# General Course Information

## Staff

Lecturer:

| | |
|---|---|
| Vivek Goyal | goyal@bu.edu |
| *Office hours: Tuesdays 11:00am–noon* | PHO 442 |
| *Office hours: Tuesdays 5:30pm–6:30pm* | PHO 404/428 |

Graduate Teaching Fellow:

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|---|---|
| Charlie Saunders | cs13@bu.edu |
| *Office hours: Mondays 4:00pm–5:00pm* | PHO 318 |
| *Office hours: Fridays 2:30pm–3:30pm* | PHO 318 |

Graders:

| | |
|---|---|
| Shengye Li | shengye@bu.edu |
| Dewei Wang | daniel36@bu.edu |

Office hours were chosen to (a) minimize conflicts with students registered as of January 16; and (b) provide availability before Wednesday homework due dates. Appointments outside of the specified times are certainly possible, within reason.

## Lectures

Lectures: Mondays and Wednesdays 10:10 am – 11:55 am Room MCS B19

A separate handout gives the tentative schedule of lecture topics. If there are significant changes, the schedule will be updated on the course website.

## Texts

The primary text is:

> *Foundations of Signal Processing*
> Martin Vetterli, Jelena Kovačević, and Vivek K Goyal
> (Cambridge University Press, 2014, c. $70.00, ISBN: 9781107038608)

A free version is available for download from http://FoundationsOfSignalProcessing.org. Please download the errata from this site and mark your copy appropriately. Note that *Exercises with solutions* and *Exercises* are redacted from the free version. The *Exercises with solutions* contain a lot of very important content. If you are attempting to get by with only the free download, also consult a printed version for the *Exercises with solutions* at the ends of the chapters.

The course will also cover a very small part of an incomplete companion volume:

> *Fourier and Wavelet Signal Processing*
> Jelena Kovačević, Vivek K Goyal, and Martin Vetterli
> (to be published by Cambridge University Press)

The manuscript is available for download from http://fourierandwavelets.org. Send comments on either book to book-errata@FourierAndWavelets.org – with the possibility of course bonus credit for being especially helpful. Two students from Spring 2014 are acknowledged in the published book, and a paid position for proofreading the second volume may be offered.

## Web resources and web-enabled interaction

The Blackboard system at `https://learn.bu.edu` will be the primary means for distributing course materials, such as homework assignments, homework solutions, and lectures slides.

I encourage you to post your questions on Piazza. The system is designed to provide fast and efficient communication with your classmates, the TA, and me. While Charlie and I will read and answer questions, we hope that you will also answer each other's questions. Discussions about class material (IRL and online) are very valuable in learning. Find our class page at: `https://piazza.com/bu/spring2018/ec416516/home`

## 416/516 combination

The course combines ENG EC 416 and ENG EC 516 with common lectures. The expectations and grading mechanisms will differ for the two courses, and the homeworks and exams may have differences.

## Prerequisites

The official prerequisites for 416 and 516 differ:

| Course | Prerequisites |
|---|---|
| ENG EC 416 | *ENG EC 401 Signals and Systems* |
| ENG EC 516 | *ENG EC 402 Control Systems*<br>or *ENG EC 415 Communication Systems*<br>or *ENG EC 416 Introduction to Digital Signal Processing* |

Not explicitly listed are *ENG EK 102 Introduction to Linear Algebra for Engineers* and *ENG EC 381 Probability Theory in Electrical and Computer Engineering*. Students must have some prior exposure to linear algebra; this is implicit because ENG EK 102 is a freshman-year course for all College of Engineering undergraduate programs. Those without good working knowledge of linear algebra should expect to review intensively in the first few weeks of the semester. Probability will be treated differently, since many undergraduates take ENG EC 381 in the same semester as ENG EC 416 or a later semester. Parts of the course that use probabilistic models will be self-contained and in some cases required only of the ENG EC 516 students.

Much more important than any formal prerequisite is an interest in and commitment to understanding concepts in depth. For example, the course will acknowledge many mathematical subtleties – not to dwell on them, but rather to have an appreciation for the boundaries of our mathematical rigor.

## Exams

There will be two exams amid the semester and a final exam. The exam date are:

| | |
|---|---|
| Exam #1: | Tuesday, February 20 (in regular lecture period) |
| Exam #2: | Monday, April 2 (in regular lecture period) |
| Final Exam: | Monday, May 7, 9:00 am – 11:00 am |

The exams will be **closed-book** and **closed-notes**. Formula sheets that are part of the exam handout itself will be provided well in advance of each exam so that you can gain an understanding of what you are and are not expected to memorize. Exams emphasize understanding of key concepts rather than remembering formulas.

## Homework

Tentatively, there will be 10 homework assignments. Working through the problems carefully is a crucial part of the learning process and will invariably have a major impact on your understanding of the material (and, in turn, your exam performance and final grade!). Moderate collaboration in the form of joint problem solving with classmates is permitted and even encouraged. Be cautioned that while convincing someone of your answer is a great part of learning, hearing someone else's solution is not. All written submissions should reflect your understanding; do not copy a solution for any other source.

Homework assignments will generally be due at 5:00pm on a Wednesday, and solutions will generally be available online later the same day. Consequently, late problem sets cannot be accepted. Each problem set that you turn in will be given a score of 0, 1, or 2. A score of 2 is given for a good effort on all or most of the problems (even if not with uniform success); 1 for a reasonable attempt, but with significant gaps; and 0 when there is little evidence of adequate effort. For additional feedback on the problems, come to any staff office hours after you have had a chance to look through the posted solutions.

To turn in homework, leave it in the manilla envelope labeled *EC 516 Turn in homework here* in the box outside PHO 435. Graded homeworks will be put a different envelope in the same box, generally by the Monday after the homework was due.

Some homework problems will have computational portions, and the provided solutions will use MATLAB. You are not required to use MATLAB; it is used because the code is relatively easy to read given familiarity with almost any programming language. Be aware that intuitions from the computational problems are often included in the exams.

## Course grade

The grades on the exams, homework assignments, and quizzes are combined with the following weighting to give a preliminary grade:

| | |
|---|---|
| Homework: | 20% |
| Exam #1: | 25% |
| Exam #2: | 25% |
| Final Exam: | 30% |

Some credit may be given for significant, constructive feedback on *Fourier and Wavelet Signal Processing*. The final grade for the course is based on the instructor's assessment of your understanding of the material *at the end of the semester*. This is influenced by your participation and demonstrated engagement and commitment. Assigning final grades is taken very seriously.

## Course content

**ENG EC 416 catalog description:** Introduces techniques of digital signal processing and application to deterministic as well as random signals. Topics include representation of discrete-time random signals, A/D conversion, D/A conversion, frequency domain and z-domain analysis of discrete-time signals and systems, discrete-time feedback systems, difference equation and FFT based realizations of digital filters, design of IIR Butterworth filters, window-based FIR filter design, digital filtering of random signals, FFT-based power spectrum analysis.

**ENG EC 516 catalog description:** Advanced structures and techniques for digital signal processing and their properties in relation to application requirements such as real-time, low-bandwidth, and low-power operation. Optimal FIR filter design; time-dependent Fourier transform and filterbanks; Hilbert transform relations; cepstral analysis and deconvolution; parametric signal modeling; multidimensional signal processing; multirate signal processing.

**This semester's content:** Most of the topics listed above will be covered, with the primary omissions being Hilbert transforms, cepstral analysis, and parametric signal modeling. The aim in topic modifications is to emphasize the principles behind the methods of modern signal processing. In particular, basis representations of signals will be explained as the foundations of approximation, acquisition, estimation, and compression – the fundamental problems in signal processing.

Boston University
Department of Electrical & Computer Engineering

# EC 416/516: Digital Signal Processing
Spring 2018

## Tentative Course Schedule

| Day | Date | | Topics, notes, etc. | FSP sections | Out | In |
|---|---|---|---|---|---|---|
| Mon | 22-Jan | L01 | Geometric view of signal processing, linear algebra review | 1, 2.B | | |
| Wed | 24-Jan | L02 | Approximations by polynomials | 6.2.2-6.2.5 | HW1 | |
| Mon | 29-Jan | L03 | Vector spaces, analysis review | 2.2, 2.A | | |
| Wed | 31-Jan | L04 | Hilbert spaces, linear operators, adjoints | 2.3 | HW2 | HW1 |
| Mon | 5-Feb | L05 | Approximations, projections, and decompositions | 2.4 | | |
| Wed | 7-Feb | L06 | Orthonormal bases | 2.5.1-2.5.2 | HW3 | HW2 |
| Mon | 12-Feb | L07 | Biorthogonal bases, truncations, diagonal estimators | 2.5.3-2.5.5, 6.4 | | |
| Wed | 14-Feb | L08 | Computational principles and review for Exam #1 | 2.6 | | HW3 |
| ***Tue*** | 20-Feb | | **Exam #1** (through Lecture 7, HW 3, Chapter 2) | | HW4 | |
| Wed | 21-Feb | L09 | Hilbert-space view of basic DTSP | 3.1-3.3 | | |
| Mon | 26-Feb | L10 | Discrete-time Fourier transform, Dirac delta function | 3.4.1-3.4.2, 3.A.4 | | |
| Wed | 28-Feb | L11 | Frequency response, phase | 3.4.3-3.4.4 | HW5 | HW4 |
| Mon | 12-Mar | L12 | z-transform | 3.5 | | |
| Wed | 14-Mar | L13 | Multirate sequences and systems | 3.7 | HW6 | HW5 |
| Mon | 19-Mar | L14 | Stochastic sequences and systems | 3.8 | | |
| Wed | 21-Mar | L15 | Minimax polynomial approximation and filter design | 6.2.5-6.2.6 | HW7 | HW6 |
| Mon | 26-Mar | L16 | Discrete Fourier transform | 3.6 | | |
| Wed | 28-Mar | L17 | Computational methods (FFTs) and review for Exam #2 | 3.9 | HW8 | HW7 |
| Mon | 2-Apr | | **Exam #2** (through Lecture 16, HW 7, Chapter 3) | | | |
| Wed | 4-Apr | L18 | Fourier transform, Fourier series, stochastic systems | 4.1-4.5 | | |
| Mon | 9-Apr | L19 | From classical sampling to shift-invariant subspaces | 5.1-5.2 | | |
| Wed | 11-Apr | L20 | Sampling of functions | 5.4 | HW9 | HW8 |
| Mon | 16-Apr | | *Patriots' Day Holiday* | | | |
| Wed | 18-Apr | L21 | Sampling of sequences | 5.3 | | |
| Mon | 23-Apr | L22 | Two-channel orthogonal filter banks | FWSP 1.1-1.3 | | |
| Wed | 25-Apr | L23 | Orthonormal wavelet transforms | FWSP 3.1-3.3 | HW10 | HW9 |
| Mon | 30-Apr | L24 | Sparsity and non-Gaussian signal models | | | |
| Wed | 2-May | L25 | Exploiting sparsity, inverse problems | | | HW10 |
| | | | | | | |
| Mon | 7-May | | **Final Exam** (comprehensive, emphasizing material after Exam #2)<br>9:00am - 11:00am | | | |

Version: 20 Jan 2018

Andres Kwasinski

# *Foundations of Signal Processing*

The landscape of signal processing books is quite populated, and it is a tall order to produce a new book that can constructively add to this landscape. Yet, *Foundations of Signal Processing* not only accomplishes this but also stands out for its distinct, consistent, and strong personality. The book's identity starts from a presentation that is faithful to its title since the topics covered in this book are thorough in explaining the foundations of signal processing. However, foundations can be built in many ways and with different materials. The distinct element in this book is that these foundations are built based on the use of Hilbert space geometry, which allows extending Euclidean geometric insights to signals. As such, the geometry of Hilbert spaces forms the common thread across the multiple topics explained in the book. This allows for a presentation where the topics, such as Fourier representations, sampling, interpolation, approximation, compression, and filter design, can be seamlessly unified across finite dimensions, discrete time, and continuous time.

The use of Hilbert space geometry, while establishing a common thread throughout the book, serves as a pathway to understand the fundamental concepts in signal processing and how they relate to each other. The approach entails a larger weight for mathematical abstraction than what is usually found in a typical book written about signal processing. In much the same way as with interpersonal relations, the identity and personality of this book is distinctive for mathematical abstraction. No personality is widely accepted; in that sense, this book will

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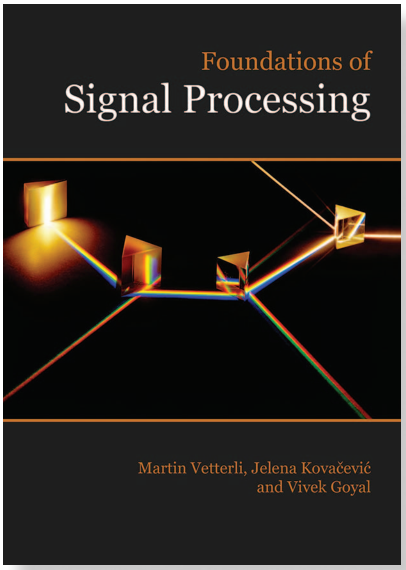
*Date of publication: 29 December 2015*




Martin Vetterli, Jelena Kovačević, and Vivek Goyal
Publisher: Cambridge University Press
Year: 2014, first edition
ISBN: 978-1-107-03860-8.

become a must-have and absolute favorite for a certain type of reader, while other readers may not be willing to appreciate the depth and style of its presentation.

## INTENDED AUDIENCE

*Foundations of Signal Processing* will be greatly enjoyed by the reader who revels in investing effort to find, through the language of mathematical abstraction, a deep understanding of signal processing concepts. This book requires a reader who is filled with curiosity for discovering the deep concepts that form the foundations for signal processing. For these readers, the rewards will be plenty, as this book presents an almost continuum of interrelated deep concepts. At the same time, this book is not for the reader wishing to find a quick explanation or a reference material of a certain signal processing technique. These readers may find an area of improvement in that, for example, the book explains that the Fourier series is the projection onto subspaces associated with frequencies and, from this point, the reader will need to work to the insight that the Fourier series coefficients represent the component of a signal for a particular frequency.

As a textbook, *Foundations of Signal Processing* is so complete in the range of covered topics that it would be applicable to more than one type of course. The book assumes the typical background knowledge on linear algebra that engineering students learn in their first year of studies and some basic knowledge of probability. More advanced topics in vector spaces are given in the second chapter. Because of the reliance on the mathematical abstraction of Hilbert space geometry, at the undergraduate level the book will find a better fit with courses with a clear applied mathematics character.

For the typical signal processing course in the undergraduate curriculum of departments such as electrical engineering and computer engineering, where students would arrive after taking courses in linear systems, circuits, and electronics (with laboratories), this book would work for a minority of students (as an arbitrary guess, maybe a third of the students). Unfortunately, it may be that the majority of students, pressed by their packed class schedules, will be reticent to invest the effort needed to reach the whole depth of the concepts in the book, or they will lack the introspection time to fully realize the implications of the abstract concept presented.

However, *Foundations of Signal Processing* would be the book that bold faculty, who have a love for signal processing, may be waiting for to redesign a signal processing course into one that challenges the students to achieve that deeper level of understanding where mathematical abstraction and technology come together. Since the book links the concepts of Fourier representation with multirate system, generalized sampling theory, signal compression, computational complexity, and wavelets representations, it would serve as a good source for an advanced signal processing course at the upper undergraduate or at the graduate level. It is clear that this book has been written with great care and dedication. It includes more than 160 homework problems (about half of them solved) and 220 examples. Also, the book is supported by companion *Mathematica* software, lecture slides, and an instructor's solution manual, accessible from the website that accompanies the book.

## CONCLUSIONS

*Foundations of Signal Processing* is written by highly accomplished researchers in the field. The book shows not only the authors' expertise but also their passion for signal processing and a genuine interest in communicating and teaching the ins and outs of this area. Beyond its classroom use, *Foundations of Signal Processing* is a must-have for scientists and engineers who have sufficient interest in owning more than a couple books on signal processing. For scientists and engineers working in signal processing, it will be a pleasure to read, even when already familiar with the presented concepts. Over time, because of its distinct, consistent, and strong personality, *Foundations of Signal Processing* may be considered a "classic" book on signal processing.

## REVIEWER

*Andres Kwasinski* (axkeec@rit.edu) is an associate professor in the Department of Computer Engineering, Rochester Institute of Technology, New York.

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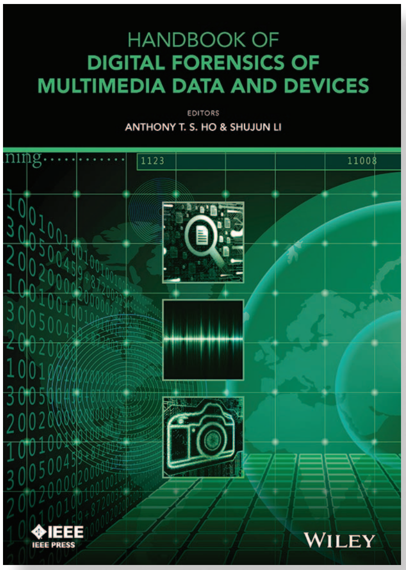
Luisa Verdoliva

# *Handbook of Digital Forensics of Multimedia Data and Devices*

The recovery and analysis of digital information has become a major component of many criminal investigations today. Given the ever-increasing number of personal digital devices, such as notebooks, tablets, and smartphones, as well as the development of communication infrastructures, we all gather, store, and generate huge amounts of data. Some of this information may be precious evidence for investigation and may be used in courts. During the last several decades, increasing research efforts have therefore been dedicated toward defining tools and protocols for the analysis of evidence coming from digital sources.




Anthony T.S. Ho and Shujun Li, Editors
Publisher: Wiley-IEEE Press
Year: 2015
ISBN: 978-1-118-64050-0
704 pages.

## BRIDGING THE GAP BETWEEN COMMUNITIES

Despite this fast-growing momentum, digital forensics has much suffered from the cultural gap between its major core disciplines: computer science and signal processing. For years, the focus on computer science methods and tools has been dominant. In comparison, signal processing research entered the digital forensics arena only recently, in large part to analyze the underlying structure of visual and audio evidence.

*Handbook of Digital Forensics of Multimedia Data and Devices,* edited by Anthony T.S. Ho and Shujun Li, attempts to link research in these two communities by providing a wide-ranging and up-to-date reference for both researchers and practitioners. The digital forensics ecosystem is surveyed with the necessary breadth in the first half of the book, by exploring all phases of the forensics workflow and detailing several tools of interest. Gaining insight into these aspects is of paramount importance for practitioners, but also for academic researchers who are often not aware of the standard practices and processes required to preserve digital evidence, e.g., for legal purposes. Similarly, practitioners have the opportunity to discover the state of the art in forensics research in the second half of the book, which is written from a signal

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