Lecture 5: More Instructions, Procedure Calls

- Today's topics:
  - Examples
  - Numbers, control instructions
  - Procedure calls

39_{10} → binary

39 ÷ 2 = 19 rem 1 ← last bit
19 ÷ 2 = 9 rem 1
9 ÷ 2 = 4 rem 1
4 ÷ 2 = 2 rem 0
2 ÷ 2 = 1 rem 0
1 ÷ 2 = 0 rem 1
0 ÷ 2 = 0 rem 0
0 ÷ 2 = 0 rem 0

HW 2 posted (due next Tuesday)

HW 1 solns posted later today (Canvas → Files)

Sign up on Piazza

0000100111

2^5 2^4 2^3 2^2 2^1 2^0

Memory Instruction Format

- The format of a store instruction:

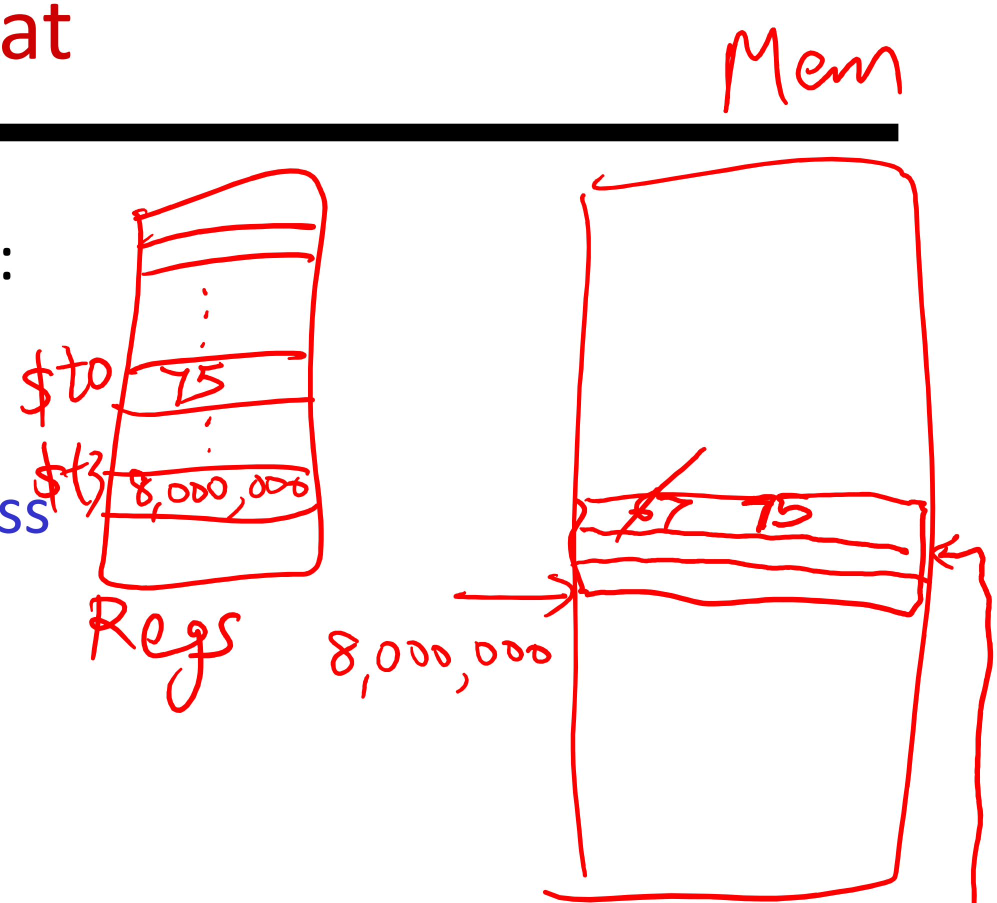
source register

destination address

sw $t0, 8($t3)

any register

a constant that is added to the register in parentheses



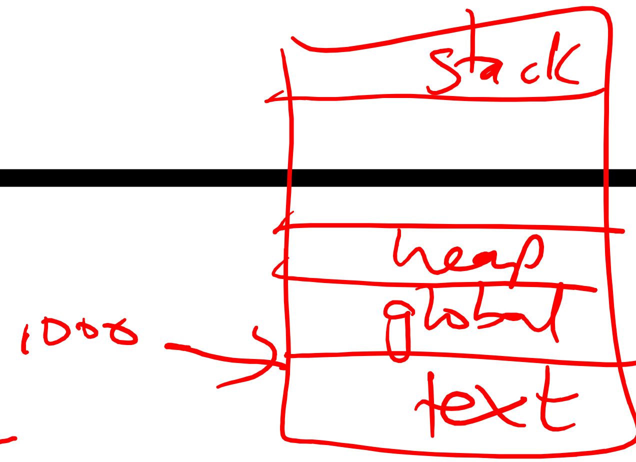
Rd $t3 8,000,000

Add 8 ⇒ 8,000,008 This is addr

Rd $t0 ⇒ get 75

Write into mem

Example




```
int a, b, c, d[10];

addi   $gp, $zero, 1000   # assume that data is stored at
                          # base address 1000; placed in $gp;
                          # $zero is a register that always
                          # equals zero
lw   $s1, 0($gp)          # brings value of a into register $s1
lw   $s2, 4($gp)          # brings value of b into register $s2
lw   $s3, 8($gp)          # brings value of c into register $s3
lw   $s4, 12($gp)         # brings value of d[0] into register $s4
lw   $s5, 16($gp)         # brings value of d[1] into register $s5
```

Example

int a, b, c, d[10] → prob 6 lines of code

Convert to assembly:

C code: d[3] = d[2] + a;

lw ← a

lw ← d[2]

add regs regs regs

sw → d[3]

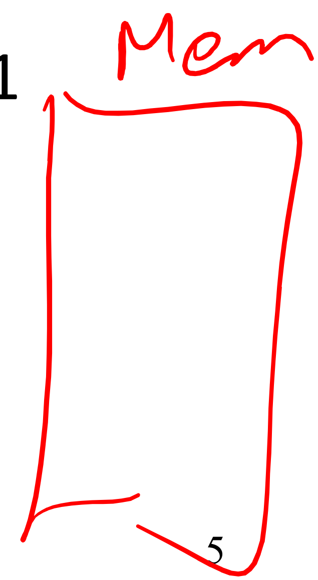
Example

Convert to assembly:

C code: d[3] = d[2] + a;

Assembly (same assumptions as previous example):

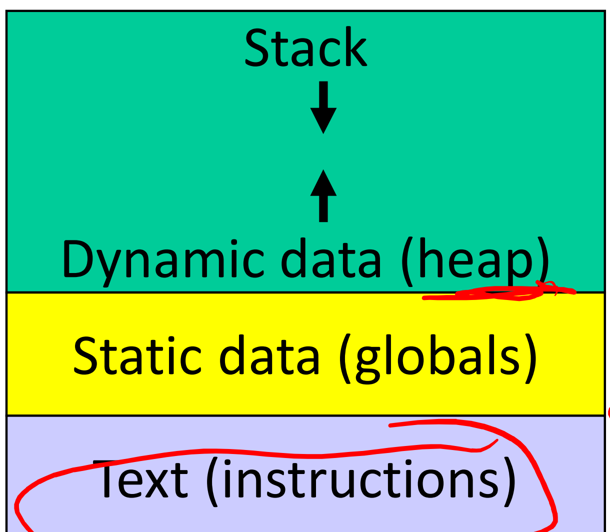
```
lw   $s0, 0($gp)    # a is brought into $s0
lw   $s1, 20($gp)   # d[2] is brought into $s1
add  $s2, $s0, $s1  # the sum is in $s2
sw   $s2, 24($gp)   # $s2 is stored into d[3]
```



Assembly version of the code continues to expand!

Memory Organization

- The space allocated on stack by a procedure is termed the activation record (includes saved values and data local to the procedure) – frame pointer points to the start of the record and stack pointer points to the end – variable addresses are specified relative to $fp as $sp may change during the execution of the procedure
- $gp points to area in memory that saves global variables
- Dynamically allocated storage (with malloc()) is placed on the heap



Recap – Numeric Representations

- Decimal $35_{10} = 3 \times 10^1 + 5 \times 10^0$
- Binary $00100011_2 = 1 \times 2^5 + 1 \times 2^1 + 1 \times 2^0$
- Hexadecimal (compact representation)

  0x 23 or $23_{hex} = 2 \times 16^1 + 3 \times 16^0$

0-15 (decimal) → 0-9, a-f (hex)

Dec	Binary	Hex	Dec	Binary	Hex	Dec	Binary	Hex	Dec	Binary	Hex
0	0000	00	4	0100	04	8	1000	08	12	1100	0c
1	0001	01	5	0101	05	9	1001	09	13	1101	0d
2	0010	02	6	0110	06	10	1010	0a	14	1110	0e
3	0011	03	7	0111	07	11	1011	0b	15	1111	0f

Instruction Formats

Instructions are represented as 32-bit numbers (one word), broken into 6 fields

R-type instruction add $t0, $s1, $s2

000000	10001	10010	01000	00000	100000
6 bits	5 bits	5 bits	5 bits	5 bits	6 bits
op	rs	rt	rd	shamt	funct
opcode	source	source	dest	shift amt	function

I-type instruction lw $t0, 32($s3)

6 bits	5 bits	5 bits	16 bits
opcode	rs	rt	constant
	($s3)	*($t0)*	

Logical Operations

Logical ops	C operators	Java operators	MIPS instr
Shift Left	<<	<<	sll
Shift Right	>>	>>>	srl
Bit-by-bit AND	&	&	and, andi
Bit-by-bit OR	|	|	or, ori
Bit-by-bit NOT	~	~	nor (with $zero)

Dec 17 sll by 3
17000 ⇒ 17×10^3

8 17,416 srl 5 → 8

srl by 5
÷ by 2^5

sll $s1, $s2, 3

$2^3 \times$

$s2: 0 00011
↓ shift left by 3
$s1: 0 00011000

Control Instructions

- Conditional branch: Jump to instruction L1 if register1 equals register2: beq register1, register2, L1
  Similarly, bne and slt (set-on-less-than)
- Unconditional branch:
  j L1
  jr $s0 (useful for big jumps and procedure returns)

Convert to assembly:

```
if (i == j)
   f = g+h;
else
   f = g-h;
```

Control Instructions

- Conditional branch: Jump to instruction L1 if register1 equals register2: beq register1, register2, L1
  Similarly, bne and slt (set-on-less-than)

- Unconditional branch:
  j L1
  jr $s0 (useful for big jumps and procedure returns)

Convert to assembly:

```
if  (i == j)                    bne   $s3, $s4, Else
    f = g+h;           then:    add   $s0, $s1, $s2
else                            j     End
    f = g-h;           Else:    sub   $s0, $s1, $s2
                       End:
```

Example

save[i]

$s6 has addr of start of save[i]

addr of save[0]

Convert to assembly:

while (save[i] == k)
    i += 1;

addr of save[1] = $s6 + 4

4($s6)

addr of save[2] = 8($s6)

$s6 + 8

Values of i and k are in $s3 and $s5 and base of array save[] is in $s6

addr of save[i] = $s6 + 4i

Example

Convert to assembly:

```
while   (save[i] == k)
    i += 1;
```

Values of i and k are in $s3 and $s5 and base of array save[] is in $s6

```
Loop: sll   $t1, $s3, 2
      add   $t1, $t1, $s6
      lw    $t0, 0($t1)
      bne   $t0, $s5, Exit
      addi  $s3, $s3, 1
      j     Loop
Exit:
```

```
      sll   $t1, $s3, 2
      add   $t1, $t1, $s6
Loop: lw    $t0, 0($t1)
      bne   $t0, $s5, Exit
      addi  $s3, $s3, 1
      addi  $t1, $t1, 4
      j     Loop
Exit:
```

Registers

- The 32 MIPS registers are partitioned as follows:
  - Register 0 : $zero always stores the constant 0
  - Regs 2-3 : $v0, $v1 return values of a procedure
  - Regs 4-7 : $a0-$a3 input arguments to a procedure
  - Regs 8-15 : $t0-$t7 temporaries
  - Regs 16-23: $s0-$s7 variables
  - Regs 24-25: $t8-$t9 more temporaries
  - Reg 28 : $gp global pointer
  - Reg 29 : $sp stack pointer
  - Reg 30 : $fp frame pointer
  - Reg 31 : $ra return address

Procedures

- Local variables, AR, $fp, $sp
- Scratchpad and saves/restores
- Arguments and returns
- jal and $ra