The Memory Subsystem

- memory subsystem typically provides capability to load or store bytes (not bits)
  - 1 byte == 8 bits (on general purpose modern machines)
- each byte has unique address, think of:
  - memory as implementing a gigantic array of bytes
  - and the address is the array index
- typically, a small (1, 2, 4, 8, ...) group of bytes can be loaded/stored in a single operation
- general purpose computers typically have complex cache systems to improve memory performance
  - if we have time we'll look at cache systems a little, late in this course
Virtual Memory

- Operating systems on general purpose computers typically provide **virtual memory**
- **Virtual memory** is not covered in this course
- **Virtual memory** make it look to every running program that it has entire address space
  - hugely convenient for multi-process systems
- Disconnects addresses running programs (processes) use from actual RAM address.
- Operating system translates (virtual) address a process uses to an physical (actual) RAM address.
- Translation needs to be really fast - needs to be largely implemented in hardware (silicon)
- **Virtual memory** can be several times larger than actual RAM size
- Multiple processes can be in RAM, allowing fast switching
- Part of processes can be load into RAM on demand.
- Provides a mechanism to share memory between processes.
most modern general purpose computers use 64-bit addresses
  - CSE servers use 64-bit addresses

some (older) general purpose computers use 32-bit addresses

many special purpose (embedded) CPUs use 32-bit addresses
  - some use 64-bit addresses
  - some use 16-bit addresses

on the MIPS32 machine implemented by mipsy, all addresses are 32-bit
  so in COMP1521 assembler we'll be using 32-bit addresses

there are 64-bit MIPS CPUs
Accessing Memory on the MIPS

- addresses are 32 bit
- only load/store instructions access memory on the MIPS
- 1 byte (8-bit) loaded/stored with `lb`/`sb`
- 2 bytes (16-bit) called a *half-word*, loaded/stored with `lh`/`sh`
- 4 bytes (32-bits) called a *word*, loaded/stored with `lw`/`sw`
- memory address used for load/store instructions is sum of a specified register and a 16-bit constant (often 0) which is part of the instruction
- for `sb` & `sh` operations low (least significant) bits of source register are used.
- `lb`/`lh` assume byte/halfword contains a 8-bit/16-bit *signed* integer
  - high 24/16-bits of destination register set to 1 if 8-bit/16-bit integer negative
- unsigned equivalents `lbu` & `lhu` assume integer is *unsigned*
  - high 24/16-bits of destination register always set to 0
- signed and unsigned integer representations covered later in course
<table>
<thead>
<tr>
<th>assembly</th>
<th>meaning</th>
<th>bit pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>lb</code> $r_t$, $I(r_s)$</td>
<td>$r_t = \text{mem}[r_s+I]$</td>
<td>100000ssssstttttIIIIIIIIIIIIIIII</td>
</tr>
<tr>
<td><code>lh</code> $r_t$, $I(r_s)$</td>
<td>$r_t = \text{mem}[r_s+I]$</td>
<td>100001ssssstttttIIIIIIIIIIIIIIII</td>
</tr>
<tr>
<td></td>
<td>$\text{mem}[r_s+I+1] \ll 8$</td>
<td></td>
</tr>
<tr>
<td><code>lw</code> $r_t$, $I(r_s)$</td>
<td>$r_t = \text{mem}[r_s+I]$</td>
<td>100011ssssstttttIIIIIIIIIIIIIIII</td>
</tr>
<tr>
<td></td>
<td>$\text{mem}[r_s+I+1] \ll 8$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\text{mem}[r_s+I+2] \ll 16$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\text{mem}[r_s+I+3] \ll 24$</td>
<td></td>
</tr>
<tr>
<td><code>sb</code> $r_t$, $I(r_s)$</td>
<td>$\text{mem}[r_s+I] = r_t &amp; 0xff$</td>
<td>101000ssssstttttIIIIIIIIIIIIIIII</td>
</tr>
<tr>
<td><code>sh</code> $r_t$, $I(r_s)$</td>
<td>$\text{mem}[r_s+I] = r_t &amp; 0xff$</td>
<td>101001ssssstttttIIIIIIIIIIIIIIII</td>
</tr>
<tr>
<td></td>
<td>$\text{mem}[r_s+I+1] = r_t &gt;&gt; 8 &amp; 0xff$</td>
<td></td>
</tr>
<tr>
<td><code>sw</code> $r_t$, $I(r_s)$</td>
<td>$\text{mem}[r_s+I] = r_t &amp; 0xff$</td>
<td>101011ssssstttttIIIIIIIIIIIIIIII</td>
</tr>
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<td></td>
<td>$\text{mem}[r_s+I+1] = r_t &gt;&gt; 8 &amp; 0xff$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\text{mem}[r_s+I+2] = r_t &gt;&gt; 16 &amp; 0xff$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\text{mem}[r_s+I+3] = r_t &gt;&gt; 24 &amp; 0xff$</td>
<td></td>
</tr>
</tbody>
</table>
# simple example of load & storing a byte
# we normally use directives and labels

main:
li $t0, 42
li $t1, 0x10000000
sb $t0, 0($t1)  # store 42 in byte at address 0x10000000
lb $a0, 0($t1)  # load $a0 from same address
li $v0, 1     # print $a0
syscall
li $a0, \n       # print '\n'
li $v0, 11
syscall
li $v0, 0    # return 0
jr $ra
mipsy has directives to initialise memory, and to associate labels with addresses.

<table>
<thead>
<tr>
<th>Label</th>
<th>Directive</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>.text</td>
<td># following instructions placed in text segment</td>
<td></td>
</tr>
<tr>
<td>.data</td>
<td># following objects placed in data segment</td>
<td></td>
</tr>
<tr>
<td>a:</td>
<td>.space 18</td>
<td>int8_t a[18];</td>
</tr>
<tr>
<td>i:</td>
<td>.word 42</td>
<td>int32_t i = 42;</td>
</tr>
<tr>
<td>v:</td>
<td>.word 1,3,5</td>
<td>int32_t v[3] = {1,3,5};</td>
</tr>
<tr>
<td>h:</td>
<td>.half 2,4,6</td>
<td>int16_t h[3] = {2,4,6};</td>
</tr>
<tr>
<td>b:</td>
<td>.byte 7:5</td>
<td>int8_t b[5] = {7,7,7,7,7};</td>
</tr>
<tr>
<td>f:</td>
<td>.float 3.14</td>
<td>float f = 3.14;</td>
</tr>
<tr>
<td>s:</td>
<td>.asciiz &quot;abc&quot;</td>
<td>char s[4] {'a','b','c','\0'};</td>
</tr>
<tr>
<td>t:</td>
<td>.ascii &quot;abc&quot;</td>
<td>char t[3] {'a','b','c'};</td>
</tr>
</tbody>
</table>
Code example: storing and loading a value

```assembly
# simple example of storing & loading a byte
main:
    li  $t0, 42
    la  $t1, x
    sb  $t0, 0($t1)  # store 42 in byte at address labelled x
    lb  $a0, 0($t1)  # load $a0 from same address
    li  $v0, 1       # print $a0
    syscall
    li  $a0, \n      # print \n
    syscall
    li  $v0, 0       # return 0
    jr  $ra

.data
x:   .space 1     # set aside 1 byte and associate label x with its address
```

Source code for load_store.s

[https://www.cse.unsw.edu.au/~cs1521/23T2/](https://www.cse.unsw.edu.au/~cs1521/23T2/)
Note the `la` (load address) instruction is used to set a register to a labelled memory address.

```
la $t8, start
```

The memory address will be fixed before the program is run, so this differs only syntactically from the `li` instruction.

For example, if `vec` is the label for memory address `0x10000100` then these two instructions are equivalent:

```
la $t7, vec
li $t7, 0x10000100
```

In both cases the constant is encoded as part of the instruction(s).

Neither `la` or `li` access memory!
They are very different to `lw` etc
Specifying Addresses: Some mipsy short-cuts

- **mipsy** allows the constant which is part of load & store instructions can be omitted in the common case it is 0.

  \[
  \textbf{sb} \quad \texttt{$t0, 0($t1)} \quad \# \text{ store $t0 in byte at address in $t1} \\
  \textbf{sb} \quad \texttt{$t0, ($t1)} \quad \# \text{ same}
  \]

- For convenience, MIPSY allows addresses to be specified in a few other ways and will generate appropriate real MIPS instructions

  \[
  \begin{align*}
  \textbf{sb} \quad \texttt{$t0, x} & \quad \# \text{ store $t0 in byte at address labelled x} \\
  \textbf{sb} \quad \texttt{$t1, x+15} & \quad \# \text{ store $t1 15 bytes past address labelled x} \\
  \textbf{sb} \quad \texttt{$t2, x($t3)} & \quad \# \text{ store $t2 $t3 bytes past address labelled x}
  \end{align*}
  \]

- These are effectively pseudo-instructions.

- You can use these short cuts but won’t help you much

- Most assemblers have similar short cuts for convenience

https://www.cse.unsw.edu.au/~cs1521/23T2/
## MIPS Memory Layout

<table>
<thead>
<tr>
<th>Region</th>
<th>Address</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>.text</td>
<td>0x004000000..</td>
<td>instructions only; read-only; cannot expand</td>
</tr>
<tr>
<td>.data</td>
<td>0x100000000..</td>
<td>data objects; read/write; can be expanded</td>
</tr>
<tr>
<td>.stack</td>
<td>..0x7fffffffef</td>
<td>this address and below; read/write</td>
</tr>
<tr>
<td>.ktext</td>
<td>0x800000000..</td>
<td>kernel code; read-only; only accessible in kernel mode</td>
</tr>
<tr>
<td>.kdata</td>
<td>0x900000000..</td>
<td>kernel data; only accessible in kernel mode</td>
</tr>
</tbody>
</table>
C data structures and their MIPS representations:

- **char** ... as byte in memory, or register
- **int** ... as 4 bytes in memory, or register
- **double** ... as 8 bytes in memory, or float register
- **arrays** ... sequence of bytes in memory, elements accessed by index (calculated on MIPS)
- **structs** ... sequence of bytes in memory, accessed by fields (constant offsets on MIPS)

A char, int or double

- can be stored in register if local variable and no pointer to it
- otherwise stored on stack if local variable
- stored in data segment if global variable
Global and static variables need an appropriate number of bytes allocated in .data segment, using `.space`:

- `double val; val: .space 8`
- `char str[20]; str: .space 20`
- `int vec[20]; vec: .space 80`

Initialised to 0 by default ... other directives allow initialisation to other values:

- `int val = 5; val: .word 5`
- `int arr[4] = {9, 8, 7, 6}; arr: .word 9, 8, 7, 6`
- `char msg[7] = "Hello\n"; msg: .asciiz "Hello\n"`
add: local variables in registers

C

```c
int main(void) {
    int x, y, z;
    x = 17;
    y = 25;
    z = x + y;
    // ...
}
```

MIPS

```mips
main:
    # x in $t0
    # y in $t1
    # z in $t2
    li $t0, 17
    li $t1, 25
    add $t2, $t1, $t0
    # ...
```
add variables in memory (uninitialized)

C

```c
int x, y, z;
int main(void) {
    x = 17;
    y = 25;
    z = x + y;
}
```

MIPS (.text)

```mips
main:
    li $t0, 17
    la $t1, x
    sw $t0, ($t1) # x = 17;
    li $t0, 25
    la $t1, y
    sw $t0, ($t1) # y = 25;
    la $t0, x # (x
    lw $t1, ($t0) #
       # +
    la $t0, y #
    lw $t2, ($t0) # y)
    add $t3, $t1, $t2
    la $t0, z
    sw $t3, 0($t0) # z = x + y;
```

MIPS (.data)

```
data
x:
    .space 4
y:
    .space 4
z:
    .space 4
```
add variables in memory (initialized)

C

```c
int x=17, y=25, z;
int main(void) {
    z = x + y;
}
```

MIPS .data

```assembly
.data
.x:  .word 17
.y:  .word 25
.z:  .space 4
```

MIPS .text

```assembly
main:
    la $t0, x    # (x
    lw $t1, ($t0) #
        # +
    la $t0, y    #
    lw $t2, ($t0) # y)
    add $t3, $t1, $t2
    la $t0, z
    sw $t3, 0($t0) # z = x + y;
```

source code for add_memory_initialized.s

https://www.cse.unsw.edu.au/~cs1521/23T2/
add variables in memory (array)

C

```c
int x[] = {17, 25, 0};
int main(void) {
    x[2] = x[0] + x[1];
}
```

MIPS .text

```mips
main:
    la $t0, x
    lw $t1, 0($t0)
    lw $t2, 4($t0)
    add $t3, $t1, $t2 # z = x + y;
    sw $t3, 8($t0)
```

source code for `add_memory_array.s`

MIPS .data

```mips
.data
x: .word 17, 25, 0 # int x[] = {17, 25, 0}
```
double array[10];
for (int i = 0; i < 10; i++) {
    printf("&array[%d]=%p\n", i, &array[i]);
}
printf("Example computation for address of array element\n");
uintptr_t a = (uintptr_t)&array[0];
printf("&array[0] + 7 * sizeof (double) = 0x%lx", a + 7 * sizeof(double));
printf("&array[0] + 7 * %lx = 0x%lx \n", sizeof(double), a + 7 * sizeof(double));
printf("0x%lx + 7 * %lx = 0x%lx\n", a, sizeof(double), a + 7 * sizeof(double));
printf("&array[7]=%p\n", &array[7]);

Source code for array_element_address.c

- this code uses types covered later in the course
Address of C 1-d Array Elements - Output

```
$ dcc array_element_address.c -o array_element_address
$ ./array_element_address
&array[0]=0x7fffdd841d00
&array[1]=0x7fffdd841d08
&array[2]=0x7fffdd841d10
&array[3]=0x7fffdd841d18
&array[4]=0x7fffdd841d20
&array[5]=0x7fffdd841d28
&array[6]=0x7fffdd841d30
&array[7]=0x7fffdd841d38
&array[8]=0x7fffdd841d40
&array[9]=0x7fffdd841d48
```

Example computation for address of array element

```
&array[0] + 7 * sizeof (double) = 0x7fffdd841d38
&array[0] + 7 * 8 = 0x7fffdd841d38
0x7fffdd841d00 + 7 * 8 = 0x7fffdd841d38
&array[7] = 0x7fffdd841d38
```
C

```
int x[10];

int main(void) {
    // sizeof x[0] == 4
    x[3] = 17;
}
```

MIPS

```
main:
    li $t0, 3
    # each array element is 4 bytes
    mul $t0, $t0, 4
    la $t1, x
    add $t2, $t1, $t0
    li $t3, 17
    sw $t3, 0($t2)
.data
x: .space 40
```
C

```c
#include <stdint.h>

int16_t x[30];

int main(void) {
    // sizeof x[0] == 2
    x[13] = 23;
}
```

MIPS

```
main:
    li $t0, 13

    # each array element is 2 bytes
    mul $t0, $t0, 2
    la $t1, x
    add $t2, $t1, $t0
    li $t3, 23
    sh $t3, 0($t2)

.data
x:   .space 60
```
C

```c
int main(void) {
    int i = 0;
    while (i < 5) {
        printf("%d\n", numbers[i]);
        i++;
    }
    return 0;
}
```

Simplified C

```c
int main(void) {
    int i = 0;
    loop:
        if (i >= 5) goto end;
        printf("%d", numbers[i]);
        printf("\c", '\n');
        i++;
        goto loop;
    end:
        return 0;
}
```
# print array of ints
# i in $t0

main:
    li $t0, 0     # int i = 0;

loop:
    bge $t0, 5, end     # if (i >= 5) goto end;
    la $t1, numbers    # int j = numbers[i];
    mul $t2, $t0, 4
    add $t3, $t2, $t1
    lw $a0, 0($t3)     # printf("%d", j);
    li $v0, 1
    syscall
    li $a0, '\n'      # printf("%c", '\n');
    li $v0, 11
    syscall
    addi $t0, $t0, 1   # i++
    b loop             # goto loop

end:

source code for print5.s

https://www.cse.unsw.edu.au/~cs1521/23T2/
end:
   li  $v0, 0 # return 0
   jr  $ra
.data
numbers: # int numbers[10] = { 3, 9, 27, 81, 243};
   .word 3, 9, 27, 81, 243

source code for print5.s
C

```c
int i = 0;
while (i < 10) {
    printf("Enter a number: ");
    scanf("%d", &numbers[i]);
    i++;
}
```

MIPS

```mips
li $t0, 0  # i = 0

loop0:
    bge $t0, 10, end0  # while (i < 10) {
    la $a0, string0  # printf("Enter a number: ");
    li $v0, 4
    syscall
    li $v0, 5  # scanf("%d", &numbers[i]);
    syscall
    mul $t1, $t0, 4  # calculate &numbers[i]
    la $t2, numbers  #
    add $t3, $t1, $t2  #
    sw $v0, ($t3)  # store entered number in array
    addi $t0, $t0, 1  # i++;
    b loop0  # }

end0:
```

source code for read10.c
source code for read10.s
i = 0;
while (i < 10) {
    printf("%d\n", numbers[i]);
    i++;
}

source code for read10.c

MIPS

li $t0, 0        # i = 0

loop1:
bge $t0, 10, end1  # while (i < 10)
mul $t1, $t0, 4   # calculate &numbers[i]
la $t2, numbers   #
add $t3, $t1, $t2 #
lw $a0, ($t3)     # load numbers[i]
li $v0, 1        # printf("%d", numbers[i])
syscall
li $a0, '\n'     # printf("%c", '
');
li $v0, 11
syscall
addi $t0, $t0, 1 # i++
b loop1           # }

end1:
li $v0, 0        # return 0
jr $ra

.data
numbers:        # int numbers[10];
    .word 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
string0:        # Enter a number: 
    .asciiz "Enter a number: 

source code for read10.s

https://www.cse.unsw.edu.au/~cs1521/23T2/
int array[X][Y];
printf("sizeof array[2][3] = %lu\n", sizeof array[2][3]);
printf("sizeof array[1] = %lu\n", sizeof array[1]);
printf("sizeof array = %lu\n", sizeof array);
printf("&array=%p\n", &array);
for (int x = 0; x < X; x++) {
    printf("&array[%d]=%p\n", x, &array[x]);
    for (int y = 0; y < Y; y++) {
        printf("&array[%d][%d]=%p\n", x, y, &array[x][y]);
    }
}

source code for 2d_array_element_address.c

- this code uses types covered later in the course
$ dcc 2d_array_element_address.c -o 2d_array_element_address
$ ./2d_array_element_address

sizeof array[2][3] = 4
sizeof array[1] = 16
sizeof array = 48

&array=0x7ffd93bb16c0
&array[0]=0x7ffd93bb16c0
&array[0][0]=0x7ffd93bb16c0
&array[0][1]=0x7ffd93bb16c4
&array[0][2]=0x7ffd93bb16c8
&array[0][3]=0x7ffd93bb16cc
&array[1]=0x7ffd93bb16d0
&array[1][0]=0x7ffd93bb16d0
&array[1][1]=0x7ffd93bb16d4
&array[1][2]=0x7ffd93bb16d8
&array[1][3]=0x7ffd93bb16dc
&array[2]=0x7ffd93bb16e0
&array[2][0]=0x7ffd93bb16e0
&array[2][1]=0x7ffd93bb16e4
&array[2][2]=0x7ffd93bb16e8
&array[2][3]=0x7ffd93bb16ec
Assume we have a 2d-array:

```c
int32_t matrix[6][5];
```

We can sum its value like this in C

```c
int row, col, sum = 0;
// row-by-row
for (row = 0; row < 6; row++) {
    // col-by-col within row
    for (col = 0; col < 5; row++) {
        sum += matrix[row][col];
    }
}
```

MIPS directives for an equivalent 2d-array

```
data
matrix: .space 120 # 6 * 5 == 30 array elements each 4 bytes
```
Computing sum of 2-d Array: MIPS

```
li $t0, 0  # sum = 0
li $t1, 0  # row = 0

loop1: bge $t1, 6, end1  # if (row >= 6) break
li $t2, 0  # col = 0

loop2: bge $t2, 5, end2  # if (col >= 5) break
la $t3, matrix
mul $t4, $t1, 20  # t1 = row*rowsize
mul $t5, $t2, 4   # t2 = col*intsize
add $t6, $t3, $t4 # offset = t0+t1
add $t7, $t6, $t5 # offset = t0+t1
lw $t5, 0($t7)   # t0 = *(matrix+offset)
add $t0, $t0, $t5 # sum += t0
addi $t2, $t0, 1 # col++
    j loop2

end2:  addi $t1, $t1, 1  # row++
    j loop1

end1:
```
int main(void) {
    int i = 0;
    while (i < 3) {
        int j = 0;
        while (j < 5) {
            printf("%d", numbers[i][j]);
            printf("%c", ' ');
            j++;
        }
        printf("%c", '\n');
        i++;
    }
    return 0;
}

source code for print2d.c
Printing 2-d Array: MIPS

# print a 2d array
# i in $t0
# j in $t1
# $t2..$t6 used for calculations

main:
    li $t0, 0  # int i = 0;

loop1:
    bge $t0, 3, end1  # if (i >= 3) goto end1;
    li $t1, 0  # int j = 0;

loop2:
    bge $t1, 5, end2  # if (j >= 5) goto end2;
    la $t2, numbers  # printf("%d", numbers[i][j]);
    mul $t3, $t0, 20
    add $t4, $t3, $t2
    mul $t5, $t1, 4
    add $t6, $t5, $t4
    lw $a0, 0($t6)
    li $v0, 1
    syscall

source code for print2d.s
https://www.cse.unsw.edu.au/~cs1521/23T2/
Printing 2-d Array: MIPS (continued)

```assembly
li $a0, ' '  # printf("%c", ' ');
li $v0, 11  syscall
addi $t1, $t1, 1 # j++;
b loop2 # goto loop2;
end2:
li $a0, '\n'  # printf("%c", '\n');
li $v0, 11  syscall
addi $t0, $t0, 1 # i++
b loop1 # goto loop1
end1:
li $v0, 0 # return 0
jr $ra
\ndata
# int numbers[3][5] = {{3,9,27,81,243},{4,16,64,256,1024},{5,25,125,625,3125}};
numbers:
    .word 3, 9, 27, 81, 243, 4, 16, 64, 256, 1024, 5, 25, 125, 625, 3125
```

source code for print2d.s

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C standard requires simple types of size $N$ bytes to be stored only at addresses which are divisible by $N$

- if `int` is 4 bytes, must be stored at address divisible by 4
- if `double` is 8 bytes, must be stored at address divisible by 8

compound types (arrays, structs) must be aligned so their components are aligned

MIPS requires this alignment

on other architectures aligned access faster
Example C with unaligned accesses

```c
char bytes[32];
int *i = (int *)&bytes[1];
// illegal store – not aligned on a 4-byte boundary
*i = 42;
printf("%d\n", *i);
```

source code for unalign.c
Example MIPS with unaligned accesses

```
.data
# data will be aligned on a 4-byte boundary
# most likely on at least a 128-byte boundary
# but safer to just add a .align directive
.align 2
.space 1
v1: .space 1
v2: .space 4
v3: .space 2
v4: .space 4
    .space 1
    .align 2 # ensure e is on a 4 (2**2) byte boundary
v5: .space 4
    .space 1
v6: .word 0 # word directive aligns on 4 byte boundary
```

source code for unalign.s

https://www.cse.unsw.edu.au/~cs1521/23T2/
Example MIPS with unaligned accesses

```mips
li $t0, 1  # will succeed because no alignment needed
sb $t0, v1  # will fail because v1 is not 2-byte aligned
sh $t0, v1  # will fail because v1 is not 4-byte aligned
sw $t0, v1  # will succeed because v2 is 2-byte aligned
sh $t0, v2  # will succeed because v2 is 2-byte aligned
sw $t0, v2  # will fail because v2 is not 4-byte aligned
sh $t0, v3  # will succeed because v3 is 2-byte aligned
sw $t0, v3  # will fail because v3 is not 4-byte aligned
sh $t0, v4  # will succeed because v4 is 2-byte aligned
sw $t0, v4  # will succeed because v4 is 4-byte aligned
sw $t0, v5  # will succeed because v5 is 4-byte aligned
sw $t0, v6  # will succeed because v6 is 4-byte aligned
li $v0, 0
jr $ra  # return
```

source code for unalign.s

https://www.cse.unsw.edu.au/~cs1521/23T2/
struct _student {
    int    id;
    char   family[20];
    char   given[20];
    int    program;
    double wam;
};
C `struct` definitions effectively define a new type.

```c
// new type called "struct student"
struct student {...};
```

```c
// new type called student_t
typedef struct student student_t;
```

Instances of structures can be created by allocating space:

```plaintext
# sizeof(Student) == 56
stu1:   # student_t stu1;
    .space 56
stu2:   # student_t stu2;
    .space 56
stu:    # student_t *stu;
    .space 4
```
Implementing Structs in MIPS

Accessing structure components is by offset, not name

```
li $t0, 5012345
la $t1, stu1
sw $t0, 0($t1)    # stu1.id = 5012345;
li $t0, 3778
sw $t0, 44($t1)   # stu1.program = 3778;

la $t2, stu2       # stu = &stu2;
li $t0, 3707
sw $t0, 44($t2)    # stu->program = 3707;
li $t0, 5034567
sw $t0, 0($t2)     # stu->id = 5034567;
```
Implementing Pointers in MIPS

```c
int i;
int *p;
p = &answer;
i = *p;
// prints 42
printf("%d\n", i);
*p = 27;
// prints 27
printf("%d\n", answer);
```

```mips
la $t0, answer  # p = &answer;
lw $t1, ($t0)   # i = *p;
move $a0, $t1   # printf("%d\n", i);
li $v0, 1
syscall
li $a0, '\n'  # printf("%c", '\n');
li $v0, 11
syscall
li $t2, 27    # *p = 27;
sw $t2, ($t0)  #
lw $a0, answer # printf("%d\n", answer);
li $v0, 1
syscall
li $a0, '\n'  # printf("%c", '\n');
li $v0, 11
syscall
li $v0, 0     # return 0 from function main
```

source code for pointer.c
source code for pointer.s
C

```c
int main(void) {
    int *p = &numbers[0];
    int *q = &numbers[4];
    while (p <= q) {
        printf("%d\n", *p);
        p++;
    }
    return 0;
}
```

Simplified C

```c
int main(void) {
    int *p = &numbers[0];
    int *q = &numbers[4];
loop:
    if (p > q) goto end;
    int j = *p;
    printf("%d", j);
    printf("%c", '\n');
    p++;
    goto loop;
end:
    return 0;
}
```

---

source code for pointer5.c

source code for pointer5.simple.c
# p in $t0, q in $t1
main:
  la $t0, numbers  # int *p = &numbers[0];
  la $t0, numbers  # int *q = &numbers[4];
  addi $t1, $t0, 16  

loop:
  bgt $t0, $t1, end  # if (p > q) goto end;
  lw $a0, 0($t0)  # int j = *p;
  li $v0, 1
  syscall
  li $a0, '\n'  # printf("%c", '\n');
  li $v0, 11
  syscall
  addi $t0, $t0, 4  # p++
  b loop  # goto loop

end:

source code for pointer5.s

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# this is closer to the code a compiler might produce
# p in $t0
# q in $t1
main:
  la $t0, numbers   # int *p = &numbers[0];
  addi $t1, $t0, 16 # int *q = &numbers[4];

loop:
  lw $a0, ($t0)    # printf("%d", *p);
  li $v0, 1
  syscall
  li $a0, \n'        # printf("%c", \n');
  li $v0, 11
  syscall
  addi $t0, $t0, 4  # p++
  ble $t0, $t1, loop # if (p <= q) goto loop;

source code for pointer5.faster.s

https://www.cse.unsw.edu.au/~cs1521/23T2/
Testing Endian-ness

C

```c
uint8_t b;
uint32_t u;

u = 0x03040506;
// load first byte of u
b = *(uint8_t *)&u;
// prints 6 if little-endian
// and 3 if big-endian
printf("%d\n", b);
```

MIPS

```
li $t0, 0x03040506
la $t1, u
sw $t0, 0($t1) # u = 0x03040506;
lb $a0, 0($t1) # b = *(uint8_t *)&u;
lia $v0, 1      # printf("%d", a0);
syscall
li $a0, \n'     # printf("%c", \n');
lia $v0, 11
syscall
li $v0, 0      # return 0
jr $ra
```

source code for endian.c

source code for endian.s

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