

Signals & Variables

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Concurrent Statement

- Block Statement
- **Process Statement**
- Component Statement
- Generate Statement
- **Concurrent Signal Assignment**
- Concurrent Assertion
- Concurrent Procedure Call

- **Architecture Body**
- **Block Statement**
- **Generate Statement**

- **Conditional Signal Assignment**
- **Selected Signal Assignemnt**

Sequential Statement

- Wait Statement
- Assertion Statement
- Report Statement
- Generate Statement
- Signal Assignment
- Variable Assignment
- Procedure Call
- If
- Case
- Loop
- Next
- Exit
- Return
- Null

- **Case Statement**
- **If Statement**
- **Loop Statement**
- **Process Statement**
- **Subprogram Body**

- Sequential Signal Assignment

- Conditional Signal Assignment
- Selected Signal Assignment

X

Conditional Signal Assignment

```
Z <= A or B [ after 1 ns ] when S0 = '1' else  
      A or C [ after 2 ns ] when S1 = '1' else  
      A or D [ after 3 ns ] ;
```

```
Z <= A or B [ after 1 ns ] when S0 = '1' else  
      A or C [ after 2 ns ] ;
```

```
Z <= A or B [ after 1 ns ] when S0 = '1' ;
```

```
Z <= A or B [ after 1 ns ] ;
```

← *simple concurrent statement*

- Concurrent Signal Assignment

- Conditional Signal Assignment
- Selected Signal Assignment

Selected Signal Assignment

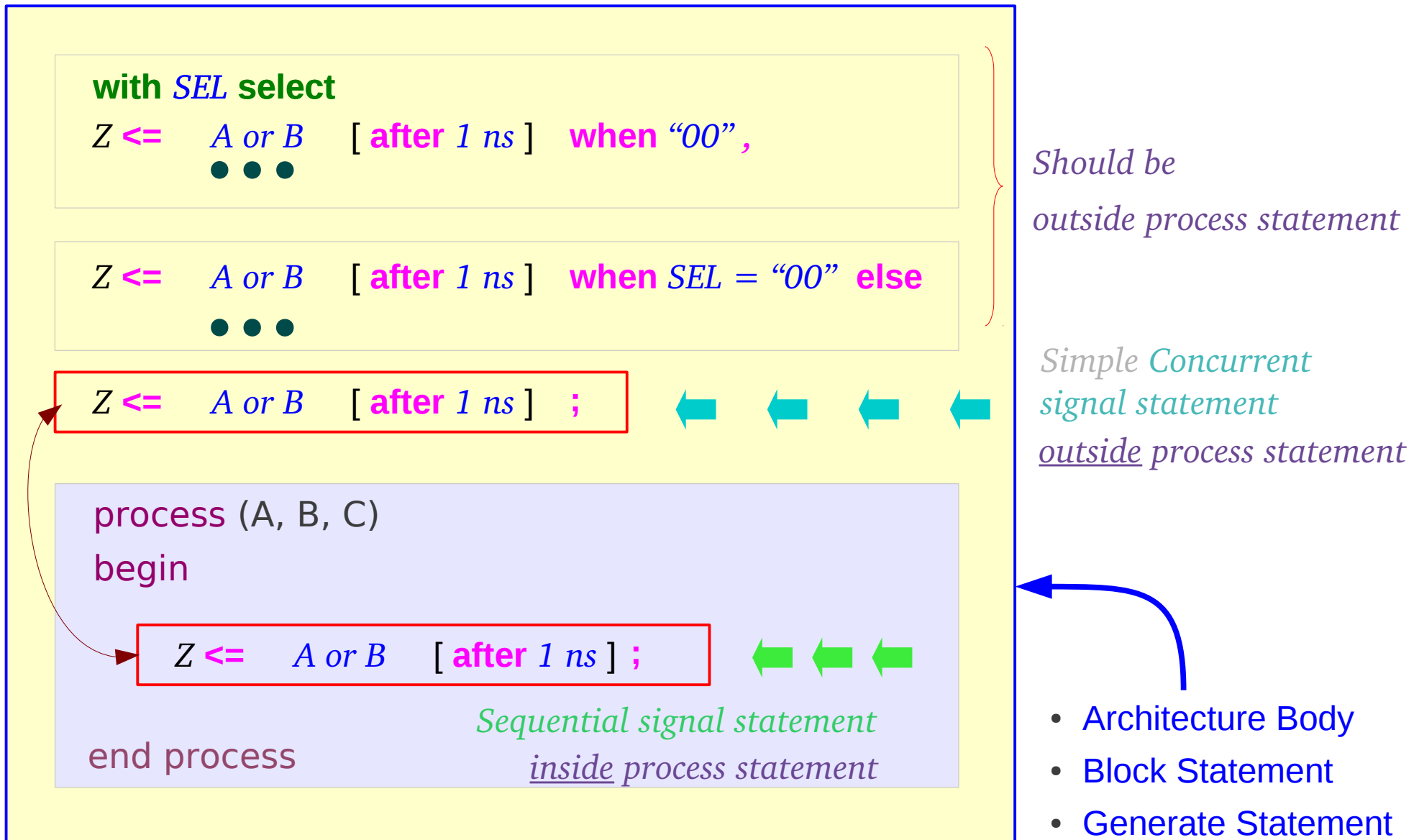
- Conditional Signal Assignment

```
Z <=  A or B  [ after 1 ns ]  when SEL = "00" else
      A or C  [ after 2 ns ]  when SEL = "01" else
      A or D  [ after 2 ns ]  when SEL = "10" else
      A or E  [ after 3 ns ]  when SEL = "11" else
      A or F  [ after 4 ns ]  ;
```

- Selected Signal Assignment

```
with SEL select
Z <=  A or B  [ after 1 ns ]  when "00",
      A or C  [ after 2 ns ]  when "01",
      A or D  [ after 3 ns ]  when "10",
      A or E  [ after 4 ns ]  when "11",
      A or F  [ after 5 ns ]  when others;
```

Concurrent vs Sequential



Order of Statements

```
architecture arch of entity ent is  
    ...  
begin
```

```
X1 <= A or B ;
```

```
Y1 <= C or D ;
```

```
Z1 <= E or F ;
```

```
process (A, B, C, D, E, F)
```

```
begin
```

```
X2 <= A or B ;
```

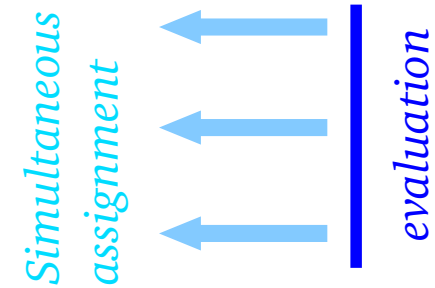
```
Y2 <= C or D ;
```

```
Z2 <= E or F ;
```

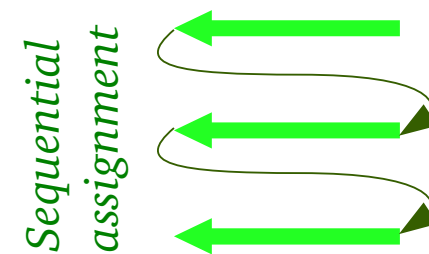
```
end process;
```

```
end
```

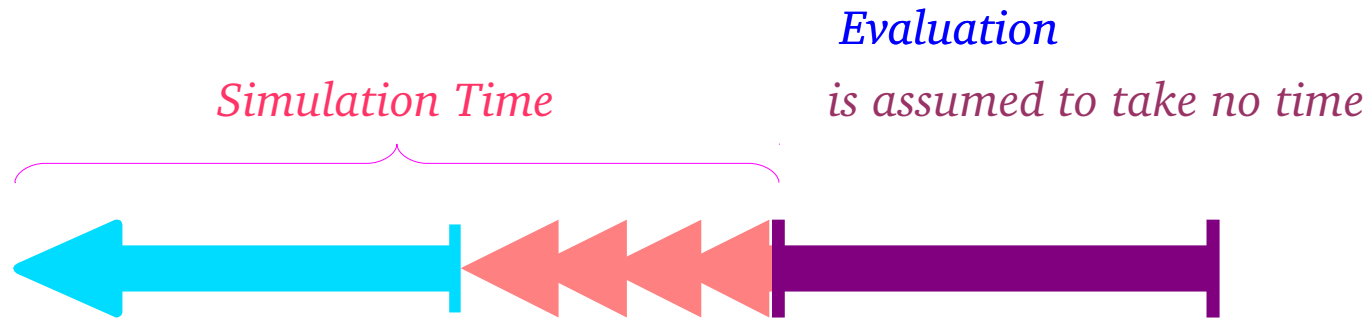
Simulation of parallel activities



The order of statements is important



Simulation Time



Unit: *ms, ns, ps, ...*

Unitless Delta Δ

Real Delay

– used for a simulator to
mimic parallel activities
simulator

$$1 \text{ ms} = 1000 \text{ ns}$$

$$1 \text{ ns} = 1000 \text{ ps}$$

$$1 \text{ ps} \neq n \cdot \Delta$$

*no integer n that make n delta
equal to 1 ps.*

$$n \cdot \Delta = 0 \text{ ps} = 0 \text{ ns} \dots$$

Zero Delay

Zero Delay Assignment

```
X1 <= A or B ;
```

```
X1 <= A or B after 0 ns;
```

Zero Delay Assignment

```
architecture arch of entity ent is
  ...
begin
```

```
X1 <= A or B ;
Y1 <= C or D ;
Z1 <= E or F ;
```

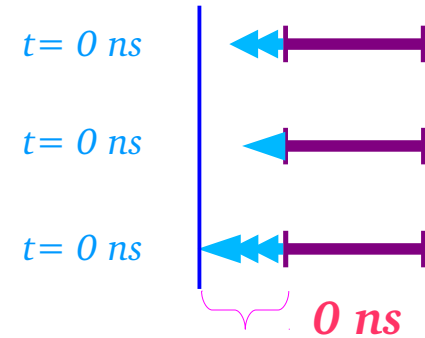
```
process (A, B, C, D, E, F)
begin
```

```
X2 <= A or B ;
Y2 <= C or D ;
Z2 <= E or F ;
```

```
end process;
```

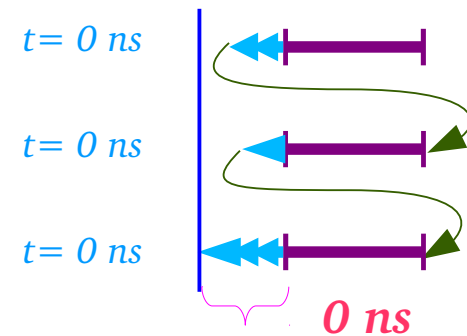
```
end
```

Δ time Evaluation



The exact no of delta is determined by the simulator and the context

Δ time Evaluation



Updated values

Non-Zero Delay Assignment

architecture *arch* of entity *ent* is

begin

X1 ← A or B after 1 ns;

Y1 ← C or D after 3 ns;

Z1 ← E or F after 2 ns;

process (A, B, C, D, E, F)

begin

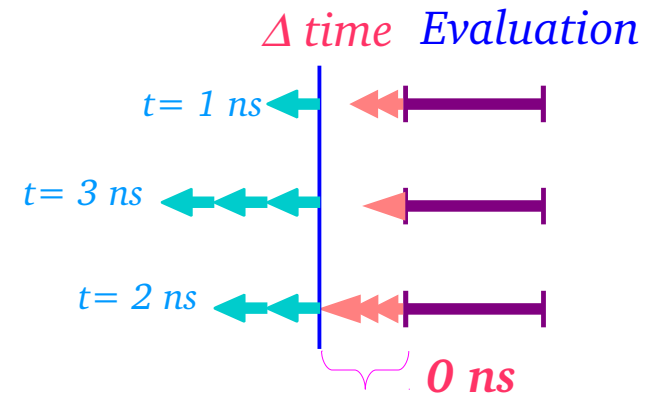
X2 ← A or B after 1 ns;

Y2 ← C or D after 3 ns;

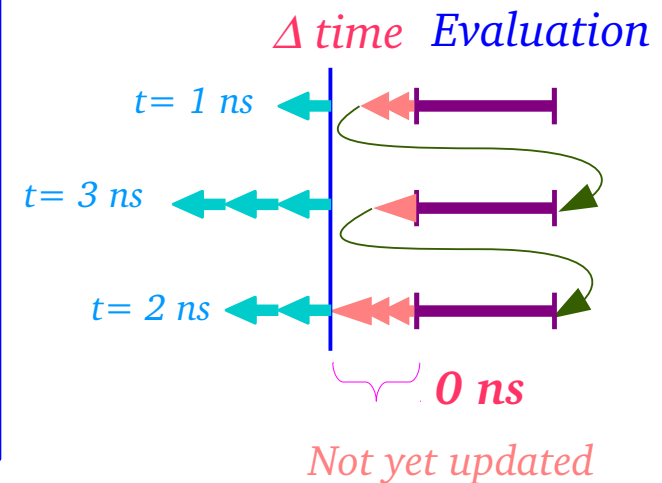
Z2 ← E or F after 2 ns;

end process;

end

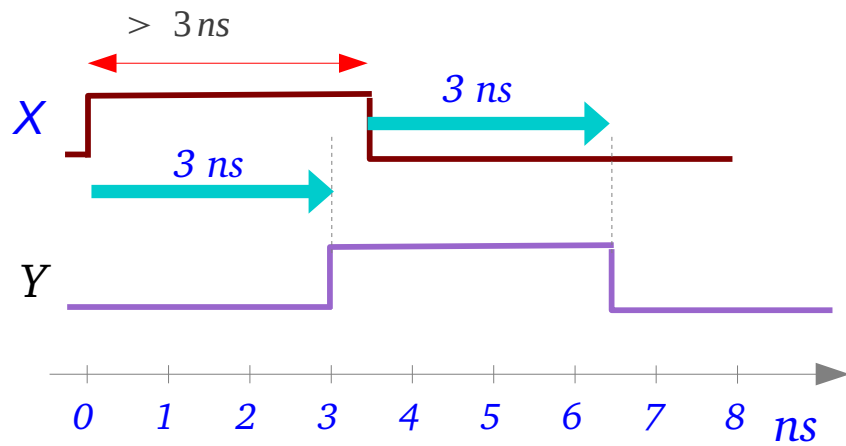


The exact no of delta is determined by the simulator and the context

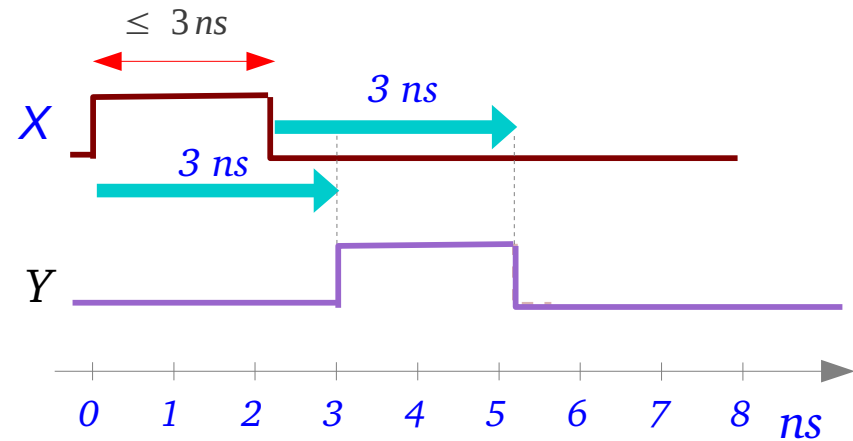
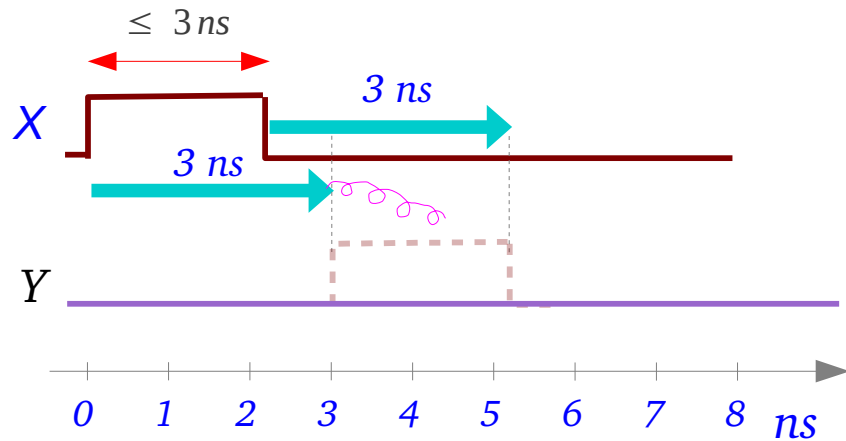
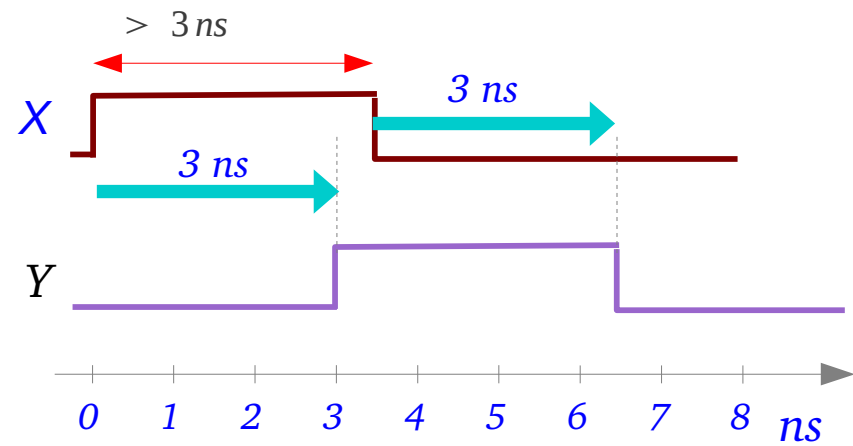


Inertial Delay & Transport Delay

```
Y <= X after 3 ns;
```



```
Y <= transport X after 3 ns;
```



Variable Assignment (1)

```
architecture arch of entity ent is
```

•••

```
begin
```

```
  X1 <= A or B after 1 ns;
```

```
  Y1 <= C or D after 3 ns;
```

```
  Z1 := E or F ;
```

```
  process (A, B, C, D, E, F)
```

```
    variable Y2, Z2 : bit;
```

```
  begin
```

```
    X2 <= A or B after 1 ns;
```

```
    Y2 := C or D after 3 ns;
```

```
    Z2 := E or F ;
```

```
  end process;
```

```
end
```

The Variable assignment is a sequential statement and cannot be used outside a process statement.

The variable is **declared** here. They are used for **local storage** in process statement and subprogram body.

The variable assignment has nothing to do with time. It executes immediately. It can not have an **after** clause

Variable Assignment (2)

```
process (A, B, C, D, E, F)
```

```
variable Z2 : bit;
```

```
begin
```

```
X2 <= A or B after 1 ns;
```

```
Y2 <= C or D after 3 ns;
```

```
Z2 := E or F ;
```

```
end process;
```

```
process (A, B, C, D, E, F)
```

```
variable Y2 : bit;
```

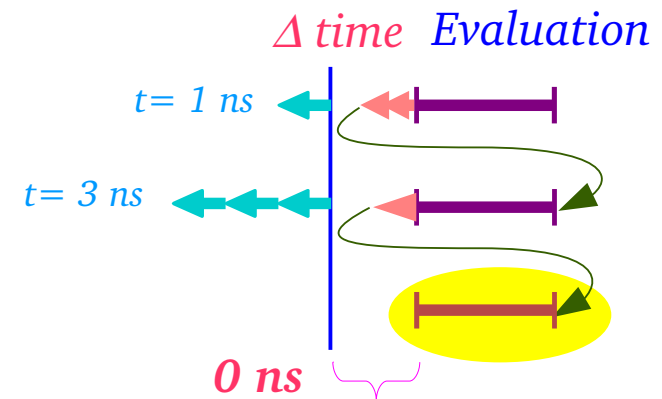
```
begin
```

```
X2 <= A or B after 1 ns;
```

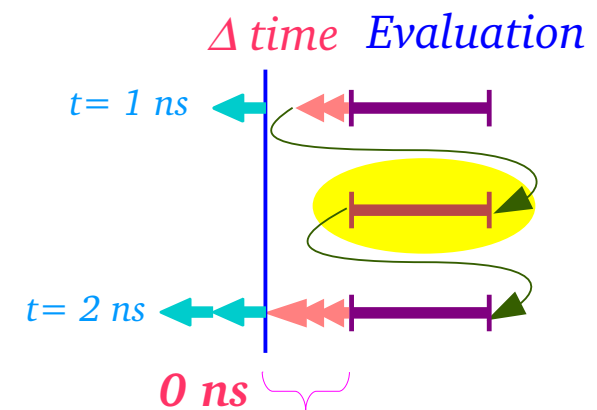
```
Y2 := C or D ;
```

```
Z2 <= E or F after 2 ns;
```

```
end process;
```



The variable assignment has nothing to do with time. It executes immediately.



Multiple Assignments to the Same Target

```
architecture arch of entity ent is
    ...
begin
    X1 <= A or B ;
    X1 <= C or D ;

    process (A, B, C, D, E, F)
        variable Z2 : bit;
    begin
        Y2 <= A or B ;
        Y2 <= C or D ;

        Z2 := A or B ;
        Z2 := C or D ;
    end process;
end
```

Multiple Concurrent Assignments

Multiple Concurrent Assignment is legal only when a resolution function is defined.

(wire-and, wire-or)

Multiple Sequential Assignments

- Overwrite
- Append
- Keep

Multiple Variable Assignments

Variable Z2 has the result of the latest assignments (The new assignment overwrites the old one)

Multiple Concurrent Assignments

```
architecture arch of entity ent is
  ...
begin
  X1 <= A or B ;
  X1 <= C or D ;

  process (A, B, C, D, E, F)
    variable Z2 : bit;
  begin
    Y2 <= A or B ;
    Y2 <= C or D ;

    Z2 := A or B ;
    Z2 := C or D ;
  end process;
end
```

Multiple Concurrent Assignments

Multiple Concurrent Assignment is legal only when a resolution function is defined.

(wire-and, wire-or)

Multiple Sequential Assignments

- Overwrite
- Append
- Keep

Multiple Variable Assignments

Variable Z2 has the result of the latest assignments (The new assignment overwrites the old one)

Resolution Function

architecture *arch* of entity *ent* is

```
FUNCTION w_and (drivers : bit_vector) RETURN bit is
```

```
BEGIN
```

```
    ...
```

```
END w_and;
```

```
SIGNAL X1 : w_and bit;
```

```
    ...
```

begin

```
X1 <= A or B ;
```

```
X1 <= C or D ;
```

```
process (A, B, C, D, E, F)
```

```
begin
```

```
    ...
```

```
end process;
```

end

Multiple Concurrent Assignment is legal only when a resolution function is defined.

(wire-and, wire-or)

X1 <= w_and(A or B, C or D) ;

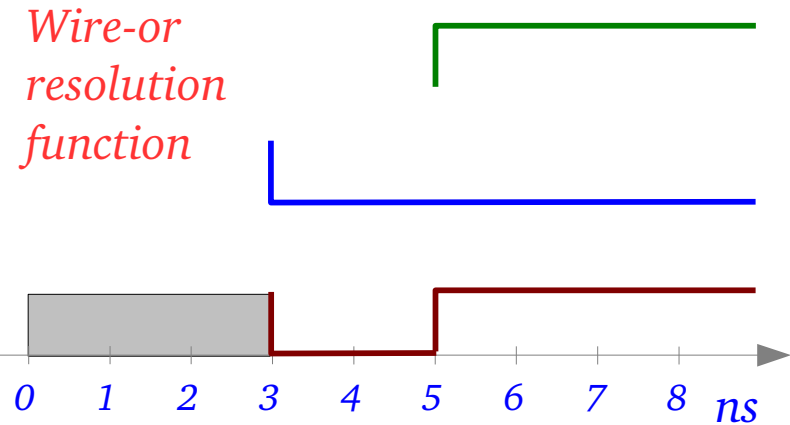


Inertial Delay

Multiple Concurrent Assignments

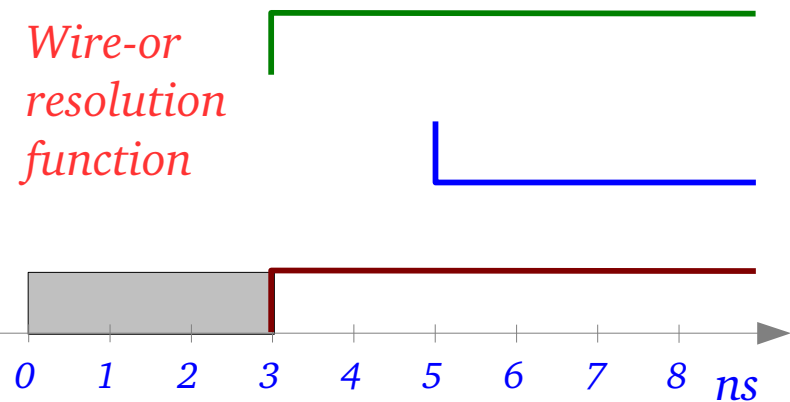
```
X2 <= '1' after 5 ns;  
X2 <= '0' after 3 ns;
```

```
process (...)  
begin  
  ...  
end process;
```



```
X2 <= '1' after 5 ns;  
X2 <= '0' after 3 ns;
```

```
process (...)  
begin  
  ...  
end process;
```

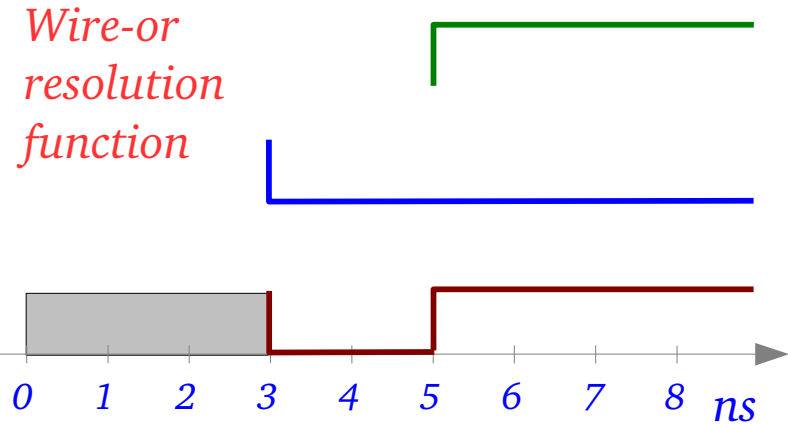


Transport Delay

Multiple Concurrent Assignments

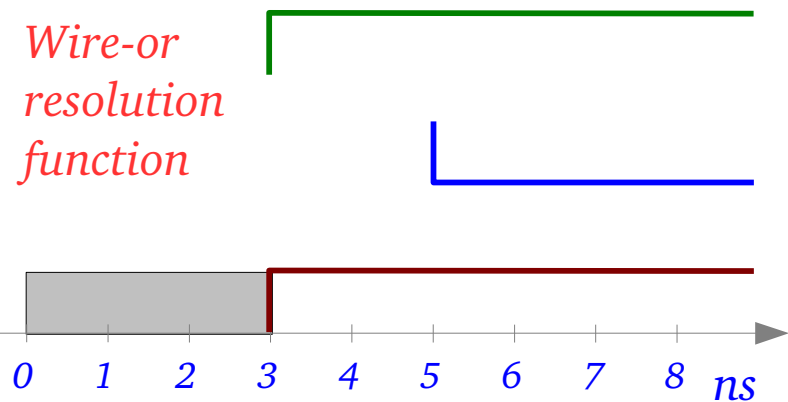
```
X2 <= transport '1' after 5 ns;  
X2 <= transport '0' after 3 ns;
```

```
process (...)  
begin  
  ...  
end process;
```



```
X2 <= transport '1' after 3 ns;  
X2 <= transport '0' after 5 ns;
```

```
process (...)  
begin  
  ...  
end process;
```



Multiple Sequential Assignments

```
architecture arch of entity ent is
    ...
begin
    X1 <= A or B ;
    X1 <= C or D ;

    process (A, B, C, D, E, F)
        variable Z2 : bit;
    begin
        Y2 <= A or B ;
        Y2 <= C or D ;

        Z2 := A or B ;
        Z2 := C or D ;
    end process;
end
```

Multiple Concurrent Assignments

Multiple Concurrent Assignment is legal only when a resolution function is defined.
(wire-and, wire-or)

Multiple Sequential Assignments

- Overwrite
- Append
- Keep

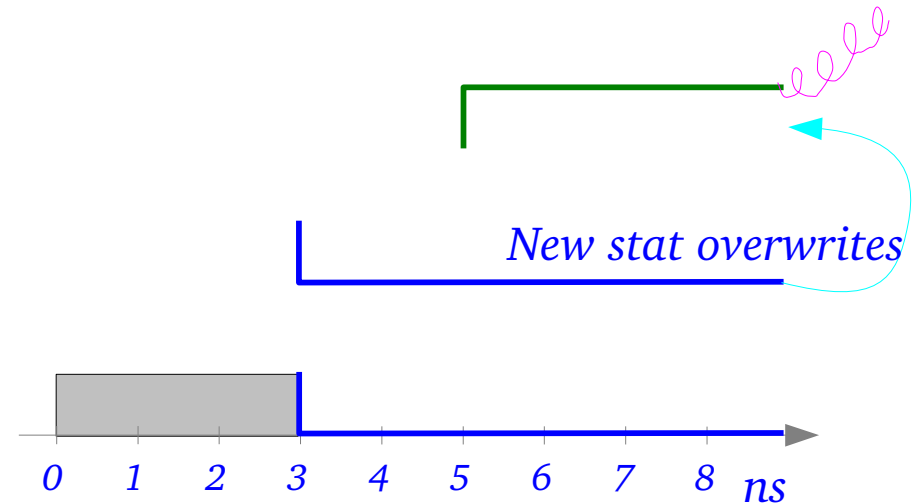
Multiple Variable Assignments

Variable Z2 has the result of the latest assignments (The new assignment overwrites the old one)

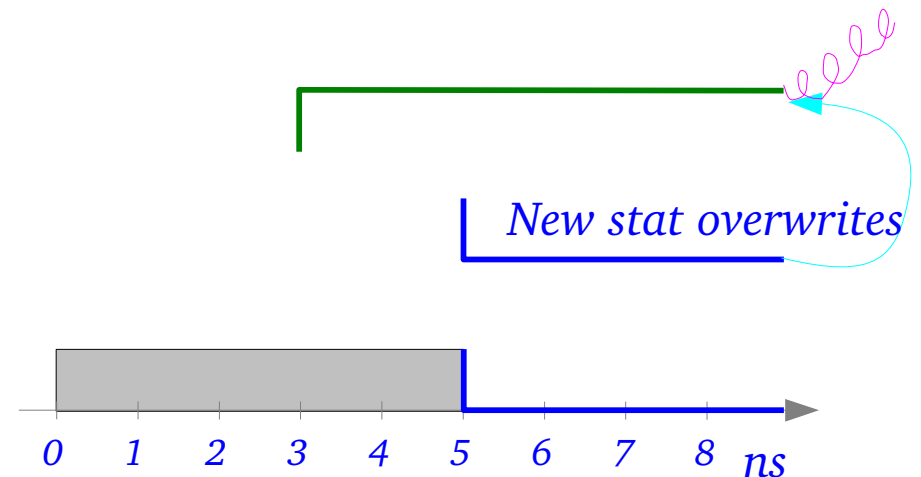
Inertial Delay (1)

Multiple Sequential Assignments

```
process (...)  
begin  
  
    X2 <= '1' after 5 ns;  
    X2 <= '0' after 3 ns;  
  
end process;
```



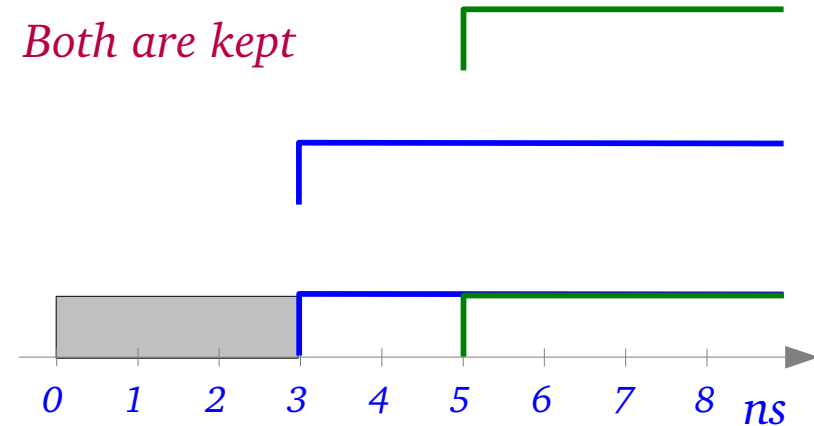
```
process (...)  
begin  
  
    X2 <= '1' after 3 ns;  
    X2 <= '0' after 5 ns;  
  
end process;
```



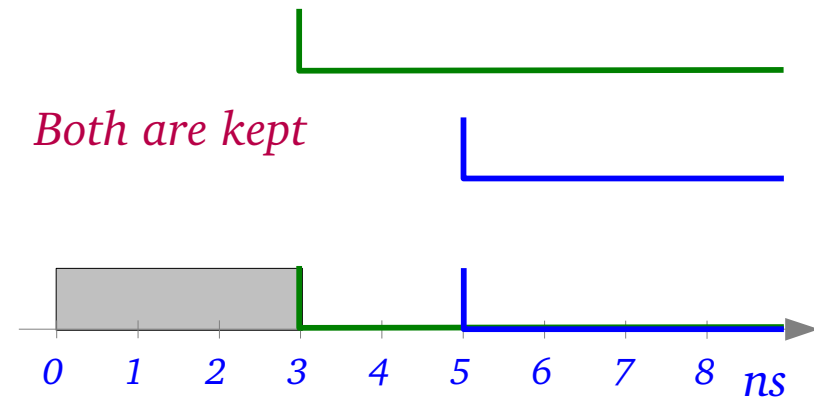
Inertial Delay (2)

Multiple Sequential Assignments

```
process (...)  
begin  
  
    X2 <= '1' after 5 ns;  
    X2 <= '1' after 3 ns;  
  
end process;
```



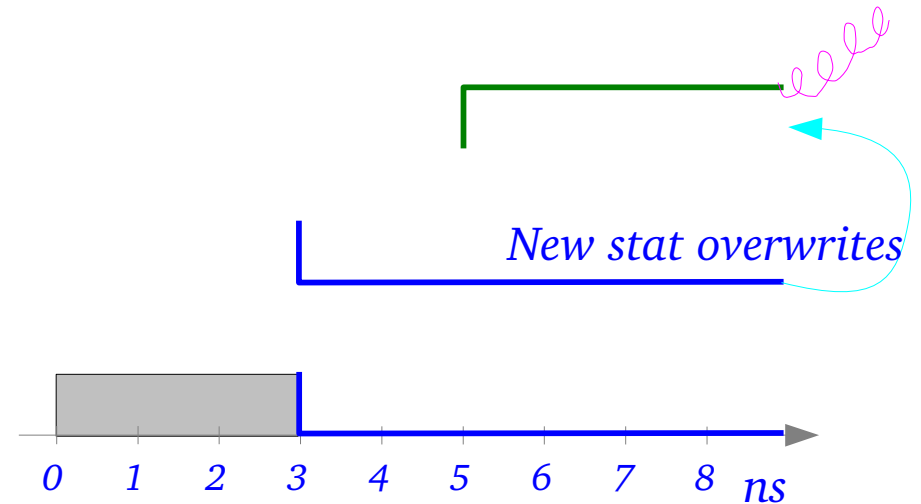
```
process (...)  
begin  
  
    X2 <= '0' after 3 ns;  
    X2 <= '0' after 5 ns;  
  
end process;
```



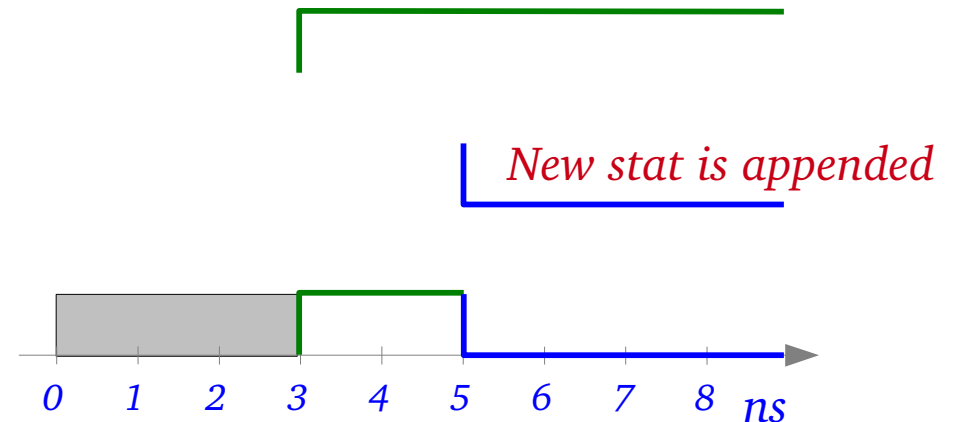
Transport Delay

Multiple Sequential Assignments

```
process (...)  
begin  
  
    X2 <= transport '1' after 5 ns;  
    X2 <= transport '0' after 3 ns;  
  
end process;
```



```
process (...)  
begin  
  
    X2 <= transport '1' after 3 ns;  
    X2 <= transport '0' after 5 ns;  
  
end process;
```



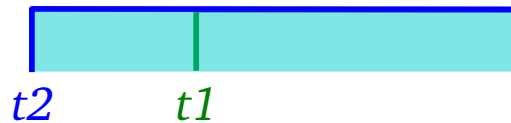
Inertial Delay

Multiple Sequential Assignments - Inertial Delay

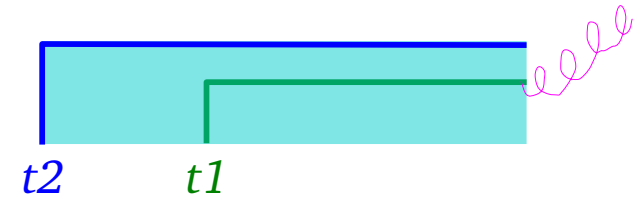
```
process (...)  
begin  
  
    X2 <= v1 after t1 ns;  
    X2 <= v2 after t2 ns;  
  
end process;
```

$t2 < t1$ $v2 = v1$ Both are kept
 $v2 \neq v1$ New stat overwrites

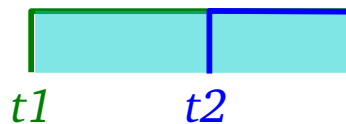
$t1 < t2$ $v1 = v2$ Both are kept
 $v1 \neq v2$ New stat overwrites



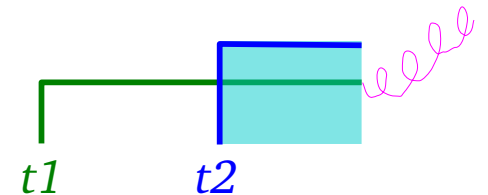
$t2 < t1$ Both are kept
 $v2 = v1$



$t2 < t1$ New stat overwrites
 $v2 \neq v1$



$t1 < t2$ Both are kept
 $v1 = v2$



$t1 < t2$ New stat overwrites
 $v1 \neq v2$

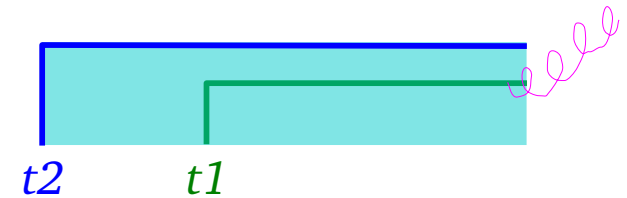
Transport Delay

Multiple Sequential Assignments - Transport Delay

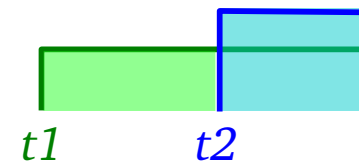
```
process (...)  
begin  
  
    X2 <= transport v1 after t1 ns;  
    X2 <= transport v2 after t2 ns;  
  
end process;
```

$t2 < t1$ *New stat overwrites*

$t1 < t2$ *New stat is appended*



$t2 < t1$ *New stat overwrites*



$t1 < t2$ *New stat is appended*

Signals & Variable Assignment Example 1

process (A, B, C)

variable V1, V2 : bit;

begin

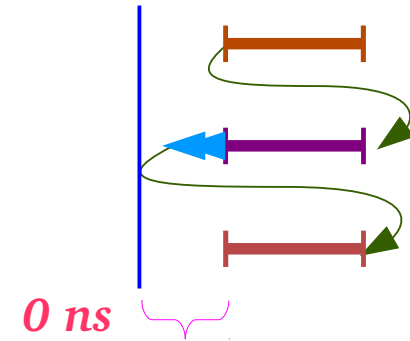
V1 \leftarrow A or B ;

Y1 \leftarrow V2 ;

V2 \leftarrow V1 or C ;

end process;

Δ time Evaluation



Y1 \leftarrow A or B ;

process (A, B, C)

variable V1, V2 : bit;

begin

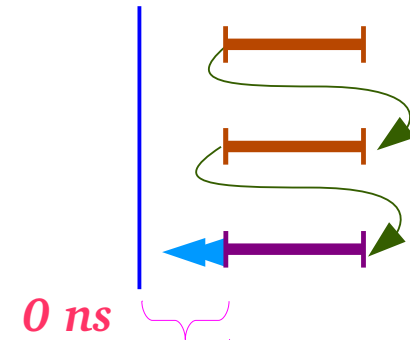
V1 \leftarrow A or B ;

V2 \leftarrow V1 or C ;

Y1 \leftarrow V2 ;

end process;

Δ time Evaluation



Y1 \leftarrow A or B or C ;

References

- [1] <http://en.wikipedia.org/>
- [2] J. V. Spiegel, VHDL Tutorial,
http://www.seas.upenn.edu/~ese171/vhdl/vhdl_primer.html
- [3] J. R. Armstrong, F. G. Gray, Structured Logic Design with VHDL
- [4] Z. Navabi, VHDL Analysis and Modeling of Digital Systems
- [5] D. Smith, HDL Chip Design
- [6] <http://www.csee.umbc.edu/portal/help/VHDL/stdpkg.html>
- [7] VHDL Tutorial - VHDL online www.vhdl-online.de/tutorial/