CMSC 313
Introduction to Computer Systems
Lecture 12
The C Preprocessor & Assembly Language

Alan Sussman
als@cs.umd.edu

Administrivia

- Project 3 spec and public tests posted, due Oct. 20
  - questions?
- Exam #1 returned today
  - Mean: 67 Median: 69 25%: 57 75%: 81
- Read Reek, Chapter 14 (Preprocessor) and start on Bryant and O'Hallaron Chapter 3 (IA-32 instruction set architecture) and 4.1 (Y86 subset)

Chapter 14, Reek

THE PREPROCESSOR

Typical uses for macros

- `#define SQUARE(x) ((x) * (x))`

```
s = SQUARE(5);
```

becomes

```
s = ((5) * (5));

s = SQUARE(a + 1);
```

becomes

```
s = ((a + 1) * (a + 1));
```

Typical uses for macros

```
#define MAX(a, b) \
   ((a) > (b) ? (a) : (b))

x = 4;
y = 9;
z = MAX(x, y);
```

becomes

```
z = ((x) > (y) ? (x) : (y));
```


Why we use all those parentheses

- Remember, substitution is essentially just find-and-replace, like in a text editor:

```
#define SQUARE1(x)  x * x
#define SQUARE2(x) (x * x)
#define BAD_SUM(x, y) (x) + (y)

s = SQUARE1(a + 1);
/* s = a + 1 * a + 1; */
s = SQUARE2(a + 1);
/* s = (a + 1 * a + 1); */
s = BAD_SUM(a + 1, b + 2) * 3;
/* s = (a + 1) + (b + 2) * 3; */
```

- This is why we use parentheses around both the macro body and macro arguments!

`#define` substitution

1. The macro arguments are checked for occurrences of **`#define`**d symbols, and values are replaced as appropriate
2. Uses of preprocessor symbols are replaced by their **`#define`**d values
3. The now modified program is rescanned for **`#define`**d symbols, and if any are found, the process begins again at step 1

But string literals are not scanned for replacement

```
#define MAX 10
printf("The value of MAX is %d.\n", MAX);
```

Output: **`The value of MAX is 10.`**

Macros aren't functions

- Macros...
  - ... are textually replaced, which can be faster than functions for short things
  - ... can't be recursive
  - ... can't be type-checked by the preprocessor
  - ... can result in difficult to find bugs when using complex macros - where is the error in the source code?
  - ... can have types as arguments:

```
#define PRINT_SIZE(type) \
    printf("%d\n", (int) sizeof(type))
```

Other issues with macros

- What if macro arguments have side effects?

```
#define MIN(x, y) ((x) < (y) ? (x) : (y))
m = MIN(++a, --b);
/* m = ((++a) < (--b) ? (++a) : (--b)); */
```

- The solution? Don't use an expression with side effects as a macro argument.
- But how do you know if it's a macro? Use the naming convention we discussed and it becomes much more clear...

Other preprocessor capabilities

- **#undef** *name*
  - needed to undefine symbols in order to assign a new value to them
  - you can undefine undefined symbols
- The compiler can define symbols at compile time:

```
gcc -D SIZE=300 -c file.c
```

  - defines **SIZE** to the value 300 while compiling the file, just as if **#define SIZE 300** appeared in the program

Conditional compilation

#if *const-expr1*
code here is included by the preprocessor iff *const-expr1* is true
#elif *const-expr2*
code here is included by the preprocessor if f *const-expr1* is false and *const-expr2* is true
#else
code here is included by the preprocessor if f *const-expr1* is false and *const-expr2* is false
#endif

- This facility is useful if code must be different on different systems, but overuse tends to make code hard to read
- One type of *const-expr* is **defined(***macro-name***)**, which has the value 1 if *macro-name* is defined, and 0 if not
- The preprocessor directive **#error** *string* stops preprocessing (and compilation) at that point, and prints *string*

File inclusion

- **#include "file.h"**
- What if **file.h #include**s another file?
  - That's fine, preprocessor can handle it
- What if two header files **#include** the same third header file?
  - Also okay, unless a program **#include**s both of the first two header files...

File inclusion example

main.c:
```
#include <stdio.h>
#include "some_struct.h"
#include "another_struct.h"

int main() {
  Some_struct ss;
  Another_struct as;
  /* some code here */
  return 0;
}
```

another_struct.h:
```
#include "common_struct.h"

typedef struct {
  float x;
  Common_struct y;
} Another_struct;

Another_struct g(void);
```

some_struct.h:
```
#include "common_struct.h"

typedef struct {
  int a;
  char b;
  float c;
} Some_struct;

void f(Some_struct s, Common_struct t);
```

common_struct.h:
```
typedef struct {
  float x;
  double y;
} Common_struct;
```

How many times is **`Common_struct`** defined in **`main.c`** after preprocessing?

File inclusion example, cont.

main.c:
```
#include <stdio.h>
#include "common_struct.h"

typedef struct {
  int a;
  char b;
  float c;
} Some_struct;

void f(Some_struct s, Common_struct t);
#include "common_struct.h"

typedef struct {
  float x;
  Common_struct y;
} Another_struct;

Another_struct g(void);

int main() {
  Some_struct ss;
  Another_struct as;
  /* some code here */
  return 0;
}
```

common_struct.h:
```
typedef struct {
  float x;
  double y;
} Common_struct;
```


File inclusion example, cont.

main.c:
```
#include <stdio.h>
typedef struct {
  float x;
  double y;
} Common_struct;

/* other code from some_struct.h */
typedef struct {
  float x;
  double y;
} Common_struct;

/* other code from another_struct.h */

int main() {
  Some_struct ss;
  Another_struct as;
  /* some code here */
  return 0;
}
```

Can't define a type twice!

File inclusion, cont.

- We can solve this problem using conditional compilation inside **`common_struct.h`**:

  `#if ! defined(COMMON_STRUCT_H)`

  `#define COMMON_STRUCT_H`

  (previous contents of **`common_struct.h`** here)

  `#endif`

- This solution is seen in many header files

Chapters 3 and 4.1, Bryant and O'Hallaron

ASSEMBLY LANGUAGE

Assembly language

- The CPU uses machine language to perform all its operations
- Assembly is a much more readable translation of machine language, and it is what we work with if we need to see what the computer is doing
- Many different kinds of assembly languages; we'll focus on the Y86 language defined in the text (with minor modifications)

An example of Y86 assembly

- The summation of all integers from 1 to 1000:

```
        irmovl $0,%eax     # sum = 0
        irmovl $1,%ecx     # num = 1
Loop:   addl   %ecx,%eax   # sum += num
        irmovl $1,%edx     # tmp = 1
        addl   %edx,%ecx   # num++
        irmovl $1000,%edx  # lim = 1000
        subl   %ecx,%edx   # if lim - num >= 0
        jge    Loop        #   loop again

        wrint  %eax        # printf("%d", sum)
        irmovl $10,%edx    # ch = '\n'
        wrch   %edx        # printf("%c", ch)
        halt
```


Assembly language concepts

- Registers
  - Fast-access locations that the CPU uses, rather than storing all variables in memory
  - In the code we'll be examining, these are named by three-letter codes, and begin with %
  - Y86 has 8 registers, listed on pg. 261
- Memory
  - Program text is here, along with any data which cannot fit in the registers
  - Since there are usually many different pieces of data involved in a program, and a limited number of registers, program variables are stored in memory when not in immediate use

Assembly language instructions

- These typically have an instruction name, a list of registers, and sometimes have a constant value as well
- Examples:

```
irmovl $1000,%edx
subl   %ecx,%edx
jge    Loop
```

- These specify which operation to perform, which registers to act upon, and any numbers that might be needed

Assembling assembly

- Machine code (pure numbers) is generated by translating each instruction into binary numbers that the CPU uses
- This process is called "assembling"; conversely, we can take assembled code and disassemble it into (mostly) human readable assembly language

Labels

- When the assembler encounters a label (e.g., **`Loop:`**), the address of the labeled instruction is used by the assembler to replace all references to that label in the program
- Labels do not need to be declared before use
- In Y86, instructions have variable lengths, and are not aligned; most take 6 bytes, but some use fewer

Label translation

```
      irmovl $0,%eax
      irmovl $1,%ecx
Loop: addl   %ecx,%eax
      irmovl $1,%edx
      addl   %edx,%ecx
      irmovl $1000,%edx
      subl   %ecx,%edx
      jge    Loop

      wrint  %eax
      irmovl $10,%edx
      wrch   %edx
      halt
```

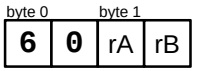
```
0x00: irmovl $0,%eax
0x06: irmovl $1,%ecx
0x0c: addl   %ecx,%eax
0x0e: irmovl $1,%edx
0x14: addl   %edx,%ecx
0x16: irmovl $1000,%edx
0x1c: subl   %ecx,%edx
0x1e: jge    0x0c

0x23: wrint  %eax
0x25: irmovl $10,%edx
0x2b: wrch   %edx
0x2d: halt
```

Instruction encoding

- In any assembly language, each instruction name has a numeric opcode associated with it; Y86 opcodes use one byte each
- Registers also have a numeric mapping, as do labels (as we just saw)
- These numbers are used to encode each instruction into a number

Encoding examples

- In Y86, the **`addl`** instruction has the opcode of **`0x60`**
- The register names **`%edx`** and **`%ecx`** map to numbers 2 and 1, respectively
- The encoding for an **`addl`** instruction is specified by the Y86 instruction set as following this format (pgs. 259, 261):
  - **`addl`** rA, rB



- So what would the numeric encoding of **`addl %edx,%ecx`** be?
  - **`0x6021`**

A full assembly

- This is the result of running the Y86 assembler on the example assembler source code:

```
0x000: 308000000000 |       irmovl $0,%eax    # sum = 0
0x006: 308101000000 |       irmovl $1,%ecx    # num = 1
0x00c: 6010         | Loop: addl   %ecx,%eax  # sum += num
0x00e: 308201000000 |       irmovl $1,%edx    # tmp = 1
0x014: 6021         |       addl   %edx,%ecx  # num++
0x016: 3082e8030000 |       irmovl $1000,%edx # lim = 1000
0x01c: 6112         |       subl   %ecx,%edx  # if lim - num >= 0
0x01e: 750c000000   |       jge    Loop       #   loop again
                    |
0x023: f308         |       wrint  %eax       # printf("%d", sum)
0x025: 30820a000000 |       irmovl $10,%edx   # ch = '\n'
0x02b: f128         |       wrch   %edx       # printf("%c", ch)
0x02d: 10           |       halt
```