UNIVERSITY of WASHINGTON

CSS 422 Hardware and Computer Organization

Introduction to the Assembler

Professor: Yang Peng

The slides are re-produced by the courtesy of Dr. Arnie Berger and Dr. Wooyoung Kim

Topic

- Assembly programming and 68000 microprocessor architecture
  - Chapter 7 by Berger
  - Chapter 2 by Clements
  - The chapters are available on canvas system: https://canvas.uw.edu/courses/1232689/pages/textbooks
  - Quick Reference: http://www.easy68k.com/files/EASy68KQuickRef.pdf

From C/C++ to Machine Code

- **Write** your code in Visual Studio, Xcode, Vim, or …
- **Compile** it using Visual Studio, Xcode, Gcc/G++, or …
  - Cross-compiler: compile the code for a (micro)computer system with a processor of different architecture
  - *Compiling, linking, and assembling*
- **Run** the compiled program (binaries, images, etc.) on the same or a different computer with a processor of the same architecture
  - Run the cross-compiled program on a system with a processor of different architecture
  - *Loading and executing*
- The compiled program is called **“Machine Code” or “Machine Language”**

Introduction to Assembly Language

- Every computer system has **a fundamental set of operations** it can perform
- **These operations** are defined by the ***instruction set*** of the processor
  - The instruction set is the **atomic element of the processor**
  - All the complex operations are achieved by building **sequences of these fundamental operations**
  - Called **Machine Language** or **Machine Code**
- Assembly language is the ***human readable*** form of the ***machine language***

Instead of writing a program in machine language as:

```
00000412  307B7048
00000416  327B704A
0000041A  1080
0000041C  B010
0000041E  67000008
00000422  1600
00000424  61000066
00000428  5248
0000042A  B0C9
```

We write the program in assembly language as:

```
MOVEA.W  (TEST_S,PC,D7),A0    *We'll use address indirect
MOVEA.W  (TEST_E,PC,D7),A1    *Get the end address
MOVE.B   D0,(A0)              *Write the byte
CMP.B    (A0),D0              *Test it
BEQ      NEXT_LOCATION        *OK, keep going
MOVE.B   D0,D3                *Copy bad data
BSR      ERROR                *Bad byte
ADDQ.W   #01,A0               *Increment the address
CMPA.W   A1,A0                *Are we done?
```

Why Assembly Language?

- Computer programming depends upon a knowledge of the processor
  - Understanding assembly language is of **understanding the computing engine**
  - **Performance optimization**
  - Debugging
  - Kernel development
    - Mixed C and Assembly language programming in Linux kernel

- Haven't compilers made assembly language obsolete?
  - *Not all processor* architectures have compilers to support

Assembly Language

- There is a **1:1 correspondence** between **assembly language** instructions and **machine language** instructions

  MOVE.B D1,D3 ⟷ **1601**

- The assembly language instructions (called ***mnemonics***) give a human readable indication of what the instruction does

- For example:
  - MOVE.B : Move (Copy) one byte of data
  - CMP.B : Compare two bytes of data
  - BEQ : Branch to a different instruction if the “result” is zero
  - ADD.W : Add two “word” values

Format of the 68000 Instruction

Each instruction has a **label**, **op-code**, **operands** (0 to 2)

Label	Op-Code	Operand1	Operand2	*Comment
THIS	MOVE.B	$1234	$5678	*an example

- **Label**: a symbolic name, usually ***refers to a memory address***
  - Label is a tool for a readable program

```
TEST_LOOP   MOVE.B   (A2),D6         *Let D6 test the patterns for done
            CMPI.B   #END_TEST,D6    *Are we done?
            BEQ      DONE            *We've done the 4 patterns
            LEA      ST_ADDR,A0      *Set up the starting address in A0
            LEA      END_ADDR,A1     *Set up the ending address in A1
            JSR      DO_TEST         *Go to the test
            ADDA.W   #01,A2          *Point to the next test pattern
            BRA      TEST_LOOP       *Go back to the next location
DONE        STOP     #EXIT           *Test is over, stop
```

Format of the 68000 Instruction

- **Op-code**: Instructions to the microprocessor
  - Example: MOVE, CMP
- **Pseudo Op-codes** (Assembler directives): Used to help *make the program readable*, instructions to the assembler program
  - Example: ORG, EQU, SET, REG, DC, DCB, DS, END
- **Operands**: (0 operand, 1 operand, 2 operands)
  - 0 operand: NOP (**N**o **OP**eration, do nothing)
  - 1 operand: BRA FOO (**BR**anch **A**lways)
  - 2 operands: ADD.W D0,D3
- Operand is one of Effective Addressing modes (where is the data?)

```
        ORG      $400      *Start of code
        MOVE.B   Y,D0      *Get first operand
        ADDI.B   #24,D0    *Add constant
        MOVE.B   D0,Sum    *Store the result

        ORG      $600      *Start of data area
Y       DC.B     27        *Store the constant 27 in memory
Sum     DS.B     1         *Reserve a byte for Sum
```

Instruction Set Architecture

- In order to program in assembly language, we must be familiar with the **programmer's model of the processor**, which includes:

  Instruction Set and ***Effective Addressing Modes***

  - **Instruction Set**
    - Tells the processor what to do (opcode)
  - **Effective Addressing Modes**
    1. Describe how the processor **accesses the data** that the instruction will operate on, and
    2. Describe **what to do with the data** after the operation
- Before we can create an assembly language program, we need to understand the architecture of the machine we are programming for
  - Unlike C/C++, **assembly language is not portable between computers with processors of different architectures**
  - E.g., an assembly language program written for a Pentium processor will not run on an ARM7 architecture processor

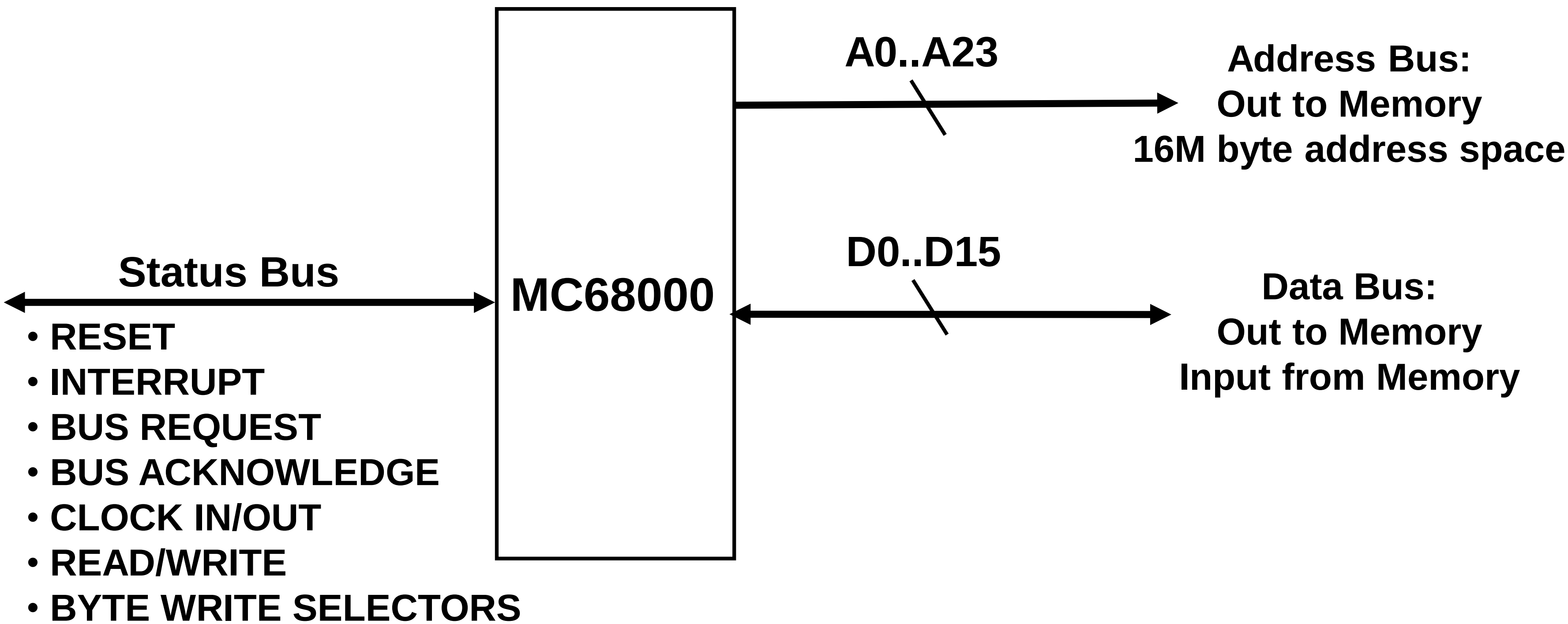
Effective Addressing Modes

- In 68K manual, each instruction has different codes for each EA mode
  - **Dn**: data register direct: D0, D1, …, D7
  - **An**: address register direct : A0, A1, …, A6
  - **(An)**: address register indirect: (A0), (A1), …, (A6)
  - **(An)+**: address register indirect with post-increment
  - **-(An)**: address register indirect with pre-decrement
  - **(xxx).W**: Absolute addressing (word)
  - **(xxx).L**: Absolute addressing (long-word)
  - **#<data>**: Immediate Addressing

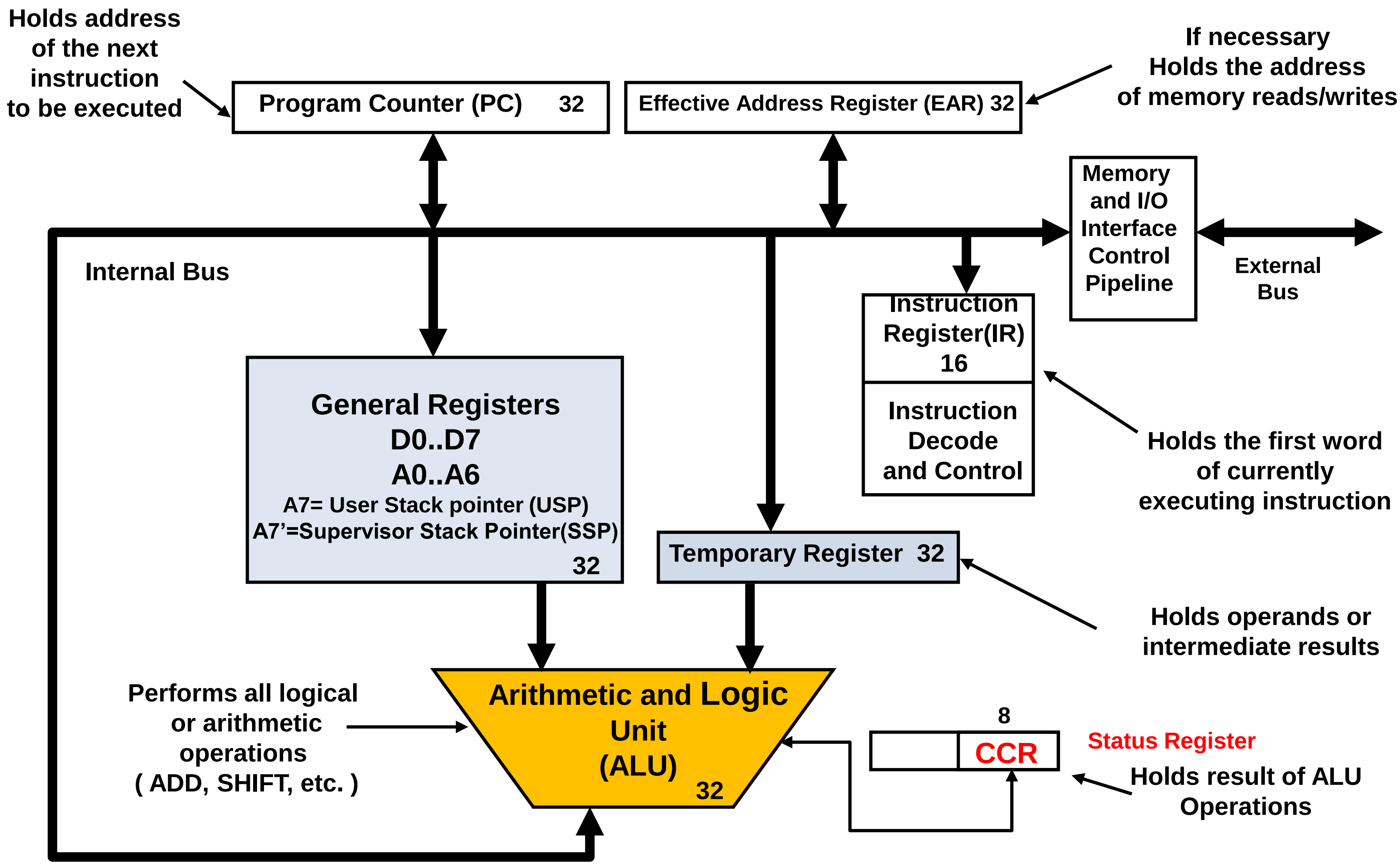
  - **(d_{16}, An)**: address register indirect with displacement (EA = (An)+d_{16})
  - **(d_8, An, Xn)**: address register indirect with index (EA = (An)+(Xn)+d_8)
  - **(d_{16}, PC)**: Program counter with displacement (EA = (PC) +d_{16})
  - **(d_8, PC, Xn)**: Program counter with index (EA = (PC)+(Xn)+d_8)

Microprocessor Component Systems

- Three major busses of an MC68000 microprocessor
  - **Address Bus**: Unidirectional, homogeneous (24 lines)
  - **Data Bus**: Bidirectional, homogeneous (16 lines)
  - **Status Bus**: Heterogeneous, additional control and housekeeping signals
  - Three-bus system, similar in other processors

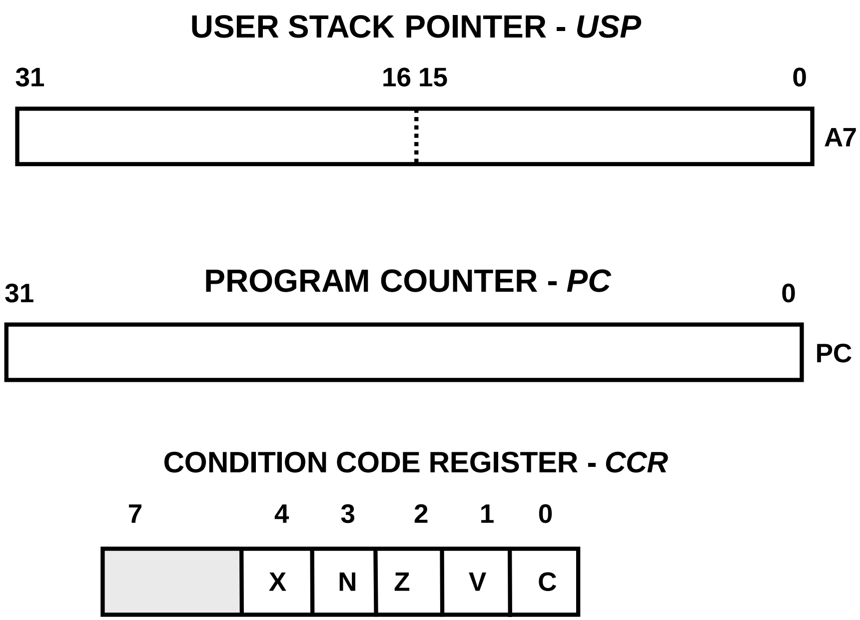


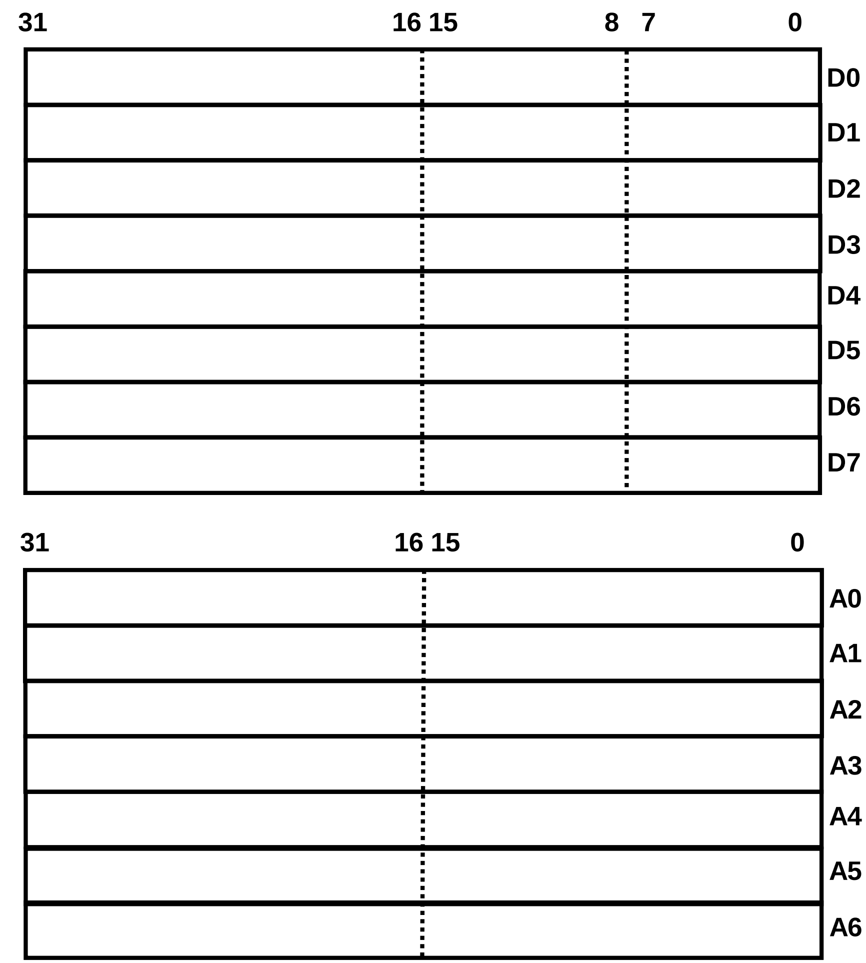
Hardware Organization of the MC68000



User Programming Model

- For most applications the architectural model of the 68000 is the ***User Programmer's Model***





CONDITION CODES (FLAGS)
- **C = Carry Flag**
- **V = Overflow Flag**
- **Z = Zero Flag**
- **N = Negative Flag**
- **X = Extend Flag**

Two’s Complement Arithmetic

- Arithmetic ***overflow***
  - Adding **two positive** number **results in a negative** number
  - Adding **two negative** number **results in a positive** number
- If the result is **out of range**, the computer results in an **incorrect answer**.

- How to detect the overflow? **Check V bit and C bit**
- 68K CCR register: XNZVC
  - ***V = 1 when overflow → out of range (error)***
  - ***C = 1 when there is a carry → got carry bit (if V=0, it is not an error)***

Two's Complement Arithmetic

- In a 4-bit system (range -8 to 7)

1. 7 + (-3) = 4

```
  0 111
+ 1 101
-------------
carry = 1   0 100
```

No overflow: V=0, C=1

carry-out bit is invisible.
Then the answer is 4 (correct)

2. (-7) + (-8)

```
  1 001
+ 1 000
-------------
carry = 1   0 001
```

Overflow (sign bit changed to 0):
V=1, C=1.

Incorrect result, error.

Introduction to Easy68K Simulator

- Step 1: Using an ***ASCII-only TEXT EDITOR***, write your program as a series of instructions, line by line, then save the file (.X68)
- Step 2: Use the assembler program, Easy68K, to assemble (**not compile**!) the ASCII text file to an **object** file (.S68) and a **listing** file (.L68)
- Step 3: Use the simulator program in Easy68K to run your program on your PC

We write the program in assembly language as:

```
MOVEA.W   (TEST_S,PC,D7),A0     *We'll use address indirect
MOVEA.W   (TEST_E,PC,D7),A1     *Get the end address
MOVE.B    D0,(A0)               *Write the byte
CMP.B     (A0),D0               *Test it
BEQ       NEXT_LOCATION         *OK, keep going
MOVE.B    D0,D3                 *copy bad data
BSR       ERROR                 *Bad byte
ADDQ.W    #01,A0                *increment the address
CMPA.W    A1,A0                 *are we done?
```

Source file

machine language

```
00000412  307B7048
00000416  327B704A
0000041A  1080
0000041C  B010
0000041E  67000008
00000422  1600
00000424  61000066
00000428  5248
0000042A  B0C9
```

Object file