CS2106
Introduction to OS

Tutorial 1

Question 1

- Write the following C program in MIPS assembly.

- Pass parameters using registers instead of stack frames.

Question 1

C

```
int a=3, b=4, y;

int main(){
      y=f(a,b)
}
```

MIPS

```
main: la   $t0, a       ;
      lw   $a0, 0($t0)  ;
      la   $t0, b       ;
      lw   $a1, 0($t0)  ;
      jal  f            ;
      la   $t0, y       ;
      sw   $v0, 0($t0)  ;
```

Load a

Load b

Call f

Question 1

C

```
int f(int x,y){
      return 2*(x+y);
}
```

MIPS

```
f:     add $t1, $a0, $a1     ;
       sll $v0, $t1, 1       ;
       jr  $ra               ;
```

x+y

2*(x+y)

Question 2

- Write the following C program in MIPS assembly.

- Use the stack to pass arguments and results instead of `$a0`, `$a1`, and `$v0`.

Question 2

- Pushing `$r0` to stack:

```
sw $r0, 0($sp)
addi $sp, $sp, 4
```

- Popping to `$s0` from from stack

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

Question 2

C

```
int a=3, b=4, y;

int main(){
      y=f(a,b)
}
```

MIPS

```
main: addi $fp, $sp, 0;
      addi $sp, $sp, 8;
```

Save $sp

Reserve 2 integers on stack for stack frame
Note that each integer is 4 bytes

Question 2

C

```
int a=3, b=4, y;

int main(){
      y=f(a,b)
}
```

MIPS

```
main: la   $t0, a       ;
      lw   $t0, 0($t0)  ;
      sw   $t0, 0($fp)  ;
      la   $t0, b       ;
      lw   $t0, 0($t0)  ;
      sw   $t0, 4($fp)  ;
      jal  f            ;
```

Write a to stack frame

Write b to stack frame

Question 2

C

```c
int f(int x,y){
        return 2*(x+y);
}
```

MIPS

```
f:      lw   $t0, 0($fp)          ;
        lw   $t1, 4($fp)          ;
        add  $v0, $t0, $t1        ;
        sll  $v0, $v0, 1          ;
        sw   $v0, 0($fp)          ;
        jr   $ra                  ;
```

Load parameters from stack frame

Save result to stack frame

Question 2

C

```
int a=3, b=4, y;

int main(){
      y=f(a,b)
}
```

MIPS

```
main: lw    $t1, 0($fp)        ;
      la    $t0, y             ;
      sw    $t1, 0($t0)        ;
      addi  $sp, $s0, -8       ;
      li    $v0, 10            ;
      syscall                  ;
```

Get results from stack frame

Pop off stack frame

Question 3

- Can your approach in Questions 1 and 2 above work for recursive or even nested function calls?

- Explain why or why not.

Question 3

MIPS

```
main: jal f

f:    jal g
      jr $ra

g:    jr $ra
```

$ra back to main is overwritten with return address of f

Where does $ra lead to now?

- $ra is not saved
- $ra is overwritten if f calls another function

Question 4

- Use a proper stack frame to implement our function call from Question 1.

- Our stack frame looks like this when calling a function:

Saved registers
$ra
Parameter n
…
Parameter 2
Paremeter 1
Saved `$sp`
Saved `$fp`

Question 4

Caller:	1. Push `$fp` and `$sp` to stack
	2. Copy `$sp` to `$fp`
	3. Reserve sufficient space on stack for parameters by adding to `$sp`
	4. Write parameters to stack using offsets from `$fp`
	5. `jal` to callee
Callee:	1. Push `$ra` to stack
	2. Allocate enough space for local variables.
	3. Push registers we intend to use onto the stack
	4. Use `$fp` to access parameters
	5. Compute result
	6. Write result to stack
	7. Restore registers we saved from the stack
	8. Get `$ra` from the stack
	9. Return to caller by doing `jr $ra`
Caller	1. Get result from stack
	2. Restore `$sp` and `$fp`

Question 4

- Caller needs to reserve 20 bytes:
  - 8 bytes for `$sp` and `$fp`
  - 8 bytes to pass a and b
  - 4 bytes for callee to save `$ra`

Offset from `$fp`	Contents
0	`$fp`
4	`$sp`
8	a
12	b
16	`$ra`

Question 4

C

```c
int a=3, b=4, y;

int main(){
    y=f(a,b)
}
```

MIPS

```
main: sw $fp, 0($sp)          ;
      mov $fp, $sp            ;
      sw $sp, 4($sp)          ;
      addi $sp, $sp, 20       ;
```

Save $fp

Copy $sp to $fp

Save $sp to stack frame

Reserve 20 bytes on stack frame

Question 4

C

```
int a=3, b=4, y;

int main(){
      y=f(a,b)
}
```

MIPS

Same logic as before (Question 2)

```
main: la   $t0, a        ;
      lw   $t0, 0($t0)  ;
      sw   $t0, 8($fp)  ;
      la   $t0, b        ;
      lw   $t0, 0($t0)  ;
      sw   $t0, 12($fp) ;
      jal  f             ;
```

Question 4

C

```c
int f(int x,y){
      return 2*(x+y);
}
```

MIPS

```
f:    sw   $ra, 16($fp)      ;
      addi $sp, $sp, 8       ;
      sw   $t0, 20($fp)      ;
      sw   $t1, 24($fp)      ;
```

Save `$ra`

Reserve 8 bytes on stack to store registers we want to use for `f`

Save `$t0` and `$t1` which we will use

Question 4

C

```
int f(int x,y){
      return 2*(x+y);
}
```

MIPS

Same logic as before

Store result to stack frame

```
f:    lw   $t0, 8($fp)        ;
      lw   $t1, 12($fp)       ;
      add  $t1, $t0, $t1      ;
      sll  $t1, $t1, 1        ;
      sw   $t1, 8($fp)        ;
```

Question 4

C

```
int f(int x,y){
      return 2*(x+y);
}
```

MIPS

```
f:    lw   $t0, 20($fp)        ;
      lw   $t1, 24($fp)        ;
      addi $sp, $sp, -8        ;
      lw    $ra, 16($fp)       ;
      jr   $ra                 ;
```

Restore $t0 and $t1

Deallocate space on stack

Restore $ra

Question 4

C

```
int a=3, b=4, y;

int main(){
      y=f(a,b)
}
```

MIPS

```
main: lw    $t0, 8($fp)        ;
      la    $t1, y             ;
      sw    $t0, 0($t1)        ;
      lw    $sp, 4($fp)        ;
      lw    $fp, 0($fp)        ;
      li    $v0, 10            ;
      syscall                  ;
```

Restore $sp

Restore $fp

Question 5

- In Question 4, the callee saved registers it intends to use onto the stack and restores them after that.
- What would happen if the callee does not do that?

Question 4

Caller:	1. Push `$fp` and `$sp` to stack
	2. Copy `$sp` to `$fp`
	3. Reserve sufficient space on stack for parameters by adding to `$sp`
	4. Write parameters to stack using offsets from `$fp`
	5. `jal` to callee
Callee:	1. Push `$ra` to stack
	2. Allocate enough space for local variables.
	3. Push registers we intend to use onto the stack
	4. Use `$fp` to access parameters
	5. Compute result
	6. Write result to stack
	7. Restore registers we saved from the stack
	8. Get `$ra` from the stack
	9. Return to caller by doing `jr $ra`
Caller	1. Get result from stack
	2. Restore `$sp` and `$fp`

Why?

Question 5

- In Question 4, the callee saved registers it intends to use onto the stack and restores them after that.

- What would happen if the callee does not do that?

- The callee does not know what registers the caller is using, and thus **may accidentally overwrite the contents of a register** that the caller was using. By saving and restoring the registers it intends to use, it **prevents errors from happening**.

Question 5

- In Question 4, the callee saved registers it intends to use onto the stack and restores them after that.

- Why don't we do the same thing for main?

Question 5

- In Question 4, the callee saved registers it intends to use onto the stack and restores them after that.
- Why don't we do the same thing for main?
- Main is likely to be invoked by the OS.
- The OS would have saved the registers needed during context switching.

Question 6

- Explain why, in step 8 of the callee, we retrieve `$ra` from the stack before doing `jr $ra`. Why can't we just do `jr $ra` directly?

Question 4

Caller:	1. Push `$fp` and `$sp` to stack
	2. Copy `$sp` to `$fp`
	3. Reserve sufficient space on stack for parameters by adding to `$sp`
	4. Write parameters to stack using offsets from `$fp`
	5. `jal` to callee
Callee:	1. Push `$ra` to stack
	2. Allocate enough space for local variables.
	3. Push registers we intend to use onto the stack
	4. Use `$fp` to access parameters
	5. Compute result
	6. Write result to stack
	7. Restore registers we saved from the stack
	8. Get `$ra` from the stack
	9. Return to caller by doing `jr $ra`
Caller	1. Get result from stack
	2. Restore `$sp` and `$fp`

Why?

Question 6

- Explain why, in step 8 of the callee, we retrieve `$ra` from the stack before doing `jr $ra`. Why can't we just do `jr $ra` directly?

- Calling another function would overwrite `$ra`.

- Saving and restoring `$ra` lets us support nesting and recursion.

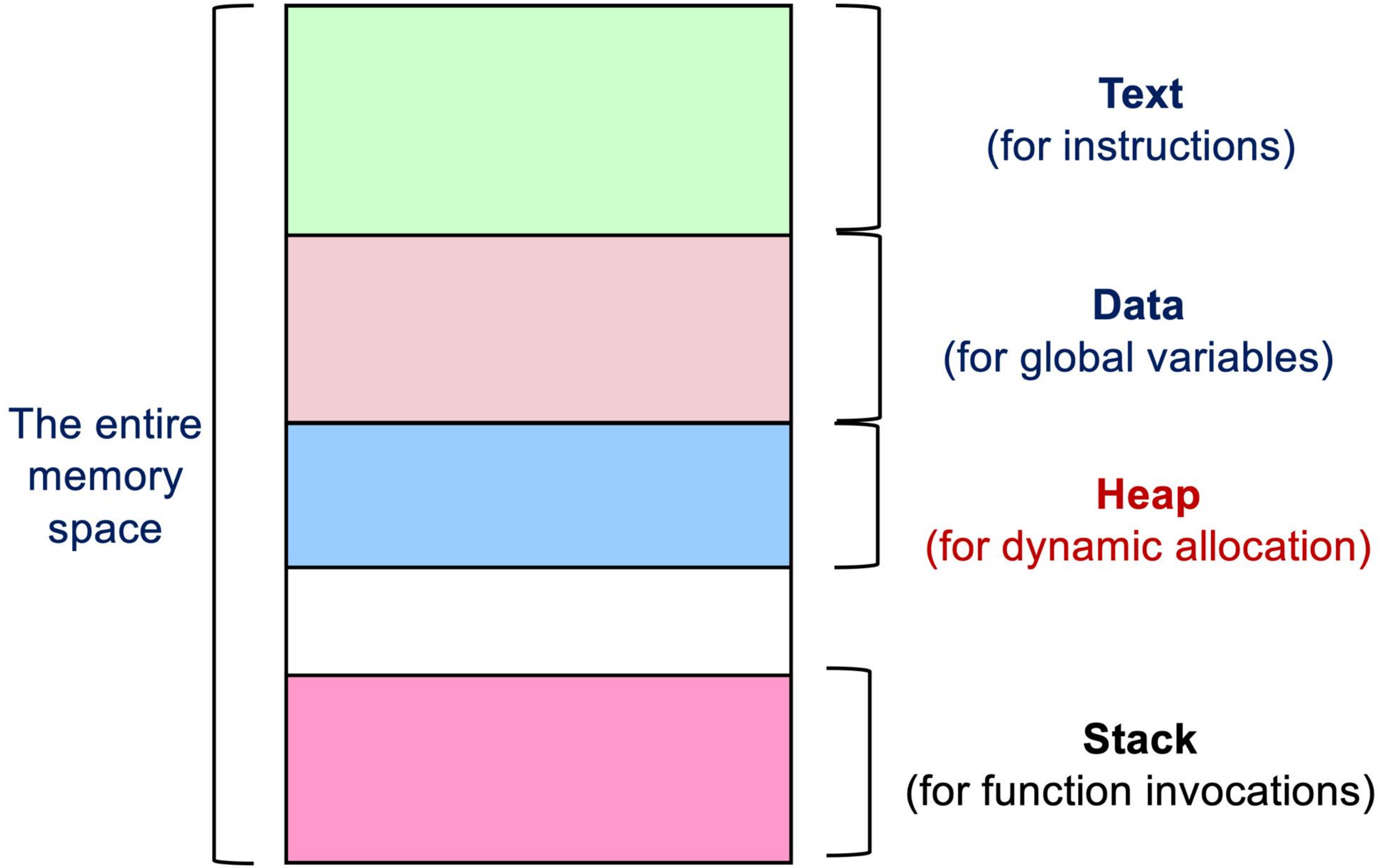
- (See Question 3)

Question 7

- Indicate in which part of a process is each of the following stored or created.

Item	Where it is stored / created
`a`	
`*a`	
`b`	
`c`	
`x`	
`y`	
`z`	
`fun1`’s return result	
`main`’s code	
Code for `f`	

Question 7



The entire memory space
Text
(for instructions)
Data
(for global variables)
Heap
(for dynamic allocation)
Stack
(for function invocations)

Question 7

- Code is stored in Text

Item	Where it is stored / created
`a`	
`*a`	
`b`	
`c`	
`x`	
`y`	
`z`	
`fun1`'s return result	
`main`'s code	Text
Code for `f`	Text

Question 7

```
int fun1(int x, int y) {
    int z = x + y;
    return 2 * (z-3);
}

int c;
```

`x, y, z:`
Information for functional invocations are stored in Stack memory

c:
Global variables are stored in Data

Question 7

```
int main() {
    int *a=NULL, b=5;
    a = (int*)malloc(sizeof(int));
    *a=3;
    c=fun1(*a,b);
}
```

c:
Information for functional invocations are stored in Stack memory

*a:
Dynamically allocated memory is stored in Heap memory

Question 7

- Information required for function invocation is stored in Stack memory

Item	Where it is stored / created
`a`	Stack
`*a`	Heap
`b`	Stack
`c`	Data memory
`x`	Stack
`y`	Stack
`z`	Stack
`fun1`'s return result	Stack
`main`'s code	Text
Code for `f`	Text

The End

```
li $v0, 10;
syscall
```