EMR'13
Lille
Sept. 2013

Summer School EMR'13
"Energetic Macroscopic Representation"

Université Lille1
Sciences et Technologies

« Energetic Macroscopic Representation »

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Université Lille1
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L2EP LILLE

- Outline -

1. **Introduction**

2. **Representation: EMR basic elements**
   - Sources
   - Accumulation
   - Conversion
   - Coupling

3. **Organization: fundamental rules**
   - Direct connections
   - Merging rules
   - Permutation rules

4. **Analysis for the simulation and the control**
   - Action and reaction paths
   - Tuning path

5. **Conclusion**

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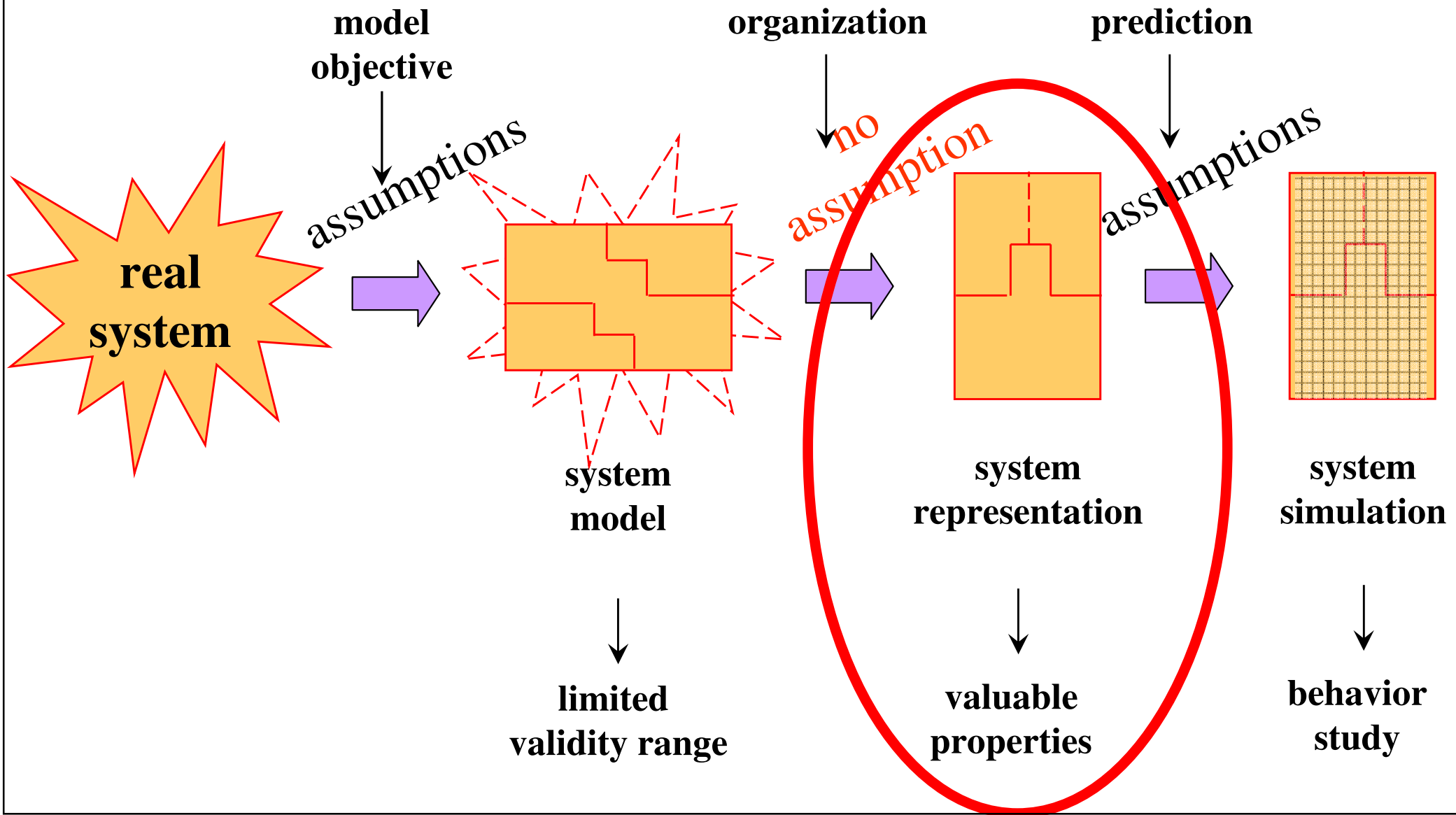
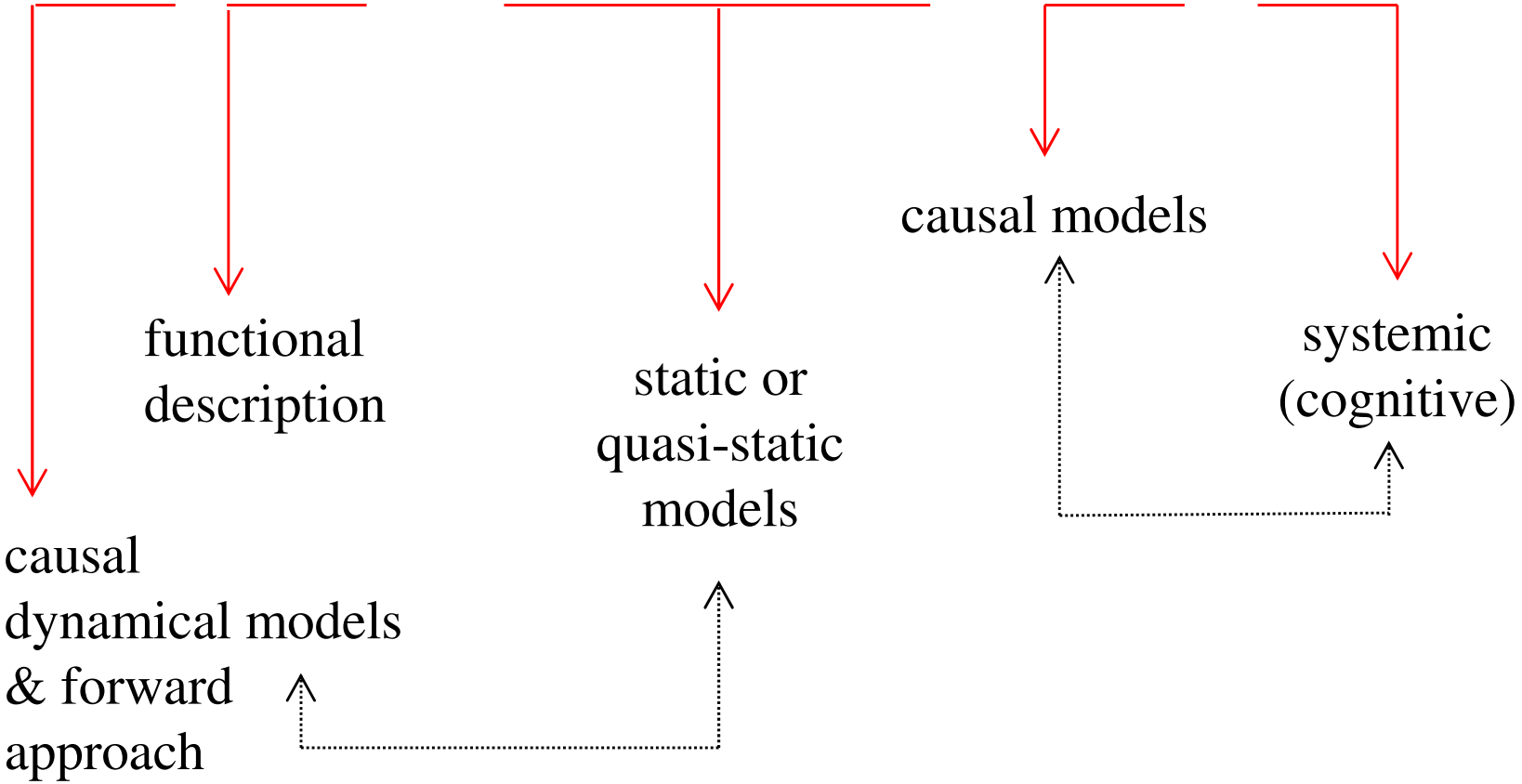
« Introduction»

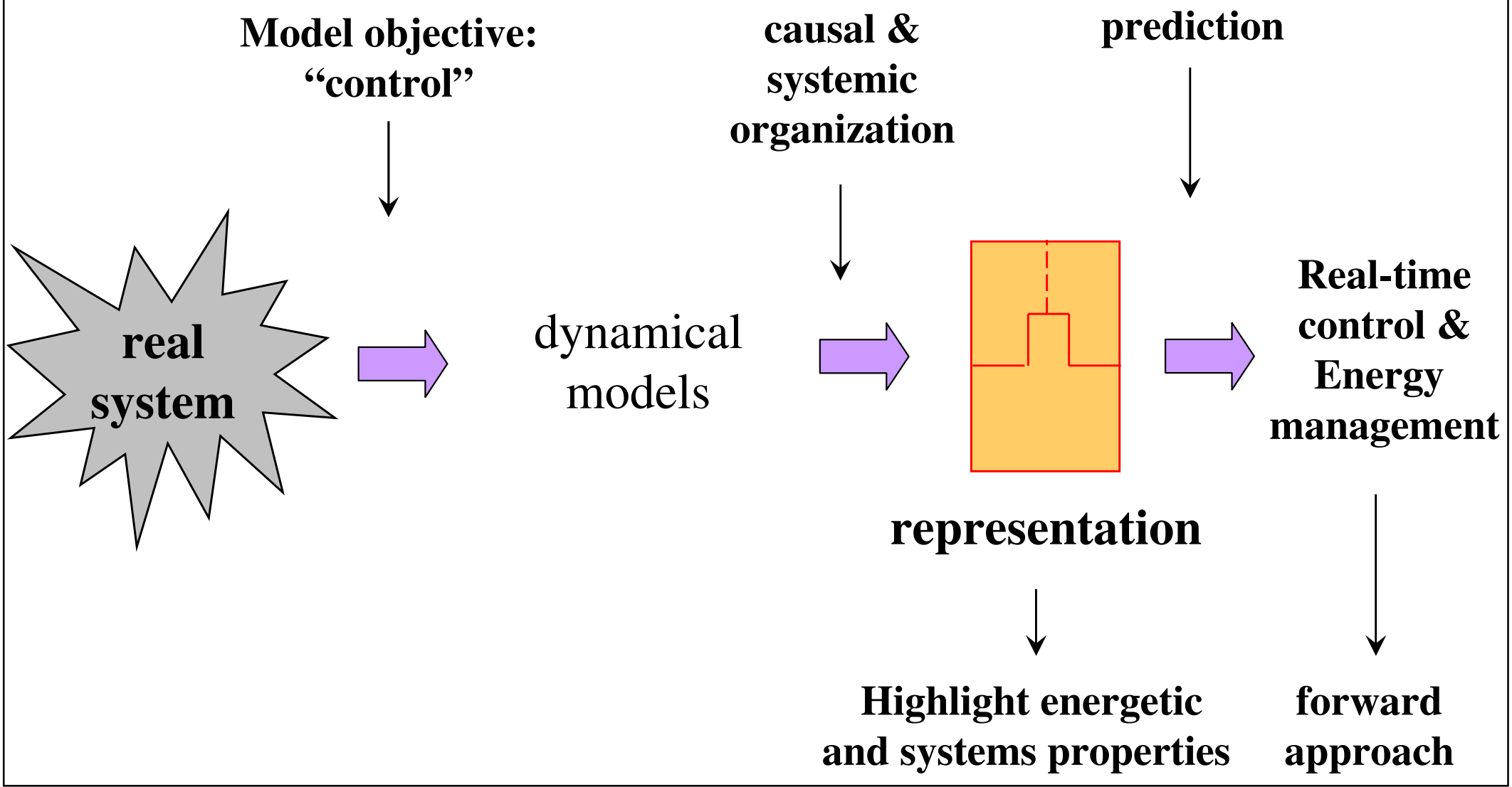
- Needs in graphical descriptions as valuable intermediary step



- The graphical description is chosen depending on objectives
  - Real-time control and energy management of energetic systems



- Objective: real-time control and energy management of energetic systems



- Objectives of the presentation -

- Define the key elements of EMR

- Define the fudamental rules
  - For connecting elements
  - For solving conflicts of associations

- Define the notions of
  - Action, reaction and tuning paths

- Assumption
  - As EMR is an intermediary step, coming after a modeling activity, one will consider that models are already defined…

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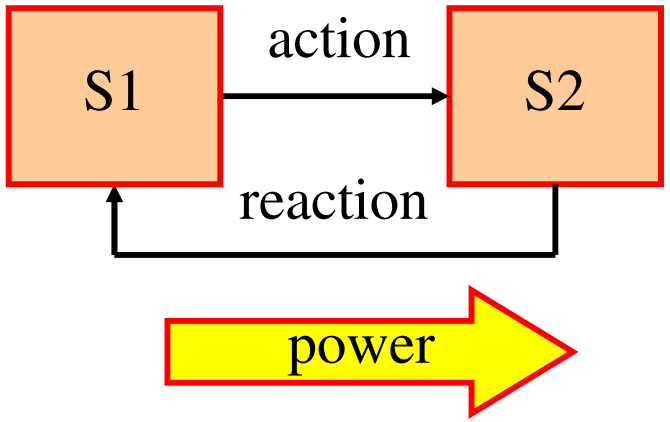
«Representation: EMR basic elements»

- Different elements -

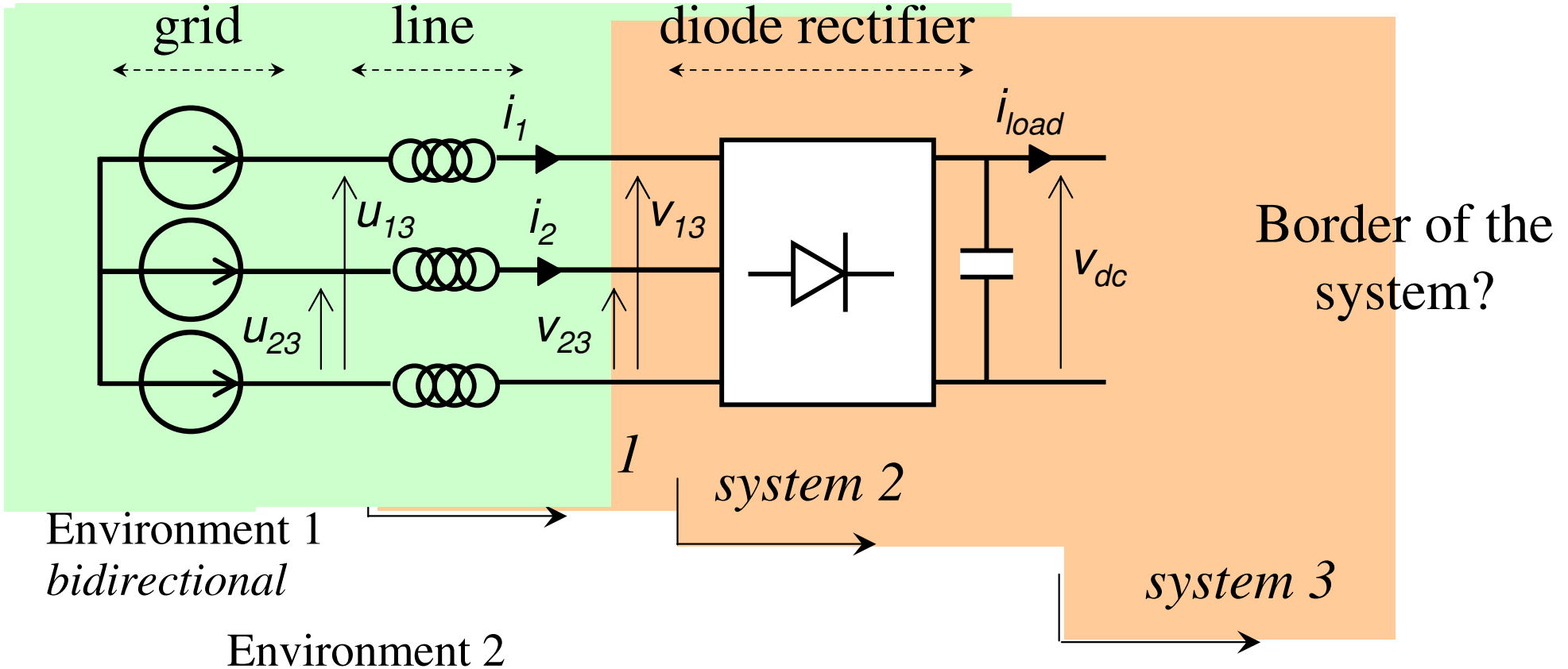
- Energetic Macroscopic Representation
  - Any energetic system
    - Energy sources
    - Energy storage elements
    - Energy conversion elements
    - Energy distribution elements
  - Key elements
    - energy storage element
      - delay, state variable, closed-loop control
    - energy distribution element
      - power flow coupling, control with criteria

- Back to definitions
  - System: interconnected subsystems organized for a common objective, in interaction with its environment.
  - Input: produced by environment, imposed to the system
  - Output: consequence of the system evolution, imposed to its environment
  - Interaction principle: each action induces a reaction

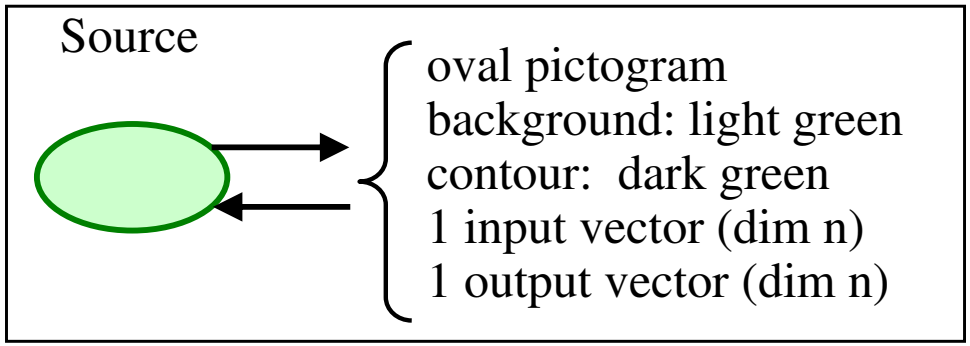


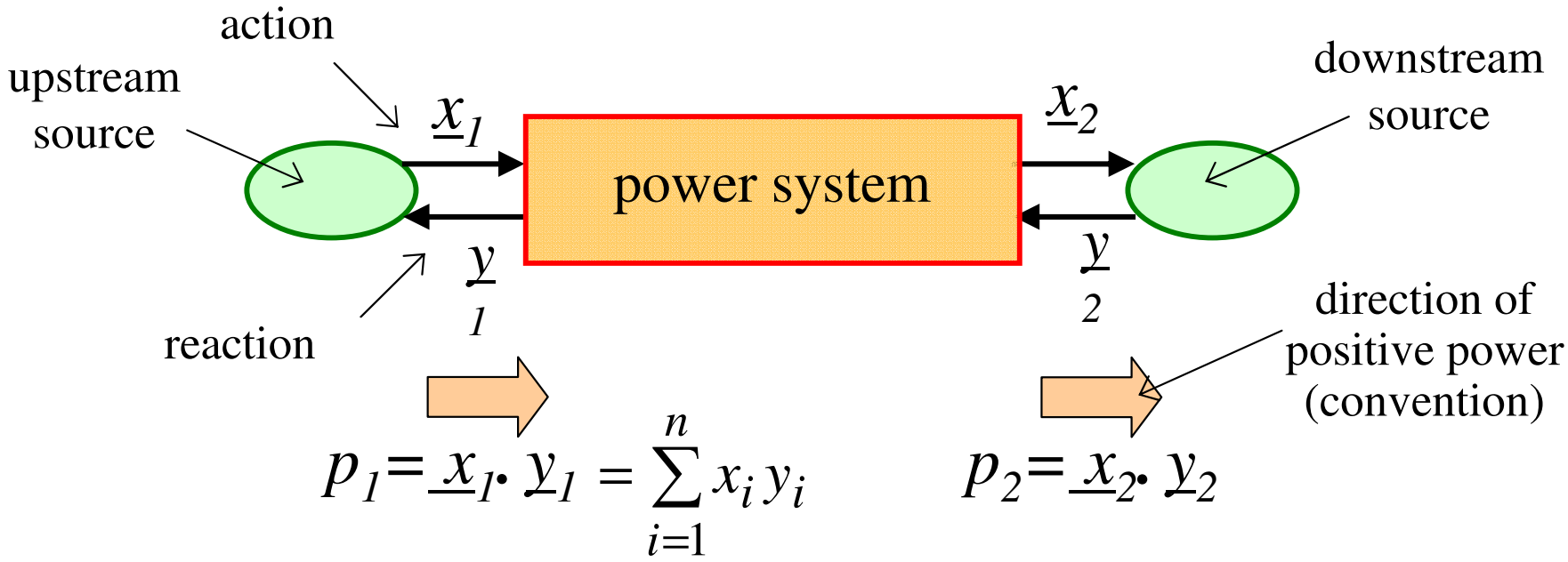
- Needs in defining an element representing the environment of a system, and its links to the studied system
  - According to the interaction principle

- Definition of the environment
  - Environment & System must be defined first



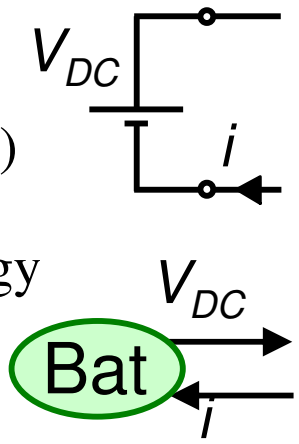
- Representation
  - Terminal element which represents the environment of the studied system
    - Generator or receptor

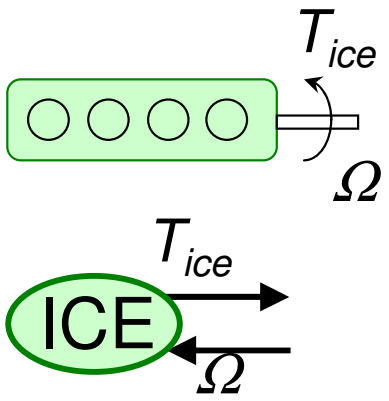




- Examples

Battery
(voltage source)
generator and
receptor of energy

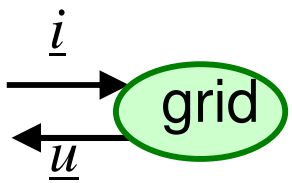




IC engine
(torque source)
generator
of energy

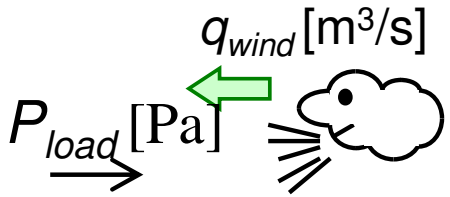
Electrical grid
(voltage source)
generator and receptor of energy

$$\underline{u} = \begin{bmatrix} u_{13} \\ u_{23} \end{bmatrix} \quad \underline{i} = \begin{bmatrix} i_1 \\ i_2 \end{bmatrix}$$

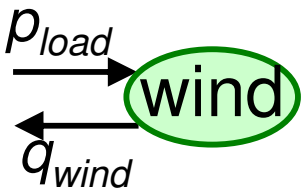


2 independent currents!

2 independent voltages!



Wind
(air flow source)
generator energy

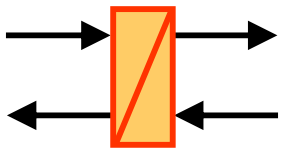


- Accumulation elements -

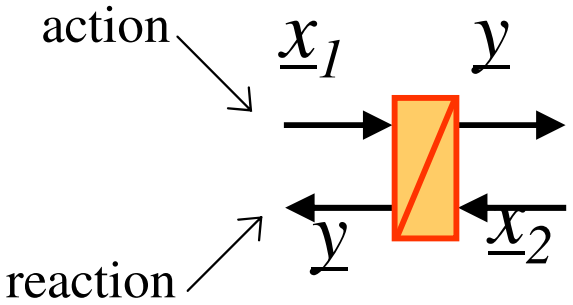
- Back to definitions
  - System: interconnected subsystems organized for a common objective, in interaction with its environment.
  - Input: produced by a subsystem, imposed to its close subsystem
  - Output: consequence of the subsystem evolution, imposed to its close subsystems
  - Interaction principle: each action induces a reaction
  - Internal accumulation of energy (with or without losses)
    - » Key transformation for safety and efficiency
    - » Output(s) is an integral function of input(s), delayed from input(s) changes
    - » Causal description: fixed input(s) and output(s)
  - Needs in defining an element representing the accumulation of energy, and the links with its close subsystems
    - According to a causal description, and to the interaction principle

- Representation
  - internal accumulation of energy (with or without losses)
    - Causality principle

Accumulator



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



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

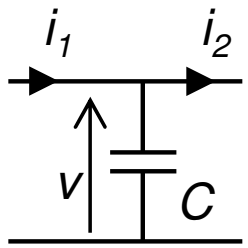
$\underline{y}$ = output, delayed from input changes

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

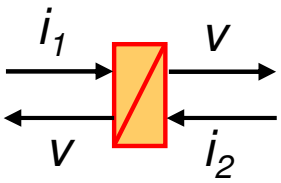
fixed I/O (causal description)

- Examples

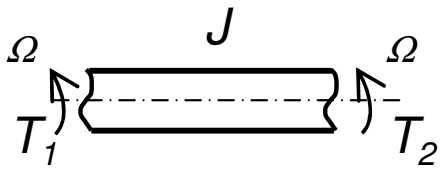
capacitor

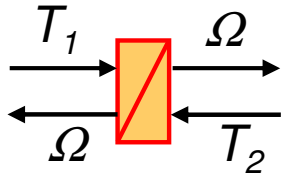


$$E = \frac{1}{2} C\, v^2$$



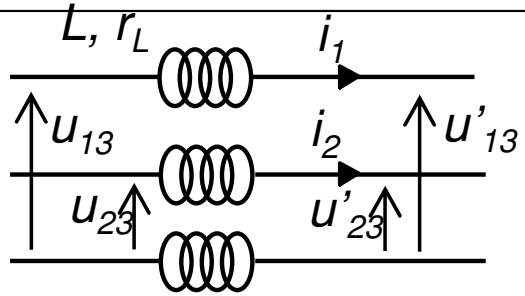
inertia



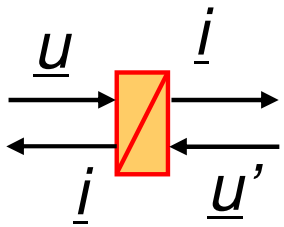


$$E = \frac{1}{2} J\, \Omega^2$$

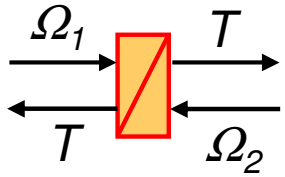
3-phase line



$$[L]\frac{d}{dt}\underline{i} + r_L\ \underline{i} = \frac{1}{3}\begin{bmatrix} 2 & -1 \\ -1 & 2 \end{bmatrix}(\underline{u} - \underline{u}')$$



stiffness

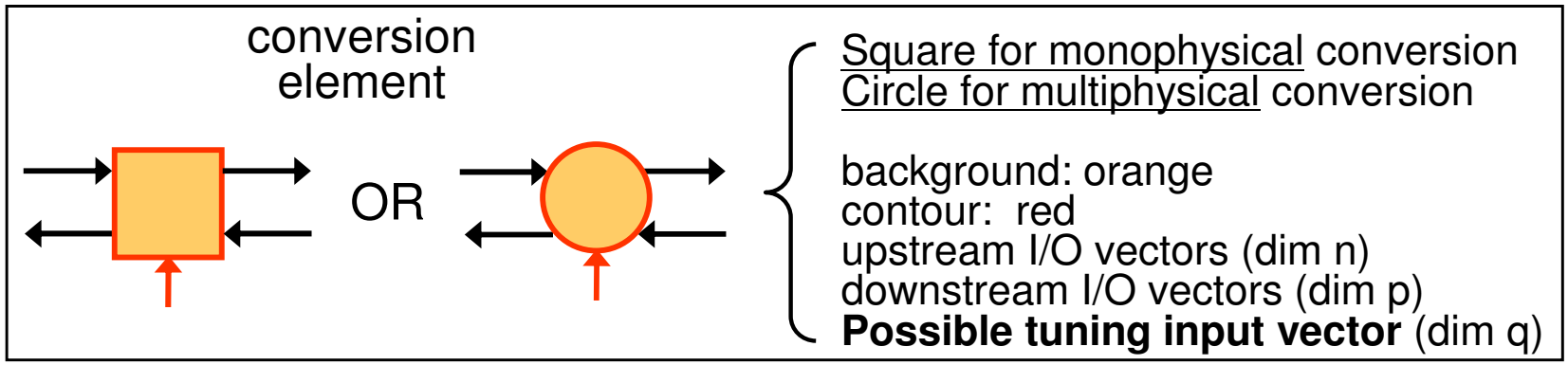


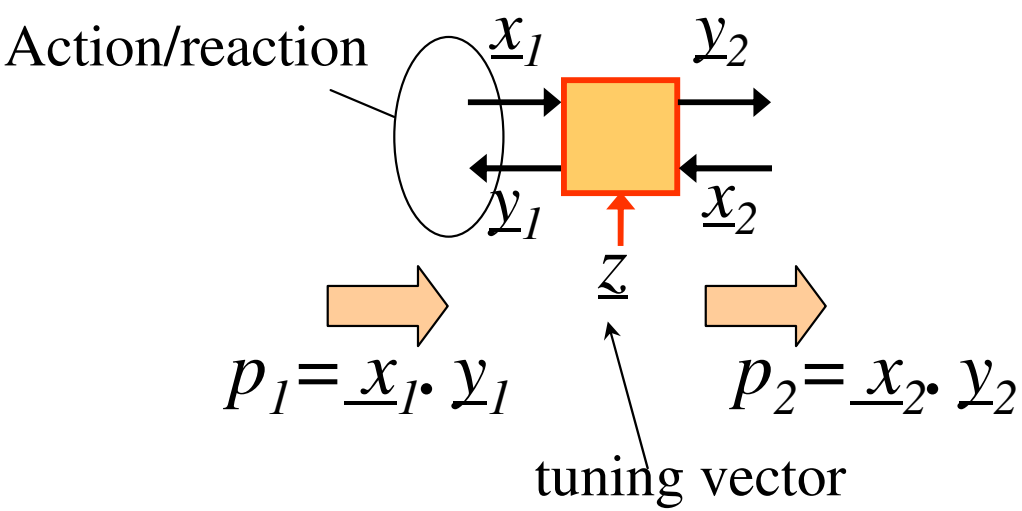
$$E = \frac{1}{2}\frac{1}{k} T^2$$

- Conversion elements -

- Back to definitions
  - System: interconnected subsystems organized for a common objective, in interaction with its environment.
  - Input: produced by a subsystem, imposed to its close subsystem
  - Output: consequence of the subsystem evolution, imposed to its close subsystems
  - Interaction principle: each action induces a reaction
  - Conversion of energy without energy accumulation (with or without losses)
    - » No delay from input(s) changes
    - » Non causal description: input(s) and output(s) can be permuted
  - Needs in defining an element representing the conversion of energy, and the links with its close subsystems
    - According to a non causal description, and to the interaction principle

- Representation
  - Conversion of energy without energy accumulation (with or without losses)
    - Two possibilities





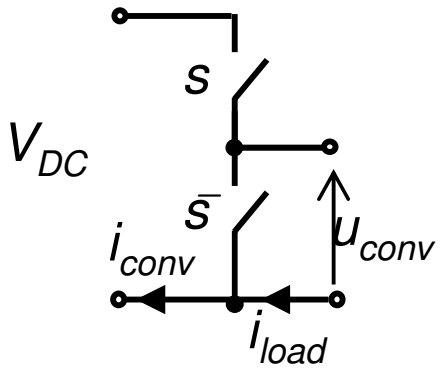
$$\begin{cases} \underline{y}_2 = f(\underline{x}_1, \underline{z}) \\ \underline{y}_1 = f(\underline{x}_2, \underline{z}) \end{cases}$$

no delay!

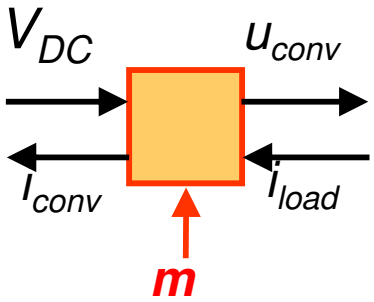
upstream and downstream I/O can be permuted (floating I/O)

- Examples

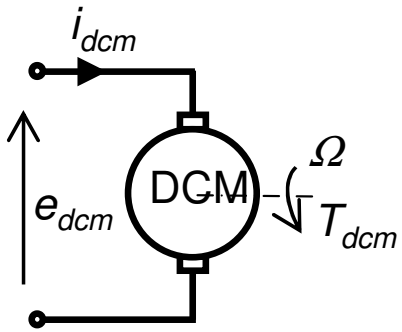
DC/DC converter



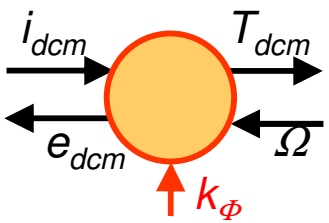
$$\begin{cases} u_{conv} = m \;\; V_{DC} \\ i_{conv} = m \;\; i_{load} \end{cases}$$



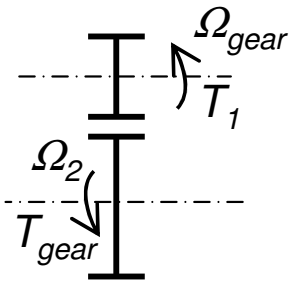
DC machine



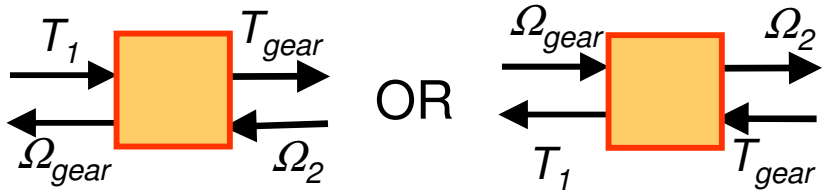
$$\begin{cases} T_{dcm} = k_{\Phi} \;\; i_{dcm} \\ e_{dcm} = k_{\Phi} \;\; \Omega \end{cases}$$



Gearbox - Fix ratio



$$\begin{cases} T_{gear} = k_{gear} \;\; T_1 \\ \Omega_{gear} = k_{gear} \;\; \Omega_2 \end{cases}$$

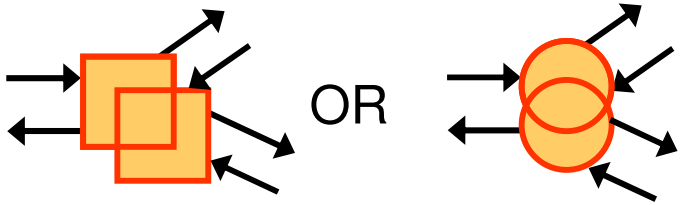


- Coupling elements -

- Back to definitions
  - System: interconnected subsystems organized for a common objective, in interaction with its environment.
  - Input: produced by a subsystem, imposed to its close subsystem
  - Output: consequence of the subsystem evolution, imposed to its close subsystems
  - Interaction principle: each action induces a reaction
  - Distribution of energy without energy accumulation (with or without losses)
    - » No delay from input(s) changes
    - » Non causal description: input(s) and output(s) can be permuted
  - Needs in defining an element representing the distribution of energy in parallel branches, and the links with its close subsystems
    - According to a non causal description, and to the interaction principle

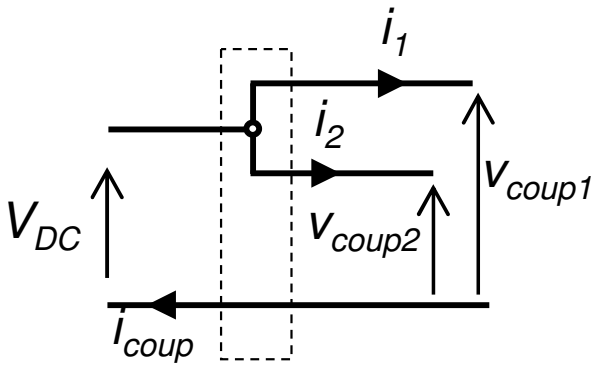
- Representation
  - Distribution of energy without energy accumulation (with or without losses)
    - Two possibilities

Coupling element

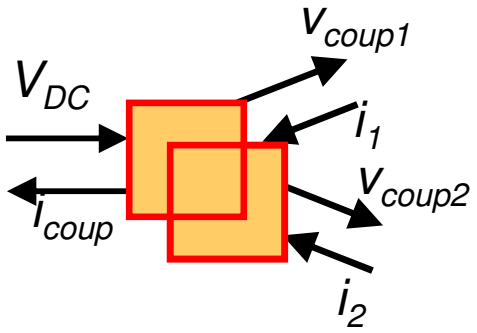


Overlapped squares for monophysical conversion
Overlapped circles for multiphysical conversion

background: orange
contour: red
no tuning input vector



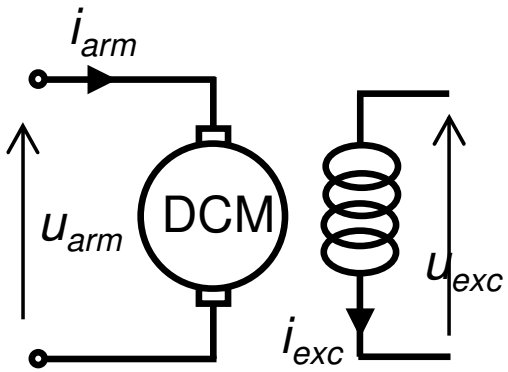
parallel connexion



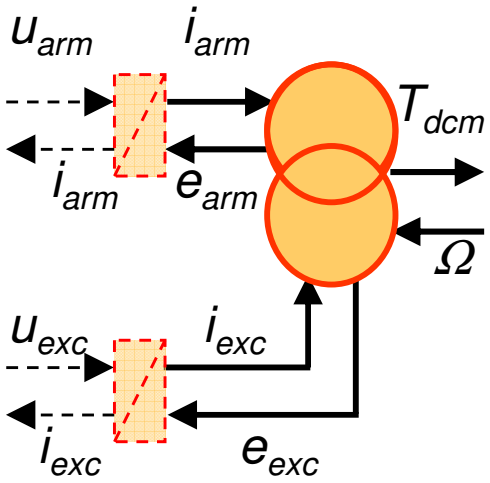
$$\begin{cases} V_{coup1} = V_{coup2} = V_{DC} \\ i_{coup} = i_1 + i_2 \end{cases}$$

- Examples

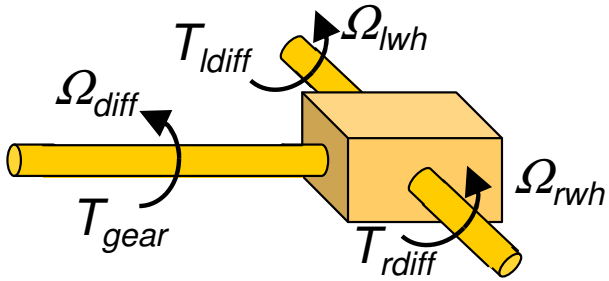
Field winding DC machine



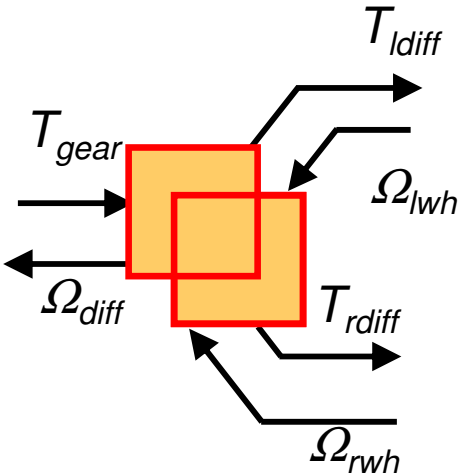
$$\begin{cases} T_{dcm} = k\, i_{exc}\, i_{arm} \\ e_{dcm} = k\, i_{exc}\, \Omega \end{cases}$$



Mechanical differential



$$\begin{cases} T_{ld} = T_{rd} = \dfrac{T_g}{2} \\ \Omega_{diff} = \dfrac{\Omega_{lwh} + \Omega_{rwl}}{2} \end{cases}$$



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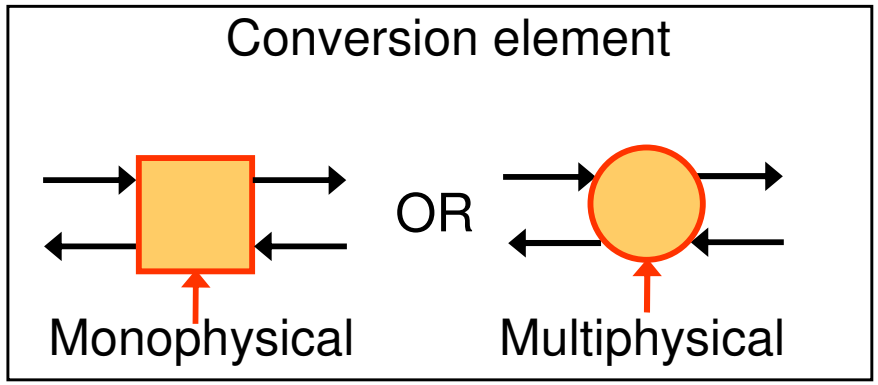
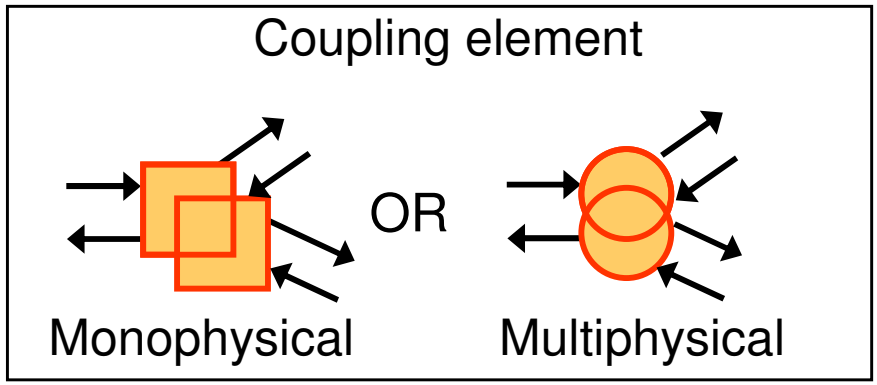
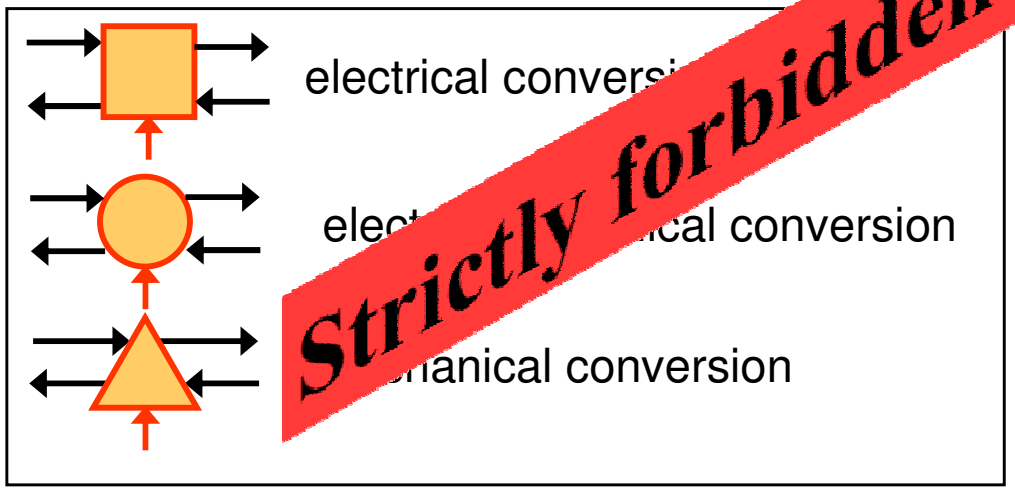
«Organization: fundamental rules»

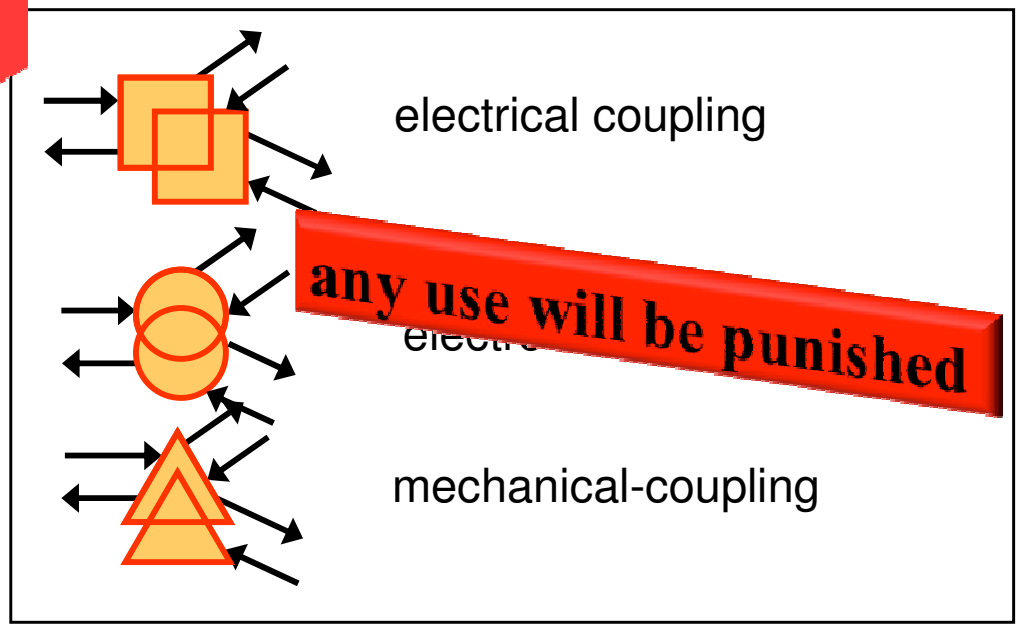
- Elements defined and to be used





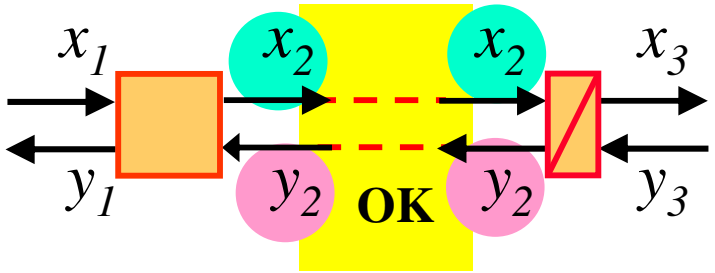
- In the past…..



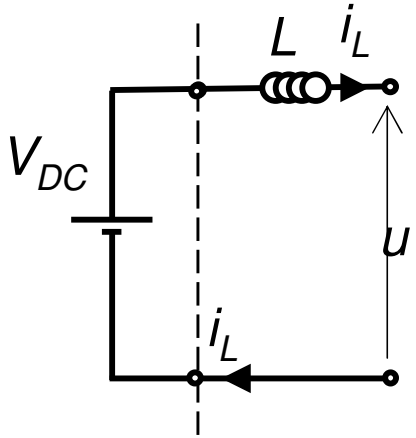


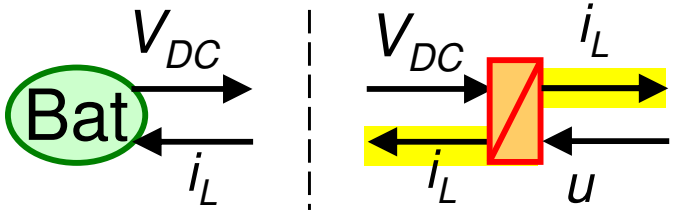
- Association rules: direct connection -

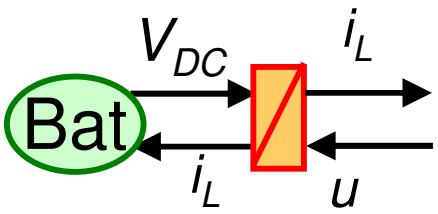
- Systemic: Science for the study of systems, and their interaction
  - Considering S1 and S2 any kind of sub-systems
    - The direct connection of S1 and S2 is only possible if
      - out(S1) = in(S2)
      - in(S1) = out(S2)



Example



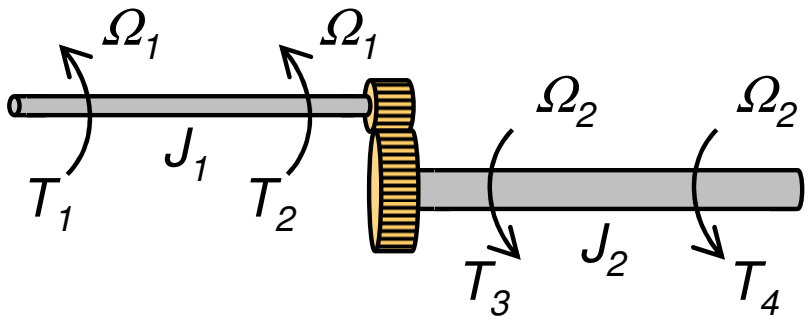




$$L\frac{d}{dt}i_L = V_{DC} - u$$

i state variable

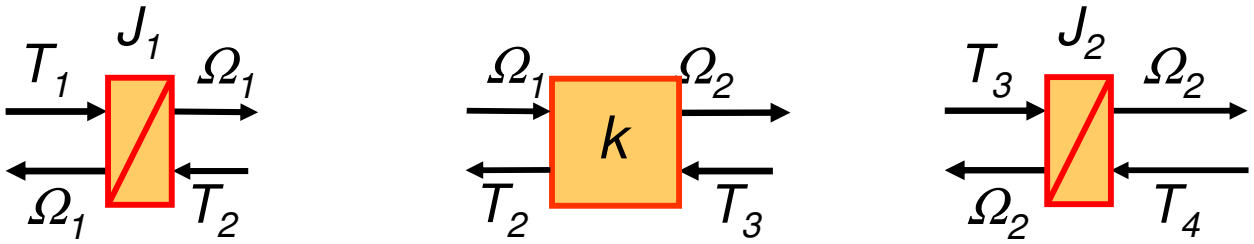
- Example: two inertia linked by a fix ratio gearbox



- Models

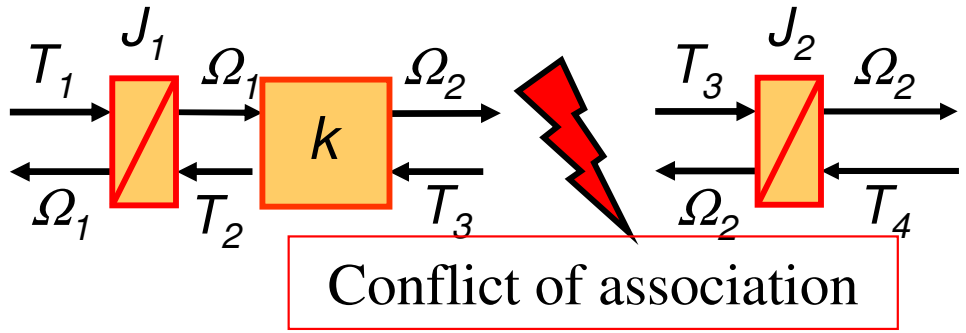
$$J_1 \frac{d\Omega_1}{dt} = T_1 - T_2 \qquad \begin{cases} \Omega_2 = K.\Omega_1 \\ T_2 = K.T_3 \end{cases} \qquad J_2 \frac{d\Omega_2}{dt} = T_3 - T_4$$

- Representation

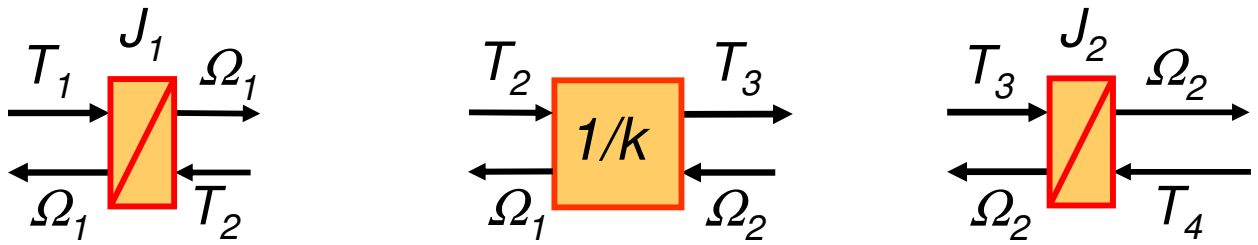


causal non causal causal

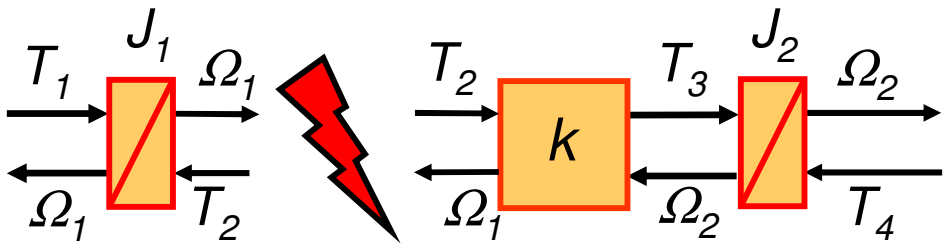
- Example: two inertia linked by a fix ratio gearbox
  - Direct connection 1:



  - Direct connection 2:
    - Use the property of a non causal element to permute inputs and outputs



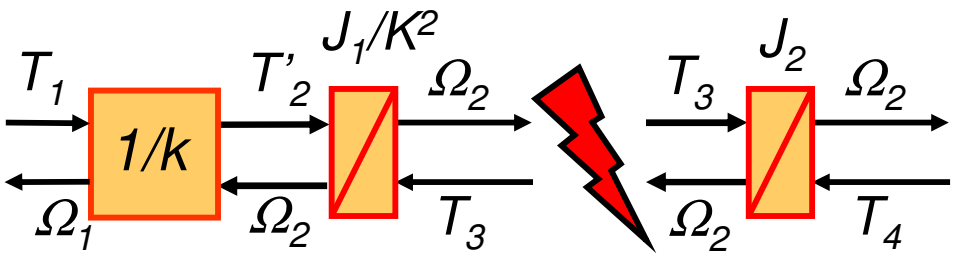
    - Still conflict of association



- Association rules: conflicts of association -

- Remain
  - The property of a non causal element to permute inputs and outputs can be efficiently used: I/Os of a non causal element are fixed by state variables (accumulation element)
    - does not necessarily solve conflicts of associations
- In case conflicts of association subsist
  - Back to the model $J_1 \frac{d\Omega_1}{dt} = T_1 - T_2$ $\quad \begin{cases} \Omega_2 = K.\Omega_1 \\ T_2 = K.T_3 \end{cases}$

$$\frac{J_1}{K}\frac{d\Omega_2}{dt} = T_1 - K.T_3 \Rightarrow \frac{J_1}{K^2}\frac{d\Omega_2}{dt} = T'_2 - T_3 \quad \text{with} \quad T'_2 = \frac{T_1}{K}$$

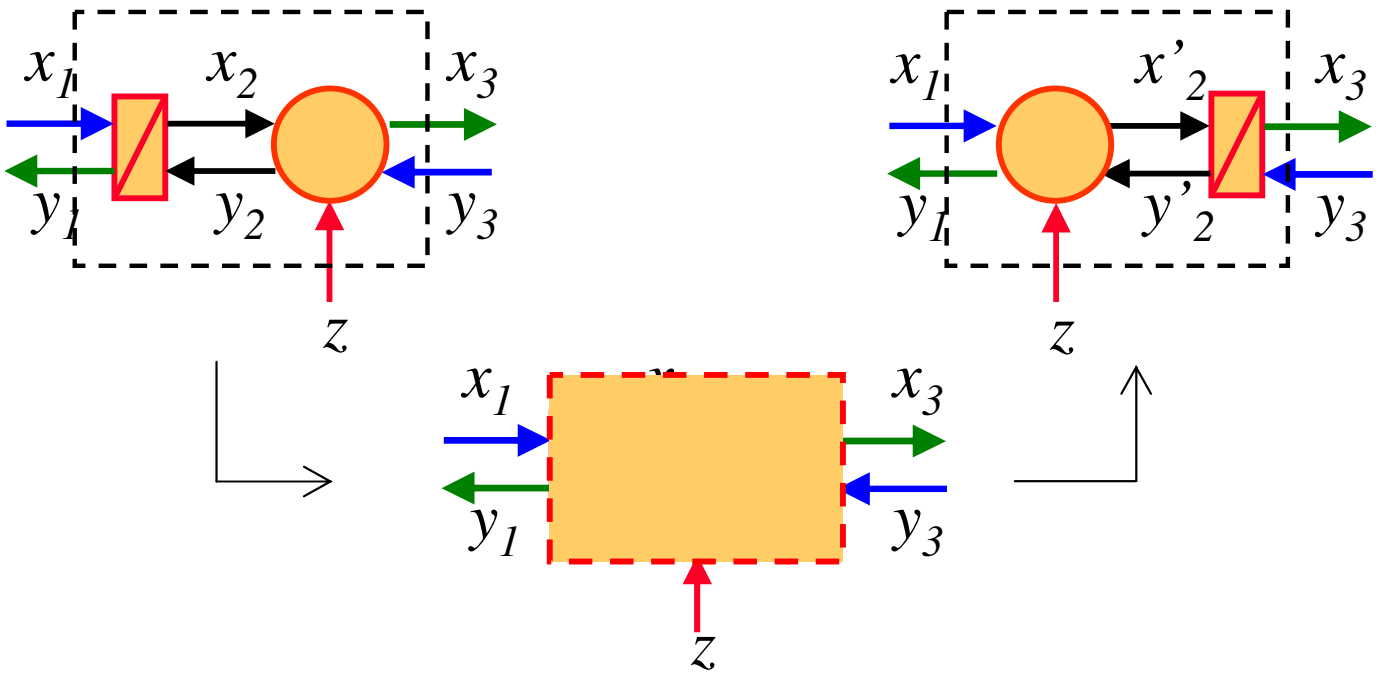


Conflict of association

2 accumulation elements would impose the same state variable x_1

- Remain
  - Permutation of elements is possible if one obtain the same global behavior:
    - strictly the same effects (y1 and x3) from the same causes (x1 , y3 and z)

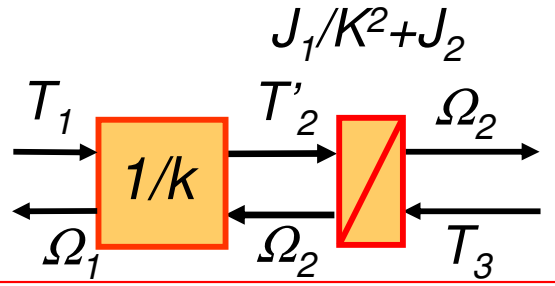
Permutation Rule



- Remain
  - The property of a non causal element to permute inputs and outputs can be efficiently used
  - Permutation rule
- In case conflicts of association subsist
  - Back to the model

$$\begin{cases} \dfrac{J_1}{K^2}\dfrac{d\Omega_2}{dt} = T'_2 - T_3 \\ J_2\dfrac{d\Omega_2}{dt} = T_3 - T_4 \end{cases} \Rightarrow \frac{J_1}{K^2}\frac{d\Omega_2}{dt} = T'_2 - J_2\frac{d\Omega_2}{dt} - T_4 \qquad \text{with} \quad T'_2 = \frac{T_1}{K}$$

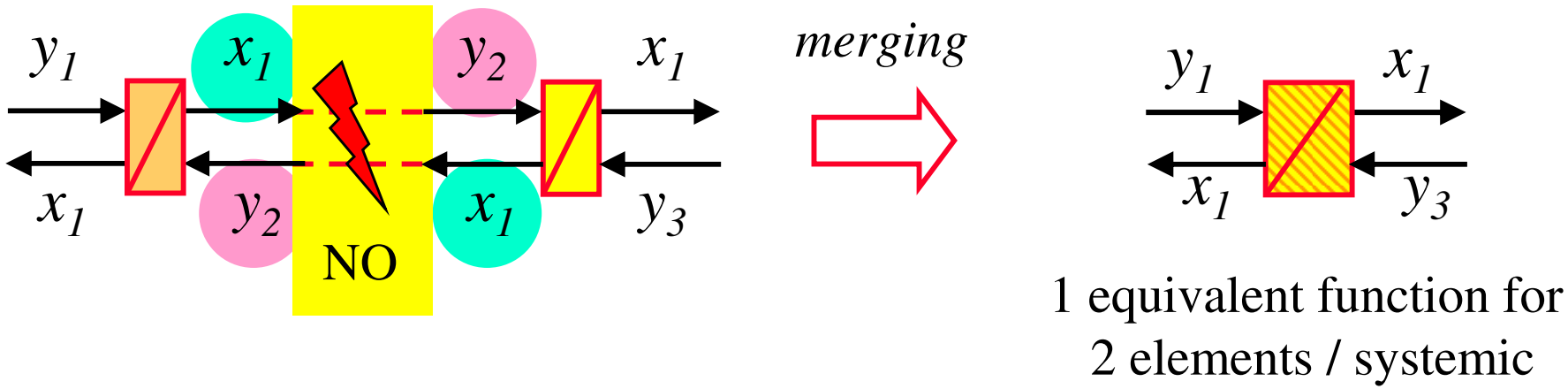
$$\left(\frac{J_1}{K^2} + J_2\right)\frac{d\Omega_2}{dt} = T'_2 - T_4$$



One has finally merged 2 accumulation elements series connected (same state variable)

- Remain
  - When 2 accumulation elements impose the same state variable
    - Conflict association
    - Solution: Merging rule

Merging Rule



1 equivalent function for
2 elements / systemic

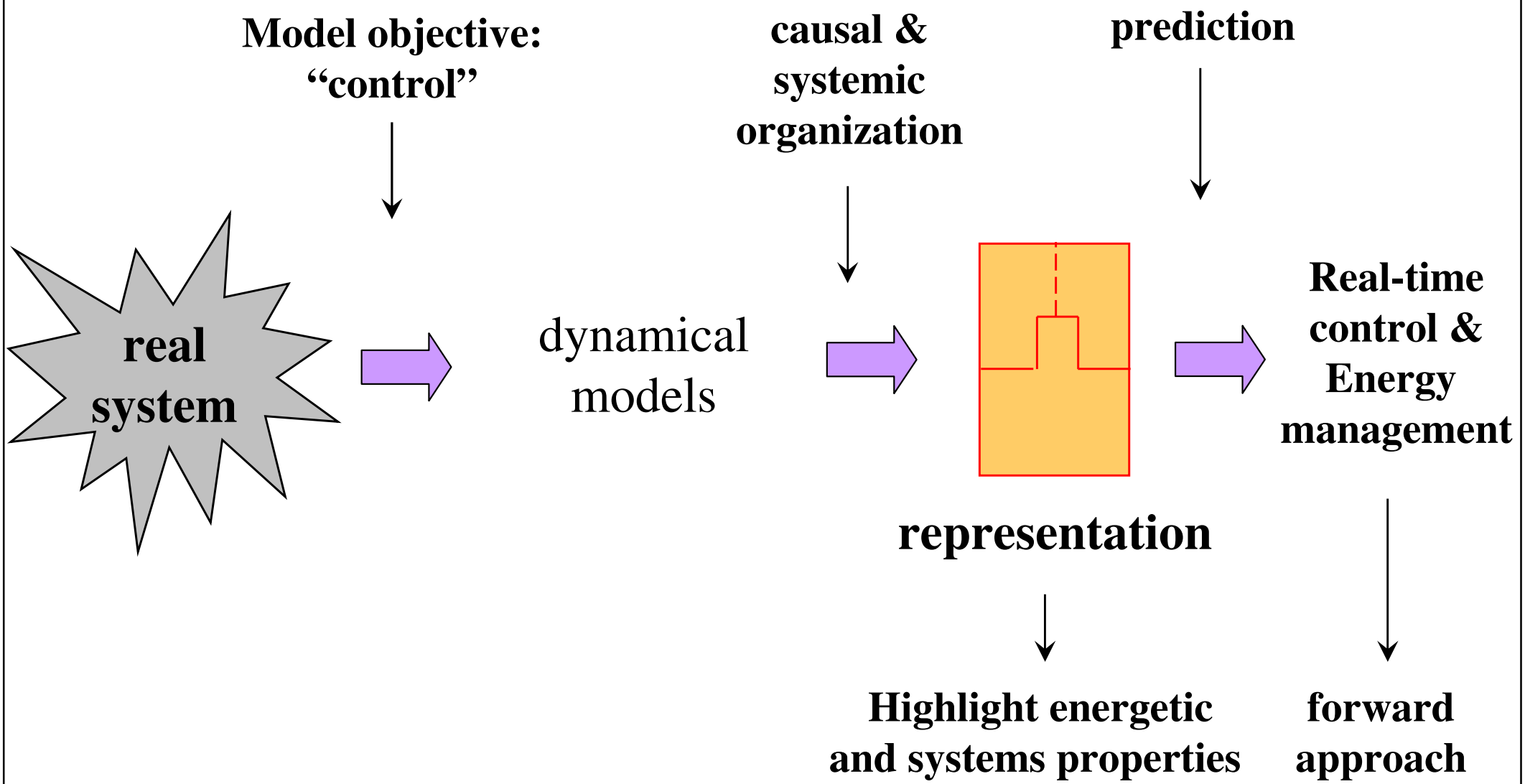
EMR'13
Lille
Sept. 2013

Summer School EMR'13
"Energetic Macroscopic Representation"

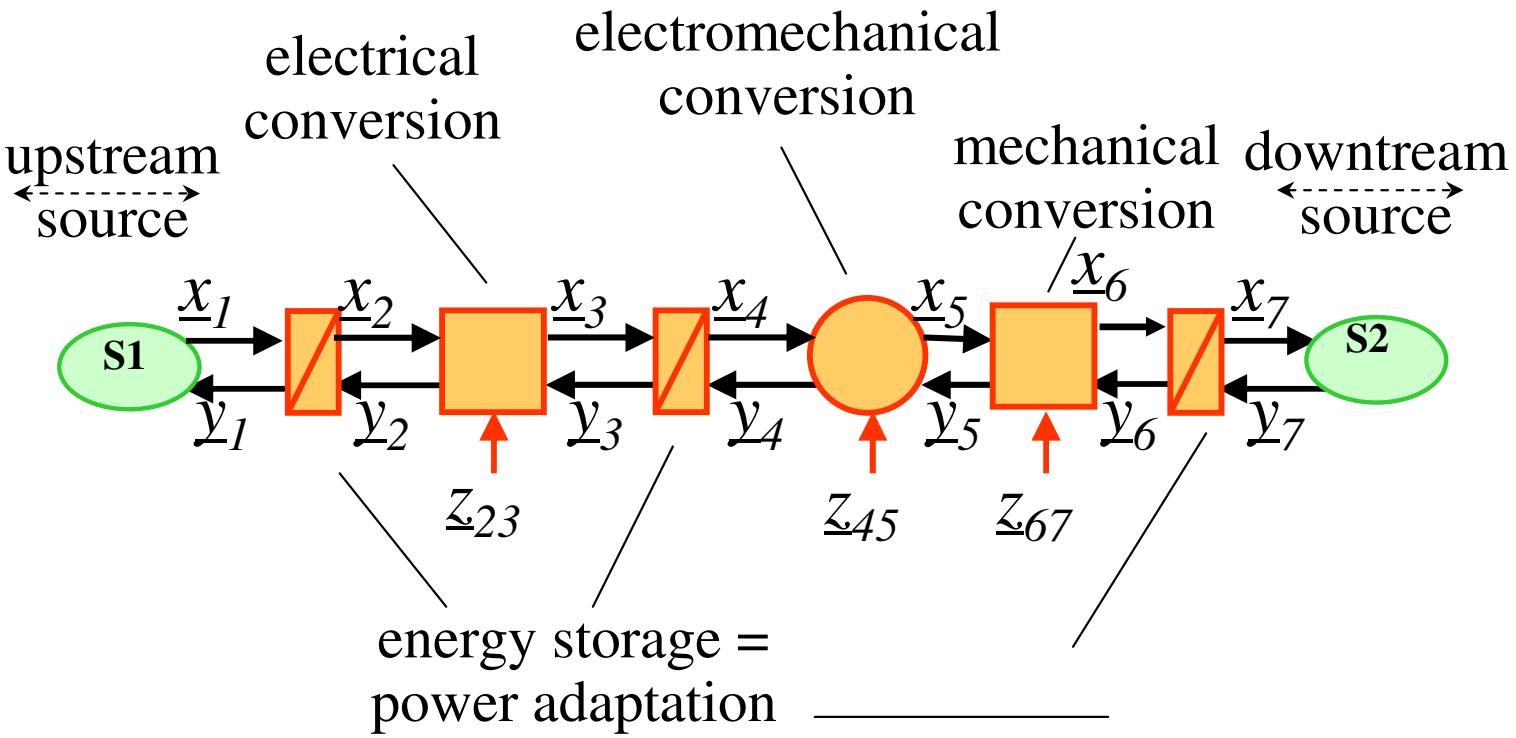
Université Lille1
Sciences et Technologies

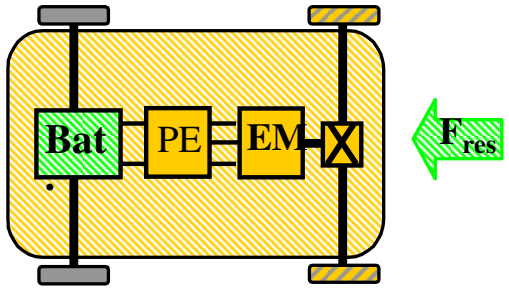
«Analysis for the simulation and control»

- Objective: real-time control and energy management of energetic systems



- Example of an electromechanical conversion system



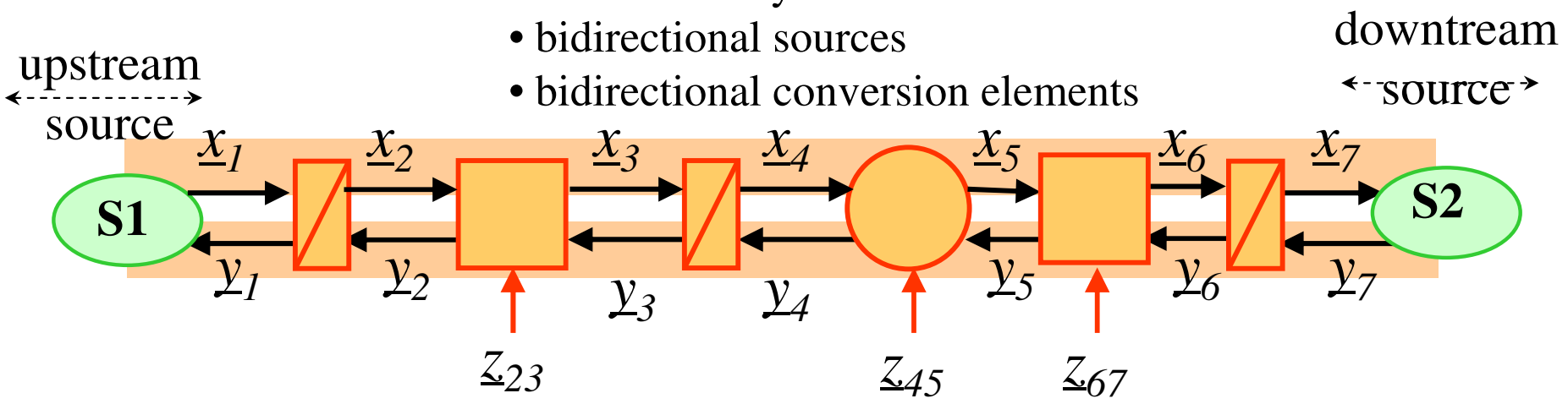


upstream source → downstream source

Convention: direction of positive power flow (could be negative for bidirectional system)

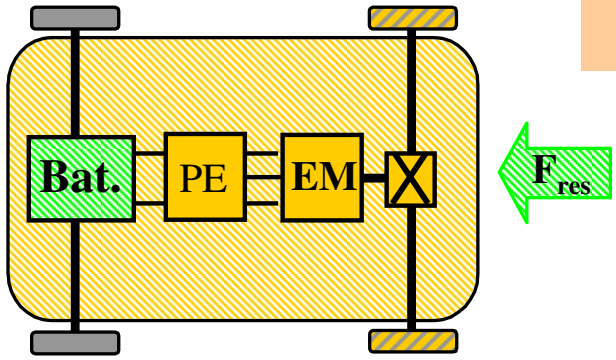
- Example of an electromechanical conversion system

Bidirectional system if:
- bidirectional sources
- bidirectional conversion elements



P > 0 action path: $\underline{x}_1 \rightarrow \underline{x}_2 \rightarrow \underline{x}_3 \rightarrow \underline{x}_4 \rightarrow \underline{x}_5 \rightarrow \underline{x}_6 \rightarrow \underline{x}_7$

(e.g. acceleration) reaction path: $\underline{y}_1 \leftarrow \underline{y}_2 \leftarrow \cdots \leftarrow \underline{y}_7$



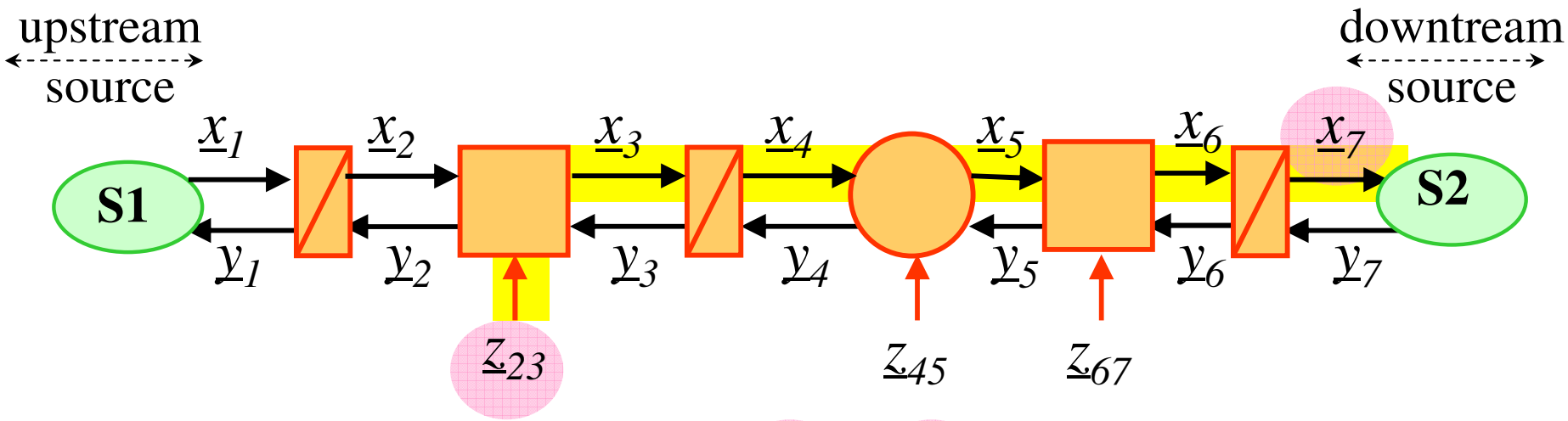
P < 0 action path: $\underline{y}_1 \leftarrow \underline{y}_2 \leftarrow \cdots \leftarrow \underline{y}_7$

(e.g. braking) reaction path: $\underline{x}_1 \rightarrow \underline{x}_2 \rightarrow \cdots \rightarrow \underline{x}_7$

I/O independent of power flow direction
action/reaction dependent of power flow direction

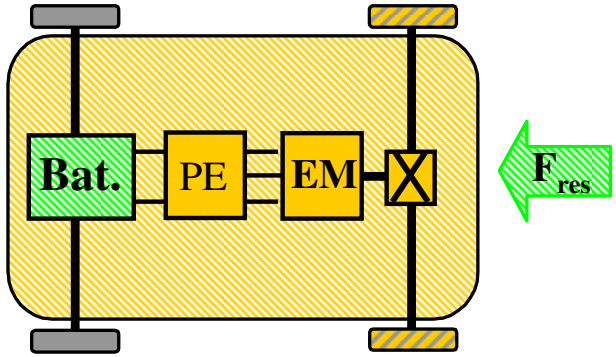
- Tuning paths-

- Example of an electromechanical conversion system



Technical requirements: action on z_{23} and x_7 to be controlled

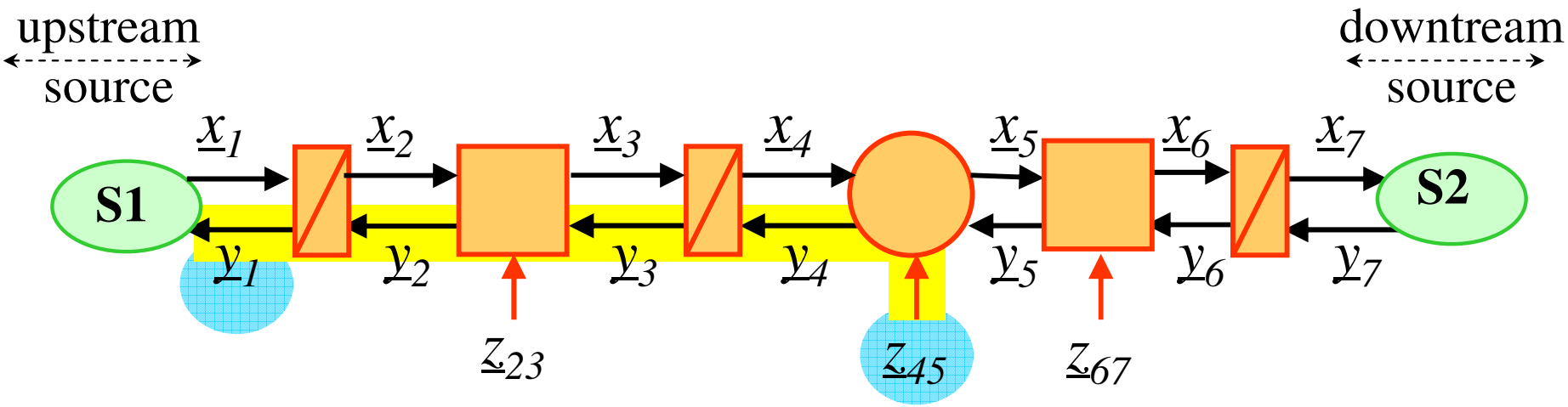
Tuning path: $z_{23} \rightarrow x_3 \rightarrow x_4 \rightarrow x_5 \rightarrow x_6 \rightarrow x_7$



The tuning path is **independent of the power flow direction**

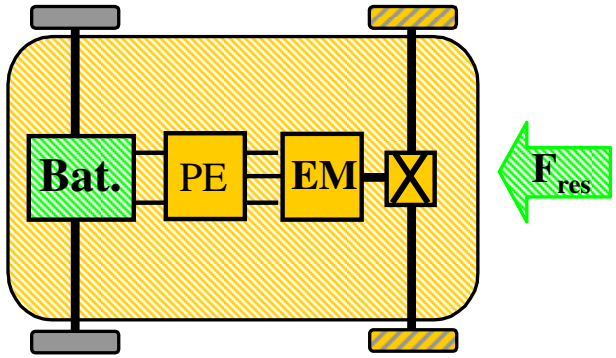
(e.g. velocity control in acceleration AND regenerative braking)

- Example of an electromechanical conversion system



Technical requirements: action on z_{45} and y_1 to be controlled

Tuning path: $y_1 \leftarrow y_2 \leftarrow y_3 \leftarrow y_4 \leftarrow z_{45}$



The tuning path depends on the technical requirements

«Conclusion»

EMR = multi-physical graphical description

based on the interaction principle (systemic)
and the causality principle (energy)

Basic elements = energetic function

sources, accumulation, conversion and distribution of energy

Association rules = holistic property of systemic

enable keeping physical causality in association conflict

Applications

analysis, simulation, control structure…

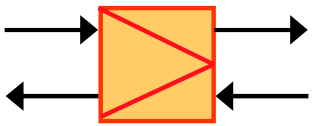
Remember = no more triangles or other kind of pictogram for the representations of conversion or coupling elements

Only the use of squares (monophysical) or circles (multiphysical) is authorized

The methodology is not frozen

A new element was introduced recently

Adaptation element



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