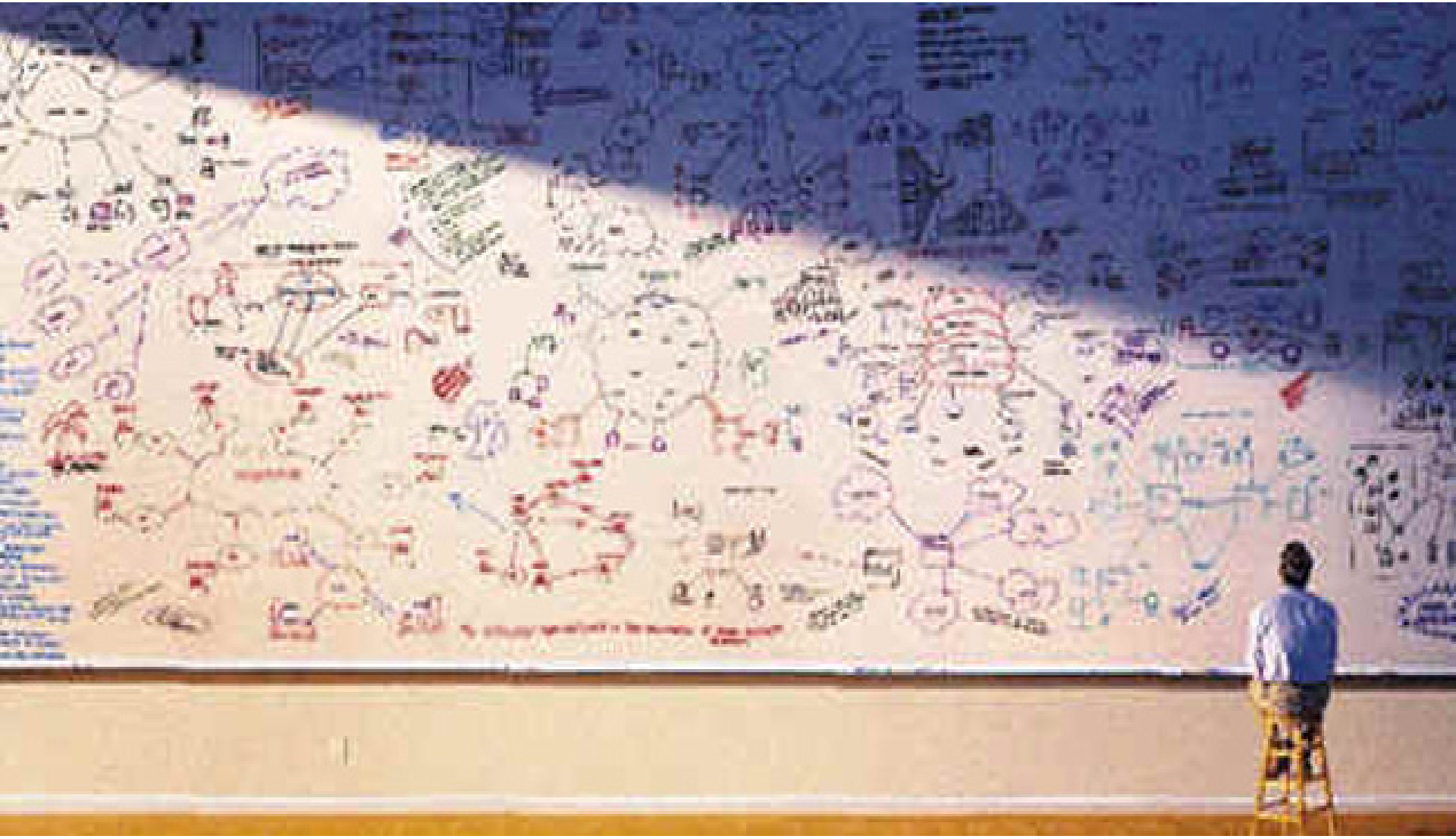
- Detached or Semi-detached
- Style (classical, modern, . . .)
- Number of Floors
- Number of rooms of different types (bedrooms, bathrooms, . . .)
- Garage, Storage, . . .
- Cellar
- . . .

Design ("How?")

note: product family

requirements – *satisfied by* → design
(i.e., a set of properties)

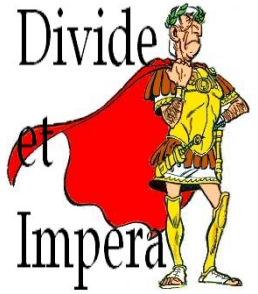
(may in turn serve as requirements ...)



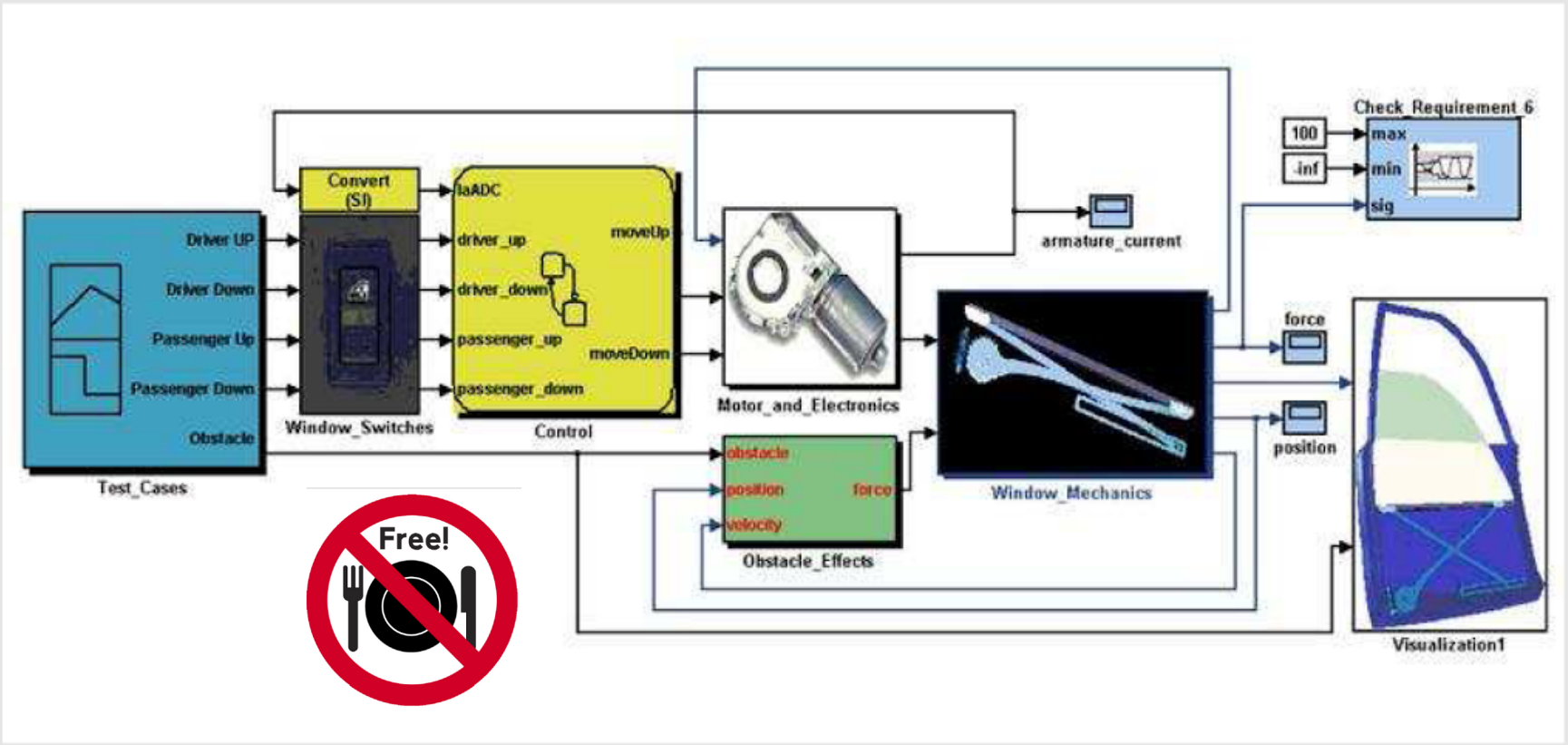
How to deal with **Complexity?**

(in engineered systems)

Most Appropriate Formalism(**s**)



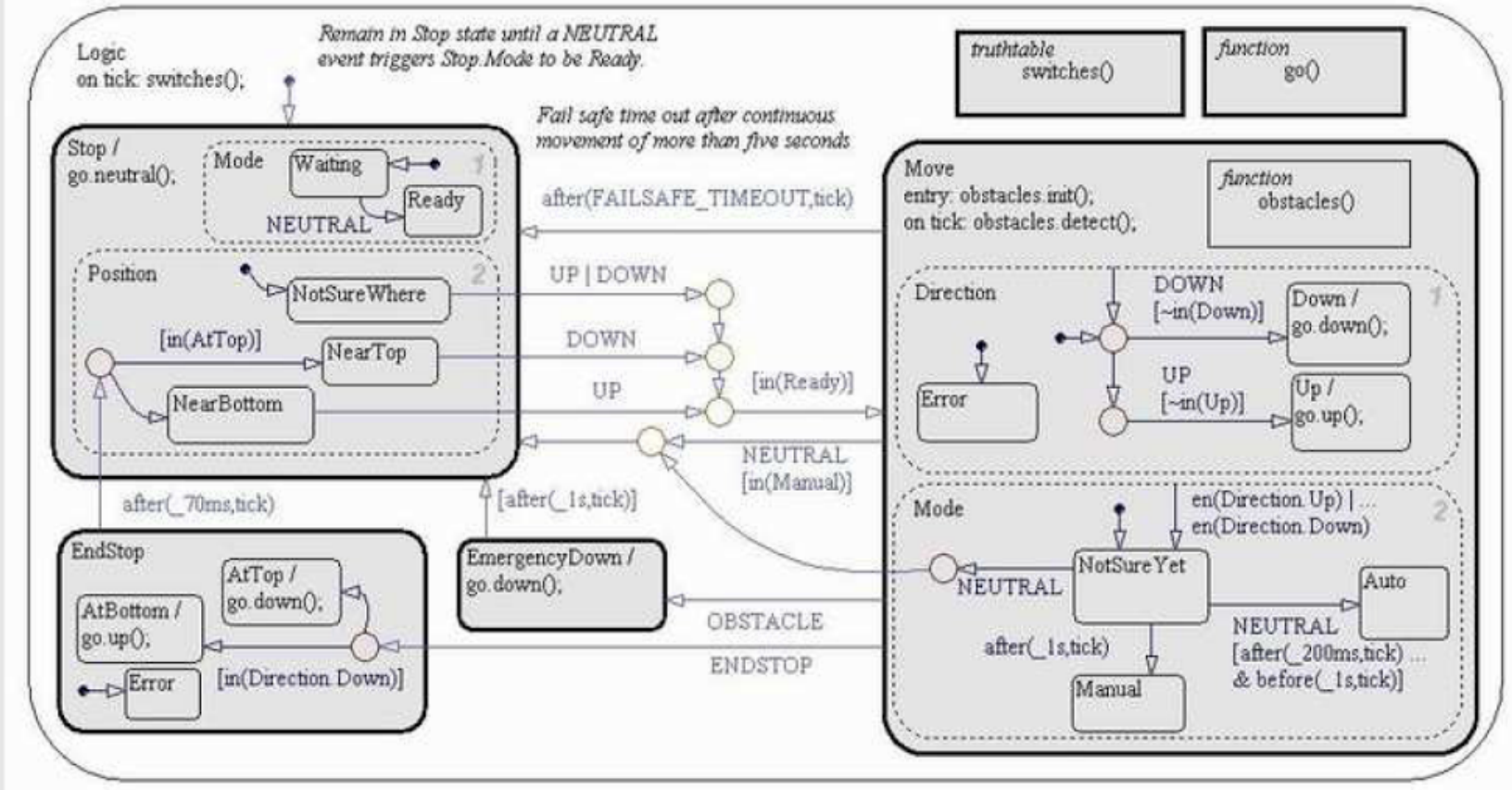
Components in Different Formalisms



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

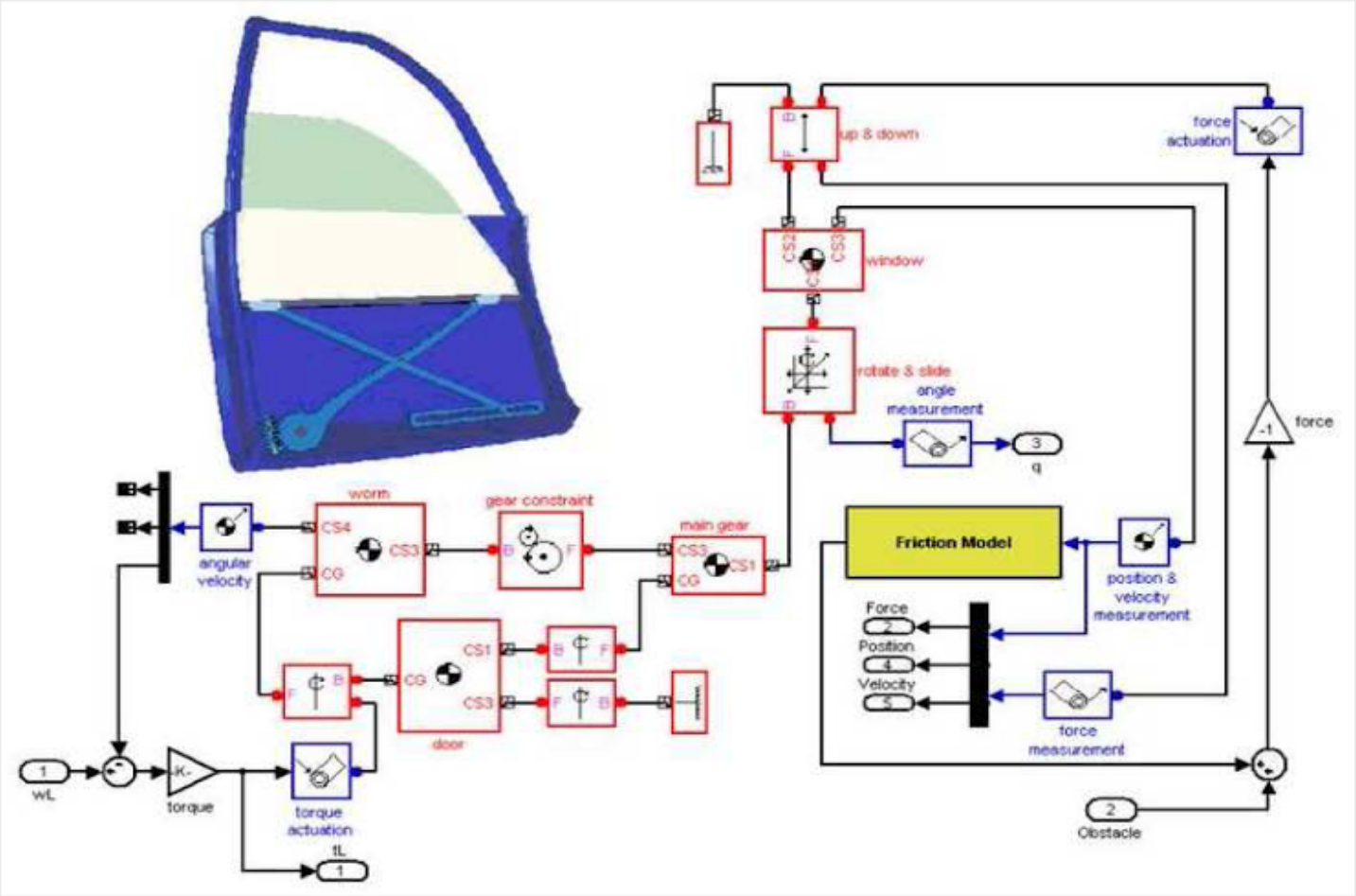
Most Appropriate Formalism(**s**)

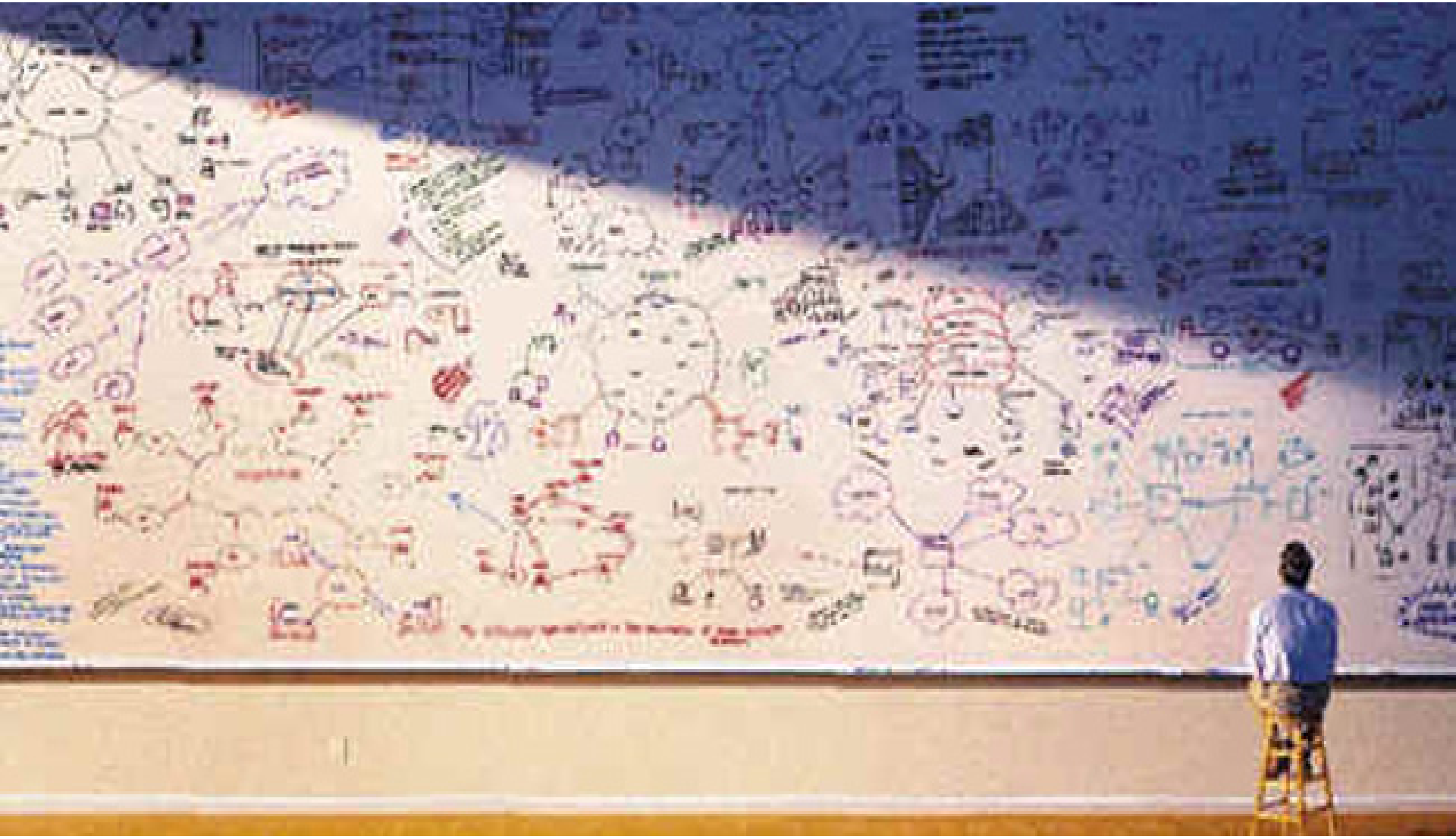
Controller, using Statechart(StateFlow) formalism



Most Appropriate Formalism(**s**)

Mechanics subsystem

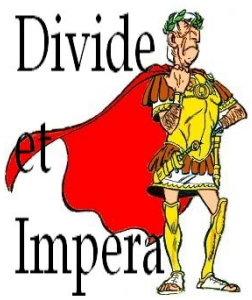


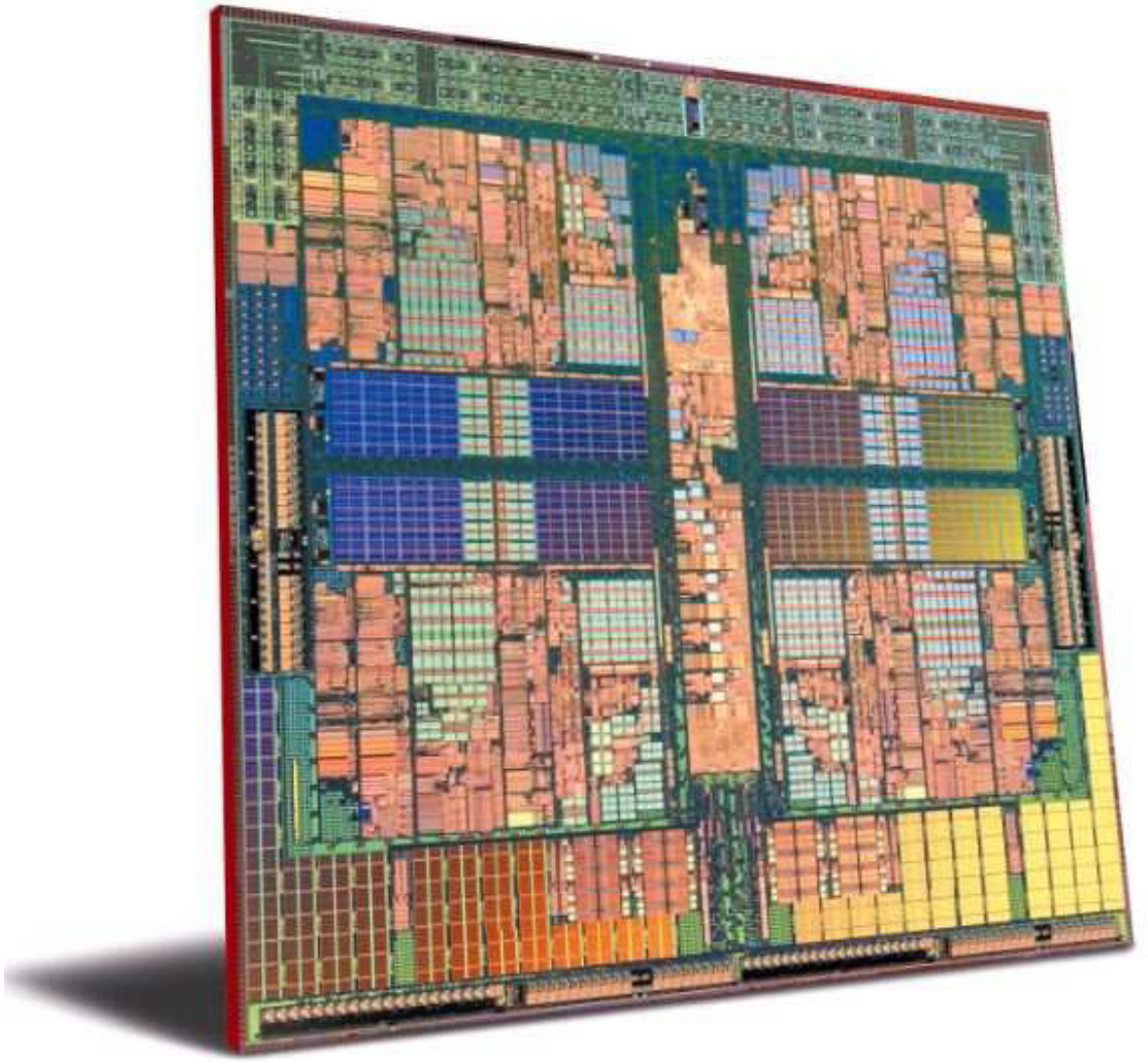


How to deal with **Complexity?**

(in engineered systems)

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





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.

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.

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

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

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

USA TODAY Home News Travel Money Sports Life Tech

Nation Inside News ▼ Car

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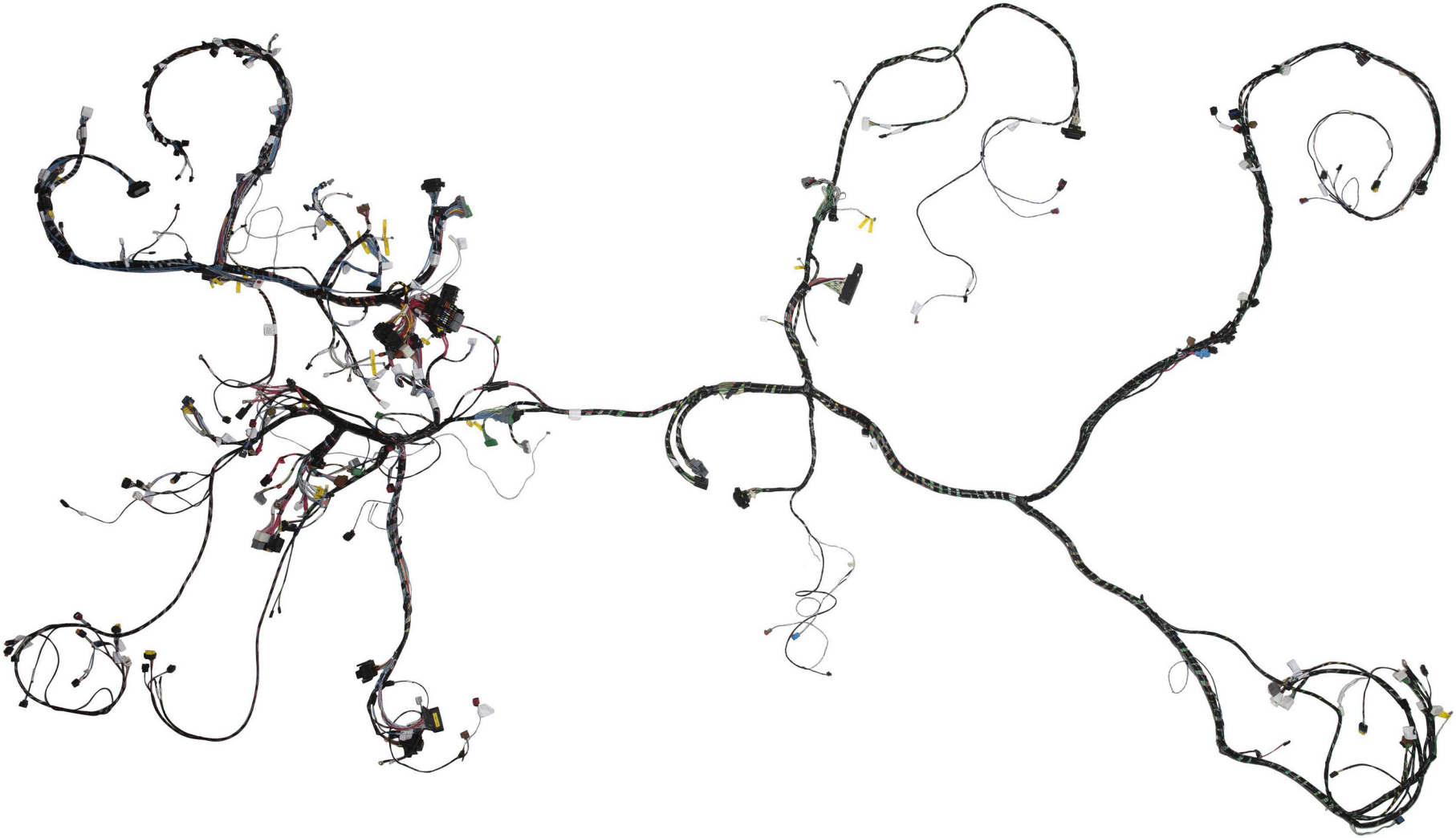
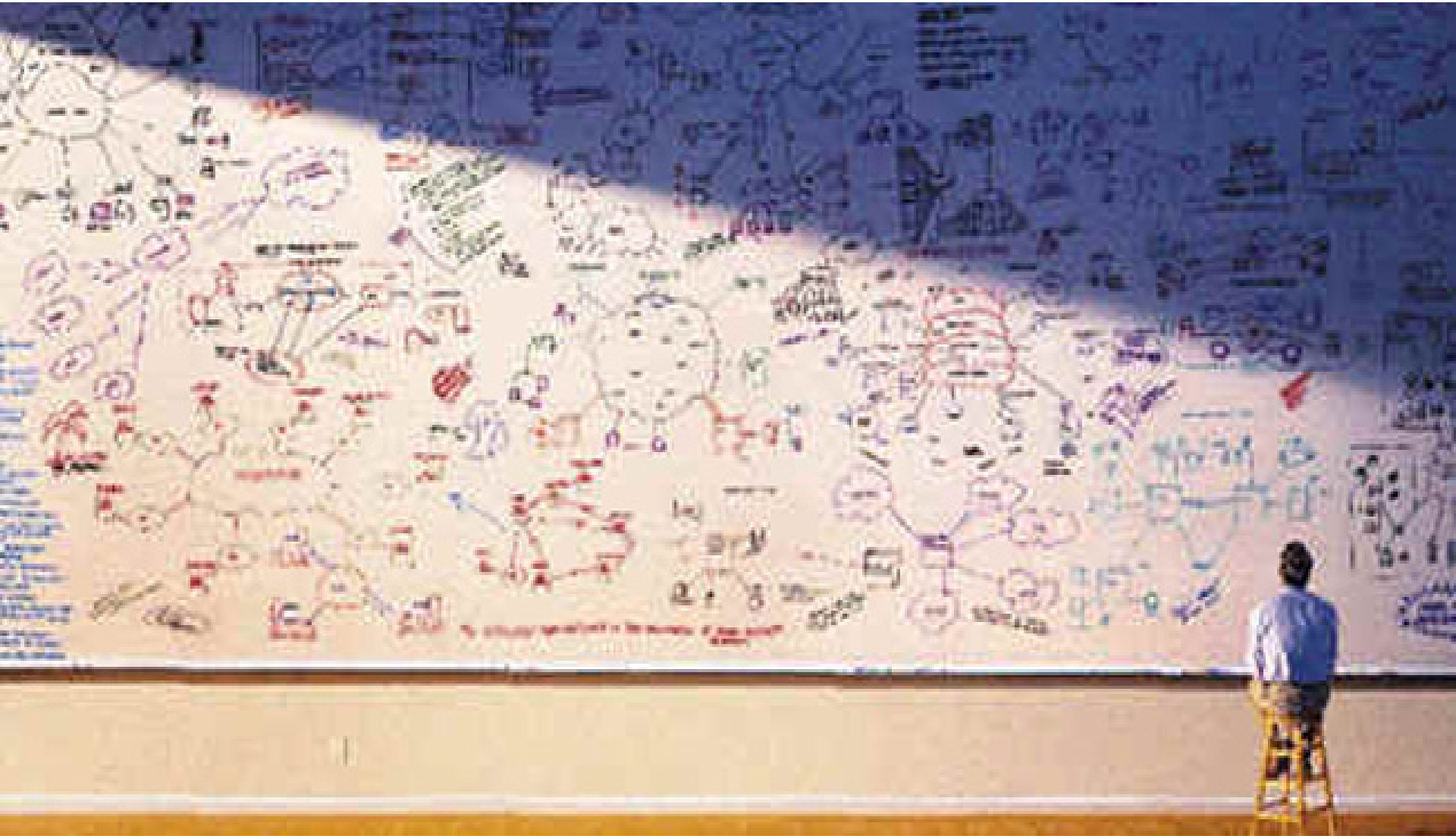



CAN

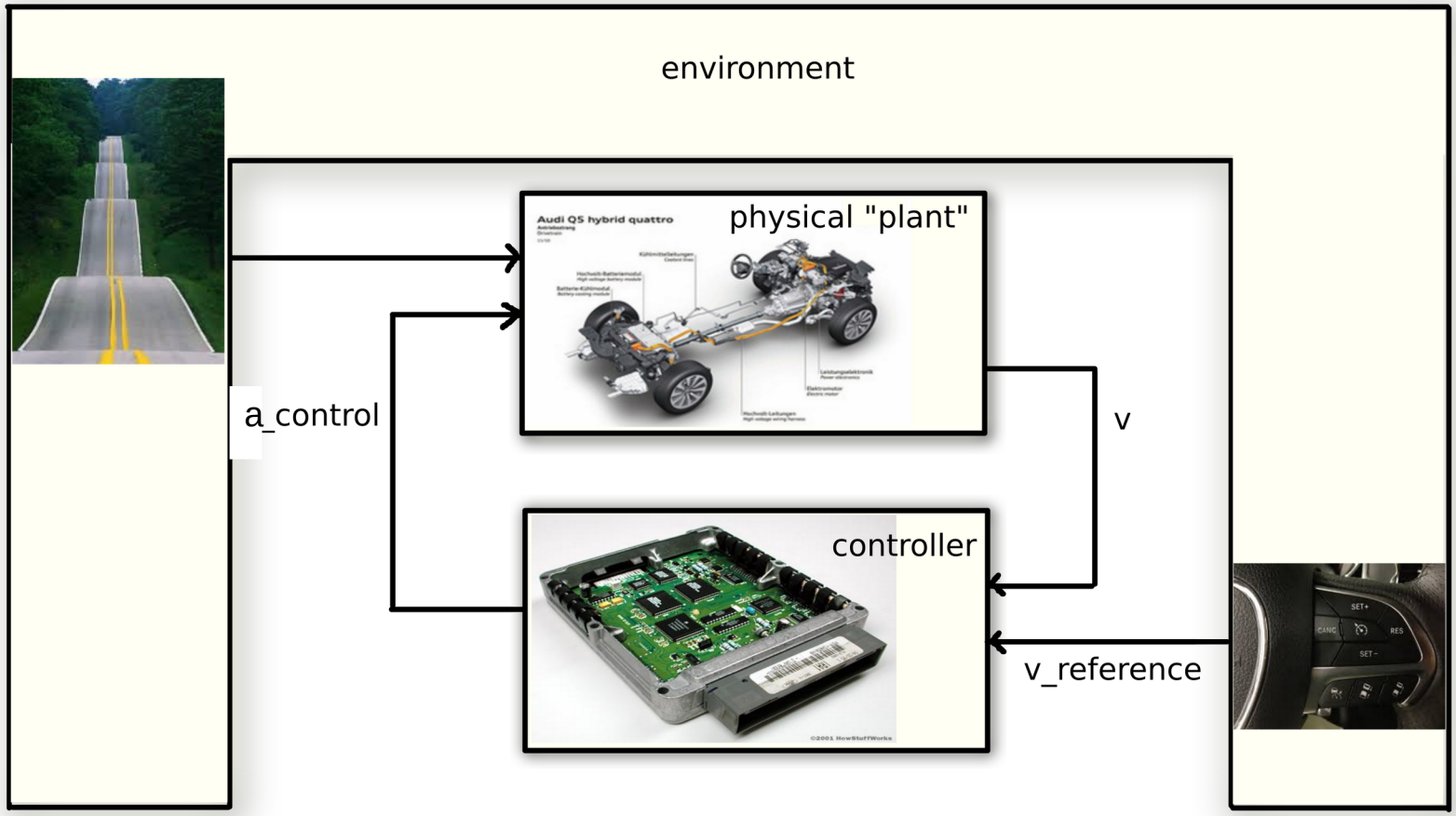
Cause of Complexity: constrained resources unanticipated interactions

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

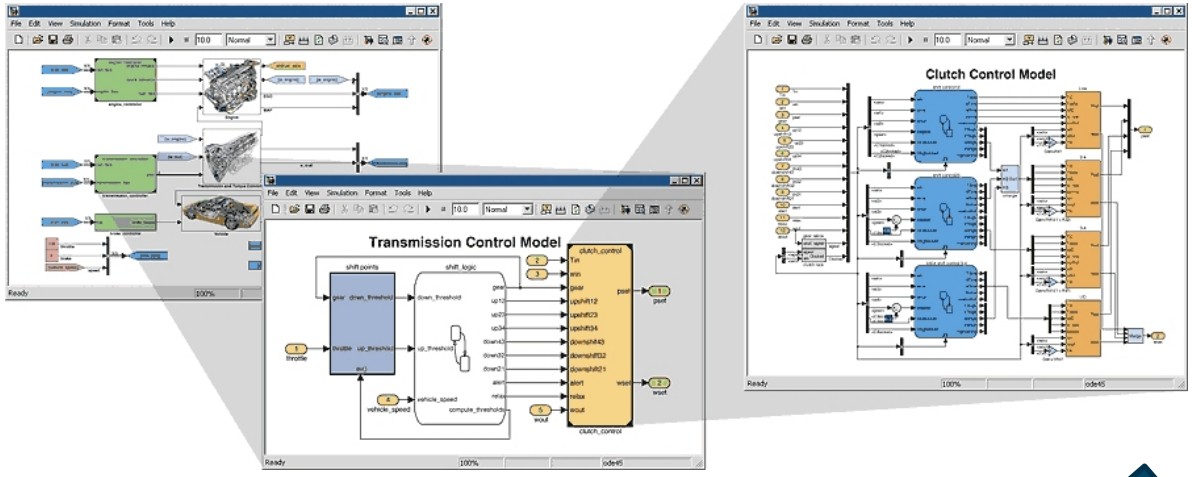


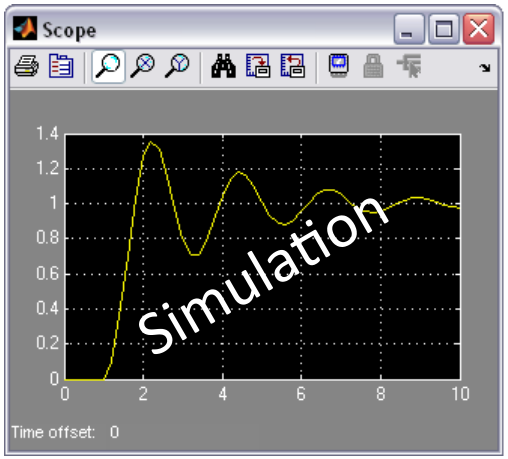
How to deal with **Complexity?**

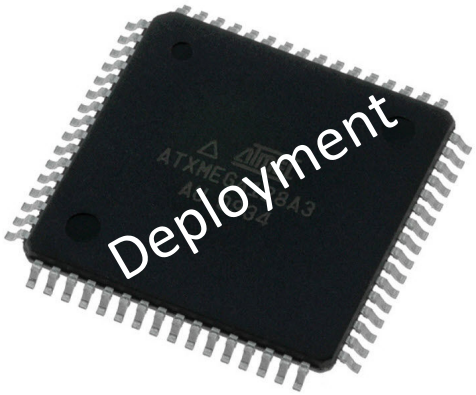
(in engineered systems)


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

Model-Based System Design



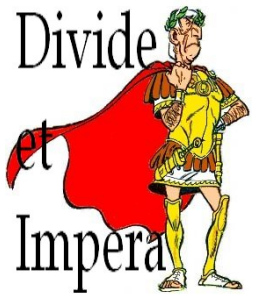




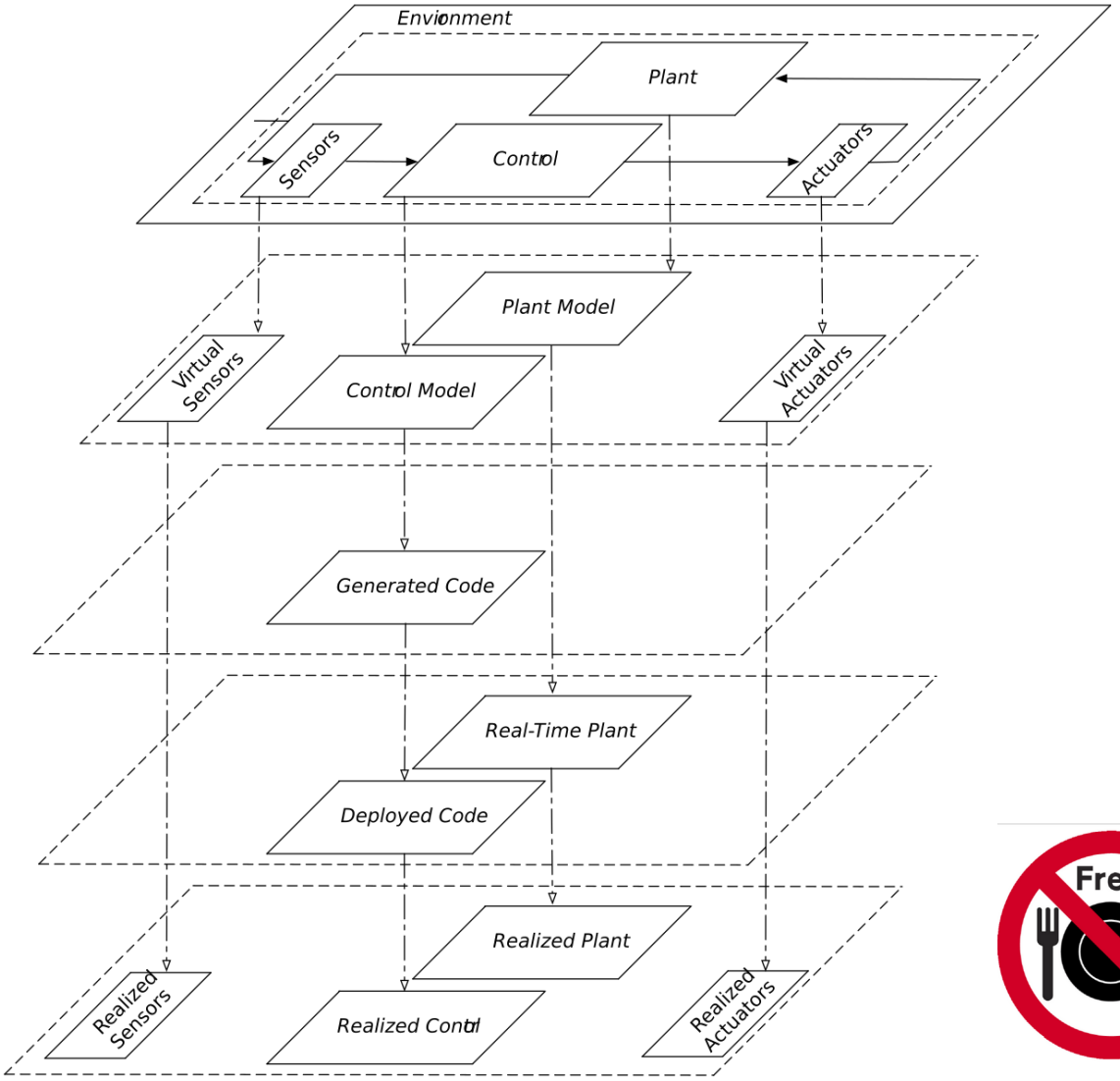
MiL, HiL, SiL, ...

XiL: X = Model, Software, Processor, Hardware

CoSys-Lab
Constrained Systems Lab
University of Antwerp



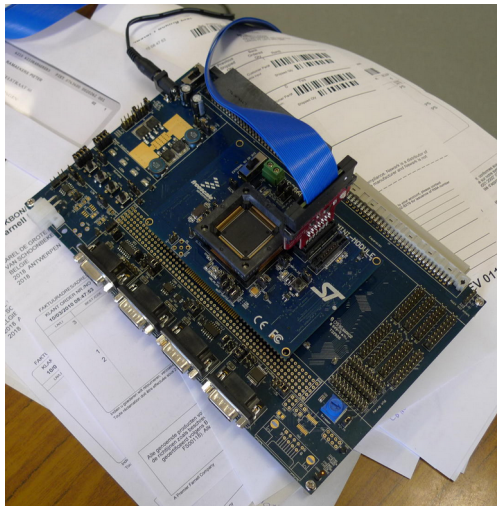
Requirements
Architectural Design
Model Design
MiL
Virtual System Design
SiL
Real-Time System Design
PiL and HiL
Real System Design
Integration Test

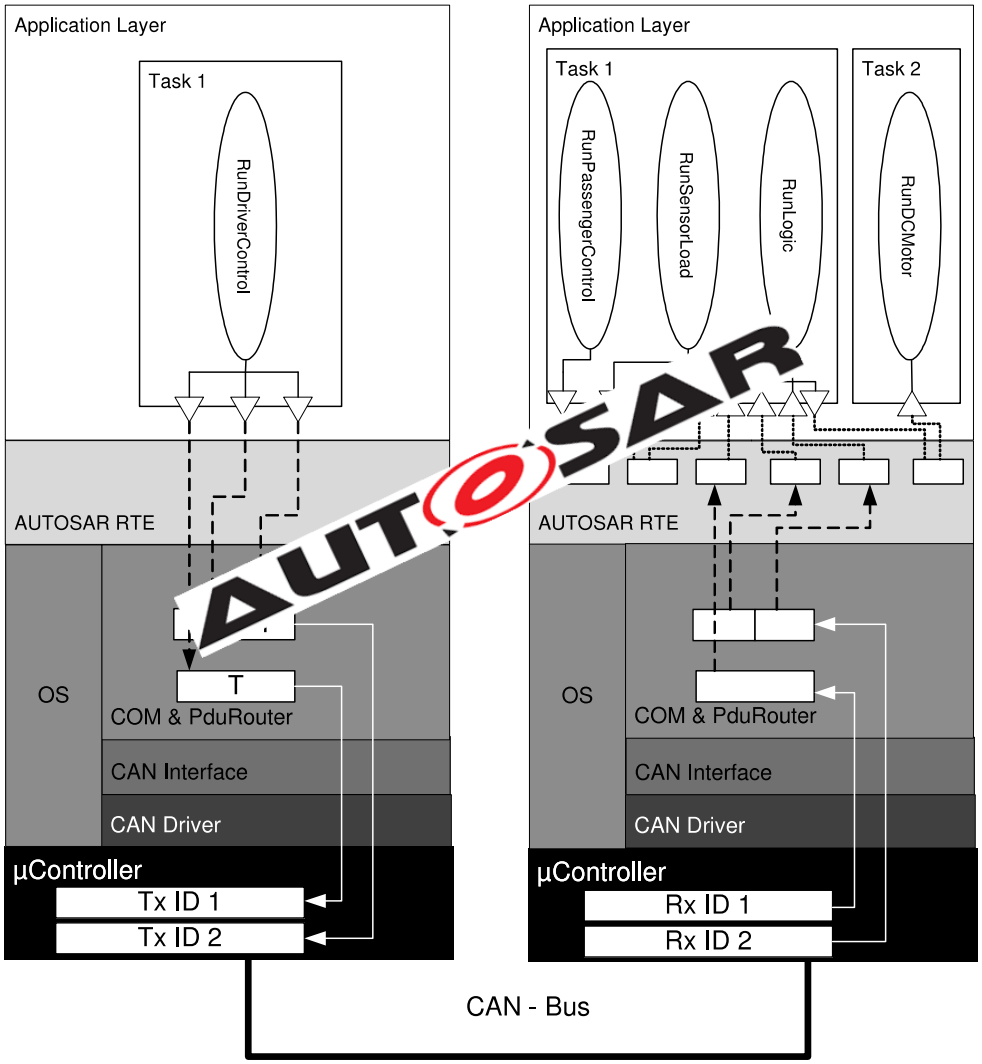


vertical consistency!

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

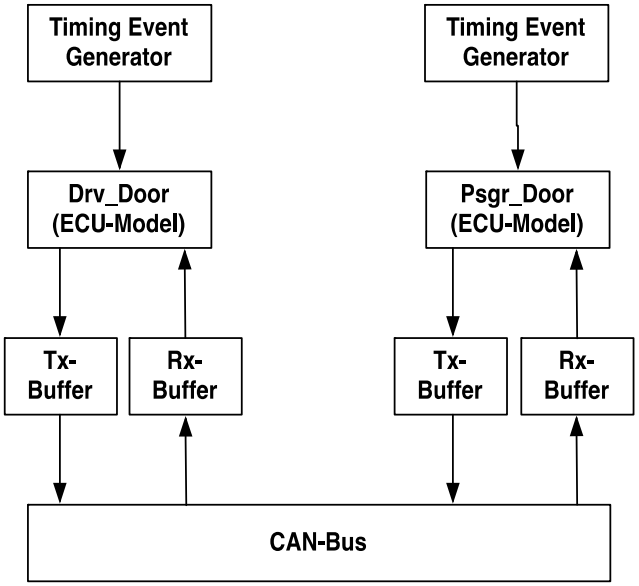
Deployment and Resource-Optimized Execution

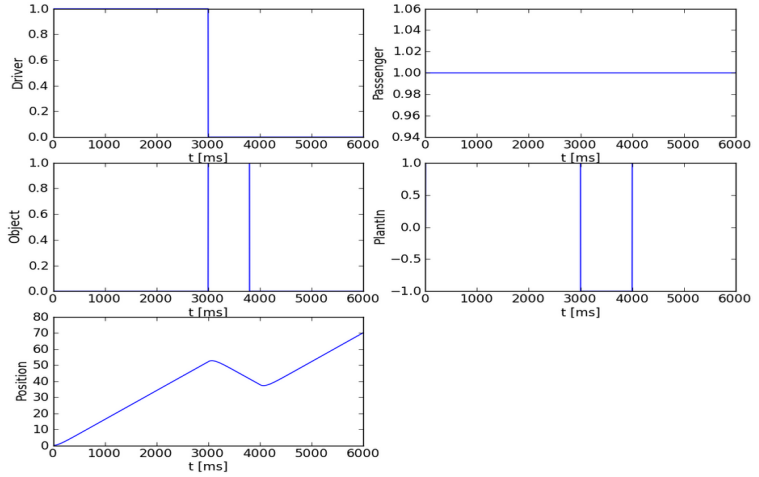


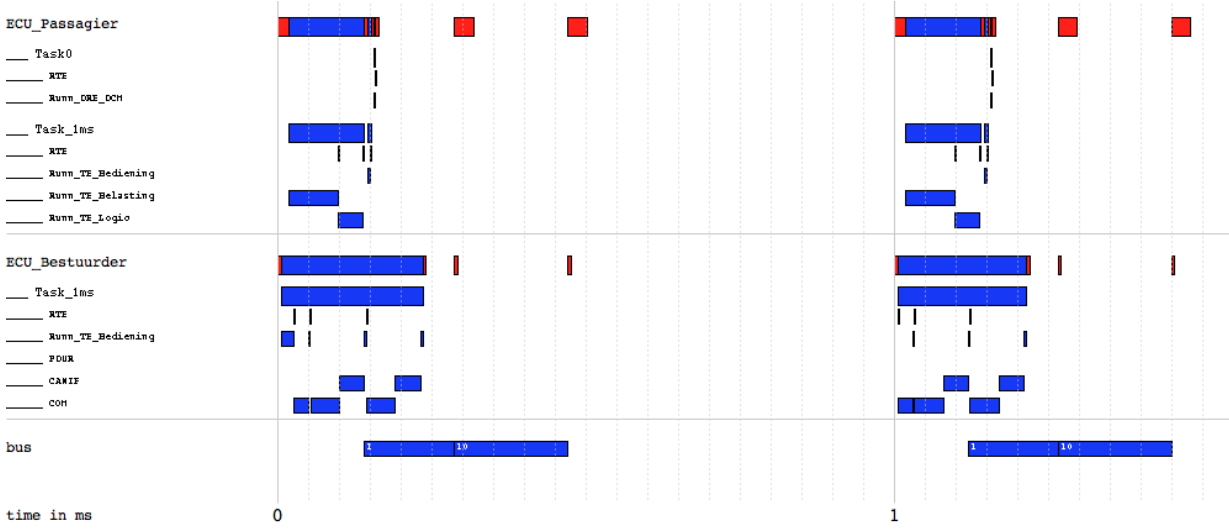


Joachim Denil, Paul De Meulenaere, Serge Demeyer, and Hans Vangheluwe. DEVS for AUTOSAR-based system deployment modeling and simulation. SIMULATION: Transactions of the Society for Modeling and Simulation International , 93(6):489 – 513, 2017.

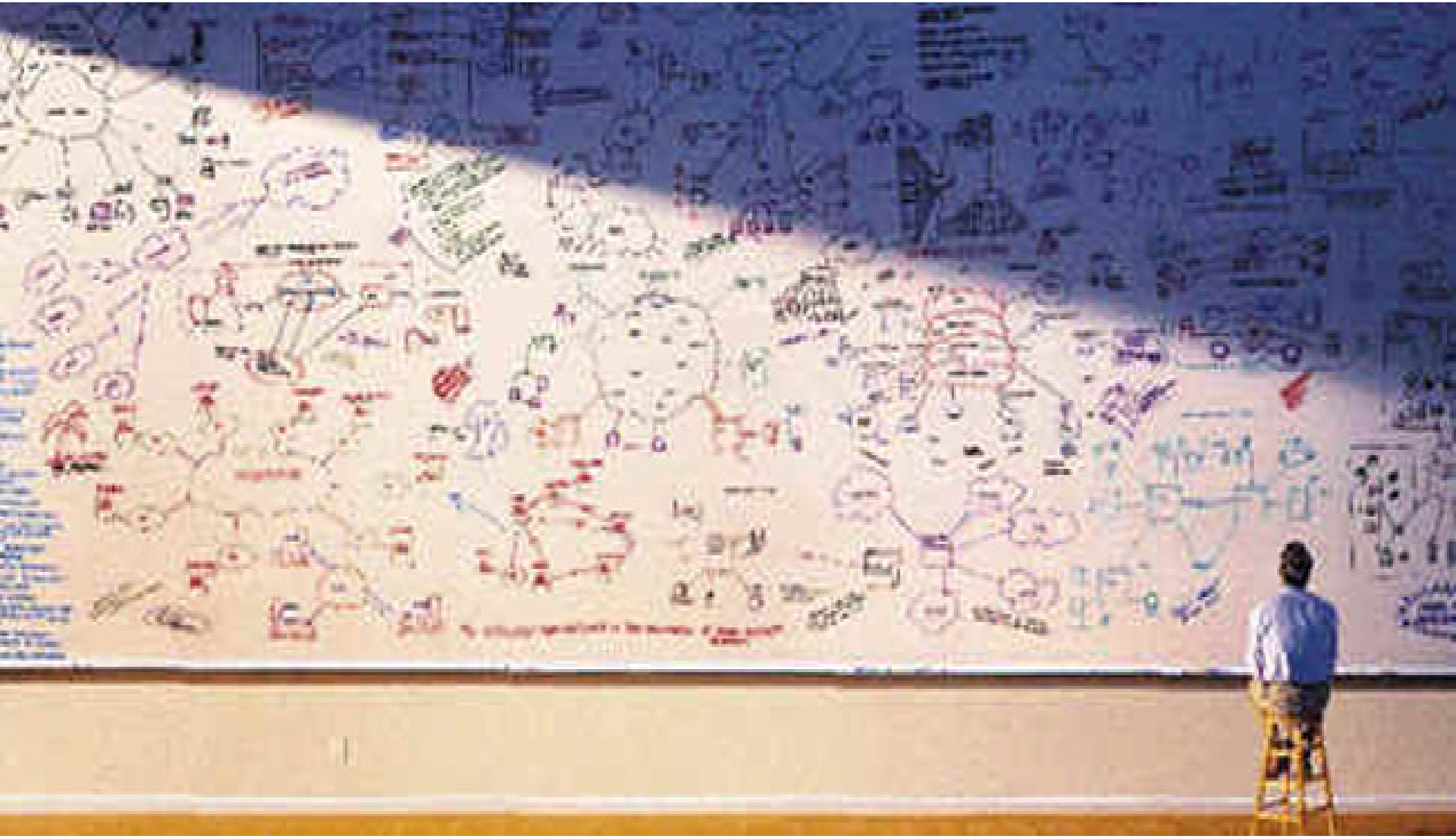
Deployment/Design-Space Exploration (trsf. To MILP, trsf. based)







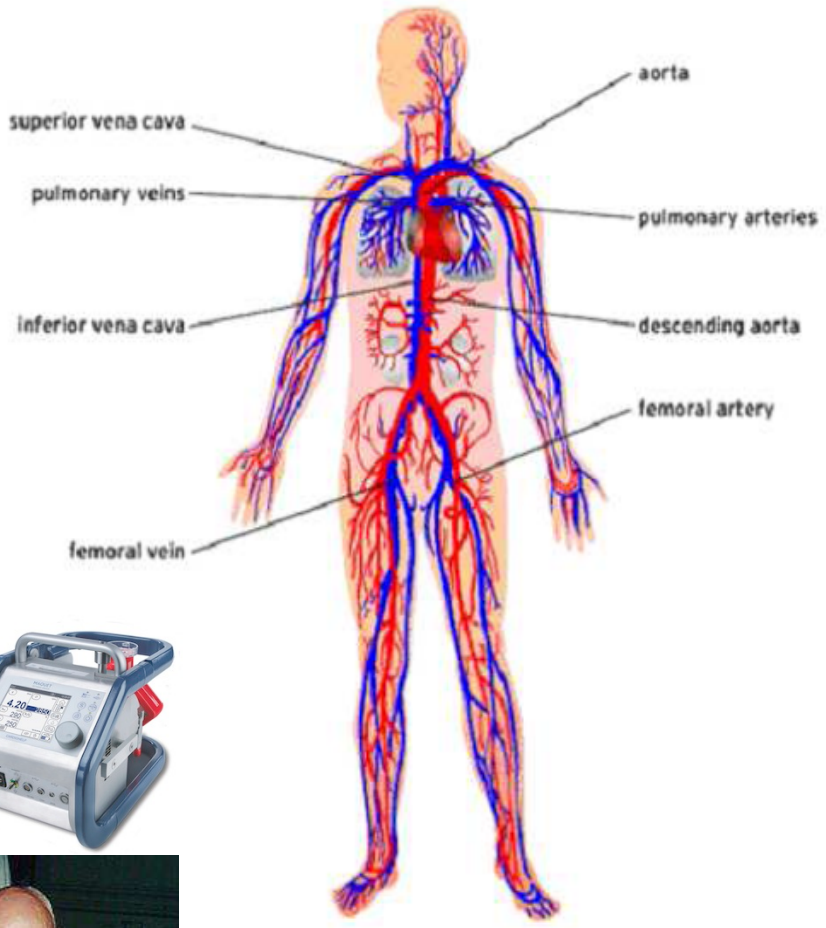
Joachim Denil, Hans Vangheluwe, Pieter Ramaekers, Paul De Meulenaere, and Serge Demeyer. DEVS for AUTOSAR platform modelling. In Spring Simulation Multiconference , pages 67 - 74. Society for Computer Simulation International (SCS), April 2011. Boston, MA, USA.

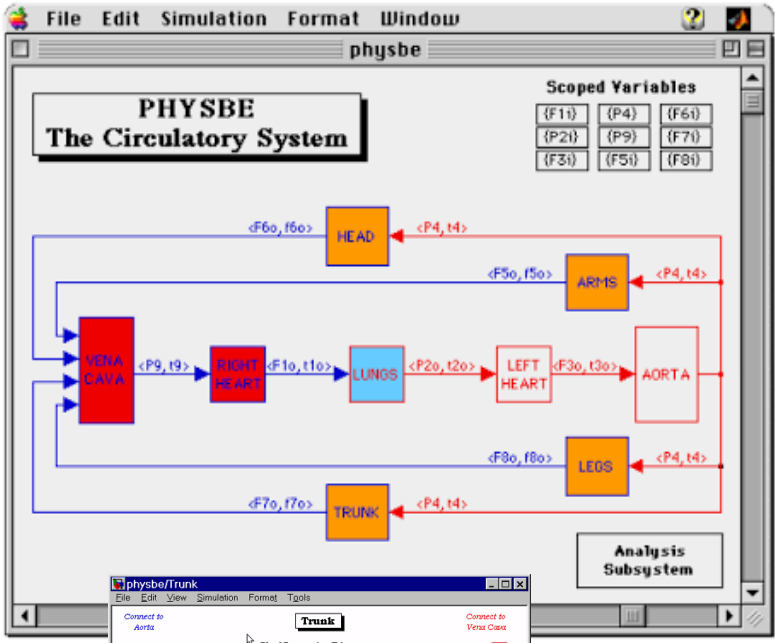


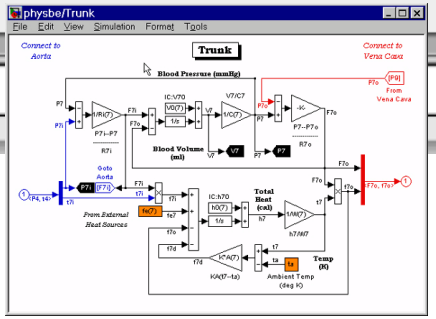
How to deal with **Complexity?**

(in engineered systems)

Different Abstraction Levels – properties preserved







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

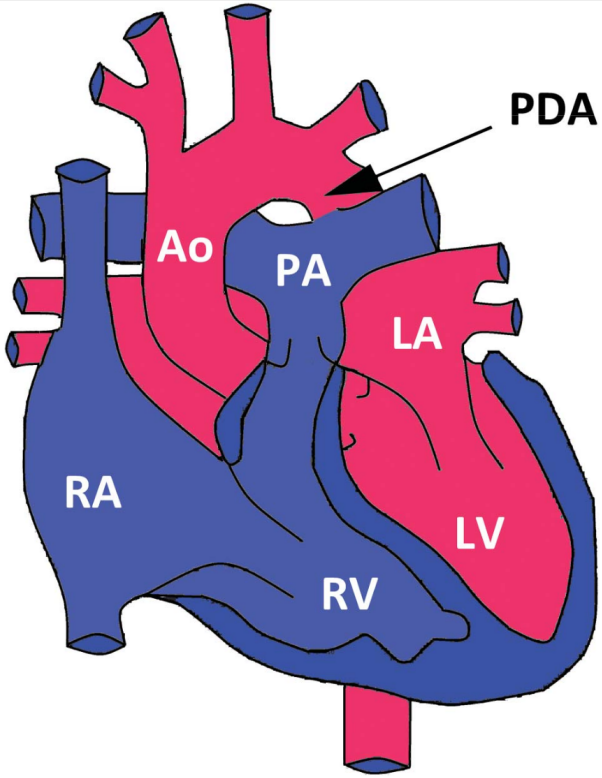
Mathematical and Computer Modelling of Dynamical Systems, 2013
Vol. 19, No. 3, 238–249, http://dx.doi.org/10.1080/13873954.2012.727187

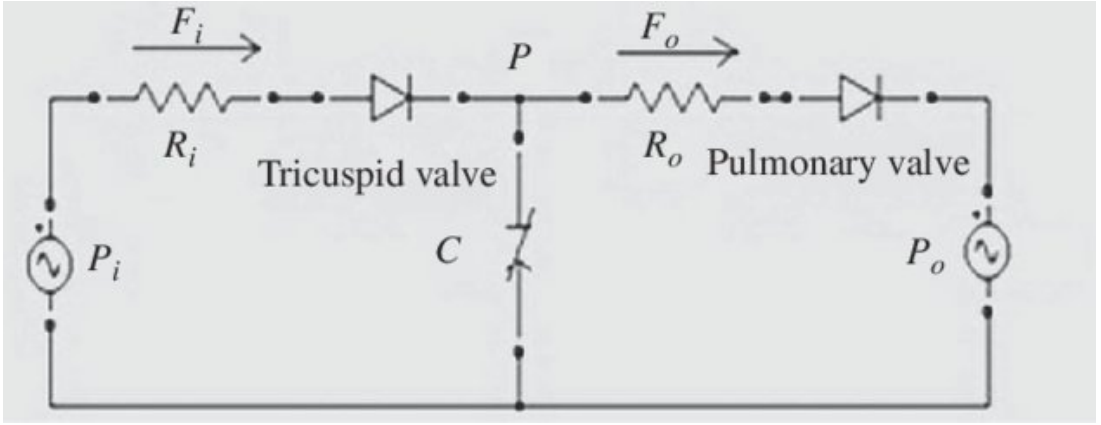
Taylor & Francis
Taylor & Francis Group

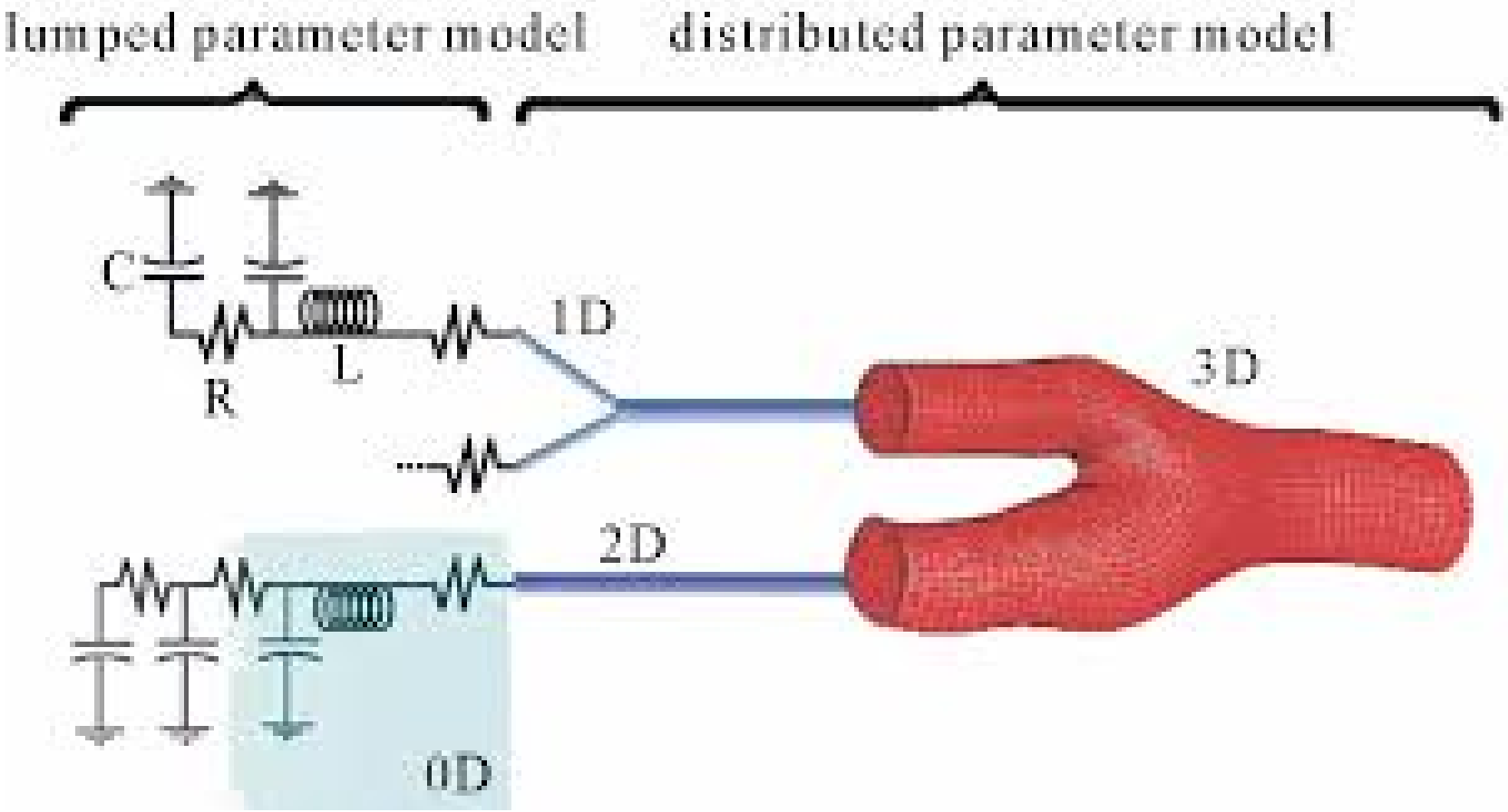
Mathematical modelling of the patent ductus arteriosus (PDA)

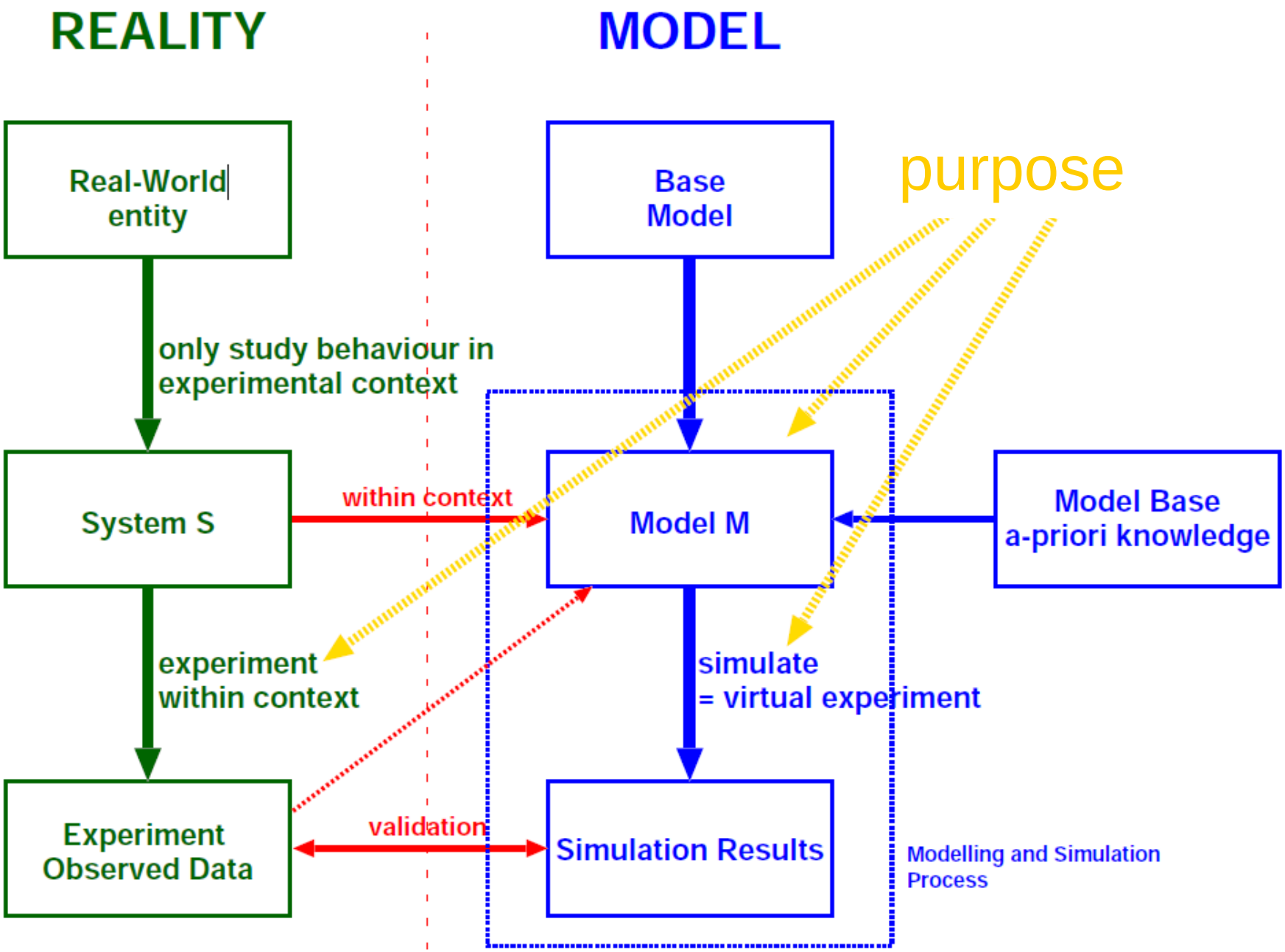
Mohamad Amin Bakhshali, Mahsa Mafi and Sabalan Daneshvar*

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






lumped parameter model
distributed parameter model
C
R
L
1D
3D
2D
0D



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.

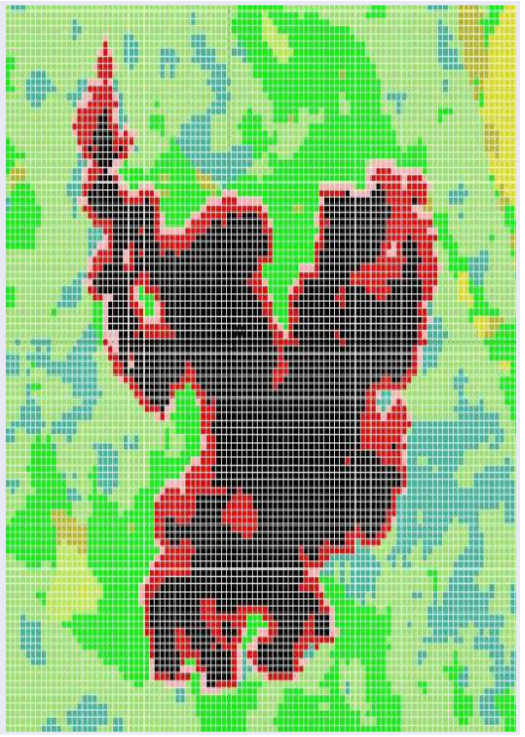
- If M_1 is an *abstraction* of M_2 with respect to P, for all $p \in P$: $M_1 \models p \Rightarrow M_2 \models p$. This is written $M_1 \sqsupseteq_P M_2$.
- M_1 is said to be a *refinement* of M_2 iff M_2 is an *abstraction* of M_1. This is written $M_1 \sqsubseteq_P M_2$.

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**)



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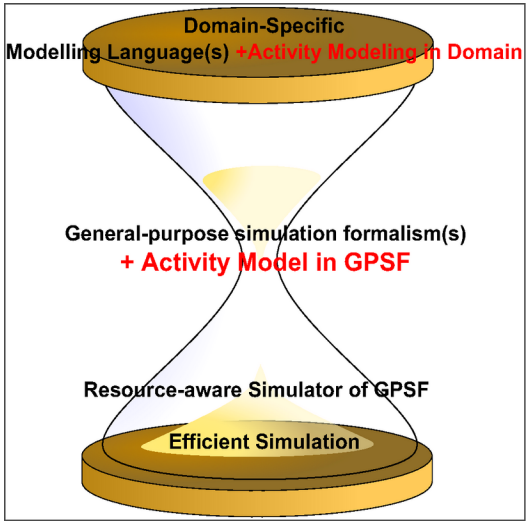
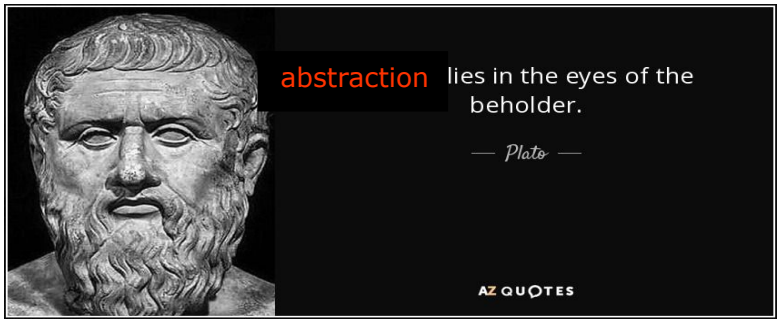


Alexandre Muzy, David R. C. Hill. What is new with the activity world view in modeling and simulation?: using activity as a unifying guide for modeling and simulation. Winter Simulation Conference 2011: 2887-2899.

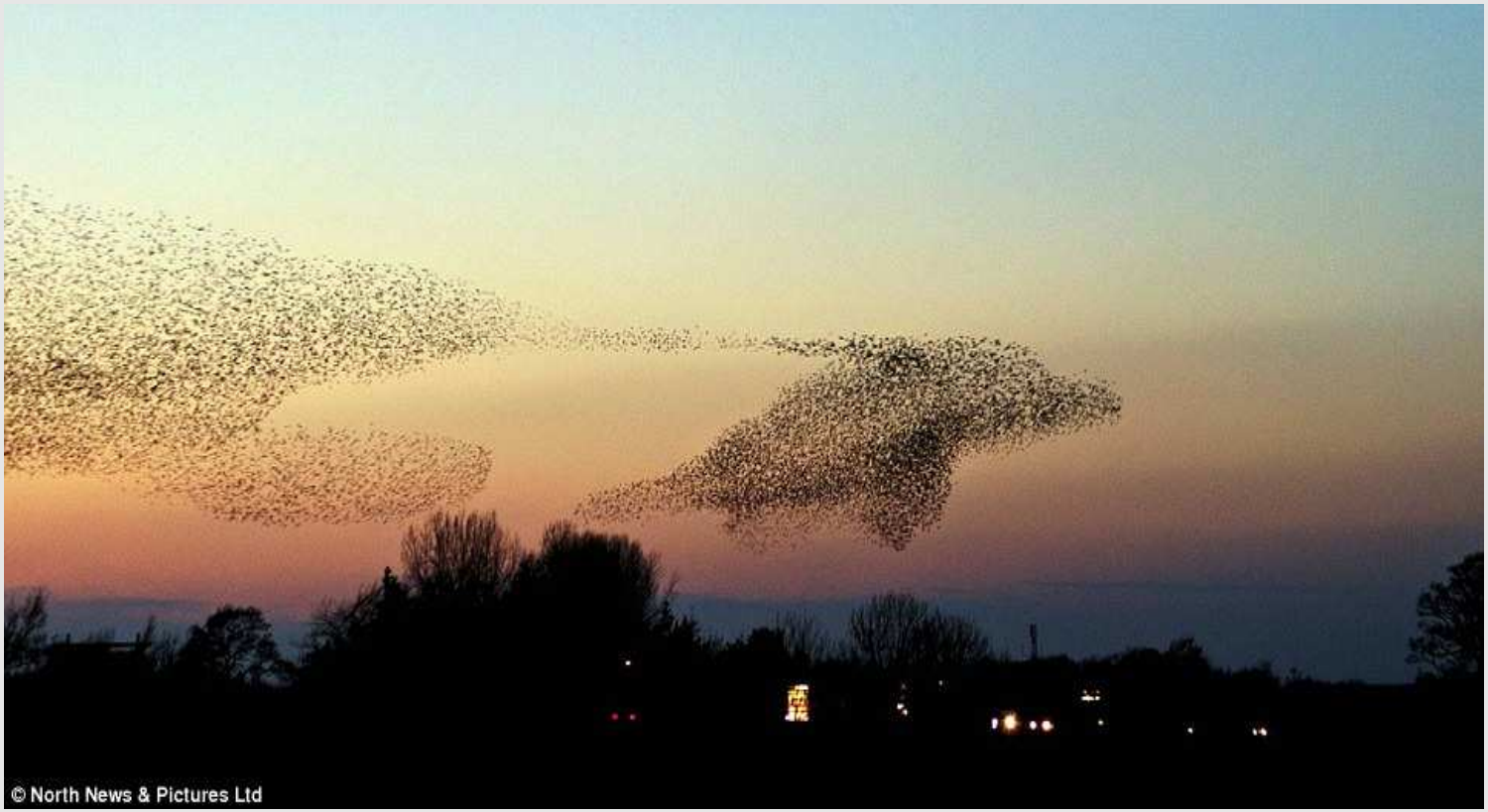
Bin Chen, Lao bing Zhang, Xiaocheng Liu, and Hans Vangheluwe. Activity-based simulation using DEVS: increasing performance by an activity model in parallel DEVS simulation. Journal of Zhejiang University - Science C, 15(1):13 – 30, 2014.



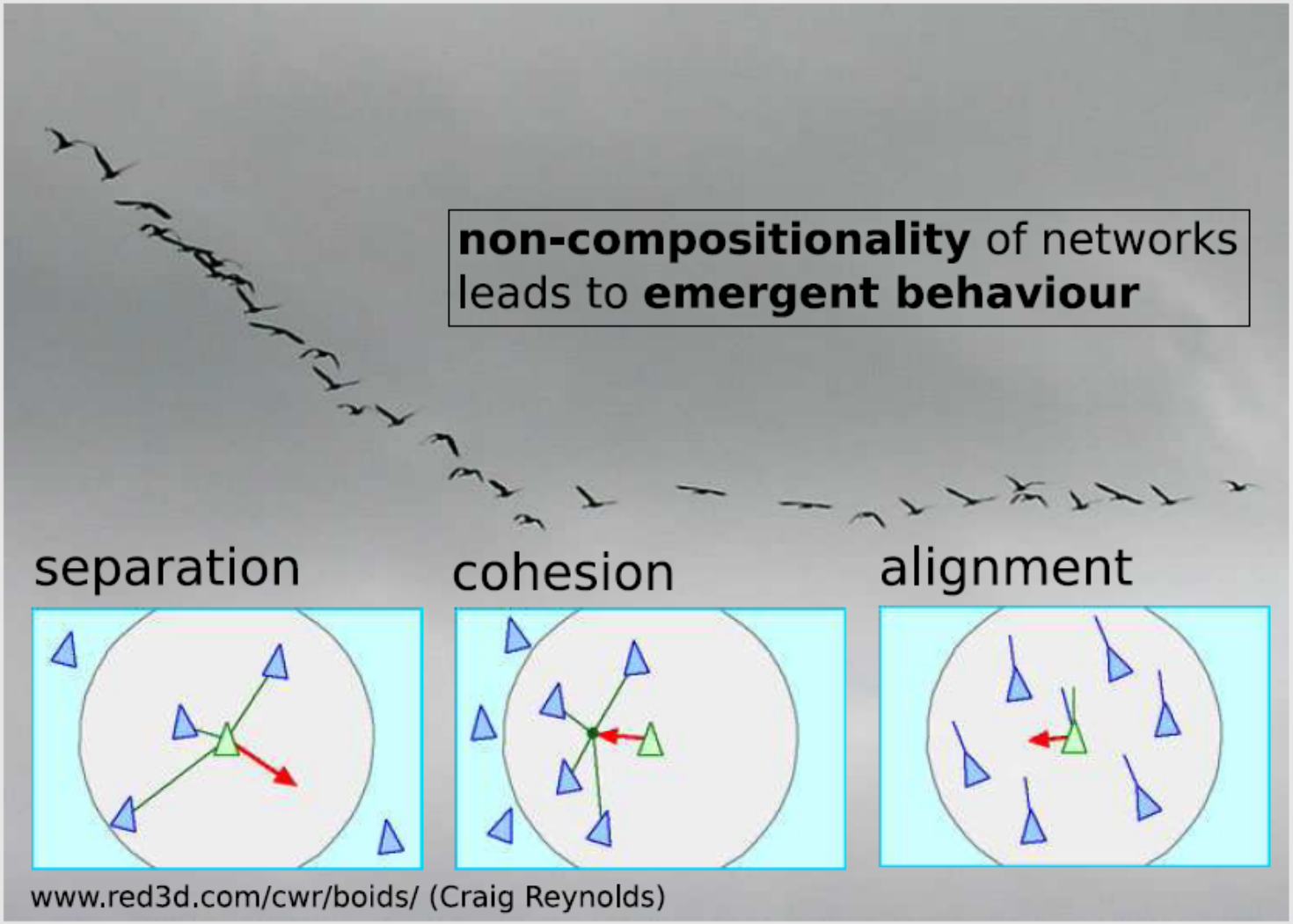
and depends

on the **properties** of interest!

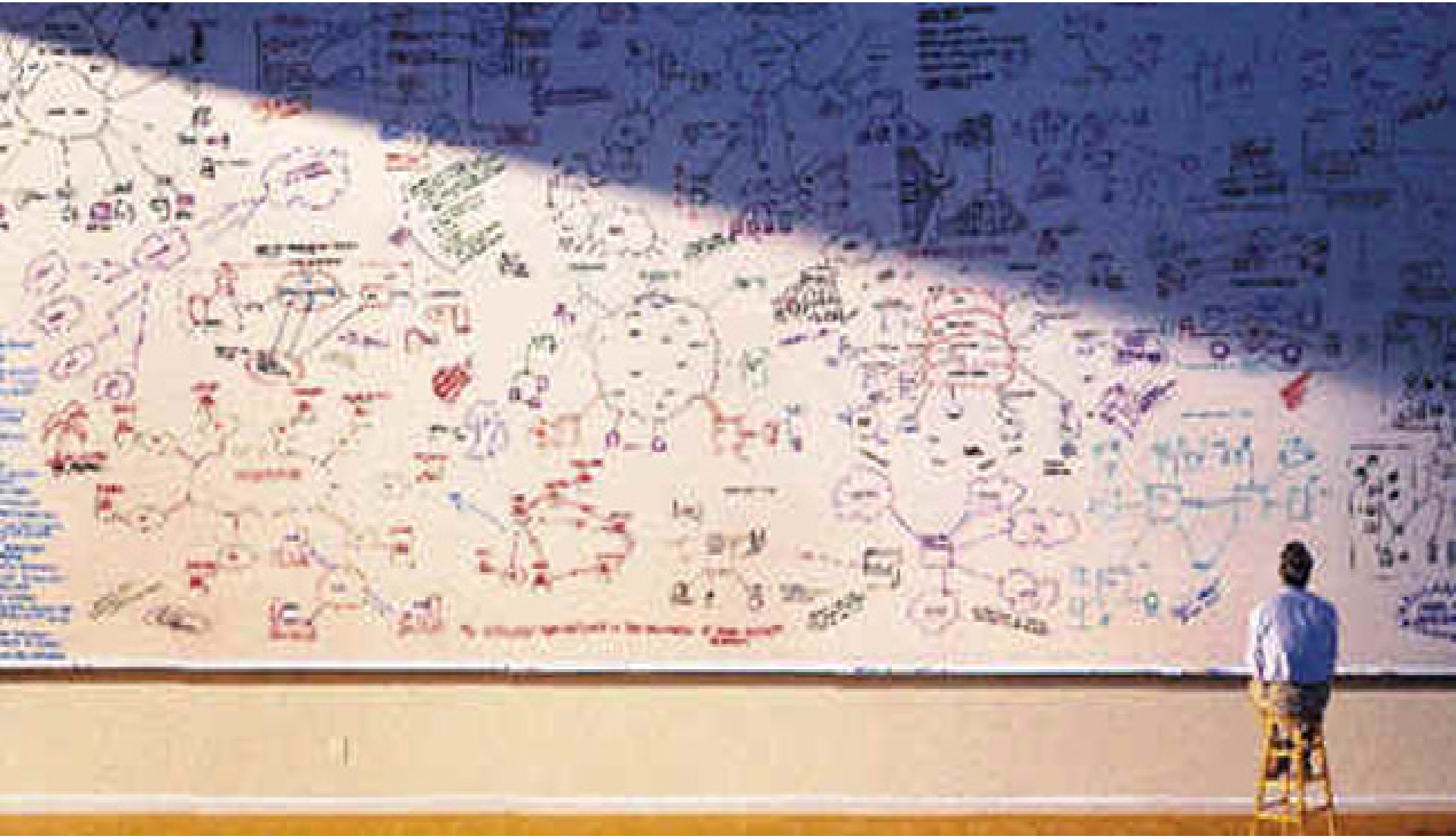
Emergent Behaviour



Non-compositional/Emergent Behaviour



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

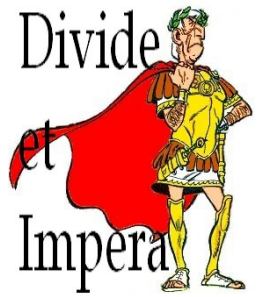


How to deal with **Complexity?**

(in engineered systems)

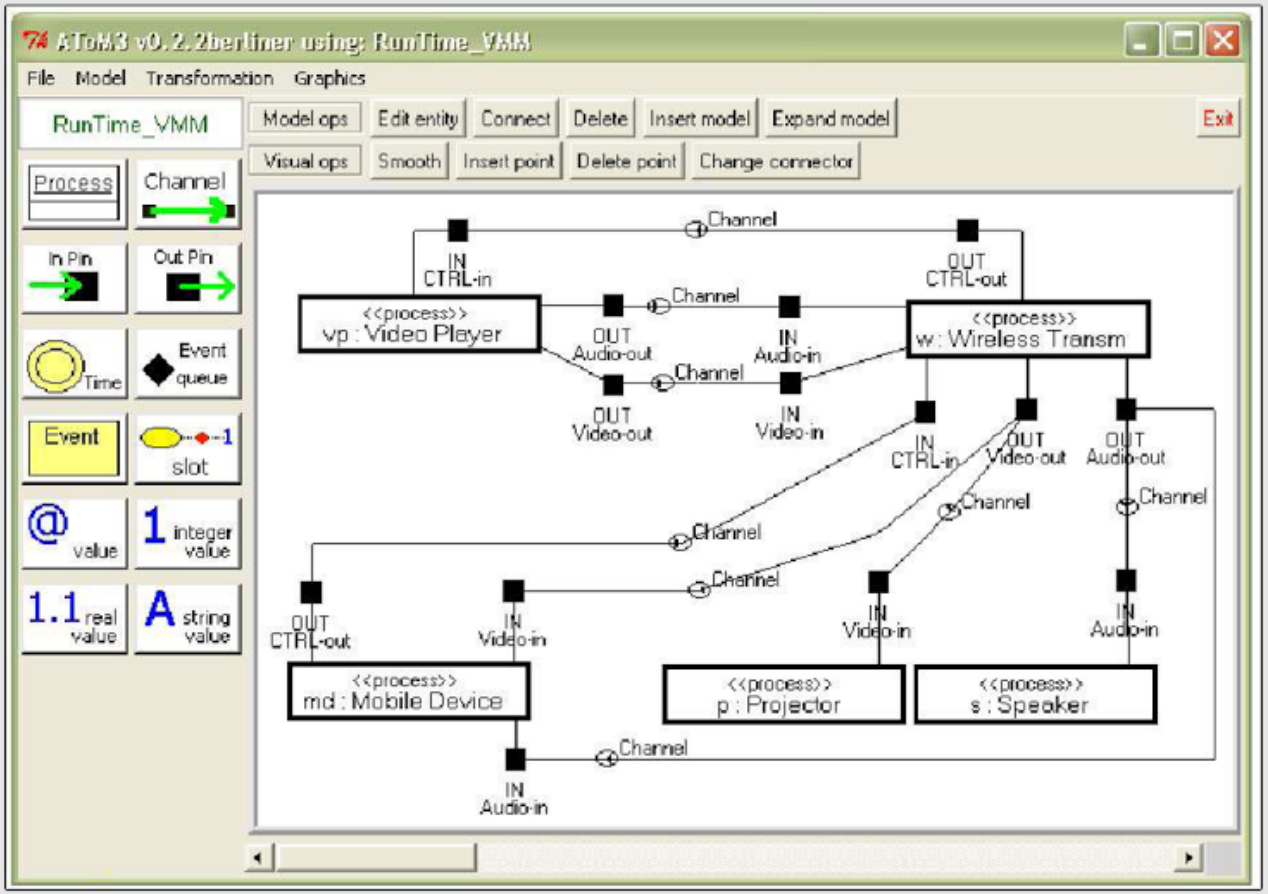
(hierarchical) decomposition, multiple formalisms, multiple abstractions, … and

multiple viewpoints

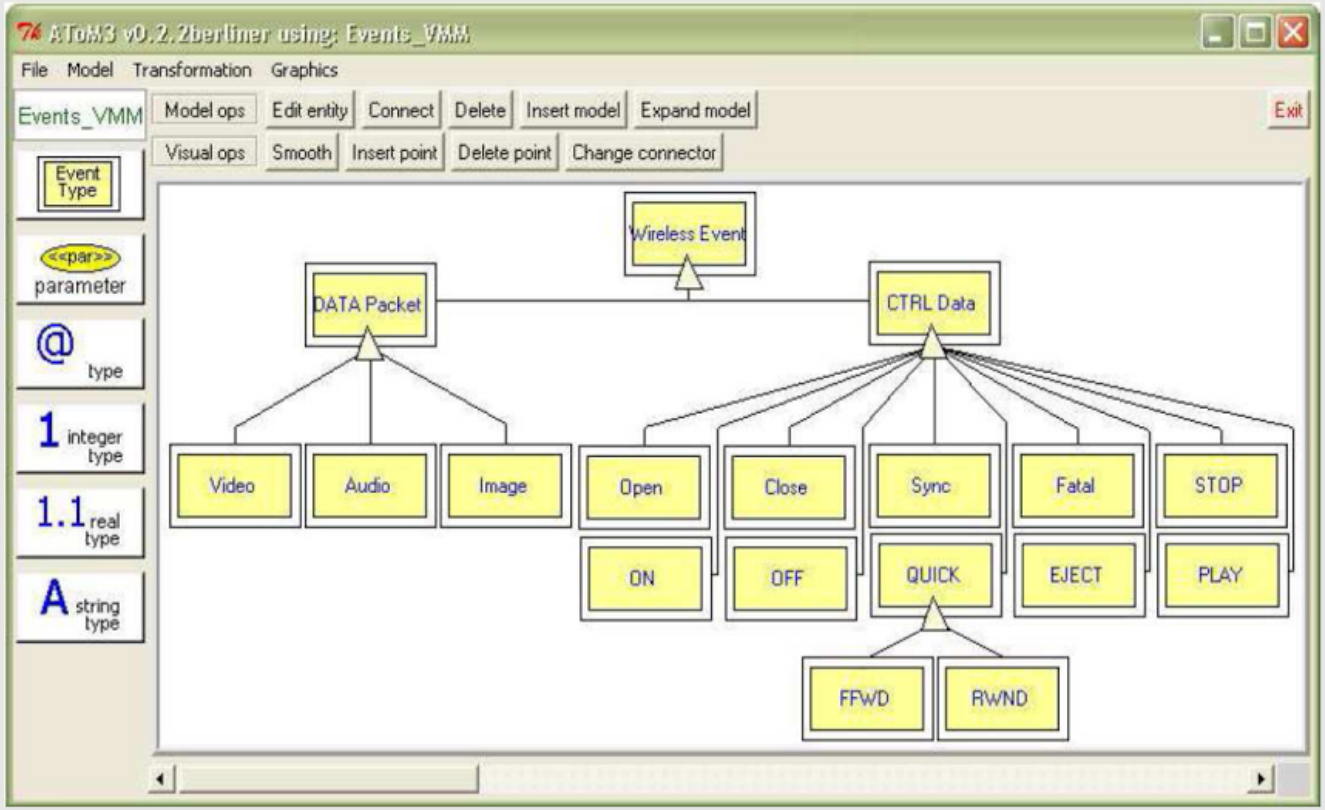


Wireless Home Entertainment System

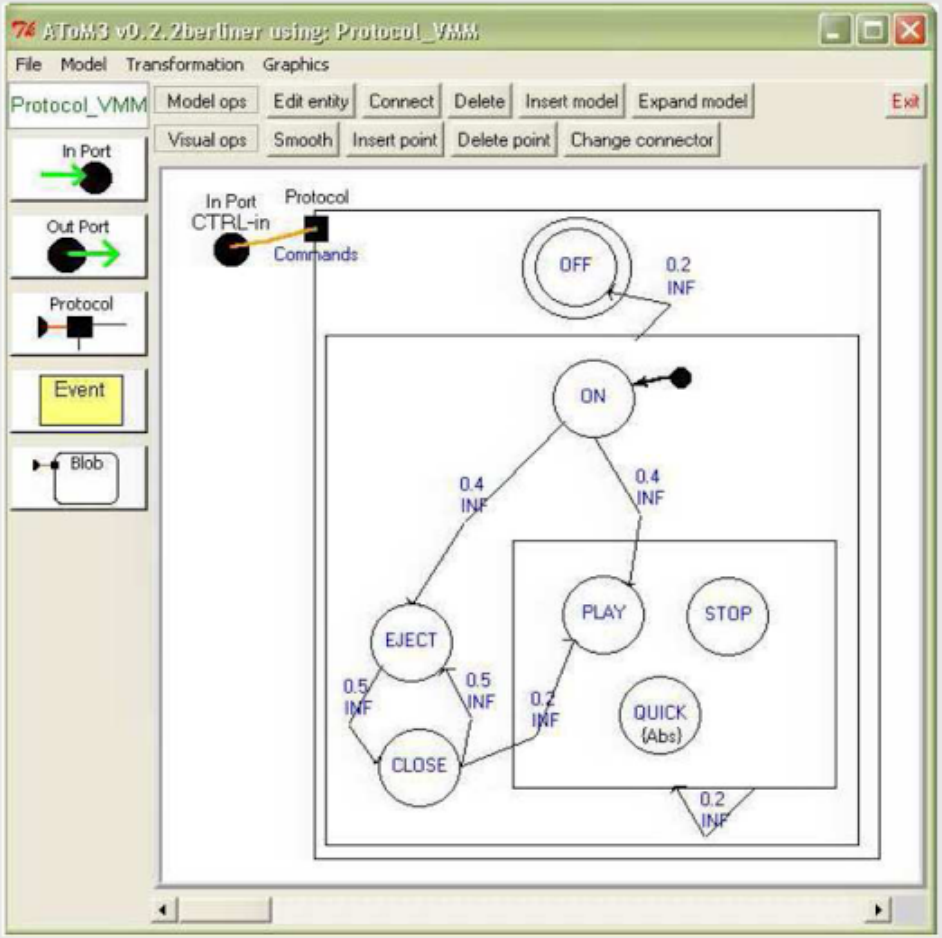
Multiple (consistent !) Views (in $\neq$ Formalisms)

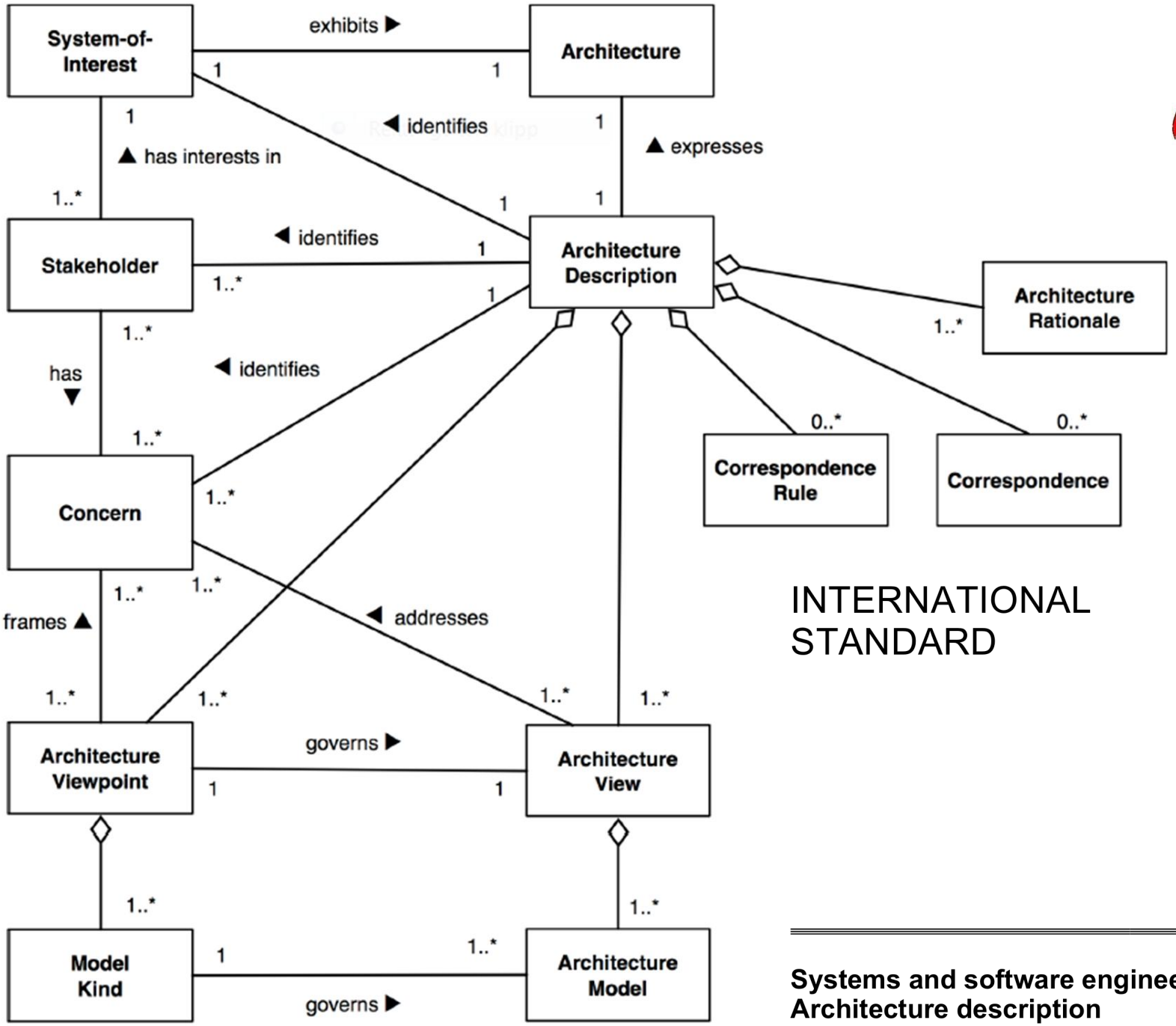


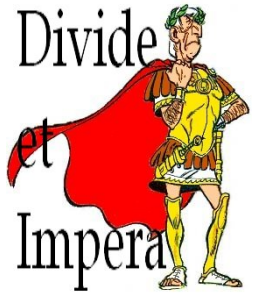
View: Events Diagram



View: Protocol Statechart







INTERNATIONAL STANDARD

ISO/IEC/ IEEE 42010

First edition
2011-12-01

Systems and software engineering — Architecture description

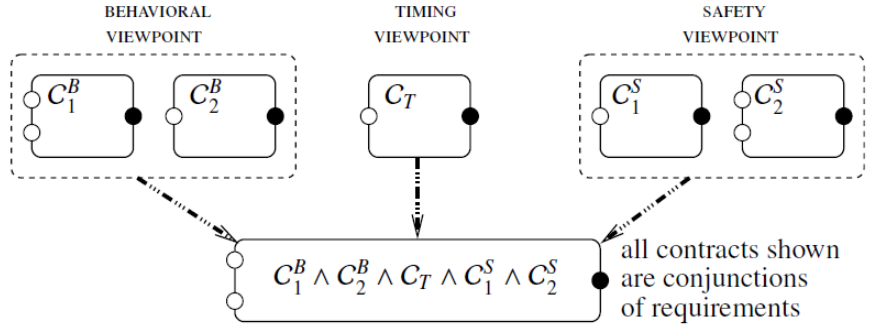
Contracts for Systems Design: Theory

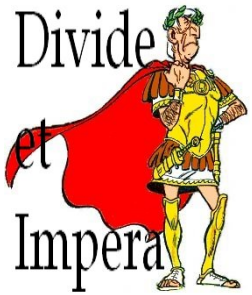
Albert Benveniste , Benoît Caillaud, Dejan Nickovic
Roberto Passerone, Jean-Baptiste Raclet
Philipp Reinkemeier, Alberto Sangiovanni-Vincentelli
Werner Damm, Tom Henzinger, Kim G. Larsen

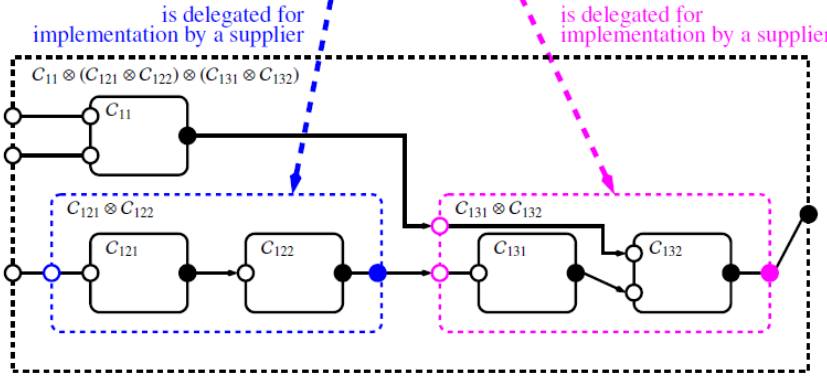
RESEARCH REPORT
N° 8759
July 2015
Project-Teams Hycomes

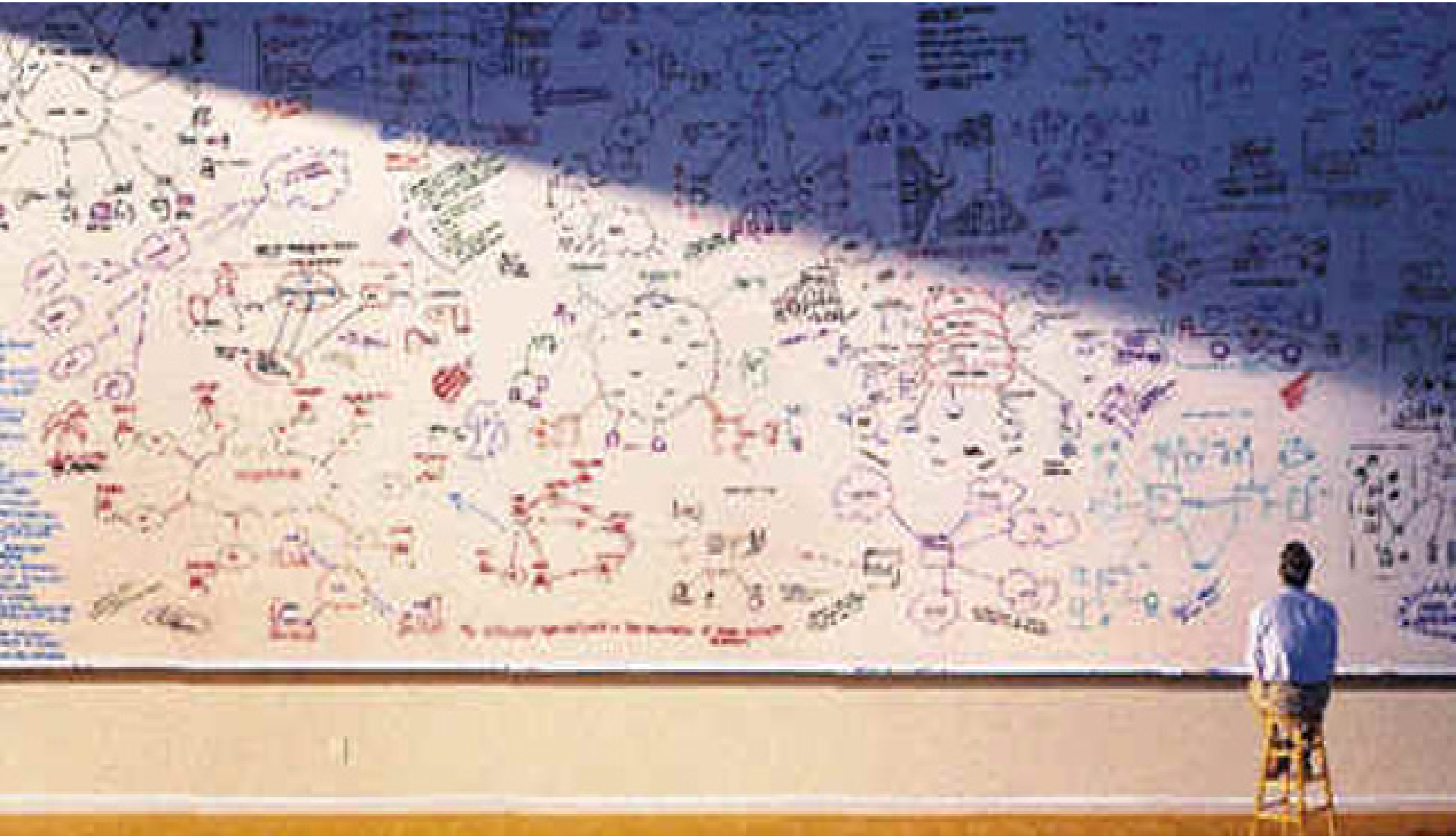
ISSN 0249-6399 ISRN INRIA/RR--8759--FR+ENG

guarantees offered by the component
assumptions on its possible context









How to deal with **Complexity?**

(in engineered systems)

Recursive workflow: from Properties to Design