Contents

1 Course Description 1
   1.1 Prerequisites ................................................................. 1
   1.2 When, Where, Who .......................................................... 1

2 Administrative Information 2
   2.1 Announcements ............................................................... 2
   2.2 Weekly Homework ............................................................ 2
   2.3 Exams ............................................................................. 2
   2.4 Grading .......................................................................... 2
   2.5 Office Hours and Getting Help ............................................ 2
   2.6 Units .............................................................................. 3
   2.7 Final Project (Optional 4th Unit) ........................................ 3
   2.8 Required Software ............................................................ 3
   2.9 Important Pointers ............................................................ 4

3 Reading 4

4 Schedule and Assignments 4
Music 421A
Spectral Audio Signal Processing

1 Course Description

Music 421A (EE 367B): Time-Frequency Audio Signal Processing

Music 421A covers typical spectrum analysis and processing arising in digital audio research. The main topics addressed are practical time-frequency analysis using Fast Fourier Transforms (FFT), spectral foundations for Music Information Retrieval (MIR) and Audio Machine Learning, sound synthesis by means of spectral models, and FFT-based signal processing.

1.1 Prerequisites

The only prerequisite for Music 421 is Music 320\(^1\) or equivalent (prior exposure to complex numbers, sinusoids, Fourier theory, linear systems theory, digital filters, and z-transform analysis). In Electrical Engineering (EE), more than adequate coverage of Fourier theory is provided by EE 261\(^2\) (Fourier Transform and its Applications). The EE Digital Filtering course, EE 264,\(^3\) covers prerequisite background pertaining to sampling and digital filtering, and there is some overlap of topics. Matlab\(^4\) or Octave\(^5\) is required for homework assignments, and is recommended for programming project work.

1.2 When, Where, Who

Class and office-hours meetings are held online over Zoom.\(^6\)

<table>
<thead>
<tr>
<th>Term: Spring Quarter</th>
<th>Location: Zoom meetings online</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time: Tuesdays and Thursdays, 3:00-4:15 PM</td>
<td></td>
</tr>
<tr>
<td>Instructor: Julius Smith (<a href="mailto:jos@ccrma.stanford.edu">jos@ccrma.stanford.edu</a>)</td>
<td></td>
</tr>
<tr>
<td>TA: Orchi (<a href="mailto:orchi@ccrma.stanford.edu">orchi@ccrma.stanford.edu</a>)</td>
<td></td>
</tr>
<tr>
<td>TA Office Hours: Wednesday evenings 4:00-6:00 PM</td>
<td></td>
</tr>
<tr>
<td>JOS Office Hours: ideally after class on Tu, Th afternoons</td>
<td></td>
</tr>
<tr>
<td>Website: <a href="https://ccrma.stanford.edu/courses/421/">https://ccrma.stanford.edu/courses/421/</a></td>
<td></td>
</tr>
</tbody>
</table>

\(^{1}\)http://ccrma.stanford.edu/courses/320/
\(^{2}\)http://www.stanford.edu/class/ee261/
\(^{3}\)http://www.stanford.edu/class/ee264/
\(^{4}\)http://www.mathworks.com/
\(^{5}\)http://www.octave.org/
\(^{6}\)https://stanford.zoom.us/
2 Administrative Information

2.1 Announcements

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

https://piazza.com/stanford/spring2020/music421a/home

You should have received an invitation from Piazza to join the class after you signed up for it in axess (using the email address known to axess). Otherwise, please join by visiting the above URL and entering your preferred email address.

2.2 Weekly Homework

There will typically be weekly to bi-weekly assignments consisting of reading, working theory problems, and carrying out lab exercises. The lab portions typically require programming in matlab.

The theory and lab assignments are normally assigned together on Thursdays. The theory part is due eight days later on Friday at 9 am, submitted on Canvas. The lab part is due on the same day at midnight.

For lab assignments, we will be using the Canvas website. To sign up, go to the Canvas website and find Music421a. 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 be penalized at 5% per day. When using late days, 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

There is no midterm or final examination this year. The one-week delay in starting spring quarter will be compensated by eliminating final-exams week.

2.4 Grading

Grades are S/NC this year, based on the homeworks/labs and class attendance/participation.

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 421A 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.

7https://canvas.stanford.edu
8https://www.piazza.com
9https://piazza.com/stanford/spring2020/music421a/home
TA weekly office hours are Wednesday evenings 4:00-6:00 PM in the Zoom meeting set up by the TA. Meetings with JOS are arranged via email for half-hour slots after class, or other times as needed.

2.6 Units
You may sign up for 3 or 4 units. Three units involves only in-class time, assigned reading, any assigned videos, and homework/lab problems. A fourth unit adds an independent project and report, which can be based on reading and/or lab work.

2.7 Final Project (Optional 4th Unit)
The purpose of the final project is to go beyond the content of the lectures and assigned reading in the direction most interesting to you. Your project can be on any topic related to lectures and assignments. A one-page project specification/proposal is due by the 4th class meeting, and the final written report is due by the end of the quarter. You are also invited to present your project results during the last class. There are two primary project types:

• Outside reading and report
• Programming project and report

Your project can consist of any combination of the above components. A research-oriented project typically consists of the following main phases:

Phase I: Outside reading (explore the topic)
Phase II: Software project (implement your best ideas from Phase I)
Phase III: Write-up

It is normal to iterate the above phases to some extent, rather than to perform them entirely sequentially.

• Must be related to lecture/lab topics (FFT+Audio)
• One-page project proposal due by the end of the second week of classes
• Final written report due by the end of the quarter
• Oral presentation during the last week of classes invited!

2.8 Required Software
Laboratory assignments in this course will require programming in the matlab language. For personal computers, the student version of Matlab\textsuperscript{10} is priced well below other versions, and you can alternatively get by fine with Octave,\textsuperscript{11} a free-software version of basic matlab. You are also welcome to work the assignments in Python, submitting your Jupyter Notebooks on Canvas.

\textsuperscript{10}http://www.mathworks.com/products/studentversion/
\textsuperscript{11}http://www.octave.org/
2.9 Important Pointers

The *course schedule and outline*\(^\text{12}\) in §4 on page 4 (also reachable from the class home page\(^\text{13}\)) lists the following information:

- Assignments
- Schedule of lectures
- Pointers to all lecture overheads and the online text.

The class home page further contains pointers to sound examples and related items of interest online.

3 Reading

The text for this course is *Spectral Audio Signal Processing*\(^\text{14}\) by JOS. It is available online in HTML format, and the printed book\(^\text{15}\) can be ordered if desired. All reading assignments will be specified in the course schedule and outline §4.

4 Schedule and Assignments

Below is our master schedule, with pointers to *all* reading assignments, lecture overheads,\(^\text{16}\) and homework/lab assignments for the course.

```
Please bookmark this Web page\(^\text{17}\) (reachable from the class home page\(^\text{18}\)) and consult it each week for assignment specifications and all other class materials.
```

- Schedule Summary by Week:
  1. Intro/Overview, Research History
  2. Fourier Theorem Review
  3. Spectrum Analysis Windows: Optimality, Choice, and Design
  4. FIR Filter Design by the Window Method
  5. Tonal Spectrum Analysis
  6. Noise Spectrum Analysis
  7. Time-Frequency Display
  8. FFT Convolution via Overlap-Add (OLA) and Filter-Bank-Summation (FBS)
  9. Sinusoidal Modeling, Phase Vocoder, Applications

\(^{12}\)http://ccrma.stanford.edu/~jos/intro421/Schedule_Assignments.html
\(^{13}\)http://ccrma.stanford.edu/courses/421/
\(^{14}\)https://ccrma.stanford.edu/~jos/sasp/
\(^{15}\)https://www.createspace.com/3751411
\(^{16}\)Links to the on-line lecture overheads appear only in the week titles in the Web version of this page.
• Week 1 - Course Intro

  – Reading
    * Music 421 Overview (this document)
    * Verify that you have had adequate prior exposure to elementary spectrum analysis\(^{19}\) and digital filter analysis.\(^{20}\)
    * First 25 pages of Chapter 5 of *Spectral Audio Signal Processing (SASP)*\(^{21}\) entitled “Spectrum Analysis of Sinusoids.”\(^{22}\) (up to but not including “Optimal Peak-Finding in the Spectrum,” which we will return to later)

  – Demos (Supplementary): Historical Overview of Audio Spectral Modeling
    * Human Hearing Description and Animation\(^{23}\)
    * Demos\(^{24}\)
  – HW#\(^{1}\)!\(^{25}\)

• Week 2 - Fourier Review, Spectrum Analysis Windows

  – Reading
    * (Supplementary) The acoustic origins of harmonic analysis by Olivier Darrigol\(^{26}\)
    * (Supplementary) A History of Spectral Audio Signal Processing\(^{27}\)
    * First three sections of Chapter 2 of *SASP* entitled “Fourier Transforms and Theorems”\(^{28}\)

  – Demos (Supplementary)
    * Historical Overview of Audio Spectral Modeling\(^{29}\)
    * DFT Visualizations\(^{30}\) (be sure to check out the spectrum analyzer on Page 39 — built up starting on page 28)
  – HW#\(^{2}\)!\(^{31}\)

• Week 3 - Spectrum Analysis Windows, Optimal Window Design by Linear Programming

  – Reading
    * Chapter 3 of *SASP* entitled “Spectrum Analysis Windows”
    * First section of Appendix G of *SASP* entitled “Examples in Matlab and Octave”

\(^{19}\)http://ccrma.stanford.edu/~jos/mdft/
\(^{20}\)http://ccrma.stanford.edu/~jos/filters/
\(^{21}\)http://ccrma.stanford.edu/~jos/sasp/
\(^{22}\)http://ccrma.stanford.edu/~jos/sasp/Spectrum_Analysis_Sinusoids.html
\(^{23}\)https://www.hearinglink.org/your-hearing/about-hearing/how-the-ear-works/
\(^{25}\)http://ccrma.stanford.edu/~jos/hw421/
\(^{26}\)http://www.edu.upmc.fr/maths prive/guilbaud/Master_Enseignement/M2/Dossiers/Fonctions_trigonometriques_Darrigol.pdf
\(^{27}\)https://ccrma.stanford.edu/~jos/sasp/History_Spectral_Audio_Signal.html
\(^{28}\)http://ccrma.stanford.edu/~jos/sasp/Fourier_Transforms_Continuous_Discrete_Time_Frequency.html
\(^{30}\)https://acko.net/files/gltalks/toolsforthought/
\(^{31}\)http://ccrma.stanford.edu/~jos/hw421/
• HW#3

• Week 4 - FIR Digital Filter Design
  – Reading
    * Chapter 4 of SASP entitled “FIR Digital Filter Design”
  – Demo: PaintFIR (iOS)
  – HW#4

• Week 5 - FIR Digital Filter Design, Sinusoidal Spectrum Analysis, Supplementary: Gaussian Windows, Transforms
  – Reading
    * Finish Chapter 5 of Spectral Audio Signal Processing (SASP)\textsuperscript{32} entitled “Spectrum Analysis of Sinusoids.”
  – HW#5
  – Supplementary: Appendix C of SASP entitled “Statistical Signal Processing”

• Week 6 - Noise Spectrum Analysis
  – Reading
    * Chapter 6 of SASP entitled “Spectrum Analysis of Noise”
  – HW#6

\textsuperscript{32}http://ccrma.stanford.edu/~jos/sasp/