ASCII and BCD Arithmetic

Chapter 11

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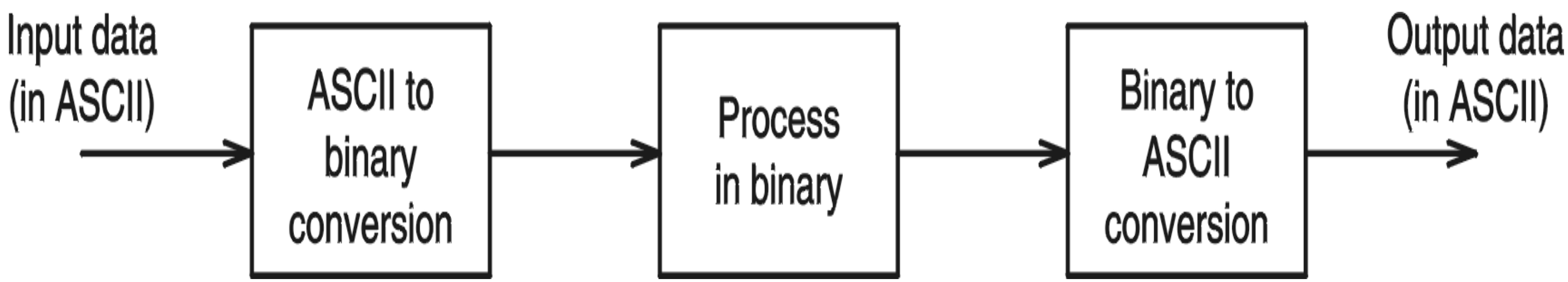
Outline

- Representation of Numbers
  - ASCII representation
  - BCD representation
    - Unpacked BCD
    - Packed BCD
- Processing ASCII numbers
    - ASCII addition
    - ASCII subtraction
    - ASCII multiplication
    - ASCII division
  - Example: Multidigit ASCII addition
- Processing packed BCD numbers
  - Packed BCD addition
  - Packed BCD subtraction
  - Example: Multibyte packed BCD addition
- Performance: Decimal versus binary arithmetic

Representation of Numbers

- Numbers are in ASCII form
  - when received from keyboard
  - when sending to the display
- Binary form is efficient to process numbers internally



Representation of Numbers (cont'd)

- Requires conversion between these two number representations
  - We have used **`GetInt`**/**`GetLint`** and **`PutInt`**/**`PutLint`** to perform these two conversions
- In some applications, processing of numbers is simple (e.g. a simple addition)
  - Does not justify the input and output conversion overheads
  - In this case, it is better to process numbers in the decimal form
- Decimal numbers can be represented in
  - ASCII
  - BCD

Representation of Numbers (cont'd)

- ASCII representation
    - Numbers are stored as a string of ASCII characters
        - Example: 1234 is stored as 31 32 33 34H
            - ASCII for 1 is 31H, for 2 is 32H, etc.
- BCD representation
    - Unpacked BCD
        - Example: 1234 is stored as 01 02 03 04H
            - Additional byte is used for sign
                - Sign byte: 00H for + and 80H for –
    - Packed BCD
        - Saves space by packing two digits into a byte
            - Example: 1234 is stored as 12 34H

Processing ASCII Numbers

- Pentium provides four instructions

  aaa – ASCII adjust after addition

  aas – ASCII adjust after subtraction

  aam – ASCII adjust after multiplication

  aad – ASCII adjust before division

- These instructions do not take any operands
  - Operand is assumed to be in AL

Processing ASCII Numbers (cont'd)

ASCII addition

Example 1	Example 2
`34H = 00110100B`	`36H = 00110110B`
`35H = 00110101B`	`37H = 00110111B`
`69H = 01101001B`	`6DH = 01101101B`
Should be 09H	Should be 13H
Ignore 6	Ignore 6 and add 9 to D

- The `aaa` instruction performs these adjustments to the byte in AL register

Processing ASCII Numbers (cont'd)

- The `aaa` instruction works as follows:
  - If the least significant four bits in AL are > 9 or if AF =1, it adds 6 to AL and 1 to AH.
    - Both CF and AF are set
  - In all cases, the most significant four bits in AL are cleared
  - Example:

```
sub     AH,AH     ; clear AH
mov     AL,'6'    ; AL = 36H
add     AL,'7'    ; AL = 36H+37H = 6DH
aaa               ; AX = 0103H
or      AL,30H    ; AL = 33H
```

Processing ASCII Numbers (cont'd)

ASCII subtraction

- The `aas` instruction works as follows:
  - If the least significant four bits in AL are > 9 or if AF =1, it subtracts 6 from AL and 1 from AH.
    - Both CF and AF are set
  - In all cases, the most significant four bits in AL are cleared
- This adjustment is needed only if the result is negative

Processing ASCII Numbers (cont'd)

- Example 1: Positive result

```
sub    AH,AH     ; clear AH
mov    AL,'9'    ; AL = 39H
sub    AL,'3'    ; AL = 39H-33H = 6H
aas              ; AX = 0006H
or     AL,30H    ; AL = 36H
```

- Example 2: Negative result

```
sub    AH,AH     ; clear AH
mov    AL,'3'    ; AL = 33H
sub    AL,'9'    ; AL = 33H-39H = FAH
aas              ; AX = FF04H
or     AL,30H    ; AL = 34H
```

Processing ASCII Numbers (cont'd)

ASCII multiplication

- The `aam` instruction adjusts the result of a `mul` instruction
  - Multiplication should not be performed on ASCII
    - Can be done on unpacked BCD
- The `aam` instruction works as follows
  - AL is divided by 10
  - Quotient is stored in AH
  - Remainder in AL
- `aam` does not work with `imul` instruction

Processing ASCII Numbers (cont'd)

- Example 1

```
mov     AL,3      ; multiplier in unpacked BCD form
mov     BL,9      ; multiplicand in unpacked BCD form
mul     BL        ; result 001BH is in AX
aam               ; AX = 0207H
or      AX,3030H ; AX = 3237H
```

- Example 2

```
mov     AL,'3'    ; multiplier in ASCII
mov     BL,'9'    ; multiplicand in ASCII
and     AL,0FH    ; multiplier in unpacked BCD form
and     BL,0FH    ; multiplicand in unpacked BCD form
mul     BL        ; result 001BH is in AX
aam               ; AX = 0207H
or      AL,30H    ; AL = 37H
```

Processing ASCII Numbers (cont'd)

ASCII division

- The `aad` instruction adjusts the numerator in AX *before* dividing two unpacked decimal numbers
  - The denominator is a single unpacked byte
- The `aad` instruction works as follows
  - Multiplies AH by 10 and adds it to AL and sets AH to 0
  - Example:
    - If AX is 0207H before **`aad`**
    - AX is changed to 001BH after **`aad`**
- `aad` instruction reverses the changes done by `aam`

Processing ASCII Numbers (cont'd)

- Example: Divide 27 by 5

```
mov     AX,0207H ; dividend in unpacked BCD form
mov     BL,05H   ; divisor in unpacked BCD form
aad              ; AX = 001BH
div     BL       ; AX = 0205H
```

- `aad` converts the unpacked BCD number in AX to binary form so that `div` can be used

Example: Multidigit ASCII addition

- ASCIIADD.ASM
- Adds two 10-digit numbers
  - Adds one digit at a time starting with the rightmost digit

Processing Packed BCD Numbers

- Two instructions to process packed BCD numbers

  `daa` – Decimal adjust after addition
  - Used after **`add`** or **`adc`** instruction

  `das` – Decimal adjust after subtraction
  - Used after **`sub`** or **`sbb`** instruction

- No support for multiplication or division
  - For these operations
    - Unpack the numbers
    - Perform the operation
    - Repack them

Processing Packed BCD Numbers (cont'd)

Packed BCD addition

Example 1

```
29H = 00101001B
69H = 01101001B
92H = 10010010B
```

Should be 98H (add 6)

Example 2

```
27H = 00100111B
34H = 00110100B
5BH = 01011101B
```

Should be 61H (add 6)

Example 3

```
52H = 01010010B
61H = 01100001B
B3H = 10110010B
```

Should be 13H (add 60H)

Processing Packed BCD Numbers (cont'd)

- The **daa** instruction works as follows:
  - If the least significant four bits in AL are > 9 or if AF =1, it adds 6 to AL and sets AF
  - If the most significant four bits in AL are > 9 or if CF =1, it adds 60H to AL and sets CF

Example:

```
mov     AL,71H
add     AL,43H        ; AL = B4H
daa                   ; AL = 14H and CF = 1
```

- The result including the carry (i.e., 114H) is the correct answer

Processing Packed BCD Numbers (cont'd)

Packed BCD subtraction

- The **`das`** instruction works as follows:
  - If the least significant four bits in AL are > 9 or if AF =1, it subtracts 6 from AL and sets AF
  - If the most significant four bits in AL are > 9 or if CF =1, it subtracts 60H from AL and sets CF

Example:

```
mov     AL,71H
sub     AL,43H        ; AL = 2EH
das                   ; AL = 28H
```

Processing Packed BCD Numbers (cont'd)

Example: Multibyte packed BCD addition

- Adds two 10-digit numbers
  - Adds two digits at a time starting from the rightmost pair

Performance: Decimal vs. Binary Arithmetic

- Tradeoffs associated with the three representations

Representation	Storage overhead	Conversion overhead	Processing overhead
Binary	Nil	High	Nil
Packed BCD	Medium	Medium	Medium
ASCII	High	Nil	High