CS 2110 Homework 03: Arithmetic Logic Units

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1 Objectives

1. To understand digital logic
2. To use logic gates to perform various operations
3. To learn how to use sub-circuits

2 Overview

All computer processors have a very important component known as the Arithmetic Logic Unit (ALU). This component allows the computer to do, as the name suggests, arithmetic and logical operations. For this assignment, you're going to build an ALU of your own.

DO NOT USE TRANSISTORS!

For this assignment you will:

1. Create a 1-bit full adder
2. Create a 4-bit full adder using the 1-bit full adder
3. Use your 4-bit full adder and other components to construct a 4-bit ALU
4. Create a 16-bit ALU (highly recommended that you create a 16-bit adder to assist, by using the 4-bit full adder)

This assignment will be demoed. More information on this and the sign-up schedule will be posted on Canvas. An announcement will be sent out and it will also be announced in Lecture/Lab when the schedule is up. You have to be present for the demo in order to get credit for this assignment.

3 Instructions

3.1 Requirements

You may use anything from the Wiring section, as well as basic gates (AND, OR, XOR, NOT, NAND, NOR, XNOR), multiplexers, and decoders. Use of anything not listed above will result in heavy deductions. Your designs for the first three problems must each be sub-circuits. More information on sub-circuits is given below.

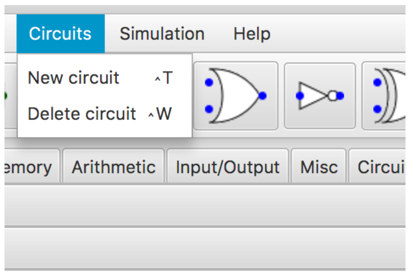
Use tunnels where necessary to make your designs more readable!

3.2 Sub-Circuit Tutorial

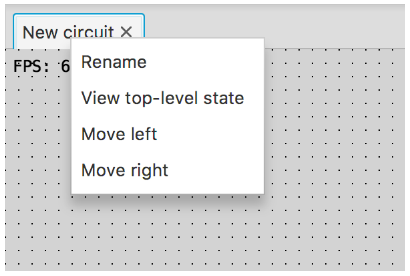
As you build circuits that are more and more sophisticated, you will want to build smaller circuits that you can use multiple times within larger circuits. Sub-circuits behave like classes in Object-Oriented languages. Any changes made in the design of a sub-circuit are automatically reflected wherever it is used. The direction of the IO pins in the sub-circuit correspond to their locations on the representation of the sub-circuit.

To create a sub-circuit:

1. Go to the "Circuits" menu and choose "New circuit"

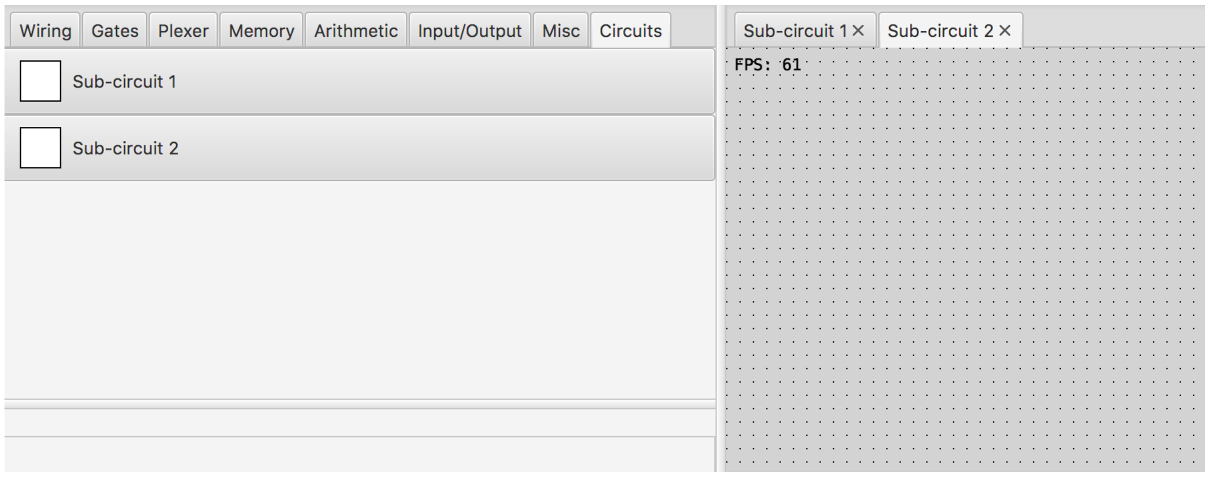


2. Name your circuit by right-clicking on the "New circuit" item and selecting "Rename"

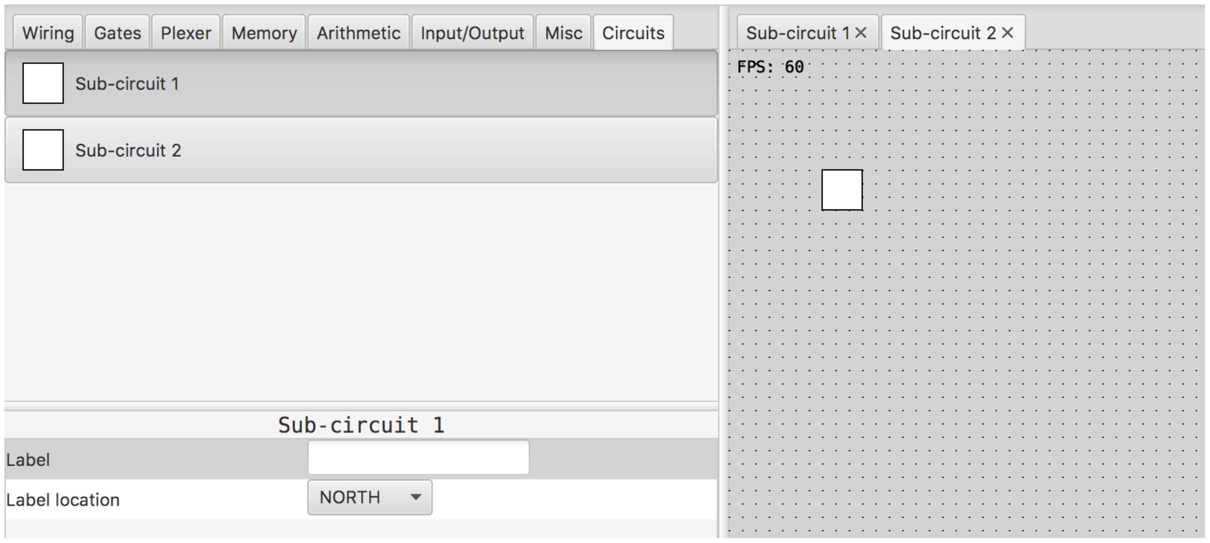


To use a sub-circuit:

1. Click the “Circuits” tab next to the “Misc” tab



2. Select the circuit you wish to use and place it in your design



Sub-circuit 1

Label	
Label location	NORTH

3.3 Part 1: 1-Bit Full Adder

The full adder has three 1-bit inputs (`A`, `B`, and `CarryIn`), and two 1-bit outputs (`Answer` and `CarryOut`). The full adder adds `A + B + CarryIn` and places the answer in `Answer` and the carry-out in `CarryOut`.

For example:

```
A = 0, B = 1, CarryIn = 0 ==> Answer = 1, CarryOut = 0
A = 1, B = 0, CarryIn = 1 ==> Answer = 0, CarryOut = 1
A = 1, B = 1, CarryIn = 1 ==> Answer = 1, CarryOut = 1
```

Hint: Making a truth table of the inputs will help you.

Make your 1-bit full adder a sub-circuit. You will use it in Part 2.

3.4 Part 2: 4-Bit Full Adder

For this part of the assignment, you will daisy-chain 4 of your 1-bit full adders together in order to make a 4-bit full adder.

This circuit should have two 4-bit inputs (`A` and `B`) for the numbers you're adding, and one 1-bit input for `CarryIn`. The reason for the `CarryIn` has to do with using the adder for purposes other than adding the two inputs. You'll see this when you do Part 4.

There should be one 4-bit output for `Answer` and one 1-bit output for `CarryOut`.

Make your 4-bit full adder a sub-circuit. You will use it in Part 3.

3.5 Part 3: 4-Bit ALU

You will create a 4-bit ALU with the following operations, using your 4-bit full adder from Part 2:

1. Addition	`[A + B]`
2. Subtraction	`[A - B]`
3. isOddNumber	`[A % 2 == 1]`
4. 2's Complement Negation	`[-A]`
5. Multiply by 8	`[A * 8]`
6. AND	`[A & B]`
7. OR	`[A | B]`
8. XOR	`[A ^ B]`

Notice that isOddNumber, 2's Complement Negation, and Multiply by 8 only operate on the `A` input. They should NOT rely on `B` being a particular value.

Note that you are doing 2's Complement Negation, NOT simply flipping the bits.

Disregard any carry-out that may result by multiplying by 8.

This ALU has two **4-bit** inputs for `A` and `B` and one **3-bit** input for `Select`, split into tunnels for `S0`, `S1`, and `S2` (the selectors for the op-code of your ALU's functions).

This ALU should have one **4-bit** output for `Answer`.

The provided autograder will check the op-codes according to the order listed above (Addition (`000`), Subtraction (`001`), etc.). However, you may assign the op-codes to the operations any way that you want as long as you implement every operation and each op-code only corresponds to one operation.

Add a label to your circuit that lists which operation each op-code corresponds to.

3.6 Part 4: 16-Bit ALU

For this part, a helper sub-circuit will assist you. Daisy-chain your 4-bit full adders into a 16-bit full adder, and then use that to create a 16-bit ALU with the following operations:

1. Addition	`[A + B]`
2. Subtraction	`[A - B]`
3. isDivisibleBy16	`[A % 16 == 0]`
4. 2's Complement Negation	`[-A]`
5. Multiply by 13	`[A * 13]`
6. AND	`[A & B]`
7. OR	`[A | B]`
8. XOR	`[A ^ B]`

Notice that isDivisibleBy16, 2's Complement Negation, and Multiply by 13 only operate on the `A` input. They should NOT rely on `B` being a particular value.

Note that you are doing 2's Complement Negation, NOT simply flipping the bits.

Disregard any carry-out that may result by multiplying by 13.

This ALU has two **16-bit** inputs for `A` and `B` and one **3-bit** input, `Select`, which serves as the selector for the op-code of your ALU's functions.

This ALU should have one **16-bit** output for `Answer`.

The provided autograder will check the op-codes according to the order listed above (Addition (`000`), Subtraction (`001`), etc.). However, you may assign the op-codes to the operations any way that you want as long as you implement every operation and each op-code only corresponds to one operation.

Add a label to your circuit that lists which operation each op-code corresponds to.

4 Testing Your Work

We have provided you with an autograder jar (`hw3-grader-tests-1.4.jar`). Run the autograder jar (in the directory with `hw03.sim`) with the following command:

```
java -jar hw3-grader-tests-1.4.jar
```

Your demoing TA will use a similar autograder to check your work if you've organized your ALUs according to the operations listed above. Otherwise, they will check the operations manually according to the op-codes you've labeled in your circuit.

5 Rubric

The grading will roughly follow this breakdown:

Part 1: 1-Bit Full Adder	10%
Part 2: 4-Bit Full Adder	10%
Part 3: 4-Bit ALU	40% (5% per operation)
Part 4: 16-Bit ALU	40% (5% per operation)

6 Deliverables

Please upload the following files to Canvas:

1. `hw03.sim`

Your designs for the four parts of this assignment must be contained in the same `.sim` file as sub-circuits.

You may also include a README file if there is anything you wish your grading TA to know about your designs. This would be a good place to discuss your choice of op-codes or other concerns. This is optional though, as you can include your op-codes as text in your `.sim` file.

Once again, this assignment will be demoed! More information on this and the sign-up schedule will be posted on Canvas. An announcement will be sent out and it will also be announced in Lecture/Lab when the schedule is up. You have to be present for the demo in order to get credit for the assignment.

Download and test your submission to make sure you submitted the right files.

7 Rules and Regulations

7.1 General Rules

1. Starting with the assembly homeworks, Any code you write (if any) must be clearly commented and the comments must be meaningful. You should comment your code in terms of the algorithm you are implementing we all know what the line of code does.

2. Although you may ask TAs for clarification, you are ultimately responsible for what you submit. This means that (in the case of demos) you should come prepared to explain to the TA how any piece of code you submitted works, even if you copied it from the book or read about it on the internet.

3. Please read the assignment in its entirety before asking questions.

4. Please start assignments early, and ask for help early. Do not email us the night the assignment is due with questions.

5. If you find any problems with the assignment it would be greatly appreciated if you reported them to the author (which can be found at the top of the assignment). Announcements will be posted if the assignment changes.

7.2 Submission Conventions

1. All files you submit for assignments in this course should have your name at the top of the file as a comment for any source code file, and somewhere in the file, near the top, for other files unless otherwise noted.

2. When preparing your submission you may either submit the files individually to Canvas or you may submit an archive (zip or tar.gz only please) of the files (preferred). You can create an archive by right clicking on files and selecting the appropriate compress option on your system.

3. If you choose to submit an archive please don't zip up a folder with the files, only submit an archive of the files we want (see Deliverables).

4. Do not submit compiled files that is .class files for Java code and .o files for C code. Only submit the files we ask for in the assignment.

5. Do not submit links to files. We will not grade assignments submitted this way as it is easy to change the files after the submission period ends.

7.3 Submission Guidelines

1. You are responsible for turning in assignments on time. This includes allowing for unforeseen circumstances. If you have an emergency let us know **IN ADVANCE** of the due time supplying documentation (i.e. note from the dean, doctor's note, etc). Extensions will only be granted to those who contact us in advance of the deadline and no extensions will be made after the due date.

2. You are also responsible for ensuring that what you turned in is what you meant to turn in. After submitting you should be sure to download your submission into a brand new folder and test if it works. No excuses if you submit the wrong files, what you turn in is what we grade. In addition, your assignment must be turned in via Canvas. Under no circumstances whatsoever we will accept any email submission of an assignment. Note: if you were granted an extension you will still turn in the assignment over Canvas.

3. There is a 6-hour grace period added to all assignments. You may submit your assignment without penalty up until 11:55PM, or with 25% penalty up until 5:55AM. So what you should take from this is not to start assignments on the last day and plan to submit right at 11:54AM. You alone are responsible for submitting your homework before the grace period begins or ends; neither Canvas, nor your flaky internet are to blame if you are unable to submit because you banked on your computer working up until 11:54PM. The penalty for submitting during the grace period (25%) or after (no credit) is non-negotiable.

7.4 Syllabus Excerpt on Academic Misconduct

Academic misconduct is taken very seriously in this class. Quizzes, timed labs and the final examination are individual work.

Homework assignments are collaborative, In addition many if not all homework assignments will be evaluated via demo or code review. During this evaluation, you will be expected to be able to explain every aspect of your submission. Homework assignments will also be examined using computer programs to find evidence of unauthorized collaboration.

What is unauthorized collaboration? Each individual programming assignment should be coded by you. You may work with others, but each student should be turning in their own version of the assignment. Submissions that are essentially identical will receive a zero and will be sent to the Dean of Students' Office of Academic Integrity. Submissions that are copies that have been superficially modified to conceal that they are copies are also considered unauthorized collaboration.

You are expressly forbidden to supply a copy of your homework to another student via electronic means. This includes simply e-mailing it to them so they can look at it. If you supply an electronic copy of your homework to another student and they are charged with copying, you will also be charged. This includes storing your code on any site which would allow other parties to obtain your code such as but not limited to public repositories (Github), pastebin, etc. If you would like to use version control, use github.gatech.edu

7.5 Is collaboration allowed?

Collaboration is allowed on a high level, meaning that you may discuss design points and concepts relevant to the homework with your peers, as well as help each other debug code. What you shouldn't be doing, however, is paired programming where you collaborate with each other on a low level. Furthermore, sending an electronic copy of your homework to another student for them to look at and figure out what is wrong with their code is not an acceptable way to help them, and it is often the case that the recipient will simply modify the code and submit it as their own.

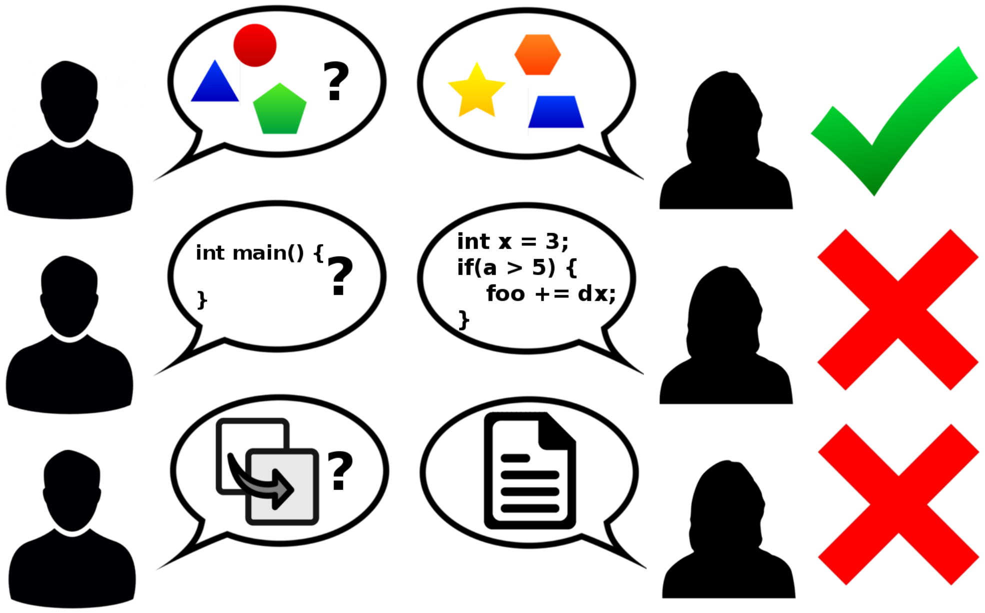


Figure 1: Collaboration rules, explained