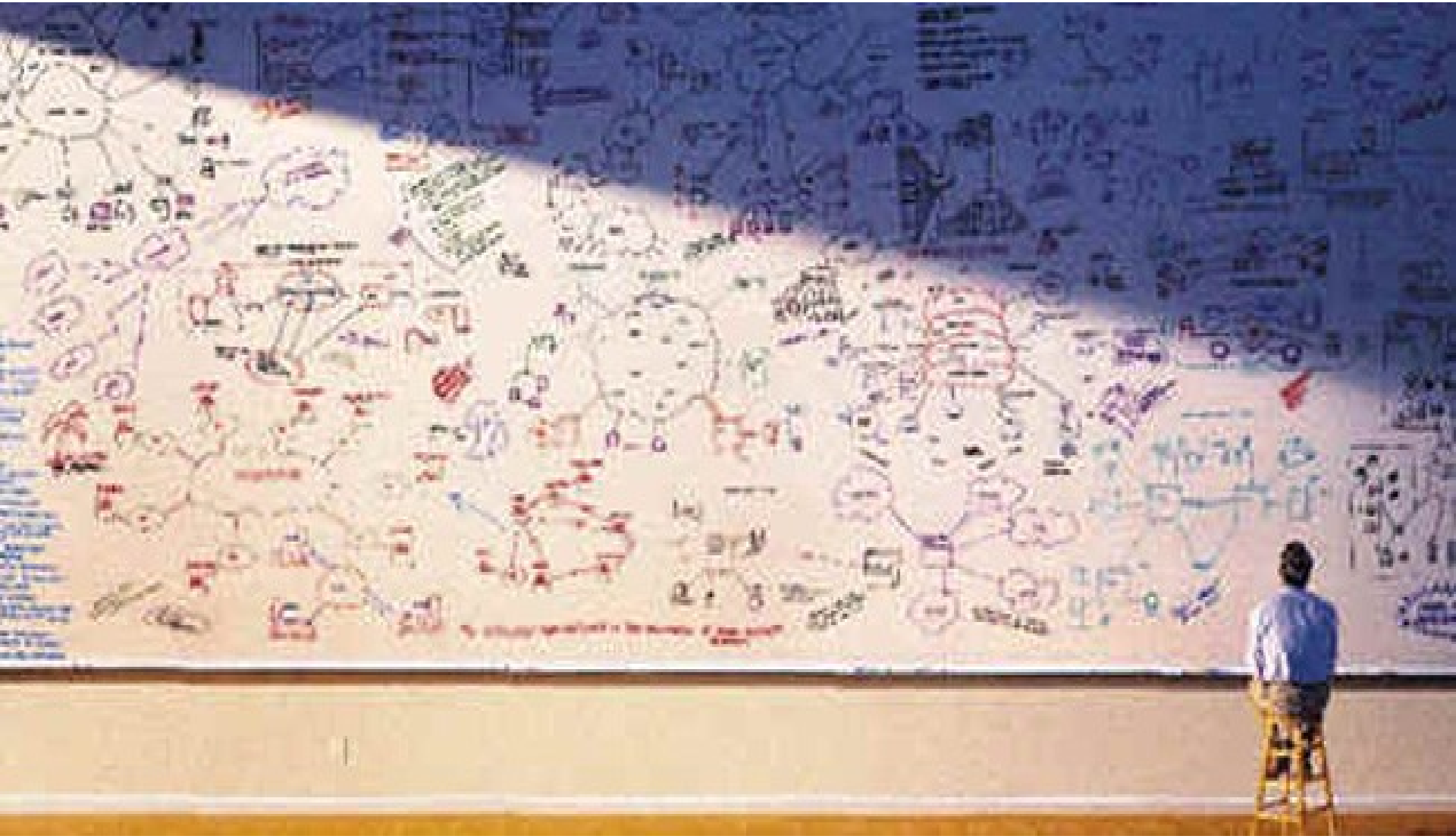
Modelling of Software Intensive Systems (MoSIS)
”dealing with complexity”

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

Hans Vangheluwe

https://www.uantwerpen.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



How to deal with **Complexity?**

(in engineered systems)

Causes of Complexity?

in **Engineering** vs. in Science

Complex vs. Complicated

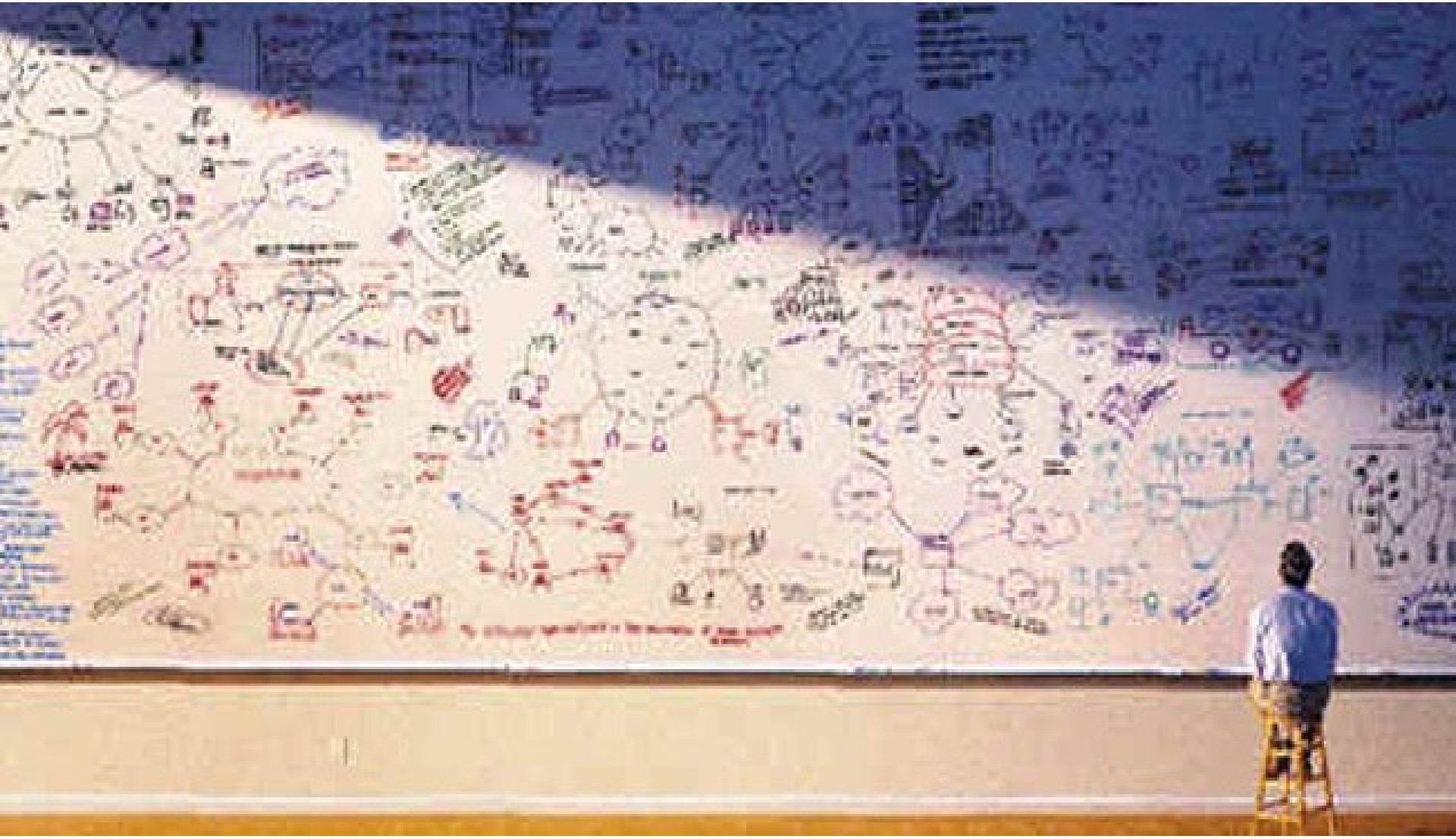
- large number of components (in an “architecture”)
- multiple concerns/views/stakeholders → consistency?

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

- emergent behaviour (due to complex, non-modular interactions)

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

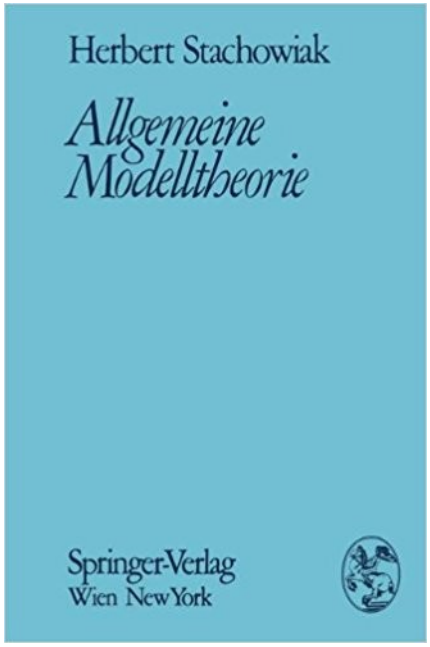
https://sonjablignaut.medium.com/7-differences-between-complex-and-complicated-fa44e0844606



How to deal with **Complexity?**

(in engineered systems)


MODEL EVERYTHING!
04/04 Bellairs, Barbados
04/05 Bellairs, Barbados
04/06 Bellairs, Barbados
10/06 Genoa, Italy
04/07 Bellairs, Barbados
10/07 Nashville, TN, USA
04/08 Bellairs, Barbados
04/09 Bellairs, Barbados
10/09 Denver, CO, USA
04/10 Bellairs, Barbados
10/10 Oslo, Norway
04/11 Bellairs, Barbados
10/11 Wellington, NZ
04/12 Bellairs, Barbados
10/12 Innsbruck, Austria
05/13 Bellairs, Barbados
09/13 Miami, FL, USA
02/14 Bellairs, Barbados
09/14 Valencia, Spain
01/15 Bellairs, Barbados
09/15 Ottawa, Canada
04/16 Bellairs, Barbados
03/17 Bellairs, Barbados
05/18 Bellairs, Barbados
04/19 Bellairs, Barbados
09/19 Munich, Germany
10/20 Montreal, Canada*
10/21 Fukuoka, Japan*
04/22 Bellairs, Barbados
10/22 Montreal, Canada
03/23 Carghjese, Corsica
05/23 Bellairs, Barbados
10/23 Västerås, Sweden
*virtual event
http://CAMPaM.MPM4CPS.eu

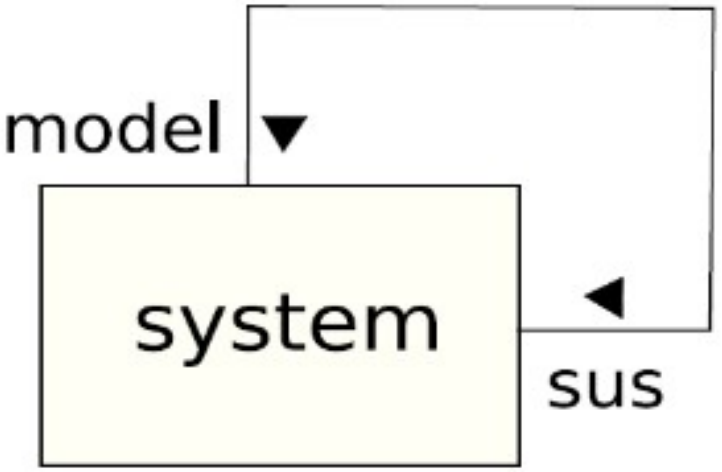


1973

“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.

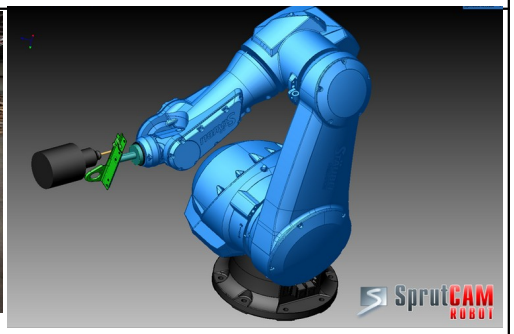
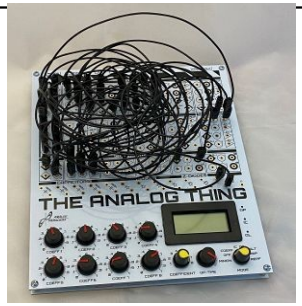
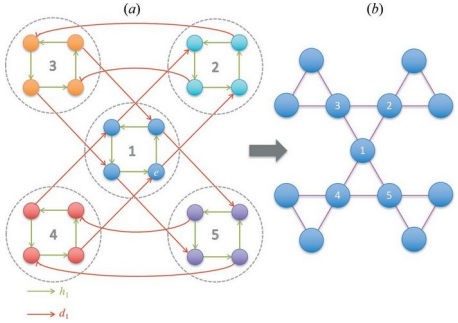
Marvin L. Minsky



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	$\frac{dx}{dt} = \alpha x - \beta xy,$ $\frac{dy}{dt} = -\gamma y + \delta xy,$ 	

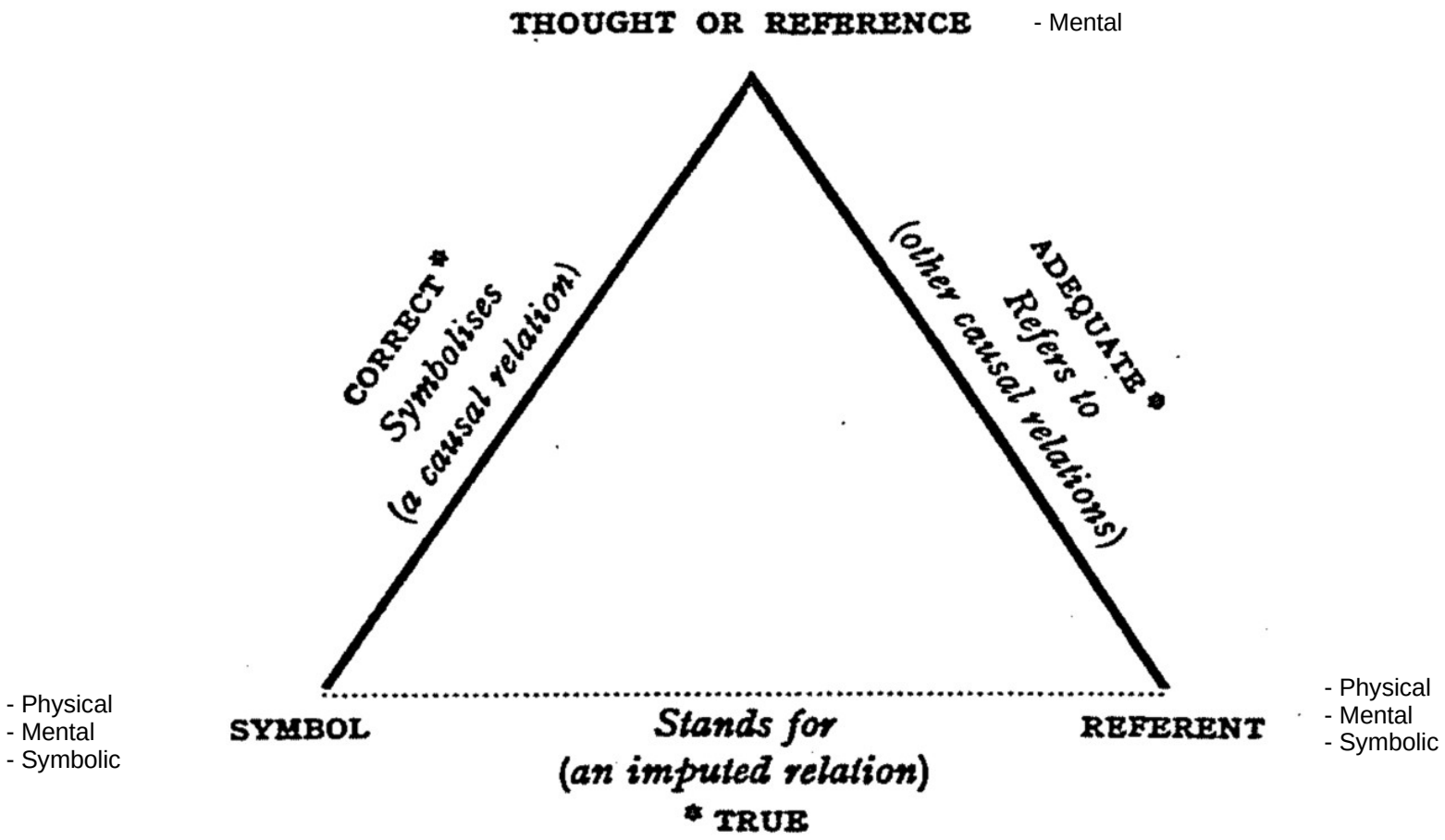
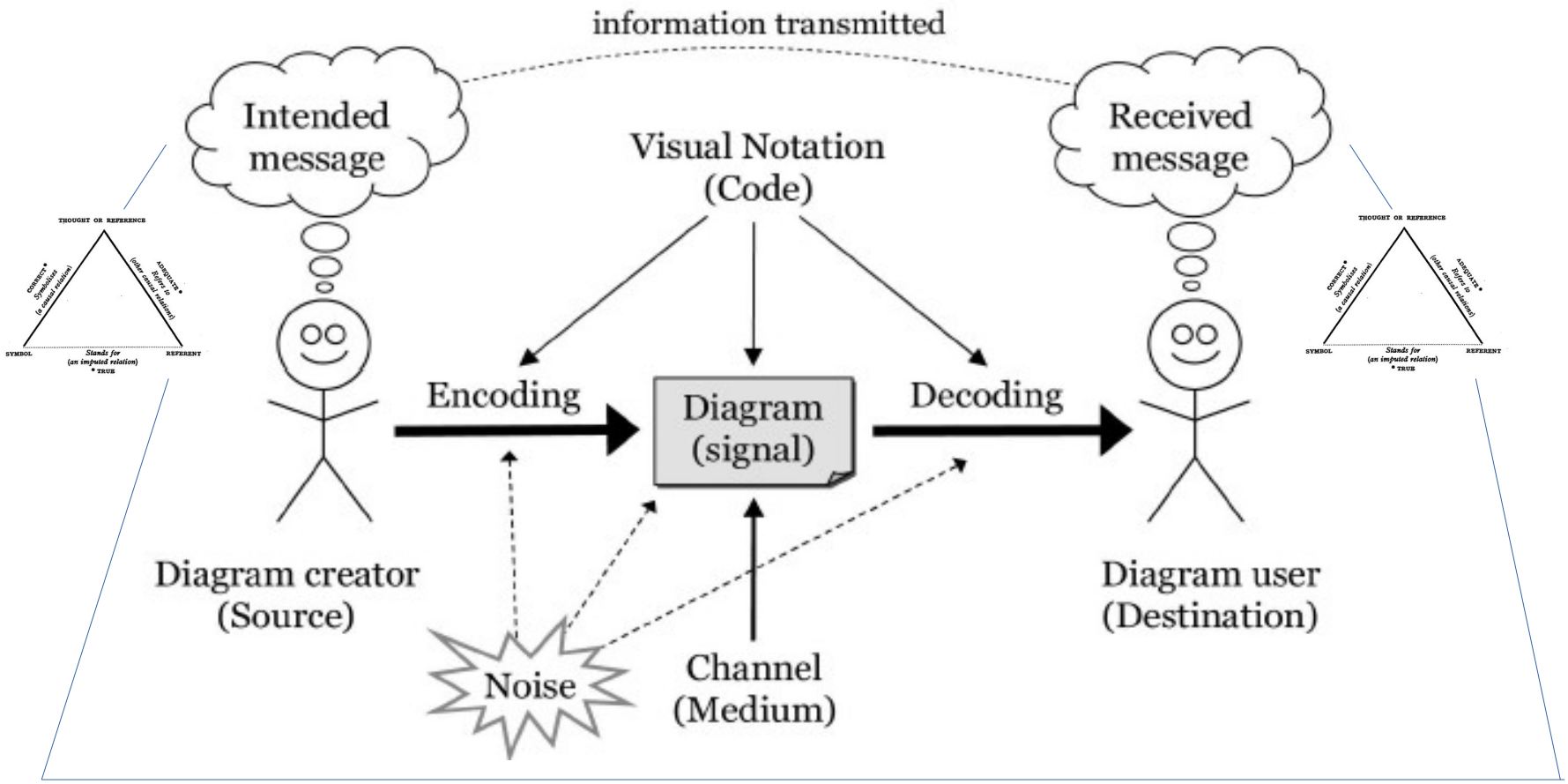
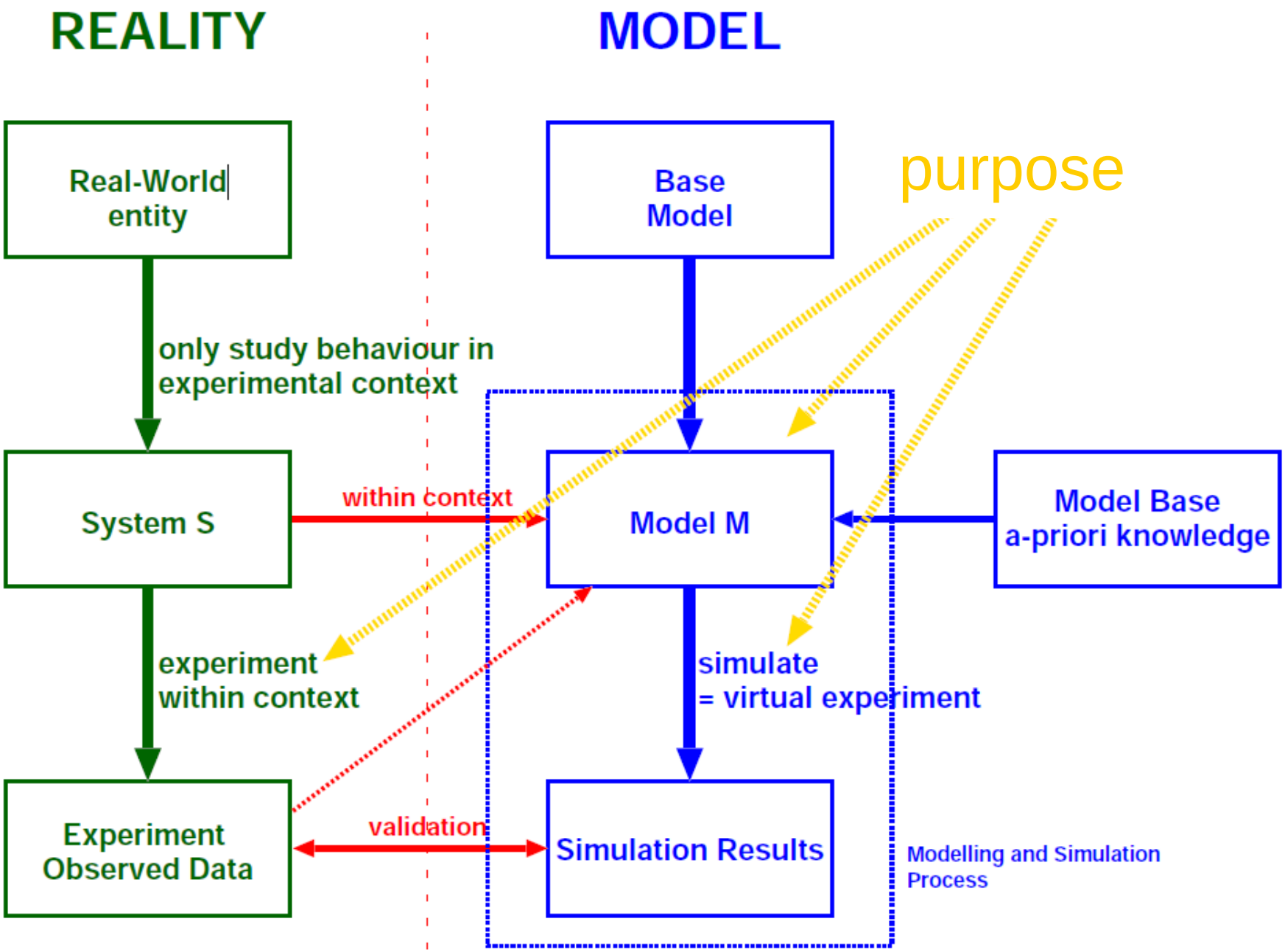


Figure taken from page 11, The Meaning of Meaning: A Study of the Influence of Language upon Thought and of the Science of Symbolism, 1923, was co-authored by C. K. Ogden and I. A. Richards, Magdalene College, University of Cambridge

Moody “Physics of Notation”: communication theory

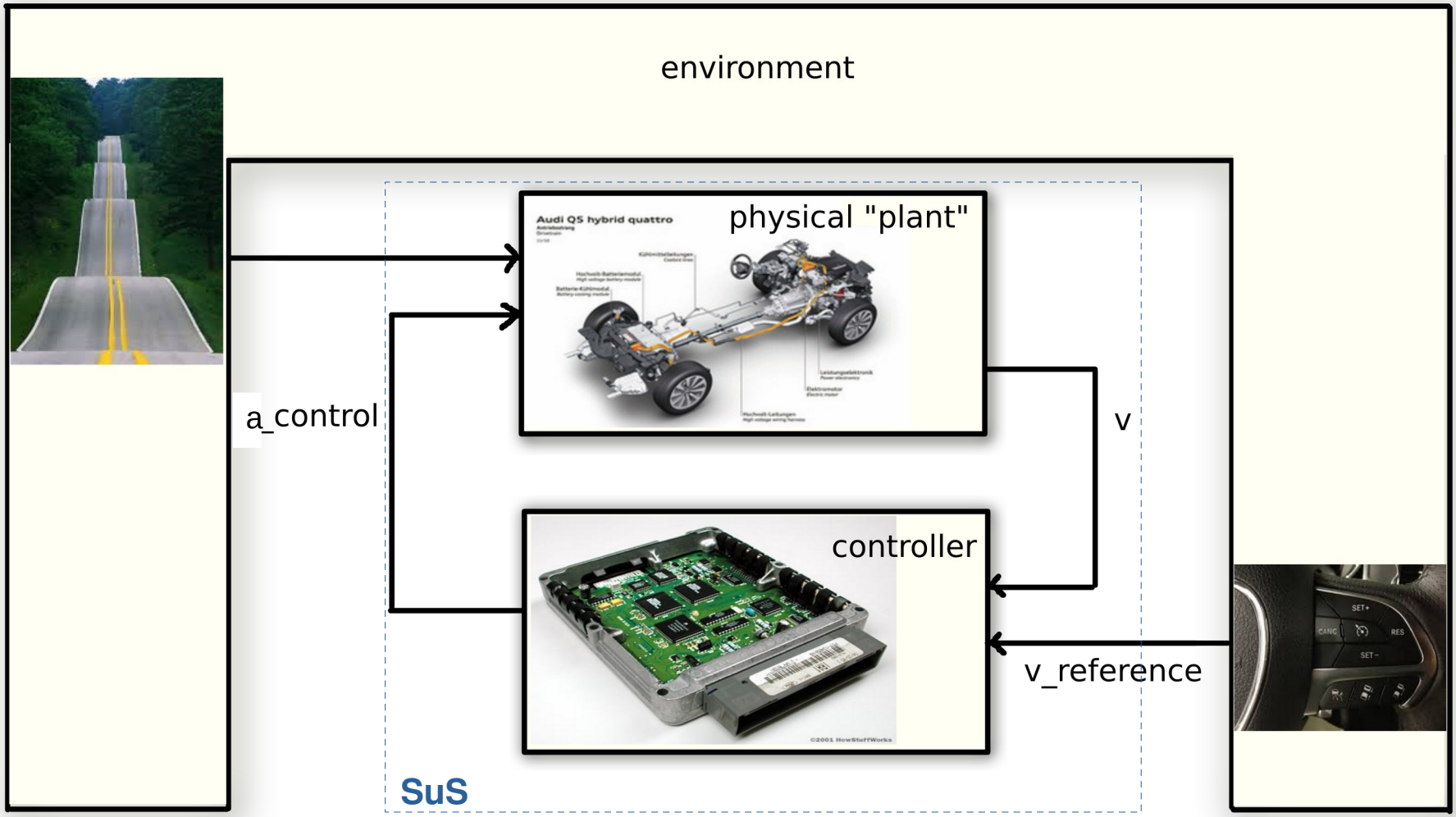




Bernard P. Zeigler. *Multi-faceted Modelling and Discrete-Event Simulation*. Academic Press, 1984.

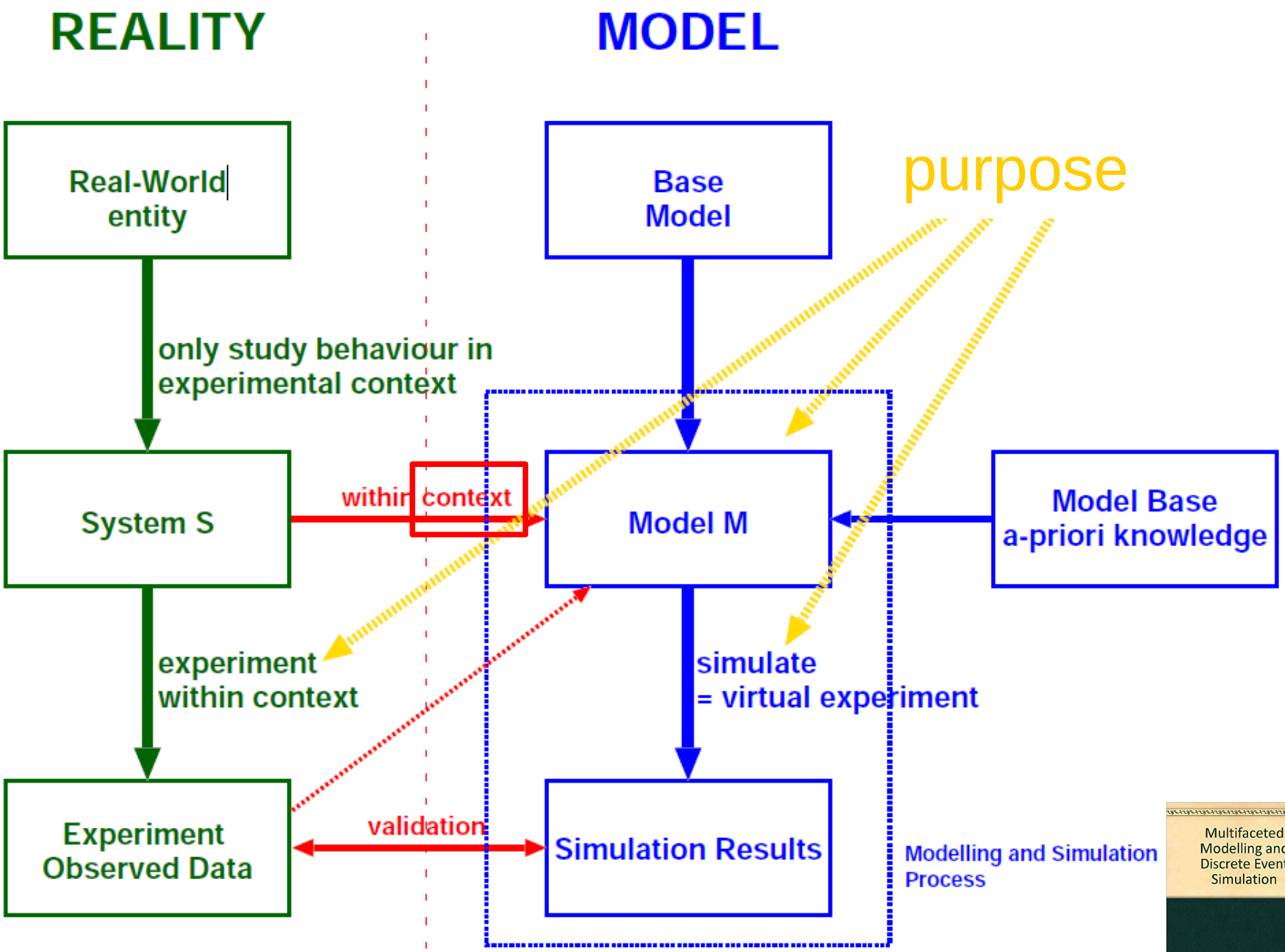
System under Study (SuS) = “plant” || controller

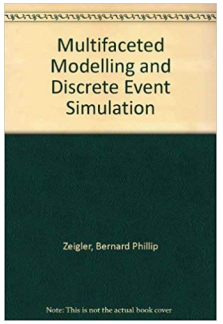
SuS is not studied in isolation: **SuS** || **environment**



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 Motivating Example: Electrical Resistor

Property of interest (PoI):

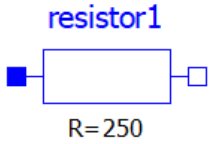
geometry

https://grabcad.com/library/resistors-0-5w-pitch-12-7mm-500mil-1

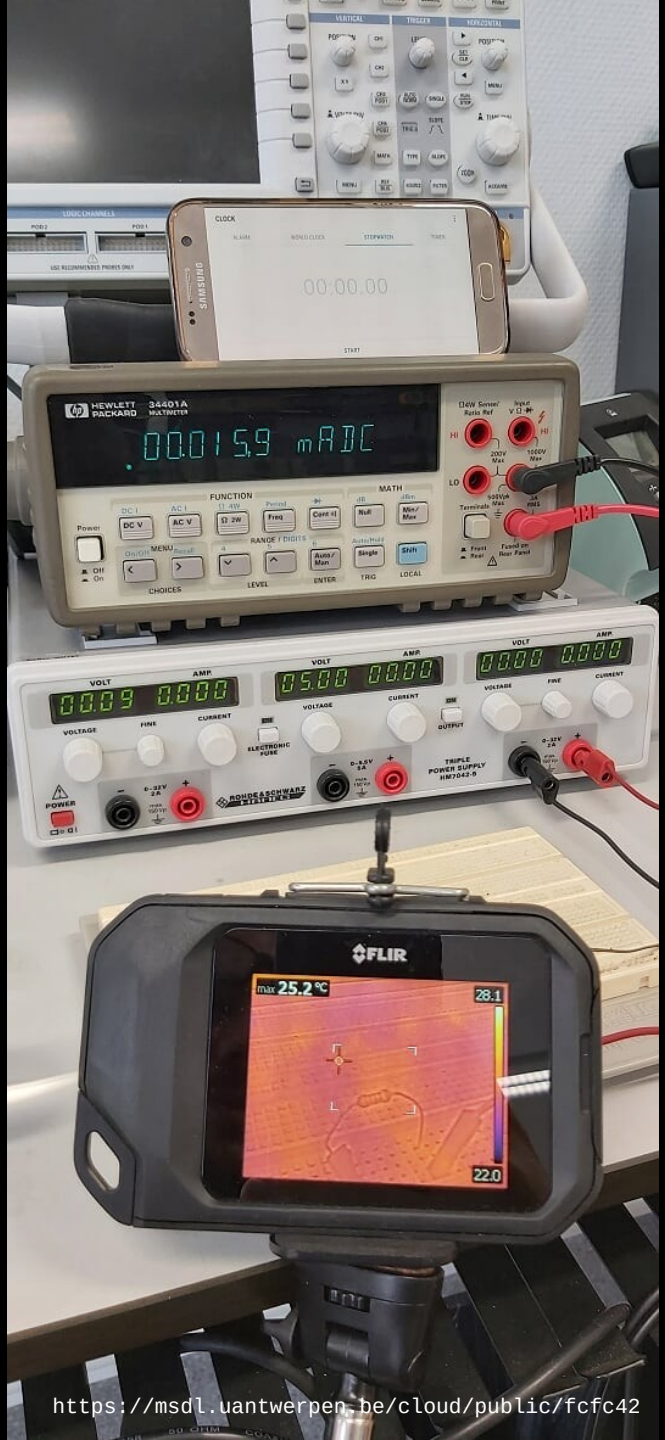
Model Validity Motivating Example: Electrical Resistor

Property of interest (PoI):

constitutive relation
between voltage drop *V* over resistor and current *i* through resistor

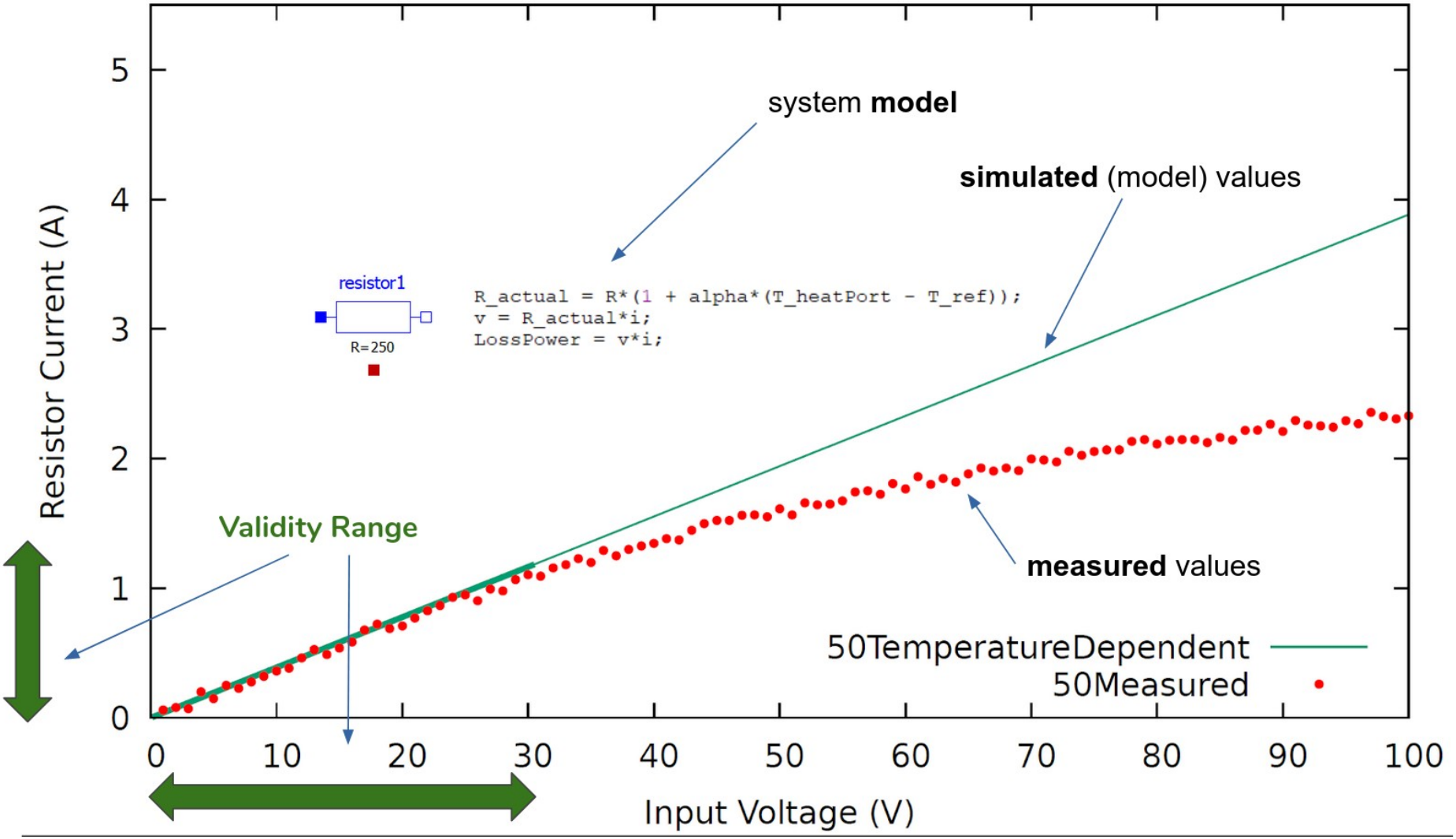



```
R*i = v
```

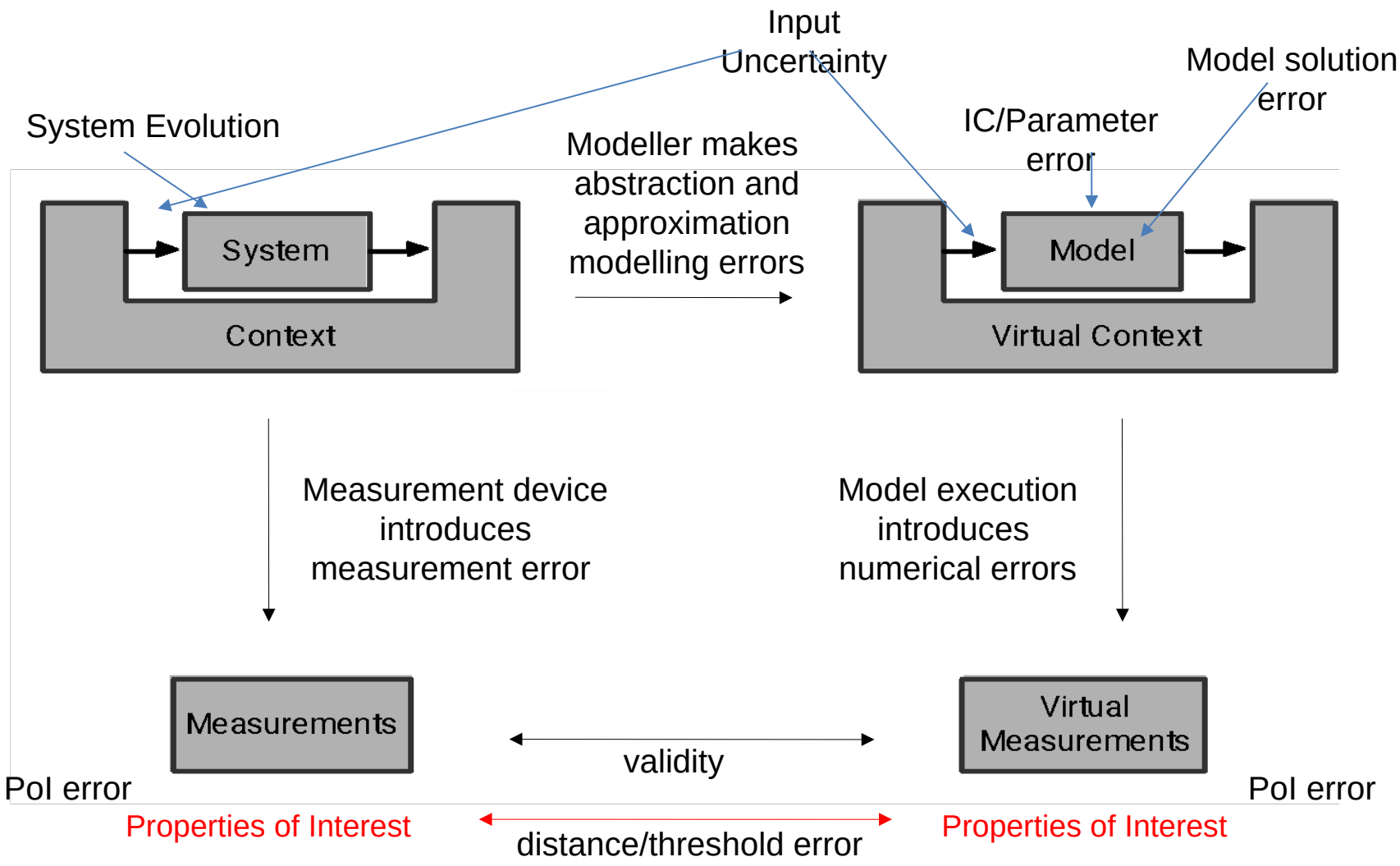


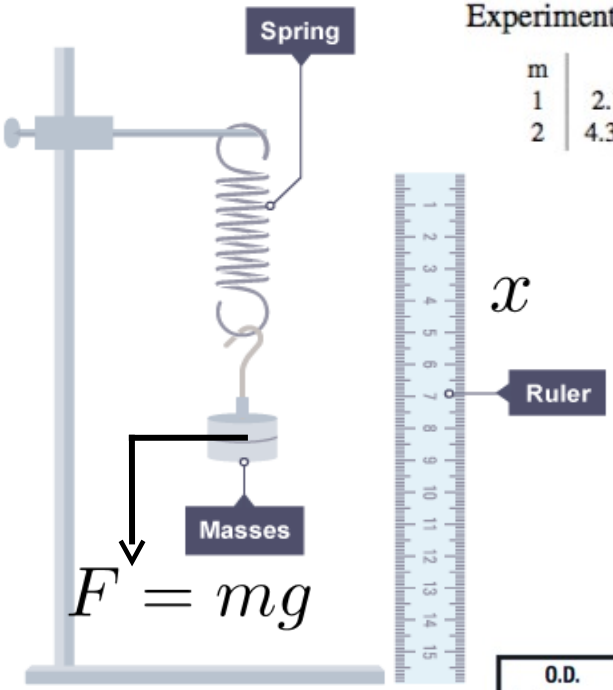
https://msdl.uantwerpen.be/cloud/public/fcfc42

Model Validity … Context?



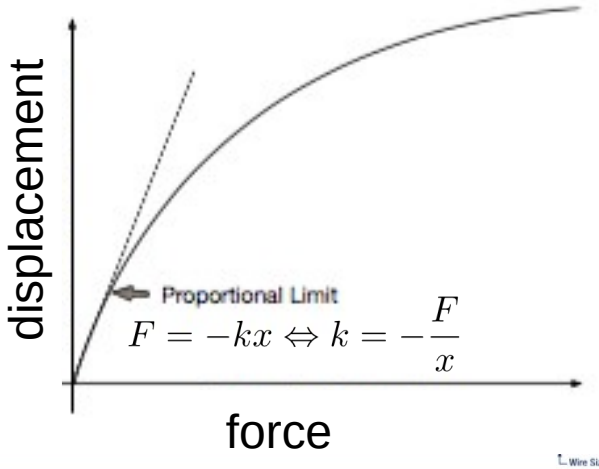
Substitutability (wrt PoI) … but ….





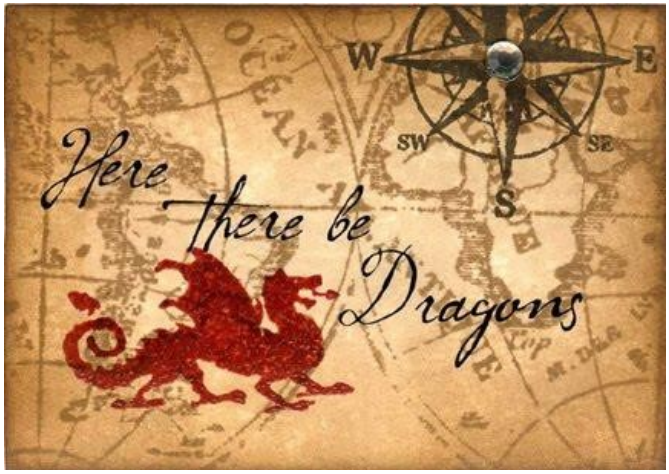
Experimental spring results, with mass m in kg and displacement x (± 0.0001) in cm

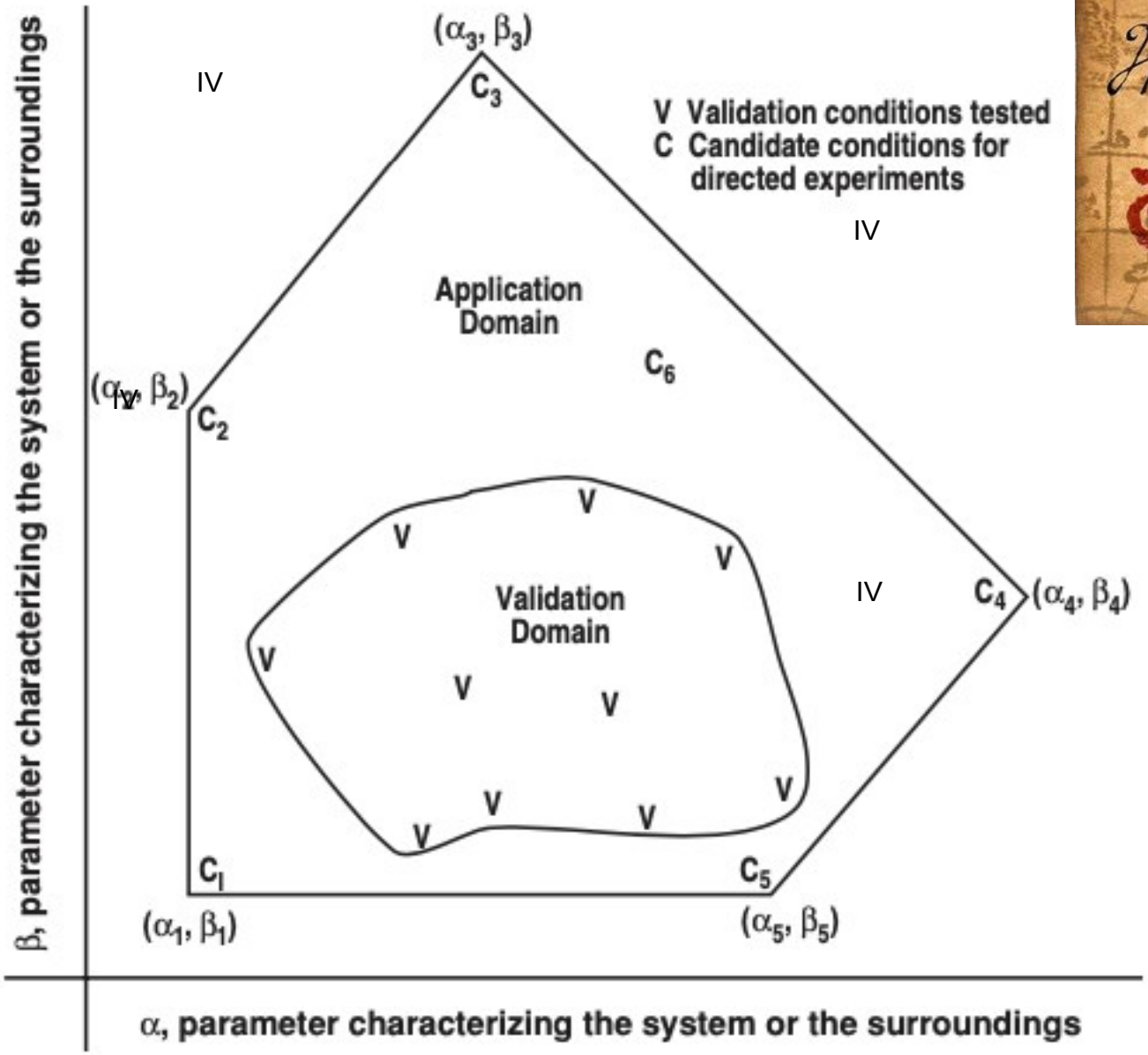
m	x	m	x	m	x	m	x	m	x
1	2.100	3	6.3749	5	10.4915	7	14.6081	9	19.0012
2	4.3166	4	8.4332	6	12.5489	8	16.7774		



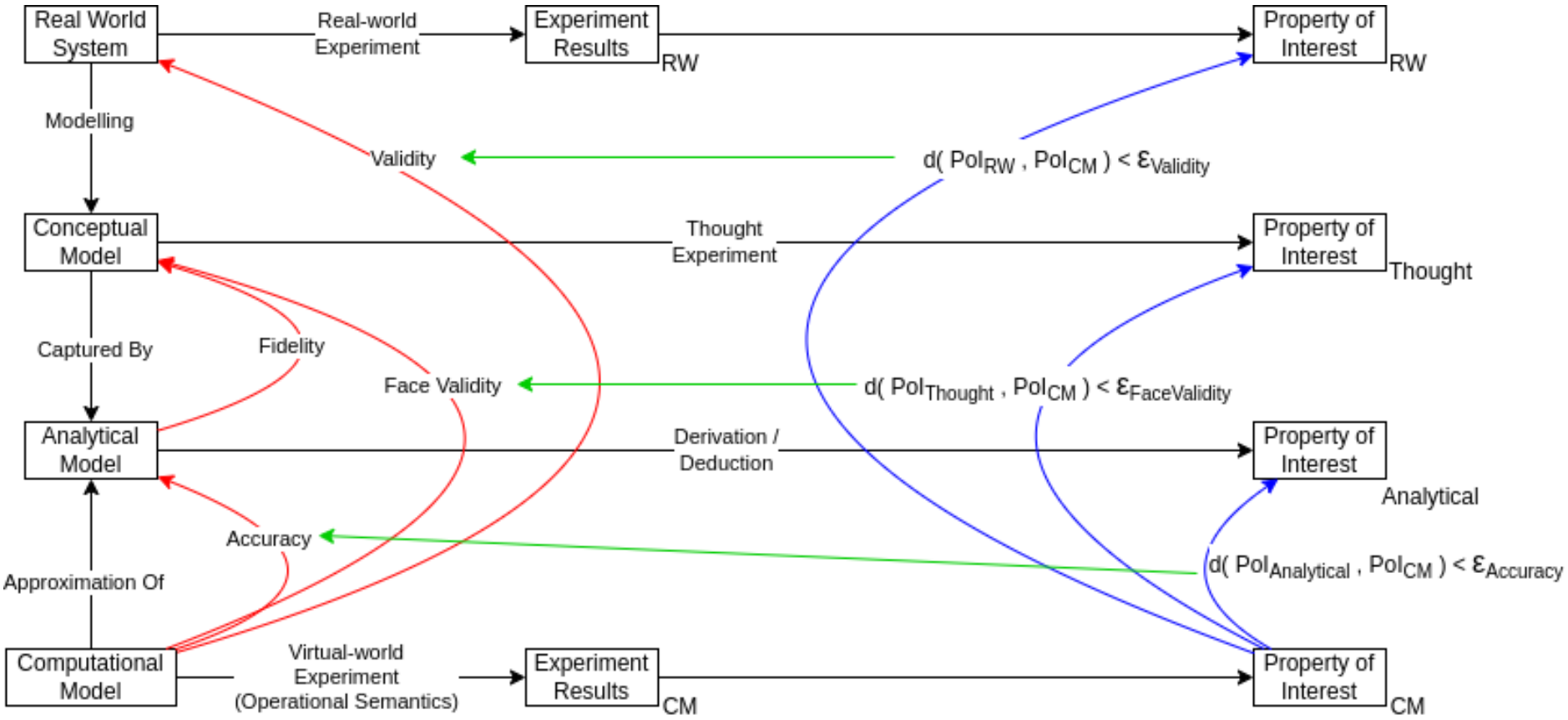
O.D. Inches	O.D. mm	CENTURY STOCK NUMBER	FREE LENGTH Inches	FREE LENGTH mm	I.D. Inches	I.D. mm	RATE Lbs./In.	RATE N/mm	SUGG. MAX. DEFL. Inches	SUGG. MAX. DEFL. mm	SUGG. MAX. LOAD Lbs.	SUGG. MAX. LOAD N	SOLID LENGTH Inches	SOLID LENGTH mm	WIRE DIA. Inches	WIRE DIA. mm	TOTAL COILS	MAT'L	ENDS	FNSH
0.036	.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

www.centuryspring.com



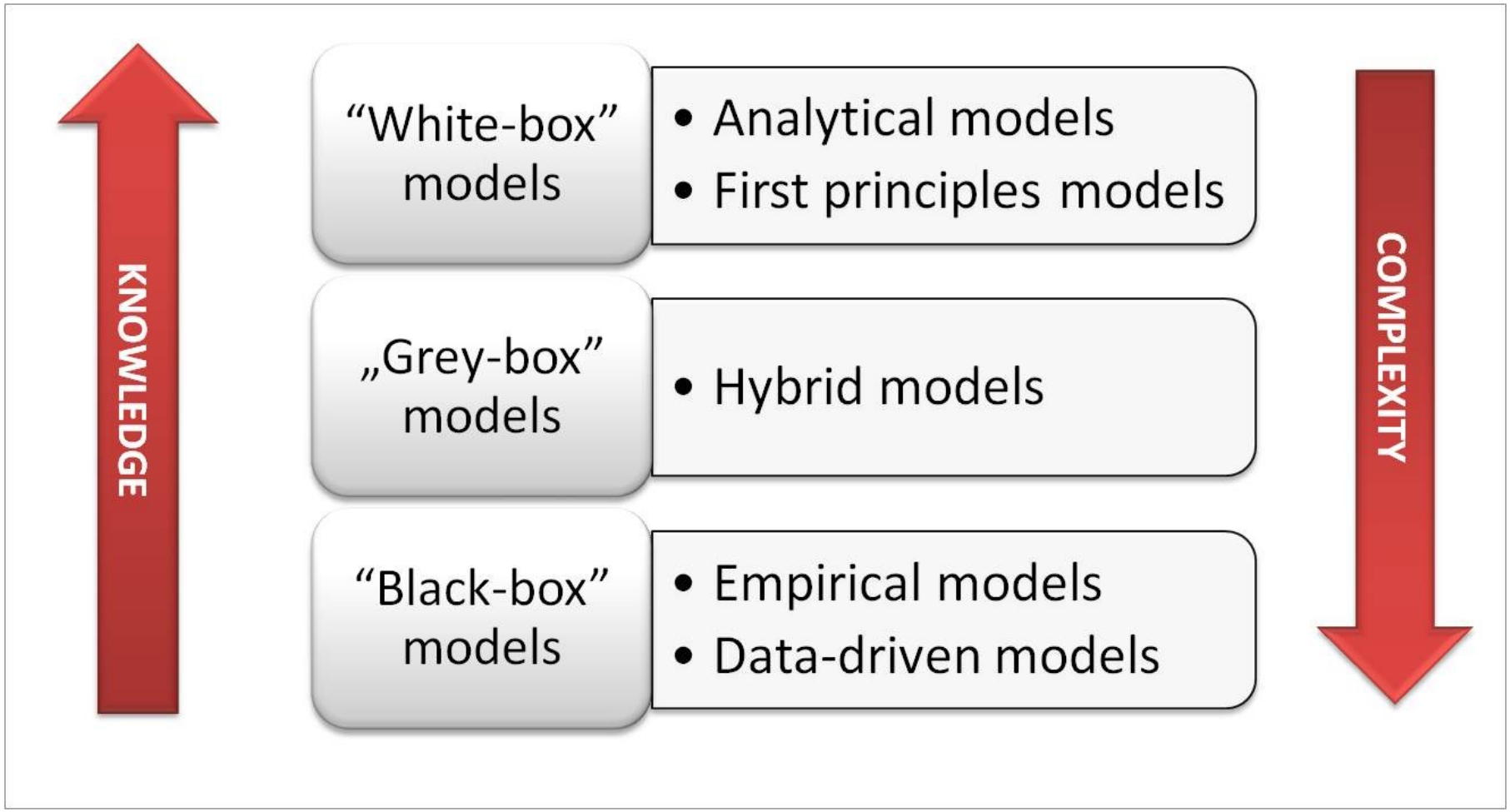


W. Oberkampf, C. Roy. *Verification and Validation in Scientific Computing.* Cambridge University Press, 2010.



++ Workflows
++ Inductive vs. Deductive

different ways of **obtaining** models
(in same or different formalisms)

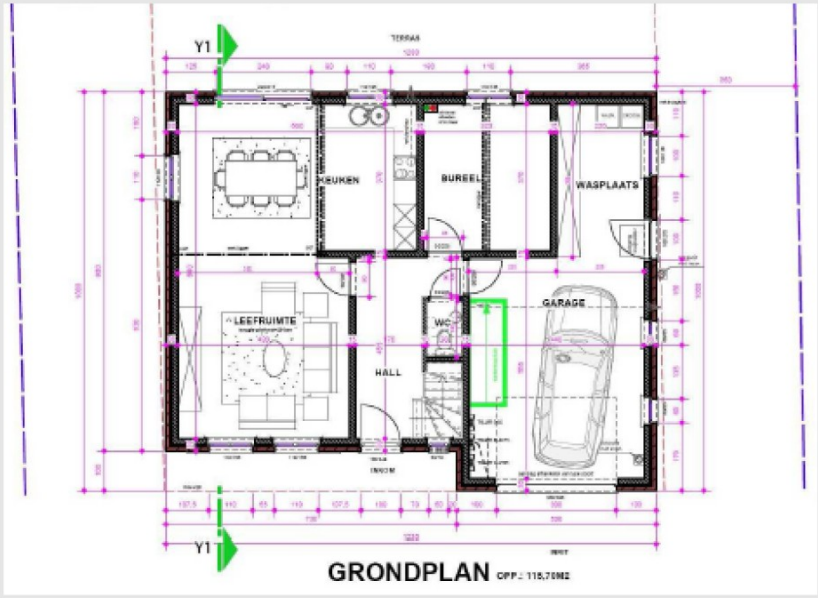


What vs. How

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?")



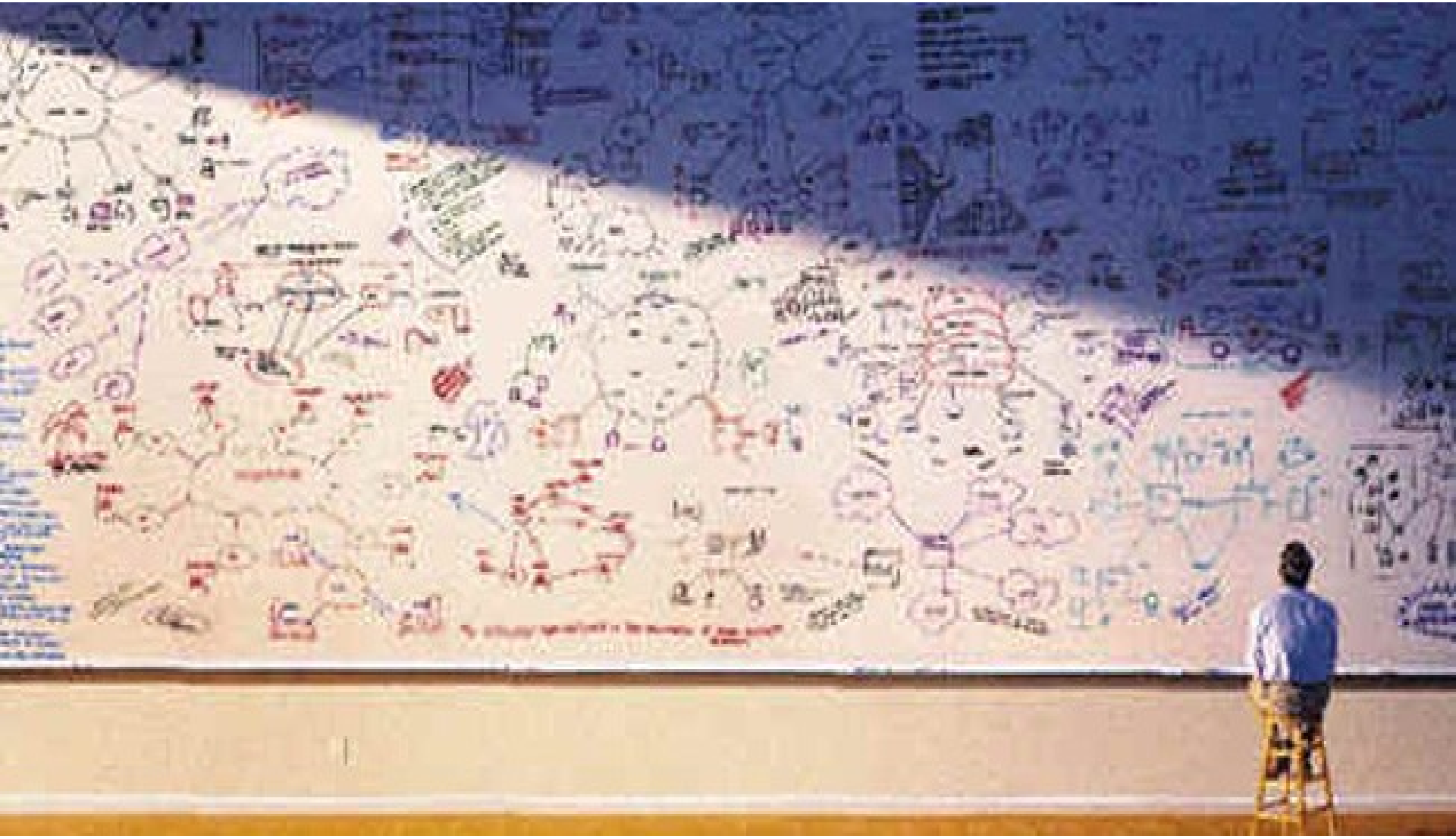
note: product family

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

– *satisfied by* →

design

(may in turn serve as requirements ...)



How to deal with **Complexity?**

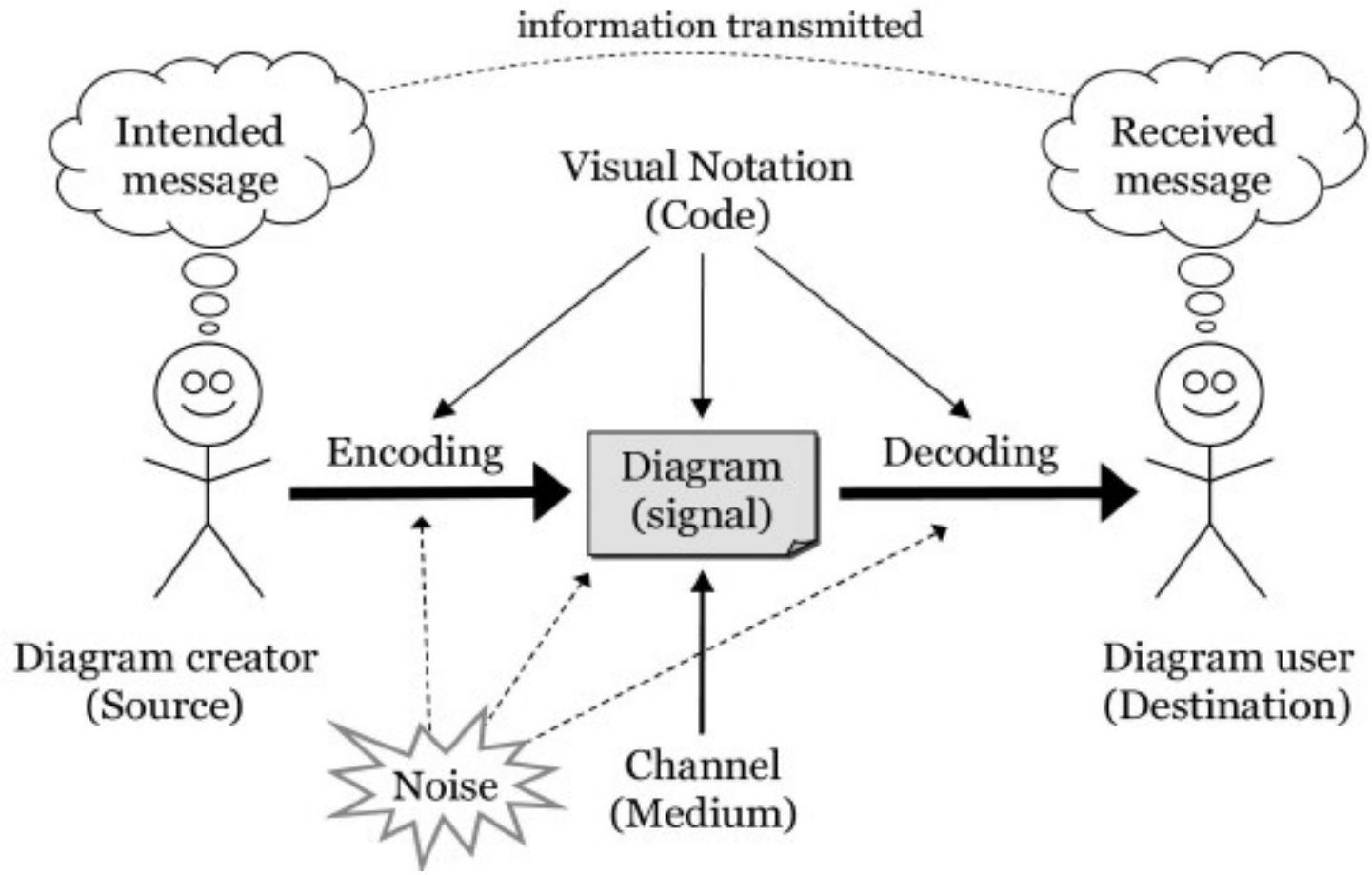
(in engineered systems)

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

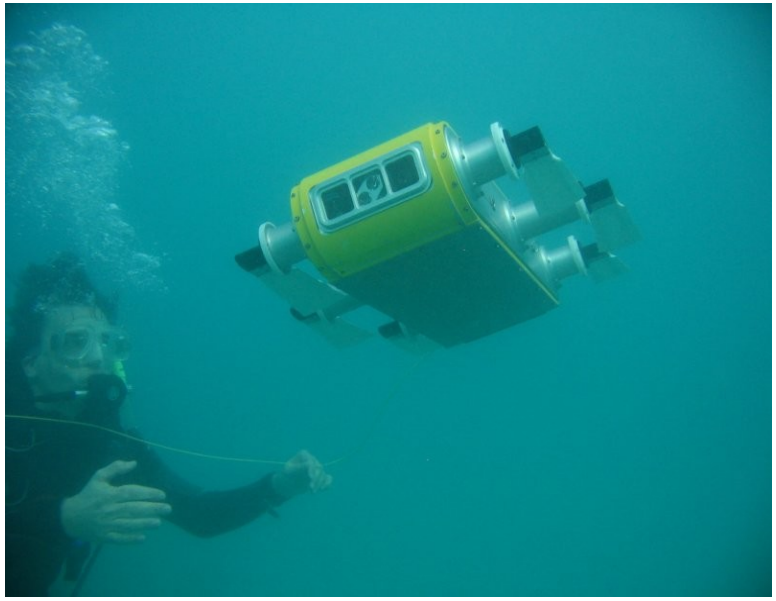
The “Physics” of Notations: Towards a Scientific Basis for Constructing Visual Notations in Software Engineering

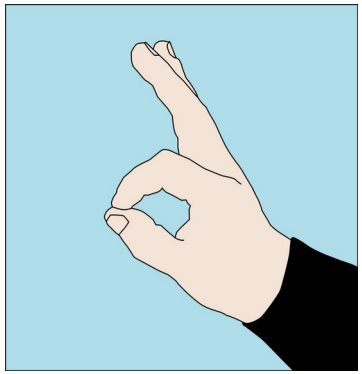
Daniel L. Moody, *Member, IEEE*

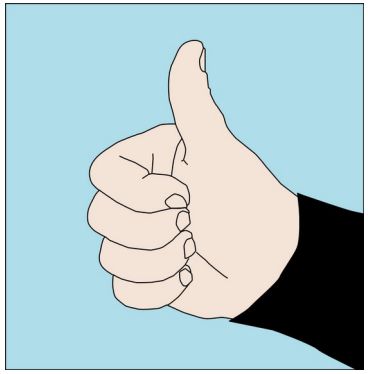
Communication Theory

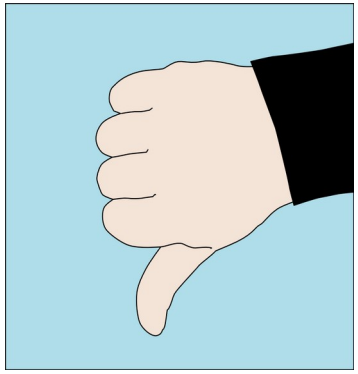


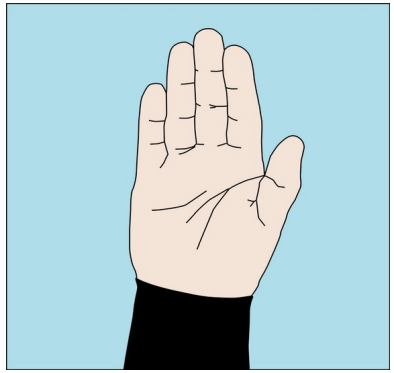
Perceptual Discriminability







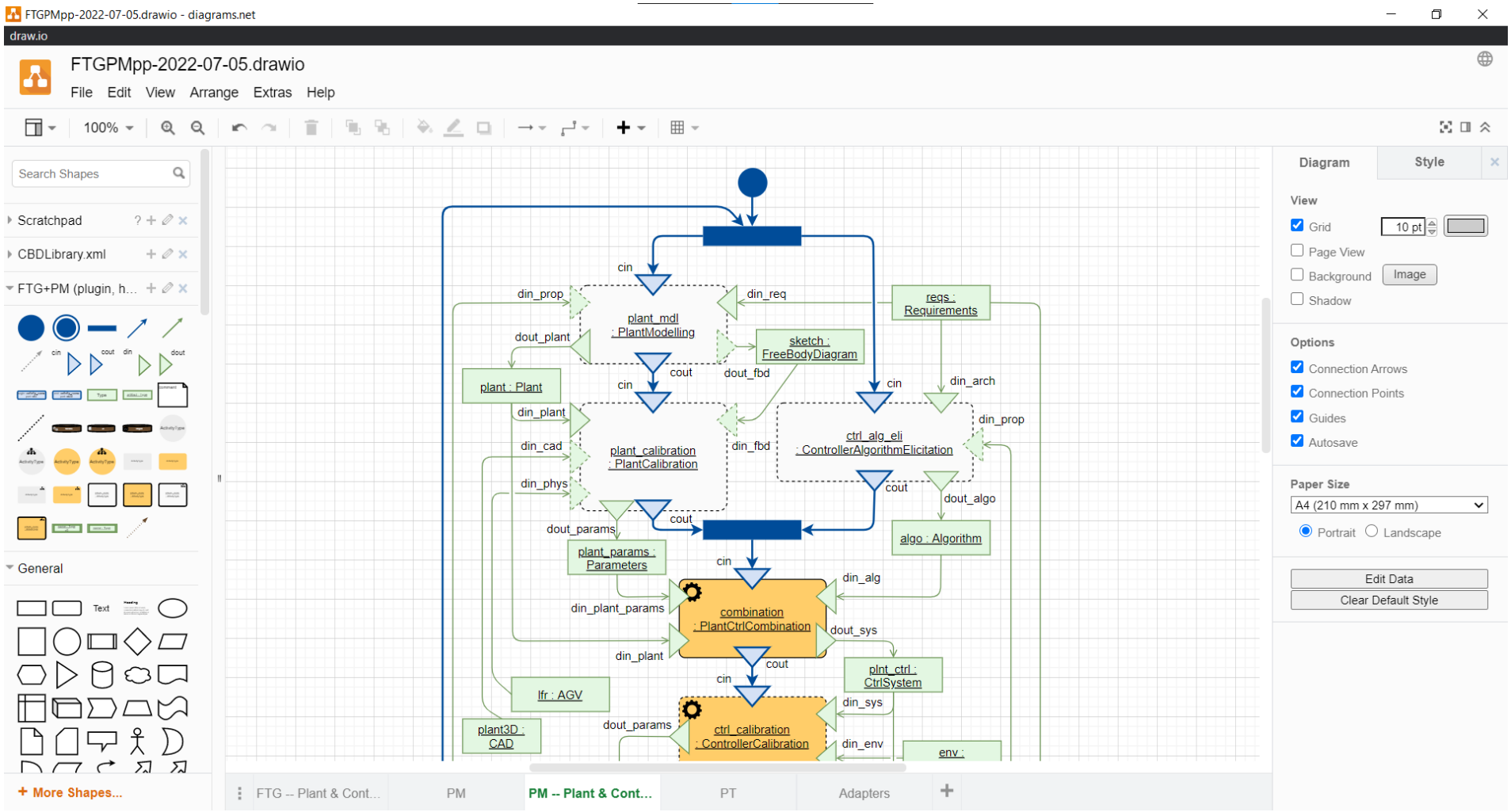




Semantic Transparency: semantically **perverse** symbols

depends on context/user/. ..

https://diagrams.net (to build a “poor man’s” DSL)

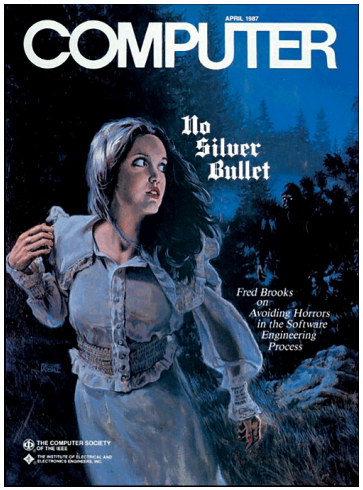


“Accidental” Complexity

vs. “essential” complexity

```
int f_by_value(int arg)
{
 int calc_res = 0;
 calc_res = arg+1;
 return calc_res;
}
```

```
f_by_value:
addiu $sp,$sp,-24
sw    $fp,16($sp)
move  $fp,$sp
sw    $4,24($fp)
sw    $0,8($fp)
lw    $2,24($fp)
addiu $2,$2,1
sw    $2,8($fp)
lw    $2,8($fp)
move  $sp,$fp
lw    $fp,16($sp)
addiu $sp,$sp,24
j     $31
```



No Silver Bullet

Essence and Accidents of Software Engineering

Frederick P. Brooks, Jr.
University of North Carolina at Chapel Hill

Fashioning complex conceptual constructs is the *essence;* *accidental* tasks arise in representing the constructs in language. Past progress has so reduced the accidental tasks that future progress now depends upon addressing the essence.

Of all the monsters that fill the nightmares of our folklore, none terrify more than werewolves, because they transform unexpectedly from the familiar into horrors. For these, one seeks bullets of silver that can magically lay them to rest.

The familiar software project, at least as seen by the nontechnical manager, has something of this character; it is usually innocent and straightforward, but is capable of becoming a monster of missed schedules, blown budgets, and flawed products. So we hear desperate cries for a silver bullet—something to make software costs drop as rapidly as computer hardware costs do.

But, as we look to the horizon of a decade hence, we see no silver bullet. There is no single development, in either technology or in management technique, that by itself promises even one order-of-magnitude improvement in productivity, in reliability, in simplicity. In this article, I shall try to show why, by examining both the nature of the software problem and the properties of the bullets proposed.

Skepticism is not pessimism, however. Although we see no startling breakthroughs—and indeed, I believe such to be inconsistent with the nature of software—many encouraging innovations are under way. A disciplined, consistent effort to develop, propagate, and exploit these innovations should indeed yield an order-of-magnitude improvement. There is no royal road, but there is a road.

The first step toward the management of disease was replacement of demon theories and humours theories by the germ theory. That very step, the beginning of hope, in itself dashed all hopes of magical solutions. It told workers that progress would be made stepwise, at great effort, and that a persistent, unremitting care would have to be paid to a discipline of cleanliness. So it is with software engineering today.

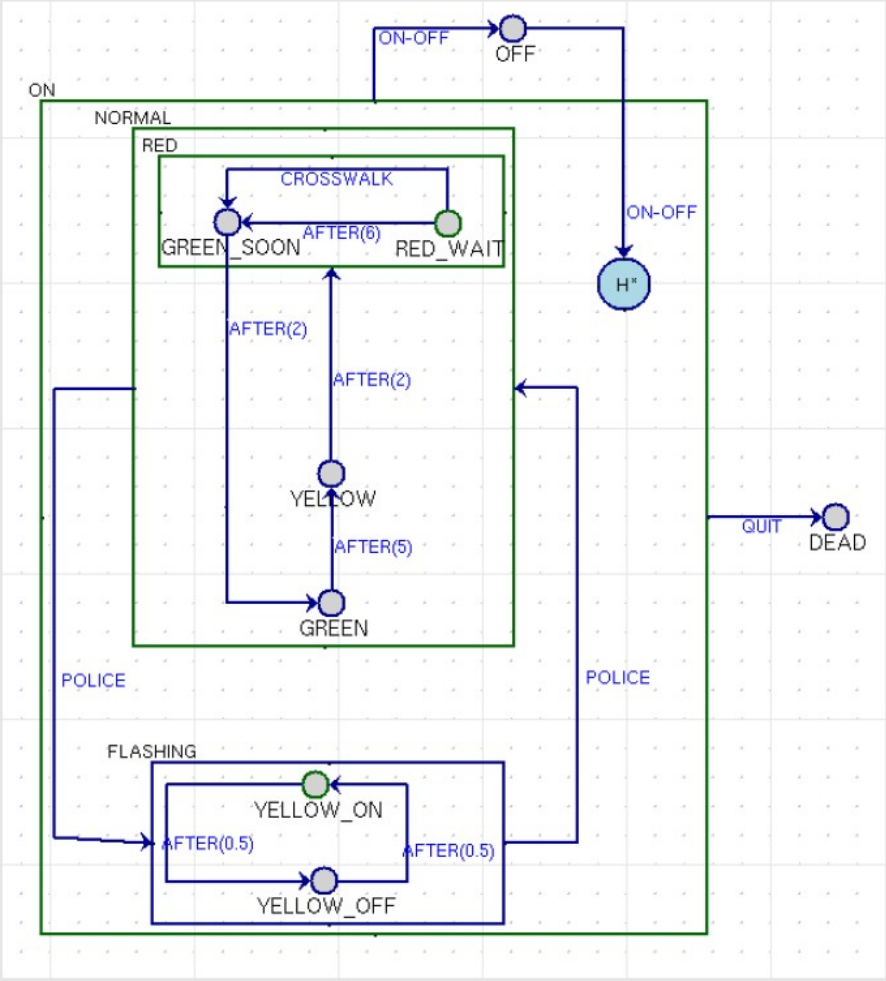
Does it have to be hard?—Essential difficulties

Not only are there no silver bullets now in view, the very nature of software makes it unlikely that there will be any—no inventions that will do for software productivity, reliability, and simplicity what electronics, transistors, and large-scale integration did for computer hardware.

This article was first published in *Information Processing '86*, ISBN No. 0-444-70077-3, H.-J. Kugler, ed., Elsevier Science Publishers B.V. (North-Holland) © IFIP 1986.

Brooks, "No Silver Bullet Essence and Accidents of Software Engineering," in Computer, vol. 20, no. 4, pp. 10-19, April 1987, doi: 10.1109/MC.1987.1663532.

Most Appropriate Formalism

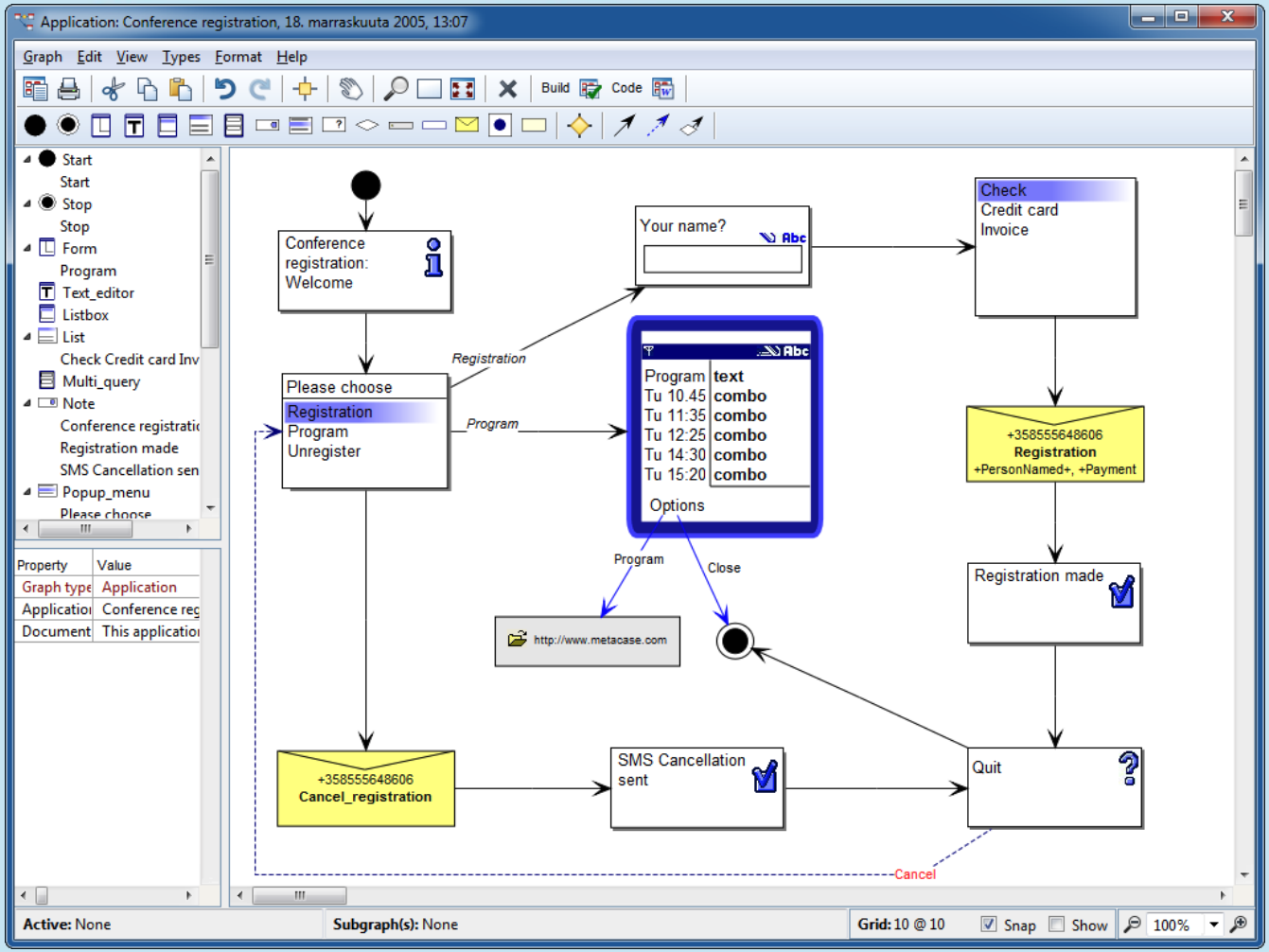


DS(V)M Example in Software Domain
smart phones, the application

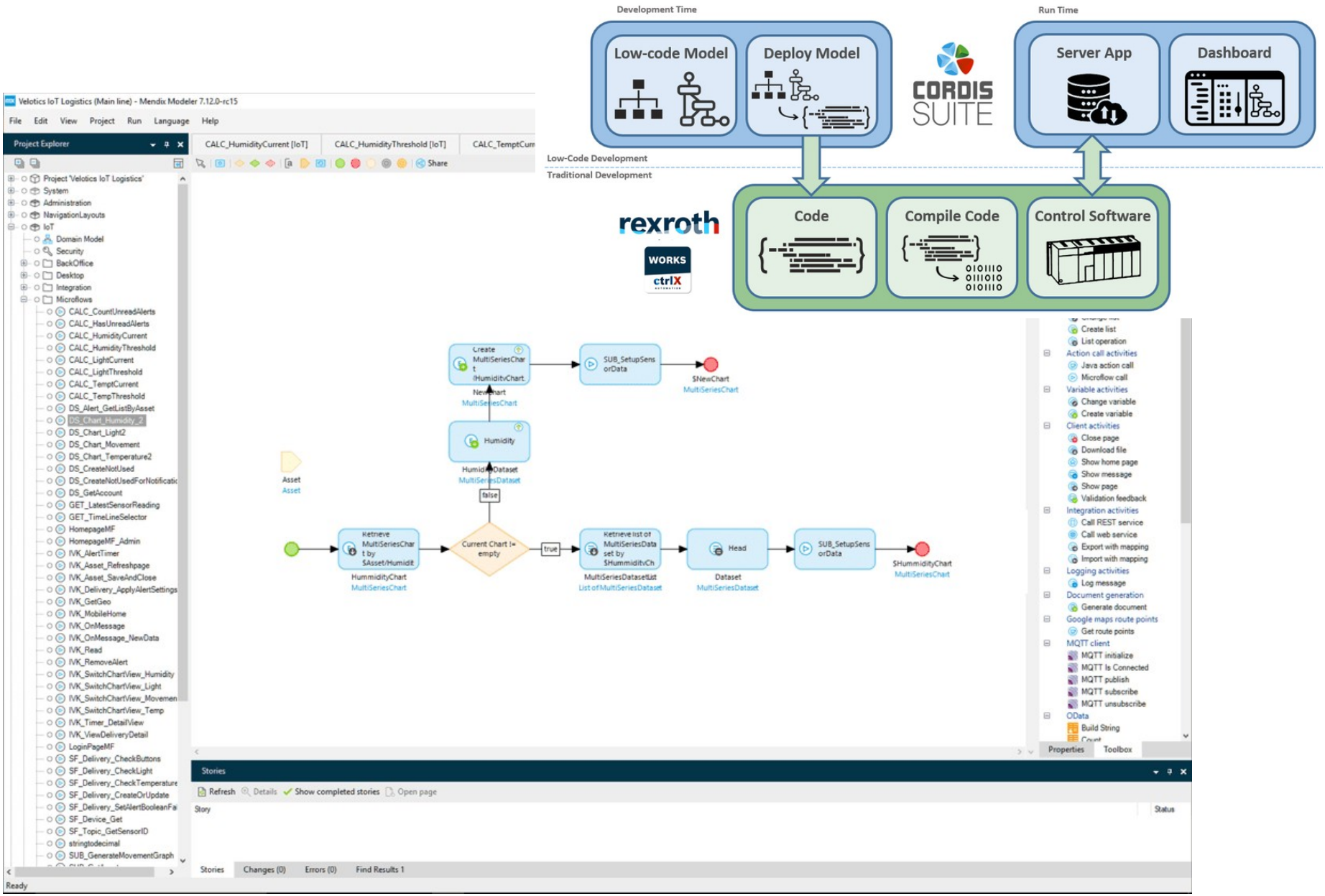
MetaEdit+ (www.metacase.com)

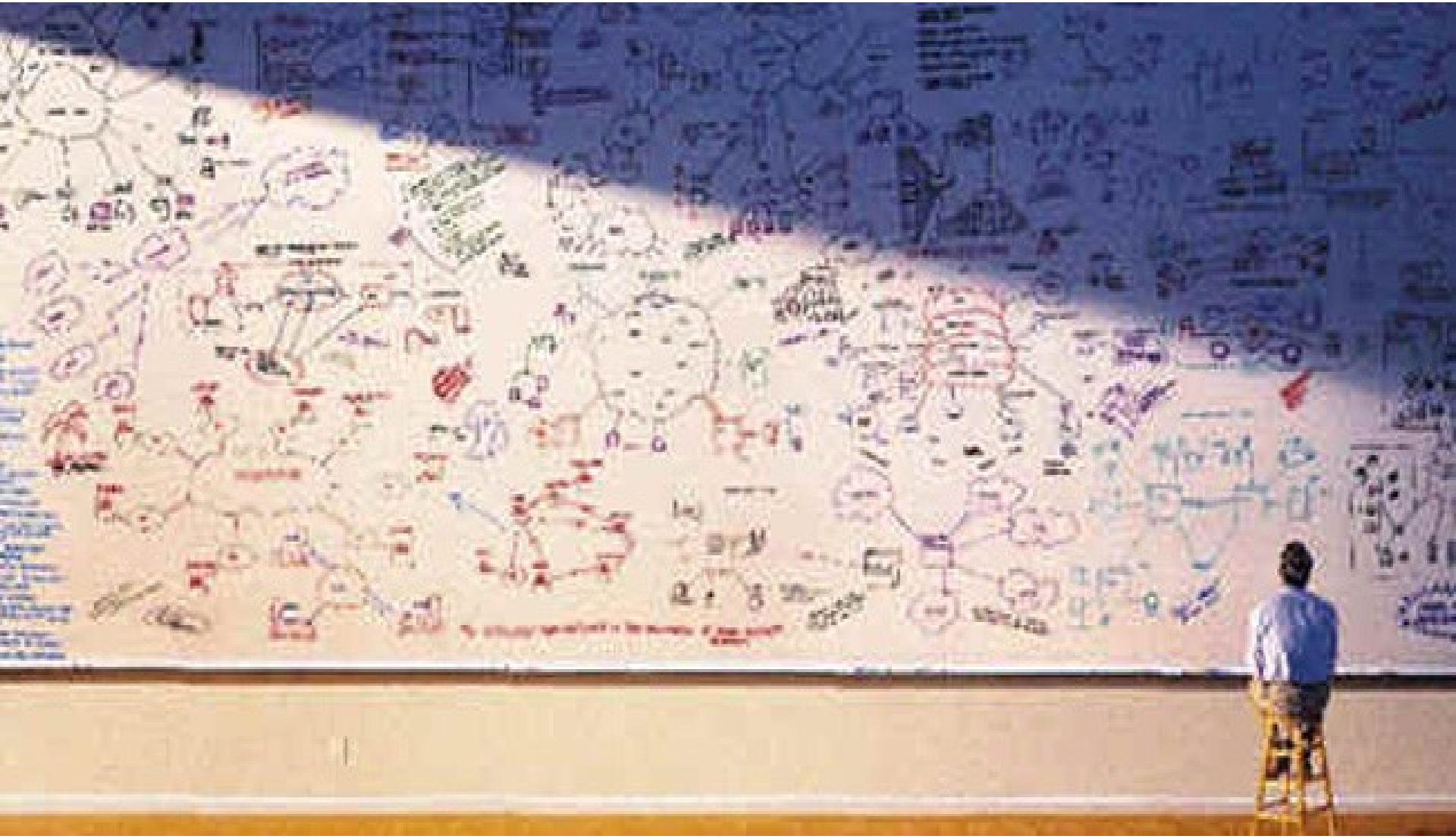
Use “most appropriate” (for purpose/user/...) Formalism
Minimize “accidental complexity”

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



Low Code/ No Code (e.g., Mendix, Cordis Suite)

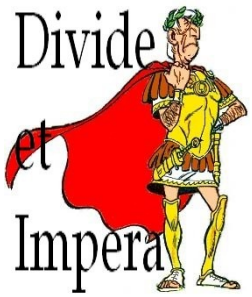


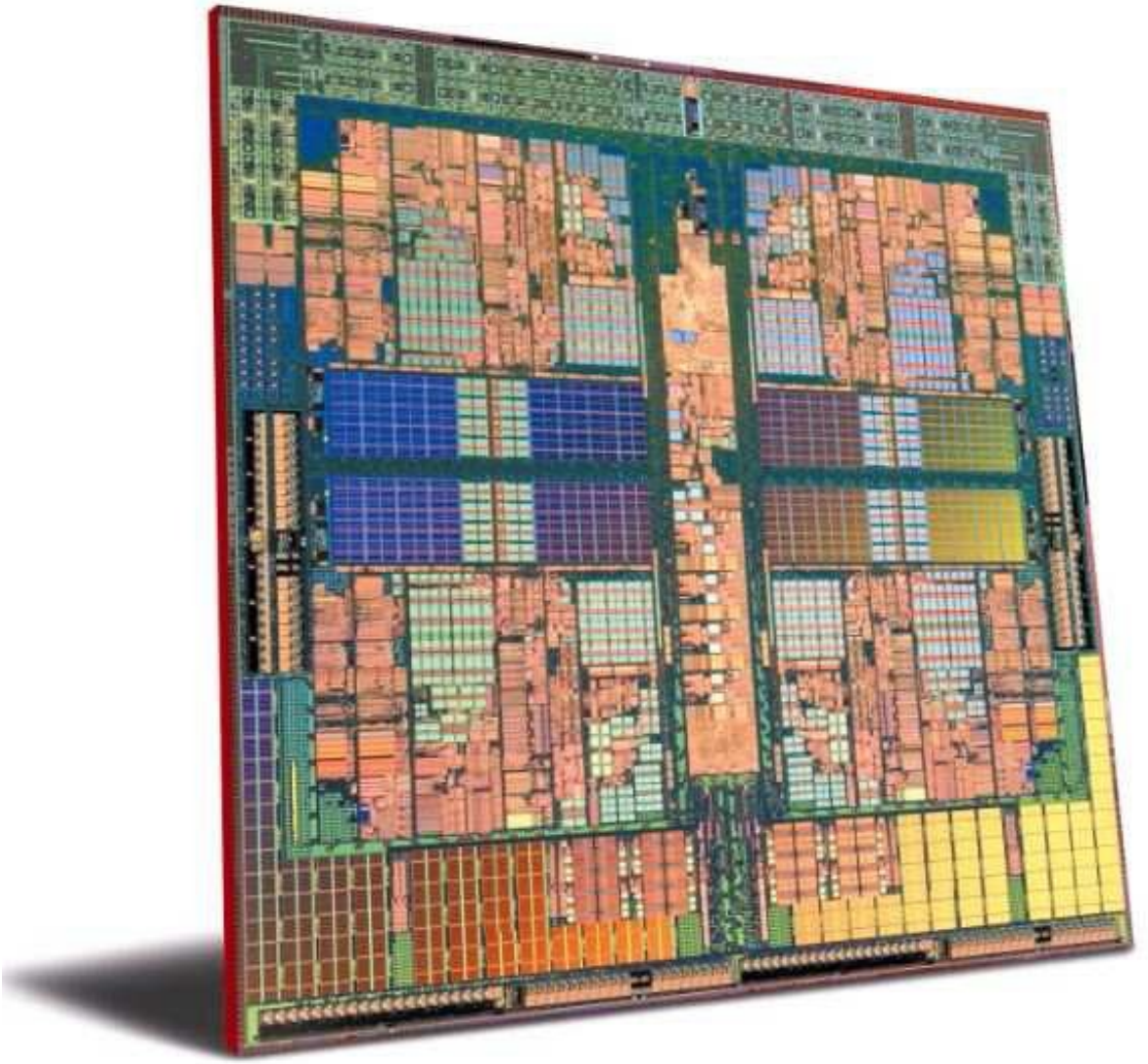


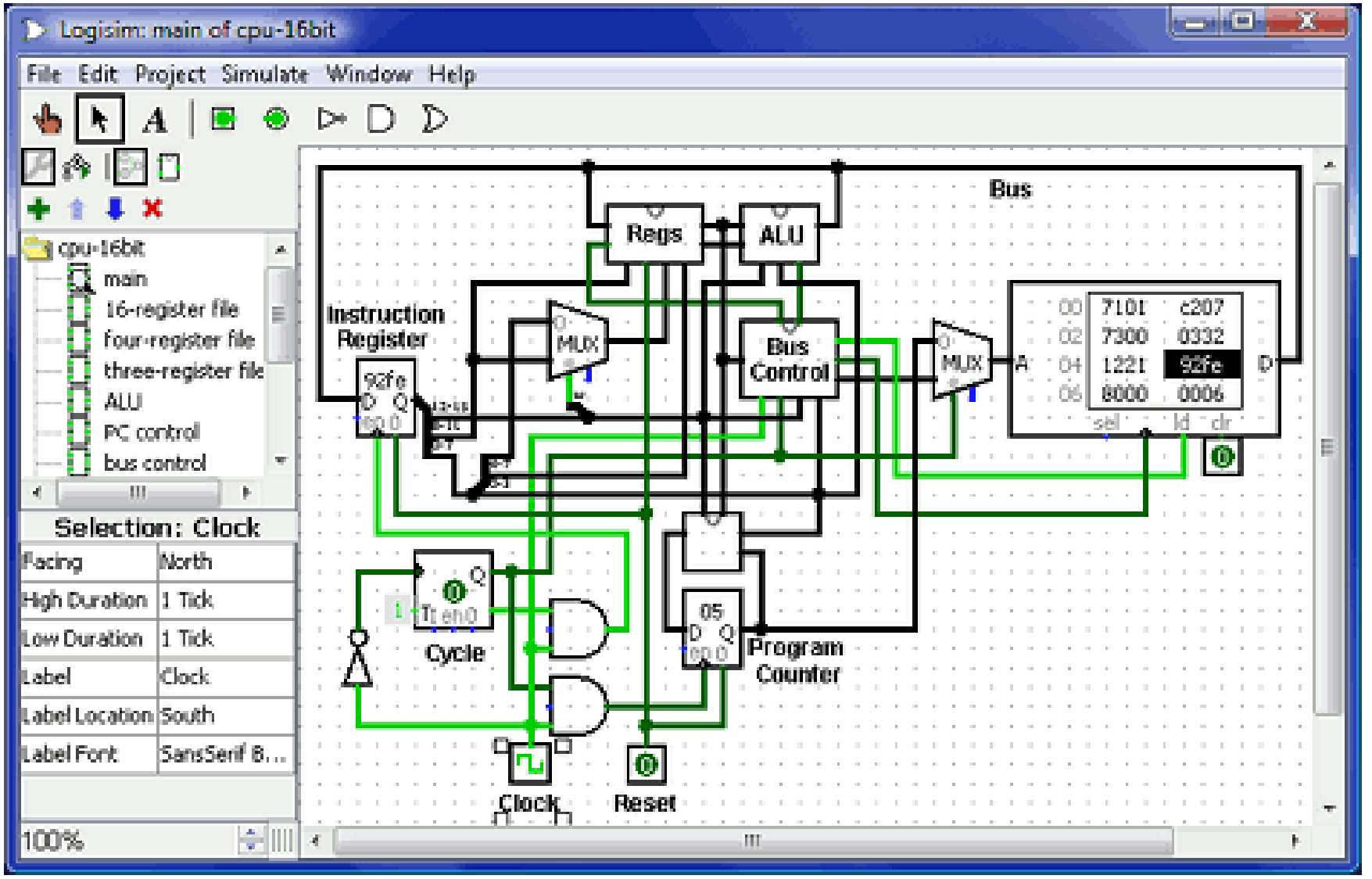
How to deal with **Complexity?**

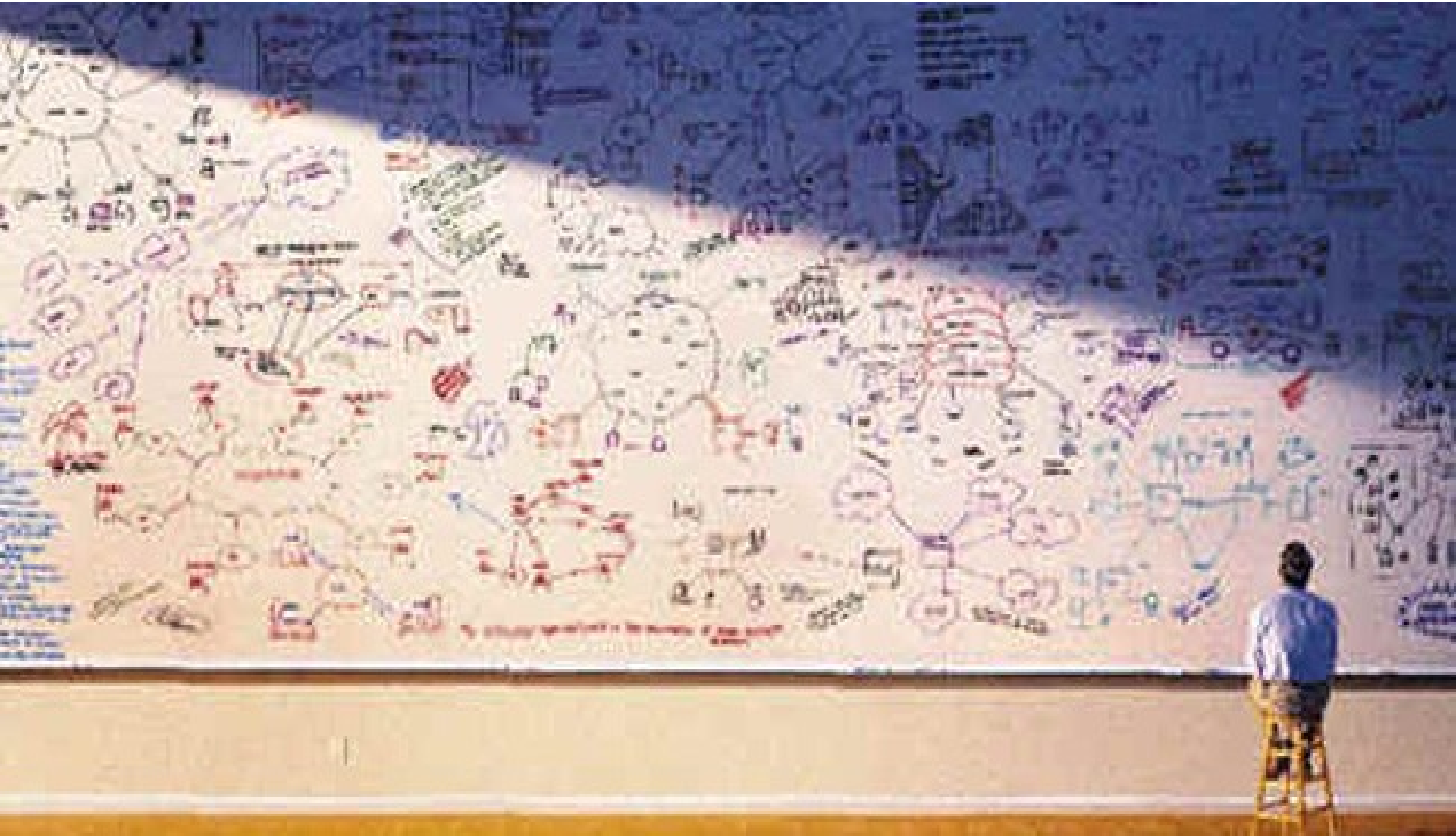
(in engineered systems)

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






Logisim: main of cpu-16bit
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 B...
100%
Bus
Regs
ALU
Instruction Register
MUX
Bus Control
MUX
00 7101 c207
02 7300 0332
04 1221 92fe
06 8000 0006
sel ld clr
92fe
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.

Copyright 2007 The Associated Press. All rights reserved. This material may not be published, broadcast, rewritten or redistributed.

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

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.

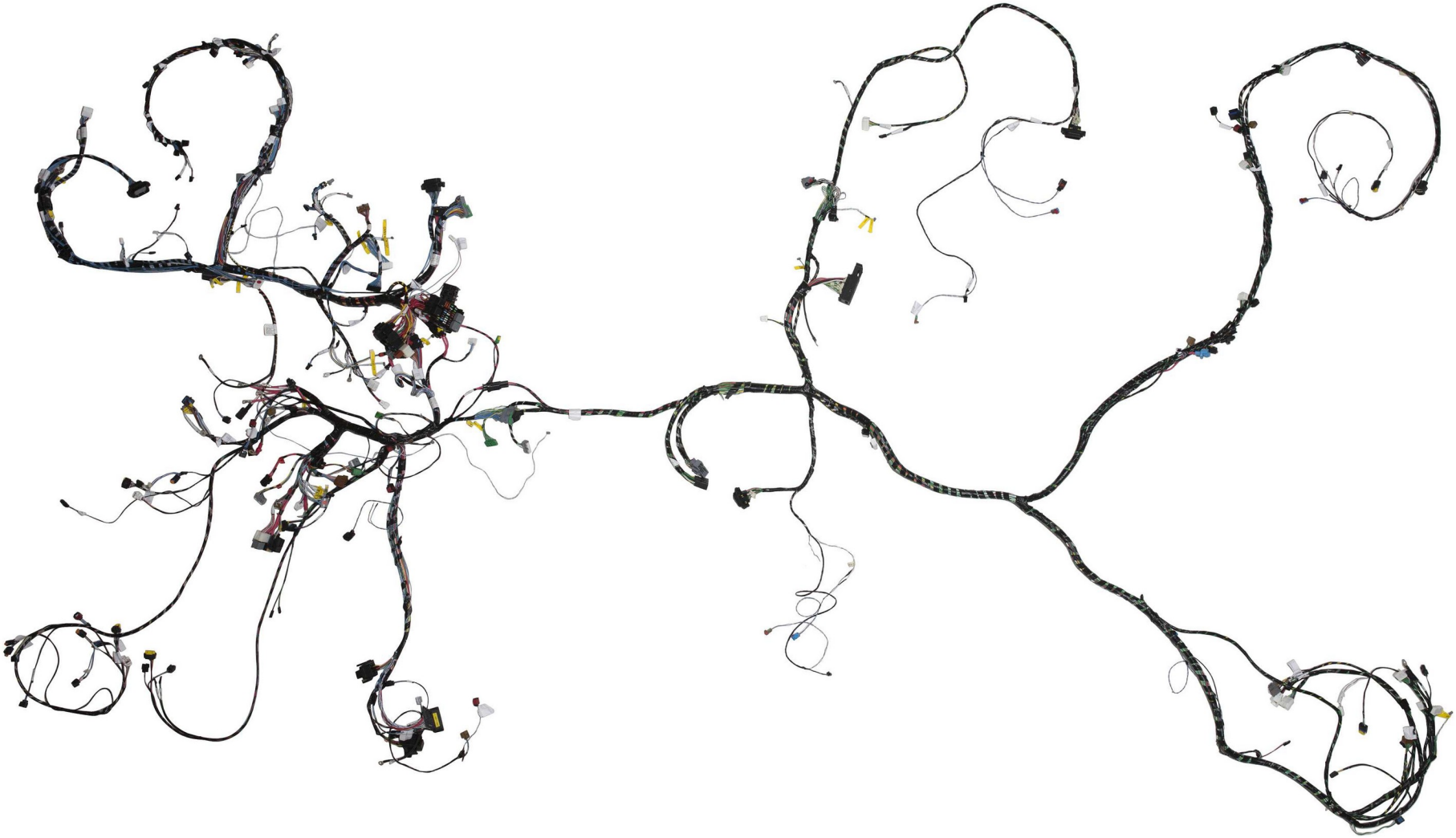
Price said the latest recall is an extension of the previous one because the company "found that there was a broader pool of vehicles that had the defective part."

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.

Copyright 2007 The Associated Press. All rights reserved. This material may not be published, broadcast, rewritten or redistributed.

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

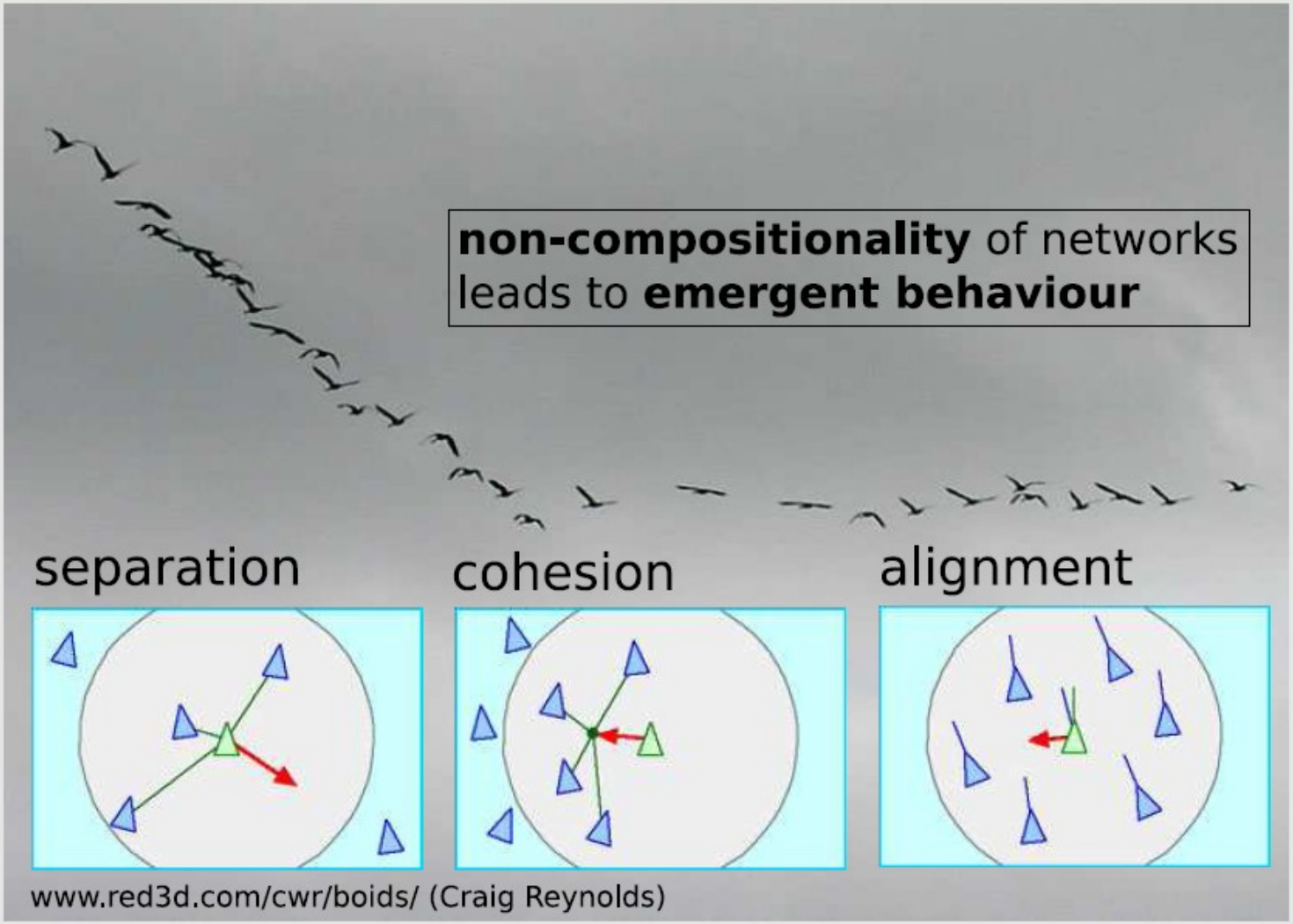



CAN

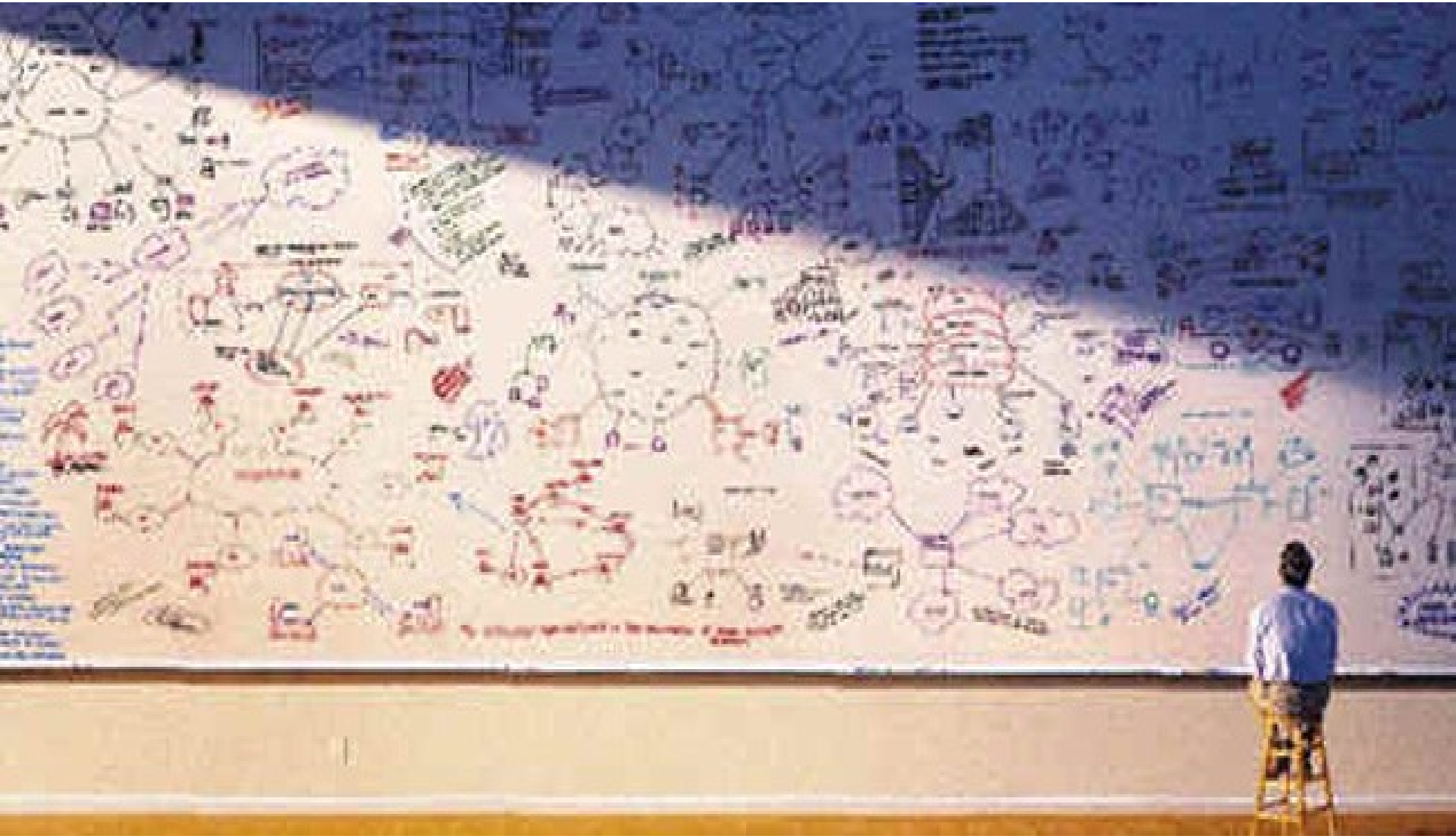
Cause of Complexity: constrained resources unanticipated interactions

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

Non-compositional/Emergent Behaviour



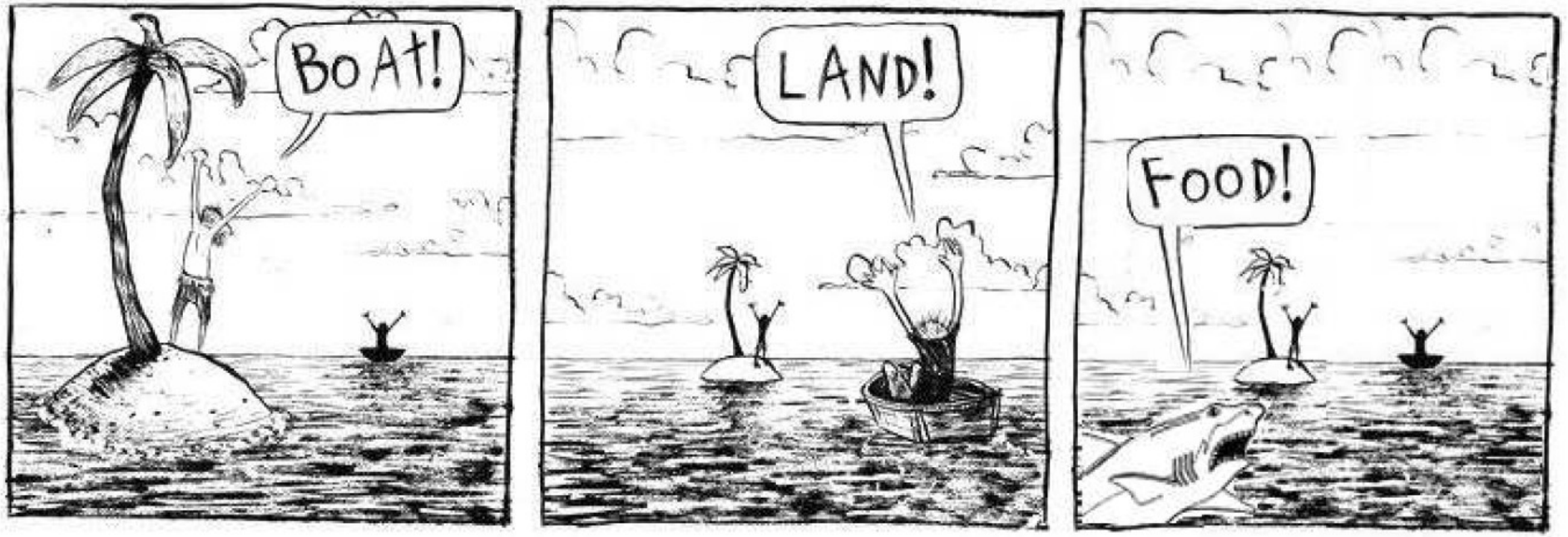
may use to reason (for a while) about abstraction “flock”



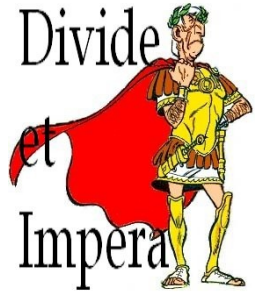
How to deal with **Complexity?**

(in engineered systems)

multiple viewpoints

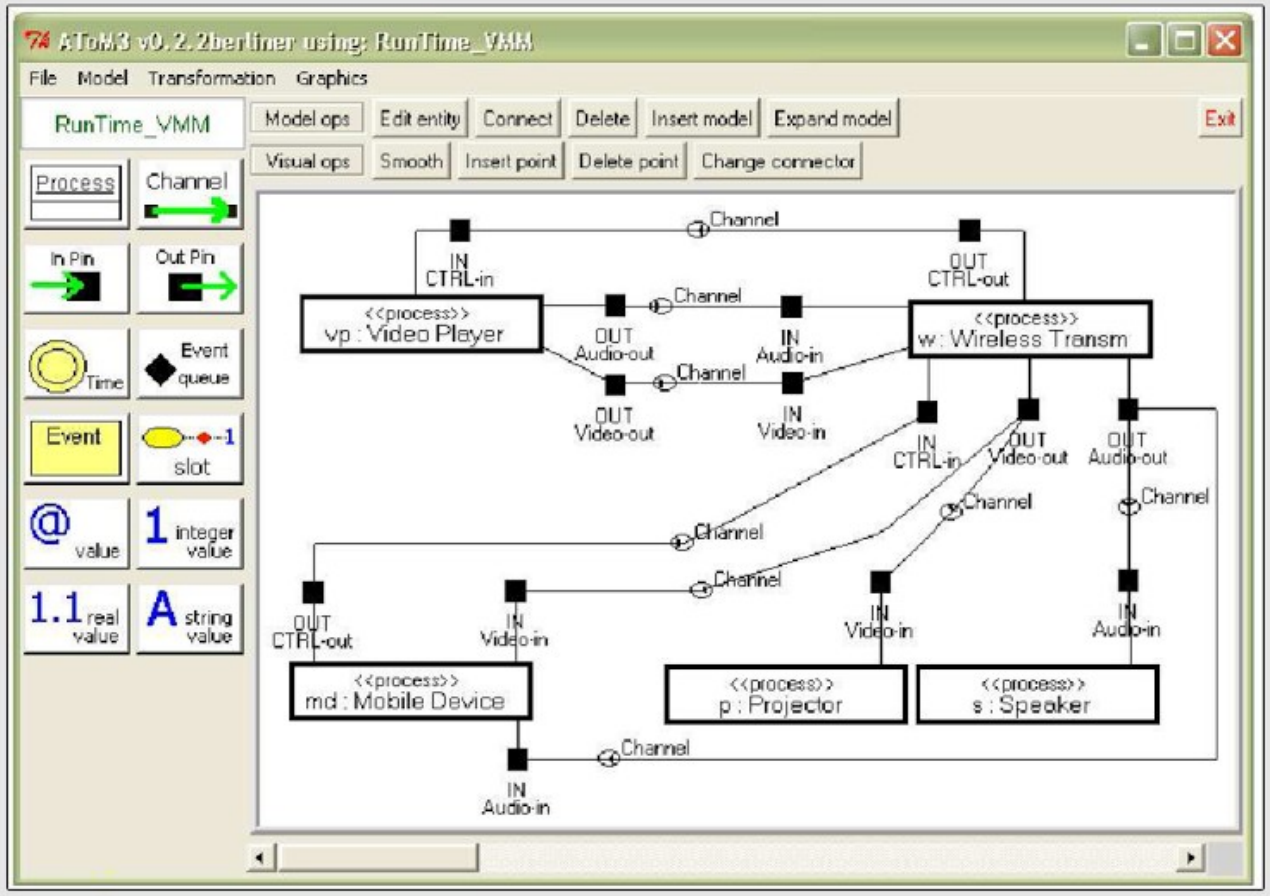


multiple viewpoints

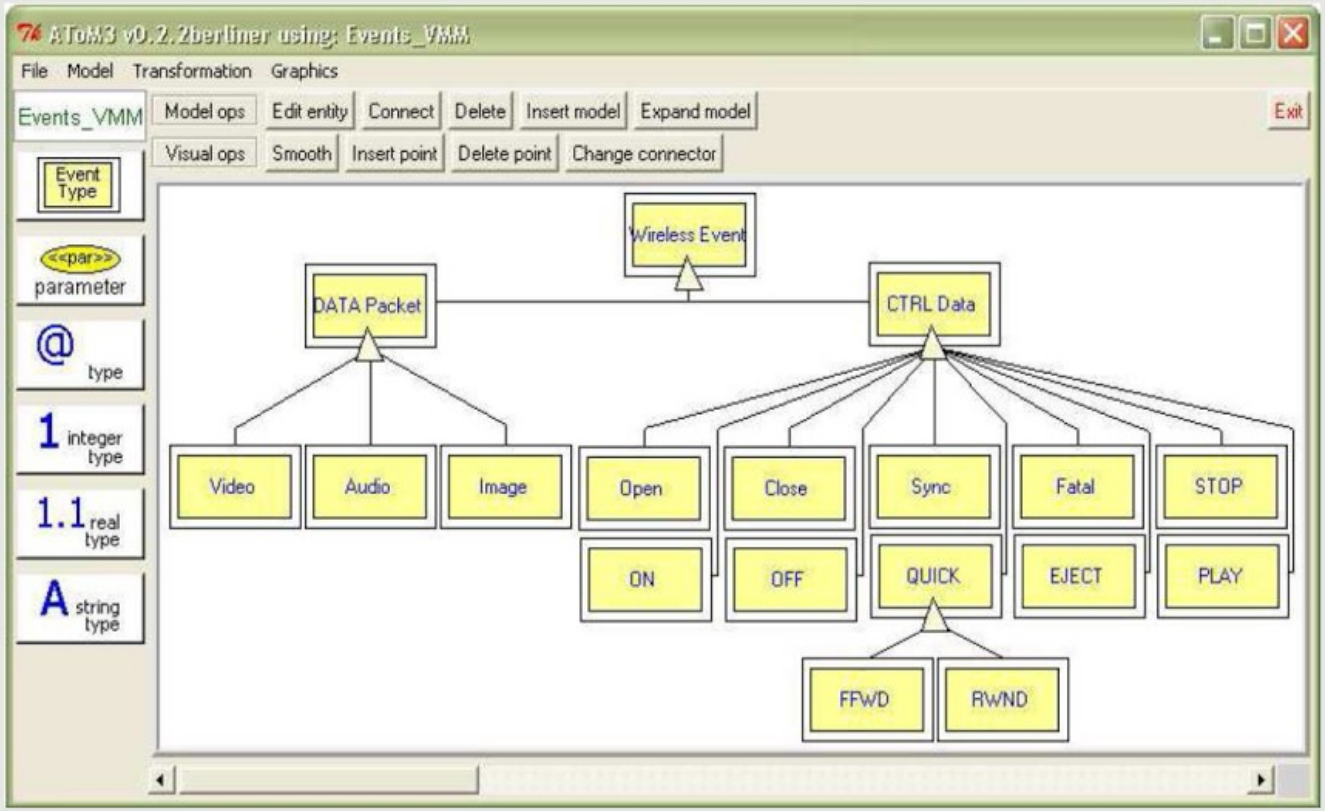


Wireless Home Entertainment System

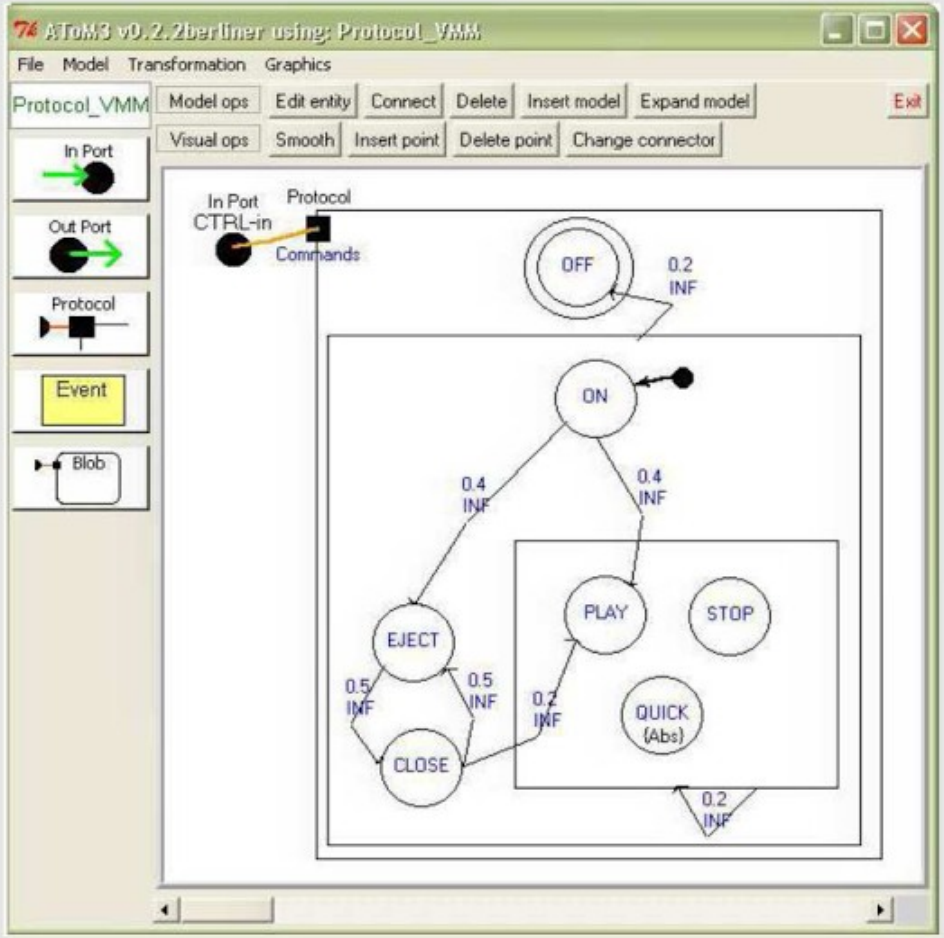
Multiple (consistent !) Views (in $\neq$ Formalisms)

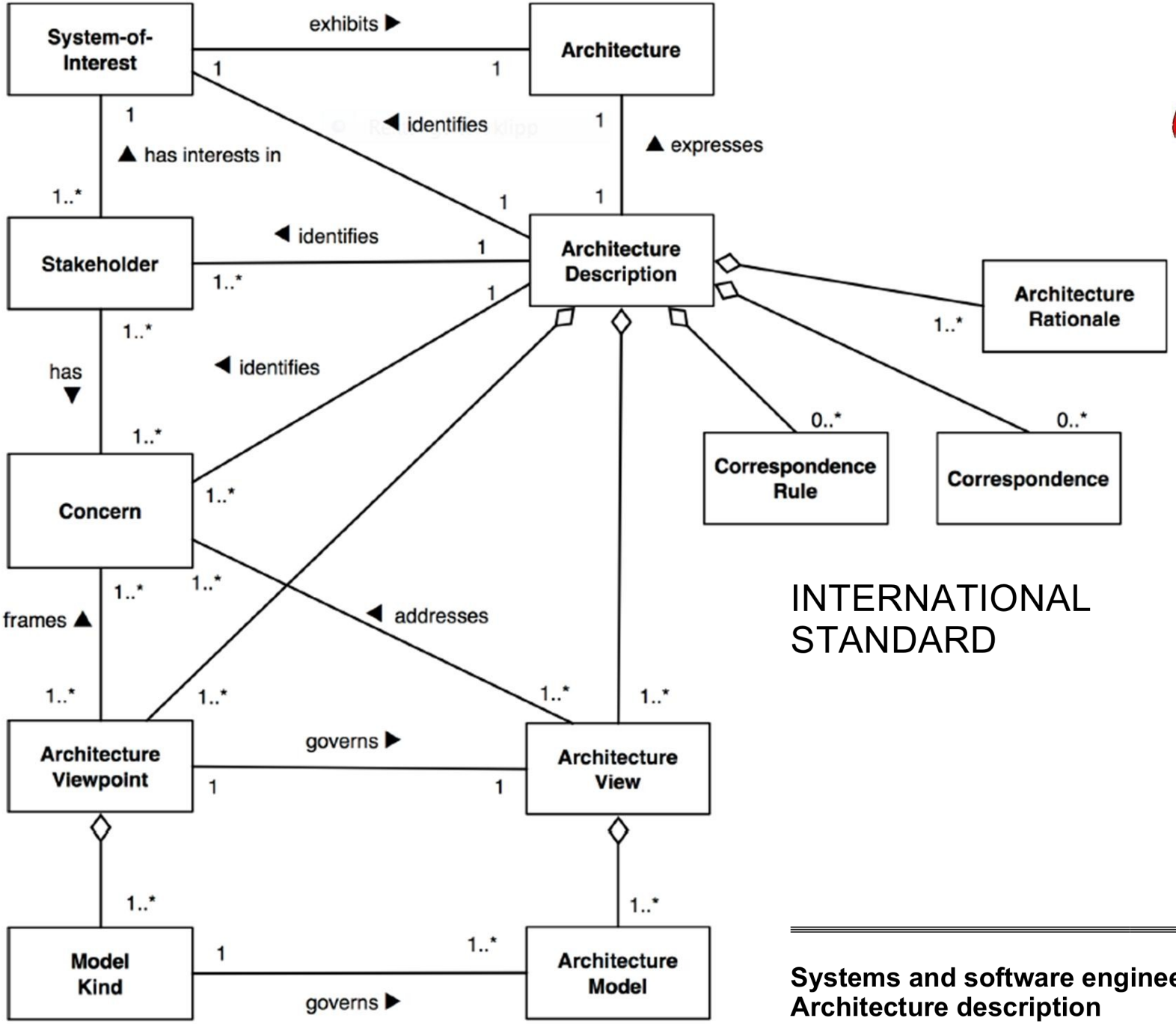


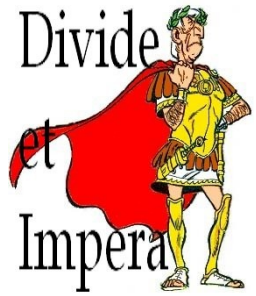
View: Events Diagram



View: Protocol Statechart







INTERNATIONAL STANDARD

ISO/IEC/ IEEE 42010

First edition
2011-12-01

Systems and software engineering — Architecture description

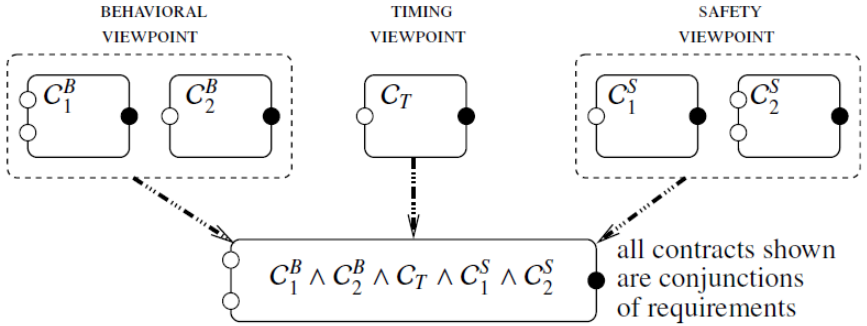
Contracts for Systems Design: Theory

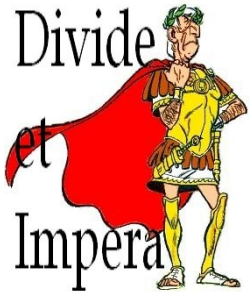
Albert Benveniste , Benoît Caillaud, Dejan Nickovic
Roberto Passerone, Jean-Baptiste Raclet
Philipp Reinkemeier, Alberto Sangiovanni-Vincentelli
Werner Damm, Tom Henzinger, Kim G. Larsen

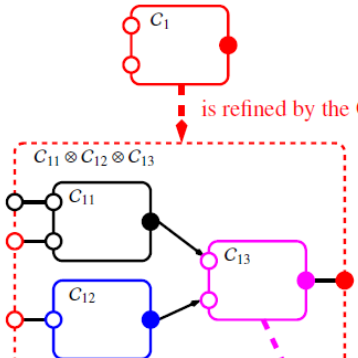
RESEARCH REPORT
N° 8759
July 2015
Project-Teams Hycomes

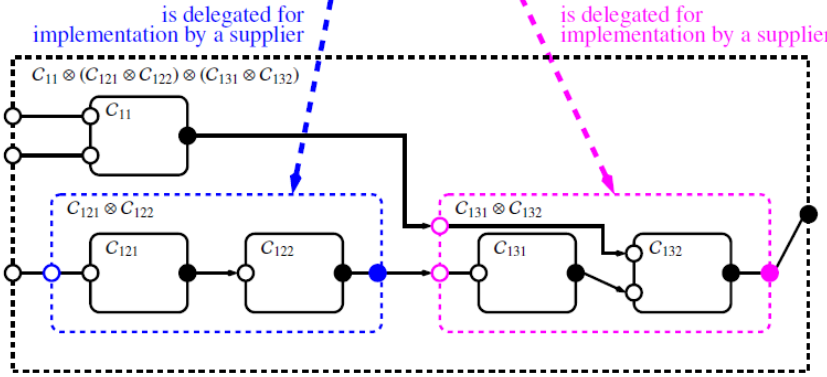
ISSN 0249-6399 ISRN INRIA/RR--8759--FR+ENG

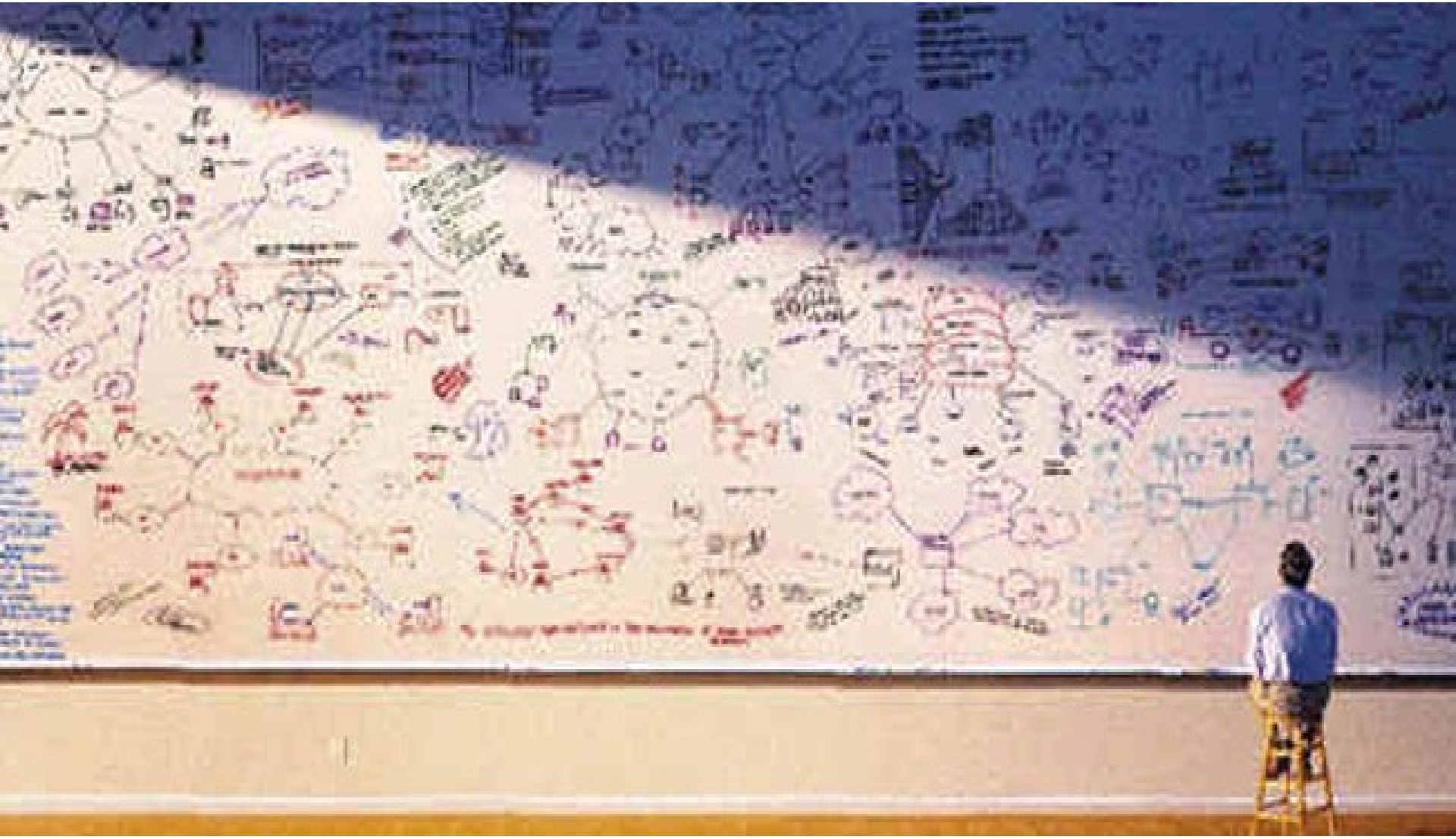
guarantees offered by the component
assumptions on its possible context







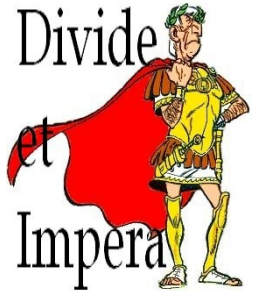




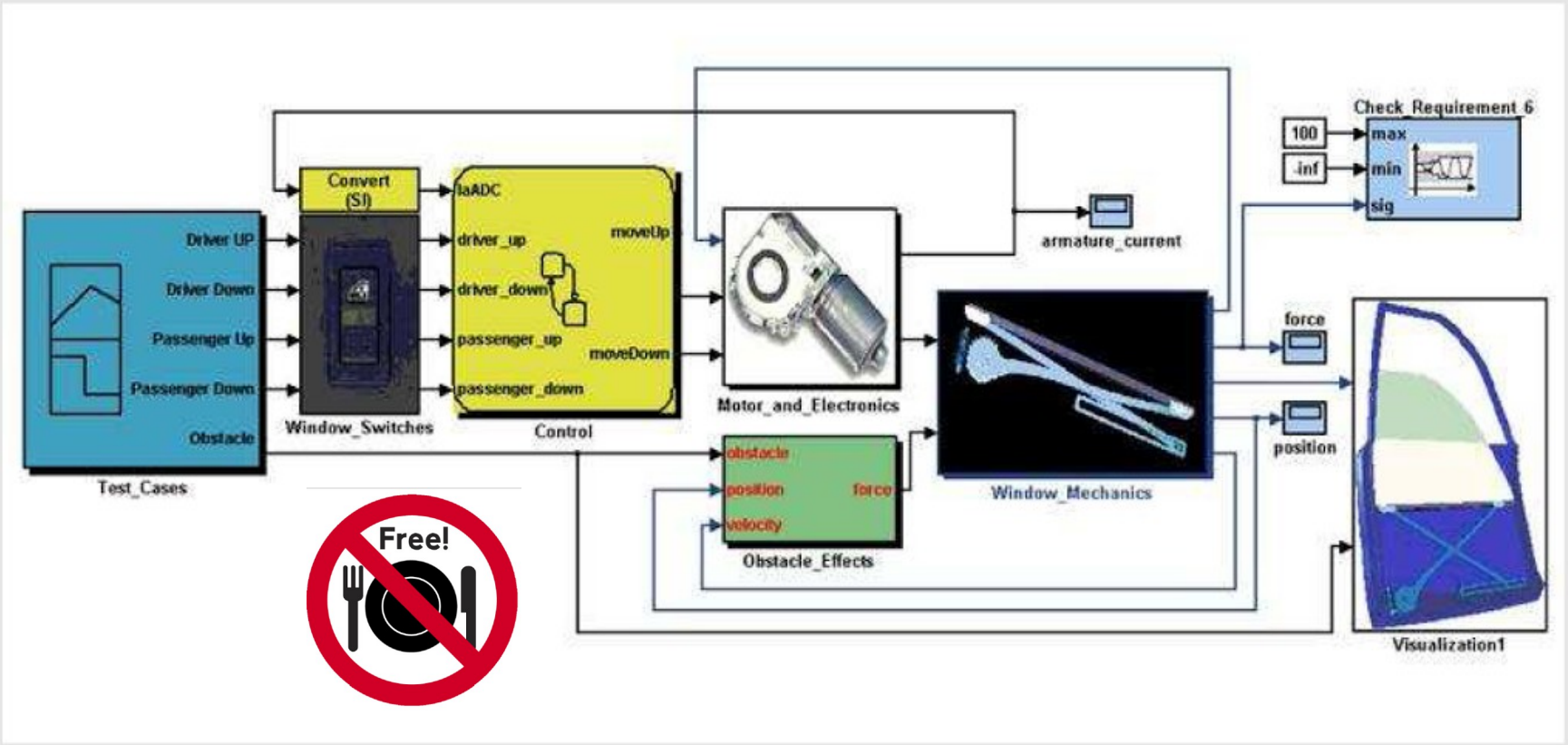
How to deal with **Complexity?**

(in engineered systems)

Most Appropriate Formalism(**s**)



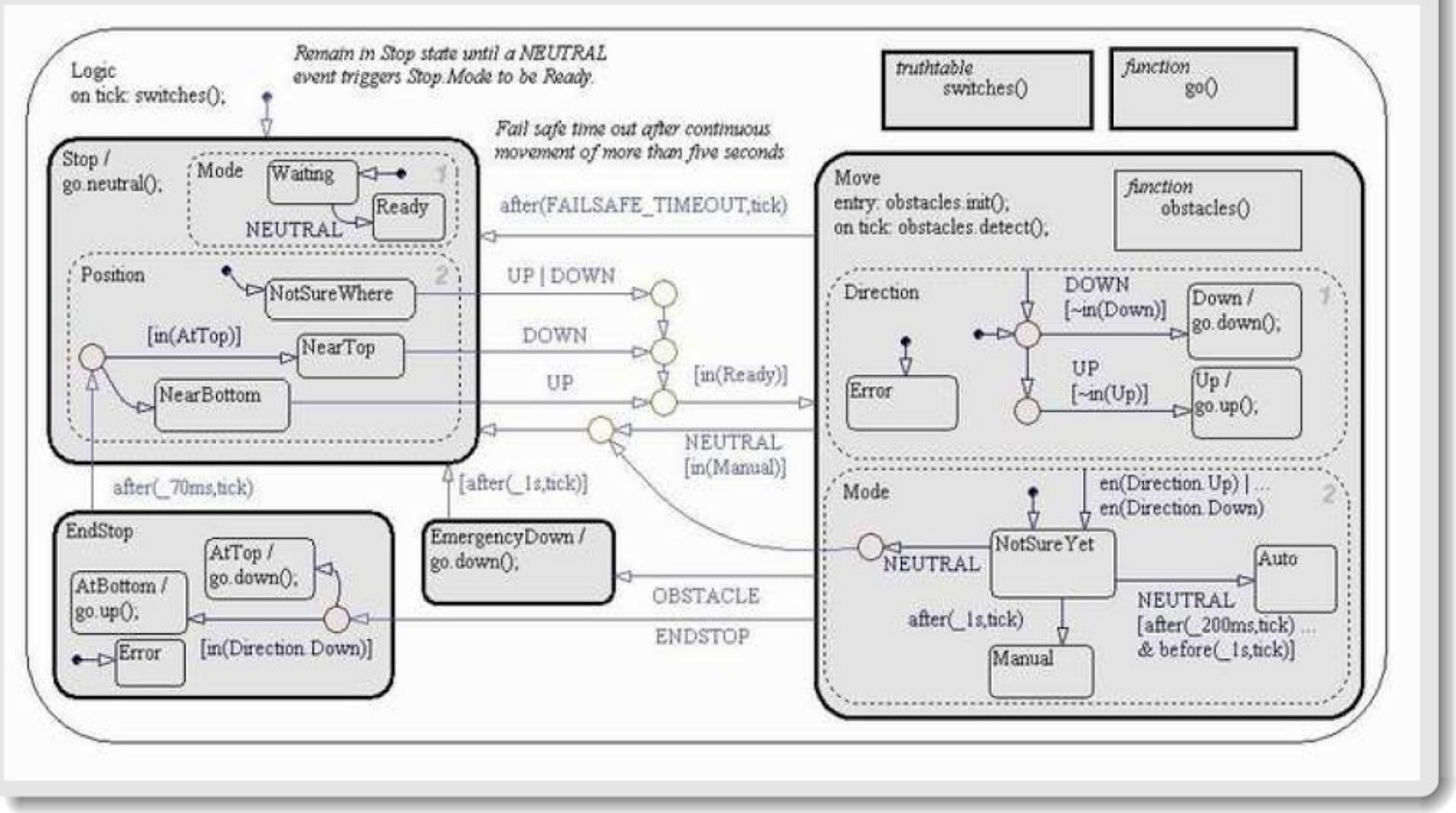
Components in Different Formalisms



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

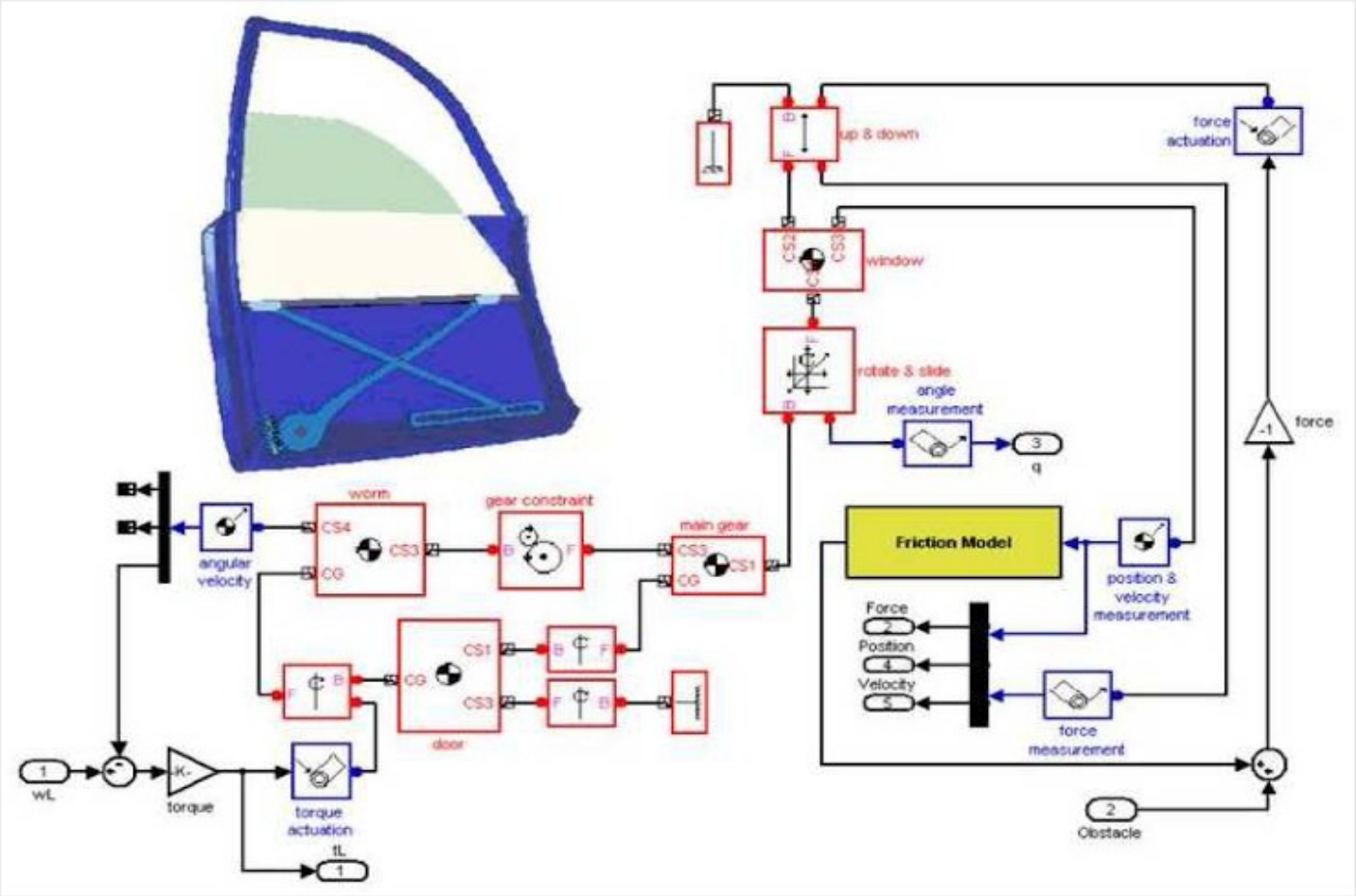
Most Appropriate Formalism(**s**)

Controller, using Statechart(StateFlow) formalism

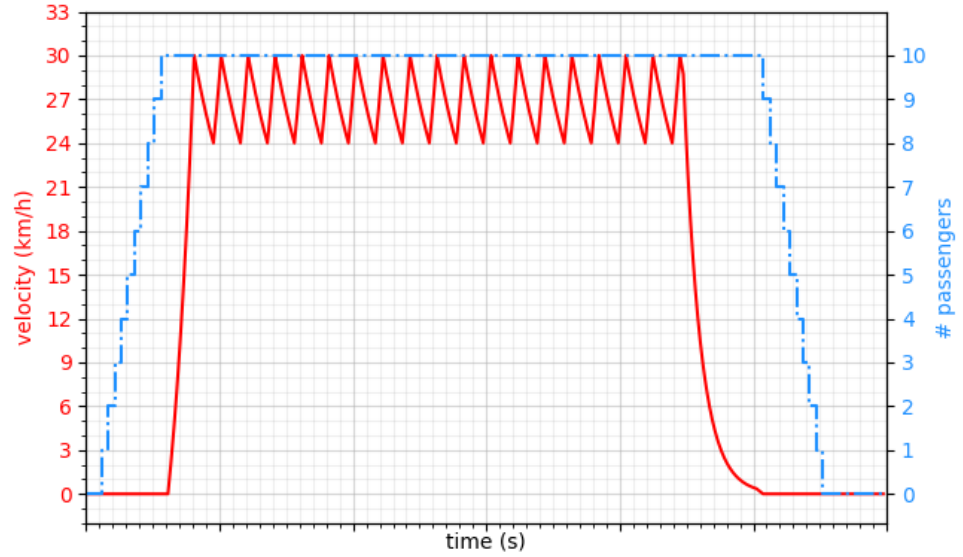


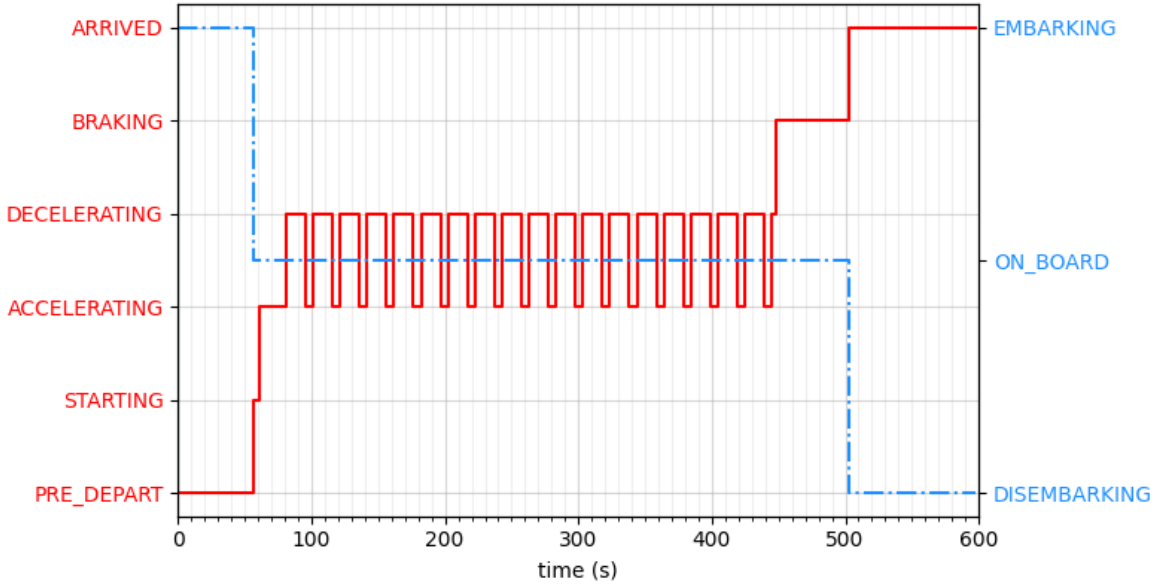
Most Appropriate Formalism(**s**)

Mechanics subsystem

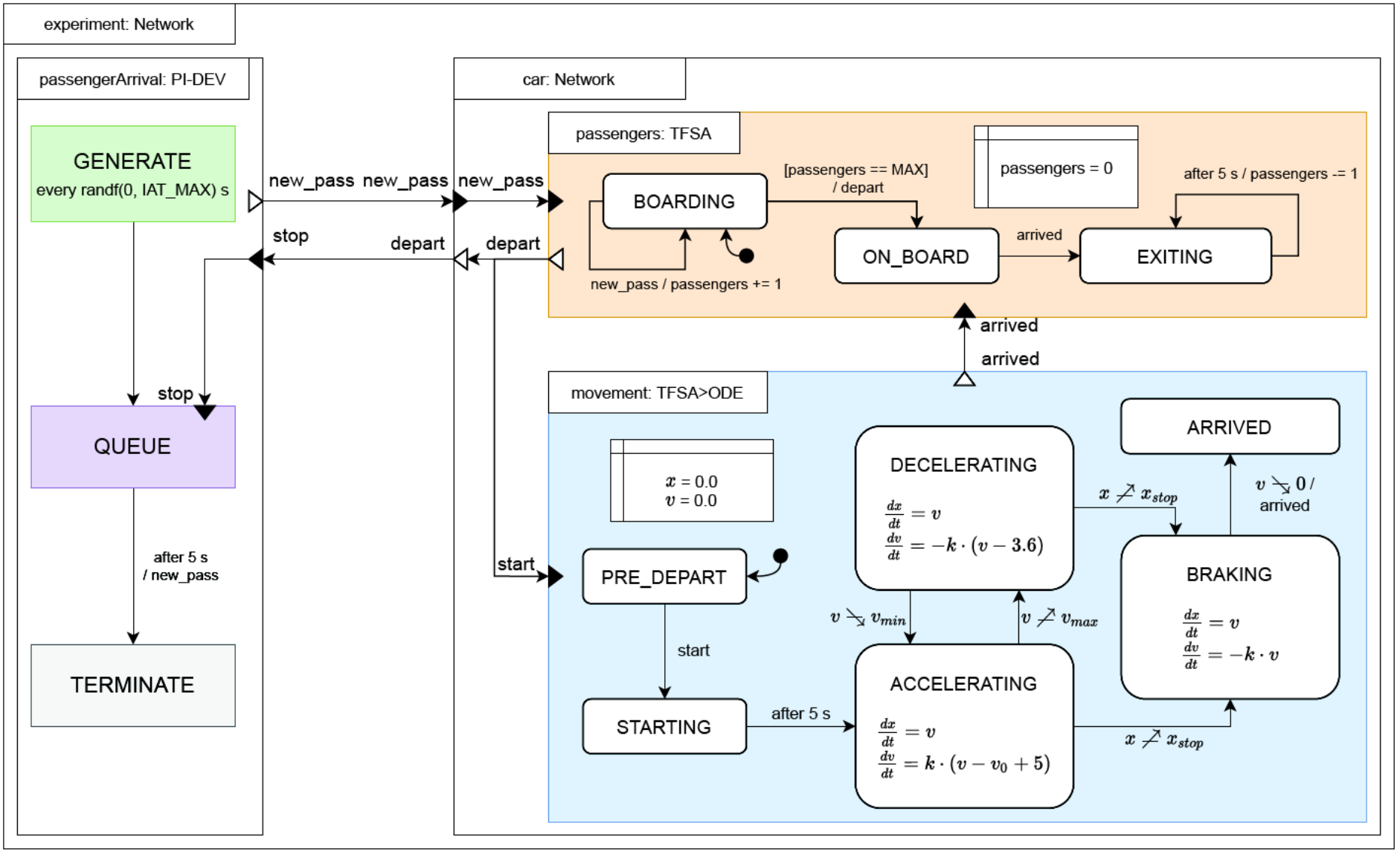


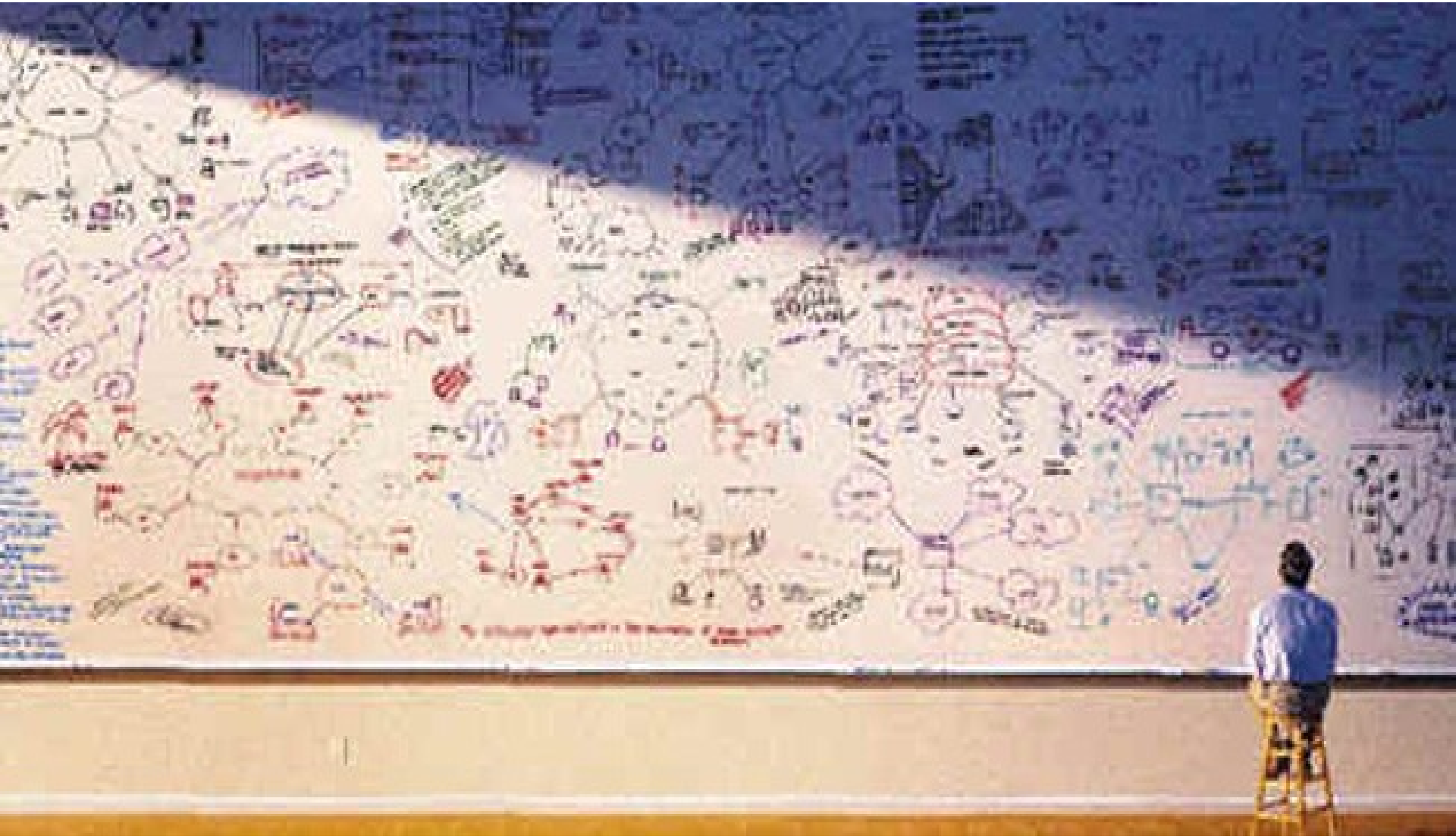

Morgantown
Personal Rapid Transit


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

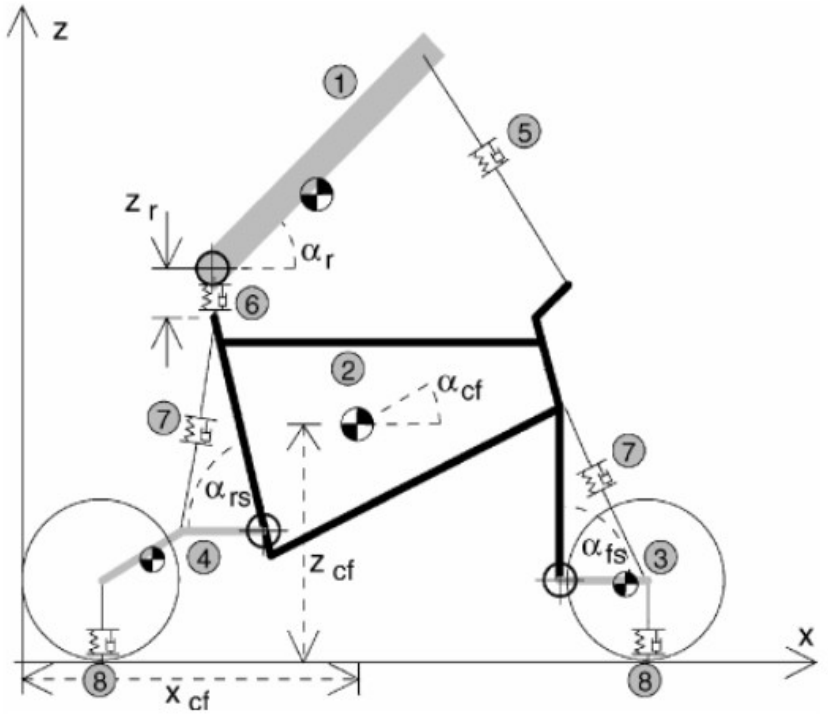




How to deal with **Complexity?**

(in engineered systems)

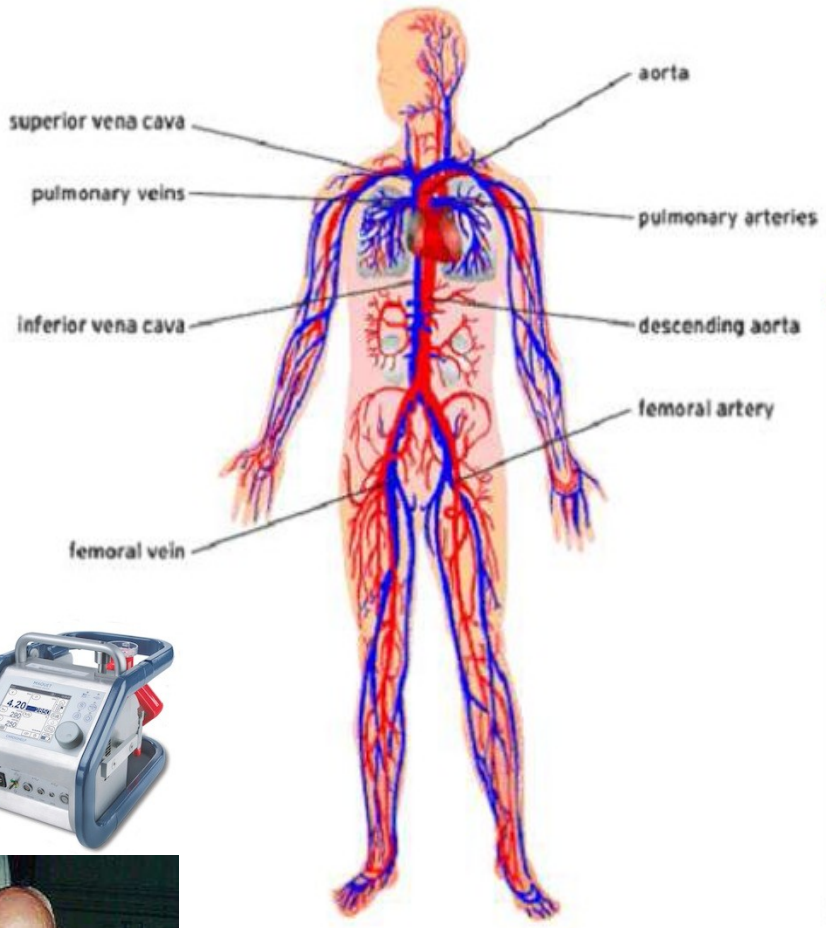
Different abstractions
(same or different formalisms)

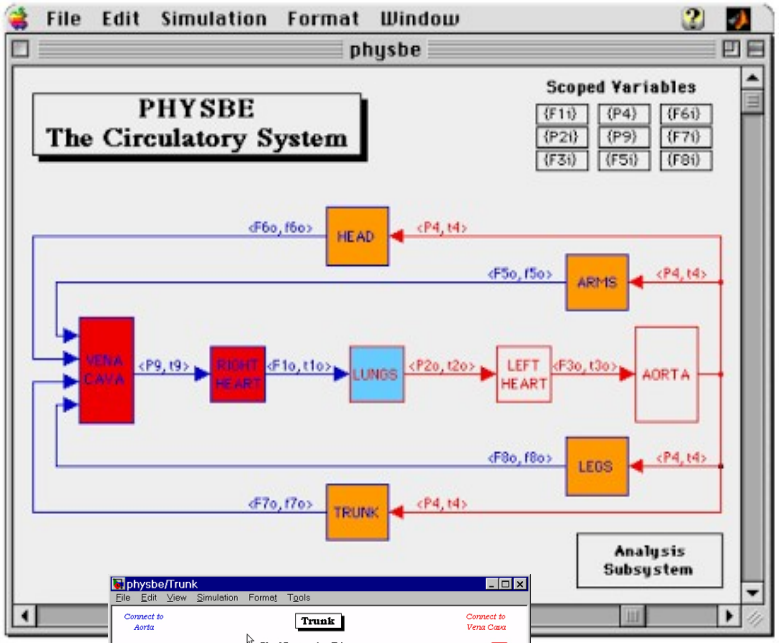


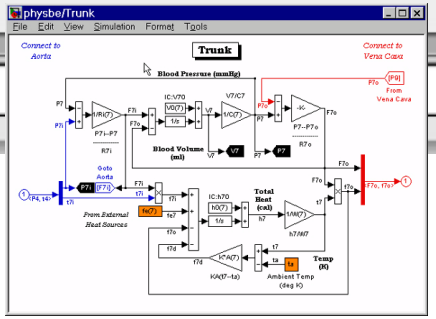
Distributed parameter

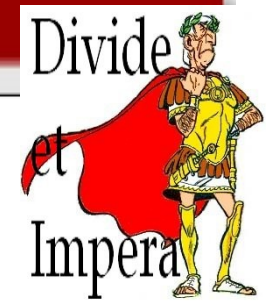
Lumped parameter

Different Abstraction Levels – properties preserved





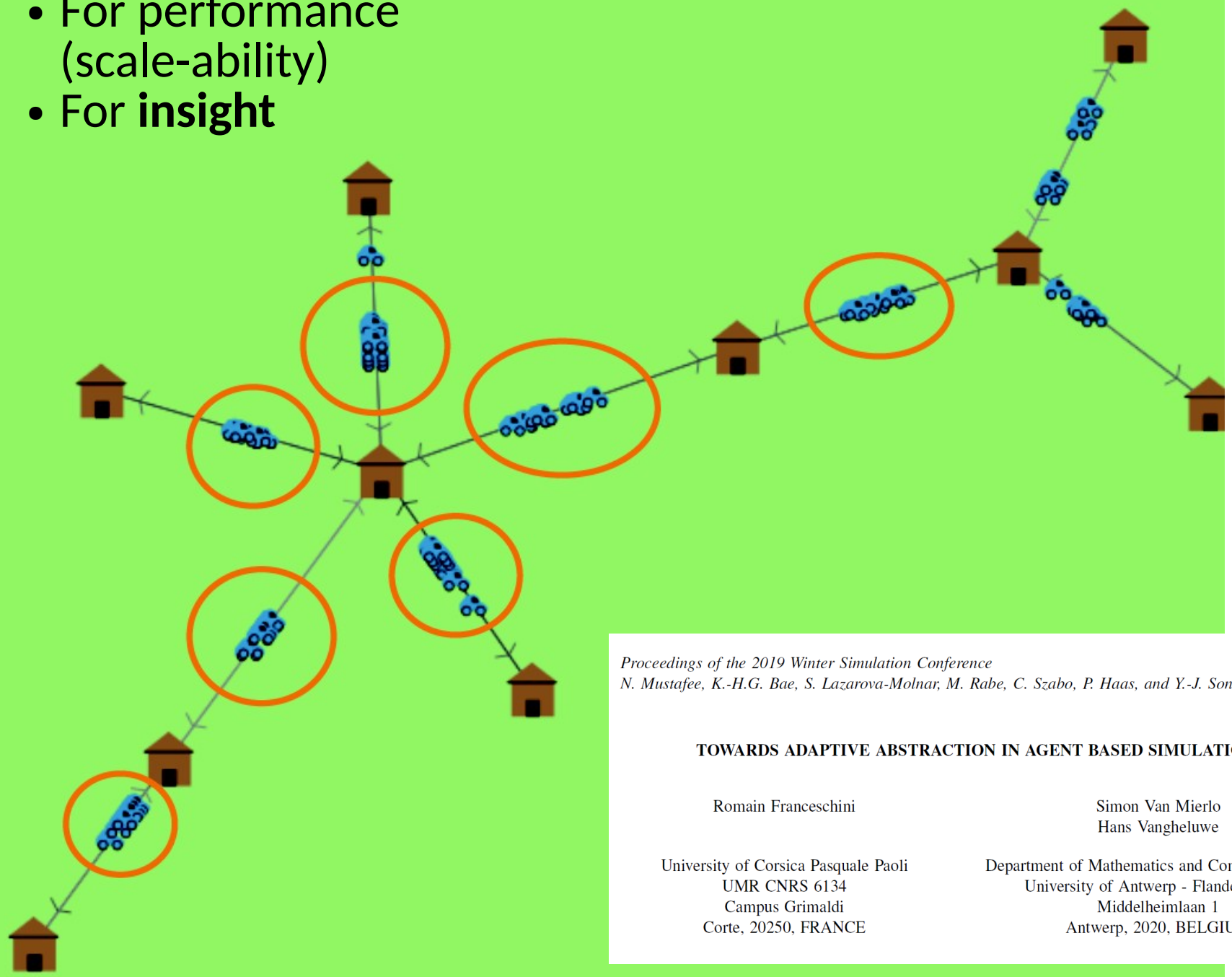




THE SOCIETY FOR MODELING & SIMULATION INTERNATIONAL

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

- 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.

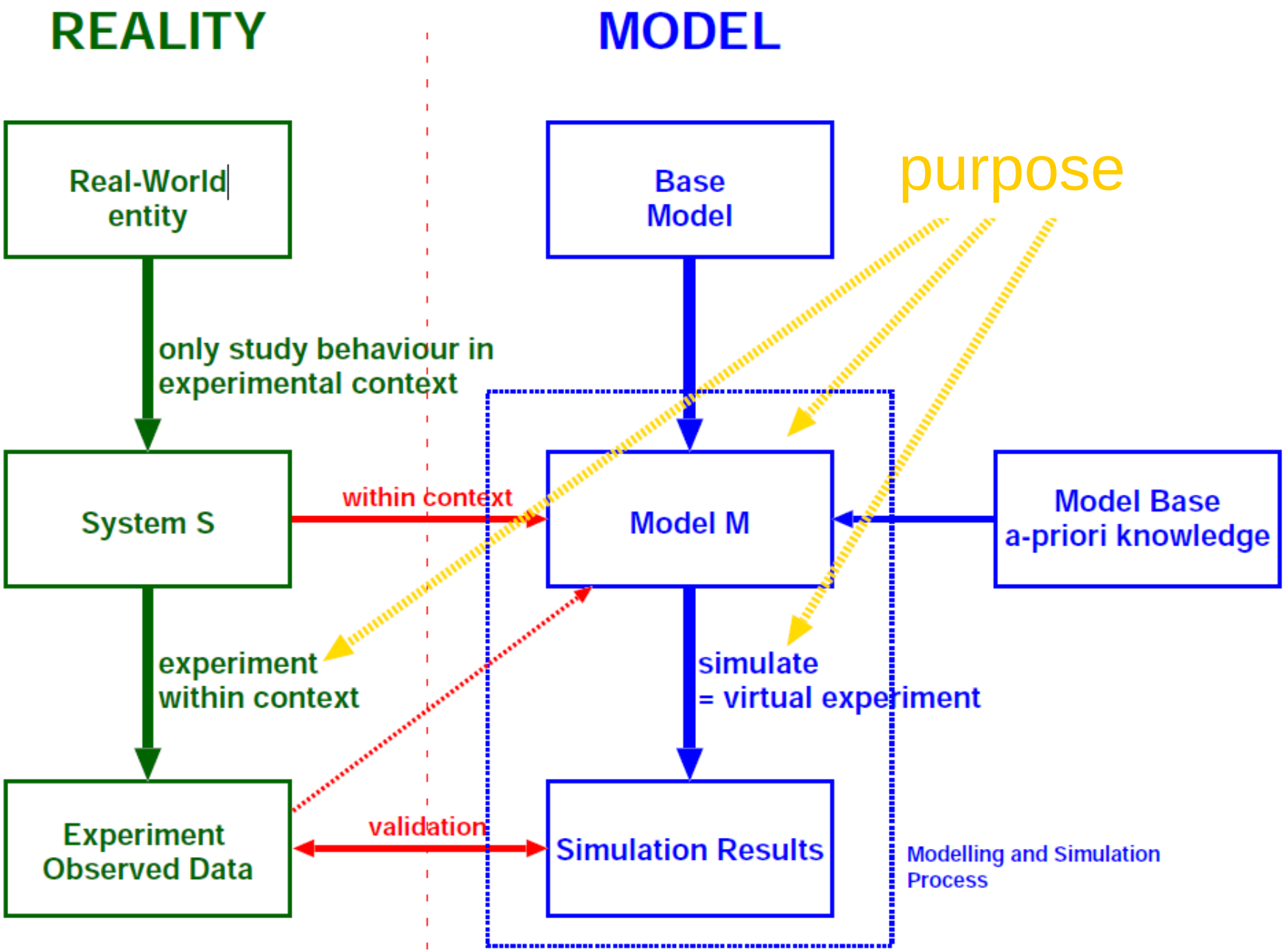
TOWARDS ADAPTIVE ABSTRACTION IN AGENT BASED SIMULATION

Romain Franceschini

University of Corsica Pasquale Paoli
UMR CNRS 6134
Campus Grimaldi
Corte, 20250, FRANCE

Simon Van Mierlo
Hans Vangheluwe

Department of Mathematics and Computer Science
University of Antwerp - Flanders Make
Middelheimlaan 1
Antwerp, 2020, BELGIUM



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

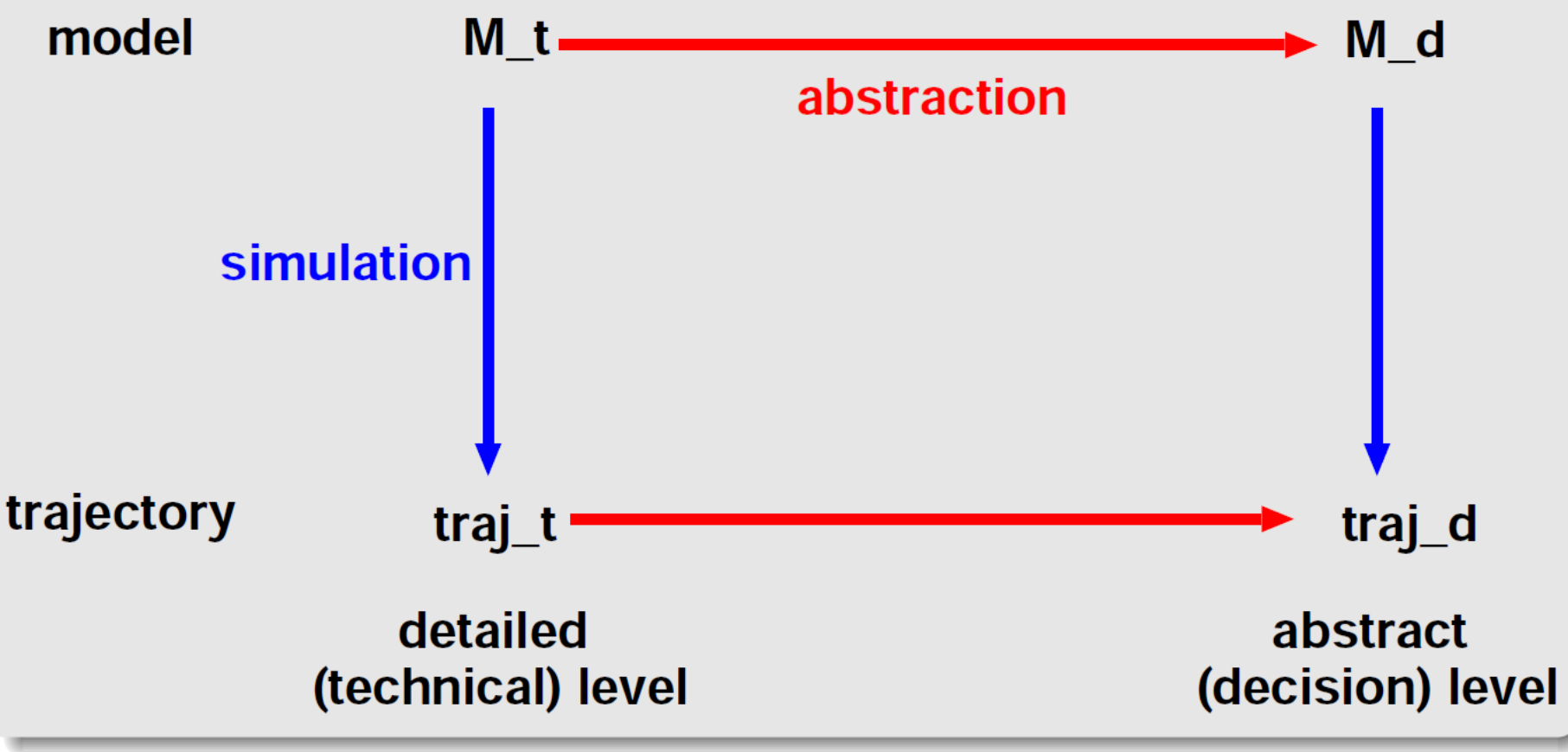
Abstraction Relationship

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.

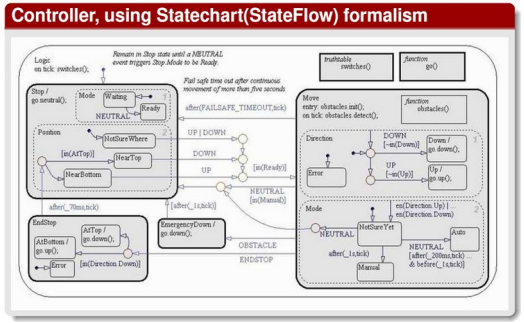
Abstraction and its opposite, *refinement* are
relative to a non-empty set of questions (properties) P.

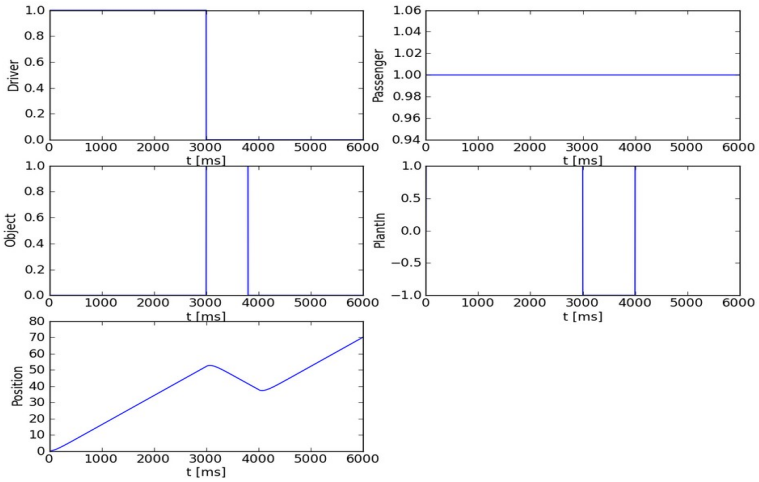
- If M_1 is an *abstraction* of M_2 with respect to P, for all $p \in P$: $M_1 \models p \Rightarrow M_2 \models p$. This is written $M_1 \sqsupseteq_P M_2$.
- M_1 is said to be a *refinement* of M_2 iff M_2 is an *abstraction* of M_1. This is written $M_1 \sqsubseteq_P M_2$.

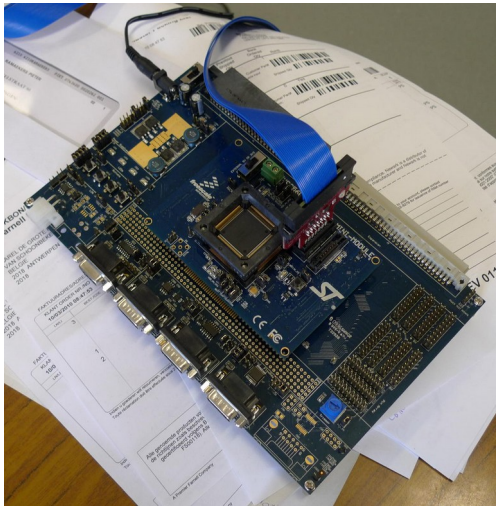
Levels of Abstraction/Views: Morphism

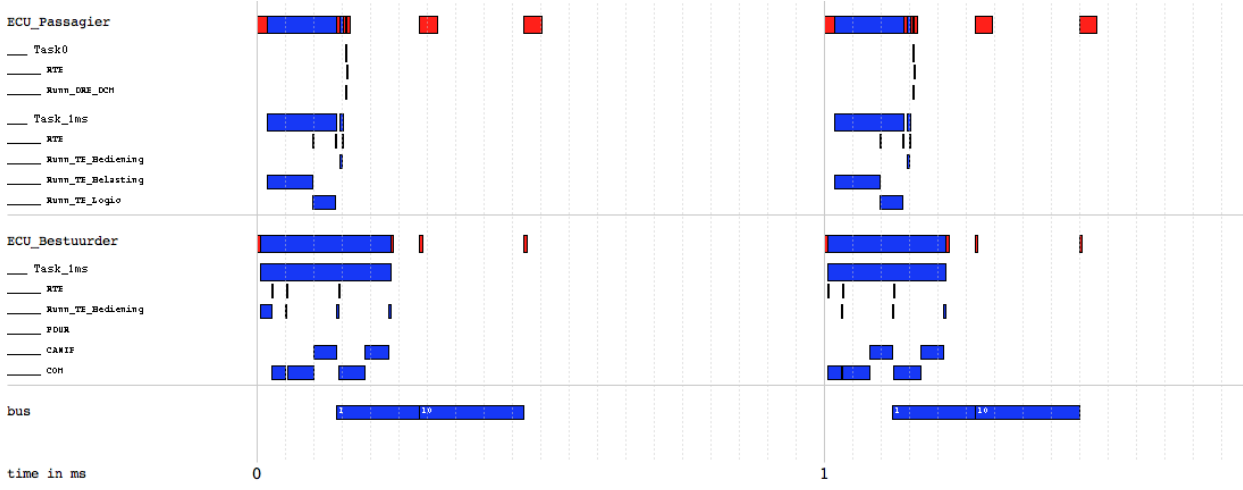


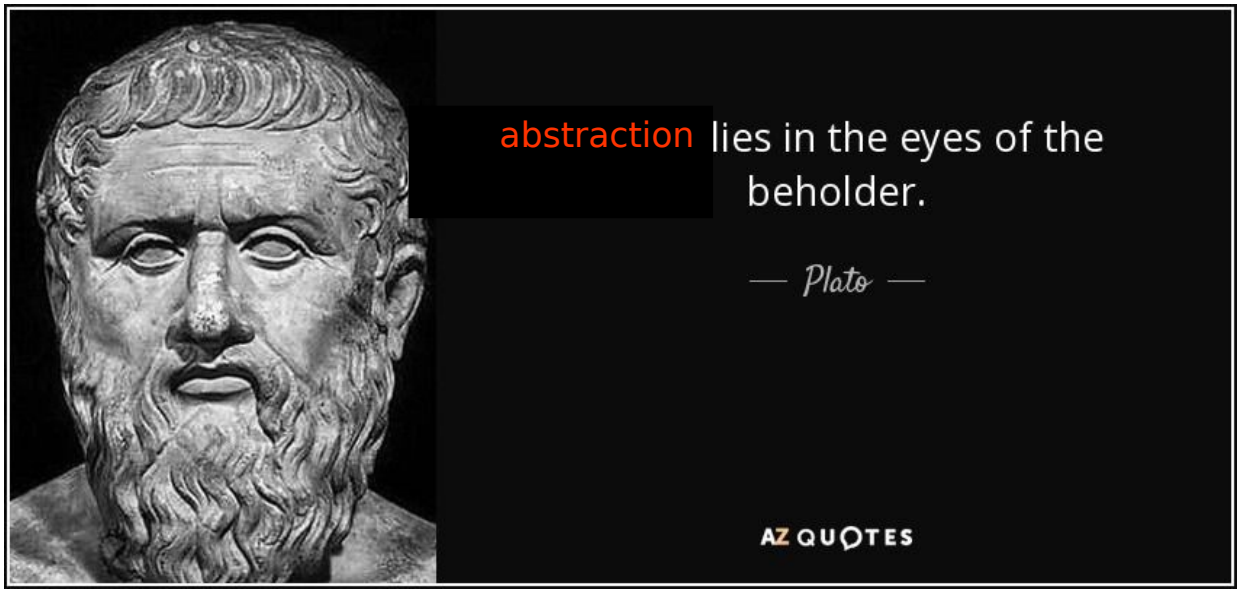
Caveat: **“Leaky” Abstractions** (and **approximations**)

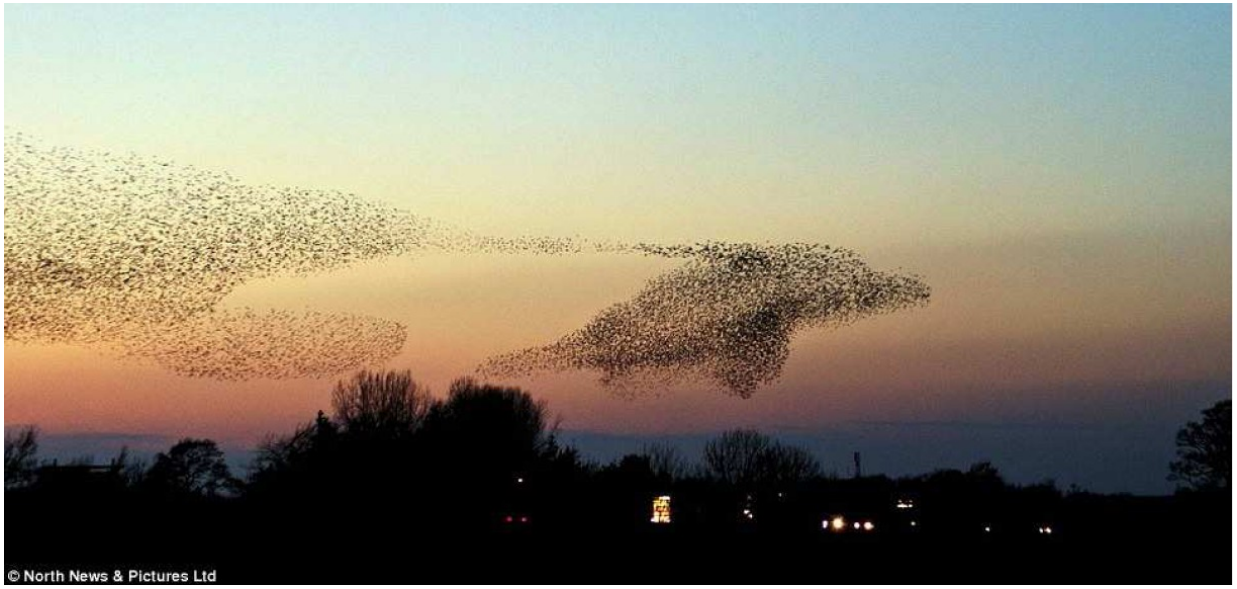






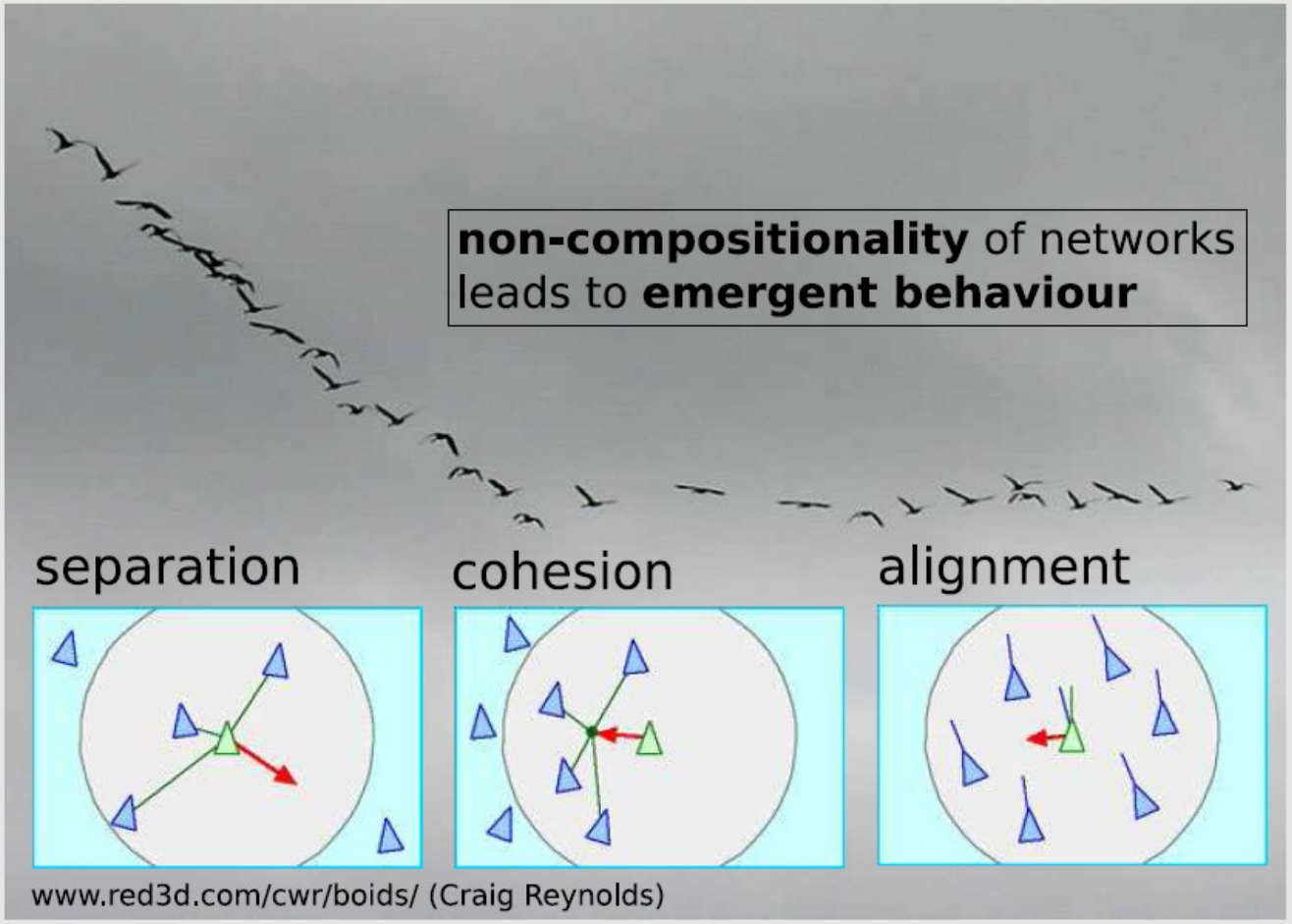



abstraction lies in the eyes of the beholder.
— Plato —
AZ QUOTES


© North News & Pictures Ltd

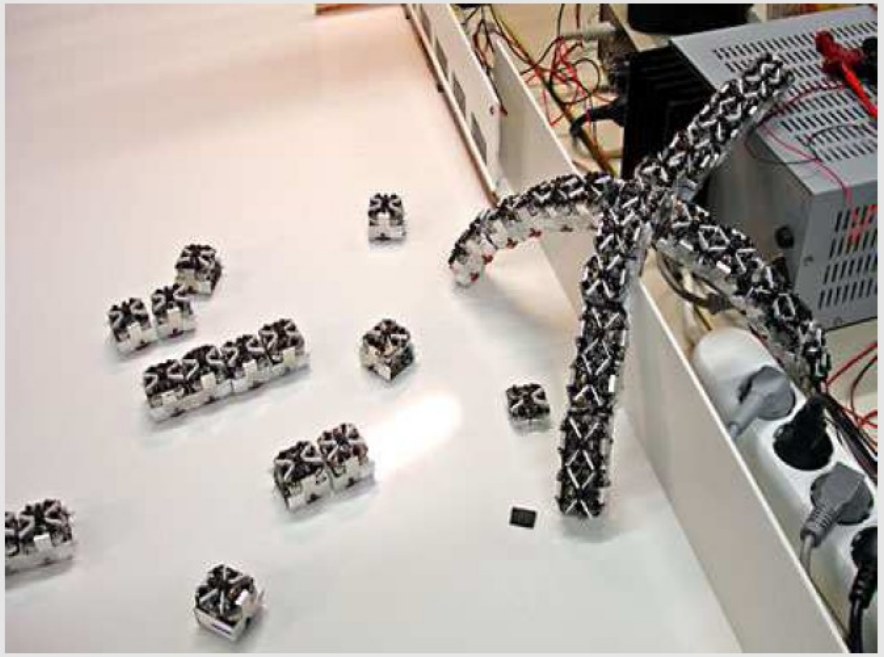
abstraction depends on the **properties** of interest!

Non-compositional/Emergent Behaviour

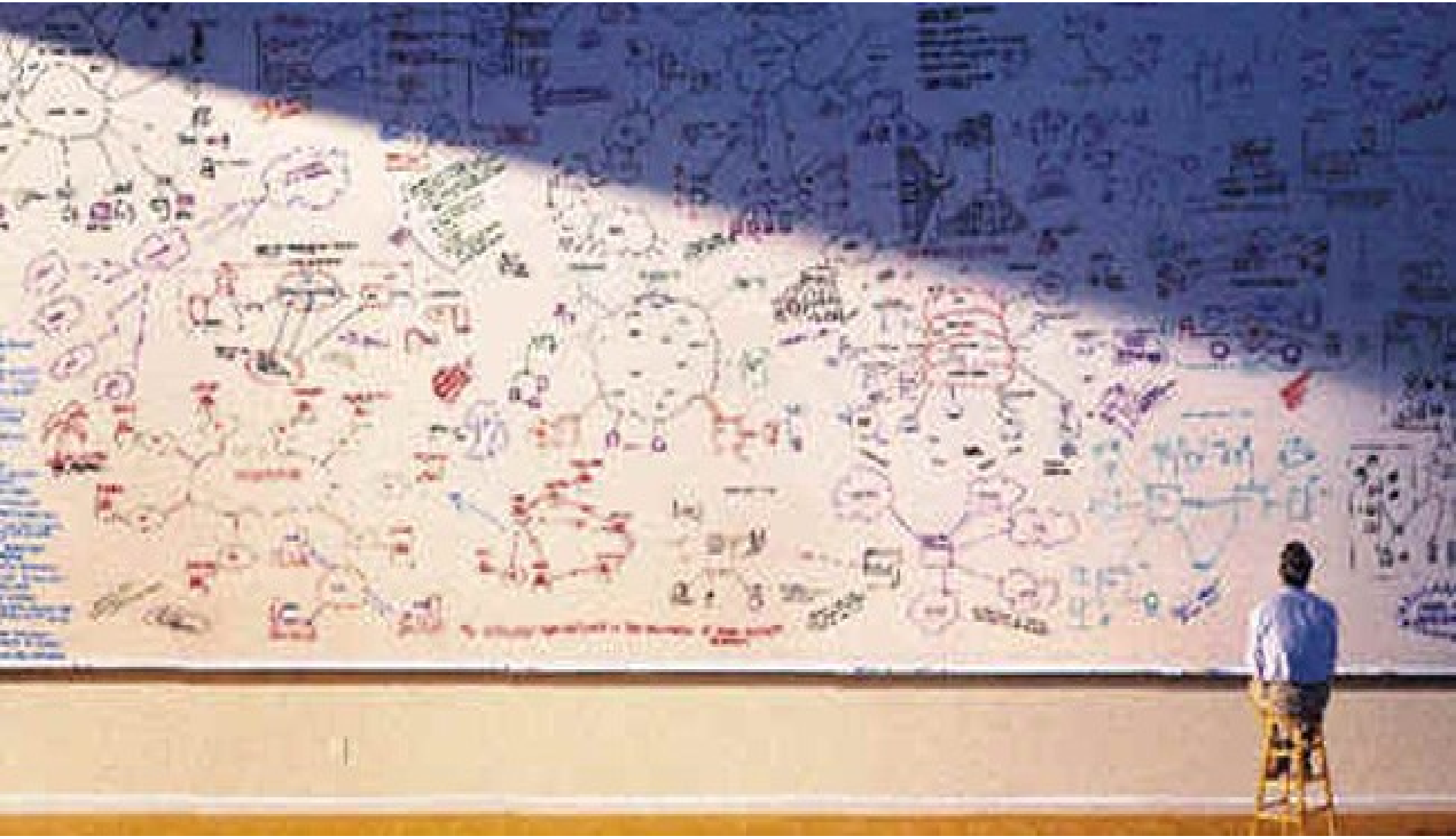


may use to reason (for a while) about abstraction “flock”

Engineered Emergent Behaviour

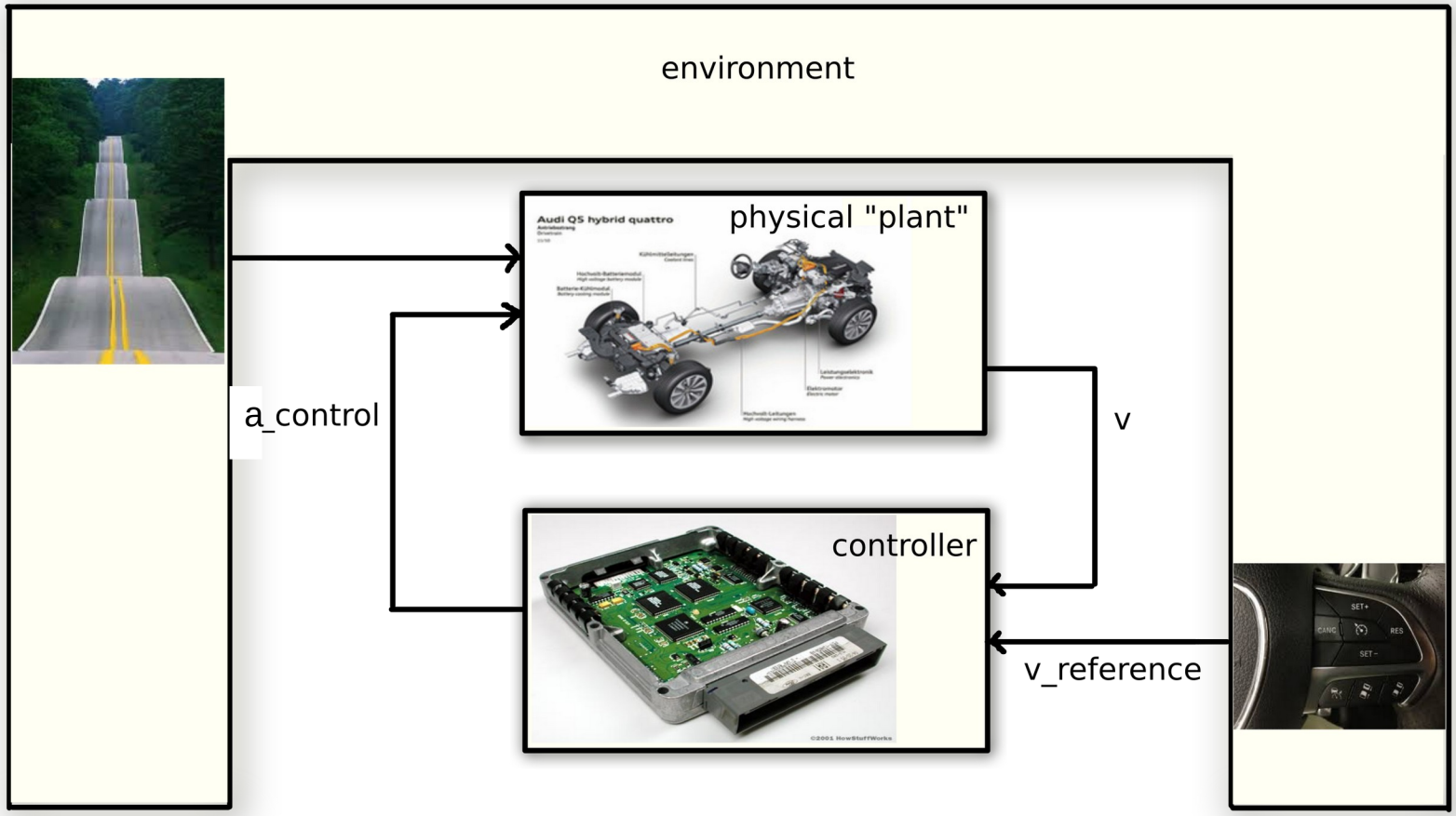


Robert Bogue. *Swarm intelligence and robotics.* Industrial Robot: An International Journal. 35(6):488 - 495, 2008.

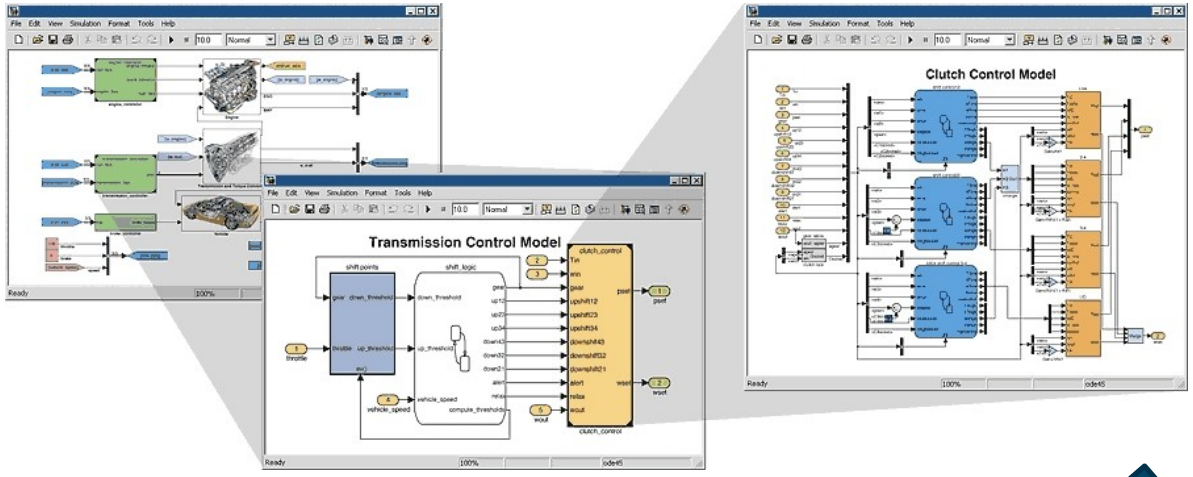


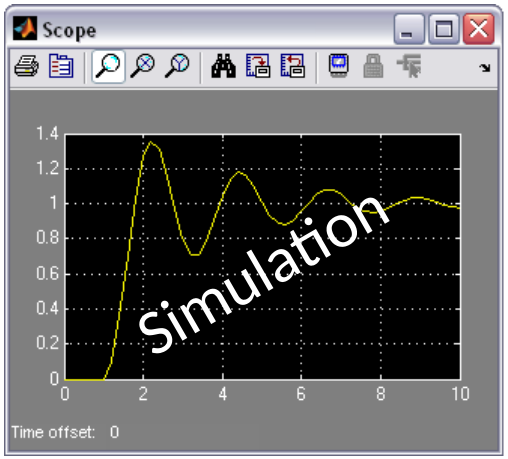
How to deal with **Complexity?**

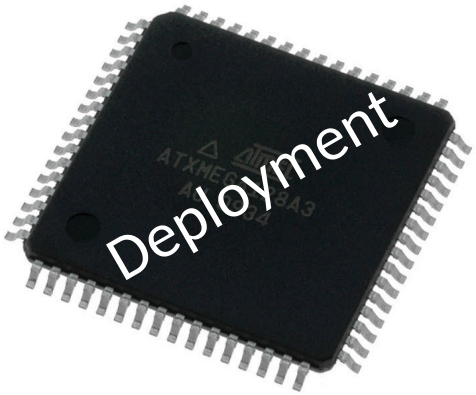
(in engineered systems)


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

Model-Based System Design







MiL, HiL, SiL, ...

Automotive MBSE

Function Model

Discretation,
Scaling,
Augmentation,
Embedding

Production Model

Autocoding

Production Code

MiL-Test

RCP

SiL-Test

PiL/HiL-Test

Integration

Simulation System

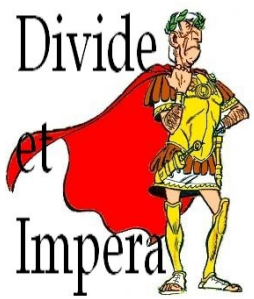
Prototyping HW +
Vehicle

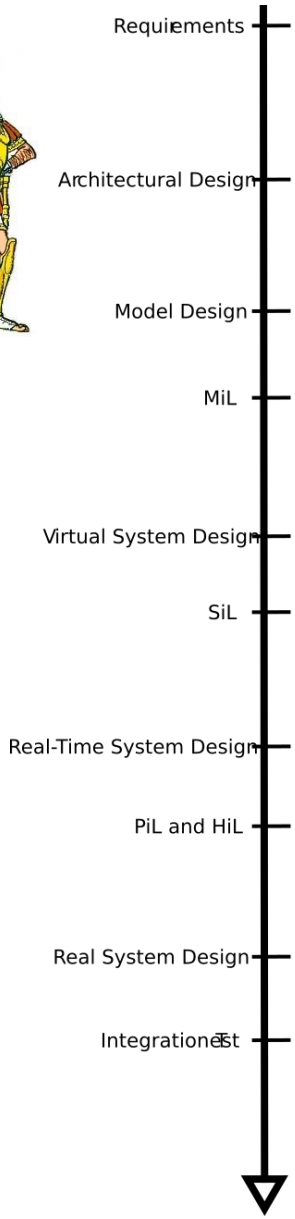
Simulation System

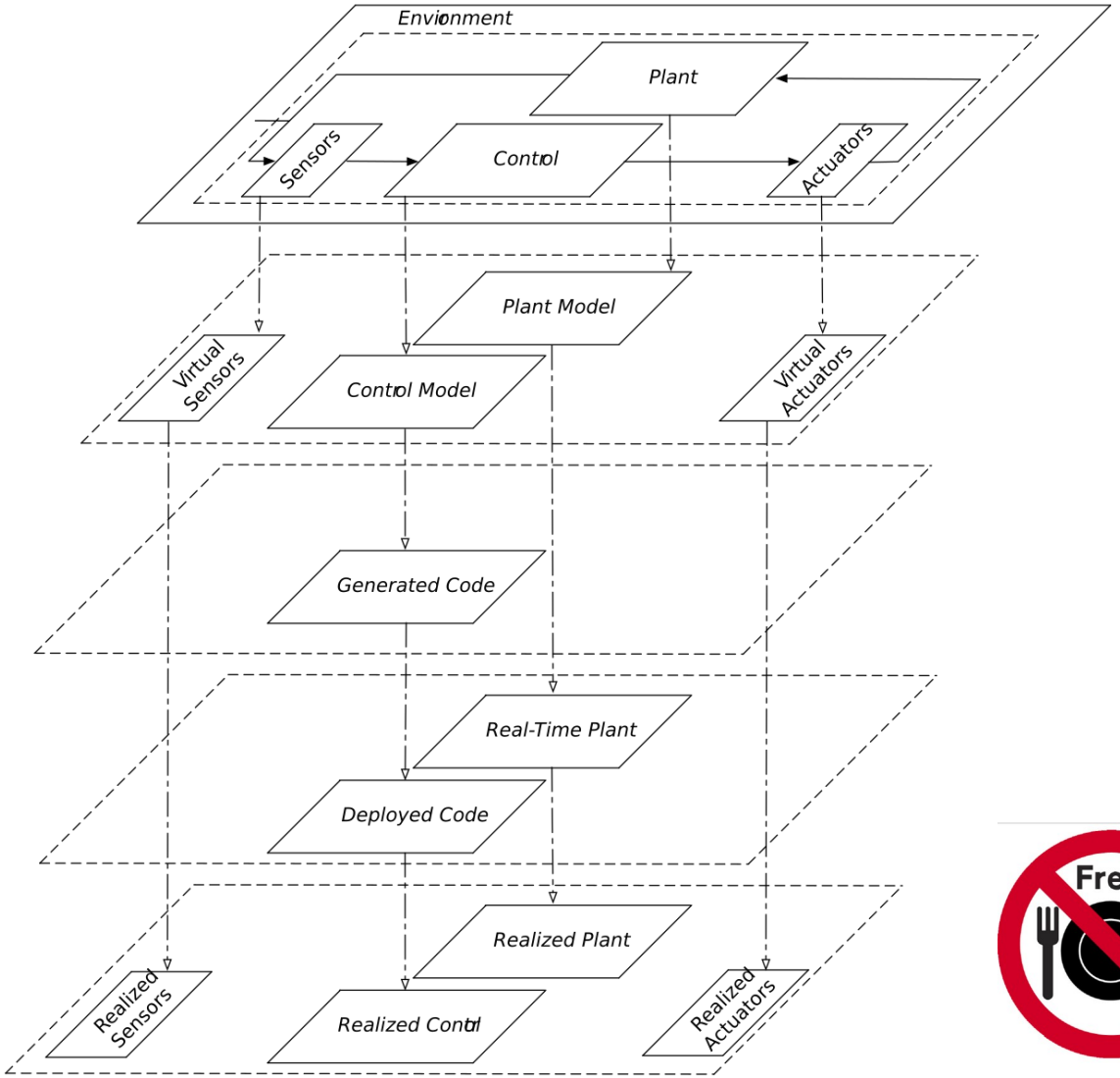
Controller +
Simulation of
Environment

Controller +
Vehicle

XiL: X = Model, Software, Processor, Hardware

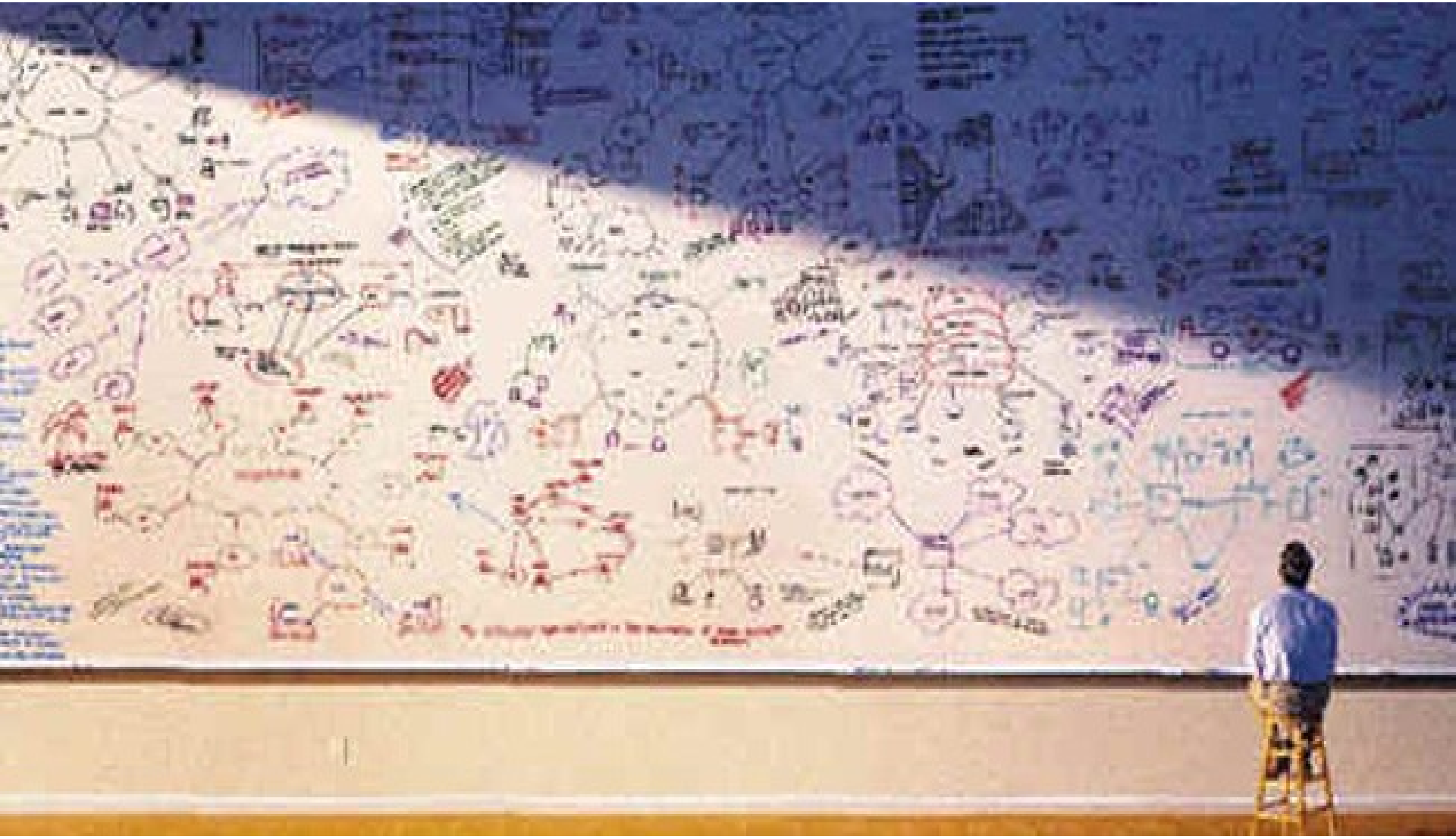






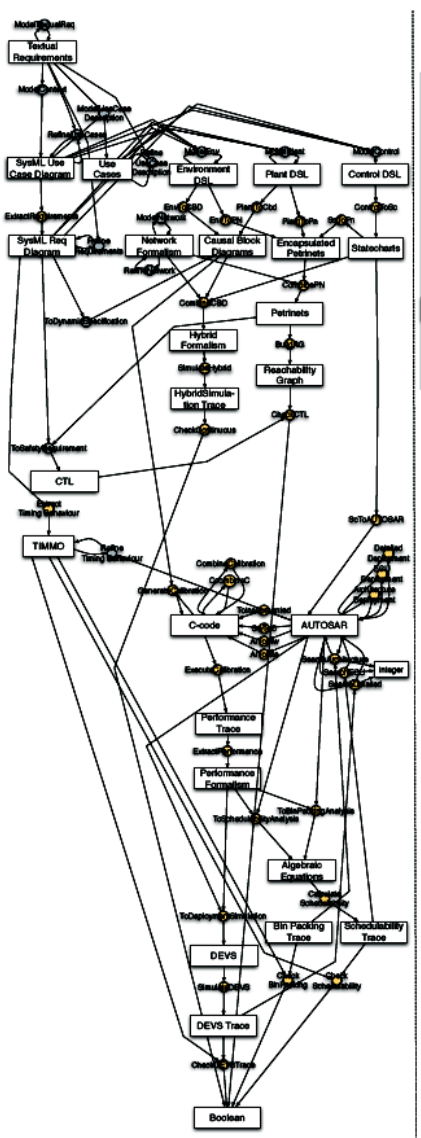
vertical consistency!

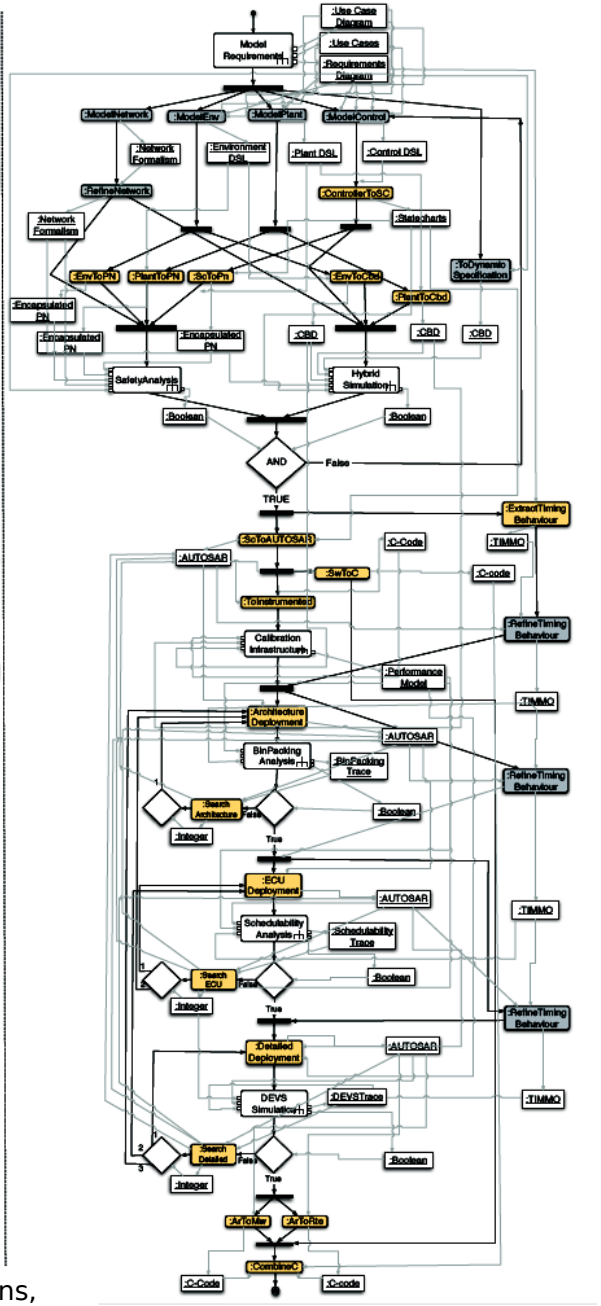
Ken Vanherpen. A contract-based approach for multi-viewpoint consistency in the concurrent design of cyber-physical systems. PhD thesis University of Antwerp. 2018.



How to deal with **Complexity?**

(in engineered systems)



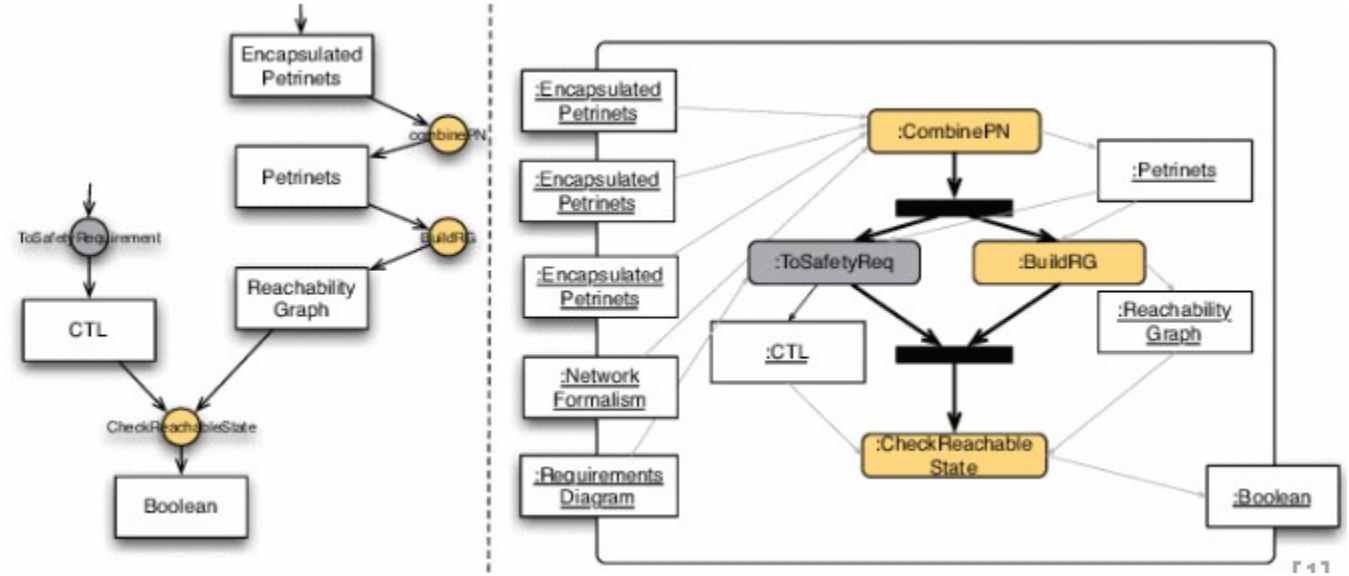


28 different modelling formalisms

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

Causes of Complexity …

and how to deal with them

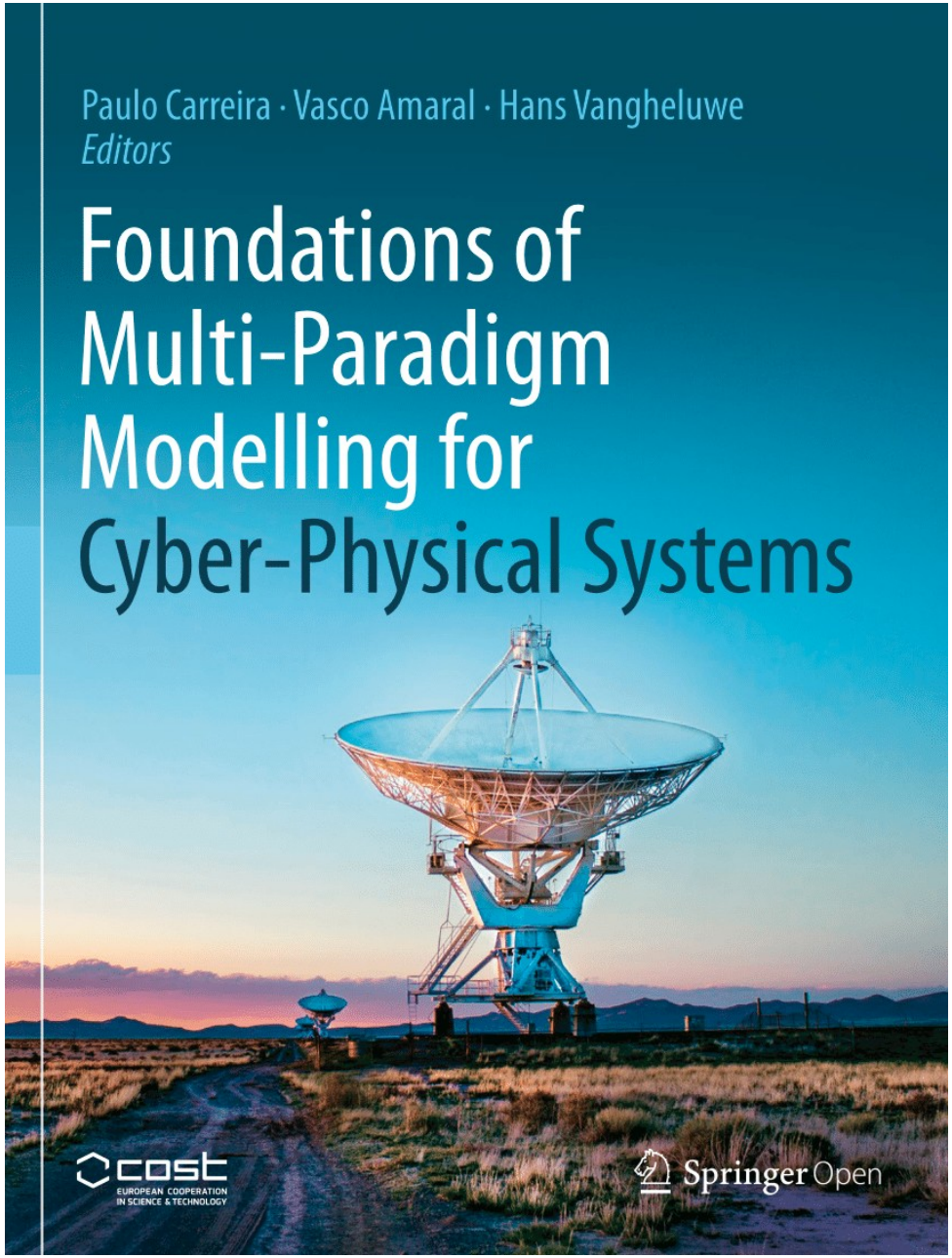
- large number of components (in an “architecture”)
- multiple concerns/views/stakeholders → consistency?

- heterogeneity of components / views
  - **different formalisms (aka modelling languages)**
  - different abstractions

- emergent behaviour (due to complex, non-modular interactions)

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

https://sonjablignaut.medium.com/7-differences-between-complex-and-complicated-fa44e0844606



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