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UCB CS61C : Machine Structures

Lecture 11 – Introduction to MIPS Procedures II & Logical Ops

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VIRTUAL HUMANS…

Prof **Paul Debevec** (UC Berkeley PhD 1996) at USC has been working to create virtual humans to keep alive the memory AND INTERACTIONS w/people into a 3D hologram. He is recording the Holocaust survivors, who tell their story, answering 500 questions about themselves. They're in a race against time…

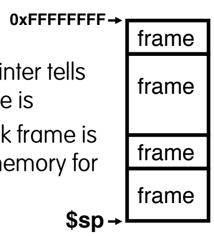
www.washingtonpost.com/national/holograms-seen-as-tools-to-teach-future-generations-about-holocaust-retell-survivors-stories/2013/02/02/558cab32-6d58-11e2-8f4f-2abd96162ba8_story_1.html

Review

- Functions called with **`jal`**, return with **`jr $ra`**.
- The stack is your friend: Use it to save anything you need. Just leave it the way you found it!
- Instructions we know so far…
  - Arithmetic: **`add, addi, sub, addu, addiu, subu`**
  - Memory: **`lw, sw, lb, sb`**
  - Decision: **`beq, bne, slt, slti, sltu, sltiu`**
  - Unconditional Branches (Jumps): **`j, jal, jr`**
- Registers we know so far
  - All of them!
  - There are CONVENTIONS when calling procedures!

The Stack (review)

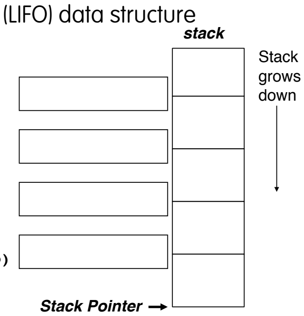
- Stack frame includes:
  - Return "instruction" address
  - Parameters
  - Space for other local variables
- Stack frames contiguous blocks of memory; stack pointer tells where bottom of stack frame is
- When procedure ends, stack frame is tossed off the stack; frees memory for future stack frames



Stack

- Last In, First Out (LIFO) data structure

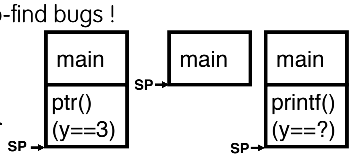
```
main ()
{ a(0);
}
  void a (int m)
  { b(1);
  }
    void b (int n)
    { c(2);
    }
      void c (int o)
      { d(3);
      }
        void d (int p)
        {
        }
```



Who cares about stack management?

- Pointers in C allow access to deallocated memory, leading to hard-to-find bugs !

```
int *ptr () {
   int y;
   y = 3;
   return &y; }
 main () {
   int *stackAddr,content;
   stackAddr = ptr();
   content = *stackAddr;
   printf("%d", content);  /* 3 */
   content = *stackAddr;
   printf("%d", content); }/*13451514 */
```



Memory Management

- How do we manage memory?
- Code, Static storage are easy: they never grow or shrink
- Stack space is also easy: stack frames are created and destroyed in last-in, first-out (LIFO) order
- Managing the heap is tricky: memory can be allocated / deallocated at any time

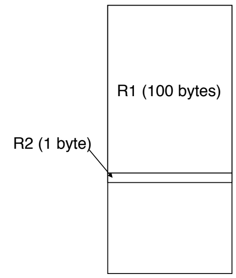
Heap Management Requirements

- Want **`malloc()`** and **`free()`** to run quickly.
- Want minimal memory overhead
- Want to avoid *fragmentation**–
  when most of our free memory is in many small chunks
  - In this case, we might have many free bytes but not be able to satisfy a large request since the free bytes are not contiguous in memory.

* This is technically called *external fragmention*

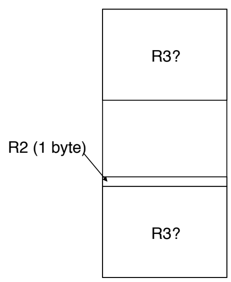
Heap Management

- An example
  - Request R1 for 100 bytes
  - Request R2 for 1 byte
  - Memory from R1 is freed
  - Request R3 for 50 bytes



Heap Management

- An example
  - Request R1 for 100 bytes
  - Request R2 for 1 byte
  - Memory from R1 is freed
    - Memory has become fragmented!
    - We have to keep track of the two *freespace* regions
  - Request R3 for 50 bytes
    - We have to search the data structures holding the freespace to find one that will fit! Choice here...



Administrivia

- Project update
  - Quick Peer Instruction question: how are you doing the project?
    - a) [0, 20%) done
    - b) [20, 40%) done
    - c) [40, 60%) done
    - d) [60, 80%) done
    - e) [80, 100%] done
- TAs, anything?

Register Conventions (1/4)

- Calle<u>R</u>: the calling function
- Calle<u>E</u>: the function being called
- When callee returns from executing, the caller needs to know which registers may have changed and which are guaranteed to be unchanged.
- Register Conventions: A set of generally accepted rules as to which registers will be unchanged after a procedure call (**`jal`**) and which may be changed.

Register Conventions (2/4) – saved

- **`$0`**: No Change. Always `0`.
- **`$s0-$s7`**: Restore if you change. Very important, that's why they're called <u>saved</u> registers. If the <u>callee</u> changes these in any way, it must restore the original values before returning.
- **`$sp`**: Restore if you change. The stack pointer must point to the same place before and after the **`jal`** call, or else the caller won't be able to restore values from the stack.
- HINT -- All saved registers start with S!

Register Conventions (2/4) – volatile

- **$ra**: Can Change. The `jal` call itself will change this register. Caller needs to save on stack if nested call.
- **$v0-$v1**: Can Change. These will contain the new returned values.
- **$a0-$a3**: Can change. These are volatile argument registers. Caller needs to save if they are needed after the call.
- **$t0-$t9**: Can change. That's why they're called temporary: any procedure may change them at any time. Caller needs to save if they'll need them afterwards.

Register Conventions (4/4)

- What do these conventions mean?
  - If function R calls function E, then function R must save any temporary registers that it may be using onto the stack before making a **`jal`** call.
  - Function E must save any S (saved) registers it intends to use before garbling up their values, and restore them after done garbling
- Remember: caller/callee need to save only temporary/saved registers they are using, not all registers.

Peer Instruction

```
r: ...     # R/W $s0,$v0,$t0,$a0,$sp,$ra,mem
   ...     ### PUSH REGISTER(S) TO STACK?
   jal e   # Call e
   ...     # R/W $s0,$v0,$t0,$a0,$sp,$ra,mem
   jr $ra  # Return to caller of r

e: ...     # R/W $s0,$v0,$t0,$a0,$sp,$ra,mem
   jr $ra  # Return to r
```

What does **`r`** have to push on the stack before "**`jal e`**"?

```
a)  1 of ($s0,$sp,$v0,$t0,$a0,$ra)
b)  2 of ($s0,$sp,$v0,$t0,$a0,$ra)
c)  3 of ($s0,$sp,$v0,$t0,$a0,$ra)
d)  4 of ($s0,$sp,$v0,$t0,$a0,$ra)
e)  5 of ($s0,$sp,$v0,$t0,$a0,$ra)
```


"And in Conclusion…"

- Register Conventions: Each register has a purpose and limits to its usage. Learn these and follow them, even if you're writing all the code yourself.
- Logical and Shift Instructions
  - Operate on bits individually, unlike arithmetic, which operate on entire word.
  - Use to isolate fields, either by masking or by shifting back and forth.
  - Use shift left logical, **`sll`**, for multiplication by powers of 2
  - Use shift right logical, **`srl`**, for division by powers of 2 of unsigned numbers (**`unsigned int`**)
  - Use shift right arithmetic, **`sra`**, for division by powers of 2 of signed numbers (**`int`**)
- New Instructions:
  `and, andi, or, ori, sll, srl, sra`