Machine Architecture - Lecture 6

```
# Get n from user and save
            li          $v0, 5    # read integer
            syscall
            move        $t0, $v0  # syscall result

# Initialize registers
            li          $t1, 0 # initialize counter i
            li          $t2, 0 # initialize sum

            # Main loop body
loop:       addi        $t1, $t1, 1      # i = i + 1
            add         $t2, $t2, $t1    # sum = sum + i
            beq         $t0, $t1, exit   # break from loop
            j           loop

exit:       # Print sum
            li          $v0, 1     # print_string
            move        $a0, $t2
            syscall

            # Exit
            li          $v0, 10    # exit
            syscall
```

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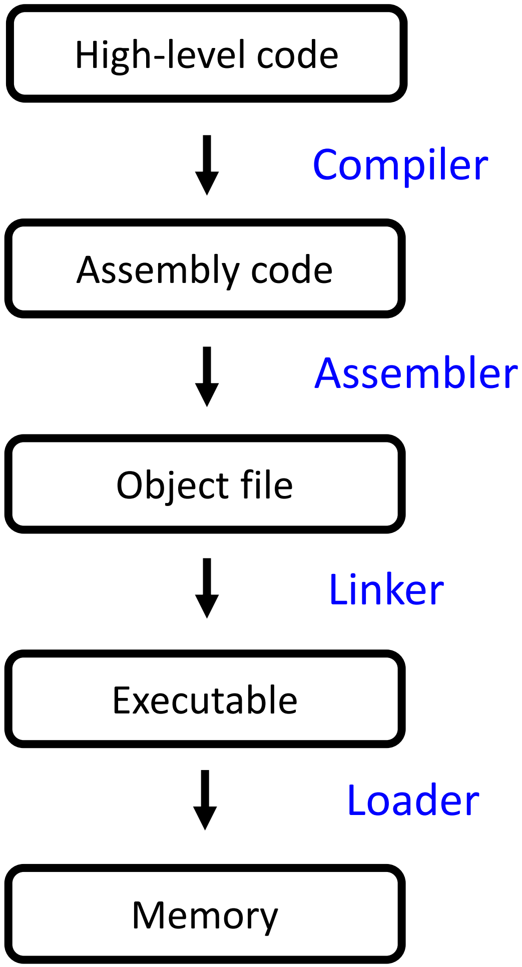
MIPS – programming

Slide material acknowledgements: Magnus Bordewich

Compiling, assembling, and loading

Translate a program from a high-level language
into machine language and start executing it

Translating and starting a program



The compiler translates the high-level code into assembly language.

The assembler turns the assembly code into machine language code (object file).

The linker combines the object file with other machine language code (e.g. from already compiled and assembled libraries).

The loader puts the executable into the memory.

Assembler

```
main:  addi  $sp, $sp, -4
       sw    $ra, 0($sp)
       addi  $a0, $0, 2
       sw    $a0, f
       addi  $a0, $0, 3
       sw    $sw, $a1, g
       jal   sum
       sw    $v0, y
       lw    $ra, 0($sp)
       addi  $sp, $sp, 4
       jr    $ra
sum:   add   $v0, $a0, $a1
       jr    $ra
```

The assembler makes two passes through the assembly code and turns it into the object file.

On the first pass, the assembler assigns instruction addresses and finds all symbols, such as labels and global variable names, and makes a symbol table.

In this example, symbols are shown in bold red.

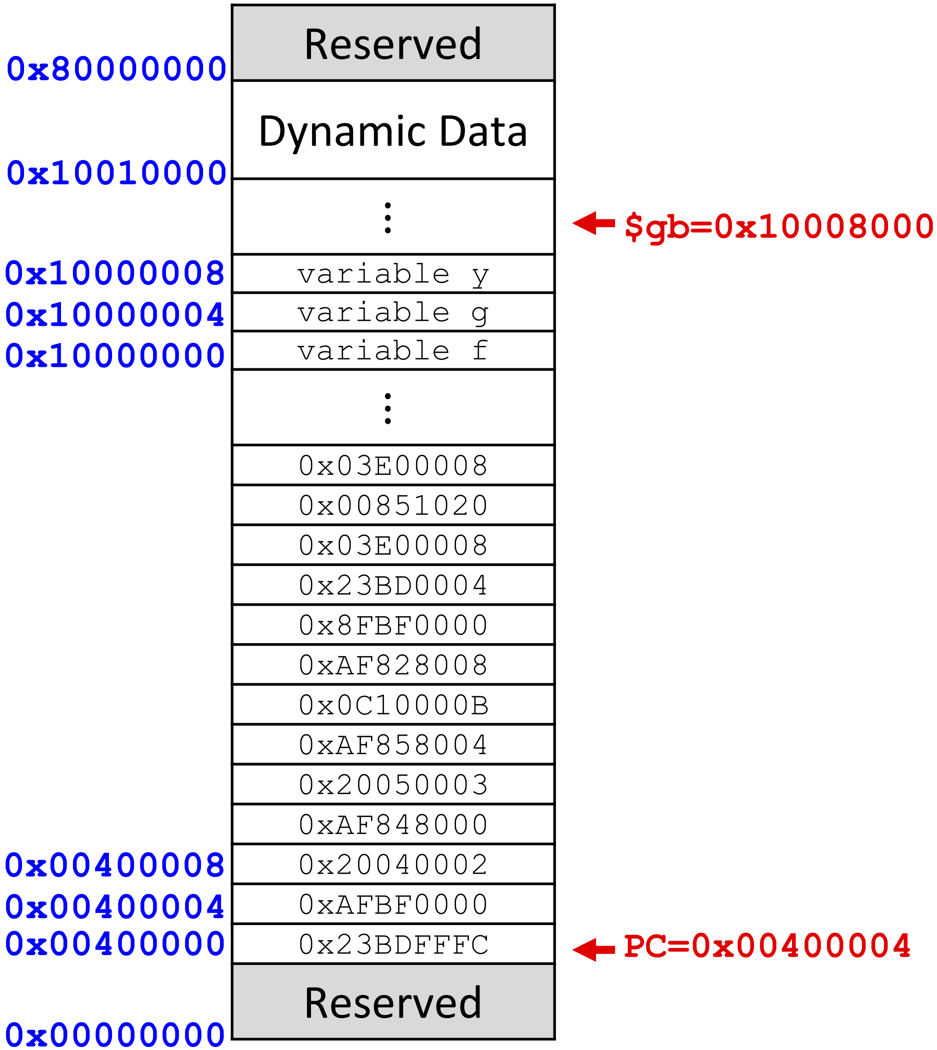
Assembler

```
0x00400000 main: addi   $sp, $sp, -4
0x00400004       sw     $ra, 0($sp)
0x00400008       addi   $a0, $0, 2
0x0040000C       sw     $a0, f
0x00400010       addi   $a0, $0, 3
0x00400014       sw     $sw, $a1, g
0x00400018       jal    sum
0x0040001C       sw     $v0, y
0x00400020       lw     $ra, 0($sp)
0x00400024       addi   $sp, $sp, 4
0x00400028        jr     $ra
0x0040002C sum:  add    $v0, $a0, $a1
0x00400030        jr     $ra
```

symbol	address
f	0x10000000
g	0x10000004
y	0x10000008
main	0x00400000
sum	0x0040002C

After the first pass of the assembler, instruction addresses have been assigned and the symbol table has been created.

Assembler, linker and loader



The second pass of the assembler generates the object file.

The linker creates the executable by combining the object file with other machine language code, e.g. code corresponding to libraries.

The loader puts the executable into the memory and its execution can start.

MIPS programming

To be read in conjunction with the material in the practical of Week 9

Functions

Functions are pieces of code which can be accessed from other parts of the program.

Using functions makes code more modular and readable.

MIPS assembly functions have inputs, called arguments, and an output called return value.

Need an agreement on how to:

call and return from a function

access the input arguments and the return value

Call and return

```
                # The caller function "main"
0x00400200      main:   jal      simple
0x00400204              ...

                # The callee function "simple"
0x00401020      simple: jr       $ra
```

The function **`main`** calls the function **`simple`** using the **`jal`** instruction.

`jal simple` (**`j`**ump **`a`**nd **`l`**ink) jumps to the address **`0x00401020`** (as **`j`** would do) but also stores in register **`$ra`** the address where the program should return after **`simple`** has been executed (here **`0x00400204`**).

`jr $ra` (**`j`**ump **`r`**egister) jumps to the address stored in a register (here **`$ra`**). Notice, that **`jr`** is an R-type not a J-type instruction.

Arguments and return value

```
main:     li   $a0, 10              # argument 0 gets the value 10
          li   $a1, 5               # argument 1 gets the value 5
          li   $a2, 20              # argument 2 has value 20
          li   $a3, 10              # argument 3 has value 10
          jal  diffofsums           # call the function
          move $s0, $v0             # put return value to $s0
          ...
diffofsums:
          add  $t0, $a0, $a1        # sum of the first two arguments
          add  $t1, $a2, $a3        # sum of the other two arguments
          sub  $t2, $t0, $t1        # difference of the two sums
          move $v0, $t2             # put return value at $v0
          jr   $ra                  # return to caller
```

`move $s0, $v0` is another pseudo-instruction like `li`. It copies the value of a register into another register. It is implemented as:

`add $s0, $v0, $0`

Arguments and return value

According to MIPS conventions on the behaviour of caller and callee:

the caller places the arguments into the registers **`$a0`** - **`$a3`**

the return value is placed into the registers **`$v0`** - **`$v1`**

the saved registers **`$s0`** - **`$s7`** are not modified by the callee

This convention can be quite restrictive, especially if the callee is going to call another function (or even call itself recursively).

Instead of directly conforming to this convention, the callee can first save all important registers in a stack (a data structure covered in the ADS module) and restore them before returning to the caller.

Loops

Exercise: Compute the n-th triangular number.

The program should take the input n and output T(n) where:

$$T(n) = 1 + 2 + ... + n$$

Loops

The code fragment shows register initialisation and the main loop.

```
        # Initialize registers
        li      $t0, 10           # load the value of N
        li      $t1, 0            # initialize the counter (i)
        li      $t2, 0            # initialize sum

        # Main loop body
loop:   addi    $t1, $t1, 1       # i = i + 1 (increment the counter)
        add     $t2, $t2, $t1     # sum = sum + i
        beq     $t0, $t1, exit    # if i = N, break from the loop
        j       loop

exit:   ...
        ...
```

Loops

The main loop is implemented through an unconditional jump instruction `j` and a branch on equal instruction `beq`, which branches out of the loop when the values in the registers `$t0` and `$t1` become equal.

```
        # Main loop body
loop:   addi    $t1, $t1, 1      # i = i + 1 (increment the counter)
        add     $t2, $t2, $t1    # sum = sum + i
        beq     $t0, $t1, exit   # if i = N, break from the loop
        j       loop

exit:   ...
        ...
```

Input / Output

Can we get the value of n from the user, through the keyboard, instead of hard encoding it?

```
# Get n from user and save
li        $v0, 5    # load the syscall code 5 to $v0
syscall             # read integer (syscall code is 5)
move      $t0, $v0  # syscall result (returned in $v0) moves to $t0
```

The syscall instruction (system call) suspends the execution of the program to provide an operating-system-like service, such as input, output, termination.

Input

```
# Get n from user and save
li        $v0, 5    # read integer (syscall code is 5)
syscall             # read integer (syscall code is 5)
move      $t0, $v0  # syscall result (returned in $v0) move to $t0
```

The type of the syscall service is specified by a code, which should be stored in **`$v0`**.

The code 5 used here corresponds to reading an integer from keyboard.

Examples of syscall services

service	syscall code	arguments	result
print integer	1	$a0 = integer	-
print string	4	$a0 = string	-
read integer	5	-	integer (in $v0)
exit	10	-	-

Output and exit

After exiting the main loop, we print the output and stop the execution.

```
exit:   # Print sum
        li      $v0, 1          # print_string syscall code = 1
        move    $a0, $t2
        syscall

        # Exit
        li      $v0, 10         # exit
        syscall
```

It is important, always, to declare the end of the program.

Otherwise, the computer will fetch the word stored immediately after the last instruction and try to execute it with unpredictable behaviour.

Putting it all together … so far

```
# Get n from user and save
        li      $v0, 5    # read integer (syscall code is 5)
        syscall
        move    $t0, $v0  # syscall result (returned in $v0) move to $t0

# Initialize registers
        li      $t1, 0              # initialize the counter (i)
        li      $t2, 0              # initialize sum

        # Main loop body
loop:   addi    $t1, $t1, 1         # i = i + 1 (increment the counter)
        add     $t2, $t2, $t1       # sum = sum + i
        beq     $t0, $t1, exit      # if i = N, break from the loop
        j       loop

exit:   # Print sum
        li      $v0, 1            # print_string syscall code = 1
        move    $a0, $t2
        syscall

        # Exit
        li      $v0, 10           # exit
        syscall
```

Text output

To make the program more user friendly, we want to add some text output describing the format of the requested input and also what the output is.

See the program triangularNumber.asm uploaded on DUO (you will be able to run it on the MARS MIPS simulator after the practical of Week 9).