Computer Architecture

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Intel-based Assembly

Intel-based Assembly

INTEL HISTORY

Intel Microprocessor History

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  - 1.2 Intel 4040
- 2 The 8-bit processors
  - 2.1 8008
  - 2.2 8080
  - 2.3 8085
- 3 Microcontrollers
  - 3.1 Intel 8048
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  - 3.3 Intel 80151
  - 3.4 Intel 80251
  - 3.5 MCS-96 Family
- 4 The bit-slice processor
  - 4.1 3000 Family
- 5 The 16-bit processors: MCS-86 family
  - 5.1 8086
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  - 5.4 80188
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tory

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- 1.1 Int
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2 The 8-bit
- 2.1 80
- 2.2 80
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3 Microcon
- 3.1 Int
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4 The bit-s
- 4.1 30

5 The 16-b
- 5.1 80
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6 32-bit proc
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- 6.2 i960
- 6.3 i860
- 6.4 XSca

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8 32-bit proc
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9 32-bit proc
- 9.1 Orig
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- 10.1 Pentium Pro
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- 10.3 Celeron (Pentium II-based)
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Product code	Marketing name(s)	Codename(s)
80500	Pentium	P5 (A-step)
80501	Pentium	P5
80502	Pentium	P54C, P54CS
80503	Pentium with MMX Technology	P55C, Tillamook
80521	Pentium Pro	P6
80522	Pentium II	Klamath
80523	Pentium II, Celeron, Pentium II Xeon	Deschutes, Covington, Drake
80524	Pentium II, Celeron	Dixon, Mendocino
80525	Pentium III, Pentium III Xeon	Katmai, Tanner
80526	Pentium III, Celeron, Pentium III Xeon	Coppermine, Cascades
80528	Pentium 4, Xeon	Willamette (Socket 423), Foster
80529	*canceled*	Timna
80530	Pentium III, Celeron	Tualatin
80531	Pentium 4, Celeron	Willamette (Socket 478)
80532	Pentium 4, Celeron, Xeon	Northwood, Prestonia, Gallatin
80533	Pentium III	Coppermine (cD0-step)
80534	Pentium 4 SFF	Northwood (small form factor)
80535	Pentium M, Celeron M 310–340	Banias
80536	Pentium M, Celeron M 350–390	Dothan
80537	Core 2 Duo T5xxx, T7xxx, Celeron M 5xx	Merom
80538	Core Solo, Celeron M 4xx	Yonah
80539	Core Duo, Pentium Dual-core T-series	Yonah
80541	Itanium	Merced

Product code	Marketing name(s)	Codename(s)
80601	Core i7, Xeon 35xx	Bloomfield
80602	Xeon 55xx	Gainestown
80603	Itanium 93xx	Tukwila
80604	Xeon 65xx, Xeon 75xx	Beckton
80605	Core i5-7xx, Core i7-8xx, Xeon 34xx	Lynnfield
80606	*canceled*	Havendale
80607	Core i7-7xx QM, Core i7-8xx QM, Core i7-9xx XM	Clarksfield
80608	*canceled*	Auburndale
80609	Atom Z6xx	Lincroft
80610	Atom N400, D400, D500	Pineview
80611	*canceled*	Larrabee
80612	Xeon C35xx, Xeon C55xx	Jasper Forest
80613	Core i7-9xxX, Xeon 36xx	Gulftown
80614	Xeon 56xx	Westmere-EP
80615	Xeon E7-28xx, Xeon E7-48xx, Xeon E7-88xx	Westmere-EX
80616	Pentium G6xxx, Core i3-5xx, Core i5-6xx	Clarkdale
80617	Core i5-5xx, Core i7-6xxM/UM/LM	Arrandale
80618	Atom E6x0	Tunnel Creek
80619	Core i7-3xxx	Sandy Bridge-EP
80620	Xeon E5-24xx	Sandy Bridge-EP-8, Sandy Bridge-EP-4
80621	Xeon E5-16xx, Xeon E5-26xx, Xeon E5-46xx	Sandy Bridge-EP-8, Sandy Bridge-EP-4
80622		Sandy Bridge-EP-8

Product
80500
80501
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https://en.wikipedia.org/wiki/List_of_Intel_microprocessors

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Intel micro-processor series

Model	Price (USD)	Cores/Threads	Base frequency (GHz)	Max turbo frequency (GHz)	L3 cache (MB)	Release
i7-8086K	$425	6/12	4.0	5.0	12	Q2 2018
i7-8700K	$359	6/12	3.7	4.7	12	Q4 2017
i7-8700	$303	6/12	3.2	4.6	12	Q4 2017
i5-8600K	$257	6/6	3.6	4.3	9	Q4 2017
i5-8500	$202	6/6	3.0	4.1	9	Q2 2018
i5-8400	$182	6/6	2.8	4.0	9	Q4 2017
i3-8350K	$168	4/4	4.0	N/A	8	Q4 2017
i3-8100	$117	4/4	3.6	N/A	6	Q4 2017

Intel micro-processor series

Model	Price (USD)	Cores/Threads	Base frequency (GHz)	Max turbo frequency (GHz)	Release
i9-7980XE	$1999	18/36	2.6	4.2	Q3 2017[1]
i9-7960X	$1699	16/32	2.8	4.2	Q3 2017[1]
i9-7940X	$1399	14/28	3.1	4.3	Q3 2017[1]
i9-7920X	$1189	12/24	2.9	4.3	Q3 2017
i9-7900X	$999	10/20	3.3	4.3	Q2 2017
i7-7820X	$599	8/16	3.6	4.3	Q2 2017
i7-7800X	$389	6/12	3.5	4.0	Q2 2017
i7-7740X	$350	4/8	4.3	4.5	Q1 2017
i7-7700K	$350	4/8	4.2	4.5	Q1 2017
i7-7700	$312	4/8	3.6	4.2	Q1 2017
i7-7700T	$312	4/8	2.9	3.8	Q1 2017
i5-7640X	$242	4/4	4.0	4.2	Q1 2017
i5-7600K	$243	4/4	3.8	4.2	Q1 2017

Intel-based Assembly

INTEL REGISTERS

Basic Execution Environment

- General-purpose registers
- Index and base registers
- Specialized register uses
- Status flags
- Floating-point, MMX, XMM registers

Some Specialized Register Uses (1 of 2)

- General-Purpose
  - RAX/EAX – accumulator
  - RCX/ECX – loop counter
  - RSP/ESP – stack pointer
  - RSI/ESI, RDI/EDI – index registers
  - RBP/EBP – extended frame pointer (stack)
- RIP/EIP/IP – instruction pointer
- RFLAGS/EFLAGS
  - status and control flags
  - each flag is a single binary bit

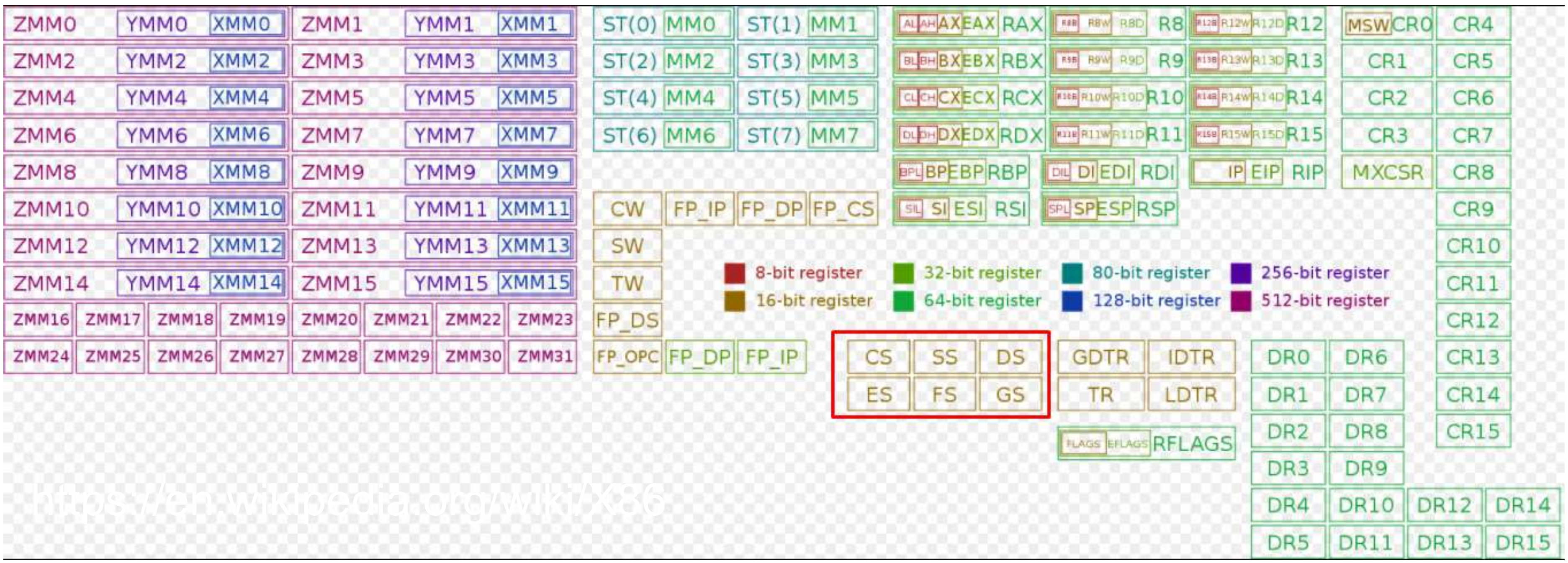
Status Flags

- Carry (CF)
  - unsigned arithmetic out of range
- Overflow (OF)
  - signed arithmetic out of range
- Sign (SF)
  - result is negative
- Zero (ZF)
  - result is zero
- Auxiliary Carry
  - carry from bit 3 to bit 4
- Parity (PF)
  - sum of 1 bits is an even number

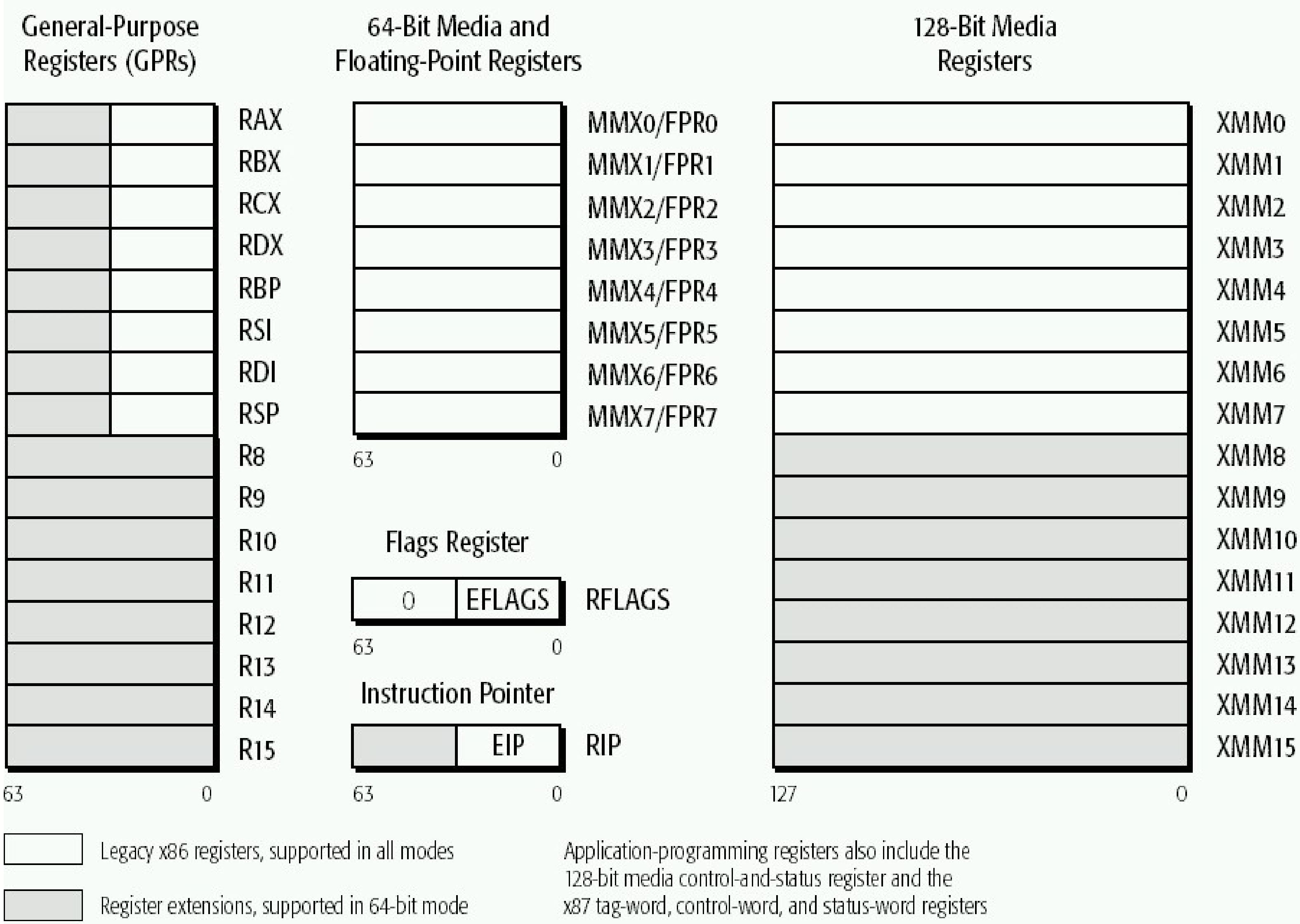
X86_64

- AMD architecture
  - http://developer.amd.com/documentation/guides/Pages/default.aspx
  - https://software.intel.com/en-us/articles/intel-sdm
- Expand the registers into 64bits, rax, rbx, rcx, rdx, …

X86-64 Intel registers



X86_64 registers



X86_64 registers (cont'd)

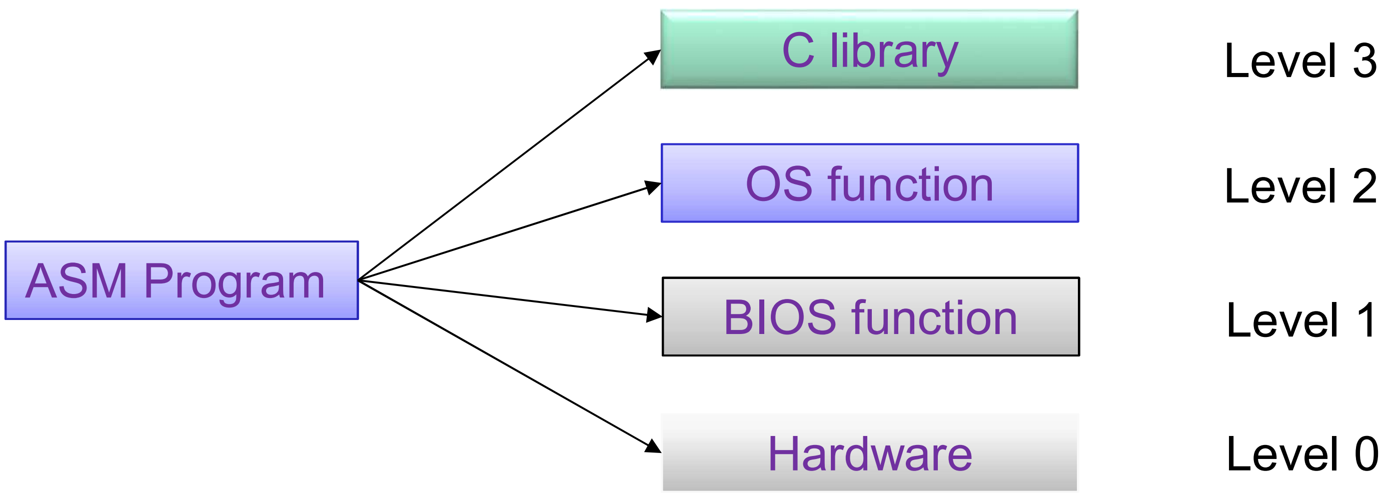
RAX	EAX	AX	AH	AL
RBX	EBX	BX	BH	BL
RCX	ECX	CX	CH	CL
RDX	EDX	DX	DH	DL
RDI	EDI	DI		DIL
RSI	ESI	SI		SIL
RBP	EBP	BP		BPL
RSP	ESP	SP		SPL
R8	R8D	R8W		R8B
…				
R15	R15D	R15W		R15B

Intel-based Assembly

BASIC INSTRUCTIONS

ASM Programming levels

ASM programs can perform input-output at each of the following levels:



Program structure

```
.section .data
output: .asciz “The processor Vendor ID is ‘%s’\n”
.section .text
.globl _start
_start:
    program_body
```

Data Definition Statement

- A data definition statement sets aside storage in memory for a variable.
- Syntax:

  [*name:*] *directive initializer* [,*initializer*] . . .
- All initializers become binary data in memory
- Data type: .byte, .short (.2byte), .int (.long, .4byte), .quad (.8byte), .float, .double, .asciz, .zero expression

```
value1:  .BYTE 'A'            # character constant
value2:  .BYTE 0              # smallest unsigned byte
str:  .asciz "Hello World"   # string
```

Operand Types

- Three basic types of operands:
  - Immediate – a constant integer
    - Imm8, imm16, imm32, imm64
  - Register – the name of a register
    - register name is converted to a number and encoded within the instruction
    - r8, r16, r32, r64, x (real number processing register)
  - Memory – reference to a location in memory
    - memory address is encoded within the instruction, or a register holds the address of a memory location
    - m8, m16, m32, m64

Instruction Operand Notation

Convention:
- w (word): 16 bits;
- d (double word): 32 bits;
- q (quadword): 64 bits

Operand	Description
r8	8-bit general purpose register: AH, AL, BH, BL, CH, CL, r8b, …
r16	16 bit general purpose register: AX, BX, CX, DX, SI, DI, r8w, …
r32	32 bit general purpose register: EAX, EBX, ECX, EDX, r8d, …
r64	64 bit general purpose register: RAX, RBX, RCX, RDX, r8, …
imm8/16/32/64	An immediate of 8, 16, 32, 63 bit
m8/16/32/64	A variable of 8, 16, 32, 64 bit
x	xmm register
r/m8/16/32/64	A register or variable of 8, 16, 32, 64
reg	any general purpose register

Assembly standards

- Intel standard
- AT&T standard

```
mov dst, src
mov eax, 4
add ebx, 1
sub ecx, ebx
```

```
mov src, dst
mov $4, %eax
add $1, %ebx
sub %ebx, %ecx
```

ADD AL, *imm8*

ADD AX, *imm16*

ADD EAX, *imm32*

ADD RAX, *imm32*

ADD *r/m8*, *imm8*

ADD *r/m8**, *imm8*

ADD *r/m16*, *imm16*

ADD *r/m32*, *imm32*

ADD *r/m64*, *imm32*

movss	M_{32}/X	X
movss	X	M_{32}
movsd	M_{64}/X	X
movsd	X	M_{64}

Manual

ADD—Add

Opcode	Instruction	Op/En	64-bit Mode	Compat/Leg Mode	Description
04 *ib*	ADD AL, *imm8*	I	Valid	Valid	Add *imm8* to AL.
05 *iw*	ADD AX, *imm16*	I	Valid	Valid	Add *imm16* to AX.
05 *id*	ADD EAX, *imm32*	I	Valid	Valid	Add *imm32* to EAX.
REX.W + 05 *id*	ADD RAX, *imm32*	I	Valid	N.E.	Add *imm32 sign-extended to 64-bits* to RAX.
80 /0 *ib*	ADD *r/m8, imm8*	MI	Valid	Valid	Add *imm8* to *r/m8.*
REX + 80 /0 *ib*	ADD *r/m8**, *imm8*	MI	Valid	N.E.	Add *sign*-extended *imm8* to *r/m64.*
81 /0 *iw*	ADD *r/m16, imm16*	MI	Valid	Valid	Add *imm16* to *r/m16.*
81 /0 *id*	ADD *r/m32, imm32*	MI	Valid	Valid	Add *imm32* to *r/m32.*
REX.W + 81 /0 *id*	ADD *r/m64, imm32*	MI	Valid	N.E.	Add *imm32 sign-extended to 64-bits* to *r/m64.*

Description

Adds the destination operand (first operand) and the source operand (second operand) and then stores the result in the destination operand. The destination operand can be a register or a memory location; the source operand can be an immediate, a register, or a memory location. (However, two memory operands cannot be used in one instruction.) When an immediate value is used as an operand, it is sign-extended to the length of the destination operand format.

Operation

DEST $\leftarrow$ DEST + SRC;

Flags Affected

The OF, SF, ZF, AF, CF, and PF flags are set according to the result.

MOV Instruction (assigment)

- Move from source to destination. Syntax:

  MOV *source, destination*

  - Both operands must be the same size
  - No more than one memory operand permitted

```
.section .data
Output:  .asciz "The result is: "
Val: .int 10
.section text
…
 mov $4, %eax        #eax=4
 mov $1, %ebx        #ebx=1
 mov $output, %rcx   #rcx=&output
 mov $12, %edx       #edx=12
…
 mov val, %eax       #eax=val
…
 mov  %eax,val       #val=eax
```

Direct-Offset Operands

An offset is added to a data label to produce an effective address (EA).

```
arr: .int 34,3,12,4,3,5
arrB:.byte 1, 2, 3, 4
…
 xor %edx,%edx                #edx=0
 mov arr(,%edx,4),%ebx        #ebx=arr[edx]; ebx = ?
 inc %edx
…
 mov %ah,arrB(,%ebx,1)        #arrB[ebx]=ah
 mov %al,[arrB+1]             # alternative notation
```

Addition and Subtraction

- INC and DEC Instructions
- ADD and SUB Instructions
- NEG Instruction
- Implementing Arithmetic Expressions
- Flags Affected by Arithmetic
  - Zero
  - Sign
  - Carry
  - Overflow

INC and DEC Instructions

- Add 1, subtract 1 from destination operand
  - operand may be register or memory
- INC *destination*
  - Logic: *destination* ← *destination* + 1
- DEC *destination*
  - Logic: *destination* ← *destination* – 1

ADD and SUB Instructions

- ADD source, destination
  - Logic: *destination* $\leftarrow$ *destination* + source
- SUB source, destination
  - Logic: *destination* $\leftarrow$ *destination* – source
- Same operand rules as for the MOV instruction

ADD and SUB Examples

```
var1: .int 0x10000
var2: .int 0x20000
…
mov var1, %eax          #eax=var1; 00010000h
mov var2, %ebx          #ebx=var2;
add %ebx,%eax,          #eax+=ebx; 00030000h
add $0xFFFF,%ax         #ax+=0xFFFF; eax=0003FFFFh
add $1,%eax              #eax+=1;
sub $1,%ax              #ax-=1;
neg %eax                #eax=-eax;
```

NEG (negate) Instruction

Reverses the sign of an operand. Operand can be a register or memory operand.

- NEG destination
  - Logic: *destination* ← - *destination*

```
valB: .BYTE -1
valW .int +32767
…
mov valB,%al  # AL = -1
neg %al       # AL = +1
neg valW      # valW = -32767
```

MUL Instruction

- Unsigned multiplication
- MUL r8/m8 - MUL r16/m16
- MUL r32/m32 - MUL r64/m64

Multiplicant	Multiplier	Product
AL	r8/m8	AX
AX	r16/m16	DX:AX
EAX	r32/m32	EDX:EAX
RAX	r64/m64	RDX:RAX

Homework: study imul instruction for signed numbers

DIV Instruction

- Unsigned multiplication
- DIV r8/m8 - DIV r16/m16 - DIV r32/m32 - DIV r64/m64

Dividend	Divisor	Quotient	Remainder
AX	r8/m8	AL	AH
DX:AX	r16/m16	AX	DX
EDX:EAX	r32/m32	EAX	EDX
RDX:RAX	r64/m64	RAX	RDX

- Division preparation: zero upper registers

Instruction	Meaning
CBW	AX=SE(AL)
CWD	DX:AX=SE(AX)
CDQ	EDX:EAX=SE(EAX)
CQO	RDX:RAX=SE(RAX)

Homework: study idiv instruction for signed numbers. Use left instructions for preparation

Flags Affected by Arithmetic

- The ALU has a number of status flags that reflect the outcome of arithmetic (and bitwise) operations
  - based on the contents of the destination operand
- Essential flags:
  - Zero flag – set when destination equals zero
  - Sign flag – set when destination is negative
  - Carry flag – set when unsigned value is out of range
  - Overflow flag – set when signed value is out of range
- The MOV instruction never affects the flags.

Zero Flag (ZF)

The Zero flag is set when the result of an operation produces zero in the destination operand.

```
mov $1,%cx     # no change in flags
sub $1,%cx     # CX = 0, ZF = 1
mov $0xFFFF,%ax
inc %ax        # AX = 0, ZF = 1
inc %ax        # AX = 1, ZF = 0
```

Remember...

- A flag is set when it equals 1.
- A flag is clear when it equals 0.

JMP Instruction

- JMP is an unconditional jump to a label that is usually within the same procedure.
- Syntax: JMP *target*
- Logic: RIP ← *target*
- Example:

```
top:
.
.
jmp top   #goto top
```

JMP Instruction

- JMP is an unconditional jump to a label that is usually within the same procedure.
- Syntax: JMP *target*
- Logic: RIP $\leftarrow$ *target*
- Example:

```
top:
.
.
jmp top
```

A jump outside the current procedure must be to a special type of label called a global label (see Section 5.5.2.3 for details).

TEST Instruction

- Performs a nondestructive AND operation between each pair of matching bits in two operands
- No operands are modified, but the Zero flag is affected.
- Example: jump to a label if either bit 0 or bit 1 in AL is set.

```
test $11,%al
jnz  ValueFound
```

CMP Instruction (1 of 3)

- Compares the destination operand to the source operand
  - Nondestructive subtraction of source from destination (destination operand is not changed)
  - The flags will be affected
  - One source or destination can be an immediate
- Syntax: CMP *source, destination*

```
mov $5,%al
cmp %al,%bl   # Zero flag set
```

- Example: destination == source?

J*cond* Instruction

- A conditional jump instruction branches to a label when specific register or flag conditions are met
- Examples:
  - JB, JC jump to a label if the Carry flag is set
  - JE, JZ jump to a label if the Zero flag is set
  - JS jumps to a label if the Sign flag is set
  - JNE, JNZ jump to a label if the Zero flag is clear
  - JRCXZ (JECXZ or JCXZ) jumps to a label if RCX (ECX or CX) equals 0

Jumps Based on Specific Flags

Instruction	Description	C instruction
JZ label	Jump if zero	if(ZF==1) goto label;
JNZ label	Jump if not zero	if(ZF==0) goto label;
JC label	Jump if carry	if(CF==1) goto label;
JNC label	Jump if not carry	if(CF==0) goto label;
JO label	Jump if overflow	if(OF==1) goto label;
JNO label	Jump if not overflow	if(OF==0) goto label;
JS label	Jump if signed	if(SF==1) goto label;
JNS label	Jump if not signed	if(SF==0) goto label;
JP label	Jump if parity (even)	if(PF==1) goto label;
JNP label	Jump if not parity (odd)	if(PF==0) goto label;

Jumps Based on Equality

cmp left, right

Instruction	Description
JE label	if(right==left) goto label;
JNE label	if(right!=left) goto label;
JCXZ label	if (%CX==0) goto label;
JECXZ	if (%ECX==0) goto label;
JRCXZ	if (%RCX==0) goto label;

Jumps Based on Unsigned Comparisons

cmp left, right

Mnemonic	Description	Flag
JA *label*	if (*right>left) goto label;*	CF=0 && ZF=0
JNBE *label*	if (*right>left) goto label;*	CF=0 && ZF=0
JAE *label*	if (*right>=left) goto label;*	CF=0
JNB *label*	if (*right>=left) goto label;*	CF=0
JB *label*	if (*right<left) goto label;*	CF=1
JNAE *label*	if (*right<left) goto label;*	CF=1
JBE *label*	if (*right<=left) goto label;*	CF=1 && ZF=1
JNA *label*	if (*right<=left) goto label;*	A=Above; E=Equal;
JE *label*	if (*right==left) goto label;*	N=Not; J=Jump
JNE *label*	if (*right!=left) goto label;*	B=Below

Jumps Based on Signed Comparisons

cmp left, right

Mnemonic	Description	Flag
JG *label*	if (*right>left*) *goto label;*	SF=OF && ZF=0
JNLE *label*	if (*right>left*) *goto label;*	SF=OF && ZF=0
JGE *label*	if (*right>=left*) *goto label;*	SF=OF
JNL *label*	if (*right>=left*) *goto label;*	SF=OF
JL *label*	if (*right<left*) *goto label;*	SF!=OF
JNGE *label*	if (*right<left*) *goto label;*	SF!=OF
JLE *label*	if (*right<=left*) *goto label;*	SF!=OF && ZF=1
JNG *label*	if (*right<=left*) *goto label;*	SF!=OF && ZF=1
JE *label*	if (*right==left*) *goto label;*	G=Greater than
JNE *label*	if (*right!=left*) *goto label;*	L=Less than

Intel-based Assembly

CONTROL STRUCTURE

Conditional Structures

- Block-Structured IF Statements
- Compound Expressions with AND
- Compound Expressions with OR
- WHILE Loops
- Table-Driven Selection

Applications

- Task: Jump to a label if unsigned EAX is greater than EBX
- Solution: Use CMP, followed by JA

```
cmp %ebx, %eax
ja  Larger
```

```
if (%eax > %ebx)
     goto  Larger
```

Applications

- Task: Jump to a label if unsigned EAX is greater than EBX
- Solution: Use CMP, followed by JA

```
cmp %ebx, %eax
ja  Larger
```

```
if (%eax > %ebx)
      goto  Larger
```

- Task: Jump to a label if signed EAX is greater than EBX
- Solution: Use CMP, followed by JG

```
cmp %ebx,%eax
jg  Greater
```

```
if (%eax > %ebx)
      goto  Larger
```

Block-Structured IF Statements

Assembly language programmers can easily translate logical statements written in C++/Java into assembly language. For example:

```
if( op1 == op2 )
  X = 1;
else
  X = 2;
```

```
        mov op1,%eax
        mov op2,%ebx
if:
        cmp %ebx,%eax
        jne else
then:   mov $1,X
        jmp endif
else:   mov $2,X
endif:
```

Your turn . . .

Implement the following pseudocode in assembly language. All values are unsigned:

```
if(ebx <= ecx )
{
  eax = 5;
  edx = 6;
}
```

(There are multiple correct solutions to this problem.)

Your turn . . .

Implement the following pseudocode in assembly language. All values are unsigned:

```
if(ebx <= ecx )
{
  eax = 5;
  edx = 6;
}
```

```
if:    cmp %ecx,%ebx
       ja  endif
then:  mov $5, %eax
       mov $6,%edx
endif:
```

(There are multiple correct solutions to this problem.)

Your turn . . .

Implement the following pseudocode in assembly language. All values are unsigned:

```
if(ebx <= ecx )
{
  eax = 5;
  edx = 6;
}
```

```
if:cmp  %ecx,%ebx
    ja   endif
    mov $5, %eax
    mov $6,%edx
endif:
```

```
if: cmp  %ecx,%ebx
    jbe  then
    jmp endif
then: mov $5, %eax
    mov $6,%edx
endif:
```

(There are multiple correct solutions to this problem.)

Compound Expression with AND (2 of 3)

```
if ((al > bl) && (bl > cl))
  X = 1;
```

This is one possible implementation . . .

```
if: cmp %bl,%al                  # first expression...
 ja  L1
 jmp endif
L1:
 cmp %cl,%bl                     # second expression...
 ja  L2
 jmp endif
L2:                              # both are true
 mov $1,X                        # set X to 1
endif:
```

Compound Expression with AND (3 of 3)

```
if ((al > bl) && (bl > cl))
  X = 1;
```

But the following implementation uses 29% less code by reversing the first relational operator. We allow the program to "fall through" to the second expression:

```
if: cmp %bl,%al                # first expression...
  jbe endif                    # quit if false
  cmp %cl,%bl                  # second expression...
  jbe endif                    # quit if false
then:  mov $1,X                # both are true
endif:
```

Your turn . . .

Implement the following pseudocode in assembly language. All values are unsigned:

```
if( ebx <= ecx
&& ecx > edx )
{
  eax = 5;
  edx = 6;
}
```

(There are multiple correct solutions to this problem.)

Your turn . . .

Implement the following pseudocode in assembly language. All values are unsigned:

```
if( ebx <= ecx
&& ecx > edx )
{
  eax = 5;
  edx = 6;
}
```

```
if:cmp %ebx,%ecx
    ja  next
    cmp %ecx,%edx
    jbe next
    mov $5,%eax
    mov $6,%edx
next:
```

(There are multiple correct solutions to this problem.)

Compound Expression with OR (1 of 2)

- When implementing the logical OR operator, consider that HLLs use short-circuit evaluation
- In the following example, if the first expression is true, the second expression is skipped:

```
if ((al > bl) || (bl > cl))
  X = 1;
```

Compound Expression with OR (1 of 2)

```
if ((al > bl) || (bl > cl))
  X = 1;
```

We can use "fall-through" logic to keep the code as short as possible:

```
if:cmp %bl,%al           # is AL > BL?
   ja  then              # yes
   cmp %cl,%bl           # no: is BL > CL?
   jbe endif             # no: skip next statement
then:mov $1, X           # set X to 1
endif:
```

WHILE Loops

A WHILE loop is really an IF statement followed by the body of the loop, followed by an unconditional jump to the top of the loop. Consider the following example:

```
while( eax < ebx)
eax = eax + 1;      #do
```

WHILE … DO Loops

A WHILE loop is really an IF statement followed by the body of the loop, followed by an unconditional jump to the top of the loop. Consider the following example:

```
while( eax < ebx){
    eax = eax + 1;
}
```

This is a possible implementation:

```
while:cmp %ebx,%eax      # check loop condition
    jae endwhile         # false? exit loop
do: inc %eax             # body of loop
    jmp while            # repeat the loop
endwhile:
```

Your turn . . .

Implement the following loop, using unsigned 32-bit integers:

```
while( ebx <= val1)
{
   ebx = ebx + 5;
   val1 = val1 - 1;
}
```

Your turn . . .

Implement the following loop, using unsigned 32-bit integers:

```
while( ebx <= val1)
{
   ebx = ebx + 5;
   val1 = val1 - 1;
}
```

```
while:cmp val1,%ebx      # check loop condition
      ja  endwhile       # false? exit loop
do:   add $5,%ebx        # body of loop
      dec val1
      jmp while          # repeat the loop
endwhile:
```

DO ...WHILE Loops

```
r8=0; rax=0;
do{
  rax++;
  r8+= rax;
}while(rax < rbx);
```

This is a possible implementation:

```
    xor %r8,%r8
    xor %rax,%rax
do:
    inc %rax              # body of loop
    add %rax,%r8
while:
    cmp %rbx,%rax         # check loop condition
    jb do                 # exit loop or repeat
```

LOOP Instruction- for loop

- The LOOP instruction creates a counting loop
- Syntax: LOOP *target*
- Logic:
  - ECX $\leftarrow$ ECX – 1
  - if ECX != 0, jump to *target*
- Implementation:
  - The assembler calculates the distance, in bytes, between the offset of the following instruction and the offset of the target label. It is called the relative offset.
  - The relative offset is added to EIP.

LOOP Instruction- for loop

Calculate the total of the first n integers (n>0)

`for(r9d=0,ecx=n;ecx>0;ecx--) r9d+=ecx;`

```
init:
   mov $0,%r9d
   mov n,%ecx
for:
   add %ecx,%r9d
   loop for
```

for loop – general case

Calculate the total of the first n integers (n>0)

`for(r9d=0,r10d=0;r10d<=n;r10d++) r9d+= r10d;`

```
init:
   mov $0,%r9d
   xor %r10d,%r10d
while:
   cmp n,%r10d
   ja endwhile
do:
   add %r10d,%r9d
   inc %r10d
   jmp while
endwhile:
```

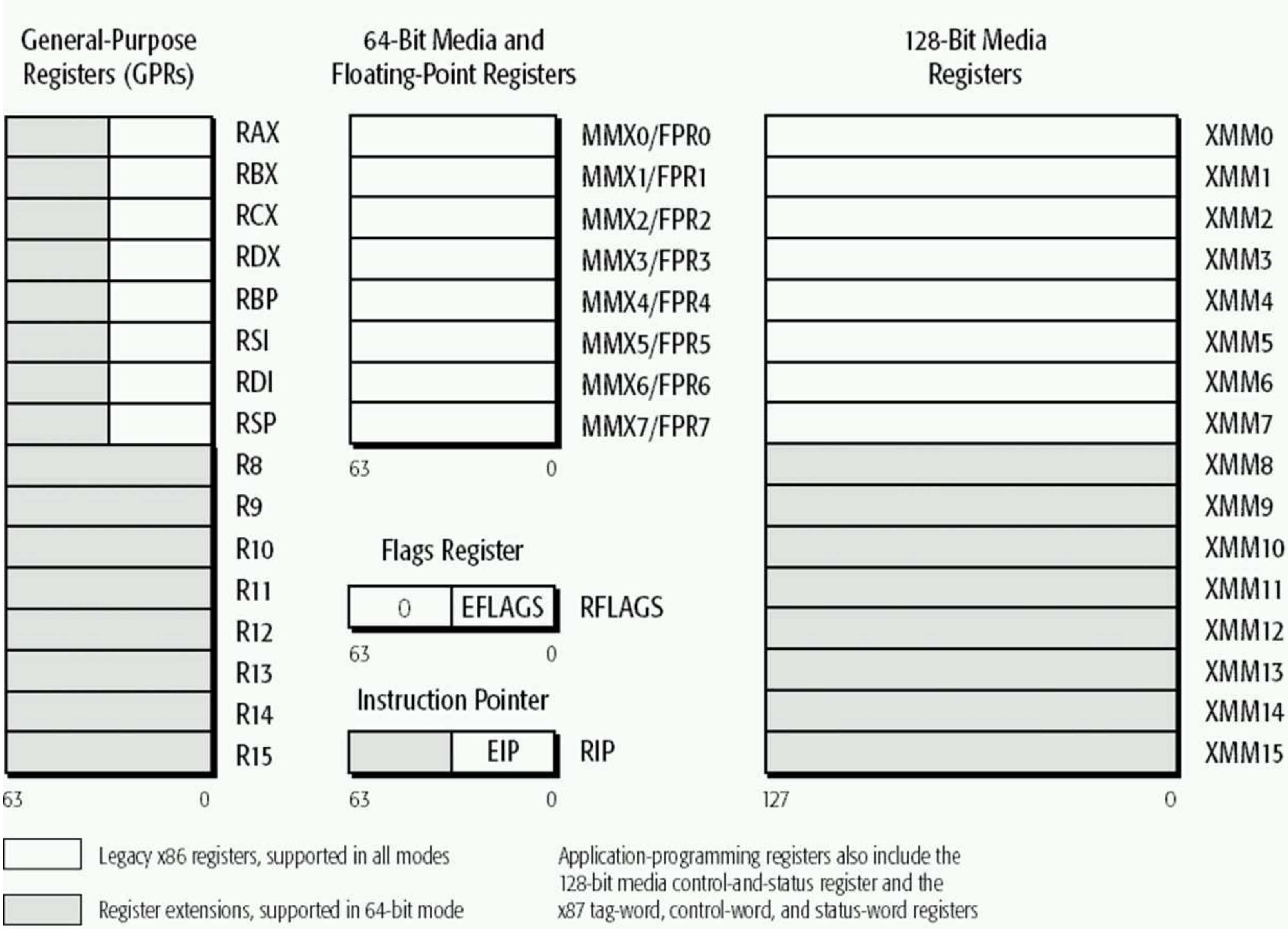
Intel-based Assembly

REAL NUMBER MANIPULATION

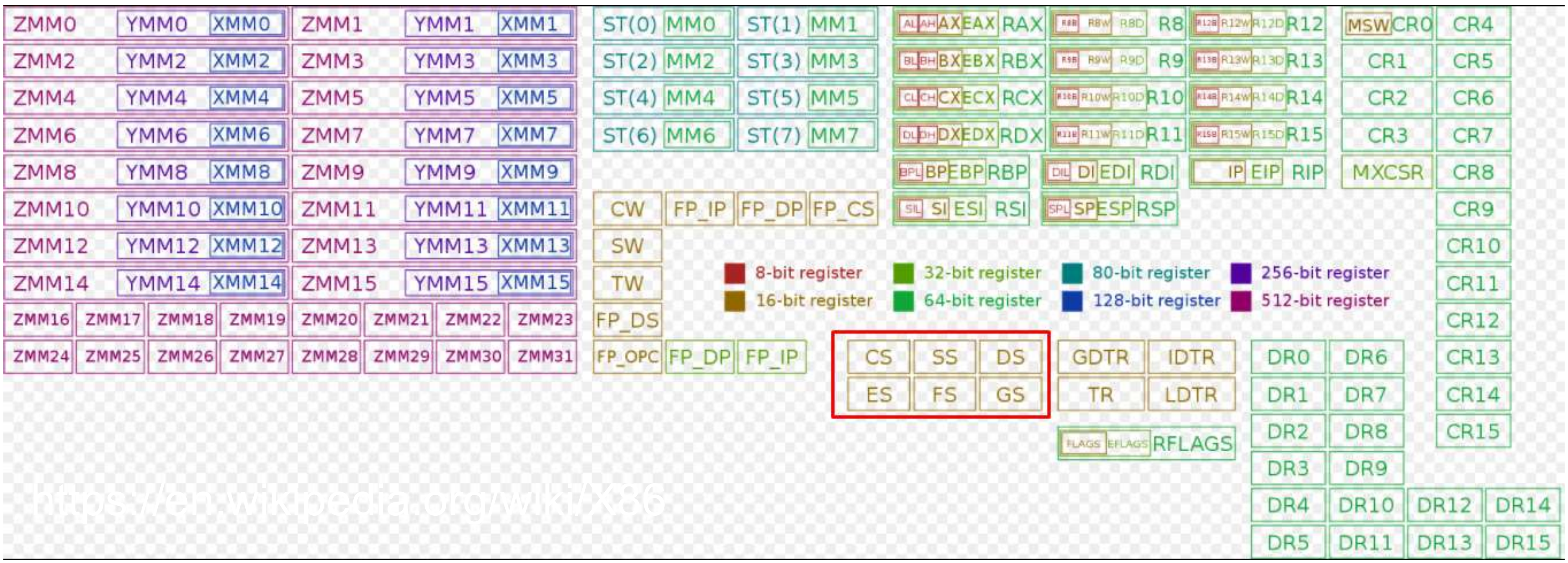
Streaming SIMD Extension (SSE)

- Use 16× 128-bit registers
- Can be used for multiple FP operands
  - 2 × 64-bit double precision
  - 4 × 32-bit single precision
  - Instructions operate on them simultaneously
    - Single-Instruction Multiple-Data
- SSE4 (version 4) is now available

SSE introduction



X86-64 Intel registers



SSE instructions: assignment

Instruction	Source	Destination	Description
movss	M32/X	X	dst=src;
movss	X	M32	dst=src;
movsd	M64/X	X	dst=src;
movsd	X	M64	dst=src;

X: XMM register (e.g., %xmm3)
R32: 32-bit general purpose register (e.g., %eax)
R64: 64-bit general purpose register (e.g., %rax)
M32: 32-bit variable / memory range
M64: 64-bit variable / memory range

SSE instructions (cont'd)

```
len: .double 23.45
result: .double 0.0
arr: .double 3.1,2.3,3.4,4.5,5.6
...
movsd len,%xmm0
movsd %xmm0,result
mov $1, %edx
movsd arr(,%edx,8),%xmm1
```

SSE instructions (cont'd)

float	double	Description
addss src, dst	addsd src, dst	dst+=src;
subss src, dst	subsd src, dst	dst-=src;
mulss src, dst	mulsd src, dst	dst*=src;
divss src, dst	divsd src, dst	dst/=src;
maxss src, dst	maxsd src, dst	dst=max(src,dst);
minss src, dst	minsd src, dst	dst=max(src, dst);
sqrtss src, dst	sqrtsd src, dst	dst=sqrt(src);

xorps S,D	D ← D xor S	S, D are xmm registers
ucomiss left,right	like cmp left, right	Compare single precision
ucomisd left,right	like cmp left, right	Compare double precision

Use JA, JB, JAE, JBE, JE, JNE to make a branch, s is an xmm or a variable

SSE instructions (cont'd)

```
len: .double 23.45
result: .double 0.0
arr: .double 3.1,2.3,3.4,4.5,5.6
...
movsd len,%xmm0
movsd arr(,%edx,8),%xmm1
addsd %xmm1,%xmm0
movsd %xmm0,result
```

SSE instructions (cont'd)

```
  …
  ucomisd %xmm1, %xmm0
  jb else
  movsd %xmm1,%xmm0
else:
  movsd %xmm0,result
…
```

Exercises

- Write a program to add two double numbers and print the result on screen
- Write a program to multiply two double numbers and print the result on screen
- Write a program to print the maximum number of the two double numbers
- Write a program to sum the elements of a double array and print the result on screen

Exercises (cont'd)

- Write a program to solve the equation $ax+b=0$
- Write a program to solve the equation $ax^2+bx+c=0$
- Write a program to print the first of n numbers of a *geometric sequence* (cấp số nhân) with a given value of a and r
- Write a program to print the first of n number in an *arithmetic sequence* (cấp số cộng) with a given value of d and u
- Write a program to find the maximum number of a double array

Intel-based Assembly

NUMERIC TYPE CONVERSION

Numeric types and conversions

- There are a number of numeric types
  - char, unsigned char, int, unsigned int, short, unsigned short, long, unsigned long, long long, unsigned long long, float, double
- There are pointers to the above types
  - how to handle these complexity

Linux 64bit C data model

Integer data type (in bits)

Model	char	short	int	long	pointer (long)
LP64	8	16	32	64	64

SSE: real-2-real, integer-2-real conversion

Instruction	Source	Destination	Description
cvtss2sd	M32/X	X	dst=double(src);//src is float
cvtsd2ss	M64/X	X	dst=float(src);//src is double
cvtsi2ss	M32/R32	X	dst=float(src); //src is int
cvtsi2sd	M32/R32	X	dst=double(src)//src is int
cvtsi2ssq	M64/R64	X	dst=float(src); //src is long
cvtsi2sdq	M64/R64	X	dst=double(src); //src is long

X: XMM register (e.g., %xmm3)
R32: 32-bit general purpose register (e.g., %eax), or int
R64: 64-bit general purpose register (e.g., %rax), or long
M32: 32-bit variable / memory range, of int or float
M64: 64-bit variable / memory range, of long or double

SSE: real-2-integer conversion

Instruction	Source	Destination	Description
cvttss2si	M32/X	R32	dst=int(src); //src is float
cvttsd2si	M64/X	R32	dst=int(src);//src is double
cvttss2siq	M32/R32	R64	dst=long(src); //src is float
cvttsd2siq	M64/R64	R64	dst=long(src)//src is double

X: XMM register (e.g., %xmm3)
R32: 32-bit general purpose register (e.g., %eax)
R64: 64-bit general purpose register (e.g., %rax)
M32: 32-bit variable / memory range
M64: 64-bit variable / memory range

unsigned Integer data conversion

unsigned char uc=12; unsigned short us=71;
unsigned int ui = 23; unsigned long ul=98;

Instruction	Description	Example
movzx r/m8, r16	us=unsigned short(uc);	movzx uc, %ax
movzx r/m8, r32	ui=unsigned int(uc);	movzx uc, %eax
movzx r/m8, r64	ul=unsigned long(uc);	movzx uc, %rax
movzx r/m16, r32	ui=unsigned int(us);	movzx us, %eax
mov r/m16, r64	ul=unsigned long(us);	movzx us, %rax
mov r/m32, r32	ul=unsigned long(ui);	mov ui, %eax #(*)

(*) Upper 32 bits of %rax will be filled by 0
=> %rax = unsigned long(ui);

Signed Integer data conversion

char c=-12; short s=71;
int i = -23; long l=98;

Instruction	Description	Example
movsx r/m8, r16	s=short(c);	movsx c, %ax
movsx r/m8, r32	i=int(c);	movsx c, %eax
movsx r/m8, r64	l=long(c);	movsx c, %rax
movsx r/m16, r32	i=int(s);	movsx s, %eax
movsx r/m16, r64	l=long(s);	movsx s, %rax
movsxd r/m32, r64	l=long(i);	movsxd i, %rax

Signed Integer data conversion

Instruction	Description
CBW	AX=SE(AL)
CWDE	EAX=SE(AX)
CDQE	RAX=SE(EAX)

Bigger to smaller Integer conversion

char c=-12; short s=71;
int i = -23; long l=98;
unsigned char uc=12; unsigned short us=71;
unsigned int ui = 23; unsigned long ul=98;

Instruction	Description
mov ul, %rax	ui=%eax; us= %ax; uc=%al;
mov l, %rax	i=%eax; s= %ax; c=%al;
mov ui, %eax	us= %ax; uc=%al;
mov l, %eax	s= %ax; c=%al;
mov us, %ax	uc=%al;
mov s, %ax	c=%al;

Integer conversions

```
i: .int -6
l: .long # l=long(i); is translated as
msg: .asciz "long value is %ld"
…
mov i , %eax
movsxd %eax, %rsi #conversion
mov %rsi, l
mov $msg, %rdi
call printf
```

Unsigned Integer conversions

```
ui: .int 0xFFAABBCC #unsigned int ui;
ul: .long # unsigned long ul;
msg: .asciz "ulong value is %lu"
#l=unsigned long(ui); is translated as
…
mov ui , %eax
mov %eax, %esi #conversion
mov %rsi, l
mov $msg, %rdi
call printf # 0xFFAABBCC
```

Intel-based Assembly

FUNCTION/PROCEDURE

Procedure/Function

- Define

```
convert:
    mov $10,%ebx
    xor %ecx, %ecx
    …
    ret
```

Parameters are passed via registers

- Call

```
call convert
```

Steps to call:

1. Assign parameters to suitable registers
2. call proc/funct
3. Use the returned value

C library function arguments

Real arguments: 1. xmm0, 2. xmm1, …; return value xmm0

64	32	16	8	Description
%rax	%eax	%ax	%al	return value
%rbx	%ebx	%bx	%bl	Callee saved
%rcx	%ecx	%cx	%cl	4^{th} argument
%rdx	%edx	%dx	%dl	3^{rd} argument
%rsi	%esi	%si	%sil	2^{nd} argument
%rdi	%edi	%di	%dil	1^{st} argument
%rbp	%ebp	%bp	%bpl	Callee saved
%rsp	%esp	%sp	%spl	Stack pointer
%r8	%r8d	%r8w	%r8b	5^{th} argument
%r9	%r9d	%r9w	%r9b	6^{th} argument

System call

- Each system call has different arguments
- Assign parameters to appropriate registers
- Use int 0x80
- Example

Exit from the program

```
mov $0, %ebx
mov $1, %eax
int $0x80
```

Print a string

```
msg: .asciz "Hello World"
mov $4, %eax
mov $1, %ebx
mov $msg, %ecx
mov $10, %edx
int $0x80
```

Call C library function

- 64bit architecture: use registers to pass arguments

```
.section .data
format_string:    .asciz "Vendor ID: %d\n"
vendor_id: .int 12
.section .text
.globl _start
_start:
#Arguments to C functions:
mov $format_string, %rdi
mov vendor_id, %esi
mov $0, %eax
call printf
call exit
```

printf("Vendor ID is: %d\n",id);

Development tools

- compiler: as, linker: ld, debugger: gdb

```
.section .data
output: .asciz "The Vendor ID is '%d'\n"
vendor_id : .byte 12
.section .text
.globl _start
_start:
mov $format_string, %edi
mov vendor_id, %esi
mov $0, %eax
call printf
call exit
```

Compile, link and run the program

$ as –o print.o printf.s

$ ld –dynamic-linker /lib64/ld-linux-x86-64.so.2 –lc –o print print.o

$ ./print

Numeric types and conversions (cont'd)

- Celcius to fahrenheit

```
double cel2fahr(float temp)
{
    return 1.8 * temp + 32;
}
convert the above function into an assembly
  procedure
```

Numeric types and conversions (cont'd)

- Celcius to fahrenheit

```
#temp is in xmm0; scale: .double 1.8
proc_cel2fahrenheit:
 mov $32,%eax                 #eax=32
 cvtsi2sd %eax,%xmm2          #xmm2=double(eax)
 movsd scale,%xmm1            #xmm1=scale
 cvtss2sd %xmm0,%xmm0 #xmm0=double(xmm0)
 mulsd %xmm1,%xmm0        #xmm0*=xmm1
 addsd %xmm2,%xmm0        #xmm0+=xmm2
 ret
```

Numeric types and conversions (cont'd)

- Celcius to fahrenheit

```
double cel2fahr(int *temp){
   return 1.8 * (*temp) + 32.0;
}
```

convert the above function into an assembly procedure

Numeric types and conversions (cont'd)

- Celcius to fahrenheit

```
#rdi=&temp
proc_cel2fahrenheit:
  mov 0(%rdi),%ebx       #ebx=*rdi;#ebx=temp
  cvtsi2sd %ebx,%xmm0    #xmm0=double(ebx)
  mov $32,%eax           #eax=32
  cvtsi2sd %eax,%xmm2    #xmm2=double(eax)
  movsd scale,%xmm1      #xmm1=scale
  mulsd %xmm1,%xmm0      #xmm0*=xmm1
  addsd %xmm2,%xmm0      #xmm0+=xmm2
  ret
```

Exercises

```
void proc(int a1, double *a1p)
{
  *a1p = a1*2.5;
}
```

Convert the above function into an assembly procedure

Exercises (cont'd)

```
double fcvt(int i, float *fp, double *dp, long *lp)
{
  float f = *fp; double d = *dp; long l = *lp;
  *lp = (long) d;
  *fp = (float) i;
  *dp = (double) l;
  return (double) f;
}
```

Convert the above function into an assembly procedure

Exercises (cont'd)

```
double funct(double a,
      float x, double b, int i)
{
   return a*x - b/i;
}
```

Convert the above function into an assembly procedure

Exercises

- Write a procedure to print a number (in %eax)
- Write a program to print the value of factorial N (N!)
- Write a program to print the value of factorial N (N!) in a recursive procedure
- Write a program to print the product of two integer numbers (a*b) by an addition procedure
- Write a program to print the dividend of two integer numbers (a%b) by a recursive subtraction procedure
- Write a program to calculate the sum of an array
- Write a program to calculate the sum of the first n natural numbers (1+2+3+…+n)

Exercises cont'd

- Write a program to print the first *n* fibonaci numbers
- Write a program to print the first of *n* numbers of a *geometric sequence* with a given value of *a* and *r*
- Write a program to print the first of n number in an *arithmetic sequence* with a given value of *d* and *u*
- Write a program to find out the greatest common divisor of the two numbers *a* and *b*
- Write a program to find out the *lowest common multiple* of the two numbers *a* and *b*
- Write a program to sort an array

Exercises cont'd

Fast calculate the function

f(x)=$a_n x^n + a_{n-1}x^{n-1} + a_{n-2}x^{n-2} + \cdots + a_1 x + a_0$ with the following method

f(x)=$(a_n x + a_{n-1})x + a_{n-2})x + \cdots + a_1)x + a_0$

Where a_i is the element of an array float a[n+1]. For example: float a[]={1, 2, 3, 4, 5}; then $a_0 = 1, a_1 = 2, \ldots, a_n = 5$

Fibonaci

```
ebx=1; eax=1;
for(ecx=3;ecx<=n;ecx++){
    r8d=ebx+eax;
    ebx=eax;
    eax=r8d;
}
```

Fibonaci-recursive version

```
unsigned long fibonaci(unsigned long
  n){
   if(n<=2) return 1;
   n1=fibonaci(n-1);
   n2=fibonaci(n-2);
   return n1+n2;
}
```

Factorial

```
eax=1;
for(ebx=1;ebx<=n;ebx++)eax*=ebx;
```

Factorial-recursive version

```
unsigned long fact(unsigned long n){
   if(n==1) return 1;
   unsigned long t=fact(n-1);
   t*=n;
   return t;
}
```

Geometric sequence

```
#a(n)=a(n-1)*r=a.r^(n-1);
xmm0=a;
xmm1=r;
for(ecx=0;exc<n;ecx++)xmm0*=xmm1;
```

Equation $ax+b=0$

```
xmm0=a; xmm2=b;xmm1=0;
if(xmm0==xmm1){  #a==0?
  if(xmm2!=xmm1)  #b==0
    edx=-1; #impossible equation
  else edx=0;   #countless solution
}else{
  edx=1; #one solution
  xmm0=-xmm2/xmm0;
}
```

Maximum number of an array

```
xmm0=a[0];
for(ecx=1;ecx<n;ecx++)
   if(xmm0<a[ecx])xmm0=a[ecx];
```

Sum of an array

```
xmm0=0;
for(ecx=0;ecx<n;ecx++)
   xmm0+=a[ecx];
```

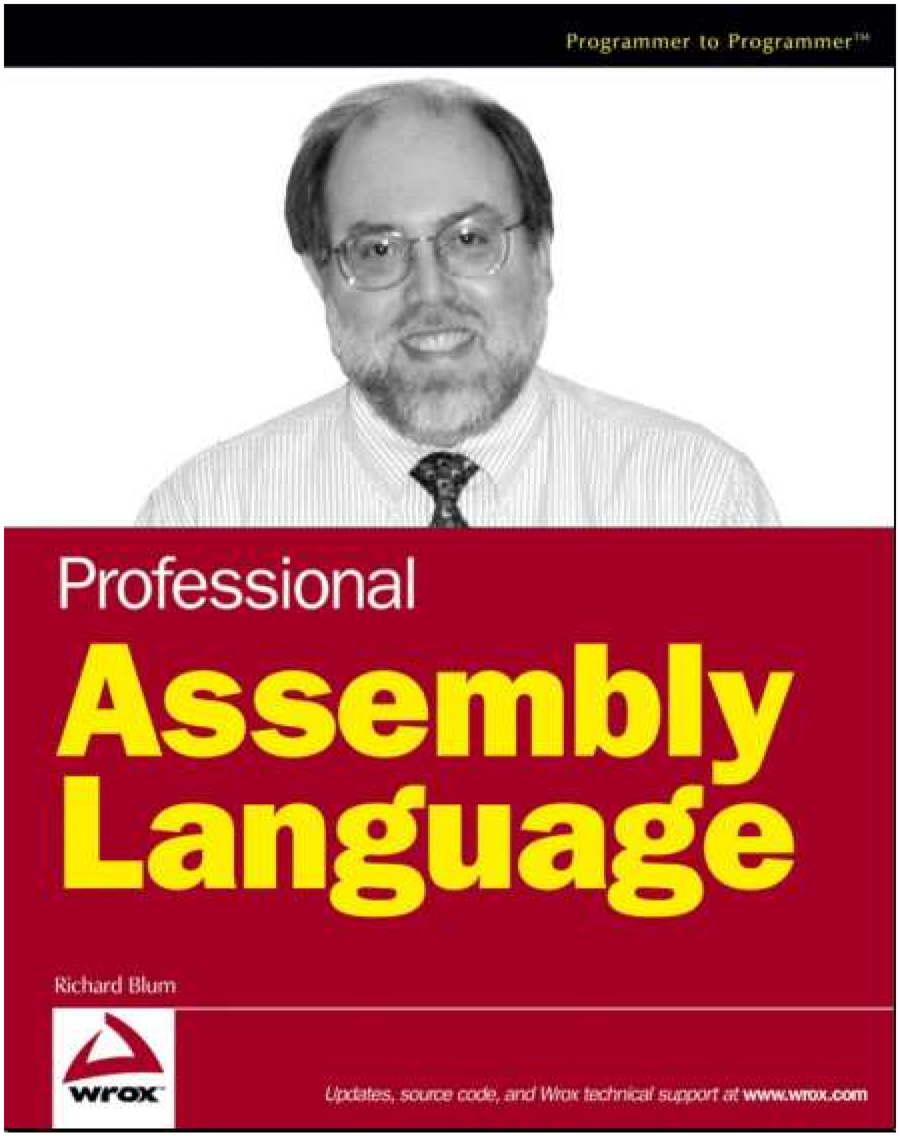
Equation $ax^2+bx+c=0$ (a!=0)

```
xmm5=a; xmm1=b;xmm2=c;xmm3=0;
xmm4=xmm1*xmm1-4*xmm5*xmm2; #delta=b*b-4*a*c;
if(xmm4<xmm3) edx=0; #impossible equation
else if(xmm4==xmm3){
  edx=1; xmm0=-xmm1/xmm5; #one solution
}else {
 edx=2;  #two solutions
 xmm0=(-xmm1-sqrt(xmm4))/(2*xmm5);
 xmm1=(-xmm1+sqrt(xmm4))/(2*xmm5);
}
```

Reference

- Professional Assembly Language,

  Richard Blum, 2005



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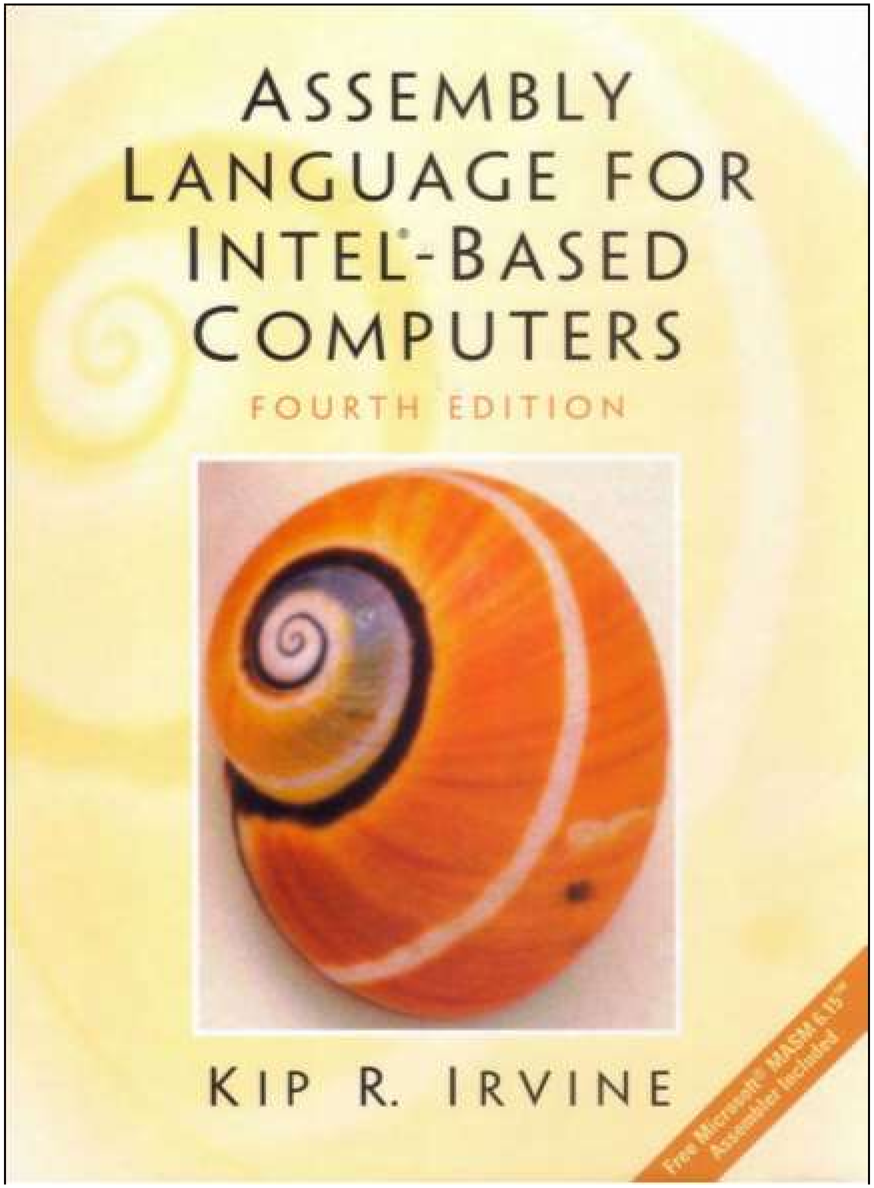

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AMD

AMD64 Technology

AMD64 Architecture Programmer's Manual

Volume 3: General-Purpose and System Instructions

Publication No.	Revision	Date
24594	3.15	November 2009

Advanced Micro Devices

End of chapter

- Happy coding!
- Any questions?

Intel-based Assembly

APPENDICES

Appendix: Call C library function in 32 bit architecture

- Use stack to pass arguments

```
.section .data
output: .asciz "The Vendor ID is '%d'\n"
buffer: .byte 12
.section .text
.globl _start
_start:
push $12
push $output
call printf
addl $8, %esp
push $0
call exit
```

x86 FP Architecture

- Originally based on 8087 FP coprocessor
  - 8 × 80-bit extended-precision registers
  - Used as a push-down stack
  - Registers indexed from TOS: ST(0), ST(1), …
- FP values are 32-bit or 64 in memory
  - Converted on load/store of memory operand
  - Integer operands can also be converted on load/store
- Very difficult to generate and optimize code
  - Result: poor FP performance

x86 FP Instructions

Data transfer	Arithmetic	Compare	Transcendental
FILD mem/ST(i) FISTP mem/ST(i) FLDPI FLD1 FLDZ	FIADDP mem/ST(i) FISUBRP mem/ST(i) FIMULP mem/ST(i) FIDIVRP mem/ST(i) FSQRT FABS FRNDINT	FICOMP FIUCOMP FSTSW AX/mem	FPATAN F2XMI FCOS FPTAN FPREM FPSIN FYL2X

- Optional variations
    - I: integer operand
    - P: pop operand from stack
    - R: reverse operand order
    - But not all combinations allowed