MUS320: Introduction to Digital Audio Signal Processing

Center for Computer Research in Music and Acoustics (CCRMA)
Department of Music, Stanford University

Autumn Quarter, 2019

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Music 320: Introduction to Digital Audio Signal Processing

1 Course Description

Music 320 is a two-quarter first-course in digital signal processing with applications in computer music and audio.

The lectures present fundamental elements of digital audio signal processing, such as sinusoids, spectra, the Discrete Fourier Transform (DFT), digital filters, $z$ transforms, transfer-function analysis, and basic Fourier analysis in the discrete-time case. Matlab is used for in-class demonstrations and homework/lab assignments. The labs focus on practical applications of the theory, with emphasis on working with waveforms and spectra, ”getting sound”, and developing proficiency in the matlab language.

Prerequisites: High-school level algebra and trigonometry, some calculus, and prior exposure to complex numbers.

Time and Place

Term: Autumn and Winter Quarters
Location: CCRMA Classroom (Knoll 217)
Lectures: Tuesdays and Thursdays 3:00–4:50 PM
Units: 4
Instructor: Jonathan Abel (abel@ccrma.stanford.edu) and Dave Berners (dberner@ccrma.stanford.edu)
TA: Doga Cavdir (cavdir@ccrma.stanford.edu)
Office Hours: See “Office Hours and Getting Help”, 2.4 below
Schedule: See “Lecture Outline, Schedule, and Assignments”, 4 below
2 Administrative Information

2.1 Announcements

Class announcements are often made via email. If you missed the sign-up sheet on the first day, please send your email address to the TA.

2.2 Weekly Homework

There will be (roughly) weekly reading and problem/lab assignments. The assignments cover a combination of theory exercises and lab work. The lab assignments typically require programming in Matlab.

Homework/Lab assignments will normally be assigned on Friday and due the following Friday in the mus320 mailbox (located in the Knoll, central wing, second floor). Please put your homework in the corresponding folder (e.g. homework #1 goes in folder titled hw1).

Lab assignments will require the use of the coursework[1] website to upload the necessary code and data.

Students are encouraged to discuss the homework assignments with each other. It is fine to learn from a classmate how to solve any of the homework problems, but each student is responsible for carrying out and writing up the assignments individually. It is an Honor Code violation to copy the work of others.

2.3 Grading

Grading will be based on the homeworks/labs, and final. The weight of the final is often adjusted, but 60% weighting on homeworks/labs and 40% weighting on the final is typical.

2.4 Office Hours and Getting Help

TA weekly office hours are Thursday evenings 5:00-7:00 PM in the Ballroom (Knoll 315), and by appointment. Office hours for the instructors are primarily Tuesdays and Thursdays before and after class. More private meetings may be arranged via email. You are also welcome, of course, to catch us whenever you see us at CCRMA. In general, email is the surest and fastest way to reach us. As a first option, please email your friendly TA regarding homework questions.

Remember that students are encouraged to freely discuss the homework assignments, but that each student is responsible for individually completing and writing up each assignment. (See 2.2 above.)

2.5 Computer Usage

Many homework and all lab exercises will be computer based. All students may obtain a computer account at CCRMA in order to use the computer facilities. It is also possible to work entirely on your own computer, as long as you have the necessary software installed on it. Since Web access to some course materials is restricted to the Stanford domain, you should have at least one Stanford computer account.

Here is how to obtain a CCRMA computer account:

1. Execute the `perl` script

   https://ccrma-mail.stanford.edu/cgi/newuser.pl

   from any CCRMA workstation, and enter the requested information. You need an existing CCRMA user (such as the TA) to log in for you while you complete this step.

2. Next, fill out a printed copy of the User Registration Form, available from the TA, or from /usr/ccrma/next/Library/CCRMA-Templates at CCRMA.

3. **Turn in the completed form** to the TA.

   The TA will obtain the instructor’s signature and forward the form to Fernando (nando@ccrma), who will set up your account and activate your Stanford ID cards for after-hours CCRMA access. This process should take on the order of a day.

   Once you have your account, please log in at CCRMA and take a look at the User’s guides\(^2\) tab in the left-frame menu of the main CCRMA website to learn more about computer usage and other facilities at CCRMA.

2.6 Students with Documented Disabilities

Students who have a disability which may necessitate an academic accommodation or the use of auxiliary aids and services in a class, must initiate the request with the Student Disability Resource Center (SDRC), located within the Office of Accessible Education (OAE). The SDRC will evaluate the request with required documentation, recommend appropriate accommodations, and prepare a verification letter dated in the current academic term in which the request is being made. Please contact the SDRC as soon as possible; timely notice is needed to arrange for appropriate accommodations. The Office of Accessible Education is located at 563 Salvatierra Walk (phone: 723-1066; TDD: 725-1067).

\(^2\)http://ccrma.stanford.edu/guides/
3 Textbooks

The first half of Music 320 is based on assigned chapters of

[Mathematics of the Discrete Fourier Transform (DFT),] by
Julius O. Smith

The second half of the course is based on assigned chapters of

[Introduction to Digital Filters,] by Julius O. Smith

See the schedule below for the list of assigned chapters. Both books are fully available on-line. Softcover versions are available from Amazon.com.
4 Lecture Outline, Schedule, and Assignments

Note: The online version of this schedule contains hyperlinks to all reading, lecture videos, and assignments.

To obtain printable versions of the assignments and solutions from off-campus locations, you can use commands such as

```
sscp you@ccrma-gate.stanford.edu:/usr/ccrma/web/html/courses/320/hw/hw1/hw1sol.pdf .
```

- Week 1 - Course Overview; Mathematics of Signal Representation; Introduction to Matlab
  - Assigned Reading
    * This course overview
    * Chapter 1 (DFT Intro) of *Mathematics of the DFT*
    * If you are not comfortable with the decibel scale, read Appendix B (Logarithms and Decibels)
    * Optional: Appendix H (Sampling Theory)
  - Lab presentation 0: Introduction to Matlab
    * Regarding the Matlab intro, if you do not know the rules of matrix multiplication, read Appendix H (Matrices)
    * Matlab Documentation
    * Read the first two sections of Appendix J (Matlab Examples) in *Mathematics of the DFT*
    * Do Lab Assignment if you are new to Matlab.
  - Assignment 1 (complex number problems)

- Week 2 - Euler, Exponentials, and Sinusoids
  - Chapter 3 (Proof of Euler’s Theorem) of *Mathematics of the DFT*
  - Chapter 4 (Sinusoids and Exponentials)
  - Assignment 2

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[1] https://ccrma.stanford.edu/~jos/intro320/LecturesAssignments.html
[12] https://ccrma.stanford.edu/~jos/hw120/
• Week 3 - Vectors and Geometrical Signal Theory
  – Chapter 5 (Geometric Signal Theory) of Mathematics of the DFT
  – Assignment 3

• Week 4 - Discrete Fourier Transform (DFT), Fourier Theorems, Convolution and Correlation
  – Chapter 6 (The DFT Derived)
  – Chapter 7 (Fourier Theorems for the DFT)
  – Assignment 4

• Week 5 - DFT Applications, Spectrograms and Correlograms
  – Chapter 8 (DFT Applications) of Mathematics of the DFT
  – Overlap Add (https://ccrma.stanford.edu/~jos/sasp/Overlap_Add_OLA_STFT_Processing.html)
  – Assignment 5

• Week 6 - Linearity and Time Invariance; Time-Domain Representations
  – Chapters 1 and 2 of Introduction to Digital Filters
  – Chapter 4 (Linearity and Time Invariance) and Chapter 5 (Time Domain Filter Representations) of Introduction to Digital Filters
  – Optionally peruse the Music 421 overheads pertaining to acyclic convolution
  – Assignment 6

• Week 7 - Analysis of Digital Filters
  – Chapter 6 (Z-transform),
  – Chapter 6 (Transfer Function Analysis)
  – First three sections of Chapter 8 (Pole-Zero Analysis)
  – Chapter 9 (Implementation Structures),
  – Assignment 7

• Week 8 - The S-plane, Z-plane and Frequency Response.
  – Chapter 7 (Frequency Response Analysis)
  – Assignment 8

• Week 9 - Bode plots and Bilinear Transform canonical first-order filters.
  – Appendix I.3 (Bilinear Transform)

1 https://ccrma.stanford.edu/~jos/filters/filters.html
– Appendix B.1 Elementary Filter Sections
– Appendix B.2 Allpass Filter Sections
– Appendix B.3 DC Blocker
– Assignment 9

• Week 10 - Parametric Filter Design, Catch-up, Review
  – Appendix B.4 Shelving Filters
  – Appendix B.5 Peaking Equalizers
  – Assignment 10

• Final Exam - Thursday, Dec. 12, 2018, 12:15-3:15 PM, CCRMA Classroom. The exam will cover:
  – Assigned readings, homework problems, and laboratory assignments.
  – The exam will be closed book, except that you may bring an 8.5” by 11” sheet of paper, covered front and back with handwritten notes.
  – No calculators allowed (you shouldn’t need one).