CSCI 210: Computer Architecture
Lecture 14: MIPS addressing

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Nov. 3, 2021

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Announcements

- Problem Set due Friday
- Lab 3 due Sunday
- Office Hours Friday 13:30 – 14:30

Basic Question of Addressing

- How do we specify which data to operate on (or instruction to jump to)?

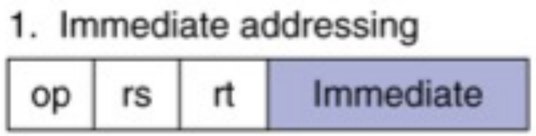
- Complication:
  - Instructions are 32 bits.
  - Memory addresses are 32 bits.
  - Data is in 32 bit words.

- Can never full specify address/data in a single instruction

Register Addressing

- Which register the data is in is specified in the instruction
- 32 registers = 5 bits per register address
- Used in add, jr, etc

Immediate Addressing



- Data is a constant within instruction

- There is no memory address/register, because we are just writing the information in the instruction itself

- 16 bits, can specify numbers up to 2^{16}-1 = 64 k

- Used in addi, ori, etc

32-bit Constants

- Most constants are small
  - 16-bit immediate is sufficient
- For the occasional 32-bit constant
- lui rt, constant
  - Copies 16-bit constant to left 16 bits of rt
  - Clears right 16 bits of rt to 0

Which of these will set $t0 to 0xF0F0F0F0?

A.
```
lui   $t0, 0xF0F0
addi  $t0, $t0, 0xF0F0
```

B.
```
lui   $t0, 0xF0F0
ori   $t0, $t0, 0xF0F0
```

C.
```
ori   $t0, $t0, 0xF0F0
lui   $t0, 0xF0F0
```

D. More than one of these will work

E. None of these will work

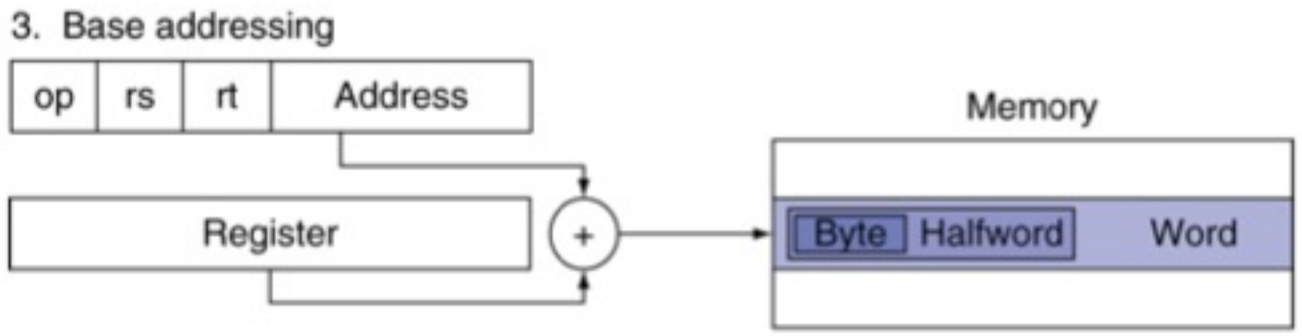
Aside: Loading and Storing Bytes

- MIPS provides special instructions to move bytes
  - `lb  $t0, 1($s3)  # load byte from memory`
  - `sb  $t0, 6($s3)  # store byte to  memory`

opcode	rs	rt	16 bit offset

- What 8 bits get loaded and stored?
  - load byte places the byte from memory in the rightmost 8 bits of the destination register
    - Byte is sign extended, other bytes in register erased
  - store byte takes the byte from the rightmost 8 bits of a register and writes it to a byte in memory
    - Other bytes in word of memory are left intact

Base + Offset Addressing



- Problem: 16 bits is not enough to address every word in memory
- Solution: Add the 16-bit offset to the 32-bit address within a register (the base)
- Used in lw, sw

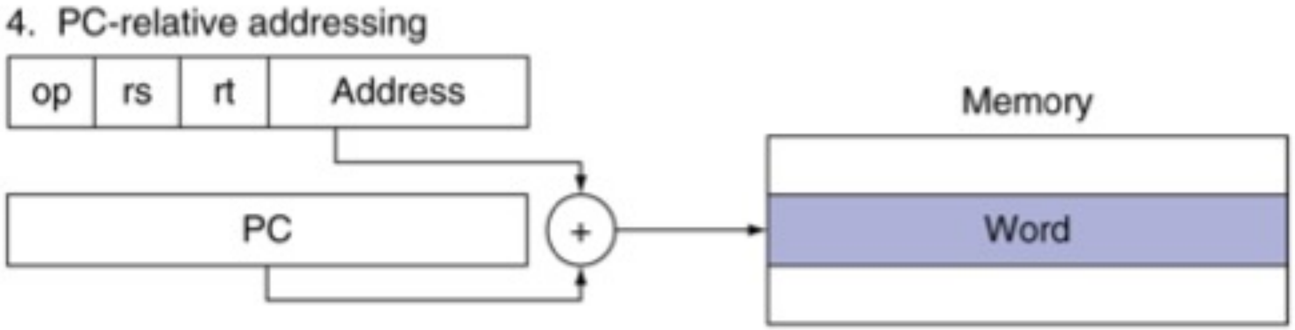
Branch Instructions' targets are

A. usually within 2^{15} instructions of the branch instruction

B. always within 2^{15} instructions of the branch instruction

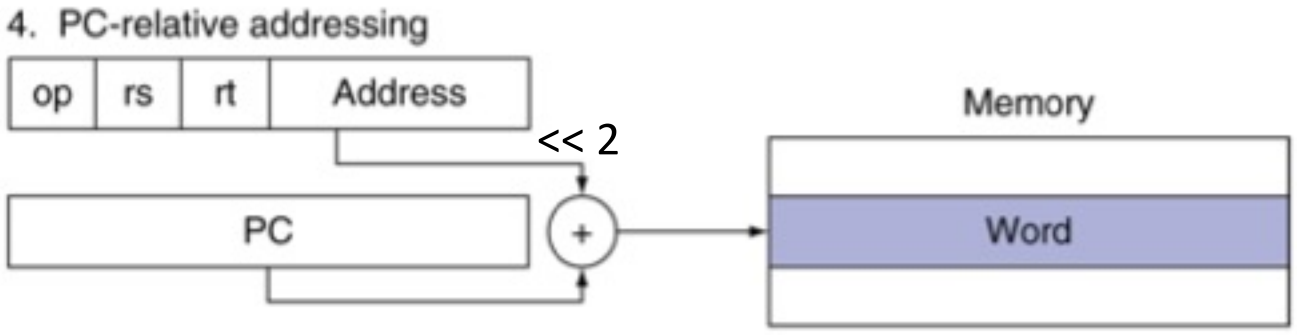
C. usually more than 2^{15} instructions away from the branch instruction

PC-relative Addressing



- Take 16 bit constant, shift left 2, add to value in PC
- Can access PC +/- 2^{17} bytes
- Used in beq, bne

Why do we shift left by two?



A. We use the last two bits of the PC instead
B. We only branch to instructions that are multiples of 4 words away from the current instruction
C. Instructions are words and addresses specify bytes, so the last two bits of the address will always be 00
D. None of the above

Which PC value in PC-relative addressing?

```
0x42000             slt    $t0, $t1, $t2
0x42004             beq    $t0, $zero, target
0x42008             addi   $s0, $s0, 1
…
0x?????      target: ori    $s0, $s0, 1
```

If the beq instruction has an immediate field of 0x0572, what is the address of the target ori instruction?

PC is the address of the *following* instruction

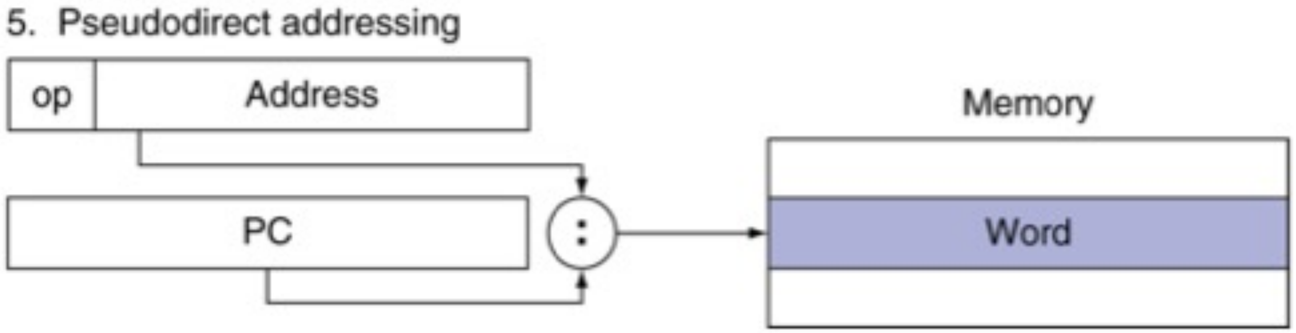
target address: 0x42004 + 4 + (0x0572 << 2)

Branching Far Away

- If branch target is too far to encode with 16-bit offset, assembler rewrites the code

-
```
        beq  $t0, $t1, far_away
```
  becomes
```
        bne  $t0, $t1, not_equal
        j    far_away
not_equal:
```

Pseudo-direct Addressing



- We have 26 bits of address in the instruction
- Shift left by two
- Concatenate first four bits of PC + 4 with address
- Used in j, jal

Consider a jal instruction at address 0xC8001074 whose 26-bit address field has the value 0x0000003. What is the address of the instruction the jal will jump to?

A. 0x00000003
B. 0x0000000C
C. 0xC0000003
D. 0xC0000007
E. 0xC000000C

Assembler directives

- Instructions to the assembler
  - .data / .text / .rodata / .bass are used to switch between global (mutable) data, executable code, read-only data, and uninitialized data in the output
  - .word x allocates space for 4 bytes with value x
  - .space n allocates n bytes of space
  - .asciiz “string” writes a 0-terminated string at that location

Arrays!

- How do we declare a 10-word array in our data section?

- Could do

```
.data
 x1:    .word  0
 x2:    .word  0
 x3:    .word  0
 ...
 x10:   .word  0
```

Declaring an Array

- Instead, just declare a big chunk of memory

```
.data
arr:  .space  40
```

```
.data
arr: .space  40

.text
    li      $t0, 0
    addi    $t1, $t0, 10
    la      $s0, arr
loop:
    beq     $t0, $t1, end
    What goes here?
    addi    $t0, $t0, 1
    j       loop
end:
```

```
int i;
for (i = 0; i < 10; i++){
	arr[i] = i;
}
```

```
sw    $t0, $t1($s0)
```

A

```
add   $t2, $s0, $t1
sw    $t0, 0($t2)
```

B

```
sw    $t0, 0($s0)
addi  $s0, $s0, 4
```

C

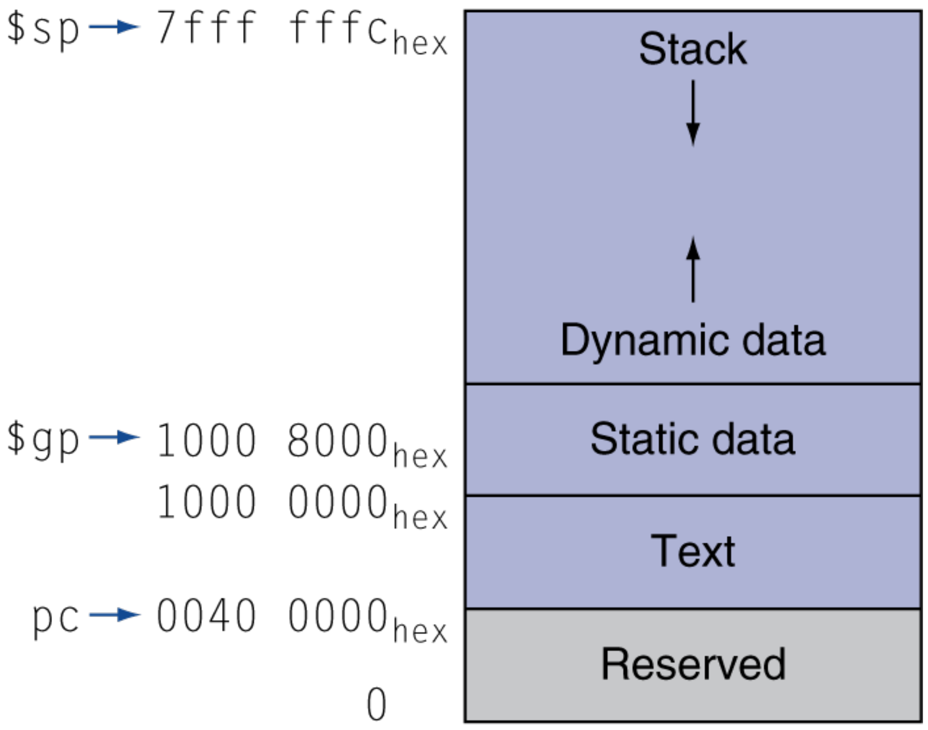
D. More than one of the above

E. None of the above

But what if we don’t know how big the array will be before runtime?

sbrk system call

- Allocates memory on the heap and returns its address in $v0
- Amount of memory is specified in bytes in $a0



System Calls

- Syscalls (when we need OS intervention)
  - I/O (print/read stdout/file)
  - Exit (terminate)
  - Get system time
  - Random values

System Calls Review

- How to use:
  - Put syscall number into register $v0
  - Load arguments into argument registers
  - Issue syscall instruction
  - Retrieve return values

- Example (print the integer in $t0):

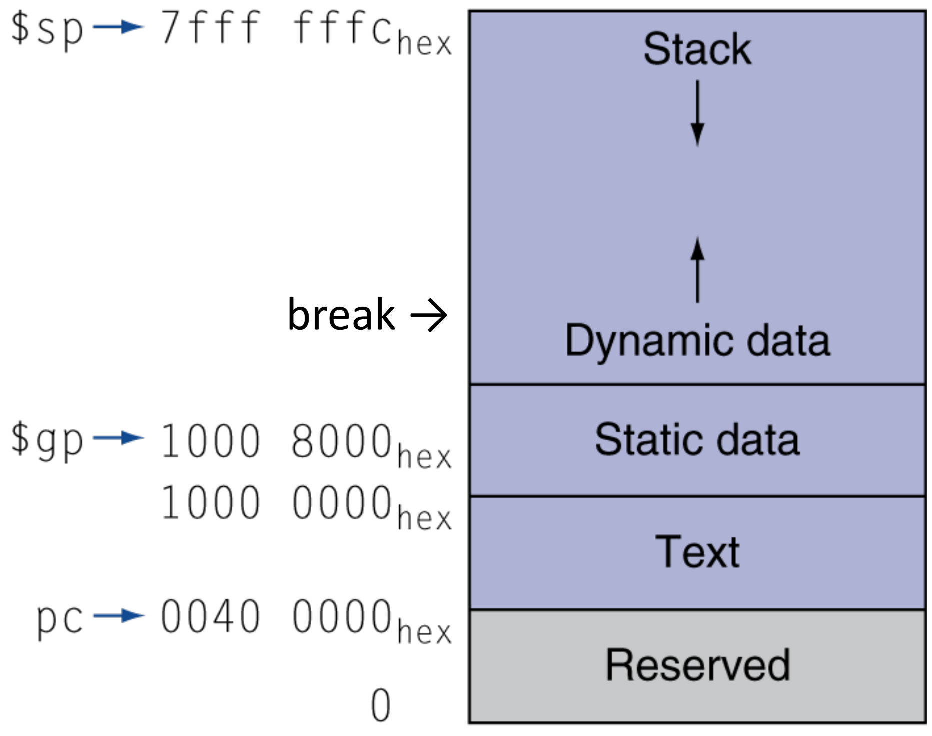
```
li       $v0, 1
move     $a0, $t0
syscall
```

System Call Codes

$v0 code	Service	Arguments	
1	Print integer	$a0=integer to print	
2	Print float	$f12=float to print	
3	Print double	$f12=double to print	
4	Print string	$a0=address of string	
5	Read integer		$v0 = read integer
6	Read float		$f0 = read float
7	Read double		$f0 = read double
8	Read string	$a0 = address of input buffer, $a1 = max number of characters	
9	Sbrk (allocate heap memory)	$a0 = number of bytes	$v0 = address
10	Exit (terminate program)		

What about freeing memory?

- Some operating systems maintain a “program break” which controls the size of the dynamic data
- sbrk requests the OS increment/decrement the break
- malloc()/free() carve the dynamic data up into chunks which the application can use and maintain lists of free chunks
- Freeing memory adds the chunk to a “free list”
- When more memory is needed, the break is changed



Reading

- Next lecture: Digital logic

- Problem set 4: Due Friday

- Lab 3 due Sunday