# Teaching the Theory of Signals and Systems
# A Proposal for a Curriculum

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## Introduction

In the University of Aveiro, a new Portuguese University (only twenty years old), the teaching of the Theory of Signals and Systems is done within the Department of Electronics and Telecommunications. This Department has interests on Electrical and Computer Engineering, and is responsible for a degree on Electronics and Telecommunications Engineering, as well as a Master´s degree on the same area.

The faculty of the Department is composed by over sixty professors and lecturers (23 with Ph.D. degrees). Annually, the Department receives around 150 undergraduate students, and over 50 graduate students. The total number of students in the Department is over one thousand.

Recently, we have reformulated the *curriculum* of the Engineering degree, which is five years long (ten semesters) and has the following structure:

| Area | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| Mathematics | X | X | | | |
| Physics | X | X | | | |
| Electronics | | X | X | X | project & options |
| Computers | X | X | X | X | project & options |
| Telecommunications | | | X | X | project & options |
| Theory of Signals and Systems | | X | X | X | project & options |

Basically, we have two years with the basics (mathematics and physics), and introductory courses on Computer Programming, basic Circuit Analysis, and the fundamentals of Signals and

Systems. These two years are followed by an additional two years of general Electronics, Computer Architecture and Operating Systems, Telecommunications, and Signal Processing. In the final year the student may choose quite freely the subjects he wants to study more deeply, together with the execution of a one-year project where he is asked to apply the acquired knowledge to a practical problem. He is also asked to prepare a written report describing his achievements during the project.

This should give to the reader a general feeling concerning the overall structure of the curriculum. In the next section we describe in detail those aspects more closely related to the teaching of Signal and Systems.

**Teaching the Theory of Signals and Systems**

The area of Signals and Systems comprises four mandatory one-semester courses, and a number of optional one-semester courses which the student is free to take in its final year. Their interdependence is illustrated in the following figure.

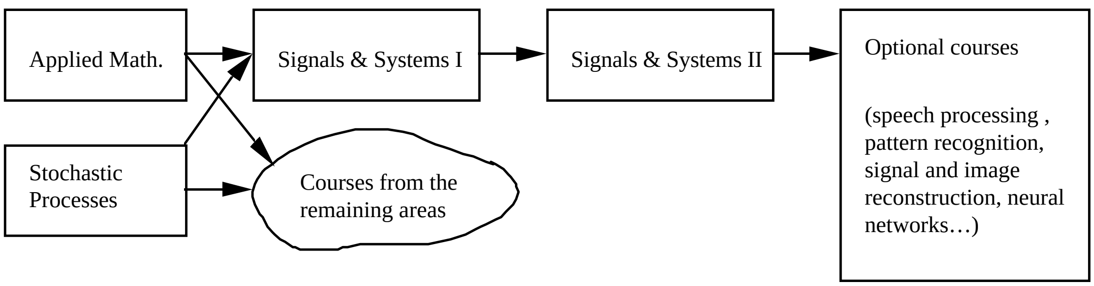


Figure 1. The figure shows the distribution of Signal and Systems courses among the different years, and their interdependencies.

The basic courses are:

Probabilities and Stochastic Processes — with this course we aim to introduce the basic ideas of probabilistic modeling useful in Electrical Engineering. After the study of elementary probability theory we present the concept of random variable, its characterization and analyze a few of the more important distributions (both discrete and continuous). After presenting the extensions to the multidimensional case we introduce the concept of stochastic processes, and the mathematical tools required for its analysis. To finish we study linear systems when the input is a signal with stochastic behavior.

Applied Mathematics — it comprises the fundamentals of signal theory, for both discrete and continuous-time signals. The basic analysis tools are also introduced at this stage: the classical and discrete Fourier series, and the Fourier integral. The discrete and continuous cases are taught simultaneously, emphasizing the similarities that exist between them. Discrete and continuous time linear time invariant systems are introduced at this point. The Z transform and the Laplace transform are studied in depth, and applied to the study of linear systems.

Signal Processing I — it discusses transfer functions in detail, the effect of the poles and zeros on the frequency response, and issues related to the transient response and stability, again for both discrete and continuous time systems. Then it moves over to the synthesis of linear time invariant systems. This includes digital and continuous filter design problems. Some implementation issues and algorithms, including the FFT algorithm and its applications, are also discussed.

Signal Processing II — it comprises topics such as image and multidimensional processing, adaptive filters, and multirate systems. The standard tools for the analysis of multidimensional signals are introduced, emphasizing applications to image processing. Next, the basic adaptive filtering techniques, algorithms and applications are discussed in detail. This includes the LMS algorithm and adaptive noise canceling, for example. The theory and practice of multirate systems is the last topic taught. Starting with the concepts of interpolation and decimation, it brings the student into contact with recent developments in filter banks, QMFs, and some of their applications.

The optional courses are much more subject to change from year to year, depending on student demand and our own research interests. To give an idea of what is being currently offered we mention the following courses:

Speech Processing — this course aims to give the students a general overview of the area. The physiology and anatomy of the speech production and auditory systems are briefly presented. The linear prediction model is studied, followed by some speech coding techniques. The last part of the course deals with isolated word recognition, using dynamic time warping and hidden Markov models.

Signal Processing Algorithms — it addresses the problem of solving sets of linear equations, using iterative and noniterative methods. It also addresses special methods for specific matrices (for example, Toeplitz matrices). Other types of equations are also studied, using tools from functional analysis (for example, fixed-point theorems). Specific applications are mentioned.

Signal and Image Reconstruction — it introduces the student to a number of signal and image reconstruction problems. More specifically, it addresses signal and image interpolation and extrapolation problems, missing samples or pixels, deconvolution, and several iterative constrained reconstruction algorithms.

DSP Hardware — it introduces the student to the architecture of the main DSP families (Texas Instruments and Motorola). Implementation problems such as finite wordlength effects are addressed. The student is asked to tackle specific problems and solve them using DSP kits (such as the TMS320C5x DSP Starter Kit, which has voice input and output capability).

Neural Networks — it introduces the fundamental principles of neural networks. Supervised and unsupervised learning paradigms such as backpropagation and competitive algorithms. Associative Memories, the feedforward and recurrent topologies. Some applications, such as image compression, character recognition are also discussed.

**Discussion and conclusions**

The motivation of the student is one aspect to which we paid close attention, and underlies the approach that we have explained. In Applied Mathematics, for example, teaching the principles of discrete and continuous signals and systems simultaneously and at an early stage makes computer simulations and practical work possible right from the beginning. This encourages the student to regard Fourier analysis, for example, as something of practical importance, and not just of mere mathematical interest. We also felt that the traditional approach, in which the tools for the analysis of discrete and continuous time signals were taught separately, often in different courses, was misleading the students and preventing them from acquiring an integrated view of signal analysis.

The possibility of offering laboratory courses depends, of course, on the availability of personal computers. We rely on low-cost i486 based machines, running Matlab. We have found that Matlab provides an easy to learn yet powerful interface, and a powerful set of commands to deal with graphics, signals, and systems.

Although we can not present a final evaluation of this experience yet, we may already report that the students reacted to the laboratory classes very well. There has been a marked increase of interest on signal analysis on behalf of the students. Even those initially more reluctant to regard the fundamental mathematical tools as relevant to their future Engineering career become increasingly aware of the power, usefulness and applications of those tools. We feel that teaching the theory of signals and systems in this way is more in agreement with the engineering perspective.