Lecture 6: Assembly Programs

- Today's topics:
  - Examples
  - Large constants
  - The compilation process
  - A full example

Example 2 (pg. 101)

```
int   fact  (int n)
{
    if (n < 1)  return (1);
        else return (n * fact(n-1));
}
```

```
fact:
    slti     $t0, $a0, 1
    beq      $t0, $zero, L1
      addi   $v0, $zero, 1
      jr     $ra
L1:
    addi     $sp, $sp, -8
    sw       $ra, 4($sp)
    sw       $a0, 0($sp)
    addi     $a0, $a0, -1
    jal      fact
    lw       $a0, 0($sp)
    lw       $ra, 4($sp)
    addi     $sp, $sp, 8
    mul      $v0, $a0, $v0
    jr       $ra
```

Notes:
The caller saves $a0 and $ra
in its stack space.
Temp register $t0 is never saved.

Dealing with Characters

- Instructions are also provided to deal with byte-sized and half-word quantities: lb (load-byte), sb, lh, sh

- These data types are most useful when dealing with characters, pixel values, etc.

- C employs ASCII formats to represent characters – each character is represented with 8 bits and a string ends in the null character (corresponding to the 8-bit number 0)

Example 3 (pg. 108)

Convert to assembly:

```
void strcpy (char x[], char y[])
{
    int i;
    i=0;
    while  ((x[i] = y[i]) != `\0’)
    i += 1;
}
```

```
strcpy:
 addi     $sp, $sp, -4
 sw       $s0, 0($sp)
 add      $s0, $zero, $zero
L1: add  $t1, $s0, $a1
 lb       $t2, 0($t1)
 add      $t3, $s0, $a0
 sb       $t2, 0($t3)
 beq      $t2, $zero, L2
 addi     $s0, $s0, 1
 j        L1
L2: lw   $s0, 0($sp)
 addi     $sp, $sp, 4
 jr       $ra
```

Notes:
Temp registers not saved.

Saving Conventions

- Caller saved: Temp registers \$t0-\$t9 (the callee won't bother saving these, so save them if you care), \$ra (it's about to get over-written), \$a0-\$a3 (so you can put in new arguments)

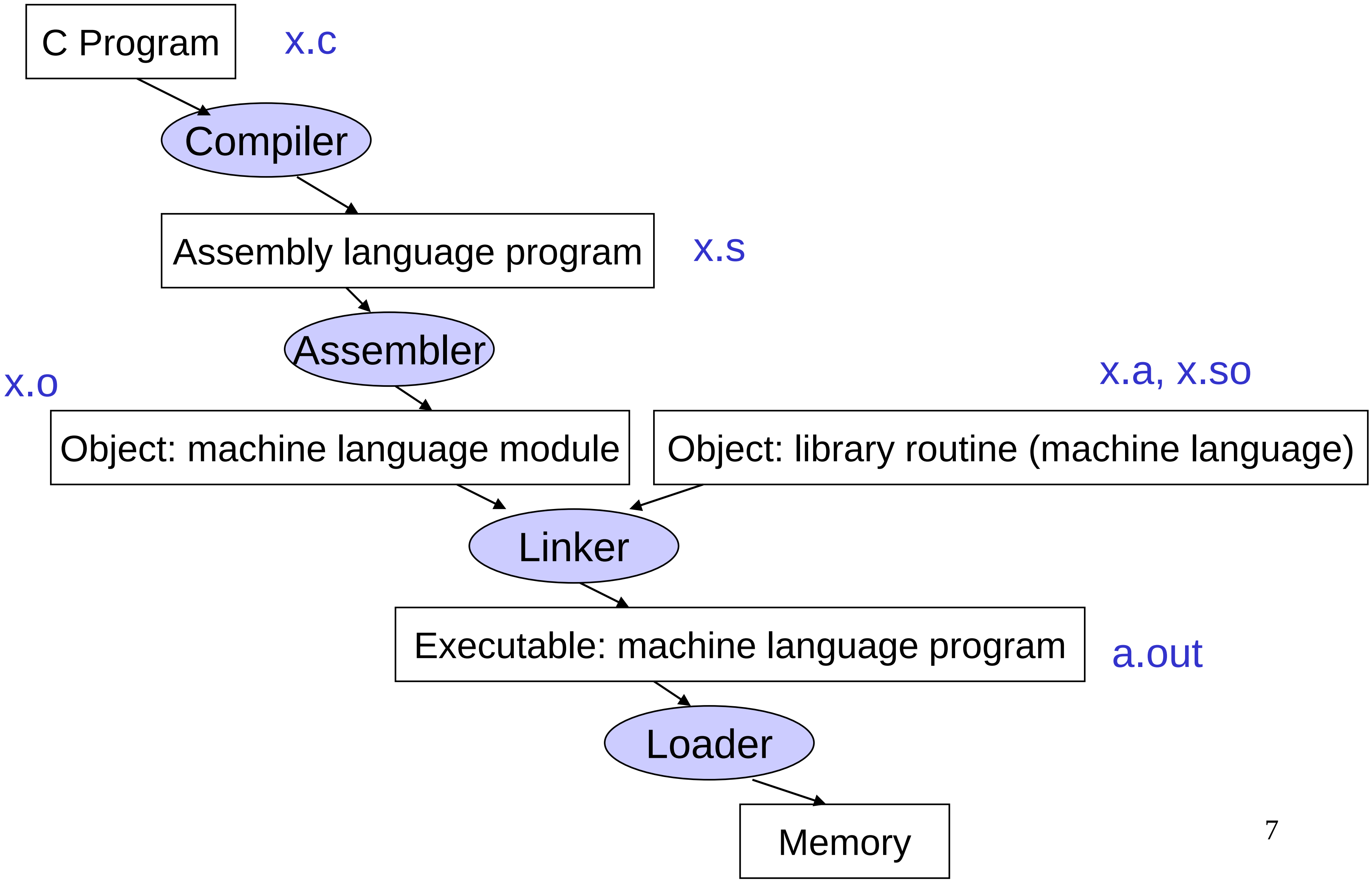
- Callee saved: \$s0-\$s7 (these typically contain "valuable" data)

- Read the Notes on the class webpage on this topic

Large Constants

- Immediate instructions can only specify 16-bit constants
- The lui instruction is used to store a 16-bit constant into the upper 16 bits of a register… combine this with an OR instruction to specify a 32-bit constant
- The destination PC-address in a conditional branch is specified as a 16-bit constant, relative to the current PC
- A jump (j) instruction can specify a 26-bit constant; if more bits are required, the jump-register (jr) instruction is used

Starting a Program



Role of Assembler

- Convert pseudo-instructions into actual hardware instructions – pseudo-instrs make it easier to program in assembly – examples: “move”, “blt”, 32-bit immediate operands, etc.

- Convert assembly instrs into machine instrs – a separate object file (x.o) is created for each C file (x.c) – compute the actual values for instruction labels – maintain info on external references and debugging information

Role of Linker

- Stitches different object files into a single executable
  - patch internal and external references
  - determine addresses of data and instruction labels
  - organize code and data modules in memory
- Some libraries (DLLs) are dynamically linked – the executable points to dummy routines – these dummy routines call the dynamic linker-loader so they can update the executable to jump to the correct routine

Full Example – Sort in C (pg. 133)

```
void sort (int v[], int n)
{
    int i, j;
    for (i=0; i<n; i+=1) {
        for (j=i-1; j>=0 && v[j] > v[j+1]; j-=1) {
            swap (v,j);
        }
    }
}
```

```
void swap (int v[], int k)
{
    int temp;
    temp = v[k];
    v[k] = v[k+1];
    v[k+1] = temp;
}
```

- Allocate registers to program variables
- Produce code for the program body
- Preserve registers across procedure invocations

The swap Procedure

- Register allocation: $a0 and $a1 for the two arguments, $t0 for the temp variable – no need for saves and restores as we're not using $s0-$s7 and this is a leaf procedure (won't need to re-use $a0 and $a1)

```
swap:   sll    $t1, $a1, 2
        add    $t1, $a0, $t1
        lw     $t0, 0($t1)
        lw     $t2, 4($t1)
        sw     $t2, 0($t1)
        sw     $t0, 4($t1)
        jr     $ra
```

```
void swap (int v[], int k)
{
    int temp;
    temp = v[k];
    v[k] = v[k+1];
    v[k+1] = temp;
}
```

The sort Procedure

- Register allocation: arguments v and n use $a0 and $a1, i and j use $s0 and $s1; must save $a0 and $a1 before calling the leaf procedure

- The outer for loop looks like this: (note the use of pseudo-instrs)

```
            move   $s0, $zero          # initialize the loop
loopbody1:  bge    $s0, $a1, exit1     # will eventually use slt and beq
            … body of inner loop …
            addi   $s0, $s0, 1
            j      loopbody1
exit1:
```

```
for (i=0; i<n; i+=1) {
  for (j=i-1; j>=0 && v[j] > v[j+1]; j-=1) {
       swap (v,j);
  }
}
```

The sort Procedure

- The inner for loop looks like this:

```
            addi   $s1, $s0, -1          # initialize the loop
loopbody2:  blt    $s1, $zero, exit2     # will eventually use slt and beq
            sll    $t1, $s1, 2
            add    $t2, $a0, $t1
            lw     $t3, 0($t2)
            lw     $t4, 4($t2)
            bgt    $t3, $t4, exit2
            … body of inner loop …
            addi   $s1, $s1, -1
            j      loopbody2
exit2:
```

```
for (i=0; i<n; i+=1) {
  for (j=i-1; j>=0 && v[j] > v[j+1]; j-=1) {
        swap (v,j);
  }
}
```

Saves and Restores

- Since we repeatedly call “swap” with $a0 and $a1, we begin “sort” by copying its arguments into $s2 and $s3 – must update the rest of the code in “sort” to use $s2 and $s3 instead of $a0 and $a1

- Must save $ra at the start of “sort” because it will get over-written when we call “swap”

- Must also save $s0-$s3 so we don’t overwrite something that belongs to the procedure that called “sort”

Saves and Restores

```
sort:   addi    $sp, $sp, -20
        sw      $ra, 16($sp)
        sw      $s3, 12($sp)
        sw      $s2, 8($sp)
        sw      $s1, 4($sp)
        sw      $s0, 0($sp)
        move    $s2, $a0
        move    $s3, $a1
          …
        move    $a0, $s2        # the inner loop body starts here
        move    $a1, $s1
        jal     swap
          …
exit1:  lw      $s0, 0($sp)
          …
        addi    $sp, $sp, 20
        jr      $ra
```

9 lines of C code → 35 lines of assembly

IA-32 Instruction Set

- Intel's IA-32 instruction set has evolved over 20 years – old features are preserved for software compatibility

- Numerous complex instructions – complicates hardware design (Complex Instruction Set Computer – CISC)

- Instructions have different sizes, operands can be in registers or memory, only 8 general-purpose registers, one of the operands is over-written

- RISC instructions are more amenable to high performance (clock speed and parallelism) – modern Intel processors convert IA-32 instructions into simpler micro-operations

Endian-ness

Two major formats for transferring values between registers and memory

Memory: low address 45 7b 87 7f high address

Little-endian register: the first byte read goes in the low end of the register

Register: 7f 87 7b 45

Most-significant bit ↗ ↖ Least-significant bit (x86)

Big-endian register: the first byte read goes in the big end of the register

Register: 45 7b 87 7f

Most-significant bit ↗ ↖ Least-significant bit (MIPS, IBM)

Title

- Bullet