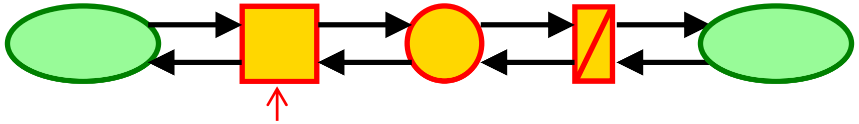
Polytech' Paris Sud

June 2014



« System, Causality and Energy »

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http://www.emrwebsite.org/

based on the Keynote at EMR'09 in collaboration
with Prof. CC Chan (University of Hong Kong)

- Outline -

1. **Model, Representation and simulation**
    - Different models
    - Different representations

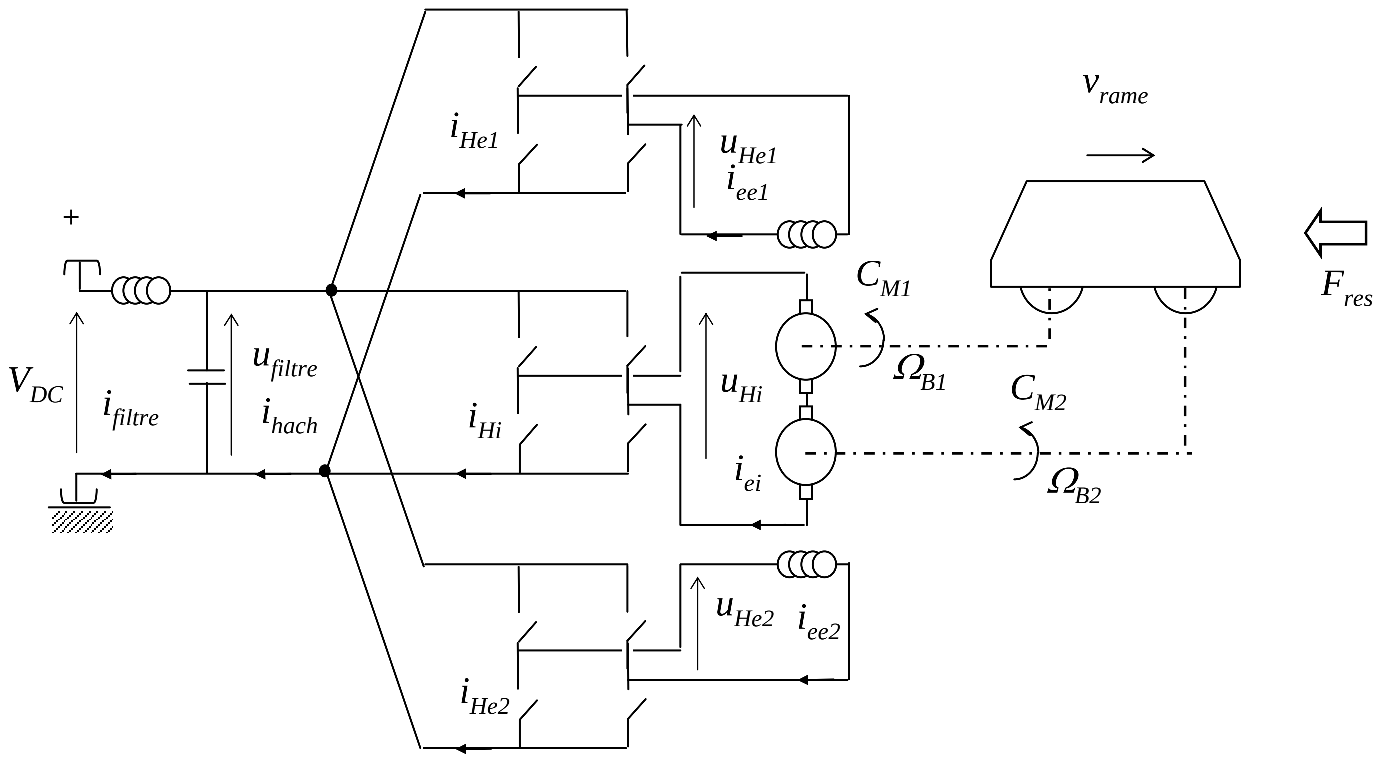
2. **Systems and interaction**
    - Systemic approach
    - Cartesian Approach

3. **Energy and causality**
    - Integral causality
    - Delay and risks

4. **Graphical descriptions**
    - Different descriptions

Traction or propulsion system

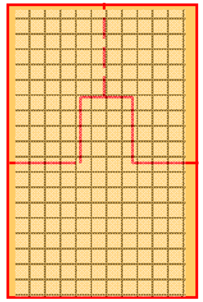
- Complex system
- Multiphysical system
- Sizing? Performances? Control?



Simulation for ever!

Launching Matlab/Simulink is more and more a "Pavlov reflex"

real system

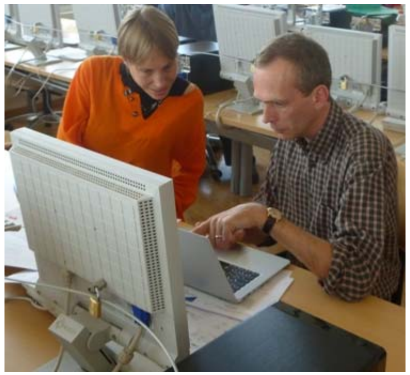


system simulation

↓

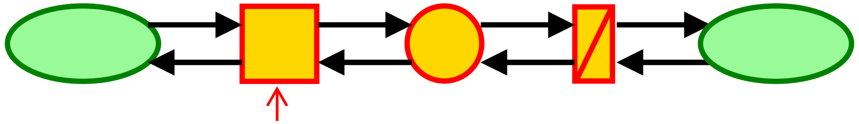
behavior study

?#@!&?



But:

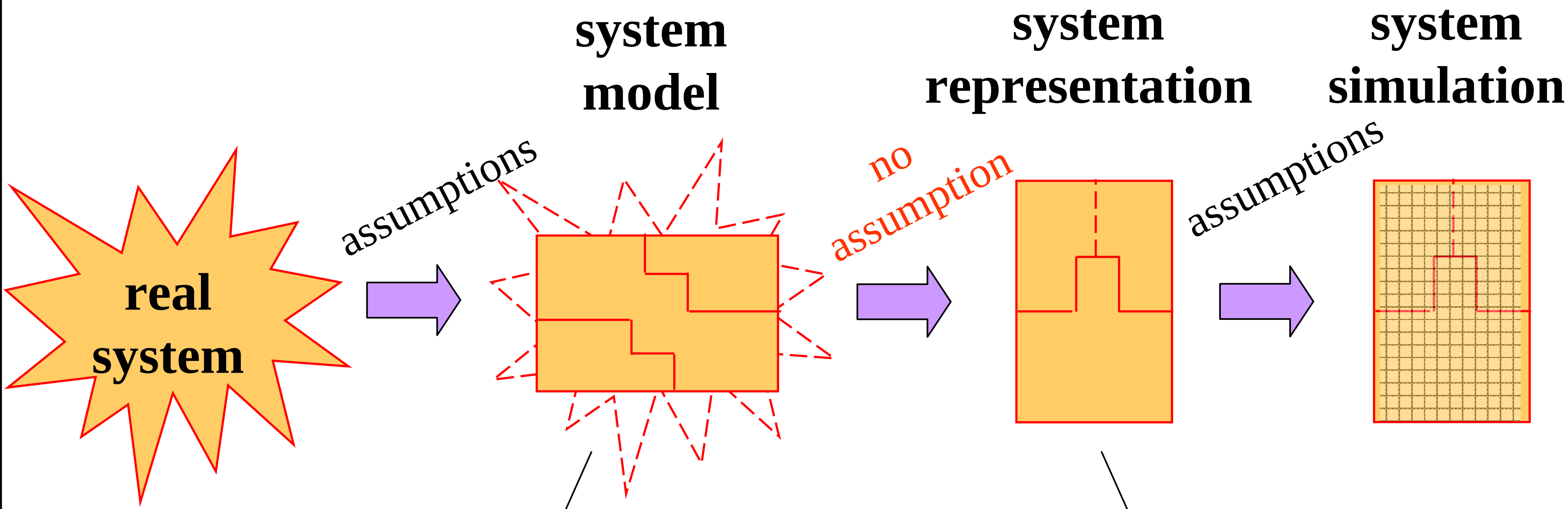
- Why simulation?
- Which constraints and objectives?
- Which level of accuracy?
- How to be sure of the results?



1. « Model, representation and simulation »

Which different steps before simulation?

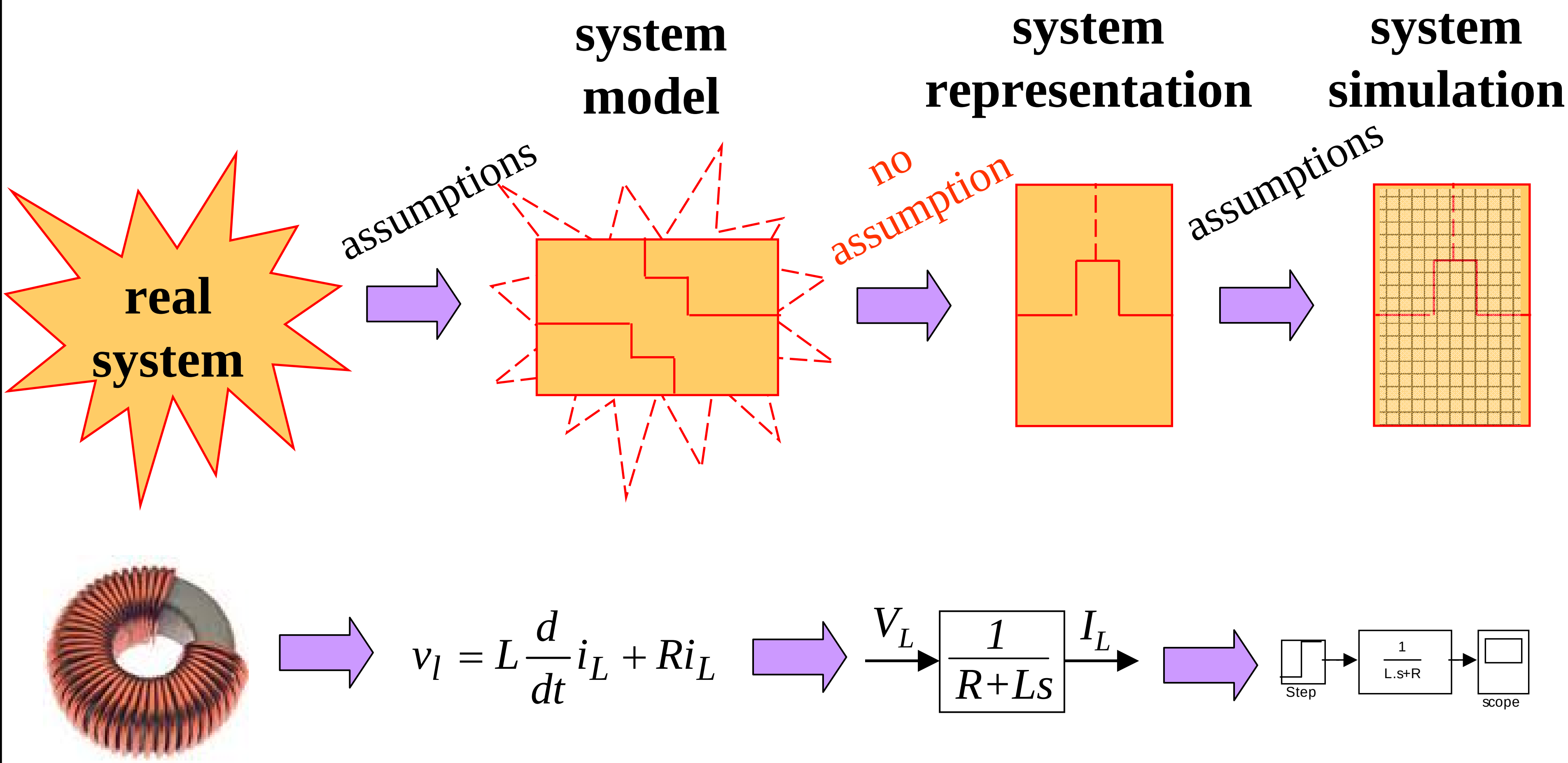
- From real systems to simulation -



Limitation to main
phenomena in function
of the objective

Organization of the
model to highlight
some properties

Intermediary steps are required for complex systems



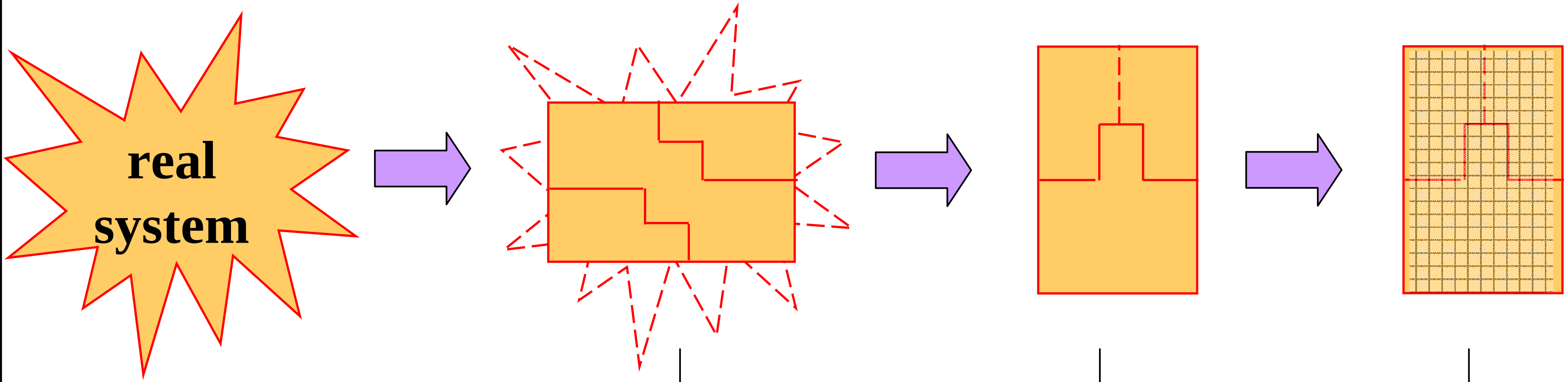
smoothing inductor

(low frequency dynamical model)

(bloc diagram +Laplace)

(Simulink © +Runge Kutta)

system model | **system representation** | **system simulation**

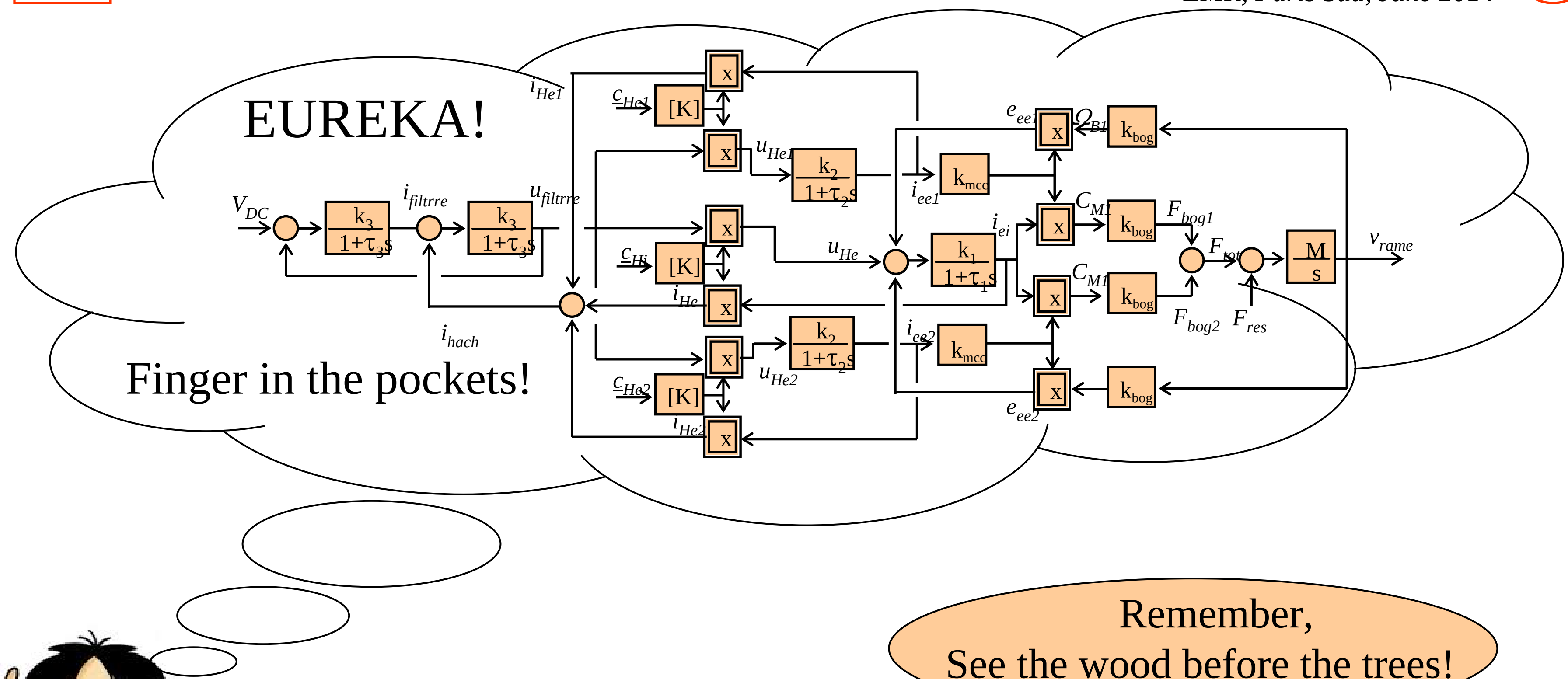


- dynamic
  / quasi-static
  / static

- structural/functional
- causal/non-causal

- backward
  / forward

Different possibilities at each step in function of the objective



Remember,
See the wood before the trees!

But block diagrams:

- can be confusing for complex systems
- are limited to continuous and linear systems
- do not highlight energy properties
- do not highlight interaction between subsystems

Which model subsystem?

Static model

- steady state operations
- no transient states
- fast computation time
- global behavior

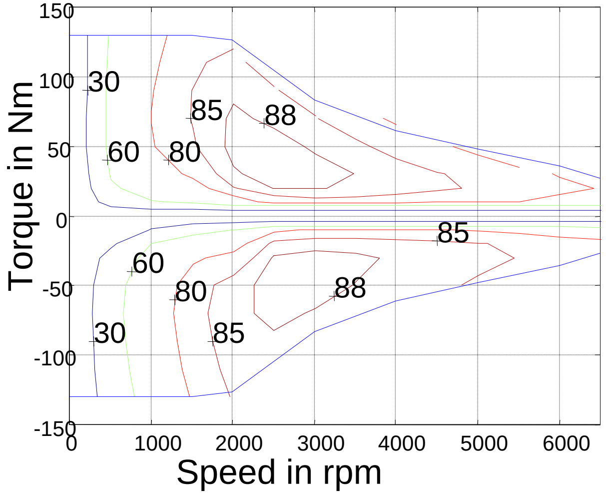
Dynamic model

- transient state operations
- but also steady state operations
- long computation time
- detailed behavior

Quasi-static model

- static model + main time constant
- intermediary computation time
- intermediary behavior

static efficiency map



$$i_{DC} = \frac{T_{em}\Omega + P_t(T_{em}, \Omega)}{U_{DC}}$$

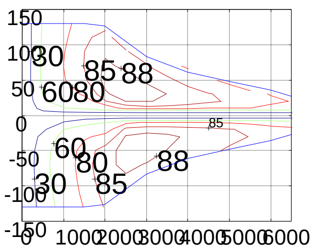
dynamic model

$$\begin{cases} V_{Sd} = R_S i_{Sd} + \cancel{\frac{d\phi_{Sd}}{dt}} - \omega_S \phi_{Sq} \\ V_{Sq} = R_S i_{Sq} + \cancel{\frac{d\phi_{Sq}}{dt}} + \omega_S \phi_{Sd} \\ 0 = R_R i_{Rd} + \cancel{\frac{d\phi_{Rd}}{dt}} - \omega_R \phi_{Rq} \\ 0 = R_R i_{Rq} + \cancel{\frac{d\phi_{Rq}}{dt}} + \omega_R \phi_{Rd} \end{cases}$$

$$T_{em} = p\frac{L_m}{L_R} \cdot (\phi_{Rd} \cdot i_{Sq} - \phi_{Rq} \cdot i_{Sd})$$

$$J\frac{d}{dt}\Omega = T_{em} - T_{load} - f\Omega$$

quasi-static model



$$+ J\frac{d}{dt}\Omega = T_{em} - T_{load} - f\Omega$$

How to describe a system?

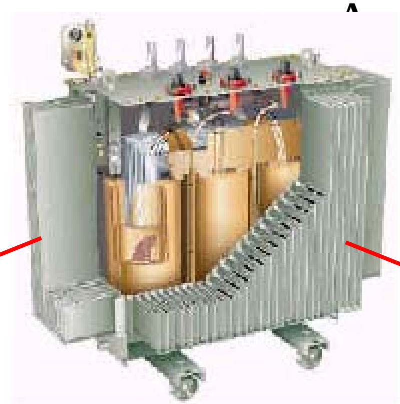
Structural description

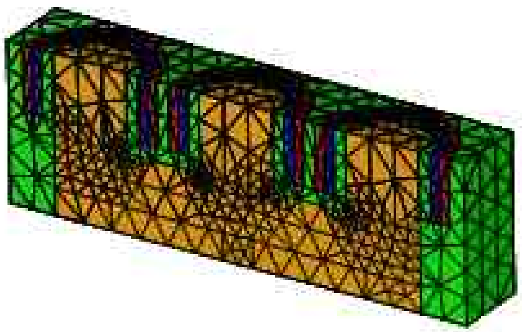
- Physical structure in priority
- Physical links between subsystems
- Design application

Functional description

- function priority
- Virtual links between subsystems
- Analysis and control application

Example





3D Finite Element Model

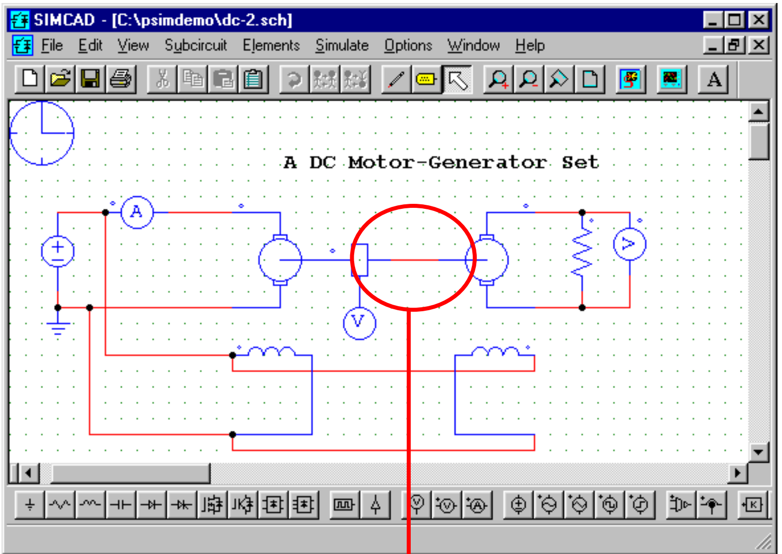
$$\begin{cases} \underline{v}_2 = m\,\underline{v}_1 \\ \underline{i}_1 = m\,\underline{i}_2 \end{cases}$$

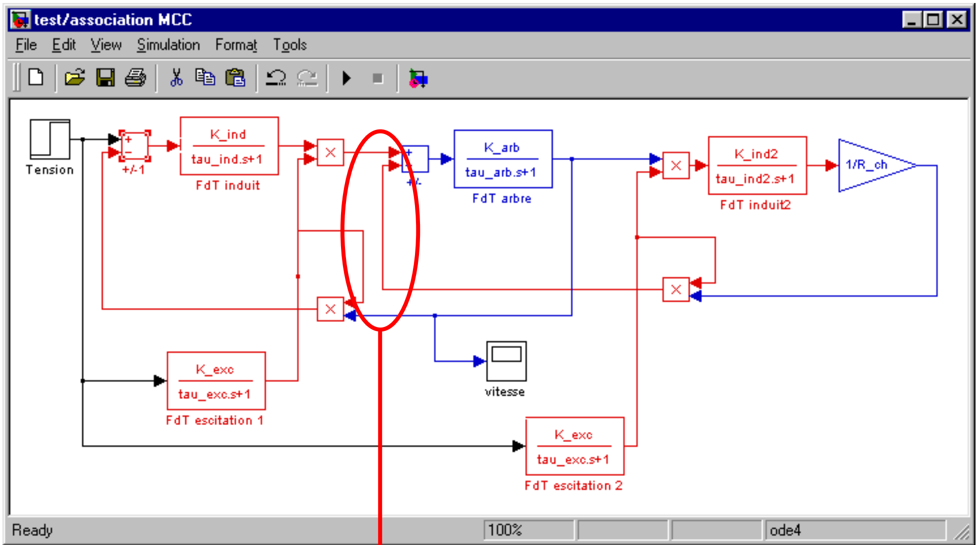
Mathematic model
Assumption:
Ideal transformer

two DC machine system

PSIM (structural)

Matlab-Simulink (functionnal)





machines connected by
a unique link (shaft)

machines connected by
two links (torque/speed)

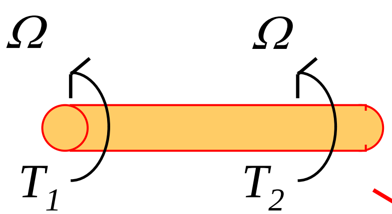
How to connect subsystem?

Causal description

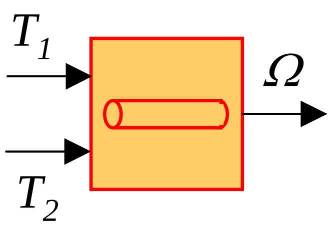
- fixed input and output
- output = integral function of inputs
- difficult interconnection subsystems
- basic solver

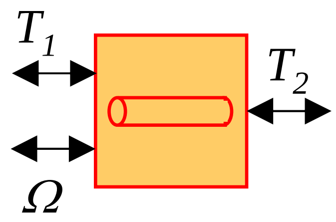
Non-causal (acausal) description

- non-fixed inputs and outputs
- different relationships
- easy subsystem interconnection
- specific solver required
- simulation library

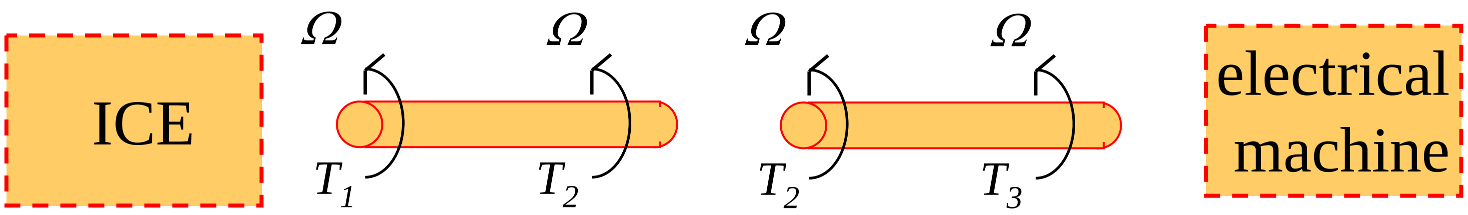


$$J \frac{d}{dt}\Omega = T_1 - T_2$$



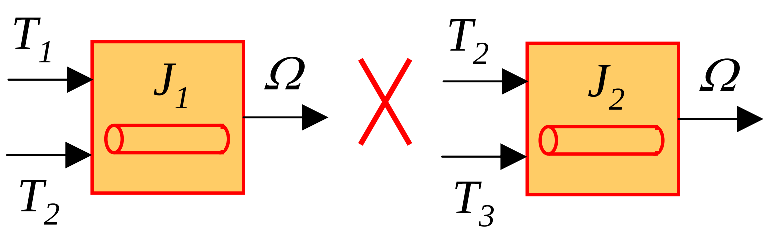


Example

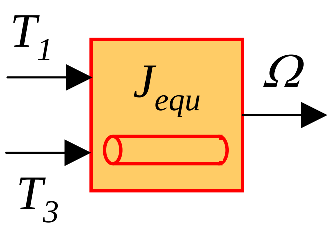


$$J_1 \frac{d}{dt}\Omega = T_1 - T_2 \qquad J_2 \frac{d}{dt}\Omega = T_2 - T_3$$

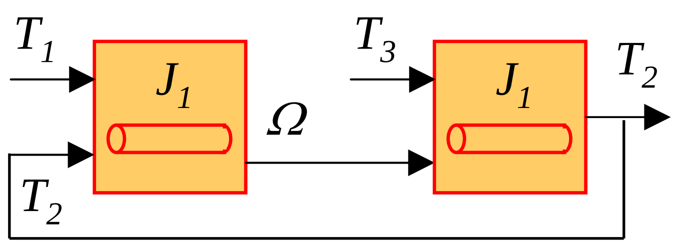
causal description



$$(J_1 + J_2)\frac{d}{dt}\Omega = T_1 - T_3$$



acausal description



derivative relationship

specific solver

Which method to compute the model?

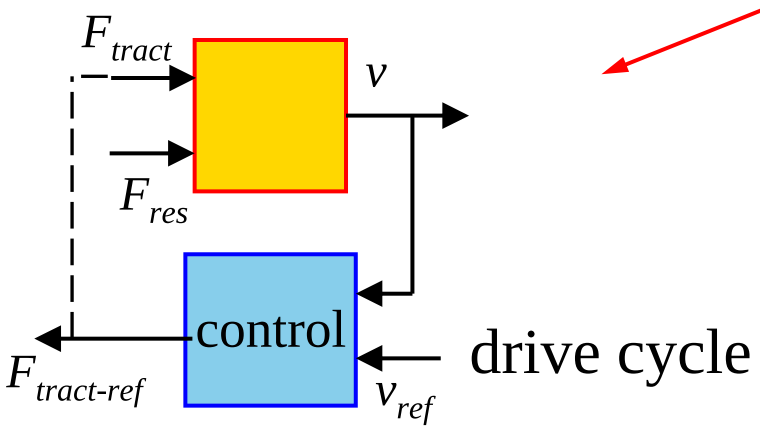
Forward approach

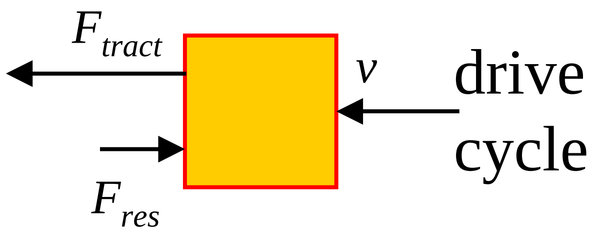
- from the cause to the effect
- respect of the energy flow
- controller required

Backward

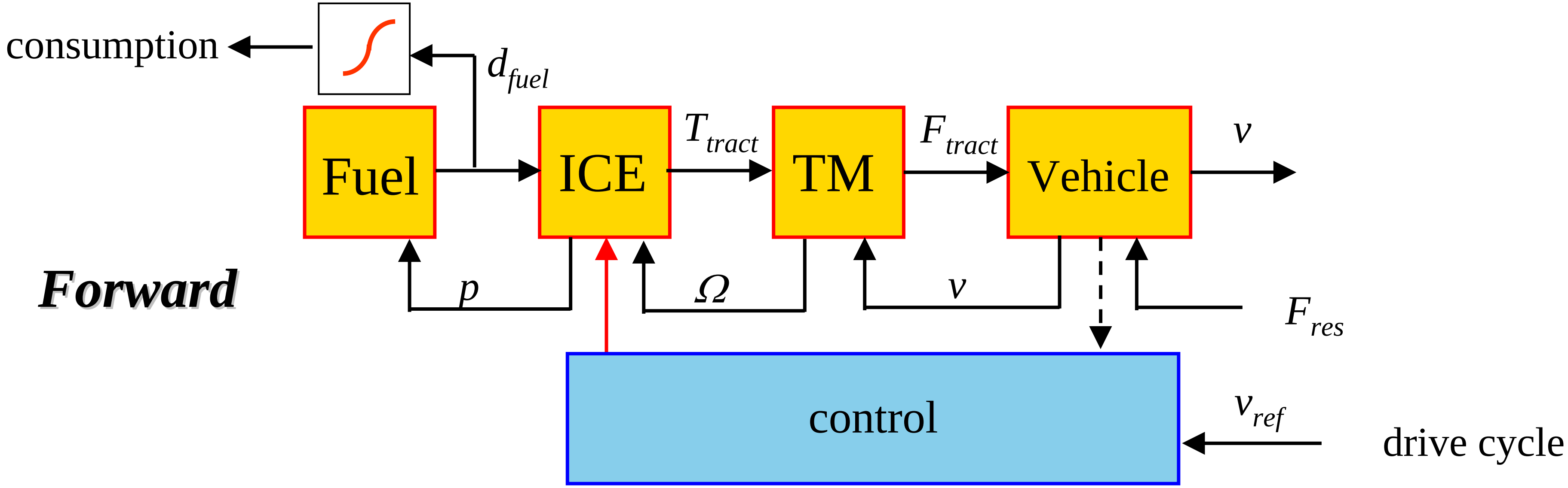
- from the desired effect to the required cause
- anticipate energy flow
- no controller required

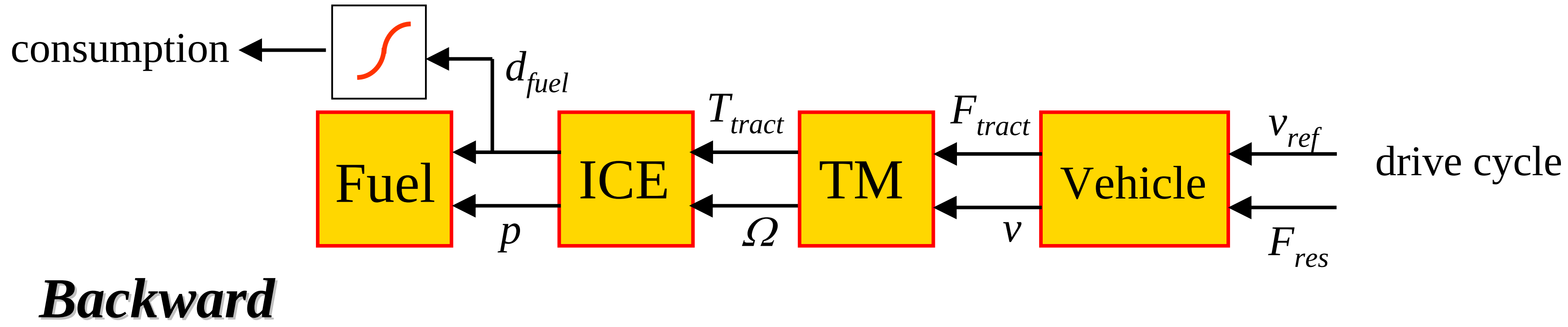
$$M\frac{d}{dt}v = F_{tract} - F_{res}$$



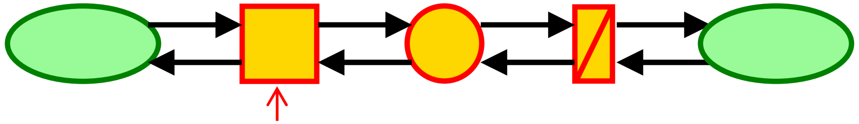


derivative relationship
(no real-time application)





could be same models, but different representations (cf. I/O)



« 2. System and Interaction »

How to connect multi-physical subsystems?

System = interconnected subsystems
organized for a common objective,
in interaction with its environment

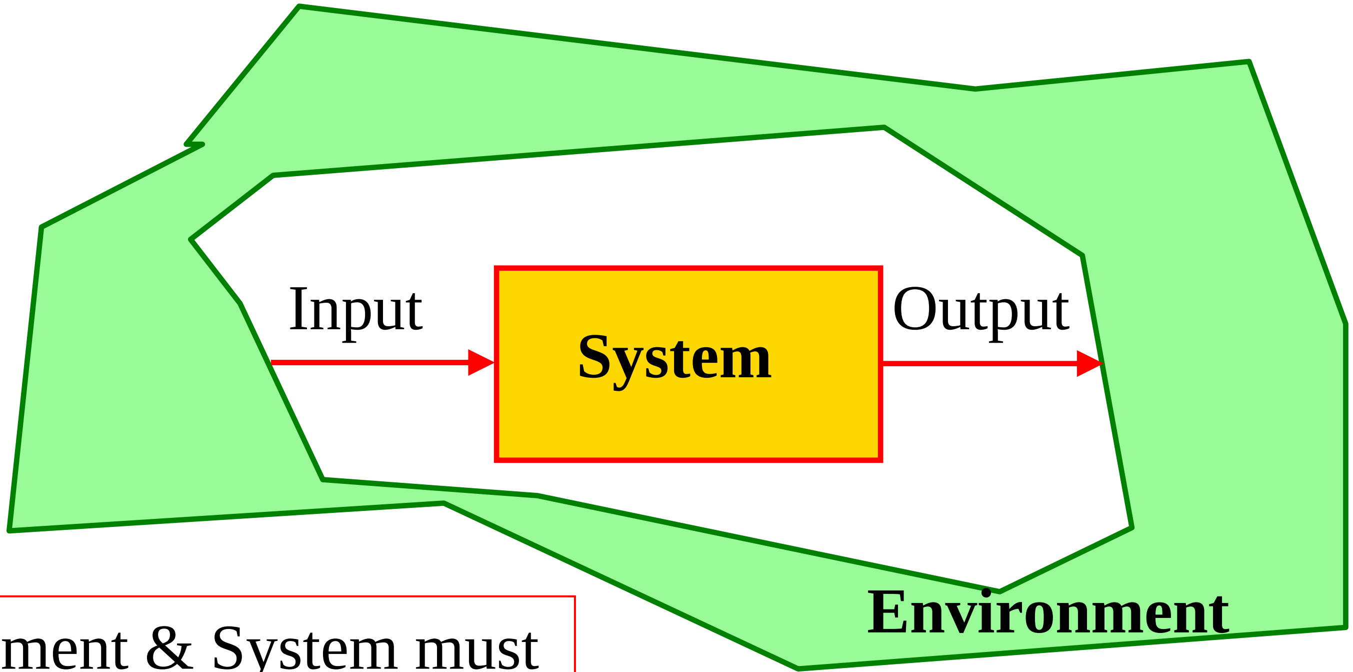
Systemic = science of study of systems and their interactions

Cartesian approach = the study of subsystems is sufficient to know the system behavior (without considering their interactions)

Interaction is the keyword

Input: variable produced by the environment, imposed to the system for evolution (independent of the system)

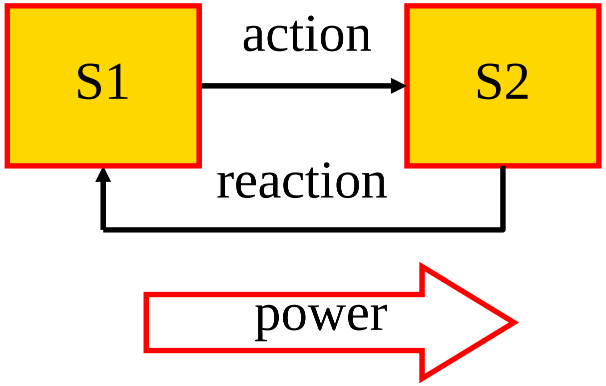
Output: consequence of the system evolution, imposed to its environment (not directly dependant on the environment)



Environment & System must be defined first!

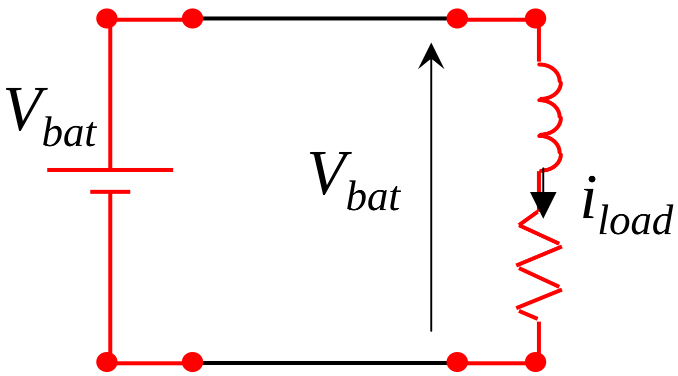
Interaction principle
Each action induces a reaction

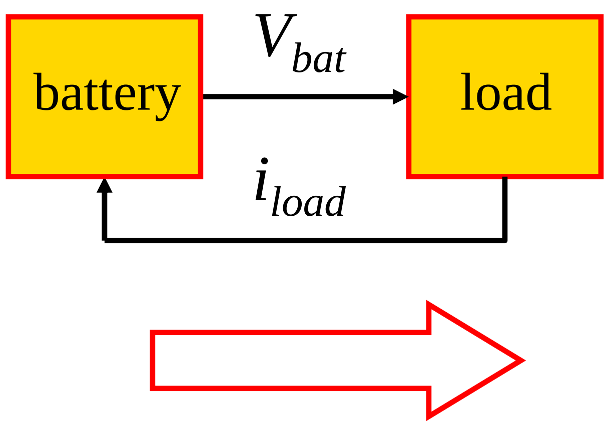
[Paynter 61][MMS 00]



Power exchanged by S1 and S2 = action x réaction

Example



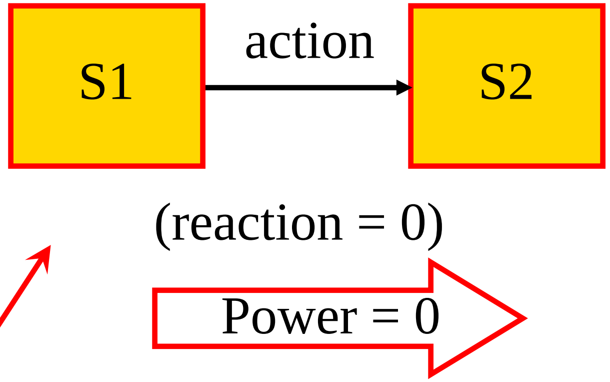


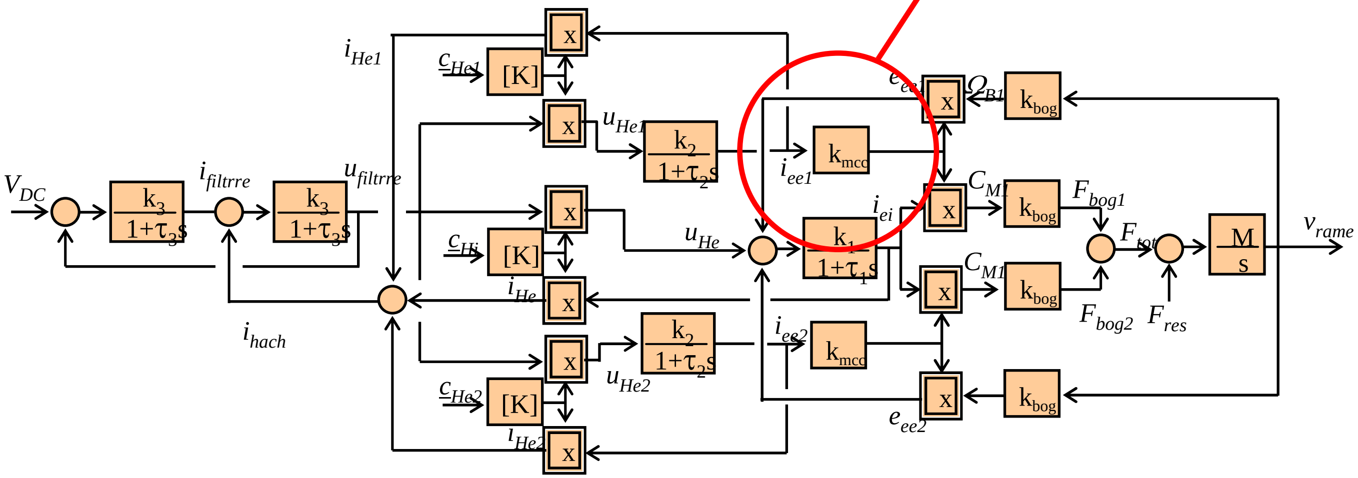
$$P = V_{bat}\, i_{load}$$

If the interaction principle is not respected for 1 subsystem

⇩

Error in the energy analysis for the whole system





System = interconnected subsystems

Systemic approach
Study of subsystems and their interactions
Holistic property: associations of subsystem induce new global properties.

Cartesian approach
The study of subsystems is sufficient to know the system behaviour.

Cybernetic systemic
black box approach.
behaviour model

Cognitive systemic
physical laws
knowledge model

For better performances of a system
Interactions and physical laws must be considered!

System 1 vs. System 2

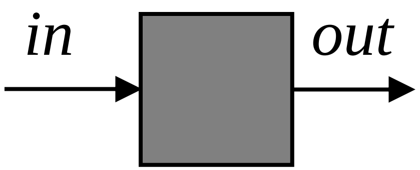
Team made of partners → Systemic approach

Group made of individualists → Cartesian approach

Spain 2 – 0 France

(EMR'12, Madrid, courtesy P. Barrade)

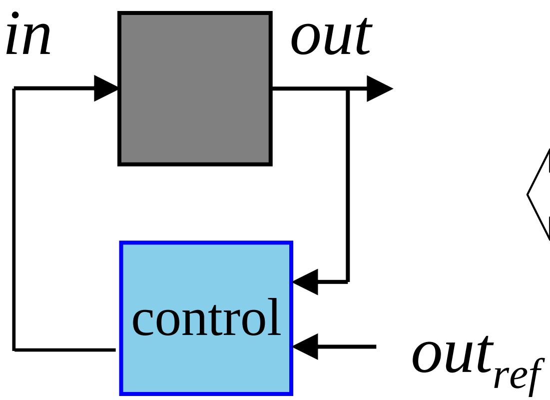
or "Black box" approach: no internal knowledge



identification test:
observation of *out(t)* from selected *in(t)*

Behavior model:
$out(t) = f(t)\, in(t)$

closed-loop control of *out*:
for uncertainty compensations

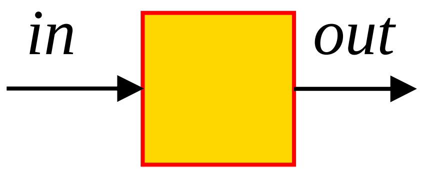


or “White box” approach: prior internal knowledge

Physical laws of system components

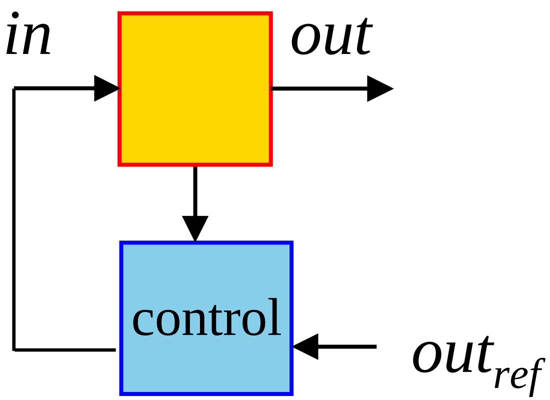
Knowledge model:

out(t) = f(t) *in(t)*

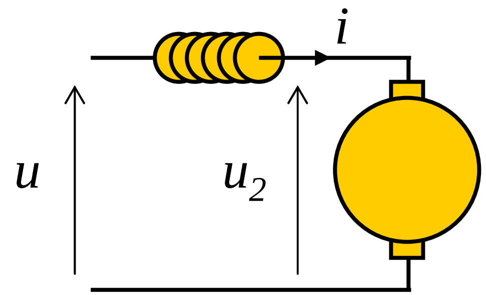


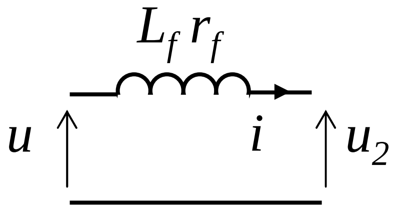
control = inversion of model:

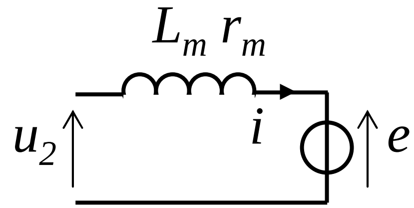
(closed loop = an inversion way)



DC machine and smoothing inductor

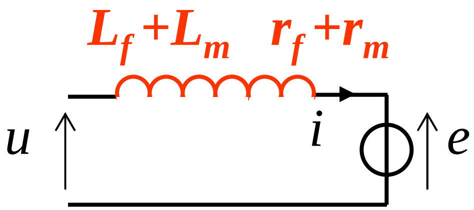






$$L_f \frac{di}{dt} = u - u_2 - r_f i$$

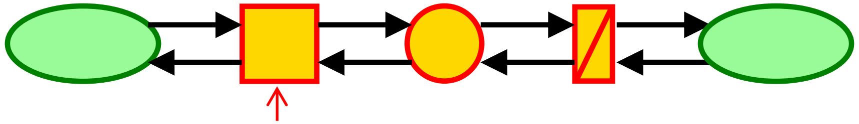
$$L_m \frac{di}{dt} = u_2 - e - r_m i$$



$$(L_f + L_m)\frac{di}{dt} = u - e - (r_f + r_m)i$$

Association of both subsystems ⇒ must be studied globally

$$\frac{L_f + L_m}{r_f + r_m} \neq \frac{L_f}{r_f} + \frac{L_m}{r_m}$$



« 3. Energy and Causality »

How to manage energy in the best way?

Energy = amount of work that can be performed by a force, an object, a system

Ideal energy conversion: energy conservation (no losses) and instantaneous transfer (no delay)

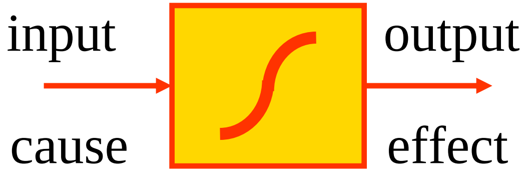
but

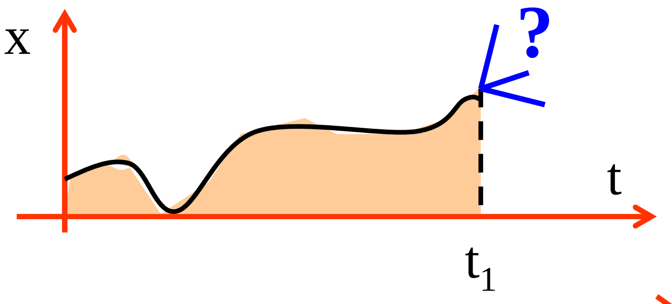
Energy dissipation: losses, reduction of efficiency

Energy accumulation: delay in energy transfer

Energy accumulation in subsystems is key transformation for safety and efficiency

Principle of causality
physical causality is integral





$\int xdt$ ⇨ area
⇩
knowledge of past evolution

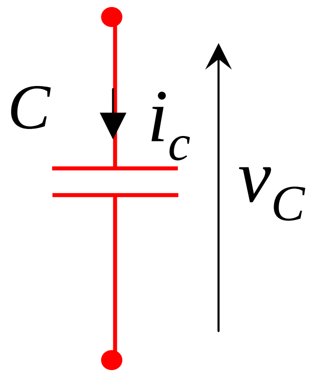
OK in real-time

~~$\frac{dx}{dt}$ ⇨ slope~~
~~⇩~~
~~knowledge of future evolution~~

impossible in real-time

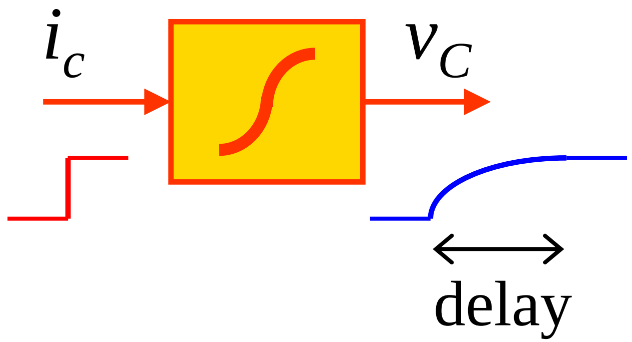
[Iwasaki 94][Hautier 96]

Example

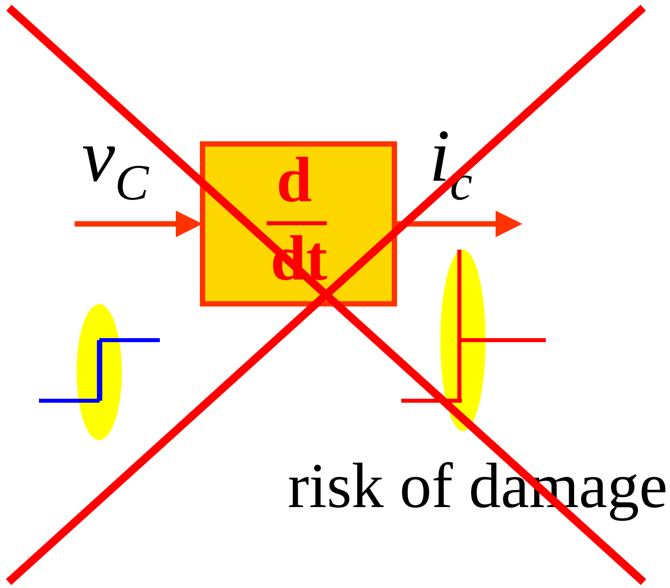


$$i_c = C\frac{d}{dt}v_c$$

$$E_c = \frac{1}{2}Cv_c^{\,2}$$



no energy disruption

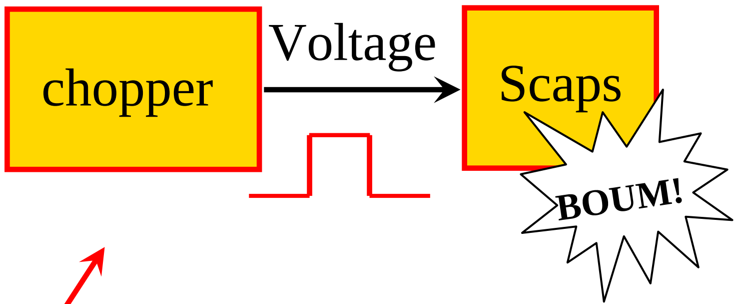


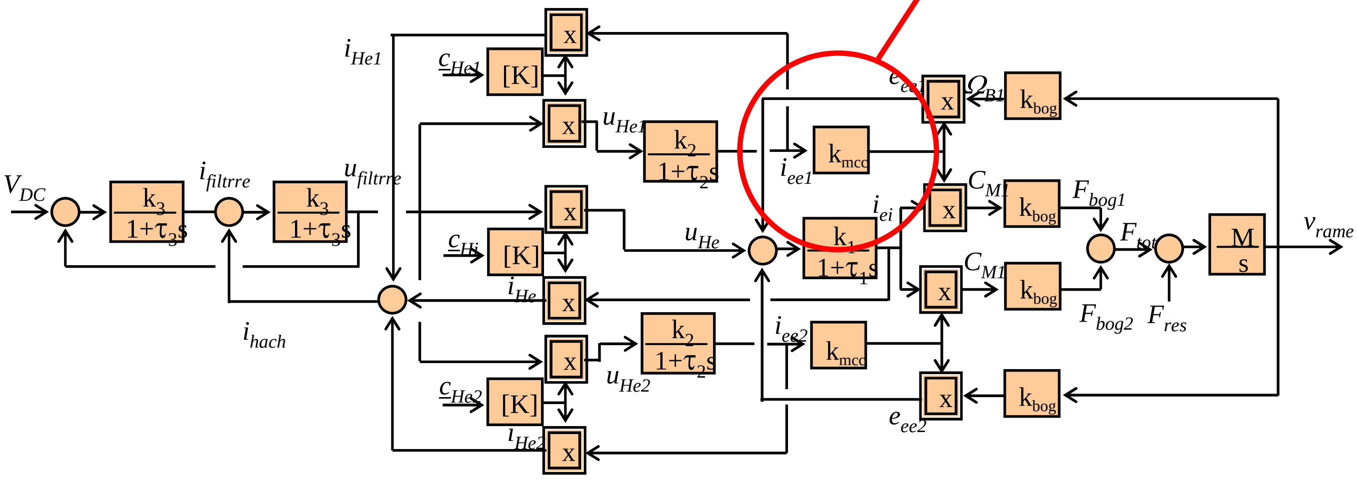
For energetic systems
physical causality is VITAL

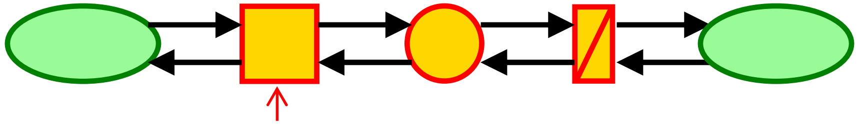
If the causality principle is not respected for 1 subsystem

⇩

Risk of damage!
No real-time management



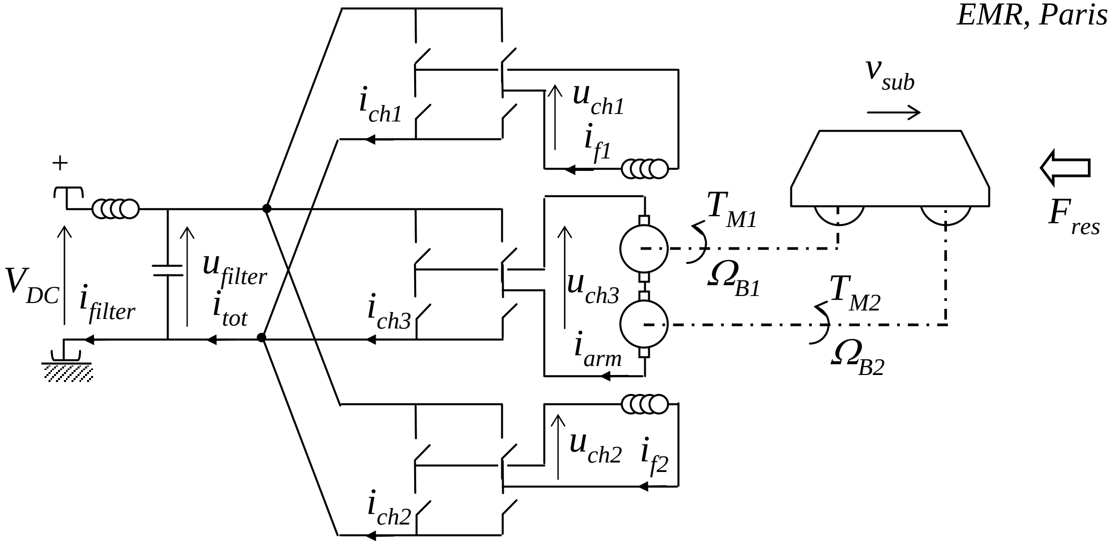




4. « Graphical descriptions for system engineering »

Interest of such an intermediary step?

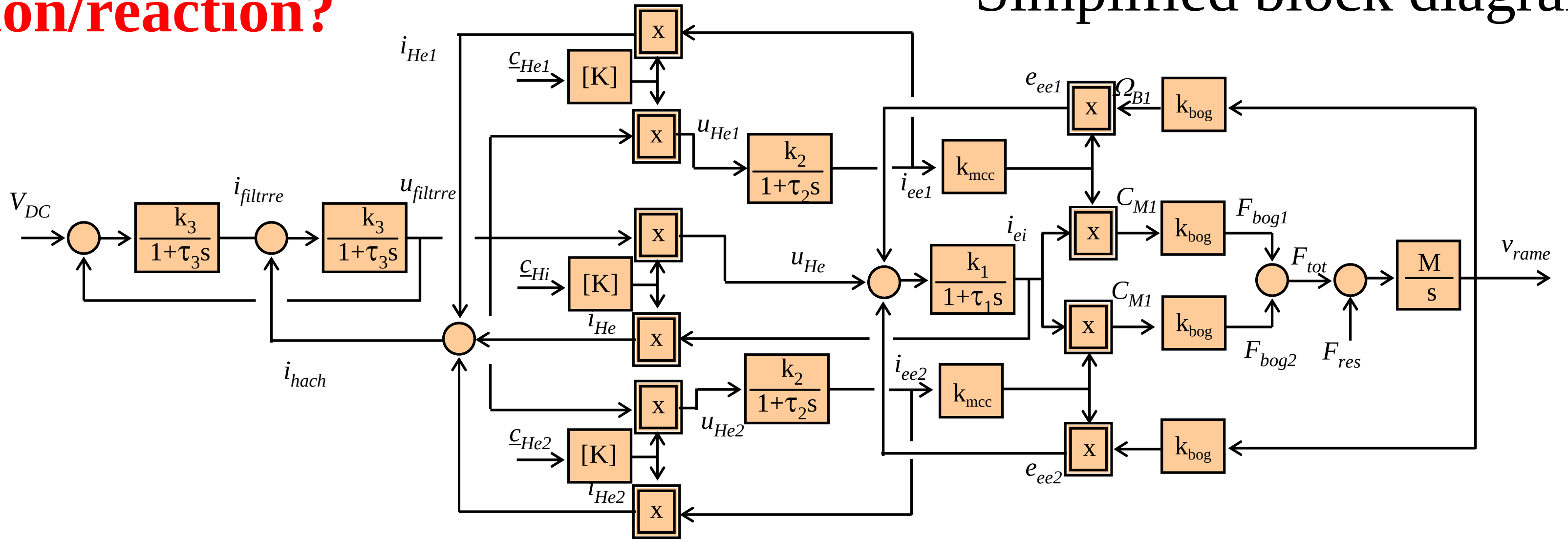
- Example of a railway traction system -



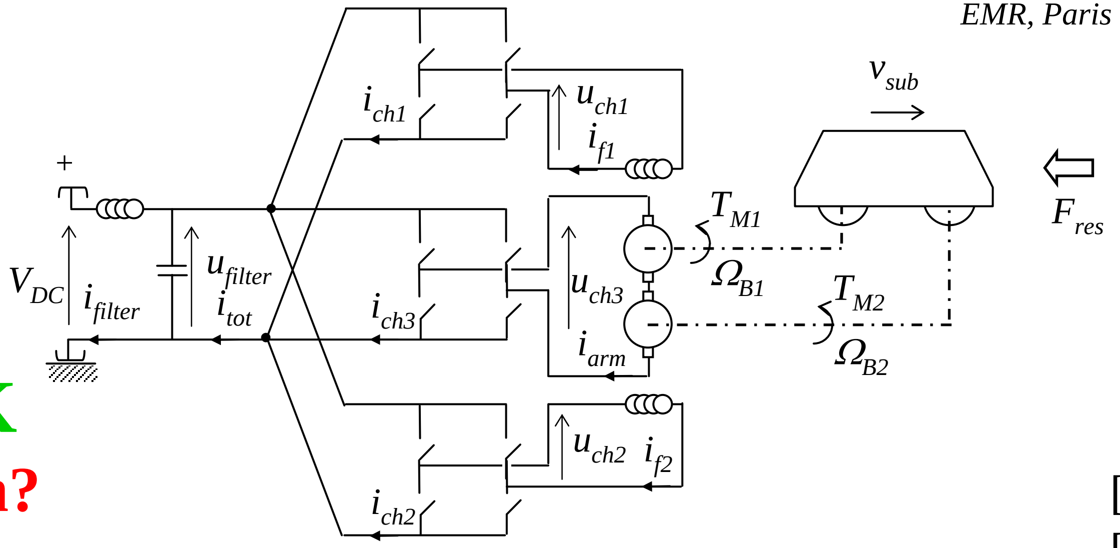
causality?

action/reaction?

Simplified block diagram



- Example of a railway traction system -

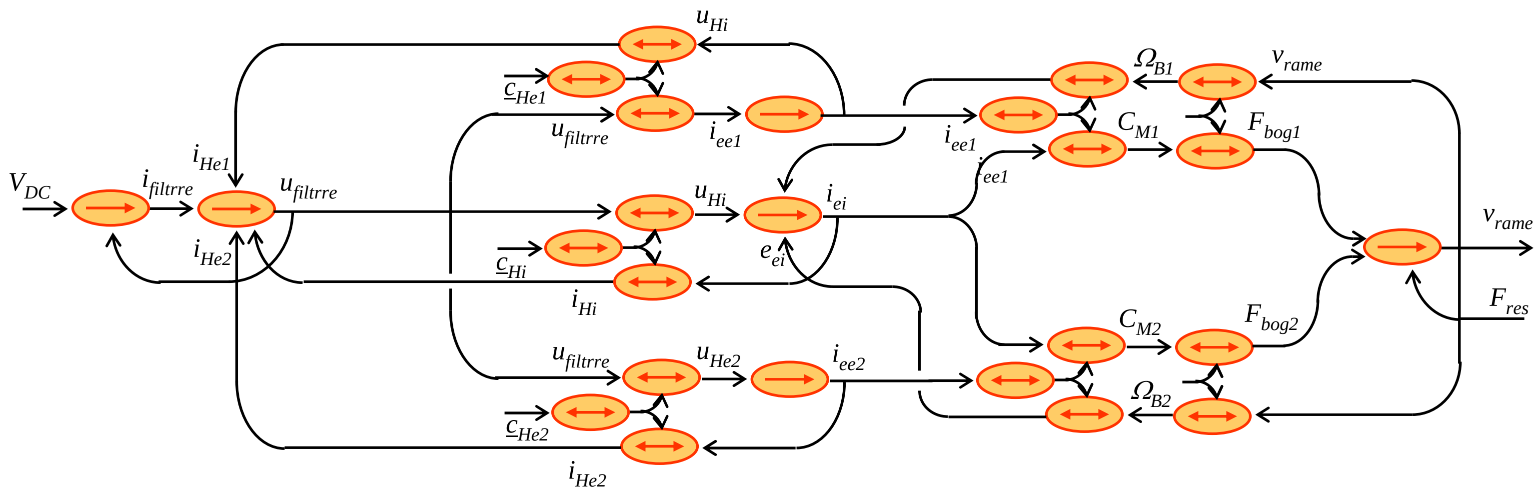


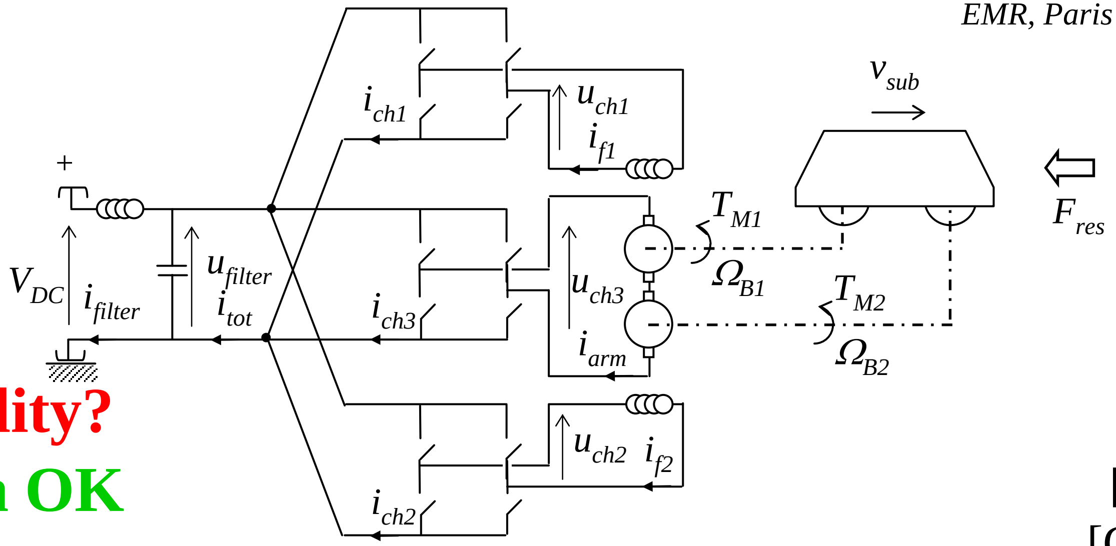
causality OK

action/reaction?

[Hautier 96]
[Hautier 04]

Causal Ordering Graph (COG)



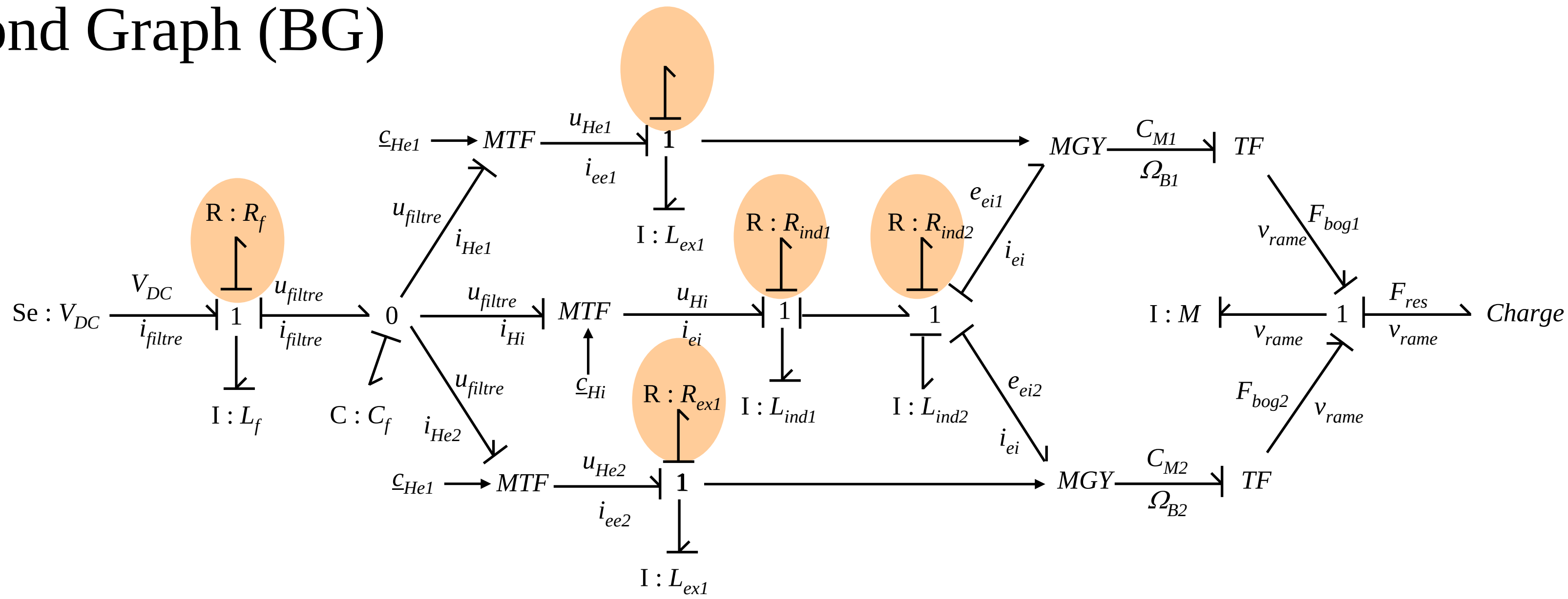


physical causality?

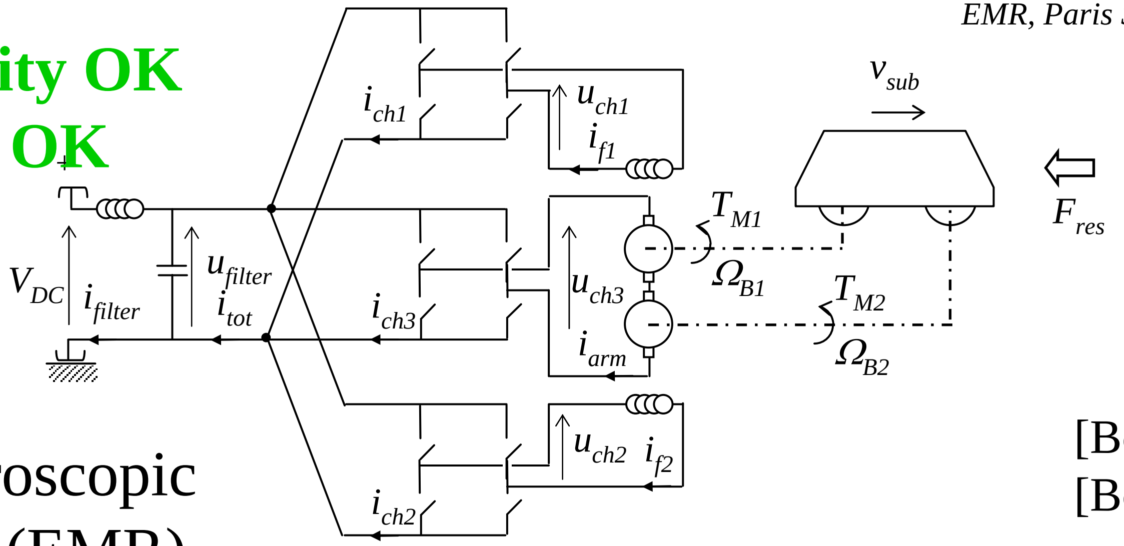
action/reaction OK

[Paynter 61]
[Gawthrop 03]

Bond Graph (BG)

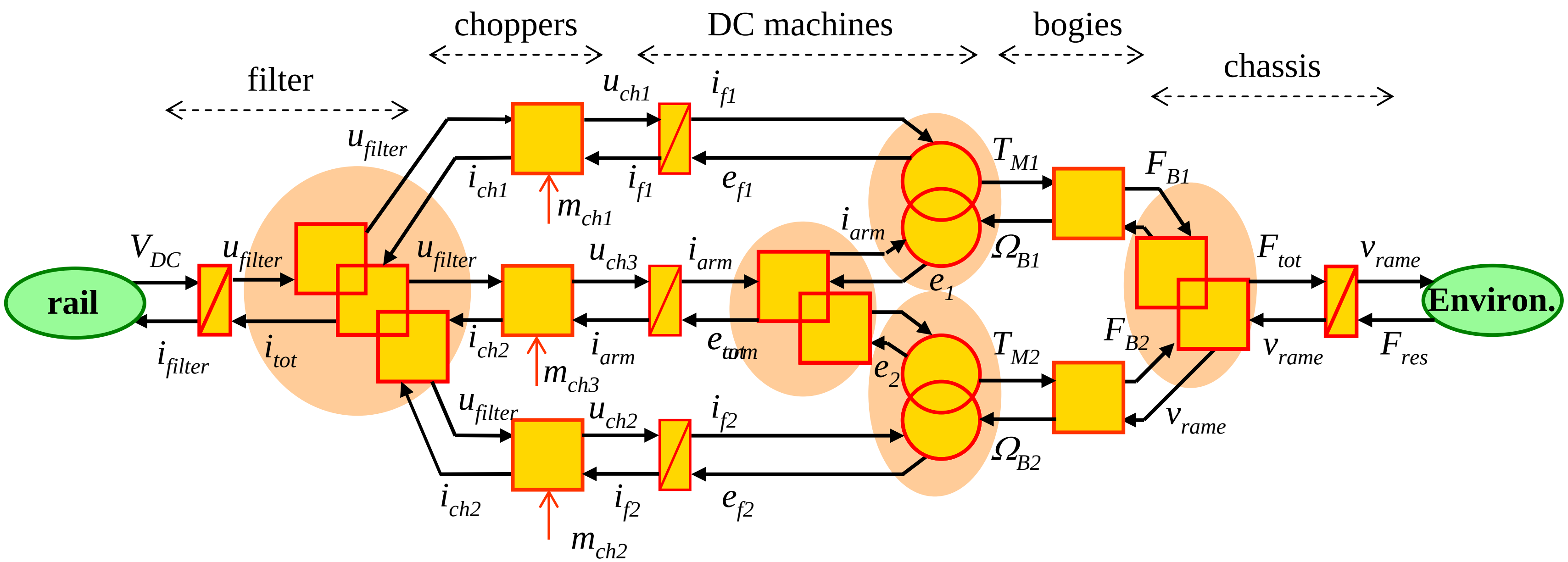


physical causality OK
action/reaction OK

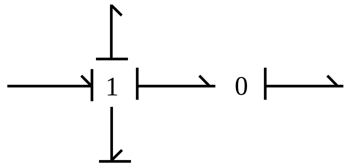


Energetic Macroscopic Representation (EMR)

[Bouscayrol 00]
[Bouscayrol 05]



Energy & System



Energetic Puzzles (Laplace, France)

Bond Graph (USA, The Netherlands…)

Power Oriented Graph (Italy)

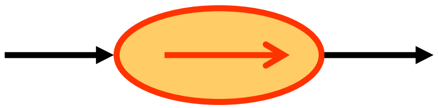
Signal Flow Diagram (Germany, Japan...)

Structural description for analysis and design ⇨ mathematical model ⇩ global controls

Block diagrams
COG (L2EP-LEEI, France)

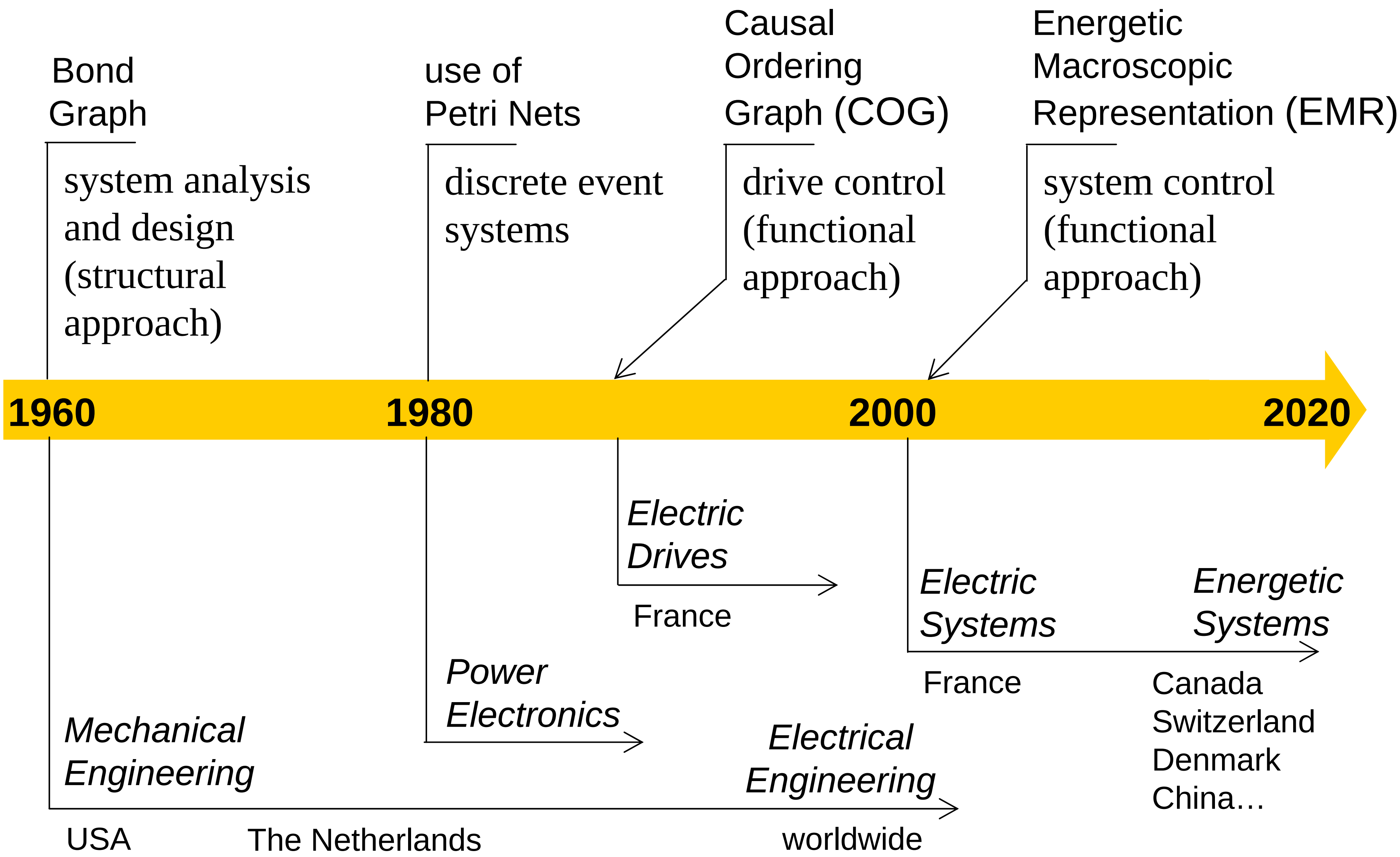
EMR (L2EP, France)

functional descriptions for simulation and control ⇨ inversion graphs ⇩ cascaded control



Remember,
divide and conquer!

- Graphical modelling tools -



- Which model for vehicle control? -

Multi-physical system	⇨	Systemic approach
Energy management	⇨	Energetic approach Causal representation
System control	⇨	Functional description
Real-time control	⇨	Dynamical modeling Causal representation

Moreover a graphical description could be a valuable intermediary step for such complex systems

« Conclusion »

system = subsystems in interaction

best performances require a systemic approach

energy = respect of the physical causality

energy management requires a causal approach

control -> inversion of a causal model of the system

in order to respect its energy properties

graphical description = model organization

useful intermediary step

Remember, follow
a disciplined procedure!

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- References -

S. Astier, A. Bouscayrol, X. Roboam, "Introduction to Systemic Design", Systemic Design Methodologies for Electrical Energy, tome 1, Analysis, Synthesis and Management, Chapter 1, ISTE Willey editions, October 2012

A. Bouscayrol, G. Dauphin-Tanguy, R Schoenfeld, A. Pennamen, X. Guillaud, G.-H. Geitner, "Different energetic descriptions for electromechanical systems", *EPE'05*, Dresden (Germany), September 2005. (common paper of L2EP, LAGIS and University Dresden).

C.C. Chan & al. "Philosophy of Engineering and Modelling of Electric Drives", ICEMS, October 2008, Wuhan (China)

C. C. Chan, A. Bouscayrol, K. Chen, "Electric, Hybrid and Fuel Cell Vehicles: Architectures and Modeling", IEEE transactions on Vehicular Technology, vol. 59, no. 2, February 2010, pp. 589-598 (common paper of Honk-Kong University and L2EP Lille).

P. J. Gawthrop, G. P. Bevan, "Bong Graph modeling, a tutorial introduction for control engineers", *IEEE Control Systems magazine*, vol. 27, no. 2, pp. 24-45, April 2007

G. H. Geitner, "Power Flow Diagrams Using a Bond graph Library under Simulink", *IEEE-IECON'06*, Paris, November 2006.

H. Grebber, "The philosophy of Engineering", IEEE Xplore, vol. 3, no. 10, 1966, pp. 112-115.

J.P. Hautier, J. Faucher, "Le graphe informationnel causal", Bulletin de l'Union des Physiciens, vol. 90, pp. 167-189, juin 1996

J. P. Hautier, P. J. Barre, "The causal ordering graph - A tool for modelling and control law synthesis", *Studies in Informatics and Control Journal*, vol. 13, no. 4, December 2004, pp. 265-283.

I. Iwasaki, H. A. Simon, "Causality and model abstraction", Artificial Intelligence, Elsevier, vol. 67, pp. 143-194, 1994.

MMS prlect, A. Bouscayrol, & al. "Multimachine Multiconverter System: application for electromechanical drives", *European Physics Journal - Applied Physics*, vol. 10, no. 2, May 2000, pp. 131-147 (common paper L2EP , GREEN, and LEEI, according to the MMS project of the GDR-SDSE).

H. Paynter, "Analysis and design of engineering systems", *MIT Press*, 1961.

R. Zanasi, R. Morselli, "Modeling of Automotive Control Systems Using Power Oriented Graphs", *IEEE-IECON'06*, Paris, November 2006.