

Assembly Language for x86 Processors

7th Edition

Kip R. Irvine

Chapter 7: Integer Arithmetic

Chapter Overview

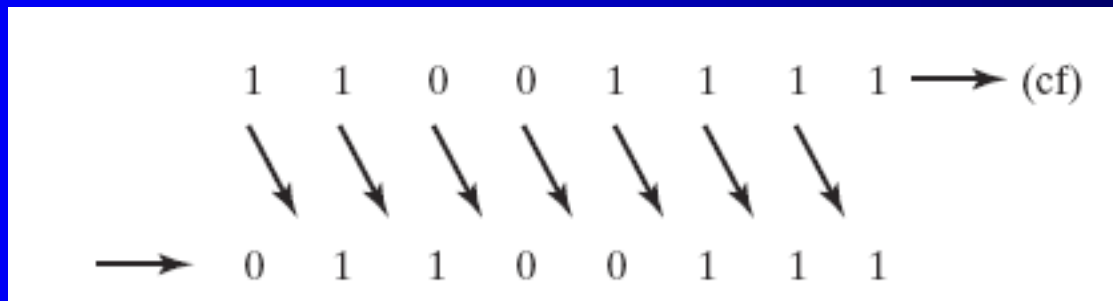
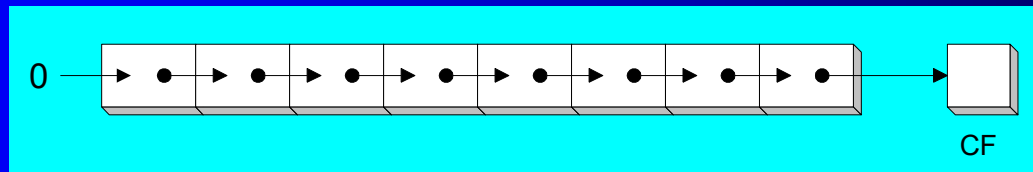
- **Shift and Rotate Instructions**
- Shift and Rotate Applications
- Multiplication and Division Instructions
- Extended Addition and Subtraction
- ASCII and Unpacked Decimal Arithmetic
- Packed Decimal Arithmetic

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

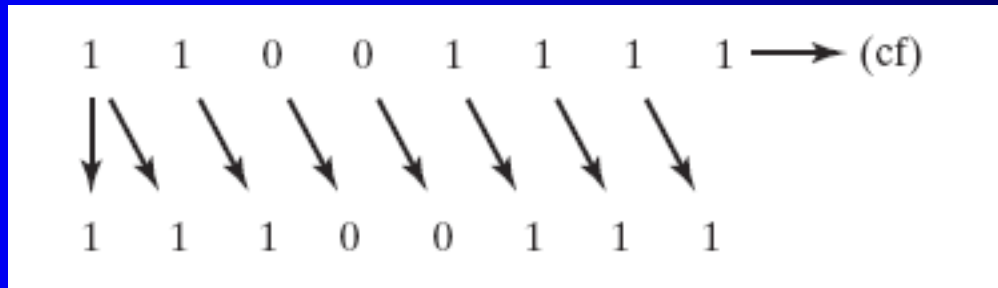
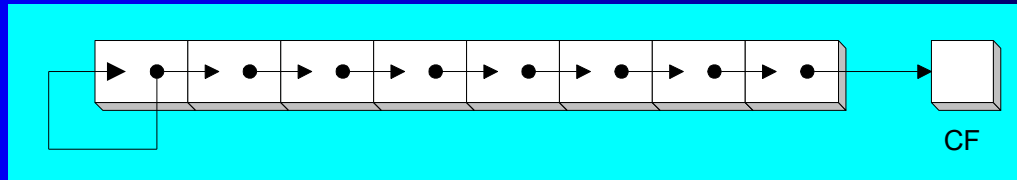
Logical Shift

- A logical shift fills the newly created bit position with zero:



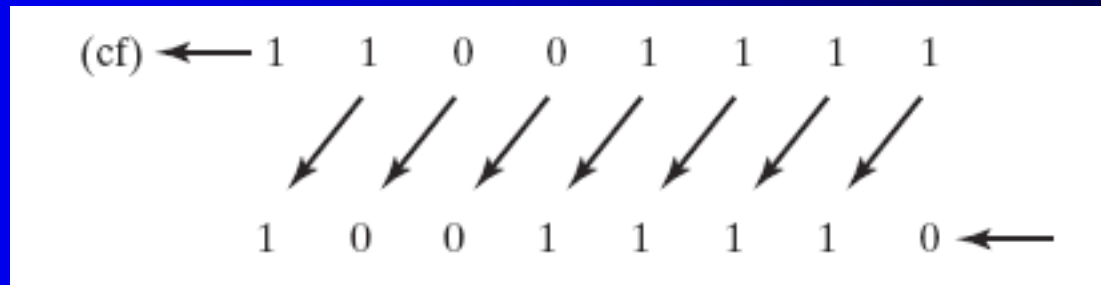
Arithmetic Shift

- An arithmetic shift fills the newly created bit position with a copy of the number's sign bit:



SHL Instruction

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



- Operand types for SHL:

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

(Same for all shift and rotate instructions)

CL: register

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

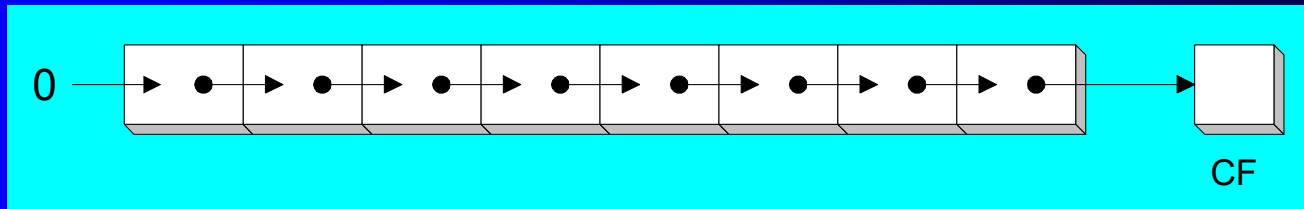
Shifting left n bits multiplies the operand by 2^n

For example, $5 * 2^2 = 20$

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

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.

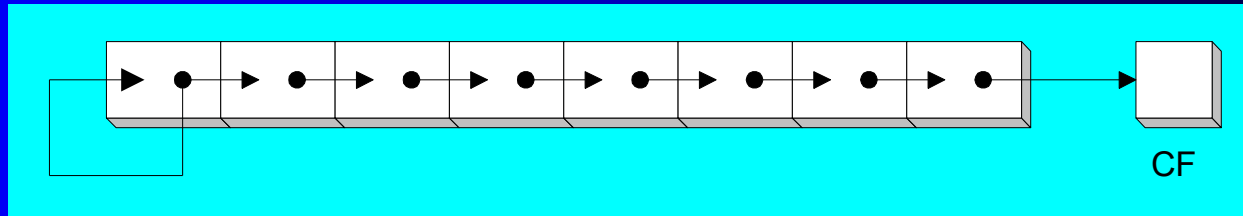


Shifting right n bits divides the operand by 2^n

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


SAL and SAR Instructions

- SAL (**shift arithmetic left**) is identical to SHL.
- SAR (**shift arithmetic right**) performs a right arithmetic shift on the destination operand.



An arithmetic shift preserves the number's sign.

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

```
mov dl,50h  
shr dl,1  
shr dl,2
```

```
mov dl,50h  
shr dl,1      dl=28h  
shr dl,1      dl=14h
```

Your turn . . .

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

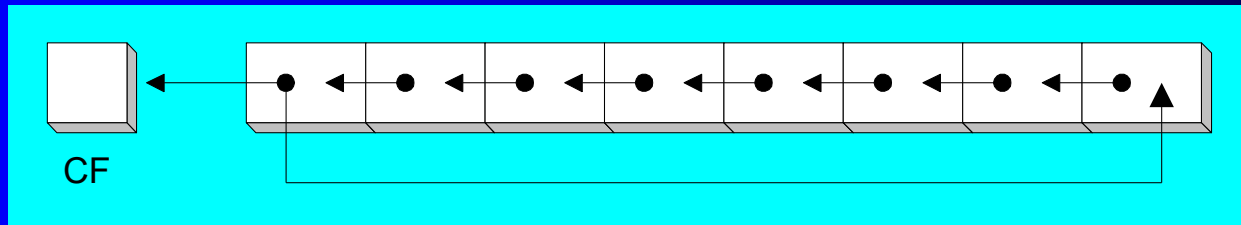
b. A8h

c. C6h

d. F8h

ROL Instruction

- ROL (**rotate left**) 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

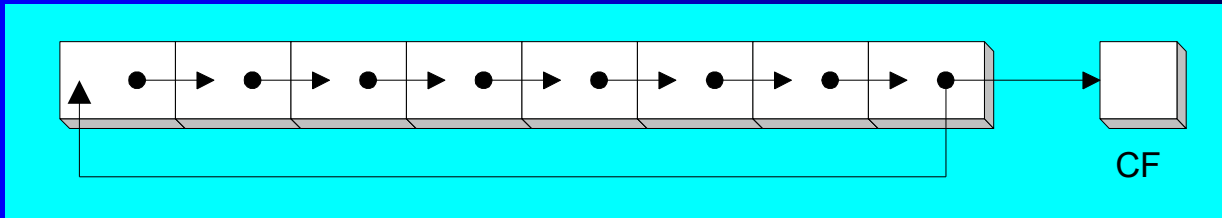


```
mov al,11110000b
rol al,1                ; AL = 11100001b
```

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

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



```
mov al,11110000b
ror al,1                ; AL = 01111000b
```

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

Your turn . . .

Indicate the hexadecimal value of AL after each rotation:

```
mov al,6Bh
```

```
ror al,1
```

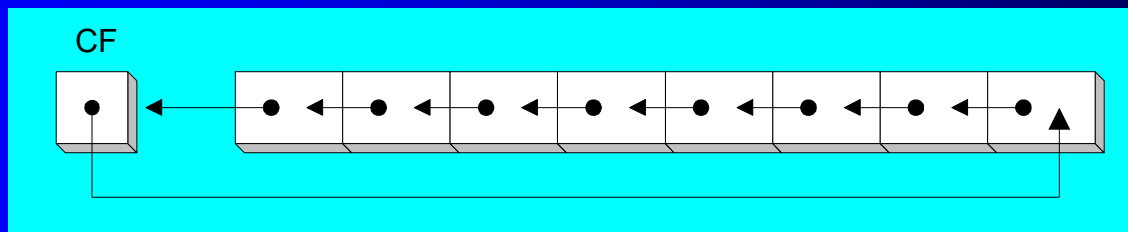
```
rol al,3
```

a. **B5h**

b. **ADh**

RCL Instruction

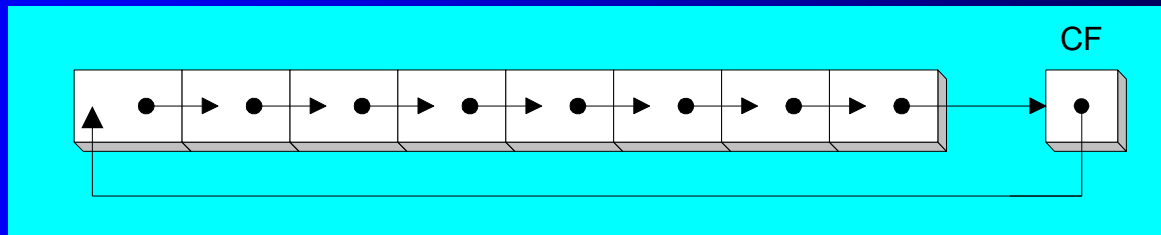
- RCL (**rotate carry left**) shifts each bit to the left
- Copies the Carry flag to the least significant bit
- Copies the most significant bit to the Carry flag



<code>cld</code>	<code>; CF = 0</code>
<code>mov bl, 88h</code>	<code>; CF, BL = 0 10001000b</code>
<code>rcl bl, 1</code>	<code>; CF, BL = 1 00010000b</code>
<code>rcl bl, 1</code>	<code>; CF, BL = 0 00100001b</code>

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
mov ah,10h         ; CF,AH = 1 00010000b
rcr ah,1           ; CF,AH = 0 10001000b
```


Your turn . . .

Indicate the hexadecimal value of AL after each rotation:

```
stc
```

```
mov al, 6Bh
```

```
rcr al, 1
```

```
rcl al, 3
```

a. B5h

b. AEh

SHLD Instruction

- Shifts a destination operand a given number of bits to the left
- The bit positions opened up by the shift are filled by the most significant bits of the source operand
- The source operand is not affected
- Syntax:
SHLD destination, source, count
- Operand types:

```
SHLD reg16/32, reg16/32, imm8/CL  
SHLD mem16/32, reg16/32, imm8/CL
```

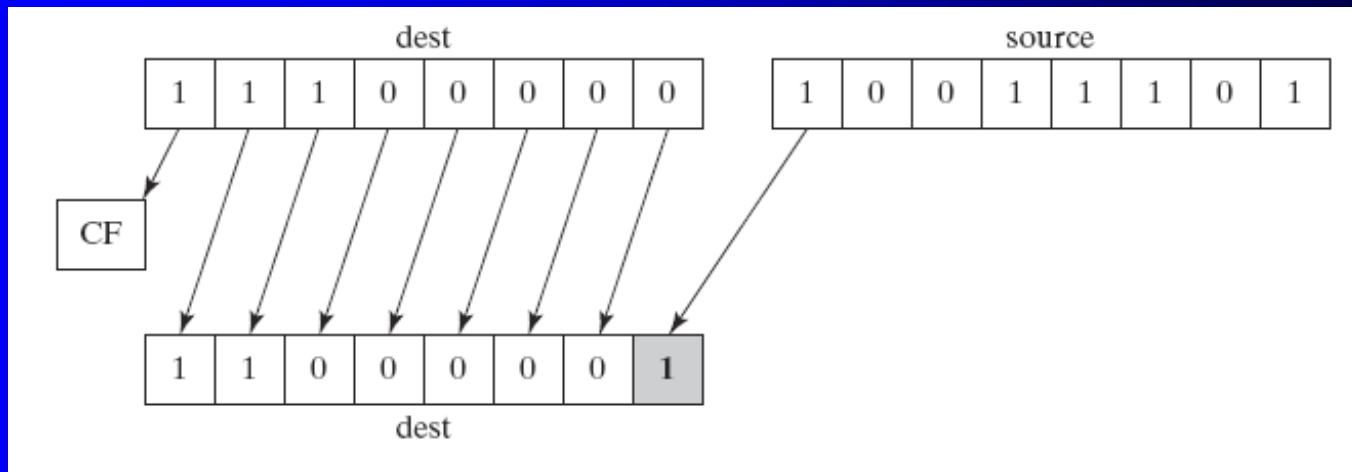
SHLD Example

Shift count of 1:

```
mov al,11100000b
```

```
mov bl,10011101b
```

```
shld al,bl,1
```



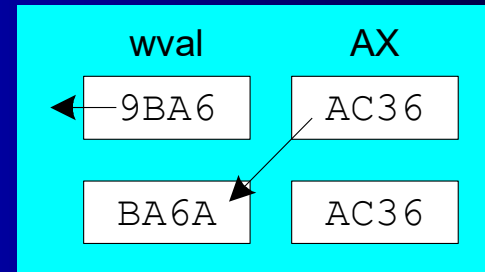
Another SHLD Example

Shift **wval** 4 bits to the left and replace its lowest 4 bits with the high 4 bits of AX:

```
.data
wval WORD 9BA6h
.code
mov  ax,0AC36h
shld wval,ax,4
```

Before:

After:



SHRD Instruction

- Shifts a destination operand a given number of bits to the right
- The bit positions opened up by the shift are filled by the least significant bits of the source operand
- The source operand is not affected
- Syntax:
SHRD destination, source, count
- Operand types:

```
SHRD reg16/32, reg16/32, imm8/CL  
SHRD mem16/32, reg16/32, imm8/CL
```

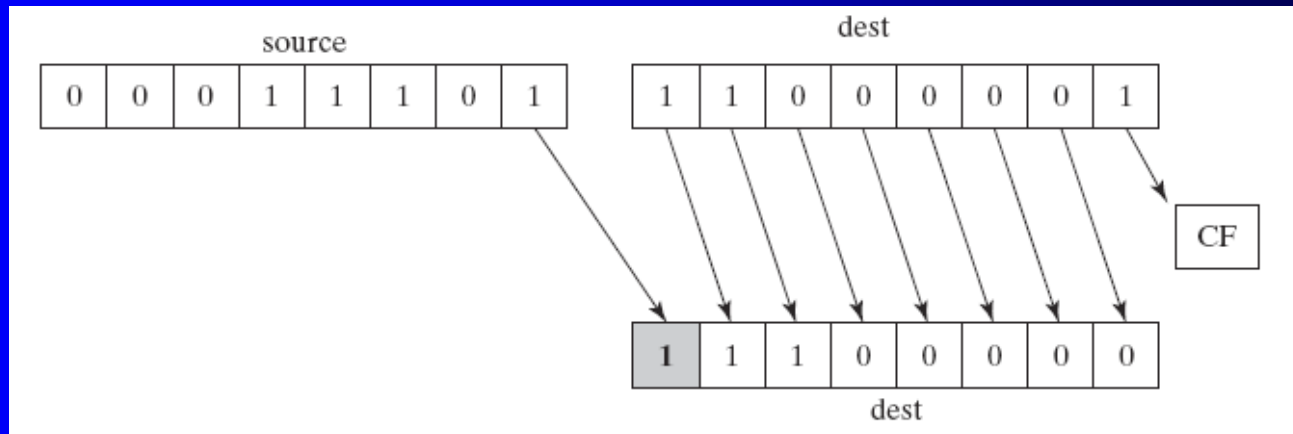
SHRD Example

Shift count of 1:

```
mov al,11000001b
```

```
mov bl,00011101b
```

```
shrd al,bl,1
```

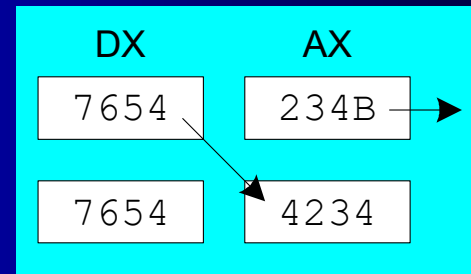


Another SHRD Example

Shift **AX** 4 bits to the right and replace its highest 4 bits with the low 4 bits of DX:

```
mov  ax,234Bh
mov  dx,7654h
shrd ax,dx,4
```

Before:



After:

Your turn . . .

Indicate the hexadecimal values of each destination operand:

```
mov    ax,7C36h
mov    dx,9FA6h
shld   dx,ax,4      ; DX = FA67h
shrd   dx,ax,8      ; DX = 36FAh
```


What's Next

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

Shift and Rotate Applications

- Shifting Multiple Doublewords
- Binary Multiplication
- Displaying Binary Bits
- Isolating a Bit String

Shifting Multiple Doublewords

- Programs sometimes need to shift all bits within an array, as one might when moving a bitmapped graphic image from one screen location to another.
- The following shifts an array of 3 doublewords 1 bit to the right (view complete [source code](#)):

```
.data
ArraySize = 3
array byte ArraySize DUP(99h)      ; 1001 1001...
.code
mov esi,0
shr array[esi + 8],1                ; high dword
rcr array[esi + 4],1                ; middle dword, include Carry
rcr array[esi],1                    ; low dword, include Carry
```

Binary Multiplication

- multiply 123 * 36

	0 1 1 1 1 0 1 1	123
×	0 0 1 0 0 1 0 0	36
	<hr/>	
	0 1 1 1 1 0 1 1	123 SHL 2
+	0 1 1 1 1 0 1 1	123 SHL 5
	<hr/>	
	0 0 0 1 0 0 0 1 0 1 0 0 1 1 0 0	4428

Binary Multiplication

- We already know that SHL performs unsigned multiplication efficiently when the multiplier is a power of 2.
- You can factor any binary number into powers of 2.
 - For example, to multiply $EAX * 36$, factor 36 into $32 + 4$ and use the distributive property of multiplication to carry out the operation:

```
EAX * 36
= EAX * (32 + 4)
= (EAX * 32) + (EAX * 4)
```

```
mov eax,123
mov ebx,eax
shl eax,5           ; mult by 25
shl ebx,2           ; mult by 22
add eax,ebx
```

Your turn . . .

Multiply AX by 26, using shifting and addition instructions.

Hint: $26 = 16 + 8 + 2$.

```
mov ax,1                ; test value

mov dx,ax
shl dx,4                 ; AX * 16
push edx                 ; save for later
mov dx,ax
shl dx,3                 ; AX * 8
shl ax,1                 ; AX * 2
add ax,dx                ; AX * 10
pop edx                  ; recall AX * 16
add ax,dx                ; AX * 26
```

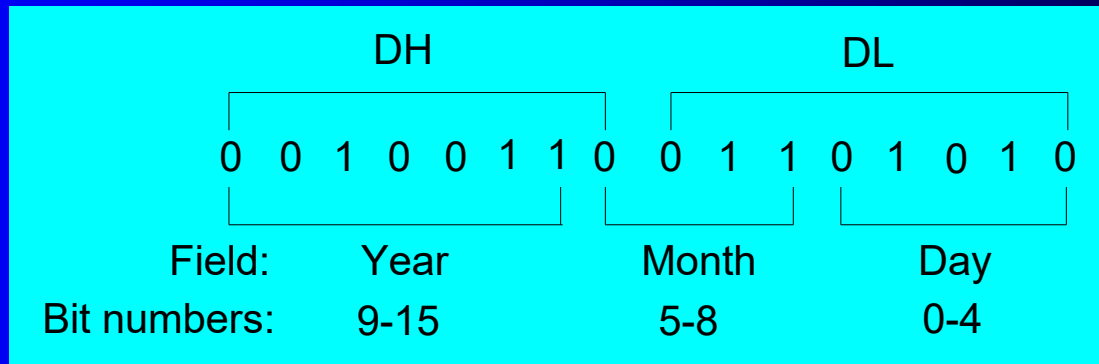
Displaying Binary Bits

Algorithm: Shift MSB into the Carry flag; If CF = 1, append a "1" character to a string; otherwise, append a "0" character. Repeat in a loop, 32 times.

```
.data
buffer BYTE 32 DUP(0),0
.code
    mov ecx,32
    mov esi,OFFSET buffer
L1: shl eax,1
    mov BYTE PTR [esi],'0'
    jnc L2                ; cf=0,jump
    mov BYTE PTR [esi],'1'
L2: inc esi
    loop L1
```

Isolating a Bit String

- The MS-DOS file date field packs the year, month, and day into 16 bits:



Isolate the Month field:

```
mov ax,dx          ; make a copy of DX
shr ax,5           ; shift right 5 bits
and al,00001111b   ; clear bits 4-7
mov month,al       ; save in month variable
```


What's Next

- Shift and Rotate Instructions
- Shift and Rotate Applications
- **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 r/m8
 MUL r/m16
 MUL r/m32

Table 7-2 MUL Operands.

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

被乘数; 乘数;

MUL Examples

100h * 2000h, using 16-bit operands:

```
.data
val1 WORD 2000h
val2 WORD 100h
.code
mov ax, val1
mul val2          ; DX:AX = 00200000h, CF=1
```

The Carry flag indicates whether or not the upper half of the product contains significant digits.

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

```
mov eax, 12345h
mov ebx, 1000h
mul ebx           ; EDX:EAX = 0000000012345000h, CF=0
```

Your turn . . .

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
```

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

Your turn . . .

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
```

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

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

Example: multiply 48 * 4, using 8-bit operands:

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

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

AL=C0H, sign bit = 1

product should be negative but actually not

IMUL Examples

Multiply 4,823,424 * -423:

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

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

Your turn . . .

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

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

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

AX=6000h, sign bit = 0

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`

Default Operands:

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

被除数

除数

商

余数

DIV Examples

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
```

Same division, using 32-bit operands:

```
mov  edx,0                ; clear dividend, high
mov  eax,8003h            ; dividend, low
mov  ecx,100h             ; divisor
div  ecx                  ; EAX = 00000080h, DX = 3
```

Your turn . . .

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,6000h  
mov bx,100h  
div bx
```

DX = 0000h, AX = 8760h

Your turn . . .

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:

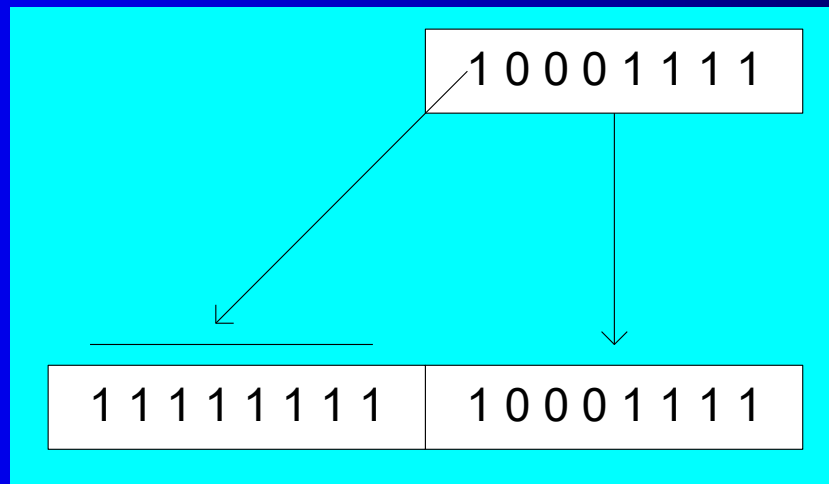
```
mov dx,0087h  
mov ax,6002h  
mov bx,10h  
div bx
```

Divide Overflow

Quotient can not be over 0xFFFF.

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
- For example, the high byte contains a copy of the sign bit from the low byte:



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
- Example:

```
.data
dwordVal SDWORD -101      ; FFFFFFF9Bh
.code
mov eax,dwordVal
cdq                      ; EDX:EAX = FFFFFFFF9Bh
```


IDIV Instruction

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

Example: 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

Example: 16-bit division of -48 by 5

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

Example: 32-bit division of -48 by 5

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

Your turn . . .

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)
-513/256

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)

Example: `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
```

Signed Arithmetic Expressions (1 of 2)

Example: `eax = (-var1 * var2) + var3`

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

Example: `var4 = (var1 * 5) / (var2 - 3)`

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

Signed Arithmetic Expressions (2 of 2)

Example: `var4 = (var1 * -5) / (-var2 % var3);`

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

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

Your turn . . .

Implement the following expression using signed 32-bit integers:

$$\text{eax} = (\text{ebx} * 20) / \text{ecx}$$

```
mov eax,20
imul ebx
idiv ecx
```

Your turn . . .

Implement the following expression using signed 32-bit integers. Save and restore EAX and EDX?:

$$eax = (ecx * edx) / eax$$

```
push    edx
push    eax                ; EAX needed later
mov     eax,ecx
imul    edx                ; left side: EDX:EAX
pop     ebx                ; saved value of EAX
idiv    ebx                ; EAX = quotient
pop     edx                ; restore EDX
```


Your turn . . .

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

$$\text{var3} = (\text{var1} * -\text{var2}) / (\text{var3} - \text{ebx})$$

```
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
```

What's Next

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

Extended Addition and Subtraction

- ADC Instruction
- Extended Precision Addition
- SBB Instruction
- Extended Precision Subtraction

The instructions in this section do not apply to 64-bit mode programming.

Extended Precision Addition

- Adding two operands that are longer than the computer's word size (32 bits).
 - Virtually no limit to the size of the operands
- The arithmetic must be performed in steps
 - The Carry value from each step is passed on to the next step.

ADC Instruction

- ADC (add with carry) instruction adds both a source operand and the contents of the Carry flag to a destination operand.
- Operands are binary values
 - Same syntax as ADD, SUB, etc.
- Example
 - Add two 32-bit integers (FFFFFFFFh + FFFFFFFFh), producing a 64-bit sum in EDX:EAX:

```
mov  edx,0
mov  eax,0FFFFFFFFh
add  eax,0FFFFFFFFh
adc  edx,0           ;EDX:EAX = 00000001FFFFFFFFh
```

Extended Addition Example

- Task: Add 1 to EDX:EAX
 - Starting value of EDX:EAX: 00000000FFFFFFFFh
 - Add the lower 32 bits first, setting the Carry flag.
 - Add the upper 32 bits, and include the Carry flag.

```
mov  edx,0           ; set upper half
mov  eax,0FFFFFFFFh  ; set lower half
add  eax,1           ; add lower half
adc  edx,0           ; add upper half
```

EDX:EAX = 00000001 00000000

SBB Instruction

- The SBB (subtract with borrow) instruction subtracts both a source operand and the value of the Carry flag from a destination operand.
- Operand syntax:
 - Same as for the ADC instruction

Extended Subtraction Example

- Task: Subtract 1 from EDX:EAX
 - Starting value of EDX:EAX: 0000000100000000h
 - Subtract the lower 32 bits first, setting the Carry flag.
 - Subtract the upper 32 bits, and include the Carry flag.

```
mov edx,1          ; set upper half
mov eax,0          ; set lower half
sub eax,1          ; subtract lower half
sbb edx,0          ; subtract upper half
```

EDX:EAX = 00000000 FFFFFFFF

What's Next

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

ASCII and Packed Decimal Arithmetic(压缩)

- Binary Coded Decimal
- ASCII Decimal
- AAA Instruction
- AAS Instruction
- AAM Instruction
- AAD Instruction
- Packed Decimal Integers
- DAA Instruction
- DAS Instruction

The instructions in this section do not apply to 64-bit mode programming.

Binary-Coded Decimal

- Binary-coded decimal (BCD) integers use 4 binary bits to represent each decimal digit
- A number using **unpacked BCD** representation stores a decimal digit in the lower four bits of each byte
 - For example, 5,678 is stored as the following sequence of hexadecimal bytes:

05	06	07	08
----	----	----	----

5678=162E

ASCII Decimal

- A number using **ASCII Decimal** representation stores a single ASCII digit in each byte
 - For example, 5,678 is stored as the following sequence of hexadecimal bytes: e.g text file, 5→'5'

35	36	37	38
----	----	----	----

AAA Instruction

- The AAA (ASCII adjust after addition) instruction adjusts the binary result of an ADD or ADC instruction. It makes the result in AL consistent with ASCII decimal representation.
 - The Carry value, if any ends up in AH
- Example: Add '8' and '2' (8+2=10)

```
mov ah,0
mov al,'8'           ; AX = 0038h
add al,'2'           ; AX = 006Ah
aaa                  ; AX = 0100h (adjust result)
or ax,3030h          ; AX = 3130h = '10'
```

Binary → decimal → ascii
+6

AAS Instruction

- The AAS (ASCII adjust after subtraction) instruction adjusts the binary result of an SUB or SBB instruction. It makes the result in AL consistent with ASCII decimal representation.
 - It places the Carry value, if any, in AH
- Example: Subtract '9' from '8'

```
mov ah,0
mov al,'8'      ; AX = 0038h
sub al,'9'      ; AX = 00FFh
aas             ; AX = FF09h, CF=1
or al,30h       ; AL = '9'
```

;al-6;ah-1

8-9=18-9=9;CF=1

AAM Instruction

- The AAM (ASCII adjust after multiplication) instruction adjusts the binary result of a MUL instruction. The multiplication must have been performed on unpacked BCD numbers.

```
mov bl,05h          ; first operand
mov al,06h          ; second operand
mul bl              ; AX = 001Eh
aam                 ; AX = 0300h
```

AAD Instruction

- The AAD (ASCII adjust before division) instruction adjusts the unpacked BCD dividend in AX before a division operation

```
.data
quotient  BYTE ?
remainder BYTE ?
.code
mov ax,0307h      ; dividend, 37=0307
aad              ; AX = 0025h, hexadecimal
mov bl,5          ; divisor
div bl           ; AX = 0207h
mov quotient,al
mov remainder,ah
```


What's Next

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

Packed Decimal Arithmetic

- **Packed decimal** integers store two decimal digits per byte
 - For example, 12,345,678 can be stored as the following sequence of hexadecimal bytes:

12	34	56	78
----	----	----	----

Packed decimal is also known as **packed BCD**.

Good for financial values – extended precision possible, without rounding errors.

DAA Instruction

- The DAA (decimal adjust after addition) instruction converts the binary result of an ADD or ADC operation to packed decimal format.
 - The value to be adjusted must be in AL
 - If the lower digit is adjusted, the Auxiliary Carry flag is set.
 - If the upper digit is adjusted, the Carry flag is set.

DAA Logic

```
If (AL(lo) > 9) or (AuxCarry = 1)
```

```
    AL = AL + 6
```

```
    AuxCarry = 1
```

```
Else
```

```
    AuxCarry = 0
```

```
Endif
```

```
If (AL(hi) > 9) or Carry = 1
```

```
    AL = AL + 60h
```

```
    Carry = 1
```

```
Else
```

```
    Carry = 0
```

```
Endif
```

```
A → A + 6 → 10
```

If $AL = AL + 6$ sets the Carry flag, its value is used when evaluating $AL(hi)$.

DAA Examples

- Example: calculate packed BCD 35 + 48

```
mov al,35h
add al,48h          ; AL = 7Dh
daa                 ; AL = 83h, CF = 0
                   ; hex → decimal
```

- Example: calculate BCD 35 + 65

```
mov al,35h
add al,65h          ; AL = 9Ah
daa                 ; AL = 00h, CF = 1
```

- Example: calculate BCD 69 + 29

```
mov al,69h
add al,29h          ; AL = 92h
daa                 ; AL = 98h, CF = 0
```

Your turn . . .

- A temporary malfunction in your computer's processor has disabled the DAA instruction. Write a procedure in assembly language that performs the same actions as DAA.
- Test your procedure using the values from the previous slide.

DAS Instruction

- The DAS (decimal adjust after subtraction) instruction converts the binary result of a SUB or SBB operation to packed decimal format.
- The value must be in AL
- Example: subtract BCD 48 from 85

```
mov  al,48h
sub  al,35h          ; AL = 13h
das                      ; AL = 13h CF = 0
```

DAS Logic

```
If (AL(10) > 9) OR (AuxCarry = 1)
```

```
    AL = AL - 6;
```

```
    AuxCarry = 1;
```

```
Else
```

```
    AuxCarry = 0;
```

```
Endif
```

```
If (AL > 9FH) or (Carry = 1)
```

```
    AL = AL - 60h;
```

```
    Carry = 1;
```

```
Else
```

```
    Carry = 0;
```

```
Endif
```

If $AL = AL - 6$ sets the Carry flag, its value is used when evaluating AL in the second IF statement.

DAS Examples (1 of 2)

- Example: subtract BCD 48 – 35

```
mov al,48h
sub al,35h          ; AL = 13h
das                ; AL = 13h CF = 0
```

- Example: subtract BCD 62 – 35

```
mov al,62h
sub al,35h          ; AL = 2Dh, CF = 0
das                ; AL = 27h, CF = 0
```

- Example: subtract BCD 32 – 29

```
mov al,32h
add al,29h          ; AL = 09h, CF = 0
daa                ; AL = 03h, CF = 0
```

DAS Examples (2 of 2)

- Example: subtract BCD 32 – 39

```
mov al,32h
sub al,39h          ; AL = F9h, CF = 1
das                ; AL = 93h, CF = 1
```

Steps:

AL = F9h

CF = 1, so subtract 6 from F9h

AL = F3h

F3h > 9Fh, so subtract 60h from F3h

AL = 93h, CF = 1

```
; AL = 93h, CF = 1
100-93=7, CF=1
```

Your turn . . .

- A temporary malfunction in your computer's processor has disabled the DAS instruction. Write a procedure in assembly language that performs the same actions as DAS.
- Test your procedure using the values from the previous two slides.

Summary

- Shift and rotate instructions are some of the best tools of assembly language
 - finer control than in high-level languages
 - SHL, SHR, SAR, ROL, ROR, RCL, RCR
- MUL and DIV – integer operations
 - close relatives of SHL and SHR
 - CBW, CDQ, CWD: preparation for division
- 32-bit Mode only:
 - Extended precision arithmetic: ADC, SBB
 - ASCII decimal operations (AAA, AAS, AAM, AAD)
 - Packed decimal operations (DAA, DAS)