University of Washington ECE Department

EE 235 Lab 3 – Convolution

In this lab, we will implement convolution on the computer to find responses of an LTI system to different signals. In particular, we will look at convolving with a pulse, and we'll revisit the time delay system from Lab 2, implemented using LTI systems and impulse responses. Finally, we apply our knowledge to another audio signal problem. Important concepts in this lab include plotting the unit impulse function, describing LTI systems using the impulse response **h(t)**, and computing output **y(t)** of an LTI system using convolution.

Lab 3 Turn-in Checklist

- 3 pre-lab exercises
- 3 Assignment check-offs with TA
- Lab report, completed and submitted as a team
  - Submit as a Jupyter notebook following the format that you used in labs 1 and 2.
  - Submit the audio file recovered in assignment 3

Note: All assignments except the prelab should be completed in groups of 2-3 people.
The pre-lab exercises are to be completed individually and submitted via Canvas before lab section.

Pre-lab

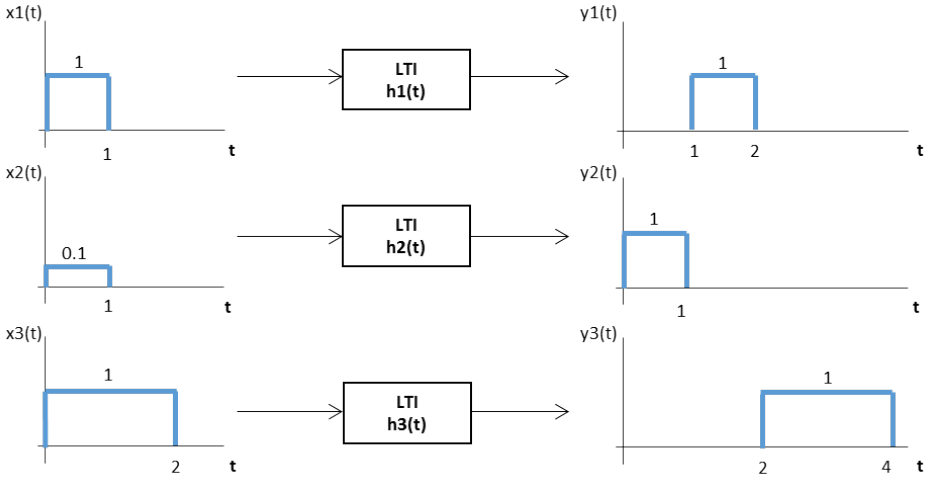
Read the Lab 3 Background document, then complete the following exercises.

1. Let x(t)=u(t-1)-u(t-3). Assuming that you have continuous time signals, sketch the result of convolving x(t) with each of the following signals:

   $h_1(t)=\delta(t-1)$ $h_2(t)=p(t)=u(t)-u(t-1)$

2. You need to create signals **x** and **h1** on the computer for the above signals for the time period [0,4] using sampling rate **fs**. What python commands would you use to do that?

3. The devious student from Lab 2 has attacked the former TA once again. This time, they corrupted some signals by dividing them into pieces. The TA deduced that the sound files had been split into three pieces: the first two are **1-sec** long, and the third is **2-sec** long. The second piece (1-sec long) has been attenuated by 10 – the other pieces are unchanged. The following systems need to be implemented to realign the audio file.



Determine the continuous-time impulse response of each system.

Lab Assignments

This lab has 3 assignments. Each should be given a separate code cell in your Notebook, and each should be associated with a markdown cell with subtitle and discussion. As in Labs 1 and 2, your notebook should start with a markdown title and overview cell, which should be followed by an import cell that has the import statements for all assignments.

For assignment 2, you will use the train signal from Labs 1 & 2. For assignment 3, your TA will assign you an audio file to upload.

You will again be working with arrays, audio files and plotting, so you may want to refer back to the Lab 1 background discussion. Be sure to include the necessary import statements. Your input cell should be similar to that used in lab 2.

Assignment 1: Convolving Signals

We will start by doing some simple convolutions. Create a new cell in your Lab 3 notebook for Assignment 1. This assignment will have four parts, A-D.

A. Create vectors for the following signals using the time range [0,4] and sampling rate **fs = 1000**:

   a. x(t)=u(t-1)-u(t-3)

   b. h1(t)=δ(t-1)

   c. h2(t)=u(t)-u(t-1) (or, try h2(t)=u(t)-u(t-0.5))

   d. h3(t)=1 for [0,0.5); = -1 for [0.5,1); 0 otherwise

      (or, try h3(t)=1 for [0,0.25); = -1 for [0.25,0.5); 0 otherwise)

You can use your prelab results for (a) and (b). The solution for (c) and (d) should build on what you did for (a).

B. Create a time vector **th** for plotting that covers time range [0,4]. Plot the following on a **3x1** subplot. Use a y-axis between -2 and 2. Label and title the graphs. Verify that the signals for (a) and (b) match what you expect from your prelab

   a. **h1 vs. th** b. **h2 vs. th** d. **h3 vs. th**

C. Use the numpy.convolve() function to find yi(t)=x(t)*hi(t) for i=1, 2, 3. Don't forget the amplitude scaling associated with the sampling time.

D. Create a time vector **ty** for plotting that covers time range [0,8]. Plot the following on a **4x1** subplot. (You may need to add zeros to make sure all signals are defined for this time range.) Use a y-axis between -2 and 2. Label and title the graphs. Verify that the signals for y1 and y2 match what you expect from your prelab

   a. **x vs. ty** b. **y1 vs. ty** c. **y2 vs. ty** d. **y3 vs. ty**

Assignment Check-Off #1 of 3: Demonstrate this Assignment to the lab TA

Report discussion: Discuss how the **hi** plots would change if you used **fs = 10**, instead of **fs = 1000**? The systems corresponding to impulse responses h2(t) and h3(t) capture different information about a signal. If you change the width of the pulse to be half as long, then it is easier to see the effect. Comment on what aspects of the input signal correspond to the largest values of y2(t) and y3(t).

Assignment 2: Revisiting Time Delay Transformation

In this exercise, we will revisit the time delay transformation from lab 2 with a real signal. To implement it here, we will use convolution and the impulse response of an LTI system. Start a new cell in your Lab 3 notebook for Assignment 2. This assignment will have four parts, A-D.

A. Read in **train32.wav**, saving its signal **x** and sampling rate **fs**. Create a time samples vector **t_x** for vector **x**.

B. Implement the impulse response **hd** of the LTI system that delays a signal by **to = 1 sec** as in assignment 1 but using **fs** from the train signal and defining the signal only for the time range [0,2). Create **t_h** as the time samples vector corresponding to **hd**.

C. Use *numpy.**convolve()*** to compute **y** as **x** convolved with **hd** and scale the amplitude according to the sampling time. Create **t_y** as the time samples vector corresponding to **y**.

D. Plot the following on a **3x1** subplot. Use an x-axis between 0 and 4. Label and title completely. Verify that your delay matches **to**.

   a. **x vs. t_x** b. **hd vs. t_h** c. **y vs. t_y**

Assignment Check-Off #2 of 3: Demonstrate this Assignment to the lab TA

Report discussion: Suppose we modify **(**C**)** by not scaling according to the sampling time. Describe (in words) what would happen to output signal **y(t)** if you used this **h(t)** instead. How will the graph of **y(t)** differ from the original and how will the sound differ?

Assignment 3: Audio File Realignment

In this section, we will perform a simple speech realignment task from a set of three signals, our understanding of unit impulses, impulse responses, and LTI systems. You will use the result of problem 3 in your pre-lab to design impulse responses, then implement the systems with convolution and sum the resulting signals to recover the original audio file:

y(t) = y1(t) + y2(t) + y3(t)

Download (from Canvas) the three audio files associated with either **s1**, **s2**, or **s3,** depending on which is assigned to you by your TA. Start a new cell for this **Assignment 3.**

A. Load the three audio files and name them **x1**, **x2** and **x3**. They should all have the same sampling rate **fs**.

B. Create discrete versions of the impulse responses for the three filters that you designed in the prelab using the sampling rate of the signals you loaded and a time window of [0,3) sec. Use the same approach as in assignments 1 and 2.

C. Use numpy.convolve() to obtain **y1, y2,** and **y3.** Make sure to scale the output if you have used the scaled version of the unit impulse.

D. Add zeros to the ends of the resulting signals so that they are all the same length and add them. Play the resulting file – you should get a recognizable soundbite if you implemented it correctly. Save the result as a wav file, which you will include with your report.

Assignment Check-Off #3 of 3: Play your recovered sound file for the TA.

Report discussion: What would the result sound like if you accidentally put x2(t) into all three filters?

Can you name the character or TV show for your selected sound file? Here are some hints:

- **S1**: This space ranger action figure is one of the main characters in the first computer animated film released by Pixar Studios. This character has appeared in multiple feature films, along with his own spinoff film and TV show. The inspiration for this character is said to be astronaut Buzz Aldrin.
- **S2**: This quote comes from a 1980 space opera film, often cited as the best film in the entire franchise. One of the most well-known quotes of that film comes from this pivotal antagonist and warrior of the dark side.

- **S3**: This animated TV character has been on the air for a very long time, probably longer than most of you have been alive! This family patriarch has been described by some as the "the greatest comic creation of all time" and one of the greatest cartoon characters "of the last 20 years."

Team Report

When you've tested and cleaned up all your code (remember, you should only submit code for the Assignments, each in their own cell), go to 'File' then 'Download as', then select '.ipynb'. The file you download is a Notebook that your TA will be able to open and grade for you, once you submit it on Canvas. Remember, only one notebook per team! Make sure that your notebook is titled Lab2-XYZ.ipynb, where XYZ are the initials of the lab partners. You may want to also download the file as pdf to have a nicer documentation of your records.

Submit via Canvas: i) the .ipynb file, and ii) the recovered audio file from assignment 3.