

**LECTURE NOTES IN CIS300**

**YUZHE (RICHARD) TANG**

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# **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**



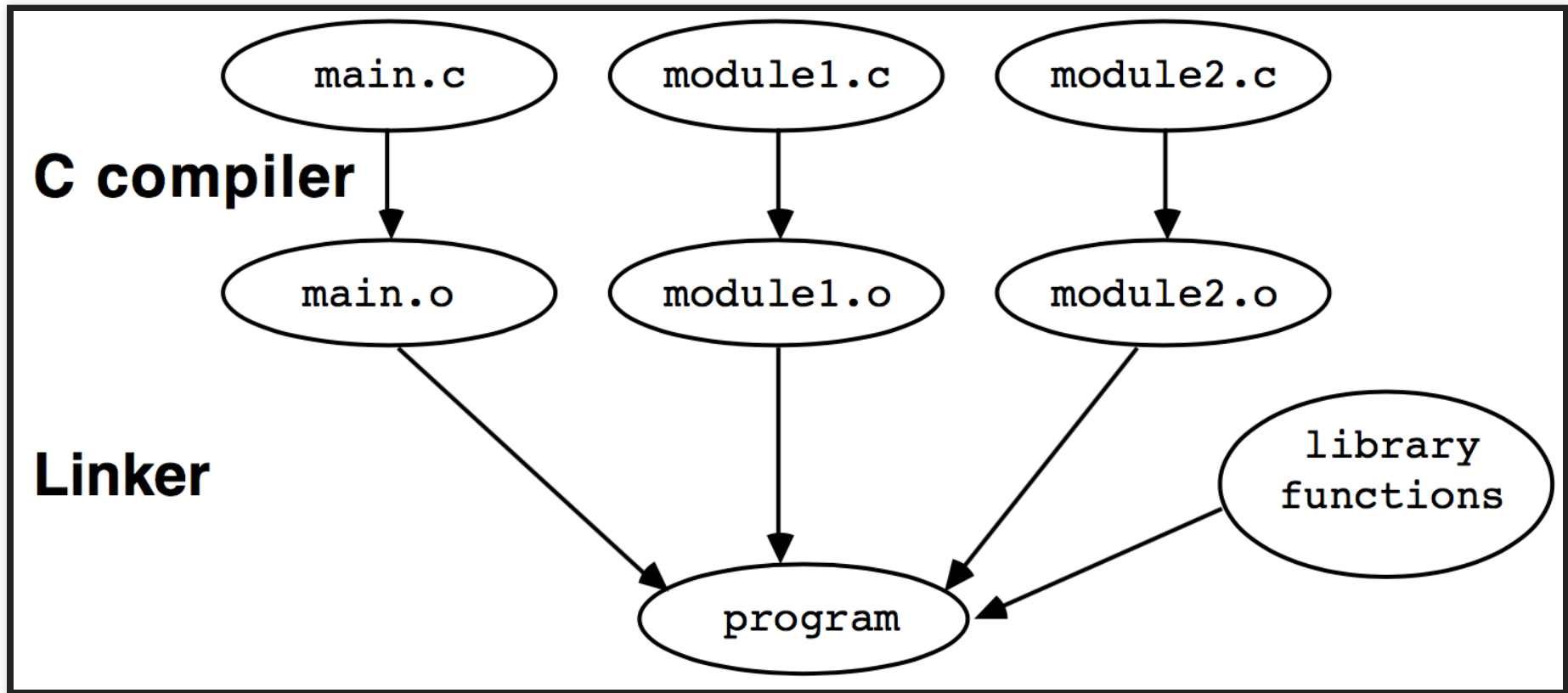
# COMPILATION (1)

- 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](https://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)

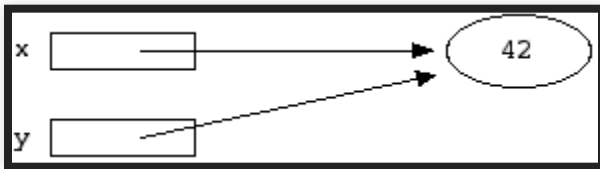
```
void main() {  
    int*    x;  // Allocate the pointers x and y  
    int*    y;  // (but not the pointees)  
    x = malloc(sizeof(int));    // Allocate an int pointee,  
                                // and set x to point to it  
    *x = 42;    // Dereference x to store 42 in its pointee  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

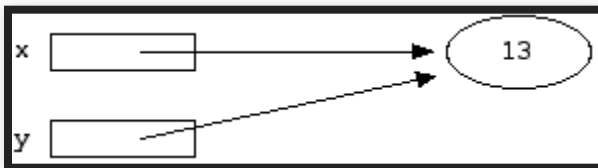


Pointer assignment



# 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=&amp;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:

}
```

# **C POINTER AND DATA TYPES**

# DATA TYPE

- C is a typed language
- Data type in C determines:
  - How much space to allocate for storing a variable in memory
  - How to interpret bit-string stored in the memory
  - How to carry out the arithmetics on primitive types

# PRIMITIVE TYPES

- types: signed, unsigned, long long, float, char

type	signed	unsigned	short	long long	float	char
<code>sizeof()</code>	4	4	2	8	4	1

- unsigned: a 32-bit unsigned integer, value from 0 to  $2^{32} - 1$ .
- signed: a 32-bit signed integer, value from  $-2^{31}$  to  $2^{31} - 1$ .
  - first bit determines whether negative
- Typecasting: convert the type of a variable.
  - `int x = 1; double f = (double) x;`

# DEMO 1: TYPE INTERPRETATION

```
#include<stdio.h>
int main(){
    unsigned int u = 2147483649;
    int v = (int) u;
    printf("unsigned vs signed: %ud,%d\n",u,v);

    int i=1;
    float f = (float) i;
    printf("float vs int: %f,%d\n",f/3,i/3);
}
```

# DEMO 2: DATA TYPE SIZE

```
#include<stdio.h>
int main(){
    signed int a;
    unsigned int b;
    short c;
    long long d;
    float e;
    char f;
    printf("signed int: %lu\n", sizeof(a));
    printf("unsigned int: %lu\n", sizeof(b));
    printf("short: %lu\n", sizeof(c));
    printf("long long: %lu\n", sizeof(d));
    printf("float: %lu\n", sizeof(e));
    printf("char: %lu\n", sizeof(f));
    return 0;
}
```



# POINTER AND ARRAY

- A array in C stores a list of elements in adjacent memory locations.
- Use pointer to access array element
  - Pointer type: `char *`, `int *`
  - Pointer arithmetic:
    - `int * p = array; p += 1;`
    - `int pp = array; pp += sizeof(int);`

```
#include<stdio.h>
int main(){
    int a[] = {2,1,0};
    int *b = a; // b points to the first element in a
    unsigned long c = (unsigned long)a;//long
    for (int i=0; i<3; i++){
        printf("%d,%d,%d,%d,%d\n",a[i],*(b+i),*(a+i),b[i],*((int *)(&c+i)))
    }
}
```

# FUNCTION POINTER

- Two classes of pointer
- Data pointer: pointer to variable, array
- Code pointer: function pointer

```
#include <stdio.h>  /* for printf */  
// https://en.wikipedia.org/wiki/Function\_pointer  
double cm_to_inches(double cm) {  
    return cm / 2.54;  
}  
int main(void) {  
    double (*func1)(double) = cm_to_inches;  
    printf("%f %s", func1(15.0));  
    return 0;  
}
```

# EXERCISE

1. Write a C program that defines function `void foo(void)` and `int bar(long x)`. Call these two functions through function pointers. Upload your program to BB.
2. Complete the following program that scans the array using index `long_index`. Upload your program to BB.

```
#include<stdio.h>
int main(){
    int a[] = {7,9,6};
    unsigned long long_index = (unsigned long)a;
    for(int i=0; i<3; i++){
        printf("%d,",*(int*)(long_index));
        long_index += XXX; // fill out XXX
    }
}
```