System Identification in a Real World

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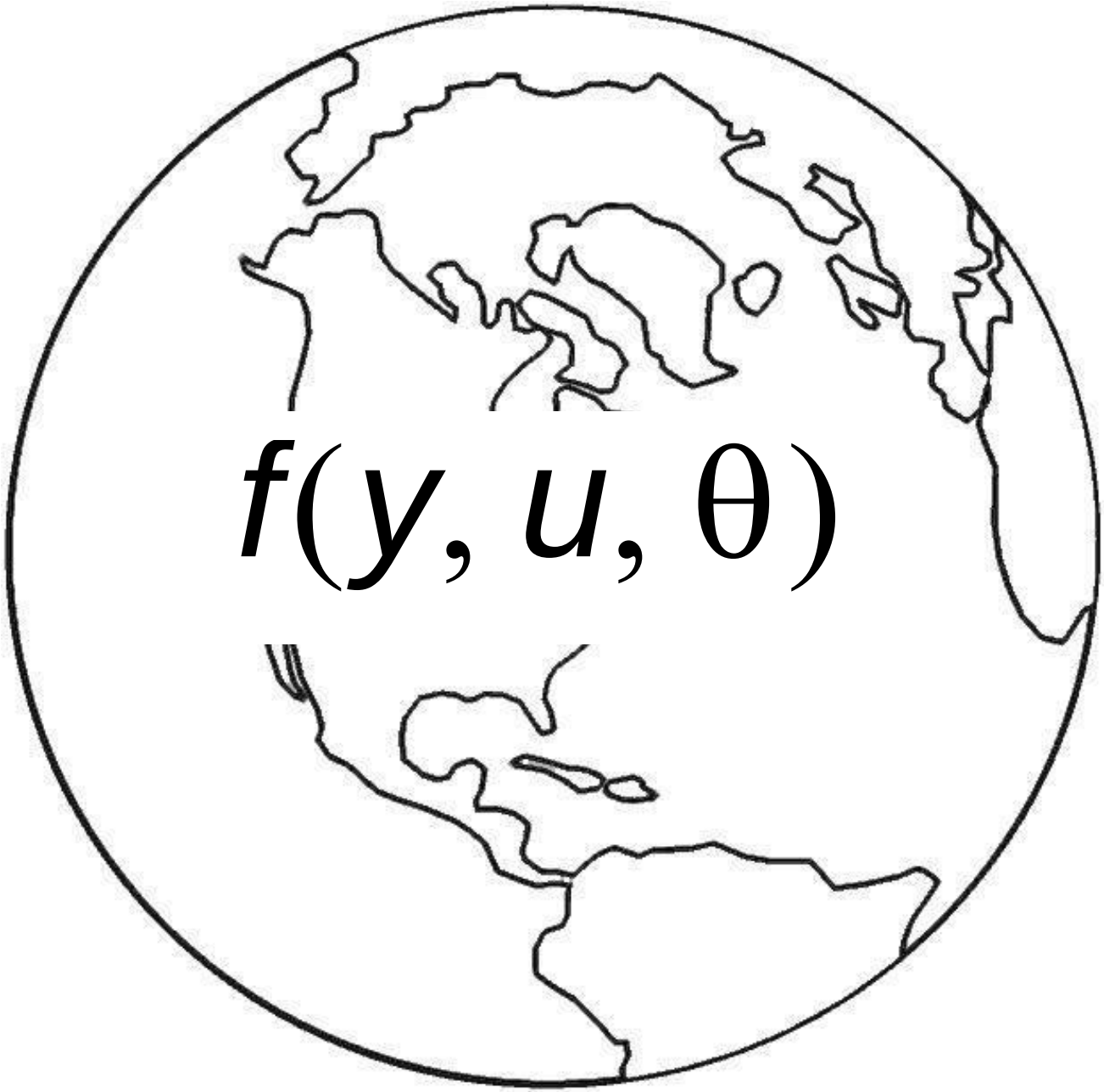
European Research Council




$f(y, u, \theta)$

System Identification

Data u, y

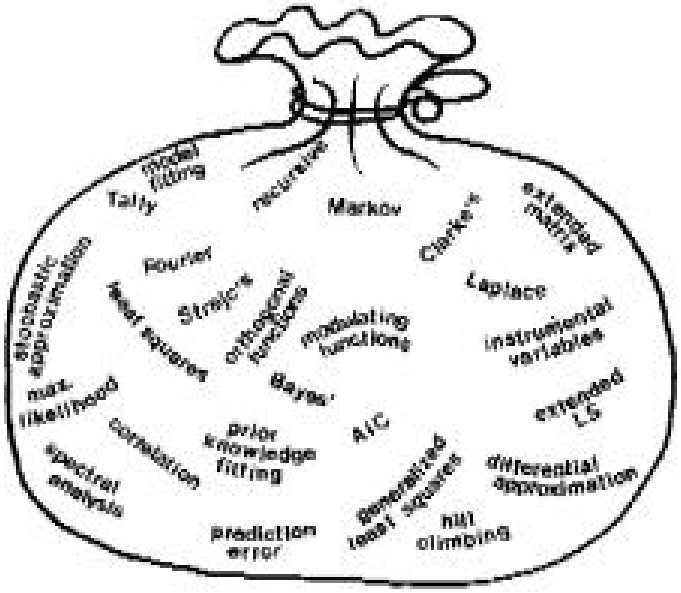


$V(u, y, \theta)$

$M(\theta)$

Linear SI

- Sixtees: a bag of tricks



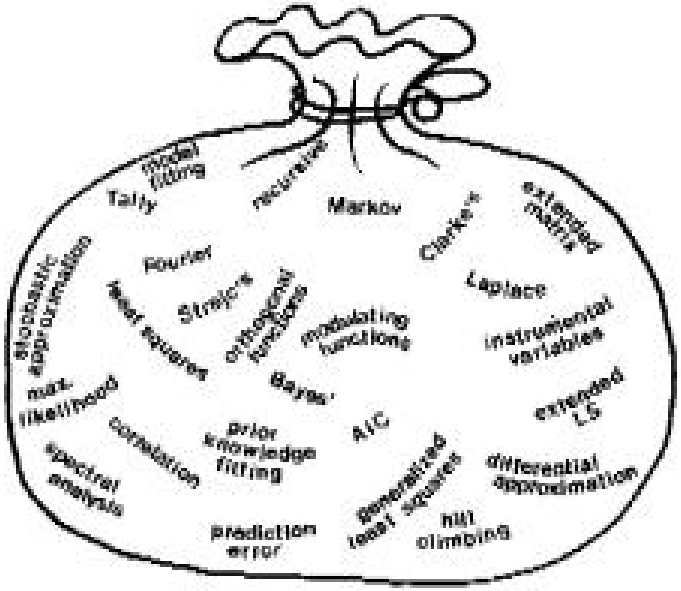


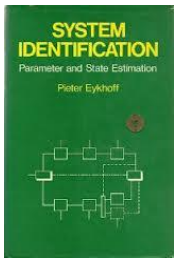
- stochastic problems
- numerical optimization
- numerical conditioning
- convergence issues
- plant model
- noise model
- excitation signals

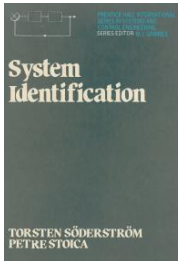
Linear SI

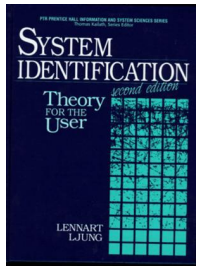
- Structured in the 70’

- Mature in the 80’







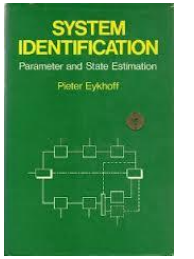


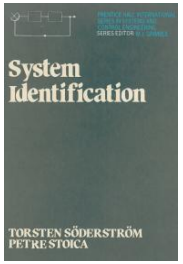


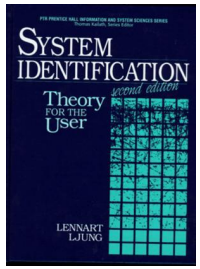
Linear SI

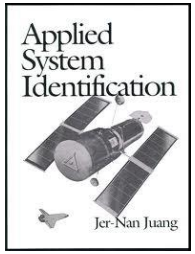
- new ideas in the 90’

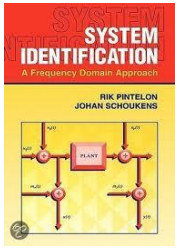


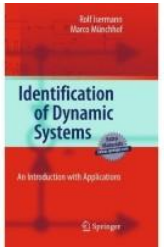




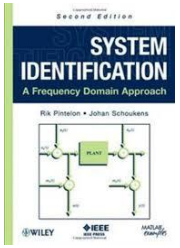


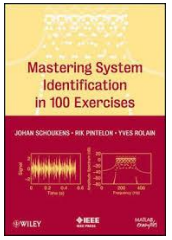












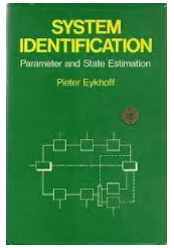
Linear SI







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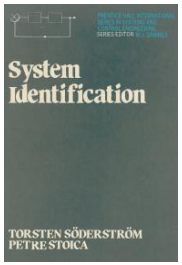
Parameter and State Estimation
Pieter Eykhoff

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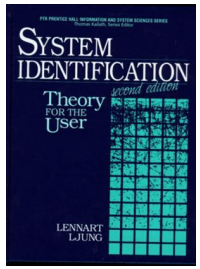
TORSTEN SÖDERSTRÖM
PETRE STOICA

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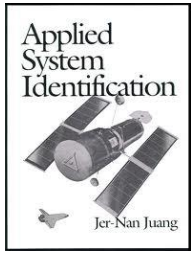
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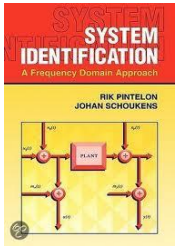
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RIK PINTELON
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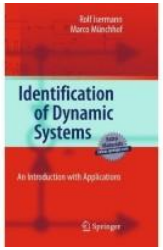
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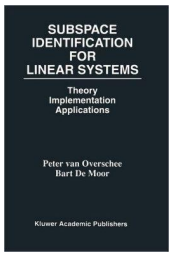
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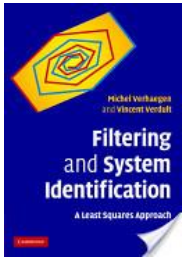
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and Vincent Verdult
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and System
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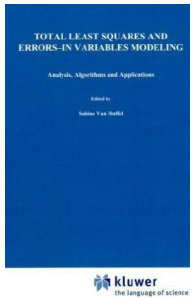
A Least Squares Approach

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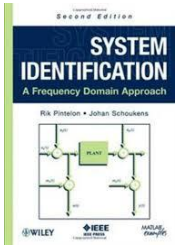
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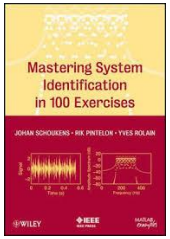
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Linear SI

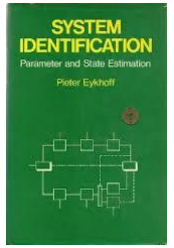
- mature field
- well developed tools
- cheap

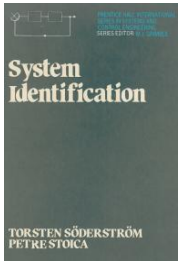


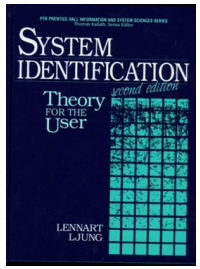


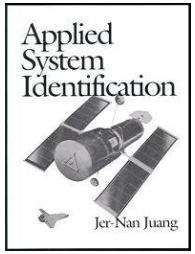


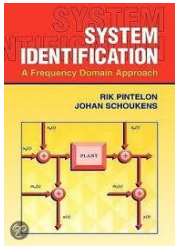


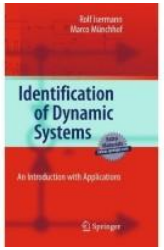


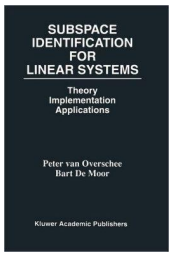


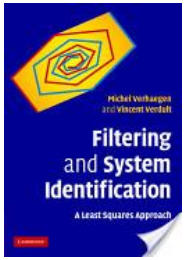


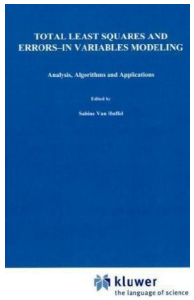




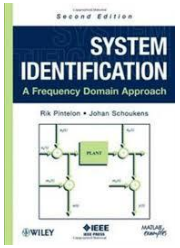


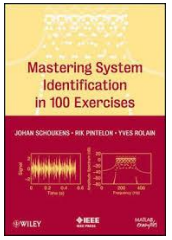












Problem solved? Mission accomplished?



System Identification in the real world

Linear



Nonlinear

Time-Varying

Linear SI versus Nonlinear SI

Linear SI

- mature field
- well developed tools
- inexpensive

Nonlinear SI

- hot research topic
- expensive

Linear SI versus Nonlinear SI

Linear SI

- mature field
- well developed tools
- inexpensive

Nonlinear SI

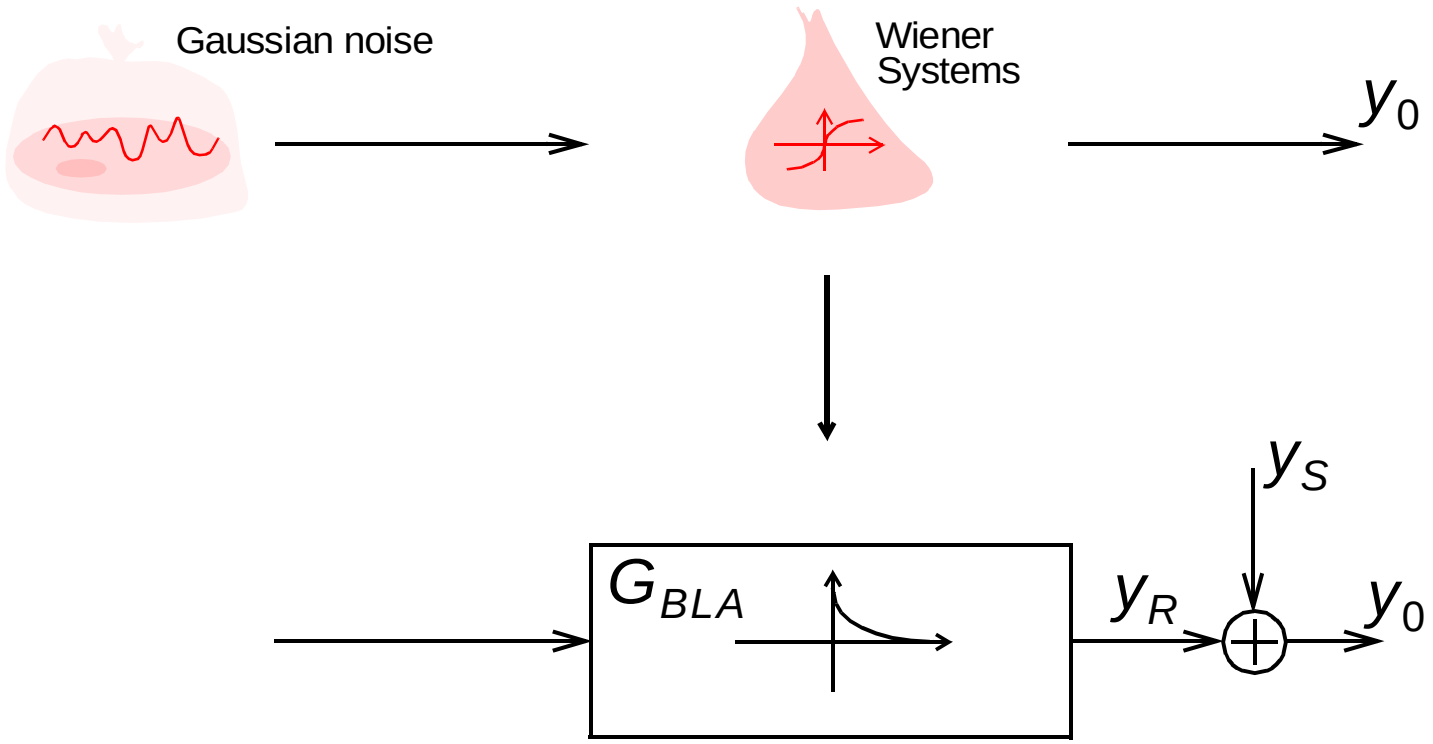
- hot research topic
- expensive

Tools needed

- detection, qualification, quantification NL
- decide: linear or nonlinear SI

Linear SI in a nonlinear setting

A new paradigm



$$Y(k) = G_{BLA}(j\omega_k)U(k) + Y_S(k)$$

Best Linear Approximation

time domain

$$g_{BLA} = \arg\min_{g} E_u\{|y - g*u|^2\}$$

frequency domain

$$G_{BLA} = \arg\min_{G} E_U\{|Y - GU|^2\}$$

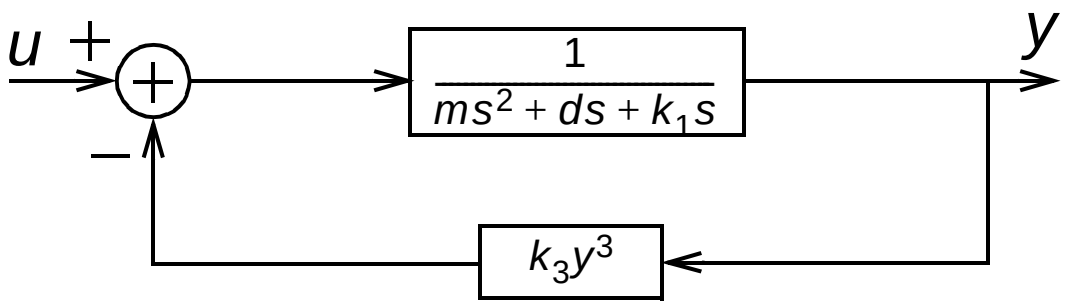
Best Linear Approximation : Nonparametric measurement

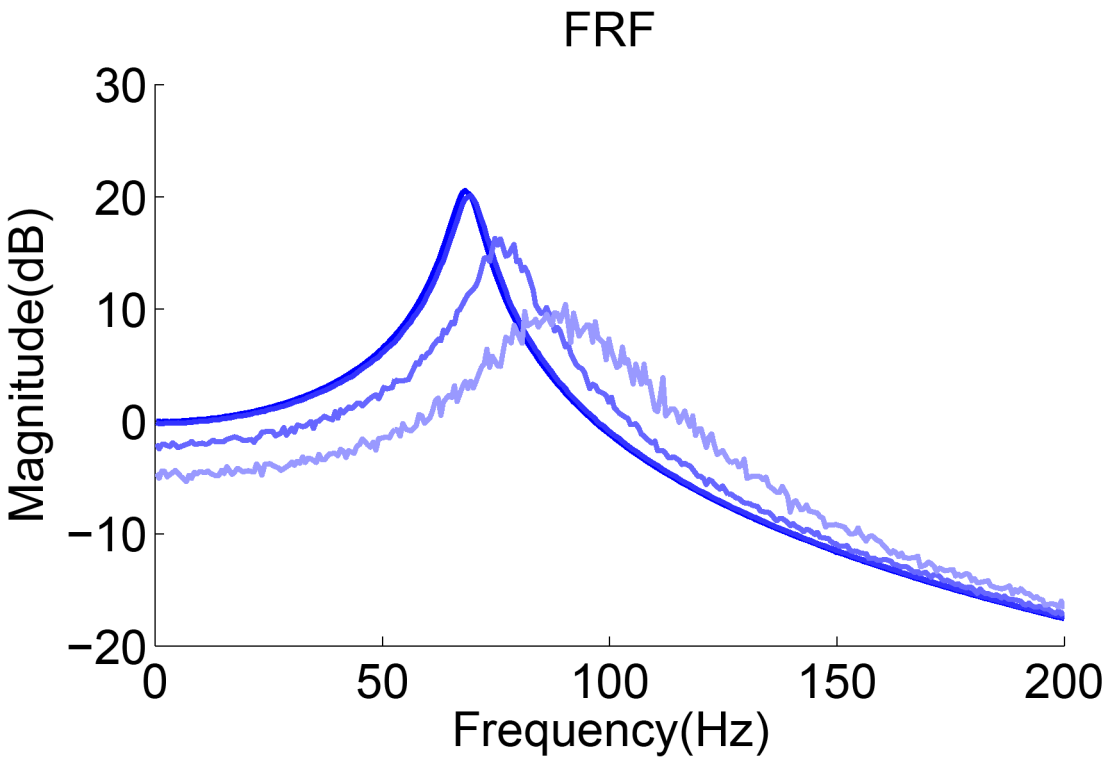
The classic linear equations still hold

$$G(\omega) = \frac{S_{YU}(\omega)}{S_{UU}(\omega)}$$

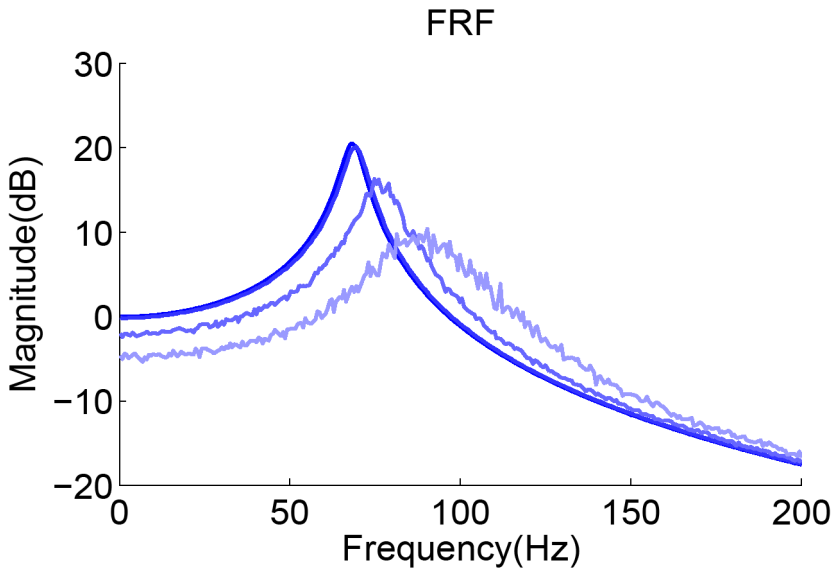
$$\sigma_G^2(\omega) = |G(\omega)| \frac{1 - \gamma^2(\omega)}{\gamma^2(\omega)}$$

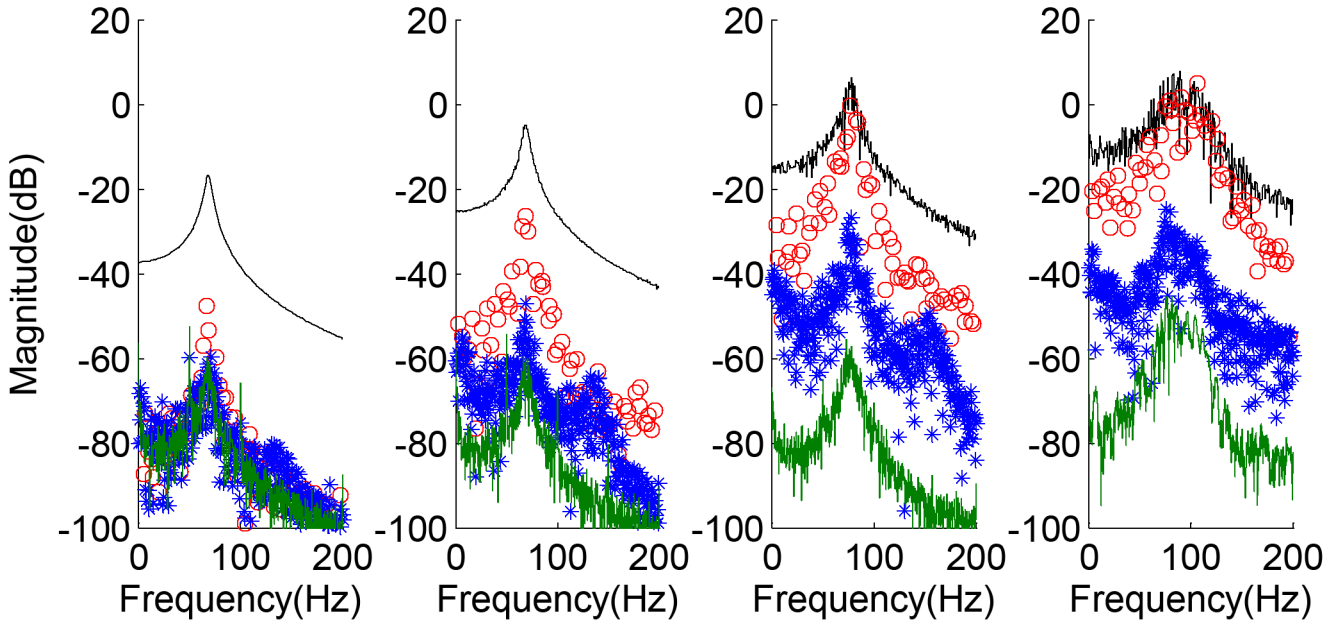
Silverbox example





Detection, qualification, quantification of nonlinear distortions



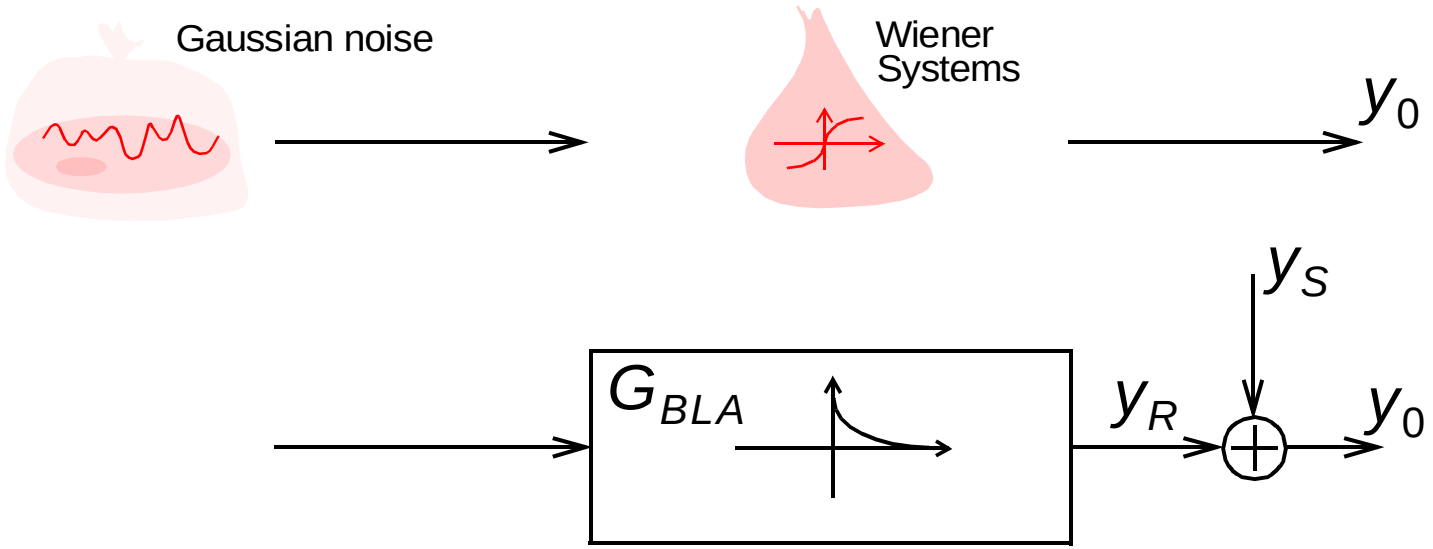


odd NL

even NL

noise

Best Linear Approximation : Parametric modelling



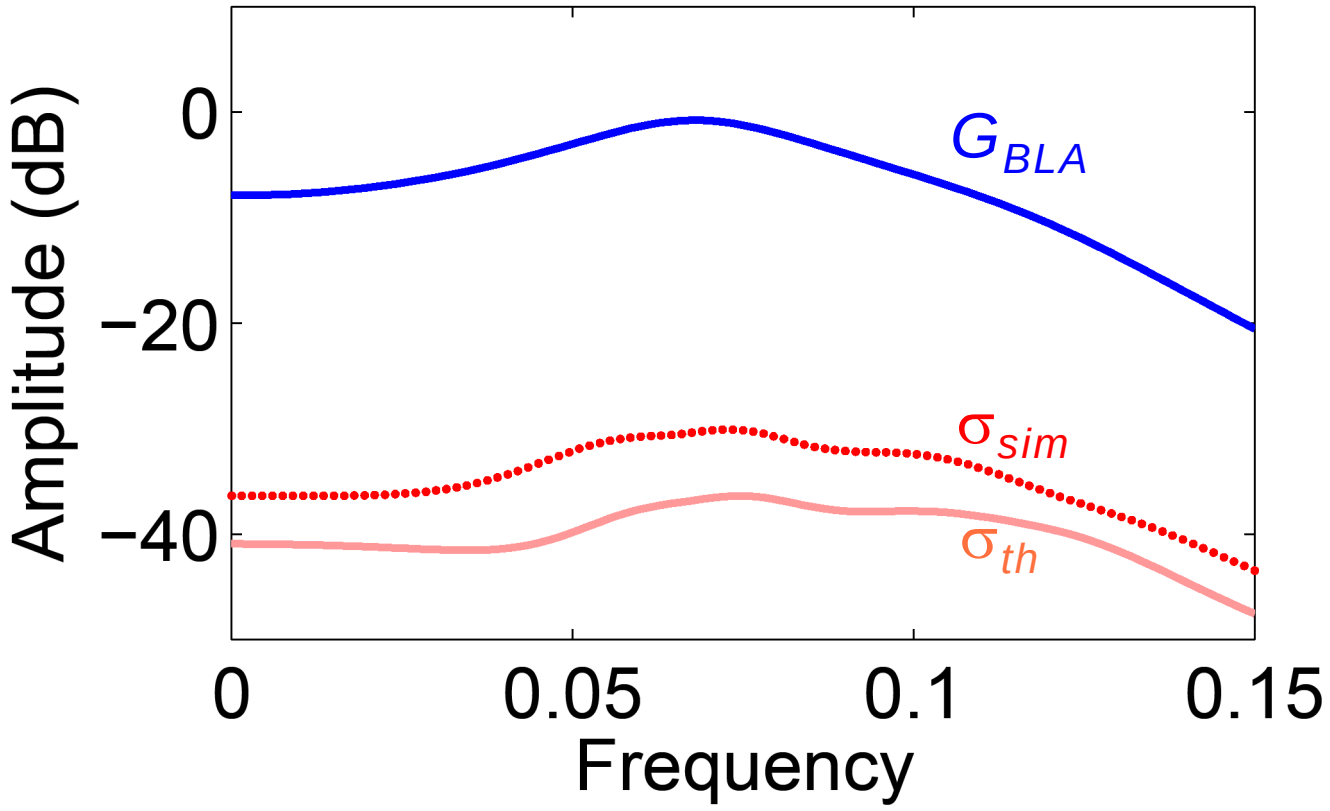
$$Y(k) = G_{BLA}(j\omega_k)U(k) + Y_S(k)$$

Linear parametric identification methods

- Consistent estimate
- Uncertainty bounds are wrong

Best Linear Approximation: Parametric modelling





Nonlinear system identification

Data



Cost

Model

Data

Good excitations?

Cost

Noise on input/output: too difficult $\rightarrow$ Output error framework

Model

Nonlinear model: a bunch of numbers?

Nonlinear models - User desires

A model should be more than a bunch of parameters

Flexible: cover a wide range of nonlinear systems

Multiple Input - Multiple Output

Reliable

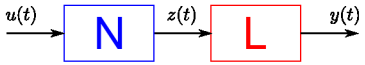
Provides intuitive insight in system behaviour

Nonlinear Models

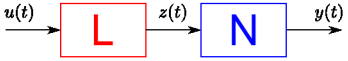
unstructured

$$x_+ = Ax + Bu + F(x,u)$$
$$y = Cx + Du + G(x,u)$$

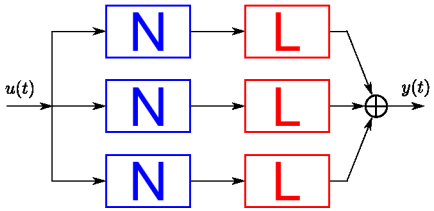
structured



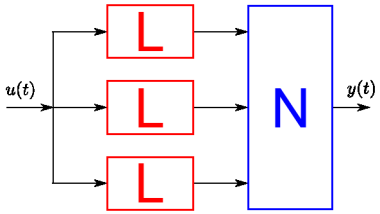
(a) Hammerstein



(b) Wiener



(c) Parallel Hammerstein



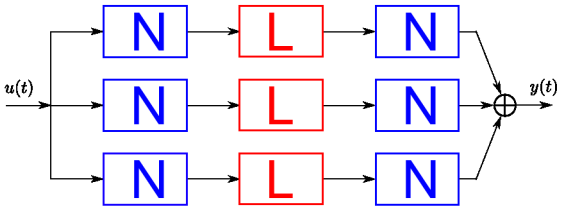
(d) Parallel Wiener



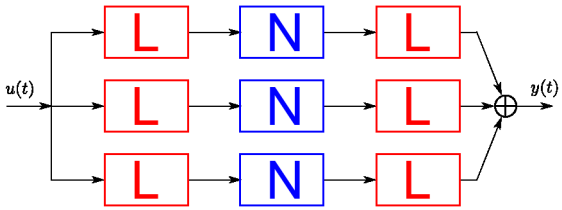
(e) Hammerstein-Wiener



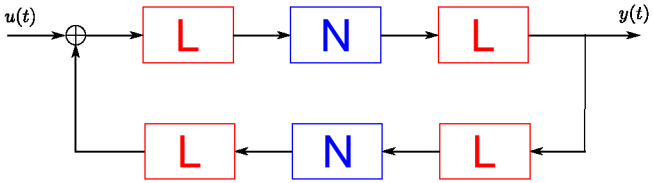
(f) Wiener-Hammerstein



(g) Parallel Hammerstein-Wiener



(h) Parallel Wiener-Hammerstein



(i) Feedback

Nonlinear Models

unstructured

$$x_+ = Ax + Bu + F(x,u)$$
$$y = Cx + Du + G(x,u)$$

Machine learning

System identification

Nonlinear Models

unstructured

$$x_+ = Ax + Bu + F(x,u)$$
$$y = Cx + Du + G(x,u)$$

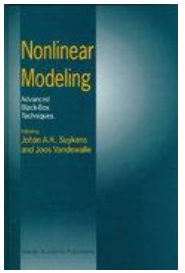
Machine learning

System identification





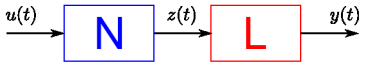




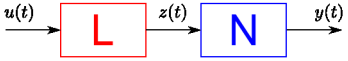
Nonlinear Models

structured

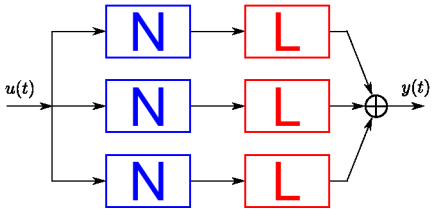
Initialization?



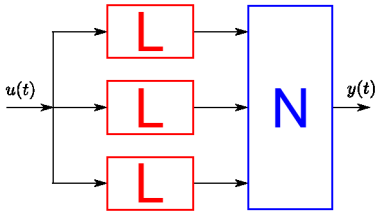
(a) Hammerstein



(b) Wiener



(c) Parallel Hammerstein



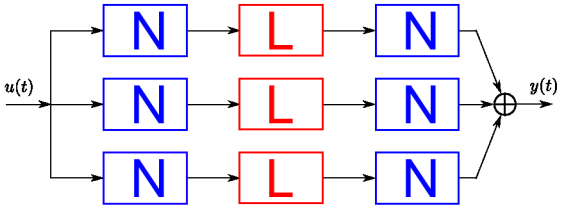
(d) Parallel Wiener



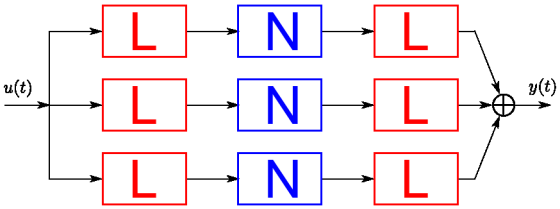
(e) Hammerstein-Wiener



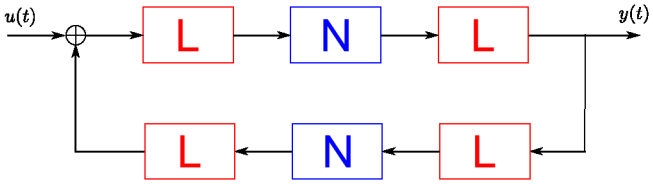
(f) Wiener-Hammerstein



(g) Parallel Hammerstein-Wiener



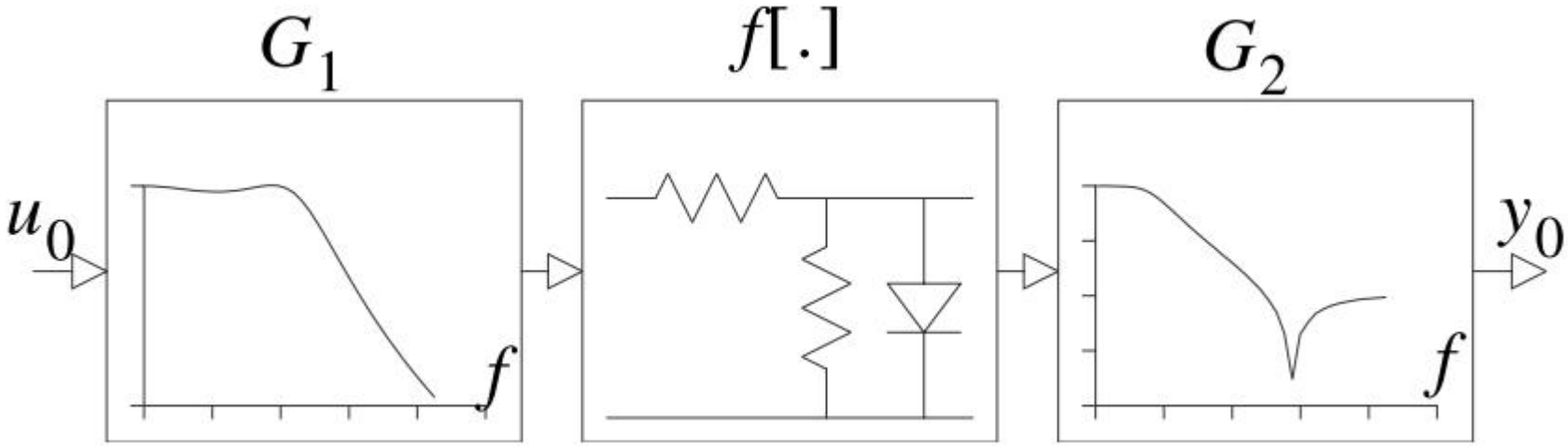
(h) Parallel Wiener-Hammerstein



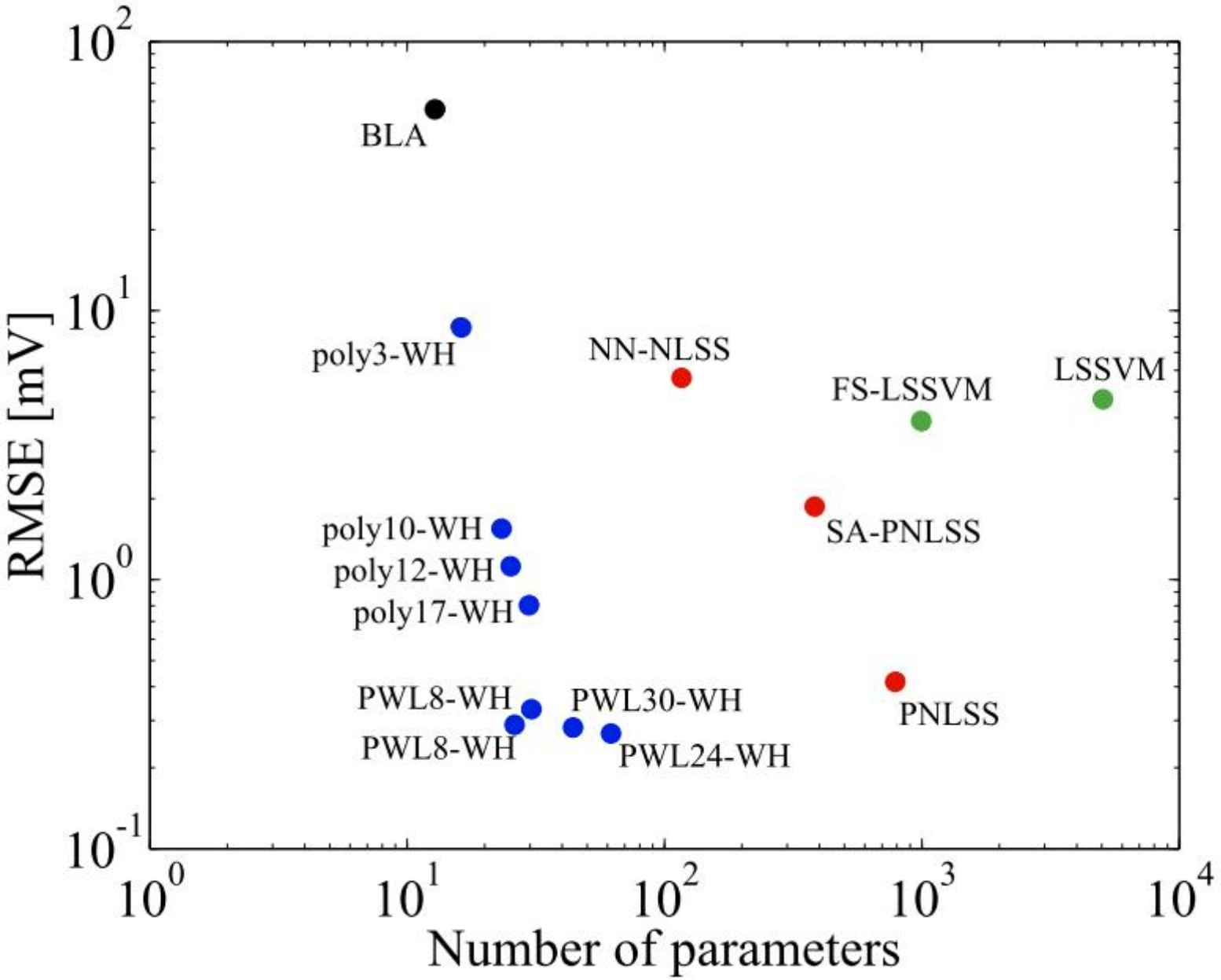
(i) Feedback

Wiener-Hammerstein benchmark

http://tc.ifac-control.org/1/1/Data%20Repository/sysid-2009-wiener-hammerstein-benchmark



Wiener-Hammerstein benchmark



Conclusions

Linear SI powerful and mature tool

Real world is nonlinear and time varying

Decide in an early phase about the needed complexity

We are looking for young and enthusiastic researchers

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Joos????







