CSC215 Lecture

Functions and Modular Programming

Outline

- Functions:
  - Need, Definition
  - Defining functions
  - Calling functions
  - Prototypes
- Scopes
  - Scope and visibility
  - Storage classes
- Recursive functions
- Multiple source files
- Makefiles

Introduction

- Design your solution so that it keeps the flow of control as simple as possible
  - top-down design:
    decompose the problem into smaller problems each can be solved easily
- Some problems are complicated
  - break them down into smaller problems
  - conquer each sub problem independently
- Your programs will consist of a collection of user-defined functions
  - each function solves one of the small problems
  - you call (invoke) each function as needed

What is a Function?

- Function: a group of statements that together perform a task
  - divide up your code into separate functions such that each performs a specific task
  - every C program has at least one function, which is **main()**
  - most programs define additional functions
- Why
  - to avoid repetitive code : “reusability” written once, can be called infinitely
  - to organize the program : making it easy to code, understand, debug and collaborate
  - to hide details : “what is done” vs “how it is done”
  - to share with others
- Defining functions:
  - Predefined (library functions): We have already seen:
    - main, printf, scanf, getchar, gets
  - User-defined

Defining Functions

- Syntax:

```
<return_type> <function_name>(<parameter_list>){
  <function_body>
}
```

  - Return_type: data type of the result
    - Use `void` if the function returns nothing
    - if no type is specified and void is not used: it defaults to `int`
  - Function_name: any valid identifier
  - Parameter_list:
    - declared variables: `<param_type> <param_name>`
    - comma separated
  - Function_body:
    - declaration statements
    - other processing statements
    - `return` statement, if not void

Example

- In many application, finding the greatest common factor is an important step
- GCF function:
  - takes two input integers
  - finds the greatest integer that divide both of them
  - returns the result to the calling context
  - Euclidean algorithm:
    - if a > b → gcf(a, b) = gcf(b, a mod b)
    - if b > a, swap a and b
    - Repeat until b is 0
- In c:

```
int gcf(int a, int b){
  /* if a < b swap them, to be discussed later*/
  while (b) {
    int temp = b ;
    b = a % b ;
    a = temp ;
  }
  return a;
}
```

Calling Functions

- Syntax:
  `<function name>(<argument list>)`
- A function is invoked (called) by writing:
  - its name, and
  - passing an appropriate list of arguments within parentheses
    - arguments must match the parameters in the function definition in:
      1- count , 2- type and 3- order
- Arguments are passed by value
  - each argument is evaluated, and
  - its value is copied to the corresponding parameter in the called function
- What if you need to pass the variable by reference?
  - you cannot
  - but you can pass its address by value

Calling Functions

- Example:

```c
/* Does not work as expected*/
void swap(int a, int b){
   int temp = a;
   a = b;
   b = temp;
}

int main(){
   int a = 3, b = 5;
   swap(a, b);
   printf("a=%d, b=%d\n", a, b);
   return 0;
}
```

```c
/* Works as expected*/
void swap(int *a, int *b){
   int temp = *a;
   *a = *b;
   *b = temp;
}

int main(){
   int a = 3, b = 5;
   swap(&a, &b);
   printf("a=%d, b=%d\n", a, b);
   return 0;
}
```

Calling Functions

- A function can be called from any function, not necessarily from `main`
- Example:

```
void swap(int *a, int *b){
  int temp = *a; *a = *b; *b = temp;
}
int gcf(int a, int b){
  if (b > a) swap(&a, &b);
  while (b) {
    int temp = b ;
    b = a % b ;
    a = temp ;
  }
  return a;
}
int main(){
  int a = 3, b = 5;
  printf("GCF of %d and %d is %d\n", a, b, gcf(a, b) );
  return 0;
}
```

Function Prototypes

- ❑ If function definition comes textually after use in program:
    - The compiler complains: `warning: implicit declaration of function`
- ❑ Declare the function before use: Prototype

  ```
  <return_type> <function_name>(<parameters_list>);
  ```
- ❑ Parameter_list does not have to name the parameters
- ❑ Function definition can be placed anywhere in the program after the prototypes.
- ❑ If a function definition is placed in front of main(), there is no need to include its function prototype.

Function Prototypes: Example

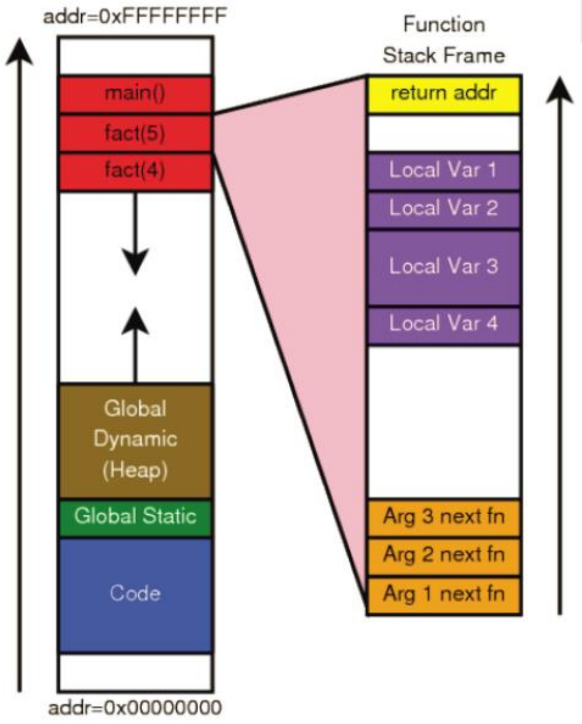
```
#include <stdio.h>
int gcf(int, int);
void swap(int*, int*);
int main(){
  int a = 33, b = 5;
  printf("GCF of %d and %d is %d\n", a, b, gcf(a, b) );
  return 0;
}
int gcf(int a, int b){
  if (b > a) swap(&a, &b);
  while (b) {
    int temp = b ;
    b = a % b ;
    a = temp ;
  }
  return a;
}
void swap(int *a, int *b){
  int temp = *a; *a = *b; *b = temp;
}
```

Function Stub

- A stub is a dummy implementation of a function with an empty body
    - A placeholder while building (other parts of) a program
        - so that it compiles correctly
    - Fill in one-stub at a time
    - Compile and test if possible

Memory Model

- Program code
    - Read only
    - May contain string literals
- Stack (automatic storage):
    - Function variables:
        - Local variables
        - Arguments for next function call
        - Return location
    - Destroyed when function ends
- Heap:
    - Dynamically allocated space
- Data segment:
    - Global variables
    - Static variables



Scopes

- ❑ Scope: the parts of the program where an identifier is visible
- ❑ Four scopes:
  - File scope
    - Identifiers defined out of any block or list of parameters
  - Function scope
    - Label names
    - Must be unique within a function
  - Block scope
    - Identifiers declared inside a block or a list of parameters
    - Local identifier A.K.A internal or automatic identifier
  - Function prototype scope
    - Identifiers declared inside a list of parameters of a function prototype
- ❑ If outer declaration of a lexically identical identifier exists in the same name space, it is hidden until the current scope terminates

Scopes: Examples

Ex1:

```c
#include <stdio.h>

void doubleX(float x){
  x *= 2;
  printf("%f\n", x);
}

int main(){
  float x = 3;
  doubleX(x);
  printf("%f\n", x);
  return 0;
}
```

```
6.000000
3.000000
```

Ex2:

```c
#include <stdio.h>

float x = 10;

void doubleX(){
  x *= 2;
  printf("%f\n", x);
}

int main(){
  float x = 3;
  doubleX();
  printf("%f\n", x);
  return 0;
}
```

```
20.000000
3.000000
```

Ex3:

```c
#include <stdio.h>

float x = 10;

void doubleX(float x){
  x *= 2;
  printf("%f\n", x);
}
void printX(){
  printf("%f\n", x);
}
int main(){
  float x = 3;
  doubleX(x);
  printf("%f\n", x);
  printX();
  return 0;
}
```

```
6.000000
3.000000
10.000000
```

Ex4:

```c
#include <stdio.h>

int main(){
  int x = 5;
  if (x){
    int x = 10;
    x++;
    printf("%d\n", x);
  }
  x++;
  printf("%d\n", x);
  return 0;
}
```

```
11
6
```

Storage Classes

- Storage Classes: a modifier precedes the variable to define its scope and lifetime
- `auto`: the default for local variables
- `register`: advice to the compiler to store a local variable in a register
    - the advice is not necessarily taken by the compiler
- `static`: tells the compiler that the storage of that variable remains in existence
    - Local variables with static modifier remains in memory so that they can be accessed later
    - Global variables with static modifier are limited to the file where they are declared
- `extern`: points the identifier to a previously defined variable
- Initialization:
    - in the absence of explicit initialization:
        - static and external variables are set to 0
        - automatic and register variables contain undefined values (garbage)

Storage Classes: Examples

Ex1 :

```
#include <stdio.h>

int main(){
  float x = xx;
             ✗

  return 0;
}

float xx;

void foo(){
  float x = xx;
             ✓
}

/*
  main doesn't know
  about xx
*/
```

Ex1 correction :

```
#include <stdio.h>

int main(){
  extern float xx;   ✓
  float x = xx;
✓

  return 0;
}

float xx;

void foo(){
  float x = xx;
✓
}

/*
  declare xx in main
  as extern to point to
  the external xx, this
  will not create new xx
*/
```

Ex2 :

```
/*file1.c        */
#include <stdio.h>
int sp = 0;
double val[1000];

int main(){
  return 0;
}

/*file2.c        */
#include <stdio.h>

void foo(){
  printf("%d", sp);      ✗
}

int bar(){
  return (int)val[0];  ✗
}
```

Ex2 correction :

```
/*file1.c        */
#include <stdio.h>
int sp = 0;
double val[1000];

int main(){
  return 0;
}

/*file2.c        */
#include <stdio.h>
extern int sp;           ✓
extern double val[];     ✓

void foo(){
  printf("%d", sp);      ✓
}
int bar(){
  return (int)val[0];  ✓
}
```

Recursive Functions

- Recursive function: a function that calls itself (directly, or indirectly)
- Example:

```
void change (count){
   ..
   ..
   change(count);
   ..
}
```

- The algorithm needs to be written in a recursive style
    - a step or more uses the algorithm on a smaller problem size
- It must contain a base case that is not recursive
- Each function call has its own stack frame
    - consumes resources

Recursive Functions: Examples

- Multiply $x \times y$:

```
int multiply(int x, int y){
  if (y == 1) return x;
  return x + multiply(x, y-1);
}
```

- Power x^y:

```
int power(int x, int y){
  if (y == 0) return 1;
  return x * multiply(x, y-1);
}
```

- Factorial $x!$:

```
int fac(int x){
  if (x == 1) return 1;
  return x * fac(x-1);
}
```

- Fibonacci:

```
int fib(int x) {
  if (x == 0) return 0;
  if (x == 1) return 1;
  return fib(x-1) + fib(x-2);
}
```

- Palindrome:

```
int isPal(char* s, int a, int b) {
  if (b >= a) return 1;
  if (s[a] == s[b])
    return isPal(s, a+1, b-1);
  return 0;
}
```

Multiple Source Files

- A typical C program: lot of small C programs, rather than a few large ones
  - each .c file contains closely related functions (usually a small number of functions)
  - header files to tie them together
  - Makefiles tells the compiler how to build them
- Example:
  - a calc program defines:
    - a stack structure and its:
    - pop and push functions
    - getch and ungetch to read one symbol at a time
    - getop function to parse numbers and operators
    - main function
  - main calls: getop, pop, and push
    getop calls: getch and ungetch
  - can be organized in 4 separate files:
  - Where to place prototypes and external declarations?
  - How to compile the program?

```
/*        stack.c       */
#include <stdio.h>
int sp = 0;
double val[1000];
void push(double x){
   ...
}
double pop(){
   ...
}
```

```
/*        getch.c       */
#include <stdio.h>

ch getch(){
   ...
}
void ungetch(char c){

}
```

```
/*        main.c        */
#include <stdio.h>

int main(){

}
```

```
/*        getop.c       */
#include <stdio.h>

int getop(char[] s){

}
```

Multiple Source Files: Header File

- Prototypes can be placed in a single file, called a header file
  - as well as all other shared definitions and declarations
  - typically contains definitions and declarations
    - but not executable code
- Example: calc program

  add a header file calc.h contains:
  - prototypes and
  - common declarations

  and **include** it where needed!

```c
/*        getch.c        */
#include <stdio.h>
#include "calc.h"
ch getch(){
  ...
}
void ungetch(char c){

}
```

```c
/*        main.c        */
#include <stdio.h>
#include "calc.h"
int main(){

}
```

```c
/*        calc.H        */
void push(double);
double pop();
ch getch();
void ungetch(charc);
int getop(char[]);
```

```c
/*        stack.c        */
#include <stdio.h>
#include "calc.h"
int sp = 0;
double val[1000];
void push(double x){
  ...
}
double pop(){
  ...
}
```

```c
/*        getop.c        */
#include <stdio.h>
#include "calc.h"
int getop(char[] s){

}
```

File Inclusion

- Syntax:
  - `#include <filename>`
    - search for the file filename in paths according to the compiler defined rules
    - replaced by the content if the file filename
  - `#include "filename"`
    - search for the file filename in source program directory or according to the compiler rules
    - replaced by the content if the file filename
- When an included file is changed
  - all files depending on it must be recompiled
- Multiple inclusion of a file: problem
- Circular inclusion: problem

Conditional Inclusion

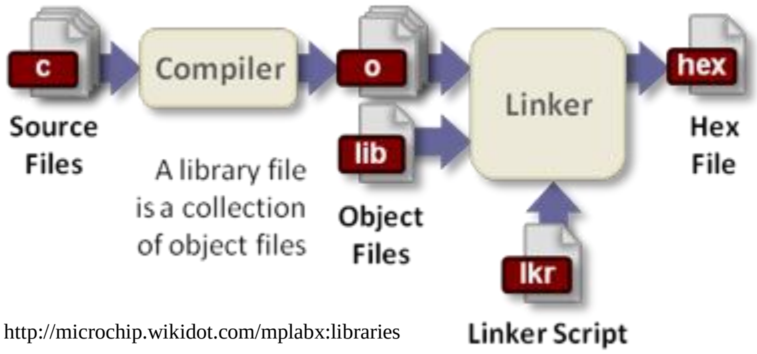
- Control preprocessing with conditional statements
- Syntax:
  - **`#if`**
    - evaluates a constant integer expression
    - if the expression is non-zero, all following lines until an #endif or #elif or #else are included
  - **`#else`** , **`#elif`**
    - provide alternative paths
  - **`#endif`**
    - marks the end of the conditional block

- Can be used to avoid repetitive and circular inclusions:
  - included file:

```
#if !defined(HDR)
#define HDR
/* contents of hdr.h go here */
#endif
```

Compiling Multiple Sources

- The compiler 1st stage is the preprocessor
  - deals with the # directives: define, include, conditional ...
- The compiler 2nd stage is translate .c files to .o files
  - each .c file will be translated to a single .o file
  - to invoke this stage only, use gcc option -c
- The compiler then links .o files together
  - along with library files



http://microchip.wikidot.com/mplabx:libraries

Makefile

- To compile multiple source files:

  ```
  gcc -Wall -ansi -o <output> <file1.c> <file2.c> ...
  ```

- Or use makefiles:
  - Special format file used to build and manage the program automatically
  - contains a collection of rules and commands

- Syntax:

  ```
  <target> [<more targets>] : [<dependent files>]
  <tab> <commands>
  ```

- Example:

  ```
  calc: main.c stack.c getch.c getop.c calc.h
      gcc -Wall -ansi -o calc main.c stack.c getch.c getop.c
  ```

  - How to use : `on the command line type: make calc⏎`

Makefile

- Conventional macros:
  - `CC` : Program for compiling C programs; default is `cc'
  - `CFLAGS`: Extra flags to give to the C compiler.
- Example:

```
CC=gcc
CFLAGS= -Wall -ansi

calc: main.c stack.c getch.c getop.c calc.h
    ${CC} ${CFLAGS} -o calc main.c stack.c getch.c getop.c
```

- Usage:

```
make
```

or

```
make calc
```

Makefile

- At object level:

```
CC=gcc
CFLAGS= -Wall -ansi

calc: main.o stack.o getch.o getop.o calc.h
    ${CC} ${CFLAGS} -o calc main.o stack.o getch.o getop.o

main.o: main.c calc.h
            ${CC} ${CFLAGS} -c main.c

stack.o: stack.c calc.h
            ${CC} ${CFLAGS} -c stack.c

getch.o: getch.c calc.h
            ${CC} ${CFLAGS} -c getch.c

getop.o: getop.c calc.h
            ${CC} ${CFLAGS} -c getop.c
```

- Can invoke any target by:
  `make <target>`
- If the dependency object file has not changed since last compile, it will linked as is. Otherwise, it is recompiled

Makefile

- With useful extra targets:

```
CC=gcc
CFLAGS= -Wall -ansi

calc: main.o stack.o getch.o getop.o
    ${CC} ${CFLAGS} -o calc main.o stack.o getch.o getop.o

main.o: main.c calc.h
            ${CC} ${CFLAGS} -c main.c

stack.o: stack.c calc.h
            ${CC} ${CFLAGS} -c stack.c

getch.o: getch.c calc.h
            ${CC} ${CFLAGS} -c getch.c

getop.o: getop.c calc.h
            ${CC} ${CFLAGS} -c getop.c

clean:
            rm *.o calc
```