Lecture 7: Examples, MARS

- Today's topics:
  - More examples
  - MARS intro

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); A is 65, a is 97

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;
}
```

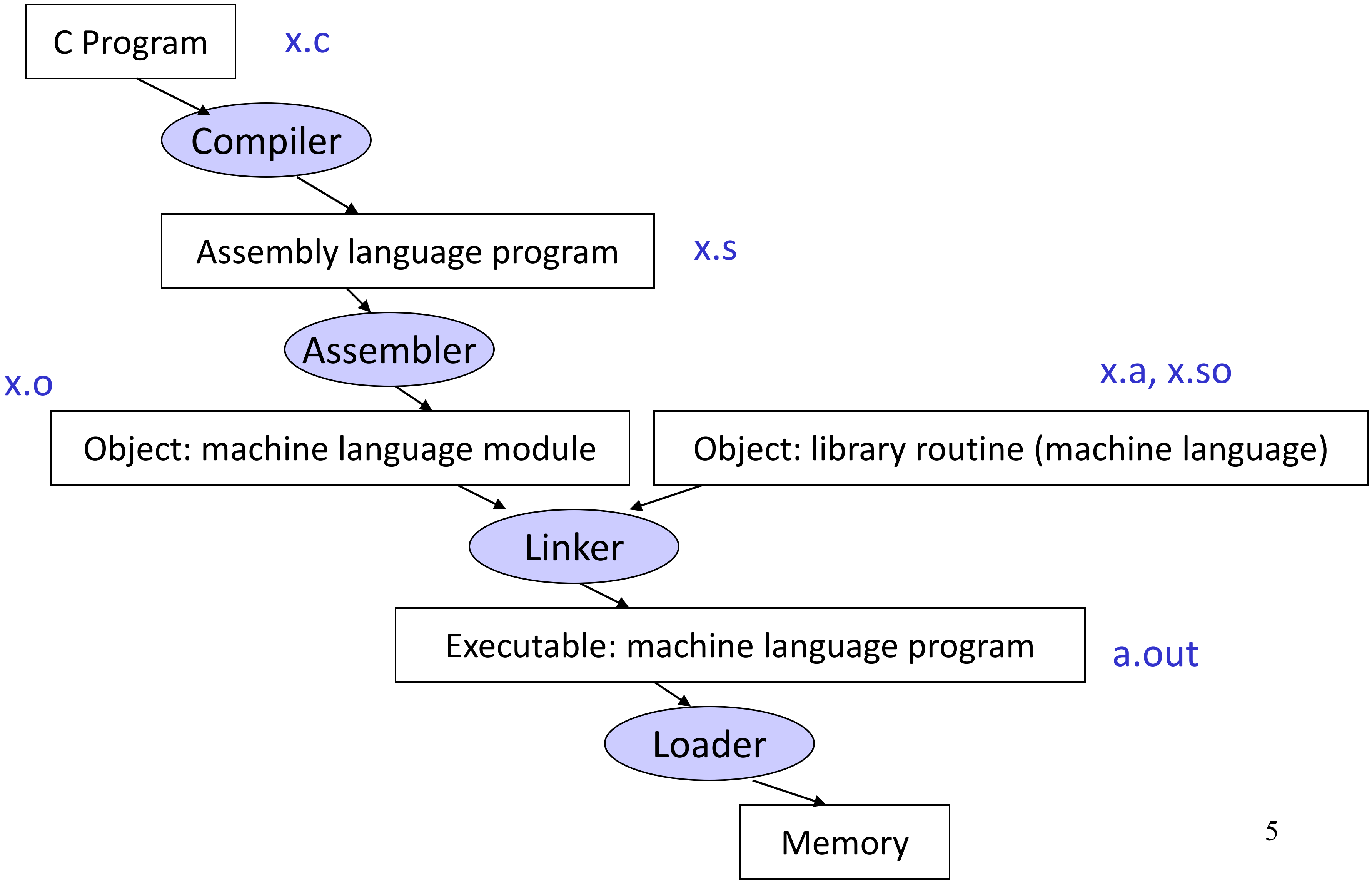
Notes:
Temp registers not saved.

```
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
```

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, labels, 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)
            ble     $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
```

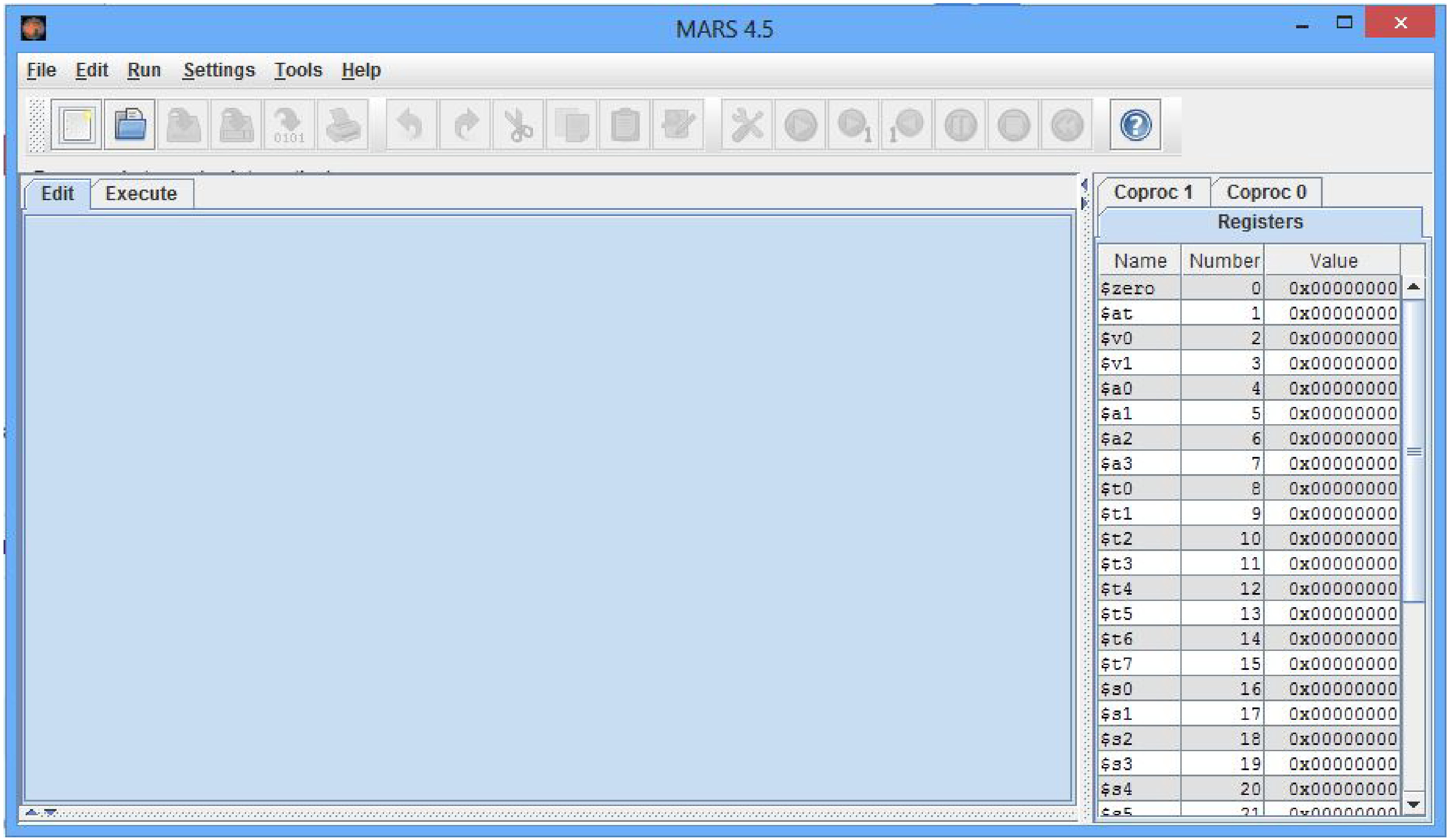
9 lines of C code → 35 lines of assembly

MARS

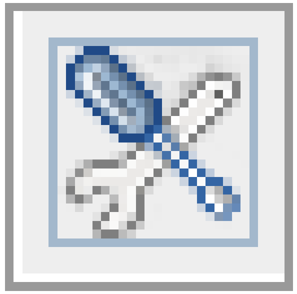
- MARS is a simulator that reads in an assembly program and models its behavior on a MIPS processor
- Note that a “MIPS add instruction” will eventually be converted to an add instruction for the host computer’s architecture – this translation happens under the hood
- To simplify the programmer’s task, it accepts pseudo-instructions, large constants, constants in decimal/hex formats, labels, etc.
- The simulator allows us to inspect register/memory values to confirm that our program is behaving correctly

MARS Intro

- Directives, labels, global pointers, system calls



MARS Intro



Text Segment

Bkpt	Address	Code	Basic	Source
☐	0x00400000	0x2009000a	addi $9,$0,0x0000000a	1: addi $t1, $zero, 10 # store value 10 into $t1
☐	0x00400004	0x200a0014	addi $10,$0,0x00000014	2: addi $t2, $zero, 20 # store value 20 into $t2
☑	0x00400008	0x012a4020	add $8,$9,$10	3: add $t0,$t1,$t2 # $t0 = 10+20
☐	0x0040000c	0x016c5022	sub $10,$11,$12	4: sub $t2,$t3,$t4 # $t2 = $t3-$t4
☐	0x00400010	0x216a0005	addi $10,$11,0x0000...	5: addi $t2,$t3, 5 # $t2 = $t3 + 5

Data Segment

Address	Value (+0)	Value (+4)	Value (+8)	Value (+c)	Value (+10)	Value (+14)	Value (+18)	Value (+1c)
0x10010000	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000
0x10010020	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000
0x10010040	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000
0x10010060	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000
0x10010080	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000
0x100100a0	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000
0x100100c0	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000
0x100100e0	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000	0x00000000

0x10010000 (.data) ☑ Hexadecimal Addresses ☑ Hexadecimal Values ☐ ASCII

MARS Intro

- Read the google doc on the class webpage for details!

Registers | Coproc 1 | Coproc 0

Name	Number	Value
$zero	0	0x00000000
$at	1	0x00000000
$v0	2	0x00000000
$v1	3	0x00000000
$a0	4	0x00000000
$a1	5	0x00000000
$a2	6	0x00000000
$a3	7	0x00000000
$t0	8	0x00000000
$t1	9	0x0000000a
$t2	10	0x00000014
$t3	11	0x00000000
$t4	12	0x00000000
$t5	13	0x00000000
$t6	14	0x00000000
$t7	15	0x00000000
$s0	16	0x00000000
$s1	17	0x00000000
$s2	18	0x00000000

Example Print Routine

```
.data
  str:    .asciiz   “the answer is ”
.text
  li      $v0, 4             # load immediate; 4 is the code for print_string
  la      $a0, str           #  the print_string syscall expects the string
                             #  address as the argument; la is the instruction
                             #  to load the address of the operand (str)
  syscall                    #  MARS will now invoke syscall-4
  li      $v0, 1             #  syscall-1 corresponds to print_int
  li      $a0, 5             #  print_int expects the integer as its argument
  syscall                    #  MARS will now invoke syscall-1
```

Example

- Write an assembly program to prompt the user for two numbers and print the sum of the two numbers

Example

```
.data
  str1:  .asciiz  “Enter 2 numbers:”
  str2:  .asciiz  “The sum is ”

.text
     li   $v0, 4
     la  $a0, str1
     syscall
     li   $v0, 5
     syscall
     add  $t0, $v0, $zero
     li   $v0, 5
     syscall
     add  $t1, $v0, $zero
     li   $v0, 4
     la  $a0, str2
     syscall
     li    $v0, 1
     add  $a0, $t1, $t0
     syscall
```