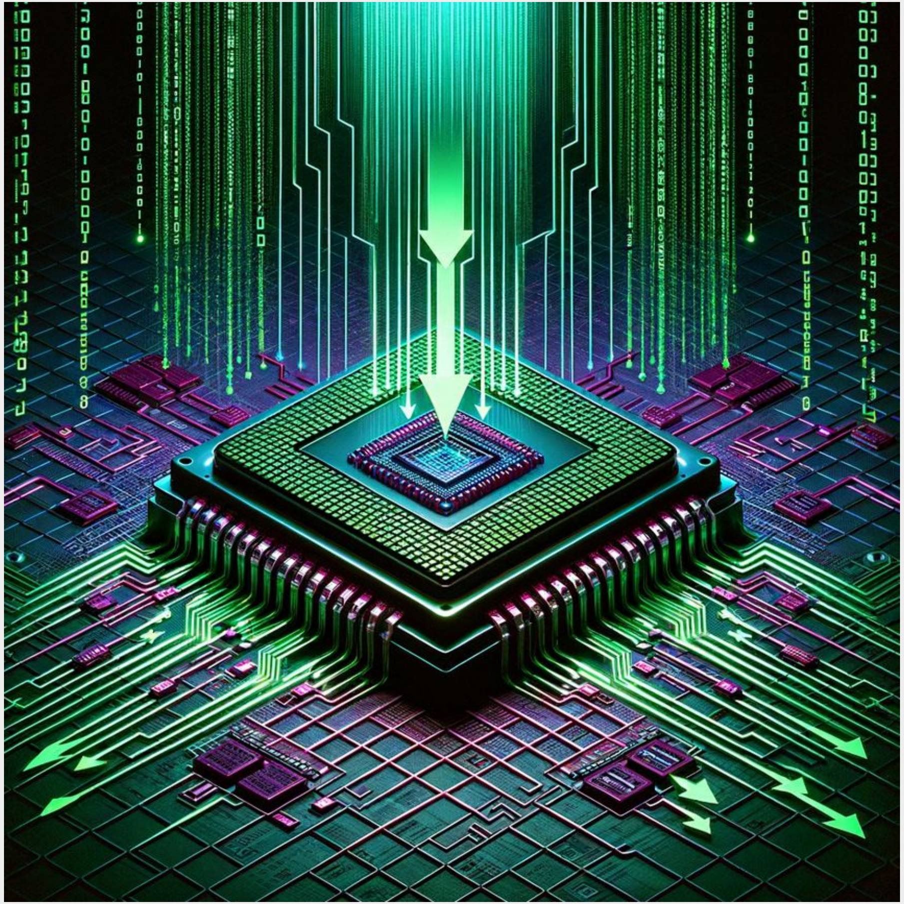
COMP1521 24T2 Lec05

MIPS: FUNctions

2024

Hammond Pearce
Adapted from Abiram's Material



Recap challenge

```
.text
main:
        la $t1, some_addr
        li $v0, 11
some_label:
        lb $a0, ($t1)
        beq $a0, $0, some_other_label
        syscall
        addi $t1, $t1, 1
        b some_label

some_other_label:
        li $v0, 0
        jr $ra
```

What does this code do?

Answer in lecture chat

A typical function call

```
result = func(expr1, expr2, ...);
```

- Expressions are evaluated and associated with each parameter
- Control flow transfers to the body of `func`
- Local variables are created for `func`
- A return value is computed
- Control flow transfers to the caller which can make use of `result`

What really is a function??

- Functions are named pieces of code
  - Which you can (optionally) supply arguments
  - Perform computations using those arguments
  - And return a value to a caller

Here's a function

```
int timesTwo(int x) {
    int two_x = x*2;
    return two_x;
}
```

- It takes an argument (x)
- It does some calculations
- It returns a value (two_x)

Functions have “prototypes”

```
//timesTwo takes an int argument and returns an int result
int timesTwo(int x);
```

- Also known as “signatures”
- These define the number and types of parameters
- And define the type of the return value

When calling a function, we must supply an appropriate number of values each with the correct type

(Some functions are special and can take “variable” numbers of arguments, e.g. printf - out of scope for COMP1521 but feel free to Google!)

Pure functions vs “impure”

- Functions take arguments and return values
- But in C we can define functions that don’t take arguments or don’t return values
- What would these be useful for??

Here's a very basic program with function

```c
#include <stdio.h>

void f(void);

int main(void) {
    printf("calling function f\n");
    f();
    printf("back from function f\n");
    return 0;
}

void f(void) {
    printf("in function f\n");
}
```

Signature comes first

Function implementation

Let’s write it in assembly

How?

Well, functions are a bit like the **labels** we have been “goto”-ing

Let’s start with that, using branch instructions “b”

Let’s write it in assembly

How?

Well, functions are a bit like the **labels** we have been “goto”-ing

Let’s start with that, using branch instructions “b”

… but what happens now if we want to call the function twice?

How do we actually call other functions?

- We use the **`jal`** instruction to call functions
- **`jal`** is a *spicy* version of the **`j`** (or pseudo-instruction **`b`**)
  - It also jumps to the given label
  - However, it also sets **`$ra`** **(return address)** to point to the next instruction before jumping
  - This gives us a mechanism to return to the caller function!
- However, this presents a problem…
  - Let’s try run our program!

Let's fix up the function call_return.c

How do we pass info to a function??

- We can use the $a registers to pass in arguments
  - We have $a0 - $a3 – four registers to pass in arguments
  - Can use the stack (more soon) if we theoretically had more than 4 arguments
    - However, you won't have to deal with this in COMP1521

Implement this:

```c
#include <stdio.h>

void f(int c);

int main(void) {
  printf("calling function f\n");
  f(22);
  printf("back from function f\n");
  return 0;
}

void f(int c) {
  printf("in function f\n");
  printf("%d", c);
  putchar('\n');
}
```

How do functions return values?

- We can use the $v registers to retrieve a function’s result
  - Values occupying 32-bits or fewer should be returned using $v0
  - Don’t have to deal with $v1 in COMP1521

Implement this:

```c
#include <stdio.h>
int f(int c);

int main(void) {
  printf("calling function f\n");
  int q = f(22);
  printf("back from function f\n");
  printf("%d", q);
  putchar('\n');
  return 0;
}

int f(int c) {
  printf("in function f\n");
  printf("%d", c);
  putchar('\n');
  c = c + 1;
  return c;
}
```

Functions - a summary

- Functions are named pieces of code
  - Which you can call
  - Which you can (optionally) supply arguments
  - Perform computations using those arguments
  - And return a value to a caller

Functions - a summary

- Functions are named pieces of code (**labels**)
  - Which you can call
  - Which you can (optionally) supply arguments
  - Perform computations using those arguments
  - And return a value to a caller

Functions - a summary

- Functions are named pieces of code (**labels**)
  - Which you can call (**`jal`**)
  - Which you can (optionally) supply arguments
  - Perform computations using those arguments
  - And return a value to a caller

Functions - a summary

- Functions are named pieces of code (**labels**)
  - Which you can call (**`jal`**)
  - Which you can (optionally) supply arguments (**`$a0 - $a3`**)
  - Perform computations using those arguments
  - And return a value to a caller

Functions - a summary

- Functions are named pieces of code (**labels**)
  - Which you can call (**`jal`**)
  - Which you can (optionally) supply arguments (**`$a0 - $a3`**)
  - Perform computations using those arguments
  - And return a value (**`$v0`**) to a caller

We've now laid some ground rules on communicating with functions.

We've now laid some ground rules on communicating with functions.

But it gets better!

The MIPS calling conventions

- lay out rules on how we should be using registers when interfacing between different functions
- forms the MIPS ABI (application binary interface), which lays out how different code should interact with each other

The MIPS calling conventions

- *Theoretically* could break these rules
  - However, makes it hard to have code that works interoperably with code from other sources
- Important to follow these rules to make sure that functions work nicely with each other

The MIPS calling conventions

- *Theoretically* could break these rules
  - However, makes it hard to have code that works interoperably with code from other sources
- Important to follow these rules to make sure that functions work nicely with each other

"The pirates' code of MIPS" - Zac Kologlu, former COMP1521 admin, COMP6991 lecturer

"You know the rules, and so do I" - Richard Paul Astley, won't give you up

The MIPS calling conventions - $t registers

- $t registers are free real estate for a function
    - Functions can completely obliterate any existing values in a $t register
- However, this has implications for the function's caller
    - The *caller* function **must** assume that the *callee* function completely obliterated any values in $t registers

Hey, but my function doesn't actually obliterate values in $t0 …

- Too bad - we MUST treat other functions like black boxes
- In fact, 'strict' autotesting for assignment 1 will intentionally destroy the existing values in your $t registers.
- The term for 'obliterating' an existing value inside a register without eventually restoring it is **clobbering**

So we can't preserve values between function calls in MIPS??

- could *theoretically* use global variables to preserve values
  - However, what if we call a function recursively?
    - Global variables need to be pre-allocated,
    - We don't know how many instances of a recursive function might exist at a given time
- Instead, we use **$s** registers to **save** values between function calls

The MIPS calling convention - $s registers

- Functions **cannot** permanently change the value of a $s register
- This means that we can rely on our callee functions not clobbering any values we keep in $s registers)
- Problem solved?? Store `input` in a $s register

Uh oh!

- Our `main` function violates the pirates’ code by modifying $s0
  - The `main` function is not special, and must also abide by these rules
- Recursive functions also have this issue - they “change” $ra!
- **Solution**: functions can *temporarily* make changes to $s/$ra registers, as long as they restore them afterwards

Uh oh!

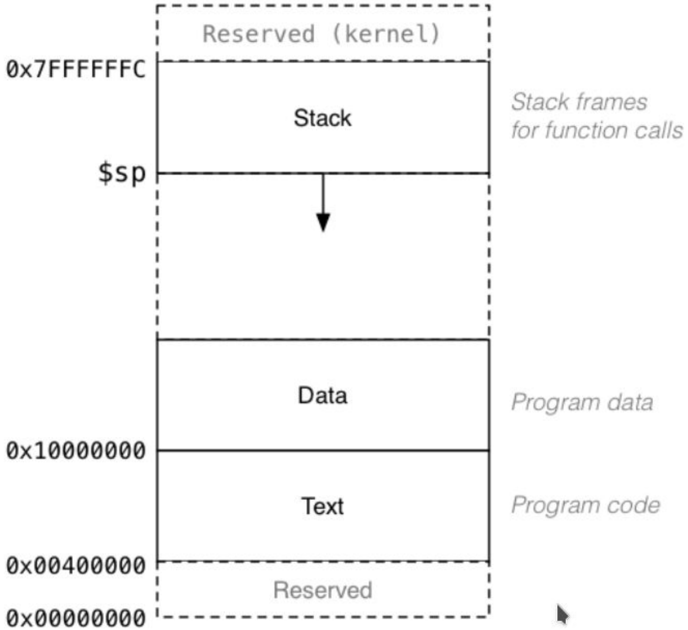
- How do we do this?
  - Save the $s/$ra register's original value to RAM at start of the function
  - Restore the $s/$ra register's original value from RAM once complete
- As far as the caller is concerned - $s/$ra register is still good

"Does it almost feel like nothing's changed at all?" - Dan Smith, lead vocalist, Bastille

Saving to the stack

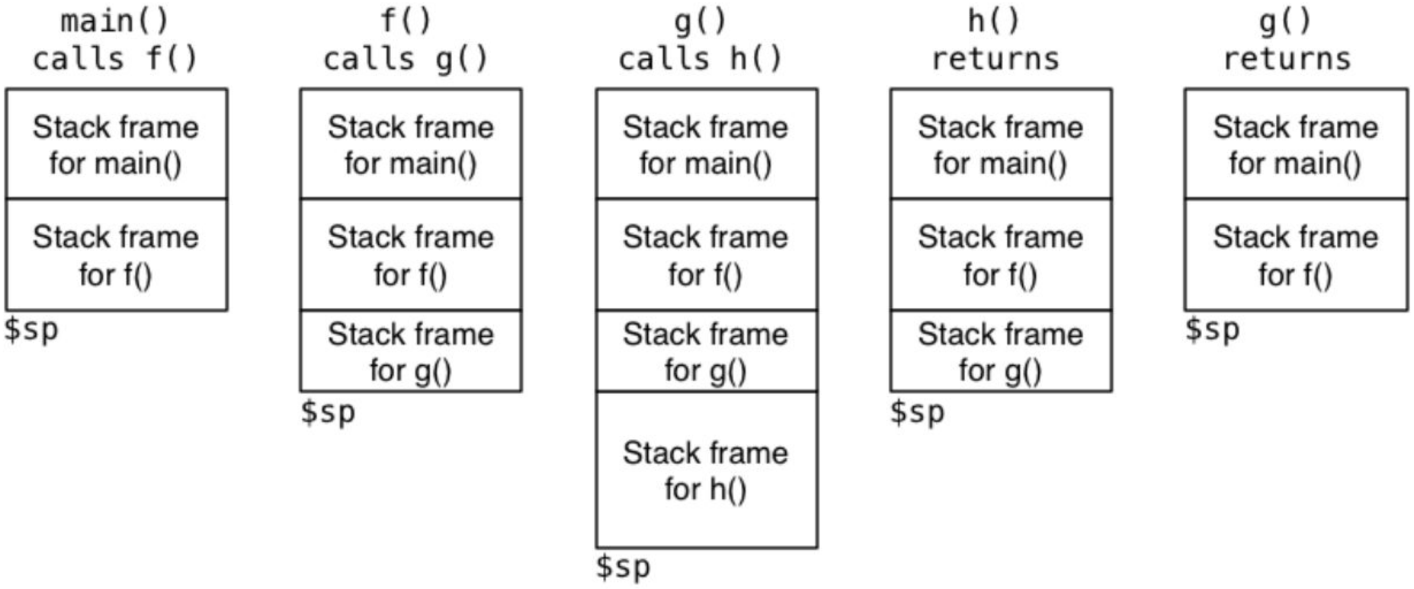
The stack

- is a region of memory which we can grow and expand
- uses the $sp (**stack pointer**) register to keep track of the top of the stack
- We can modify the stack pointer to allocate more room on the stack for us to store values



The stack: growing and shrinking

This is how the stack changes as functions are called and return:



The MIPS calling conventions - $sp

- Functions are free to use the stack as they need - as long as they restore $sp to its original value once done
  - That is, a function must restore the stack to its original size
- Failure to do so may lead to disastrous consequences

The MIPS calling conventions - $sp

- For example,
  - If I subtract a total of 8 from $sp at the start of my function,

```
addi $sp, $sp, -4
sw   $s0, ($sp)
addi $sp, $sp, -4
sw   $s1, ($sp)
```

  - I must add 8 to $sp before my function returns,

```
lw   $s1, ($sp)
addi $sp, $sp, 4
lw   $s0, ($sp)
addi $sp, $sp, 4
```

push and pop: the stack on easy mode

- For convenience, we provide you with two pseudo-instructions to interact with the stack: **push** and **pop**
- **push R_t**
  - ‘allocates’ 4 bytes on the stack ($sp = $sp - 4)
  - stores the value of R_t to the stack
- **pop R_t**
  - restores the value on the top of the stack into R_t
  - ‘deallocates’ 4 bytes on the stack ($sp = $sp + 4)

push and pop: the stack on easy mode

- These are **pseudo-instructions** provided by mipsy - won't work on other MIPS emulators
- This means that you can get through this course without ever directly interacting with `$sp`

Prologues and epilogues

- Prologues are the start of a function's story
  - We use the **begin** instruction (more on this soon)
  - We need to **push** $ra onto the stack
  - We **push** the values of any $s registers we want to use
- Epilogues are the end of a function's story
  - You may sometimes set the return value (`$v0`) here
  - We restore (**pop**) any $s registers we saved to the stack, in reverse order
  - We **pop** $ra
  - We use the **end** instruction (more on this soon)
  - We then return to the caller with `jr $ra`

- You should **not** do anything else in the prologue/epilogue
- You should **not** need to push/pop outside prologue/epilogue in this course
  - Caller-preservation of $t registers is theoretically possible but out of scope and discouraged

Leaf functions

- Are functions that don’t call any other functions (eg. every main function you saw before this lecture)
- Leaf functions don’t need to preserve $ra
  - They don’t use jal, so they never actually modify $ra
- Leaf functions *shouldn’t* need to even use $s registers
  - We only use $s registers when we want to preserve a value across a function call
  - But leaf functions don’t have any function calls within them (by definition), so they can use $t registers
- Since there is no need to preserve values for a leaf function, they do not *need* a prologue and epilogue

The MIPS pirates' code: a summary

- `$t` registers are free real estate
  - But they're free real estate for other functions too, so we must assume that other functions destroy them
- A function must restore the original values of `$sp`, `$fp`, `$s0`..`$s7`
  - But as a result, we can assume that any function we call leaves these registers unchanged
- Functions need to preserve `$ra` if they overwrite it
  - Otherwise, our function will lose track of where to return to
- `$a0`..`$a3` contain arguments - these are also not preserved by callees (like $t)
- `$v0` contains the return value

Out of scope for COMP1521

- Floating point registers exist to pass/return floats/doubles
    - These have similar conventions
- Stack used to pass more than 4 arguments
- Stack used to pass/return values too large for registers
    - eg. we can pass structs to functions in C, but structs can be much larger than 4 bytes

The frame pointer

- $fp is another register that points to the stack
  - It points to the bottom of a given function's stack frame
  - In other words, it points to the same value as **`$sp`** before a function does any pushes/pops
- Used by debuggers to analyse the stack
  - The frame pointer, combined with saving older values of **`$fp`** to the stack essentially forms a linked list of stack frames
- Using a frame pointer is optional (both in COMP1521 and generally)
  - Compilers omit the use of a frame pointer when fast execution/smaller code is a priority
- Since the frame pointer tracks the original value of the stack pointer (at the start of the function), it gives us a mechanism to prevent chaos if a function pushes/pops too much

The frame pointer - easy mode

- We don't expect you to fully understand the frame pointer in COMP1521
- Instead, we provide you with two pseudo-instructions in mipsy
    - **`begin`**
        - saves the old $fp to the stack (keep track of the previous stack frame)
        - sets $fp to the current $sp
        - should be the first thing in the prologue
    - **`end`**
        - restore $sp to point to the top of the previous stack frame
        - restore the $fp to point to the previous value of $fp (bottom of the previous stack frame)
        - should be right before **`jr $ra`**
- This makes situations where you push/pop too much easier to debug
- Not *necessary* but makes debugging much much easier - **strongly advised**

Function skeleton

```
func:
        # [header comment]
func__prologue:
        begin
        push    $ra
        push    $s0
        push    $s1

func__body:
        # do stuff

        li      $a0, 42
        jal     foo         # foo(42)

        # foo return val in $v0

func__epilogue:
        pop     $s1
        pop     $s0
        pop     $ra
        end

        jr      $ra
```