# Lecture 5: More Instructions, Procedure Calls

- Today's topics:
  - Memory layout, numbers, control instructions
  - Procedure calls
  - Recaps: cycle time and frequency, addr/value

# Example

Convert to assembly:

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

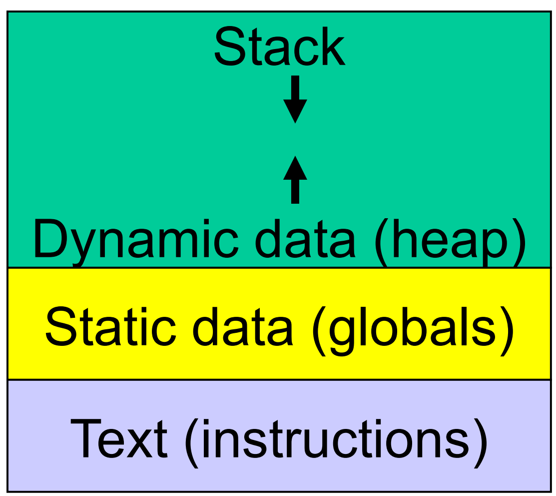
Assembly (same assumptions as previous example):

```
lw   $s0, 0($gp)      #  a is brought into $s0
lw   $s1, 20($gp)     #  d[2] is brought into $s1
add  $t1, $s0, $s1    #  the sum is in $t1
sw   $t1, 24($gp)     #  $t1 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 |

# 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 |

# 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;
```

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Convert to assembly:

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

# 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

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```
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

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