

# Hardware Description Language

# Outline

1. Overview on hardware description language
2. Basic VHDL Concept via an example
3. VHDL in development flow

# 1. Overview on hardware description language

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# Programming language

- Can we use C or Java as HDL?
- A computer programming language
  - Semantics (“meaning”)
  - Syntax (“grammar”)
- Develop of a language
  - Study the characteristics of the underlying processes
  - Develop syntactic constructs and their associated semantics to model and express these characteristics.

# Traditional PL

- Modeled after a sequential process
  - Operations performed in a sequential order
  - Help human's thinking process to develop an algorithm step by step
  - Resemble the operation of a basic computer model

# HDL

- Characteristics of digital hardware
  - Connections of parts
  - Concurrent operations
  - Concept of propagation delay and timing
- Characteristics cannot be captured by traditional PLs
- Require new languages: HDL

# Use of an HDL program

- Formal documentation
- Input to a simulator
- Input to a synthesizer

# Modern HDL

- Capture characteristics of a digital circuit:
  - entity
  - connectivity
  - concurrency
  - timing
- Cover description
  - in Gate level and RT level
  - In structural view and behavioral view



- Highlights of modern HDL:
  - Encapsulate the concepts of entity, connectivity, concurrency, and timing
  - Incorporate propagation delay and timing information
  - Consist of constructs for structural implementation
  - Incorporate constructs for behavioral description (sequential execution of traditional PL)
  - Describe the operations and structures in gate level and RT level.
  - Consist of constructs to support hierarchical design process

# Two HDLs used today

- VHDL and Verilog
- Syntax and "appearance" of the two languages are very different
- Capabilities and scopes are quite similar
- Both are industrial standards and are supported by most software tools

# VHDL

- VHDL: VHSIC (Very High Speed Integrated Circuit) HDL
- Initially sponsored by DoD as a hardware documentation standard in early 80s
- Transferred to IEEE and ratified it as IEEE standard 1176 in 1987 (known as VHDL-87)
- Major modification in '93 (known as VHDL-93)
- Revised continuously

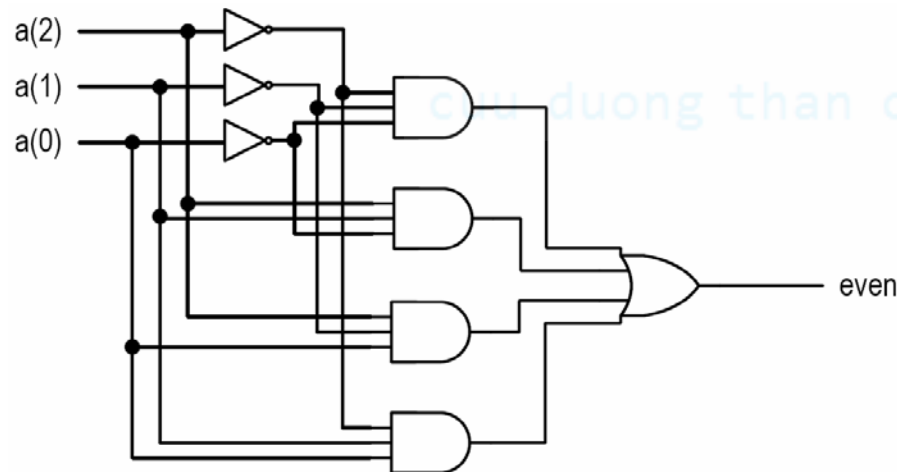
# IEEE Extensions

- IEEE standard 1076.1 Analog and Mixed Signal Extensions (VHDL-AMS)
- IEEE standard 1076.2 VHDL Mathematical Packages
- IEEE standard 1076.3 Synthesis Packages
- IEEE standard 1076.4 VHDL Initiative Towards ASIC Libraries (VITAL)
- IEEE standard 1076.6 VHDL Register Transfer Level (RTL) Synthesis
- IEEE standard 1164 Multivalued Logic System for VHDL Model Interoperability
- IEEE standard 1029 VHDL Waveform and Vector Exchange to Support Design and Test Verification (WAVES)

## 2. Basic VHDL Concept via an example

# Even parity detection circuit

- Input:  $a(2)$ ,  $a(1)$ ,  $a(0)$
- output: even



$a(2)$	$a(1)$	$a(0)$	even
0	0	0	1
0	0	1	0
0	1	0	0
0	1	1	1
1	0	0	0
1	0	1	1
1	1	0	1
1	1	1	0

$$\text{even} = a(2)' \cdot a(1)' \cdot a(0)' + a(2)' \cdot a(1) \cdot a(0) + a(2) \cdot a(1)' \cdot a(0) + a(2) \cdot a(1) \cdot a(0)'$$

# VHDL Listing 2.1

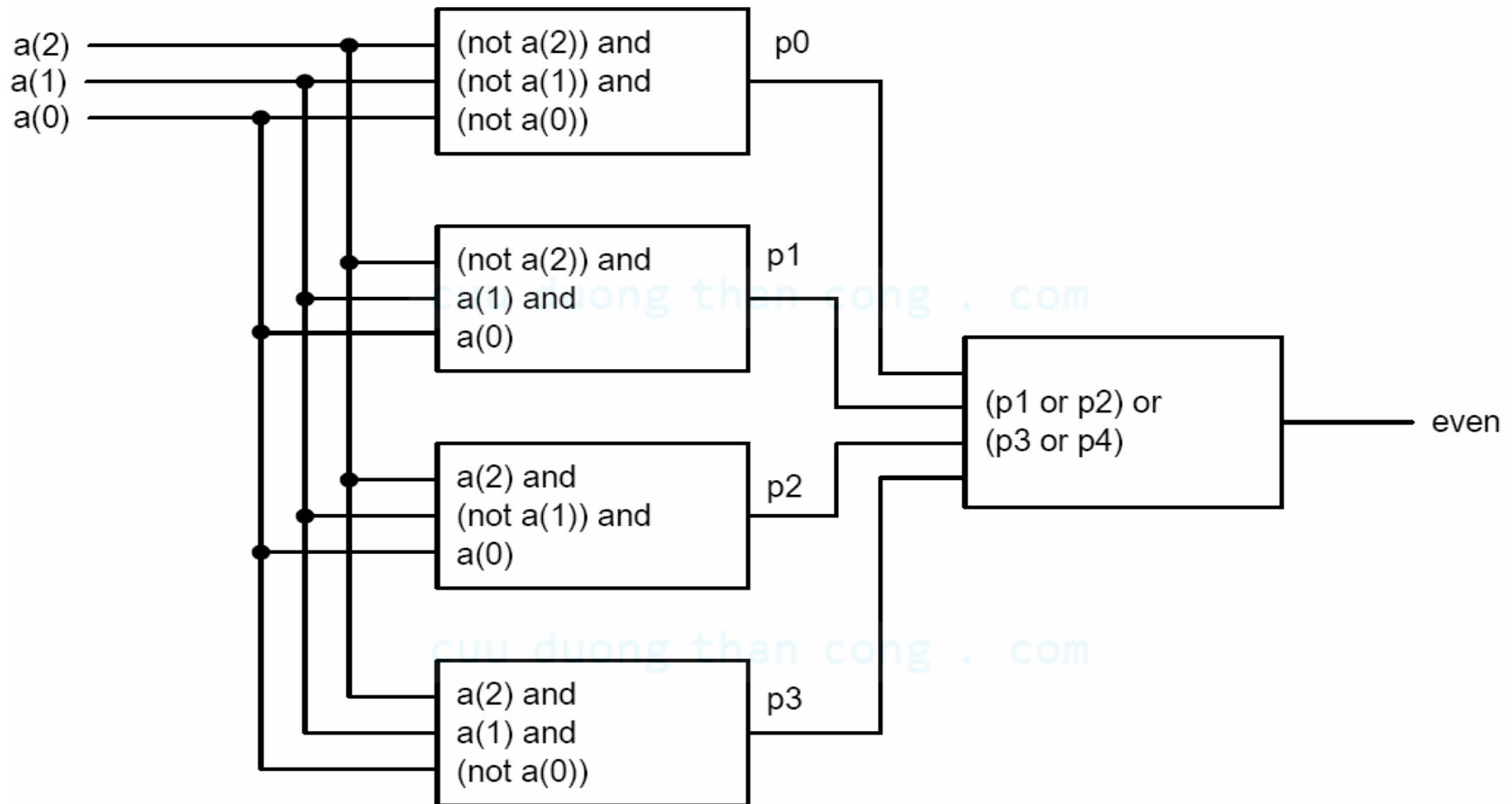
```
library ieee;
use ieee.std_logic_1164.all;
entity even_detector is
    port(
        a: in std_logic_vector(2 downto 0);
        even: out std_logic);
end even_detector;

architecture sop_arch of even_detector is
    signal p1, p2, p3, p4 : std_logic;
begin
    even <= (p1 or p2) or (p3 or p4) after 20 ns;
    p1 <= (not a(2)) and (not a(1)) and (not a(0)) after 15 ns;
    p2 <= (not a(2)) and a(1) and a(0) after 12 ns;
    p3 <= a(2) and (not a(1)) and a(0) after 12 ns;
    p4 <= a(2) and a(1) and (not a(0)) after 12 ns;
end sop_arch ;
```

- Entity declaration
  - i/o ports (“outline” of the circuit)
- Architecture body
  - Signal declaration
  - Each concurrent statement
    - Can be thought s a circuit part
    - Contains timing information
  - Arch body can be thought as a “collection of parts”
- What’s the difference between this and a C program

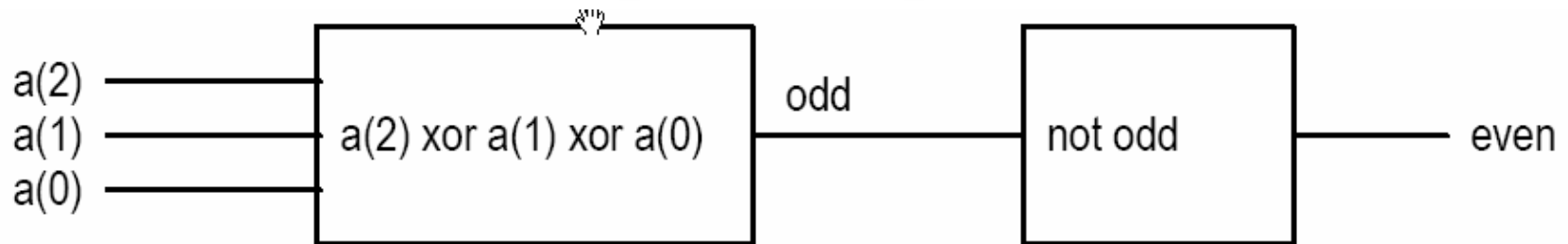


# Conceptual interpretation



# VHDL Listing 2.2

```
architecture xor_arch of even_detector is
    signal odd: std_logic;
begin
    even <= not odd;
    odd <= a(2) xor a(1) xor a(0);
end xor_arch;
```

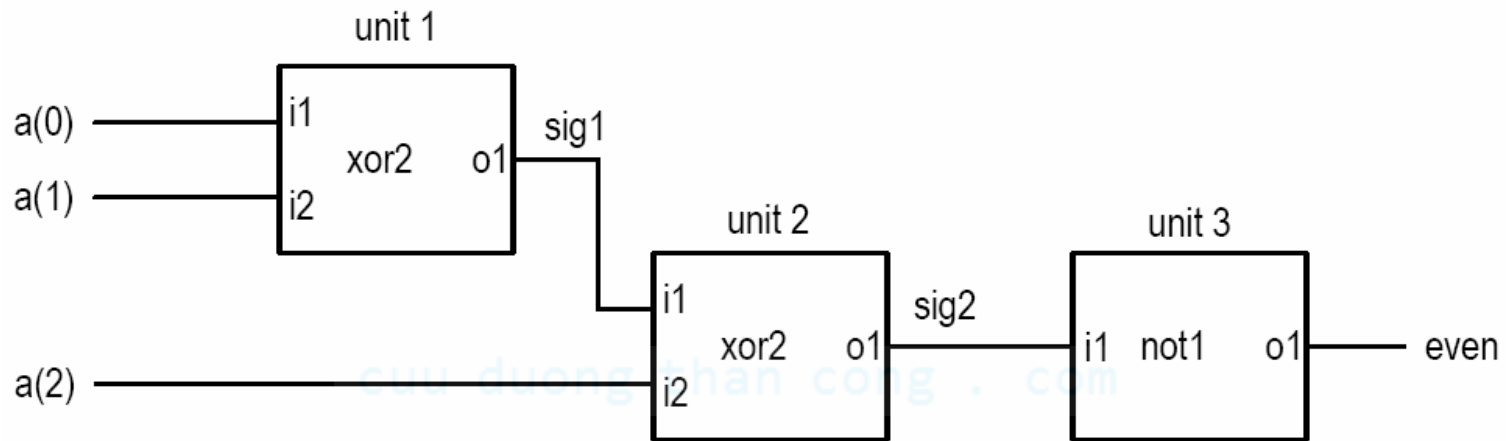


- Same entity declaration
- Implicit  $\delta$ -delay (delta delay)

# Structural description

- In structural view, a circuit is constructed by smaller parts.
- Structural description specifies the types of parts and connections.
- Essentially a textual description of a schematic
- Done by using “component” in VHDL
  - First *declared* (make known)
  - Then *instantiated* (used)

# Example



- Even detector using previously designed components (xor2 and not1)

# VHDL Listing 2.3

```
architecture str_arch of even_detector is
    component xor2
        port(
            i1, i2: in std_logic;
            o1: out std_logic);
    end component;
    component not1
        port(
            i1: in std_logic;
            o1: out std_logic);
    end component;
    signal sig1,sig2: std_logic;

begin
    unit1: xor2
        port map (i1 => a(0), i2 => a(1), o1 => sig1);
    unit2: xor2
        port map (i1 => a(2), i2 => sig1, o1 => sig2);
    unit3: not1
        port map (i1 => sig2, o1 => even);
end str_arch;
```

# Somewhere in library

```
library ieee;  
use ieee.std_logic_1164.all;  
entity xor2 is  
    port(  
        i1, i2: in std_logic;  
        o1: out std_logic);  
end xor2;
```

```
architecture beh_arch of xor2 is  
begin  
    o1 <= i1 xor i2;  
end beh_arch;
```

```
library ieee;  
use ieee.std_logic_1164.all;  
entity not1 is  
    port(  
        i1: in std_logic;  
        o1: out std_logic);  
end not1;  
architecture beh_arch of not1 is  
begin  
    o1 <= not i1;  
end beh_arch;
```

# “Behavioral” description

- No formal definition on “behavioral” in VHDL
- VHDL “process”: a language construct to encapsulate “sequential semantics”
  - The entire process is a concurrent statement
  - Syntax:

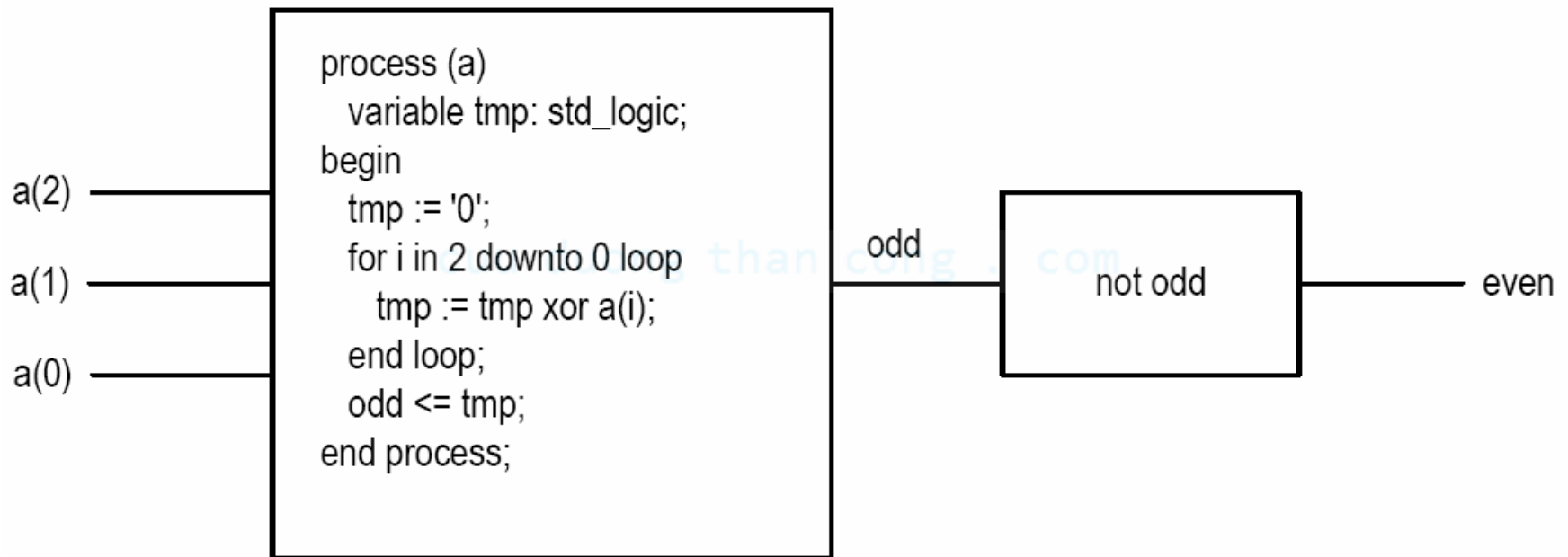
```
process (sensitivity_list)
    variable declaration;
begin
    sequential statements;
end process;
```

# Listing 2.5

```
architecture beh1_arch of even_detector is
    signal odd: std_logic;
begin
    even <= not odd;
    process (a)
        variable tmp: std_logic;
    begin
        tmp := '0';
        for i in 2 downto 0 loop
            tmp := tmp xor a(i);
        end loop;
        odd <= tmp;
    end process;
end beh1_arch;
```



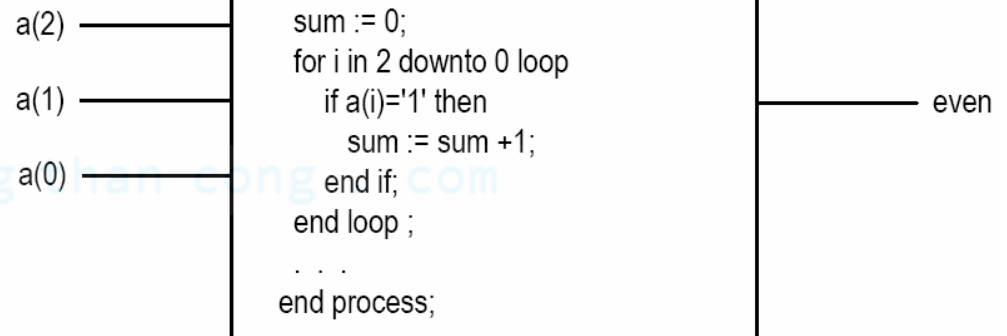
# Conceptual interpretation



# Listing 2.6

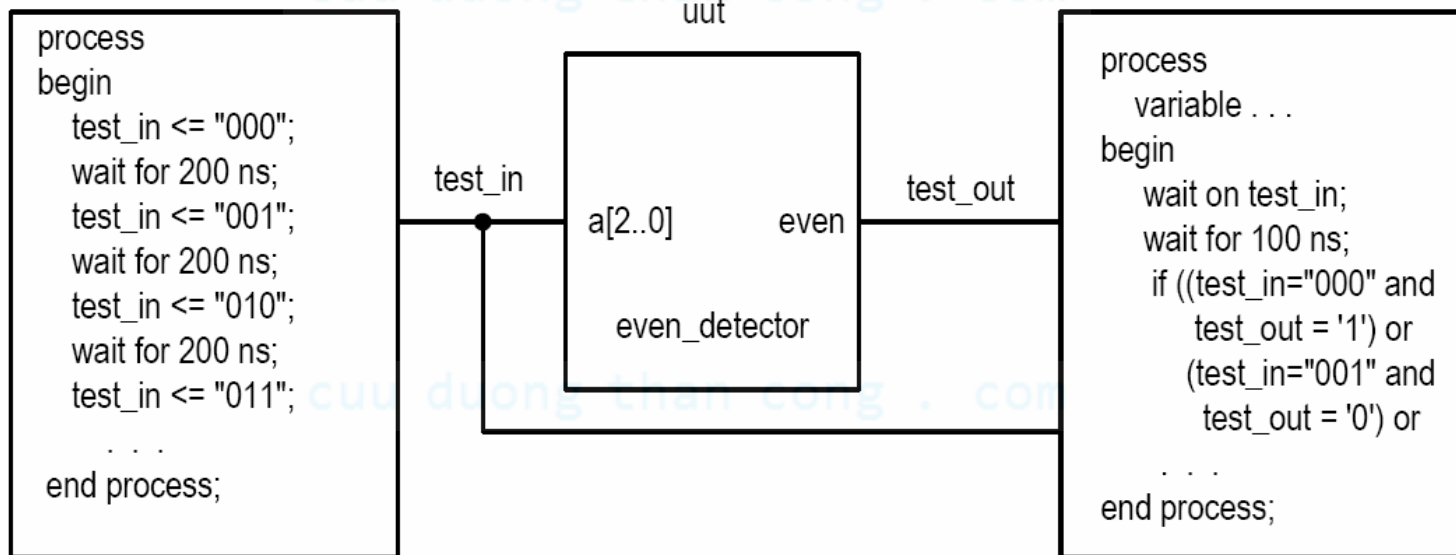
**architecture** beh2\_arch of even\_detector is  
**begin**

```
    process (a)
        variable sum, r: integer;
    begin
        sum := 0;
        for i in 2 downto 0 loop
            if a(i)='1' then
                sum := sum +1;
            end if;
        end loop ;
        r := sum mod 2;
        if (r=0) then
            even <= '1';
        else
            even <= '0';
        end if;
    end process;
```



# Testbench

- a “virtual” experiment table
  - Circuit to be tested
  - Input stimuli (e.g., function generator)
  - Output monitor (e.g., logic analyzer)
- e.g.,



# VHDL Listing 2.7

```
library ieee;
use ieee.std_logic_1164.all;
entity even_detector_testbench is
end even_detector_testbench;

architecture tb_arch of even_detector_testbench is
    component even_detector
        port (
            a: in std_logic_vector(2 downto 0);
            even: out std_logic);
    end component;
    signal test_in: std_logic_vector(2 downto 0);
    signal test_out: std_logic;

begin
    -- instantiate the circuit under test
    uut: even_detector
        port map( a=>test_in, even=>test_out);
```

```

-- test vector generator
process
begin
    test_in <= "000";
    wait for 200 ns;
    test_in <= "001";
    wait for 200 ns;
    test_in <= "010";
    wait for 200 ns;
    test_in <= "011";
    wait for 200 ns;
    test_in <= "100";
    wait for 200 ns;
    test_in <= "101";
    wait for 200 ns;
    test_in <= "110";
    wait for 200 ns;
    test_in <= "111";
    wait for 200 ns;
end process;

```

```

--? verifier
process
    variable error_status: boolean;
begin
    wait on test_in;
    wait for 100 ns;
    if ((test_in="000" and test_out = '1') or
        (test_in="001" and test_out = '0') or
        (test_in="010" and test_out = '0') or
        (test_in="011" and test_out = '1') or
        (test_in="100" and test_out = '0') or
        (test_in="101" and test_out = '1') or
        (test_in="110" and test_out = '1') or
        (test_in="111" and test_out = '0'))
    then
        error_status := false;
    else
        error_status := true;
    end if;
    -- error reporting
    assert not error_status
        report "test failed."
        severity note;
end tb_arch;

```

# Configuration

- Multiple architecture bodies can be associated with an entity declaration
  - Like IC chips and sockets
- VHDL configuration specifies the *binding*
- E.g.,

```
configuration demo_config of even_detector_testbench is
  for tb_arch
    for uut: even_detector
      use entity work.even_detector(sop_arch);
    end for;
  end for;
end demo_config;
```

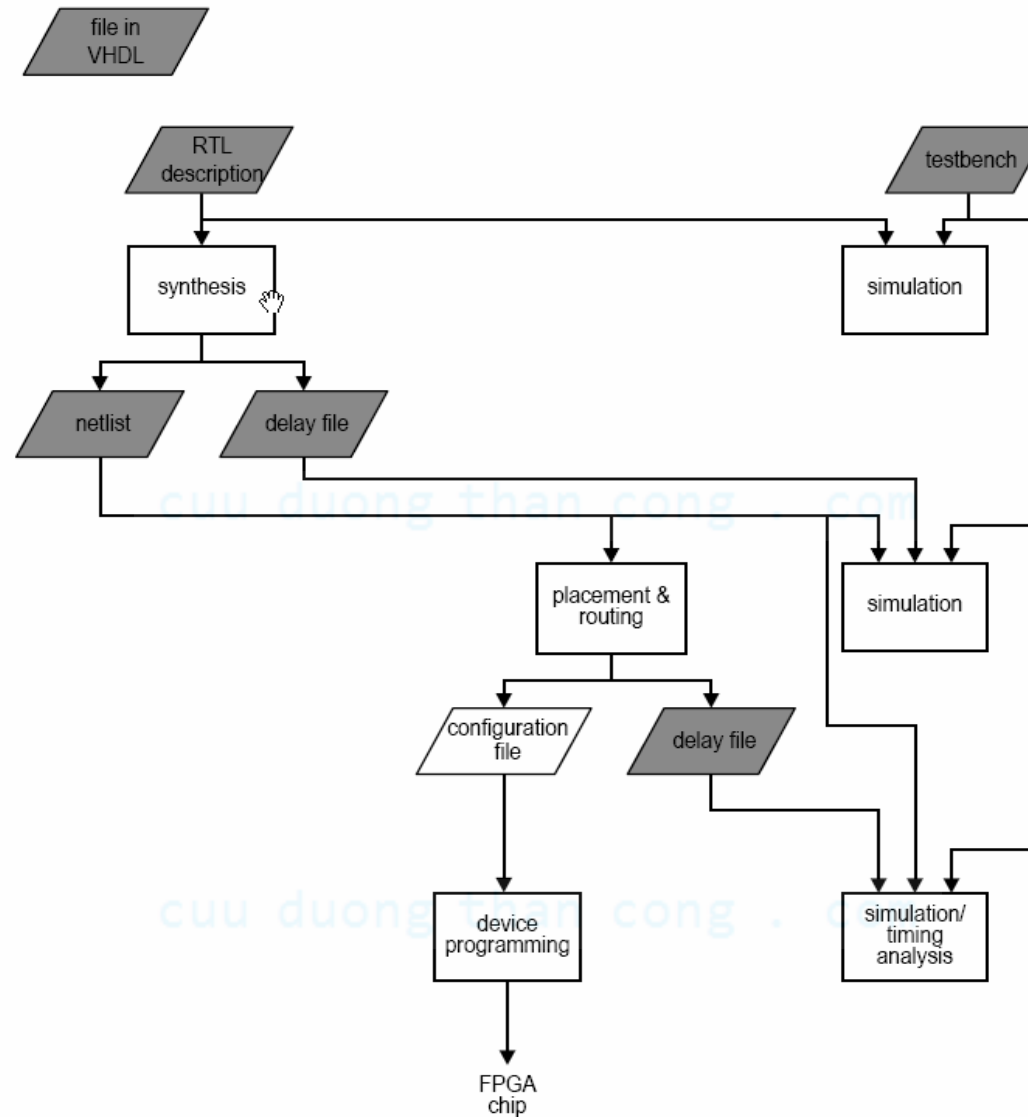
# 3. VHDL in development flow

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# Scope of VHDL



# Coding for synthesis

- “Execution” of VHDL codes
  - Simulation:
    - Design “realized” in a virtual environment (simulation software)
    - All language constructs can be “realized”
    - “realized” by a single CPU

## – “Synthesis

- Design realized by hardware components
- Many VHDL constructs can be synthesized (e.g, file operation, floating-point data type, division)
- Only small subset can be used
- E.g., 10 additions
- Syntactically correct code  $\neq$  Synthesizable code
- Synthesizable code  $\neq$  Efficient code
- Synthesis software only performs transformation and local search

- The course focuses on hardware, not VHDL (i.e., the “H”, not “L” of HDL)
- Emphasis on coding for synthesis:
  - Code accurately describing the underlying hardware structure
  - Code providing adequate info to guide synthesis software to generate efficient implementation