EMR'22
Sion
June 2022

EMR'22 Summer School
"Energetic Macroscopic Representation"

INVERSION-BASED CONTROL DEDUCED FROM EMR

Alain BOUSCAYROL[1], Pierre SICARD[2]

[1] L2EP, University of Lille, France
[2] Université du Québec à Trois Rivières, Canada

Université de Lille

L2EP Laboratoire d'électrotechnique et d'électronique de puissance de Lille

UQTR Université du Québec à Trois-Rivières

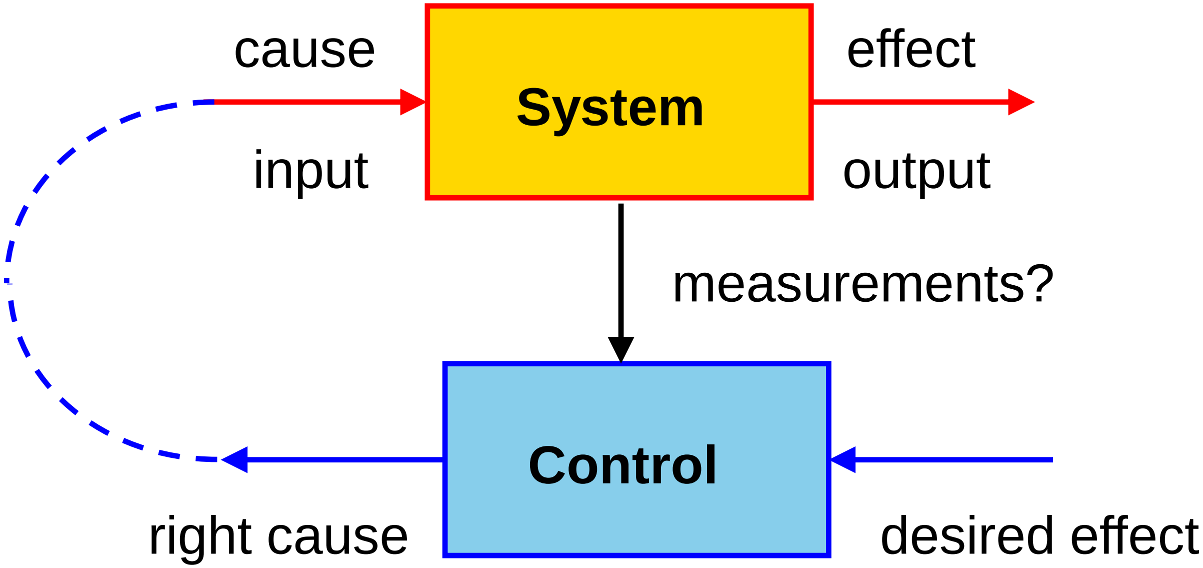
1. **Principle of model-based control**

2. **Inversion of EMR elements**

3. **Inversion-based control schemes**

1. Principle of model-based control

[Hautier 96]

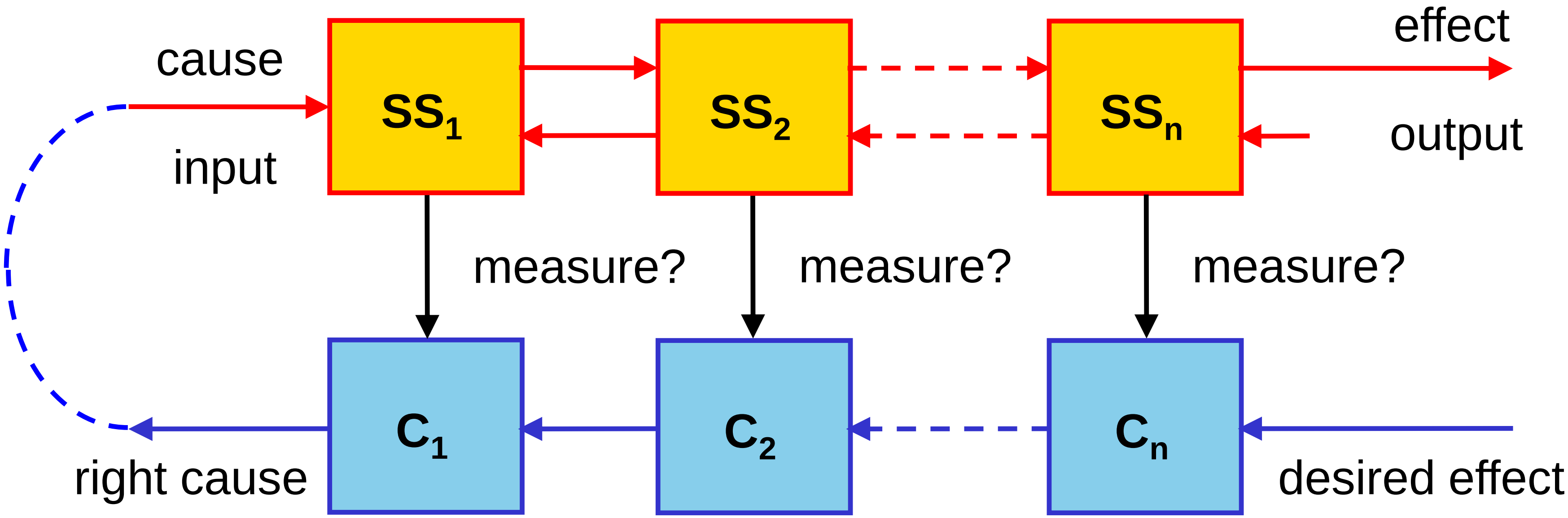


Model $out = \mathrm{f}\,(in)$

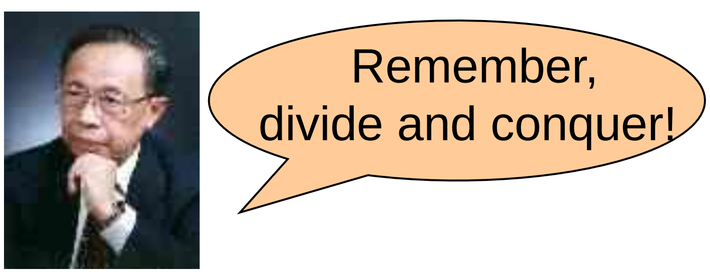
⇩

Control $in = \mathrm{g}\,(out_{ref})$

control = inversion of the system functionality

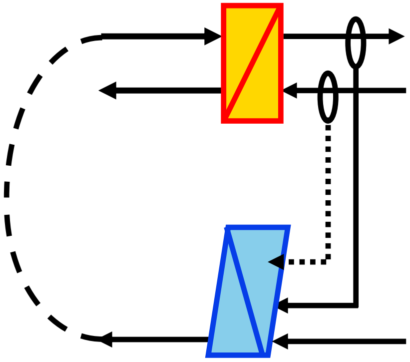


EMR = system decomposition in basic energetic subsystems (SS_n)



Inversion-based control: systematic inversion of each subsystem

2. Inversion of EMR elements



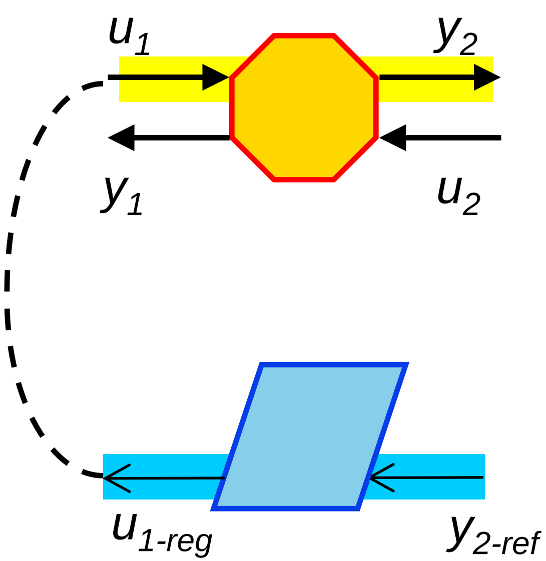
Model $out = f(in)$ ⇨ Control $in = g(out_{ref})$

I/O relation without delay → direct inversion

I/O relation with delay → Indirect inversion (closed-loop control)

I/O relation with multiple Inputs → Multiple solutions

Objective: to control y_2



$y_2 = f(u_1)$

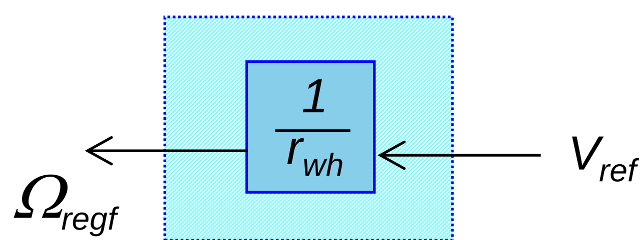
$u_{1\text{-}reg} = f^{-1}(y_{2\text{-}ref})$

Direct Inversion

Ex : wheel

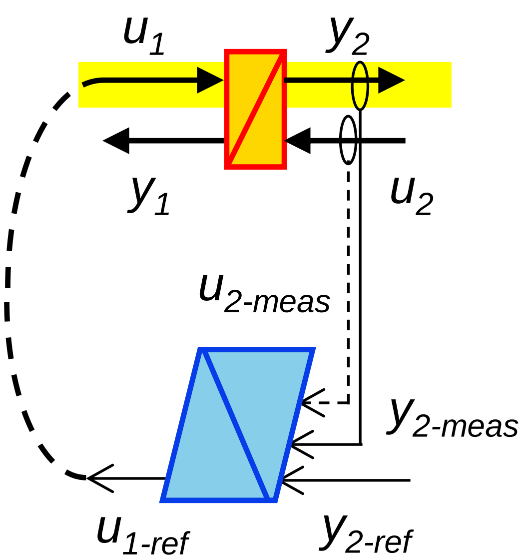
$$\begin{cases} V = r_{wh}\,\Omega \\ T = r_{wh}\,F \end{cases}$$

$$\Omega_{ref} = V_{ref} / r_{wh}$$



- Inversion of an accumulation element (1) -

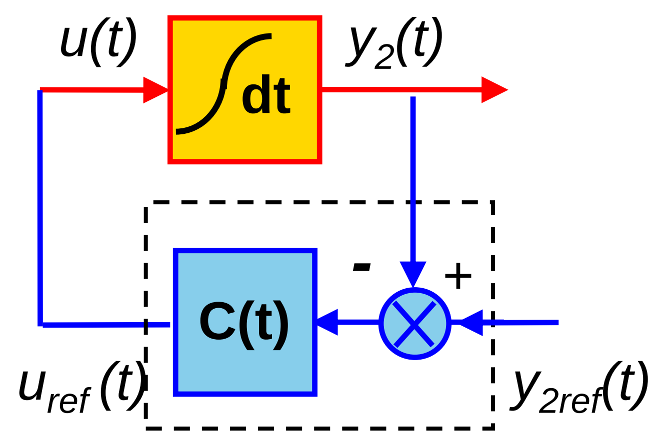
Objective: to control y_2



$y_2 = f(u_1, u_2)$

f is in integral form

$u(t) = u_1(t) - u_2(t)$



direct inversion

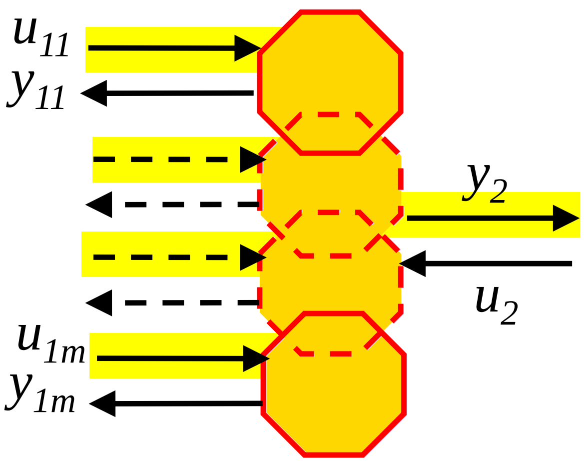
$$u_{ref}(t) = \frac{d}{dt} y_{ref}(t)$$

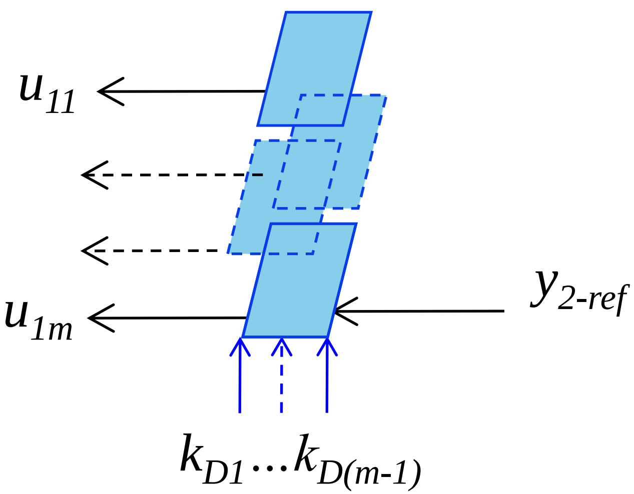
not possible in real-time

indirect inversion

$$u_{ref}(t) = C(t)[y_{2ref}(t) - y_{2meas}(t)]$$

closed loop controller





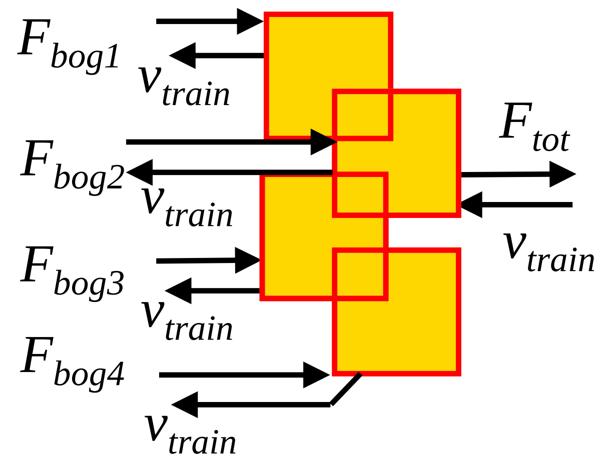
no measurement

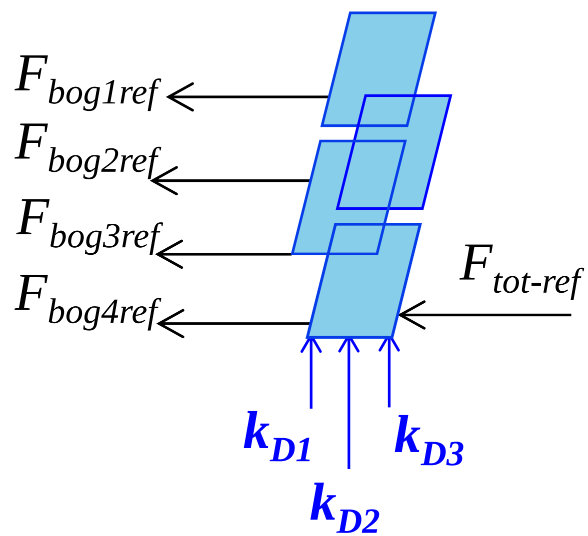
no controller

(m - 1) **distribution variables**

$$\begin{cases} u_{11} = k_{D1} y_{2ref} \\ \dots \\ u_{1(m-1)} = k_{D(m-1)} y_{2ref} \\ u_{1m} = (1 - \sum k_{Di}) y_{2ref} \end{cases}$$

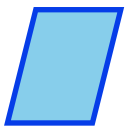
Example: chassis of a train

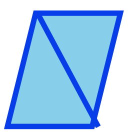




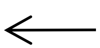
Legend

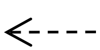
Control = light blue Parallelograms with dark blue contour

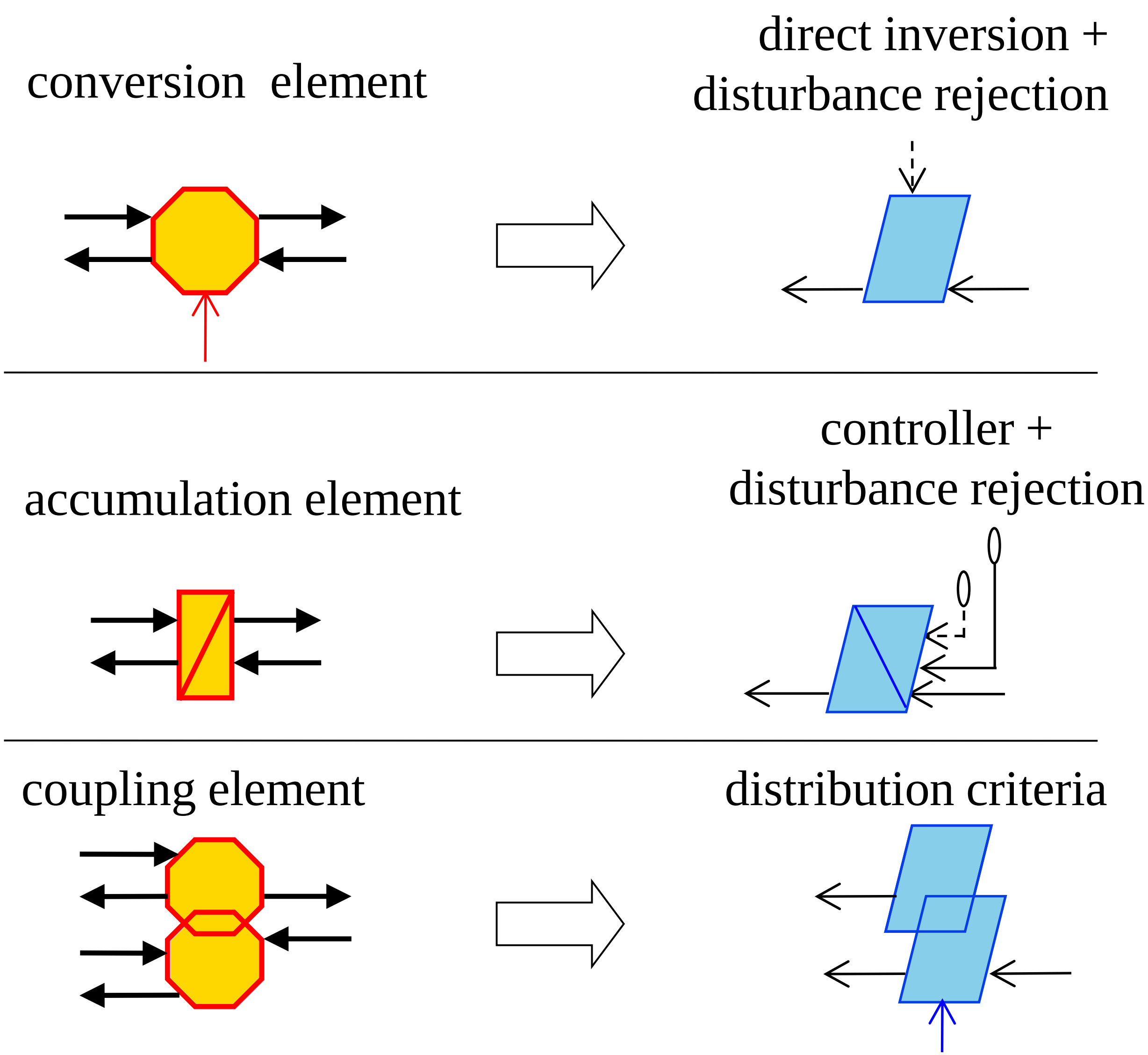

direct inversion


indirect inversion

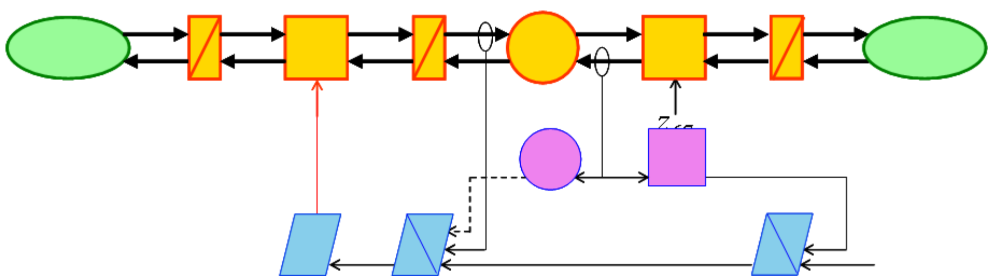

sensor


mandatory link

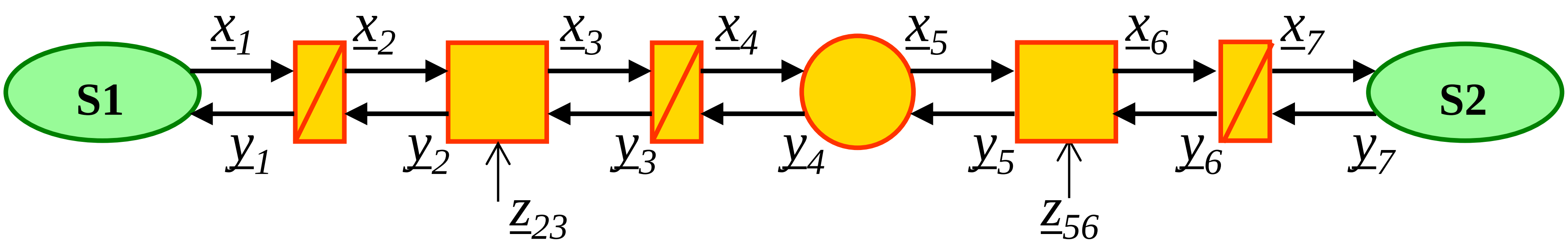

facultative link



3. Inversion-based control schemes



1. EMR of the system

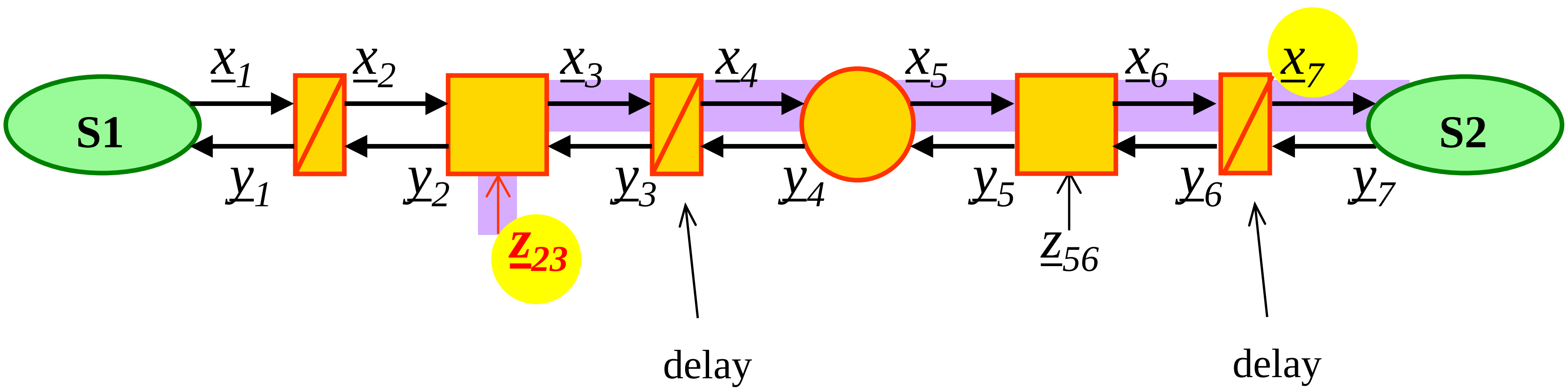


EMR depends on:

- the study objective (limits between system and sources)
- the physical laws of subsystems (physical causality)
- the association of subsystems (systemic approach)

1. EMR of the system

2. Tuning path



The tuning path is:

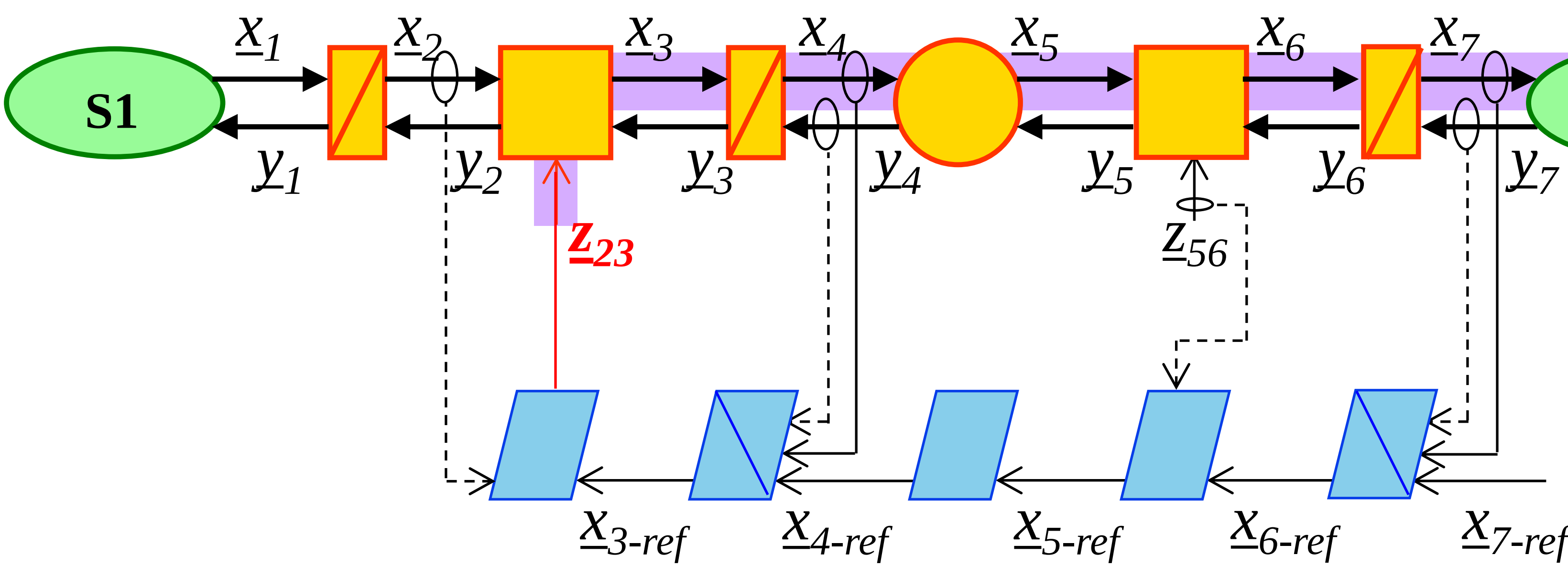
- dependant on the technical requirements (chosen tuning input / output to control)
- **independent of the power flow direction**

1. EMR of the system

2. Tuning path

3. Inversion step-by-step

Strong assumption: all variables can be measured!



Maximal Control Structure (or scheme):
- maximum of sensors
- maximum of operations

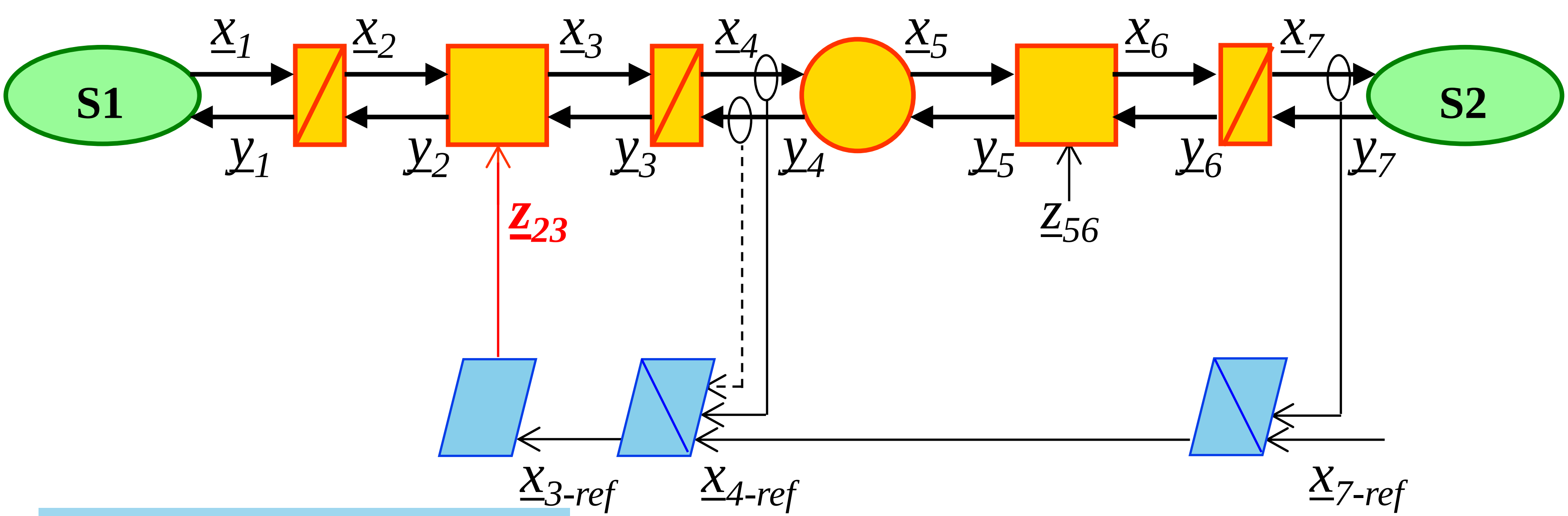
Example:
- 5 sensors
- 2 closed-loop controllers

1. EMR of the system

2. Tuning path

3. Inversion step-by-step

Strong assumption: all variables can be measured!



4. Simplification of control

Simplifications:

- non-consideration of disturbances
- merging control blocks…

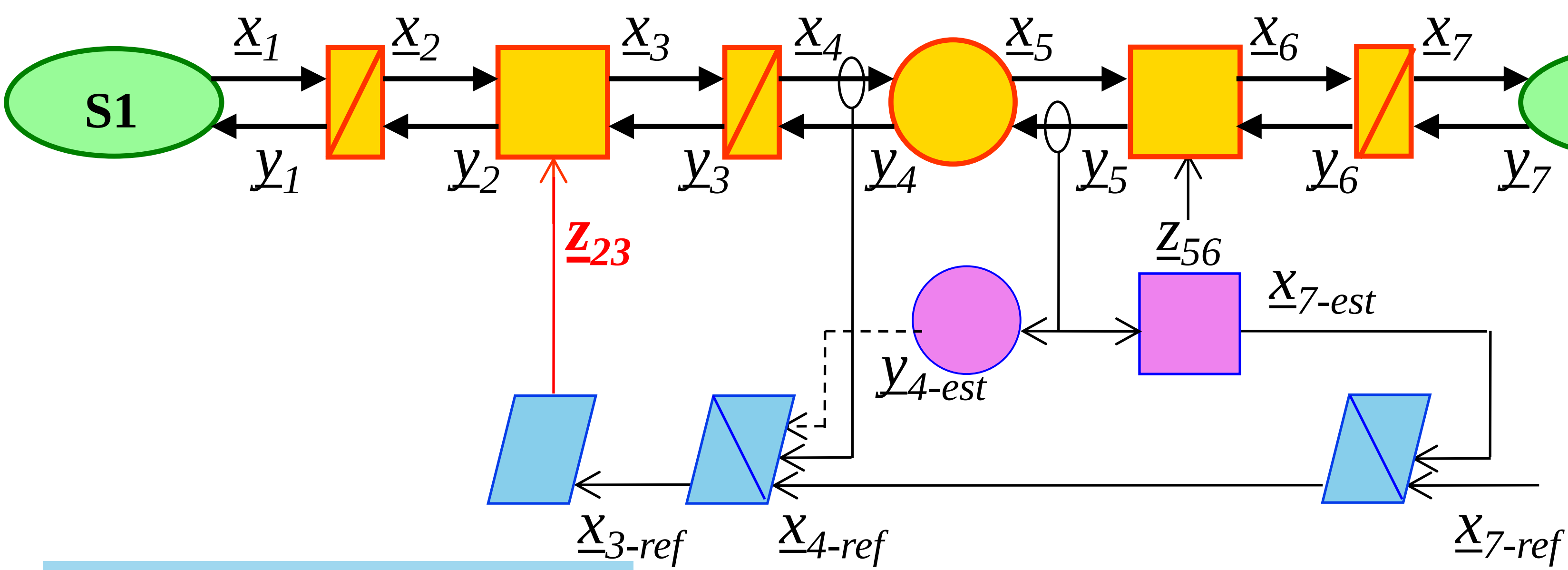
⇨ impact on the tuning and on the performances

1. EMR of the system

2. Tuning path

3. Inversion step-by-step

Strong assumption: all variables can be measured!



4. Simplification of control

5. Estimation of non-measured variables

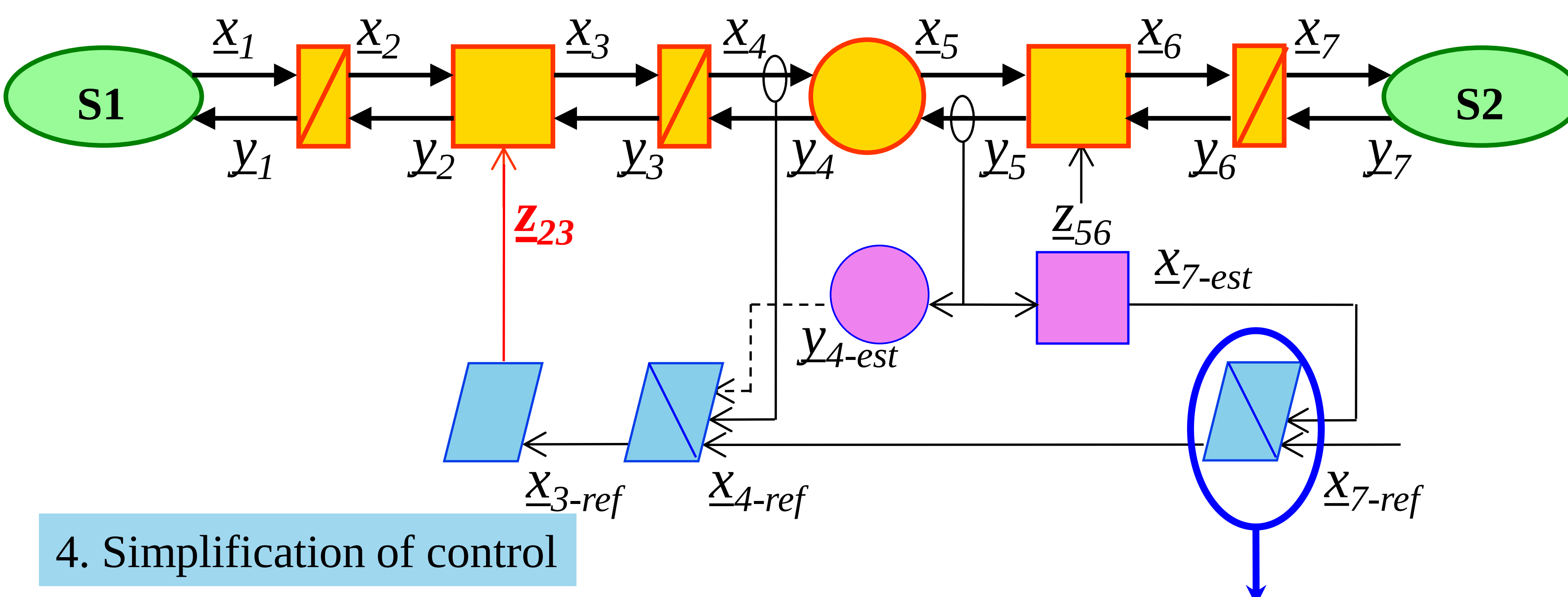
from measured variables

1. EMR of the system

2. Tuning path

3. Inversion step-by-step

Strong assumption: all variables can be measured!



4. Simplification of control

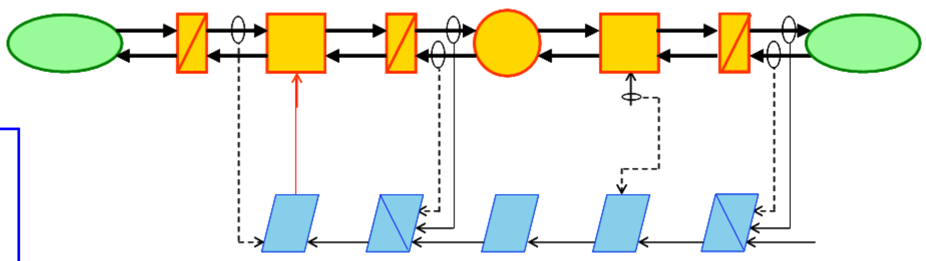
5. Estimation of non-measured variables

6. Tuning of controllers

PI / PID / fuzzy controller?
Calculation of parameters?

- Inversion-based control of a system -

1. EMR of the system
2. Tuning path
3. Inversion step-by-step

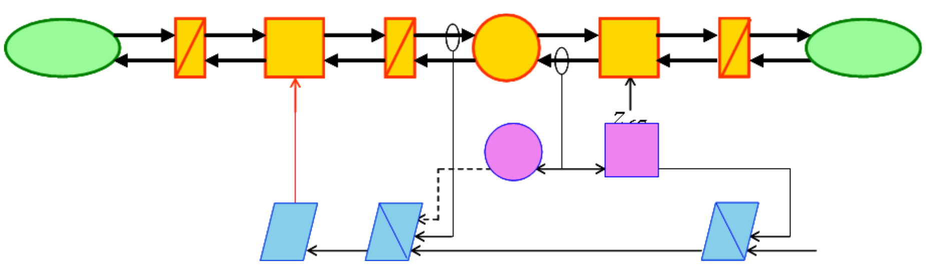


Maximal Control Scheme

- mirror of the EMR (systematic)
- unique and theoretical solution

---

4. Simplification of control
5. Estimation of variables
6. Tuning of controllers



Practical Control Schemes

- several solutions (expertise)
- reduced performances

Conclusion

Inversion based control = inversion of EMR
based on the cognitive systemic
and the causality principle (energy)

Inversion rule for control scheme
closed-loop control to invert accumulation, direct inversion for conversion element, degrees of freedom for coupling element

BIOGRAPHIES AND REFERENCES

- References -

[Barre 2006] P. J. Barre, A. Bouscayrol, P. Delarue, E. Dumetz, F. Giraud, J. P. Hautier, X. Kestelyn, B. Lemaire-Semail, E. Semail, "Inversion-based control of electromechanical systems using causal graphical descriptions", *IEEE-IECON'06*, Paris, November 2006.

[Bouscayrol 2000] A. Bouscayrol, B. Davat, B. de Fornel, B. François, J. P. Hautier, F. Meibody-Tabar, M. Pietrzak-David, “Multimachine multiconverter system: application for electromechanical drives”, *European Physics Journal - Applied Physics*, vol. 10, no. 2, May 2000, p. 131-147 (common paper GREEN Nancy, L2EP Lille and LEEI Toulouse, according to the SMM project of the GDR-SDSE).

[Bouscayrol 2012] 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

[Delarue 2003] 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, 28(8), pp. 1159-1324 (common paper L2EP and Jeumont SA).

[Leclercq 2004] A. Leclercq, P. Sicard, A. Bouscayrol, B. Lemaire-Semail,"Control of a triple drive paper system based on the Energetic Macroscopic Representation", *IEEE-ISIE'04*, Ajaccio (France), May 2004, pp. 889-893.

[Djani 2006] Djani Wankam, Y., P. Sicard, A. Bouscayrol "Maximum control structure of a five-drive paper system using Energetic Macroscopic Representation*," IEEE IECON'2006*, Special Session Graphical Description for Modeling and Control Power Systems, Paris, France, November 2006, 5332-5337.

[Sicard 2009] P. Sicard, A. Bouscayrol, “Inversion-based control of electromechanical systems”, EMR'09 summer school, Trois-Rivières, Canada, September 2009