MUS320A&B: Introduction to Digital Audio Signal Processing

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

320A (spectra): Autumn Quarter
320B (filters): Winter Quarter
2017–2018

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Music 320 A & B: 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.

2 Time and Place

Term: Autumn and Winter Quarters
Location: CCRMA Classroom (Knoll 217)
Lectures: Tuesdays and Thursdays 3:00–4:50 PM
Units: 3–4
Instructor: Julius O. Smith (jos@ccrma.stanford.edu)
TA: Orchi Das (orchi@ccrma.stanford.edu)
Office Hours: See “Office Hours and Getting Help" below
Schedule: See “Schedule and Pointers" below

2.1 Announcements

Class announcements are often made via email. For this we are presently using Piazza:

https://piazza.com/stanford/fall2016/music320a/home

If you signed up for the class in axess before the first day of classes, you should receive an invitation from Piazza to join the class (using the email address known to axess). Otherwise, please join by visiting the above URL and entering your preferred email address.

http://ccrma.stanford.edu/~jos/intro320/Office_Hours_Getting_Help.html
http://ccrma.stanford.edu/~jos/intro320/
2.2 Assignments

There are five homework/lab assignments, each covering roughly two weeks of the course. In each two-week “section”, the first week is devoted primarily to theory while the second week is focused more on software and applications. Thus, each assignment contains both a theory and laboratory part. The lab portion typically requires programming in matlab.

Each assignment is typically announced on Tuesday in the first week of the section. The theory part is normally due the following Tuesday at 3:15 pm in the 320 mailbox (located in the Knoll, central wing, second floor, facing the printer). The lab part is normally due by midnight the following Friday, i.e., at the end of the two-week section.

For lab assignments, we will be using the Canvas website. To sign up, go to the Canvas website and find Music320A. Once you are enrolled in the class, you can upload your matlab files in the “drop box” on the left menu.

See §2.5 below regarding obtaining help with theory and lab assignments.

Regarding late homeworks, 7 free late days are allowed (with hours rounded up to the nearest day). Late homeworks beyond this will not be accepted. Only up to 3 late days can be used for any one assignment. When using late days, students are required to write the number of late days used at the top of the assignment (date and time).

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 Exams

The final examination will be held in the CCRMA Classroom (Knoll 217) on the University-assigned date, also listed for convenience in the class schedule (§6 on page 4).

2.4 Grading

Grades are based on the homeworks/labs (60%), and the final exam (40%). There are also bonus points available based on general participation. The weightings may be changed as we see fit.

2.5 Office Hours and Getting Help

We will be using Piazza for sharing answers to posted questions with the whole class. To sign up, see the 320 Piazza site. It is free and allows you to view past questions from other students, and discuss questions together. Try it first for any homework questions you may have. You are also welcome, of course, to catch us whenever you see us at CCRMA, such as during office hours, etc.

TA weekly office hours will be announced in class and via email to the class. Meetings with JOS are arranged via email for half-hour slots after class, or other times when necessary.

References:

https://canvas.stanford.edu
https://www.piazza.com
https://piazza.com/stanford/fall2016/music320a/home
2.6 Computer Usage

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. However, note that some course materials are restricted to on-campus access, so you should have at least one Stanford computer account from which you access those.

Here is how to obtain a CCRMA computer account:

https://cm-knoll.stanford.edu/usersignup

Note: This link only works at CCRMA.

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

3 Textbooks

Music 320A (fall) is based on assigned chapters of

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

Music 320B (winter) is based on assigned chapters of

Introduction to Digital Filters by Julius O. Smith

See § for the list of assigned chapters. Both books are fully available on-line. Softcover versions are available from Amazon.com.

4 The Partially Flipped Classroom

With the lectures recorded, class time is freed up for other activities. Here is how a typical “partially flipped class” is organized:

- Q&A session on the reading/video content
- Review of main points in the reading/videos
- Demos in support of the reading/videos
- Presentation of the homework/lab assignment
- Worked problems similar to those in the homework
- Matlab session on theory/lab-related topics
- Live coding in matlab

Additional available time may be devoted to

- More demos
- More discussion

http://ccrma.stanford.edu/guides/
http://ccrma.stanford.edu/~jos/mdft/
http://ccrma.stanford.edu/~jos/filters/
• “Backwards learning” examples:
  • Plugins using spectral techniques
  • Faust language and some of its examples
• More on applications and why all this is useful
• Preview material coming up
• General in-class discussion
• Getting to know your fellow class-members better

5 A Recipe for Learning

Learning something new requires multiple passes on the material. For example:

1. Do the assigned reading at a fixed pace to get a picture of what’s covered
2. Watch the lecture videos, pausing and taking notes on anything newly learned
3. Make a first pass on the homework, flagging and skipping when stuck on a problem
4. Discuss nonobvious homework problems with other students, the TA, and/or JOS
5. Write up the homework problems, everything now understood
6. Exam prep: Reread the text for full comprehension
7. Exam prep: Reread your notes
8. Prepare your one-page summary of the course allowed in the exam
9. Exam experience: Exercise in problem solving using the material

These multiple engagements result in a good amount of learning.

6 320A Schedule and Pointers

Note: The online version\(^9\) 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

\[
\text{scp you@ccrma-gate.stanford.edu:/usr/ccrma/web/html/courses/320/hw/hw1/hw1.pdf}.
\]
\[
\text{scp you@ccrma-gate.stanford.edu:/usr/ccrma/web/html/courses/320/hw/hw1/hw1sol.pdf}.
\]

For more info, see [https://ccrma.stanford.edu/guides/remoteaccess/](https://ccrma.stanford.edu/guides/remoteaccess/).

You can alternatively use VPN\(^{10}\) (Virtual Private Network) access.

\(^9\)[https://ccrma.stanford.edu/~jos/intro320/Lectures_Assignments.html]
\(^{10}\)[https://uit.stanford.edu/service/vpn]
6.1 Section 1: Course Overview, Signal Math, Intro to Matlab

A “section” is typically two weeks in duration, with the first week devoted primarily to theory, and the second primarily to software and applications.

- **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)
  - **Assignment** (complex number problems)

- **Supplementary Demos, Reading, and Exercises**
  - You have already encountered the functions sine and cosine \([\sin(\theta) \text{ and } \cos(\theta)]\) in your high-school math background. We will be using sums of these functions as fundamental building-blocks for all kinds of signals in this class. For this purpose, \(\theta\) will be a linear function of time, i.e., \(\theta = \omega t + \phi\), where \(\omega\) is the **radian frequency** (frequency in radians per second), and \(\phi\) is the **phase**. We call any function of the form \(x(t) = A \cos(\omega t + \phi)\), where \(A\) is an arbitrary **amplitude**, a **sinusoid**. The essence of **Fourier theory** is that any signal can be expressed as a sum of sinusoids. The history of this development is fascinating and recommended. See “The Acoustic Origins of Harmonic Analysis” by Olivier Darrigol for an excellent treatment (published in the Archive for History of the Exact Sciences, vol. 61, no. 4, July 2007).
  - Discrete Fourier Transform Demo (Truncated Sinc Spectrum)
  - Supplementary Demo: Building up a Spectrum Analyzer in WebGL
  - For an educational Matlab GUI on **sinusoids**, download sindrill from the Educational Matlab GUIs collection at Georgia Tech. There are other nice Matlab-based exercises that can use later in the quarter and next quarter.
  - There is another Matlab GUI illustrating **Fourier series** approximations, i.e., using sums of sinusoids to approximate classic waveforms such as square wave, sawtooth, and triangle. Download fseriesdemo from the Educational Matlab GUIs collection at Georgia Tech.

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1. [https://ccrma.stanford.edu/courses/320/](https://ccrma.stanford.edu/courses/320/)
4. [https://ccrma.stanford.edu/~jos/mdft/Logarithms_Decibels.html](https://ccrma.stanford.edu/~jos/mdft/Logarithms_Decibels.html)
5. [https://ccrma.stanford.edu/~jos/hw320/](https://ccrma.stanford.edu/~jos/hw320/)
8. [https://acko.net/files/gltalks/toolsforthought/#29](https://acko.net/files/gltalks/toolsforthought/#29)
9. [http://users.ece.gatech.edu/mcclella/matlabGUIs/ZipFiles/sindrill-v209.zip](http://users.ece.gatech.edu/mcclella/matlabGUIs/ZipFiles/sindrill-v209.zip)
10. [http://users.ece.gatech.edu/mcclella/matlabGUIs/](http://users.ece.gatech.edu/mcclella/matlabGUIs/)
11. [http://users.ece.gatech.edu/mcclella/matlabGUIs/ZipFiles/fseriesdemo-v130.zip](http://users.ece.gatech.edu/mcclella/matlabGUIs/ZipFiles/fseriesdemo-v130.zip)
12. [http://users.ece.gatech.edu/mcclella/matlabGUIs/](http://users.ece.gatech.edu/mcclella/matlabGUIs/)
Chapter 2 (Complex Numbers)

If you need more practice with complex numbers, work some Khan Academy exercises.

For a Matlab GUI providing complex-number drills, download zdrill from the Educational Matlab GUI collection at Georgia Tech.

Here also are some prerequisite-level Khan Academy exercises on dealing with polynomials (you can skip “Synthetic Division” and stop before “Partial Fraction Expansions” since we get to that in 320B next quarter).

For more advanced math studies, beyond what’s needed for this course, but needed for more advanced signal processing: Georgia Tech Online Mathematics Textbooks.

- Lecture Videos:

  IMPORTANT NOTICE: The videos are hosted on YouTube and they use annotations for corrections and supplementary information. These annotations are not supported on mobile devices. It is therefore unfortunately important to view these videos in a Web browser on a desktop/laptop computer.

- Music 320A Overview (first class recording in fall 2014)
- Introductory Demonstrations for 320A and 320B
- Administrative overview (this document, discussed only in class (no video), so definitely read it if you missed the first class
- Intro to the Fourier Transform (FT) and the Discrete Fourier Transform (DFT) [30:52]
- Albert Michelson’s Harmonic Analyzer [First three: 3:30+5:00+3:30]
- Euler’s Identity, Complex Sinusoids [9:43]
- Complex Plane Intro [4:53]
- Euler’s Identity Corollaries [12:38]
- Review of DFT and Euler Identity Intro presented 10/02/2014
- Introduction to Piazza, Coursework, and Matlab

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23 https://ccrma.stanford.edu/~jos/mdft/Complex_Numbers.html
24 https://www.khanacademy.org/math/algebra2/complex-numbers-a2
25 http://users.ece.gatech.edu/mcclella/matlabGUIs/ZipFiles/zdrill-v210.zip
26 http://users.ece.gatech.edu/mcclella/matlabGUIs/
27 https://www.khanacademy.org/math/algebra2/polynomial_and_rational
28 http://people.math.gatech.edu/~cain/textbooks/onlinebooks.html
29 https://www.youtube.com/watch?v=jo6qZk7zB3I&list=PLsBNrw11MWkYH5pb5pwq2rjzg3RyXysPY
30 https://www.youtube.com/watch?v=hSkdaqNQH6N
31 https://ccrma.stanford.edu/courses/320/
32 https://www.youtube.com/watch?v=Gw6654dYTID8
33 https://www.youtube.com/watch?v=NAAsM30MAHLg&list=PL0lNSsTTU1k20Y09Mck-i5rHqGfN5AeEyQ
34 https://www.youtube.com/watch?v=ugrZu6f6qQ
35 https://www.youtube.com/watch?v=gCAl_rUWbuv
36 https://www.youtube.com/watch?v=1zWEO-ASWng
37 https://www.youtube.com/watch?v=kF1BeUq-den0&list=PLsBNrw11MkaGkKJ0rnx--jPm8s5Cdpp
38 https://www.youtube.com/watch?v=uLPc22shNM
* Regarding the Matlab intro, if you do not know the rules of matrix multiplication, read Appendix H (Matrices)\[^39\]
* Matlab Documentation\[^40\]
* Read the first two sections of Appendix J (Matlab Examples)\[^41\] in Mathematics of the DFT
* Do Lab Assignment\[^42\] if you are new to Matlab.

[URL footnotes are mostly suppressed below, but links persist in the online version of this page.]

[^39]: https://ccrma.stanford.edu/~jos/mdft/Matrices.html
[^41]: https://ccrma.stanford.edu/~jos/mdft/Matlab_Octave_Examples.html
[^42]: https://ccrma.stanford.edu/~jos/hw320/