Computer Systems and Networks

ECPE 170 – Jeff Shafer – University of the Pacific

Introduction to MARIE

Schedule

- **Today**
  - Introduce MARIE
- **Wed 15th and Fri 17th**
  - Assembly programming tutorial

Recap – MARIE Overview

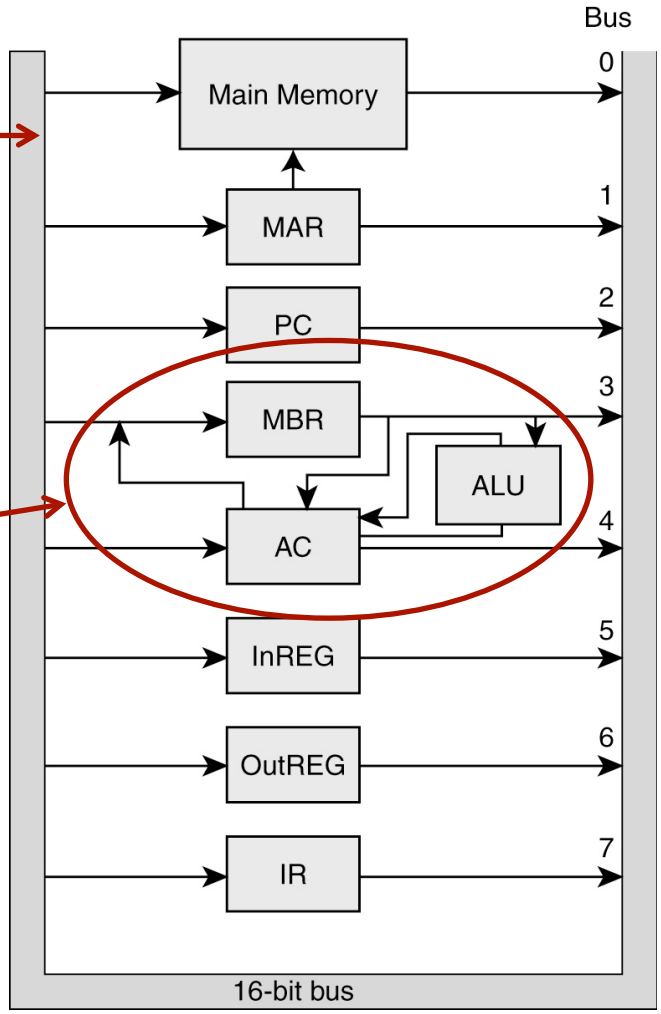
- **How does the MARIE architecture represent positive/negative numbers?**
  - Binary, two's complement data representation
- **How is MARIE's main memory configured? (# of words, size of each word)**
  - 4K words, 16 bits wide, word-addressable

Recap – MARIE Overview

- MARIE has **seven registers** for control and data movement
  - **AC?**
  - **MAR?**
  - **MBR?**
  - **PC?**
  - **IR?**
  - **InReg?**
  - **OutReg?**

Recap – MARIE Data Path

- **Common data bus**
  - Links main memory and registers
  - Each device identified by unique number
  - Bus has control lines that identify device used in operation
- **Dedicated data paths**
  - Permits data transfer between accumulator (AC), memory buffer register (MBR), and ALU without using main data bus



Recap – MARIE ISA

- **What is an Instruction Set Architecture (ISA)?**
  - Interface between hardware and software
  - Specifies the format of processor instructions
  - Specifies the primitive operations the processor can perform

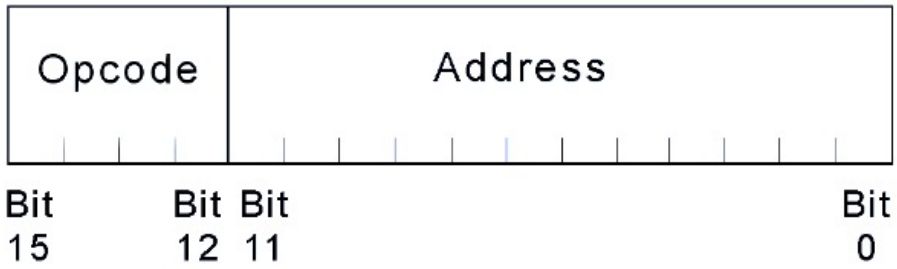
Recap – MARIE Instructions (Full)

Binary	Hex	Instruction	Meaning
0001	1	**LOAD X**	Load contents of address X into AC
0010	2	**STORE X**	Store contents of AC at address X
0011	3	**ADD X**	Add contents of address X to AC
0100	4	**SUBT X**	Subtract contents of address X from AC
0101	5	**INPUT**	Input value from keyboard into AC
0110	6	**OUTPUT**	Output value in AC to display
0111	7	**HALT**	Terminate program
1000	8	**SKIPCOND**	Skip next instruction on condition based on AC value
1001	9	**JUMP X**	Load value of X into PC
1010	A	**CLEAR**	Set AC to 0
1011	B	**ADDI X**	Add contents of address Mem[X] to AC
1100	C	**JUMPI X**	Load contents of address Mem[X] into PC
1101	D	**LOADI X**	Load contents of address Mem[X] into AC
1110	E	**STOREI X**	Store contents of AC at address Mem[X]

See table 4.7 in book!

Recap – MARIE Instructions

- **How does MARIE format instructions in computer memory?**



- Two fields
  - **Opcode** (4 bits) – Operation code
  - **Address** (12 bits) – Address to operate to/from

MARIE Programming

A Simple Program

- Consider this simple MARIE program

Address	Instruction	Binary Contents of Memory Address	Hex Contents of Memory
100	Load 104	0001000100000100	1104
101	Add 105	0011000100000101	3105
102	Store 106	0100000100000110	4106
103	Halt	0111000000000000	7000
104	0023	0000000000100011	0023
105	FFE9	1111111111101001	FFE9
106	0000	0000000000000000	0000

A Simple Program

- What happens inside the computer when our program runs?
  - Instruction 1: **LOAD 104**

Step	RTN	PC	IR	MAR	MBR	AC
(initial values)		100	------	------	------	------
Fetch	MAR ← PC	100	------	100	------	------
	IR ← M[MAR]	100	1104	100	------	------
	PC ← PC + 1	101	1104	100	------	------
Decode	MAR ← IR[11–0]	101	1104	104	------	------
	(Decode IR[15–12])	101	1104	104	------	------
Get operand	MBR ← M[MAR]	101	1104	104	0023	------
Execute	AC ← MBR	101	1104	104	0023	0023

A Simple Program

- Instruction 2: **ADD 105**

Step	RTN	PC	IR	MAR	MBR	AC
(initial values)		101	1104	104	0023	0023
Fetch	MAR ← PC	101	1104	101	0023	0023
	IR ← M[MAR]	101	3105	101	0023	0023
	PC ← PC + 1	102	3105	101	0023	0023
Decode	MAR ← IR[11–0]	102	3105	105	0023	0023
	(Decode IR[15–12])	102	3105	105	0023	0023
Get operand	MBR ← M[MAR]	102	3105	105	FFE9	0023
Execute	AC ← AC + MBR	102	3105	105	FFE9	000C

Assembler

Role of Assembler

- Mnemonic instructions: LOAD 104
  - "Easy" for humans to write and understand
  - Impossible for computers to understand
- Role of **assembler**
  - Translate instructions from assembly language (*for humans*) into machine language (*for computers*)

Assembler versus Compiler

- **What's the difference between an assembler and a compiler? Which has the harder job?**
  - Assembly language ➔ machine language
    - One-to-one correspondence
    - **Assembler** is simple!
  - High-level language ➔ machine language
    - Many-to-one correspondence
    - **Compiler** is complicated!

Assembler Operation

- Assemblers create an **object file** *(containing machine code)* from mnemonic assembly source code in **two passes**
- Pass 1
  - Assemble as much of the program as possible
  - Builds a **symbol table** (contains memory references for all *symbols* in the program)
- Pass 2
  - Complete instructions. Fill in addresses stored in the symbol table

Assembler Operation

- Example program
  - HEX and DEC directives to specify radix of constants
- Assembler **Pass #1**
  - Create symbol table
  - Create partially-assembled instructions

Address	Instruction
100	Load X
101	Add Y
102	Store Z
103	Halt
104 X,	DEC 35
105 Y,	DEC -23
106 Z,	HEX 0000

Symbol Table: ***Name, Address***

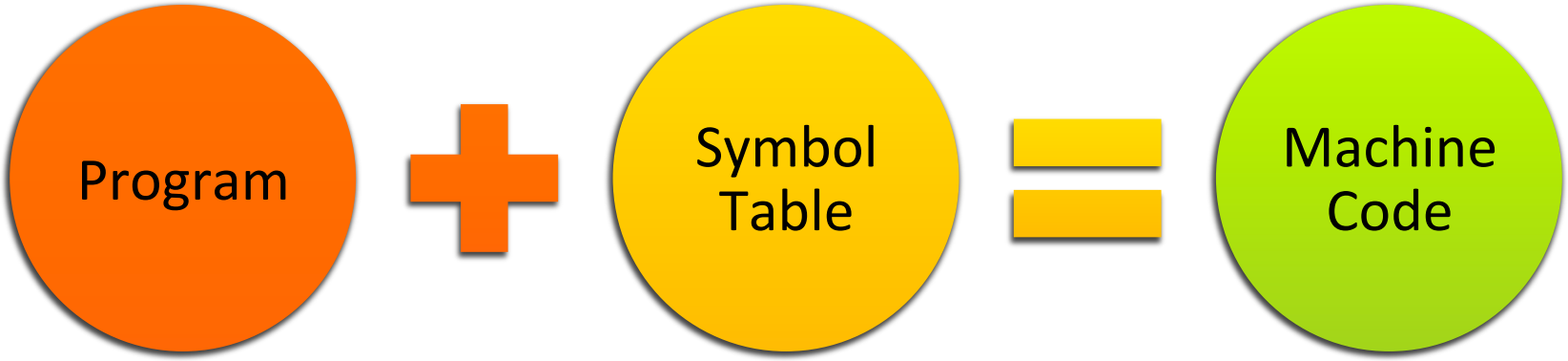
X	104
Y	105
Z	106

Partially-Assembled Program:

1	X
3	Y
2	Z
7 0 0 0	

Assembler Operation

- Assembler **Pass #2**
  - Fill in details from symbol table



Assembler Operation

Program:

Address	Instruction
100	Load X
101	Add Y
102	Store Z
103	Halt
104 X,	DEC 35
105 Y,	DEC -23
106 Z,	HEX 0000

Symbol Table:

X	104
Y	105
Z	106

Machine Code:

1 1 0 4
3 1 0 5
2 1 0 6
7 0 0 0
0 0 2 3
F F E 9
0 0 0 0

More MARIE Instructions

New Addressing Modes!

- **Direct addressing mode**
  - *All the instructions covered to date…*
  - The address of the operand is explicitly stated in the instruction
- New: **Indirect addressing mode**
  - The address of the address of the operand is given in the instruction
  - Just like **pointers** in COMP 51/53

Indirect Addressing Mode Instructions

- Four new instructions use *indirect* addressing mode: Load / store / add / jump indirect
- `LOADI X` and `STOREI X` – specified the address of the address of the operand to be loaded or stored
  - In RTL :

LOADI X

```
MAR ← X
MBR ← M[MAR]
MAR ← MBR
MBR ← M[MAR]
AC ← MBR
```

STOREI X

```
MAR ← X
MBR ← M[MAR]
MAR ← MBR
MBR ← AC
M[MAR] ← MBR
```

Indirect Addressing Mode Instructions

- `ADDI X` - Combination of `LOADI X` and `ADD X`:
  - In RTL:

ADDI X

```
MAR ← X
MBR ← M[MAR]
MAR ← MBR
MBR ← M[MAR]
AC ← AC + MBR
```

Subroutine Instructions

- Remember subroutines? (i.e. functions)
- Machine instructions can make subroutines easier to implement
  - Jump-and-store instruction (`JNS X`) provides limited subroutine functionality
  - RTL:

```
MBR ← PC
MAR ← X
M[MAR] ← MBR
MBR ← X
AC ← 1
AC ← AC + MBR
PC ← AC
```

Does JNS permit recursive calls?

No, PC is stored at address X, and we jump to address X+1. You can't do this repeatedly!

Clear Instruction

- `CLEAR` instruction
  - Set the contents of the accumulator to all zeroes.
- RTL for CLEAR: **AC ← 0**

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1000	8	**SKIPCOND**	Skip next instruction on condition based on AC value
1001	9	**JUMP X**	Load value of X into PC
1010	10	**CLEAR**	Set AC to 0
1011	11	**ADDI X**	Add contents of address Mem[X] to AC
1100	12	**JUMPI X**	Load contents of address Mem[X] into PC
1101	13	**LOADI X**	Load contents of address Mem[X] into AC
1110	14	**STOREI X**	Store contents of AC at address Mem[X]