Bit and Bitwise Operations

Bit, Numerals Systems and Bitwise Operations

01

SoftUni Team

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Bit

What is a bit?

Bit

- Unit **used in computing**
- Unit of **information**
- Have only one of **two values** – either a **0** or **1**
- Anything with **two separate states** can store 1 bit
  - Logical values (True/False)
  - Algebraic signs (+/-)
  - Activation States (On/Off)

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5

101_b

0x8

Numerals Systems

Decimal, Binary and Hexadecimal

Numeral Systems

- System for **expressing numbers**
- Different systems represent **real** and **integer numbers**
- Each system has a **base** (e.g. 2, 10, 16)

Decimal	Binary	Hexadecimal
30	111110	1E
45	101101	2D
60	111100	3C

Decimal Numbers

- Decimal numbers (**base 10**)
  - Represented using 10 numerals
    - **0, 1, 2, 3, 4, 5, 6, 7, 8, 9**
  - Each position represents a **power of 10**

$$
\begin{aligned}
401 &= 4*10^2 + 0*10^1 + 1*10^0 = \\
&= 4*100 + 0*10 + 1*1 = \\
&= 400 + 0 + 1 = 401
\end{aligned}
$$

Binary Numeral System

- The **binary system** is used in computation
- Binary numbers (**base 2**)
  - Represented by **sequence of 0** or **1**

$$5 \rightarrow 101_b$$

  - Each position represents a **power of 2**

$$101_b = 1*2^2 + 0*2^1 + 1*2^0 = 4 + 0 + 1 = 5$$

$$1010_b = 1*2^3 + 0*2^2 + 1*2^1 + 0*2^0 = 8 + 0 + 2 + 0 = 10$$

Binary and Decimal Conversion

- Binary to Decimal

$$1011_b = 1*2^3 + 0*2^2 + 1*2^1 + 1*2^0 =$$
$$= 1*8 + 0*4 + 1*2 + 1*1 =$$
$$= 8 + 0 + 2 + 1 =$$
$$= 11$$

- Decimal to Binary

```
11 / 2 = 5 (1)
5 / 2 = 2 (1)
2 / 2 = 1 (0)
1 / 2 = 0 (1)
```

Problem: Binary Digits Count

- You are given a positive integer number **N** and one binary digit **B** (0 or 1)
- Write a program that finds the number of **B** digits in **N**

```
20
0
```
→
```
3
```

```
15
1
```
→
```
4
```

```
10
0
```
→
```
2
```

```
23
1
```
→
```
4
```

Solution: Binary Digits Count

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- Read the input from the user – **n** and **b**
- Convert the number in binary numeral system
- Count the **b** digits in **n**
- Print the count

Hexadecimal Numbers

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- Hexadecimal Numbers (**base 16**)
  - Represented using **16 literals**
    - **0, 1, 2, …9, A, B, C, D, E and F**
- Usually **prefixed with 0x** (0x8) in computer science
- Each position represents a **power of 16**

$$
\begin{aligned}
9786_{hex} &= 9*16^3 + 7*16^2 + 8*16^1 + 6*16^0 = \\
&= 9*4096 + 7*256 + 8*16 + 6*1 = \\
&= 36864 + 1792 + 128 + 6 = 38790
\end{aligned}
$$

Hexadecimal Conversions

- Hexadecimal to Decimal

```
1F4hex = 1*16² + 15*16¹ + 4*16⁰ =
       = 1*256 + 15*16 + 4*1 =
       = 256 + 240 + 4 =
       = 500
```

- Decimal to Hexadecimal

```
500 / 16 = 31 (4)
31 / 16 = 1 (F)
1 / 16 = 0 (1)
```

Hexadecimal Conversions (2)

- The conversion from **binary** to **hexadecimal** (and back) is straightforward
  - Each hex digit corresponds to a **sequence of 4 binary digits**

```
A2E3F = 1010 0010 1110 0011 1111
A = 1010
2 = 0010
E = 1110
3 = 0011
F = 1111
```

1010 0010 1110 0011 1111 = A2E3F

$1010_b = 10_{dec} = A_{hex}$

$0010_b = 2_{dec} = 2_{hex}$

$1110_b = 14_{dec} = E_{hex}$

$0011_b = 3_{dec} = 3_{hex}$

$1111_b = 15_{dec} = F_{hex}$

Storing Information

Integer and Floating-Point Numbers and text

Representing Integers

- Integer numbers are sequence of bits
- The sign is determined by the **Most Significant Bit** (**MSB**)
- Leading **0** means **positive number**
- Leading **1** means **negative number**
- Example (8 bit numbers)

```
0XXXXXXX_b > 0 //00010010_b = 18
00000000_b = 0
1XXXXXXX_b < 0 //10010010_b = -110
```

Representation of Integer Numbers

- Positive **8-bit** numbers have the format **0XXXXXXX**
  - The value is the decimal value of their last **7 bits** (**XXXXXXX**)
- Negative **8-bit** numbers have the format **1YYYYYYY**
  - The value is **128**(2^7) minus the decimal value of **YYYYYYY**

-2^7

$10010010_b = -(2^7 - 10010_b) = -(128 - 18) = -110$

Positive and Negative Integers

- The largest 8-bit integer is:

```
127 = (2⁷ – 1) = 01111111b
```

- The smallest negative 8-bit integer is:

```
-128 = (-2⁷) = 10000000b
```

- The largest 32-bit integer is:

```
2147483647 = (2³¹ – 1) = 0111…1111b
```

- The smallest negative 32-bit integer is:

```
-2147483648 = (-2³¹) = 1000…0000b
```

2^7

2^{31}

Representing Real Numbers

- **IEEE 754** - **technical standard** for floating-point computation
- Addressed **many problems** found in the **floating point implementations**
- The standard defines:
  - Arithmetic Formats – sets of binary and decimal floating-point data
  - Exchange formats – encoding (bit sequences)
  - Rounding Rules
  - Operations – arithmetic and other operations
  - Exceptions – such as division by zero

Storing Floating-Point Numbers

- Sequence of bits
- Consists of **sign bit**, **exponent** and **mantissa**

$$\overbrace{\underbrace{1}_{\text{Sign}}\ \underbrace{10000011}_{\text{Exponent}}.\underbrace{01010010100000000000000}_{\text{Mantissa}}}^{\text{32 Bits}}$$

- Errors in **calculations** and **precision**
  - Cannot be represented as a **sum of powers of the number 2**

Representing Text

- System that uses **binary numbers** (**0** and **1**) to represent chars
  - Letters, numerals, etc.
- In the **ASCII** each character consists of **8 bits**
- In the **Unicode** encoding each character consists of **16 bits**

Binary	Decimal	Character
01000001	65	A
01000010	66	B

A

Sequence of Characters

- **String** is the text representation in the programming
  - **String** is an **array of characters**

0	1	2	3	4
H	E	L	L	O

  - Characters in the string can be:
    - 8 bit (ASCII)
    - 16 bit (UTF-16)

Bitwise Operations

Bitwise Operators and Bit Shifts

Bitwise Operators

- Bitwise operator `~` turns all `0` to `1` and all `1` to `0`
  - Like `!` for boolean expressions but bit by bit
- The operators `|`, `&` and `^` behave like `||`, `&&` and `^` for boolean expressions but bit by bit
- Behavior of the operators `|`, `&` and `^`:

<table>
<tr><th>Operator</th><th>|</th><th>|</th><th>|</th><th>&</th><th>&</th><th>&</th><th>^</th><th>^</th><th>^</th></tr>
<tr><td>Operand</td><td>0</td><td>1</td><td>1</td><td>0</td><td>1</td><td>1</td><td>0</td><td>0</td><td>1</td></tr>
<tr><td>Operand2</td><td>0</td><td>0</td><td>1</td><td>0</td><td>0</td><td>1</td><td>0</td><td>1</td><td>1</td></tr>
<tr><td>Result</td><td>0</td><td>1</td><td>1</td><td>0</td><td>0</td><td>1</td><td>0</td><td>1</td><td>0</td></tr>
</table>

Bitwise Operators Examples

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- Bitwise **NOT (~)**

```
5       //0101
~5      //1010
```

- Bitwise **AND (&)**

```
5       //0101
3       //0011
5 & 3   //0001
```

- Bitwise **OR (|)**

```
5       //0101
3       //0011
5 | 3   //0111
```

- Bitwise **XOR(^)**

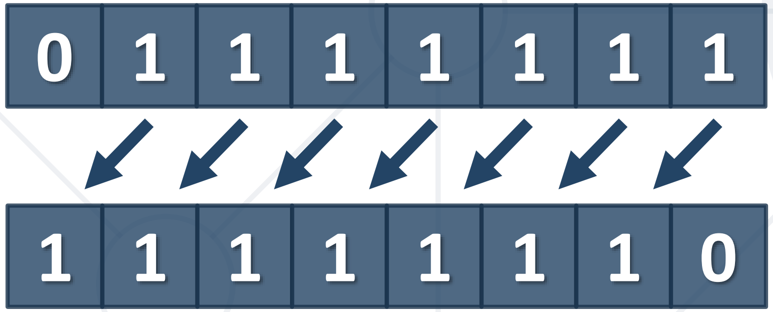
```
5       //0101
3       //0011
5 ^ 3   //0110
```

Bit Shifts

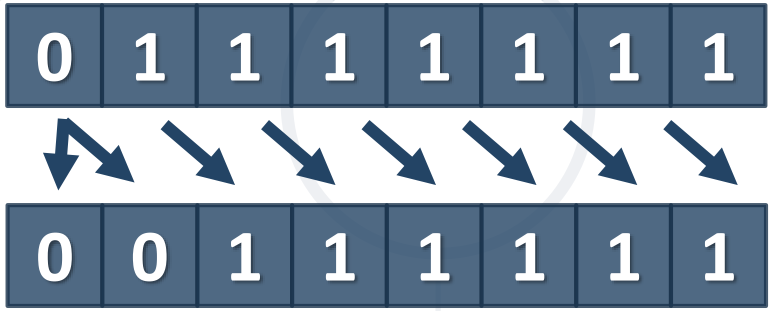
- Bits are moved (**shifted**) to the **left** or **right**
- Registers in a computer have **fixed width**
  - The bits that fall outside the number are **lost** and **replaced with 0**
- **Left** and **Right** Shifts
- **Logical** and **Arithmetic** Shifts

Arithmetic Shift

- Bits that are shifted out of either end are discarded
- Left Arithmetic Shift (<< operator)

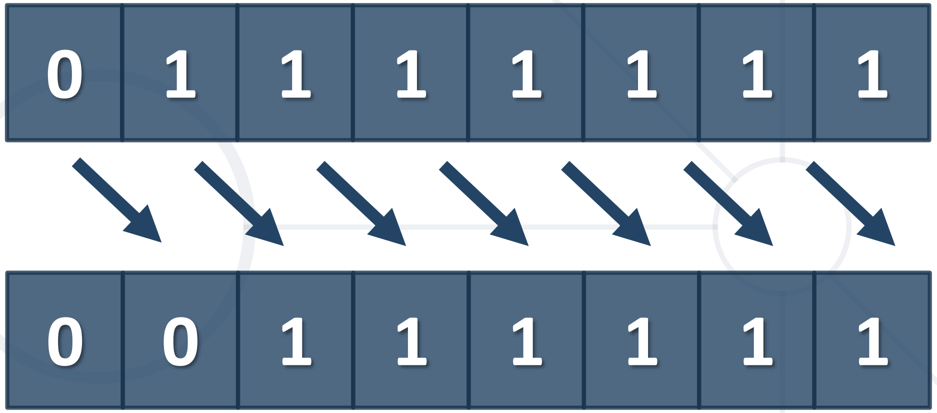


- Right Arithmetic Shift (>> operator)



Logical Shift

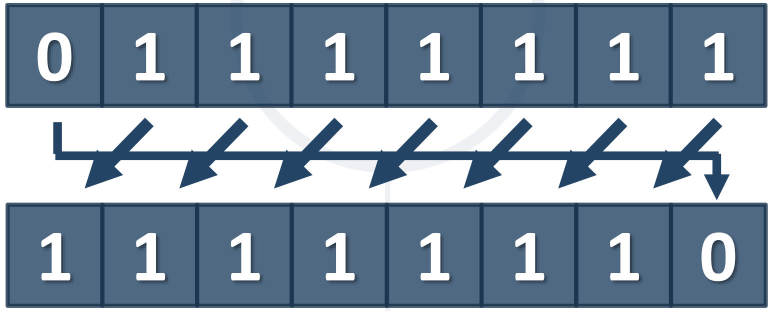
- Arithmetic and Logical Shifts are **very similar**
- The main difference is in the **right-shift**
  - Logical Right Shift **inserts 0** in the **MSB**, **instead of copying the sign bit**
  - Arithmetic Right Shift is ideal for **unsigned binary numbers**
  - Logical Right Shift is ideal for **signed binary numbers**



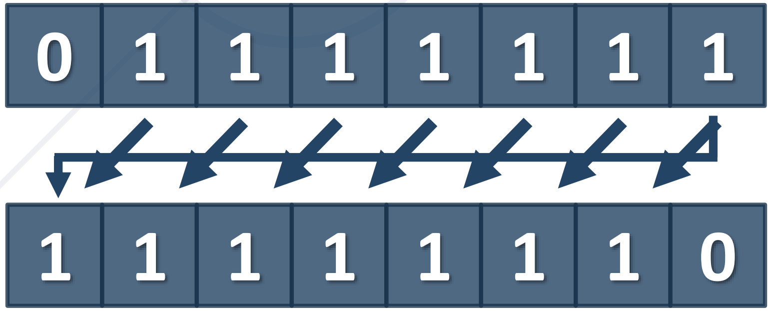
Circular Shift

- Bits are "rotated" as if
  the **left** and **right ends** were **joined**
- Operation is useful if it is necessary
  to **retain all existing bits**
- It is frequently used in **digital cryptography**

Left Circular Shift



Right Circular Shift



Simple Bitwise Operations

- How to get the bit at position **p** from a number **n**

```
p = 5                 //00000101
n = 125               //01111101
125 >> p              //00000011 = 3
3 & 1                 //1
```

- How to set the bit at position **p** to **0** or **1**

```
p = 5                 //00000101
n = 125               //01111101
mask = ~(1 << p)      //00100000
result = n & mask     //01011101
```

```
p = 5                 //00000101
n = 125               //01111101
mask = 1 << p         //00100000
result = n | mask     //01111101
```

Problem: First Bit

- Write a program that prints the bit at position 1 of a number

51	1	24	0
13	0	2	1

- Solution:

```
p = 1               //00000001
n = 51              //01111101
n = n >> p          //00011001 = 25
n & 1               //1
```

Live Exercises

Summary

- Computers store information using **bits**
- Representing data in different **numeral systems**
- Modifying bits using **bitwise operators** and **simple masks**

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