Compiling Techniques

Lecture 10: An Introduction to MIPS assembly

Hugh Leather

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Assembly program template

`.data`

Data segment: constant and variable definitions go here (including statically allocated arrays)

- format for declarations: `name: storage_type value`
- create storage for variable of specified type with given name and value
- `var1:    .word 3 # one word of storage with initial value 3`
- `array1: .space 40 # 40 bytes of storage for array1`

`.text`

Text segment: assembly instructions go here

Components of an assembly program

Category	Example
Comment	# I am a comment
Assembler directives	.data, .asciiz
Operation mnemonic	add, addi, lw, bne
Register name	$zero, $t3
Address label (declaration)	loop1:
Address label (use)	loop1
Integer constant	8, -4, 0xA9
Character constant	'h', '\t'
String constant	"Hello, world\n"

Hello world example

```
# Description: a simple hello world program

.data

hellostr:   .asciiz "Hello, world\n"

.text

  li  $v0, 4            # setup print syscall
  la  $a0, hellostr    # argument to print string
  syscall              # tell the OS to do the system call
  li  $v0, 10           # setup exit syscall
  syscall              # tell the OS to perform the syscall
```

Registers

- 32 general-purpose registers
- register preceded by $ in assembly language
- two formats for addressing (name or number: $zero or $0)
- holds 32 bits value (= 4 bytes = 1 word)
- stack grows from high memory to low memory

Registers

Register number	Alternative name	Description
0	$zero	the value 0
1	$at	assembler temporary: reserved by the assembler
2-3	$v0-$v1	values: from expression evaluation and function results
4-7	$a0-$a3	arguments: first four parameters for function (no preserved across function call)
8-15	$t0-$t7	temporaries (not preserved across function calls)
16-23	$s0-$s7	saved temporaries (preserved across function calls)
24-25	$t8-$t9	temporaries: (not preserved across function calls)
26-27	$k0-$k1	reserved for use by the interrupt/trap handler
28	$gp	global pointer : base of global data segment
29	$sp	stack pointer : points to last location on stack
30	$s8/$fp	saved value / frame pointer (preserved across function call)
31	$ra	return address

- Special Hi and Lo registers (not shown above) holds result of multiplication and division (see example later)

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Arithmetic Instructions

- Most use three operands
- All operands are registered (no memory access)
- All operands are 4 bytes (a word)

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Arithmetic Instructions

```
add      $t0,$t1,$t2
# $t0 = $t1 + $t2;
# add as signed (2's complement) integers

sub      $t2,$t3,$t4 # $t2 = $t3 - $t4
addi     $t2,$t3, 5  # $t2 = $t3 + 5;   "add immediate"
addu     $t1,$t6,$t7 # $t1 = $t6 + $t7;  add as unsigned integers
subu     $t1,$t6,$t7 # $t1 = $t6 + $t7;  subtract as unsigned integers

mult     $t3,$t4
# multiply 32-bit quantities in $t3 and $t4, and store 64-bit
# result in special registers Lo and Hi:  (Hi,Lo) = $t3 * $t4

div      $t5,$t6
# Lo = $t5 / $t6    (integer quotient)
# Hi = $t5 mod $t6 (remainder)

mfhi     $t0
# move quantity in special register Hi to $t0:   $t0 = Hi
mflo     $t1
# move quantity in special register Lo to $t1:   $t1 = Lo

move     $t2,$t3      # $t2 = $t3
```

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Load / Store Instructions

- Memory access only allowed with explicit load and store instructions (load/store architecture)
- All other instructions use register operands

- Load
  - `lw  register_destination, mem_source`
    copy a word (4 bytes) at source memory location to destination register
  - `lb  register_destination, mem_source`
    copy a byte to low-order byte of destination register (sign extend higher-order bytes)
  - `li  register_destination, value`
    load immediate value into destination register

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Load / Store Instructions

- Store
  - sw register_source, mem_destination
    store a word (4 bytes) from source register to memory location
  - sb register_source, mem_destination
    store a byte (low-order) from source register to memory
    location

Example

```
.data
var1:  .word 23 # declare storage for var1; initial value is 23

.text
lw  $t0, var1 # load contents of mem location into register $t0:  $t0 = 23
li  $t1, 5    #  $t1 = 5   ("load immediate")
sw  $t1, var1 # store contents of $t1 into mem:  var1 = 5
```

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Indirect and Based Addressing

- load address:
    - `la  $t0, var1`
      copy memory address of var1 into register $t0
- indirect addressing:
    - `lw  $t1, ($t0)`
      load word at memory address contained in $t0 into $t2
    - `sw  $t2, ($t0)`
      store word in register $t2 into memory at address contained in $t0
- based/indexed addressing (useful for field access in struct):
    - `lw  $t2, 4($t0)`
      load word at memory address ($t0+4) into register $t2
    - `sw  $t2, -12($t0)`
      store content of register $t2 into memory at address ($t0-12)

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Indirect and Based Addressing

Example

```
.data
array1:    .space  12   #   declare 12 bytes of storage

.text
la $t0, array1   #   load base address of array into $t0
li $t1, 5        #   $t1 = 5   ("load immediate")
sw $t1, ($t0)    #   first array element set to 5
li $t1, 13       #    $t1 = 13
sw $t1, 4($t0)   #   second array element set to 13
li $t1, -7       #    $t1 = -7
sw $t1, 8($t0)   #   third array element set to -7
```

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Exercise

Write the assembly program corresponding to the following C code:

```c
struct point_t {
  int x;
  int y;
}

struct point_t p;
int arr[12];

void main() {
  p.x = 2;
  p.y = 4;
  arr[3] = 6;
}
```

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Control structures

- Branches:

```
b       target          #  unconditional branch to target
beq     $t0,$t1,target  #  branch to target if  $t0 = $t1
blt     $t0,$t1,target  #  branch to target if  $t0 < $t1
ble     $t0,$t1,target  #  branch to target if  $t0 <= $t1
bgt     $t0,$t1,target  #  branch to target if  $t0 > $t1
bge     $t0,$t1,target  #  branch to target if  $t0 >= $t1
bne     $t0,$t1,target  #  branch to target if  $t0 <> $t1
```

All branch instructions use a target label: example

```
  addi  $t0, $zero, 0  # t0 = 0
  addi  $t1, $zero, 10 # t1 = 10
loop:
  addi  $t0, $t0, 1     # t0 = t0+1
  blt   $t0, $t1, loop # branch to loop if t0<t1 (t0<10)
```

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Control structures

- Jumps:

```
j        target
#   unconditional jump to program label target

jr       $t3
#   jump to address contained in $t3 ("jump register")
```

- Subroutine (function) call:

```
jal  label #  "jump and link"
```

  - copy program counter (return address) to register $ra (return address register)
  - jump to program instruction at label

```
jr $ra #  "jump register"
```

  - jump to return address in $ra (stored by jal instruction)

In case of nested function calls, the return address should be saved to the stack and restored accordingly.

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System Calls

System calls are used to interface with the operating systems. For instance input/output or dynamic memory allocation.

Using system calls:

1. load the service number in register $v0
2. load argument values in $a0, $a1, . . .
3. issue the syscall instruction
4. retrieve return value if any

Example: printing integer on the console

```
li   $v0 , 1
# service 1 is print integer

add $a0 , $t0 , $zero
# load desired value into argument register $a0

syscall
```

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System calls tables:

Service	$v0	Arguments	Result
print integer	1	$a0 = integer to print	
print string	4	$a0 = address of null-terminated string to print	
print character	11	$a0 = character to print	
read integer	5		$v0 = integer read
read character	12		$v0 = character read
allocate heap memory	9	$a0 = number of bytes to allocate	$v0 = address of allocated memory

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Next lecture:

- Introduction to Code Generation