ENCM 369 Winter 2023 Lab 1 for the Week of January 16

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Administrative details

Each student must hand in their own assignment

Later in the course, you may be allowed to work in pairs on some assignments.

Due Dates

The Due Date for this assignment is 6:00pm Friday, January 20.
The Late Due Date is 6:00pm Saturday, January 21.

The penalty for handing in an assignment after the Due Date but before the Late Due Date is 3 marks. In other words, X/Y becomes (X–3)/Y if the assignment is late. There will be no credit for assignments turned in after the Late Due Date; they will be returned unmarked.

Marking scheme

B	6 marks
G	6 marks
H	4 marks
total	16 marks

How to package and hand in your assignments

You must submit your work as a *single PDF file* to the D2L dropbox that will be set up for this assignment. The dropbox will be configured to accept only file per student, but you may replace that file as many times as you like before the due date.

Please check carefully that you are submitting in *all* of the material you are supposed to be handing in. "I forgot" is not an acceptable excuse for handing in part or all of an exercise after the Due Date.

The reason for the "one file only" rule is that it is much easier for a teaching assistant to mark an assignment by scrolling through a single file than by opening and closing several different file.

You may prepare your PDF file with whatever hardware and software you like. Pencil-and-paper is probably the easiest method for making diagrams, but it is also fine to use a tablet or computer to make diagrams. Apps such as Microsoft Lens are good for making digital copies of pencil-and-paper drawings using a phone or tablet.

You can copy and paste program source code from your text editor into whatever application you are using to create the document you will be submitting. Similarly, you can copy and paste text from your terminal window to show output and input from program runs. If you find it easier to paste screenshots of source code and output into your document, that's fine, but please make sure that the screenshots are complete and easy to read.

Please make sure all your work is *easy to read* and *conveniently organized*; this will be a *big help* to the teaching assistants who have the difficult job of marking your assignments. Please check your work before you submit it. If you find blurry screenshots or scans, you should replace them with better-quality images.

You document should start with a cover page with this information on it:

- your *name* (but not your ID number)
- your *lab section number* (B02, B03, or B04)
- the name of this course—*ENCM 369*
- which lab assignment it is—*Lab 1* this week, *Lab 2* next week, and so on

Exercise A: Practice editing C code and building an executable

Read This First

There are no marks for this exercise, but I *strongly* recommend that you make a serious effort to get it done before your first lab period. If you are unsuccessful, please be ready to ask questions at the *beginning* of the lab period.

What to do, Part I

If you don't have you computer set up for command-line C programming, please see the relevant documents and videos in the D2L Content module called "Setting up C programming on your own computer".

What to do, Part II

Open a Cygwin Terminal window or a macOS Terminal window. Create a directory (folder) called `encm369` in an appropriate place within your file system. Within your `encm369` directory, create a directory called `lab01`, and within that create a directory called `exA`.

Start up your preferred text editor. Type in the first line from Figure 1, then use a `Save as ...` command to save the file with name `exA.c`, in your `encm369/lab01/exA` directory. Use the `ls` command to confirm that a file called `exA.c` exists within that directory.

Return to the text editor, and finish typing in the rest of the code from Figure 1. When you have finished, save the file and return to your terminal window.

In the terminal window, build an executable with the command

```
gcc -Wall exA.c
```

If there are errors or warnings, go back to the text editor, try to fix the errors, then try again to build an executable. If there are no errors or warnings, run the Cygwin command

```
./a.exe
```

Figure 1: C code for Exercise A.

```
#include <stdio.h>

int main(void)
{
    int n = 0;
    int power = 1;

    printf("%12s%12s%12s\n", "n      ", "2**n   ", "2**n");
    printf("%12s%12s%12s\n", "decimal", "decimal", "hex ");
    while (n <= 16) {
        printf("%12d%12d%12x\n", n, power, power);
        power = power + power;
        n++;
    }
    return 0;
}
```

or the macOS/Linux command

```
./a.out
```

You should see a table of powers of 2^n for values of n from 0 to 16, displayed in both base ten and base sixteen.

Keep working on this exercise until you are sure you know what you are doing—if you do not, you will have serious problems with all of the remaining exercises!

What to Put in Your PDF Submission

Nothing.

Exercise B: Global variables, review of pointer arithmetic

Read This First

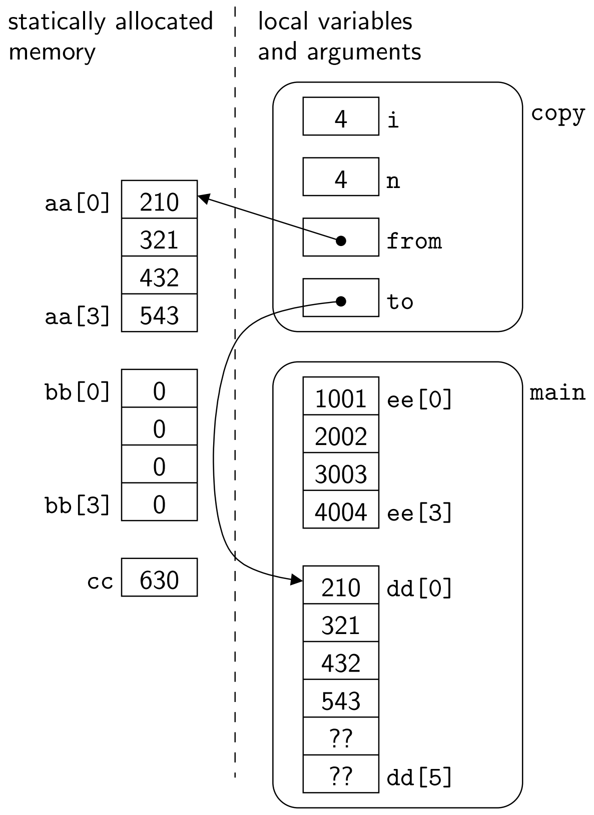
Most variables you saw or created in programs in ENCM 335 or ENSF 337 were *local variables.* A local variable can be directly accessed only within the function definition in which it appears. (A local variable of one function can be *indirectly* accessed by another function, if that other function has a pointer to the variable.)

C variables declared outside of all function definitions in a C source file are called *global variables* or *external variables.* Unlike local variables, global variables can be directly accessed from many different function definitions.

There are two kinds of global variables: those declared to be `static` and those *not* declared to be `static`. Global variables declared to be `static` can be directly accessed by all functions in the source file where the variable is declared. (This use of the keyword `static` is confusing, because it has nothing to do with static memory allocation.) Global variables *not* declared to be `static` can be directly accessed by all functions in a program.

(If you are working on a program where a global variable is in fact accessed from more than one source file, you need to know the rules regarding the `extern` keyword. See a good C text for details, and read carefully.)

Figure 2: The state of the Exercise B program at the moment when `point one` is reached. At that moment, functions `update_cc` and `reverse` are not active, so their arguments and local variables do not exist. The notation ?? is used to indicate uninitialized local variables. **Important note for ENCM 369:** As the course progresses, we will see that some of the local variables and arguments of a program are in a region of main memory called *the stack*, and other local variables and arguments are in *registers*; we'll see later in the course that for RISC-V the arrays `dd` and `ee` would be allocated on the stack, but the integers and pointers belonging to `copy` would be in general-purpose registers, *not* in memory at all!



Global variables, regardless of whether they are declared as `static`, are always statically allocated. So, according to rules you should have learned in ENCM 335 or ENSF 337, global variables are found in the static storage region, are allocated and initialized before `main` starts, and remain allocated as long as the program runs.

Unlike *automatic* variables (which are the "normal" kind of local variables of functions) global variables that don't have initializers are initialized to zero. For example, consider this variable declaration:

```
int arr[5];
```

If `arr` were local to some function, you could not count on the elements of `arr` to have any particular values. But if `arr` were a global variable, its elements would all be initialized to zero.

What to do

Part 1

Download the file `globals1B.c`

Figure 3: Example of a pointer pointing "just beyond" the last element of an array. Here `arr[3]` does not exist, but the *address* of `arr[3]` *does* exist. This concept is useful for setting up a condition to quit a loop, when the loop uses pointer arithmetic to step through an array.

```
// fragment of a C function
int arr[] = { 10, 11, 12 };
int *p;
p = arr + 3;
```

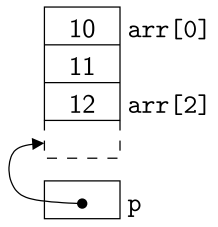


Figure 4: Table for Exercise B, Part 2.

instant in time	`dest`	`src`	`guard`	`k`
`point two`, first time	`0x100078`			
`point two`, second time				
`point two`, third time				
`point two`, last time				

Study the file carefully and make sure you understand the diagram of program state at `point one` given in Figure 2.

Make a similar diagram to show the state of the program when it reaches `point three.` (*Note:* In ENCM 369, whenever you are asked to hand in diagrams, you may draw them neatly by hand or by computer, whichever you find more convenient.)

Figure 3 should give you a hint about how to draw part of the diagram.

Part 2

Instead of using arrows to show what addresses are contained by pointers, let's track pointers as actual numbers.

We'll assume that the size of an `int` is 4 bytes. We'll use hexadecimal numbers, writing them in C language notation. For example, `0x7ffe18` represents a number we would have written as $7FFE18_{16}$ in ENEL 353.

Suppose that the address of `ee[0]` is `0x7ffe58`. Then the addresses of elements 1, 2, 3 in the array must be `0x7ffe5c`, `0x7ffe60`, and `0x7ffe64`—each address is 4 greater than the previous one. (Here is a fact you will use often in this course: In base sixteen, adding `0xc` and `0x4` generates a sum digit of zero and a carry out of one.)

Now suppose that `&bb[0]` is `0x100078` and `&ee[0]` is `0x7ffe40`. Use that information to fill in all of the addresses in all of the cells in a copy of the table of Figure 4.

What to Put in Your PDF Submission

Include a diagram for Part 1 and a completed table for Part 2.

Exercise C: goto statements

Read This First

goto statements are available in C and C++, and their equivalents are available in many other programming languages (but not Python or Java).

You can have a long career writing high-quality C and C++ code for a huge variety of applications and never once use a goto statement. Just about everything you can do with goto can be done more clearly some other way. Use of goto tends to make code unreasonably hard to understand and debug.

Nevertheless, it's useful to know what goto does, for the following reasons:

(1) You might find goto in code that somebody else wrote.
(2) C code generated by a program (as opposed to code written by a human being) may have goto statements in it.
(3) Writing goto statements is similar to writing branch instructions in assembly language.

It's reason (3) that makes the goto statement relevant to ENCM 369.

Consider the following simple program:

```
#include <stdio.h>
int main(void)
{
  int i;
  for (i = 0; i < 4; i++)
    printf("i is %d.  ", i);
  printf("\n");
  return 0;
}
```

Obviously, the output is

```
i is 0.  i is 1.  i is 2.  i is 3.
```

Here is an equivalent program written using goto statements:

```
#include <stdio.h>
int main(void)
{
  int i;
  i = 0;
 loop_beginning:
  if (!(i < 4)) goto past_loop_end;
  printf("i is %d.  ", i);
  i++;
  goto loop_beginning;
 past_loop_end:
  printf("\n");
  return 0;
}
```

The output is exactly the same as that of the earlier program with the for loop.

The identifiers loop_beginning and past_loop_end are examples of what are called *labels*. A label is used to name a particular statement; a colon must appear between a label and the statement it names. A goto statement has the following syntax:

`goto` *label*;

A `goto` statement causes the flow of statement execution to jump to whatever statement is named by the label. This should be reasonably clear from the example.

What to Do

Determine the output of the following program by tracing its execution line by line with a pencil and paper.

```c
#include <stdio.h>
int main(void)
{
  int outer, inner;
  outer = 3;
 outer_loop:
  if (outer == 0) goto quit_outer_loop;
  inner = 0;
 inner_loop:
  if (inner > outer) goto quit_inner_loop;
  printf(" %d", 100 * outer + inner);
  inner++;
  goto inner_loop;
 quit_inner_loop:
  printf(" **\n");
  outer--;
  goto outer_loop;
 quit_outer_loop:
  printf("*****\n");
  return 0;
}
```

Check your work by typing in the program, compiling it, and running it. (If it doesn't compile, goes into an infinite loop when it runs, or crashes, you have made a typing error.)

What to Put in Your PDF Submission

Nothing.

Goto-C: Read this before starting Exercises D–H

From now on in this course, the term "Goto-C" refers to a programming language that is C with the following modifications:

- The only kind of `if` statement allowed in Goto-C is the following:

  `if (`*expression*`) goto` *label*`;`

- Goto-C does not have the following keywords and operators:

  `else while for do switch && ||`

- Goto-C does not have `?:`, the conditional operator.

As you will soon see, Goto-C is an annoying language, significantly harder to read and write than normal C. However, working with Goto-C will help you learn how to code algorithms in assembly language.

Consider the following simple fragment of normal C:

```
if (x >= 0)
  y = x;
else
  y = -x;
```

The above is illegal in Goto-C for two reasons: the `if` statement is not in an acceptable form, and the banned keyword `else` is used. One way to translate the fragment to Goto-C is as follows:

```
 if (x < 0) goto else_code;
 y = x;
 goto end_if;
else_code:
 y = -x;
end_if:
```

Technical Note: The C standard does not permit code like the following:

```
void f(int i)
{
    if (condition) goto L;
    code
  L:
}
```

The reason is that the label `L` is followed by a closing brace, which is not a statement. To write standard-compliant code, use the empty statement—a semicolon all by itself . . .

```
void f(int i)
{
    if (condition) goto L;
    code
  L:
    ;
}
```

Exercise D: Translating `if / else-if / else` code to Goto-C

What to Do

Download the file `temperature1D.c`

Read the file, then make an executable and run it. Then recode the function `report` in Goto-C. Make sure that the output of your modified program exactly matches the output of the original program.

What to Put in Your PDF Submission

Nothing.

Exercise E: Simple loops in Goto-C

Read This First

Simple C `while` and `for` loops are easy to code in Goto-C. You need a statement of the form `if (`*condition*`) goto `*label*`;`

at the top of the loop to skip past the end of the loop when appropriate and you need a statement of the form

`goto `*label*`;`

to jump backwards after the loop body has been executed. For example, this code:

```
  while (i >= 0) {
    printf("%d\n", i);
    i--;
  }
```

can be written as:

```
 loop_top:
  if (i < 0) goto past_end;
  printf("%d\n", i);
  i--;
  goto loop_top;
 past_end:
```

Remember that the condition to quit looping is the opposite of the condition to continue looping.

What to Do

Download the file `simple_loops1E.c`

Read the file and follow the instructions in the comment at the top of the file.

What to Put in Your PDF Submission

Nothing.

Exercise F: `&&` and `||` in Goto-C

Read This First

You should recall from ENCM 335 or ENSF 337 that *short-circuit evaluation* is used when the `&&` and `||` operators are encountered in C (and C++) code. For example, the right-hand operand of `&&` is not evaluated if the left-hand operand is false. It's quite easy to translate expressions with `&&` into Goto-C. For example,

```
  if (y > 0 && x / y >= 10) {
    foo(x);
    bar(y);
  }
```

can be coded as

```
  if (y <= 0) goto end_if;
  if (x / y < 10) goto end_if;
  foo(x);
  bar(y);
 end_if:
```

Expressions with `||` can be coded in goto-C using a simple adjustment of the technique used for expressions with `&&`.

What to Do

Download the file `logical_or1F.c`

Read the file and follow the instructions in the comment at the top of the file.

What to Put in Your PDF Submission

Nothing.

Exercise G: A more complicated program in Goto-C

What to Do

Copy the file `lab1exG.c`

Read the file carefully. Make an executable using the following command:

```
gcc -Wall exG.c
```

Run the executable seven times, using the following text as input:

INPUT	DESCRIPTION
`1.0 x`	first run, test with invalid input
`1.0 0`	second run, also invalid input
`0.8 10`	third run
`2.2 10`	fourth run
`-1.07 10`	fifth run
`-0.8 10`	sixth run
`-4.8 10`	seventh run

Translate the definitions of `main` and `polyval` to Goto-C. Be careful to translate *every* use of a C feature that is not allowed in Goto-C.

Test your modified program with the same input given above for the original program. Make sure it always generates *exactly* the same output as the original program.

What to Put in Your PDF Submission

Listings of the final version of your source file and and the outputs of all of your test runs.

Exercise H: Nested loops in Goto-C

What to Do

Download the file `lab1exH.c`

Read the file, then make an executable and run it to check what the program does.

Translate the definitions of `print_array` and `sort_array` to Goto-C. Be careful to translate *every* use of a C feature that is not allowed in Goto-C.

Make sure your modified program generates *exactly* the same output as the original program.

What to Put in Your PDF Submission

A listing of the final version of your source file.