« ENERGETIC MACROSCOPIC REPRESENTATION (EMR) »

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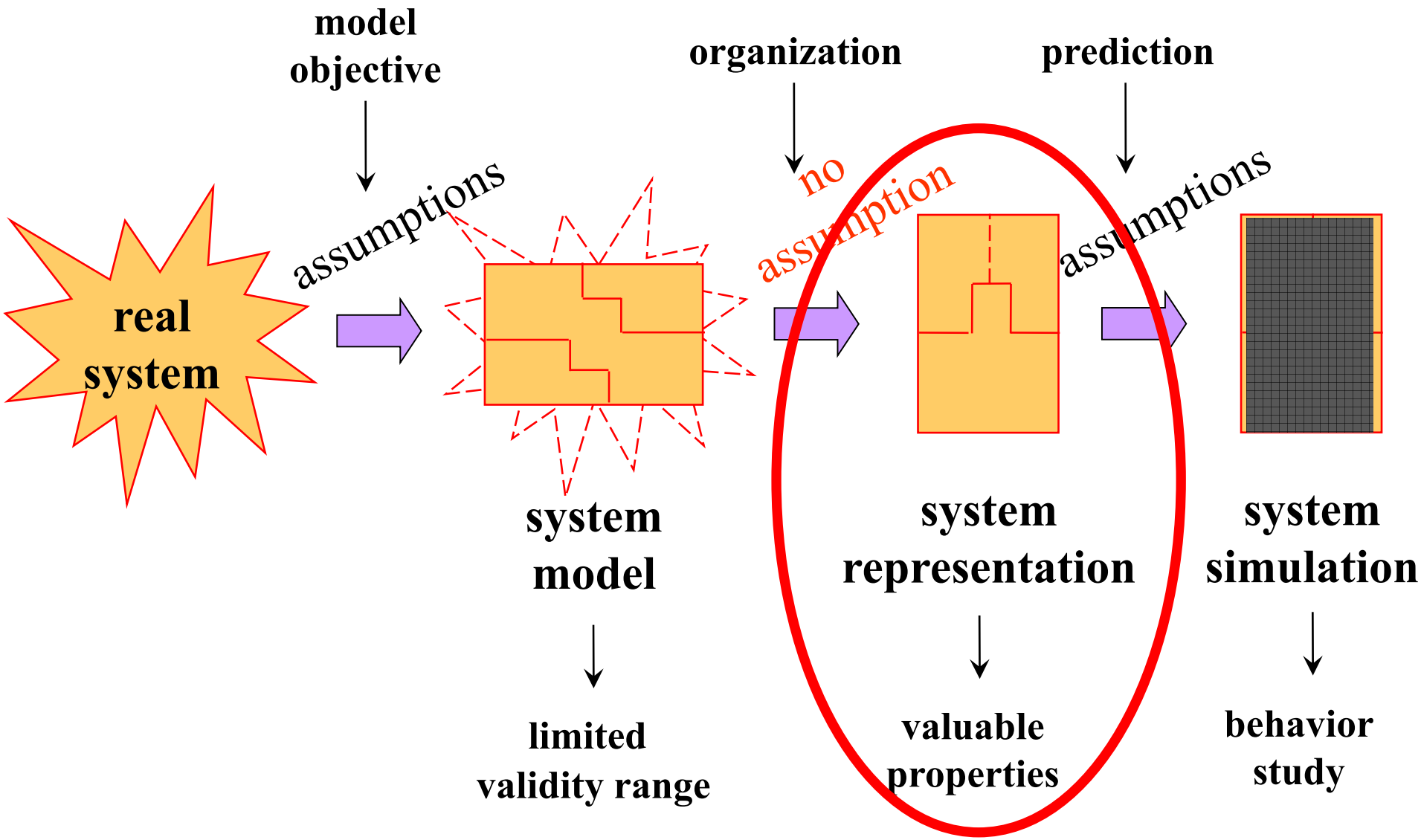

model objective
organization
prediction
assumptions
no assumption
assumptions
real system
system model
limited validity range
system representation
valuable properties
system simulation
behavior study

« EMR Basic Elements »

Only 4 energy functions

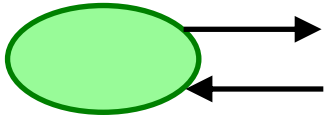
are required to describe

energy conversion systems

- Energy sources
- Energy storage
- Energy conversion
- Energy distribution

EMR = 4 graphical elements associated
with the 4 energy functions

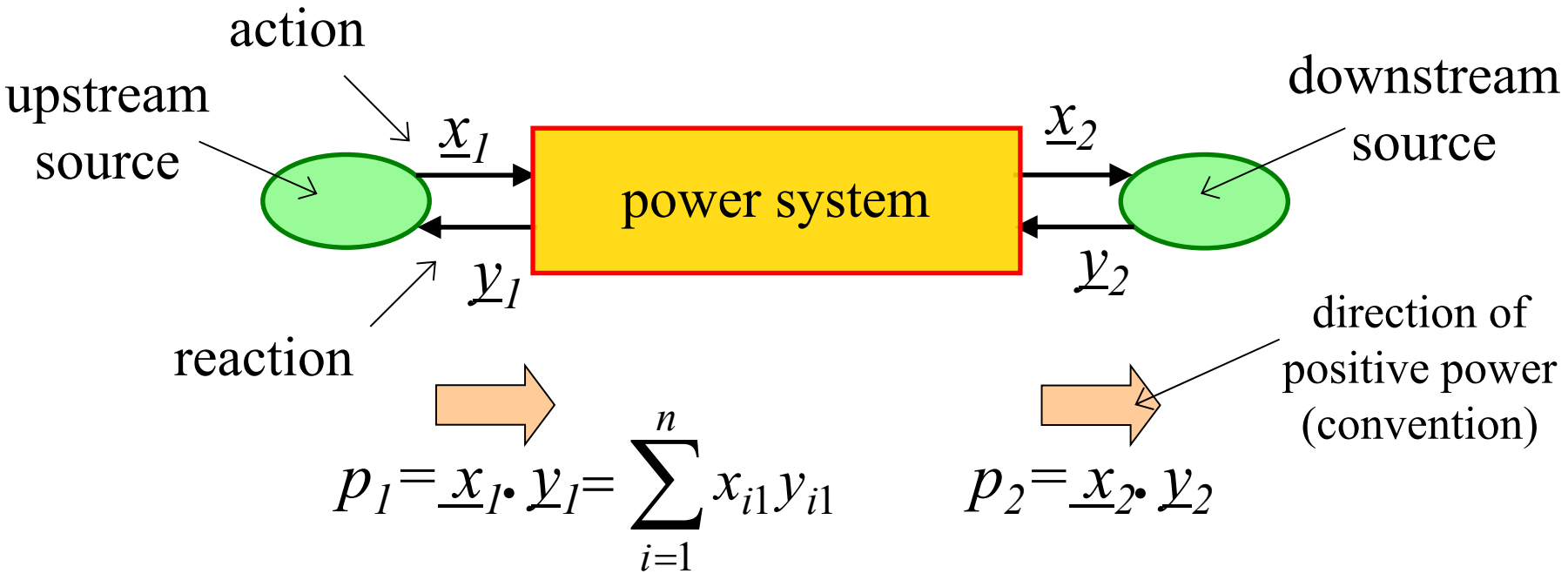
Source



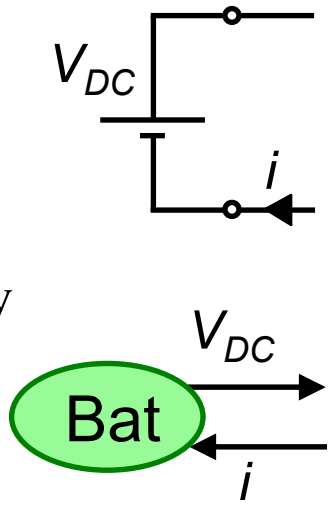
oval pictogram
background: light green
contour: dark green
1 input vector (dim n)
1 output vector (dim n)

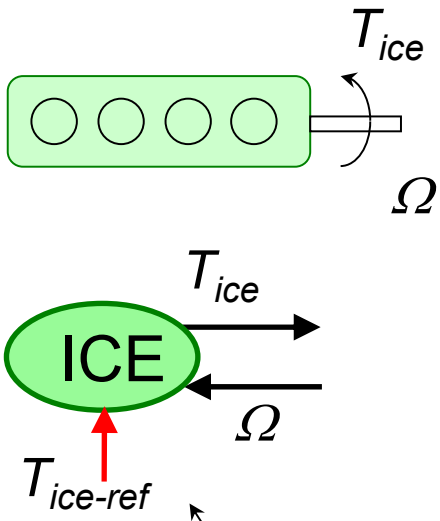
terminal elements which represent the environment of the studied system

generator and/or receptor of energy



Battery
(voltage source)
generator and
receptor of energy

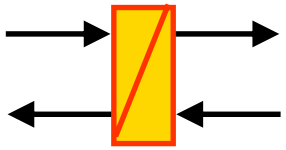




IC engine
(torque source)
generator
of energy

tuning input

Accumulator

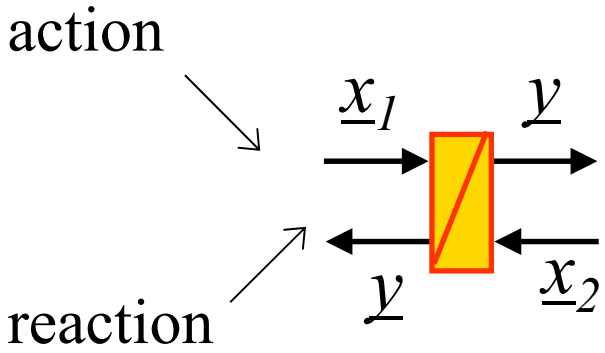


rectangle with an oblique bar
background: orange
contour: red
upstream I/O vectors (dim n)
downstream I/O vectors (dim n)

internal accumulation of energy (with or without losses)

causality principle

Output variable = Energetic variable



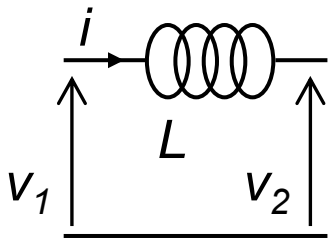
$$p_1 = \underline{x}_1 \cdot \underline{y} \qquad p_2 = \underline{x}_2 \cdot \underline{y}$$

$$\text{output(s)} = \int \text{input(s)}$$

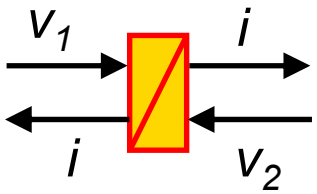
$$\underline{y} \propto \int f(\underline{x}_1, \underline{x}_2)\,dt$$

$\underline{y}$ = output, delayed with regard to input changes

fixed I/O (causal description)



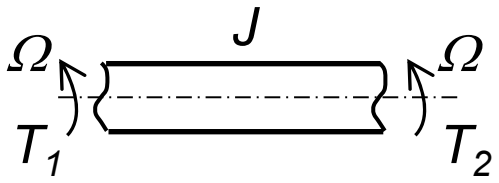
inductor



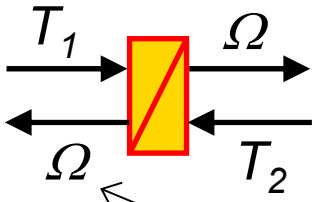
$$E = \frac{1}{2} L\, i^2$$

Energetic variable

$$i = \frac{1}{L}\int (V_1 - V_2).\, dt$$



inertia

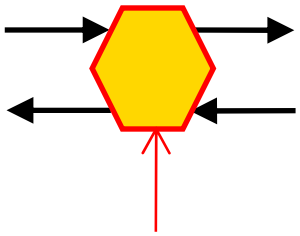


$$E = \frac{1}{2} J\, \Omega^2$$

Energetic variable

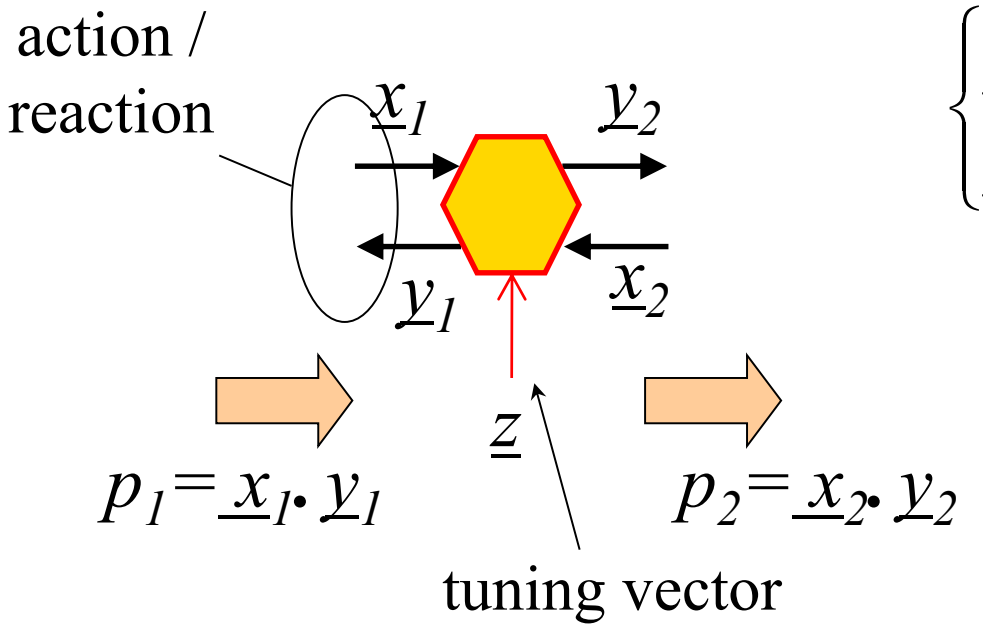
$$\Omega = \frac{1}{J}\int (T_1 - T_2).\, dt$$

conversion element



various pictograms
background: orange
contour: red
upstream I/O vectors (dim n)
downstream I/O vectors (dim p)
Possible tuning input vector (dim q)

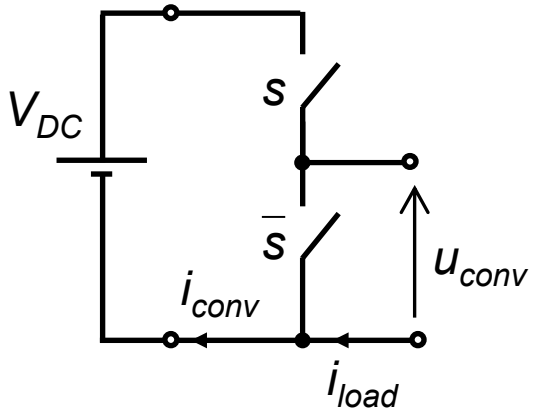
conversion of energy without energy accumulation (with or without losses)

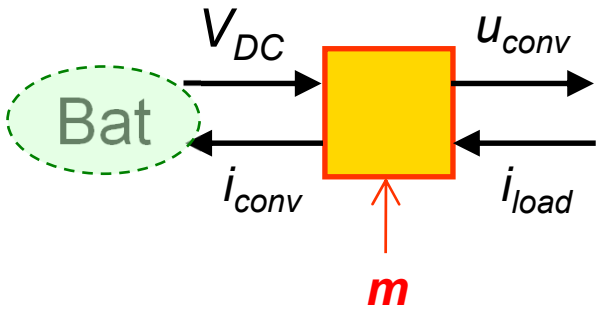


$$\begin{cases} \underline{y}_2 = f(\underline{x}_1, \underline{z}) \\ \underline{y}_1 = f(\underline{x}_2, \underline{z}) \end{cases}$$

no delay!

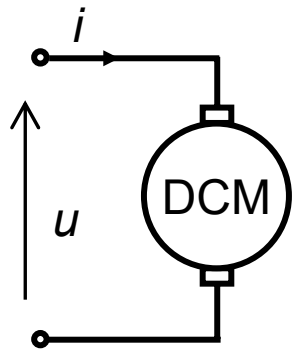
upstream and downstream I/O can be permuted (floating I/O)

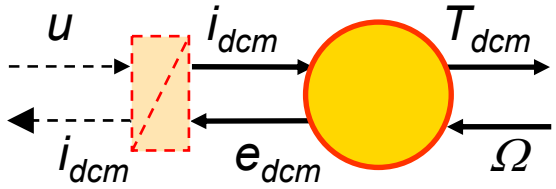




$$\begin{cases} u_{conv} = m \;\; V_{DC} \\ i_{conv} = m \;\; i_{load} \end{cases}$$

tuning input

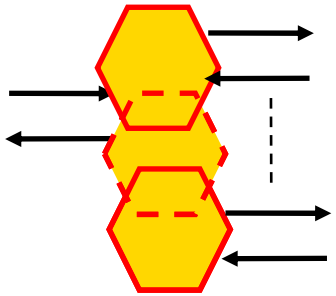




$$L \frac{d}{dt} i_{dcm} + r \; i_{dcm} = u - e_{dcm}$$

$$\begin{cases} T_{dcm} = k_{\Phi} \; i_{dcm} \\ e_{dcm} = k_{\Phi} \; \Omega \end{cases}$$

coupling element



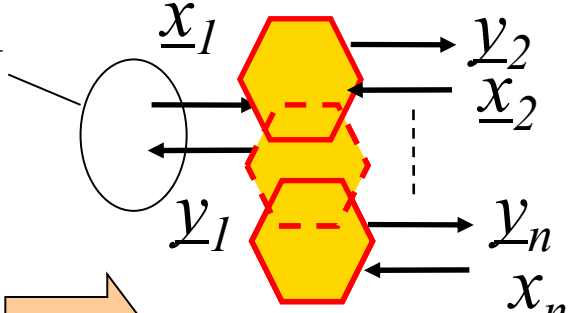
various overlapped pictograms
background: orange
contour: red
pairs of I/O vectors
N pairs, N-1 pictograms

distribution of energy
without energy accumulation
without tuning
(with or without losses)

no delay!

$$\begin{cases} \underline{y}_1 = f_1(\underline{x}_1,..\underline{x}_n) \\ ... \\ \underline{y}_n = f_n(\underline{x}_1,..\underline{x}_n) \end{cases}$$

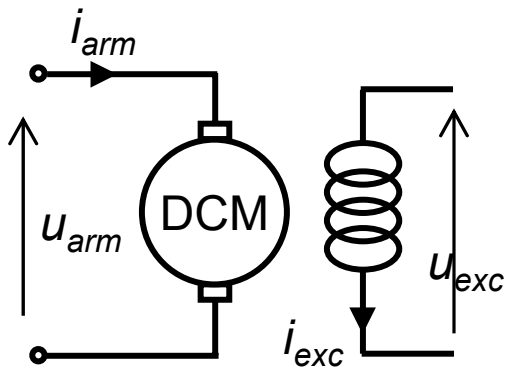
action / reaction



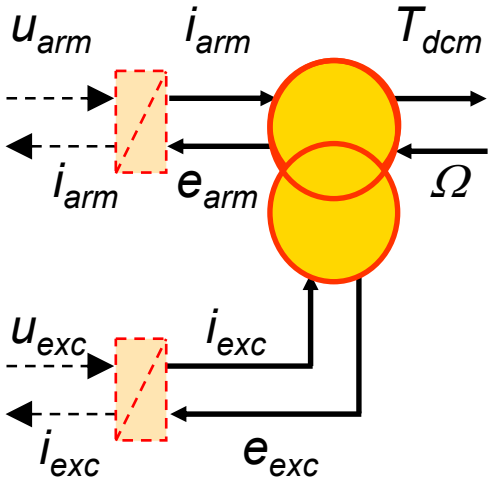
$p_1 = \underline{x}_1 \cdot \underline{y}_1$

$p_s = \sum_{i=2}^{n} \underline{x}_n \cdot \underline{y}_n$

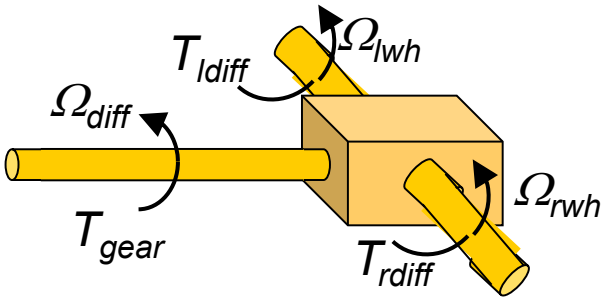
Field winding DC machine



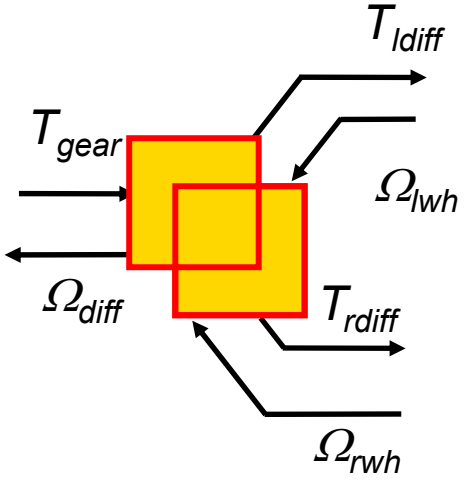
$$\begin{cases} T_{dcm} = k\, i_{exc}\, i_{arm} \\ e_{arm} = k\, i_{exc}\, \Omega \end{cases}$$



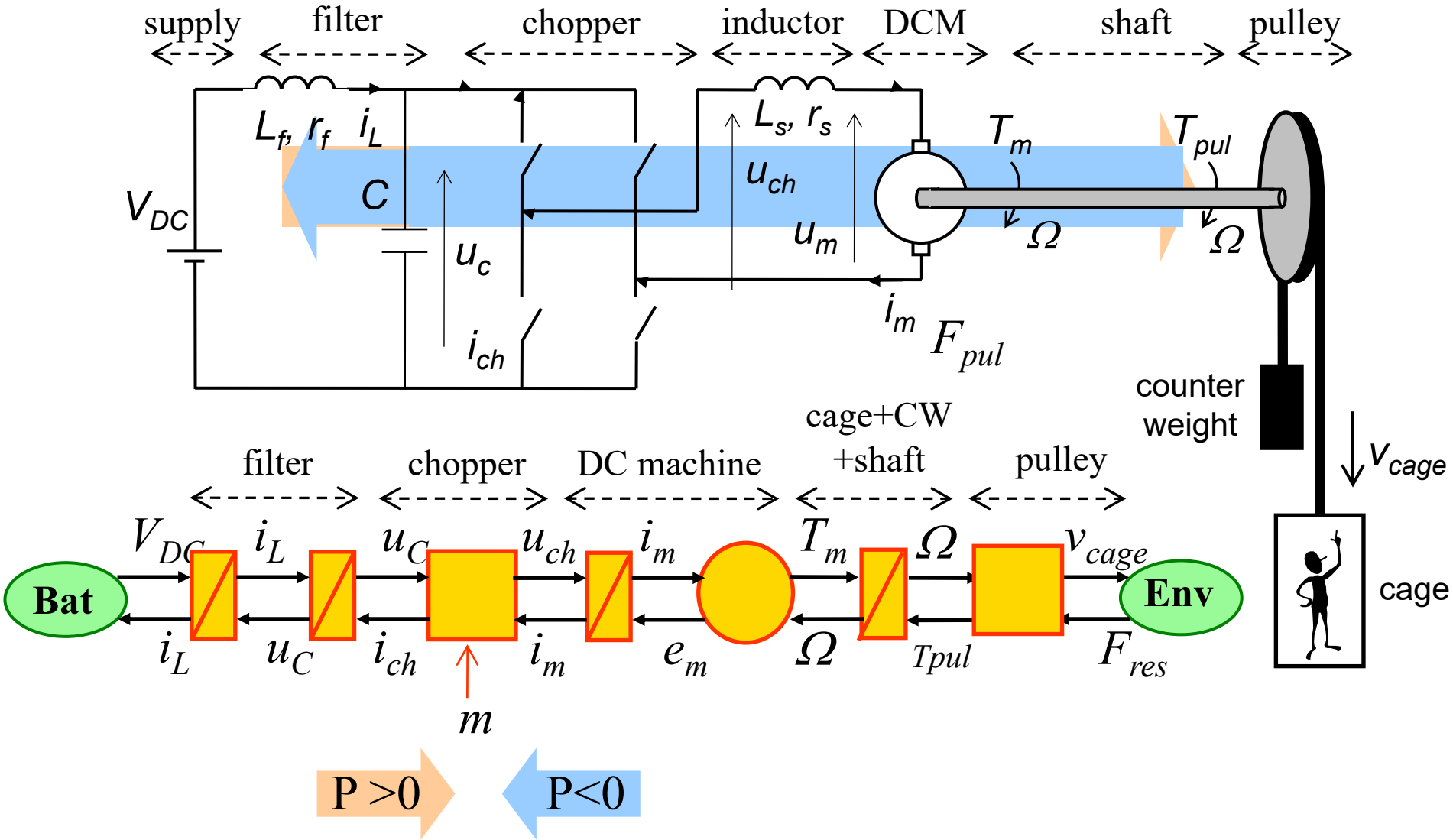
Mechanical differential

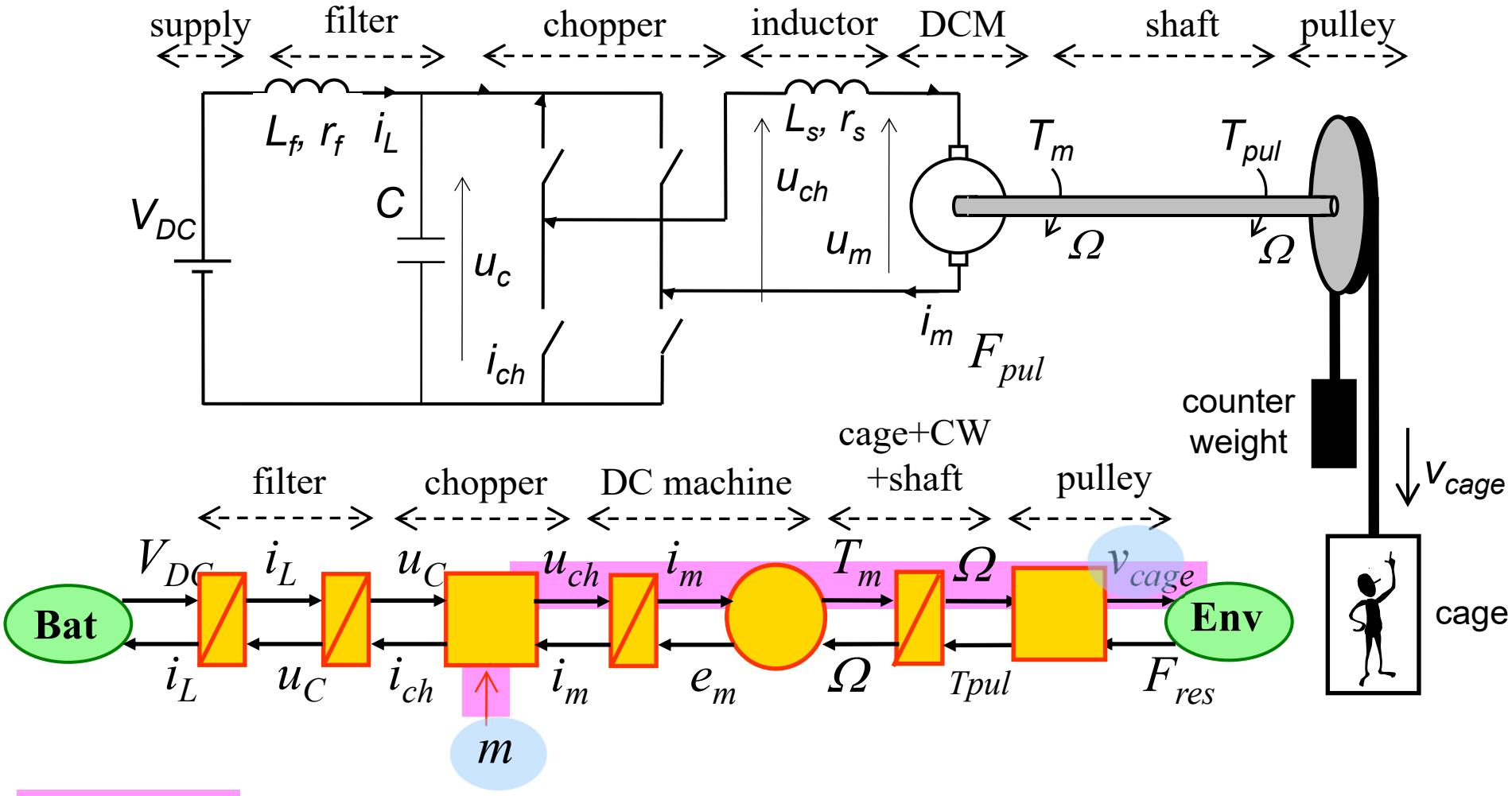


$$\begin{cases} T_{ldif} = T_{rdif} = \dfrac{T_{gear}}{2} \\ \Omega_{diff} = \dfrac{\Omega_{lwh} + \Omega_{rwh}}{2} \end{cases}$$



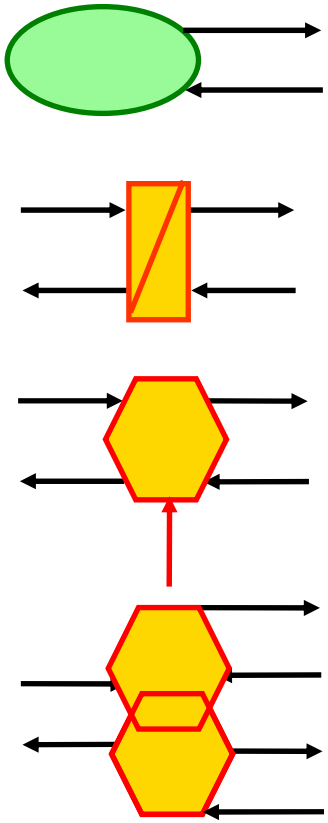
« Example of complete EMR »


supply
filter
chopper
inductor
DCM
shaft
pulley
L_f, r_f
i_L
V_{DC}
C
u_c
i_{ch}
L_s, r_s
u_{ch}
u_m
i_m
F_{pul}
T_m
Ω
T_{pul}
Ω
counter weight
v_{cage}
cage
filter
chopper
DC machine
cage+CW +shaft
pulley
Bat
V_{DC}
i_L
u_C
u_{ch}
i_m
T_m
Ω
v_{cage}
Env
i_L
u_C
i_{ch}
i_m
e_m
Ω
Tpul
F_{res}
m
P >0
P<0


supply
filter
chopper
inductor
DCM
shaft
pulley
L_f, r_f
i_L
C
V_{DC}
u_c
i_{ch}
L_s, r_s
u_{ch}
u_m
i_m
F_{pul}
T_m
T_{pul}
Ω
Ω
counter weight
v_{cage}
cage
filter
chopper
DC machine
cage+CW +shaft
pulley
Bat
Env
V_{DC}
i_L
u_C
u_{ch}
i_m
T_m
Ω
v_{cage}
i_L
u_C
i_{ch}
i_m
e_m
Ω
Tpul
F_{res}
m
tuning path

EMR = multi-physical graphical description

Basic elements = energetic functions



Energy source (potential tuning)

Energy accumulation

Energy conversion (potential tuning)

Energy distribution

Systemics: elements connected by action/reaction

Causality: I/O defined by accumulation elements and sources

Association rules

enable keeping physical causality in conflict of association

Tuning paths

can be deduced from EMR

valuable for control design

« BIOGRAPHIES AND REFERENCES »

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Head of L2EP Lille
Coordinator of the GDR TACT (CNRS French research cluster on Touch)
Coordinator of the COMASYS project (Energy Continuum) of Univ. of Lille
PhD in Electrical Engineering of Uniiversity of Paris 6 (1990)
Research topics: piezo-electric actuators and tactile devices using EMR

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Prof. Alain BOUSCAYROL, University of Lille, L2EP,
Head of the Master "Automatic control & Electrical Systems"
Coordinator of the CUMIN interdisciplinary programme
Coordinator of the PANDA European project
Chair of the steering committee of IEEE-VPP Conference of IEEE-VTS
PhD in Electrical Engineering at University of Toulouse (1995)
Research topics: EMR formalism, HIL testing, control & EV-HEVs

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 GREEN Nancy, L2EP Lille and LEEI Toulouse, according to the SMM project of the GDR-SDSE).

A. Bouscayrol, "Formalism of modelling and control of multimachine multiconverter electromechanical systems" (Texte in French), HDR report, University Lille1, Sciences & technologies, December 2003

A. Bouscayrol, J. P. Hautier, B. Lemaire-Semail, "Graphic Formalisms for the Control of Multi-Physical Energetic Systems", Systemic Design Methodologies for Electrical Energy, tome 1, Analysis, Synthesis and Management, Chapter 3, ISTE Willey editions, October 2012, ISBN: 9781848213883

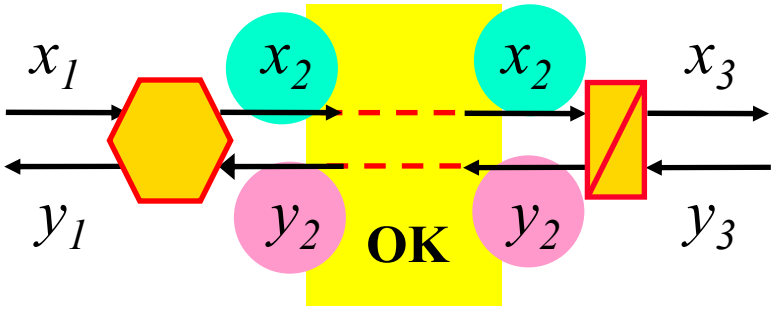
K. Chen, A. Bouscayrol, W. Lhomme, "Energetic Macroscopic Representation and Inversion-based control: Application to an Electric Vehicle with an electrical differential", Journal of Asian Electric Vehicles, Vol. 6, no.1, June issue, 2008, pp. 1097-1102.

P. Delarue, A. Bouscayrol, A. Tounzi, X. Guillaud, G. Lancigu, "Modelling, control and simulation of an overall wind energy conversion system", Renewable Energy, July 2003, vol. 28, no. 8, p. 1159-1324 (common paper L2EP Lille and Jeumont SA).

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.

W. Lhomme, "Energy management of hybrid electric vehicles based on energetic macroscopic representation", PhD Dissertation, University of Lille (text in French), November 2007 (common work of L2EP Lille and LTE-INRETS according to MEGEVH network).

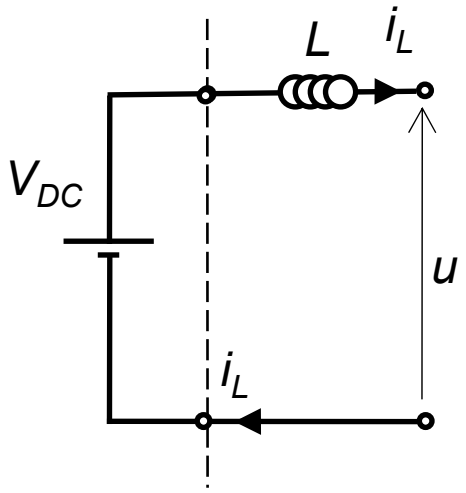
« Association Rules »

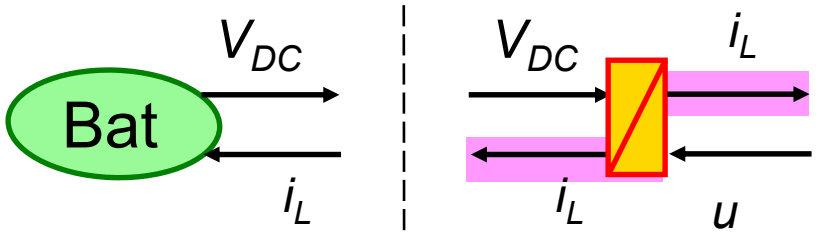


direct connection if:
Out(S1) = In (S2)
In(S1) = Out(S2)

S1 and S2 any sub-systems

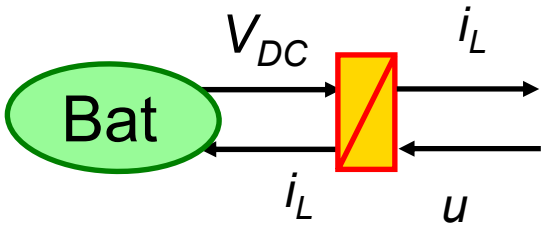
Example



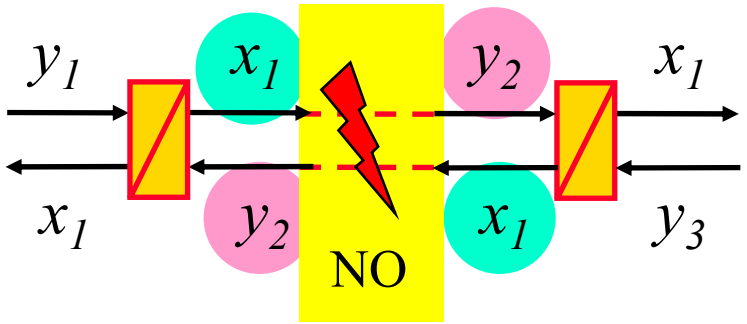


$$L\frac{d}{dt}i_L = V_{DC} - u$$

i_L state variable



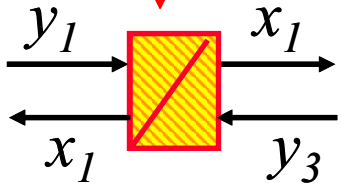
- Association rules: merging rule -



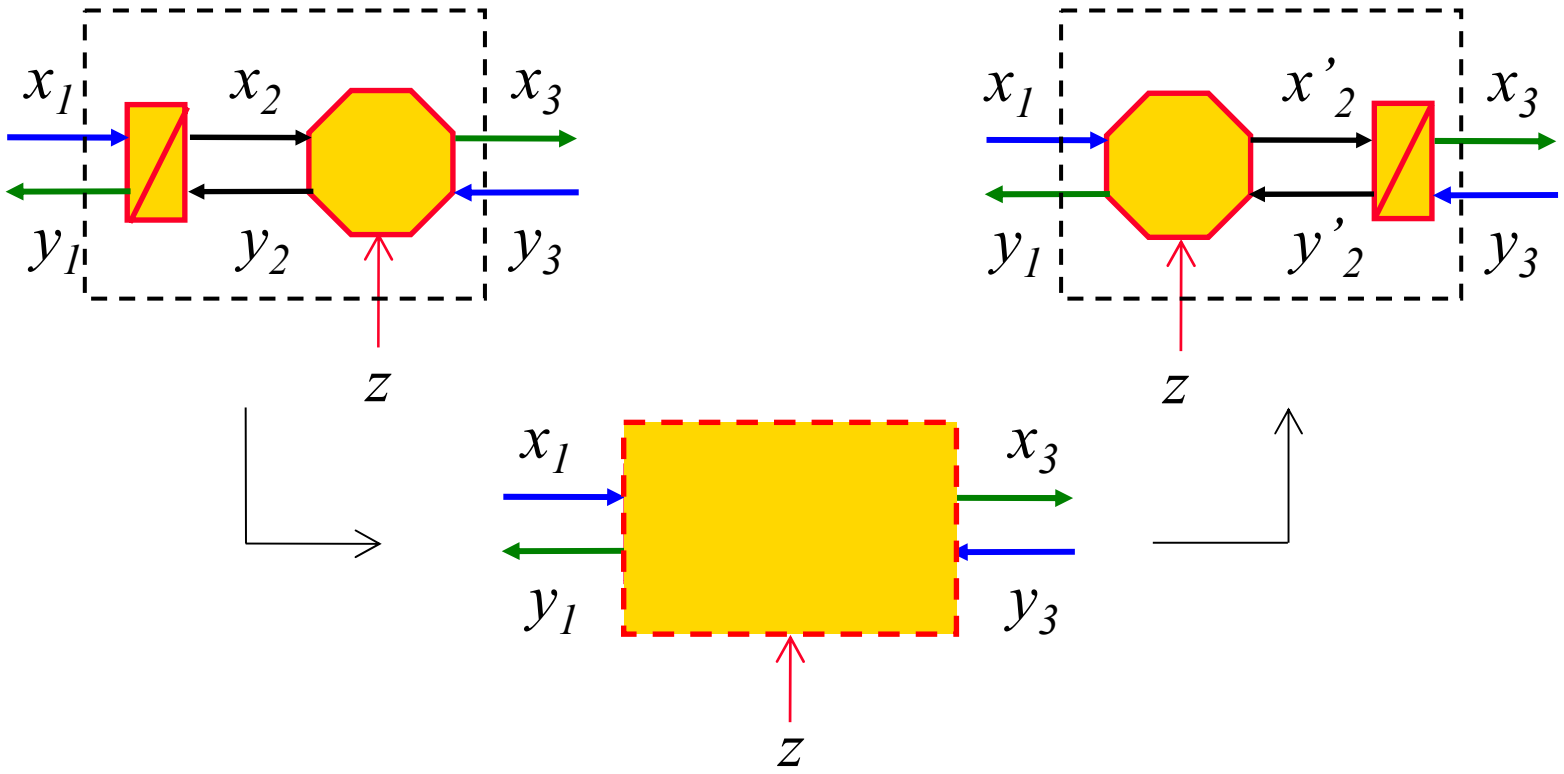
2 accumulation elements would impose the same state variable x_1

Conflict of association

merging

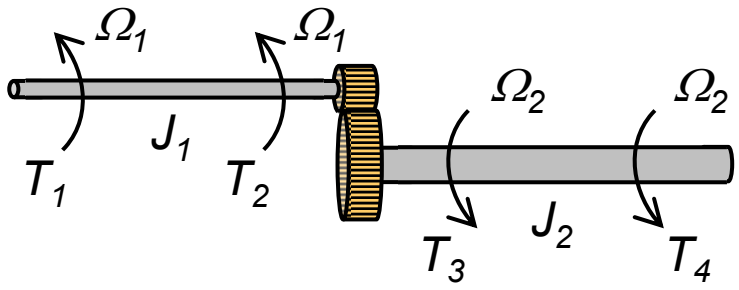


1 equivalent function for 2 elements / systemic



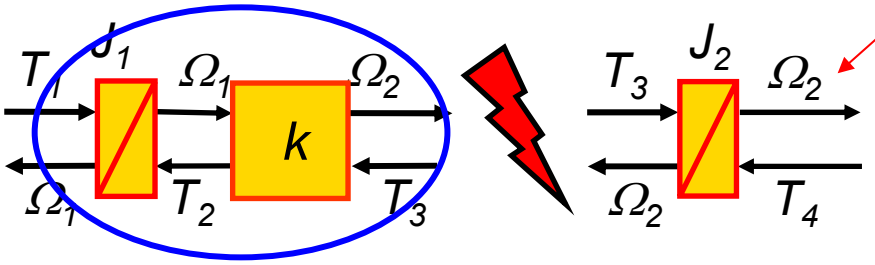
permutation possible if same global behavior:
strictly the same effects (y_1 and x_3) from the same causes (x_1, y_3 and z)

$$J_1 \frac{d\Omega_1}{dt} = T_1 - T_2$$

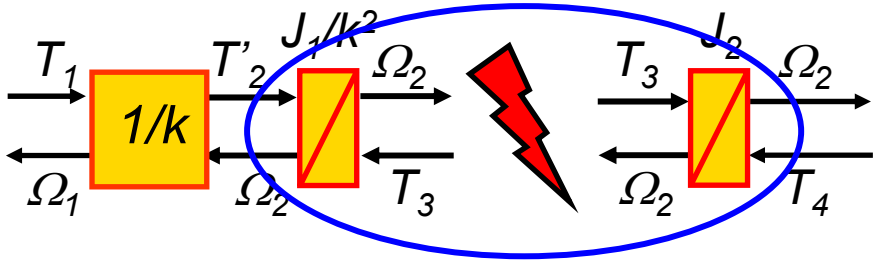


$$J_2 \frac{d\Omega_2}{dt} = T_3 - T_4$$

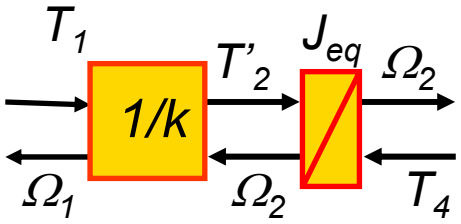
$$\begin{cases} \Omega_2 = K.\Omega_1 \\ T_2 = K.T_3 \end{cases}$$



permutation



merging



to solve conflict of association

$$J_{eq} = \frac{J_1}{k^2} + J_2$$