CSC 3210 Computer Organization and Programming

CHAPTER 7: INTEGER ARITHMETIC

Outline

- **Shift and Rotate Instructions**
- Multiplication and Division Instructions
- Extended Addition and Subtraction
- ASCII and Unpacked Decimal Arithmetic
- Packed Decimal Arithmetic

Shift and Rotate Instructions

- **Bit shifting** means to **move** bits **right** and **left** inside an **operand**
- x86 processors provide a particularly set of instructions
- These instructions affect the Overflow and Carry flags

Table 7-1 Shift and Rotate Instructions.

SHL	Shift left
SHR	Shift right
SAL	Shift arithmetic left
SAR	Shift arithmetic right
ROL	Rotate left
ROR	Rotate right
RCL	Rotate carry left
RCR	Rotate carry right
SHLD	Double-precision shift left
SHRD	Double-precision shift right

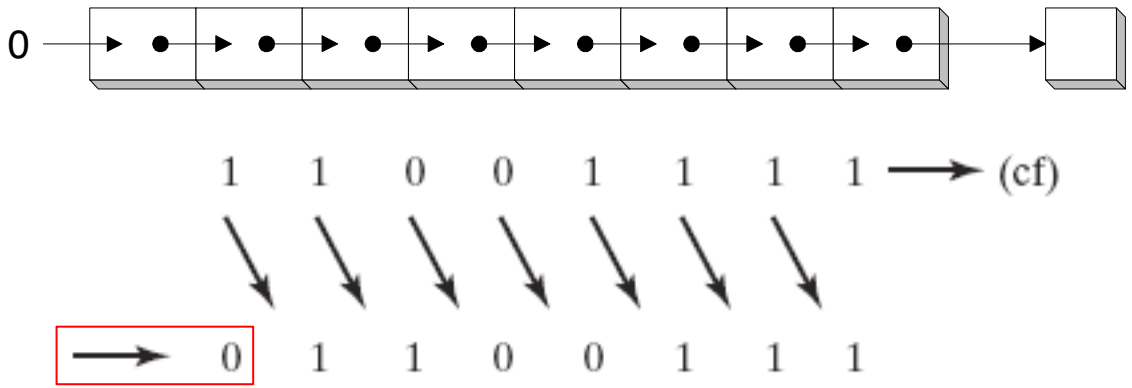
Shift and Rotate Instructions

- **Logical vs Arithmetic Shifts**
- SHL Instruction
- SHR Instruction
- SAL and SAR Instructions
- ROL Instruction
- ROR Instruction
- RCL and RCR Instructions
- SHLD/SHRD Instructions

Logical Shift

- There are **two ways** to shift an operand's bits
  - **The first**: **logical shift**, fills the newly created bit position **with zero**

- **Example:**
  - A byte is logically shifted one position to **the right**
  - Each bit is moved to the next lowest bit position
  - Note that **bit 7** is **assigned** 0:

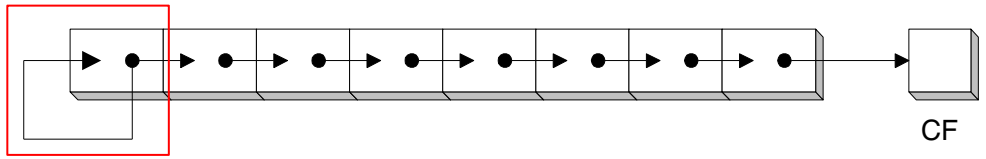


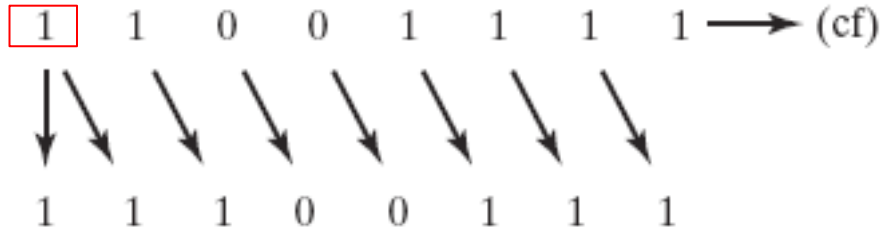
The **lowest bit** is shifted into the **Carry flag**

Arithmetic Shift

- **The Second**: **arithmetic shift**, the newly created bit position is filled with a copy of the original **number's sign bit**

- **Example:**
  - Binary **11001111** has a 1 in the sign bit
  - When shifted **arithmetically** 1 bit to the right, it becomes **11100111**:





Shift and Rotate Instructions

- Logical vs Arithmetic Shifts
- **SHL Instruction**
- SHR Instruction
- SAL and SAR Instructions
- ROL Instruction
- ROR Instruction
- RCL and RCR Instructions
- SHLD/SHRD Instructions

SHL Instruction

- The **SHL** (shift left) instruction
  - Performs a **logical left shift** on the destination operand, **filling** the **lowest bit with 0.**

```
SHL reg,imm8
SHL mem,imm8
SHL reg,CL
SHL mem,CL
```

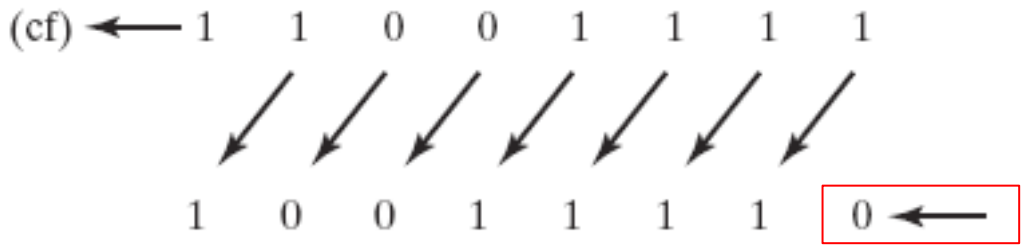
- **CL** register can contain a shift count.

Same for all shift and rotate instructions:
SHR, SAL, SAR, ROR, ROL, RCR, and RCL

SHL Instruction

- The SHL (shift left) instruction
  - **Example:**
    - **BL** is shifted once to the left.
    - The highest bit is copied into the **Carry flag** and the lowest bit position is assigned zero:

```
mov bl,8Fh          ; BL = 10001111b
shl bl,1            ; CF = 1, BL = 00011110b
```




```
SHL reg,imm8
SHL mem,imm8
SHL reg,CL
SHL mem,CL
```

SHL Instruction

- When a value is **shifted leftward multiple times**,
  - The **Carry flag** contains **the last bit** to be shifted out of the most significant bit (MSB)
- **Example:**
  - **bit 7** does not end up in the **Carry flag** because it is replaced by bit 6 (a zero):

```
mov al,10000000b
shl al,2                    ; CF = 0, AL = 00000000b
```

- Similarly, when a value is **shifted rightward multiple times**,
  - The **Carry flag** contains the last bit to be shifted out of the least significant bit (LSB)

SHL Instruction

- **Fast Multiplication**
  - Shifting left 1 bit **multiplies a number by 2**

```
mov dl,5
shl dl,1
```

Before: 0 0 0 0 0 1 0 1 = 5

After: 0 0 0 0 1 0 1 0 = 10

  - **Shifting left** *n* bits **multiplies** the operand by 2^n
    - **For example**, $5 * 2^2 = 20$

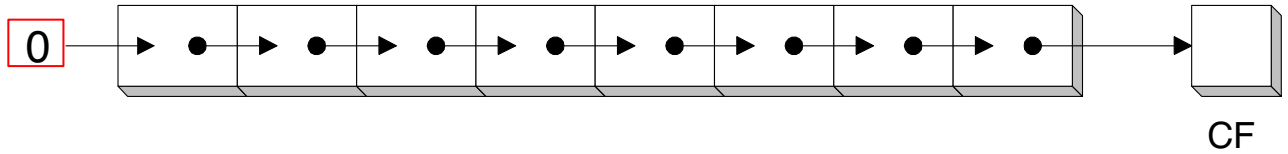
```
mov dl,5
shl dl,2        ; DL = 20
```

Shift and Rotate Instructions

- Logical vs Arithmetic Shifts
- SHL Instruction
- **SHR Instruction**
- SAL and SAR Instructions
- ROL Instruction
- ROR Instruction
- RCL and RCR Instructions
- SHLD/SHRD Instructions

SHR Instruction

- The **SHR** (**shift right**) instruction **performs a logical right shift** on the destination operand
- The highest bit position is **filled with a zero**.



- **Example**,
  - The 0 from the lowest bit in AL is copied into the Carry flag,
  - And the highest bit in AL is filled with a zero:

```
mov al,0D0h          ; AL = 11010000b
shr al,1             ; AL = 01101000b,     CF = 0
```

SHR Instruction

- In a **multiple shift** operation,
  - the **last bit to be shifted** out of position 0 (the LSB) ends up in the **Carry flag**:

```
mov al,00000010b
shr al,2                    ; AL = 00000000b,   CF = 1
```

SHR Instruction

- **Fast Division**
  - **Shifting right** *n* bits divides the operand by 2^n

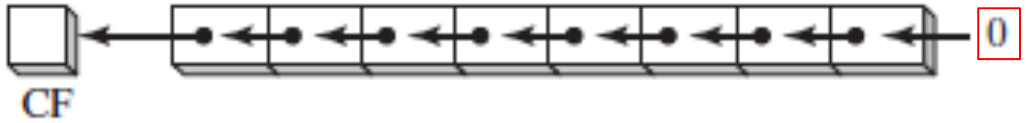
```
mov dl,80
shr dl,1                ; DL = 40   ????
shr dl,2                ; DL = 10   ????
```

Shift and Rotate Instructions

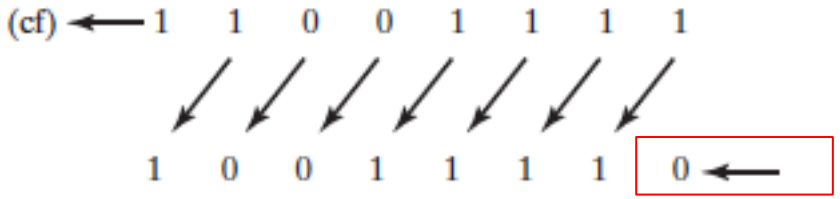
- Logical vs Arithmetic Shifts
- SHL Instruction
- SHR Instruction
- **SAL and SAR Instructions**
- ROL Instruction
- ROR Instruction
- RCL and RCR Instructions
- SHLD/SHRD Instructions

SAL Instruction

- **SAL** (shift arithmetic left) is **identical** to **SHL**
  - The **lowest** bit is assigned 0
  - The **highest** bit is moved to the **Carry flag**,
  - And the bit that was in the Carry flag is **discarded**:

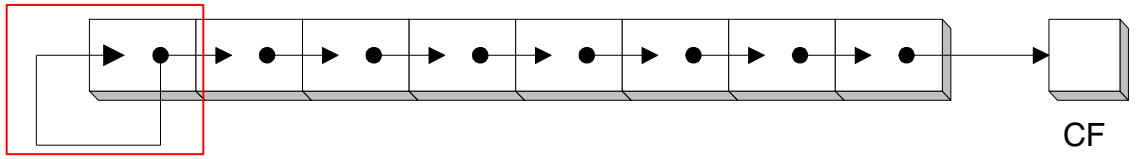


- If you shift binary 11001111 to **the left** by one bit,
  - it becomes 10011110:



SAR Instruction

- **SAR** is **identical** to **SHR**
- **SAR** (shift arithmetic right) performs a **right arithmetic shift** on the destination operand



- The following example shows how SAR **duplicates the sign bit**.
  - **AL** is negative before and after it is shifted to the right:

```
mov al,0F0h          ; AL = 11110000b (-16?)
sar al,1             ; AL = 11111000b ( -8 ?)      CF = 0
```

SAR Instruction

- **SAR** is **identical** to **SHR**

```
mov dl,-80
sar dl,1              ; DL = -40      CF=?
sar dl,2              ; DL = -10      CF=?
```

Application

- Indicate the hexadecimal value of **AL** after each shift:

```
mov al,6Bh
shr al,1
shl al,3

mov al,8Ch
sar al,1
sar al,3
```

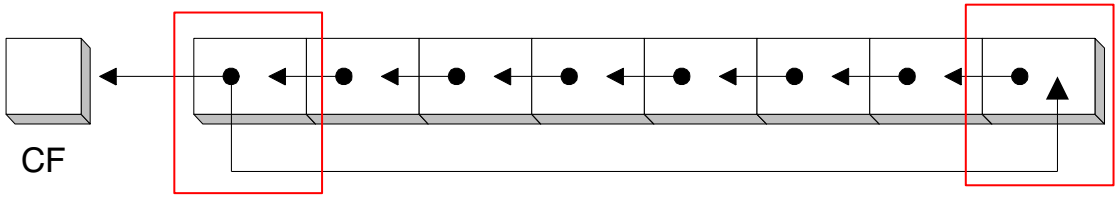
a. 35h
b. A8h
c. C6h
d. F8h

Shift and Rotate Instructions

- Logical vs Arithmetic Shifts
- SHL Instruction
- SHR Instruction
- SAL and SAR Instructions
- **ROL Instruction**
- ROR Instruction
- RCL and RCR Instructions
- SHLD/SHRD Instructions

ROL Instruction

- **ROL** (rotate) **shifts** each bit to the **left**
- **The highest bit** is copied into both the **Carry flag** and into the **lowest** bit
- **No bits are lost**



Example1:

```
mov al,11110000b
rol al,1                    ; AL = 11100001b, CF = ?
```

ROL Instruction

- **ROL** (rotate) **shifts** each bit to the **left**

Example2:

```
mov al,40h      ; AL = 01000000b
rol al,1        ; AL = 10000000b,   CF = 0
rol al,1        ; AL = 00000001b,   CF = 1
rol al,1        ; AL =00000010b,    CF = 0
```

ROL Instruction

- **Multiple Rotations**
  - When using a rotation count greater than 1,
  - Carry flag **contains the last bit rotated out of the MSB** position:

```
mov al,00100000b
rol al,3                ; CF = 1, AL = 00000001b
```

ROL Instruction

- **Exchanging Groups of Bits (Application)**
  - You can use ROL to exchange the upper (bits 4–7) and lower (bits 0–3) halves of a byte

```
mov al,26h
rol al,4          ; AL = 62h
```

Shift and Rotate Instructions

- Logical vs Arithmetic Shifts
- SHL Instruction
- SHR Instruction
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- ROL Instruction
- **ROR Instruction**
- RCL and RCR Instructions
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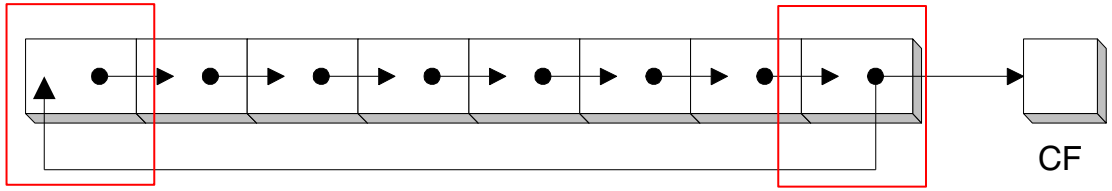
ROR Instruction

- ROR (rotate right) shifts each bit to the right
- The lowest bit is **copied into both** the Carry flag and into the highest bit
- No bits are lost



Example1:

```
mov al,01h      ; AL = 00000001b
ror al,1        ; AL = 10000000b, CF = 1
ror al,1        ; AL = 01000000b, CF = 0
```

ROR Instruction

- ROR (rotate right) shifts each bit to the right

Example2:

```
mov dl,3Fh
ror dl,4        ; DL = F3h
```

ROR Instruction

- **Multiple Rotations**
  - When using a rotation count greater than 1,
  - **Carry flag** **contains the last bit rotated out of the LSB** position:

```
mov al,00000100b
ror al,3                ; AL = 10000000b,      CF = 1
```

Application

- Indicate the hexadecimal value of AL after each rotation:

```
mov al,6Bh
ror al,1
rol al,3
```

a. **B5h**
b. **ADh**

Shift and Rotate Instructions

- Logical vs Arithmetic Shifts
- SHL Instruction
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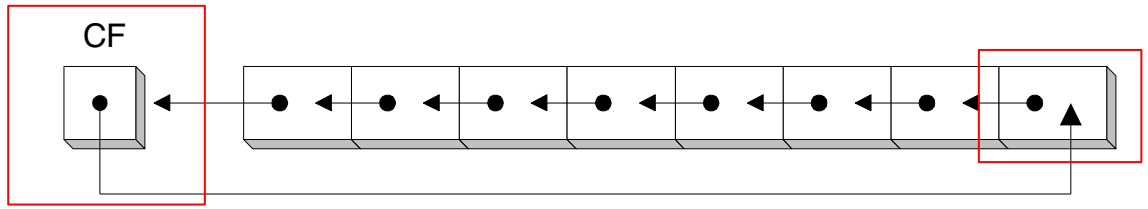
RCL Instruction

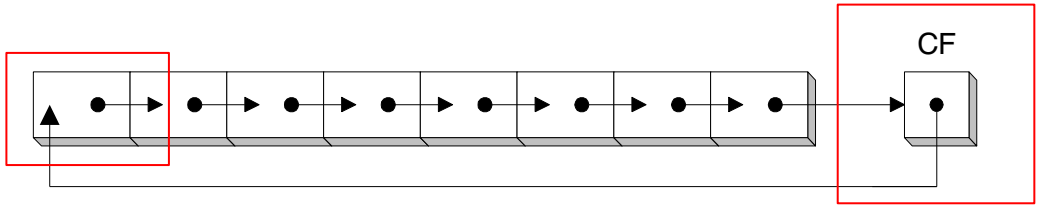
- RCL (rotate carry left) shifts each bit to the left
  - **Copies the Carry flag** to the **least significant bit**
  - **Copies the most significant bit** to **the Carry flag**




```
clc                 ; CF = 0 , CLC instruction clears the Carry flag
mov bl,88h          ; CF = 0 , BL= 10001000b
rcl bl,1            ; CF = 1 , BL= 00010000b
rcl bl,1            ; CF = 0 , BL= 00100001b
```

RCR Instruction

- RCR (rotate carry right) shifts each bit to the right
  - **Copies the Carry flag** to the **most significant bit**
  - **Copies the least significant** bit to **the Carry flag**




```
stc                 ; CF = 1  , STC to set the Carry flag
mov ah,10h          ; CF = 1 , AH = 00010000b
rcr ah,1            ; CF = 0 , AH = 10001000b
```

Application

- Indicate the hexadecimal value of AL after each rotation:

```
stc
mov al,6Bh
rcr al,1
rcl al,3
```

a. B5h
b. AEh

Shift and Rotate Instructions

- Logical vs Arithmetic Shifts
- SHL Instruction
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- RCL and RCR Instructions
- **SHLD/SHRD Instructions: See the book**

Table 7-1 Shift and Rotate Instructions.

SHL	Shift left
SHR	Shift right
SAL	Shift arithmetic left
SAR	Shift arithmetic right
ROL	Rotate left
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RCL	Rotate carry left
RCR	Rotate carry right
SHLD	Double-precision shift left
SHRD	Double-precision shift right

Outline

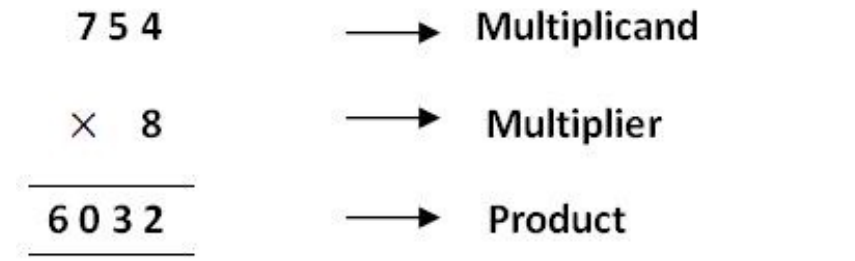
- Shift and Rotate Instructions
- **Multiplication and Division Instructions**
- Extended Addition and Subtraction
- ASCII and Unpacked Decimal Arithmetic
- Packed Decimal Arithmetic

Multiplication and Division Instructions

- **MUL Instruction**
- IMUL Instruction
- DIV Instruction
- Signed Integer Division
- CBW, CWD, CDQ Instructions
- IDIV Instruction
- Implementing Arithmetic Expressions

MUL Instruction

- In 32-bit mode, MUL (unsigned multiply) instruction **multiplies** an 8-, 16-, or 32-bit operand **by** either AL, AX, or EAX.
- The instruction formats are:




```
MUL  reg/mem8
MUL  reg/mem16
MUL  reg/mem32
```

Multiplier operands

MUL Instruction

- The instruction formats are:

```
MUL  reg/mem8
MUL  reg/mem16
MUL  reg/mem32
```

Multiplier operands

```
 7 5 4      →  Multiplicand
 ×   8      →  Multiplier
-------
 6 0 3 2    →  Product
```

Table 7-2 MUL Operands.

Multiplicand	Multiplier	Product
AL	reg/mem8	AX
AX	reg/mem16	DX:AX
EAX	reg/mem32	EDX:EAX

Because the destination operand is **twice the size** of the multiplicand and multiplier, overflow **cannot occur**.

The colon (:) means **concatenation**. This means that **DX** are the bits 16-31 and **AX** are bits 0-15 of the input number

over sized data

MUL Instruction

MUL Examples

The following statements multiply AL by BL, storing the product in AX. The Carry flag is clear (CF = 0) because AH (the upper half of the product) equals zero:

```
mov  al,5h
mov  bl,10h
mul  bl
```

```
; AX = 0050h, CF = 0
```

The following diagram illustrates the movement between registers:

Table 7-2 MUL Operands.

Multiplicand	Multiplier	Product
AL	reg/mem8	AX
AX	reg/mem16	DX:AX
EAX	reg/mem32	EDX:EAX

The Carry flag indicates whether or not the upper half of the product contains **significant digits (?)**

Because the destination operand is **twice the size** of the multiplicand and multiplier, overflow **cannot occur**.

MUL: Example1

- **Example1: 100h * 2000h**, unsigned 16-bit operands:

```
.data
val1 WORD 2000h
val2 WORD 0100h
.code
mov ax,val1
mul val2          ; DX:AX = 00200000h, CF=1
```

Table 7-2 MUL Operands.

Multiplicand	Multiplier	Product
AL	reg/mem8	AX
AX	reg/mem16	DX:AX
EAX	reg/mem32	EDX:EAX

Result = 200000h

Because the destination operand is **twice the size** of the multiplicand and multiplier, overflow **cannot occur**.

The Carry flag indicates whether or not the upper half of the product contains **significant digits (?)**

MUL: Example2

- 12345h * 1000h, using 32-bit operands:

```
mov eax,12345h
mov ebx,1000h
mul ebx              ; EDX:EAX = 00000000 12345000h, CF=0
```

Result = 12345000h

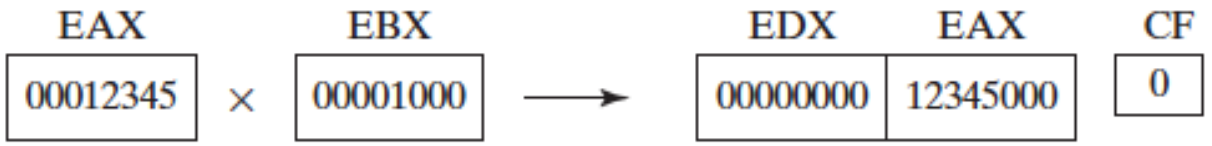


Table 7-2 MUL Operands.

Multiplicand	Multiplier	Product
AL	reg/mem8	AX
AX	reg/mem16	DX:AX
EAX	reg/mem32	EDX:EAX

The Carry flag indicates whether or not the upper half of the product contains **significant digits (?)**

MUL: Example3

- What will be the hexadecimal values of DX, AX, and the Carry flag after the following instructions execute?

```
mov ax,1234h
mov bx,100h
mul bx
```

Result = 123400h

DX = 0012h, AX = 3400h, CF = 1

Table 7-2 MUL Operands.

Multiplicand	Multiplier	Product
AL	reg/mem8	AX
AX	reg/mem16	DX:AX
EAX	reg/mem32	EDX:EAX

MUL: Example4

- What will be the hexadecimal values of EDX, EAX, and the Carry flag after the following instructions execute?

```
mov eax,00128765h
mov ecx,10000h
mul ecx
```

Result = 1287650000h

EDX = 00000012h, EAX = 87650000h, CF = 1

Table 7-2 MUL Operands.

Multiplicand	Multiplier	Product
AL	reg/mem8	AX
AX	reg/mem16	DX:AX
EAX	reg/mem32	EDX:EAX

Multiplication and Division Instructions

- MUL Instruction
- **IMUL Instruction**
- DIV Instruction
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- Implementing Arithmetic Expressions

IMUL Instruction

- IMUL (signed integer multiply) **multiplies** an 8-, 16-, or 32-bit **signed** operand **by** either AL, AX, or EAX
- Preserves the sign of the **product** by **sign-extending it into the upper half** of the **destination** register
- x86 instruction set supports **three formats for the IMUL instruction**:
  - **One** operand, **two** operands, and **three** operands.

IMUL Instruction

- IMUL (signed integer multiply) **multiplies** an 8-, 16-, or 32-bit **signed** operand **by** either AL, AX, or EAX

1. The **one-operand format**, the **multiplier and multiplicand** are **the same size** and the **product is twice their size**

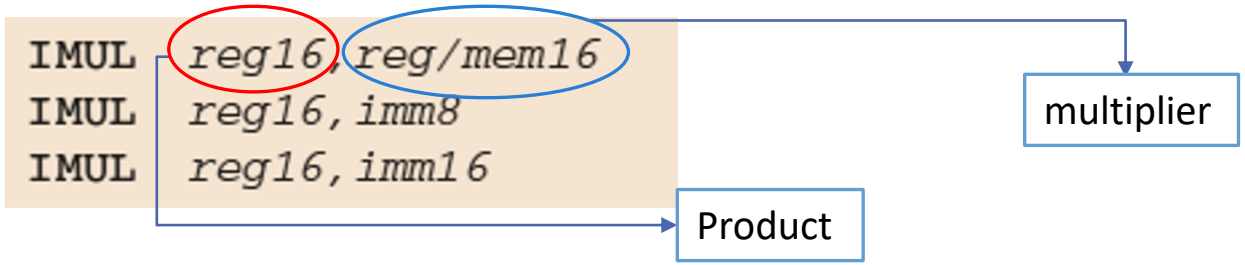
```
IMUL   reg/mem8     ; AX = AL * reg/mem8
IMUL   reg/mem16    ; DX:AX = AX * reg/mem16
IMUL   reg/mem32    ; EDX:EAX = EAX * reg/mem32
```

Multiplier operands

IMUL Instruction

2. **The two-operand** version of the IMUL instruction in **32-bit mode**
   - Stores the **product** **in the first operand**, which **must** be a **register**
   - The **second operand** (the **multiplier**) can be a **register**, a **memory** operand, or an **immediate** value

- Following are the **16-bit formats**:



IMUL Instruction

2. The two-operand version of the IMUL instruction in **32-bit mode**

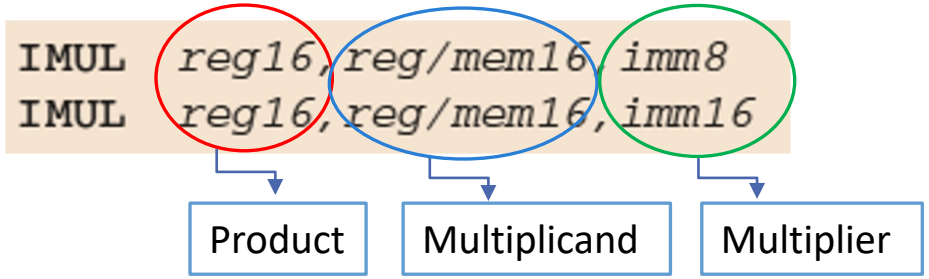
- **The 32-bit operand** types showing that the **multiplier** can be
  - a 32-bit register, a32-bit memory operand, or an immediate value (8 or 32 bits):

```
IMUL   reg32,reg/mem32
IMUL   reg32,imm8
IMUL   reg32,imm32
```

- **The two-operand formats truncate** the **product** to the **length of the destination**
- If significant digits are lost,
  - ❑ the **Overflow** and **Carry** flags are set
  - ❑ Be sure to check one of these flags after performing an IMUL operation with two operands

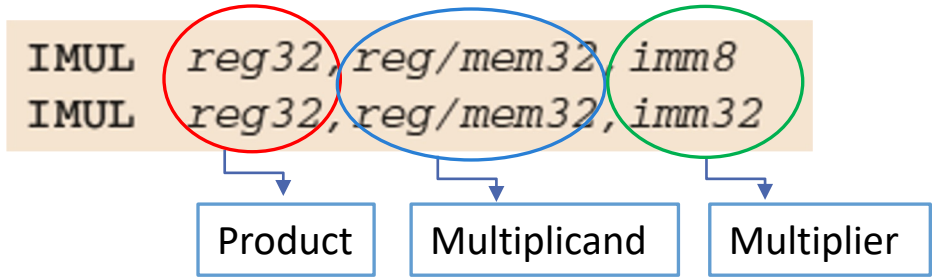
IMUL Instruction

3. **The three-operand** formats in **32-bit mode**
   - Store the **product** **in the first operand**
   - The **second operand** can be
     - a 16-bit register or memory operand, which is multiplied by the third operand,
     - the third operand can be an 8- or 16-bit immediate value:



IMUL Instruction

- A 32-bit register or memory operand can be **multiplied** by
  - an 8- or 32-bit immediate value:



- **Truncate** the **product** to the **length of the destination,** If significant digits are lost,
  - ❑ the **Overflow** and **Carry** flags are set
  - ❑ Be sure to **check one of these flags after performing an IMUL operation** with **two operands**

IMUL: Example1

- The following instructions demonstrate **one-operand formats**:
- multiply 48 * 4, using 8-bit operands:

```
mov  al,48
mov  bl,4
imul bl                    ; AX = 00C0h, OF=1
```

```
IMUL   reg/mem8
IMUL   reg/mem16
IMUL   reg/mem32
```

Multiplier operands

OF=1 because AH **is not a sign extension** of AL.

Preserves the sign of the **product** by **sign-extending it into the upper half** of the **destination** register

IMUL: Example2

- The following instructions demonstrate **one-operand formats**:
- Multiply 4,823,424 * -423:

```
mov eax,4823424
mov ebx,-423
imul ebx              ; EDX:EAX = FFFFFFFF86635D80h, OF=0
```

```
IMUL   reg/mem8
IMUL   reg/mem16
IMUL   reg/mem32
```

Multiplier operands

OF=0 because EDX **is a sign extension of EAX**.

Preserves the sign of the **product** by **sign-extending it into the upper half** of the **destination** register

IMUL: Example3

- The following instructions demonstrate **one-operand formats**:
- What will be the hexadecimal values of DX, AX, and the Carry flag after the following instructions execute?

```
mov ax,8760h
mov bx,100h
imul bx
```

```
IMUL   reg/mem8
IMUL   reg/mem16
IMUL   reg/mem32
```

Multiplier operands

DX = FF87h, AX = 6000h, OF = 1

Product = 876000h

DX is not a sign extension

Preserves the sign of the product by **sign-extending it into the upper half** of the **destination** register

IMUL: Example4

- The following instructions demonstrate **two-operand formats**:

```
.data
word1   SWORD   4
dword1 SDWORD 4
.code
mov ax,-16          ; AX = -16
mov bx,2            ; BX = 2
imul bx,ax          ; BX = -32
imul bx,2           ; BX = -64
imul bx,word1       ; BX = -256
```

```
mov eax,-16         ; EAX = -16
mov ebx,2           ; EBX = 2
imul ebx,eax        ; EBX = -32
imul ebx,2          ; EBX = -64
imul ebx,dword1     ; EBX = -256
```

```
IMUL   reg16, reg/mem16
IMUL   reg16, imm8
IMUL   reg16, imm16
```

Product

```
IMUL   reg32, reg/mem32
IMUL   reg32, imm8
IMUL   reg32, imm32
```

IMUL: Example5

- The following instructions demonstrate **two-operand formats**:

```
mov ax,-32000
imul ax,2          ; OF = 1
```

```
IMUL   reg16,reg/mem16
IMUL   reg16,imm8
IMUL   reg16,imm16
```

- The **two-operand** and t**hree-operand IMUL** instructions use a destination operand that is **the same size as the multiplier**.
- Therefore, it is possible for **signed overflow to occur**.

- signed overflow because **64,000** cannot fit within the **16-bit destination operand**

2^{16}= 65536 (UNSIGNED) : 0 to 65535

2^{15}= 32768(SIGNED) : -1 to -32768 and 0 to 32767

IMUL: Example6

- The following instructions demonstrate **three-operand formats**:

```
.data
word1   SWORD   4
dword1 SDWORD 4
.code
imul bx,word1,-16                ; BX = word1 * -16
imul ebx,dword1,-16              ; EBX = dword1 * -16
imul ebx,dword1,-2000000000      ; signed overflow!
```

```
IMUL   reg16,reg/mem16,imm8
IMUL   reg16,reg/mem16,imm16
```

Product | Multiplicand | Multiplier

```
IMUL   reg32,reg/mem32,imm8
IMUL   reg32,reg/mem32,imm32
```

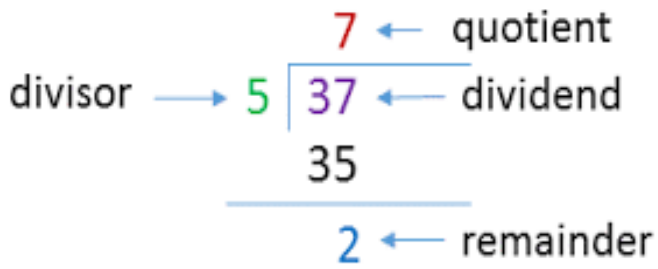
- The **two-operand** and t**hree-operand IMUL** instructions use a destination operand that is the same size as the multiplier.
- Therefore, it is possible for **signed overflow to occur**.

Multiplication and Division Instructions

- MUL Instruction
- IMUL Instruction
- **DIV Instruction**
- Signed Integer Division
- CBW, CWD, CDQ Instructions
- IDIV Instruction
- Implementing Arithmetic Expressions

DIV Instruction

- The DIV (unsigned divide) instruction performs 8-bit, 16-bit, and 32-bit division on unsigned integers



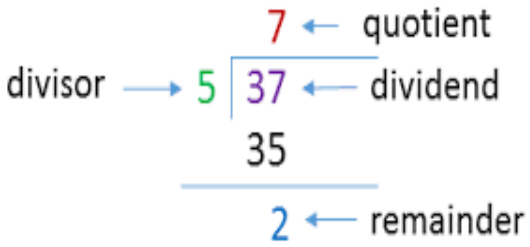
- A **single operand** is supplied (register or memory operand), which is assumed to be the **divisor**
- Instruction formats:

```
DIV reg/mem8
DIV reg/mem16
DIV reg/mem32
```

} divisor

DIV Instruction

- The DIV (unsigned divide) instruction performs 8-bit, 16-bit, and 32-bit division on unsigned integers




```
DIV reg/mem8
DIV reg/mem16
DIV reg/mem32
```

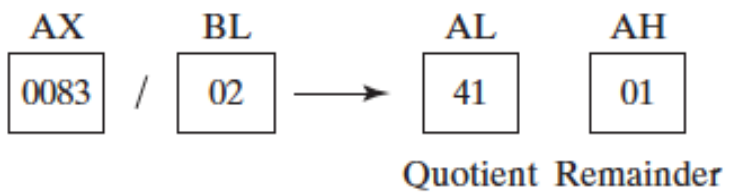
divisor

Dividend	Divisor	Quotient	Remainder
AX	*r/m8*	AL	AH
DX:AX	*r/m16*	AX	DX
EDX:EAX	*r/m32*	EAX	EDX

DIV: Example1

- The following instructions perform 8-bit unsigned division (83h/2),
  - producing a **quotient** of **41h**
  - and a **remainder** of **1**

```
mov ax,0083h        ; dividend
mov bl,2            ; divisor
div bl              ; AL = 41h, AH = 01h
```

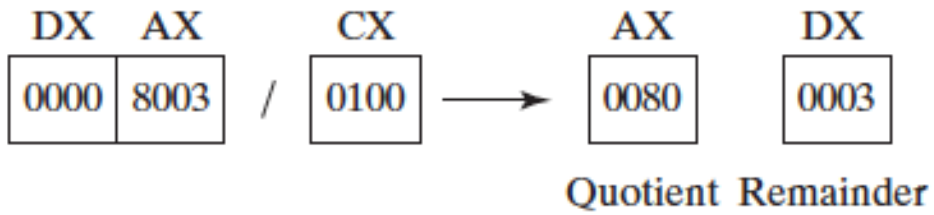


Dividend	Divisor	Quotient	Remainder
AX	*r/m8*	AL	AH
DX:AX	*r/m16*	AX	DX
EDX:EAX	*r/m32*	EAX	EDX

DIV: Example2

- Divide 8003h by 100h, **using 16-bit operands**:

```
mov dx,0          ; clear dividend, high
mov ax,8003h      ; dividend, low
mov cx,100h       ; divisor
div cx            ; AX = 0080h, DX = 3
```



Dividend	Divisor	Quotient	Remainder
AX	*r/m8*	AL	AH
DX:AX	*r/m16*	AX	DX
EDX:EAX	*r/m32*	EAX	EDX

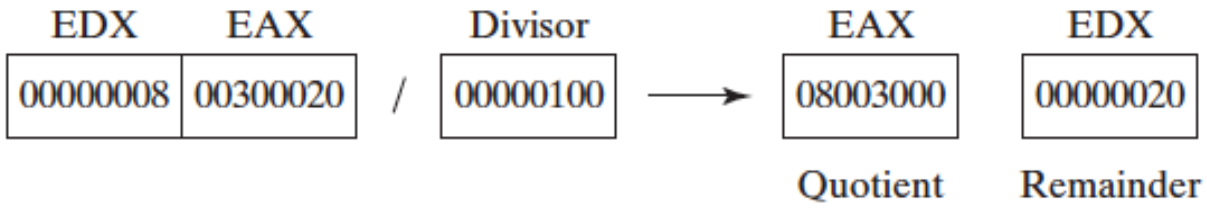
DIV: Example3

Dividend	Divisor	Quotient	Remainder
AX	*r/m8*	AL	AH
DX:AX	*r/m16*	AX	DX
EDX:EAX	*r/m32*	EAX	EDX

- Same division, **using 32-bit operands**:

000800300020h

```
mov edx,0008h              ; dividend, high
mov eax,00300020h          ; dividend, low
mov ecx,100h               ; divisor
div ecx                    ; EAX =              , DX =
```



DIV: Example4

- What will be the hexadecimal values of DX and AX after the following instructions execute? Or, if divide overflow occurs, you can indicate that as your answer:

00876000h

```
mov dx,0087h
mov ax,6000h
mov bx,100h
div bx
```

Quotient = 8760, Rem = 0

DX = , AX =

Use Visual Studio

Dividend	Divisor	Quotient	Remainder
AX	*r/m8*	AL	AH
DX:AX	*r/m16*	AX	DX
EDX:EAX	*r/m32*	EAX	EDX

DIV: Example5

- What will be the hexadecimal values of DX and AX after the following instructions execute? Or, if divide overflow occurs, you can indicate that as your answer:

```
mov dx,0087h
mov ax,6002h
mov bx,10h
div bx
```

Answer: Divide Overflow

Dividend	Divisor	Quotient	Remainder
AX	*r/m8*	AL	AH
DX:AX	*r/m16*	AX	DX
EDX:EAX	*r/m32*	EAX	EDX

If a division operand produces a quotient that will not fit into the destination operand, a divide overflow condition results

- **All arithmetic status flag values** are **undefined after executing DIV and IDIV**

DIV: Division by Zero

- To prevent division by zero, **test the divisor** before dividing:

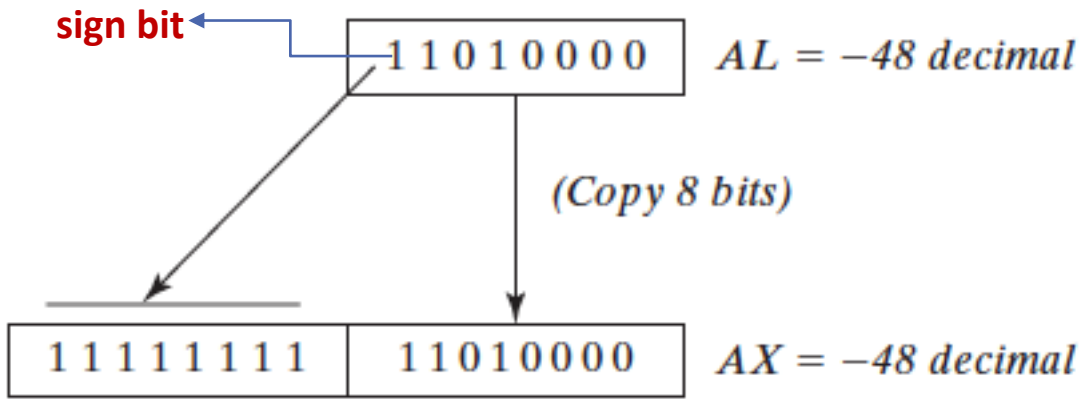
```
mov ax,dividend
mov bl,divisor
cmp bl,0                ; check the divisor
je NoDivideZero         ; zero? display error
div bl                   ; not zero: continue
.
.
NoDivideZero:            ;(display "Attempt to divide by zero")
```

Multiplication and Division Instructions

- MUL Instruction
- IMUL Instruction
- DIV Instruction
- **Signed Integer Division**
- CBW, CWD, CDQ Instructions
- IDIV Instruction
- Implementing Arithmetic Expressions

Signed Integer Division (IDIV)

- **Signed integers MUST** be **sign-extended before division** takes place
  - **Fill high byte/word/doubleword** with **a copy of the low byte/word/doubleword's sign bit**
- **Example**: **The high byte** contains a copy of **the sign** bit from **the low byte**:



Dividend	Divisor	Quotient	Remainder
AX	*r/m8*	AL	AH
DX:AX	*r/m16*	AX	DX
EDX:EAX	*r/m32*	EAX	EDX

How to do sign-extension 🤔?

CBW, CWD, CDQ Instructions

- The **CBW**, **CWD**, and **CDQ** instructions provide important **sign-extension operations**:
  - **CBW** (convert byte to word) **extends** **AL** into **AH**
  - **CWD** (convert word to doubleword) **extends** **AX** into **DX**
  - **CDQ** (convert doubleword to quadword) **extends** **EAX** into **EDX**

Dividend	Divisor	Quotient	Remainder
AX	*r/m8*	AL	AH
DX:AX	*r/m16*	AX	DX
EDX:EAX	*r/m32*	EAX	EDX

- **Example**:

```
.data
dwordVal SDWORD -101        ; FFFFFF9Bh
.code
mov eax,dwordVal
cdq                         ; EDX:EAX = FFFFFFFFFFFFFF9Bh
```

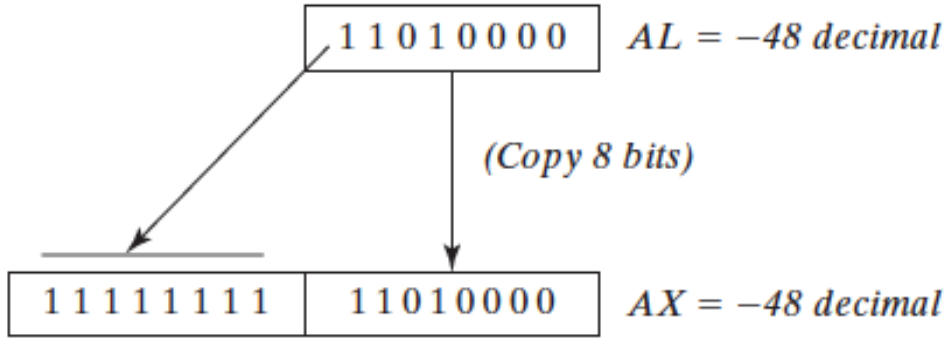
IDIV Instruction

Dividend	Divisor	Quotient	Remainder
AX	*r/m8*	AL	AH
DX:AX	*r/m16*	AX	DX
EDX:EAX	*r/m32*	EAX	EDX

- **IDIV** (signed divide) performs **signed integer division**
- **Same syntax and operands** as **DIV** instruction

- **Example1**: 8-bit division of –48 by 5

```
mov  al,-48
cbw                    ; extend AL into AH
mov  bl,5
idiv bl                ; AL = -9,  AH = -3
```



IDIV Examples

- **Example2**: 16-bit division of –48 by 5

```
mov  ax,-48
cwd                     ; extend AX into DX
mov  bx,5
idiv bx                 ; AX = -9,  DX = -3
```

Dividend	Divisor	Quotient	Remainder
AX	*r/m8*	AL	AH
DX:AX	*r/m16*	AX	DX
EDX:EAX	*r/m32*	EAX	EDX

- **Example3**: 32-bit division of –48 by 5

```
mov  eax,-48
cdq                     ; extend EAX into EDX
mov  ebx,5
idiv ebx                ; EAX = -9,  EDX = -3
```

IDIV Examples

- **Example4**: What will be the hexadecimal values of DX and AX after the following instructions execute? Or, if divide overflow occurs, you can indicate that as your answer:

```
mov  ax,0FDFFh          ; -513
cwd
mov  bx,100h
idiv bx
```

DX = FFFFh (-1), AX = FFFEh (-2)

Dividend	Divisor	Quotient	Remainder
AX	*r/m8*	AL	AH
DX:AX	*r/m16*	AX	DX
EDX:EAX	*r/m32*	EAX	EDX

Unsigned Arithmetic Expressions

- Some good reasons to learn how to implement integer expressions:
  - Learn how do compilers do it
  - Test your understanding of MUL, IMUL, DIV, IDIV
  - Check for overflow (Carry and Overflow flags)

Unsigned Arithmetic Expressions

- **Example1**: **var4 = (var1 + var2) * var3**

; Assume **unsigned** operands

Table 7-2 MUL Operands.

Multiplicand	Multiplier	Product
AL	reg/mem8	AX
AX	reg/mem16	DX:AX
EAX	reg/mem32	EDX:EAX

A good reason **for checking the Carry flag after executing MUL** is to know whether the upper half of the product can safely be ignored.

Unsigned Arithmetic Expressions

- **Example1**: **var4 = (var1 + var2) * var3**

```
; Assume unsigned operands

mov  eax,var1
add  eax,var2          ; EAX = var1 + var2
mul  var3              ; EAX = EAX * var3
jc   TooBig            ; check for carry
mov  var4,eax          ; save product
```

Table 7-2 MUL Operands.

Multiplicand	Multiplier	Product
AL	reg/mem8	AX
AX	reg/mem16	DX:AX
EAX	reg/mem32	EDX:EAX

A good reason **for checking the Carry flag after executing MUL** is to know whether the upper half of the product can safely be ignored.

Unsigned Arithmetic Expressions

- **Example2**: **eax = (-var1 * var2) + var3**

; Assume **signed** operands

Table 7-2 MUL Operands.

Multiplicand	Multiplier	Product
AL	reg/mem8	AX
AX	reg/mem16	DX:AX
EAX	reg/mem32	EDX:EAX

Lecture-22-Chapter-7-Integer-Arithmetic-w

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Unsigned Arithmetic Expr

- **Example2**: eax = (-var1 * var2) + var3

; Assume **signed** operands

Table 7-2 MUL Operands.

Multiplicand	Multiplier	Product
AL	reg/mem8	AX
AX	reg/mem16	DX:AX
EAX	reg/mem32	EDX:EAX

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windows10_fall21 [Running]

File Edit View Git Project Build Debug Test Analyze Tools Extensions Window Help | Search (Ctrl+Q) | Project4

Debug | x86 | Local Windows Debugger

Source.asm* | Project4.lst

```
1   .386
2   .MODEL flat, stdcall
3   .STACK 4096
4   ExitProcess Proto, dwExitCode:DWORD
5   .DATA
6   var1 DWORD 1122h
7   var2 DWORD 3344h
8   var3 DWORD 5566h
9
10  .CODE
11  main PROC
12      neg var1
13      mov eax, var1
14      mul var2
15
16      add eax, var3
17
18
19
20
21
22      INVOKE ExitProcess, 0
23  main ENDP
24  END main
25
26
```

Output | Show output from:

120 % | No issues found

Ready

Project4 - Microsoft Visual Studio

Type here to search

Unsigned Arithmetic Expressions

- **Example2**: **eax = (-var1 * var2) + var3**

; Assume **signed** operands

```
mov  eax,var1
neg  eax
imul var2
jo   TooBig                ; check for overflow
add  eax,var3
jo   TooBig                ; check for overflow
```

Table 7-2 MUL Operands.

Multiplicand	Multiplier	Product
AL	reg/mem8	AX
AX	reg/mem16	DX:AX
EAX	reg/mem32	EDX:EAX

Unsigned Arithmetic Expressions

- **Example3**: **var4 = (var1 * 5) / (var2 – 3)**

  Do not modify any variables other than var4:

  ; Assume **unsigned** operands

Table 7-2 MUL Operands.

Multiplicand	Multiplier	Product
AL	reg/mem8	AX
AX	reg/mem16	DX:AX
EAX	reg/mem32	EDX:EAX

Dividend	Divisor	Quotient	Remainder
AX	*r/m8*	AL	AH
DX:AX	*r/m16*	AX	DX
EDX:EAX	*r/m32*	EAX	EDX

Unsigned Arithmetic Ex

- **Example3**: **var4 = (var1 * 5) / (var2 – 3)**

  Do not modify any variables other than var4

  ; Assume **unsigned** operands

Table 7-2 MUL Operands.

Multiplicand	Multiplier	Product
AL	reg/mem8	AX
AX	reg/mem16	DX:AX
EAX	reg/mem32	EDX:EAX

Dividend	Divisor	Quotient	Remainder
AX	r/m8	AL	AH
DX:AX	r/m16	AX	DX
EDX:EAX	r/m32	EAX	EDX

```
1   .386
2   .MODEL flat, stdcall
3   .STACK 4096
4   ExitProcess Proto, dwExitCode:DWORD
5   .DATA
6   var1 DWORD 1122h
7   var2 DWORD 3344h
8   var3 DWORD 5566h
9   var4 DWORD 7788h
10
11  .CODE
12  main PROC
13
14      mov eax, 5
15      mul var1
16
17      mov ebx, var2
18      sub ebx, 3
19
20      div ebx
21
22
23
24
25
26      INVOKE ExitProcess, 0
27  main ENDP
```

var4 = (var1 * 5) / (var2 – 3)

37/5

EDX:EAX

EBX

EBX

Unsigned Arithmetic Expressions

- **Example3**: **var4 = (var1 * 5) / (var2 – 3)**

  Do not modify any variables other than var4:

```
; Assume unsigned operands

mov  eax,var1          ; left side
mov  ebx,5
mul ebx                ; EDX:EAX = product
mov  ebx,var2          ; right side
sub  ebx,3
div ebx                ; EAX = quotient
mov  var4,eax
```

Table 7-2 MUL Operands.

Multiplicand	Multiplier	Product
AL	reg/mem8	AX
AX	reg/mem16	DX:AX
EAX	reg/mem32	EDX:EAX

Dividend	Divisor	Quotient	Remainder
AX	*r/m8*	AL	AH
DX:AX	*r/m16*	AX	DX
EDX:EAX	*r/m32*	EAX	EDX

Var1=-2
Var2=20
Var3=2

Unsigned Arithmetic Expressions

- **Example4**: **var4 = (var1 * -5) / (-var2 / var3);**

; assume signed 32-bit integers

Dividend	Divisor	Quotient	Remainder
AX	*r/m8*	AL	AH
DX:AX	*r/m16*	AX	DX
EDX:EAX	*r/m32*	EAX	EDX

Table 7-2 MUL Operands.

Multiplicand	Multiplier	Product
AL	reg/mem8	AX
AX	reg/mem16	DX:AX
EAX	reg/mem32	EDX:EAX

Sometimes it's easiest to calculate the right-hand term of an expression first.

Lecture-22-Chapter-7-Integer-Arithmetic

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Unsigned Arithmetic Exp

- **Example4:** var4 = (var1 * -5) / (-var2 / var3

; assume signed 32-bit integers

Dividend	Divisor	Quotient	Remainder
AX	r/m8	AL	AH
DX:AX	r/m16	AX	DX
EDX:EAX	r/m32	EAX	EDX

Table 7-2 MUL Operands.

Multiplicand	Multiplier	Product
AL	reg/mem8	AX
AX	reg/mem16	DX:AX
EAX	reg/mem32	EDX:EAX

Sometimes it's easiest to calculate the right-hand tern

88

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windows10_fall21 [Running]

File Edit View Git Project Build Debug Test Analyze Tools Extensions Window Help Search (Ctrl+Q) Project4

Debug x86 Local Windows Debugger

Source.asm* Project4.lst

```
1   .386
2   .MODEL flat, stdcall
3   .STACK 4096
4   ExitProcess Proto, dwExitCode:DWORD
5   .DATA
6   var1 DWORD 1122h
7   var2 DWORD 3344h
8   var3 DWORD 5566h
9   var4 DWORD 7788h
10
11  .CODE
12  main PROC
13      neg var2
14      mov eax, var2
15      cdq
16
17      idiv var3
18
19      mov ebx, eax
20
21      mov eax, -5
22      imul var1
23
24      idiv ebx
25
26      mov var4, eax
27
28
```

Output

Show output from:

120 % No issues found Ln: 26 Ch: 12 Col: 15 TABS CRLF

Ready

var4 = (var1 * -5) / (-var2 / var3)

var1 * EAX

EDX:EAX / var3

EDX:EAX

EAX / EBX

EAX ⟷ var4

Var1=-2
Var2=20
Var3=2

Unsigned Arithmetic Expressions

- **Example4**: **var4 = (var1 * -5) / (-var2 / var3);**

```
; assume signed 32-bit integers
mov  eax,var2          ; begin right side
neg  eax
cdq                    ; sign-extend dividend
idiv var3              ; EDX = remainder
mov  ebx,eax           ; EBX = right side
mov  eax,-5            ; begin left side
imul var1              ; EDX:EAX = left side
idiv ebx               ; final division
mov  var4,eax          ; quotient
```

Dividend	Divisor	Quotient	Remainder
AX	*r/m8*	AL	AH
DX:AX	*r/m16*	AX	DX
EDX:EAX	*r/m32*	EAX	EDX

Table 7-2 MUL Operands.

Multiplicand	Multiplier	Product
AL	reg/mem8	AX
AX	reg/mem16	DX:AX
EAX	reg/mem32	EDX:EAX

Sometimes it's easiest to calculate the right-hand term of an expression first.

Lecture-21-Chapter-7-Integer-Arithmetic-

Slide Show Review View Acrobat

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imul

Unsigned Arithmetic Expres

- **Example5:** Implement the following expression us
- Do not modify any variables other than var3:

var3 = (var1 * -var2) / (var3 – ebx)

Dividend	Divisor	Quotient	Remainder
AX	*r/m8*	AL	AH
DX:AX	*r/m16*	AX	DX
EDX:EAX	*r/m32*	EAX	EDX

Table 7-2 MUL Operands.

Multiplicand	Multiplier	Product
AL	reg/mem8	AX
AX	reg/mem16	DX:AX
EAX	reg/mem32	EDX:EAX

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windows10_fall21 [Running]

File Edit View Git Project Build Debug Test Analyze Tools Extensions Window Help Search (Ctrl+Q)

Debug x86 Local Windows Debugger

Server Explorer Toolbox

Source.asm* Project4.lst

```
4   ExitProcess Proto, dwExitCode:DWORD
5   .DATA
6   var1 DWORD 1100h
7   var2 DWORD 1000h
8   var3 DWORD 1300h
9   var4 DWORD ?
10  .CODE
11  main PROC
12
13      mov eax, var1
14      mov ecx, var2
15      neg ecx
16
17      imul ecx
18
19      mov ecx, var3
20      sub ecx, ebx
21
22      idiv ecx
23
24      mov var3, eax
25
26
27      INVOKE ExitProcess, 0
28  main ENDP
29  END main
30
31
```

Output

Show output from: Build

```
Build started...
------ Build started: Project: Project4, Configurat
Assembling Source.asm...
Project4.vcxproj -> C:\Users\Zulkar\Source\Repos\Pr
========== Build: 1 succeeded, 0 failed, 0 up-to-da
```

120 % No issues found Ln: 16 Ch: 5 TABS CRLF

var3 = (var1 * -var2) / (var3 - ebx)

eax * ecx

EDX:EAX / ecx

EAX

Unsigned Arithmetic Expressions

- **Example5:** Implement the following expression using **signed 32-bit** integers.
- Do not modify any variables other than var3:

var3 = (var1 * -var2) / (var3 – ebx)

Dividend	Divisor	Quotient	Remainder
AX	*r/m8*	AL	AH
DX:AX	*r/m16*	AX	DX
EDX:EAX	*r/m32*	EAX	EDX

Table 7-2 MUL Operands.

Multiplicand	Multiplier	Product
AL	reg/mem8	AX
AX	reg/mem16	DX:AX
EAX	reg/mem32	EDX:EAX

Lecture-22-Chapter-7-Integer-Arithmetic-with-annot

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Unsigned Arithmetic Express

- **Example5:** Implement the following expression usi
- Do not modify any variables other than var3:

var3 = (var1 * -var2) / (var3 – ebx)

Dividend	Divisor	Quotient	Remainder
AX	*r/m8*	AL	AH
DX:AX	*r/m16*	AX	DX
EDX:EAX	*r/m32*	EAX	EDX

Table 7-2 MUL Operands.

Multiplicand	Multiplier	Product
AL	reg/mem8	AX
AX	reg/mem16	DX:AX
EAX	reg/mem32	EDX:EAX

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You are screen sharing Stop Share

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Debug x86 Local Windows Debugger

Source.asm* Project4.lst

```
1   .386
2   .MODEL flat, stdcall
3   .STACK 4096
4   ExitProcess Proto, dwExitCode:DWORD
5   .DATA
6   var1 DWORD 1122h
7   var2 DWORD 3344h
8   var3 DWORD 5566h
9   var4 DWORD 7788h
10
11  .CODE
12  main PROC
13      mov edx, var2
14      neg edx
15      mov eax, var1
16      imul edx
17
18      mov ecx,var3
19      sub ecx, ebx
20
21      idiv ecx
22
23      mov var3, eax
24
25
26
27
28
```

Output

Show output from:

var3 = (var1 * -var2) / (var3 - ebx)

EAX

EDX:EAX

(ECX - ebx)

ECX

EAX

Project4 - Microsoft Visual Studio

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Unsigned Arithmetic Expressions

- **Example5:** Implement the following expression using **signed 32-bit** integers.
- Do not modify any variables other than var3:

var3 = (var1 * -var2) / (var3 – ebx)

```
mov  eax,var1
mov  edx,var2
neg  edx
imul edx                ; left side: EDX:EAX
mov  ecx,var3
sub  ecx,ebx
idiv ecx                ; EAX = quotient
mov  var3,eax
```

Dividend	Divisor	Quotient	Remainder
AX	*r/m8*	AL	AH
DX:AX	*r/m16*	AX	DX
EDX:EAX	*r/m32*	EAX	EDX

Table 7-2 MUL Operands.

Multiplicand	Multiplier	Product
AL	reg/mem8	AX
AX	reg/mem16	DX:AX
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Outline

- Shift and Rotate Instructions
- Shift and Rotate Applications
- Multiplication and Division Instructions
- Extended Addition and Subtraction See the book
- ASCII and Unpacked Decimal Arithmetic See the book
- Packed Decimal Arithmetic See the book

Extended Addition and Subtraction

- **Extended precision addition and subtraction** is the technique of
  - **adding** and **subtracting** numbers having **an almost unlimited size**

```
mov al,0FFh
add al,0FFh          ; AL = FEh
```

  - In assembly language, the **ADC** instruction is well suited to this type of operation
- How about subtraction?

```
mov eax,1
sub eax,2          ;EAX= ?
```

  - the **SBB** instruction is well suited to this type of operation