Lecture Notes 0
Course Introduction

- EE 278 in EE Curriculum
- Statistical Signal Processing
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- Topics
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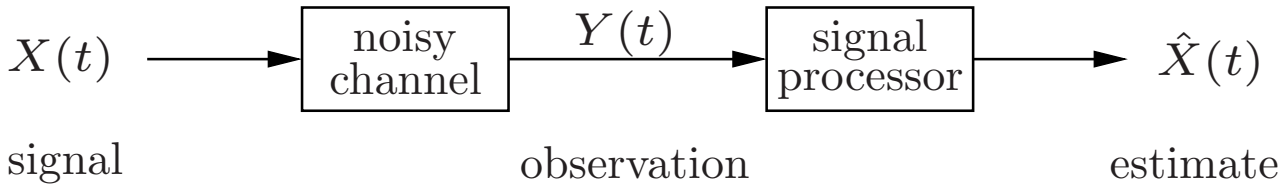
EE 278 in EE Curriculum

- EE 278 is one of three core ISL graduate courses:
  - EE 261 and EE 263 deal with deterministic (linear) systems
  - EE 278 deals with statistical systems
- EE 278 is a prerequisite to courses in signal processing, image and video processing, communications, stochastic control, and machine learning
- It also provides a good background for other areas (e.g., noise in devices, circuits, biological systems, . . .)

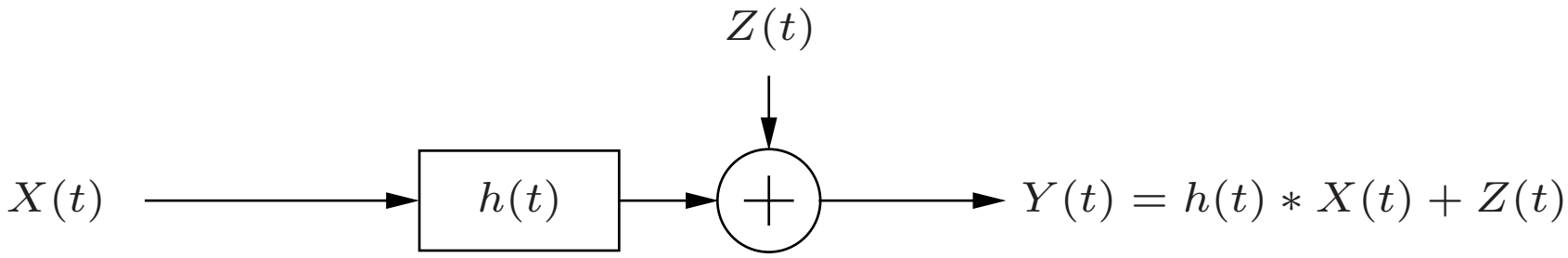
Statistical Signal Processing

- Focus is on extracting information (signals) from noisy observations
- Applications are all around us — cell phones, digital cameras, base stations, medical devices, sensor networks . . .
- Generic signal processing problem:

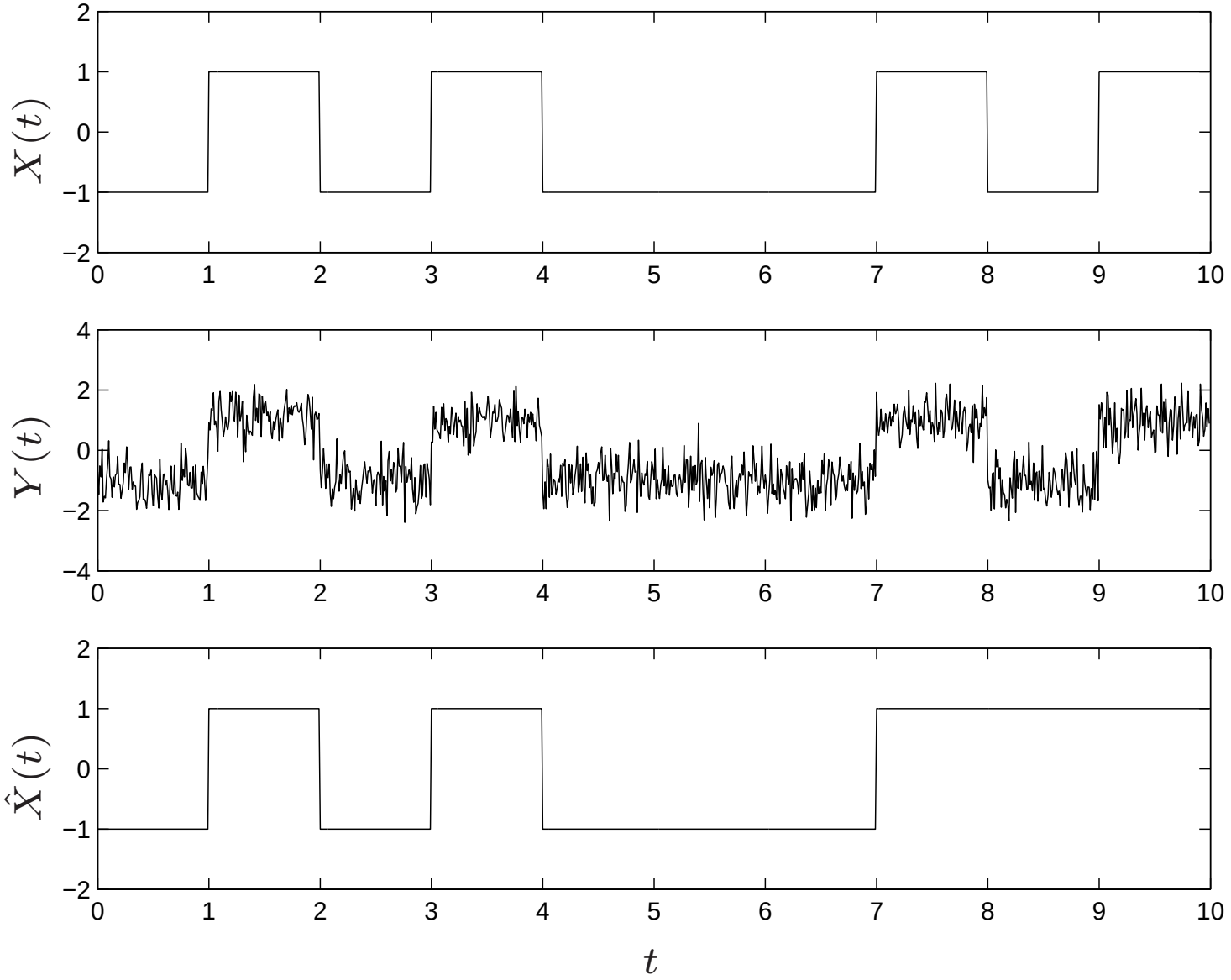


- Signal: (coded) digital data, audio, image, geophysical, medical, sensor . . .
- Channel: twisted pair, optical, wireless, satellite, computer memory, electronic circuit, layers of earth, biological, . . .
- Channel is modeled as a statistical system — linear vs. nonlinear, time invariant vs. time varying
- Noise (physically generated or due to interference) and often signals are modeled as random processes, i.e., sequences of random variables indexed by time

- Signal processor: attempts to recover the signal from observation via
  - estimation: find an estimate that is close to the signal $X(t)$, for example, one that minimizes the mean square error (MSE)
  - detection: decide which signal out of a finite number of possible signals (e.g., 0 and 1) was sent — goal: minimize the probability of error
- Statistical signal processing deals with both modeling of signals and channels and design of "optimal" signal processing algorithms
- Example: many real channels (twisted pair, wireless model, . . .) are modeled as linear time-invariant (LTI) system with additive noise



- Very simple case: $h(t) = \delta(t)$, $X(t)$ binary waveform



Course Goal

- To provide the statistical signal processing background:
  - provide relevant random vectors and processes background
  - introduce statistical models for noise and signals
  - introduce detection and estimation
- Courses that require EE278 as prerequisite include:
  - communications courses: EE276, EE279, EE376A,B and EE379A,B
  - signal and image processing and estimation courses: EE378, EE355, EE359, EE363, EE368, EE372
- Prerequisites:

  EE178 or equivalent,

  linear systems and transforms, e.g., EE102A,B
- EE 278 may not provide sufficient background for research in communication or signal processing; more mathematical courses, e.g., Stats 217, 218, 310A,B, C may be needed

Course Topics

- Probability and random variables: Lectures Notes 1 and 2; lectures 1–4. Axioms, basic laws, conditional probability, Bayes rule, and independence. Random variables; cumulative distribution function, probability mass function, probability density function, joint, marginal and conditional distributions, functions of random variables. Applications: Generation of random variables, scalar detection. Expectation; mean, variance, covariance and correlation. Inequalities; Markov and Chebyshev. Scalar MSE estimation; linear estimation and orthogonality principle.

- Random vectors: Lecture Notes 3 and 4; lectures 5–9. Specifying random vectors. Covariance matrix. Whitening and coloring. Gaussian random vectors. Vector detection and MSE estimation; innovations; Kalman filter.

- Convergence and limit theorems: Lecture notes 5; lecture 10.

- Random processes: Lecture Notes 6,7, and 8; lectures 11–17. Definition and examples of discrete and continuous random processes: IID, random walk, independent increment processes, Poisson process, Gaussian random processes. Stationarity, autocorrelation function and power spectral density. White noise, bandlimited processes. Response of linear systems to random inputs. KTC noise in circuits. Linear estimation; infinite smoothing, spectral factorization, Wiener filter.

Lecture Notes

- Help to organize and reduce note taking in lectures
- You will need to take some notes, e.g., clarifications, missing steps in derivations, solutions to additional examples
- Slide title indicates a topic that often continues over several consecutive slides
- Lecture notes + your notes + review sessions should be sufficient. (You may want to refer to textbooks for more explanations or different approaches)
- These lecture notes are always evolving. Please give me feedback on what can be improved

References

The following books should be on reserve at the Engineering Library:

- Leon-Garcia, *Probability and Random Processes for Electrical Engineers*
- Papoulis, *Probability, Random Variables and Stochastic Processes*. A great classic book but a bit too terse to use as a text.
- H. Vincent Poor, *An Introduction to Signal Detection and Estimation*. A classic book on estimation and detection.
- Gallager, *Stochastic Processes: Theory for Applications*.

In addition, the following resources are available online:

- B. Hajek, *Random Processes for Engineers*. http://www.ifp.illinois.edu/ hajek/Papers/randomprocJuly14.pdf. Notes for EE 534 at UIUC.
- Gray and Davisson, *An Introduction to Statistical Signal Processing*, also available through Prof. Robert Gray's webpage and EE 278 webpage.