CS 252 (Summer 19): Computer Organization

Sim #2

Logic, Adders, and ALUs

due at 5pm, Thu 27 Jun 2019

1 Purpose

Complex logic circuits, such as those inside a CPU, are implemented from simpler parts. In this project, you will implement some Java classes which represent simple hardware components, and then assemble them into a single large object which implements a multi-bit adder.

After you've completed this, you will implement an ALU. You will build three additional classes: one to implement a MUX, one to implement a 1-bit ALU element, and one to implement the entire ALU.

1.1 Required Filenames to Turn in

Name your files

```
Sim2_HalfAdder.java
Sim2_FullAdder.java

Sim2_AdderX.java

Sim2_MUX_8by1.java
Sim2_ALUElement.java
Sim2_ALU.java
```

1.2 Files

You can find the files for this project in the following locations:

- The GitHub Classroom repository
- The project directory on the class website: `http://lecturer-russ.appspot.com/classes/cs252/summer19/sim/sim2/`.
- The mirror of the class website, accessible on any department computer: `/home/russelll/cs252m19_website/`

2 Even More Limitations!

Like Simulation 1, you are not allowed to use any addition operator except for `++`, and even that operator is only legal as part of your `for()` loops. You **may** use subtraction - but only for calculating your indices for carrying logic - (it is very nice to be able to copy a value from column `i-1` into column `i`).

Second, in this project, you **also** cannot use any `if()` statements in any of your classes. This is because, in hardware, you don't have `if()` - instead, all hardware is running all the time. Instead, build your logic from gates: AND/OR/NOT.

Why am I placing such restrictions on you? Because I'm hoping to show you that we don't need fancy operators - or even something as simple as `if()` statements - in order to implement complex logic. **Everything** in your computer is just complex arrangements of `AND, OR, NOT` (plus memory).

3 Tasks

Like with Simulation 1, you will implementing a few Java classes (no C code this time) to model a few simple logic circuits. Unlike Simulation 1, each of the classes in this project will require that you build logic from simpler elements.

Unlike Simulation 1, I won't be providing any Java files for you to modify; instead, you'll write your own from scratch.

All of the classes that you write will have a single `execute()` method, **except** for the ALU Element class. That one will be a little different: it will have two different methods - representing the two-pass nature of how the ALU works.

3.1 Common Requirements

Each of the classes you write will build (somewhat) complex logic out of simpler parts. As you did in Simulation 1 (and as you'll see in the NAND example I've provided), you must create objects inside the constructor of your class - never inside `execute()`.

Basically, the **only** things that your `execute()` methods should do is to (a) copy values around, and (b) call `execute()` on other objects.

NOTE 1: I have provided an example of this style of object (one that is composed of smaller objects). Take a look at `NAND_example.java` to see how this all works.

NOTE 2: Testcase 00, which I've provided, doesn't really check any logic. Instead, it simply exists to double-check the types of the inputs and outputs. If you can link with that testcase, then you'll be able to link with any other testcases I write.

3.2 Half Adder

Write a class named `Sim2_HalfAdder`. This class has the same inputs as AND/OR/XOR (two `RussWire` objects, named `a,b`). However, it has two outputs, `RussWire` objects named `sum` and `carry`. This class will implement a Half Adder: remember that this is a 1-bit adder, which does **not** have a carry-in bit.

3.3 Full Adder

Write a class named `Sim2_FullAdder`. This must have three inputs: `a,b,carryIn` and two outputs `sum,carryOut`.

You **must** implement the full adder by linking two half adders together.

3.4 Multi-Bit Adder

Write a class named `Sim2_AdderX`, which implements a multi-bit adder by linking together many full adders. (This is known as a "ripple carry" adder.) **Your adder must be composed of many different full adders; don't try to get more fancy than this[1].**

The constructor for this class must take a single `int` parameter; this is the number of bits in the adder. You may assume that the parameter is `>=2`; other than that, you must support any size at all. (We'll call this parameter `X` in the descriptions below.)

The inputs to this class must be two arrays of `RussWire` objects, each with exactly `X` wires. Name the inputs `a,b`. The outputs from this class are a `X` wire array named `sum`, a two single bits: `carryOut,overflow`.

This class has the same restrictions as all the rest. Since you're doing it `X` times, I'll allow you to use a `for()` loop in this method. Also note that subtraction is allowed for copying a carry bit from one column to another, so you can copy from `i-1` into `i`. However, remember that `if()` is still banned!

NOTE: This class doesn't actually perform subtraction - that's why there isn't any control bit to select it.

3.5 MUX

Write a class named `Sim2_MUX_8by1`. It must have a 3-bit `control[]` input, and a 8-bit `in[]` input; both are arrays of `RussWire` objects. It must have a single `RussWire` output, which is named `out` (not an array).

This class must have a single `execute()` method.

This class models a 8-input MUX, where each input is a single bit wide. Since it has 8 inputs, there are 3 control bits. (As with our adders, treat element 0 of the control array as the LSB of the control input.)

Something to think about:
How could you adapt this class to represent a 2-input MUX as well - without adding any new control bits?

[1] Sometimes students want to use a bunch of full adders, and a single half adder for the least-significant-bit. I'll allow this, but frankly, it's not worth your time. We'll use a full adder for the LSB later, when we are doing subtraction!

3.6 ALU Element

Write a class named `Sim2_ALUElement`. It must have several inputs:

- `aluOp` (3 bits)

  As we normally do, element 0 is the LSB of this field. It has 5 possible values:

  - 0 - AND
  - 1 - OR
  - 2 - ADD
  - 3 - LESS
  - 4 - XOR

  (You may assume that this input will never be set to 5,6,7.)

  Of course, XOR is not a standard ALU operation according to the design in the textbook - I'm adding it just for fun.

- `bInvert` (1 bit)
- `a,b` (1 bit each)
- `carryIn` (1 bit)
- `less` (1 bit)

  This input is the value that this ALU Element should give as the result if `aluOp==3`. (Obviously, this input will not be set before the first pass, so it should only be read during the second pass.)

The class must also have several outputs:

- `result` (1 bit)

  This is the output from this ALU element. It might be the result of calculating AND, OR, ADD, or LESS.

- `addResult` (1 bit)

  This is the output from the adder. It should always be set - no matter what the `aluOp` is set to. This is the add result for **this bit only**.

  (If `aluOp==2`, then `result` and `addResult` will - eventually - be the same.)

- `carryOut` (1 bit)

3.6.1 ALU Element - Two Passes

The `Sim2_ALUElement` class must have **two** execute methods, named `execute_pass1()` and `execute_pass2()`.

`execute_pass1()` represents (surprise!) the first pass through the ALU Element. When this is called, all of the inputs to the element will be set **except** for `less`. Your code must run the adder (including, of course, handling the `bInvert` input), and must set the `addResult` and `carryOut` outputs. It **must not** set the `result` output yet - because, at this point in time, the value of the `less` input might not be known.[2]

`execute_pass2()` represents the second pass through each ALU Element. When this function is called, all of the inputs will be valid (including `less`), and you must generate the `result` output.

When should you generate the AND value and OR value, and when should you copy the AND, OR, ADD values into the inputs of the MUX? You get to choose.

3.7 ALU

Write a class named `Sim2_ALU`, which represents a complete ALU. It **must** use an array of ALU Element objects internally.

You must write this class so that it can handle inputs with any number of bits (not just 32). We'll pass the required size of the ALU as a parameter to the constructor of your class; you can assume that it will be ≥ 2. (We'll call this value X below.)

This class must have the following inputs:

- `aluOp` (3 bits)

  See the ALU Element description above to see how the ALU operation is encoded.

- `bNegate` (1 bit)

- `a,b` (X bits each)

This class must have a single X bit output, named `result`.

This class must have a single `execute()` method. It must deliver the inputs to the various ALU Elements, call `execute_pass1()` on them, set up the `less` inputs for each element, and then call `execute_pass2()` on each. (There are a few variations in the order in which you perform these steps. You may use the order that makes most sense to you. But write comments to explain what you're doing!)

[2] Tempted to use an `if()` statement, and set the `result` sometimes? Remember that `if()` is banned!

4 A Note About Grading

Your code will be tested automatically. Therefore, your code must:

- Use exactly the filenames that we specify (remember that names are case sensitive).
- **Not** use any other files (unless allowed by the project spec) - since our grading script won't know to use them.
- Follow the spec precisely (don't change any names, or edit the files I give you, unless the spec says to do so).
- (In projects that require output) match the required output **exactly!** Any extra spaces, blank lines misspelled words, etc. will cause the testcase to fail.

To make it easy to check, I have provided the grading script. I **strongly recommend** that you download the grading script and all of the testcases, and use them to test your code from the beginning. You want to detect any problems early on!

4.1 Testcases

You can find a set of testcases for this project in the GitHub Classroom; they are also present on the class website.

For assembly language programs, the testcases will be named `test_*.s` . For C programs, the testcases will be named `test_*.c` . For Java programs, the testcases will be named `Test_*.java` . (You will only have testcases for the languages that you have to actually write for each project, of course.)

Each testcase has a matching output file, which ends in `.out`; our grading script needs to have both files available in order to test your code.

For many projects, we will have "secret testcases," which are additional testcases that we do not publish until after the solutions have been posted. These may cover corner cases not covered by the basic testcase, or may simply provide additional testing. **You are encouraged to write testcaes of your own, in order to better test your code.**

4.2 Automatic Testing

We have provided a testing script (in the same directory), named `grade_sim2`. Place this script, all of the testcase files (including their `.out` files if assembly language), and your program files in the same directory. (I recommend that you do this on Lectura, or a similar department machine. It **might** also work on your Mac, but no promises!)

4.3 Writing Your Own Testcases

The grading script will grade your code based on the testcases it finds in the current directory. Start with the testcases I provide - however, I encourage you to write your own as well. If you write your own, simply name your testcases using the same pattern as mine, and the grading script will pick them up.

While you normally cannot share code with friends and classmates, **testcases are the exception.** We encourage you to share you testcases - ideally by posting them on Piazza. Sometimes, I may even pick your testcase up to be part of the official set, when I do the grading!

5 Turning in Your Solution

You must turn in your code using GitHub Classroom. Turn in only your program; do not turn in any testcases.

Make sure that your code is actually on GitHub before the deadline. This will require that you add the file **and** then push it to GitHub. (You can confirm that you have uploaded the files correctly by viewing your repo through the GitHub website.)