University of Windsor

School of Computer Science
Faculty of Science

COMP-2650: Computer Architecture I: Digital Design
Fall 2020

Lab#	Date	Title	Due Date	Grade Release Date
Lab 03	Oct 05-07, 2020	**L03: Number Systems**	Oct. 21, 2020 Wednesday Midnight AoE	Oct. 28, 2020

The third lab's objectives will be for you to master the topics in number systems, esp., conversion, and arithmetic, by implementing the algorithms with a programing language, herein, C/C++.

Step 1. Environment Setup

Our programing environment is the same as the first lab (Lab 01). In this lab, we want to extend our Lab 01 and Lab 02 to support binary numbers conversion to other bases and more arithmetic operations. For instance, we want to convert binary numbers to octal or hexadecimal. Also, we want to calculate the addition or subtraction of two binary systems.

As we discussed in the lectures, if we increase the base in a number system, there would be less position required to represent the same numbers. For instance, the number $(1111)_2$ is $(17)_8$ and $(F)_{16}$. As seen, although we are writing programs to work with binary numbers, it would be preferable for the user to input numbers faster using a smaller number of digits or seeing a shorter representation of numbers instead of seeing a long stream of 0 and 1. In C/C++, the octal and hexadecimal numbering systems are already available for printing output:

```
01 #include <stdio.h>
02 int main(void) {
03
04     setbuf(stdout, NULL);
05     int x;
06
07     printf("Enter an integer number:\n");
08     scanf("%d", &x);
09
10     printf("The number is: \n");
11     //printf("Binary: %b \n",x); There is no option for binary!
12     printf("Octal: %o \n",x);
13     printf("Decimal: %d \n",x);
14     printf("Hexadecimal: %x \n",x); //Alphabet in small letters
15     printf("HEXAdecimal: %X \n", x); //Alphabet in capital letters
16     return 0;
17 }
```

As shown in lines# 12 to 15, there are *format specifiers* that output the value of x in the base-[8,10,16]. 20 Unfortunately, there is no format specifier for base-2 or binary. An example run would be:

```
Enter an integer number:
15
The number is:
Octal: 17
```

```
Decimal: 15
Hexadecimal: f
HEXAdecimal: F
```

Also, you can ask the user to input a value in octal, hexadecimal, or decimal in line# 7.

```
01 #include <stdio.h>
02 int main(void) {
03
04      setbuf(stdout, NULL);
05      int x;
06
07      printf("Enter an integer number:\n");
08      scanf("%x", &x);
09
10      printf("The number is: \n");
11      //printf("Binary: %b \n",x); There is no option for binary!
12      printf("Octal: %o \n",x);
13      printf("Decimal: %d \n",x);
14      printf("Hexadecimal: %x \n",x); //Alphabet in small letters
15      printf("HEXAdecimal: %X", x); //Alphabet in capital letters
16      return 0;
17 }
```

An example run would be:

```
Enter an integer number:
ff01
The number is:
Octal: 177401
Decimal: 65281
Hexadecimal: ff01
HEXAdecimal: FF01
```

Unfortunately, the format specifiers in C/C++ cannot be used for our program since we store the binary digits in an integer array. So, we have to write the conversion functions for octal, hexadecimal, and decimal.

Step2. Writing Modular Programs

Before adding new functionalities to our program, let's organize it better. In our previous lab (Lab 02), all the functions for operations such as AND, OR, 1's complement, etc., were supposed to be in the same file as the `main()` function. As we add more functions, this file will become bigger and bigger and hard to maintain. So, it's better to put related functions to different files.

For instance, let's put all logical operations such as AND, OR, NOT in a separate file, named `logic_tools.cpp`. Also, we can put all functions related to calculating complement in another separate file, named `comp_tools.cpp`. Further, we will put all functions related to conversion in another separate file, named `convert_tools.cpp`.

logic_tools.cpp

```
#define MAX 8//Byte = 8 bits
void func_and(int a[], int b[], int result[]){...}
void func_or(int a[], int b[], int result[]){...}
void func_not(int a[], int result[]){...}
```

comp_tools.cpp

```
#include "logic_tools.h"//Required as we use func_not for doing 1's comp!
```

```
#define MAX 8//Byte = 8 bits
void func_1s_comp(int a[], int result[]){...}
void func_2s_comp(int a[], int result[]){...}
void func_2s_comp_star(int a[], int result[]){...}
```

In C/C++, in order to call the functions in other files, we have to add header files in the main file of our program or any other files that use the functions (e.g., we added `logic_tools.h` in `comp_tools.cpp` as we used `func_not` for doing 1's complement). Let's create the header files for each of our new file first:

logic_tools.h

```
void func_and(int a[], int b[], int result[]);
void func_or(int a[], int b[], int result[]);
void func_not(int a[], int result[]);
```

comp_tools.h

```
void func_1s_comp(int a[], int result[]);
void func_2s_comp(int a[], int result[]);
void func_2s_comp_star(int a[], int result[]);
```

As seen, header files contain only the signatures of the functions and not the bodies. Please look at the ';' in the end of each function. Now we are ready to add the headers to our main program and use the functions in each separate file:

```
01 #include <stdio.h>
02 #include "logic_tools.h"
03 #include "comp_tools.h"
04 #define MAX 8//Byte = 8 bits
05 int main(void) {
06     setbuf(stdout, NULL);
07
08     int x[MAX];
09     int y[MAX];
10
11     printf("Enter the first binary number:\n");
12     for(int i=0; i < MAX; i = i + 1){
13         scanf("%d", &x[i]);
14     }
15     printf("Enter the second binary number:\n");
16     for(int i=0; i < MAX; i = i + 1){
17         scanf("%d", &y[i]);
18     }
19
20     int z[MAX];
21     //func_and(x, y, z);
22     //func_not(x, z);
23     func_1s_comp(x, z);
24     printf("The first number AND second binary yield:\n");
25     for(int i=0; i < MAX; i = i + 1){
26          printf("%d", z[i]);
27     }
28
29    return 0;
30}
```

Lab Assignment

You should complete the above program under the name of a project COMP2650_Lab03_{UWinID} that firstly outputs a menu of commands as follows:

```
Enter the command number:
0) Exit
1) AND
2) OR
3) NOT
4) 1's complement
5) 2's complement
6) 2's complement*
```

Based on the user's chosen number of commands, the program should then ask for the input(s). After that, the program asks to what base the user wants to see the results. Then, it applies the command and prints out the result in the requested base. For instance, if a user selects (1), the program should accept two inputs as follows:

```
Enter the first binary number:
x0 =
x1 =
...
x7 =

Enter the second binary number:
y0 =
y1 =
...
y7 =
```

When the user enters the two binary numbers, the program asks for a base number to print out the result:

```
Enter the output base:
1) Binary
2) Octal
3) Decimal
4) Hexadecimal
```

Then the program applies the AND command on the input x and y and prints the result on the selected base and comes back to the main menu. Other commands should follow the same flow. If the user selects (0), the program ends. Please restrict the user to enter inputs within the range {0,1}. For instance, if the user enters 2, -1, …, print out an error message and come back to ask for correct inputs. It is required to write a *modular* program according to the following instructions:

1. Reorganized the previous functions in Lab02 in separate files as I did in this manual.
2. For the base conversion, create `conver_tools.cpp` and `convert_tools.h`.
3. Write functions in `conver_tools.cpp` to output the result according to the selected base by the user by calling the functions from `main.cpp` file:

```
void to_octal(int a[]){}
void to_decimal(int a[]){}
void to_hexadecimal(int a[]){}
```

For converting binary numbers to octal or hexadecimal, you can use either the steps explained in the class or the fast method explained in assignment Lec01. For converting to decimal, you can use the sum of powers of 2, as described in the class.

Deliverables

You will prepare and submit the program in one single zip file `COMP2650_Lab03_{UWinID}.zip` containing the following two items:

1. The entire project folder `COMP2650_Lab03_{UWinID}`, including the code (source) files and executable file.
2. The result of the commands in the file `COMP2650_Lab03_Results_{UWinID}.jpg`. Simply make a screenshot of the results and save it.
3. A lab report document in the PDF file `COMP2650_Lab03_Report_{UWinID}.pdf`. It should include:
    a. Your name, UWinID, and student number
    b. The description of the program that you attached, along with any prerequisites that are needed to build and run the program. *Please note that if your program cannot be built and run on our computer systems, you will lose marks.*

In sum, your final zip file for the submission includes 1 folder (entire project folder), 1 image (results snapshot) and 1 pdf (report). *Please follow the naming convention as you lose marks otherwise.* Instead of {UWinID}, use your own UWindsor account name, e.g., mine is hfani@uwindsor.ca, so,

```
COMP2650_Lab03_hfani.zip
  - COMP2650_Lab03_hfani
      o src
          ▪ logic_tools.cpp
          ▪ logic_tools.h
          ▪ comp_tools.cpp
          ▪ comp_tools.h
          ▪ convert_tools.cpp
          ▪ convert_tools.h
          ▪ main.cpp
      o COMP2650_Lab03_hfani [.exe in MS-Windows]
  - COMP2650_Lab03_Report_hfani.pdf
  - COMP2650_Lab03_Results_hfani.jpg
```