Practical C Issues:

Preprocessor Directives, Typedefs, Multi-file Development, and Makefiles

CS449 Fall 2016

Preprocecessor Directives

#define

- Defines macros
  - Macro: rule that specifies textual replacement of one string for another
- Often used to assign names to constants

```
#define PI 3.1415926535
#define MAX 10

float f = PI;
for(i=0;i<MAX;i++) …
```

#define

- Good macros are generic
  (do not make assumptions about inputs)
- Good:
  - `#define MAX(a,b) (a > b) ? a : b`
  - `Only assumes 'a' can be compared to 'b'`
- Not so good:
  - `#define SWAP(a,b) {int t=a; a=b; b=t;}`
  - `Makes assumption that types are 'int'`
- Better
  - `#define SWAP(T,a,b) {T t=a; a=b; b=t;}`

#if

- #if <condition known to preprocessor>
  - Preprocessor emits code inside #if directive to the compiler only if condition is true
  - Condition evaluated at preprocessing time (cf. C if statement is evaluated at execution time)
- What does preprocessor know?
  - Values of #defined variables
  - Constants (0, 1, 2, “Linux”, “x86”, …)
  - Arithmetic (+, -, *, /, >, <, ==, &&, ll, …)

Example

```
#include <stdio.h>
int main()
{
  #if 0
    printf(“This is not compiled\n”);
    I can doodle here when I am bored.
  #endif
  printf(“This is compiled\n”);
  return 0;
}
```

Example 2

```
#include <stdio.h>
#define LIBRARY_VERSION 7
int main()
{
  #if LIBRARY_VERSION >= 5
    some_function_included_in_version_5();
    printf("This is compiled\n");
  #endif
  return 0;
}
```

#else

```
#if
    ...
#elif
    ...
#else
    ...
#endif
```

#if defined

- #if defined
  - Checks to see if a macro has been defined, but doesn't care about the value
  - A defined macro might expand to nothing, but is still considered defined

Example

```
#include <stdio.h>
#define MACRO

int main()
{
   #if defined MACRO
       printf(“This is printed\n”);
   #endif
   printf(“This is also printed\n”);
   return 0;
}
```

#undef

- Undefines a macro:

```
#include <stdio.h>
#define MACRO
#undef MACRO

int main()
{
   #if defined MACRO
       printf(“This is not printed\n”);
   #endif
   printf(“This is printed\n”);
   return 0;
}
```

Shortcuts

- #if defined → #ifdef
- #if !defined → #ifndef

Uses

- Handle code specific to a library, OS, processor, etc …
- Turn on / off different features
  - Debugging:

```
#ifdef DEBUG
    printf(…)
#endif
```

  - More convenient debugging

```
//easier to modify functionality of PrintDebug later
#ifdef DEBUG
#define PrintDebug(args…) fprintf(stderr, args)
#else
#define PrintDebug(args…)
#endif
```

Notes

- Can define variables from the commandline with `-D`
  - `gcc -o test -DVERSION=5 test.c`
  - `gcc -o test -DMACRO test.c`

Pre-Defined Macros

Macro	Meaning
`__FILE__`	The currently compiled file
`__LINE__`	The current line number
`__DATE__`	The current date
`__TIME__`	The current time
`__STDC__`	Defined if compiler supports ANSI C
…	Many other compiler-specific flags

Other Preprocessor Details

- # - quotes a string
  - `#define CALL(f) { printf(#f); f(); }`
  - `CALL(foo)` → `{ printf("foo"); foo(); }`
- ## - concatenates two things
  - `#define CALL(f) f ## _debug ()`
  - `CALL(foo)` → `foo_debug()`
- #pragma: Change behavior of compiler
- #warning: Emit warning message
- #error: Emit error message and exit

Pragma Example

```
#include <stdio.h>

#pragma message "Compiling " __FILE__ "
   using " __VERSION__
int main() {
  return 0;
}
```

```
>> gcc ./pragma.c
./pragma.c:3: note: #pragma message:
Compiling ./pragma.c using 4.4.7
20120313 (Red Hat 4.4.7-4)
```

- Pragma message prints a message during compilation of file
- Use of two pre-defined macros: __FILE__ and __VERSION__
- Many more pragmas
  - To control compiler optimizations
  - To control code generation

Error Directive Example

```
#include <stdio.h>

#ifndef __i386__
#error "Needs i386 architecture."
#endif
int main() {
  return 0;
}
```

```
>> gcc ./error.c
./error.c:3:2: error: #error "Needs i386 architecture.
>> gcc –m32 ./error.c
```

- Tests whether hardware platform is i386 (x86) and displays error
- Initially fails because default compilation target is x86_64
- '-m32' option changes target to x86, allowing compilation to proceed
- #error: prevents compilation
  #warning: allows compilation but with warning message

Concatenation example

```
#include <stdio.h>
#ifdef DEBUG
#define CALL(f) f ## _debug ()
#else
#define CALL(f) f ()
#endif

void foo() {
  printf("foo normal\n");
}
void foo_debug () {
  printf("foo debug\n");
}
int main() {
  CALL(foo);
  return 0;
}
```

```
>> gcc ./concat.c
>> ./a.out
foo normal
>> gcc –DDEBUG ./concat.c
>> ./a.out
foo debug
```

- Calls original foo function by default
- Calls a debug version of foo when DEBUG macro is defined
- Can switch over all calls done by CALL macro to debug versions just by passing –DDEBUG to gcc

Multi-file Development

Multi-file Development

- Multi-file development breaks up a program into multiple files. Pros:
  - Parallel development involving multiple authors
  - Quicker compilation (only compile modified file)
  - Modularity (can reuse object file / library)
  - Encapsulation (easier to read / maintain)
- Use smallest scope to enforce encapsulation
  - Avoids polluting global namespace (Minimizes chances of name conflicts)
  - Minimizes scope of code to read to understand all uses of a function or variable

Local Scope

- Scope: **Local** (e.g. within a function)
- Lifetime: **Automatic** (duration of function)

```
void f(…) {
  int x;
  …
}
```

Static Local Scope

- Scope: **Local** (e.g. within a function)
- Lifetime: **Static** (life of program)

```
void f(…) {
  static int x;
  …
}
```

Static Global Scope

- Scope: **File**
- Lifetime: **Static** (life of program)

```
static int x;
void f(…) {
  …
}
```

Global Scope

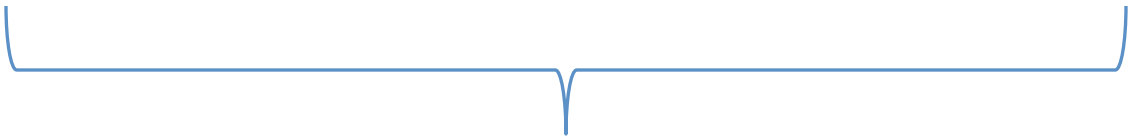
- Scope: **Program**
- Lifetime: **Static** (life of program)
- extern maybe be used to import variables from other files

File A

```
int x;
```

File B

```
extern int x;
```



Will refer to the same memory location

Example

a.c

```
int x = 0;

int f(int y)
{
      return x+y;
}
```

b.c

```
#include <stdio.h>

extern int x;
int f(int);

int main()
{
      x = 5;
      printf("%d", f(0));

      return 0;
}
```

Compiling

```
gcc a.c b.c

./a.out
5
```

Static

a.c

```
static int x = 0;

static int f(int y)
{
        return x+y;
}
```

b.c

```
#include <stdio.h>

extern int x;
int f(int);

int main()
{
        x = 5;
        printf("%d", f(0));

        return 0;
}
```

Compiling

```
gcc a.c b.c

/tmp/cccyUCUA.o(.text+0x6): In
  function `main':
: undefined reference to `x'
/tmp/cccyUCUA.o(.text+0x19): In
  function `main':
: undefined reference to `f'
collect2: ld returned 1 exit status
```

Header Files

- **Declarations** that need to be shared across multiple C (.c) files are put into **header** (.h) files
  - Functions (prototype declarations)
  - Variables (extern declarations)
  - #defines (macro declarations)
  - Type definitions
  - Other header files
- **Definitions** of symbols should be left to **C files**
  - Otherwise can lead to multiple definition link errors

Headers and Implementation

mymalloc.h

```
void *my_buddy_malloc(int size);

void my_free(void *ptr);
```

mymalloc.c

```
static void *base;

void *my_buddy_malloc(int size)
{
    ...
}

void my_free(void *ptr)
{
    ...
}
```

#include

- Copies the contents of specified file into current file
- < > means: look in a known location for includes
  - Usually /usr/include
- “ “ means: look in the current directory or specified path (using –I option)
  - E.g. gcc –I ~/local/include main.c

```
#include <stdio.h>
#include “myheader.h”
```

  - Looks for stdio.h under /usr/include
  - Looks for myheader.h under cur. directory AND ~/local/include

Including a Header File

- Driver program:

  #include “mymalloc.h”

- Can now use those functions
- Compile:

```
gcc -o malloctest mymalloc.c mallocdriver.c
```

- Why not also compile mymalloc.h?
  - Does not define or reference any symbols
    - Nothing to generate an object file out of
    - Hence nothing to link / compile
  - Only contains declarations to help compile .c files

Including a Header File Once

- Including same header twice can lead to compile errors
  - Redefinition of the same type, etc..
  - Sometimes not so obvious with multiple levels of nested headers

```
#ifndef _MYHEADER_H_
#define _MYHEADER_H_

…Declarations only to be included once

#endif
```

Makefiles

- Used with the GNU Make utility to build projects containing multiple files
- Goal: if any source files are modified, build smallest set required
  - By expressing what files depend upon others
- Composed of a collection of *rules* which look like

target: dependencies

    action

- Action must be followed by <tab>, not spaces

Makefile

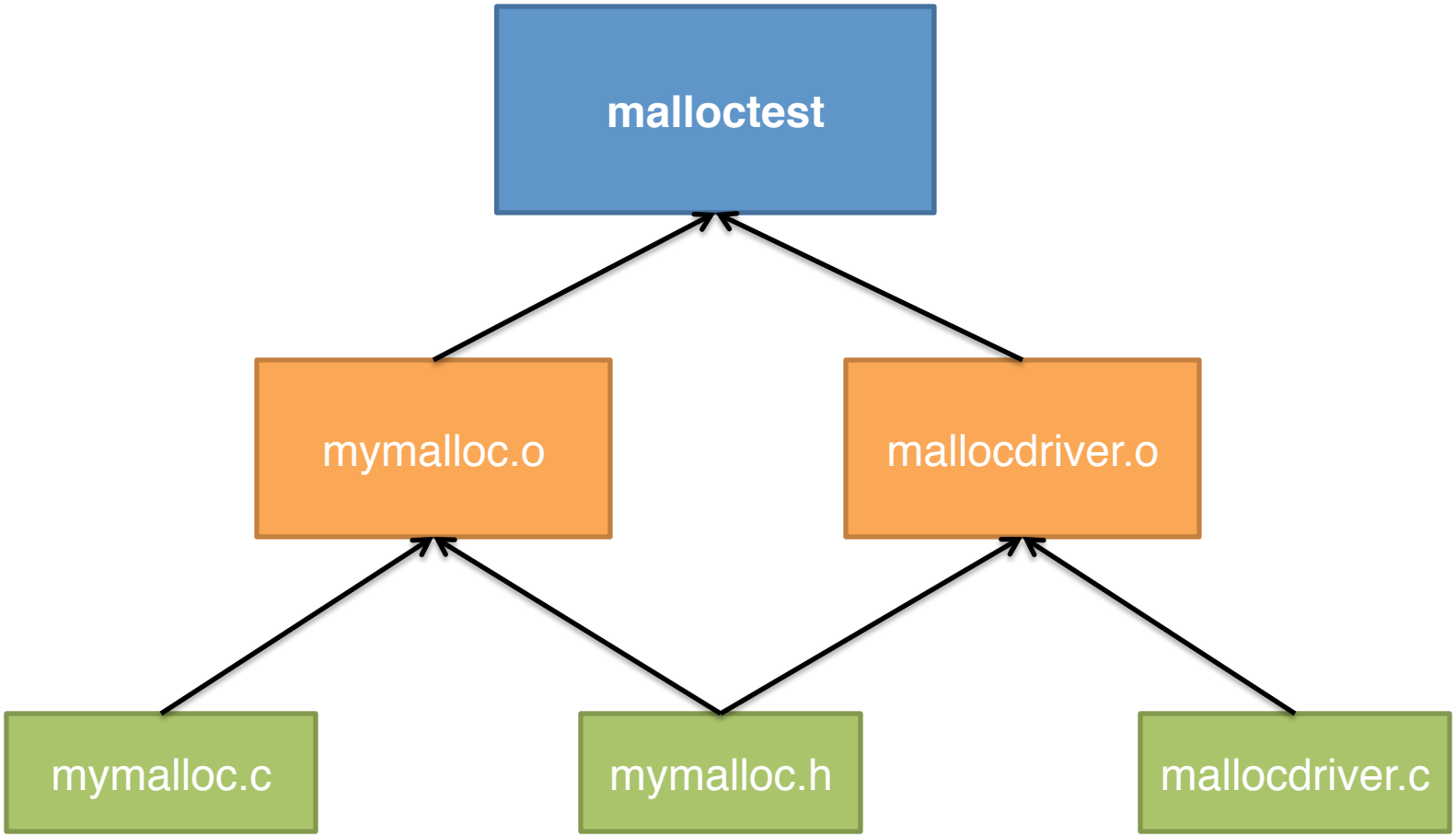
```
malloctest: mymalloc.o mallocdriver.o
   gcc -o malloctest mymalloc.o mallocdriver.o

mymalloc.o: mymalloc.c mymalloc.h
   gcc -c mymalloc.c

mallocdriver.o: mallocdriver.c mymalloc.h
   gcc -c mallocdriver.c

clean:
   rm -f *.o malloctest
```

Dependency Graph



Using a Makefile

- Build from scratch

```
thoth $ ls
Makefile  mallocdrv.c  mymalloc.c  mymalloc.h
thoth $ make
gcc -c mymalloc.c
gcc -c mallocdrv.c
gcc -o malloctest mymalloc.o mallocdrv.o
thoth $ make
make: `malloctest' is up to date.
```

- Partial build after modifying mymalloc.c

```
thoth $ touch mymalloc.c
thoth $ make
gcc -c mymalloc.c
gcc -o malloctest mymalloc.o mallocdrv.o
```

Defining Variables in Makefiles

- Works like macros (text replacement)
- Syntax: <name> := ... or <name> = ...
- Example:
  - Instead of:

```
malloctest: mymalloc.o mallocdriver.o
   gcc -o malloctest mymalloc.o mallocdriver.o
```

  - Can do:

```
OBJECTS = mymalloc.o mallocdriver.o
malloctest: $(OBJECTS)
   gcc -o malloctest $(OBJECTS)
```

Automatic Variables

- $@: The file name of the target. E.g.:

```
malloctest: $(OBJECTS)
   gcc -o $@ $(OBJECTS)
```

- $<: The name of the first prerequisite. E.g.:

```
mymalloc.o: mymalloc.c mymalloc.h
   gcc -c $<
```

- $^: The names of all prerequisites. E.g.:

```
malloctest: $(OBJECTS)
   gcc -o $@ $^
```

Pattern Matching

- Character '%' can stand for a pattern
- Example:

```
%.o: %.c
	gcc -c $< -o $@
```

- What it means:
  - For all targets matching <some string>.o
  - Dependency is <that string>.c
  - Action is gcc –c <that string>.c –o <that string>.o
- Rule is used to produce any .o file from .c file

Concise Makefile

```
malloctest: mymalloc.o mallocdriver.o
	gcc -o $@ $^

%.o: %.c
	gcc -c $< -o $@

mymalloc.o: mymalloc.h
mallocdriver.o: mymalloc.h

clean:
	rm -f *.o malloctest
```

Make Utility Options

- Usage:

  `make [-f makefile] [options] [targets]`
- `-f makefile`: Can specify a different makefile
- `targets`: Can specify targets you want to build
- `Options`:
  - `<name> = <value>`: Define a variable.
  - `-C <dir>`: Change to directory dir before building.
  - `-n`: Dry run. Just print commands and don't execute.
  - `-d`: Debug mode. Print verbose information.

Device Driver Makefile

```
obj-m := hello_dev.o

KDIR  := /u/SysLab/shared/linux-2.6.23.1
PWD   := $(shell pwd)

default:
	$(MAKE) -C $(KDIR) M=$(PWD) modules
```

- Default target of ‘make’ is first target (default:)
- -C option changes to kernel directory before building
- Invokes Makefile with variable ‘M’ defined as ‘PWD’ to build target ‘modules:’

Typedefs

typedef

```
typedef type-declaration synonym;
```

Examples:

```
typedef int * int_pointer;
typedef int * int_array;
```

Typedefs for Type Clarity

```
void takes_int(int_pointer x)
{
   *x = 3;
}
```

```
void takes_array(int_array x,
   int n)
{
   int i;
   for(i=0; i<n; i++)
        printf("%d\n", x[i]);
}
```

Typedefs for Structures

With Typedef

```
typedef struct node {
  int i;
  struct node *next;
} Node;

Node *head;
```

Without Typedef

```
struct Node {
  int i;
  struct Node *next;
};

struct Node *head;
```

- Saves the trouble of typing ‘struct’ all the time

Typedefs for Function Pointers

With Typedef

```
#include <stdio.h>
#include <stdlib.h>

typedef void (*FP)(int, int);

void f(int a, int b) {
  printf("%d\n", a+b);
}

void g(int a, int b) {
  printf("%d\n", a*b);
}

int main() {
  FP fp1 = f;
  FP fp2 = g;

  fp1(2,3);
  fp2(2,3);
  return 0;
}
```

Without Typedef

```
#include <stdio.h>
#include <stdlib.h>

void f(int a, int b) {
  printf("%d\n", a+b);
}

void g(int a, int b) {
  printf("%d\n", a*b);
}

int main() {
  void (*fp1)(int, int) = f;
  void (*fp2)(int, int) = g;

  fp1(2,3);
  fp2(2,3);
  return 0;
}
```

Function Pointers As Parameters

- In <stdlib.h>,

```
void qsort (
  void *base ,
  size_t num ,
  size_t size ,
  compar_fn_t comparator
);
typedef int (*compar_fn_t) (const void *,
  const void *);
```

Function Pointers As Parameters

```
int compare_ints(const void *a, const void *b)
{
   int *x = (int *)a;
   int *y = (int *)b;
   return *x - *y;
}
int main()
{
   int a[100];
   qsort(a, 100, sizeof(int), compare_ints);
}
```

- Function passed as parameter is called a *callback* function
- Device driver ‘read’ function was a callback function

Thank you

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