(13-1) Bits and Operations H&K Appendix C

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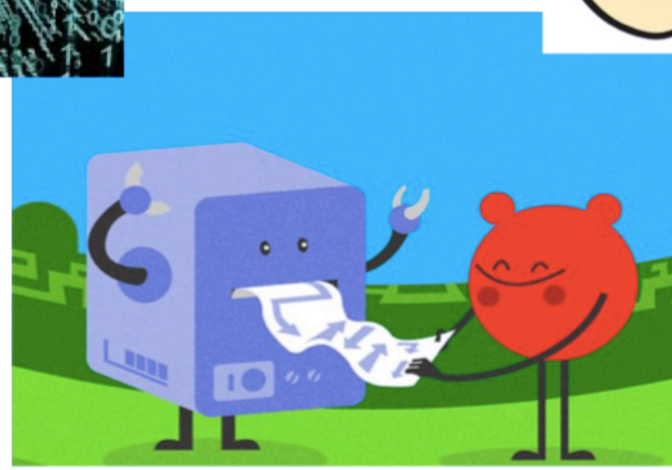
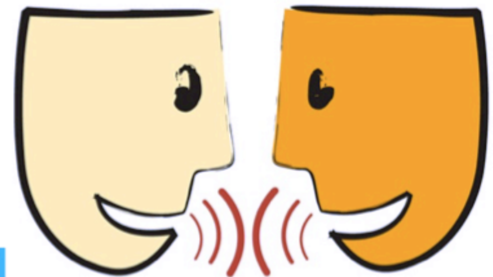
Basic Memory Concepts (1)





Pictures are from:
https://catborrow.wordpress.com/2011/04/17/hello-world/
https://fcw.com/articles/2018/04/10/odni-cio-cdo-organization.aspx

Basic Memory Concepts (1)

https://www.alamy.com/binary-code-data-bit-screen-display-on-laptop-computer-screen-matrix-of-data-flow-rise-of-the-big-data-ai-age-artificial-intelligence-data-transfer-image207314809.html

Basic Memory Concepts (1)

- Recall when a variable is declared, memory is allocated based on its data type
- Recall some of the major data types in C include:
  - Char (**1 byte**), int (**4 bytes**), and double (**8 bytes**)
- A basic English character (char) requires less memory than an integer (int)
- An integer (int) requires less memory than a double precision floating-point value (double)
- sizeof (char) < sizeof (int) < sizeof (double)
  - Recall sizeof ( ) in C returns the number of bytes allocated for a variable or data type

We already talked about ”sizeof” to calculate the length of an array!
Thank you for your questions!

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Basic Memory Concepts (2)

- All information is stored in memory as *bit(s)* of data
  - Bit is derived from binary digit
  - A binary digit or bit has two possible values; 0 or 1
- A sequence of 4-bits is called a *nibble*
  - One example of a nibble of data is 1111_2
    - This is the number 15 in decimal
    - Note the leftmost 1 is referred to as the most significant bit (msb) and the rightmost 1 is the least significant bit (lsb)
- A sequence of 8-bits is called a *byte* (***8 bits => a byte***)

'A' is a char => 1 Byte => 8 bits

"A" can be represented as: $0100\ 0001_2$
(This is the number 65 in decimal)

Number Systems (1)

- Decimal and binary systems are called *positional* number systems
- A digit from one of these systems has a *weight* dependent upon its position or location within the string of digits
- Each position is weighted as the *base* of the system to a power
  - Decimal is base 10
  - Binary is base 2
- A *binary number* consists of one or more bits

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Number Systems (2)

- A decimal number 123_{10} actually means the following:
  - 10^2 10^1 10^0
  - 1 2 3
    - The 1 is in the hundreds or 10^2 position
    - The 2 is in the tens or 10^1 position
    - The 3 is in the ones or 10^0 position
- To evaluate a number in a positional number system; pick each digit and multiply by its weighted position and compute the sum
  - $1 * 10^2 + 2 * 10^1 + 3 * 10^0 = 123_{10}$

Details and examples were written on the white board

How Do We Convert from Decimal to Binary? (1)

Number	294		
divide by 2			
result	147	remainder	0 (LSB)
divide by 2			
result	73	remainder	1
divide by 2			
result	36	remainder	1
divide by 2			
result	18	remainder	0

divide by 2			
result	9	remainder	0
divide by 2			
result	4	remainder	1
divide by 2			
result	2	remainder	0
divide by 2			
result	1	remainder	0
divide by 2			
result	0	remainder	1 (MSB)

Given the decimal number 294_{10}

<=>

100100110_2 in binary

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Example is from: https://www.electronics-tutorials.ws/binary/bin_2.html

How Do We Convert from Decimal to Binary? (1) -- Coding

Part 1:
- A number % 2; store the remainder
- update the number by the division

```
int num, bi_arr[32], i;
while(num> 0)
{
  bi_arr[i] = num % 2;
  num = num / 2;
  i++;
}
```

Part 2:
- print out in the reversed order

```
  int j;
  for (j = 31; j > -1; j --)
  {
    printf("%d ", bi_arr[j]);
  }
```


Example is from: https://www.electronics-tutorials.ws/binary/bin_2.html

How Do We Convert from Decimal to Binary? (1)

- Let's convert 123_{10} to a binary number represented by one byte or 8-bits:
  - First note we need the following weights for an 8-bit number
    - 2^7 2^6 2^5 2^4 2^3 2^2 2^1 2^0
  - Then determine if the largest power of 2 (2^7 in this case) goes into 123_{10}
    - No it does not! Recall 2^7 is 128_{10}; so place a 0 in the 2^7 position
  - Next determine if 2^6 goes into 123_{10}
    - Yes it does! Recall 2^6 is 64_{10}; so place a 1 in the 2^6 position
    - Subtract 64_{10} from 123_{10}; result is 59_{10}

Details and examples were written on the white board

How Do We Convert from Decimal to Binary? (2)

- Next determine if 2^5 goes into 59_{10}
  - Yes it does! Recall 2^5 is 32_{10}; so place a 1 in the 2^5 position
  - Subtract 32_{10} from 59_{10}; result is 27_{10}
- Let's try one more; does 2^4 go into 27_{10}
  - Yes it does! Recall 2^4 is 16_{10}; so place a 1 in the 2^4 position
  - Subtract 16_{10} from 27_{10}; result is 11_{10}

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How Do We Convert from Decimal to Binary? (3)

- Can you finish the rest of the process?

- The binary number should be:
  - 2^7 2^6 2^5 2^4 2^3 2^2 2^1 2^0
  - 0 1 1 1 1 0 1 1_2
  - Note the digit in the 2^0 position is 1; this means the number is odd; otherwise it would be 0

Details and examples were written on the white board

How Do We Convert From Binary to Decimal?

- Let's convert a nibble 1010_2 to a decimal number:
  - First note we need the following weights for a 4-bit number
    - 2^3 2^2 2^1 2^0, where the leftmost or msb 1 is in the 2^3 position, and the rightmost or lsb 0 is in the 2^0 position
  - Next pick off the each digit from the binary number and multiply by its corresponding positional weight
    - $1 * 2^3 = 8_{10}$
    - $0 * 2^2 = 0_{10}$
    - $1 * 2^1 = 2_{10}$
    - $0 * 2^0 = 0_{10}$
  - Lastly, sum up each individual result
    - $8_{10} + 0_{10} + 2_{10} + 0_{10} = 10_{10}$
  - The final result is 10_{10}

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Getting Started with Bitwise Operations in C

- The C language supports several bit operations – i.e. operations that are applied to each individual bit in a number
  - These include: left shift (<<), right shift (>>), negation (~), bitwise AND (&), bitwise OR (|), and exclusive OR, also known as XOR, (^)

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Applying Bitwise Operators (1)

- $1011_2 << 2$; means shift each bit in the number to the left by two positions and rotate in zeros
  - The result is 1100_2 if only a nibble of memory is available; otherwise it's 101100_2
- $1011_2 >> 1$; means shift each bit in the number to the right by one position and rotate in zeros
  - The result is 0101_2; note the lsb is lost in the result

Applying Bitwise Operators (2)

- 1010_2 & 0011_2; means AND each bit in each corresponding position
  - The result is 0010_2
- 1010_2 | 0011_2; means OR each bit in each corresponding position
  - The result is 1011_2

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Applying Bitwise Operators (3)

- 1010_2 ^ 0011_2; means XOR each bit in each corresponding position
  - The result is 1001_2
- ~1010_2; means negate or "flip" each bit
  - The result is 0101_2

Why Apply Bitwise Operators? (1)

- Each position shifted to the left with a binary number indicates multiplication by 2
  - i.e. 8_{10} << 3 results in 64_{10}
- Each position shifted to the right with a binary number indicates division by 2
  - i.e. 4_{10} >> 1 results in 2_{10}
- Shift operations are much more efficient than multiplication and division operations!

Why Apply Bitwise Operators? (2)

- Bitwise AND may be used to clear bits; AND any bit with 0, the result is 0
- Bitwise OR may be used to set bits; OR any bit with 1, the result is 1
- XOR may be used to toggle bits; XOR any bit with 1, the result is the negation of the bit
  - 0 → 1 or 1 → 0, where → represents "becomes"

Basic Bit Manipulation

- Set union A | B
- Set intersection A & B
- Set subtraction A & ~B
- Set negation ALL_BITS ^ A or ~A
- Extract last bit A&-A or A&~(A-1) or x^(x&(x-1))
- Remove last bit A&(A-1)
- Get all 1-bits ~0

How to Interpret Bits?

- A bit may represent the state of a physical light switch
  - i.e. 1 means the light switch is on; 0 means the light switch is off
- A bit may also represent the state of an operation
  - i.e. is x == y? 1 means yes; 0 means no
- Can bitwise operators be used to encrypt/decrypt data?
- Many other interpretations exist. Be creative!

Next Lecture…

- Dynamic memory allocation

References

- J.R. Hanly & E.B. Koffman, *Problem Solving and Program Design in C (8th Ed.)*, Addison-Wesley, 2016
- P.J. Deitel & H.M. Deitel, *C How to Program (7th Ed.)*, Pearson Education , Inc., 2013.

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Collaborators

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