MATHEMATICA LAB SKILLS ACTIVITY 2: ANALYZING DATA IN MATHEMATICA

LEARNING GOALS

You will be…

1. …able to define and use functions in Mathematica.
2. …able to scale and shift lists (arrays) of data.
3. …able to use a Rigol DG1022 waveform generator to create a desired oscillatory signal.
4. …able to use a Rigol DS1052e oscilloscope to measure a signal.
5. …able to save data from your oscilloscope onto a USB flash drive and transfer onto your computer.
6. ...able to import saved data into Mathematica.
7. …able to efficiently select columns, rows, and other subsets from data sets.
8. …able to generate combine plots of data and functions.
9. …able perform least-squares fits of data saved from the oscilloscope.
10. …able to create pretty looking plots.

A FEW MORE MATHEMATICA BASICS

Defining functions that perform a sequence of mathematical or logical steps is a key part of every programming language. Watch the screencast on defining and using functions in Mathematica (www.youtube.com/watch?v=1A4f91yMVhA).

Question 1	a. Define a function in Mathematica that represents $f(x) = \sin(x)/x$ b. Explain the difference between how Mathematica interprets the following two expressions: • `y = x^2` • `y[x] := x^2`

A "List" in Mathematica is the equivalent of an "array" in most other programming languages (like C, Python, MATLAB). This exercise requires you to create a list and perform the basic list manipulations like shifting and scaling all list values by a constant. You may need to consult the Mathematica help documentation.

Question 2	a. Create a list named `sinTable` using the `Table` function to evaluate the expression `Sin[x]` at 100 points between 0 and 4π. b. Increase all values of the list `sinTable` by a constant (e.g., 1). c. Multiply all the values of the list `sinTable` by a constant value (e.g., 10).

USING THE OSCILLOSCOPE AND WAVEFORM GENERATOR

This lesson starts off with using the oscilloscope and waveform generator to generate a large data set which you will eventually import into Mathematica and plot.

Question 3	In pairs, go to the optics bays. All you need to use are the oscilloscope and waveform generator. Be careful to not bump your classmates' optics as you are doing this. a. Create a sine or square wave with an amplitude and frequency of your choosing. Don't use the default settings. Record your settings in your lab notebook. [NOTE: Choose the frequency to be less than 10 kHz. The oscilloscope rounds the saved time column to the nearest microsecond, so will have trouble using the saved data for signals faster than 500 kHz.] b. Measure the output of the waveform generator with your scope so that you can see many periods of oscillation.

SAVING DATA FROM THE RIGOL DS1052E OSCILLOSCOPE ONTO A USB FLASH DRIVE

There are three options for getting data from the oscilloscope onto your computer.

1. LabVIEW interface.
2. Standalone program for interfacing with Rigol scopes (PC only, limited to 600 data points)
3. Saving data onto a USB flash drive (simplest, full control over saved data)

This section will go over the 3rd option, saving data from the oscilloscope onto a USB flash drive as a "Comma Separated Values" (.CSV) file. A comma separated values file is a text-based format that can be open and viewed by any text editor. In a CSV file the columns are separated by commas, and the rows are on a new line.

Question 4	a. Follow the procedure given below for saving the oscilloscope data as a "comma separated values" file onto a USB flash drive. **Make sure you are acquiring both CH1 and CH2.** b. Copy the saved data file onto your computer.

1. Insert USB drive into front USB port on the Rigol DS1052E Oscilloscope.
    a. A message should briefly appear on the screen which says `USB DEVICE INSTALLED`
2. Press the `Acquire` menu button
    a. Select **`MemDepth`** (number of data points) and switch the setting between "`Normal`" and "`Long Mem`". Choose "`Normal`".
3. Press the **`Storage`** menu button
    a. Select the **`Storage`** `format` button. You should see a list of options: "`Waveform`", "`Setups`", "`Bit map`", "`CSV`", "`Factory`". Choose "`CSV`.
    b. Select the **`Data Depth`** button and switch between "`Maximum`" (16,384 points) and "`Displayed`" (`600` points). Choose "`Maximum`"
    c. Select the **`External`** button
        i. A directory menu should show up
        ii. Select the **`New File`** button
            1. A file name dialog box should appear.
        iii. Change the file name if you desire, but it is slow and awkward to change it.
        iv. Press the **`Save`** button.

1. Wait for the saving to complete. The saving should take less than 20 seconds.

4. Pull out your USB flash drive.

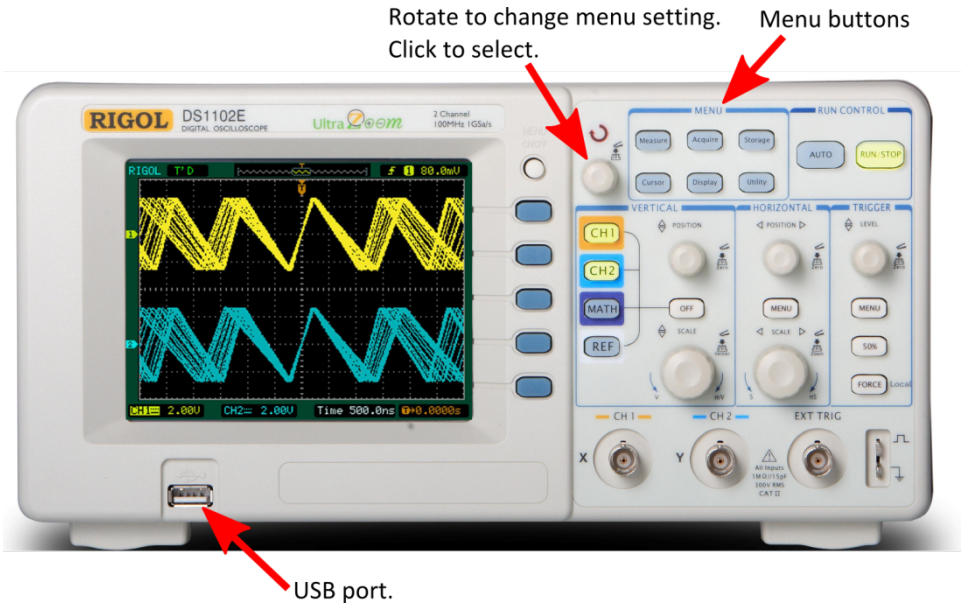

Figure 1 Front panel of the DS1052E and DS1102E oscilloscopes are identical. The knob indicated by the arrow is used for selecting menu options.

IMPORTING DATA INTO MATHEMATICA

Starting in week 2 of this course, importing data for analysis will be a key part of the course.

Watch the screencast on importing data into Mathematica. (http://youtu.be/MmS3JNk7JE4)

Question 5	a. Use a text editor like notepad (Win) or TextEdit (Mac) to open the CSV file you saved from the oscilloscope. In this way you can preview the data set before attempting to import it into Mathematica. You can also verify the delimiter is a comma and not a space, a tab, or something else. b. Import the CSV file into Mathematica using the `Import` function.
Question 6	There are many other formats that Mathematica can import. In this problem you will import another text-based data format containing outdoor temperature measurements from Boulder, CO. The file is available on the course website. (www.colorado.edu/physics/phys4430/phys4430_sp15/sample_data/2011_boulder_temperature_data.txt) a. Open the temperature data in your browser or in a text editor. Is the delimiter between columns a comma, or something else? b. How should you decide between using `Import` with the `CSV`, `TSV`, or `Table` file format options? c. Import the temperature data and make a plot.

SELECTING SUBSETS OF DATA

Often times it is necessary to select a subset of your data. Common examples include trimming the beginning or the end from a data set. Another example is when you import data with more than two columns, as is the case with data from the oscilloscope. After completing this part of the activity you will be able to easily plot your imported oscilloscope data.

Watch the screencast on selecting a subset of 1D and 2D lists. (www.youtube.com/watch?v=xfrXrtySiTI)

Also, check out the Quick Reference Chart on Selecting Subsets available on the course website. (www.colorado.edu/physics/phys4430/phys4430_sp15/Mathematica/Slicing a 2D Array Quick Reference Chart.pdf)

Question 7	a. Make a plot of your imported oscilloscope data. Make a plot of Channel 1 or Channel 2 versus time. b. How would you change the code to switch between plotting Channel 1 and Channel 2?

CREATING PLOTS OF DATA AND FUNCTION TOGETHER

In Mathematica `Plot` is used for plotting functions and `ListPlot` is used for plotting data. If we want to combine a plot of a theoretical prediction or a best fit curve with our data we need to combine these two different kinds of plots. The key method is Mathematica's `Show` function.

Watch the screencast on combining plots of data and functions. (www.youtube.com/watch?v=NDA90htObC4).

Question 8	a. Write down a mathematical expression for the predicted output signal of your waveform generator based on the settings you chose. b. Make a plot of your prediction. Mathematica has built in functions for `Sin`, `SquareWave`, `SawtoothWave`, and `TriangleWave`. Consult Mathematica's help for using these appropriately. c. Combine the plot of your oscilloscope data with your prediction. Do they match up exactly? If not, did you make a mistake, or is there a good reason for the difference?

FITTING DATA

Almost every week you will be asked to plot data and fit it. After completing this activity you will be able to use the `LinearModelFit` and `NonlinearModelFit` functions for doing least squares fitting of data. You will demonstrate your proficiency by fitting an exponential decay. The data are the number of counts detected as a function of time for cosmic ray muon decays. The data were taken in a previous semester as part of the muon lifetime lab. The decay time you estimate from the least-squares fit is the lifetime of the muon. The muon data is available on the course website.
(www.colorado.edu/physics/phys4430/phys4430_sp15/sample_data/Muon_lifetime_data.csv)

Watch the screencast on fitting data in Mathematica. (www.youtube.com/watch?v=KolZZm8If9Q)

Question 9	a. Write down a mathematical expression for the function you will use to fit your data. b. How many free parameters do you need? Give a brief explanation in words, or with a graph to explain what they mean. c. How do you relate your fit parameters to the muon lifetime τ_{muon}? d. Is the fit function linear or nonlinear? e. Fit the data and obtain τ_{muon}. f. Make a combined plot of the data and fit.

MAKING CLASSY PLOTS IN MATHEMATICA

The default plot style in Mathematica does not look very good for presentation quality graphics. This screencast give some options for changing the plot style. Figure 2 shows an example of the plot style changes you will be able to implement after watching the screencast. The screencast also demonstrates the use of the `SetOptions` function which allows you to set the default plot options.

Watch the screencast on changing the plot style. (http://www.youtube.com/watch?v=MftXG9SNHGk)

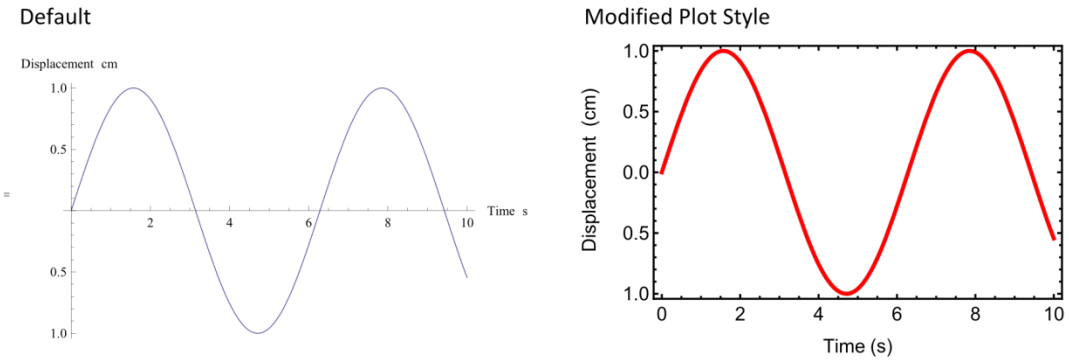

Figure 2: Plot of sin(t) for t between 0 and 10. Modifying the plot options can improve the viewing of the plot within Mathematica and for printing. Notice that the default axes and sine curve are very thin when printed.

Default	`Plot[Sin[x], {x, 0, 10},` `  AxesLabel -> {"Time (s)", "Displacement (cm)"}]`

Modified	`Plot[Sin[x], {x, 0, 10},`
	`  Frame -> True,`
	`  Axes -> False,`
	`  LabelStyle -> {FontFamily -> "Arial", FontSize -> 13},`
	`  FrameLabel -> {"Time (s)", "Displacement (cm)"},`
	`  FrameStyle -> Thickness[0.005],`
	`  PlotStyle -> {Red, Thickness[0.01]}]`

Question 10	Modify any one of the plots produced earlier in this activity and make it “classier”