Class 02
VHDL Introduction

VHDL ENTITY and ARCHITECTURE

entity name

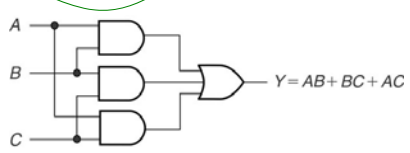
```
-- majority vote
ENTITY majority_vote IS
        PORT(
                a, b, c: IN BIT;
                y :  OUT BIT);
END majority_vote;

ARCHITECTURE maj_vote OF majority_vote IS
BEGIN
        y <= (a and b) or (b and c) or (a and c);
END maj_vote;
```

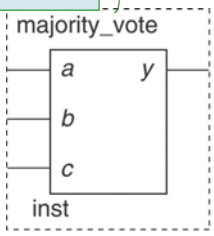
port definition

entity declaration

Architecture name

architecture body





VHDL is case-insensitive

AOI

- Solve $Y = \overline{AB + \overline{A}\overline{C} + D}$

```
-- This is comment
ENTITY logic_circuit IS
        PORT(
                a, b, c, d: IN BIT;
                y: OUT BIT);
END logic_circuit;

ARCHITECTURE cct OF logic_circuit IS
BEGIN
        y <= not ((a and b) or ((not a) and (not c)) or d);
END cct;
```

Comment

Mode

Type

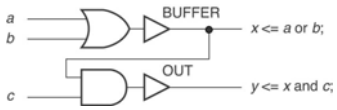
Logic operations: and, or, not, xor, nand, nor

assign

Modes and Types

BUFFER is the same as OUT, but allows to be fed back to the CPLD logic to be reused by another function.

- Modes:
  - IN, OUT, INOUT, BUFFER



- Types
  - BIT:
    - BIT, BIT_VECTOR
  - STD_LOGIC:
    - STD_LOGIC, STD_LOGIC_VECTOR
  - INTEGER
    - INTEGER, NATURAL, POSITIVE

One bit

Multiple bits/Array of bits

Logic operations: and, or, not, xor, nand, nor

Equal or larger than 0

Equal or larger than 1

4-Bit AND Array

```
d(3) <= '0'; d(2) <= '1';
d(1) <= '0'; d(0) <= '1';
```

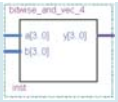
```
IN BIT_VECTOR (3 downto 0)
d  <= "0101";
```

```
IN BIT_VECTOR (0 to 3)
d  <= "1010";
```

```
-- 4-bit bitwise and function
-- y = a and b;
ENTITY bitwise_and_vec_4 IS
  PORT(
    a, b: IN  BIT_VECTOR(3 downto 0);
    y: OUT BIT_VECTOR(3 downto 0));
END bitwise_and_vec_4;

ARCHITECTURE and_gate OF bitwise_and_vec_4 IS
BEGIN
    y <= a and b;
END and_gate;
```

Ports defined as vectors

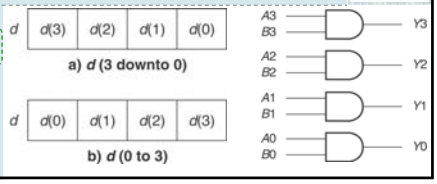
Outputs assigned as a vector



```
-- 4-bit bitwise and function
-- y0 = a0 and b0; y1 = a1 and b1; etc.
ENTITY bitwise_and_4 IS
          PORT(
            a0, a1, a2, a3 : IN  BIT;
            b0, b1, b2, b3 : IN  BIT;
            y0, y1, y2, y3 : OUT BIT);
END bitwise_and_4;

ARCHITECTURE and_gate OF bitwise_and_4 IS
BEGIN
          y0 <= a0 and b0;
          y1 <= a1 and b1;
          y2 <= a2 and b2;
          y3 <= a3 and b3;
END and_gate;
```

Ports defined individually

Outputs assigned individually



WITH … SELECT

D_3	D_2	D_1	D_0	Y
0	0	0	0	0
0	0	0	1	0
0	0	1	0	0
0	0	1	1	1
0	1	0	0	0
0	1	0	1	0
0	1	1	0	1
0	1	1	1	0
1	0	0	0	0
1	0	0	1	1
1	0	1	0	0
1	0	1	1	0
1	1	0	0	1
1	1	0	1	0
1	1	1	0	0
1	1	1	1	0

```
ENTITY select_example IS
  PORT(
    d: IN  BIT_VECTOR(3 downto 0);
    y: OUT BIT);
END select_example;

ARCHITECTURE cct OF select_example IS
BEGIN
  WITH d SELECT
    y <= '1' WHEN "0011",
         '1' WHEN "0110",
         '1' WHEN "1001",
         '1' WHEN "1100",
         '0' WHEN others;
END cct;
```

Select y based on d

d(3) d(0)

Value of y

Default is required

STD_LOGIC and STD_LOGIC_VECTOR

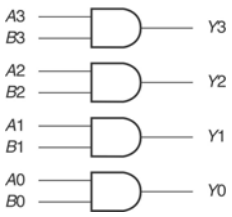
- STD_LOGIC is also called **IEEE Std.1164 Multi-Valued Logic**
- To use STD_LOGIC, we must include the package:

```
LIBRARY ieee;
USE ieee.std_logic_1164.ALL;
```

' U '	Uninitialized
' X '	Forcing Unknown (Input)
' 0 '	Forcing 0
' 1 '	Forcing 1
' Z '	High Impedance (Output)
' W '	Weak Unknown
' L '	Weak 0 (pull-down resistor)
' H '	Weak 1 (pull-up resistor)
' - '	Don't Care

STD_LOGIC and STD_LOGIC_VECTOR (Cont.)

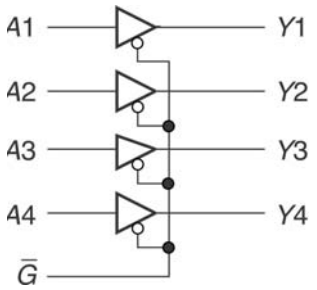
```
LIBRARY ieee;
USE ieee.std_logic_1164.ALL;

ENTITY bitwise_and_std_4 IS
  PORT(
    a, b: IN  STD_LOGIC_VECTOR(3 downto 0);
    y: OUT STD_LOGIC_VECTOR(3 downto 0));
END bitwise_and_std_4;

ARCHITECTURE and_gate OF bitwise_and_std_4 IS
BEGIN
    y <= a and b;
END and_gate;
```



Tristate

```
LIBRARY ieee;
USE ieee.std_logic_1164.ALL;

ENTITY quad_tri IS
  PORT(
    a: IN   STD_LOGIC_VECTOR(4 downto 1);
    g: IN   STD_LOGIC;
    y: OUT STD_LOGIC_VECTOR(4 downto 1));
END quad_tri;

ARCHITECTURE quad_buff OF quad_tri IS
BEGIN
  WITH g SELECT
    y <=    a          WHEN '0',
          "ZZZZ"       WHEN others;
END quad_buff;
```

Y1	Y2	Y3	Y4	$\overline{G}$
A1	A2	A3	A4	0
'Z'	'Z'	'Z'	'Z'	1



INTEGER

```
LIBRARY ieee;
USE ieee.std_logic_1164.ALL;

ENTITY truth_table IS
  PORT(
    d: IN    INTEGER RANGE 0 to 7;
    y: OUT STD_LOGIC);
END  truth_table;

ARCHITECTURE a OF truth_table IS
BEGIN
  WITH d SELECT
    y <=    '1'          WHEN 1,
            '1'          WHEN 5,
            '1'          WHEN 6,
            '0'          WHEN others;
END a;
```

STD_LOGIC

integer

```
LIBRARY ieee;
USE ieee.std_logic_1164.ALL;

ENTITY truth_table IS
  PORT(
    d: IN    STD_LOGIC_VECTOR(2 downto 0);
    y: OUT STD_LOGIC);
END  truth_table;

ARCHITECTURE a OF truth_table IS
BEGIN
  WITH d SELECT
    y <=    '1'          WHEN "001",
            '1'          WHEN "101",
            '1'          WHEN "110",
            '0'          WHEN others;
END a;
```

D_2	D_1	D_0	Y
0	0	0	0
0	0	1	1
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	1
1	1	0	1
1	1	1	0

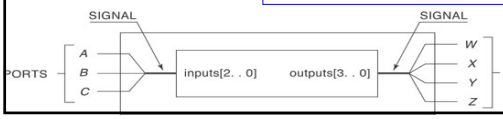
SIGNAL

- SIGNAL can bundle inputs or outputs into a single group.

```
LIBRARY ieee;
USE ieee.std_logic_1164.ALL;

ENTITY signal_ex IS
  PORT(
    a, b, c :   IN  STD_LOGIC;
    w, x, y, z :OUT STD_LOGIC);
END signal_ex;

ARCHITECTURE sig OF signal_ex IS
  -- Declaration area
  -- Define signals here
  SIGNAL inputs : STD_LOGIC_VECTOR(2 downto 0);
  SIGNAL outputs: STD_LOGIC_VECTOR(3 downto 0);
BEGIN
  -- Concatenate input ports into 3-bit signal
  inputs <= a & b & c;
```

```
  WITH inputs SELECT
   outputs   <=
      "1000" WHEN "000",
      "0100" WHEN "001",
      "0110" WHEN "010",
      "1001" WHEN "011",
      "0110" WHEN "100",
      "0001" WHEN "101",
      "1001" WHEN "110",
      "0010" WHEN "111",
      "0000" WHEN others;
  -- Separate signal
  w <= outputs(3);
  x <= outputs(2);
  y <= outputs(1);
  z <= outputs(0);
END sig;
```

A	B	C	W	X	Y	Z
0	0	0	1	0	0	0
0	0	1	0	1	0	0
0	1	0	0	1	1	0
0	1	1	1	0	0	1
1	0	0	0	1	1	0
1	0	1	0	0	0	1
1	1	0	1	0	0	1
1	1	1	0	0	1	0

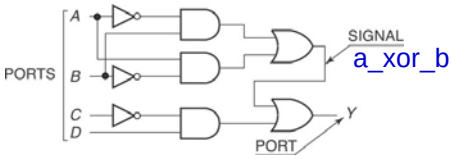


	inputs(2)	inputs(1)	inputs(0)
inputs	a	b	c

	outputs(3)	outputs(2)	outputs(1)	outputs(0)
outputs	w	x	y	z

Single-Bit SIGNAL

$$Y = \overline{A}B + A\overline{B} + \overline{C}D$$



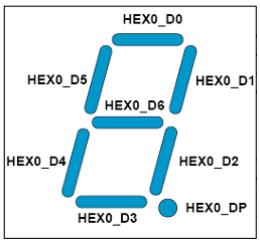

```
--Combine single-bit and multiple-bit signals:

d:IN STD_LOGIC_VECTOR(2 downto 0);
enable: IN STD_LOGIC;
…
SIGNAL inputs: STD_LOGIC_VECTOR (3 downto 0);
…
inputs <= enable & d;  -- combine
```

```
LIBRARY ieee;
USE ieee.std_logic_1164.ALL;

ENTITY signal_ex2 IS
  PORT(
    a, b, c, d : IN  STD_LOGIC;
    y : OUT STD_LOGIC);
END signal_ex2;

ARCHITECTURE cct of signal_ex2 IS
  -- Declare signal
  SIGNAL a_xor_b : STD_LOGIC;
BEGIN
  -- Define signal in terms of ports a and b
  a_xor_b <= ((not a) and b) or (a and (not b));
  -- Combine signal with ports c and d
  y <= a_xor_b or ((not c) and d);
END cct;
```

7-Segment Control

```
LIBRARY ieee;
USE ieee.std_logic_1164.ALL;

ENTITY SevenSegment Is
   PORT (
      sw: IN STD_LOGIC_VECTOR(2 downto 0);
      pb: IN STD_LOGIC;
      hex0: OUT STD_LOGIC_VECTOR(0 to 7));
END SevenSegment;

ARCHITECTURE a OF SevenSegment IS
BEGIN
   WITH pb & sw  SELECT
      hex0 <=          "00000011" WHEN "0000",
                       "10011111" WHEN "0001",
                       "00100101" WHEN "0010",
                       "00001101" WHEN "0011",
                       "10011001" WHEN "0100",
                       "01001001" WHEN "0101",
                       "01000001" WHEN "0110",
                       "00011111" WHEN "0111",
                       "11111111" WHEN others;
END a;
```

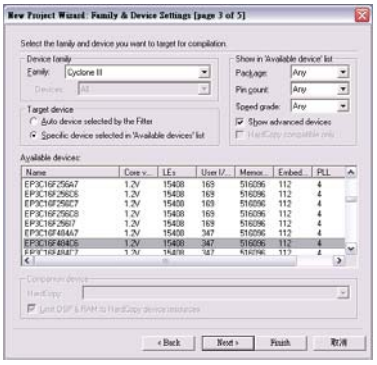
pb sw(2) sw(1) sw(0)



Signal Name	FPGA Pin No.
HEX0_D[0]	PIN_E11
HEX0_D[1]	PIN_F11
HEX0_D[2]	PIN_H12
HEX0_D[3]	PIN_H13
HEX0_D[4]	PIN_G12
HEX0_D[5]	PIN_F12
HEX0_D[6]	PIN_F13
HEX0_DP	PIN_D13

VHDL Design with Quartus II

- Example: When the BUTTON0 is pressed,
  - LEDG0 shows the ANDed result of SW0 and SW1.
  - LEDG1 shows the ORed result of SW0 and SW1.
- Step 1: Start a new project
  - Select File → New Project Wizard
    - Working directory: Class02
    - Project name: Class02
    - Top-level design entry: Class02
  - Family & Device Settings
    - Device family: Cyclone III
    - Available device: EP3C16F484C6
  - EDA Tool Settings
    - Leave it alone at the moment



VHDL Design with Quartus II (Cont.)

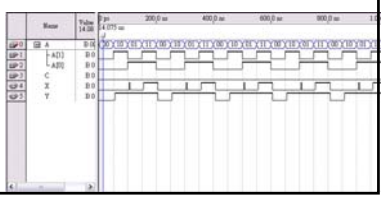
- Step 2: Design entry using the text editor
  - Select File → New → VHDL File (.vhd)
  - Save as "Class02.vhd" (check "Add file to current project")
  - Edit "Class02.vhd"

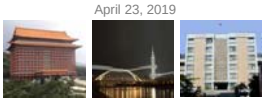
```
ENTITY Class02 IS
        PORT(
                A: IN BIT_VECTOR(1 downto 0);
                C: IN BIT;
                X: OUT BIT;
                Y: OUT BIT);
END Class02;

ARCHITECTURE and_or OF Class02 IS
BEGIN
        X <= A(1) and A(0) and (not C);
        Y <= (A(1) or A(0)) and (not C);
END and_or;
```

  - Select "Start Compilation" to compile the circuit

VHDL Design with Quartus II (Cont.)

- Step 3: Simulation with Vector Waveform File (.vwf)
  - Select File → New → Vector Waveform File (.vwf)
  - Save as "Class02.vwf" (check "Add file to current project")
  - Select "Edit → Insert → Insert Node or Bus → Node Finder" to add input/output pins into the simulation.
  - Select "Edit → End Time" and select "Edit → Grid Size" to config the simulation period and count period. (e.g., End time 4us, grid size: 50ns)
    - A(0): count value, binary, count every 50ns, multiplied by 1.
    - A(1): count value, binary, count every 50ns, start time: 0ns, multiplied by 2.
    - C: forcing high or forcing low.
  - Select "Start Simulation" to simulate the circuit.
  - Functional simulation
    - Select "Assignments → Settings → Simulator Settings" to set "Simulation mode" as Functional.
    - Select "Processing → Generate Functional Simulation Netlist"
    - Select "Start Simulation" to simulate the circuit.



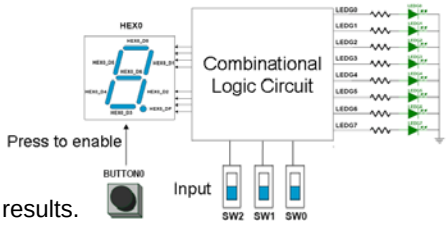


VHDL Design with Quartus II (Cont.)

- Step 3: Pin assignment and Programming
  - Select "Assignments → Device" to configure the board settings.
    - Set Family as Cyclone III and Device as EP316F484C6
    - Select "Device and Pin Options"
      - Select and set "Unsigned Pings" as "As input tri-stated" and
      - Select "Configuration" to set configuration scheme as "Active Serial" and configuration device as "EPCS4"
  - Select "Assignments → Pins" to activate the "Pin Planner".
  - Select "Start Compilation" to compile the circuit with circuit assignment.
  - Select "Tools → Programmer" to download the .soft file to the FPGA board for testing.

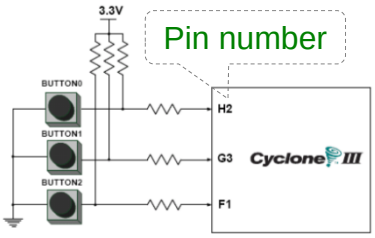
Node Name	Direction	Location
A[1]	Input	PIN_H5
A[0]	Input	PIN_J6
C	Input	PIN_H2
X	Output	PIN_J1
Y	Output	PIN_J2

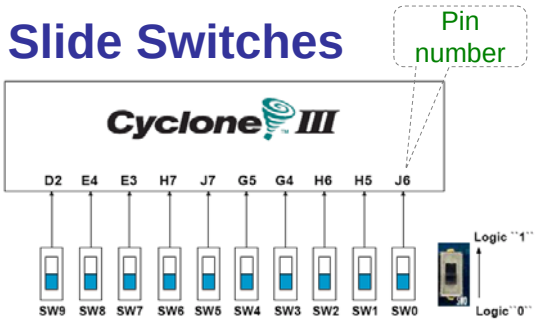
Lab 02



- Part 1 - Simulation
  - Use VHDL to design a NAND gate with one output pin ***f*** and two input pins ***a*** and ***b***. Then use Vector Waveform File (.vwf) to simulate the results.
    - A: count value, binary, simulation period=4us, advanced by 1 every 100ns
    - B: count value, binary, simulation period=4us, advanced by 1 every 200ns
- Part 2: When the BUTTON0 is pressed,
  - LEDG0 shows the ANDed result of SW0 and SW1.
  - LEDG1 shows the ORed result of SW0 and SW1.
- Part 3 - Transferring a Design to a Target FPGA
  - Use three slides (SW2-SW0) as the binary input value. Solve the following problems with VHDL.
    - The corresponding LED (LEDG0-7) is on when selected by the binary input. Other LEDs are off. E.g., 100 (SW2-SW0) lights LEDG4.
    - The first 7-segment LED (HEX0) shows the decimal value of the binary input when the first pushbutton (BUTTON0) is pressed. Otherwise, HEX0 is off. E.g., When BUTTON0 is pressed and the binary input is 101 (SW2-SW0), HEX0 shows 5.

Pushbutton and Slide Switches





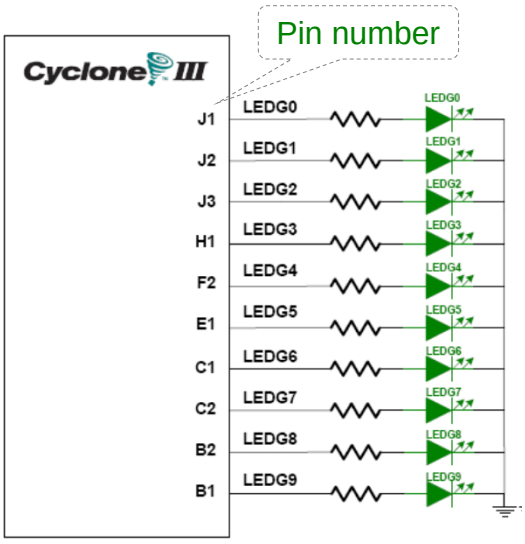
3 Pushbutton switches:
Not pressed → Logic High
Pressed → Logic Low

Signal Name	FPGA Pin No.
BUTTON [0]	PIN_ H2
BUTTON [1]	PIN_ G3
BUTTON [2]	PIN_ F1

10 Slide switches (Sliders):
Up → Logic High
Down → Logic

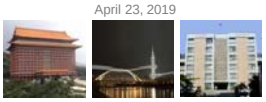
SW[0]	PIN_J6	SW[5]	PIN_J7
SW[1]	PIN_H5	SW[6]	PIN_H7
SW[2]	PIN_H6	SW[7]	PIN_E3
SW[3]	PIN_G4	SW[8]	PIN_E4
SW[4]	PIN_G5	SW[9]	PIN_D2

LEDs

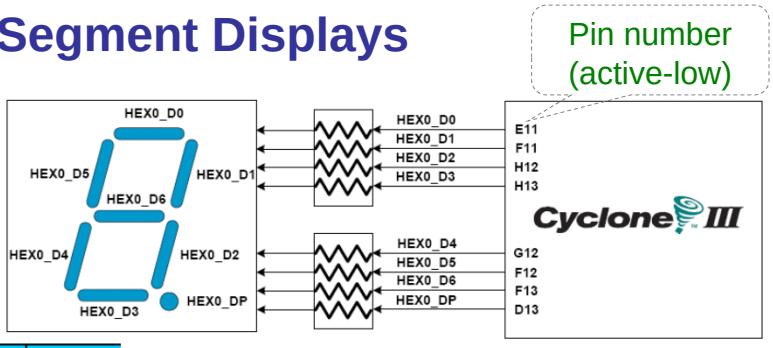


10 LEDs
Opuput high → LED on
Output low → LED off

Signal Name	FPGA Pin No.
LEDG[0]	PIN_J1
LEDG[1]	PIN_J2
LEDG[2]	PIN_J3
LEDG[3]	PIN_H1
LEDG[4]	PIN_F2
LEDG[5]	PIN_E1
LEDG[6]	PIN_C1
LEDG[7]	PIN_C2
LEDG[8]	PIN_B2
LEDG[9]	PIN_B1



7-Segment Displays



Signal Name	FPGA Pin No.
HEX0_D[0]	PIN_E11
HEX0_D[1]	PIN_F11
HEX0_D[2]	PIN_H12
HEX0_D[3]	PIN_H13
HEX0_D[4]	PIN_G12
HEX0_D[5]	PIN_F12
HEX0_D[6]	PIN_F13
HEX0_DP	PIN_D13

HEX1_D[0]	PIN_A13
HEX1_D[1]	PIN_B13
HEX1_D[2]	PIN_C13
HEX1_D[3]	PIN_A14
HEX1_D[4]	PIN_B14
HEX1_D[5]	PIN_E14
HEX1_D[6]	PIN_A15
HEX1_DP	PIN_B15

HEX2_D[0]	PIN_D15
HEX2_D[1]	PIN_A16
HEX2_D[2]	PIN_B16
HEX2_D[3]	PIN_E15
HEX2_D[4]	PIN_A17
HEX2_D[5]	PIN_B17
HEX2_D[6]	PIN_F14
HEX2_DP	PIN_A18

HEX3_D[0]	PIN_B18
HEX3_D[1]	PIN_F15
HEX3_D[2]	PIN_A19
HEX3_D[3]	PIN_B19
HEX3_D[4]	PIN_C19
HEX3_D[5]	PIN_D19
HEX3_D[6]	PIN_G15
HEX3_DP	PIN_G16