Data-based Modelling for Control and Optimization

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Delft Center for Systems and Control

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Contents

- Introduction: from data to model to control
- Identification for control: 1990-2004
- Some general viewpoints
- Acievements and challenges

Models from data

- Substantial part of effort towards efficient operation of technical processes is in modelling.
- Models from physics and information from data: ultimate validation on the basis of measurements
- Validation of models is directly related towards their intended use

Good model for one purpose can be poor for another!

Models from data

- What to include in the models and what not?

  Question equally valid for physical and data-driven models

- From an identification perspective:

  How to identify models that are suited for control design?

- From a control design perspective:

  Which plant information is required for control design, and how to obtain this information from experiments?

"Here is a dynamical process with which you are allowed to experiment (preferably cheap).

Design and implement a high-performance control system".

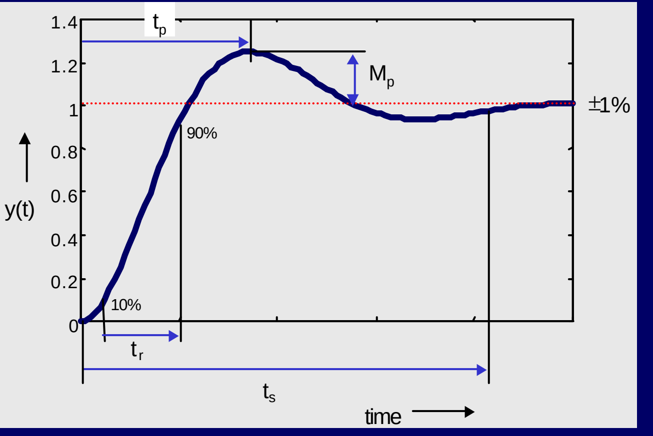
Issues involved:

- Experiment design
- Modelling / identification
- Characterization of disturbances and uncertainties
- Choice of performance measure
- Control design and implementation

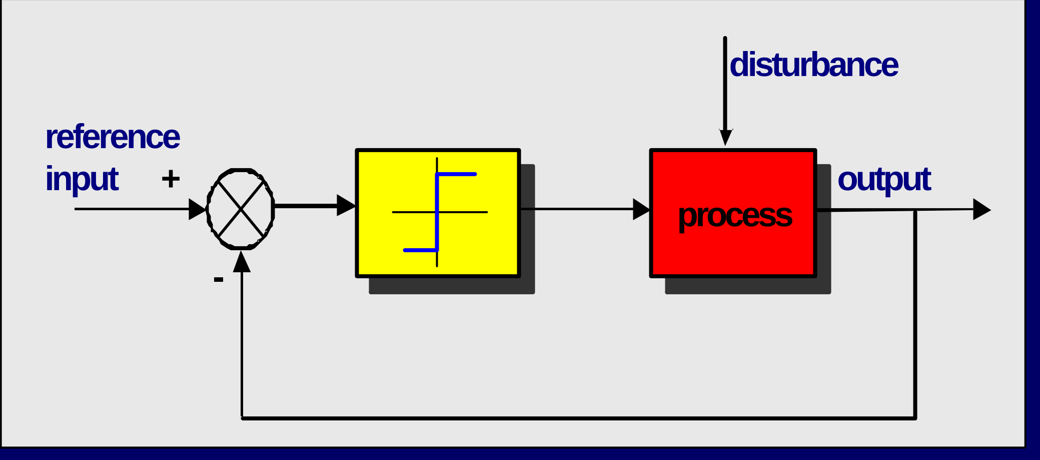
experimental issues dependent on application area

Classical experiments for finding control-relevant dynamics

- Ziegler/Nichols tuning rules
  for PID-controllers



- Relay feedback: amplitude and frequency at -180° phase



- Ad-hoc simple cases to be extended to general methodology for model-based control, including issues of robustness induced by model uncertainties

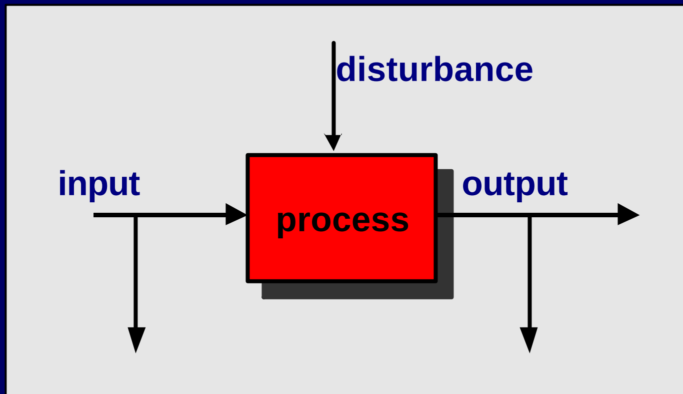
Identification for Control: 1990-2004

- Basic principles for identifying models, well sorted out
- Relation with control through
  Certainty equivalence principle:
  “Controller based on exact model is suited for implementation on the plant”

However:

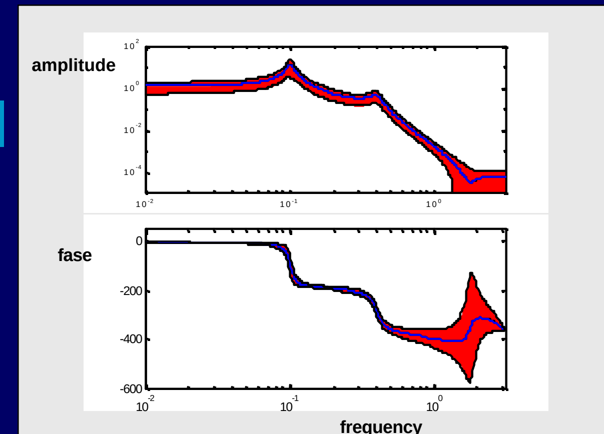
- Identification had been extended to identify *approximate models*
- Control design had been evolved to *robust control* taking account of model uncertainties

Experiments:



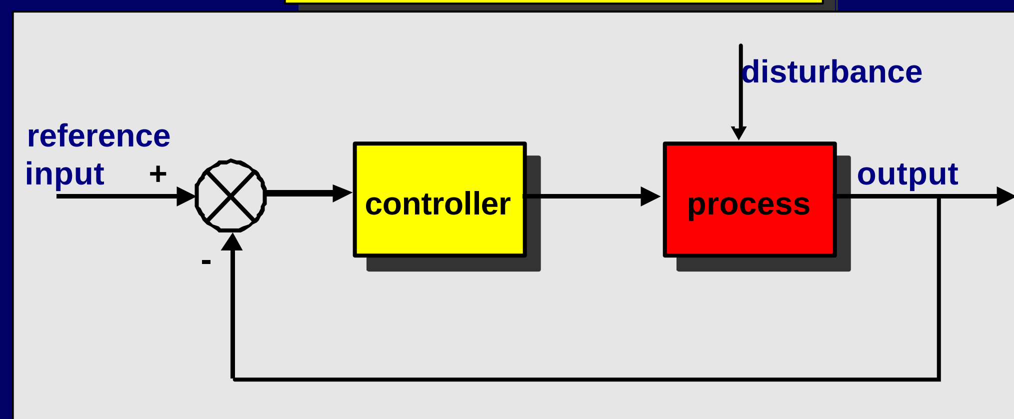
Identification

Data → Model



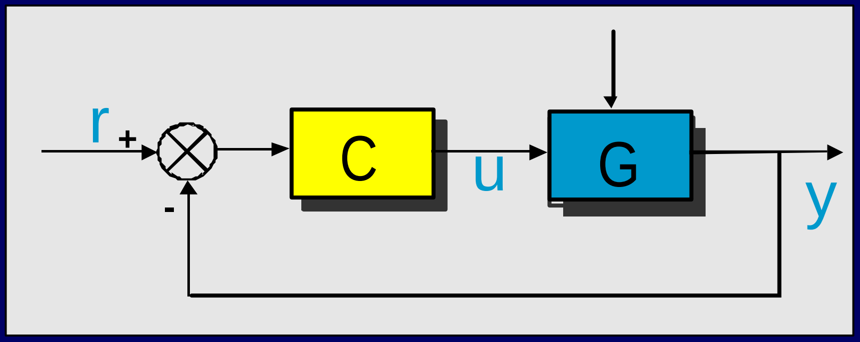
Feedback control system

Model → Controller

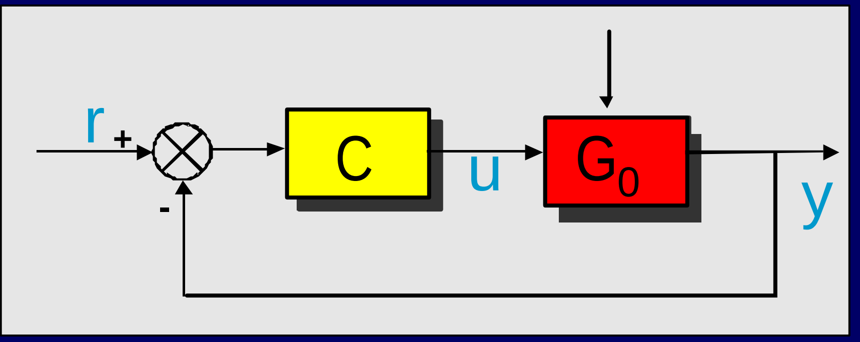


When is a model suitable for control?

For a given controller C:



Designed loop



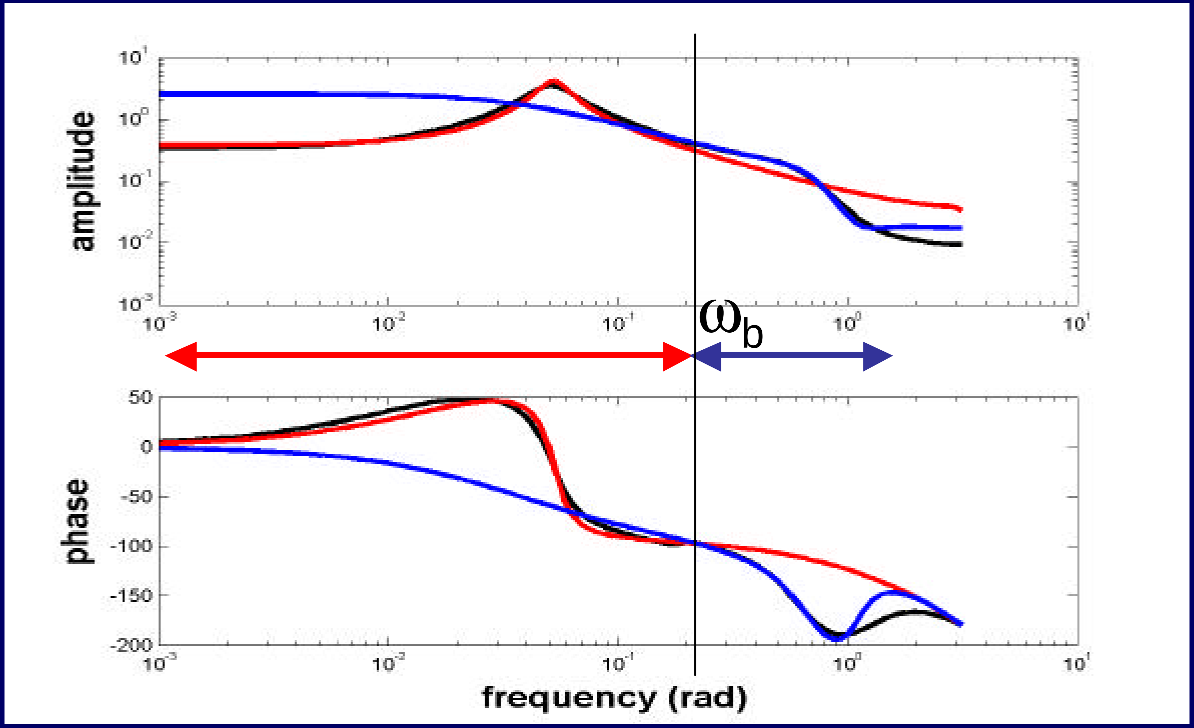
Achieved loop

Both loops should be “close”:

$$\frac{CG_0}{1+CG_0} - \frac{C\hat{G}}{1+C\hat{G}}$$ should be small

Can be achieved by closed-loop identification with C

When is a model suitable for control?



plant
model1: accurate for $\omega < \omega_b$
model2: accurate for $\omega > \omega_b$

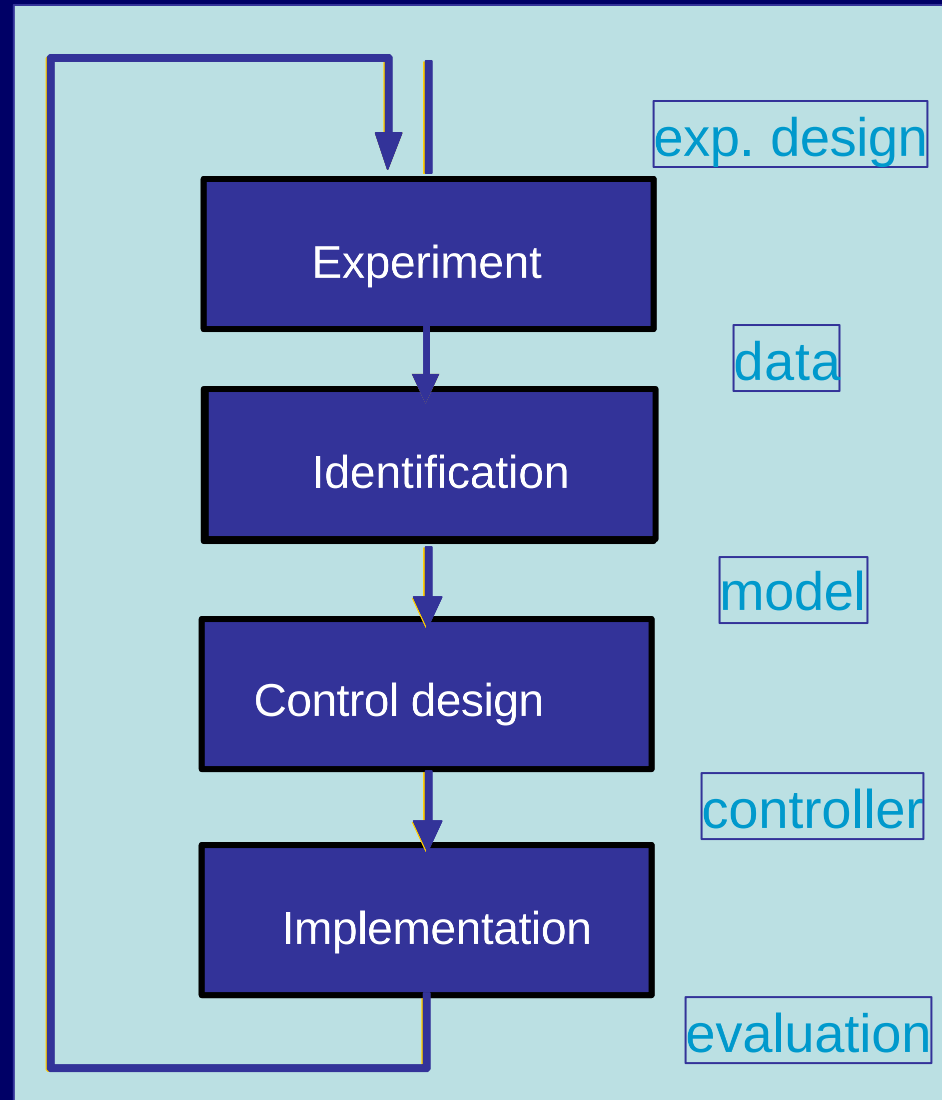
Model quality becomes dependent on control bandwidth (to be designed)

Control bandwidth
is based on model + ..

If models are uncertain/approximate due to limited experiment, achievable performance needs to be discovered

! modelling for control

is learning
(Schrama, 1992; Gevers, 1993)



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Development trend:

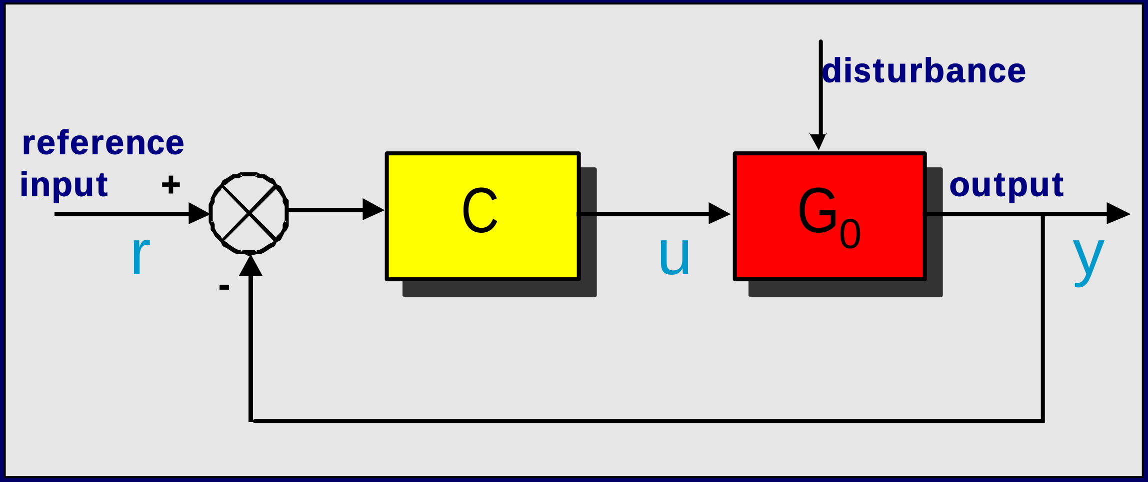
Modelling	Control
• control-relevant nominal model	• nominal control
• nominal model + uncertainty bound	• nominal control + stab/perf robustness
• control-relevant model uncertainty set	• robust control; worst-case performance optimization
• design of “cheap” experiments for id of uncertainty sets	• control under performance guarantees

- Development of methods in which the model is even removed:
  Iterative Feedback Tuning (Hjalmarsson, 2002)

- Application of methods to
  - Positioning control in waferstepper, CD-player
  - Control loops in industrial processes (Solvay)
  - Sugar mills (Australia), EDF

Some general viewpoints

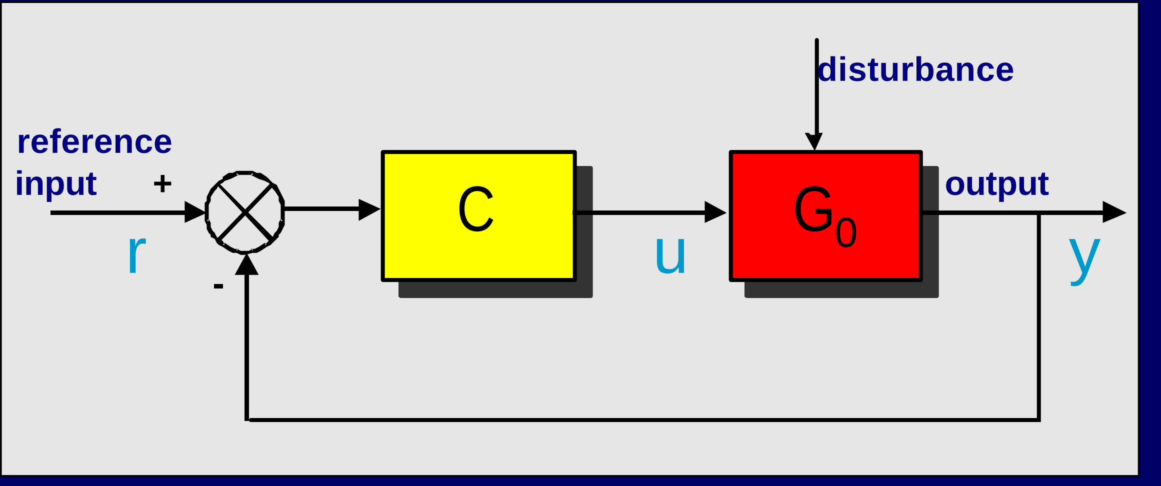
Closed-loop identification



From problematic situation to easily applicable identification tools on the basis of r, u and y

direct / two-stage / coprime factor / indirect – dual-Youla / IV *(Van den Hof, 1998; Forssell & Ljung, 1999)*

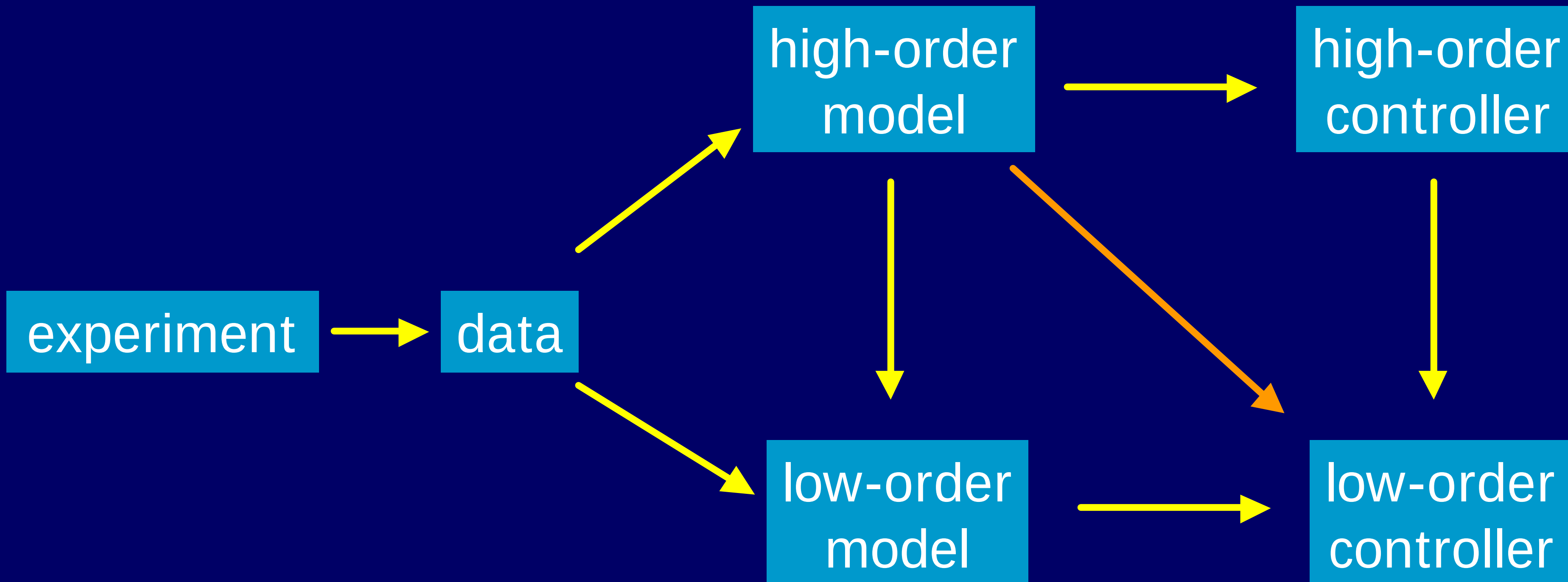
Closed-loop identification



Advantage: loop signals u and y are shaped with sensitivity function $S = 1/(1+CG_0)$:

Identification of models, such that $\frac{CG_0}{1+CG_0} - \frac{C\hat{G}}{1+C\hat{G}}$ is small: models relevant for C.

From experiment to control



Current opinion:

- Extract all information from data, but
- Keep experiments simple

Achievements

- Insight into the structural relation between model construction and control
- Tools for closed-loop identification and uncertainty bound quantification
- Robustness analysis/synthesis tools for identified uncertainty models
- Iterative schemes for modelling and control tuning, renewing “classical” adaptive control

Challenges ahead

- Design of cheap experiments:
  - least disturbing,
  - satisfying process constraints
  - minimum length,

  providing sufficient information for performance improvement

  Problem: “all” theory is asymptotic in N

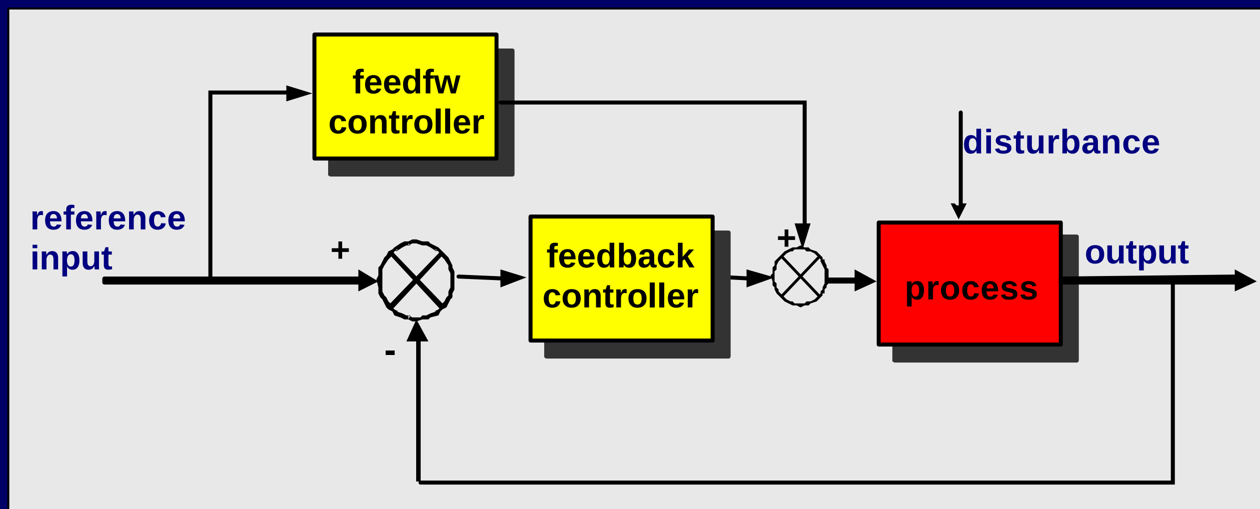
  Requirement:

  Integration of experiment / modelling / control

Most important for process control applications

Challenges ahead

- From feedback control only, to constrained optimization:



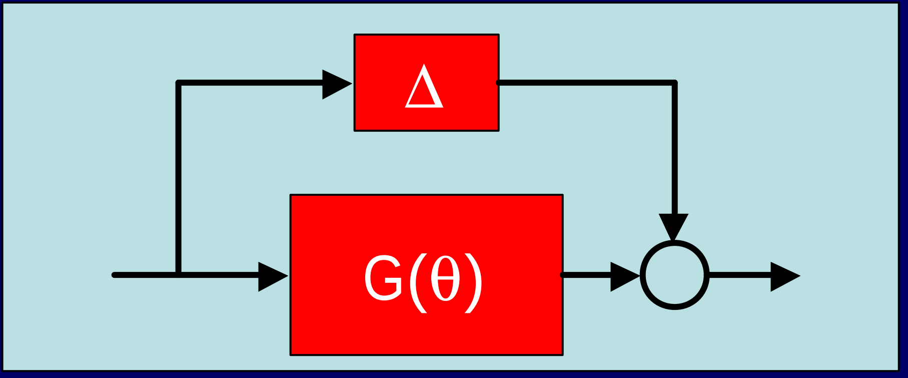
on the basis of:

- process model
- disturbance characterization

} + uncertainties

Challenges ahead

- Exploiting physical knowledge in the models:
  - Combining physical process models with data-based disturbance models
  - Parameter estimation in non-complete physical models



Consequences for estimated θ under presence of some bounded Δ

Joint work with:

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