MIPS Functions

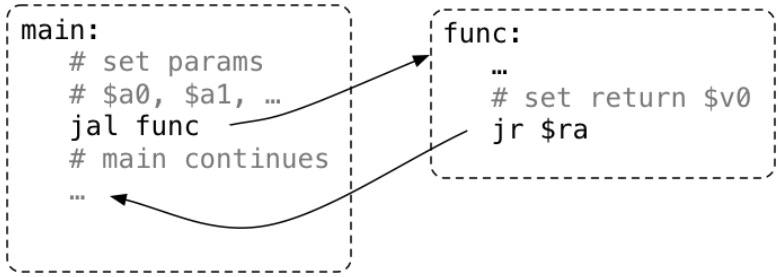
When we call a function:

- the arguments are evaluated and set up for function
- control is transferred to the code for the function
- local variables are created
- the function code is executed in this environment
- the return value is set up
- control transfers back to where the function was called from
- the caller receives the return value

Function Calls

Simple view of function calls:

- load argument values into $a0..
- invoke : loads PC+4 into $ra, jumps to function
- function puts return value in $v0
- returns to caller using $ra



Function with No Parameters or Return Value

- **jal hello** sets **$ra** to address of following instruction and transfers execution to **hello**
- **jr $ra** transfers execution to the address in **$ra**

```
int main(void) {
    hello();
    return 0;
}

void hello(void) {
    printf("hi\n");
}
```

```
main:
    ...
    jal  hello
    ...
hello:
    la $a0, string
    li $v0, 4
    syscall
    jr $ra
    .data
string:
    .asciiz "hi\n"
```

Function with a Return Value but No Parameters

- by convention return value is passed back in *$v0*

```
int main(void) {
    int a = answer();
    printf("%d\n", a);
    return 0;
}

int answer(void) {
    return 42;
}
```

```
main:
    ...
    jal  answer
    move $a0, $v0
    li   $v0, 1
    syscall
    ...
answer:
    li $v0, 42
    jr $ra
```

Function with a Return Value and Parameters

- by convention first 4 parameters passed in **$a0 .. $a3**
- if there are more parameters they are passed on the stack

```
int main(void) {
    int a = product(6, 7);
    printf("%d\n", a);
    return 0;
}

int product(int x, int y) {
    return x * y;
}
```

```
main:
    ...
    li   $a0, 6
    li   $a1, 7
    jal  product
    move $a0, $v0
    li   $v0, 1
    syscall
    ...
product:
    mul  $v0, $a0, $a1
    jr   $ra
```

Function calling another function - How NOT to Do It

- a function that calls another function must save **$ra**
- in the example below **jr $ra** in main will fail because **jal hello** changed **$ra**

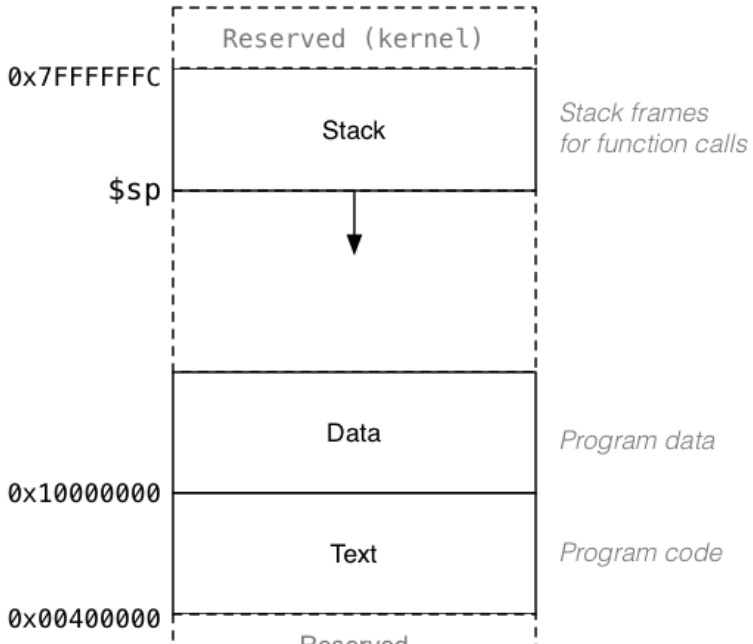
```
int main(void) {
    hello();
    return 0;
}

void hello(void) {
    printf("hi\n");
}
```

```
main:
    jal  hello
    li $v0, 0
    # THIS WILL FAIL
    jr $ra
hello:
    la $a0, string
    li $v0, 4
    syscall
    jr $ra
    .data
string: .asciiz "hi\n"
```

more_calls.c more_calls.s

Stack - Where it is in Memory

Data associated with a function call placed on the stack:



Stack - Allocating Space

- $sp (stack pointer) initialized by operating system
- always 4-byte aligned (divisible by 4)
- points at currently used (4-byte) word
- grows downward
- a function can do this to allocate 40 bytes:

```
sub  $sp, $sp, 40     # move stack pointer down
```

- a function **must** leave $sp at original value
- so if you allocated 40 bytes, before return (**jr $ra**)

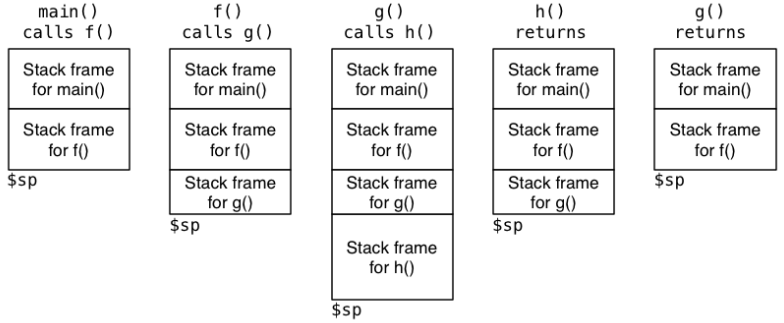
```
add  $sp, $sp, 40     # move stack pointer back
```

Stack - Using stack to Save/Restore registers

```
f:
    sub  $sp, $sp, 12    # allocate 12 bytes
    sw   $ra, 8($sp)     # save $ra on $stack
    sw   $s1, 4($sp)     # save $s1 on $stack
    sw   $s0, 0($sp)     # save $s0 on $stack

    ...

    sw   $s0, 0($sp)     # restore $s0 from $stack
    sw   $s1, 4($sp)     # restore $s1 from $stack
    sw   $ra, 8($sp)     # restore $ra from $stack
    add  $sp, $sp, 12    # move stack pointer back
    jr   $ra             # return
```

Stack - Growing & Shrinking

How stack changes as functions are called and return:



Function calling another function - How to Do It

- a function that calls another function must save **$ra**

```
main:
    sub  $sp, $sp, 4     # move stack pointer down
                         # to allocate 4 bytes
    sw   $ra, 0($sp)     # save $ra on $stack

    jal  hello           # call hello

    lw   $ra, 0($sp)     # recover $ra from $stack
    add  $sp, $sp, 4     # move stack pointer back up
                         # to what it was when main called
    li   $v0, 0          # return 0
    jr   $ra             #
```

MIPS Register usage conventions

- **$a0..$a3** contain first 4 arguments
- **$v0** contains return value
- **$ra** contains return address
- if function changes **$sp**, **$fp**, **$s0..$s7** it restores their value
- callers assume **$sp**, **$fp**, **$s0..$s7** unchanged by call (**jal**)
- a function may destroy the value of other registers e.g. **$t0..$t7**
- callers must assume value in e.g. **$t0..$t7** changed by call (**jal**)

MIPS Register usage conventions - not covered in COMP1521

- floating point registers used to pass/return float/doubles
- similar conventions for saving floating point registers
- stack used to pass arguments after first 4
- stack used to pass arguments which do not fit in register
- stack used to return value which do not fit in register
- for example C argument or return value can be a struct, which is any number of bytes

Storing A Local Variables On the Stack

- some local (function) variables must be stored on stack
- e.g. variables such as arrays and structs

```c
int main(void) {
    int squares[10];
    int i = 0;
    while (i < 10) {
        squares[i] = i * i;
        i++;
    }
```

```
main:
    sub  $sp, $sp, 40
    li   $t0, 0
loop0:
    mul  $t1, $t0, 4
    add  $t2, $t1, $sp
    mul  $t3, $t0, $t0
    sw   $t3, ($t2)
    add  $t0, $t0, 1
    b    loop0
end0:
```

What is a Frame Pointer

- frame pointer **$fp** is a second register pointing to stack
- by convention set to point at start of stack frame
- provides a fixed point during function code execution
- useful for functions which grow stack (change **$sp**) during execution
- makes it easier for debuggers to forensically analyze stack
- e.g if you want to print stack backtrace after error
- frame pointer is optional (in COMP1521 and generally)
- often omitted when fast execution or small code a prioirity

Example of Growing Stack Breaking Function Return

```c
void f(int a) {
    int length;
    scanf("%d", &length);
    int array[length];
    // ... more code ...
}
```

```
f:
    sub  $sp, $sp, 4
    sw   $ra, 0($sp)
    li   $v0, 5
    syscall
    # allocate space for
    # array on stack
    mul  $t0, $v0, 4
    sub  $sp, $sp, $t0
    # ... more code ...
    # breaks because $sp
    # has changed
    lw   $ra, 0($sp)
    add  $sp, $sp, 4
    jr   $ra
```

Example of Frame Point Use

```c
void f(int a) {
    int length;
    scanf("%d", &length);
    int array[length];
    // ... more code ...
}
```

```
f:
    sub  $sp, $sp, 8
    sw   $fp, 4($sp)
    sw   $ra, 0($sp)
    add  $fp, $sp, 8
    li   $v0, 5
    syscall
    mul  $t0, $v0, 4
    sub  $sp, $sp, $t0
    # ... more code ...
    lw   $ra, -4($fp)
    move $sp, $fp
    lw   $fp, 0($fp)
    jr   $ra
```