COMP1521 25T3

Week 3 Lecture 1

MIPS FUNctions

Announcements

- Help Session Schedule is out
  - COMP1521 25T3 — COMP1521 Help Sessions
  - Sessions start tomorrow! (but usually run on Mondays too)
  - BYOD as they are not in labs
- Labs 1 and 2: due **Today** 12:00 (midday)
- Assignment 1 out later this week

- Labour day public holiday Monday next week
  - Please arrange an alternate time with your tutors
    Or join another TLB (please email tutors of the TLB you wish to join for approval)

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

Topic for week 3 test: MIPS basics, control.

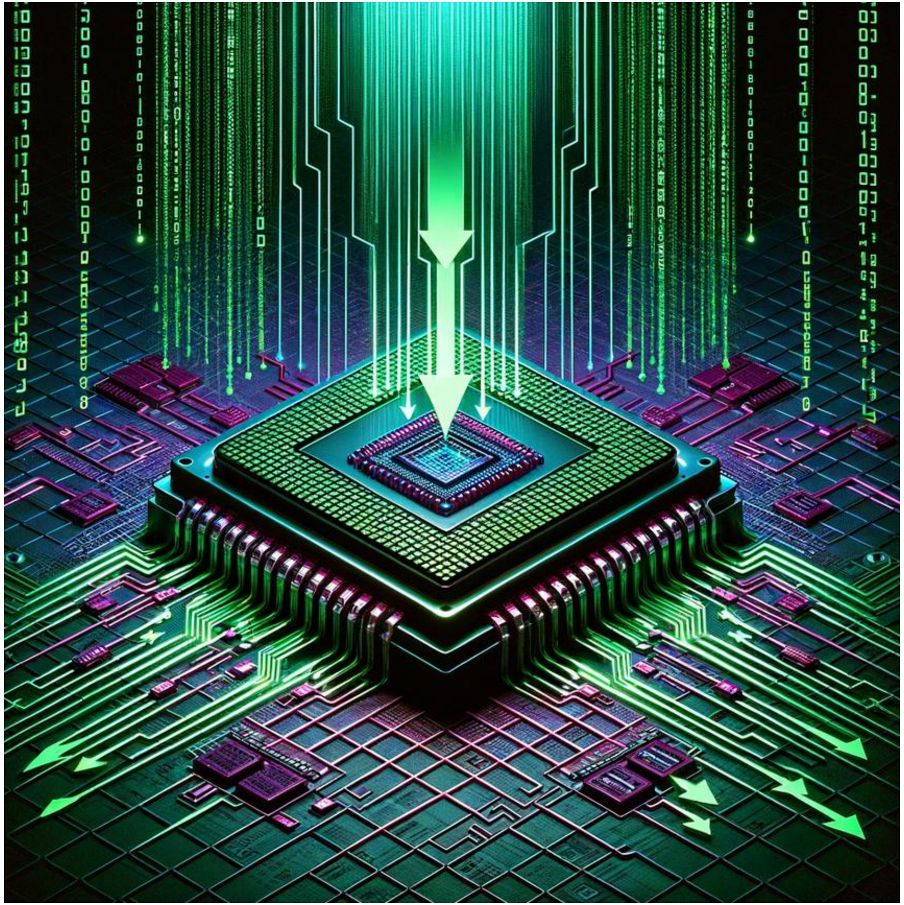
Self-enforced exam conditions!

You can use mips documentation

Today’s Lecture

- Recap last lecture
    - .data and 1D arrays
- More on .data
    - 2D Arrays
    - Structs

- Functions!



Mipsy assembler directives

```
.text                   # following instructions placed in text segment
.data                   # following objects placed in data segment

a:  .space 18           # int8_t a[18];
.align 2                # align next object on 4-byte addr
i:  .word 42            # int32_t i = 42;
v:  .word 1,3,5         # int32_t v[3] = {1,3,5};
h:  .half 2,4,6         # int16_t h[3] = {2,4,6};
b:  .byte 7:5           # int8_t b[5] = {7,7,7,7,7};
f:  .float 3.14         # float f = 3.14;
s:  .asciiz "abc"       # char s[4] {'a','b','c','\0'};
t:  .ascii "abc"        # char t[3] {'a','b','c'};
```

Recap: Address of Array Elements

char array: address of a[i] = address of a + i

integer array: address of a[i] = address of a + (i * 4)

In general:

address of element = address of array + index * sizeof(element)

2D Arrays in MIPS

```
char array2D[3][4];
```

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

^ row

RAM is really just a 1D array. A 2D array is really represented in memory with each row next to each other.

We need to map our 2 indexes to the appropriate offset

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

2D Arrays in MIPS

```
char array2D[3][4];
```

	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:

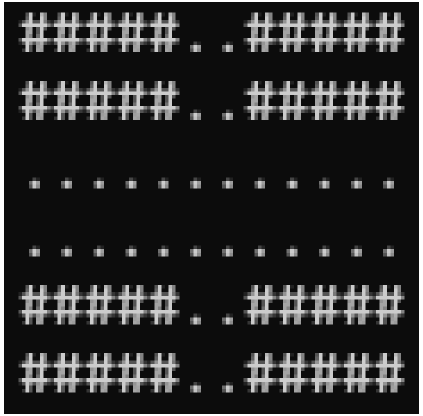
col * sizeof(element)

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

MIPS 2d array coding examples (flag.c)

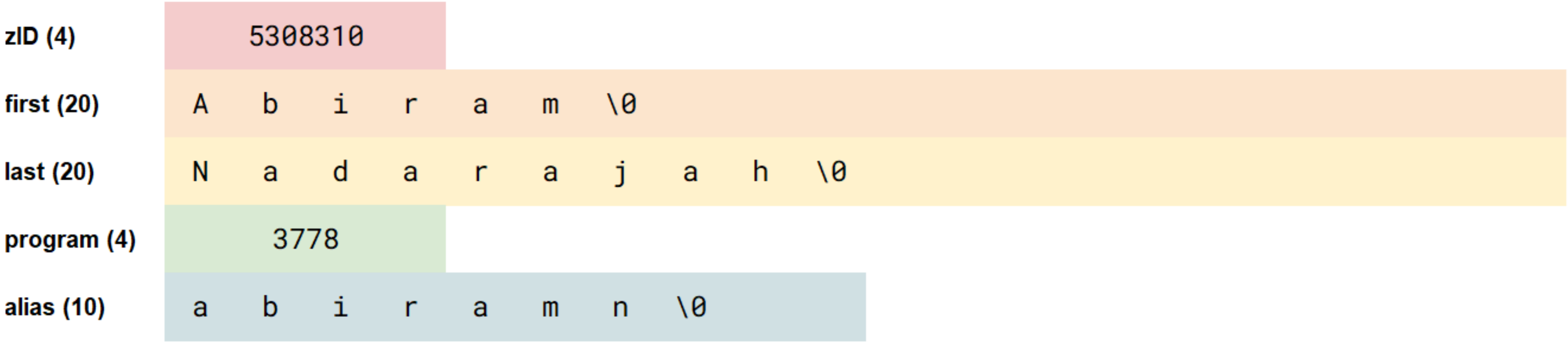


```
#####..#####
#####..#####
............
............
#####..#####
#####..#####
```

Structs

```
struct student {
    int zid;
    char first[20];
    char last[20];
    int program;
    char alias[10];
};
```

structs are really just sets of variables at known offsets

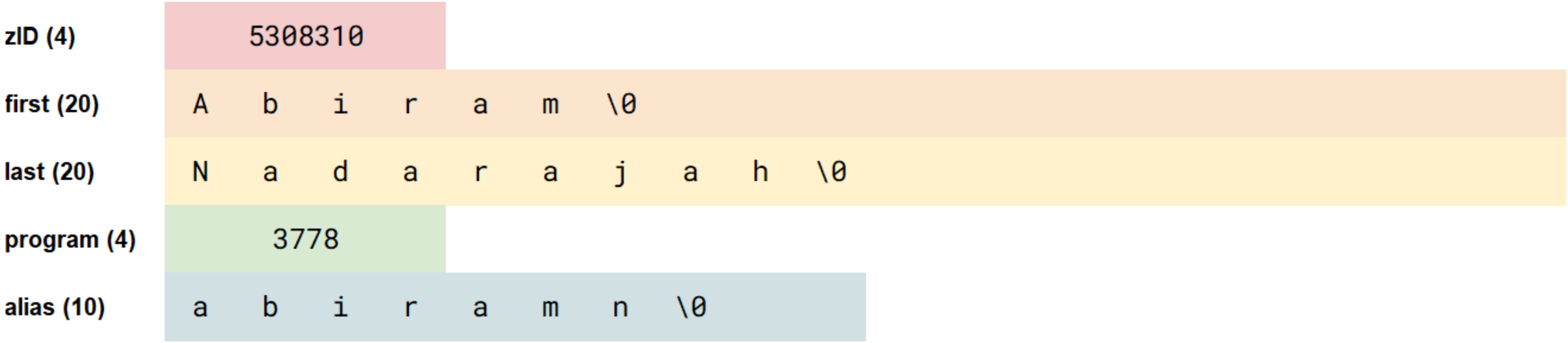


zID (4)	5308310									
first (20)	A	b	i	r	a	m	\0			
last (20)	N	a	d	a	r	a	j	a	h	\0
program (4)	3778									
alias (10)	a	b	i	r	a	m	n	\0		

Structs

```
struct student {
    int zid;            //Offset 0
    char first[20];
    char last[20];
    int program;
    char alias[10];
};
```

structs are really just sets of variables at known offsets

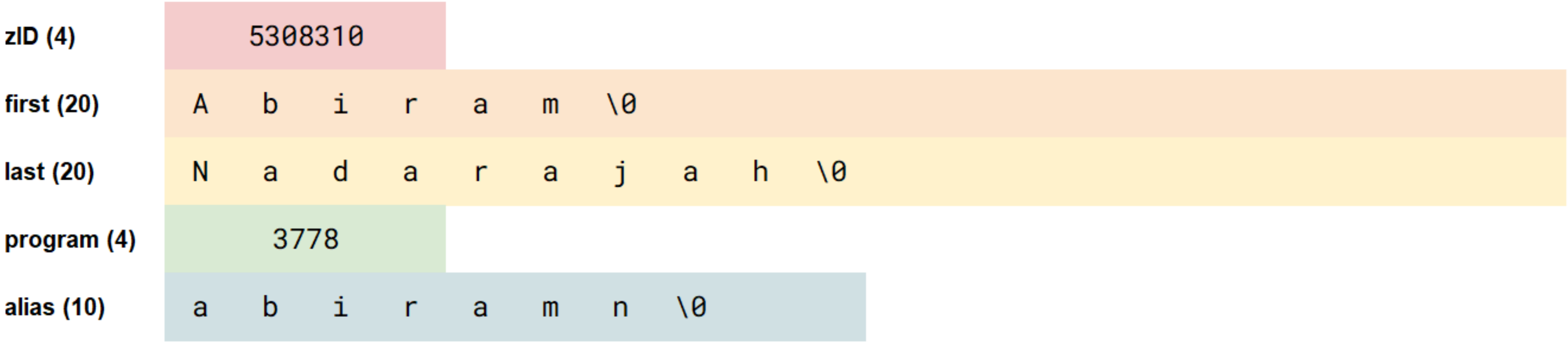


zID (4)	5308310									
first (20)	A	b	i	r	a	m	\0			
last (20)	N	a	d	a	r	a	j	a	h	\0
program (4)	3778									
alias (10)	a	b	i	r	a	m	n	\0		

Structs

```
struct student {
    int zid;           //Offset 0
    char first[20];    //Offset 0+4 = 4
    char last[20];
    int program;
    char alias[10];
};
```

structs are really just sets of variables at known offsets

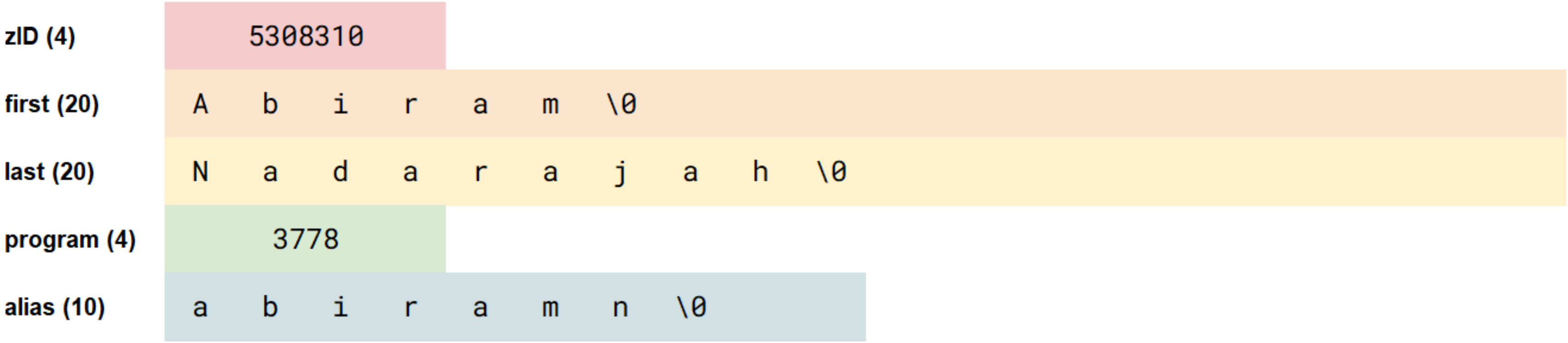


zID (4)	5308310								
first (20)	A	b	i	r	a	m	\0		
last (20)	N	a	d	a	r	a	j	a	h	\0
program (4)	3778								
alias (10)	a	b	i	r	a	m	n	\0	

Structs

```
struct student {
    int zid;            //Offset 0
    char first[20];     //Offset 4
    char last[20];      //Offset 4+20=24
    int program;
    char alias[10];
};
```

structs are really just sets of variables at known offsets

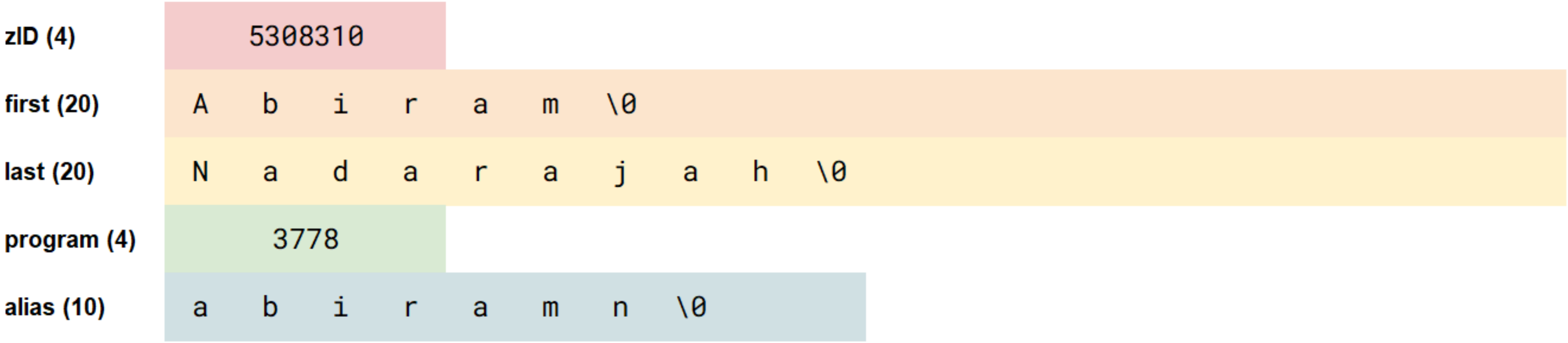


zID (4)	5308310									
first (20)	A	b	i	r	a	m	\0			
last (20)	N	a	d	a	r	a	j	a	h	\0
program (4)	3778									
alias (10)	a	b	i	r	a	m	n	\0		

Structs

```c
struct student {
    int zid;            //Offset 0
    char first[20];     //Offset 4
    char last[20];      //Offset 24
    int program;        //Offset 24+20=44
    char alias[10];
};
```

structs are really just sets of variables at known offsets

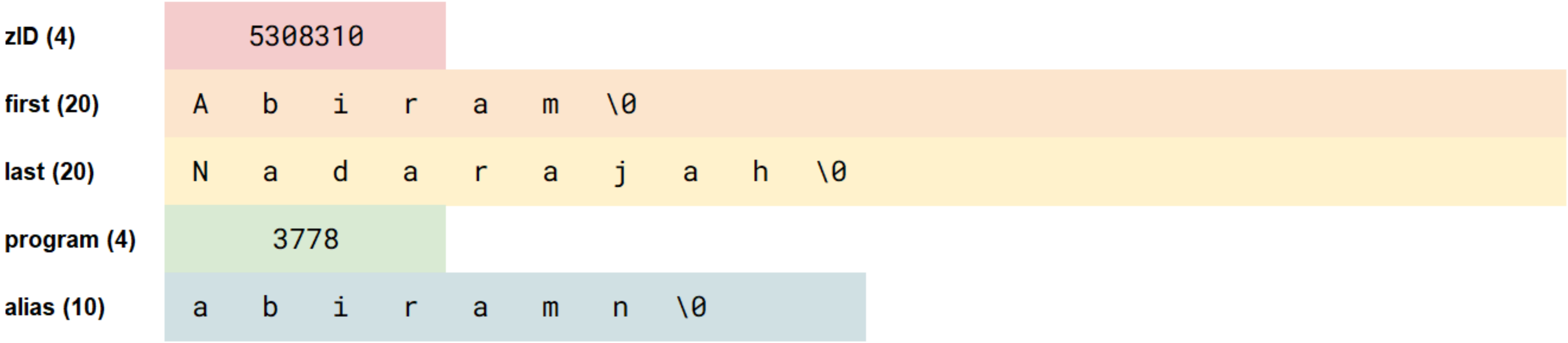


zID (4)	5308310									
first (20)	A	b	i	r	a	m	\0			
last (20)	N	a	d	a	r	a	j	a	h	\0
program (4)	3778									
alias (10)	a	b	i	r	a	m	n	\0		

Structs

```
struct student {
    int zid;            //Offset 0
    char first[20];     //Offset 4
    char last[20];      //Offset 24
    int program;        //Offset 44
    char alias[10];     //Offset 44+4=48
};
```

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

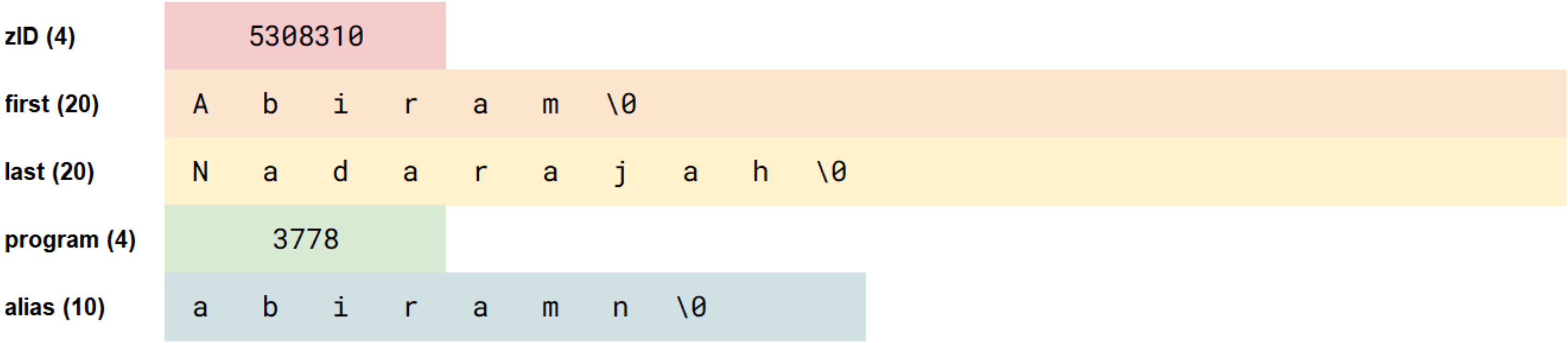
program (4) 3778

alias (10) a b i r a m n \0

Structs

```
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									
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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		

Structs

C code:

cgi.cse.unsw.edu.au/~cs1521/25T3/topic/mips_data/code/struct.c

We will jump straight to ASM today:

cgi.cse.unsw.edu.au/~cs1521/25T3/topic/mips_data/code/struct.s

More MIPS array and struct coding examples

Many more examples at:
cgi.cse.unsw.edu.au/~cs1521/25T3/topic/mips_data/code/

Try these for an exercise:
print2d.c
pointer5.c

Functions

Here’s a function

```c
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);
```

- 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, ...);
```

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

Here’s a very basic program with a 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

Demo mipsy command line

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

```c
#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;
}
```

Declaration 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`
  - 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

- 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?
  - Yes.... But...
  - Function could change $t0
    - Functions can call functions that can call functions.
    - We have recursive functions too.
    - How many registers would we need? We have 32 registers max…

Solution: Save and restore on the stack

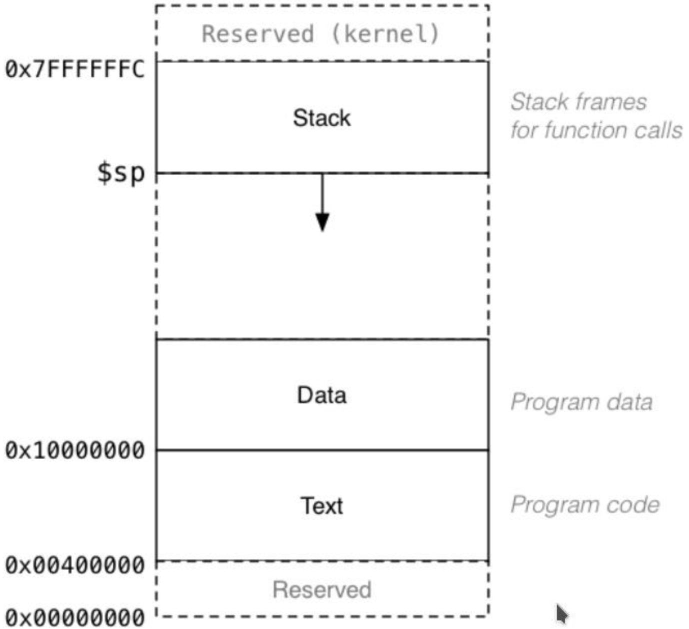
- **Solution**: functions can *temporarily* make changes to registers, as long as they save them first and restore them afterwards.

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

Saving to the Stack

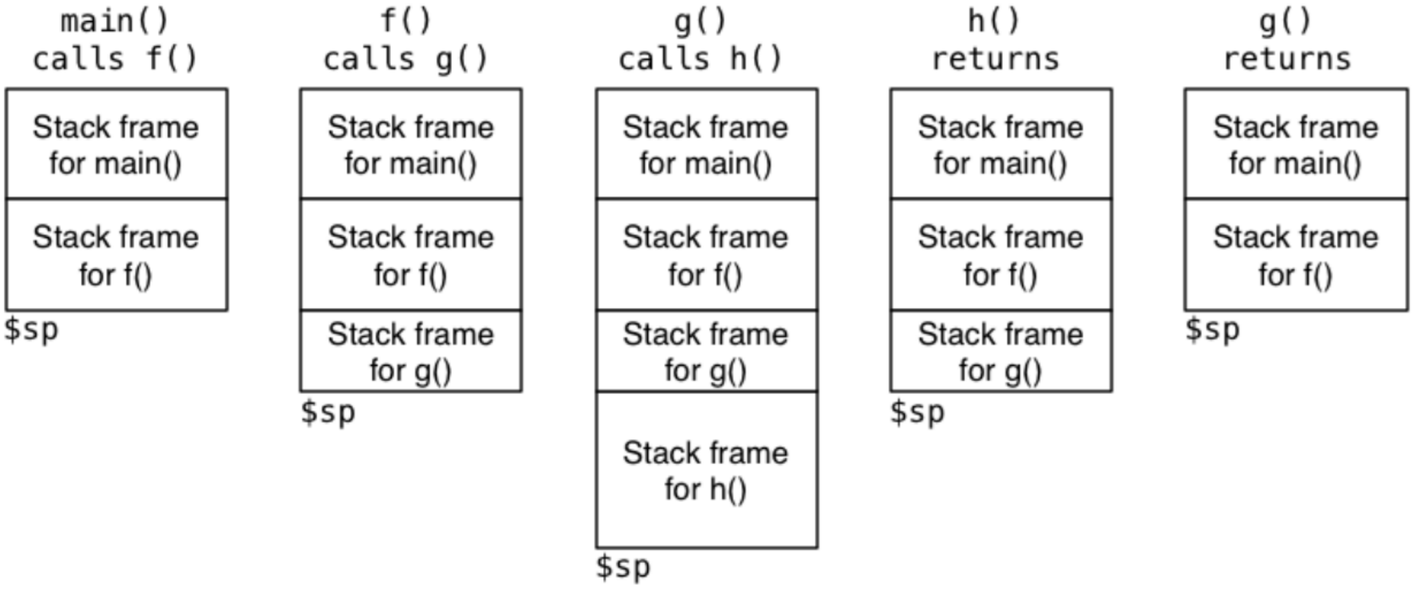
The stack

- 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, -8
sw   $ra, 0($sp)
sw   $s0, 4($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   $s0, 4($sp)
lw   $ra, 0($sp)
addi $sp, $sp, 8
```

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

- For convenience, mipsy provides us with two pseudo-instructions for stack interaction: **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)

- push/pop 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`

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`

Why only $s?

- This is by convention
- Burdensome for callee to save/restore all registers that it clobbers
- Convention:
    - Choose a limited number of registers and agree across all functions that the value in those registers must be preserved
    - Registers 16..23 ($s0..$s7) must be preserved by the callee
    - Caller ***must*** assume that other registers will be clobbered

But my function doesn’t actually clobber values in $t0 …

- 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.

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 use $s registers
  - We only use $s registers when we want to preserve a value across a function call
  - Leaf functions don't have any function calls within them (by definition), so they can assume $t registers are never clobbered
- So leaf functions do not *need* a prologue and epilogue

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 in general)
  - 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
```

Passing arguments and returning values

How do we pass data to/from a function??

- Registers keep their value across function calls
- We could use any registers that we like to pass values!
  - What if all functions expected arguments in different registers?
  - What if we edit a function to use different registers?
  - This could lead to confusion...
  - And fragile code...

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 - $t registers

- $t registers are free real estate for a function
  - Functions can clobber any existing values in a $t register
  - Callers must assume that called functions have clobbered $t

The MIPS calling convention - $s registers

- Functions **cannot** permanently change the value of an $s register

- This means that we can rely on our callee functions to save values in $s registers before they are used and restore them before returning.

Passing data to a function

- We use the $a registers to pass in arguments
    - We have $a0 - $a3 – four registers to pass in arguments

Out of scope for COMP1521:

- Using the stack if we have more than 4 arguments, or arguments don’t fit in a register (structs).
- Floating point registers to pass/return floats/doubles

Implement this: Arguments

```c
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 of 32-bits (or fewer) should be returned using $v0
  - Values of 64-bits should also use $v1
    (But 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 + 1;
  return x;
}
```

Functions - a summary

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

MIPS ABI: 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 (e.g. using `jal`)
  - 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
  - 2D arrays, structs
  - Functions in MIPS

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

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
	Mind HUB	student.unsw.edu.au/**mind-hub** Online Self-Help Resources
	In Australia Call Afterhours UNSW Mental Health Support Line	1300 787 026 5pm-9am
	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**
Reporting Sexual Assault/Harassment	**Equity Diversity and Inclusion (EDI)**	— edi.unsw.edu.au/**sexual-misconduct**
Educational Adjustments To Manage my Studies and Disability / Health Condition	**Equitable Learning Service (ELS)**	— student.unsw.edu.au/**els**
Academic and Study Skills	**Academic Language Skills**	— student.unsw.edu.au/**skills**
Special Consideration Because Life Impacts our Studies and Exams	Special Consideration	— student.unsw.edu.au/**special-consideration**