DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
University of Washington
Spring Quarter 2022

Course: EE P 518
Title: Discrete-Time Signal Processing for Machine Learning **Credits:** 4 Units
Prerequisite: EE PMP Introductory class 502, or similar.
Class website: https://canvas.uw.edu/courses/1547219

Why take this class? This class is intended for engineers and scientists within and outside Electrical Engineering. What is it useful for? Some examples, from basic to advanced: How many engineers and scientists know that linear interpolation is a poor way to increase sample rate? And why are cubic splines also, under most conditions, a bad choice? How can you do a better job of interpolation? What is an optimal interpolator and what metric space is it optimal for? What are the best signal representations for machine learning systems which generalize well, that is do well outside their training data? How do linear time invariant systems generalize?

Why is a Fourier transform and frequency important? How does the concept of frequency have principled depth which goes way beyond simply decomposing arbitrary signals into oscillating components? Yet what are the limitations of Fourier transforms, and how do more general *z*-transforms and perhaps wavelets get around these limitations?

Knowing the theory of *z*-transforms can, among many other applications, allow you to potentially massively decrease the number of operations needed for changing the sample rate of signals, images, and video. This same transform can also be applied to equalizing communication channels with magnitude and phase distortion. Why is phase distortion so important? What is the difference between phase delay and group delay? Under what conditions are phase delay and group delay identical and why is that equality such an important thing to achieve, unusually by well-known computer algorithms which approximately equalize channels for high bit rate communication?

A fast Fourier transform is a well-known fast implementation of a discrete Fourier transform. How does the fast Fourier transform potentially massively speed up the discrete Fourier transform? But how is a discrete Fourier transform (and hence a fast Fourier transform) often a really poor approximation of a true discrete-time Fourier transform? Why is a fast Fourier transform usually unsuitable for signal filtering? What are some better and often much more efficient filters, which also won't ring close to their transition frequencies? What is a design criteria and metric space (hint: it's not Euclidean or l_2) which allows for, in practice, the more generally useful frequency filter designs? And why do convolutional neural networks, as used in modern machine learning, often seem to automatically learn Fourier basis functions.

Also: How can you best characterize signals from time-varying systems, like real-world examples of speech, patches of images, and video? Why do Fourier transforms not fit this problem and how can they be modified? How do adaptive, Wiener, and Kalman filters fit this problem? Why are more recent and popular concepts like convolutional[1] and recurrent[2] neural and deep networks potentially more than simply hype and perhaps useful for your future engineering work?

EE 518 Prerequisite: PMP 502 or similar such as *recent undergraduate signal processing or other quantitative, particularly Fourier transform, theory background is required. You need to be comfortable with complex numbers, know at least elementary matrix theory, and know what a Fourier transform is.* If you have an undergraduate background in DSP, this class will still be challenging. For example, it will cover graduate level DSP concepts such as signal processing for signals from time-varying systems, multirate signal processing, and non-Euclidean decomposition spaces, which are needed to understand much of the more advanced signal processing, control, and related literature.

This EE 518 course quickly reviews linear time-invariant systems, discrete-time signals, sampling, Fourier transforms and bilateral *z*-transforms. If you don't have this background, these two inexpensive books can be suitable for quick and intense self-study: Hayes, **Schaum's Outline of Theory and Problems of Digital Signal Processing**, and, more basic, Hsu, **Schaum's Outline of Signals and Systems**, 2nd Edition. Note that some on-line courses also provide fine background, but most don't provide the kind of in-depth problem solving that will be central to EE 518.

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[1] For first use of convolution within artificial neural networks, see right side of figure 1 of Homma, Atlas, and Marks, "An Artificial Neural Network for Spatio-Temporal Bipolar Patterns," *Proc. Neural Information Processing Systems (NIPS)*, 1987.

[2] For an early paper on recurrent networks, which also overlaps statistical signal processing, see: Connor, Martin, and Atlas. For a recent recurrent net paper, see this example just published in *Proc. Neural Information Processing Systems*, Nov. 2016. For a more general modern background see, for example, http://www.deeplearningbook.org/ .

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Course: EE P 518
Title: Principles of Discrete-Time Signal Processing
Credits: 4

Course Web Site: https://canvas.uw.edu/courses/1547219

Course Description: This class addresses the representation, analysis, and design of discrete time signals and systems. The major concepts covered include: Discrete-time processing and modeling of continuous-time signals and systems; decimation, interpolation, and sampling rate conversion; time-and frequency-domain design techniques for non-recursive (FIR) filters; prediction; discrete Fourier transforms, fast Fourier transform (FFT) algorithms and turning block into stream processing; short-time Fourier analysis and filter banks; multirate techniques; and various applications of these techniques. Some of the class homework will make use of Python or MATLAB™ programs on computers within the UW or on your work or home computer. The course grade will be based upon weekly homework, a midterm exam, and the final exam. Prerequisites: ECE P 502 class. A mathematical/quantitative undergraduate degree, with knowledge of Fourier transforms, and some discrete math and linear algebra.

Lecture Time: Thursday 6:00–8:50 pm likely via a class Zoom link, with a break at about 7:20–7:35 pm.
Instructor: Prof. Les Atlas, atlas@uw.edu
Atlas Office Hours: T 5:00–5:50 pm
Optional Discussion/Problem Session: To be arranged

Discussion/Problem Session: To be arranged
Teaching Assistant: To be arranged
TA Office Hours: To be arranged

Required Textbooks:
Oppenheim and Schafer, **Discrete-Time Signal Processing**, 3rd Edition, Pearson Prentice Hall, 2010.

Homework: Weekly homework is due in class on Thursday (no later than 6:00 pm on Thursday at the start of discussion), starting with Homework #1, due Thursday 4/7, 6:00 pm. Solutions will be posted on the class website. Solutions will be covered in the same Thursday discussion section. Late Homework will not be accepted.

Midterm Exam: 6:00-8:50 on Thursday, May 5. Open books and notes. No turned-on electronic devices (calculators, phones, etc.) allowed.

Final Exam: 6:00-8:50 pm on Tuesday, June 7. Open books and notes. No turned-on electronic devices (calculators, phones, etc.) allowed.

Course Grading:
- Discussion contribution: 5%

Each lecture will have small group breakout sessions where students will discuss problems. Each student is expected to present a summary of their group’s discussion.
- Weekly Homework: 15%
- Midterm Exam (5/5): 30% (Open book and notes.)
- Final Exam (6/7): 50% (Open book and notes.)

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Date	Week	Topic (subject to change)	Oppenheim *et al* chapter sections
03/31/22	1	Introduction, discrete-time (DT) sequences, DT systems, properties, LTI systems, convolution sum, difference equations, eigenfunctions, frequency domain, frequency response, Fourier operator, Fourier transform symmetries, and Fourier transform theorems	1, 2.0-2.9
04/07/22	2	*z*-transforms, region of convergence, inverse *z*-transforms, properties and uses of the *z*-transform	3
04/14/22	3	Sampling, DT vs. CT processing, downsampling, upsampling, sample rate conversion	4.0-4.6
04/21/22	4	Multirate signal processing, A/D & D/A conversion, and polyphase structures	4.7-4.8, 5.0-5.2
04/28/22	5	Frequency response of LTI systems, phase and group delay, pole/zero diagrams, all pass and minimum phase systems	5.3-5.6
05/05/22	6	**Midterm Exam: 6:00-8:50.** **Covers all lectures, homework, and discussion through Week 5**	
		Review Midterm Solutions 9:00-9:50	
05/12/22	7	Generalized linear phase and FIR types, FIR filter design by windowing	5.7, 7.1, 7.5-7.6
05/19/22	8	Optimal (equiripple) approximations for FIR filters	7.7-7.9, and Atlas' Notes
05/26/22	9	Discrete Fourier series, circularity, the discrete Fourier transform (DFT), spectral analysis with the DFT	8.0-8.7, 10.1-10.2
06/2/22	10	The fast Fourier transform (FFT) and fast convolution. Tutorials on linear prediction, Kalman filtering, and adaptive systems which use gradient descent.	9.3-9.4 Atlas' Notes
Tuesday **06/07/22**	**Final Exam: 6:00-8:50** **Covers all material from Week 1 through Week 10, with less detail on Week 10** **Review Final Exam Solutions 9:00-9:50**		