WEEK 1

ALU = Arithmetic/Logic Unit

CACHE = an area of fast temporary storage

IP = Instruction Pointer

IR = Instruction Register

Instruction Execution Cycle

1. Fetch next instruction
2. Increment IP to point to next inst
3. Decode instruction in IR
4. If instr requires mem access
    a. Determine Mem Add
    b. Fetch operand from memory into register
5. Execute micro-program for instr
6. Go to step 1

Protected Mode – 4 GB available

Real-address mode – 1 MB

wait state – time delay due to differences between the CPU, system bus, etc.

3 types of buses – Data, Address, Control

Parts of instruction from left to right:

- Label, mnemonic, operand, comment

<u>Declare an array as follows:</u>

Data Types:

Type	Used For
BYTE	Character, string, 1-byte int
WORD	2 byte int, address
SWORD	2 byte signed int
DWORD	4 byte unsigned int, addres
SDWORD	4 byte signed int
FWORD	6-byte int
QWORD	8 byte int
TBYTE	10-byte int
REAL4	4-byte floating-point
REAL8	8-byte floating-point
REAL10	10-byte floating-point

someBytes WORD 42 DUP(0)

It means they are initialized to 0.

<u>Integer Information:</u>

- A signed integers stores the sign in the most significant bit.
- The integer range of ASCII codes is 0 to 127
- 32 bit signed integer range:
    - 2^{31} – 1 to -2^{31}

<u>MOVZX = 0 extend move</u>

<u>MOVSX = sign-extend move</u>

Irvine Library:

Clrscr – Clear the screen

- Pre: none
- Post: screen cleared and cursor at upper left

Crlf – New line

- Pre: none
- Post: cursor is at beg of next line

ReadInt – Reads an integer from keyboard, terminated by Enter key

- Pre: none
- Post: value entered is in EAX

ReadString – Reads a string from keyboard, terminated by the Enter key

- Pre: OFFSET of memory destination in EDX, size of memory destination in ECX
- Post: String entered is in memory, Length of string entered is in EAX

WriteInt, WriteDec – Writes an integer to the screen

- Pre: value in EAX
- Post: value displayed,
- WriteInt displays +/-

WriteString – Writes a null-terminated string to the screen

- Pre: OFFSET of memory location in EDX
- Post: string displayed

WriteChar – Writes a character

- Pre: mov character to al
- Post: Character displayed

Constants:

- Two ways to define a constant, however do both before .data
- PI = 3.1416 or PI EQU <3.1416>
- NAME EQU <"Kevin Lewis", 0>

$ = Current location in data segment

Two's Complement

- Change every bit to its opposite then at 1 to the result.

Conversion:

- To binary – Divide by 2 until you get 0, remainders are binary code
- To Hex – Divide by 16 until you get 0, remainders are hex code.

16 Bit sign vs unsigned range:

- Unsigned = 0 - 65535
- Signed = -32768 to 32767

<u>Flags:</u>

Carry (CF)

- Number is larger than the size of the holder. 16 bit number in an 8 bit reg.
- Or if a negative number is produced on with an unsigned subtraction.
- INC instruction does not affect it

Overflow (OF)

- Sum of two numbers with sign bits off yields a result number with the sign bit on.
- Sum of two number with the sign bits on yields a result number with the sign bit off (doesn't care if signed or unsigned)

Push and Pop:

Push – decrements the stack pointer and copies the operand into the stack at the location pointed to by the stack pointer.

ESP – points to the last value to be added to or pushed on the top of stack

Linker – Combines object files into an executable file.

WEEK 3:

Big Endian – Bytes ordered from left to right (most significant to least)

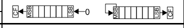
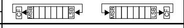
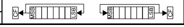
Little Endian – Bytes ordered least significant to most significant (left to right)

Floating Point:

- Decimals in 2^{-1}, 2^{-2}, 2^{-3}, cont..
- Convert integral part in the usual way
- Fractional part in successive multiplication by 2, when the remainder (.x) part multiplied by two is greater than 1, record 1.
- 3 parts
    - 1 sign bit
    - biased exponent (single: 8 bit, double: 11 bit, extended: 15 bits)
    - normalized mantissa (single: 23 bits, double: 52 bits, extended: 64 bits)
    - You need to drop the 1 in the mantissa, becomes part of the exponent

TRANSFER				Flags								
Name	Comment	Code	Operation	O	D	I	T	S	Z	A	P	C
MOV	Move (copy)	MOV Dest,Source	Dest:=Source									
XCHG	Exchange	XCHG Op1,Op2	Op1:=Op2 , Op2:=Op1									
STC	Set Carry	STC	CF:=1									1
CLC	Clear Carry	CLC	CF:=0									0
CMC	Complement Carry	CMC	CF:= ¬CF									±
STD	Set Direction	STD	DF:=1 (string op's downwards)		1							
CLD	Clear Direction	CLD	DF:=0 (string op's upwards)		0							
STI	Set Interrupt	STI	IF:=1			1						
CLI	Clear Interrupt	CLI	IF:=0			0						
PUSH	Push onto stack	PUSH Source	DEC SP, [SP]:=Source									
PUSHF	Push flags	PUSHF	O, D, I, T, S, Z, A, P, C 286+: also NT, IOPL									
PUSHA	Push all general registers	PUSHA	AX, CX, DX, BX, SP, BP, SI, DI									
POP	Pop from stack	POP Dest	Dest:=[SP], INC SP									
POPF	Pop flags	POPF	O, D, I, T, S, Z, A, P, C 286+: also NT, IOPL	±	±	±	±	±	±	±	±	±
POPA	Pop all general registers	POPA	DI, SI, BP, SP, BX, DX, CX, AX									
CBW	Convert byte to word	CBW	AX:=AL (signed)									
CWD	Convert word to double	CWD	DX:AX:=AX (signed)	±				±	±	±	±	±
CWDE	Conv word extended double	CWDE 386	EAX:=AX (signed)									
IN *i*	Input	IN Dest, Port	AL/AX/EAX := byte/word/double of specified port									
OUT *i*	Output	OUT Port, Source	Byte/word/double of specified port := AL/AX/EAX									

i for more information see instruction specifications   Flags: ±=affected by this instruction ?=undefined after this instruction

ARITHMETIC				Flags								
Name	Comment	Code	Operation	O	D	I	T	S	Z	A	P	C
ADD	Add	ADD Dest,Source	Dest:=Dest+Source	±				±	±	±	±	±
ADC	Add with Carry	ADC Dest,Source	Dest:=Dest+Source+CF	±				±	±	±	±	±
SUB	Subtract	SUB Dest,Source	Dest:=Dest-Source	±				±	±	±	±	±
SBB	Subtract with borrow	SBB Dest,Source	Dest:=Dest-(Source+CF)	±				±	±	±	±	±
DIV	Divide (unsigned)	DIV Op	Op=byte: AL:=AX / Op AH:=Rest	?				?	?	?	?	?
DIV	Divide (unsigned)	DIV Op	Op=word: AX:=DX:AX / Op DX:=Rest	?				?	?	?	?	?
DIV 386	Divide (unsigned)	DIV Op	Op=doublew.: EAX:=EDX:EAX / Op EDX:=Rest	?				?	?	?	?	?
IDIV	Signed Integer Divide	IDIV Op	Op=byte: AL:=AX / Op AH:=Rest	?				?	?	?	?	?
IDIV	Signed Integer Divide	IDIV Op	Op=word: AX:=DX:AX / Op DX:=Rest	?				?	?	?	?	?
IDIV 386	Signed Integer Divide	IDIV Op	Op=doublew.: EAX:=EDX:EAX / Op EDX:=Rest	?				?	?	?	?	?
MUL	Multiply (unsigned)	MUL Op	Op=byte: AX:=AL*Op if AH=0 ♦	±				?	?	?	?	±
MUL	Multiply (unsigned)	MUL Op	Op=word: DX:AX:=AX*Op if DX=0 ♦	±				?	?	?	?	±
MUL 386	Multiply (unsigned)	MUL Op	Op=double: EDX:EAX:=EAX*Op if EDX=0 ♦	±				?	?	?	?	±
IMUL *i*	Signed Integer Multiply	IMUL Op	Op=byte: AX:=AL*Op if AL sufficient ♦	±				?	?	?	?	±
IMUL	Signed Integer Multiply	IMUL Op	Op=word: DX:AX:=AX*Op if AX sufficient ♦	±				?	?	?	?	±
IMUL 386	Signed Integer Multiply	IMUL Op	Op=double: EDX:EAX:=EAX*Op if EAX sufficient ♦	±				?	?	?	?	±
INC	Increment	INC Op	Op:=Op+1 (Carry not affected !)	±				±	±	±	±	
DEC	Decrement	DEC Op	Op:=Op-1 (Carry not affected !)	±				±	±	±	±	
CMP	Compare	CMP Op1,Op2	Op1-Op2	±				±	±	±	±	±
SAL	Shift arithmetic left (≡ SHL)	SAL Op,Quantity		*i*				±	±	?	±	±
SAR	Shift arithmetic right	SAR Op,Quantity		*i*				±	±	?	±	±
RCL	Rotate left through Carry	RCL Op,Quantity		*i*								±
RCR	Rotate right through Carry	RCR Op,Quantity		*i*								±
ROL	Rotate left	ROL Op,Quantity		*i*								±
ROR	Rotate right	ROR Op,Quantity		*i*								±

i for more information see instruction specifications   ♦ then CF:=0, OF:=0 else CF:=1, OF:=1

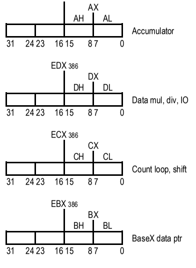
LOGIC				Flags								
Name	Comment	Code	Operation	O	D	I	T	S	Z	A	P	C
NEG	Negate (two-complement)	NEG Op	Op:=0-Op if Op=0 then CF:=0 else CF:=1	±				±	±	±	±	±
NOT	Invert each bit	NOT Op	Op:=¬Op (invert each bit)									
AND	Logical and	AND Dest,Source	Dest:=Dest∧Source	0				±	±	?	±	0
OR	Logical or	OR Dest,Source	Dest:=Dest∨Source	0				±	±	?	±	0
XOR	Logical exclusive or	XOR Dest,Source	Dest:=Dest (exor) Source	0				±	±	?	±	0
SHL	Shift logical left (≡ SAL)	SHL Op,Quantity		*i*				±	±	?	±	±
SHR	Shift logical right	SHR Op,Quantity		*i*				±	±	?	±	±

MISC				Flags								
Name	Comment	Code	Operation	O	D	I	T	S	Z	A	P	C
NOP	No operation	NOP	No operation									
LEA	Load effective address	LEA Dest,Source	Dest := address of Source									
INT	Interrupt	INT Nr	interrupts current program, runs spec. int-program			0	0					

JUMPS (flags remain unchanged)							
Name	Comment	Code	Operation	Name	Comment	Code	Operation
CALL	Call subroutine	CALL Proc		RET	Return from subroutine	RET	
JMP	Jump	JMP Dest					
JE	Jump if Equal	JE Dest	(≡ JZ)	JNE	Jump if not Equal	JNE Dest	(≡ JNZ)
JZ	Jump if Zero	JZ Dest	(≡ JE)	JNZ	Jump if not Zero	JNZ Dest	(≡ JNE)
JCXZ	Jump if CX Zero	JCXZ Dest		JECXZ	Jump if ECX Zero	JECXZ Dest	386
JP	Jump if Parity (Parity Even)	JP Dest	(≡ JPE)	JNP	Jump if no Parity (Parity Odd)	JNP Dest	(≡ JPO)
JPE	Jump if Parity Even	JPE Dest	(≡ JP)	JPO	Jump if Parity Odd	JPO Dest	(≡ JNP)

JUMPS Unsigned (Cardinal)				JUMPS Signed (Integer)			
JA	Jump if Above	JA Dest	(≡ JNBE)	JG	Jump if Greater	JG Dest	(≡ JNLE)
JAE	Jump if Above or Equal	JAE Dest	(≡ JNB ≡ JNC)	JGE	Jump if Greater or Equal	JGE Dest	(≡ JNL)
JB	Jump if Below	JB Dest	(≡ JNAE ≡ JC)	JL	Jump if Less	JL Dest	(≡ JNGE)
JBE	Jump if Below or Equal	JBE Dest	(≡ JNA)	JLE	Jump if Less or Equal	JLE Dest	(≡ JNG)
JNA	Jump if not Above	JNA Dest	(≡ JBE)	JNG	Jump if not Greater	JNG Dest	(≡ JLE)
JNAE	Jump if not Above or Equal	JNAE Dest	(≡ JB ≡ JC)	JNGE	Jump if not Greater or Equal	JNGE Dest	(≡ JL)
JNB	Jump if not Below	JNB Dest	(≡ JAE ≡ JNC)	JNL	Jump if not Less	JNL Dest	(≡ JGE)
JNBE	Jump if not Below or Equal	JNBE Dest	(≡ JA)	JNLE	Jump if not Less or Equal	JNLE Dest	(≡ JG)
JC	Jump if Carry	JC Dest		JO	Jump if Overflow	JO Dest	
JNC	Jump if no Carry	JNC Dest		JNO	Jump if no Overflow	JNO Dest	
				JS	Jump if Sign (= negative)	JS Dest	
				JNS	Jump if no Sign (= positive)	JNS Dest	

General Registers:



Example:

```
        .DOSSEG             ; Demo program
        .MODEL SMALL
        .STACK 1024
Two     EQU 2               ; Const
        .DATA
VarB    DB ?                ; define Byte, any value
VarW    DW 1010b            ; define Word, binary
VarW2   DW 257              ; define Word, decimal
VarD    DD 0AFFFFh          ; define Doubleword, hex
S       DB "Hello !",0      ; define String
        .CODE
main:   MOV AX,DGROUP       ; resolved by linker
        MOV DS,AX           ; init datasegment reg
        MOV [VarB],42       ; init VarB
        MOV [VarD],-7       ; set VarD
        MOV BX,Offset[S]    ; addr of "H" of "Hello !"
        MOV AX,[VarW]       ; get value into accumulator
        ADD AX,[VarW2]      ; add VarW2 to AX
        MOV [VarW2],AX      ; store AX in VarW2
        MOV AX,4C00h        ; back to system
        INT 21h
        END main
```

KEEP IT SIMPLE, STUPID (AND SHORT) - KISS

Flags: - | - | - | - | O | D | I | T | S | Z | - | A | - | P | - | C

Control Flags (how instructions are carried out):

D: Direction 1 = string op's process down from high to low address

I: Interrupt whether interrupts can occur. 1= enabled

T: Trap single step for debugging

Status Flags (result of operations):

C: Carry result of unsigned op. is too large or below zero. 1 = carry/borrow

O: Overflow result of signed op. is too large or small. 1 = overflow/underflow

S: Sign sign of result. Reasonable for Integer only. 1 = neg. / 0 = pos.

Z: Zero result of operation is zero. 1 = zero

A: Aux. carry similar to Carry but restricted to the low nibble only

P: Parity 1 = result has even number of set bits

Hamming Code:

- Required number of parity bits is $\log_2 m + 1$

Test: does an AND operation sets CF to zero, SF to MSB and ZF, only if it is zero afterwards

AND = if both are 1 then 1

OR = Either one is One

XOR = they are different

WEEK 4:

CALL

- pushes the offset of the next instruction in the calling procedure onto the system stack.
- Copies the address of the called procedure into EIP
- Executes the called procedure until RET

RET

- Pops the top of stack into EIP
- Syntax RET n, n causes n to be added to the stack pointer after EIP is assigned a value (for variables passed to the stack)

PUSH

- Decrements the stack pointer by 4
- Actual decrements depends on operand

POP

- Copies value at ESP into a register or variable

Week 5

Activation record:

- Area of the stack used for a procedure's return address, passed parameters, saved registers, and local variables
- Created by the following steps:
  - Calling program pushes arguments onto the stack and calls the procedure
  - The called procedure pushes EBP onto the stack, and sets EBP to ESP

Addressing Modes:

- Register Indirect: Access memory through address in a register
  - mov [edx+12], eax
- Indexed: array name, with "distance" to element in a register
  - mov list[edi], eax
- Base-indexed: starting address in one register, offset in another; add and access memory
  - mov eax, [edx + ecx]

Randomize procedure: must be called once at the beginning of the program.

RandomRange – Generates a random number in [0 .. N – 1]

- Pre: N > 0 in eax
- Post: random integer in [0 .. N-1] in eax
- Range = hi – lo + 1

Week 6

OFFSET

- returns the distance in bytes, of a label from the beginning of its enclosing segment.

PTR

- Overrides the default type of a label, provides the flexibility to access part of a variable
- EX:
  - myDouble DWORD 12345678h
  - mov ax, mydouble -→ error
  - mov ax, WORD PTR myDouble ->> 5678h
  - mov WORD PTR myDouble, 1357h → saves 1357h

Little Endian order is used when storing data in memory: in memory 78h 56h 34h 12h

mov al, BYTE PTR [myDouble + 1] = 56h

TYPE

- Returns the size, in bytes, of a single element of a data declaration
- var1 BYTE
- move eax, TYPE var1 ;1

LENGTHOF

- Counts the number of elements in a single data declaration
- List1 WORD 30 DUP (?) ;30
- Byte1 BYTE 10, 20, 30 ;3
- digitStr BYTE "1234567",0 ;8

SIZEOF

- operator retuns a value that is equivalent to multiplying LENGTHOF by TYPE

A data declaration spans multiple lines if each line ends with a comma.

mov edx, listD[esi * TYPE listD]

Note: you can declare a pointer variable that contains the offset of another variable

Example:

```
List    DWORD       100 DUP(?)
Ptr     DWORD       list
;Contains OFFSET list
```

Two Dimensional Arrays:

Example:

Matrix DWORD 5 DUP (3 DUP (?)) ; 15 elements

- An elements address is calculated as the base address plus an offset BaseAddress + elementSize *[(row# * elementsPerRow) + column#]

String Primitives:

lodsb

- Moves byte at [esi] into the AL register
- Increments esi if direction flag is 0
- Decrements esi if the direction flag is 1

stosb

- Moves byte in the AL register to memory at [edi]
- Increments edi if direction flag is 0
- Decrements edi if direction flag is 1

cld

- Sets the direction flag to 0
- Causes esi and edi to be incremented by lodsb an stosb
- Use for moving "forward" through an array

std

- Sets direction flag to 1
- Causes esi and edi to be decremented by lodsb and stosb
- Used for moving "backward" through an array

ReadInt Algorithm:

```
Get str
X = 0
for k = 0 to (len(str) – 1)
    if 48 <= str[k] <= 57
        x = 10 * x + (str[k] – 48)
    else
        break
```

Floating Point:

- Pushdown stack
- Operations are defined for the "top" one or two registers
- Registers referenced by name ST(x)
- ST = ST(0) = top of stack
- Instruction Format
  - OPCODE
  - OPCODE destination
  - OPCODE destination, source
- FINIT initialize FPU register stack
- FLD MemVar
  - Push ST(i) "down" to ST(I + 1) for I = 0 .. 6
  - Load ST(0) with Mem Var
- FST MemVar
  - Move top of stack to memory
  - Leave result in ST(0)
- FSTP MemVar
  - Pop top of stack to memory
  - Move ST(i) "up" to ST(i-1) for i=1..7
- FADD: Addition (pop top two, add, push result)
- FSUB: Subtraction
- FMUL: Multiplication
- FDIV: Division
- FDIVR: Division (reverses operands)
- FSIN: Sine (uses radians)
- FCOS: Cosine (uses radians
- FSQRT: Square Root
- FABS: Absolute Value
- FYL2X: Y*log2(X) X is in ST(0), Y is in ST(1))
- FYL2XP1: Y * log2(X) + 1

Week 7:

- Procedure
  - During assembly, procedure code is translated once
  - During execution, control is transferred to the procedure at each call, may be called many times.
- Macro
  - Once defined, it can be invoked one or more times
  - During assembly, entire macro code is substituted for each call
  - A macro must be defined before it can be invoked

```
Macroname MACRO [param-1, param-2 ..]
   Statement-list
ENDM
mWriteStr Macro buffer
   push edx
   move dx, OFFSET buffer
   call WriteString
   pop  edx
ENDM
```

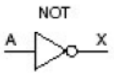
- Should specify that a label is LOCAL

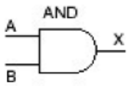
Macro vs Procedure:

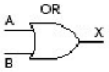
- Macros are very convenient
- Macros execute faster than procedure
- Macros are invoked by name
- If macro is called many times, the assembler produces "fat code"
- Use a macro for short code that is called "a few" times and uses only a few registers
- Use a procedure for more complex code or code that is called "many" times

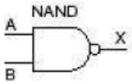
Boolean Expressions

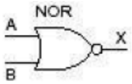
Func	Log	Boolean
NOT(A)	~A	A/
AND(A,B)	A AND B	AB
OR(A,B)	A OR B	A+B
XOR(A,B)	A XOR B	A⊕B
NAND(A,B)	A NAND B	AB/
NOR(A,B)	A NOR B	A+B/
XNOR(A,B)	A XNOR B	A⊕B

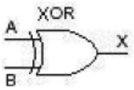


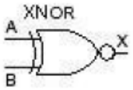












Function of n binary variables has 2^n possible combinations of values for the variables

Week 8:

- Internal Bus
  - Control Unit, ALU, Registers, Addressing Unit communicate via a bus.
  - Speed depends on bus width and bus length

Random access memory (RAM)

Read Only Memory (ROM)

- Clock Cycles
  - Near light speed
  - Clock cycle length determines CPU speed (mostly)

RISC – Reduced Instruction Set Computer

- Clock Cycles
- Instruction executed directly by hardware
- Only LOAD and STORE instuctions reference memory

Multiprocessor parallelism – Shared memory

Multicomputer Parallelism – distributed memory

- Multi-Processor
  - Difficult to build
  - Relatively Easy to Program
- Multi-Computer
  - Easy to build
  - Extremely difficult to program

Amdahl's Law

Speedup = n / (1 + (n – 1) f)

Total time = f*T + (1-f)*T / n

Max speed up = 1/f