EMR'22
Sion
June 2022

EMR'22 Summer School
"Energetic Macroscopic Representation"

« ENERGETIC MACROSCOPIC REPRESENTATION (EMR) »

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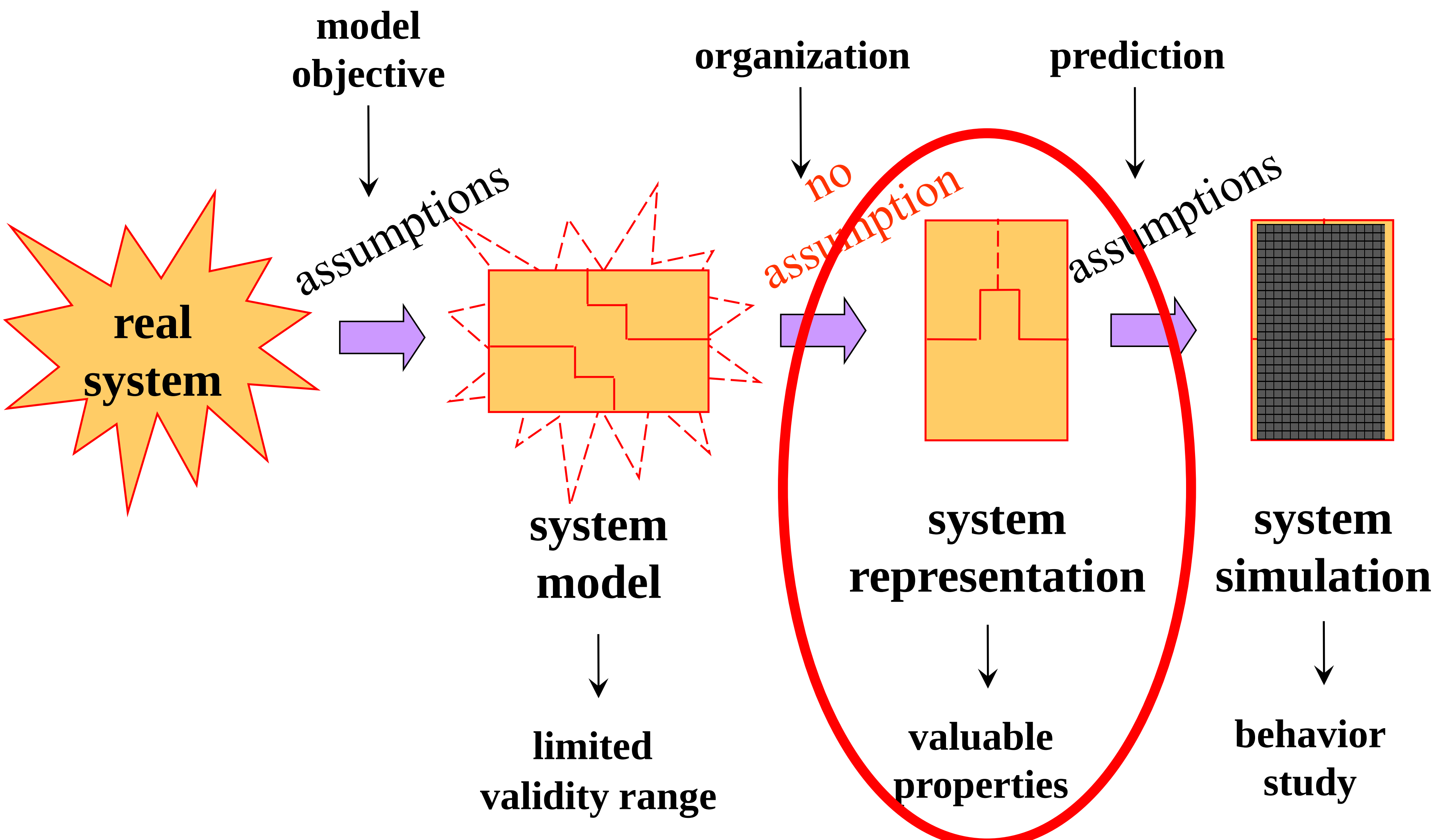

model
objective
organization
prediction
assumptions
no
assumption
assumptions
real
system
system
model
system
representation
system
simulation
limited
validity range
valuable
properties
behavior
study

« EMR Basic Elements »

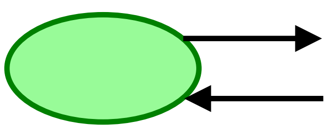
Only 4 energy functions are required to describe energy conversion systems:

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

EMR = 4 graphical elements associated with the 4 energy functions

- Energetic sources -

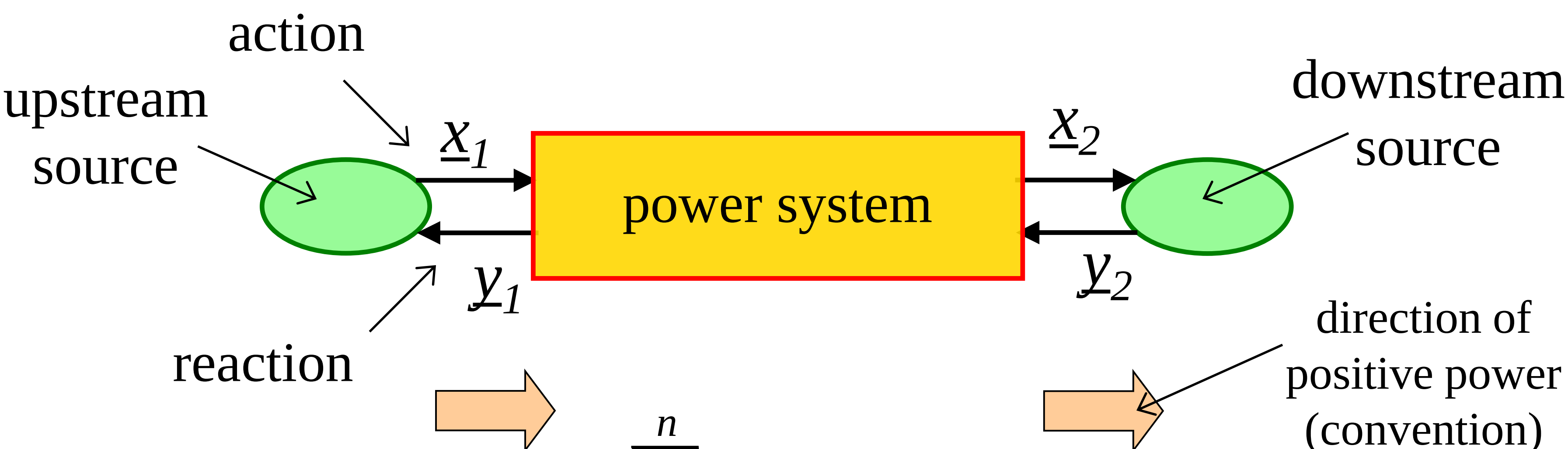
Source



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

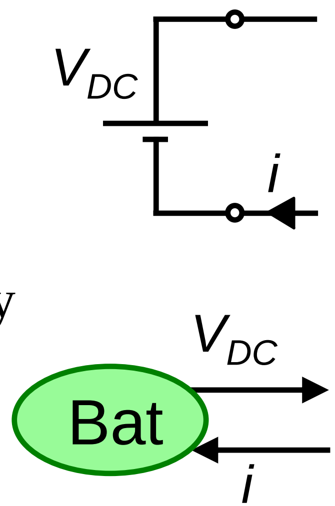
terminal elements which represent the environment of the studied system

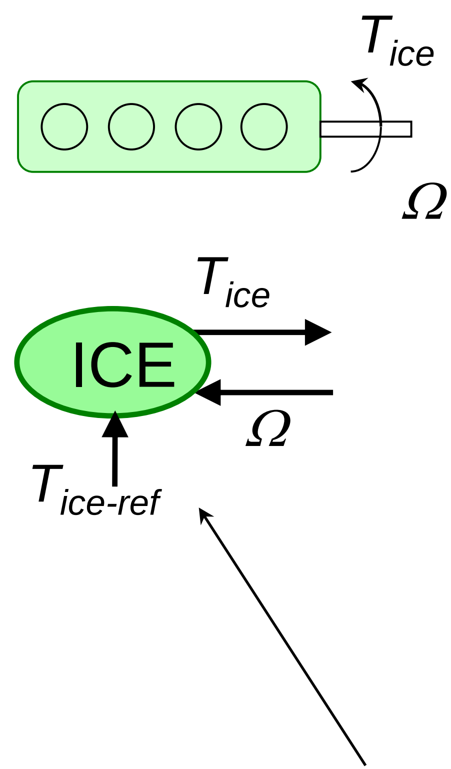
generator and/or receptor of energy



$$p_1 = \underline{x}_1 \cdot \underline{y}_1 = \sum_{i=1}^{n} x_{i1} y_{i1} \qquad p_2 = \underline{x}_2 \cdot \underline{y}_2$$

Battery
(voltage source)
generator and
receptor of energy



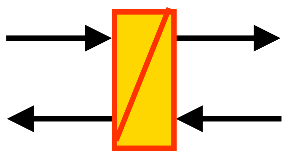


tuning input

IC engine
(torque source)
generator
of energy

- Accumulation elements -

Accumulator

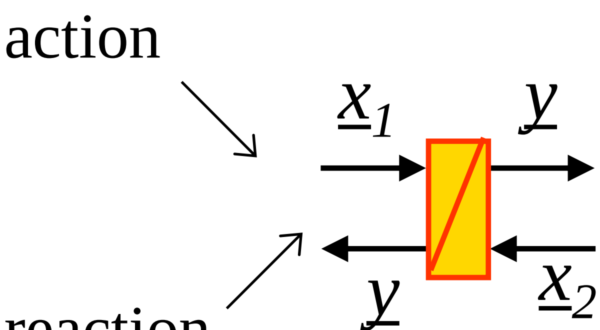


- rectangle with an oblique bar
- background: orange
- contour: red
- upstream I/O vectors (dim n)
- downstream I/O vectors (dim n)

internal accumulation of energy (with or without losses)

→ **causality principle**

Output variable = Energetic variable



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

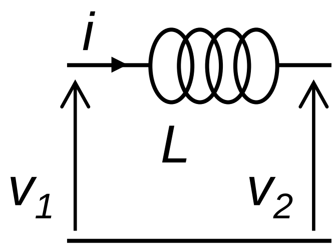
$$\text{output(s)} = \int \text{input(s)}$$

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

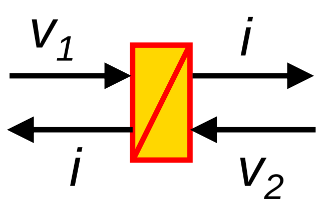
$\underline{y}$ = output, delayed with regard to input changes

fixed I/O (causal description)

- Accumulation elments: examples -



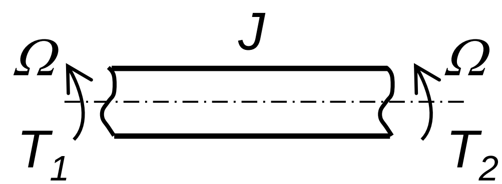
inductor



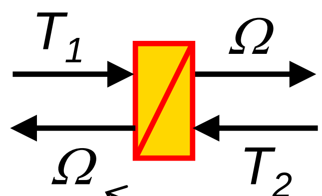
$$E = \frac{1}{2} L\, i^2$$

Energetic variable

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



inertia

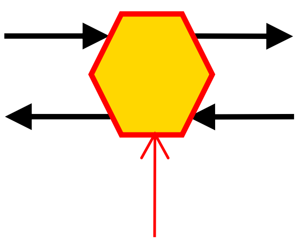


$$E = \frac{1}{2} J\, \Omega^2$$

Energetic variable

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

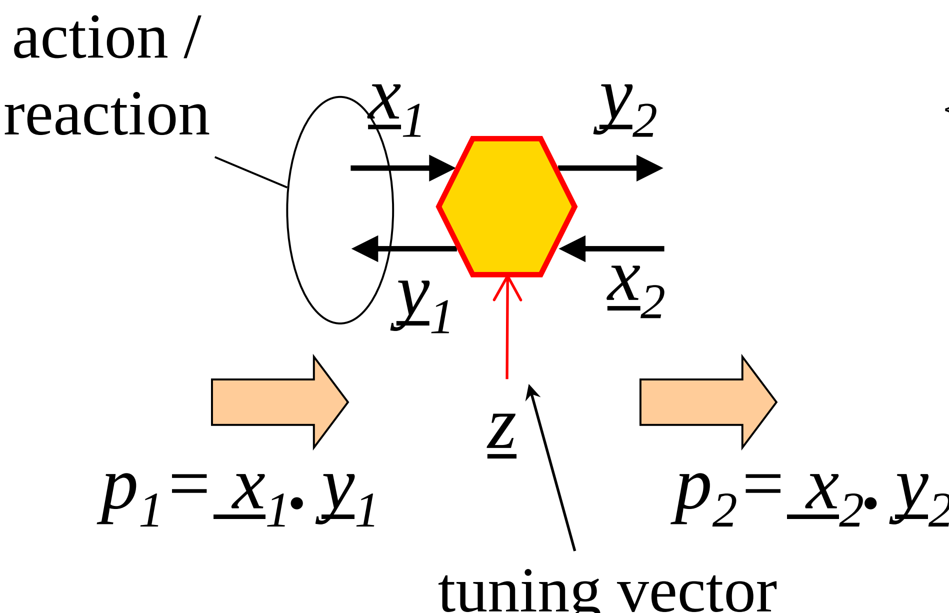
conversion element



- 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

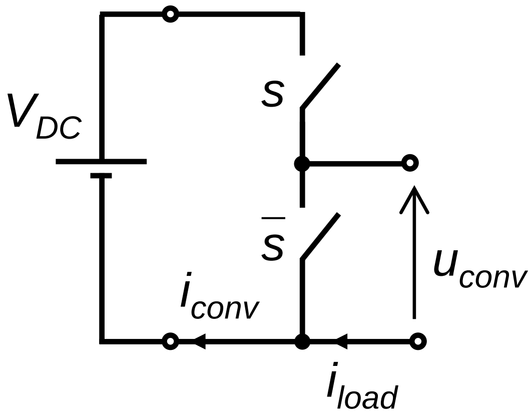
(with or without losses)

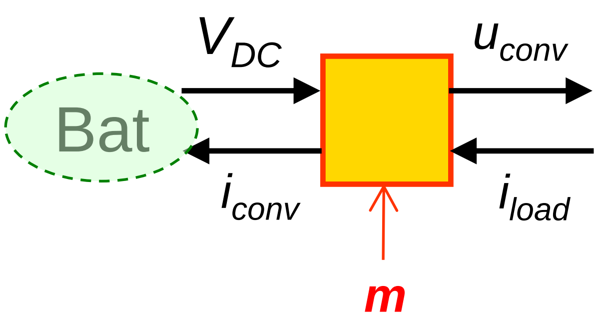


$$\begin{cases} \underline{y}_2 = f(\underline{x}_1, \underline{z}) \\ \underline{y}_1 = f(\underline{x}_2, \underline{z}) \end{cases}$$

no delay!

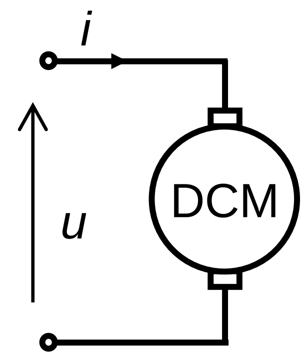
upstream and downstream I/O can be permuted (floating I/O)

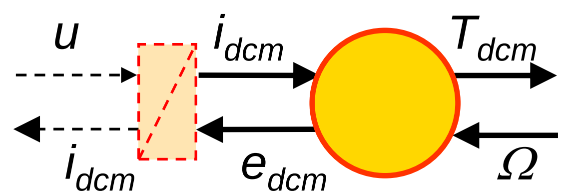




tuning input

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

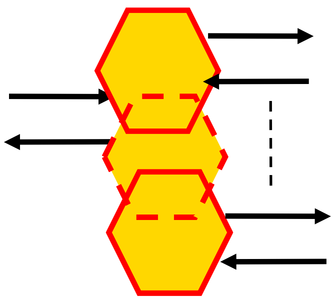




$$L \frac{d}{dt} i_{dcm} + r \; i_{dcm} = u - e_{dcm}$$

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

coupling element



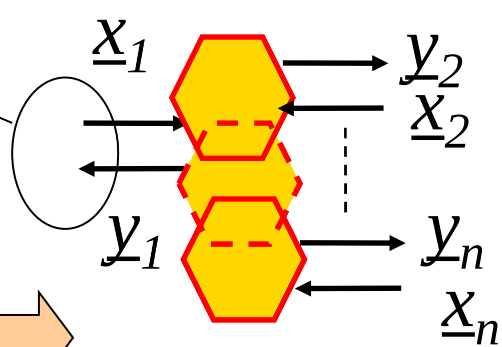
- various overlapped pictograms
- background: orange
- contour: red
- pairs of I/O vectors
- N pairs, N-1 pictograms

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

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

no delay!

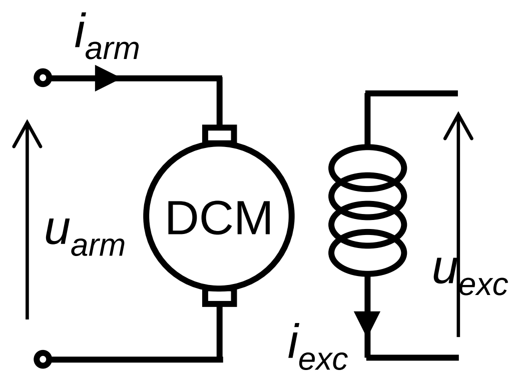
action / reaction



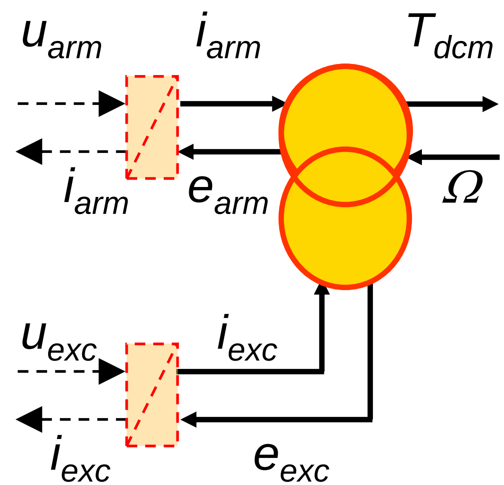
$$p_1 = \underline{x}_1 . \underline{y}_1$$

$$p_s = \sum_{i=2}^{n} x_n . y_n$$

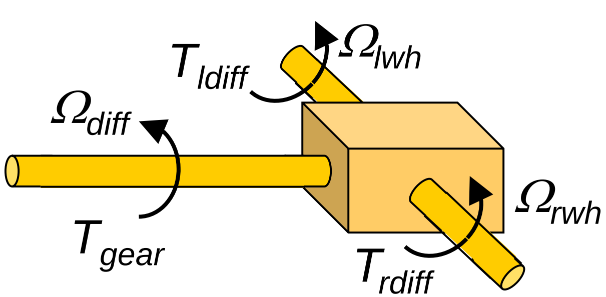
Field winding DC machine



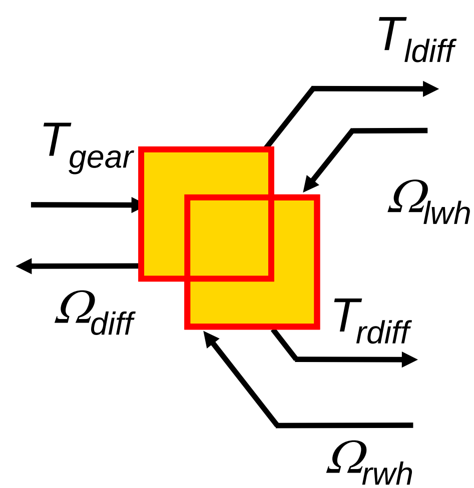
$$\begin{cases} T_{dcm} = k\, i_{exc}\, i_{arm} \\ e_{arm} = k\, i_{exc}\, \Omega \end{cases}$$



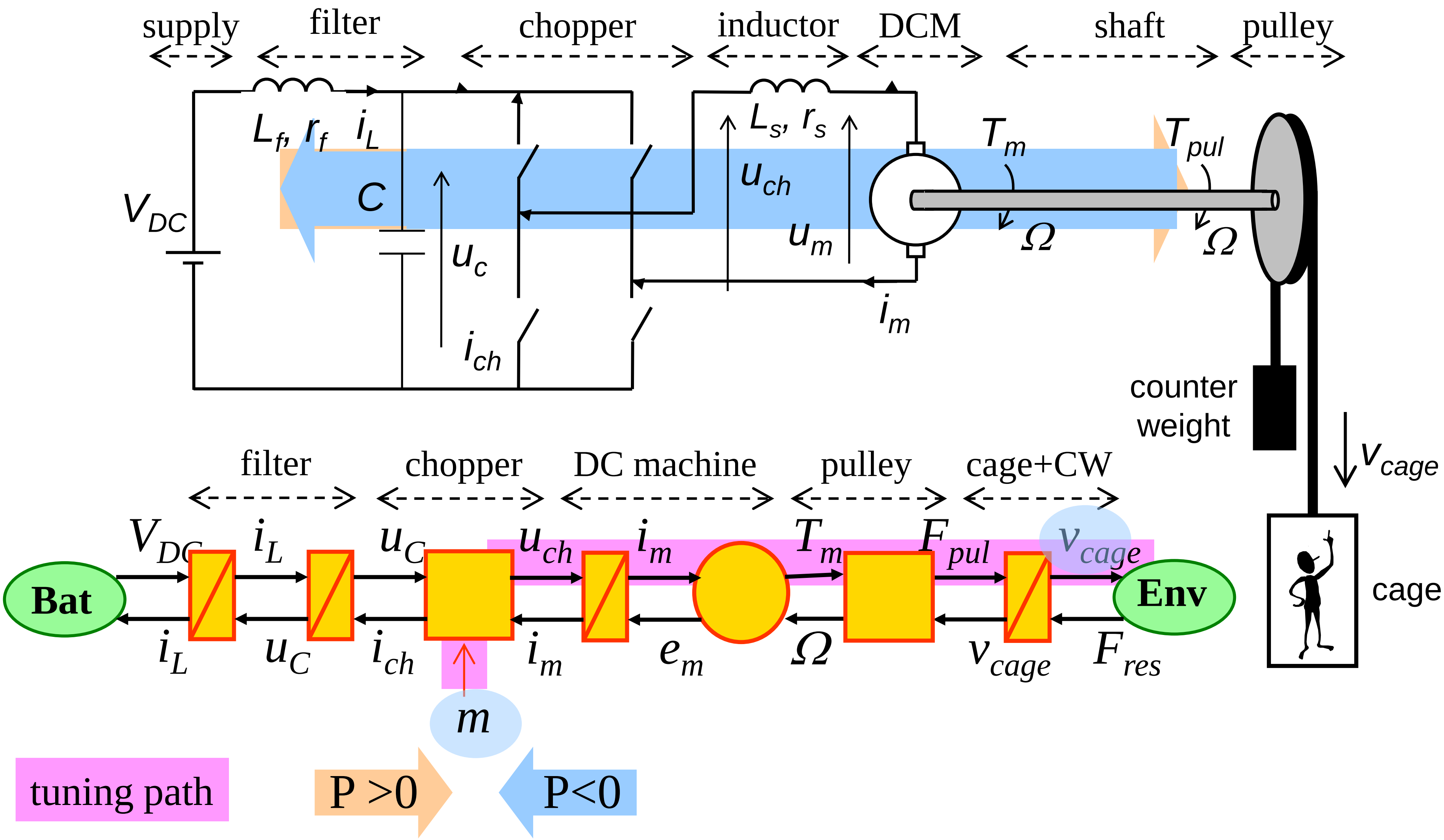
Mechanical differential



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



« Example of complete EMR »



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

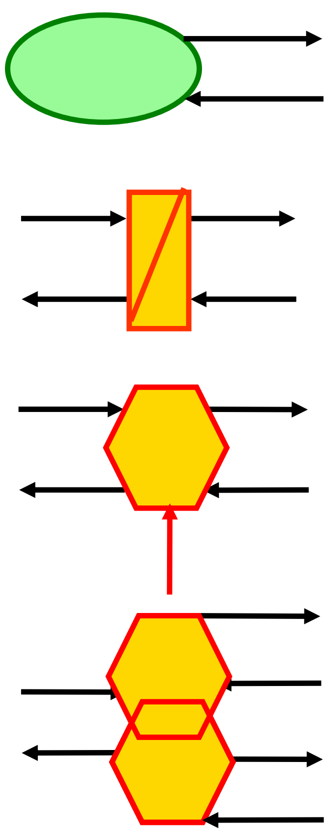
« Conclusion »

EMR = multi-physical graphical description

Systemics: elements connected by action/reaction

Causality: I/O defined by accumulation elements

Basic elements = energetic functions



Energy source (potential tuning)

Energy accumulation

Energy conversion (potential tuning)

Energy distribution

Association rules

enable keeping physical causality in conflict of association (not presented here)

Tuning paths

can be deduced from EMR

valuable for control design