IN THE NAME OF GOD

BEAM-FORMING

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CONTENT

INTRODUCTION

- Growing the demand for wireless mobile communications services at an explosive rate

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- Limited available frequency spectrum

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SULUTION?

INTRODUCTION…

Smart antenna

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An array of antennas

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Array signal processing

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Diversity combining

Beam-forming

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Increasing the reliability & **capacity** of the system

INTRODUCTION …

- Smart ⟹ the ability of the antenna to adapt itself to different signal environments through the use of different algorithms.

INTRODUCTION …

- **Exp :** smart antenna in a nonstationary environment

dynamic

Signal processing algorithms

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Position of the desired source

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Beam-forming algorithms

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Forming the beam in the direction of the source

INTRODUCTION…

Beam-forming

↓

Spatial filtering

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Several users can use
the same frequency channel
at the same time

INTRODUCTION…

- Smart antenna was first used about **40** years ago in **RADAR** applications.

- The first issue of IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, published in **1964**.

CONTENT

SMART ANTENNA AND SDR

- Smart antenna and SDR complement each other .
  - Smart antenna help software radio to adapt to different protocols, systems, channel conditions and … trough the use of signal processing algorithms to either **combine** the received signals in an optimum manner or **beam-forming** .
  - Implementation of smart antenna algorithms require software and flexibility in hardware that is provided by software radios.

CONTENT

- Introduction
- Smart antenna and SDR
- Several beam-forming methods
- Essential signal-processing algorithms
- Adaptive beam-forming algorithms
- summery

SEVERAL BEAM-FORMING METHODS

- Terminology and signal model:
  - An array of **L** omnidirectional elements in the far field of **M** uncorrelated sinusoidal point sources of frequency f_0 ⟹ **narrow band beam-forming**
  - The time taken by a plane wave arriving from the ***i*** th source in direction (φ_i, θ_i) and measured from the ***l*** th element to the origin is $\tau_l(\varphi_i, \theta_i)$.

SEVERAL BEAM-FORMING METHODS

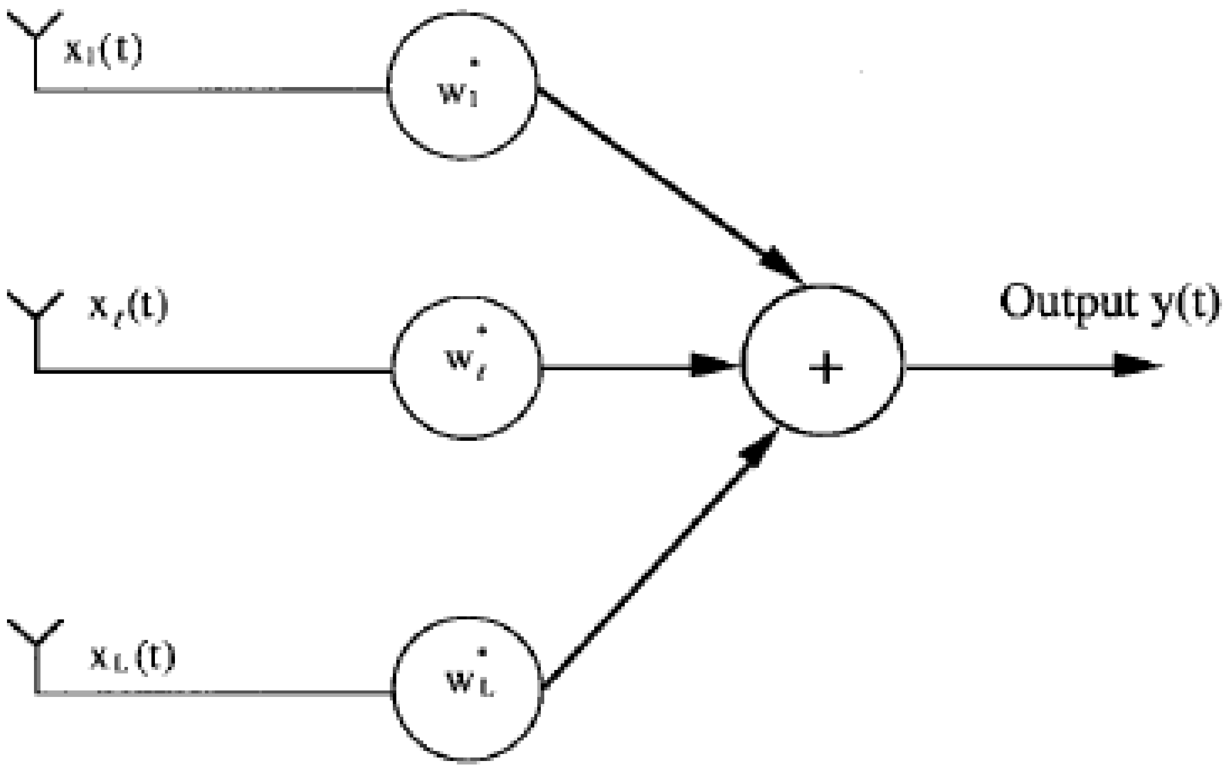
(φ_0, θ_0) :Look direction

$$\underline{s}_0 = [\exp(j2\pi f_0 \tau_1(\varphi_0, \theta_0)), \ldots, \exp(j2\pi f_0 \tau_l(\varphi_0, \theta_0))]$$

SEVERAL

BEAM -FORMING

METHODS…



Narrow-band beam-former structure

SEVERAL BEAM-FORMING METHODS …

$$\underline{w} = [w_1, w_2, \ldots, w_L]^T$$

$$\underline{x}(t) = [x_1(t), x_2(t), \ldots, x_L(t)]^T$$

$$y(t) = \underline{w}^H \underline{x}(t) = \sum_{l=1}^{L} w_l^* x_l(t)$$

SEVERAL BEAM-FORMING METHODS …

- $\underline{x}(t) \rightarrow$ zero mean stationary process ⟹

  - The mean output power of the processor is :

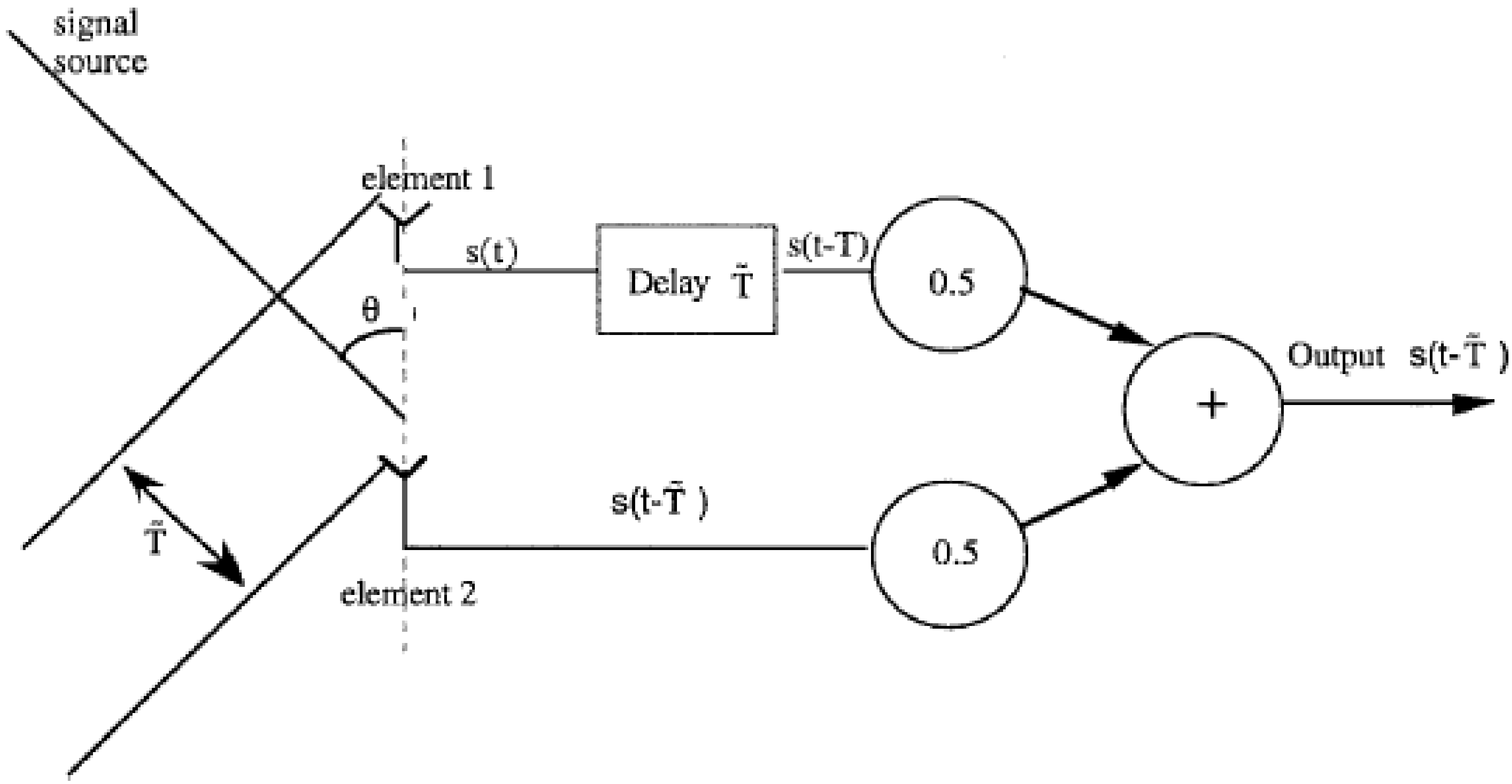
$$P(\underline{w}) = E[y(t)y^*(t)] = \underline{w}^H R\,\underline{w}$$

Where **R** is the array correlation matrix :

$$R = E[\underline{x}(t)\,\underline{x}^H(t)]$$

R_{ij} : correlation between ***i*** th and ***j*** th element .

Conventional (delay and sum) beam-former



Two-element delay and sum beam-former structure

SEVERAL BEAM-FORMING METHODS …

- Null-steering Beam-Former :
  - **Goal** :

Producing a null in the response pattern in a response pattern in a known direction

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Cancelling the plane wave arriving from that direction

SEVERAL BEAM-FORMING METHODS …

- Limitations of null-steering beam-former :

  - It requires knowledge of the directions of interferers.

  - It does not maximize the output **SNR** .

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The **optimal beam-forming** overcome these limitations .

SEVERAL BEAM-FORMING METHODS …

- Optimal Beam-Forming (in the sense of output SINR) :
  - Optimal beam-former solves the following optimization problem :

$$\min_{\underline{w}} \quad \underline{w}^H R \, \underline{w}$$

$$\textit{subject to} \quad \underline{w}^H \underline{s}_0 = 1$$

Where $\underline{w}^H R \, \underline{w}$ is the mean output power.

SEVERAL BEAM-FORMING METHODS …

Minimizing the total output power while maintaining the desired signal power in the output equal to the desired source power

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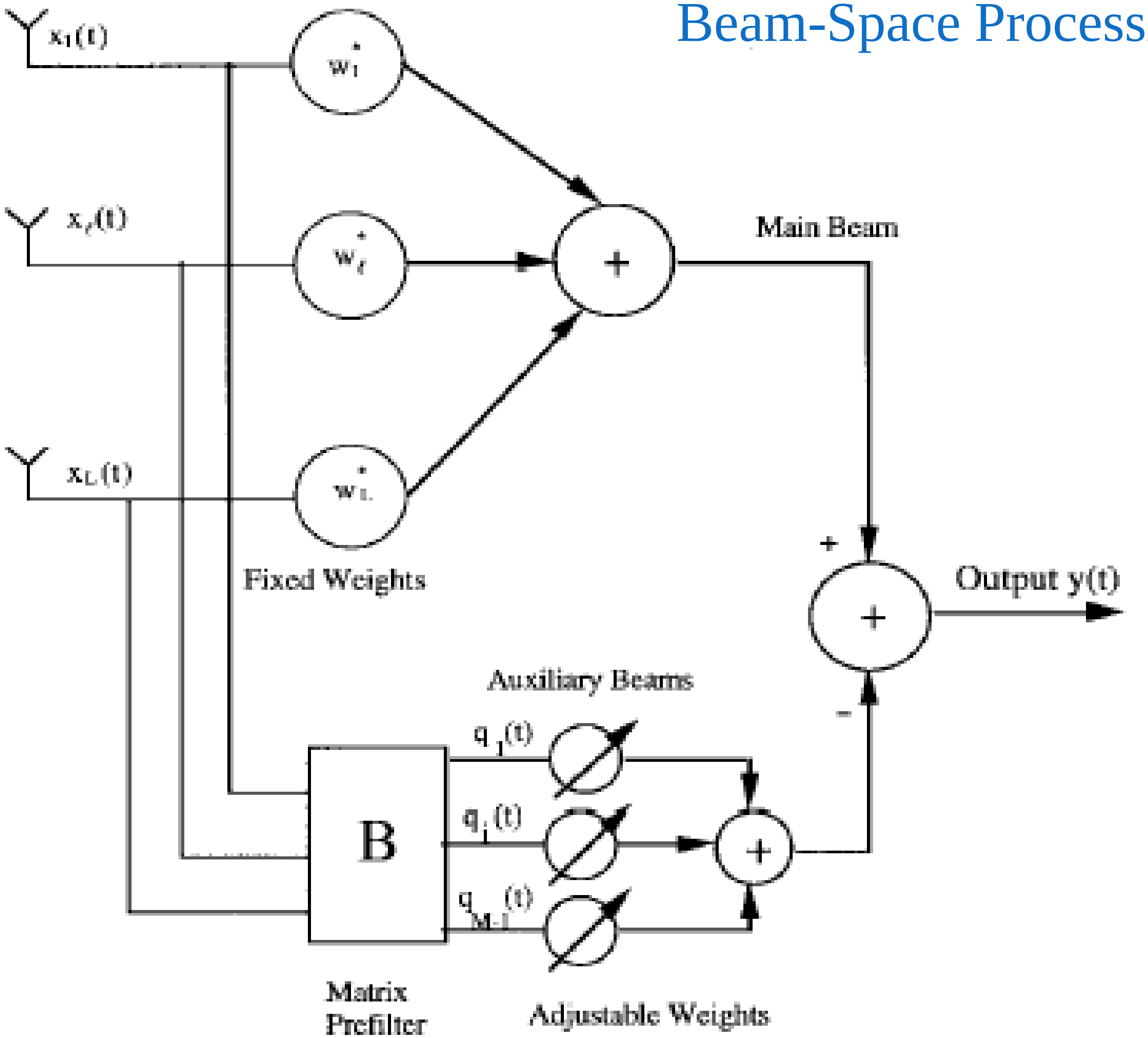
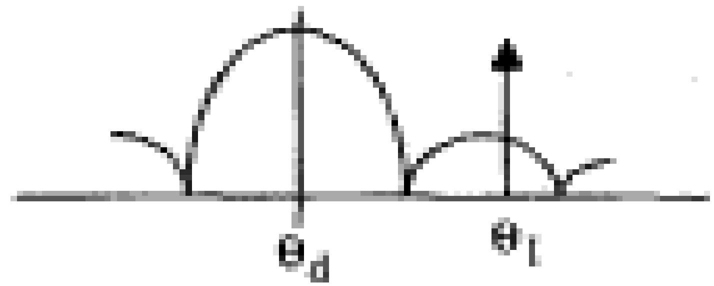
Maximizing the output **SINR**

- An increase of **a few decibels** in the output **SNR** can make a significant increase in the **channel capacity** of the system possible.

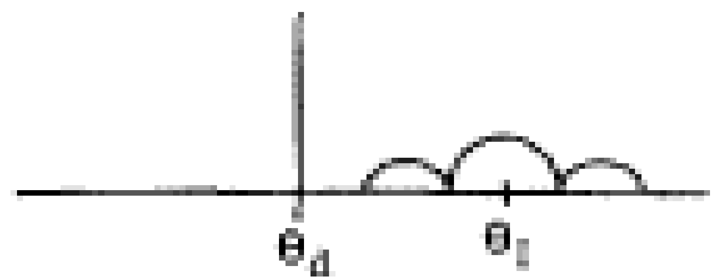
Beam-Space Processing



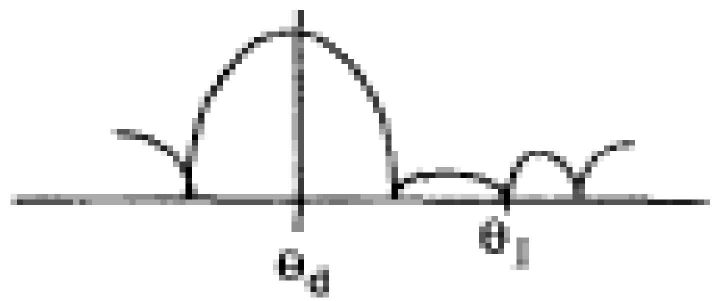
Main beam



Weighted sum of secondary beams



Final output



SEVERAL BEAM-FORMING METHODS …

- Other beam-formers
  - Broad- band beam-formers
  - Frequency-domain beam-former
  - …

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ADAPTIVE BEAM-FORMING ALGORITHMS

- Adaptive Algorithms :
  - To calculate the optimal weights (in different senses) we usually need the correlation matrix **R**.

    For example in optimal beam-former the solution of the optimization problem is :

$$\hat{\underline{w}} = \frac{R^{-1}\underline{s}_0}{\underline{s}_0^H R^{-1}\underline{s}_0}$$

- However, in practice **R** is not available .

ADAPTIVE BEAM-FORMING ALGORITHMS …

➡ The weights are **adjusted** using available information derived from the array output, array signals and so on to make an **estimate** of the optimal weights.

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There are many such schemes, which are normally referred to **adaptive algorithms** .

- LMS Algorithm (unconstrained) :
  - **Reference signal :**

    For some applications, enough may be known about the desired signal (arriving from the look direction) to generate an appropriate **reference signal**.

➡ The weights are chosen to minimize the **mean square error** between the beam-former output and the reference signal.

ADAPTIVE BEAM-FORMING ALGORITHMS …

- For example, if the desired signal is **amplitude modulated**, then acceptable performance is often obtained by setting the **reference signal** equal to the **carrier**.

- In the unconstrained LMS algorithm reference signal is used.

ADAPTIVE BEAM-FORMING ALGORITHMS …

In this algorithm :

$$\underline{w}(n+1) = \underline{w}(n) - \mu\, \underline{g}(\underline{w}(n))$$

Where :

$\underline{w}(n+1)$: new weights computed at the (n+1) th iteration

μ : a positive scalar (gradient step size)

$\underline{g}(\underline{w}(n))$: an estimate of the gradient of the **MSE** between the beam-former output and the reference signal

Mean= $E[\underline{w}(n)]$

Estimated weights

Covariance =

$$E[(\underline{w}(n)-\underline{\bar{w}})(\underline{w}(n)-\underline{\bar{w}})^T]$$

ADAPTIVE BEAM-FORMING ALGORITHMS …

- The algorithm updates the weights at each iteration by estimating the gradient of the MSE surface and then moving the weights in the negative direction of the gradient by a small amount (μ).

  - μ should be small enough for **convergence** of the algorithm to the optimum weights .
    (**convergence** : convergence the **mean** of the estimated weights to the optimal weights)

- **Convergence speed :**

  The speed by which the mean of the estimated weights (ensemble average of many trials) approaches the optimal weights .

  - The larger the eigenvalue spread of the correlation matrix **R**, the longer it takes for the algorithm to converge.

ADAPTIVE BEAM-FORMING ALGORITHMS …

- The availability of time for an algorithm to converge for mobile communications depends on:

1-System design ⟹ the duration that the user signal is present (e.g. User slot duration in a TDMA system)

2-The rate of the fading :

The higher the rate at which the signal fades ⟹ algorithm needs to converge faster

ADAPTIVE BEAM-FORMING ALGORITHMS …

- Even when the **mean** of the estimated weights converges to the optimal weights, they have finite **covariance** .

The average **MSE** is more than **MMSE**

Misadjustment = (average excess **MSE**) **/MMSE**

Misadjustment → the size of the region that weights wandering around it after the convergence.

ADAPTIVE BEAM-FORMING ALGORITHMS …

- Increasing μ increases the misadjustment .

- An increase in μ causes the algorithm to converge faster.

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We have a **trade off** in

the selection of the **gradient step size** μ

ADAPTIVE BEAM-FORMING ALGORITHMS …

- This trade off is between :

1-Reaching vicinity of the solution point more quickly but wandering around over a larger region and causing a bigger misadjustment .

2-Arriving near the solution point slowly with the smaller movement in the weights at the end.

- We select μ based on the following considerations :

- The mentioned trade off
- Being small enough for convergence
- Application and requirements

CONTENT

SUMMARY

- ✓ Smart antenna
  - ➡ Beam-forming
  - Diversity combining
  - …
- ✓ Smart antenna and SDR
- ✓ Different beam-formers
  - Delay and sum beam-former

SUMMARY

- Null-steering beam-former
- Optimal beam-former
  - Correlation matrix **R** is required
- **R** is not available in practice

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- Adaptive algorithms
  - **LMS** algorithm
    - **Trade off** in selecting **step size**

QUESTIONS ?

THANKS FOR YOUR ATTENTION