Addressing, Complete Example

CSE 410 - Computer Systems

October 12, 2001

Readings and References

- Reading
  - Sections 3.7 through 3.10, A.1 through A.4, Patterson and Hennessy, Computer Organization & Design
    - note error in figure page 149, address 80012 repeated

- Other References
  - Sun demo of QuickSort vs BubbleSort

<http://java.sun.com/applets/jdk/1.1/demo/SortDemo/example1.html>

Beyond Numbers

- "Most computers today use 8-bit bytes to represent characters"
- How many characters can you represent in an 8-bit byte?
  - 256
- How many characters are needed to represent all the languages in the world?
  - a gazillion, approximately

char

- American Standard Code for Information Interchange (ASCII)
  - published in 1968
  - defines 7-bit character codes ...
  - which means only the first 128 characters
  - after that, it's all "extensions" and "code pages"
- ISO 8859-x
  - codify the extensions to 8 bits (256 characters)

ISO 8859-x

- Each “language” defines the extended chars
  - Latin1 (West European) , Latin2 (East European), Latin3 (South European), Latin4 (North European), Cyrillic, Arabic, Greek, Hebrew, Latin5 (Turkish), Latin6 (Nordic)
  - see http://czyborra.com/charsets/iso8859.html
- How many languages are there?
  - a gazillion, approximately

Unicode

- Universal character encoding standard
  - http://www.unicode.org/
- 16 bits should cover just about everything ...
  - “original goal was to use a single 16-bit encoding that provides code points for more than 65,000 characters”
  - the Java char type is a 16-bit character
- How many characters are needed? ...

Unicode does a million

Table 3-1. UTF-8 Bit Distribution

Scalar Value	UTF-16	1st Byte	2nd Byte	3rd Byte	4th Byte
000000000xxxxxxx	000000000xxxxxxx	0xxxxxxx			
00000yyyyyxxxxxx	00000yyyyyxxxxxx	110yyyyy	10xxxxxx		
zzzzyyyyyyxxxxxx	zzzzyyyyyyxxxxxx	1110zzzz	10yyyyyy	10xxxxxx	
uuuuuzzzzyyyyyyxxxxxx	110110wwwwzzzzyy+ 110111yyyyxxxxxx	11110uuu[a]	10uuzzzz	10yyyyyy	10xxxxxx

unicode scalar value:

a number N from 0 to $10FFFF_{16}$ ($1,114,111_{10}$)

Some character URLs

- ANSI X3.4 (ASCII)
  - http://czyborra.com/charsets/iso646.html
- ISO 8859 (International extensions)
  - http://czyborra.com/charsets/iso8859.html
- Unicode
  - http://www.unicode.org/
  - http://www.unicode.org/iuc/iuc10/x-utf8.html

Moving bytes

- A byte can contain an 8-bit character
- A byte can contain really small numbers

  0 to 255_{10} or -128_{10} to 127_{10}

- Sign extension desired effect:
  - sign bit not extended for characters
  - sign bit extended for numbers

Loading bytes

- Unsigned: `lbu $reg, a($reg)`
  - the byte is 0-extended into the register

0000 0000	0000 0000	0000 0000	xxxx xxxx

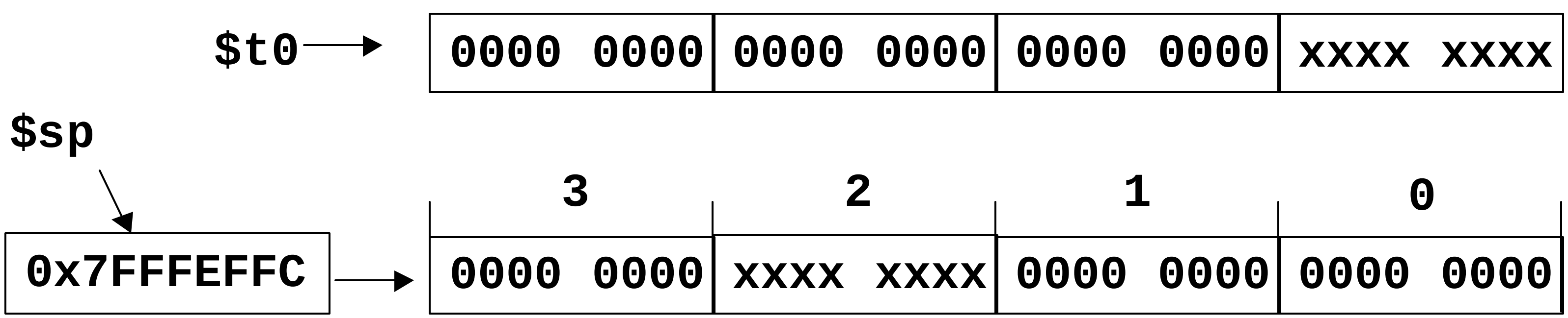
- Signed: `lb $reg, a($reg)`
  - bit 7 is extended through bit 31

0000 0000	0000 0000	0000 0000	0xxx xxxx

1111 1111	1111 1111	1111 1111	1xxx xxxx

Storing bytes

- No sign bit considerations
  - the right most byte in the register is jammed into the byte address given
  - **`sb $t0, 2($sp)`**



Storing strings

- Counted strings (for example Pascal strings)
  - byte str[0] holds length: max 255 char
- Counted strings (for example Java strings)
  - int variable holds length: max 2B char
- Terminated strings (for example C strings)
  - no length variable, must count: max n/a

`strcpy` example

```
char *strcpy(char *dst, const char *src) {
  char *s = dst;
  while ((*dst++ = *src++) != '\0')
      ;
  return s;
}
```

- prototype matches libc
- pointers, not arrays
- better loop

`strcpy` compiled

```
strcpy:
        move    $v1,$a0           # remember initial dst
loop:
        lbu     $v0,0($a1)        # load a byte
        sb      $v0,0($a0)        # store it
        sll     $v0,$v0,24        # toss the extra bytes
        addu    $a1,$a1,1         # src++
        addu    $a0,$a0,1         # dst++
        bne     $v0,$zero,loop    # loop if not done
        move    $v0,$v1           # return initial dst
        j       $ra               # return
```

Manipulating the bits

- Shift Logical
  - sll, srl, sllv, srlv - shift bits in word, 0-extend
  - use these to isolate bits in a word
  - shift amount in instruction or in register
- Bit by bit
  - and, andi - clear bits in destination
  - or, ori - set bits in destination

Example: bit manipulation

```
sll  $t1,$t1,24
```

```
0000 0000 0000 0000 0000 1111 1010 1111
1010 1111 0000 0000 0000 0000 0000 0000
```

```
srl  $t1,$t1,28
```

```
1010 1111 0000 0000 0000 0000 0000 0000
0000 0000 0000 0000 0000 0000 0000 1010
```

```
ori  $t1,$t1,0x100
```

```
0000 0000 0000 0000 0000 0000 0000 1010
0000 0000 0000 0000 0000 0001 0000 1010
```

Example: C bit fields

- Example in the book on page 229 is a typical application of bit fields

`... unused ...`	`received byte`	`e`	`r`

- But, note poor choice of field locations
  - the received byte is not aligned
  - the byte must be shifted before it can be used
- To: EE designers of interfaces
  - please consider alignment when selecting fields

Multiply and Divide

- There is a separate integer multiply unit
- Use pseudo-instructions to access

```
mul     $t0,$t1,$t2    # t0 = t1*t2
div     $t0,$t1,$t2    # t0 = t1/t2
```

- These are relatively slow
  - multiply 5-12 clock cycles
  - divide 35-80 clock cycles

Addressing modes

- Register `jr   $ra`
- Offset + Register `lw   $t0,0($sp)`
- Immediate `addi $t0,17`
- PC relative `bnez $t0,loop`
- Pseudodirect `jal  proc`

Register only

- Use the 32 bits of the specified register as the desired address
- Can specify anywhere in the program address space, without limitation
- **`jr $ra`**
  - return to caller after procedure completes

Offset + Register

- Specify 16-bit signed offset to add to the base register
- Transfer (lw, sw) base register is specified
  - **`lw    $t0,4($sp)`**
  - **`sw    $t0,40($gp)`**

Immediate

- The 16-bit field holds the constant value

```
0x34080001  ori $8, $0, 1          ; 4: li $t0,1
0x3c01ffff  lui $1, -1             ; 5: li $t0,-1
0x3428ffff  ori $8, $1, -1
0x3408ffff  ori $8, $0, -1         ; 6: li $t0,0xFFFF
0x3c010001  lui $1, 1              ; 7: li $t0,0x1FFFF
0x3428ffff  ori $8, $1, -1
0x3c015555  lui $1, 21845          ; 8: li $t0,0x5555AAAA
0x3428aaaa  ori $8, $1, -21846
0x3c010040  lui $1, 64 [main]      ; 9: la $t0,main
0x34280020  ori $8, $1, 32 [main]
```

PC relative

- Branch (beq, bne) base register is PC
  - `beq   $t0,$t1,skip`
- The 16-bit value stored in the instruction is considered to be a word offset
  - multiplied by 4 before adding to PC
  - can branch over ± 32 K instruction range

Pseudodirect

- The specified offset is 26 bits long
  - Considered to be a word offset
  - multiplied by 4 before use
- The top 4 bits of the PC are concatenated with the new 28 bit offset to give a 32-bit address
- Can jump within 256 MB segment

Starting a Program

- Two phases from source code to execution
- Build time
  - **compiler** creates assembly code
  - **assembler** creates machine code
  - **linker** creates an executable
- Run time
  - **loader** moves the executable into memory and starts the program

Build Time

- You're experts on compiling from source to assembly and hand crafted assembly
- Two parts to translating from assembly to machine language:
  - Instruction encoding (including translating pseudoinstructions)
  - Translating labels to addresses
- Label translations go in the *symbol table*

Symbol Table

- Symbols are **names** of global variables or labels (including procedure entry points)
- Symbol table associates **symbols** with their **addresses** in the object file
- This allows files compiled separately to be linked

`LabelA:`	`0x01031ff0`
`bigArray`	`0x10006000`

Modular Program Design

- Small projects might use only one file
  - Any time any one line changes, recompile and reassemble the whole thing (death of Pascal)
- For larger projects, recompilation time and complexity management is significant
- Solution: split project into modules
  - compile and assemble modules separately
  - link the object files

The Compiler + Assembler

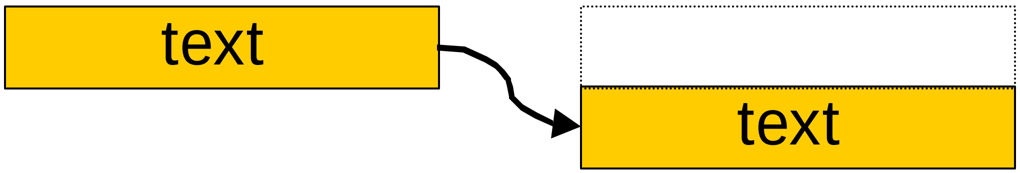
- Translate source files to object files
- Object files
  - Contain machine instructions (1's & 0's)
  - Bookkeeping information
    - Procedures and variables the object file defines
    - Procedures and variables the source files use but are undefined (unresolved references)
    - Debugging information associating machine instructions with lines of source code

The Linker

- The linker’s job is to “stitch together” the object files:
  1. Place the data modules in memory space
  2. Determine the addresses of data and labels
  3. Match up references between modules
- Creates an executable file

Determining Addresses

- Some addresses change during memory layout
- Modules were compiled in isolation
- *Absolute* addresses must be *relocated*
- Object file keeps track of instructions that use absolute addresses



Resolving References

- For example, in a word processing program, an input module calls a spell check module
- Module address is *unresolved* at compile time
- The linker matches unresolved symbols to locations in other modules at link time
- In SPIM, “main” is resolved when your program is loaded

Linker Example

main.o

code:
```
main:A=area(5.0)
```
static data:
```
PI = 3.1415
```
defined symbols:
```
main, PI
```
undefined symbols:
```
Area
```

area.o

code:
```
Area:return PI*r*r
```
static data:

defined symbols:
```
Area
```
undefined symbols:
```
PI
```

main.exe

header

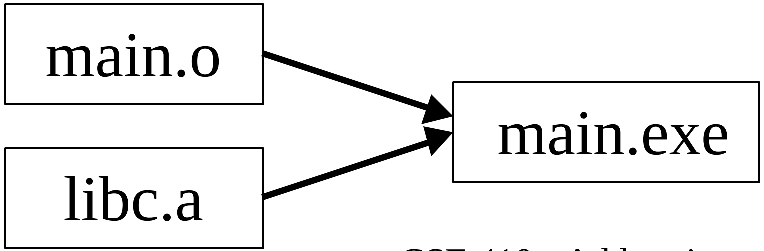
code: `main:A=area(5.0)`
`Area:return PI*r*r`

static data: `PI = 3.1415`

defined symbols: `main, PI, Area`

Libraries

- Some code is used so often, it is bundled into *libraries* for common access
- Libraries contain most of the code you use but didn't write: e.g., printf()
- Library code is (often) merged with yours at link time



The Executable

- End result of compiling, assembling, and linking: the *executable*
  - Header, listing the lengths of the other segments
  - Text segment
  - Static data segment
  - Potentially other segments, depending on architecture & OS conventions

Run Time

- When a program is started ...
  - Some *dynamic linking* may occur
    - some symbols aren't defined until run time
    - Windows' dlls (dynamic link library)
  - The segments are loaded into memory
  - The OS transfers control to the program and it runs
- We'll learn a lot more about this during the OS part of the course

QuickSort example

- QuickSort vs BubbleSort
  - don’t ever use a bubble sort, many better sort routines are available as source or library files
- The example QuickSort.c is taken from the Java example on the Sun demo page
- I converted it to C and compiled with gcc
- Helpful to review register usage, stack allocation, branching techniques