MIPS ASSEMBLY

LECTURE 08-1

JIM FIX, REED COLLEGE CS2-S20

TODAY'S PLAN

- ON-LINE COURSE LOGISTICS
- REVIEW OF MIPS ASSEMBLY, BUT DONE VIA...
- ... MY SOLUTIONS TO HOMEWORK 07
- MIPS MEMORY OPERATIONS (WITH EXERCISES)

LOGISTICS

- Lectures via Zoom. *Probably won't be interactive today, but we'll improve...*
  - 3-4pm MWF pacific standard time
  - Will send an email link for each lecture, with a password.
  - Will try to record, but don't yet know how to store/share the video.
- Will post slides and lecture materials over syllabus page on GitHub.
  - Including lecture notes, sample code.
- End of lecture exercises (optional) will be given instead of lab exercises.
- Week-long **homework assignments** will be given ***each Wednesday***.
- Still working out office hours, tutoring, and lab instruction replacement.

TODAY'S TEACHING ASSISTANT

- Introducing Rocco:

- He may chime in now and then with some ideas about lecture...

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SOLUTION TO HOMEWORK 07 EXERCISE 1

- Below is the "kernel" of my MIPS code to multiply using repeated addition:

```
1.  multiply:
2.      li      $t0, 0          # product = 0
3.  multiply_loop:
4.      beqz    $t2, report     # if y == 0 goto report
5.      addu    $t0, $t0, $t1   # product += x
6.      addiu   $t2, $t2, -1    # y -= 1
7.      b       multiply_loop
8.  report:
```

- It uses registers t0 to compute the product, repeatedly adding t1 to it.
- It starts with a product of 0, performs the addition at line 5 t2 times.

C++ SOLUTION TO HOMEWORK 07 EXERCISE 1

- Here is C++ code that mimics that MIPS code. The "kernel" loop is in **green**.

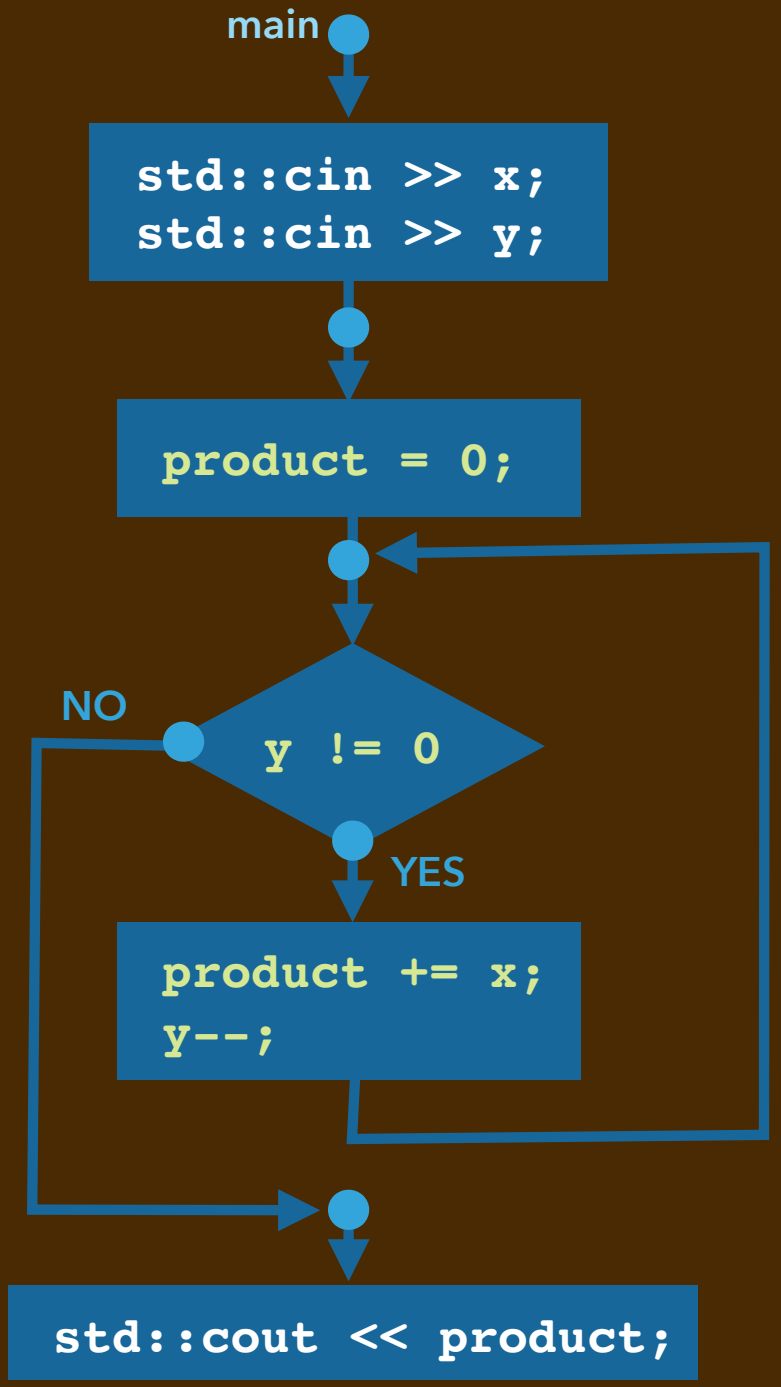
```
1.  int main() { int x,y, product;
2.    std::cin >> x;
3.    std::cin >> y;
4.    product = 0;
5.    while (y != 0) {
6.      product += x;
7.      y--;
8.    }
9.    std::cout << product;
10.   return 0;
11. }
```

- Let's convert it to MIPS code, maybe how a compiler might...

FLOWCHART OF SOLUTION

```
1.  int main() { int x,y, product;
2.    std::cin >> x;
3.    std::cin >> y;
4.    product = 0;
5.    while (y != 0) {
6.      product += x;
7.      y--;
8.    }
9.    std::cout << product;
10.   return 0;
11. }
```

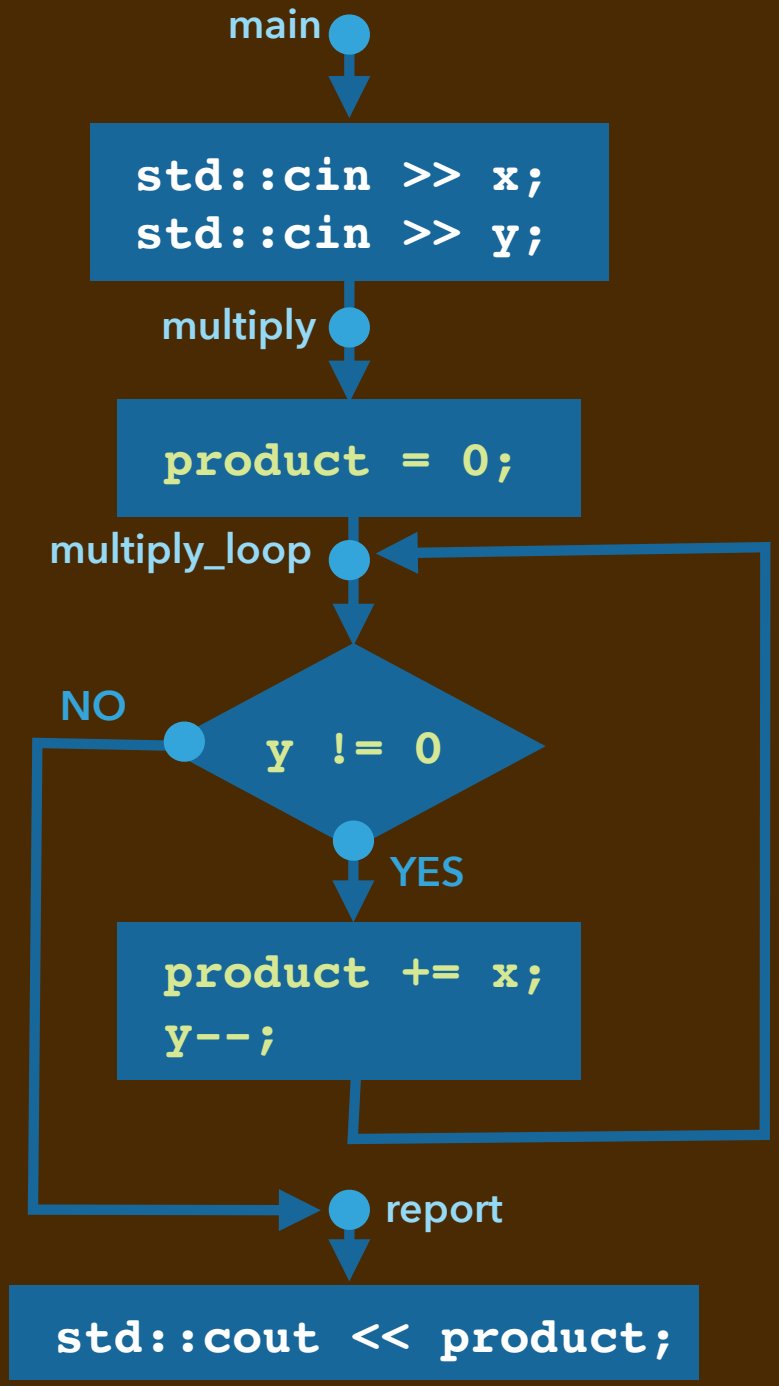
- Here is the "flow logic" of that code:
- Let's convert it to MIPS...



CONVERSION TO MIPS

```
1.  main:
2.    std::cin >> x;
3.    std::cin >> y;
4.  multiply:
5.    product = 0;
6.  multiply_loop:
7.    while (y != 0) {
8.      product += x;
9.      y--;
10.   }
11. report:
12.   std::cout << product;
13. end_main:
14.   return 0;
```

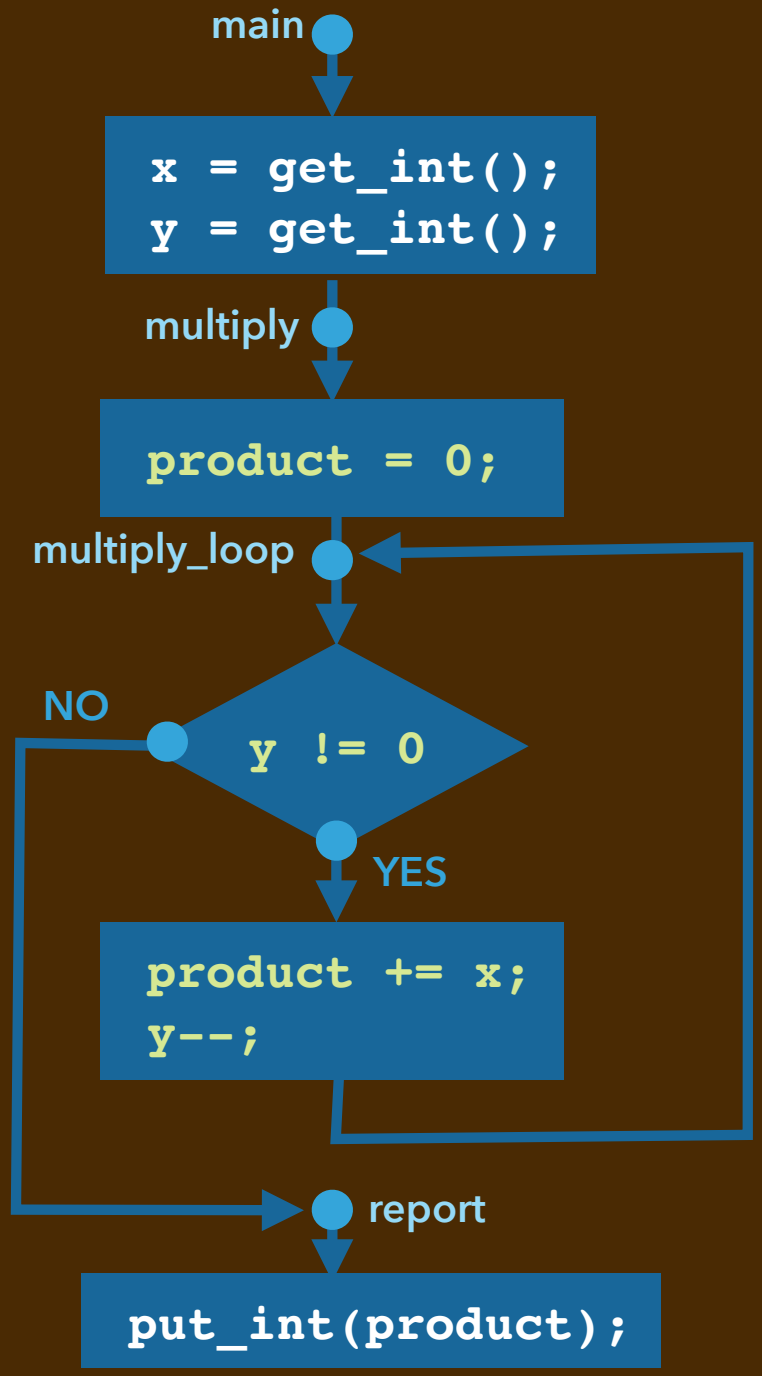
- Let's label the flow's targets.



CONVERSION TO MIPS

```
1.  main:
2.    x = get_int();
3.    y = get_int();
4.  multiply:
5.    product = 0;
6.  multiply_loop:
7.    while (y != 0) {
8.      product += x;
9.      y--;
10.   }
11. report:
12.   put_int(product);
13. end_main:
14.   return 0;
```

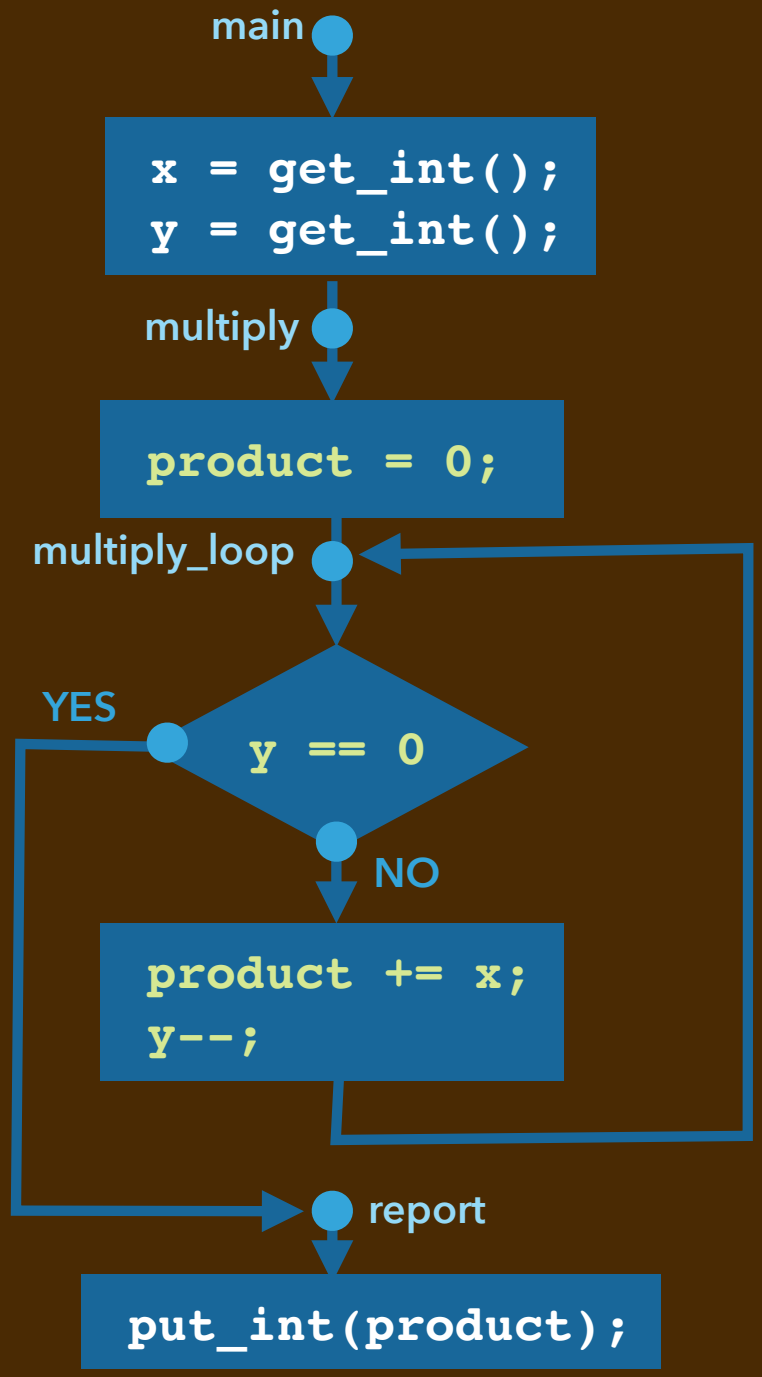
- Substitute system calls.



CONVERSION TO MIPS

```
1.  main:
2.     x = get_int();
3.     y = get_int();
4.  multiply:
5.     product = 0;
6.  multiply_loop:
7.     if (y == 0) goto report;
8.     product += x;
9.     y--;
10.    goto multiply_loop;
11. report:
12.    put_int(product);
13. end_main:
14.    return 0;
```

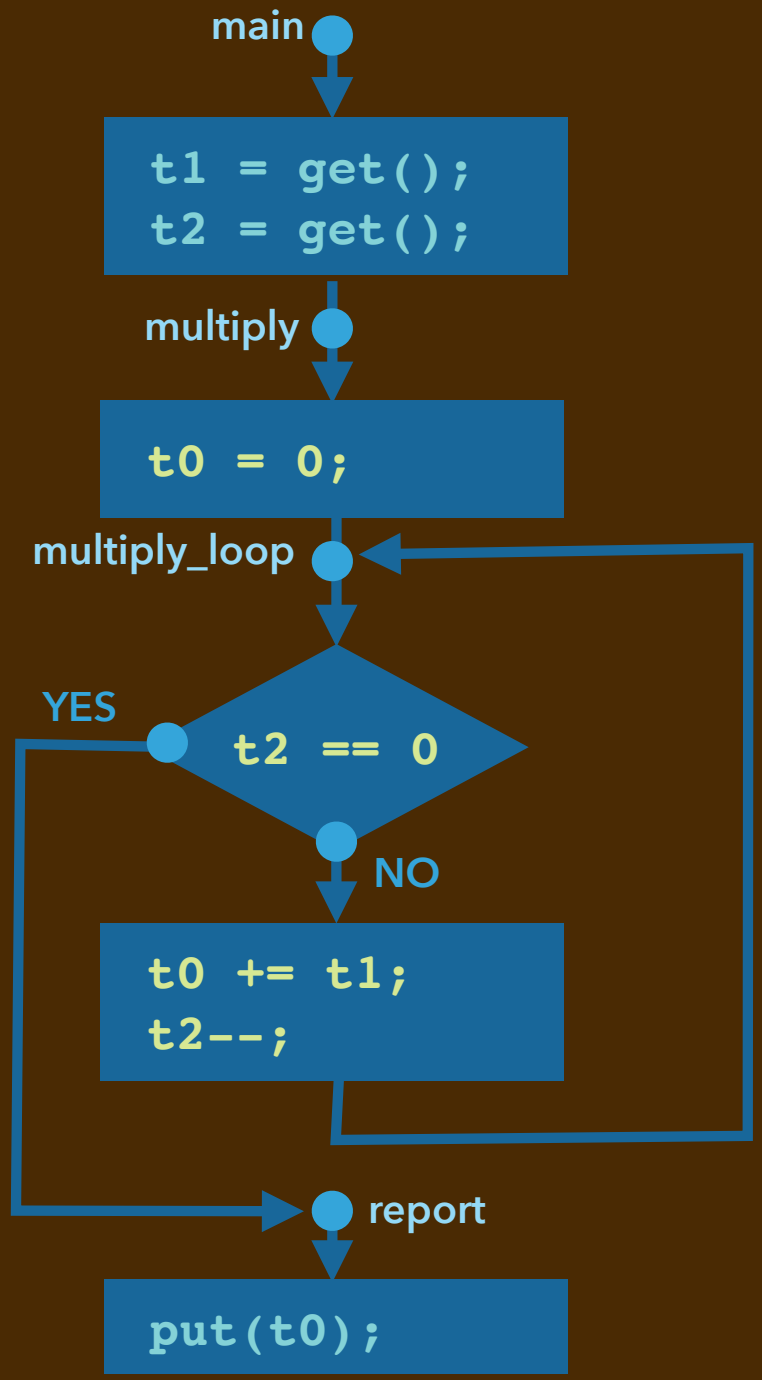
- Replace "structured" conditional statements with GOTOs.



CONVERSION TO MIPS

```
1.  main:
2.    t1 = get_int();
3.    t2 = get_int();
4.  multiply:
5.    t0 = 0;
6.  multiply_loop:
7.    if (t2 == 0) goto report;
8.    t0 += x;
9.    t1--;
10.   goto multiply_loop;
11. report:
12.   put_int(t0);
13. end_main:
14.   return 0;
```

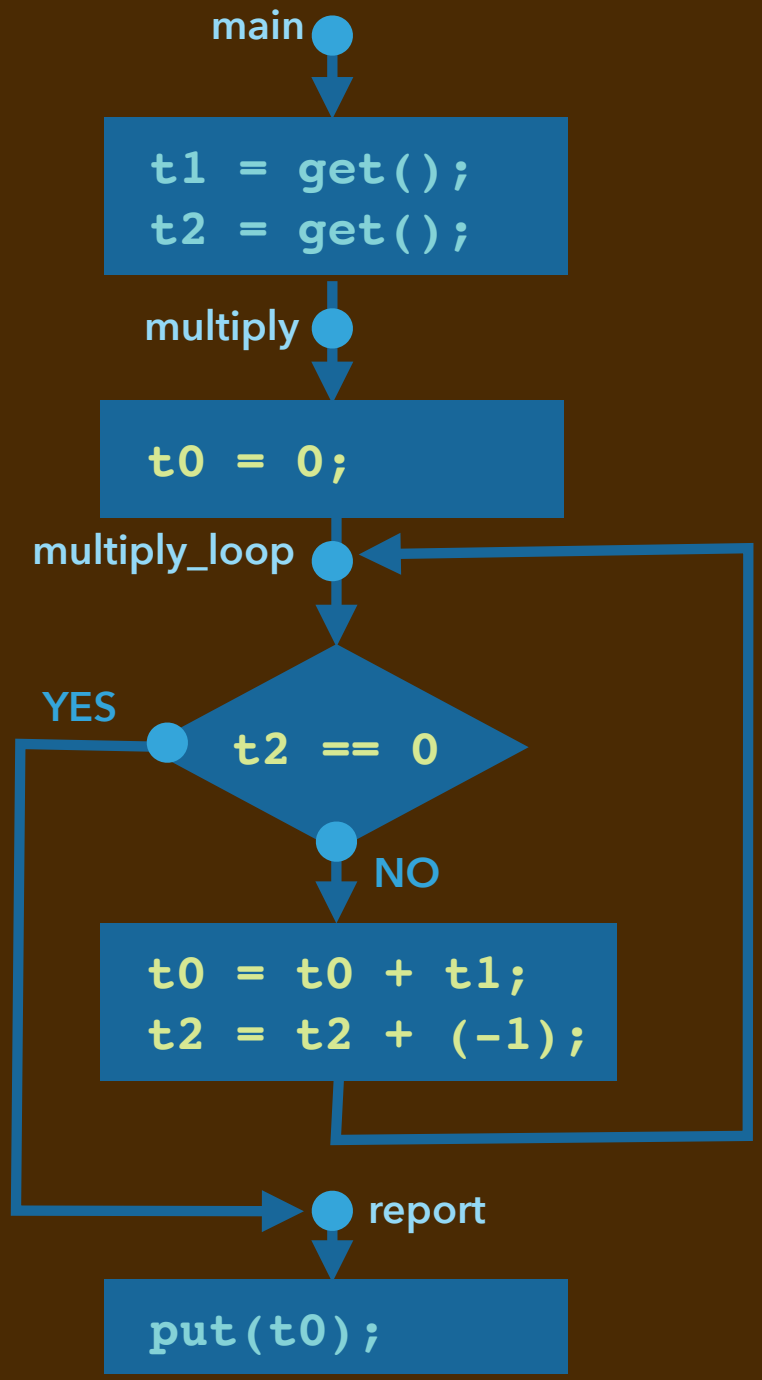
- Choose registers.



CONVERSION TO MIPS

```
1.  main:
2.     t1 = get_int();
3.     t2 = get_int();
4.  multiply:
5.     t0 = 0;
6.  multiply_loop:
7.     if (t2 == 0) goto report;
8.     t0 = t0 + t1;
9.     t1 = t1 + (-1);
10.    goto multiply_loop;
11. report:
12.    put_int(t0);
13. end_main:
14.    return 0;
```

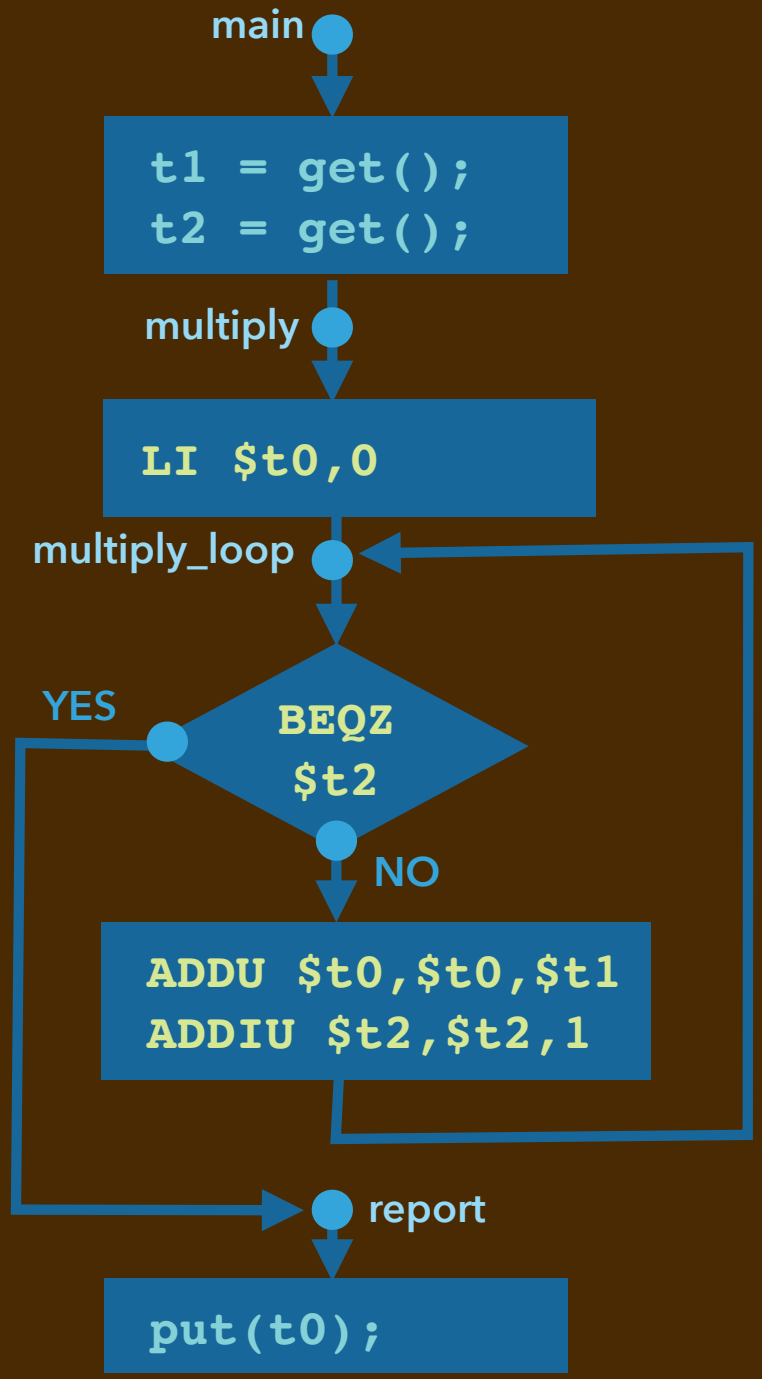
- Convert assignments to machine-like statements.



CONVERSION TO MIPS

```
1.  main:
2.     t1 = get_int();
3.     t2 = get_int();
4.  multiply:
5.     LI $t0,0
6.  multiply_loop:
7.     BEQZ $t2,report
8.     ADDU $t0,$t0,$t1
9.     ADDIU $t2,$t2,-1
10.    B multiply_loop
11. report:
12.    put_int(t0);
13. end_main:
14.    return 0;
```

- Change C statements to MIPS instructions.



LET'S REVIEW SOME OF THESE INSTRUCTIONS...

```
1. multiply:
2.    LI $t0,0
3. multiply_loop:
4.    BEQZ $t2,report
5.    ADDU $t0,$t0,$t1
6.    ADDIU $t2,$t2,1
7.    B multiply_loop
8. report:
```

LET'S REVIEW SOME OF THESE INSTRUCTIONS...

```
1.  multiply:
2.    LI $t0,0
3.  multiply_loop:
4.    BEQZ $t2,report
5.    ADDU $t0,$t0,$t1
6.    ADDIU $t2,$t2,-1
7.    B multiply_loop
8.  report:
```

LOAD IMMEDIATE

- Format:

  LI *destination register*, *value*

- Meaning: load a register with a specific value.
- NOTES:
  - destination can be any MIPS register
  - value must be a 32-bit constant, including negative values using 2's complement encoding
  - "immediate" because bits of value are in the instruction's code

LET'S REVIEW SOME OF THESE INSTRUCTIONS...

```
1. multiply:
2.    LI $t0,0
3. multiply_loop:
4.    BEQZ $t2,report
5.    ADDU $t0,$t0,$t1
6.    ADDIU $t2,$t2,-1
7.    B multiply_loop
8. report:
```

ADD (UNTRAPPED)

- Format:

  ADDU *destination*, *source1*, *source2*

- Meaning: add the contents of two registers, store sum the sum in a register
- NOTES:
  - destination can be any MIPS register
  - sources can be any registers
  - "untrapped" means errors (e.g. overflow) can be ignored by the machine
  - there's SUBU and bitwise AND, OR, XOR also

LET'S REVIEW SOME OF THESE INSTRUCTIONS...

```
1.  multiply:
2.    LI $t0,0
3.  multiply_loop:
4.    BEQZ $t2,report
5.    ADDU $t0,$t0,$t1
6.    ADDIU $t2,$t2,-1
7.    B multiply_loop
8.  report:
```

ADD IMMEDIATE (UNTRAPPED)

- Format:

  ADDIU *destination*, *source*, *value*

- Meaning: compute the some of a register's contents to a value, store the sum in a register
- NOTES:
  - source and destination can be any MIPS registers
  - value is a 16-bit constant, including negative values. Assumes 2's complement encoding.
  - (there's no SUBIU instruction)

LET'S REVIEW SOME OF THESE INSTRUCTIONS...

```
1. multiply:
2.    LI $t0,0
3. multiply_loop:
4.    BEQZ $t2,report
5.    ADDU $t0,$t0,$t1
6.    ADDIU $t2,$t2,-1
7.    B multiply_loop
8. report:
```

BRANCH IF EQUAL TO ZERO

- Format:

  BEQZ *register*, *target-label*

- Meaning: go to the labeled instruction if a register's value is zero. Continue below if not.

LET'S REVIEW SOME OF THESE INSTRUCTIONS...

```
1.  multiply:
2.    LI $t0,0
3.  multiply_loop:
4.    BEQZ $t2,report
5.    ADDU $t0,$t0,$t1
6.    ADDIU $t2,$t2,-1
7.    B multiply_loop
8.  report:
```

BRANCH IF EQUAL TO ZERO

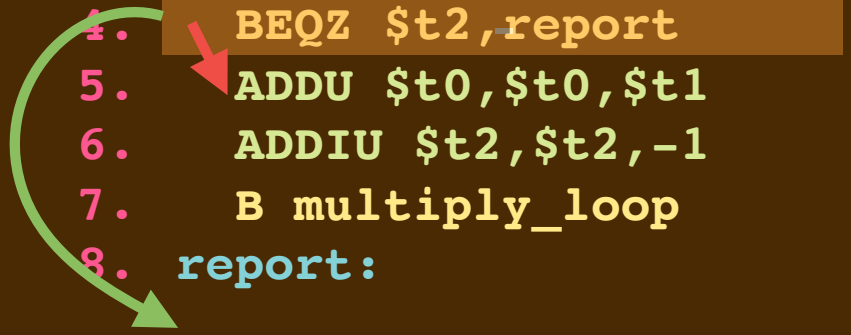
- Format:

  BEQZ *register*, *target-label*

- Meaning: go to the labeled instruction **if a register's value is zero**. Continue below if not.

LET'S REVIEW SOME OF THESE INSTRUCTIONS...

```
1.  multiply:
2.    LI $t0,0
3.  multiply_loop:
4.    BEQZ $t2,report
5.    ADDU $t0,$t0,$t1
6.    ADDIU $t2,$t2,-1
7.    B multiply_loop
8.  report:
```



BRANCH IF EQUAL TO ZERO

- Format:

  BEQZ *register*, *target-label*

- Meaning: go to the labeled instruction **if a register's value is zero**. Continue below **if not**.

LET'S REVIEW SOME OF THESE INSTRUCTIONS...

```
1.  multiply:
2.    LI $t0,0
3.  multiply_loop:
4.    BEQZ $t2,report
5.    ADDU $t0,$t0,$t1
6.    ADDIU $t2,$t2,-1
7.    B multiply_loop
8.  report:
```

```
product = 0;
while (y != 0) {
  product += x;
  y--;
}
```

BRANCH IF EQUAL TO ZERO

- Format:

  BEQZ *register*, *target-label*

- Meaning: go to the labeled instruction if a register's value is zero. Continue below if not.
- NOTE:
  - if "guarding" a while loop, the **condition** specifies when the loop should ***stop***, the opposite of the condition for continuing

LET'S REVIEW SOME OF THESE INSTRUCTIONS...

```
1. multiply:
2.    LI $t0,0
3. multiply_loop:
4.    BEQZ $t2,report
5.    ADDU $t0,$t0,$t1
6.    ADDIU $t2,$t2,-1
7.    B multiply_loop
8. report:
```

BRANCH IF EQUAL TO ZERO

- Format:

  BEQZ *register*, *target-label*

- Meaning: go to the labeled instruction if a register's value is zero. Continue below if not.
- NOTES:
  - branch target can be above or below
  - there is BEQZ, BNEZ, BLTZ, BGTZ, BLEZ, BGEZ
  - these are $=, \neq, <, >, \leq, \geq$ tests with 0

LET'S REVIEW SOME OF THESE INSTRUCTIONS...

```
1.  multiply:
2.     LI $t0,0
3.  multiply_loop:
4.     BEQZ $t2,report
5.     ADDU $t0,$t0,$t1
6.     ADDIU $t2,$t2,-1
7.     B multiply_loop
8.  report:
```

BRANCH (UNCONDITIONALLY)

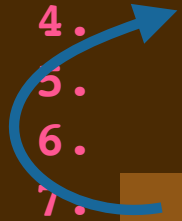
- Format:

  B *target-label*

- Meaning: go to the labeled instruction

LET'S REVIEW SOME OF THESE INSTRUCTIONS...

```
1.  multiply:
2.     LI $t0,0
3.  multiply_loop:
4.     BEQZ $t2,report
5.     ADDU $t0,$t0,$t1
6.     ADDIU $t2,$t2,-1
7.     B multiply_loop
8.  report:
```



BRANCH (UNCONDITIONALLY)

- Format:

  B *target-label*

- Meaning: go to the labeled instruction

WHAT ABOUT INPUT AND OUTPUT?

- There are several different ***system calls*** you can make that SPIM understands.
  - get an integer input from the console
  - print an integer output to the console
  - print a null-terminated character sequence out to the console

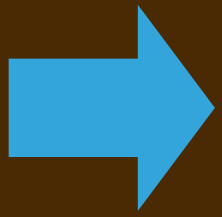
    ➡ Each has a number that identifies it.

    ➡ You tell the system which should run by setting register v0 to that number.

SYSTEM CALLS

- Getting an integer input is *system call #5*.

```
t1 = get_int();
```



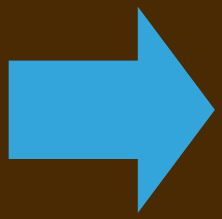
```
LI $v0,5
syscall
MOVE $t1,$v0
```

- Meaning of the MIPS code:
  - We load register v0 with the system call number.
  - We make the system call.
    - ➡A special sequence of instructions gets executed by the system to read input from the console. The integer read gets placed in register v0.
  - We copy (i.e. "move") its value to register t1, our storage for the first multiplicand.

SYSTEM CALLS

- Outputting an integer is *system call #1*.

```
put_int(t0);
```



```
LI $v0,1
MOVE $a0,$t0
syscall
```

- Meaning of the MIPS code:
  - We load register v0 with the system call number.
  - We load register a0 with the "argument", the value we want the system to output.
    - ➡This has us copy (again, "move") the register for the product into a0.
  - We make the system call.
    - ➡A sequence of instructions gets executed to output the value in a0 to the console.

THE (POORLY NAMED) MOVE INSTRUCTION

MOVE

- Format:

  MOVE *destination-register* **,** *source-register*

- Meaning:
  copy the contents of the source register into the destination register
- NOTE: the value in the source register ***doesn't change***
  - For example the MIPS code

    ```
    MOVE $t0,$t1
    ```

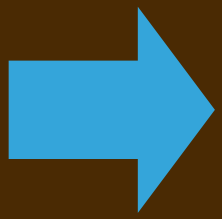
    would be like the C++ code

    ```
    product = x;
    ```

RETURNING FROM MAIN

- Our (main) program must return an integer value to the system.

```
return 0;
```



```
LI $v0,0
JR $ra
```

- We'll see (on Friday) how to write functions and procedures and use them.
- These two instructions hint at how that works. In short:
  - Functions, by convention, return a value by setting register v0 to that value.
  - A register named ra stores information about who called **`main`**.
    - ➡ This is called the ***return address*** of the "caller" code.
    - ➡The **`JR`** instruction "jumps back" to that instruction.
- *For now, just make sure your main code always ends with these two lines.*

THE FULL SOLUTION TO HOMEWORK 07 EXERCISE 1

```
1.  main:
2.    li       $v0,5
3.    syscall
4.    move     $t1,$v0
5.    li       $v0,5
6.    syscall
7.    move     $t2,$v0
8.  multiply:
9.    li       $t0,0
10. multiply_loop:
11.   beqz     $t2,report
12.   addu     $t0,$t0,$t1
13.   addiu    $t2,$t2,-1
14.   b        multiply_loop
15. report:
16.   li       $v0, 1
17.   move     $a0, $t0
18.   syscall
19.   li       $v0, 0
20.   jr       $ra
```

THE HOMEWORK 07 EXERCISE 2 SOLUTION LOOKS SIMILAR

```
1.  main:
2.     li       $v0,5
3.     syscall
4.     move     $t1,$v0
5.     li       $v0,5
6.     syscall
7.     move     $t2,$v0
8.  divide:
9.     li       $t0,0
10. divide_loop:
11.    blt      $t1,$t2,report
12.    addiu    $t0,$t0,1
13.    subu     $t1,$t1,$t2
14.    b        divide_loop
15. report:
...      # now $t0 contains the quotient, $t1 the remainder. We output them with two system calls.
22.    li       $v0, 0
23.    jr       $ra
```

C++ SOLUTION TO HOMEWORK 07 EXERCISE 2

- Here is the C++ for it. Again, the kernel of the code is **green**.

```
1.  int main() { int number, divisor, quotient;
2.    std::cin >> number;
3.    std::cin >> divisor;
4.    quotient = 0;
5.    while (number >= divisor) {
6.      quotient++;
7.      number -= divisor;
8.    }
9.    std::cout << quotient << std::endl;
10.   std::cout << number << std::endl;
11.   return 0;
12. }
```

- It repeatedly subtracts the divisor until only a remainder is left.
- It counts the number of subtractions made. That count is the quotient.

SOME MORE INSTRUCTIONS WORTH HIGHLIGHTING

```
1.  main:
2.     li       $v0,5
3.     syscall
4.     move     $t1,$v0
5.     li       $v0,5
6.     syscall
7.     move     $t2,$v0
8.  divide:
9.     li       $t0,0
10. divide_loop:
11.    blt      $t1,$t2,report
12.    addiu    $t0,$t0,1
13.    subu     $t1,$t1,$t2
14.    b        divide_loop
15. report:
...    # output $t0 and $t1
22.    li       $v0, 0
23.    jr       $ra
```

BRANCH IF LESS THAN

- Format:

  BLT *source1, source2 , target-label*

- Meaning: go to the labeled instruction if the first source register is less than the second. Continue below if not.
- NOTES:
  - there is BLT, BGT, BLE, BGE, BEQ, BNE
  - these are $<, >, \leq, \geq, =, \neq$

SOME MORE INSTRUCTIONS WORTH HIGHLIGHTING

```
1.  main:
2.     li       $v0,5
3.     syscall
4.     move     $t1,$v0
5.     li       $v0,5
6.     syscall
7.     move     $t2,$v0
8.  divide:
9.     li       $t0,0
10. divide_loop:
11.    blt      $t1,$t2,report
12.    addiu    $t0,$t0,1
13.    subu     $t1,$t1,$t2
14.    b        divide_loop
15. report:
...    # output $t0 and $t1
22.    li       $v0, 0
23.    jr       $ra
```

SUBTRACT (UNTRAPPED)

- Format:

  SUBU *destination*, *source1*, *source2*

- Meaning: subtract source2 from source1, store the difference in a register
- NOTES:
  - destination is a register
  - sources are registers
  - "untrapped" means errors (e.g. borrow) can be ignored by the machine
  - does not modify the source registers

THERE'S MORE THAN JUST CODE THERE

```
1.      # quotient.asm
2.      #
3.      # This code asks for two integers and then
4.      # outputs the quotient and remainder due to
5.      # their division.
6.
7.      .data
8.  prompt_num:   .asciiz "Enter an integer: "
9.  prompt_div:   .asciiz "Enter an integer divisor: "
10. fdbk1:        .asciiz "Dividing "
11. fdbk2:        .asciiz " by "
12. fdbk3:        .asciiz " yields a quotient of "
13. fdbk4:        .asciiz " with a remainder of "
14. fdbk5:        .asciiz ".\n"
15.
16.     .globl main
17.     .text
18. main:
19.     # Key:
20.     #       $t0 - the number to be divided
21.     #       $t1 - the divisor
22.     #       $t2 - the remainder
23.     #       $t3 - the quotient, a count
24.      li       $v0,5
25.      ...
```

SEGMENTS IN A PROGRAM MEMORY IMAGE

- In MIPS assembly we specify the contents of a program's ***text*** and ***data segments***:
  - **`.text`** contains the bytes of the executable code of the program
  - **`.data`** contains additional sequences of bytes, and for various types of values
    - SPIM loads all the bytes of a program's image, both the text and the data.
- For example, "output100.asm" holds two strings and an integer in its data:

```
            .data
report:     .asciiz "The value held in memory is "
dot_eoln:   .asciiz ".\n"
value:      .word 100
            .globl main
            .text
main:
  la        $a0, report
  ...
```

SEGMENTS IN A PROGRAM MEMORY IMAGE

- Here is the full "output100.asm" program:

```
1.              .data
2.  report:     .asciiz "The value held in memory is "
3.  dot_eoln:   .asciiz ".\n"
4.  value:      .word 100
5.              .globl main
6.              .text
7.  main:
8.    la        $a0,report
9.    li        $v0,4
10.   syscall
11.   la        $t0,value
12.   lw        $a0,($t0)
13.   li        $v0,1
14.   syscall
15.   la        $a0,eoln
16.   li        $v0,4
17.   syscall
18.   li        $v0,0
19.   jr        $ra
```

LOADING A VALUE STORED AT AN ADDRESS

- Here is the full "output100.asm" program:

```
1.              .data
2.  report:     .asciiz "The value held in memory is "
3.  dot_eoln:   .asciiz ".\n"
4.  value:      .word 100
5.              .globl main
6.              .text
7.  main:
8.    la        $a0,report
9.    li        $v0,4
10.   syscall
11.   la        $t0,value
12.   lw        $a0,($t0)
13.   li        $v0,1
14.   syscall
15.   la        $a0,eoln
16.   li        $v0,4
17.   syscall
18.   li        $v0,0
19.   jr        $ra
```

LOAD ADDRESS INTO A REGISTER

- Format:

  LA *destination*, *program-label*

- Meaning: loads a register with the address of a labelled item in the code
- NOTE: For a string (.asciiz), this is the address of the first letter of its sequence.

LOADING A VALUE STORED AT AN ADDRESS

- Here is the full "output100.asm" program:

```
1.              .data
2.  report:     .asciiz "The value held in memory is "
3.  dot_eoln:   .asciiz ".\n"
4.  value:      .word 100
5.              .globl main
6.              .text
7.  main:
8.    la        $a0,report
9.    li        $v0,4
10.   syscall
11.   la        $t0,value
12.   lw        $a0,($t0)
13.   li        $v0,1
14.   syscall
15.   la        $a0,eoln
16.   li        $v0,4
17.   syscall
18.   li        $v0,0
19.   jr        $ra
```

LOAD ADDRESS INTO A REGISTER

- Format:

  LA *destination*, *program-label*

- Meaning: loads a register with the address of a labelled item in the code
- NOTE: For an integer (.word), this is the address of the first of its four bytes.

LOADING A VALUE STORED AT AN ADDRESS

- Here is the full "output100.asm" program:

```
1.              .data
2.  report:     .asciiz "The value held in memory is "
3.  dot_eoln:   .asciiz ".\n"
4.  value:      .word 100
5.              .globl main
6.              .text
7.  main:
8.    la        $a0,report
9.    li        $v0,4
10.   syscall
11.   la        $t0,value
12.   lw        $a0,($t0)
13.   li        $v0,1
14.   syscall
15.   la        $a0,eoln
16.   li        $v0,4
17.   syscall
18.   li        $v0,0
19.   jr        $ra
```

LOAD A VALUE STORED AT AN ADDRESS

- Format:

`LW` *destination*`,(`*source*`)`

- Meaning: loads a register with the (4-byte word) value stored at an address
- NOTE: ***source*** is a register that holds the address., i.e. a pointer to the loaded data.

LOADING A VALUE FROM MEMORY

LOAD A (FOUR BYTE) VALUE FROM AN ADDRESS IN MEMORY

```
LW destination,(source)
```

- NOTES:
  - This is sometimes called a "memory-to-register" transfer or "fetch."
  - *source* is a register holding the address of the data we're fecthing.
  - We can think of the source register as a pointer. So **LW** is like the C code:

```
int* source_pointer;
...
int destination_value = *source_pointer;
```

REGISTERS VERSUS MEMORY

- A MIPS processor has only 32 registers for storing calculated values.
  - It can also access a large memory using addresses.
- MIPS is a *"load/store" computer architecture*.
  - It can only perform calculations on data stored in its registers
  - To modify a value stored in memory it must:
    1. *load* a value from memory by its address into a register
    2. modify that value, computing a new value, within registers
    3. *store* that changed value into memory at that same address

EXAMPLE: INCREMENTING A VALUE IN MEMORY

- Here is MIPS code that adds 10 to a location in memory:

```
1.  LA    $a0,value
2.  LW    $t0,($a0)
3.  ADDIU $t0,$t0,10
4.  SW    $t0,($a0)
```

STORING A VALUE TO MEMORY

STORE A (FOUR BYTE) VALUE TO AN ADDRESS IN MEMORY

```
sw source,(destination)
```

- NOTES:
  - This is sometimes called a "register-to-memory" transfer.
  - *destination* is a register holding the address where we're storing the data in the *source* register

WORDS VERSUS BYTES

- Recall that the fundamental quantity manipulated by a MIPS32 instruction set is 32-bits long.
  - ➡ Registers hold 32 bits, i.e 4 bytes, of data.
  - ➡ Integers are 32 bits, i.e. 4 bytes, long.
  - ➡ Addresses are 32 bits, i.e. 4 bytes, long.
- So in MIPS32, a ***word*** is 32 bits, i.e. 4 bytes.
  - ➡The **LW** instruction reads 4 bytes of data from memory.
  - ➡The **SW** instruction write 4 bytes of data out to memory.
- There are also the **LB** and **SB** instructions for accessing a *single byte* in memory.
  - ➡NOTE: strings are sequences of characters, each character is a byte of data.

LOADING A BYTE AND STORING A BYTE

LOAD A BYTE'S VALUE FROM AN ADDRESS IN MEMORY

```
LB destination,(source)
```

- NOTES:
  - This is sometimes called a "memory-to-register" transfer or a "fetch."
  - *source* is a register holding the address where we're fetching the data in *destination*

STORE A BYTE'S VALUE TO AN ADDRESS IN MEMORY

```
SB source,(destination)
```

- NOTES:
  - This is sometimes called a "register-to-memory" transfer.
  - *destination* is a register holding the address where we're storing the data of *source*

PRINTING STRINGS AND CHANGING STRINGS ("HELLOBYE.ASM")

```
1.    .data
2.  hello_ptr: .asciiz "hello\n"
3.    .globl main
4.    .text
5.  main:
6.  print_hello:
7.    li $v0, 4
8.    la $a0, hello_ptr
9.    syscall
10.   j   change_string
11. print_bye:
12.   li $v0, 4
13.   la $a0, hello_ptr
14.   syscall
15. end_main:
16.   li $v0, 0
17.   jr $ra
18. change_string:
19.   la $t0, hello_ptr
20.   li $t1, 'b'
21.   sb $t1, ($t0)
22.   addiu $t0, $t0, 1
23.   li $t1, 'y'
24.   sb $t1, ($t0)
25.   addiu $t0, $t0, 1
26.   li $t1, 'e'
27.   sb $t1, ($t0)
28.   addiu $t0, $t0, 1
29.   li $t1, '\n'
30.   sb $t1, ($t0)
31.   addiu $t0, $t0, 1
32.   li $t1, 0
33.   sb $t1, ($t0)
34.   j print_bye
```

PRINTING STRINGS AND CHANGING STRINGS ("HELLOBYE.ASM")

```
1.    .data
2.  hello_ptr: .asciiz "hello\n"
3.    .globl main
4.    .text
5.  main:
6.  print_hello:
7.    li $v0, 4
8.    la $a0, hello_ptr
9.    syscall
10.   j   change_string
11. print_bye:
12.   li $v0, 4
13.   la $a0, hello_ptr
14.   syscall
15. end_main:
16.   li $v0, 0
17.   jr $ra
18. change_string:
19.   la $t0, hello_ptr
20.   li $t1, 'b'
21.   sb $t1, ($t0)
22.   addiu $t0, $t0, 1
23.   li $t1, 'y'
24.   sb $t1, ($t0)
25.   addiu $t0, $t0, 1
26.   li $t1, 'e'
27.   sb $t1, ($t0)
28.   addiu $t0, $t0, 1
29.   li $t1, '\n'
30.   sb $t1, ($t0)
31.   addiu $t0, $t0, 1
32.   li $t1, 0
33.   sb $t1, ($t0)
34.   j print_bye
```

- The code jumps around to fit neatly on this slide...

PRINTING STRINGS AND CHANGING STRINGS ("HELLOBYE.ASM")

```
1.    .data
2.  hello_ptr: .asciiz "hello\n"
3.    .globl main
4.    .text
5.  main:
6.  print_hello:
7.    li $v0, 4
8.    la $a0, hello_ptr
9.    syscall
10.   j   change_string
11. print_bye:
12.   li $v0, 4
13.   la $a0, hello_ptr
14.   syscall
15. end_main:
16.   li $v0, 0
17.   jr $ra
18. change_string:
19.   la $t0, hello_ptr
20.   li $t1, 'b'
21.   sb $t1, ($t0)
22.   addiu $t0, $t0, 1
23.   li $t1, 'y'
24.   sb $t1, ($t0)
25.   addiu $t0, $t0, 1
26.   li $t1, 'e'
27.   sb $t1, ($t0)
28.   addiu $t0, $t0, 1
29.   li $t1, '\n'
30.   sb $t1, ($t0)
31.   addiu $t0, $t0, 1
32.   li $t1, 0
33.   sb $t1, ($t0)
34.   j print_bye
```

- It first prints the string "hello\n" **in lines 6-9**.

PRINTING STRINGS AND CHANGING STRINGS ("HELLOBYE.ASM")

```
1.    .data
2.  hello_ptr: .asciiz "hello\n"
3.    .globl main
4.    .text
5.  main:
6.  print_hello:
7.    li $v0, 4
8.    la $a0, hello_ptr
9.    syscall
10.   j   change_string
11. print_bye:
12.   li $v0, 4
13.   la $a0, hello_ptr
14.   syscall
15. end_main:
16.   li $v0, 0
17.   jr $ra
18. change_string:
19.   la $t0, hello_ptr
20.   li $t1, 'b'
21.   sb $t1, ($t0)
22.   addiu $t0, $t0, 1
23.   li $t1, 'y'
24.   sb $t1, ($t0)
25.   addiu $t0, $t0, 1
26.   li $t1, 'e'
27.   sb $t1, ($t0)
28.   addiu $t0, $t0, 1
29.   li $t1, '\n'
30.   sb $t1, ($t0)
31.   addiu $t0, $t0, 1
32.   li $t1, 0
33.   sb $t1, ($t0)
34.   j print_bye
```

- It then jumps to **line 18**.

PRINTING STRINGS AND CHANGING STRINGS ("HELLOBYE.ASM")

```
1.    .data
2.  hello_ptr: .asciiz "hello\n"
3.    .globl main
4.    .text
5.  main:
6.  print_hello:
7.    li $v0, 4
8.    la $a0, hello_ptr
9.    syscall
10.   j   change_string
11. print_bye:
12.   li $v0, 4
13.   la $a0, hello_ptr
14.   syscall
15. end_main:
16.   li $v0, 0
17.   jr $ra
18. change_string:
19.   la $t0, hello_ptr
20.   li $t1, 'b'
21.   sb $t1, ($t0)
22.   addiu $t0, $t0, 1
23.   li $t1, 'y'
24.   sb $t1, ($t0)
25.   addiu $t0, $t0, 1
26.   li $t1, 'e'
27.   sb $t1, ($t0)
28.   addiu $t0, $t0, 1
29.   li $t1, '\n'
30.   sb $t1, ($t0)
31.   addiu $t0, $t0, 1
32.   li $t1, 0
33.   sb $t1, ($t0)
34.   j print_bye
```

- In Lines 19-30, it overwrites the bytes of the string with "**bye\n**"

PRINTING STRINGS AND CHANGING STRINGS ("HELLOBYE.ASM")

```
1.    .data
2.  hello_ptr: .asciiz "hello\n"
3.    .globl main
4.    .text
5.  main:
6.  print_hello:
7.    li $v0, 4
8.    la $a0, hello_ptr
9.    syscall
10.   j   change_string
11. print_bye:
12.   li $v0, 4
13.   la $a0, hello_ptr
14.   syscall
15. end_main:
16.   li $v0, 0
17.   jr $ra
18. change_string:
19.   la $t0, hello_ptr
20.   li $t1, 'b'
21.   sb $t1, ($t0)
22.   addiu $t0, $t0, 1
23.   li $t1, 'y'
24.   sb $t1, ($t0)
25.   addiu $t0, $t0, 1
26.   li $t1, 'e'
27.   sb $t1, ($t0)
28.   addiu $t0, $t0, 1
29.   li $t1, '\n'
30.   sb $t1, ($t0)
31.   addiu $t0, $t0, 1
32.   li $t1, 0
33.   sb $t1, ($t0)
34.   j print_bye
```

- It then jumps to line 11 to continue the work of **main**.

PRINTING STRINGS AND CHANGING STRINGS ("HELLOBYE.ASM")

```
1.    .data
2.  hello_ptr: .asciiz "hello\n"
3.    .globl main
4.    .text
5.  main:
6.  print_hello:
7.    li $v0, 4
8.    la $a0, hello_ptr
9.    syscall
10.   j   change_string
11. print_bye:
12.   li $v0, 4
13.   la $a0, hello_ptr
14.   syscall
15. end_main:
16.   li $v0, 0
17.   jr $ra
18. change_string:
19.   la $t0, hello_ptr
20.   li $t1, 'b'
21.   sb $t1, ($t0)
22.   addiu $t0, $t0, 1
23.   li $t1, 'y'
24.   sb $t1, ($t0)
25.   addiu $t0, $t0, 1
26.   li $t1, 'e'
27.   sb $t1, ($t0)
28.   addiu $t0, $t0, 1
29.   li $t1, '\n'
30.   sb $t1, ($t0)
31.   addiu $t0, $t0, 1
32.   li $t1, 0
33.   sb $t1, ($t0)
34.   j print_bye
```

- It prints the string at that same address using **lines 11-14**.

PRINTING STRINGS AND CHANGING STRINGS ("HELLOBYE.ASM")

```
1.    .data
2.  hello_ptr: .asciiz "hello\n"
3.    .globl main
4.    .text
5.  main:
6.  print_hello:
7.    li $v0, 4
8.    la $a0, hello_ptr
9.    syscall
10.    j    change_string
11. print_bye:
12.   li $v0, 4
13.   la $a0, hello_ptr
14.   syscall
15. end_main:
16.   li $v0, 0
17.   jr $ra
18. change_string:
19.   la $t0, hello_ptr
20.   li $t1, 'b'
21.   sb $t1, ($t0)
22.   addiu $t0, $t0, 1
23.   li $t1, 'y'
24.   sb $t1, ($t0)
25.   addiu $t0, $t0, 1
26.   li $t1, 'e'
27.   sb $t1, ($t0)
28.   addiu $t0, $t0, 1
29.   li $t1, '\n'
30.   sb $t1, ($t0)
31.   addiu $t0, $t0, 1
32.   li $t1, 0
33.   sb $t1, ($t0)
34.   j print_bye
```

- But the contents of the string have changed because of 5 **SB** instructions.

PRINTING STRINGS AND CHANGING STRINGS ("HELLOBYE.ASM")

```
1.    .data
2.  hello_ptr: .asciiz "hello\n"
3.    .globl main
4.    .text
5.  main:
6.  print_hello:
7.    li $v0, 4
8.    la $a0, hello_ptr
9.    syscall
10.   j   change_string
11. print_bye:
12.   li $v0, 4
13.   la $a0, hello_ptr
14.   syscall
15. end_main:
16.   li $v0, 0
17.   jr $ra
18. change_string:
19.   la $t0, hello_ptr
20.   li $t1, 'b'
21.   sb $t1, ($t0)
22.   addiu $t0, $t0, 1
23.   li $t1, 'y'
24.   sb $t1, ($t0)
25.   addiu $t0, $t0, 1
26.   li $t1, 'e'
27.   sb $t1, ($t0)
28.   addiu $t0, $t0, 1
29.   li $t1, '\n'
30.   sb $t1, ($t0)
31.   addiu $t0, $t0, 1
32.   li $t1, 0 -
33.   sb $t1, ($t0)
34.   j print_bye
```

- Notice we set the 5th character to 0. This ***null terminates*** that string.

SUMMARY: LOADING FROM AND STORING TO MEMORY

LOAD A WORD FROM MEMORY

```
LW destination,(source)
```

STORE A WORD TO MEMORY

```
SW source,(destination)
```

LOAD A BYTE FROM MEMORY

```
LB destination,(source)
```

STORE A BYTE TO MEMORY

```
SW source,(destination)
```

(OPTIONAL) EXERCISES FOR WEDNESDAY

- Change "hello.asm" so that it instead outputs this to the console

```
hello
ello
llo
lo
o
```

  - ➡Each line starts from a different place in the character string.

- Change "hello.asm" so that it instead outputs this to the console

```
hello
elloh
llohe
lohel
ohell
```

  - ➡Each line is a result of rotating the string's contents by one character.

- BONUS: have each instead operate on a string read as input from the console.
  - ➡See "string.asm" to see how to input a character string into memory.

LOADING FROM AND STORING TO MEMORY

LOAD A (FOUR BYTE) VALUE FROM AN ADDRESS IN MEMORY

```
LW destination,(source)
```

- NOTES:
  - This is sometimes called a "memory-to-register" transfer or a "fetch."
  - *source* is a register holding the address where we're fetching the data in *destination*

STORE A (FOUR BYTE) VALUE TO AN ADDRESS IN MEMORY

```
SW source,(destination)
```

- NOTES:
  - This is sometimes called a "register-to-memory" transfer.
  - *destination* is a register holding the address where we're storing the data of *source*