Lab 03

Trigonometric Functions

Description

In this lab, you will use a hardware description to approximate the sine and cosine functions in hardware using Taylor series.

Procedure

Introduction and Background

- The instructor will introduce the topic for today's lab and give a brief lecture on the background of trigonometric function representation using Taylor series.

Discussion of Hardware

- The subject of today's lab is a black box, with the following properties:
  - Input x – angle in radians
    - 4 bits integer, 16 bits fraction, range roughly $[-3, 3]$
  - Output $\sin x$ and $\cos x$
    - Output as integers, but divide by 2^{16}
    - Range $[-1, 1]$

Hardware Description Review

1. Download the VHDL file `lab03.vhd` from Canvas and place it in a new folder titled `Lab03`.

2. Open Vivado and create a new project.
    - From the Quick Start menu, select `Create Project`.
    - Click `Next`.
    - On the second page, if desired, give the project an appropriate and change the location. Click `Next`.
    - Ensure `RTL Project` is selected. Click `Next`.
    - On the `Add Sources` page, click `Add Files` and add `lab03.vhd` from where you downloaded it.
    - Ensure `Copy sources into project` is checked. Click `Next`.
    - Click next – constraints are not needed for this lab.
    - Select the following:
        - Category: `General Purpose`
        - Family: `Artix-7`
        - Package: `cpg236`
        - Speed: `-1`
    - Finally, select the middle option: `xc7a35tcpg236-1`.
    - Click `Next`.
    - Click `Finish`.
3. When Vivado finishes creating the project, run synthesis.
    - From the left side pane, click `Run Synthesis`.
        - If a popup appears, click `OK`.
    - After synthesis completes, you may see a popup with the options `Run Implementation`, `Open Synthesized Design`, and `View Reports`.
        - Here you can either click `Cancel`, or select `View Reports` and click `OK`.
4. While we wait for synthesis to complete, open the file in the editor, and follow along with the instructor to review the hardware description.
    - To do this: inside the `Project Manager` pane, under the `Sources` subpane, and under the `Design Sources` folder, double-click the `lab03.vhd` file.

Hardware Simulation

5. Make a copy of the template datasheet for your lab group's simulation results: https://docs.google.com/spreadsheets/d/1VU7yeTY62XRbNFxh09OKpoA-UU9S5EVNhFx7ttC47xc/edit?usp=sharing
6. Follow along with the instructor to review the testing and verification program: https://pl.kotl.in/3zbv8P94-

7. Setup the behavioral simulation.
    - In Vivado, from the left side pane, click `Run Simulation`, then `Run Behavioral Simulation`.
    - Minimize the two panes on the left with `Scope` and `Objects` tabs to make the wave view bigger.
    - Optionally, minimize the bottom pane (`Tcl Console/Messages/Log`).
    - Optionally, drag the handle next to `Value` to make the columns larger.
    - Set the radix for `x` to `Binary`.
        - Within the waveform graph, under the `Name` column, right-click the input `x`.
        - Click `Radix`, and select `Binary`.
    - Similarly, set the radix for `sin_x` and `cos_x` to `Signed Decimal`.
8. Run the simulation with various input values. Record results in your datasheet.
    - Right-click `x` and select `Force constant`.
    - Change the value radix to `Binary`.
    - Using the test program, determine the binary value of $\pi/6$.
    - Enter the binary value provided by the test program as the `Force value`.
    - Click `OK`.
    - At the top, run for a specified time by clicking the play button with `(T)` under it. Alternatively, press `Shift+F2`.
        - This is directly left of the text box and dropdown with `10` and `us`, respectively.
            - Your value may be `us` (microseconds) or `ns` (nanoseconds). You can change to `ns` if desired. For this lab, it does not matter, but technically the latter is more realistic.
    - At this point, you should see the value you entered along with the intermediate values and the outputs.
        - Note that the intermediate values will be inside the arrays, below `sin_x` and `cos_x`.
9. Repeat step 8 for all values in the datasheet (i.e., each major angle on the unit circle).
    - While holding `Ctrl`, you can use the mouse scroll wheel to zoom in and out in the waveform view.
    - While holding `Shift`, you can use the mouse scroll wheel to navigate horizontally along the waveform view.
    - If you accidentally close the waveform view, go to `Window` in the toolbar, and click `Waveform`.

10. Once you have acquired all data, close the simulation.
    - If prompted, save the waveform configuration and add it to the project (click `Save`). This is not necessary, but is helpful if you close the simulation and need to simulate again.

Discussion of Results

11. With your lab group (or as a class, per the instructor's directions), discuss the following questions. Your answers should be included in your informal report for this lab.
    - Were the simulation results accurate enough?
    - How could the accuracy be improved?

Deliverables

Lab Report

- Submit an **informal report** including the following:
    - Your lab group's *completed datasheet*
    - Your lab group's answers to the *discussion questions* in step 11.

Outcomes

- Understand how the sine and cosine functions are implemented in hardware.
- Practice working with VHDL.
- Practice using Vivado for hardware simulation.
- Understand one method of representing fixed-point binary numbers.