

LECTURE NOTES IN CIS300

YUZHE (RICHARD) TANG

SPRING, 2018

SECTION 2: C/C++ PROGRAMMING

REFERENCES

- "Unix Programming Tools", [[link](#)]
- Computer Systems: A Programmer's Perspective, Randal E. Bryant and David R. O'Hallaron, Chapter 1, [[online pdf](#)]

HELLOWORLD C

```
#include <stdio.h> //preprocessor
int y = 3; //global var. (def. & init.)
//extern int y; //global var. (dec.)
int main() //function (def.)
{
    int x = 0; //local var. (def. & init.), literal,
    printf("helloworld: y = %d\n",y); //function (invocation)
    return 0;
}
```

- printf: format string
- header files

LIFE OF A C CONSTRUCT

	variable	function
declare	<code>extern int x;</code>	<code>void foo();</code>
define	<code>int x;</code>	<code>void foo(){ }</code>
initialize	<code>int x=6;</code>	
reference	<code>y=x;x=1;</code>	<code>foo();</code> (invocation)
destroy		

COMPILATION & EXECUTION: BASICS

- GCC: GNU Compilation Collection
- In your terminal, run the following commands

```
gcc hello.c  
./a.out
```

EXERCISES

- Write a C program that prints out your name. Compile and execute it in Ubuntu. Submit the C program to BB.
- Write a C program that computes the sum of 1,2,3,...,956. Compile and execute the program in Ubuntu. Submit the C program to BB.

GCC

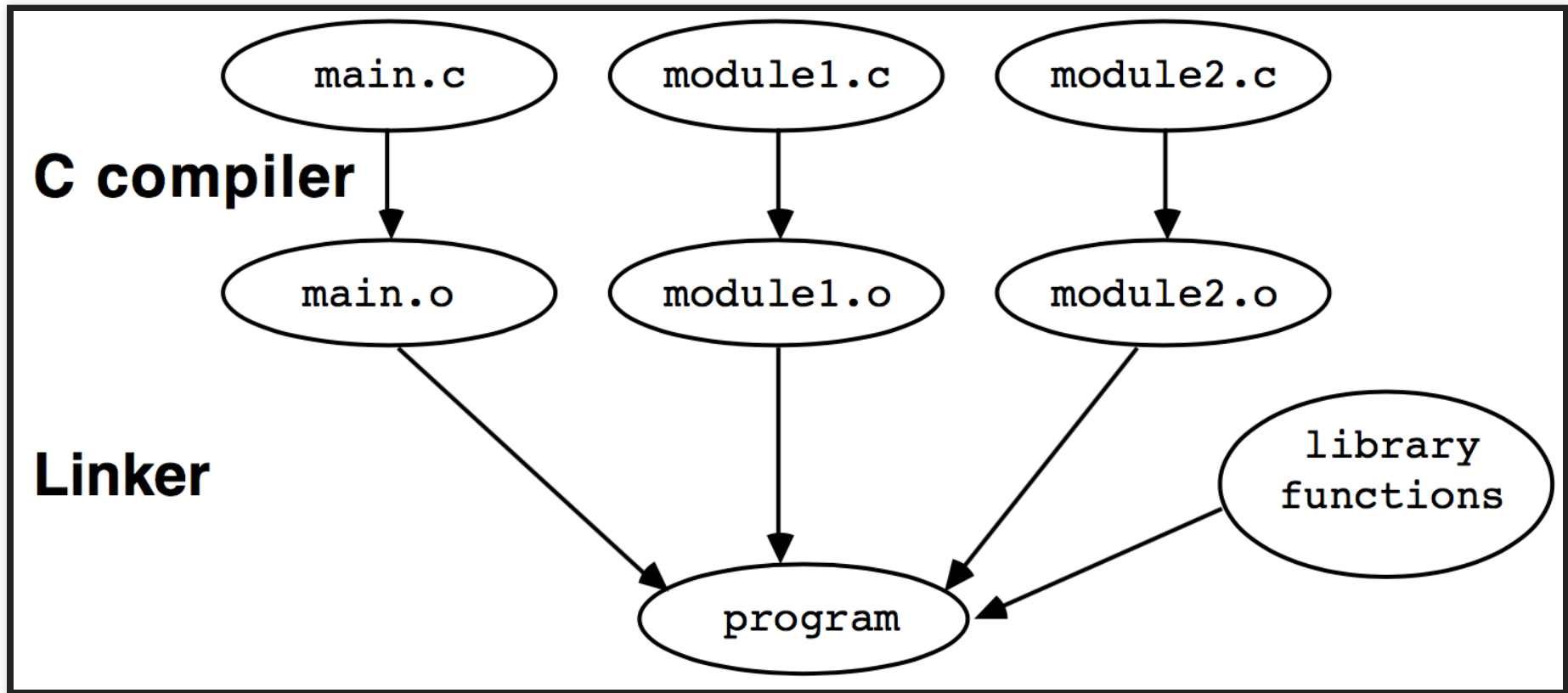
COMPILATION (1)

- Two steps of compilation:
 - *compiling*: text `.c` file to relocatable `.o` (object) file
 - *linking*: multiple relocatable `.o` files to one executable `.o` file
 - *symbol*: reference to link construct (declaration) in one `.o` file to construct (definition) in another `.o` file

COMPILATION (2)

```
gcc hello.c -o a.out  
gcc -S hello.c -o hello.s #compiler  
gcc -c hello.s -o hello.o #assembler  
gcc hello.o -o a.out #linker
```

- compilation system
 - tools: *gcc/gdb* for compiling and debugging
 - 1. **preprocessor**: from source file to source
 - 2. **compiler**: from source to assembly file
 - *assembly file*
 - 3. **assembler**: from assembly file to relocatable object file
 - 4. **linker**: from multiple objects to an executable object



Linker

COMPILING MULTIPLE C PROGRAMS

In file1.c:

```
#include <stdio.h>
extern void foo();
int main(){
    printf("main();\n");
    foo();
}
```

In file2.c:

```
#include <stdio.h>
void foo(){
    printf("foo();\n");
}
```

COMPILING MULTIPLE C PROGRAMS (2)

```
gcc file1.c file2.c  
# try this?  
gcc file1.c  
gcc file2.c
```

COMPILING MULTIPLE C PROGRAMS (3)

```
gcc -c file1.c # compiler & assembler  
gcc -c file2.c # compiler & assembler  
gcc file1.o file2.o # linker
```

Or

```
gcc -S file1.c # compiler  
gcc -c file1.s # assembler  
gcc -S file2.c # compiler  
gcc -c file2.s # assembler  
gcc file1.o file2.o # linker
```

LINK LIBRARY FILES

```
gcc -S file1.c # compiler  
gcc -c file1.s # assembler  
gcc file1.o file2.o # linker
```

```
mv file2.o ../libfile2.a  
gcc file1.o ../libfile2.a # linker  
gcc file1.o -L.. file2.o # linker  
gcc file1.c -L.. file2.o # linker
```

- Gcc flag: `-Ldir -lmylib` for library to link

INCLUDE HEADER FILE

In header1.h:

```
extern foo();
```

In file1.c:

```
#include <stdio.h>
#include "header1.h"
int main(){
    printf("main();\n");
    foo();
}
```

```
gcc file1.c file2.c
```


INCLUDE HEADER FILE (2)

Header file in another directory

```
mv header1.h ..  
#will this work?  
gcc file11.c file2.c  
gcc -I .. file11.c file2.c
```

- Gcc flag: `-I dir`

GCC FLAGS (SUMMARY)

- `-c` for compile, `-o` for output
- `-Ldir -lmylib` for linking a library
 - search library for unsolved symbols (functions, global variables) when linking
- `-I` for `#include`
 - header file (storing declarations)
- `-Wall, w` for warning
- `-g` for debug (later): `gcc -g file1.c file2.c`
- ref [[link](#)]

EXERCISE

- Write two C files:
 - `filea.c` defines functions `main()` and `bar()`
 - `fileb.c` defines function `foo()`
 - function `main()` calls `foo()`
 - function `foo()` calls `bar()`
 - Compile your program.
 - Submit the program and commands to BB.

MAKE AND MAKEFILE

DOWNLOAD COURSE REPO.

To download course repository, type the following commands

```
sudo apt-get update
sudo apt-get upgrade
sudo apt-get install git
git clone https://github.com/SUCourses/cis300-18spring.git
```

MAKEFILE: DEPENDENCY RULES

- `make` is a tool for project management in shell
- `Makefile` is the configuration file that tells the `make` tool what to do
- A `Makefile` is a series of dependency rules
- Each dep. rule is a IFTTT clause (if-this-then-that)

```
target: files/objects  
(tab)commands
```

There is a **tab** before the commands

HELLOWORLD MAKEFILE

In Makefile (All files are under demos/mar7 dir.)

```
all:
    gcc file1.c file2.c
```

To run it, in shell terminal

```
make
```

(Try change `file.c`, and make it again).

MAKEFILE OF MULTIPLE RULES

```
c:
    gcc file1.c file2.c

exec: c
    ./a.out

clean:
    rm *.o *.out
```

Note there are empty lines btwn. rules.

USE MAKEFILE TO LINK (1)

Recall how to run compiler, assembler and linker

```
gcc -c file1.c # compiler & assembler  
gcc -c file2.c # compiler & assembler  
gcc file1.o file2.o # linker
```

USE MAKEFILE TO LINK (2)

A Makefile that does them separately

```
link: file1.o file2.o
    gcc file1.o file2.o

file1.o: file1.c
    gcc -c file1.c

file2.o: file2.c
    gcc -c file2.c
```

```
make
make
```

USE MAKEFILE TO LINK (3)

Use default rule to compile individual C file

```
link: file1.o file2.o  
    @gcc file1.o file2.o
```

```
make  
make
```

- @ used to hide the command in printout.

MAKEFILE: USING VARIABLES

```
SRCS = file1.c file2.c
OBJS = $(SRCS:.c=.o)
CFLAGS = -g -Iheaders
#LDFLAGS = -L. -lxxx

link: $(OBJS)
      $(CC) $(LDFLAGS) $(OBJS)
```

MAKEFILE: USING VARIABLES (2)

- A Makefile variable is a text string
- There're standard variables
 - CC is the compiler
 - `OBJS = $(SRCS:.c=.o):`
 - This incantation says that the object files have the same name as the .c files, but with .o extension
 - LDFLAGS library search path (`-L`)
 - CFLAGS default compile flags

EXERCISE

1. Write a `Makefile` such that `make` always clean `.o` files, recompiles all `.c` files and executes the new `.o` file.
2. Write a `Makefile` such that `make link` will compile a `file.c` file against a library file `libxxx.a`

GDB

REFERENCES

- "Reviewing gcc, make, gdb, and Linux Editors", [[pdf](#)]
- "Unix Programming Tools", [[link](#)]

A BUGGY C PROGRAM

```
#include<stdio.h> //printf
int array_stack[] = {0,1,2};
int main(){
    int sum; // local variable
    for(int i=0; i<=3; i++){
        sum += array_stack[i];
    }
    printf("sum = %d\n", sum);
    return 0;
}
```

USE GDB TO FIND BUG

- Installing gdb
 - on MacOS: [youtu.be/Vj33vsrDkE80]
 - on Ubuntu: `sudo apt-get install gdb`
- Compile: `gcc -g`
- Run gdb: `gdb a.out`

GDB COMMAND: CONTROL EXECUTION

- CPU executes a C program statement by statement
- Breakpoint: tell where the CPU should stop/pause execution
 - `break/b file:n|fn|file:fn`: breakpoint can be file:line number, function name or file:function name.
 - `disable/enable/delete i`: `i` is the index of breakpoint
- Stepping: tell CPU to resume the execution
 - `run/r`: run
 - `next/n`: next statement (step over a function call)
 - `continue/c`: continue till breakpoint

GDB COMMAND: EXAMINE RUNTIME

- Examine runtime data
 - `print v/p` `v`: print variable `v`
- Examine code (with `gcc -g`)
 - `list/l`
- Examine execution environment: e.g. stack (later)

GDB COMMANDS

functionality	commands
breakpoints	b,disable/enable/delete breakpoi
stepping	r,s,n,c,finish,return
examine_data	p/i v,display/undisplay,watch,set
examine_code	list
examine_stack	bt,where,info,up/down,frame
misc.	editmode vi,b fn if expression,h disassembler,shell cmd

DEMO

- Debug the following program using gdb

```
#include<stdio.h> //printf
int array_stack[] = {0,1,2};
int main(){
    int sum; // local variable
    for(int i=0; i<=3; i++){
        sum += array_stack[i];
    }
    printf("sum = %d\n", sum);
    return 0;
}
```

EXERCISE

- Exercise: Debug the following program using gdb, upload the correct program to BB.

```
#include<stdio.h>
int main() {
    int x = 5;
    int y = 3;
    int z = x - y;
    int a = x * y;
    int b = a - 7*z;
    b--;
    int c = z + y;
    int d = c / b;
    int e = a + 12;
    int f = e - b;
    printf("%d\n",f);
}
```

POINTER IN C

REFERENCES

- Pointer Basics: [<http://cslibrary.stanford.edu/106/>]
- Point fun with Binky: [<http://cslibrary.stanford.edu/104/>]

C POINTER

- A C pointer is a C variable that stores the reference to something.
 - "something", called pointee, is usually another variable.
- In the figure below, a pointer variable named `x` stores a reference to a "pointee" variable of value 42.



pointer pointee

POINTER OPERATIONS

- Definition/initialization: `int *p1 = p2;`
- Assignment: `p1 = p2;`
- Dereference: `*p`
- Get reference of: `& a`
 - get the *address* (memory location) of variable a

```
#include<stdio.h>
int main(){
    int a = 10;
    int * p = & a;
    int b = *p;
    printf("a=%d,b=%d,*p=%d,p=%p\n",a,b,*p,p);
}
```

BINKY'S CODE (1)

```
void main() {  
    int*    x;  // Allocate the pointers x and y  
    int*    y;  // (but not the pointees)  
}
```



Allocate pointer

BINKY'S CODE (2)

```
void main() {  
    int*    x;  // Allocate the pointers x and y  
    int*    y;  // (but not the pointees)  
    x = malloc(sizeof(int));    // Allocate an int pointee,  
                                // and set x to point to it  
}
```



Allocate pointee

BINKY'S CODE (3)

```
void main() {  
    int*    x;  // Allocate the pointers x and y  
    int*    y;  // (but not the pointees)  
    x = malloc(sizeof(int));    // Allocate an int pointee,  
                                // and set x to point to it  
    *x = 42;    // Dereference x to store 42 in its pointee  
}
```



Dereference pointer

BINKY'S CODE (4)

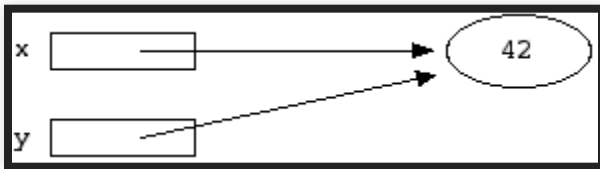
```
void main() {  
    int*    x;  // Allocate the pointers x and y  
    int*    y;  // (but not the pointees)  
    x = malloc(sizeof(int));    // Allocate an int pointee,  
                                // and set x to point to it  
    *x = 42;    // Dereference x to store 42 in its pointee  
    *y = 13;    // CRASH -- y does not have a pointee yet  
}
```



Dereference failure

BINKY'S CODE (5)

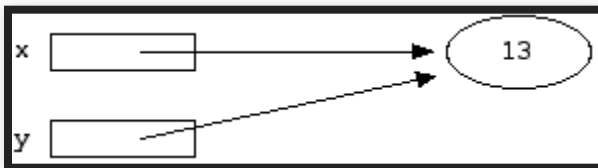
```
void main() {  
    int*    x;  // Allocate the pointers x and y  
    int*    y;  // (but not the pointees)  
    x = malloc(sizeof(int));    // Allocate an int pointee,  
                                // and set x to point to it  
    *x = 42;    // Dereference x to store 42 in its pointee  
    *y = 13;    // CRASH -- y does not have a pointee yet  
    y = x;      // Pointer assignment sets y to point to x's pointee  
}
```



Pointer assignment

BINKY'S CODE (6)

```
void main() {  
    int*    x;  // Allocate the pointers x and y  
    int*    y;  // (but not the pointees)  
    x = malloc(sizeof(int));    // Allocate an int pointee,  
                                // and set x to point to it  
    *x = 42;    // Dereference x to store 42 in its pointee  
    *y = 13;    // CRASH -- y does not have a pointee yet  
    y = x;     // Pointer assignment sets y to point to x's pointee  
    *y = 13;    // Dereference y to store 13 in its (shared) pointee  
}
```



Deference pointer

LIFE CYCLE OF A C POINTER

	pointer	variable	function
declare	<code>extern int * p</code>	<code>extern int x</code>	<code>void</code>
define	<code>int *p;</code>	<code>int x</code>	<code>void</code>
initialize	<code>int *p=&a;</code>	<code>int x=6</code>	
	<code>int*q=malloc(7)</code>		
(de)reference	<code>*p=x; x=*p</code>	<code>y=x</code>	<code>for</code>
destroy	<code>delete p</code>		

EXERCISE

- Do the following to complete the code snippet at the bottom. Then compile and execute your program. Submit the completed program to BB.
 1. define two pointers p1 and p2, both pointing to variable x.
 2. Use p1 to update x's value to 5.
 3. Then use p2 to read the value of variable x and `printf` it on terminal.

```
#include<stdio.h>
int main(){
    int x = 4;
    // To complete the program below:

}
```