Advanced Control Systems Detection, Estimation, and Filtering

Graduate Course on the MEng PhD Program Spring 2012/2013

Chapter 1
Motivation

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Summary:

- Motivation for estimation, detection, filtering, and identification in stochastic signal processing

- Methodologies on how to design optimal estimation algorithms

- Characterization of estimators and tools to study their performance

- To provide an overview in all principal estimation approaches and the rationale for choosing a particular technique

Both for parameter and state estimation,

always on the presence of stochastic disturbances

In RADAR (Radio Detection and Ranging), SONAR(sound navigation and ranging), speech, image, sensor networks, geo-physical sciences,…

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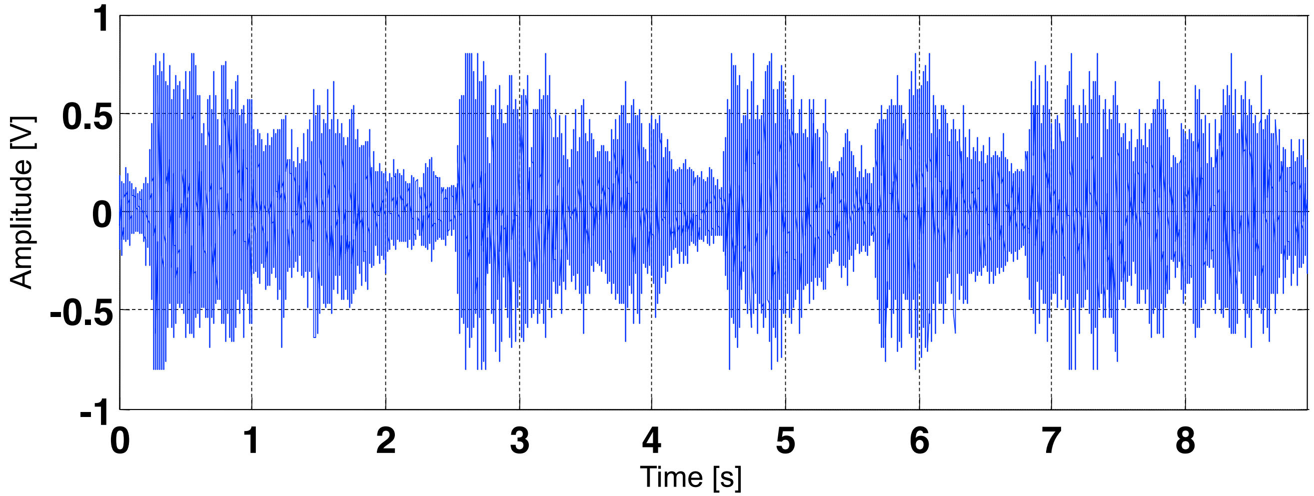
Speech



Signals can be represented by functions (continuous time) or by vectors (where a sampling operation takes place)

Examples of speech/sound processing:

Automatic systems commanded by voice;

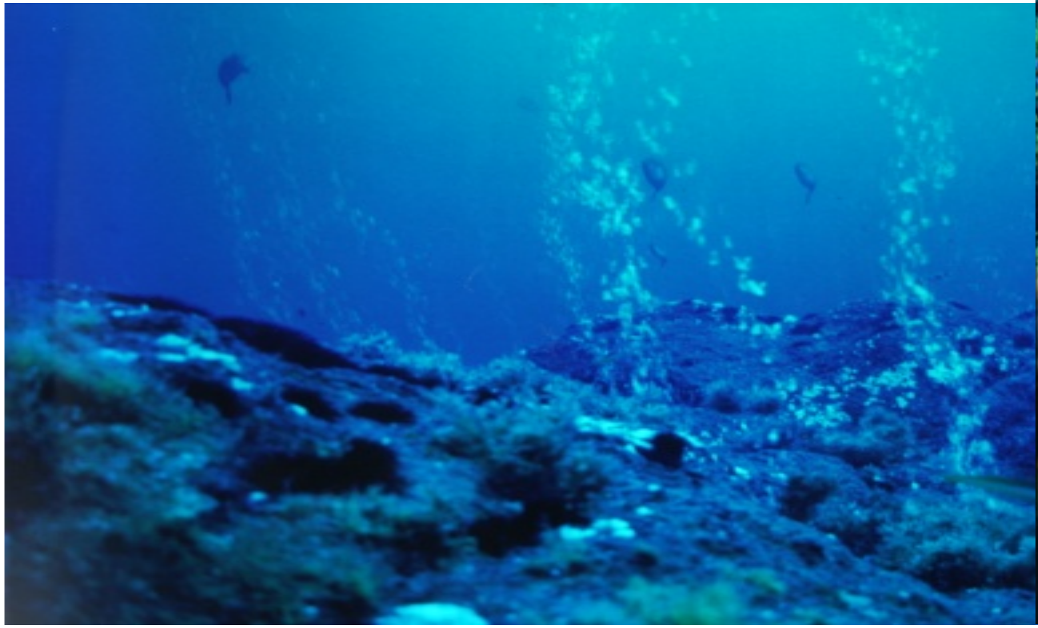
Automatic translation; Voice recognition

Synthesis of voice

Echograms

The quest for hydrothermal vents

D. João de Castro bank



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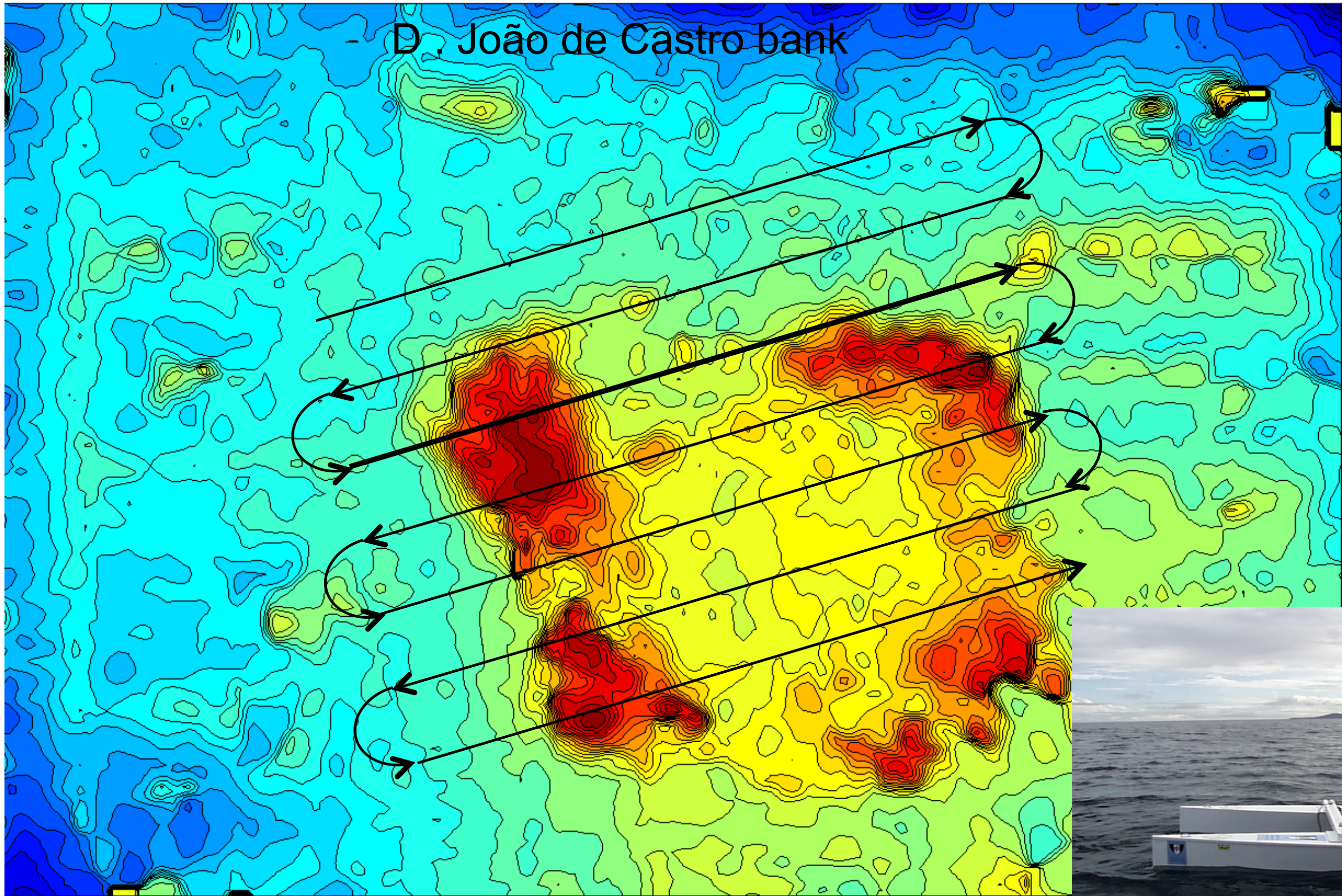
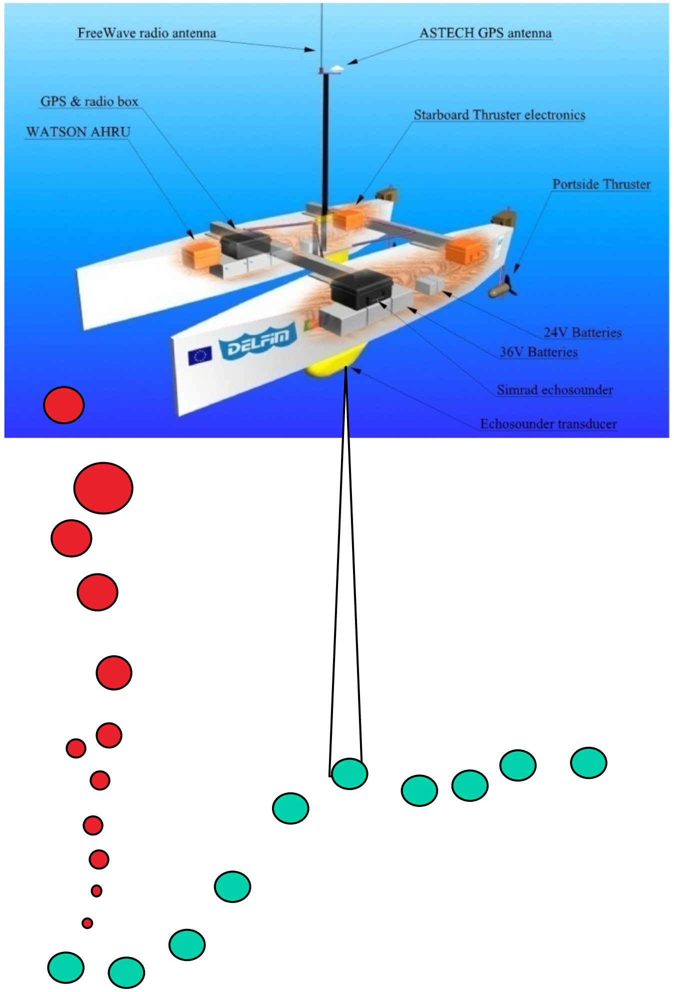
Echograms

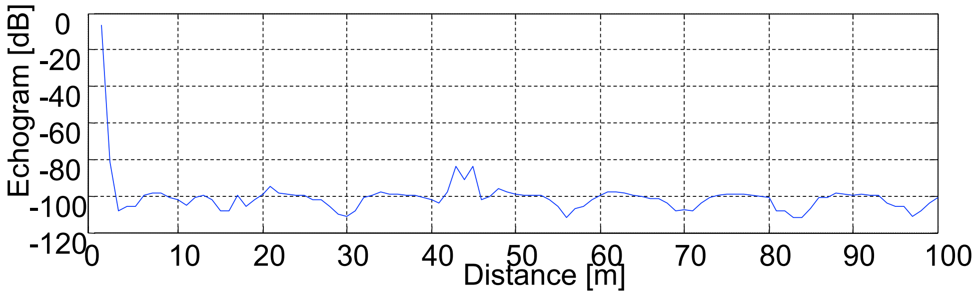
The quest for hydrothermal vents (cont.)

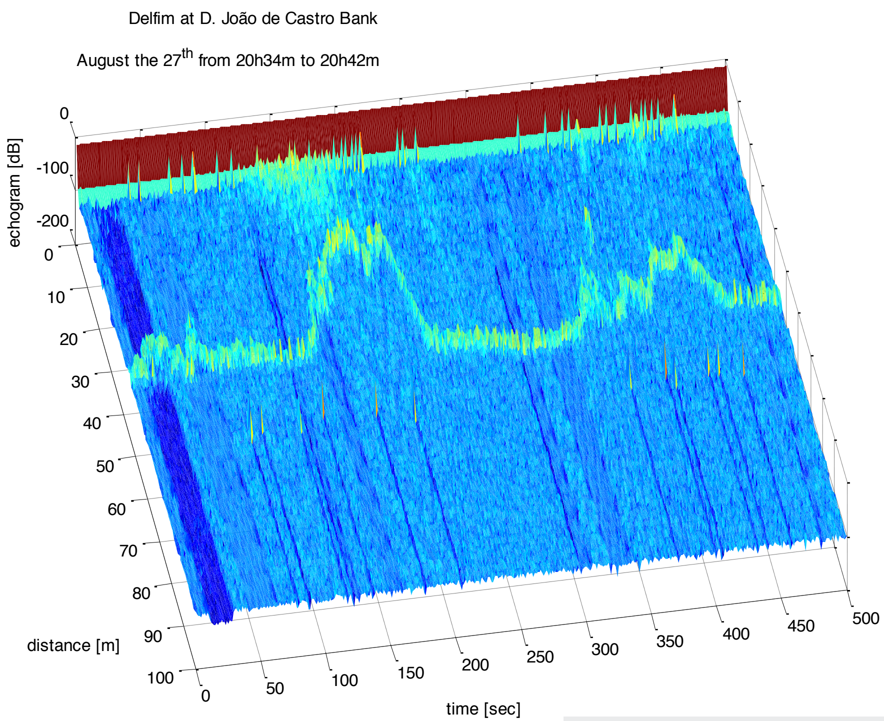


Echograms

The quest for hydrothermal vents (cont.)







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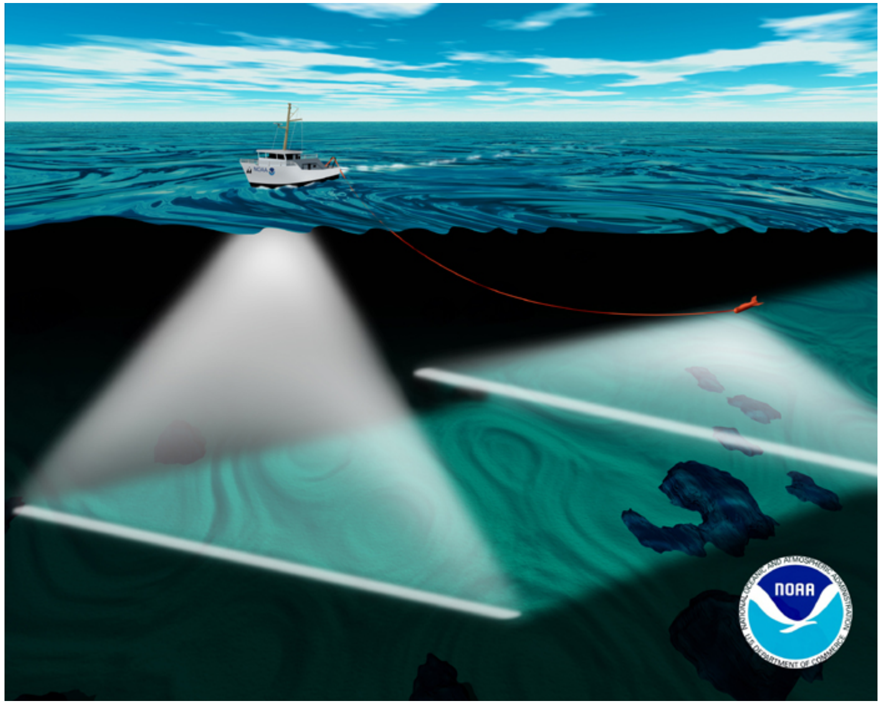
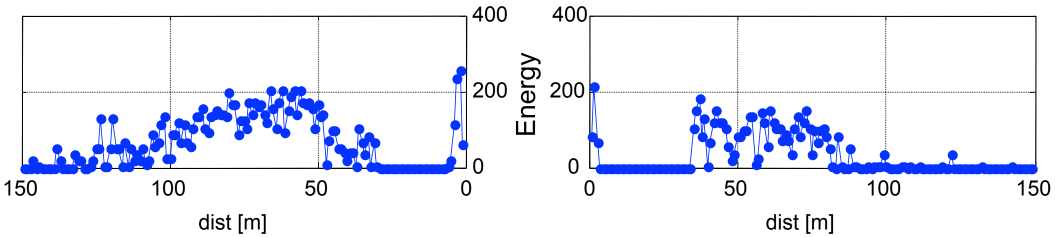
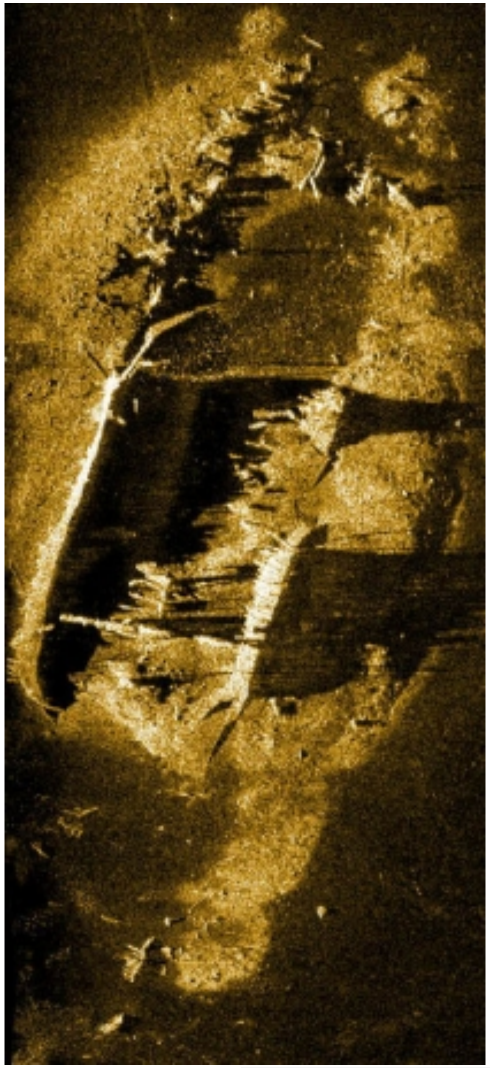
Sidescan Sonar Imaging







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GPS – Global Positioning System

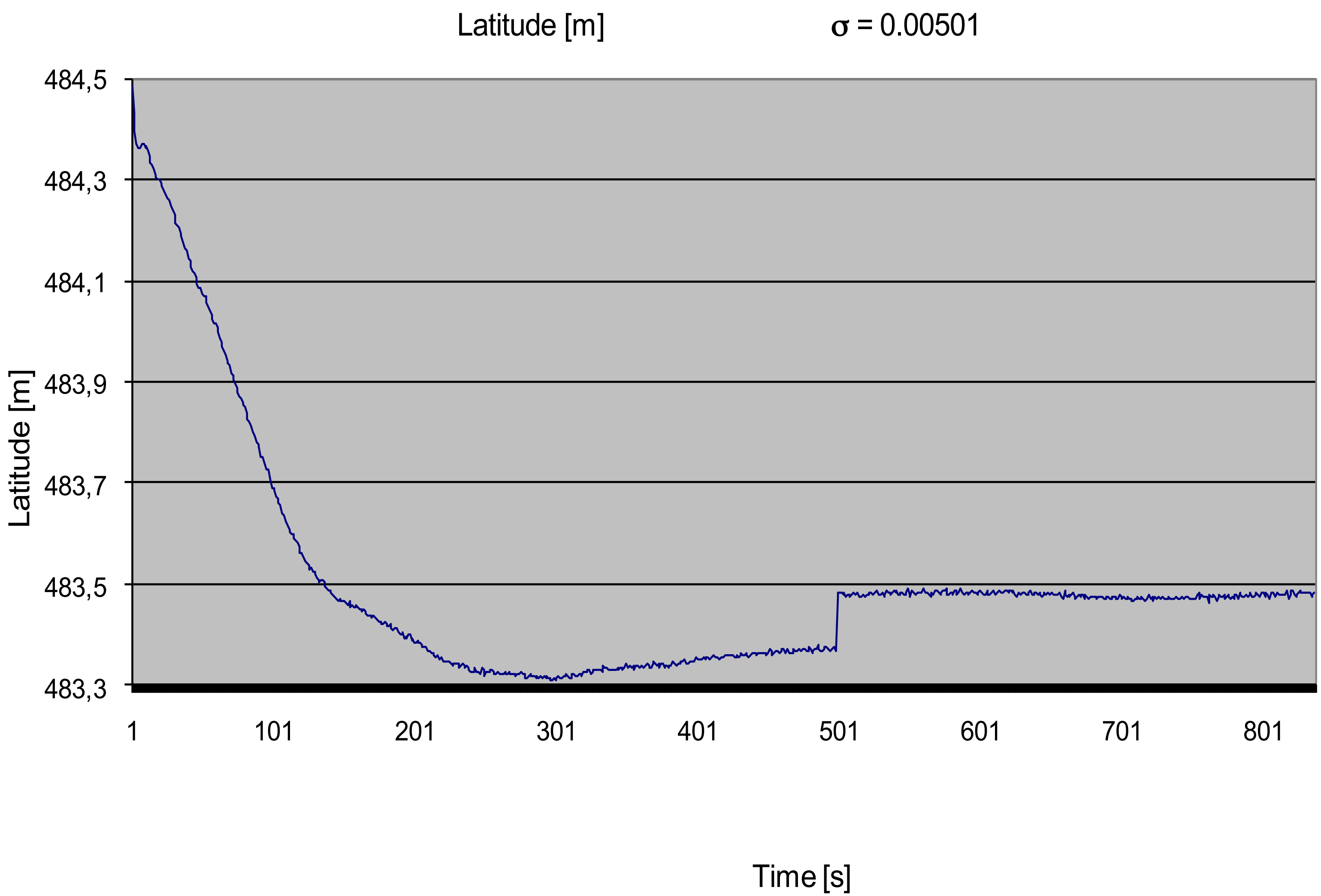
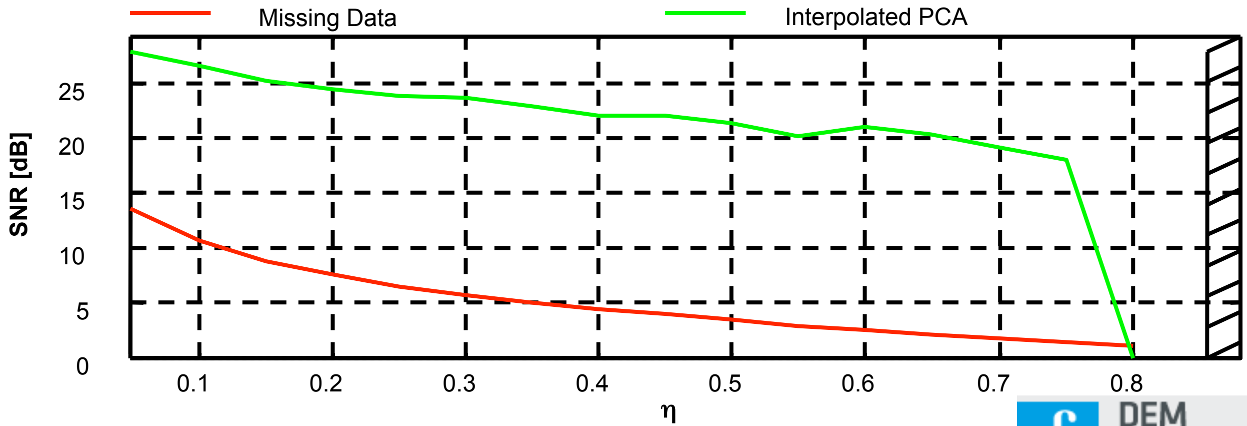


Image with missing data

Reconstruction

η=0.1 η=0.2 η=0.3 η=0.4 η=0.5 η=0.6 η=0.7



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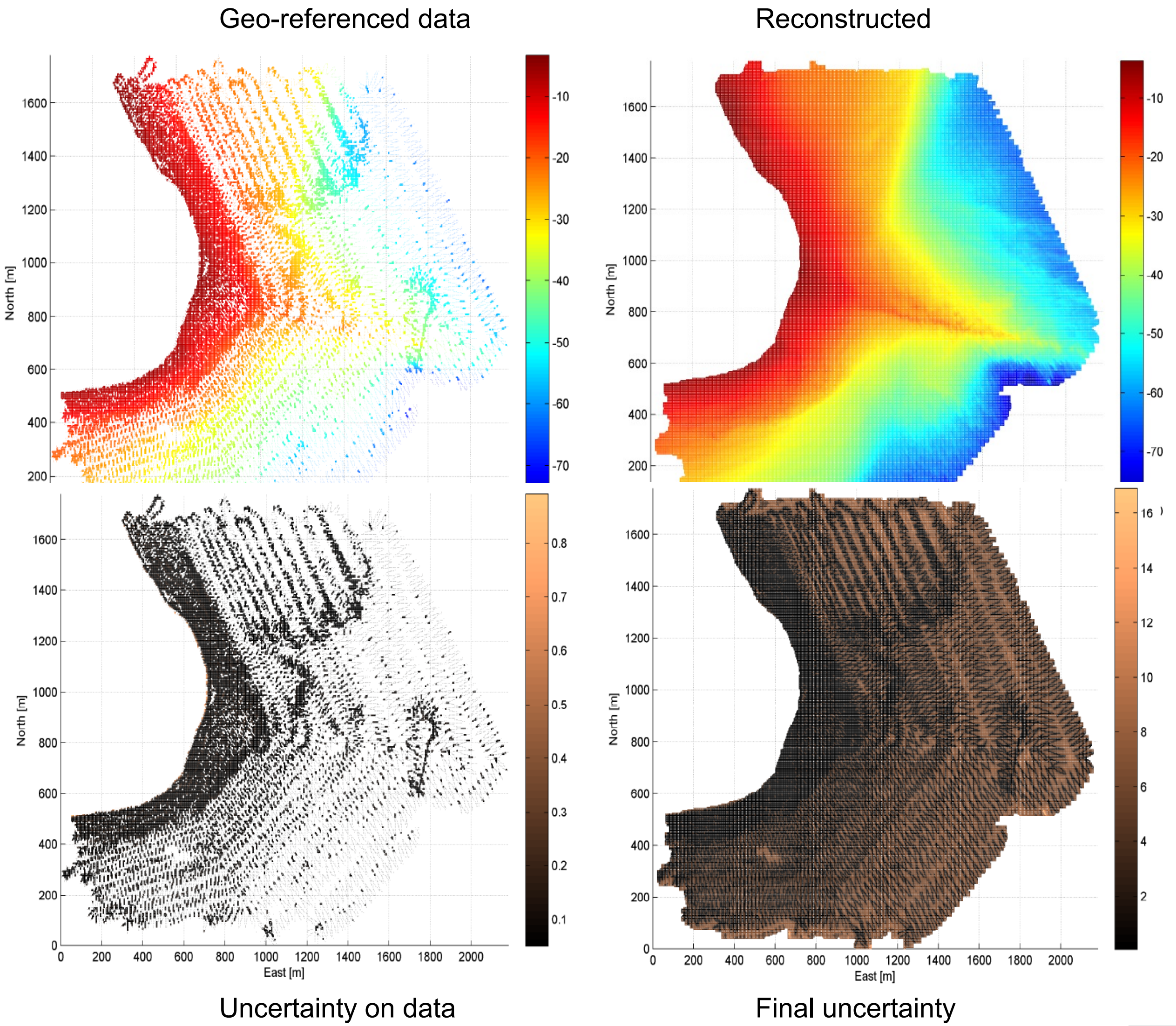
Bathymetric survey



PO 1213

Deblurring an image

Original Image

Blurred Image

Restored image

Causes:

- Out of focus acquisition
- Camera-object movement
- Shaking
- Shallow field of view …

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Stock Exchange

Models that explain evolution of phenomena

- Causality
- Number of parameters
- Type of model
- Uncertainty

Courtesy Jornal de Negócios

Is it possible to predict the market price tomorrow, next week, next month, next year,?…

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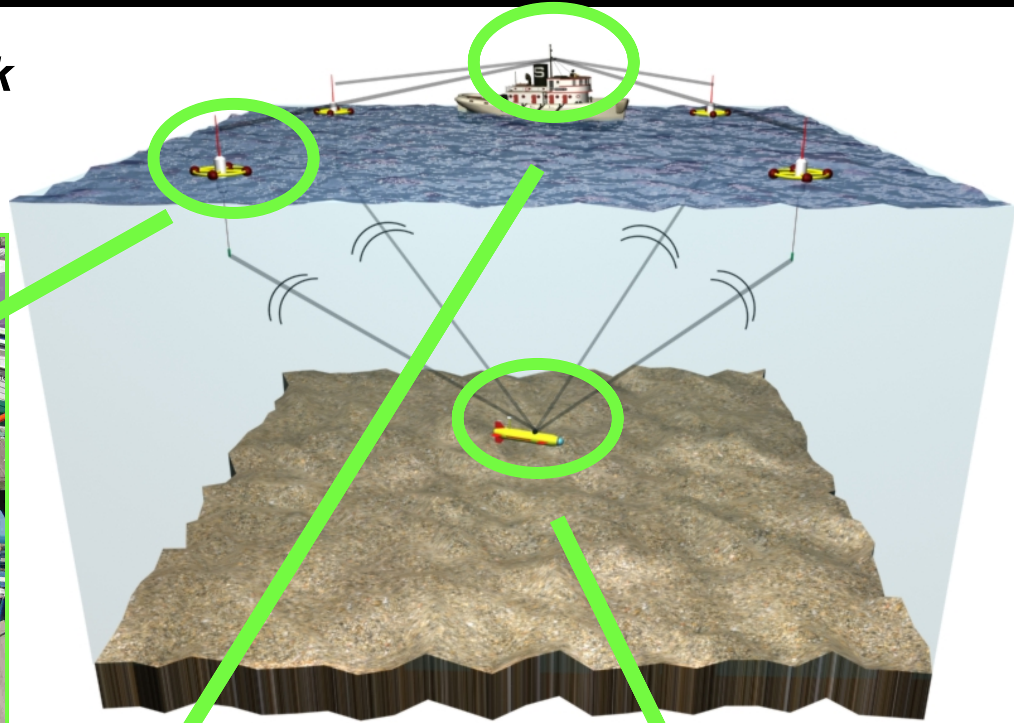
GPS Intelligent Buoys(GIB)-ACSA/ORCA

Tracking with a Sensor Network

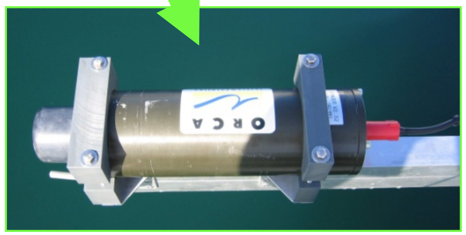


Surface buoys with

- *DGPS receivers*
- *Hydrophones*
- *Radio link*

Control Station

- *DGPS receiver*
- *Radio link*
- *PC with tracking software*



Acoustic pinger

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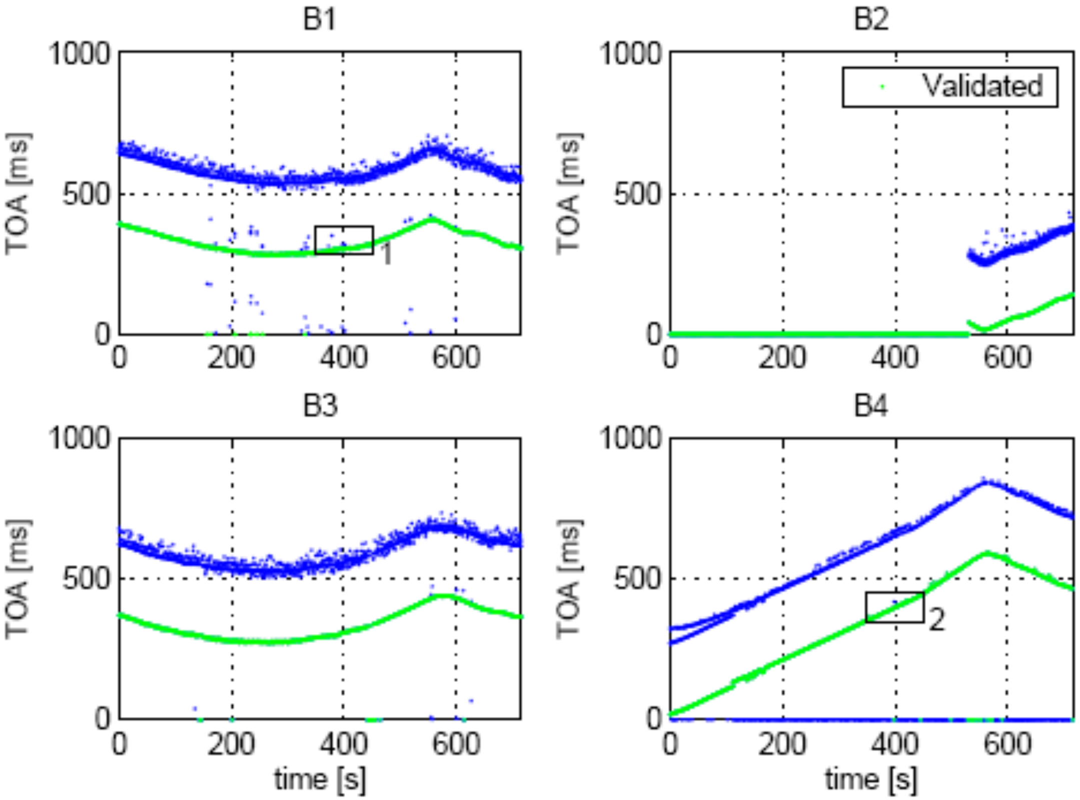
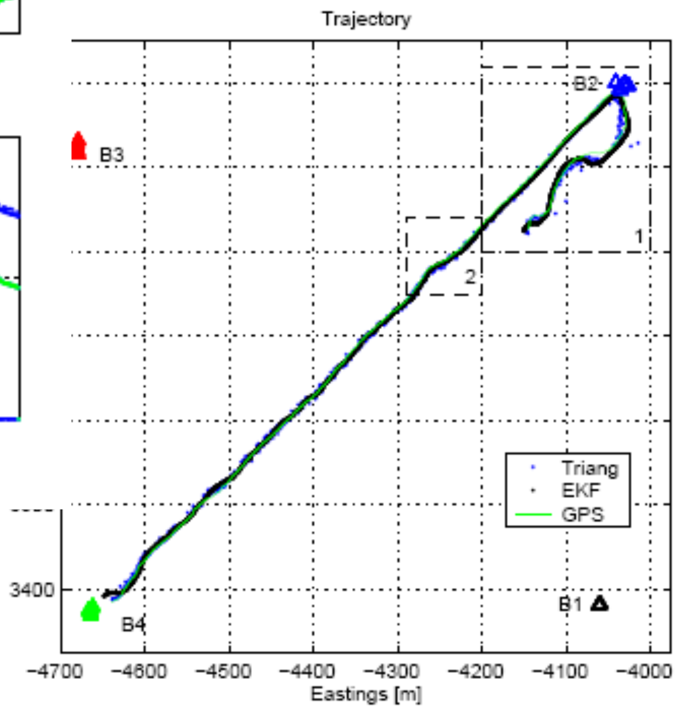
GPS Intelligent Buoys(GIB)-ACSA/ORCA

Tracking with a Sensor Network (cont.)





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The mathematical estimation problem

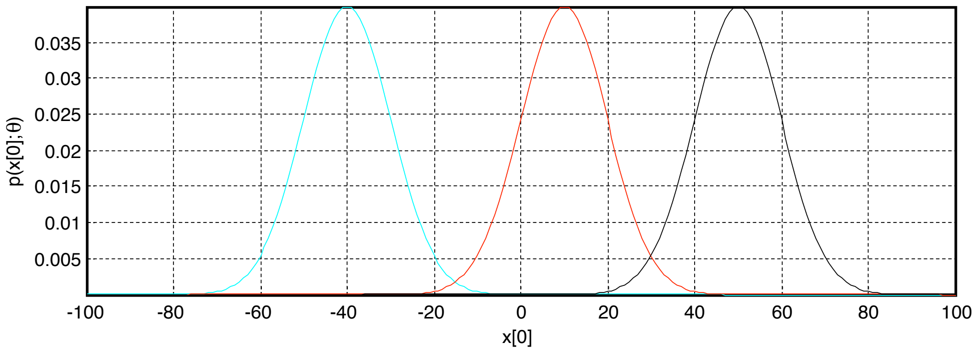
To be possible to design estimators, first the data must be modeled.

Example I:

Assume that one sample x is available (scalar example, i.e. N=1) with constant **unknown** mean θ.

The probability density function (PDF) is

$$p(x;\theta) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\theta)^2}{2\sigma^2}}$$



For instance if x[0]<0 it is doubtful that the unknown parameter is >>0.

In a actual problem, we are not given a PDF, but must be chosen to be consistent with the data and with the prior knowledge.

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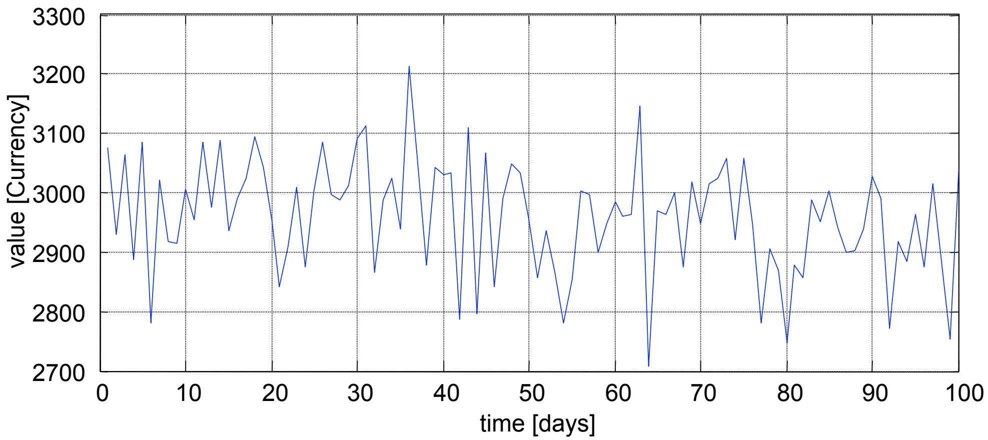
The mathematical estimation problem

Example II:

Now the following sequence ***x*** is given. Note that the value along time appears to be decreasing. Lets consider that the phenomena is described by



$$x[n] = A + Bn + w[n] \qquad n = 0,1,\ldots,N-1$$

where A and B are constant unknown parameters and w[n] is assumed to be white Gaussian noise, with PDF $N(0,\sigma^2)$. For $\boldsymbol{\theta}$*=[A B]* and **x***=[x[0] x[1] …x[n]] the data PDF is*

$$p(\mathbf{x}\,|\,\theta) = \frac{1}{(2\pi\sigma^2)^{\frac{N}{2}}} e^{-\frac{1}{2\sigma^2}\sum_{n=0}^{N-1}(x[n]-A-Bn)^2}$$

Where the uncertainty in the samples is assumed to be uncorrelated.

The performance of the estimators is dependent on the models used, so they must be mathematically treatable..

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The mathematical estimation problem

Classical estimation techniques

Parameters are assumed deterministic but unknown

Bayesian techniques

Parameters are used to be unknown but are stochastic also described by a PDF.

The joint PDF would then be $p(\mathbf{x}, \theta) = p(\mathbf{x} \mid \theta)\, p(\theta)$

Dependence of data on the parameters

Prior knowledge

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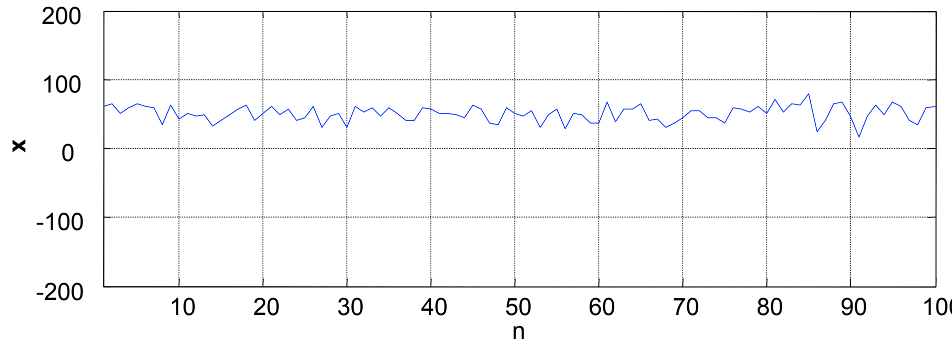
Exploiting simple estimators

Example III (Quiz):

Given a data sequence from a signal with PDF as described by one of three models

Which one is the correct model?

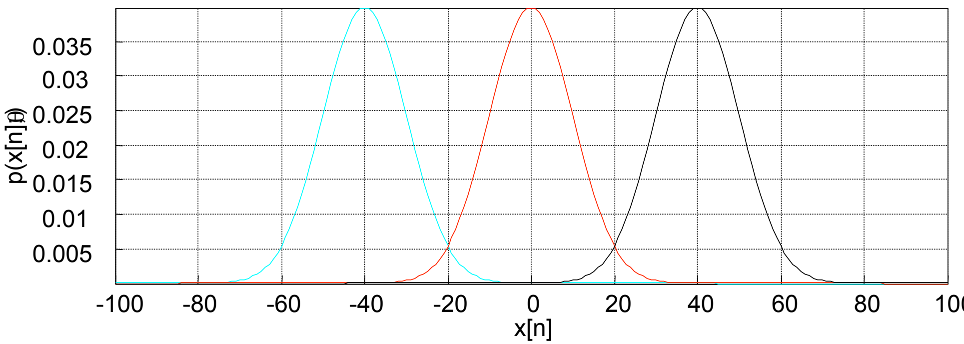


First scenario:

$$N = 100$$

$$\theta \in \{-40, 0, 40\}$$

$$\sigma^2 = 10^2$$



For the signal

$$x[n] = \theta + w[n] \qquad n = 0, 1, \ldots, N-1$$

The answer is obvious:

θ = 40!

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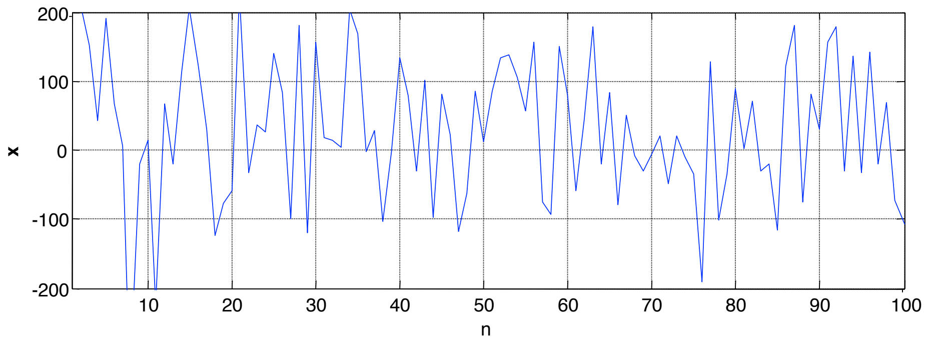
Exploiting simple estimators

Second scenario

(lousy sensor quality or lousy data):

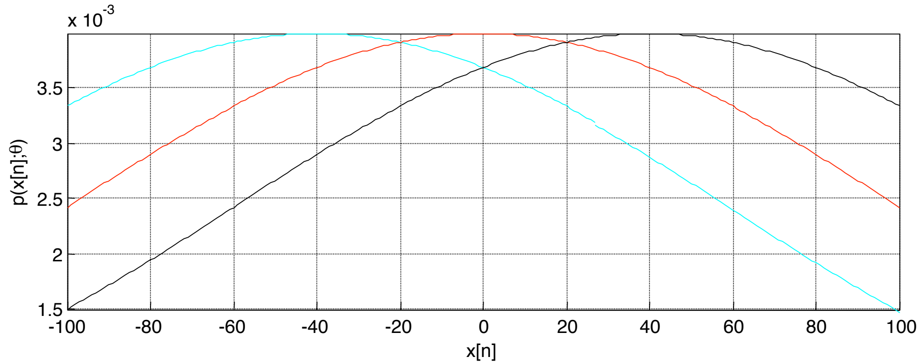
Lets *repeat the problem with*

$$\sigma^2 = 100^2$$



$$N = 100$$

$$\theta \in \{-40, 0, 40\}$$



The answer is not obvious anymore!

Lets propose a couple of estimators

and to study them…

$$\hat{\theta}_1 = x[0] \qquad \hat{\theta}_2 = \frac{1}{N}\sum_{n=0}^{N-1} x[n]$$

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Assessing estimator performance

Estimators depend only on observed data thus can be viewed as a function

$$\boldsymbol{\theta} = g\left(x[0], \quad \dots \quad x[N]\right) = g\left(\boldsymbol{x}\right)$$

The study of estimator properties must be done resorting to statistic tools.

Is it exact?, i.e. Does it return the true value of the unknown parameters?

Is this a good estimator? If many experiments can be performed, is it expected that the unknown parameter is achievable? Or are the results expected to be biased?

$$E\left[\hat{\theta}_1\right] = E\left[x[0]\right] = \theta$$

$$E\left[\hat{\theta}_2\right] = E\left[\frac{1}{N}\sum_{n=0}^{N-1} x[n]\right] = $$
$$= \frac{1}{N}\sum_{n=0}^{N-1} E\left[x[n]\right] = $$
$$= \frac{1}{N} N\theta = \theta$$

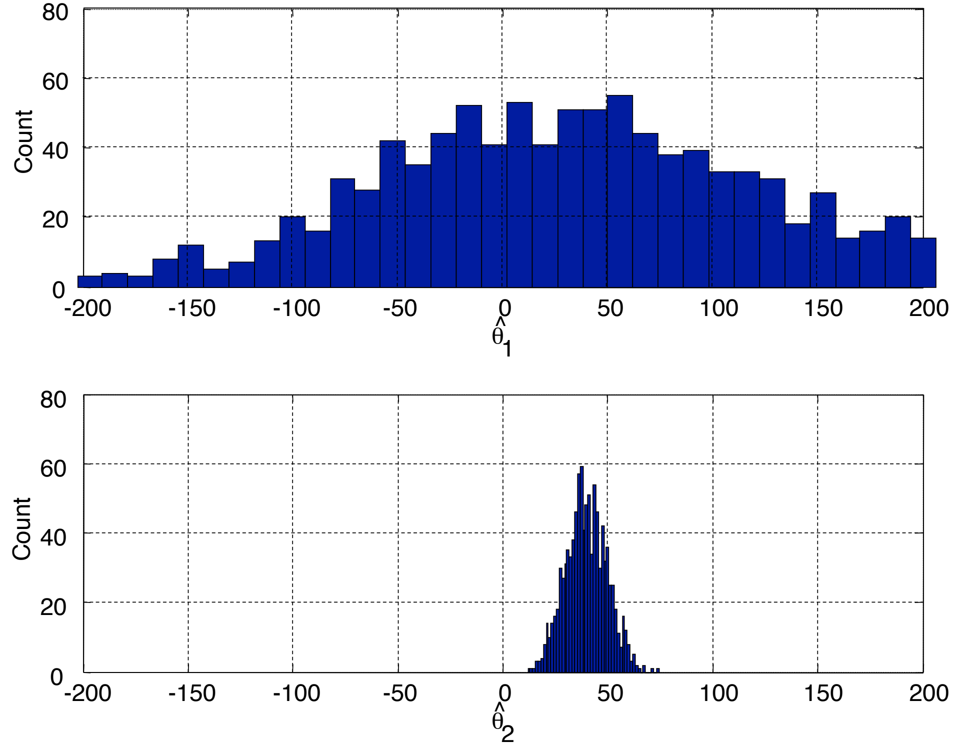
Assessing estimator performance

How good is an estimator? How much uncertainty corresponds to the computed value?

The use of computational tools is a good idea? No!

Formal methods are required

For our quiz:



$$\operatorname{var}\left(\hat{\theta}_1\right) = \operatorname{var}\left(x[0]\right) = \sigma^2$$

$$\operatorname{var}\left(\hat{\theta}_2\right) = \operatorname{var}\left(\frac{1}{N}\sum_{n=0}^{N-1} x[n]\right) = \frac{1}{N^2}\sum_{n=0}^{N-1} \operatorname{var}\left(x[n]\right) == \frac{1}{N^2} N\sigma^2 = \frac{\sigma^2}{N}!$$

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Assessing estimator performance

Questions triggered from this simple example but valid to all our problems:

- **The second estimator is much better than the first estimator.**

- **The quality of the estimate increases with the number of points. Is it reasonable? Is it plausible?**

- **Do we have always data available? How to get data?**

- **Is this the best one can do with N samples?**

- **Are there better estimators that we can exploit?**

Answers to this questions will be provided along the course…

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Further reading

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See for instance http://www.**ieee**.org/portal/site

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