Kuwait University
College of Engineering and Petroleum

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ME319 MECHATRONICS

Part I: The Brains – Microcontrollers, Software and Digital Logic

Lecture 3: Digital Logic

Spring 2021

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Lecture Plan

- Objectives:
    - Review the basics of Logic Gates
    - Review the basics of bitwise logical operations in C/C++

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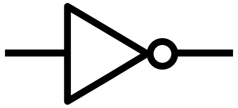
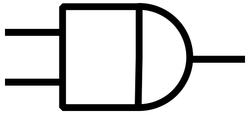
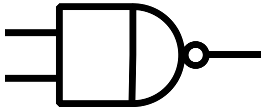
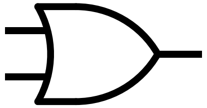
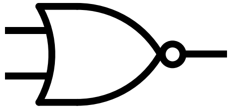
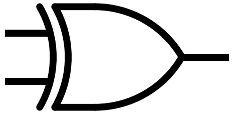
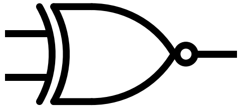
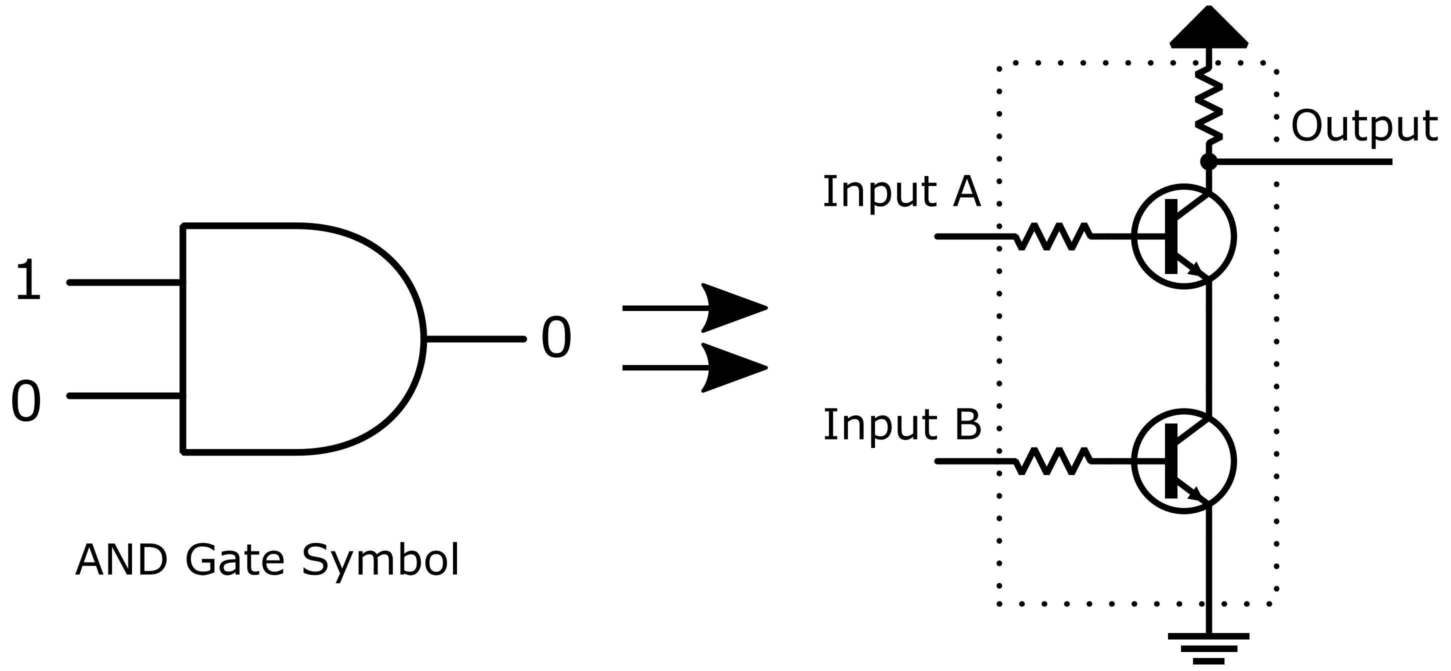
Name	NOT	AND	NAND	OR	NOR	XOR	XNOR
Alg. Expr.	$\bar{A}$	AB	$\overline{AB}$	$A+B$	$\overline{A+B}$	$A \oplus B$	$\overline{A \oplus B}$
Symbol							
True Table	A X 0 1 1 0	B A X 0 0 0 0 1 0 1 0 0 1 1 1	B A X 0 0 1 0 1 1 1 0 1 1 1 0	B A X 0 0 0 0 1 1 1 0 1 1 1 1	B A X 0 0 1 0 1 0 1 0 0 1 1 0	B A X 0 0 0 0 1 1 1 0 1 1 1 0	B A X 0 0 1 0 1 0 1 0 0 1 1 1

- In its simplest form, a computer is composed of
  - Transistors: states (1 or 0), and
  - Logic gates: operations on 1s and 0s
- Logic gates are built from electrical circuit



AND Gate Symbol

Electronic AND Gate

The building blocks of computers

- Millions of transistors and logic gates build memory and logic to form
  - Basic operations
  - Programming Languages translate complex algorithms to basic operations
- When you program in: $\text{int}\ a = 8 + 2;$, this code ultimately translates to:
  - Memory being allocated (transistor states being changed),
  - Current passing through transistors: **1** (or not passing through: **0**) and going through a combination of logic gates to perform:
    - Memory assignment, retrieval, addition, allocation
- From basic add / subtract / store / compare etc., we stack higher level algorithms: complex operating systems, flight control systems, financial trading algorithms, etc.

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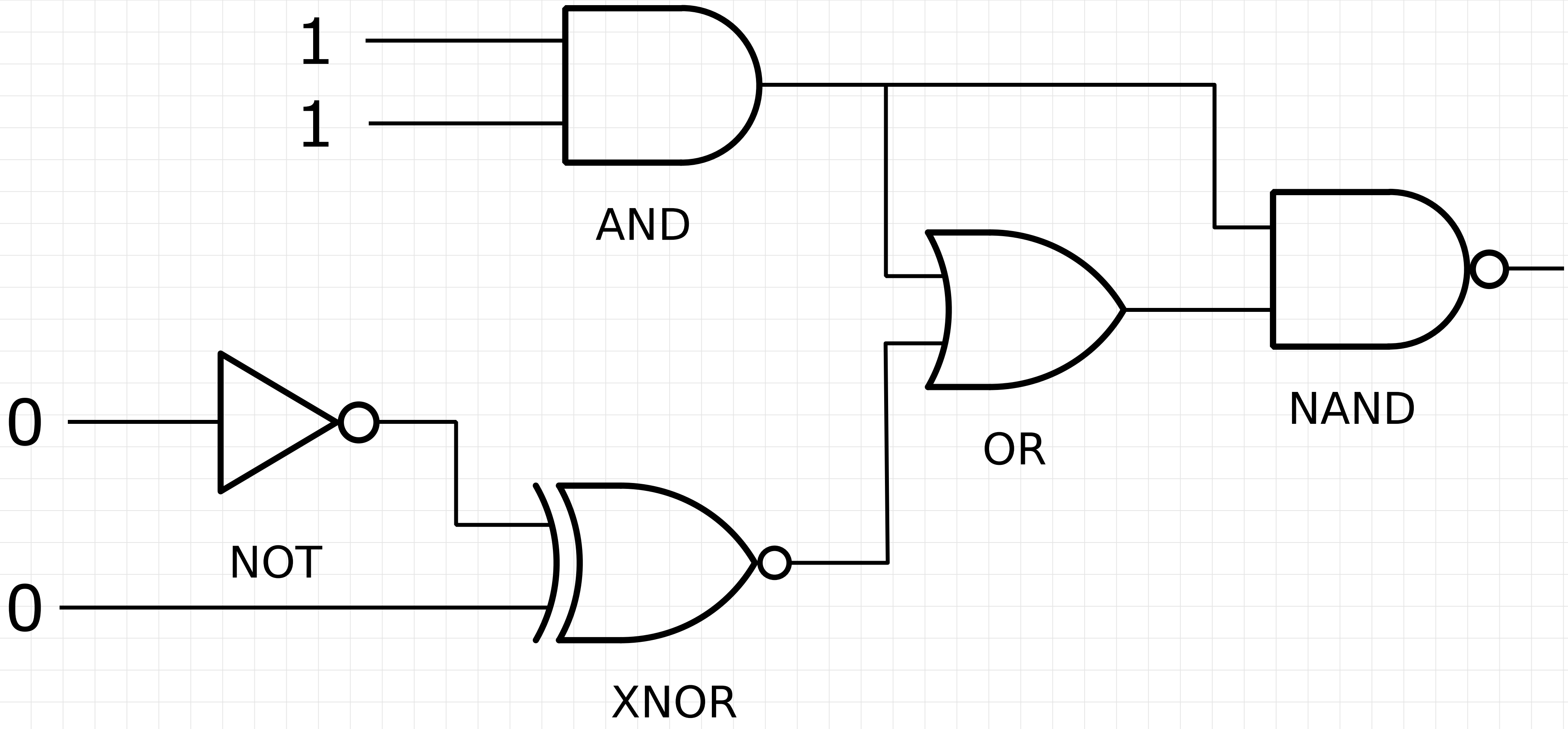
Complete the Logic Gate sequence



Math Shortcuts

- When working with unsigned binary numbers:
  - Shifting the bits one location to the right, halves the number
  - Shifting the bits one location to the left, doubles the number

$$00001100_2 = 12_{10} \Leftrightarrow 00000110_2 = 6_{10} \Leftrightarrow 00000011_2 = 3_{10}$$

- This technique can be used to produce faster mathematical power operations, but can cause loss of precision or overflow

Left Shift: $11000000_2 = 192_{10} \Rightarrow 10000000_2 = 64_{10}$: incorrect due to overflow

Right Shift: $00000011_2 = 3_{10} \Rightarrow 00000001_2 = 1_{10}$

- ***Overflow***: storing a number larger than what memory location can handle

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- Manipulating memory and variables on a bit level is essential in embedded programming

Operator	Name	Description
&	Bitwise AND	Performs AND operation on each corresponding bit of two arguments and returns result
|	Bitwise OR	Performs OR operation on each corresponding bit of two arguments and returns result
^	Bitwise Exclusive OR	Performs Exclusive OR operation on each corresponding bit of two arguments and returns result
~	Bitwise NOT	Performs a NOT operation on all the bits of an argument and returns the result
<< or >>	Right shift or Left shift	Shift bits of argument 1 right/left by argument 2 places

Bitwise Operations - Logical

- Numbers can be expressed in binary, hex as well as decimal.
- Bit-level logic can be performed as shown.

```
#include <cstdint>
#include <iostream>

using namespace std;

int main(int argc, char* argv[]) {

    uint8_t a = 0b00001000;
    uint8_t b = 0b10001111;
    uint8_t c = 0xF7; /* 11110111 */

    uint8_t r1 = a & b; /* AND operation, result: 00001000 */
    uint8_t r2 = a | c; /* OR operation,  result: 11111111 */
    uint8_t r3 = a ^ b; /* NOR operation, result: 10000111 */
    uint8_t r4 = ~c;    /* NOT operation, result: 00001000 */

    r1 |= b; /* OR operation, result: 10001111 */
    return 1;
}
```

- It is often convenient, especially in embedded programming, to shift bits left or right.

```
#include <cstdint>
#include <iostream>

using namespace std;

int main(int argc, char* argv[]) {

    uint8_t a = 0b00000100;
    uint8_t b = 0b10001111;
    uint8_t c = 0xF7; /* 11110111 */

    uint8_t r1 = a >> 2; /* Shift operation, result: 00000001 */
    uint8_t r2 = b << 4; /* Shift operation, result: 11110000 */
    uint8_t r3 = (a<<1) | c; /* Shift + OR NOR operation, result: 11111111 */

    bitset<8> bin(r3);
    cout << hex << bin << endl;
    return 1;
}
```

Manipulating Individual Bits

- Given the following binary number: 10101111
- What if you wanted to change the 4th bit to 1: 10101111
  - We can assign a new number, but that is not practical
  - Instead, we perform a bitwise logical operation

```
#include <cstdint>
int main(int argc, char* argv[]) {

    uint8_t a = 0b10101111;
    /* Change the 4th bit to 1 */
    a = 0b10111111; /* You can replace the whole number by a new one */
    /* Or you can manipulate the individual bit, by performing an OR operation */
    a |= 0b00010000;
    /* 0b00010000 is called a bitmask, we can use a shift operator to create a bitmask */
    a |= (1<<4); /* OR operation with 1 shifted to the left 4 bits: 00010000 */
    return 1;
}
```

Manipulating Multiple Bits

- We can extend the bitwise logical operations to multiple bits
  - Examples of: Setting, Clearing and Toggling Bits

```cpp
#include <cstdint>
#include <iostream>
#include <bitset>
using namespace std;
int main(int argc, char* argv[]) {

    uint8_t a = 0b00101000;
    /* Change the 0th and 4th bits to 1 */
    a |= (1<<4) | 1; /* OR Operation with Bitmask: 00010000 | 00000001 = 00010001 */
    /* Change the 3rd and 5th bits to 0 */
    a &= ~((1<<5) | (1<<3)); /* AND Operation with NOT of bitmask */
    /* Toggle the 7th bit */
    a ^= (1<<7); /* XOR: Exclusive OR Operation with the bitmask */

    bitset<8> binarynumber(a);
    cout << binarynumber << endl; /* Output: 10010001 */
    return 1;
}
```

Complete the following code:

Example 2

```
int main(int argc, char* argv[]) {

    uint8_t a = 0xF0;
    /* Toggle all the bits of a */

    a

    /* Set the 1st nibble (first 4 bits) */

    a

    /* Clear the 2nd nibble */

    a


    return 1;
}
```

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