

# vhdl-cheatsheet

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summarizes most important things to recognize about vhdl

1. [librarys](#)
2. [entities](#)
3. [architectures](#)
4. [signals](#)
5. [processes](#)
6. [assignments](#)
7. [operators](#)
8. [datatypes](#)
9. [ghdl](#)
10. [gtkwave](#)
11. [testing](#)
12. [links](#)

## librarys

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```
library IEEE;
use IEEE.std_logic_1164.all;      -- contains std_logic and std_logic_vector (and more)
use IEEE.numeric_std.all;        -- contains unsigned and signed arithmetics
```

## entities

---

```
entity multiplexer is
  port(
    a, b: in std_logic;
    s: in std_logic;
    c: out std_logic    -- no semicolon here!
  );
end entity multiplexer;
```

- blackbox view defining inputs and outputs

## architectures

---

```
architecture multiplexer_logic of multiplexer is
begin
  c <= a when s = '0' else
```

```

        b when s = '1';
end multiplexer_logic;

```

- whitebox view defining the logic, always belonging to an entity
- there can be multiple architectures for a single entity
- you cannot write to inputs!
- you cannot read from outputs!
- all assignments are processes!
  - all processes happen in parallel!
  - a signal takes its state at the end of a process!
  - that means that assigning a value to a signal in one process won't affect another process using that signal (not in the same "loop")!
- use signals to reuse your "output"!

## types of architectures

There are three types of architectures. I'll explain them by implementing following 1-mux:

```

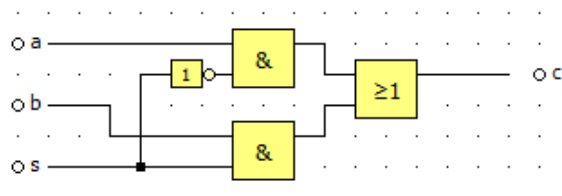
entity multiplexer is
  port(
    a, b: in std_logic;
    s: in std_logic;
    c: out std_logic
  );
end entity multiplexer;

```

### 1. structural

"The description of a structural body is based on component instantiation and generate statements."

That means first of all we create a component for each logic gate we need. Then we use these logic gates to exactly define the multiplexer's structure.



```

architecture structural of multiplexer is

  component and_gate
    port(a, b: in std_logic; c: out std_logic);
  end component;
  component or_gate
    port(a, b: in std_logic; c: out std_logic);
  end component;
  component not_gate

```

```

    port(a: in std_logic; b: out std_logic);
end component;

signal s_not: std_logic;
signal first_and: std_logic;
signal second_and: std_logic;

begin
    n1: not_gate port map(s, s_not);
    a1: and_gate port map(a, s_not, first_and);
    a2: and_gate port map(b, s, second_and);
    o1: or_gate port map(first_and, second_and, c);
end structural;

```

## 2. dataflow

"The Dataflow description is built with concurrent signal assignment statements. Each of the statements can be activated when any of its input signals changes its value."

That means we just use simple assignments and logical operators.

```

architecture dataflow of multiplexer is

begin
    c <= (a and not s) or (b and s);
end dataflow;

```

## 3. behavioural

"The architecture body describes only the expected functionality (behavior) of the circuit, without any direct indication as to the hardware implementation. Such description consists only of one or more processes, each of which contains sequential statements."

```

architecture behavioural of multiplexer is

begin
    process(a, b, s)
    begin
        if(b and s) then
            c <= '1';
        elsif(a and not s) then
            c <= '1';
        else
            c <= '0';
        end if;
    end process;
end behavioural;

```

## reusing entities

---

```

architecture structural of full_adder is
signal s1, s2, s3: bit;
component half_adder  -- 1. define the reused component's black box view inside the architecture
  port (
    x, y : in bit;
    sum, cout : out bit
  );
end component;
begin
  u1 : half_adder port map (x, y, s1, s2);  -- 2. map (input/output) signals to the reused component
  u2 : half_adder port map (s1, cin, sum, s3);
  cout <= s2 OR s3;
end structural;

```

## signals

```

architecture some_random_architecture of some_random_entity is
signal internal_signal: std_logic;
begin
  internal_signal <= a xor internal_signal;
  c <= internal_signal;
end some_random_architecture;

```

- useful for reusing "outputs"
- are declared inside the architecture's declarative part

## initialising signals

```

signal internal_signal: std_logic := '1';

```

- remember: initialization isn't synthesizable!

## processes

```

process(clk)
begin
  if(rising_edge(clk) then
    a <= '1';
  else
    a <= '0';
  end if;
end process;

```

- processes are only "called" if the value of at least one signal in the sensitivity list changes
- common assignments (outside a process) are processes too, all processes happen in parallel!
- signals take their states at the end of a process

## if-statements

---

```
if (a = '1') or (c > d) then
  statements;
elsif condition then
  statements;
else
  statements;
end if;
```

- can only be used inside processes
- elsif and else clauses are optional

## case-statements

---

```
case a is
  when "00" => b <= "1000";
  when "01" => b <= "0100";
  when "10" => b <= "0010";
  when "11" => b <= "0001";
  when others => b <= "0000"; -- fallback case
  -- when others =>; -- commonly used to do "nothing"
end case;
```

## assignments

---

### simple assignments

---

```
a <= '1';
```

### when else assignments

---

```
a <= "11" when b = "00" else
  "10" when b = "01" else
  "01" when b = "10" else
  "00" when b = "11";
```

its also possible to define a fallback value

```
a <= "11" when b = "00" else
  "10" when b = "01" else
  "01" when b = "10" else
  "00" when b = "11" else
  "00";
```

## with select assignments

---

this is equal to the code above

```
with b select a <=
    "11" when "00", -- use commas here
    "10" when "01",
    "01" when "10",
    "00" when "11",
    "00" when others; -- fallback value
```

## operators

---

### arithmetical

---

`+`, `-`, `/`, `*`, `mod`

### relational

---

`=`, `<`, `<=`, `>`, `>=`

### logical

---

`not`, `or`, `and`, `xor`, `nand`, `nor` and `xnor`.

`not` has the highest precedence, all other operators have the same precedence (!). so just use parenthesis^^.

```
c <= a or not b or (f and (g xor h));
```

## concatentation-operator

---

`&` is an operator allowing you to concatenate vectors.

```
signal a: std_logic_vector(3 downto 0);
signal b: std_logic_vector(3 downto 0);
signal c: std_logic_vector(8 downto 0);
(...)
c <= a & b;
```

## datatypes

---

### simple

---

## boolean

can be `true` or `false` . used for conditions.

## bit

can be `1` or `0` . represents a signal.

## std\_logic

the better bit. can be `0` (logic 0, all fine), `1` (logic 1, all fine), `z` (high impedance), `-` (don't care), `u` (uninitialised, cannot know), `x` (unknown, can't determine), `L` (weak signal, probably 0), `H` (weak signal, probably 1), `w` (weak signal, can't tell).

useful for detecting errors while simulating.

## vectors / arrays

---

vectors are array-like one-dimensional collections of signals having the same type. they are indexed by an integer number starting with 0.

### defining ranges

- `downto` corresponds to *little endian*
- `to` corresponds to *big endian*

e.g.

```
signal big_endian : std_logic_vector(0 to 7) := "0000_0001";      -- results in index 7 havir
signal little_endian : std_logic_vector(7 downto 0) := "0000_0001"; -- results in index 0 havir
```

## assigning arrays

### assigning single elements

```
my_array(0) <= '1';
```

### assigning a part of the array

```
my_array(3 downto 0) <= "0101";
```

### positional association

```
my_array <= ('0', '1', '0', '1');
```

### named association

```
my_array <= (0 => '1', others => '0');           -- 0000_0001
my_array <= (0 | 3 | 5 => '1', others => '0');    -- 0010_1001
my_array <= (4 downto 1 => '1', others => '0');    -- 0001_1110
```

## creating custom vector types

first you have to define your array type:

```
type 4bit_vector is array(3 downto 0) of bit;
```

after that you can simple use it:

```
signal a: 4bit_vector;
```

## std\_logic\_vector

represents a vector of bits (std\_logic). does not support arithmetics.

```
signal a: std_logic_vector(7 downto 0);
```

## unsigned

represents a vector of bits (std\_logic) supporting unsigned arithmetics.

```
signal a: unsigned(7 downto 0) := 7;  -- default value is 'U' (uninitialised) to every bit
(...)
a <= a + 1;
```

## signed

represents a vector of bits (std\_logic) supporting signed arithmetics.

```
signal a: signed(7 downto 0) := -7;  -- default value is 'U' (uninitialised) to every bit
(...)
a <= a + 1;
```

## integer

represents an integer. similar to signed/unsigned.

but you

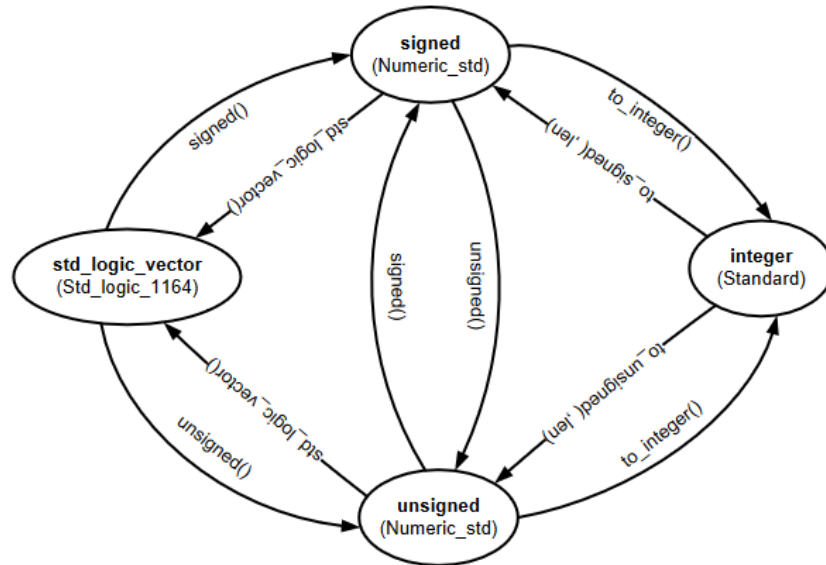
- cannot assign binary or hex values
- cannot use bitwise/logical operators
- cannot set the bit count using (8 downto 0) or (0 to 3)
  - instead you have to use range value1 to value2-syntax



- cannot access single bits

```
signal a_number: integer range -256 to 255;
```

## converting between std\_logic\_vector, unsigned, signed and integer



[Source](#)

## ghdl

```
sudo apt install ghdl
sudo apt install ghdl-gcc
```

## gtkwave

```
sudo apt install gtkwave
```

## testing

## compiling files

```
ghdl-gcc -a *.vhd
```

## generating the simulator

```
ghdl-gcc -e testbench
```

- use the entity's name

## running the simulation

---

```
ghdl-gcc -r testbench --vcd=output.vcd --stop-time=20us
```

- use the entity's name

## gtkwave

---

```
gtkwave file.vcd
```

- quick-tip: use WaveTrace plugin on vscode

## links

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- [VHDL Online Help](#)
- [University of Minnesota Duluth PDF](#)
- [VHDL Grundlagen, Universität Ulm](#)