COMP1521 26T1

Week 3 Lecture 1

MIPS FUNctions

Weekly Tests start this week

Released: Thursday 3pm
Time limit: 1 hour
Due: Thursday Week 4 at 3pm. (And then another test comes out)
Submitted via **give**
You can get 50% max for questions submitted after the hour is up
Self Enforced Exam Conditions

Topic for week 3 test: MIPS basics, control.
Can use mips documentation

Help Sessions and Assignment 1

- Help Session Schedule is out
  - BYOD
  - Optional, drop in help!
  - They will get busy around assignment 1 deadline!
  - Get in now!

- Assignment 1 out this week
  - Walkthrough video coming soon

https://cgi.cse.unsw.edu.au/~cs1521/26T1/help-sessions/

Today’s Lecture

- Recap last lecture
  - Arrays
  - Structs
- Functions

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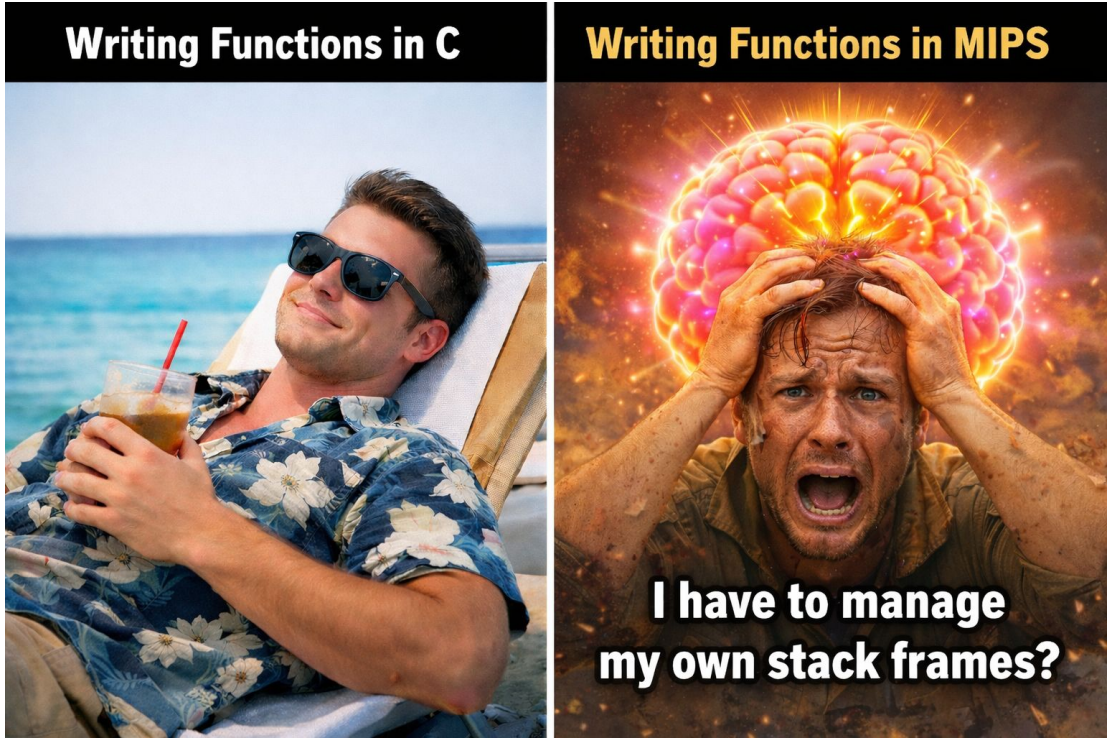

Address of Array Elements

In general:

address a[i] = address of a + i * sizeof(element)

a[0]	a[1]	a[2]	a[3]	a[4]
' a '	' z '	' b '	' f '	' G '
0x100	0x101	0x102	0x103	0x104

a[0]	a[1]	a[2]	a[3]	a[4]
16	4	1	9	2
0x100	0x104	0x108	0x10c	0x110

2D Arrays in MIPS

	0	1	2	3	< col
0	a	b	c	d	
1	e	f	g	h	
2	i	j	k	l	

^ row

Offset of start of relevant row:

(row * N_COLS) * sizeof(element)

Offset within row:

col * sizeof(element)

Total offset:

(row * N_COLS + col) * sizeof(element)

a	b	c	d	e	f	g	h	i	j	k	l
0	1	2	3	4	5	6	7	8	9	10	11

Recap: MIPS array coding examples

read_array_words.c

modify_2d.c

Recap Structs: recap_struct.c

```
struct person{
    char first_initial;
    char last_initial;
    int age;
};
```

What size will this struct be?

What offsets will each field have?

Let’s write code in MIPS to create a global variable of this type

Read in data and print it out again.

Recap Structs: recap_struct.c

```
struct person{
    int age;
    char first_initial;
    char last_initial;
};
```

What if we do it like this?

Structs: struct.c struct.s

```c
struct student {
    int zid;          //Offset 0
    char first[20];   //Offset 4
    char last[20];    //Offset 24
    int program;      //Offset 44
    char alias[10];   //Offset 48
};// Total size: 48 + 10 + 2 (for alignment) = 60
```

structs are really just sets of variables at known offsets

zID (4)	5308310									
first (20)	A	b	i	r	a	m	\0			
last (20)	N	a	d	a	r	a	j	a	h	\0
program (4)	3778									
alias (10)	a	b	i	r	a	m	n	\0		

Functions

Here’s a function

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

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

Functions have “prototypes”

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

- 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! varargs c)

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`

Here's a very basic program with function

```
#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");
}
```

Declaration comes first

Definition comes later

How could we do this in MIPS?

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

Maybe we can use labels and a branch instruction “b” or jump “j” instruction.

What is the problem with this?

What if we want to call the function again???

```
#include <stdio.h>

void f(void);

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

Signature comes first

Calling function again

How do we actually call other functions?

- We use the **`jal`** instruction to call functions
- **`jal`** is a *special* 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!

Clobbering the $ra register

- We are overwriting the $ra register when we use **`jal`**
  - we can’t return properly from the main function!
  - we end up in an infinite loop!
- Maybe we could temporarily save it in a register, like $t0 and then restore it when we need it again?

Clobbering the $ra register

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  - we can’t return properly from the main function!
  - we end up in an infinite loop!
- Maybe we could temporarily save it in a register, like $t0 and then restore it when we need it again?
  - What is the worry with this?
    - The other function could change $t0
    - Functions can call functions can call functions and we have recursive functions too. How many registers would we need? We have 32 registers max…

How do we pass data 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, or arguments that don’t fit in a register.
    - However, you won’t have to deal with this in COMP1521

Implement this: Arguments

```
void f(int x);

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

void f(int x) {
  printf("in function f\n");
  printf("%d", x);
  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
  - We don't have to deal with $v1 in COMP1521

Implement this: return value

```c
int f(int x);

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

```c
int f(int x) {
  printf("in function f\n");
  printf("%d", x);
  putchar('\n');
  x = x * 2;
  return x;
}
```

There must be a better way…

We have made a mess using $t registers to

- save and restore the $ra
- save $a0 and $v0
- local variables and temporary values

This is with only a tiny program with 1 main and 1 other simple function!

There must be a more consistent way of doing this!

There must be a better way…

We could *theoretically* use global variables to preserve values

- This could still get messy
- Also 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
- If only there was another segment in memory that could help us..

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

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  - Perform computations using those arguments
  - And return a value (**`$v0`**) to a caller

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

But it gets better!

The MIPS calling conventions

- The MIPS ABI (application binary interface), lays out how different code should interact with each other
- It specifies rules on how we should be using registers to ensure compatibility between functions
- We *theoretically* could break these rules
    - However, makes it hard to have code that works interoperably with code from other sources

The MIPS calling conventions - $t registers

- $t registers are free real estate for a function
  - Functions can completely **clobber** (overwrite and destroy) 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 clobbered any values in $t registers

But the function I am calling does not even use any $t registers …

- Too bad - we MUST treat other functions like black boxes
  - We have to assume they will delete everything in our t registers.
- In fact, ‘strict’ autotesting for assignment 1 will intentionally destroy the existing values in your $t registers.

The MIPS calling convention - $s registers

- Use **$s** registers to **save** values between function calls
  - Functions **cannot** permanently change the value of a $s register
    - This includes the main function
  - This means that we can rely on our callee functions not clobbering any values we keep in $s registers

The MIPS calling convention - $s registers

- Problem solved?? Store `$ra` in a $s register?
  - But functions can call functions so we could run out of $s registers just like $t registers
- How can any function use $s registers if they can't permanently change them?

Solution: Save and restore on the stack

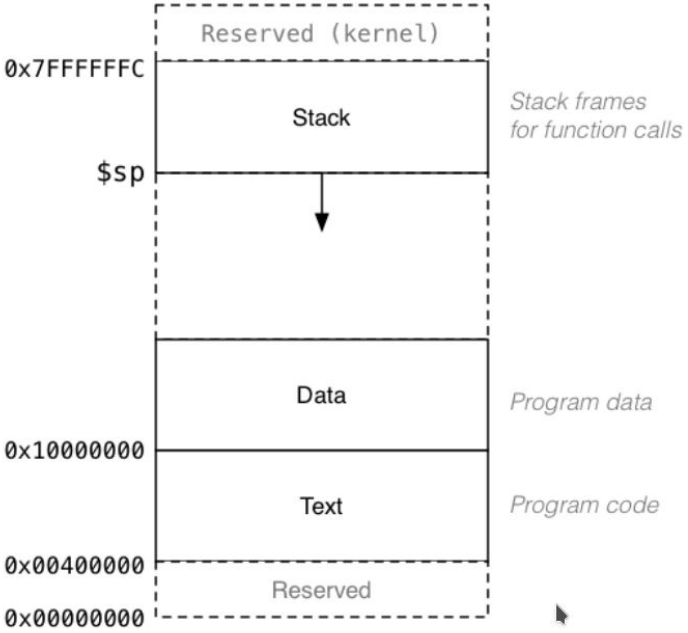
- **Solution:** functions can *temporarily* make changes to $s/$ra registers, as long as they save and restore them afterwards

- How do we do this?
  - Save the $s/$ra register's original value to RAM (the stack) at start of the function
  - Restore the $s/$ra register's original value from RAM (the stack) once complete

Saving to the Stack

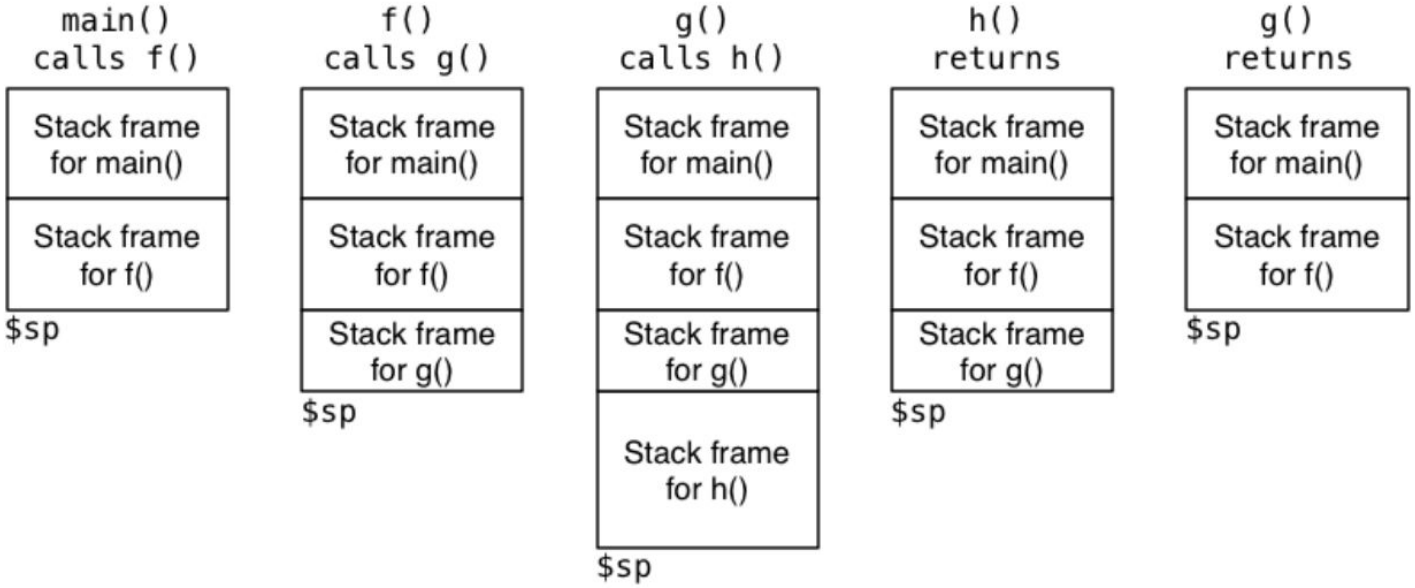
The stack

- 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

Example - $sp and the stack (the hard way)

If I subtract a total of 8 from $sp at the start of my function, and store $ra and $s0

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

I must reverse this by adding a total of 8 from $sp and restore $s0 and $ra at the end of the function

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

Example - $sp and the stack (the easy way)

- 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)

Example - $sp and the stack (the easy way)

- These are **pseudo-instructions** provided by mipsy
  - They won't work on other MIPS emulators
- This means that you can get through this course without ever directly interacting with $sp
- You may need it for challenge questions where you might store local variables or extra arguments on the stack.

Prologues and Epilogues

Prologues: 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: the end of a function's story

- 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`

Leaf Functions

- Are functions that don't call any other functions
- 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
- They do not usually *need* a prologue and epilogue in our course

Out of scope for COMP1521

- Floating point registers exist to pass/return floats/doubles
  - These have similar conventions
- The following may appear in challenges:
  - Stack is used to pass more than 4 arguments
  - Stack is 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
  - Stack is used to store local variables

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

The Frame Pointer

- 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
- We don't expect you to fully understand the frame pointer in COMP1521
- Instead, we provide you with two pseudo-instructions in mipsy
  - **begin** and **end**

The Frame Pointer: Easy Mode

- **`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`**
- Not *necessary* but makes debugging in situations where you push and pop 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

# at the end of the function
func__epilogue:
        pop     $s1
        pop     $s0
        pop     $ra
        end

        jr      $ra
```

MIPS function rules: Summary

- **`$t`** registers are free real estate
  - So we must assume that other functions destroy them
- A function must restore the original values of **`$sp`**, **`$fp`**, **`$s0`**..**`$s7`**
  - So we can assume that any function we call leaves these registers unchanged
- Functions need to preserve **`$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

What did we learn today?

- MIPS
  - recap arrays, structs
  - Functions in MIPS
- Next lecture:
  - More examples of functions in MIPS
  - A MIPS application, putting everything together

Feedback Please!

Your feedback is valuable!

If you have any feedback from today's lecture, please follow the link below or use the QR Code.

Please remember to keep your feedback constructive, so I can action it and improve your learning experience.

https://forms.office.com/r/44yfBBqDXD

Reach Out

Content Related Questions:

[Forum]

Admin related Questions email:

cs1521@cse.unsw.edu.au

Student Support | I Need Help With…

My Feelings and Mental Health Managing Low Mood, Unusual Feelings & Depression	**Mental Health Connect**	student.unsw.edu.au/**counselling** Telehealth	**In Australia Call Afterhours UNSW Mental Health Support Line**	1300 787 026 5pm-9am
	Mind HUB	student.unsw.edu.au/**mind-hub** Online Self-Help Resources	**Outside Australia Afterhours 24-hour Medibank Hotline**	+61 (2) 8905 0307
Uni and Life Pressures Stress, Financial, Visas, Accommodation & More	**Student Support** **Indigenous Student Support**	student.unsw.edu.au/**advisors**		
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