MUS420A Administrative Info

Center for Computer Research in Music and Acoustics (CCRMA)
Department of Music, Stanford University
Stanford, California 94305

Winter Quarter, 2019-2020

Contents

Music 420A: Signal Processing Models in Musical Acoustics

1 Course Overview

Music 420A is about computational electroacoustic modeling for digital audio effects, sound synthesis, and signal processing for physical modeling in general.
Explore Courses Listing[1]

1.1 When, Where, Who

Term:	Winter Quarter
Location:	Main CCRMA Classroom (Knoll 217)
Time:	Tuesdays and Thursdays, 3:00-4:15 PM,
Instructor:	Julius Smith (jos@ccrma.stanford.edu)
TA:	Mark Rau (mrau@ccrma.stanford.edu)
TA Office Hours:	TBD in the place to be announced
JOS Office Hours:	by appointment after class and/or other times as arranged by email
Piazza:	`https://piazza.com/class/k4x0jaq6cmo79`
Explore Courses:	`https://explorecourses.stanford.edu/search?q=music+420a`
Website:	`https://ccrma.stanford.edu/courses/420/`

1.2 Prerequisites

The prerequisites for Music 420A consist of prior first courses in signal processing and elementary dynamics, together with programming in `C++` and matlab. Familiarity with UNIX-style programming tools (`make`, `bash`, etc.) is desirable.

Example Prerequisite Courses

At CCRMA, Music 320 and Music 256A generally provide adequate preparation in conjunction with a physics background up to and including dynamics (all about "$f = ma$"):

- Music 320[2] or equivalent (prior exposure to complex numbers, sinusoids, elementary linear systems theory, digital filters, Laplace and z transform analysis);
- Music 256A[3] or equivalent (prior experience with C++ programming for real-time audio applications);
- Physics 21 (mechanics), or equivalent experience with Newton's law of motion, "$f = ma$". Having taken Music 256A will support more advanced independent project work.

Prerequisite Software

`C++` and Matlab[4] (or Octave[5]) are required for many of the exercises and starter software.

[1] `https://explorecourses.stanford.edu/search?q=music+420a`
[2] `https://ccrma.stanford.edu/courses/320/`
[3] `https://ccrma.stanford.edu/courses/256A/`
[4] `http://www.mathworks.com/`
[5] `http://www.octave.org/`

2 Administrative Information

2.1 Announcements

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

`https://piazza.com/class/k4x0jaq6cmo79`

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 and basic `C++`.

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[6] website. To sign up, go to the Canvas website and find Music420A. Once you are enrolled in the class, you can upload your matlab files in the "drop box" on the left menu.

See §2.3 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 Office Hours and Getting Help

We will be using Piazza[7] for sharing answers to posted questions with the whole class. To sign up, see the 420A Piazza site.[8] 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.

TA weekly office hours are TBD in the place to be announced.

2.4 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.

[6] `https://canvas.stanford.edu`
[7] `https://www.piazza.com`
[8] `https://piazza.com/class/k4x0jaq6cmo79`

2.5 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!

2.6 Required Software

Lab exercises in this course require basic `C++` programming, on the level of the Synthesis Tool Kit[9] (STK). Also, for sound analysis and display, proficiency with (and access to) Matlab or Octave is assumed.

2.7 Important Pointers

The *course schedule and outline*[10] in §3 on page 4 (also reachable from the class home page[11]) lists all topics covered, lecture overheads, reading assignments, lecture videos, and hw/lab assignments.

2.8 Textbook

The text for this course is **Physical Audio Signal Processing**[12] by JOS:

- Available for free online in HTML format.
- Printed hardcopies[13] also available.
- Reading assignments will be specified in the course schedule and outline.

[9] `https://ccrma.stanford.edu/software/stk/`
[10] `https://ccrma.stanford.edu/~jos/intro420/Schedule_Assignments.html`
[11] `https://ccrma.stanford.edu/courses/420/`
[12] `https://ccrma.stanford.edu/~jos/pasp/`
[13] `https://ccrma.stanford.edu/~jos/pasp/pasp-hardcopy.html`

2.9 Prerequisite-Level Reading

This course assumes the student is familiar with elementary signal processing on the level of the following textbooks:

- **Mathematics of the Discrete-Time Fourier Transform (DFT)**[14] — prerequisite material pertaining to the DFT (Music 320 text 1)
- **Introduction to Digital Filters**[15] — prerequisite material in the area of digital filtering and linear systems theory (Music 320 text 2)

3 Schedule

Below is our current schedule, with pointers to all reading assignments, lecture overheads, and theory/lab exercises for the course. Anything marked "Supplementary" is not required for the course, but may be of interest.

- Schedule Summary by Week:
  1. Intro and Overview, Prerequisites Review
  2. Digitizing Mass-Spring Systems, Parallel and Series Connections
  3. Finite Difference Schemes Backward/Forward Euler, Bilinear Transform
  4. Finite Difference Schemes, State Space Models, State Variable Filters
  5. Mass-Spring Chain and Traveling Waves below Cutoff
  6. Acoustic Modeling with Digital Delay, Comb Filters, Allpass Filters
  7. Interpolation of Delay Lines and Sampled Signals
  8. Wave Scattering
  9. Wave Digital Filters
  10. Applications, Review, Worked Problems
- Week 1: Course Intro (this document), Intro to Demos,
  Demos (interactive demos), Basic physics and signal-processing demos (HTML) (PDF),
  History of Virtual Musical Instruments Based on Physical Modeling (video),
  Laplace Transform,
  Comparison of s and z planes
  - **Reading:**
    - "MUS420A Administrative Info" (this document)
    - Chapter 1 of **PASP**: "Introduction to Physical Signal Models"
    - Review as needed elementary spectrum analysis and digital filter analysis.
    - Review Matlab, as needed.
  - **Supplementary Tutorial Video on Laplace and Fourier Transforms:**

[14] `https://ccrma.stanford.edu/~jos/mdft/`
[15] `https://ccrma.stanford.edu/~jos/filters/`

    - What does the Laplace Transform really tell us?A visual explanation (plus applications) [20:24]
  - Excercise 1

- Week 2: Finite Difference Schemes
  - **Reading:**
    - Chapter 1 of **PASP** entitled "Introduction to Physical Signal Models"
    - Chapter 7 of **PASP** entitled "Lumped Models"
    - Supplementary: **Dynamical Analogies** by Harry F. Olson, 1943
    - Supplementary: Simple Friction Model
      "Friction is in fact a very complex phenomenon which cannot be represented by a simple model. Almost every simple statement you make about friction can be countered with specific examples to the contrary."
    - Supplementary: More Advanced Friction Modeling
  - Ex#2

- Week 3: Finite Difference Schemes
  - **Reading:**
    - Lumped Models
    - Finite-Difference Schemes
    - If needed: Introduction to Matrices
    - State Space Filters
    - **Supplementary:** Germain and Werner: Design Principles for Lumped Model Discretisation Usin
  - Ex#3

- Week 4: Finite Difference Schemes, State Variable Filters
  - **Reading (continuing from last week):**
    - Lumped Models
    - Digital State-Variable Filters,
    - Finite-Difference Schemes
    - If needed: Introduction to Matrices
    - State Space Filters

- Week 5: Mass-Spring Chain, Delay Lines, Comb Filters, TDLs, Allpass Filters
  - **Reading:**
    - Lumped Models,
    - Chapter 2 of **PASP** entitled "Acoustic Modeling with Delay."
  - Physical Animation Demos:
    - Waves on a String
    - Triply Plucked String

    - Traveling Waves and their Sum
  - Ex#4

- Week 6: Delay Lines, Comb Filters, TDLs, Allpass Filters, Interpolating Delay Lines
  - **Reading:**
    - Chapter 4 of **PASP** entitled "Delay/Signal Interpolation"
    - Room Acoustics Modeling with Interactive Visualizations, by Lauri Savioja
  - Ex#5

- Week 7: Interpolating Delay Lines, Commuted Synthesis, Impedance and One-Ports, Simple String Models, Scattering Junctions
  - **Reading:**
    1. Chapter 6 of **PASP** entitled "Digital Waveguide Models"
    2. First 8 pages of Chapter 9 of **PASP** entitled "Virtual Musical Instruments"
    3. Supplementary: Diode Clipper Simulation

- Week 8: Scattering Junctions, Ideal String Struck by a Mass
  - **Reading:**
    - Chapter 9 of **PASP** entitled "Virtual Musical Instruments"
    - Appendix F of **PASP** entitled "Digital Waveguide Theory"
  - Ex#6

- Week 9: Wave Digital Filters (WDF)
  - **Reading:**
    - Appendix of **PASP** entitled "Wave Digital Filters"
    - Simulating Guitar Distortion Circuits Using Wave Digital and Nonlinear State-Space Formulation
    - Supplementary: David Yeh Thesis
    - Supplementary: Werner et al. DAFx15 I
    - Supplementary: Werner et al. DAFx15 II

- Week 10 (All Supplementary): Project Presentations, Current Research, Special Topics, Applications, Demos, David Yeh WDF Tutorial, Piano Modeling, Wave Digital Piano Hammer, Physical Model Overview, Related Research (PDF)
  - Wave Digital Filters
  - Mark Rau Recent Research
  - Jatin Chowdhury Nonlinear Filters
  - Brendan Larkin Adaptive Filters

- Final Exam - Thursday, March 19, 2020, 12:15-3:15 PM, via emailed PDF.
  The exam will cover

- homework/lab assignments, and
- topics discussed in class (not including “supplementary”).
- The exam will be *open everything*.
- **Practice Questions**