Tackling Complexity by Modelling

a short introduction

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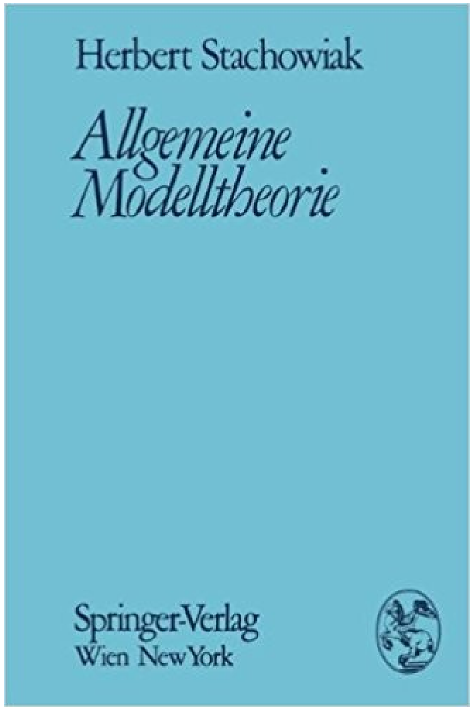
http://msdl.cs.mcgill.ca/

CUSO Winter School in Computer Science

Modelling of knowledge and the cyber-physical systems

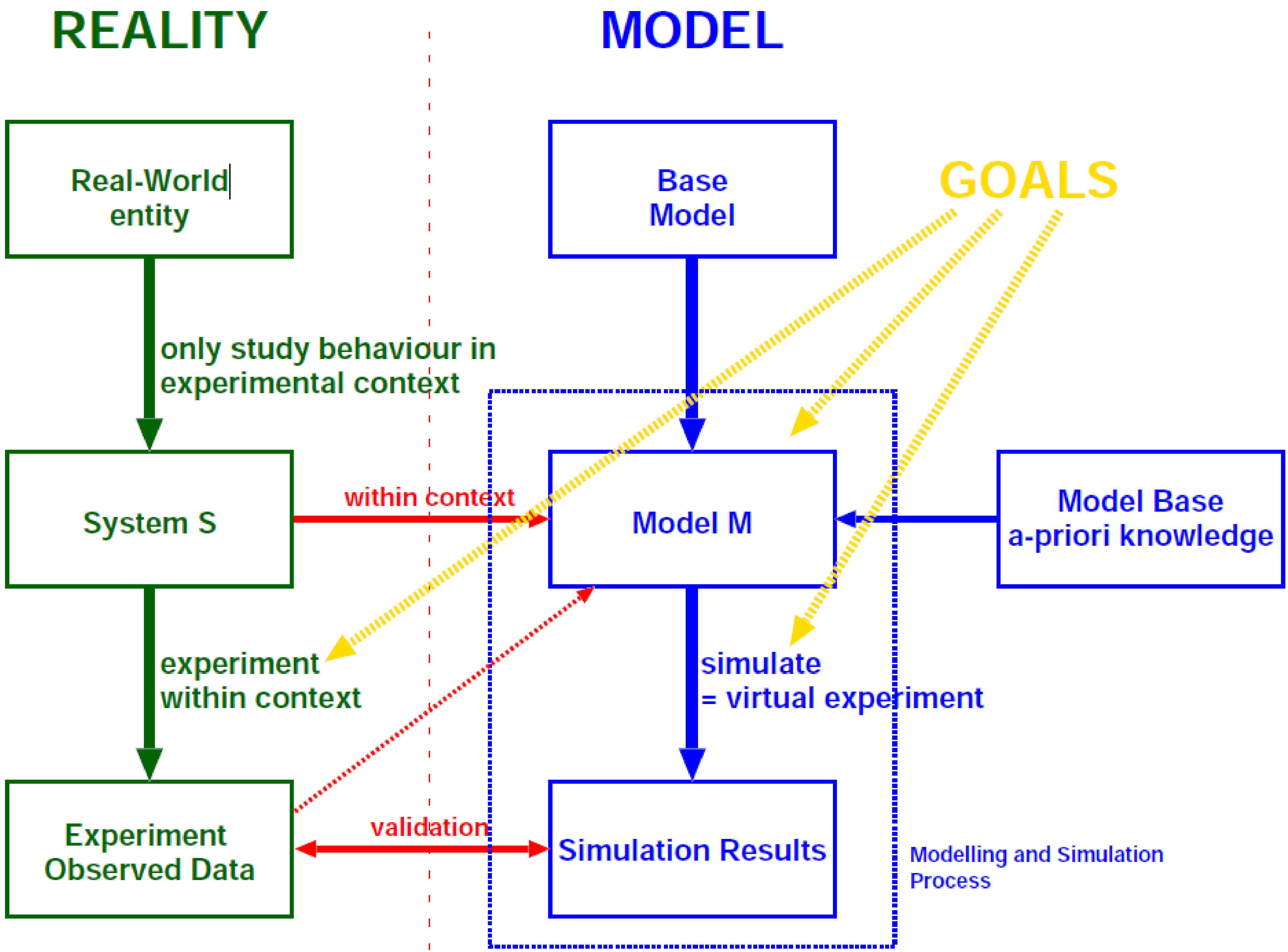
5 – 9 February 2018
Champéry, Switzerland

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



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.



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

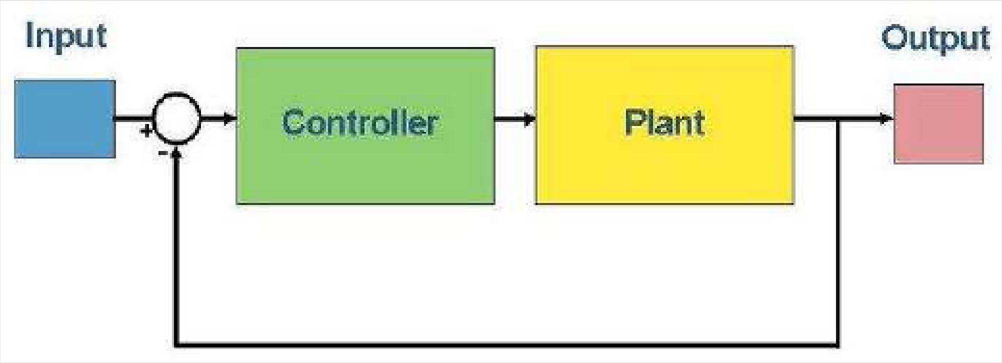
"System"

System Boundaries

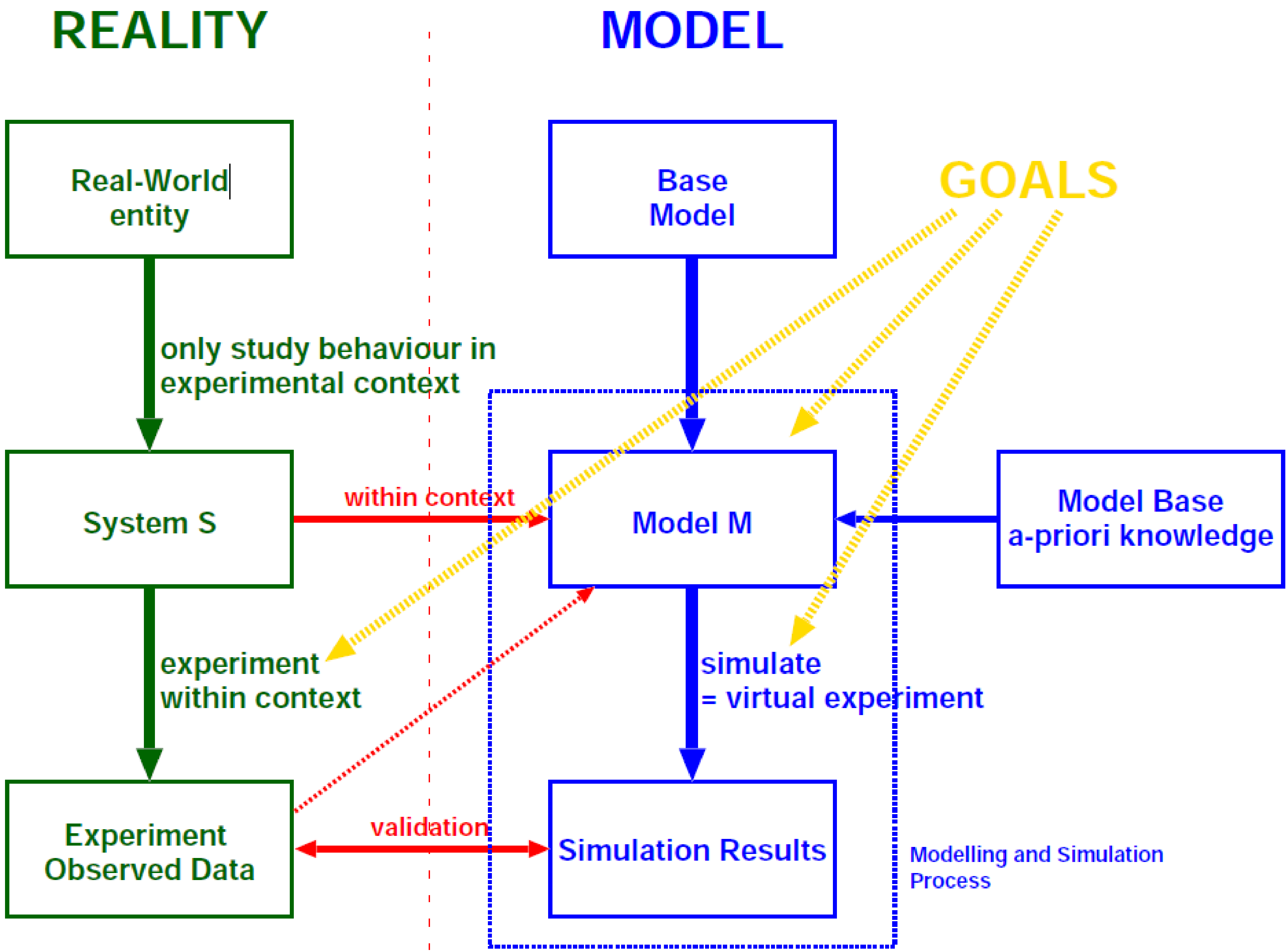
- **System** to be built/studied
- **Environment** with which the system interacts


“System”

System vs. “Plant”

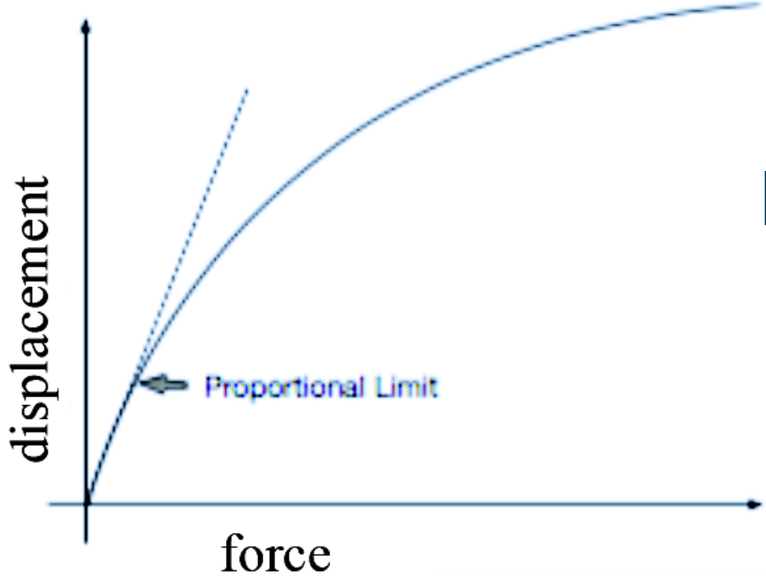


“Plant”?!



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

Model Validity Range



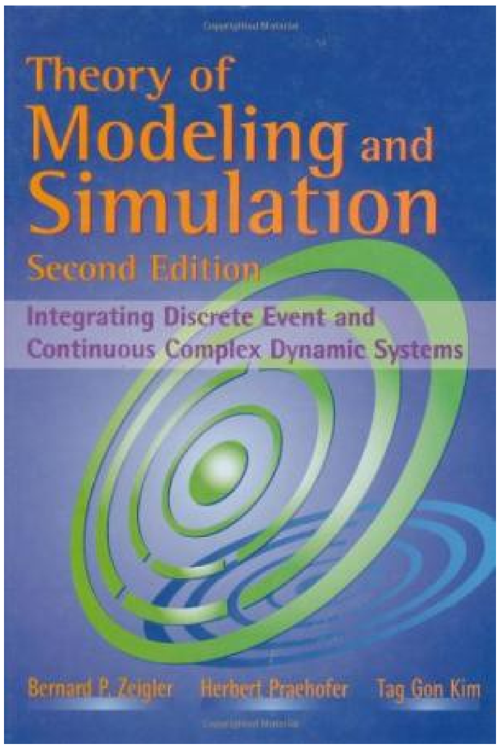
$$F = -kx$$

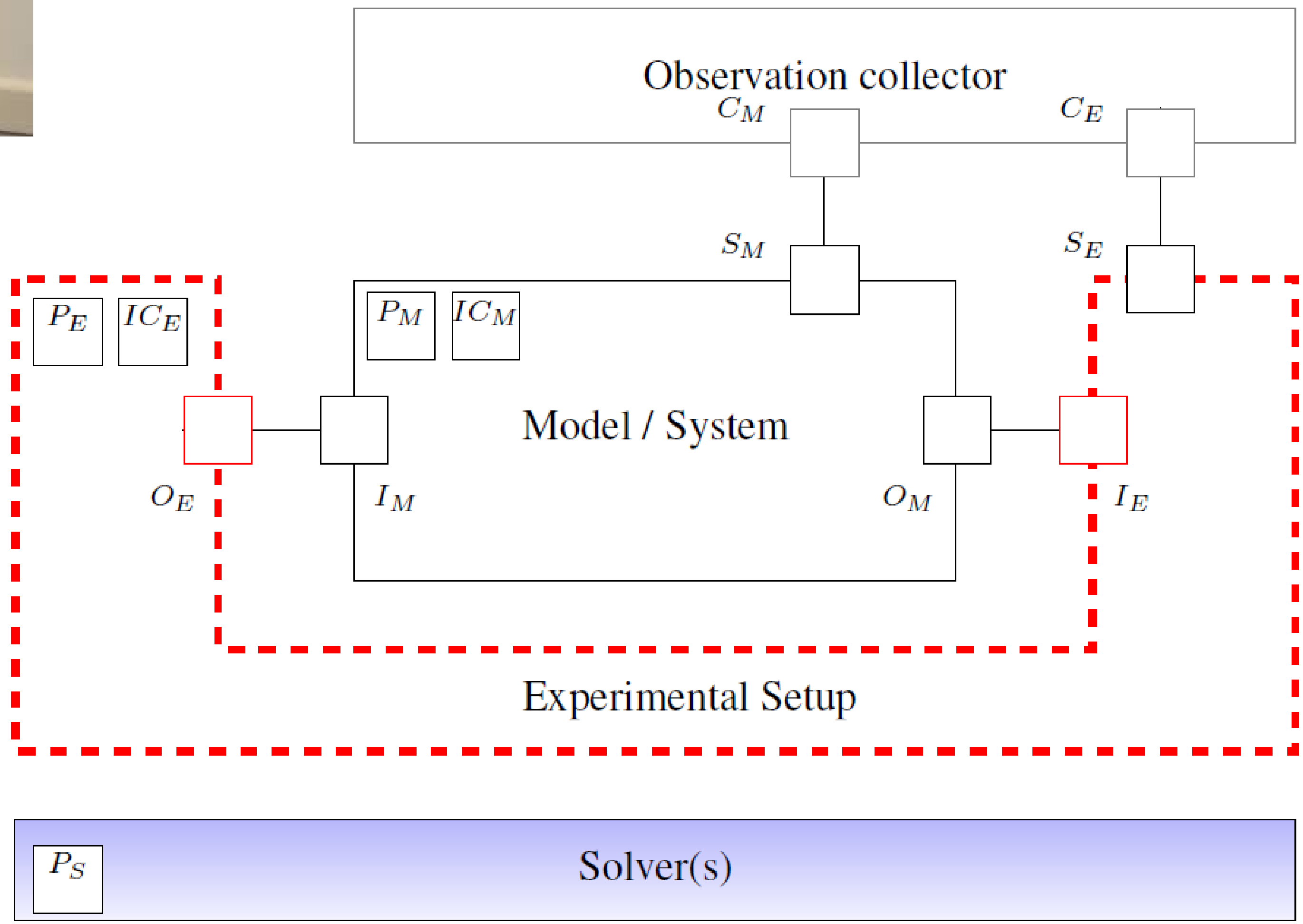
Wire Size

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

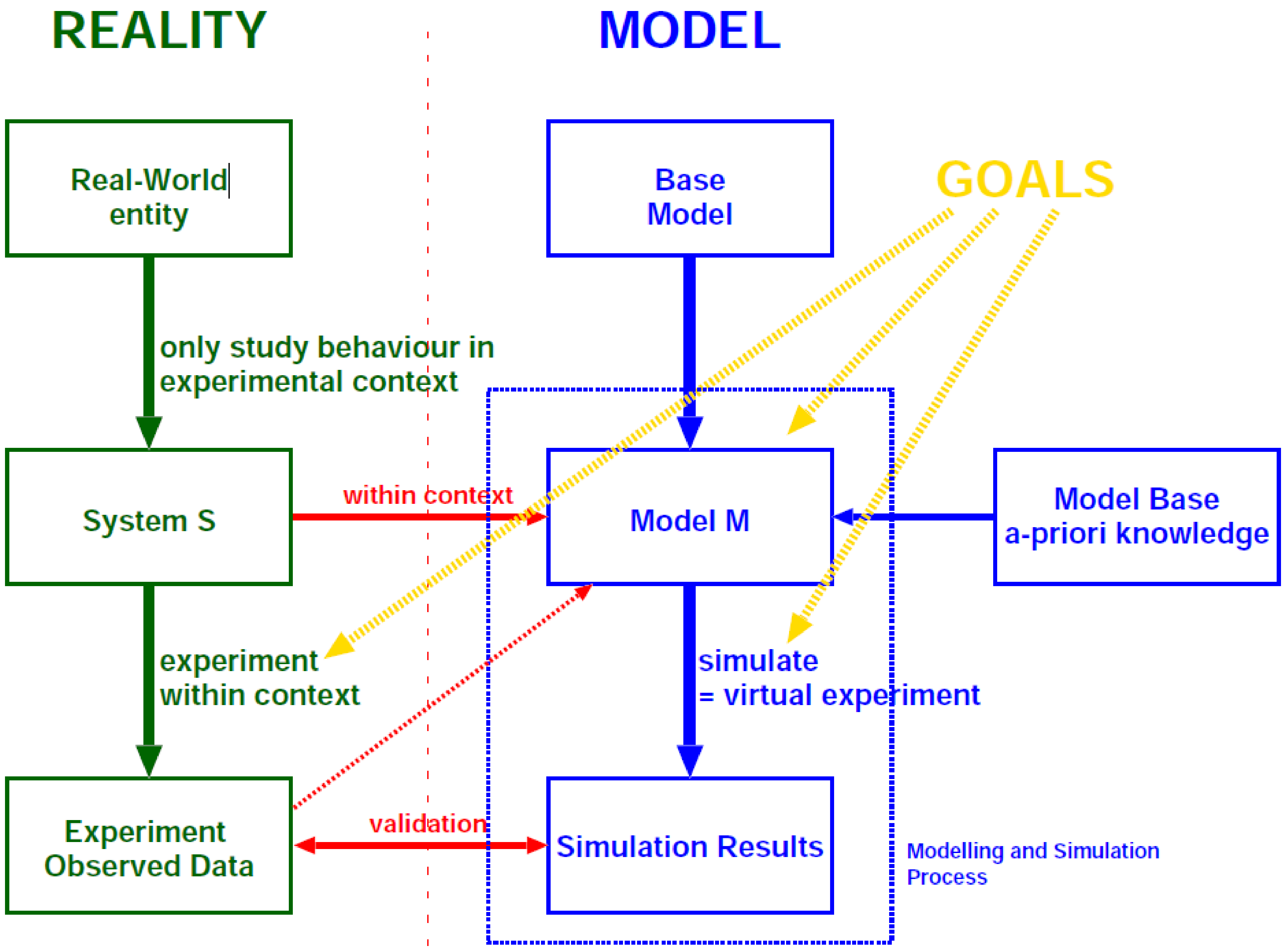
www.centuryspring.com

Experimental (Validity) Frame





Joachim Denil, Stefan Klikovits, Pieter J. Mosterman, Antonio Vallecillo, and Hans Vangheluwe. The experiment model and validity frame in M&S. In Proceedings of the 2017 Symposium on Theory of Modeling and Simulation - DEVS , TMS/DEVS '17, part of the Spring Simulation Multi-Conference, pages 1085 – 1096. Society for Computer Simulation International, April 2017.



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

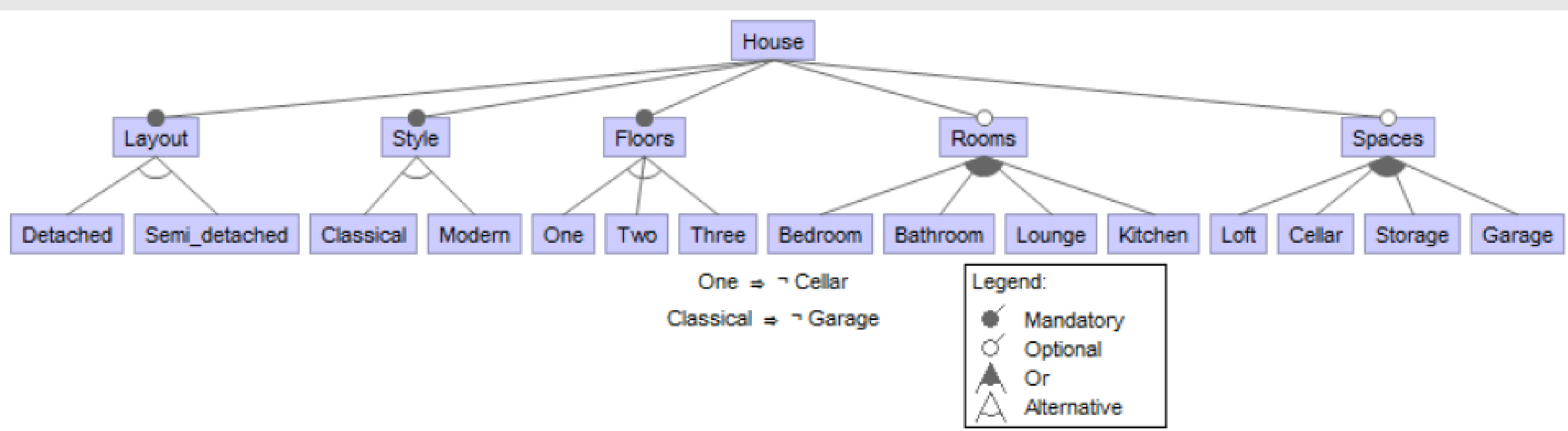
Engineered Systems: What vs. How

Requirements ("What?")

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

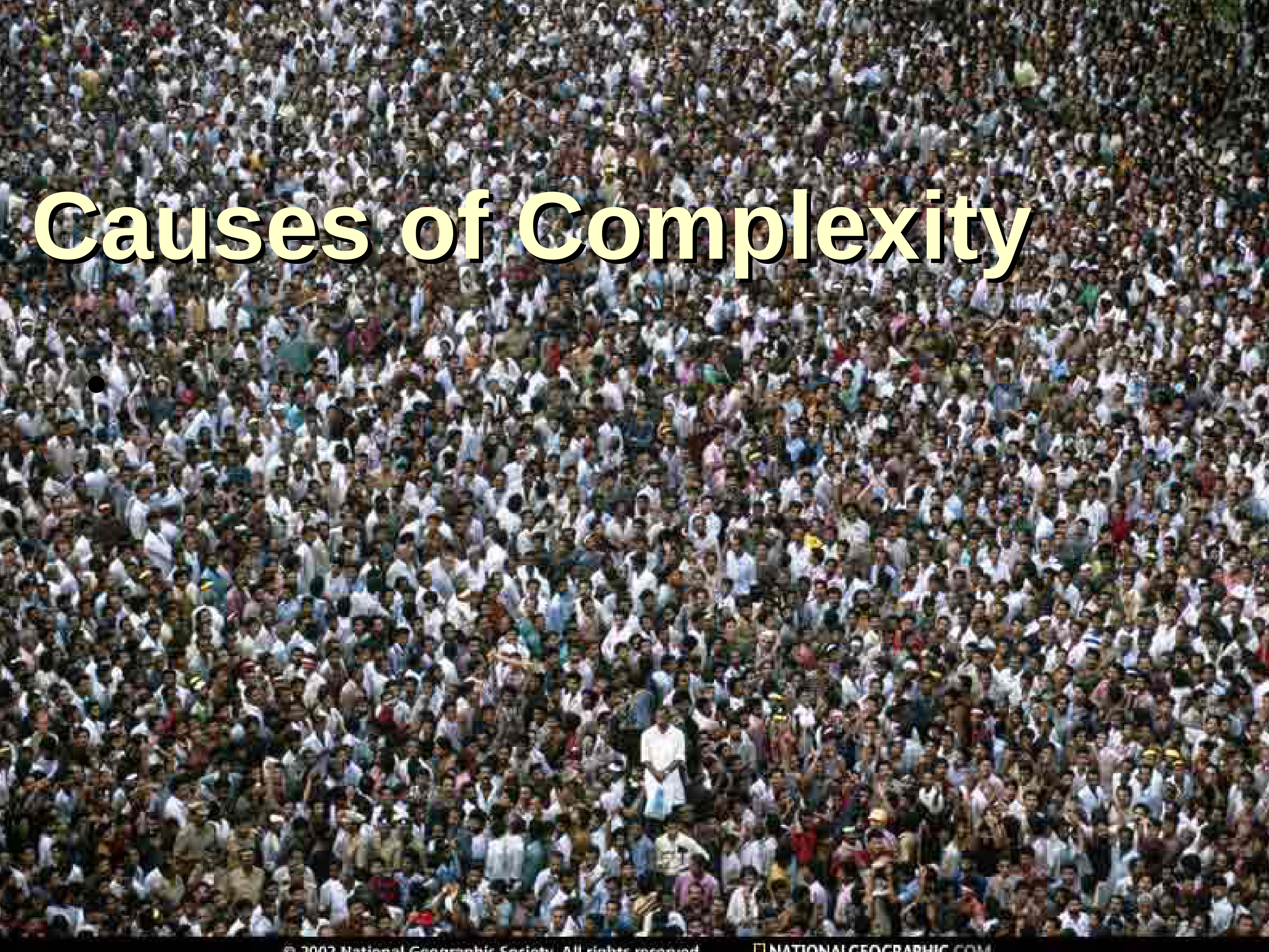
Design ("How?")

Requirements ("What?"): Feature Model of a Product Family



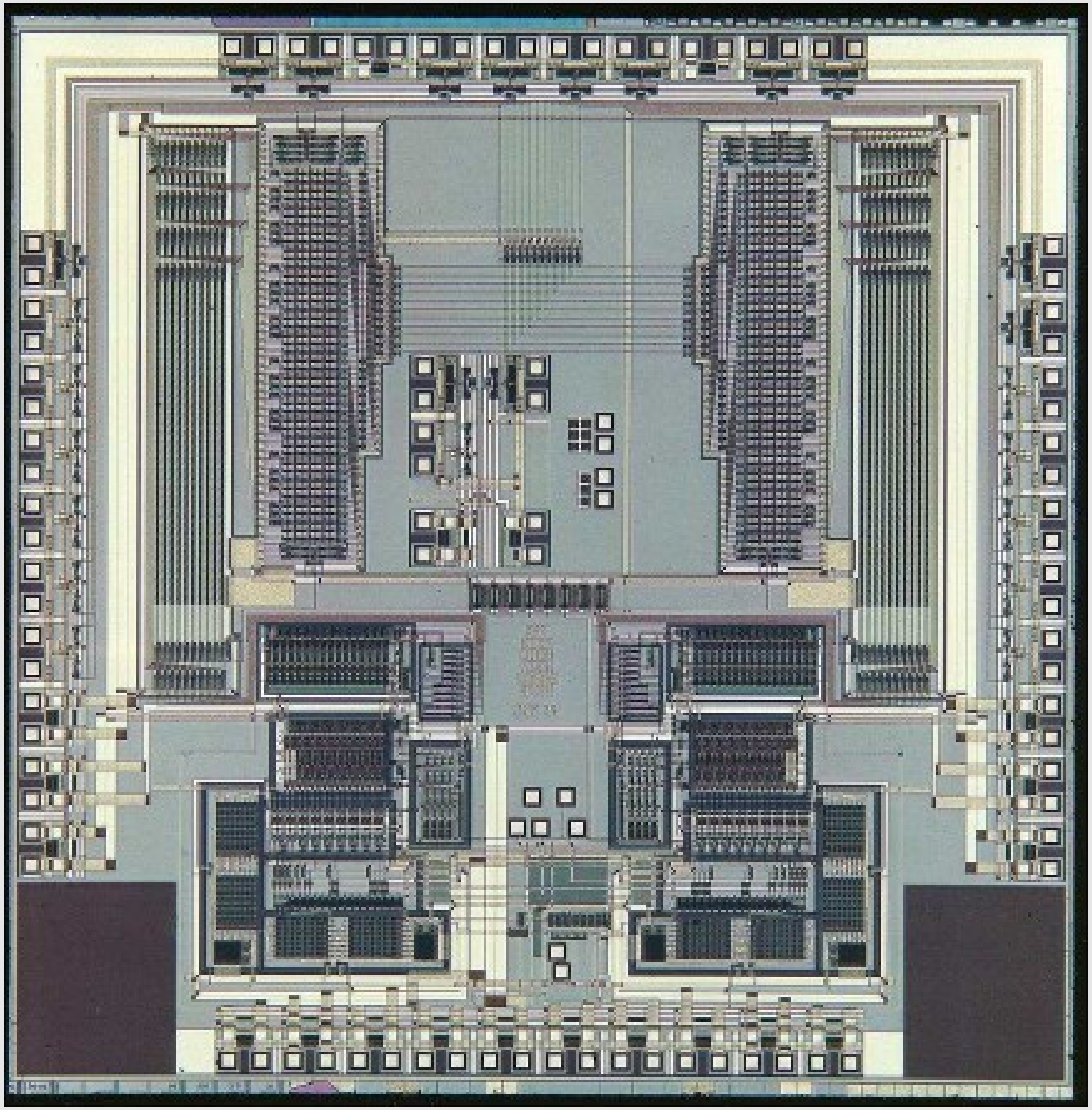
Causes of Complexity

•



Causes of Complexity

Number of Components – hierarchical (de-)composition



Causes of Complexity

Diversity of Components: Power Window

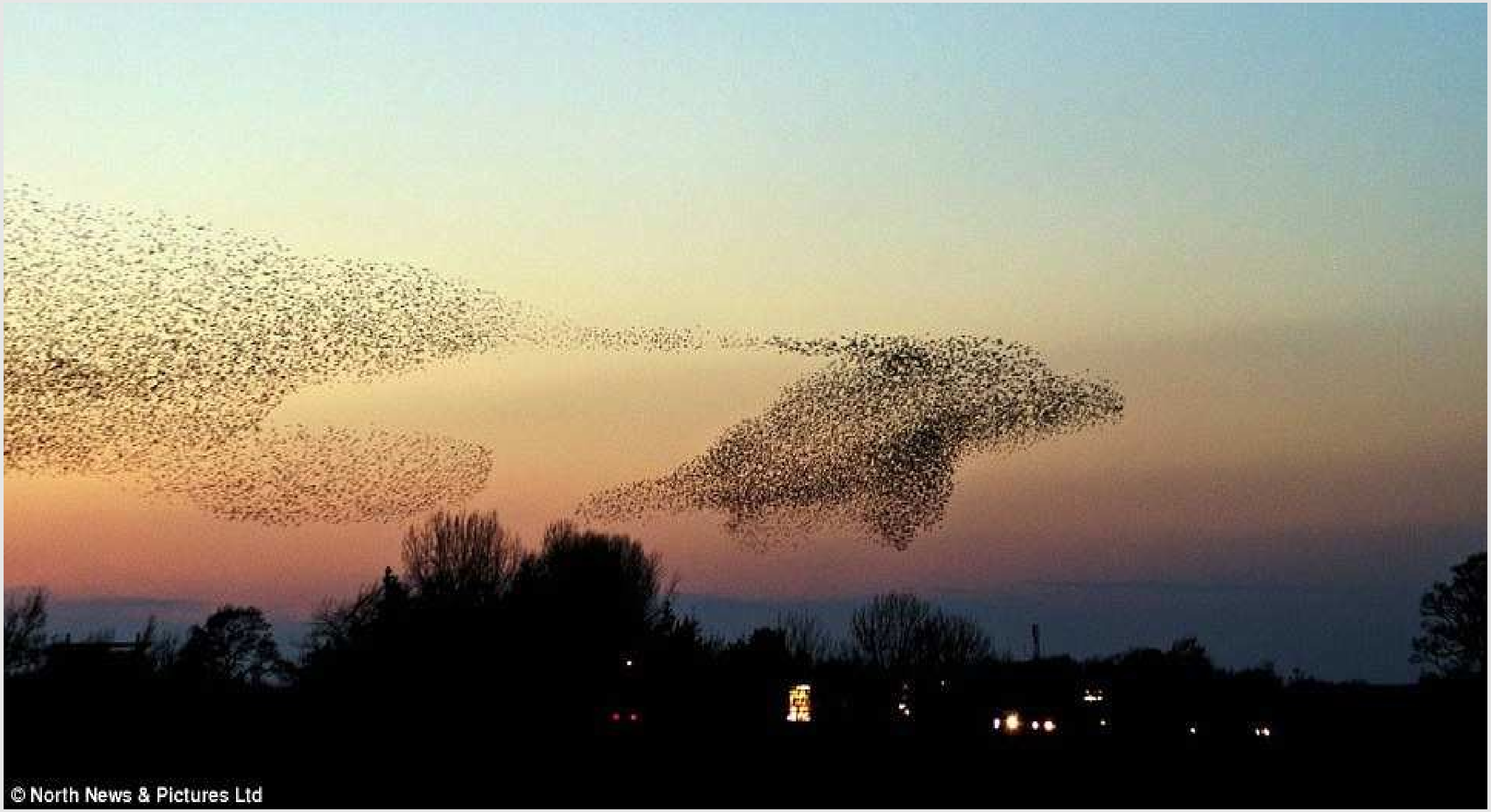
Causes of Complexity

Crowds: diversity, interaction

www.3dm3.com

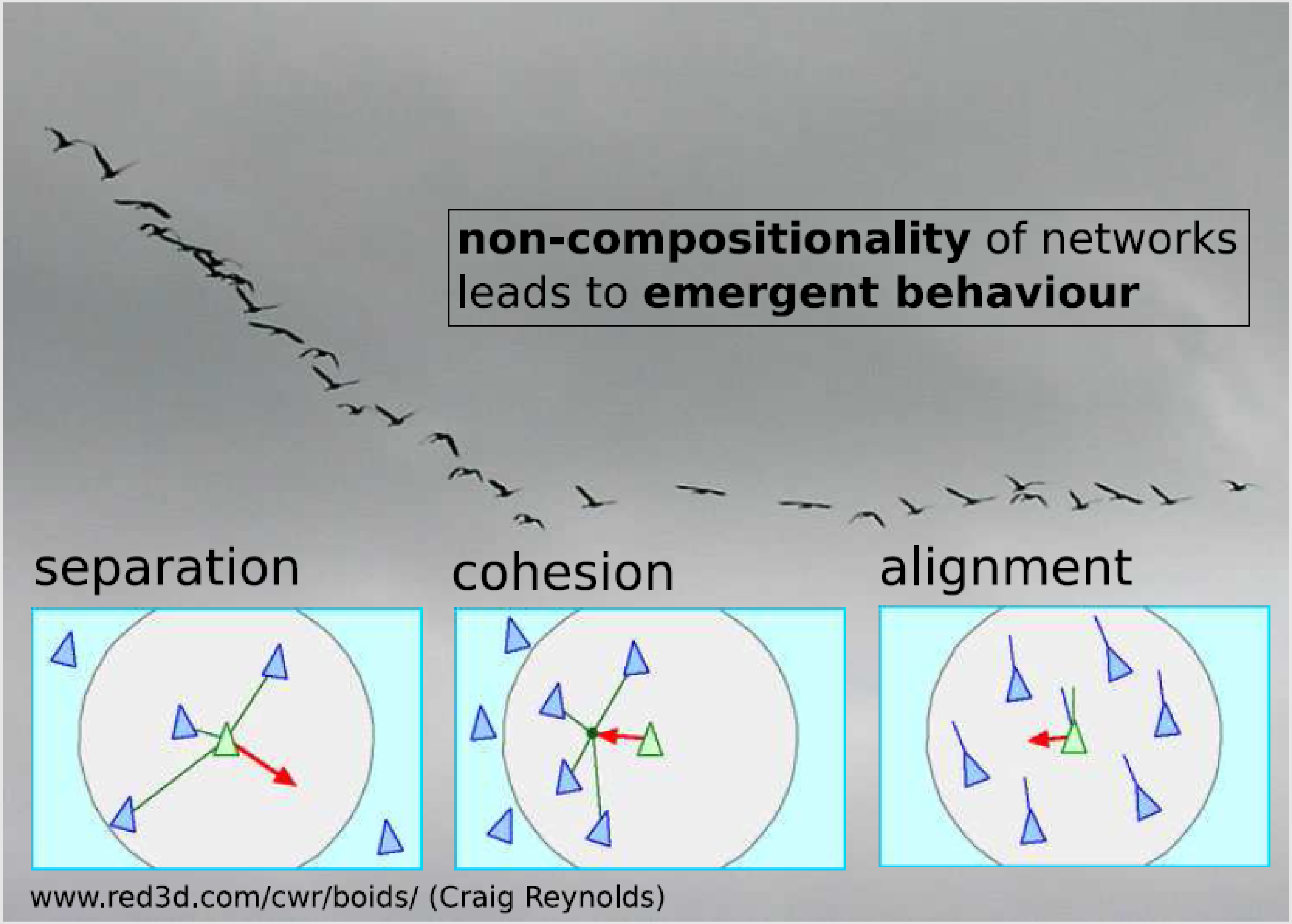
Causes of Complexity

Emergent Behaviour



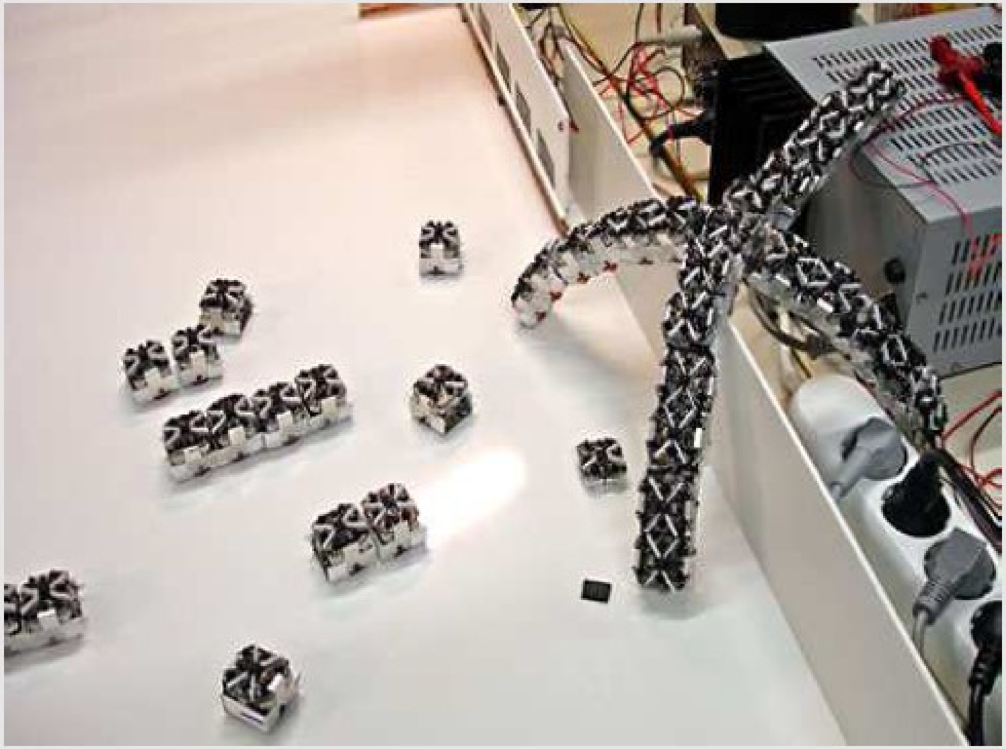
Causes of Complexity

Non-compositional/Emergent Behaviour



Causes of Complexity

Engineered Emergent Behaviour

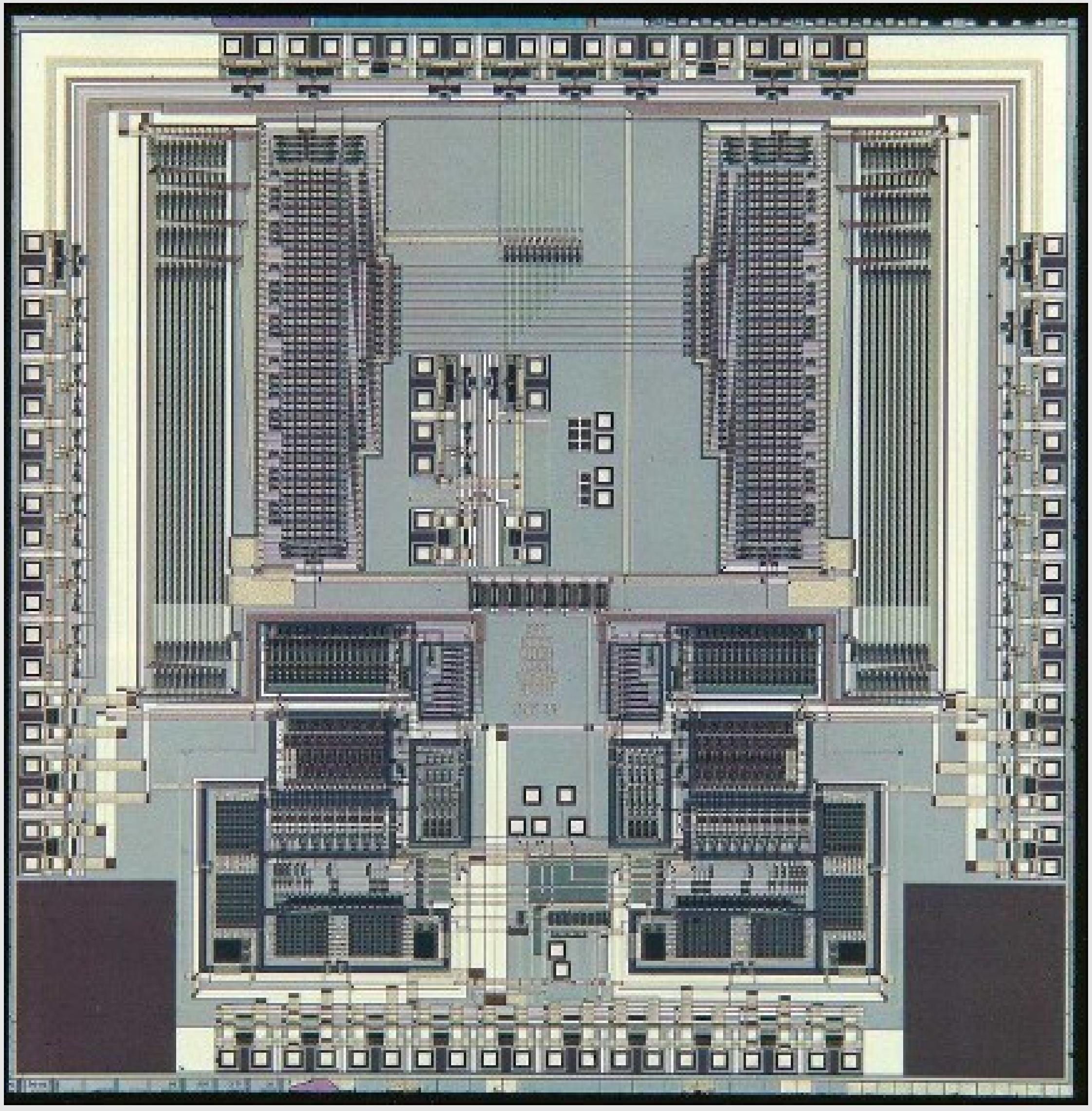


Robert Bogue. *Swarm intelligence and robotics.* Industrial Robot: An International Journal. 35(6):488 - 495, 2008.

Dealing with Complexity!

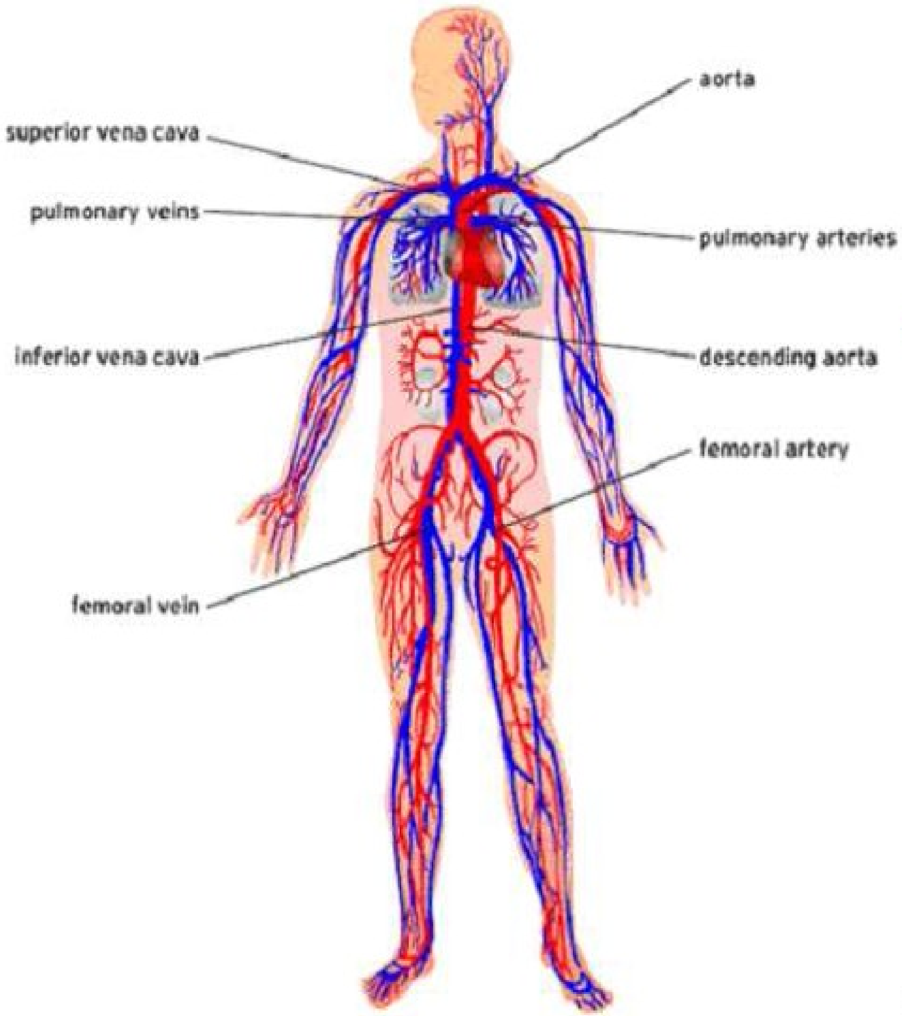
Dealing with Complexity

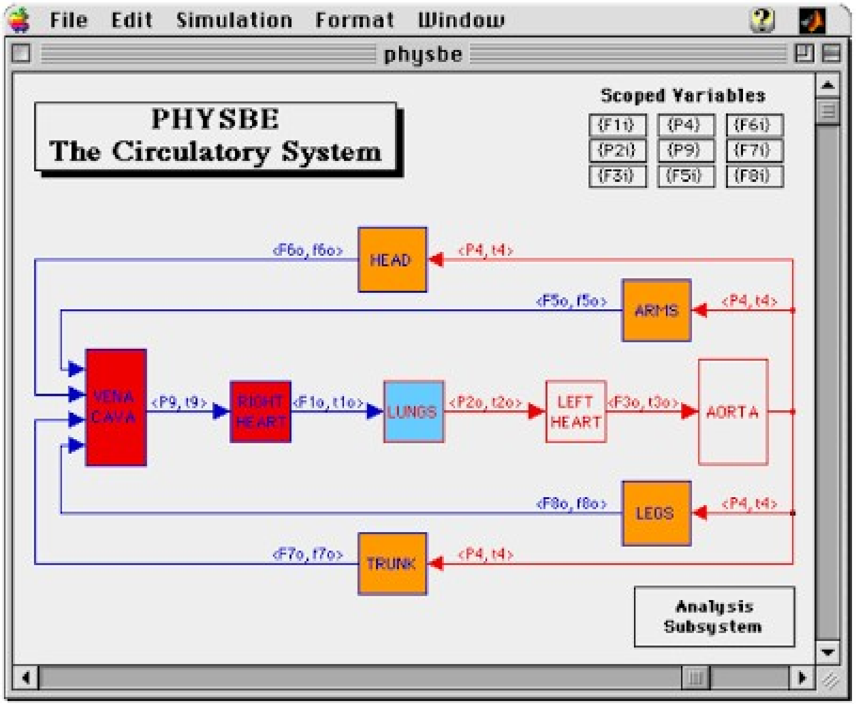
Number of Components – hierarchical (de-)composition



Dealing with Complexity

Different Abstraction Levels – properties preserved





Dealing with Complexity

Abstraction Relationship

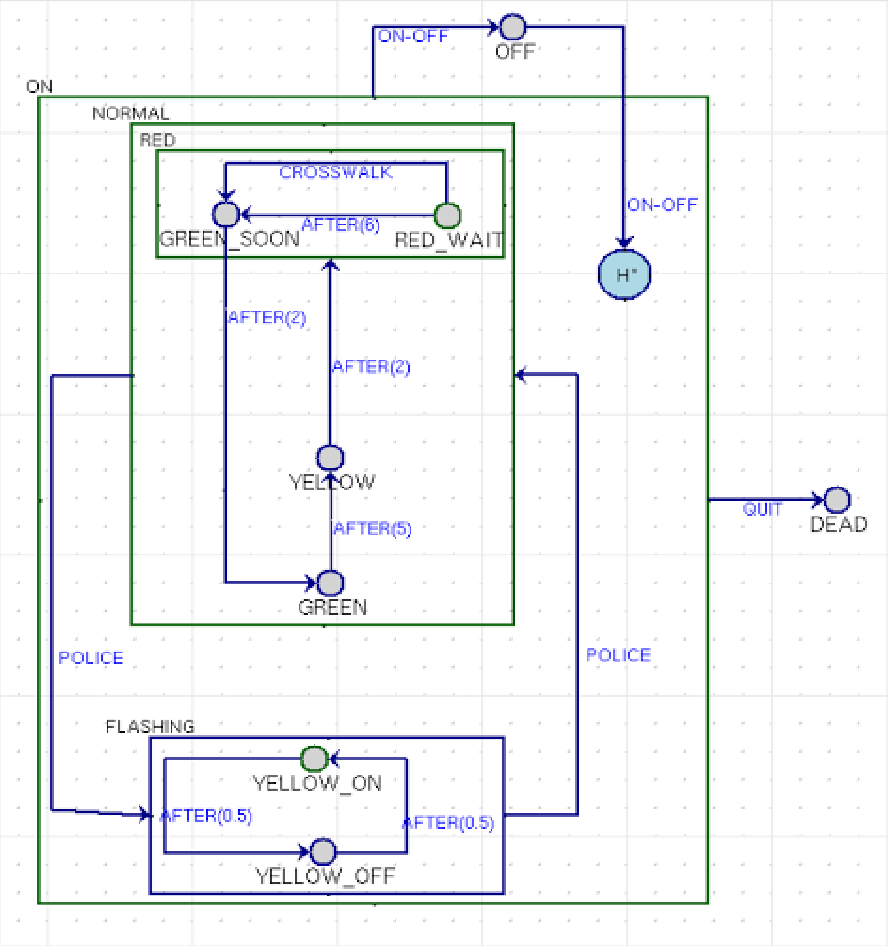
foundation: the *information* contained in a model M.
Different *questions* (properties) $P = I(M)$ which can be asked concerning the model.
These questions either result in true or false.

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 $M_1 \sqsubseteq_P M_2$.

Dealing with Complexity

Most Appropriate Formalism

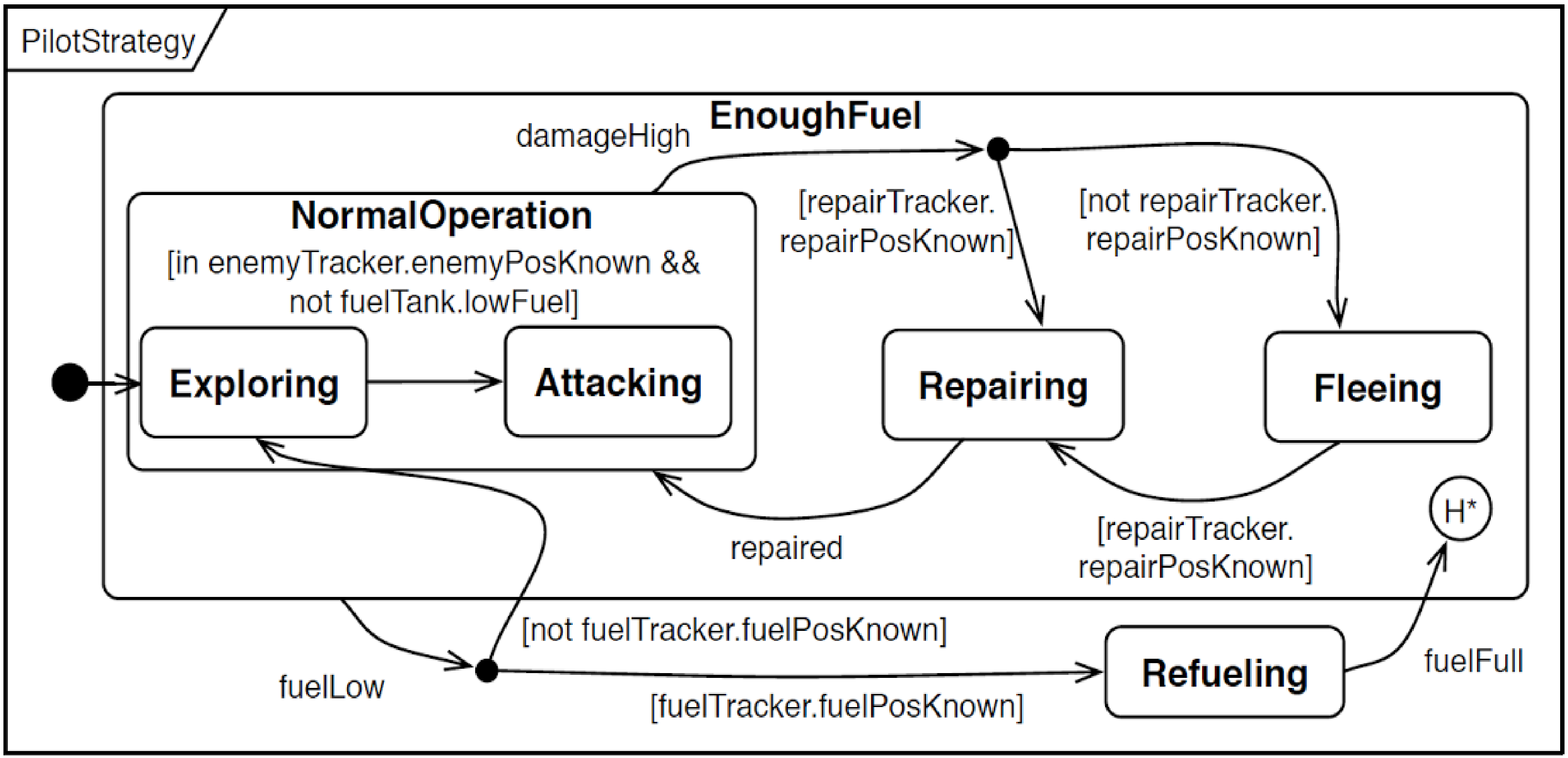


Dealing with Complexity

www.planeshift.it

Massively Multiplayer Online Role Playing games need Non-Player Characters (NPCs)

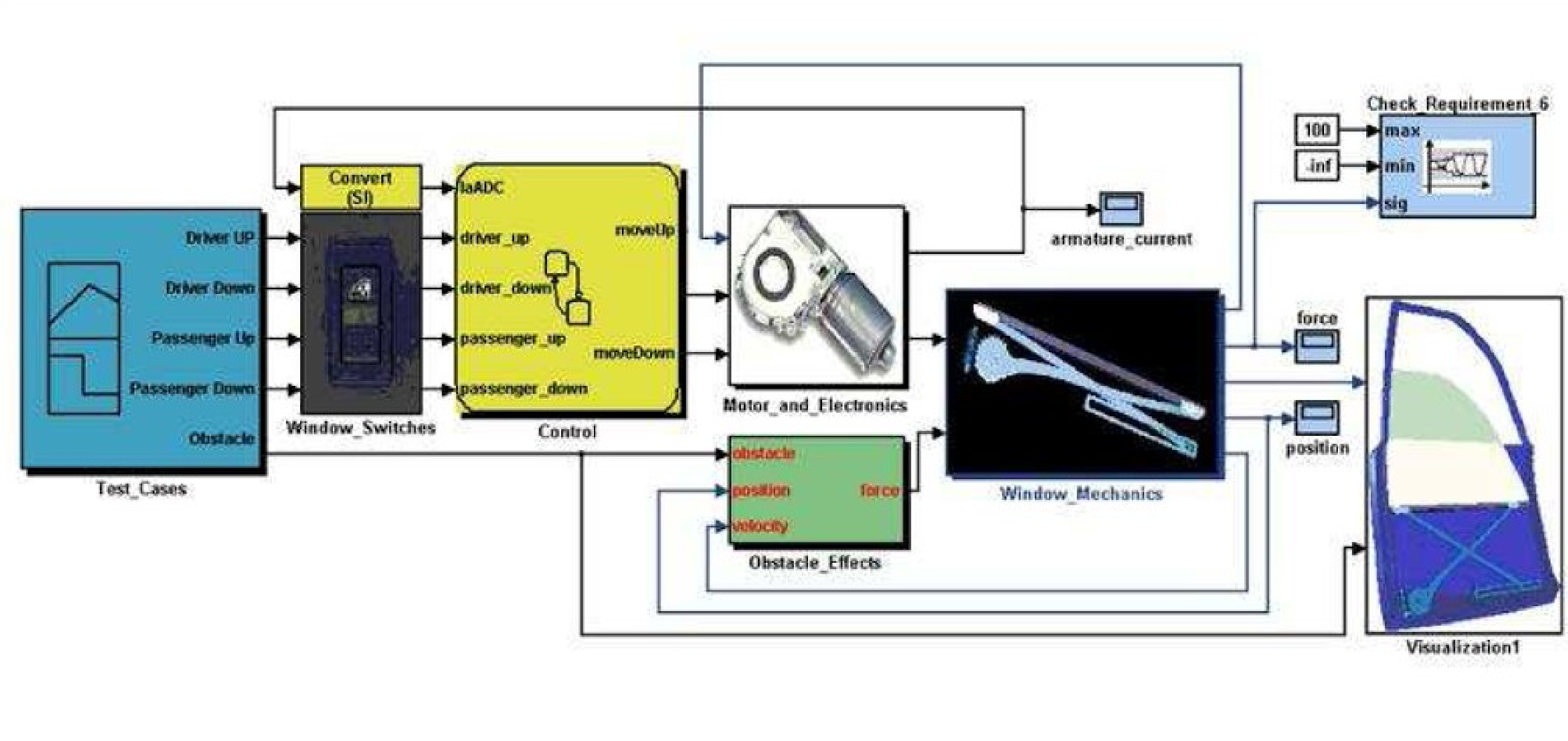
Dealing with Complexity



Jörg Kienzle, Alexandre Denault, Hans Vangheluwe. Model-Based Design of Computer-Controlled Game Character Behavior. MoDELS 2007: 650-665

Dealing with Complexity

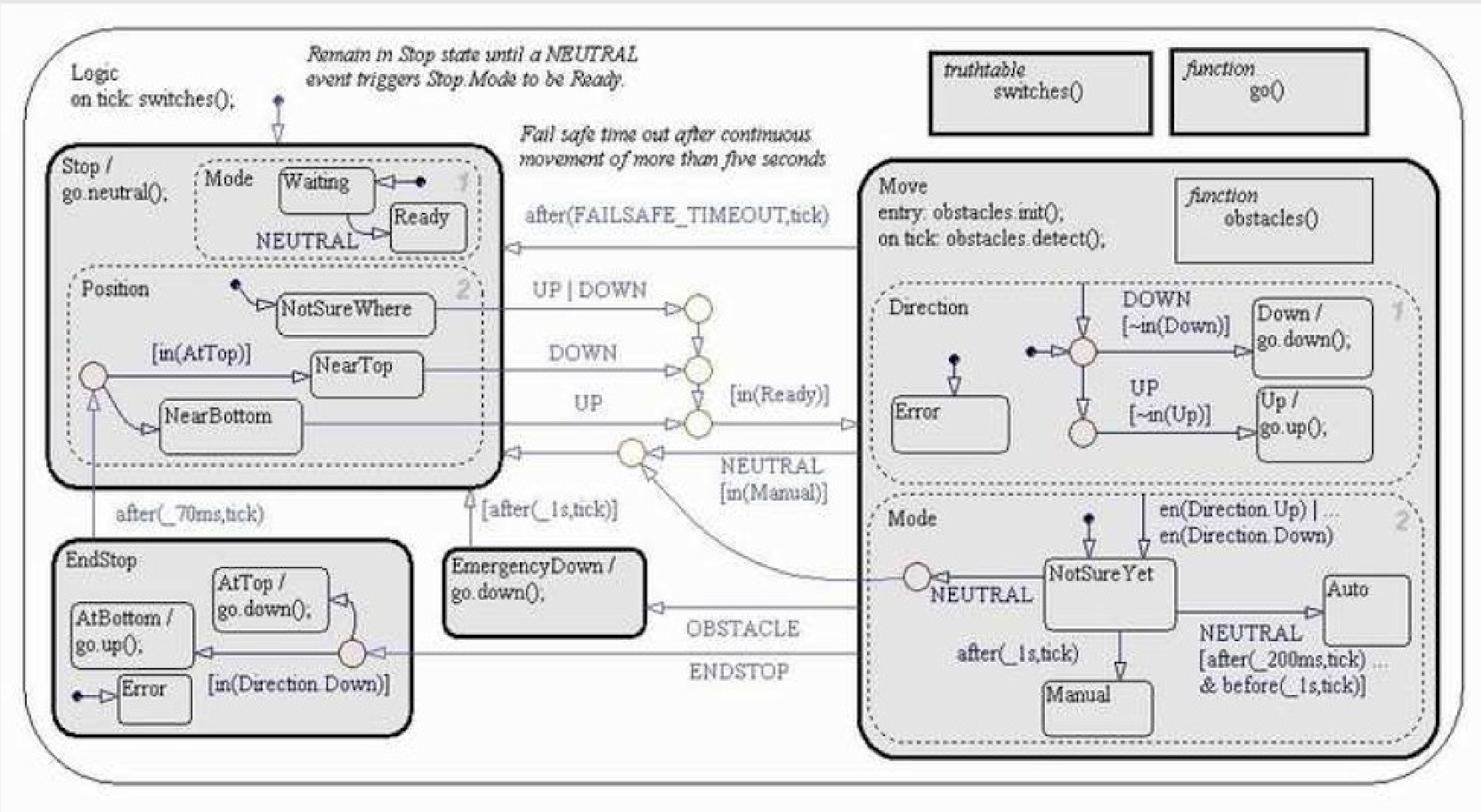
Components in Different Formalisms



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

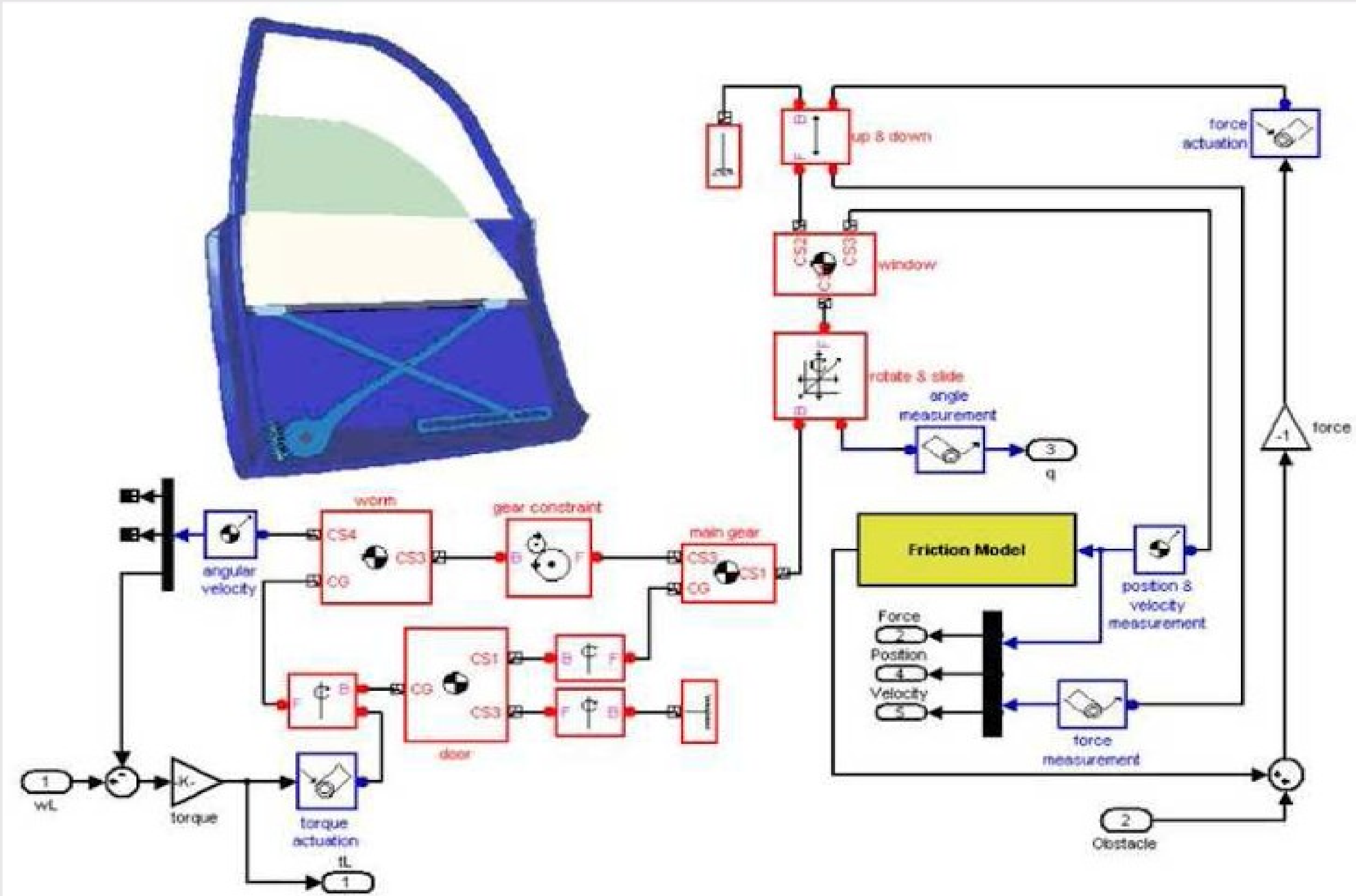
Dealing with Complexity

Controller, using Statechart(StateFlow) formalism



Dealing with Complexity

Mechanics subsystem

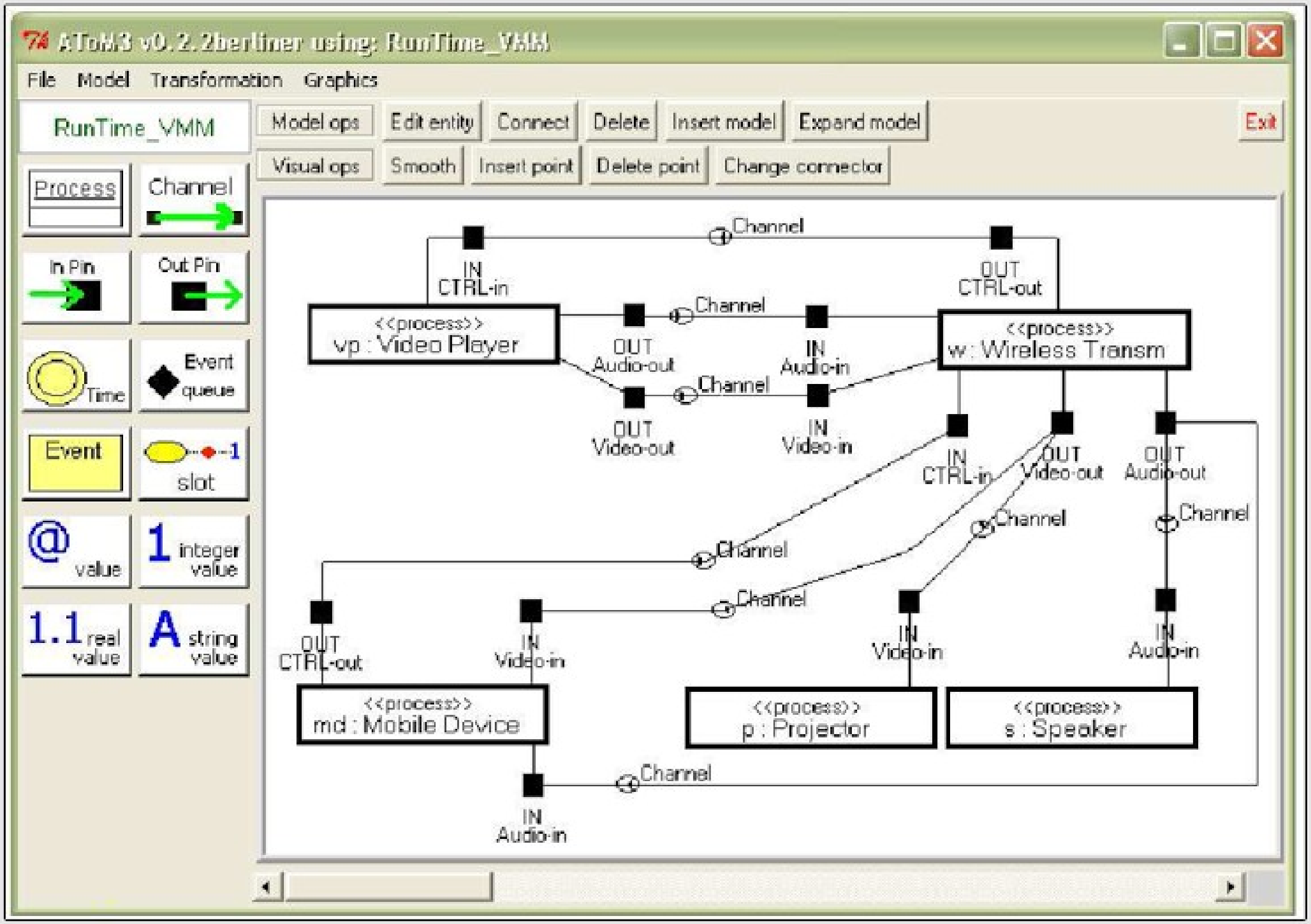


Dealing with Complexity

Wireless Home Entertainment System

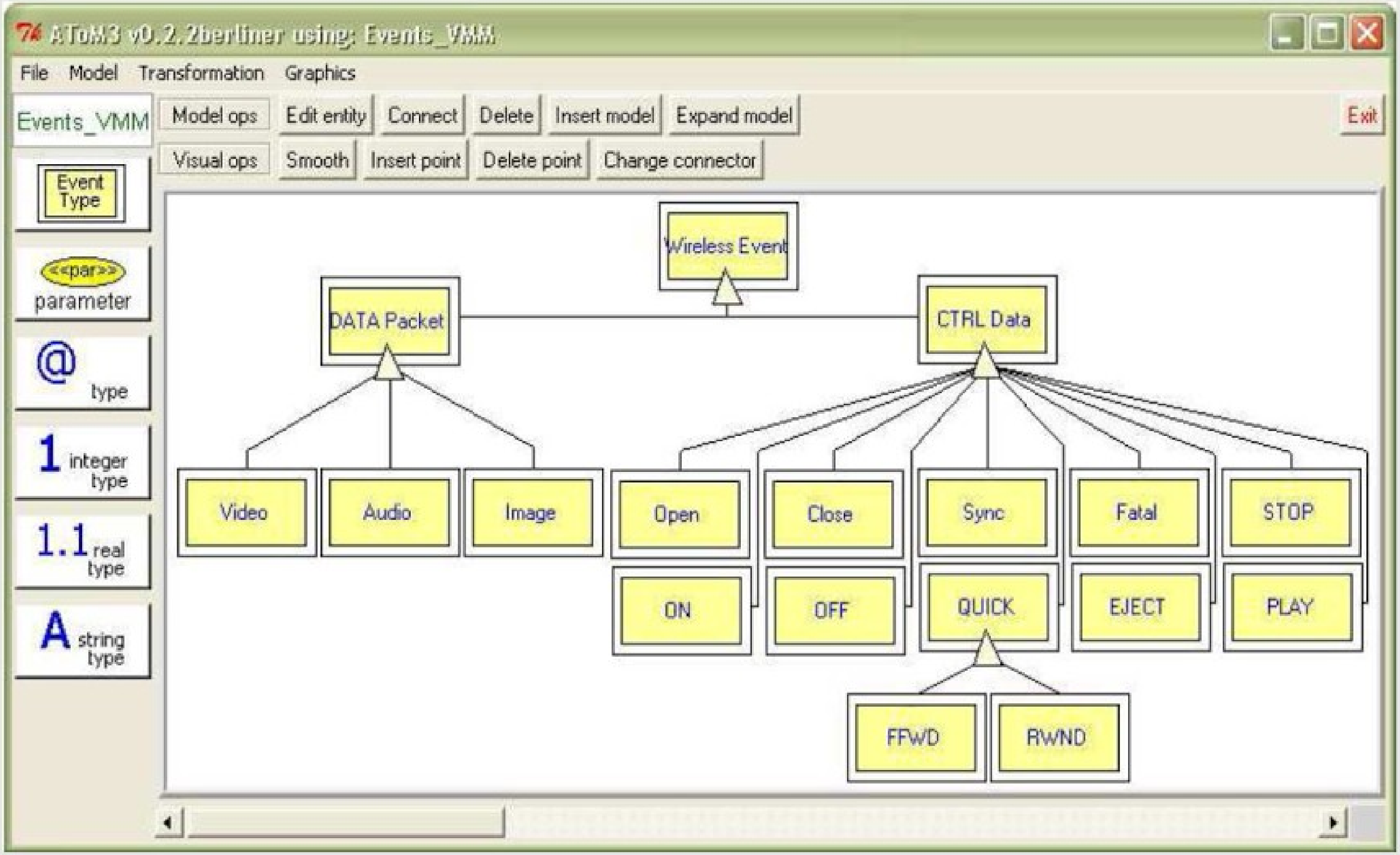
Dealing with Complexity

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



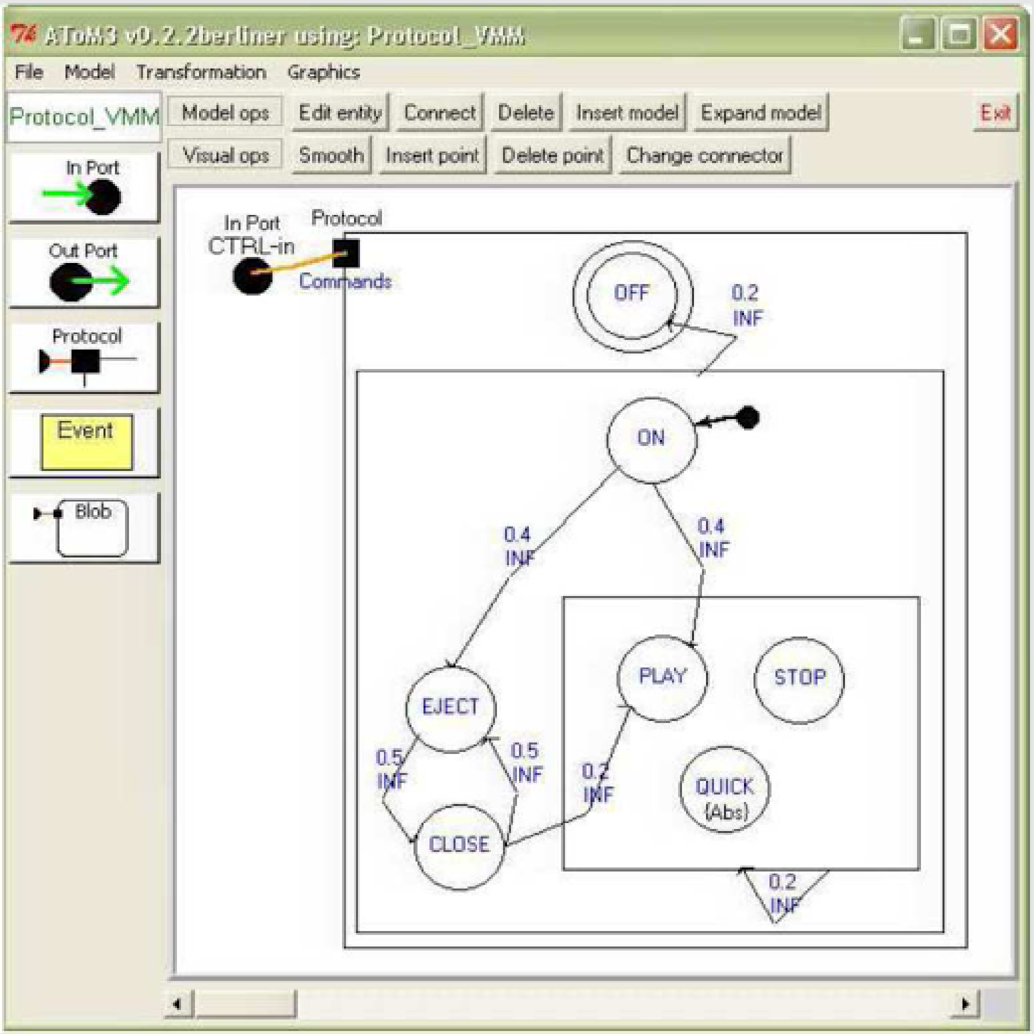
Dealing with Complexity

View: Events Diagram



Dealing with Complexity

View: Protocol Statechart



Dealing with Complexity

No Free Lunch!

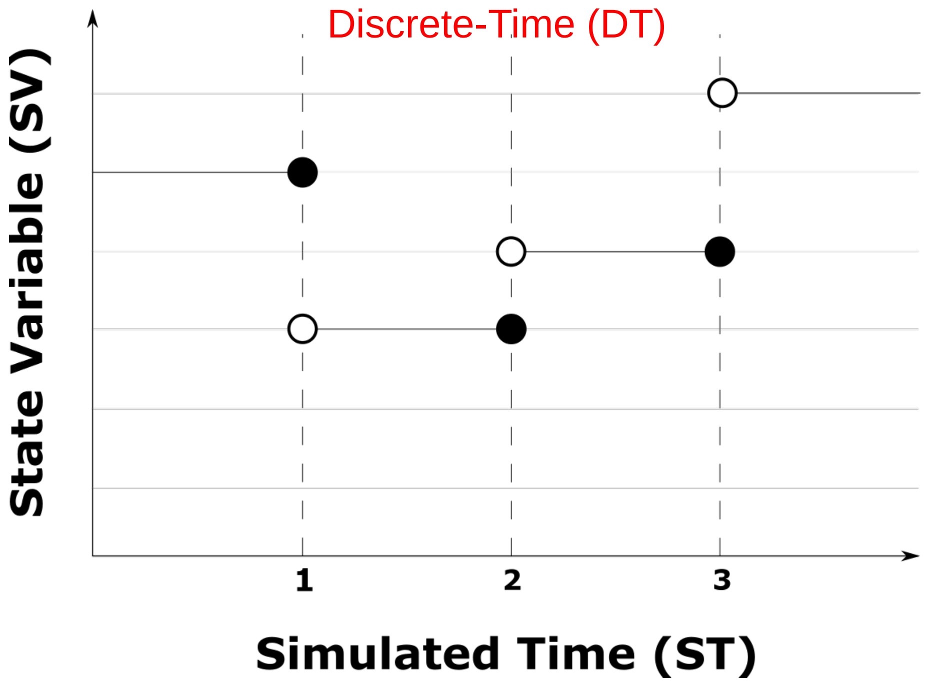
Solutions often introduce
their **own accidental complexity**

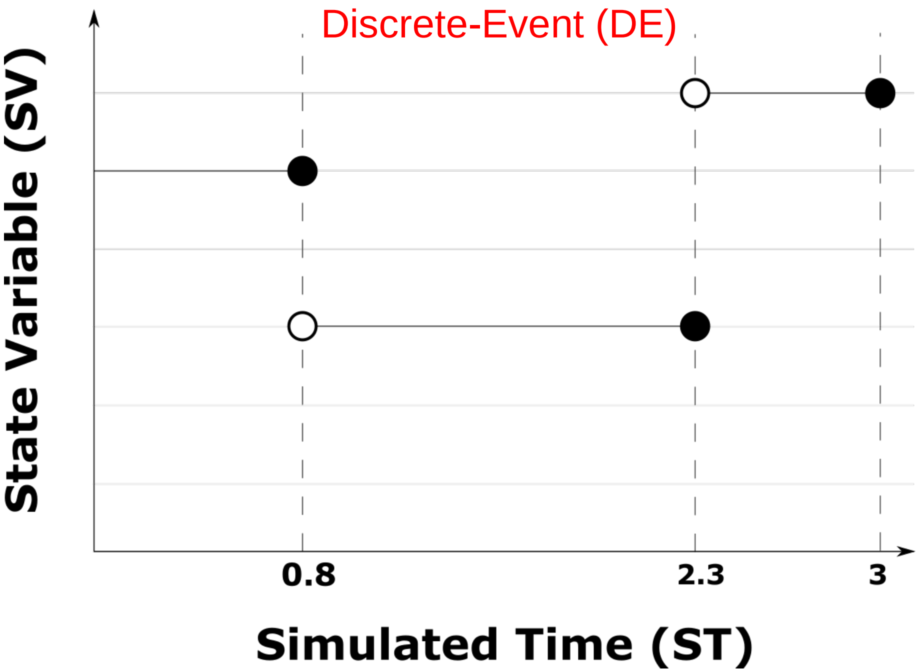
- multiple abstraction levels (need **morphism**)
- optimal formalism (need **precise meaning**)
- multiple formalisms (need **relationship**)
- multiple views (need **consistency**)

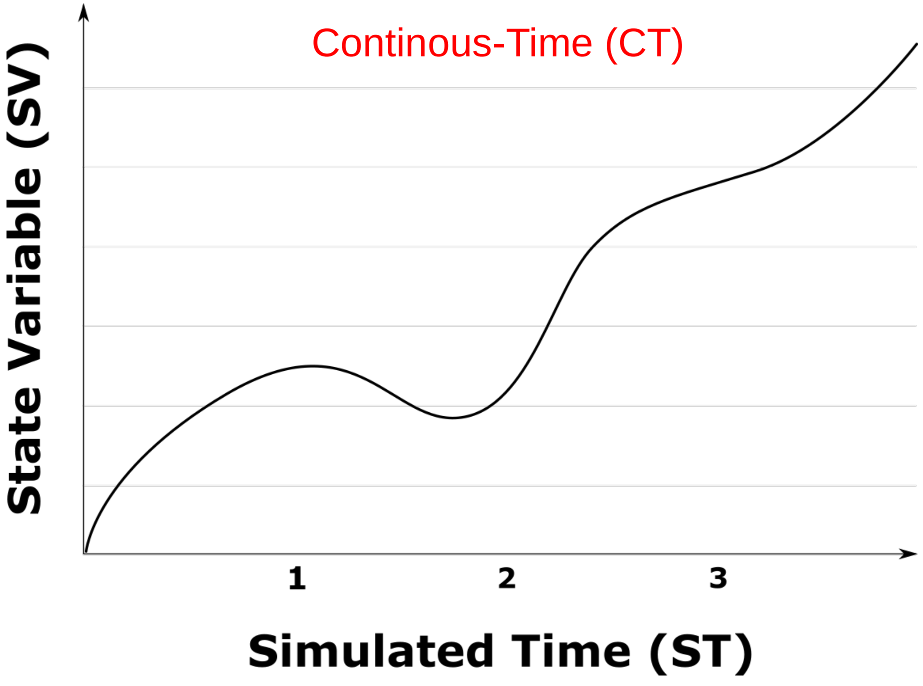
at the most appropriate level(s) of abstraction
using the most appropriate formalism(s)
explicitly modelling processes

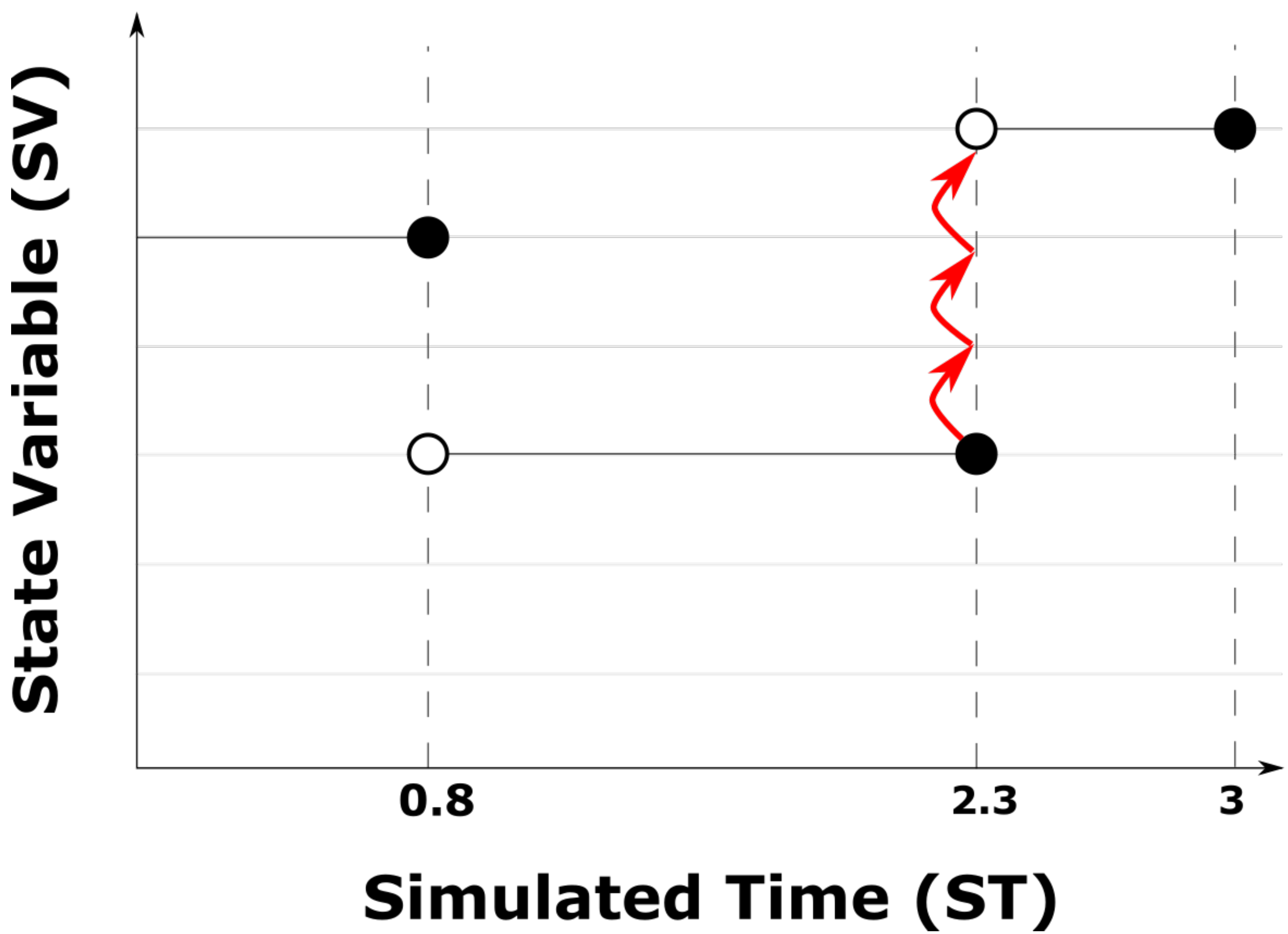
Enabler: (domain-specific) modelling language engineering,
including model transformation

simulation of a **model** of the **dynamics** of a system produces **behaviour traces**

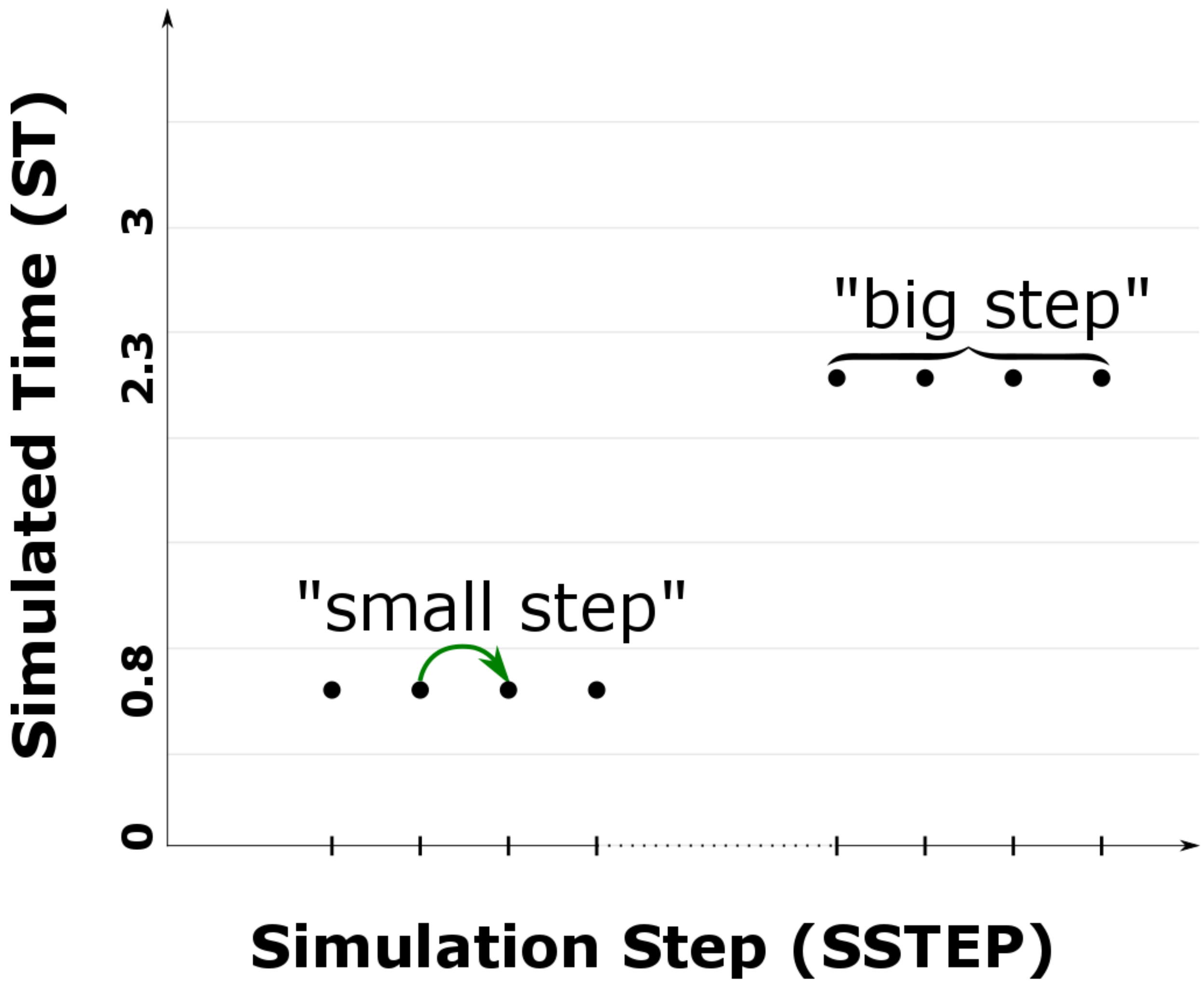








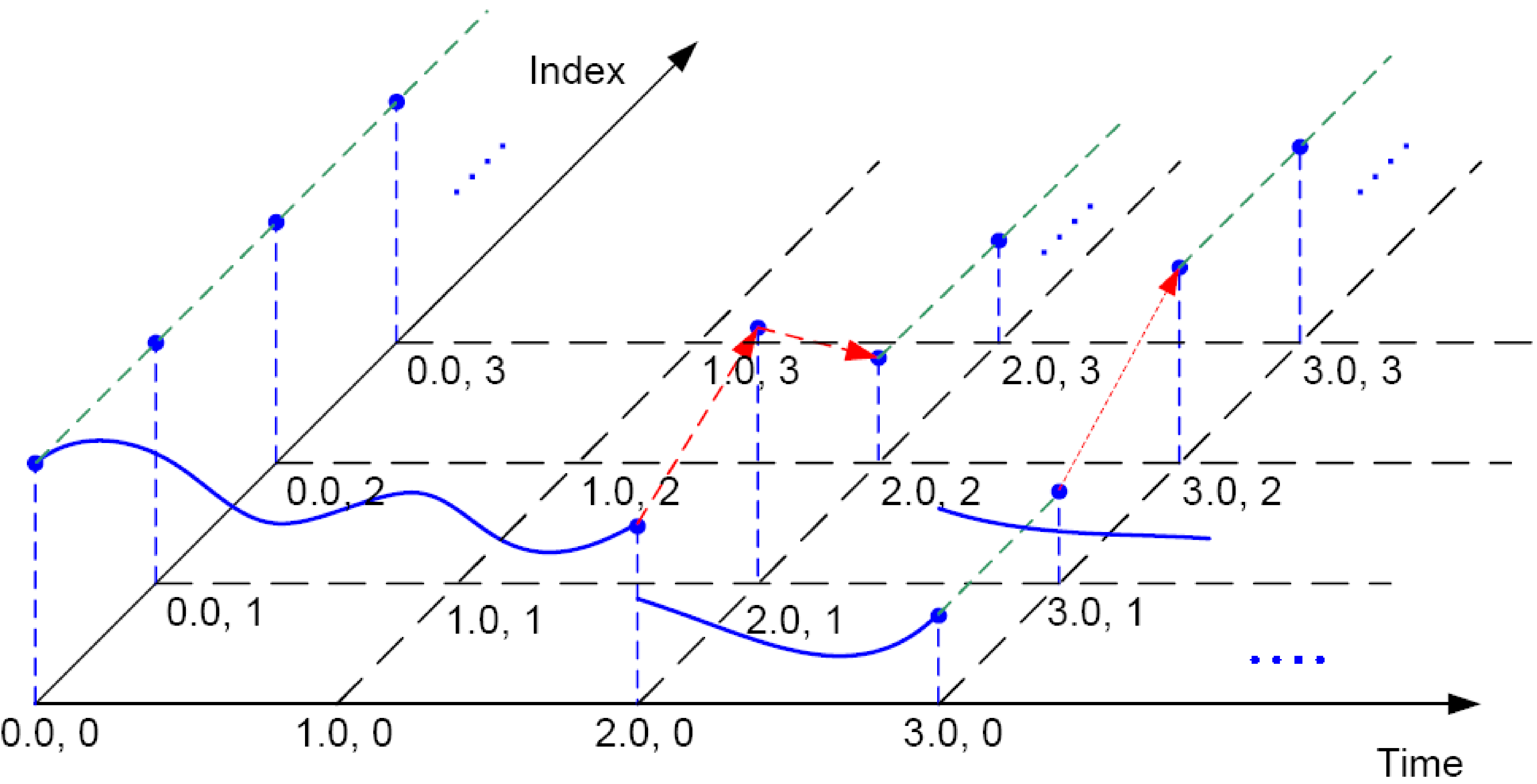
State Variable (SV)
0.8
2.3
3
Simulated Time (ST)

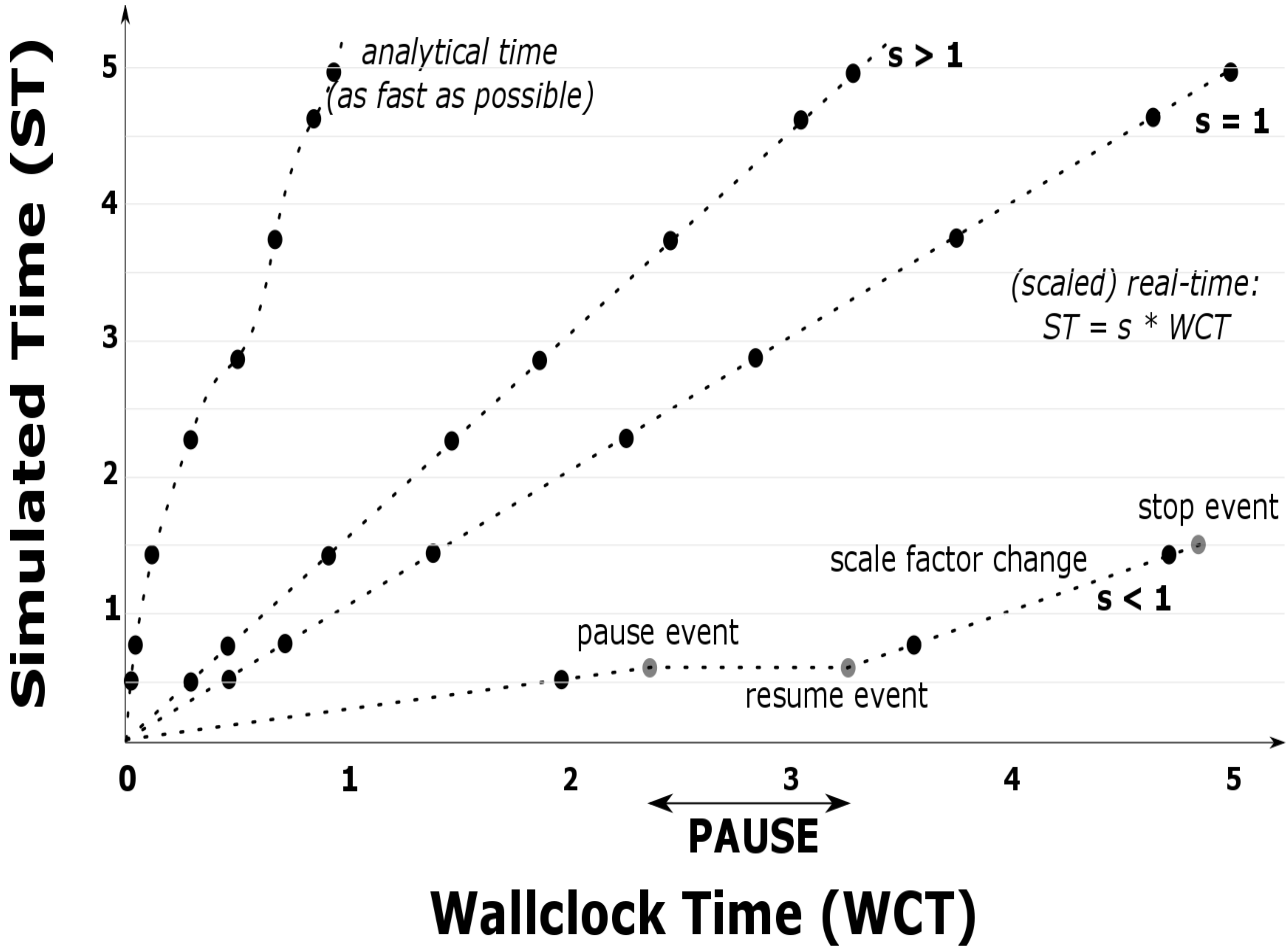


Simulated Time (ST)
3
2.3
0.8
0
"big step"
"small step"
Simulation Step (SSTEP)

Superdense Time (Edward Lee)

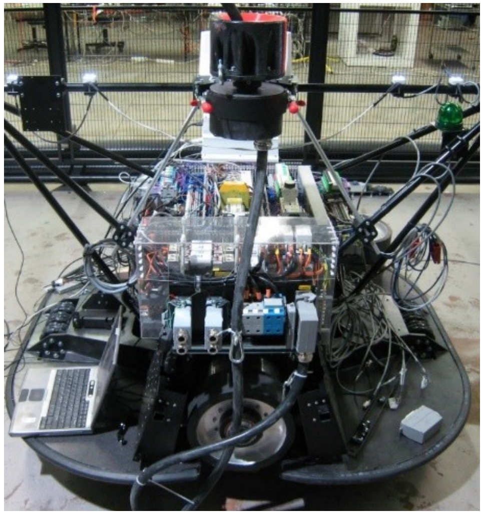
$$T = \mathbb{R}_+ \times \mathbb{N}$$

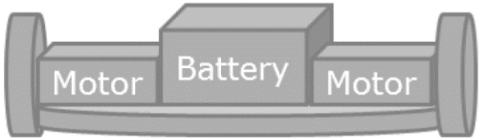




Simulated Time (ST)
5
4
3
2
1
analytical time
(as fast as possible)
s > 1
s = 1
(scaled) real-time:
ST = s * WCT
stop event
scale factor change
s < 1
pause event
resume event
0
1
2
3
4
5
PAUSE
Wallclock Time (WCT)

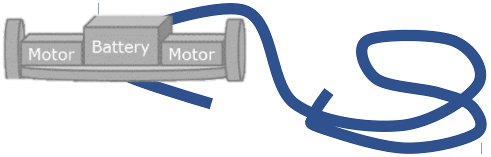
AGV example



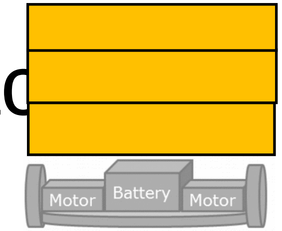


requirements:

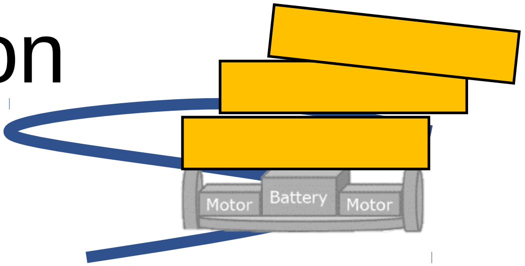
- Max. autonomy



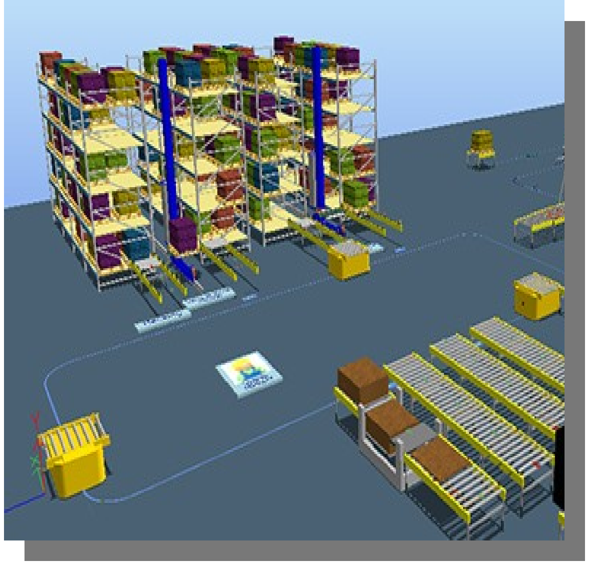
- Max. load capac



- Max. acceleration



- Min. task duration



[1] Case Study by Kristof Berx , Davy Maes, and Klaas Gadeyne, from Flanders Make
[2] Dávid, I., Syriani, E., Verbrugge, C., Buchs, D., Blouin, D., Cicchetti, A., & Vanherpen, K. (2016). Towards inconsistency tolerance by quantification of semantic inconsistencies. In *1st International Workshop on Collaborative Modelling in MDE* (Vol. 1717, pp. 35–44).

co-simulation (and co-modelling)

In co-simulation the different **subsystems** which form a **coupled** problem
are **modeled** and **simulated** in a **distributed** manner (in space and/or time).

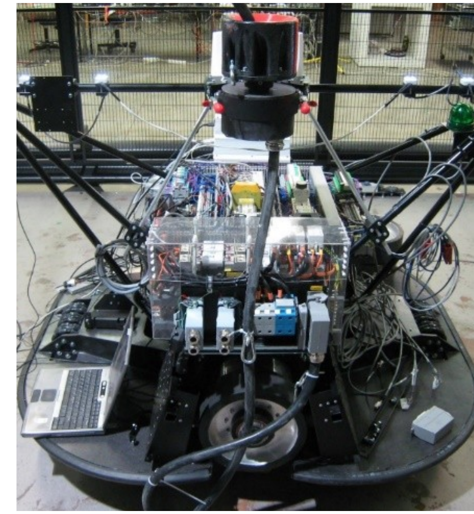
Hence, the modeling is done on the subsystem level
without having the coupled problem in mind.

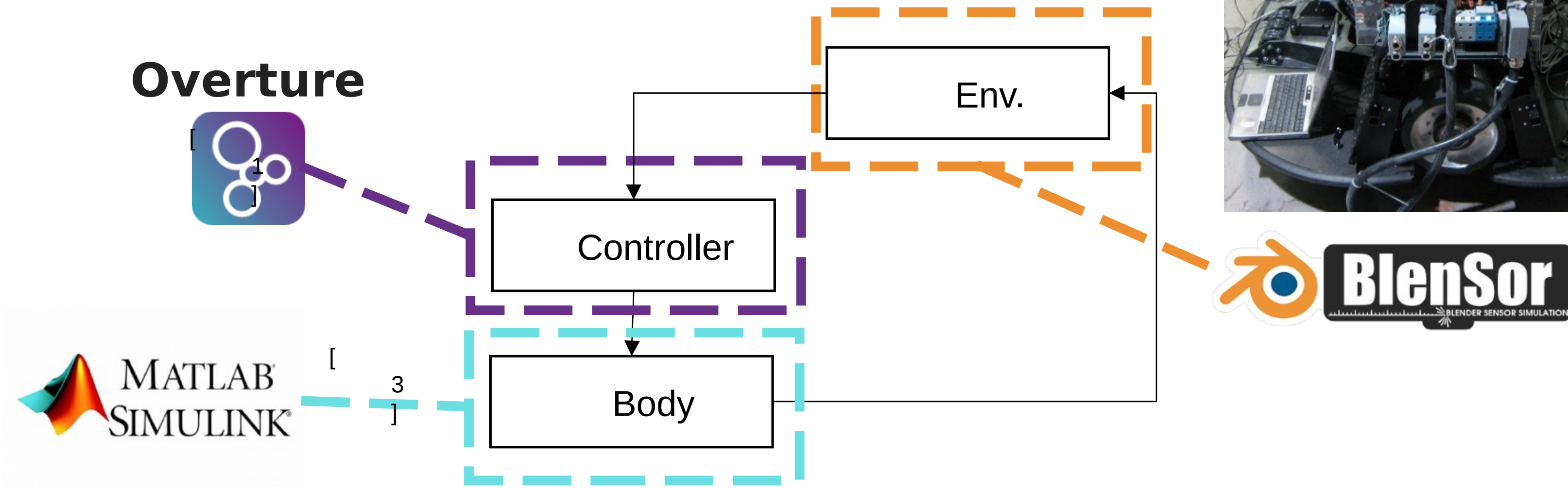
Furthermore, the coupled simulation is carried out
by running the subsystems in a **black-box** manner.

Sicklinger, S.; Belsky, V.; Engelmann, B.; Elmqvist, H.; Olsson, H.; Wüchner, R.; Bletzinger, K.-U. .
Interface Jacobian-based Co-Simulation.
International Journal for Numerical Methods in Engineering 98 (6): 418–444. (11 May 2014)

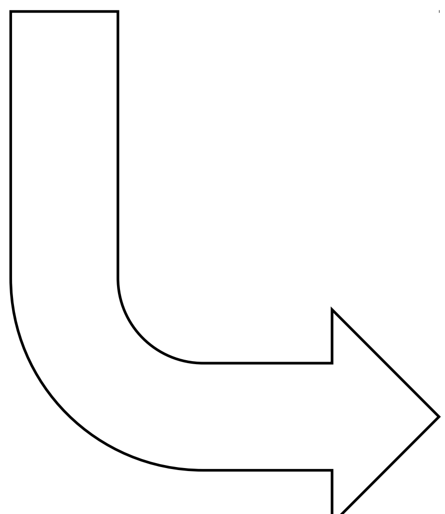
Co-simulation

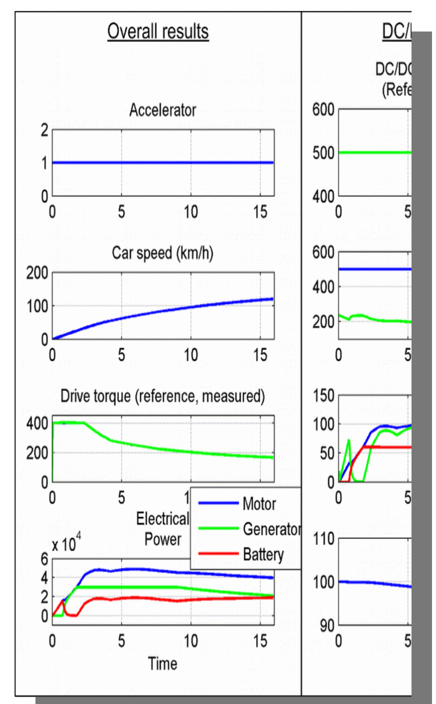
(the essence)





a technique to combine sub-system simulators





[1] http://overturetool.org/
[2] http://www.blensor.org/
[3] https://nl.mathworks.com/products/simulink.html