

MODEL-FREE CONTROL: A MATHEMATICAL TOOL FOR INDUSTRIAL APPLICATIONS

COLLOQUE EN L'HONNEUR DE MARCEL-PAUL SCHÜTZENBERGER
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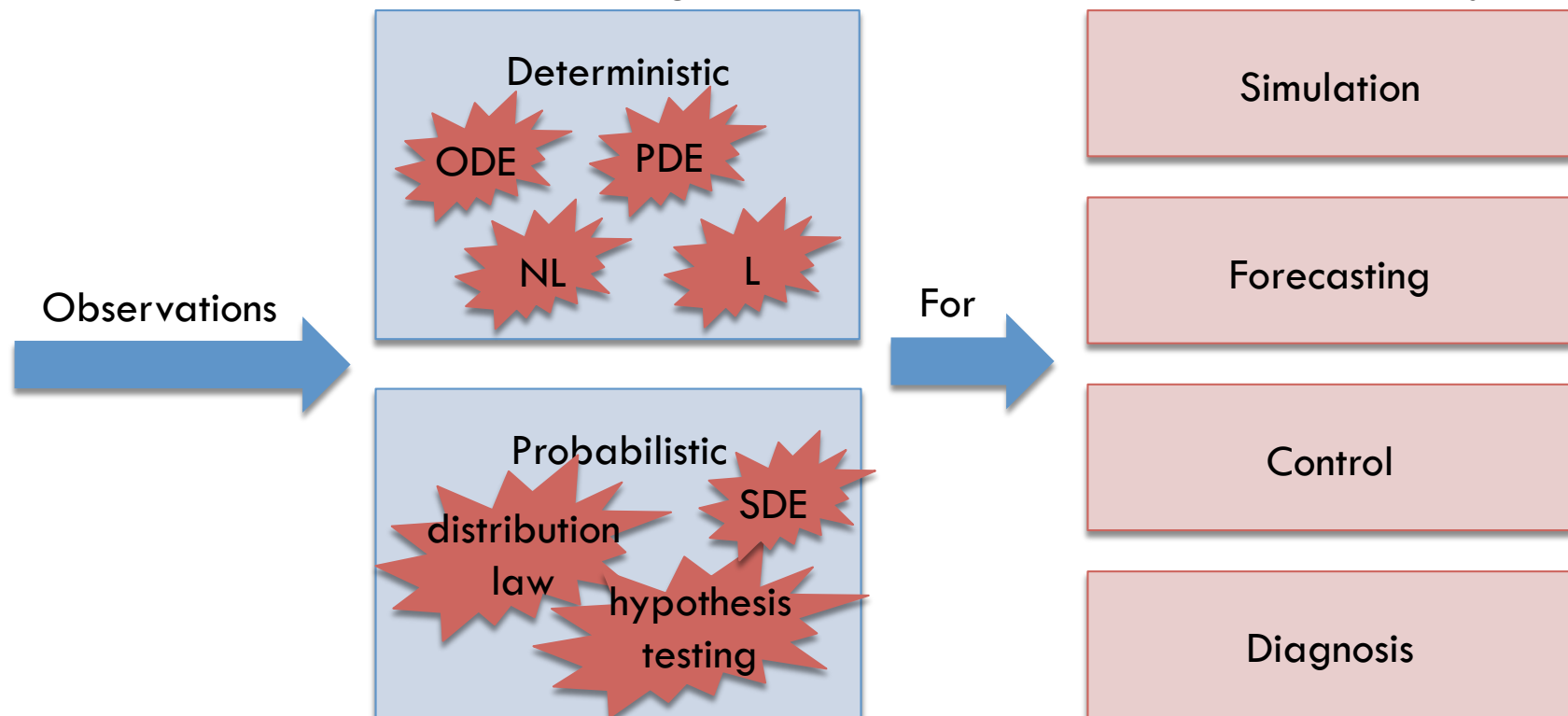
- Modeling: Pavlovian conditioning ?
- Control engineering
 - ▣ Introduction
 - ▣ PID: >95% industrial control implementation
- Model-free control
 - ▣ Main idea
 - ▣ Algebraic estimation technique
 - ▣ In general
- Examples

Modeling: Pavlovian conditioning

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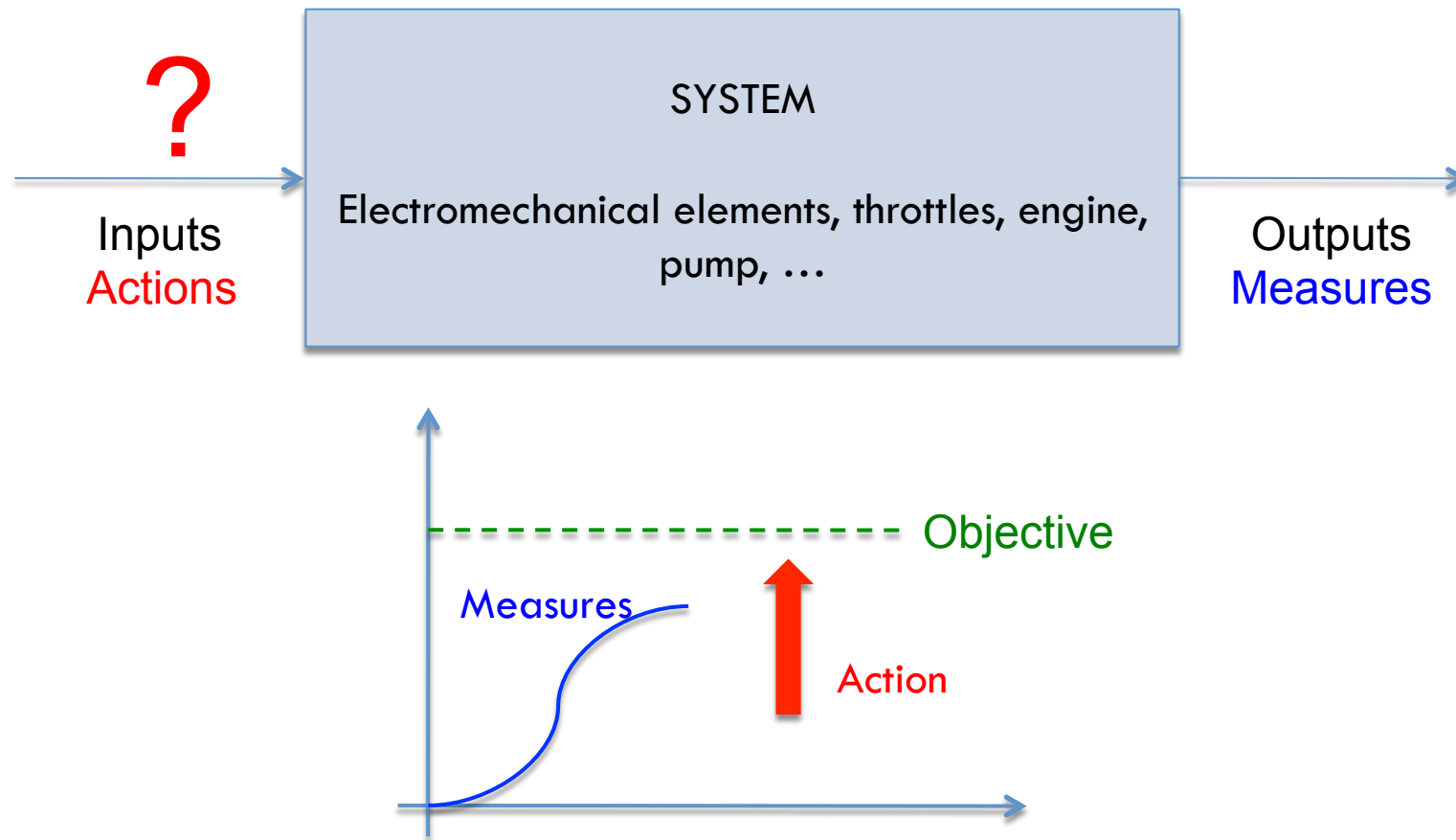
Applied problem

the first academic move : modelling via differential equations and probability laws

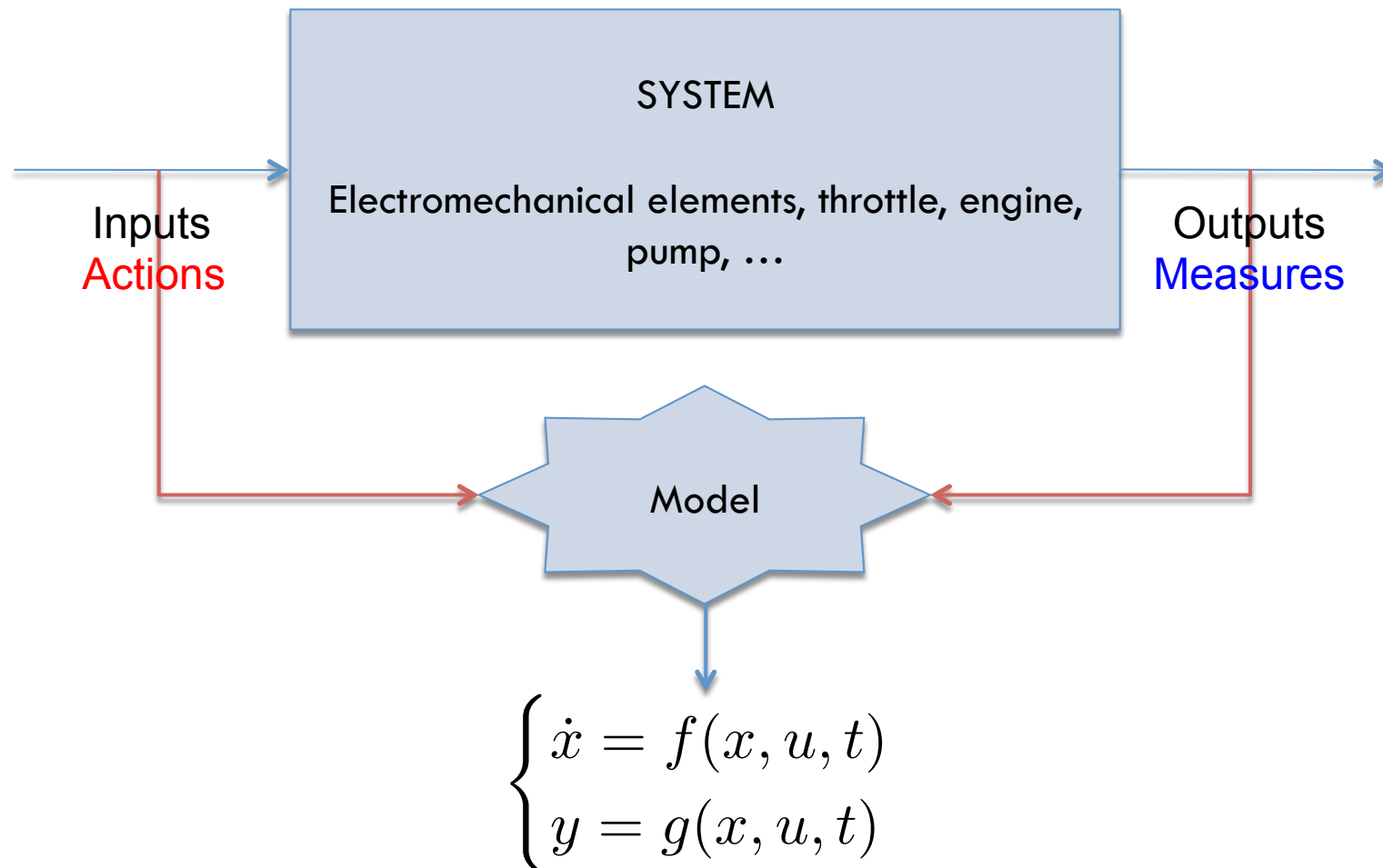


Objectives

How to control a system in order to obtain good performances?



Most existing works: need precise mathematical modelling.



Modelling in real life:

- **always** long and difficult
- **difficult** parameter calibration
- **only experts** can do it

Time needed for modelling:

more than 80%

PID (Proportional Integral Derivative) **most common control law in practice (>95%)**:

$$Control = K_p e + K_i \int e + K_d \frac{d}{dt} e$$

e : tracking error

- **simplicity of the concept**
- no **need of a precise** modelling

but

poor performances:

- with severe **nonlinearities** (friction, hysteresis, ...)
- change of **system characteristics** (ageing, faults, ...)
- **high dimension**

Model-free control

Main idea
Algebraic technique
In general

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Objective

Our control law: the same advantages as for PID controllers but without disadvantages.

- Same conceptual simplicity as PID controllers.
- No need of precise modelling.

Ensuring



very large application domains

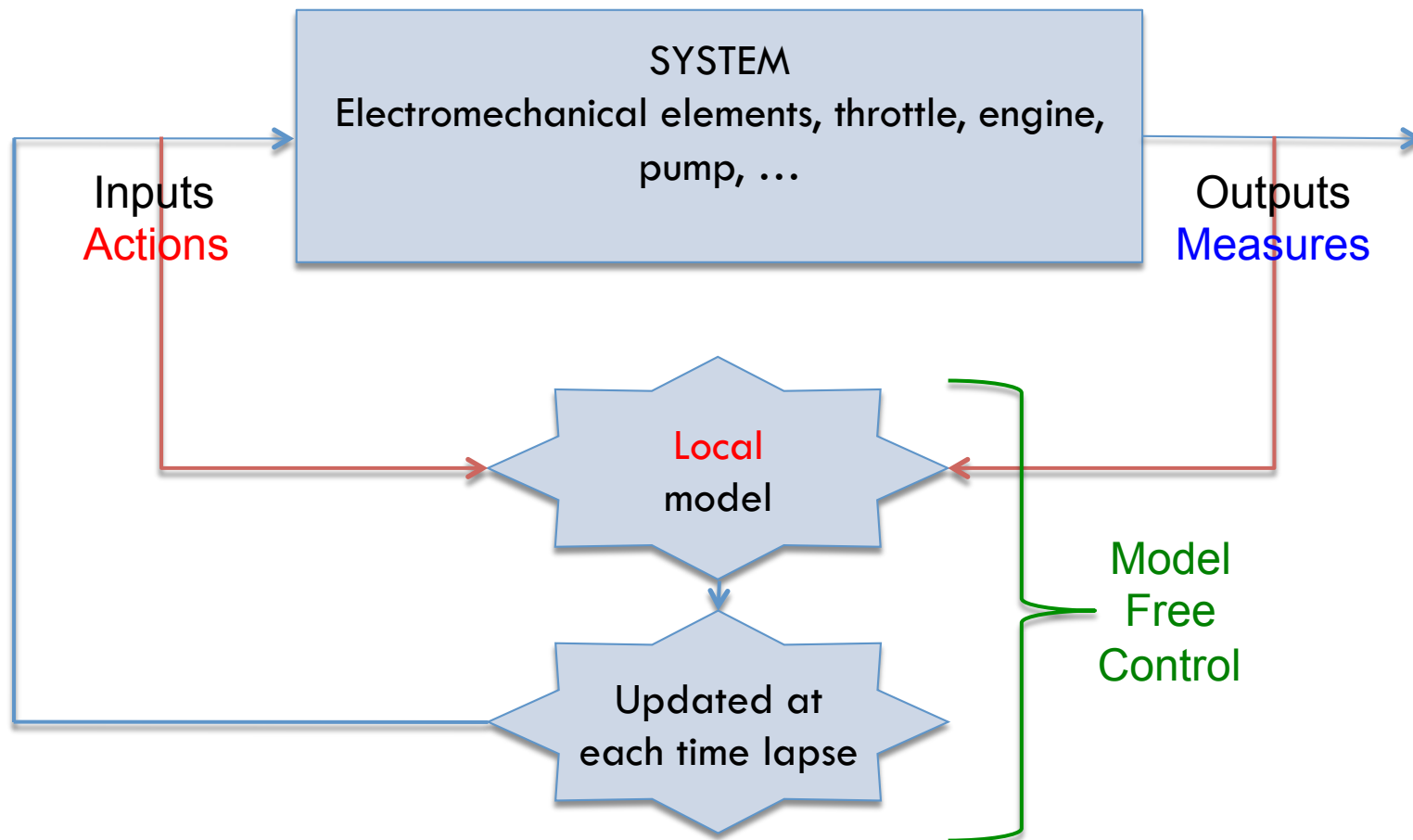
Model-free control

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How ?

Control law independent from usual **modelling**.



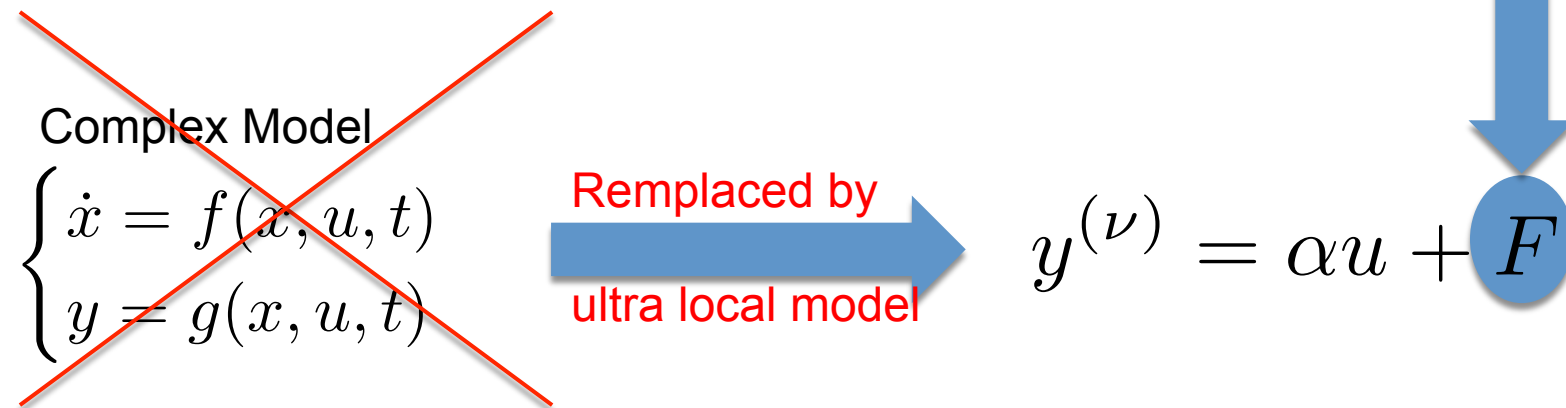
Model-free control

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How ?

Estimated and updated
at each time lapse



Ultra local model control based

$$u = \frac{1}{\alpha} \left(-F + y_*^{(\nu)} \right) + \text{Correction}(e)$$

Crucial point : estimation of F

For the example, consider the following ultra-local model

$$\dot{y} = F + \alpha u$$

a "well" approximation of is a piecewise constant approximation Φ ,

$$Y = \frac{\Phi}{s} + \alpha U + y(0) \quad \leftarrow \text{in operational domain}$$

$$Y + s \frac{dY}{ds} = -\frac{\Phi}{s^2} + \alpha \frac{dU}{ds} \quad \leftarrow \text{after } \frac{d}{ds}$$

$$F_{est}(t) = -\frac{6}{\tau^3} \int_{t-\tau}^t (\tau - 2\sigma) y(\sigma) + \alpha \sigma (\tau - \sigma) u(\sigma) d\sigma \quad \leftarrow \text{in time domain}$$

Model-free control

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MFC in general case

$$y^{(\nu)} = F + \alpha u$$

$$u = \frac{-F_{\text{est}} + y^{*(\nu)} + \mathfrak{F}(e)}{\alpha}$$

$$e = y^* - y$$

$$e^{(\nu)} + \mathfrak{F}(e) = 0$$

α is a non-physical constant parameter,
chosen by the practitioner such that αu and $y^{(\nu)}$ are of the same magnitude

ν is selected by the practitioner (until today = {1,2})

$$u = \frac{-F_{\text{est}} + \dot{y}^* + K_P e + K_I \int e}{\alpha} \quad \leftarrow iPI$$

$$u = - \frac{-F_{\text{est}} + \dot{y}^* + K_P e}{\alpha} \quad \leftarrow iP$$

In general, with Model-Free Control

performances increase

and

- development costs decrease
- maintenance costs decrease
- energetic costs decrease

MFC has already applied to

Academic concrete cases:

- greenhouse (Toulon University)
- vehicle control (Paris-Mines, LSS-Supélec, University of Madrid)
- shape memory alloy (Brest-ENIB)
- robotics (Lyon-INSa, Montpellier University, LSS-Supélec, IUT Tarbes, CEA France, University of Madrid, University of Poznan)
- dc/dc converters (FPGA) (Trois-Rivières University)
- ...

MFC has already applied to

Industrial concrete cases:

- PSA: control engine
- EdF: several hydropower plans
- DIR(s): traffic control
- CIAT
- Schneider
- Suez
- ALSTOM
- GE
- ...





Presentation by PSA engineers at a French Workshop

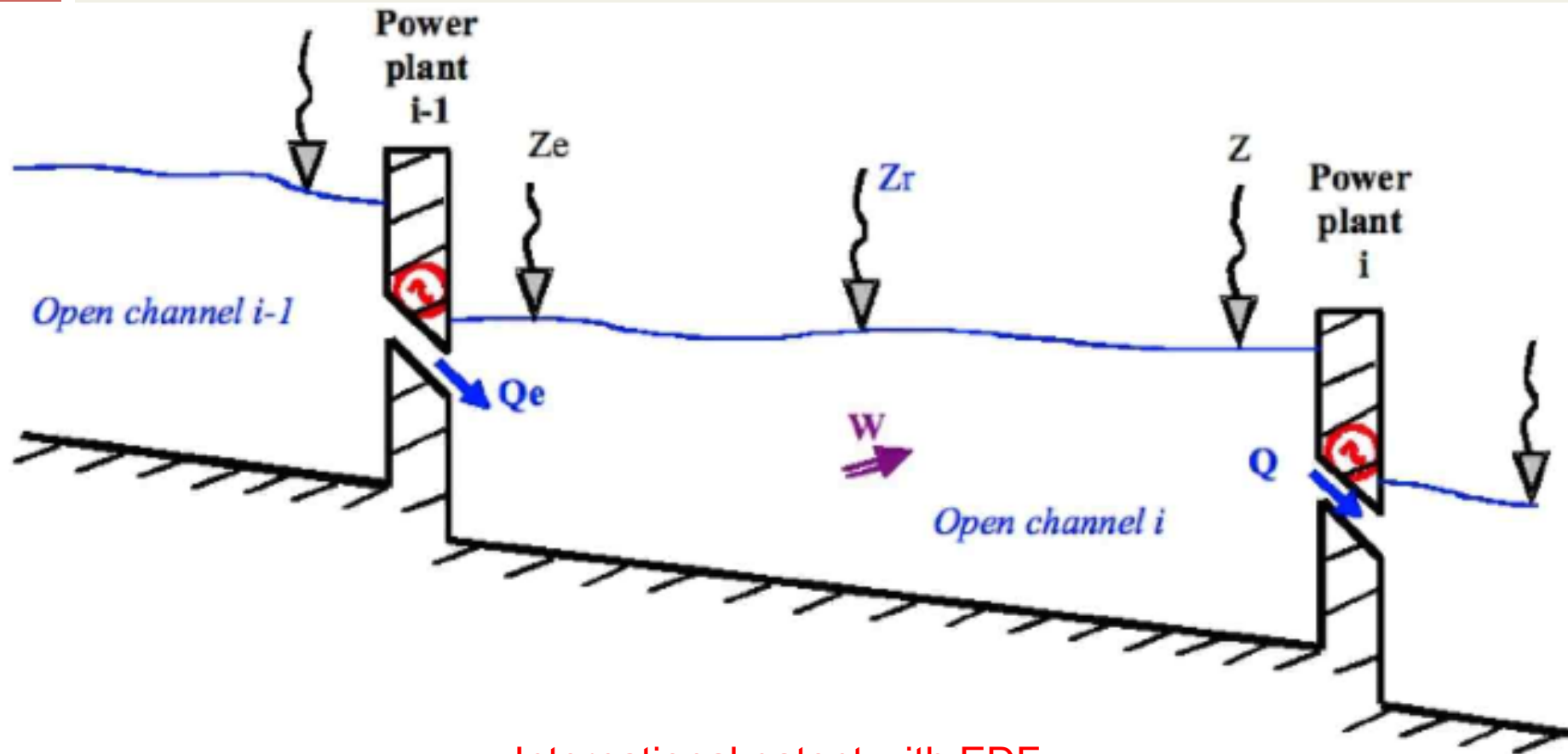
Conclusions

- **La commande sans modèle**
 - Technique particulière de calcul en temps réel des paramètres du régulateur
 - **sans connaissance à priori du modèle mathématique de l'actionneur**
 - Par l'utilisation de **méthodes de dérivées numériques**
 - Permet de se libérer de l'identification des paramètres
 - Permet de découpler la solution de contrôle des performances de l'actionneur
- **Les premiers résultats avec essais moteur sont prometteurs. Elle permet un gain de performance et de temps de mise en œuvre considérable.**

Examples

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EDF



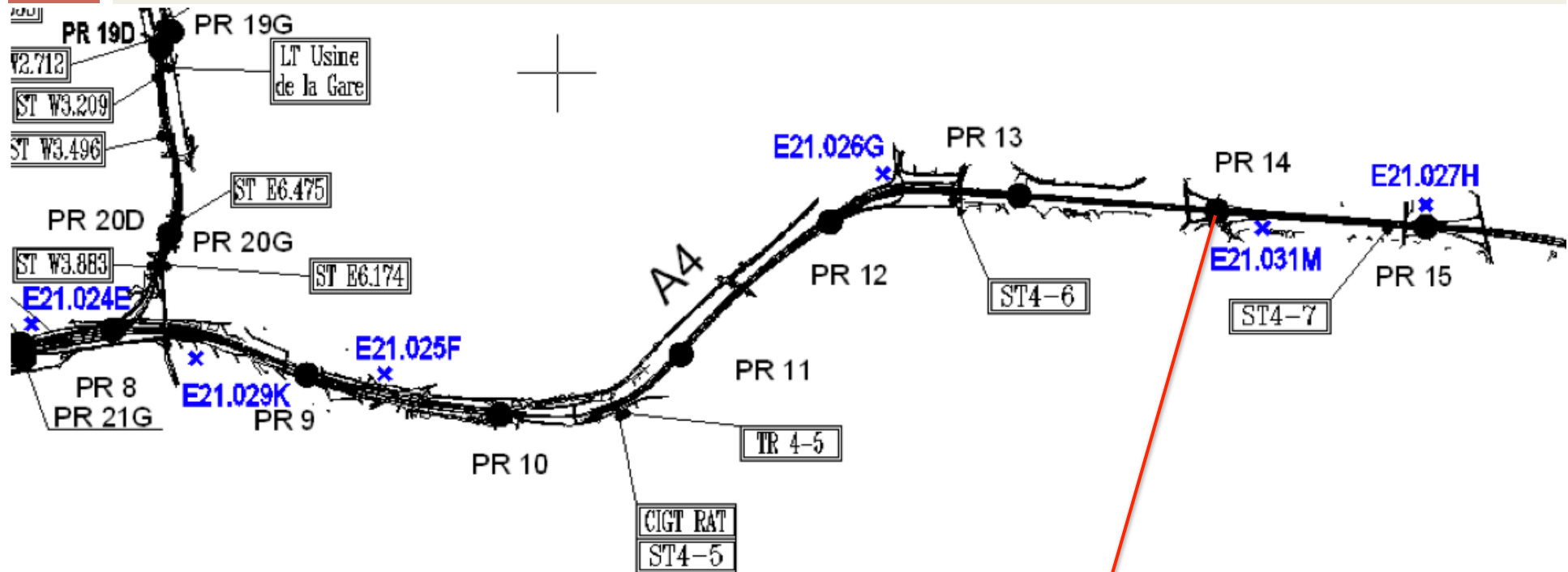
International patent with EDF

Innovation price of Ecole Polytechnique 2010

Examples

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DIRN, DIRIF



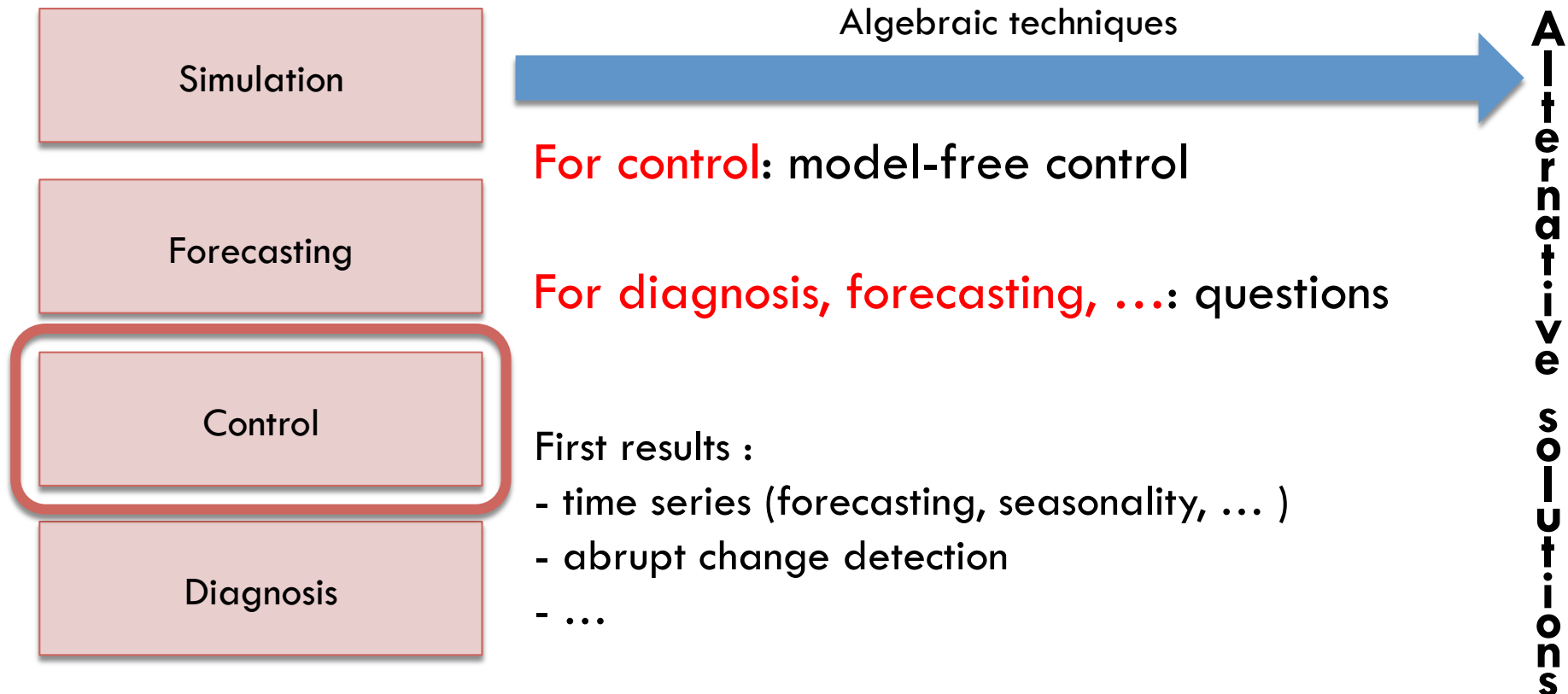
International patent

With large improvement
compared to usual
methods.



To conclude

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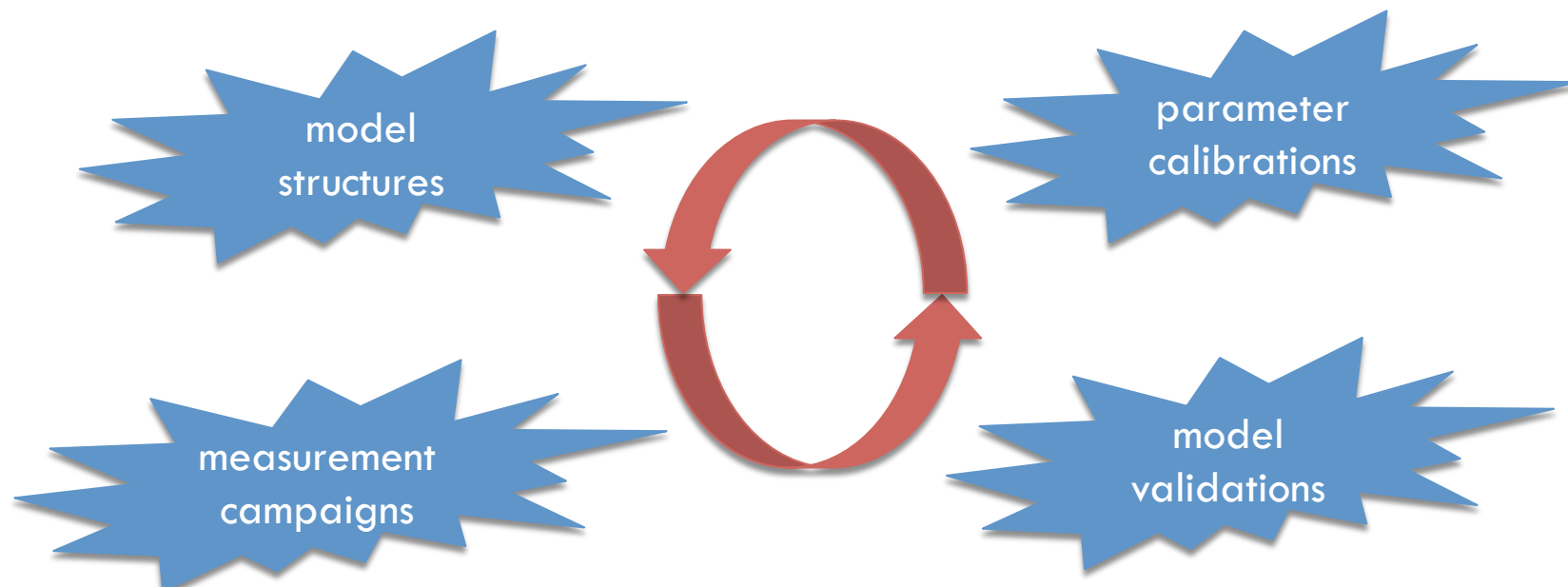
To conclude

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Epistemological break

Simulations: more complicated than control ?

Concrete example: traffic road



Thank you for your attention