

Final Exam Review Slides

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Review Topics

- ◆ Number Representation
- ◆ Transistors and Gates
- ◆ Combinational Logic
- ◆ LC-3 Programming
- ◆ Memory Model
- ◆ C Programming

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Number Representation

Hexadecimal to Binary Conversion

- Method: Convert hexadecimal digits to binary using table.
- Question: What is hexadecimal **0x1234CDEF** in binary?

1 2 3 4 c d e f
0001 0010 0011 0100 1100 1101 1110 1111

- Answer:
00010010001101001100110111101111

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Hexadecimal	Binary
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
A	1010
B	1011
C	1100
D	1101
E	1110
F	1111

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Number Representation

Binary to Hexadecimal Conversion

- Method: Group binary digits, convert to hex digits using table.
- Question: What is binary **01100111100010011111111011011010** in hexadecimal?

0110 0111 1000 1001 1111 1110 1101 1010
6 7 8 9 F E D A

- Answer: **0x6789FEDA**

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Hexadecimal	Binary
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
A	1010
B	1011
C	1100
D	1101
E	1110
F	1111

Number Representation

Decimal to Binary Conversion

- Method: Convert decimal to binary with divide by 2, check odd/even.
- Question: What is decimal 49 in binary?

$$2^5 + 2^4 + 2^0 = 32 + 16 + 1 = 49$$

Answer: 110001

2^n	Decimal
2^0	1
2^1	2
2^2	4
2^3	8
2^4	16
2^5	32
2^6	64
2^7	128
2^8	256
2^9	512
2^{10}	1024

Number Representation

Two's Complement

- Invert all the bits, and add 1.
- Question: What is the value -8 in (16-bit) 2's complement form?

8 = 0x0008 = 0000 0000 0000 1000

Invert bits 1111 1111 1111 0111

Add one + 0000 0000 0000 0001

Answer = 111111111111111000 (binary)

Answer = 0xFFF8

Answer: **0xFFF8 = -8 decimal**

Binary to Floating Point Conversion

- Single-precision IEEE floating point number:

1 01111110 100000000000000000000000

\uparrow \uparrow \uparrow

sign *exponent* *fraction*

- Or 0xBF400000
- Sign is 1 – number is negative.
- Exponent field is 01111110 = 126 – 127 = -1 (decimal).
- Fraction is 1.100000000000... = 1.5 (decimal).

- Value = $-1.5 \times 2^{(126-127)} = -1.5 \times 2^{-1} = -0.75$

Number Representation

Floating Point to Binary Conversion

- Value = **4.25**
 - Number is positive – sign is **0**
 - Fraction is 100.01 (binary), normalize to **1.0001×2^2**
 - Exponent is $2 + 127 = 129$ (decimal) = **10000001**

- Single-precision IEEE floating point number:

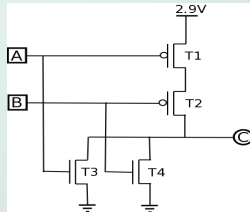
0 10000001 000100000000000000000000

↑ ↑ ↑
sign *exponent* *fraction*

- or **0x40880000**

Transistors and Gates

NOR Gate



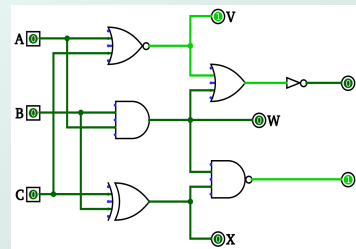
A	B	T1	T2	T3	T4	C
0	0	Closed	Closed	Open	Open	1
0	1	Closed	Open	Open	Closed	0
1	0	Open	Closed	Closed	Open	0
1	1	Open	Open	Closed	Closed	0

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Combinational Logic

Combinational Circuit to Truth Table



A	B	C	V	W	X	Y	Z
0	0	0	1	0	0	0	1
0	0	1	0	0	1	1	1
0	1	0	1	0	1	0	1
0	1	1	0	0	0	1	1
1	0	0	0	0	0	1	1
1	0	1	0	0	1	1	1
1	1	0	0	1	1	0	0
1	1	1	0	1	0	0	1

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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		00			SR2	
ADD ⁺	0001			DR				SR1		1					imm5	
AND ⁺	0101			DR				SR1		0		00			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				00							BaseR	000000
LD ⁺	0010														DR	PCoffset9

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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															PCoffset9
LDR ⁺	0110															offset6
LEA ⁺	1110															PCoffset9
NOT ⁺	1001															111111
RET	1100															000000
RTI	1000															0000000000
ST	0011															PCoffset9
STI	1011															PCoffset9
STR	0111															offset6
TRAP	1111															trapvect8

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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*

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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**

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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	imm5
15:12	11:9	8:6	5:0
1001	111	110	111111

- Step 3) Build machine instruction: **1001111110111111**

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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

```

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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

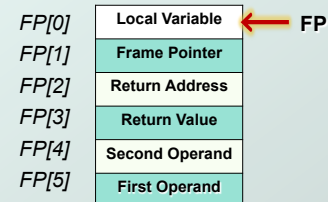
- Function code to illustrate stack convention:

```
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-->0)
    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
};
```