Chapter 10

The Stack and More...

Next Semester

Yes

- **CSE 121/131: Programming Languages and Techniques II**
- **CSE 260: Math. Foundations of CS**
- **CSE 371/372: Digital Systems Organization and Design**

Maybe

- **CSE 112: Networked Life**
- **CSE 313: Computational Linear Algebra (Math 114)**
- **CSE 341: Intro. to Compilers and Interpreters (120/121, 260,time change!)**
- **CSE 377: Virt. World Design (no freshman, strong programming)**
- **CSE 391: Introduction to Artificial Intelligence (121, 262?)**
- **CSE 399/001: Computer Vision (anal. geom, lin. alg., Math 114,115, 240, or perm)**

Probably not

- **CSE 320: Introduction to Algorithms (262 or A- in 260)**
- **CSE 398: Quantum Computing and Information Science (260,261?,262, Math 240, and permission)**
- **CSE 455: Internet and Web Systems (120/121, 330, 380)**

To Muddle (According to Webster)

Main Entry: 1 mud·dle

Pronunciation: `'m&-d&l`

Function: *verb*

Inflected Form(s): **mud·dled**; **mud·dling** /`'m&d-li[ng], 'm&-d&l-i[ng]`/

Etymology: probably from obsolete Dutch *moddelen,* from Middle Dutch, from *modde* mud; akin to Middle Low German *mudde*

transitive senses

1 : to make turbid or muddy

2 : to befog or stupefy especially with liquor

3 : to mix confusedly

4 : to make a mess of **:** BUNGLE

***intransitive senses* : to think or act in a confused aimless way**

- **mud·dler** /`'m&d-l&r, 'm&-d&l-&r`/ *noun*

Review: Using Memory

Memory

- **Just a big “array”**
- **“Indexed” by address**
- **Accessed with loads and stores**

LD/LDR/LDI

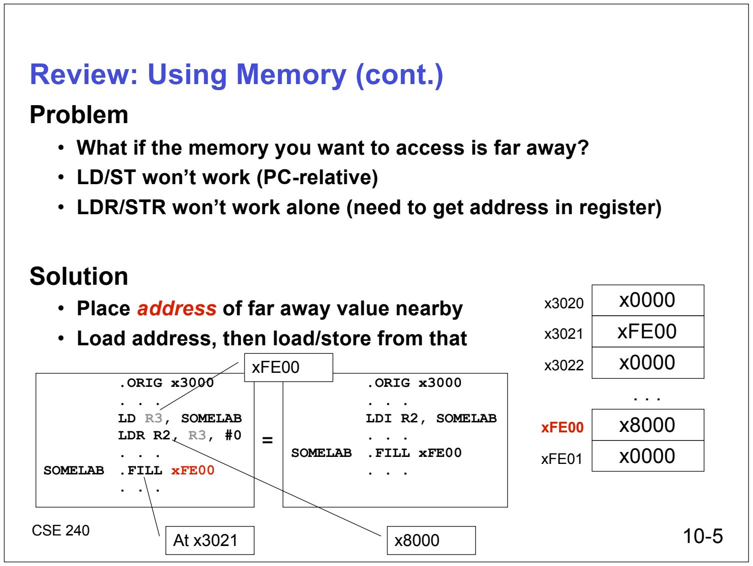
- **Read a word out of memory**
- **Use different addressing mode**

ST/STR/STI

- **Place a word in memory**
- **Use different addressing mode**

Memory

Address	Value
x0000	x00A0
x0001	x5007
x0002	x0201
x0003	x0203
x0004	x3002
	. . .
xFFFC	x5007
xFFFD	x0201
xFFFE	x0203
xFFFF	x3002



Review: Using Memory (cont.)

Problem

- What if the memory you want to access is far away?
- LD/ST won't work (PC-relative)
- LDR/STR won't work alone (need to get address in register)

Solution

- Place *address* of far away value nearby
- Load address, then load/store from that

```
         .ORIG x3000
         . . .
         LD R3, SOMELAB
         LDR R2, R3, #0
         . . .
SOMELAB  .FILL xFE00
         . . .
```

=

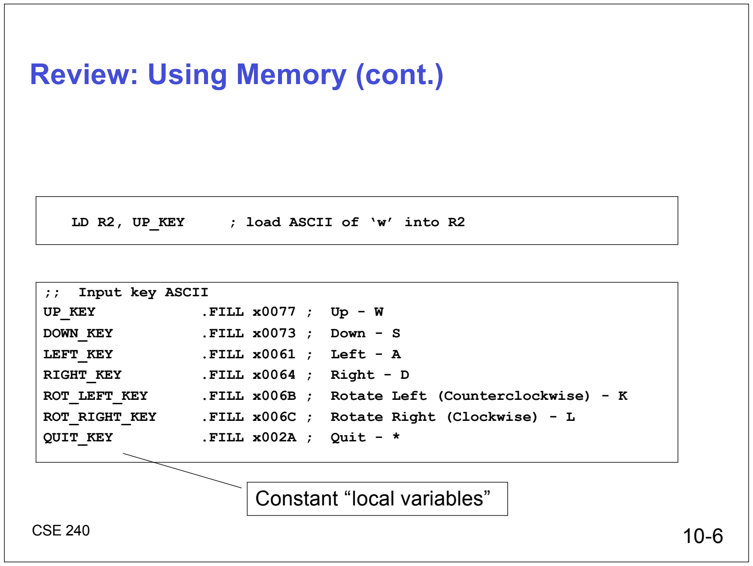
```
         .ORIG x3000
         . . .
         LDI R2, SOMELAB
         . . .
SOMELAB  .FILL xFE00
         . . .
```

xFE00

At x3021

x8000

x3020	x0000
x3021	xFE00
x3022	x0000
	. . .
xFE00	x8000
xFE01	x0000

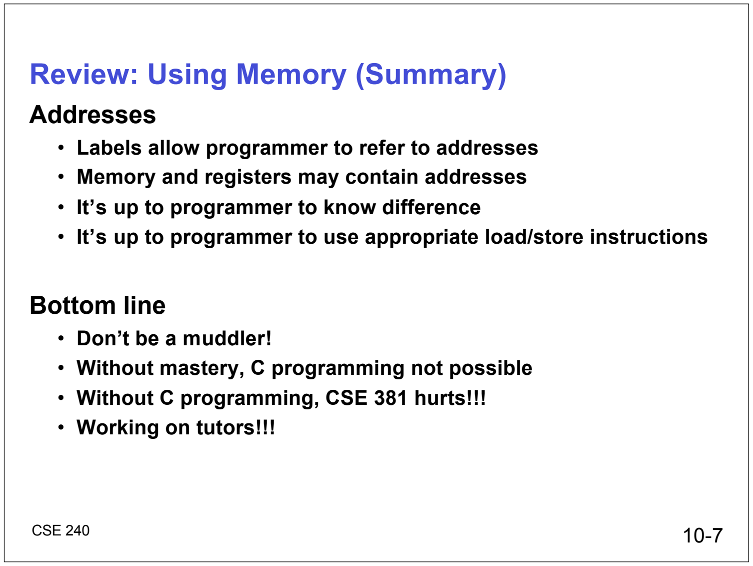


Review: Using Memory (cont.)

```
   LD R2, UP_KEY     ; load ASCII of 'w' into R2
```

```
;;  Input key ASCII
UP_KEY              .FILL x0077 ;  Up - W
DOWN_KEY            .FILL x0073 ;  Down - S
LEFT_KEY            .FILL x0061 ;  Left - A
RIGHT_KEY           .FILL x0064 ;  Right - D
ROT_LEFT_KEY        .FILL x006B ;  Rotate Left (Counterclockwise) - K
ROT_RIGHT_KEY       .FILL x006C ;  Rotate Right (Clockwise) - L
QUIT_KEY            .FILL x002A ;  Quit - *
```

Constant "local variables"



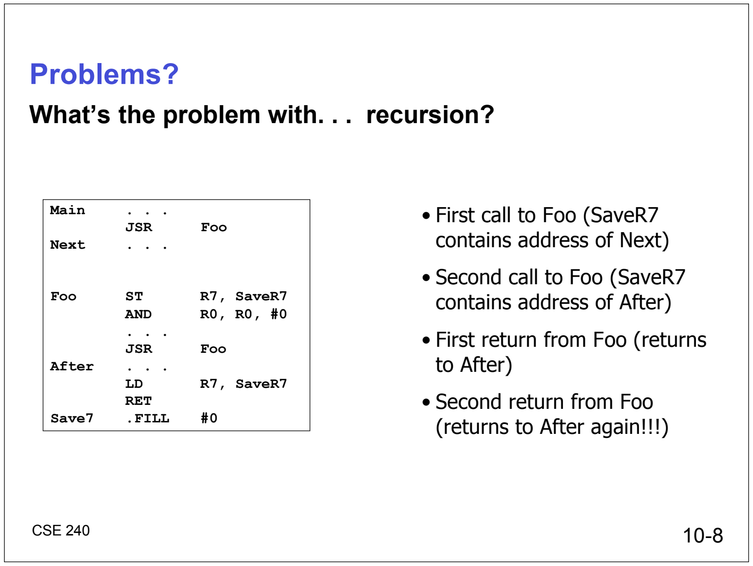
Review: Using Memory (Summary)

Addresses

- Labels allow programmer to refer to addresses
- Memory and registers may contain addresses
- It's up to programmer to know difference
- It's up to programmer to use appropriate load/store instructions

Bottom line

- Don't be a muddler!
- Without mastery, C programming not possible
- Without C programming, CSE 381 hurts!!!
- Working on tutors!!!



Problems?

What's the problem with. . . recursion?

```
Main    . . .
        JSR     Foo
Next    . . .


Foo     ST      R7, SaveR7
        AND     R0, R0, #0
        . . .
        JSR     Foo
After   . . .
        LD      R7, SaveR7
        RET
Save7   .FILL   #0
```

- First call to Foo (SaveR7 contains address of Next)
- Second call to Foo (SaveR7 contains address of After)
- First return from Foo (returns to After)
- Second return from Foo (returns to After again!!!)

Recursion

Need

- Per-subroutine-invocation data space (*activation record*)

Approach

- Allocate new *activation record* on a stack whenever a subroutine is called
- Subroutine uses its own activation record to hold invocation-specific data (*e.g.,* local variables, saved registers)

Note

- Given that Breakout is recursive, we will need activation records

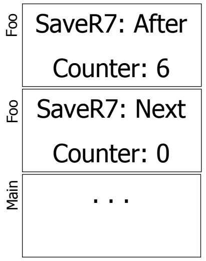
Big Picture

Each subroutine invocation gets its own activation record

. . . but how?

```
Main      . . .
          JSR     Foo
Next      . . .


Foo       ST      R7, SaveR7
          AND     R0, R0, #0
          ST      R0, Counter
          . . .
          JSR     Foo
After     . . .
          LD      R7, SaveR7
          RET
SaveR7    .FILL   #0
Counter   .FILL   #0
```



SaveR7: After

Counter: 6

SaveR7: Next

Counter: 0

. . .

Stacks (Review)

A LIFO (last-in first-out) storage structure

- The first thing you put in is the last thing you take out
- The last thing you put in is the first thing you take out

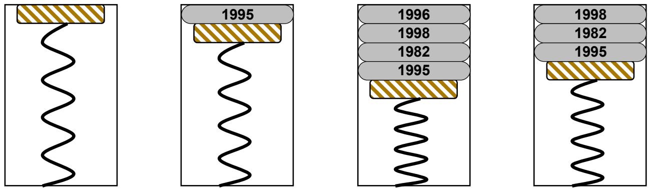
Two main operations

PUSH: add an item to the stack

POP: remove an item from the stack

A Physical Stack

Coin holder



Initial State

After One Push

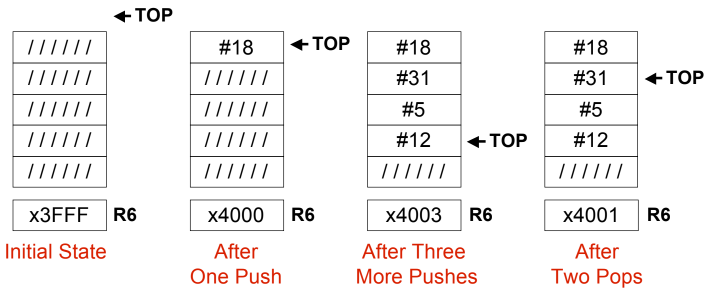
After Three More Pushes

After One Pop

Last quarter in is the first quarter out (LIFO)

A Software Stack

Data items don't move in memory, just our idea about where TOP of the stack is



By convention, R6 holds the Top of Stack (TOS) pointer

Basic Push and Pop Code

Push

```
ADD  R6, R6, #1   ; increment stack ptr
STR  R0, R6, #0   ; store data (R0)
```

Pop

```
LDR  R0, R6, #0   ; load data from TOS
ADD  R6, R6, #-1  ; decrement stack ptr
```

Note

- **Stacks can grow in either direction (toward higher address or toward lower addresses)**

Activation Records in a Stack

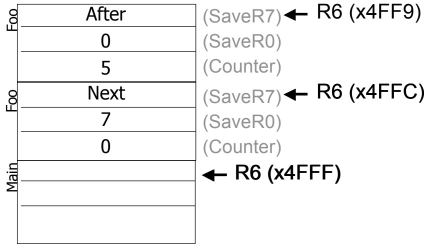
```
Main    . . .
        JSR     Foo
Next    . . .


Foo     ADD     R6,R6,#-3
        ST      R7,R6,#0
        ST      R0,R6,#1
        AND     R0, R0, #0
        ST      R0, R6,#2
        . . .
        JSR     Foo
After   . . .
        LD      R0,R6,#1
        LD      R7, R6,#0
        ADD     R6,R6,#3
        Ret
```

Allocate activation record

Use activation record

Deallocate activation record


Foo
After
0
5
(SaveR7)
(SaveR0)
(Counter)
R6 (x4FF9)
Foo
Next
7
0
(SaveR7)
(SaveR0)
(Counter)
R6 (x4FFC)
Main
R6 (x4FFF)