

Conditional Concurrent Signal Assignment

The conditional concurrent signal assignment statement is modeled after the “if statement” in software programming languages.

The general format for this statement is:

```
target_signal <= value1 WHEN condition1 ELSE
                    value2 WHEN condition2 ELSE
                    value3 WHEN condition3 ELSE
                    .....
                    valueN;
```

When one or more of the signals on the right-hand side change value, the statement executes, evaluating the condition clauses in textual order from top to bottom. If a condition is found to be true, the corresponding expression is executed and the values is assigned to the target signal.

The conditions must evaluate to a boolean value. i.e, True or False

Example:

```
z_out <=  a_input WHEN (select = "00") ELSE
          b_input WHEN (select = "01") ELSE
          c_input WHEN (select = "10") ELSE
          d_input WHEN (select = "11") ELSE
          "X"; -- what am I?
```

Conditional Concurrent Signal Assignment

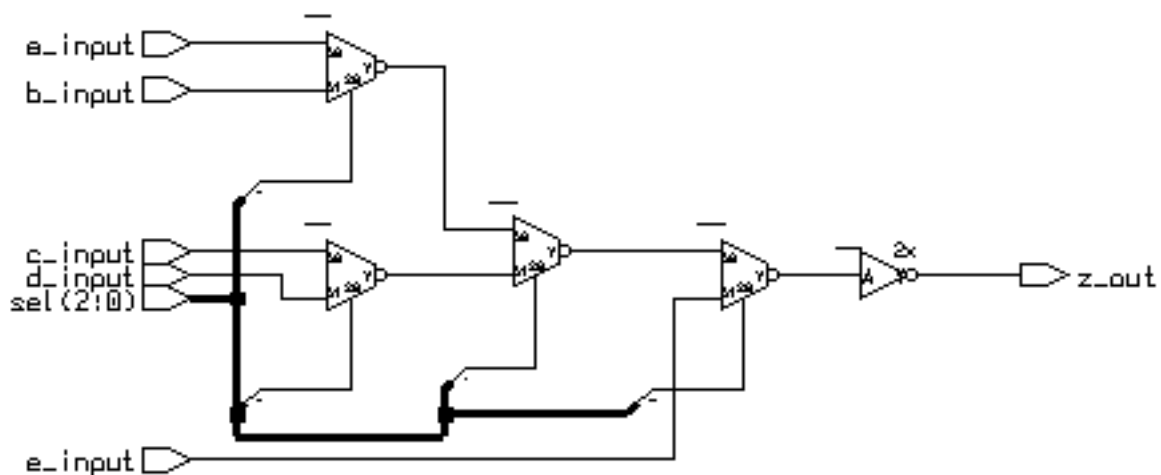
What happens when we don't completely specify all the choices?

First, lets do it right.

```
--5:1 mux, 1 bit wide
LIBRARY ieee;
USE ieee.std_logic_1164.ALL;

ENTITY mux5_1_1wide IS
  PORT(
    a_input   : IN STD_LOGIC;  --input a
    b_input   : IN STD_LOGIC;  --input b
    c_input   : IN STD_LOGIC;  --input c
    d_input   : IN STD_LOGIC;  --input d
    e_input   : IN STD_LOGIC;  --input e
    sel       : IN STD_LOGIC_VECTOR(2 DOWNTO 0);  --sel input
    z_out     : OUT STD_LOGIC  --data out
  );
END mux5_1_1wide;
ARCHITECTURE beh OF mux5_1_1wide IS
  BEGIN
    z_out <= a_input WHEN (sel = "000") ELSE
           b_input WHEN (sel = "001") ELSE
           c_input WHEN (sel = "010") ELSE
           d_input WHEN (sel = "011") ELSE
           e_input WHEN (sel = "100") ELSE
           'X';
  END beh;
```

When synthesized, we get:

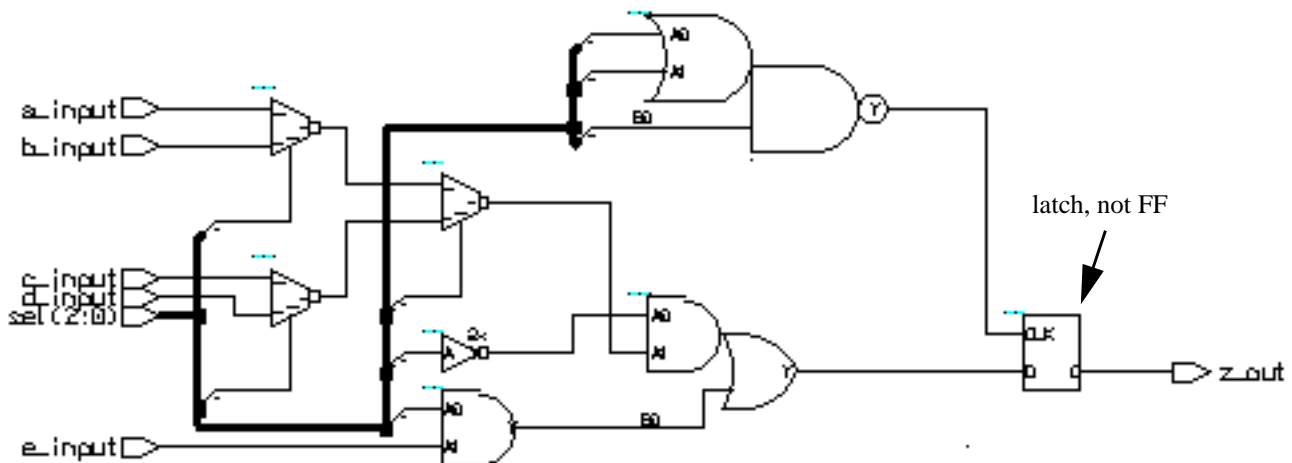


Conditional Concurrent Signal Assignment

Now let's incompletely specify the choices.

```
ARCHITECTURE noelse OF mux5_1_1wide IS
BEGIN
    z_out <= a_input WHEN (sel = "000") ELSE
           b_input WHEN (sel = "001") ELSE
           c_input WHEN (sel = "010") ELSE
           d_input WHEN (sel = "011") ELSE
           e_input WHEN (sel = "100"); -- no ending else
END beh;
```

When synthesized:



What happened?

- How does a transparent latch operate?
- What is the truth table for the decoder to the latch "clk" pin?

<u>sel(2:0)</u>	<u>latch enable pin</u>	<u>behavior</u>
000	1	latch is transparent
001	1	ditto
010	1	ditto
011	1	ditto
100	1	ditto
101	0	latch is in "hold" state
110	0	hold state
111	0	hold state

Selected Concurrent Signal Assignment

The selected concurrent signal assignment statement is modeled after the “case statement” in software programming languages.

The general form of this statement:

```
WITH discriminant SELECT
  target_signal <= value1 WHEN choice1,
                    value2 WHEN choice2,
                    value3 WHEN choice3,
                    . . . . .
                    valueN WHEN choiceN;
[default_value WHEN OTHERS];
```

This statement executes when any the discriminant, value or choice expressions changes value. When it does execute, the choice clauses are evaluated. The target signal is assigned the value corresponding to the choice that matches the discriminant.

Important points for this statement:

- The discriminant must have finite discrete values. (can be enumerated).
ERROR: Expression must return a discrete value.
- You must use or list all possible values for “choice”.
ERROR: Case statement only covers 5 out of 729 cases.
- Only one of the choices can match the discriminant.
ERROR: Case choice has already been specified on line 32

About “OTHERS”

The keyword **OTHERS** can be powerfully used in many situations. In general it is used to allow matching to an unspecified number of possible values of a variable. There ay be only one alternative that uses the others choice and if included in a list, it must be the last choice. In essence, it says, if a match has not yet been found and the value of the variable is within range of its type, then match with **OTHERS**.

We will see several other uses of **OTHERS** in the future.

Selected Concurrent Signal Assignment

An example from “SPAM”

```
-----  
--2:1 mux, 16 bits wide  
-----  
LIBRARY ieee;  
USE ieee.std_logic_1164.ALL;  
  
ENTITY mux2_1_16wide IS  
  PORT(  
    in_a    : IN  STD_LOGIC_VECTOR(15 DOWNTO 0);  --input a  
    in_b    : IN  STD_LOGIC_VECTOR(15 DOWNTO 0);  --input b  
    sel     : IN  STD_LOGIC;                       --select input  
    output  : OUT STD_LOGIC_VECTOR(15 DOWNTO 0)   --data output  
  );  
  END mux2_1_16wide;  
  
ARCHITECTURE beh OF mux2_1_16wide IS  
  BEGIN  
    WITH sel SELECT  
      output <= in_a WHEN '0',  
              in_b  WHEN '1',  
              (OTHERS => 'X') WHEN OTHERS;  
  END beh;
```

OTHERS again

Here we see **OTHERS** used to match cases where sel is not ‘1’ or ‘0’ in the **WHEN OTHERS** clause. i.e.:

```
(OTHERS => 'X') WHEN OTHERS;
```

OTHERS is also used to provide a shorthand method of saying, “make all the bits of the target signal ‘X’ for however many bits are in target signal.

```
(OTHERS => 'X') WHEN OTHERS;
```

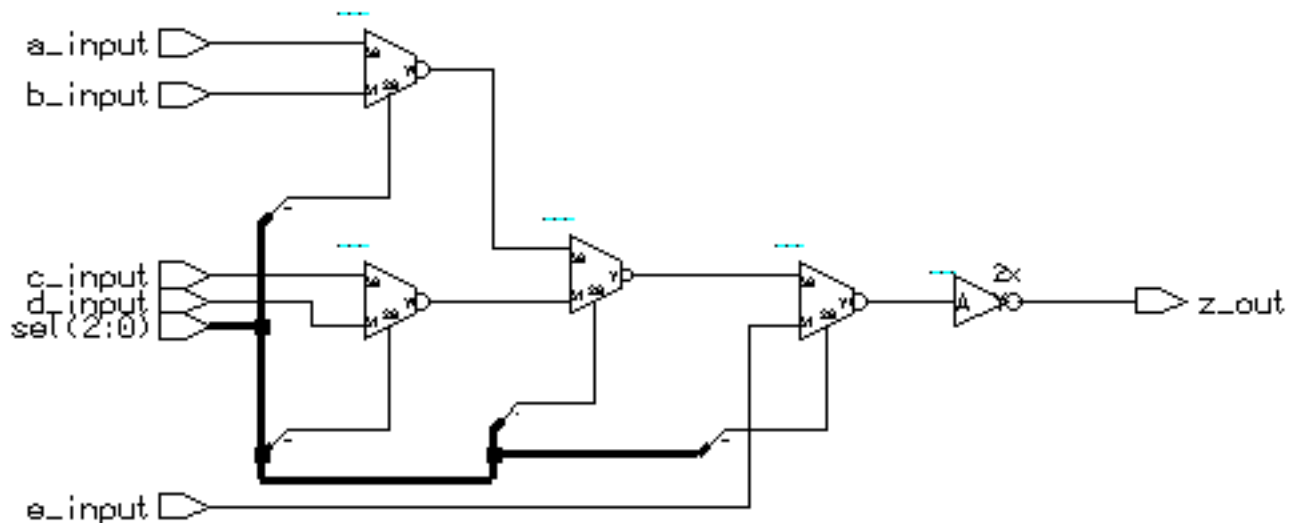
Why was ‘X’ assigned to output when sel was neither ‘0’ or ‘1’?

Selected Concurrent Signal Assignment

A more simple example with synthesis results.

```
--5:1 mux, 1 bit wide
LIBRARY ieee;
USE ieee.std_logic_1164.ALL;

ENTITY mux5_1_1wide IS
  PORT(
    a_input    : IN STD_LOGIC;  --input a
    b_input    : IN STD_LOGIC;  --input b
    c_input    : IN STD_LOGIC;  --input c
    d_input    : IN STD_LOGIC;  --input d
    e_input    : IN STD_LOGIC;  --input e
    sel        : IN STD_LOGIC_VECTOR(2 DOWNTO 0);  --sel input
    z_out      : OUT STD_LOGIC  --data out
  );
END mux5_1_1wide;
ARCHITECTURE beh OF mux5_1_1wide IS
  BEGIN
    WITH sel SELECT
      z_out <= a_input WHEN "000",
              b_input WHEN "001",
              c_input WHEN "010",
              d_input WHEN "011",
              e_input WHEN "100",
              'X' WHEN OTHERS; --if sel could be be 110, 111? correct?
  END beh;
```



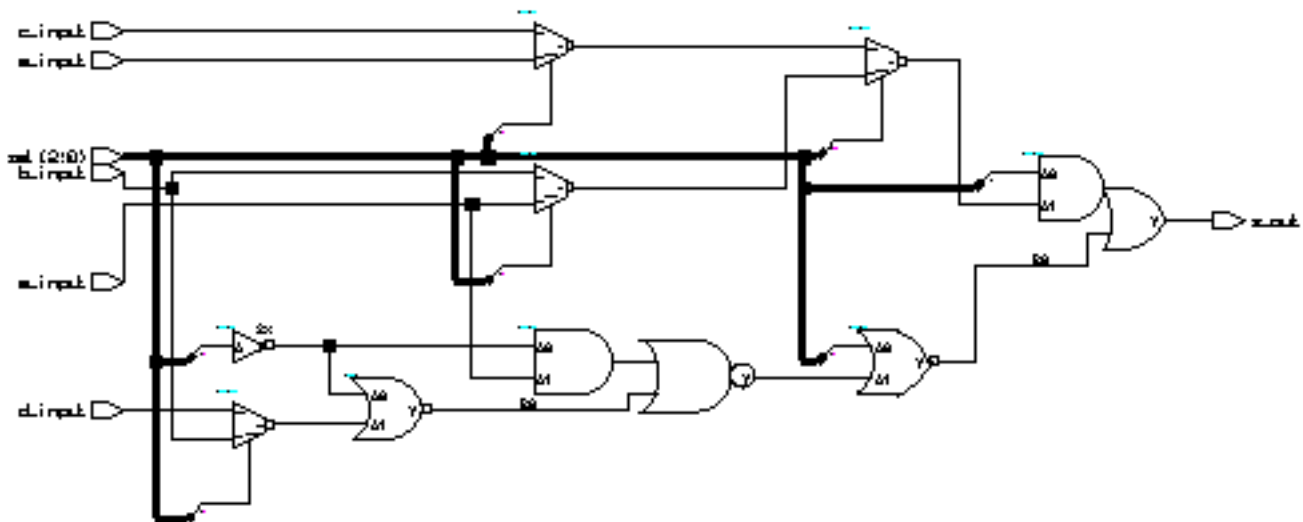
How will this circuit react to sel(2:0) values greater than “100”?

Making Choices

When we want the same target signal assignment to happen for several discriminant choices how do we specify it? Lets alter the function of our mux example as follows. The entity declaration is identical to before.

```
ARCHITECTURE beh OF mux5_1_1wide IS
  BEGIN
    WITH sel SELECT
      z_out <= a_input WHEN "000" | "001" | "111",
              b_input WHEN "011" | "101",
              c_input WHEN "010",
              d_input WHEN "100",
              e_input WHEN "110",
              'X' WHEN OTHERS;
  END beh;
```

The signal z_out gets the value of a_input when sel is equal to “000”, “001” or “111”. Signal z_out gets the value of b_input when sel is equal to “011” or “101”. The synthesized version of this mux looks like this:



As you can see, once a model is synthesized it can be hard to figure out how it works.

Concurrent Statements - Component Instantiation

Another concurrent statement is known as *component instantiation*. Component instantiation can be used to connect circuit elements at a very low level or most frequently at the top level of a design.

VHDL written in this form is known as *Structural VHDL*.

The instantiation statement connects a declared component to signals in the architecture.

The instantiation has 3 key parts:

- *Label* - Identifies unique instance of component
- *Component Type* - Select the desired declared component
- *Port Map* - Connect component to signals in the architecture

Example:

```
u1 : reg1 PORT MAP(d=>d0, clk=>clk, q=>q0);
```

↑
label

↑
component type

the pin "clk" on reg1

↑ ↑
wire that pin "clock" is connected to

When instantiating components:

- Local and actual must be of same data type.
- Local and actual must be of compatible modes.

Locally declared signals do not have an associated mode and can connect to a local port of any mode.

Labels

Labels are used to provide internal documentation.

May be used with:

- **Concurrent Assertion Statements**
- **Concurrent Signal Assignments**
- **Process Statements**
- **Loop Statements**
- **Generate Statements**

Must be used with:

- **Component Instantiation Statements**

Component Instantiation

5:1 mux using component instantiation:

```
--5:1 mux, 1 bit wide
LIBRARY ieee;
USE ieee.std_logic_1164.ALL;

LIBRARY adk;
USE adk.all;

ENTITY mux5_1_1wide IS
    PORT(
        a_input    : IN STD_LOGIC;  --input a
        b_input    : IN STD_LOGIC;  --input b
        c_input    : IN STD_LOGIC;  --input c
        d_input    : IN STD_LOGIC;  --input d
        e_input    : IN STD_LOGIC;  --input e
        sel        : IN STD_LOGIC_VECTOR(2 DOWNTO 0);  --sel input
        z_out      : OUT STD_LOGIC  --data out
    );
END mux5_1_1wide;
ARCHITECTURE beh OF mux5_1_1wide IS

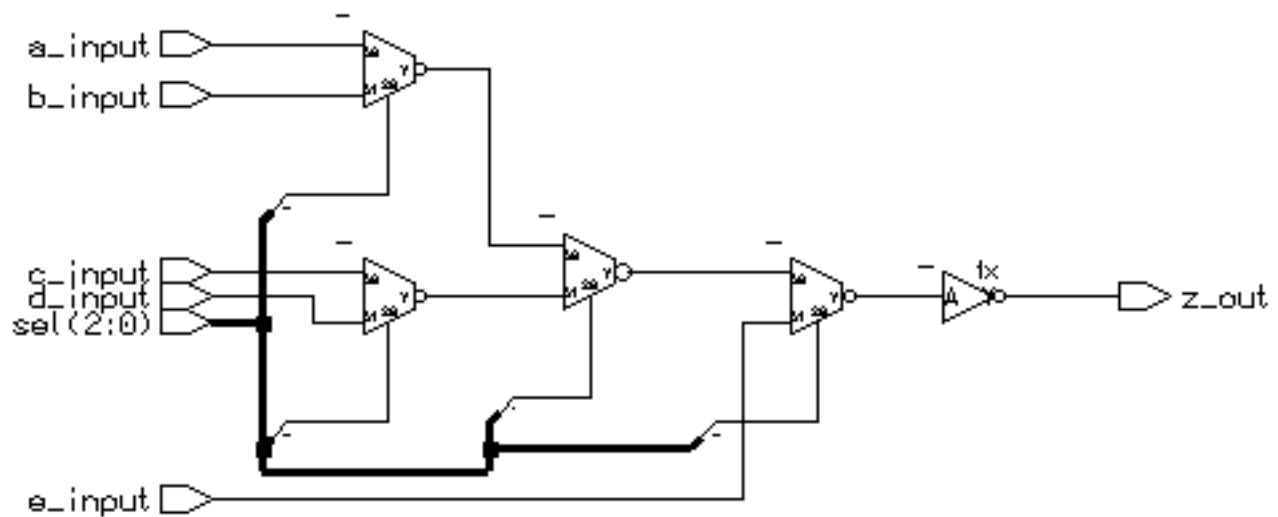
    SIGNAL temp0, temp1, temp2, temp3 : STD_LOGIC;

    COMPONENT mux21 PORT( a0,a1,s0 : IN  STD_LOGIC;
                        y : OUT STD_LOGIC);  END COMPONENT;
    COMPONENT inv01 PORT( a : IN  STD_LOGIC;
                        y : OUT STD_LOGIC);  END COMPONENT;

    BEGIN
    U1 : mux21 PORT MAP(a0 => a_input,
                      a1 => b_input,
                      s0 => sel(0),
                      y => temp0);
    U2 : mux21 PORT MAP(a0 => c_input,
                      a1 => d_input,
                      s0 => sel(0),
                      y => temp1);
    U3 : mux21 PORT MAP(a0 => temp0,
                      a1 => temp1,
                      s0 => sel(1),
                      y => temp2);
    U4 : mux21 PORT MAP(a0 => temp2,
                      a1 => e_input,
                      s0 => sel(2),
                      y => temp3);
    U5 : inv01  PORT MAP(a  => temp3,
                      y   => z_out);
    END beh;
```

The synthesized structural 5:1 mux

The synthesized mux is a faithful representation of our structural VHDL. (it better be!) Actually the synthesis tools “hands” are tied. The structural VHDL told exactly how the components were to be wired. It also specified exactly what logic cells were to be used. The synthesis tool actually had nothing to do except make the edif netlist and schematic.



Component Instantiation (cont.)

A few notes about the structural 5:1 mux code:

The logic cells used here were in a library called *adk*. To access these cells the declaration of this library was necessary at the top of the file.

```
LIBRARY adk;  
USE adk.all;
```

Before we can use the cells in an instantiation statement, we must declare them. This is seen in the statements:

```
COMPONENT mux21 PORT( a0,a1,s0 : IN  STD_LOGIC;  
                      y      : OUT STD_LOGIC);  END COMPONENT;  
COMPONENT inv01 PORT( a : IN  STD_LOGIC;  
                      y : OUT STD_LOGIC);  END COMPONENT;
```

To wire the mux21 cells together, temporary signals, *temp0*, *temp1*, *temp2* and *temp3* were declared.

```
SIGNAL temp0, temp1, temp2, temp3 : STD_LOGIC;
```

Finally, the component instantiations stitch the design together.

```
U1 : mux21 PORT MAP(a0 => a_input,  
                   a1 => b_input,  
                   s0 => sel(0),  
                   y  => temp0);
```

The PORT MAP statement describes the connections between pins of the cell and the signals. The connections are described by the format:

```
pin_on_module => signal_name,
```

The first name is the module pin name, the second is the name of the signal the pin is to be connected to. This format is called *named association*.

With named association, the order of associations is not required to be in the same order as port declaration in the component.

Named vs. Positional Association

As previously mentioned, pin/signal pairs used with a PORT MAP may be associated by position. For example,

```
U1 : mux21 PORT MAP(a_input,b_input,sel(0),temp0);
```

This form is not preferred because any change in the port list (it often happens in the design phase) will be difficult to incorporate. Try doing it for entities with 50 or more signals and you'll begin to appreciate the point.

For example, some real code.....

Sample PORT MAP (w/named association)

```
dramfifo_0: dramfifo
PORT MAP(
    reg_data          => reg_data          ,
    dram_state_ps     => dram_state_ps     ,
    dram_cnt_ps       => dram_cnt_ps       ,
    dram_cycle_type   => dram_cycle_type   ,
    addr_adv          => addr_adv          ,
    line_shift        => line_shift        ,
    cycle_start       => cycle_start       ,
    done              => done              ,
    any_rdgnt         => any_rdgnt         ,
    any_wrgnt         => any_wrgnt         ,
    test_mode         => test_mode         ,
    scl_ratio_ack     => scl_ratio_ack     ,
    y_wrptrlo_wen    => y_wrptrlo_wen    ,
    y_wrptrhi_wen    => y_wrptrhi_wen    ,
    u_wrptrlo_wen    => u_wrptrlo_wen    ,
    u_wrptrhi_wen    => u_wrptrhi_wen    ,
    v_wrptrlo_wen    => v_wrptrlo_wen    ,
    v_wrptrhi_wen    => v_wrptrhi_wen    ,
    wrcntrlo_wen     => wrcntrlo_wen     ,
    wrcntrhi_wen     => wrcntrhi_wen     ,
    y_rdptrlo_wen    => y_rdptrlo_wen    ,
    y_rdptrhi_wen    => y_rdptrhi_wen    ,
    u_rdptrlo_wen    => u_rdptrlo_wen    ,
    u_rdptrhi_wen    => u_rdptrhi_wen    ,
    v_rdptrlo_wen    => v_rdptrlo_wen    ,
    v_rdptrhi_wen    => v_rdptrhi_wen    ,
    rdcntrlo_wen     => rdcntrlo_wen     ,
    rdcntrhi_wen     => rdcntrhi_wen     ,
    yeol_cntr_wen    => yeol_cntr_wen    ,
    ueol_cntr_wen    => ueol_cntr_wen    ,
    veol_cntr_wen    => veol_cntr_wen    ,
    line_length_wen  => line_length_wen  ,
    ptr_rollbit_wen  => ptr_rollbit_wen  ,
    clk_24            => clk_24            ,
    clk_48            => clk_48            ,
    rst_24            => rst_24            ,
    rst_48            => rst_48            ,
    s_capt_en        => s_capt_en        ,
    vsync             => vsync             ,
    even_fld         => even_fld         ,
    qual_hsync       => qual_hsync       ,
    sr_sel           => sr_sel           ,
    current_sr       => current_sr       ,
    allow_rdreq      => allow_rdreq      ,
    allow_wrreq      => allow_wrreq      ,
    wr_addr          => wr_addr          ,
    rd_addr          => rd_addr          ,
    last_line_segment => last_line_segment ,
    start_of_video   => start_of_video   ,
    end_of_video     => end_of_video     ,
    line_length_rback => line_length_rback ,
    dcu_status       => dcu_status);
```

Same PORT MAP (w/positional association)

```
-- dram fifo address control
dramfifo_0: dramfifo
PORT MAP(reg_data, dram_state_ps, dram_cnt_ps, dram_cycle_type,
addr_adv, line_shift, cycle_start, done, any_rdgnt, any_wrgnt,
test_mode, scl_ratio_ack, y_wrpctrl_lo_wen, y_wrpctrl_hi_wen, u_wrpctrl_lo_wen,
u_wrpctrl_hi_wen, v_wrpctrl_lo_wen, v_wrpctrl_hi_wen, wrctr_lo_wen,
wrctr_hi_wen, y_rdpctrl_lo_wen, y_rdpctrl_hi_wen, u_rdpctrl_lo_wen,
u_rdpctrl_hi_wen, v_rdpctrl_lo_wen, v_rdpctrl_hi_wen, rdctr_lo_wen,
rdctr_hi_wen, yeol_cntrl_wen, ueol_cntrl_wen, veol_cntrl_wen,
line_length_wen, ptr_rollbit_wen, clk_24, clk_48, rst_24, rst_48,
s_capt_en, vsync, even_fld, qual_hsync, sr_sel, current_sr,
allow_rdreq, allow_wrreq, wr_addr, rd_addr, last_line_segment,
start_of_video, end_of_video, line_length_rback, dcu_status);
```

Now, let's say you need to add an extra signal in the module *dramfifo*. You want to put it just after *ueol_cntrl_wen*. But let's say your signals do not necessarily have the same names as the pins. This means you would have to manually count through the list of signals to find out where to put the new one in the port map in exactly the same order. How would you know for sure it's in the right position? Count through the list again! Do you have time to do this?

The Moral of the Story: Use named association.

Association lists - Some last items...

Suppose you have a module that is a four to one mux, but you only need three inputs. What do you do with the unused input? What about unused outputs?

If the module you are instantiating has a defined *default port value*, the keyword **OPEN** can be used to allow the input to be assigned the default port value. Thus the entity for a 4:1 mux with a defined default port value would look like this:

```
ENTITY mux41 IS
  PORT(
    a0    : IN STD_LOGIC := '0'; --input a0 can be left OPEN
    a1    : IN STD_LOGIC := '0'; --input a1 can be left OPEN
    a2    : IN STD_LOGIC := '0'; --input a2 can be left OPEN
    a3    : IN STD_LOGIC := '0'; --input a3 can be left OPEN
    sel   : IN STD_LOGIC_VECTOR(1 DOWNTO 0); --sel input
    z_out : OUT STD_LOGIC --data out
  );
END mux21;
```

The initialization expression “:= ‘0’” in the port declaration states that the input signals *a_input*, *b_input*, *c_input* and *d_input* will take on the default value ‘0’ if they are left unconnected by a component instantiation.

Thus we could instantiate the 4:1 mux as follows:

```
U1 : mux41 PORT MAP(a0    => a_input,
                    a1    => b_input,
                    a2    => c_input,
                    a3    => OPEN, --a3 is assigned the value '0'
                    sel   => sel_input),
                    z_out => data_out);
```

Unconnected output ports are also designated by using the keyword **OPEN**. However, the associated design entity does not have to supply a default port value. Here is an adder with a unused carry output.

```
U17 : adder PORT MAP(a_in    => a_data,
                    b_in    => b_data,
                    sum     => output,
                    carry_out => OPEN);
```


Association lists - Some last items...

What about inputs to a module that are tied constantly high or low?

As usual with VHDL there are several solutions.

```
--four to one mux with one input tied low
logic_zero <= '0'; --a ground signal
U1 : mux41 PORT MAP(a0 => a_input,
                   a1 => b_input,
                   a2 => c_input,
                   a3 => logic_zero,
                   sel => select,
                   y  => temp0);
```

This is a little cleaner:

```
--four to one mux with one input tied low
logic_zero <= '0'; --a ground signal
U1 : mux41 PORT MAP(a0 => a_input,
                   a1 => b_input,
                   a2 => c_input,
                   a3 => '0',
                   sel => select,
                   y  => temp0);
```

However, you cannot do this:

```
--four to one mux with one input tied low
U1 : mux41 PORT MAP(a0 => a_input,
                   a1 => b_input,
                   a2 => c_input,
                   a3 => (a_input AND c_input),
                   sel => select,
                   y  => temp0);
```

The expressions supplied as connections to the module or cell pins must be constant values only.