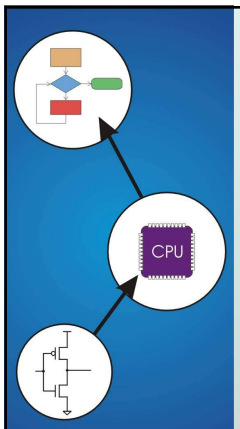


Second Midterm
Review Slides

Original slides from Gregory Byrd, North Carolina State University

Modified slides by Chris Wilcox, Colorado State University

Review Topics

- LC-3 Programming
- Memory Model/Stack Execution
- C Programming

LC-3 Architecture

Instruction Set (First Half)

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ADD+	0001				DR			SR1			0	0	0		SR2	
ADD+	0001				DR			SR1			1	imm5				
AND+	0101				DR			SR1			0	0	0		SR2	
AND+	0101				DR			SR1			1	imm5				
BR	0000				n		z		p	PCoffset9						
JMP	1100				000			BaseR			000000					
JSR	0100				1	PCoffset11										
JSRR	0100				0	0	0	BaseR			000000					
LD+	0010				DR			PCoffset9								

LC-3 Architecture

Instruction Set (Second Half)

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LDI+	1010				DR			i	PCoffset9							
LDR+	0110				DR			BaseR			offset6					
LEA+	1110				DR			PCoffset9								
NOT+	1001				DR			SR			111111					
RET	1100				000			111			000000					
RTI	1000				000000000000											
ST	0011				SR			PCoffset9								
STI	1011				SR			PCoffset9								
STR	0111				SR			BaseR			offset6					
TRAP	1111				0000					trapvect8						

LC-3 Architecture

Addressing Modes

- Load -- read data **from memory to register**
  - **LD:** PC-relative mode
  - **LDR:** base+offset mode
  - **LDI:** indirect mode
- Store -- write data **from register to memory**
  - **ST:** PC-relative mode
  - **STR:** base+offset mode
  - **STI:** indirect mode
- Load pointer: **compute address, save in register**
  - **LEA:** immediate mode
  - *does not access memory*

LC-3 Architecture

Machine Code to Assembly

- What is the assembly code for machine instruction `0101010010111101`?
- Step 1) Identify opcode: `0101` = AND
- Step 2) Parse entire instruction (use reference)
- Step 3) Get values from each field

OPCODE	DR	SR	1	imm5
15:12	11:9	8:6	5	4:0
0101	010	010	1	11101
AND	R2	R2		-3

- Step 4) Translate to mnemonics: `AND R2,R2,#-3`

LC-3 Architecture

Assembly to Machine Code

- What is the machine code for assembly instruction `NOT R7,R6`?
- Step 1) Identify opcode: NOT = **1001**
- Step 2) Put values into each field:

NOT	R7	R6	
OPCODE	DR	SR	111111
15:12	11:9	8:6	5:0
1001	111	110	111111

- Step 3) Build machine instruction: `1001111110111111`

LC-3 Architecture

Assembly Code Syntax

```
          .ORIG   x3000
MAIN      AND     R0,R0,#0      ; Initialize Sum
          JSR COMPUTE           ; Call function
          ST      R0, SUM       ; Store Sum
          HALT                  ; Program complete
COMPUTE   LD      R1,OPERAND1   ; Load Operand1
          LD      R2,OPERAND2   ; Load Operand2
          ADD     R0,R1,R2      ; Compute Sum
          RET                   ; Function return
;; Input data set
OPERAND1 .FILL     x1234        ; Operand1
OPERAND2 .FILL     x4321        ; Operand2
SUM       .BLKW    1            ; Sum
          .END
```

Memory Model

Push and Pop Stack

- Assume POP and PUSH code as follows:

```
MACRO PUSH(reg)
        ADD R6,R6,#-1  ; Decrement SP
        STR reg,R6,#0  ; Store value
END

MACRO POP(reg)
        LDR reg,R6,#0   ; Load value
        ADD R6,R6,#1   ; Increment SP
END
```


Memory Model

Detailed Example

- Main program to illustrate stack convention:

```
        .ORIG x3000
MAIN    LD R6,STACK    ; init stack pointer
        LD R0,OPERAND0 ; load first operand
        PUSH R0        ; PUSH first operand
        LD R1,OPERAND1 ; load second operand
        PUSH R1        ; PUSH second operand
        JSR FUNCTION   ; call function
        LDR R0,R6,#0   ; POP return value
        ADD R6,R6,#3   ; unwind stack
        ST  R0,RESULT  ; store result
        HALT
```


Memory Model

Detailed Example

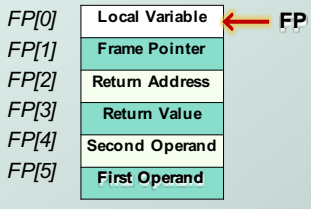
- Function code to illustrate stack convention:

```
FUNCTION
        ADD R6,R6,#-1  ; alloc return value
        PUSH R7        ; PUSH return address
        PUSH R5        ; PUSH frame pointer
        ADD R5,R6,#-1  ; FP = SP-1

        ADD R6,R6,#-1  ; alloc local variable
        LDR R2,R5,#4   ; load first operand
        LDR R3,R5,#5   ; load second operand
        ADD R4,R3,R2   ; add operands
        STR R4,R5,#0   ; store local variable
```


Memory Model

Detailed Example



Stack before STR instruction

Memory Model
Detailed Example

- Function code to illustrate stack convention:

```
FUNCTION ; stack exit code
        STR R4,R5,#3   ; store return value
        ADD R6,R5,#1   ; SP = FP+1
        POP R5         ; POP frame pointer
        POP R7         ; POP return address
        RET            ; return

OPERAND0  .FILL x1234  ; first operand
OPERAND1  .FILL x2345  ; second operand
RESULT    .BLKW 1      ; result
STACK     .FILL x4000  ; stack address
```


C Programming
Bitwise Operators

- C code with bitwise operators:

```
int i = 0x11223344;
int j = 0xFFFF0000;
printf("0x%x\n", ~i); 0xEEDDCCBB
printf("0x%x\n", i & j); 0x11220000
printf("0x%x\n", i | j); 0xFFFF3344
printf("0x%x\n", i ^ j); 0xEEDD3344
```


C Programming
Logical Operators

- C code with logical operators:

```
int i = 0x11223344;
int j = 0x00000000;
printf("0x%x\n", !i); 0x00000000
printf("0x%x\n", !j); 0x00000001
printf("0x%x\n", i && j); 0x00000000
printf("0x%x\n", i || j); 0x00000001
```


C Programming
Arithmetic Operators

- C code with arithmetic operators:

```
int i = 10;
int j = 2;
printf("d\n", i + j); 12
printf("d\n", i - j); 8
printf("d\n", i * j); 20
printf("d\n", i / j); 5
```

C Programming
Functions

- C function prototypes
- must precede implementation of function

```
int addInt(int i, int j);
float addFlt(float u, float v);
void addInt(int param0, int param1, int *result);
void addFlt(float f0, float f1, float *result);
bool writeFile(char *filename, Instructions[]);
void input(Instruction *pInstruction);
char *printInt(int number);
```


C Programming
Control Structures

- C conditional and iterative statements
  - if statement

```
if (value == 0x12345678)
    printf("value matches 0x12345678\n");
```

  - for loop

```
for (int i = 0; i < 8; ++i)
    printf("i = %d\n", i);
```

  - while loop

```
int j = 6;
while (j--)
    printf("j = %d\n", j);
```


C Programming
Pointers and Arrays

- C pointers and arrays

```
void foo(int *pointer)
{
    *(pointer+0) = pointer[2] = 0x1234;
    *(pointer+1) = pointer[3] = 0x5678;
}
int main(int argc, char *argv[])
{
   int array[]= {0, 1, 2, 3};
   foo(array);
   for (int i = 0; i <= 3; ++i)
      printf("array[%d] = %x\n", i, array[i]);
}
```


C Programming
Data Structures

- C data structures

```
// Structure definition
struct sCoordinate
{
    float X;
    float y;
    float z;
}
typedef struct
{
    …
} Coordinate;
```

C Programming
Data Structures

- C data structures

```
// Structure allocation
struct sCoordinate coordinates[10]; // no typedef
Coordinate coordinates[10]; // typedef
Coordinate *coordinates =
  (Coordinate *) malloc(sizeof(Coordinate) *10);

// Structure access
coordinates[5].X = 1.0f;
pCoordinate->X = 1.0f;
```


C Programming
Strings

- C strings

```
char *string = "hello";
char *carray = { 'h','e','l','l','o' };
char label[20];
strcpy(label, "hello");
strcat(label, " world");
printf("%s\n", label); hello world
printf("%d\n", strlen(label)); 11
printf("%d\n", sizeof(label)); 20
```


C Programming
Include Files

- C include files

```
#include <stdio.h> - FILE, stdout, stdin, stderr,
putchar, getchar, printf, scanf, fprintf, fscanf,
fopen, fclose, …
#include <stdlib.h> - atof, atoi, malloc, free,
rand, exit, getenv, system, …
#include <stddef.h> - NULL, size_t, …
#include <stdbool.h> - bool, true, false
#include <string.h> - memcpy, memset, strcpy,
strcat, strlen, strtok, …
#include <math.h> - sin, cos, tan, exp, log,
fmod, fabs, floor, ceil, …
```


C Programming
Main Program

- C include files
- command line arguments are passed to main
- arguments are strings, may need to convert
- getenv function queries environment variables

```
int main(int argc, char *argv[])
{
    printf("%d\n", argc); // # of arguments
    printf("%s\n", argv[0]); // program name
    printf("%s\n", argv[1]); // first argument
    printf("%s\n", argv[2]); // second argument
};
```