Concurrent Signal Assignment Statements (CSAs)

- Digital systems operate with concurrent signals

- Signals are assigned values at a specific point in time.

- VHDL uses **signal assignment** statements

  - Specify value and time
- Multiple **signal assignment** statements are executed concurrently
  - **C**oncurrent **S**ignal **A**ssignment Statements (**CSA**s)

Half-Adder CSA

- VHDL must specify:
  - Events
  - Delays
  - Concurrency

```
architecture concurrent_behavior of half_adder is
begin
sum <= (x xor y) after 5 ns;
carry <= (x and y) after 5 ns;
end concurrent_behavior;
```

CSA Statements

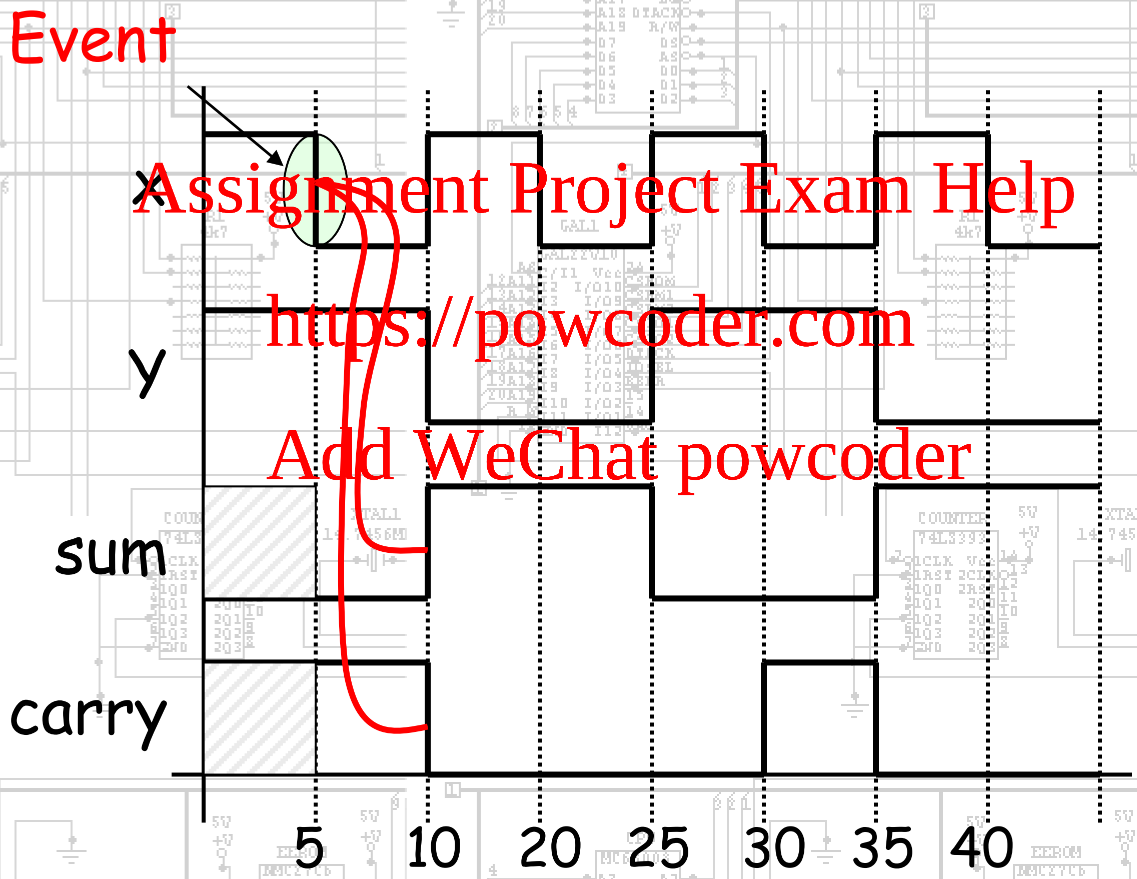
- concurrent_behavior
  - Name of architecture that defines the half_adder entity.

- signal assignment statements

  - sum <= (x xor y) after 5 ns;
  - carry <= (x and y) after 5 ns;

- Signal assignment operator <=
  - Describes how output signals depend on input signals
- An output signal changes if an input signal has changed.

Half Adder Operation



after Keyword

- Signal propagation of the XOR and AND gates must be taken into account.
  - Both gates require 5 ns propagation delay
- signal assignment statements define this through the after Keyword.
- This keyword specifies when the output signal is set to the result of an evaluation after an input signal transition (event).
- The textual order of the assignment statement has no influence on the timing.

library and use clauses

```
library IEEE;
use IEEE.STD_LOGIC_1164.ALL;

entity 2BA4 is

  ...
```

- A library contains design entities that be used
- The library IEEE clause defines the IEEE library.
- The library may contain packages.
- The above example specifies through the use clause the IEEE.STD_LOGIC_1164.ALL packages.
- This package is required for std_logic type declaration.

Full-Adder VHDL

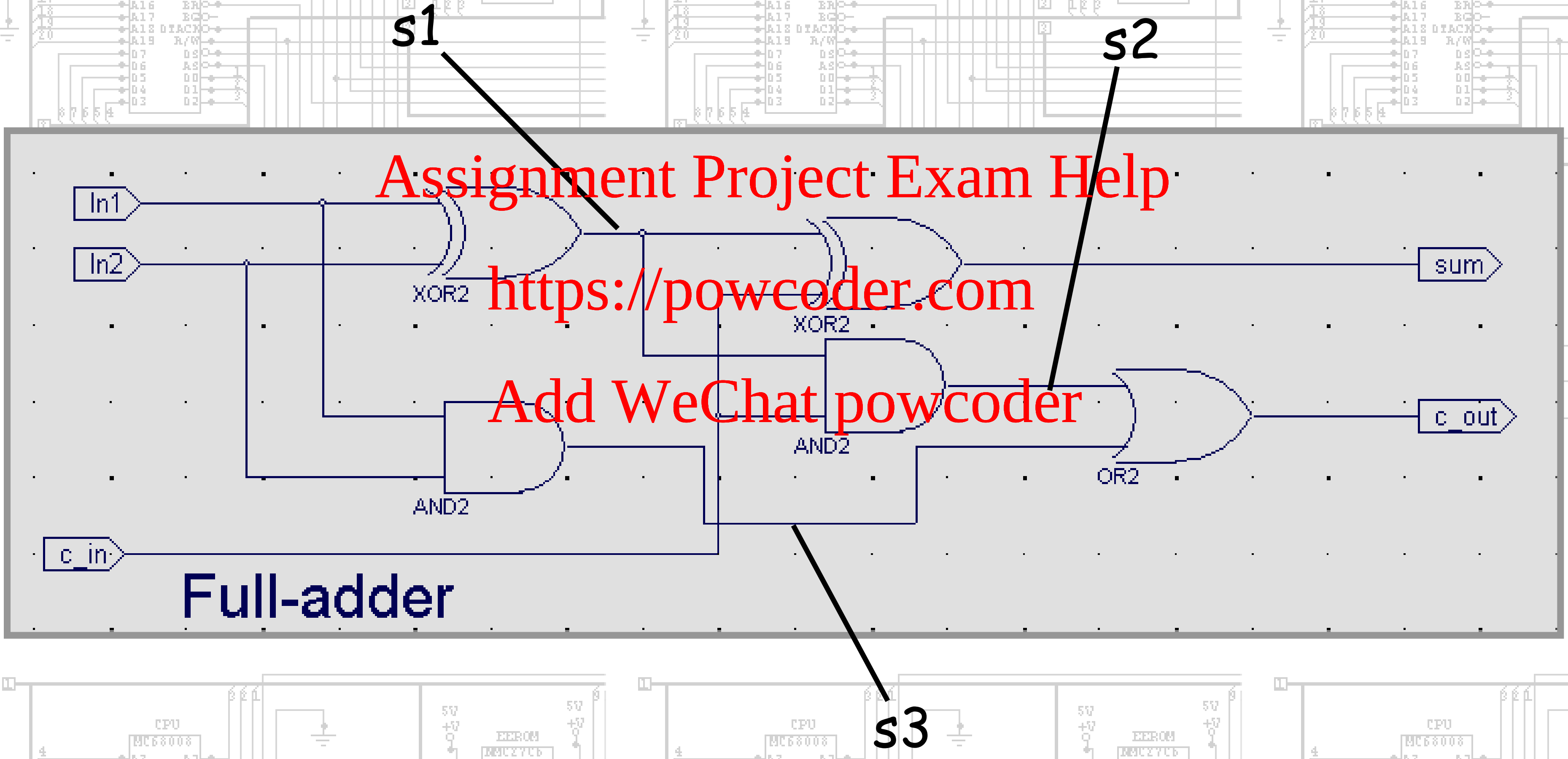
```
library IEEE;
use IEEE.STD_LOGIC_1164.ALL;

entity full_adder is
    Port (in1, in2, c_in:in std_ulogic;
          sum, c_out:out std_ulogic );
end full_adder;

architecture dataflow of full_adder is
signal s1,s2,s3: std_ulogic;
constant gate_delay: Time := 5 ns;

begin
s1 <= (In1 xor In2) after gate_delay;
s2 <= (c_in and s1) after gate_delay;
s3 <= (In1 and In2) after gate_delay;
sum <= (s1 xor c_in) after gate_delay;
c_out <= (s2 or s3) after gate_delay;
end dataflow;
```

Full-Adder Schematic



Architecture Declaration

```
library IEEE;
use IEEE.STD_LOGIC_1164.ALL;

entity full_adder is
    Port (in1, in2, c_in:in std_ulogic;
              sum, c_out:out std_ulogic );
end full_adder;

architecture dataflow of full_adder is
signal s1,s2,s3: std_ulogic;
constant gate_delay: Time := 5ns;
begin
s1 <= (In1 xor In2) after gate_delay;
s2 <= (c_in and s1) after gate_delay;
s3 <= (In1 and In2) after gate_delay;
sum <= (s1 xor c_in) after gate_delay;
c_out <= (s2 or s3) after gate_delay;
end dataflow;
```

Architecture Body

```vhdl
library IEEE;
use IEEE.STD_LOGIC_1164.ALL;

entity full_adder is
    Port (in1, in2, c_in:in std_ulogic;
          sum, c_out:out std_ulogic );
end full_adder;

architecture dataflow of full_adder is
signal s1,s2,s3: std_ulogic;
constant gate_delay: Time := 5ns;
begin
s1 <= (In1 xor In2) after gate_delay;
s2 <= (c_in and s1) after gate_delay;
s3 <= (In1 and In2) after gate_delay;
sum <= (s1 xor c_in) after gate_delay;
c_out <= (s2 or s3) after gate_delay;
end dataflow;
```

The Full-Adder Model

- The full-adder simulates the signal transitions at gate-level
- The model has three internal signals
- These signals are not ports to the entity
- The internal signals are declared in the architectural declaration
- The Boolean equations define how each signal is derived as function of:
  - Other signals
  - Propagation delay
- Constant can be used to declare a constant of a particular type.
- In this case Time

Signals

- Signals are not variables
  - History of values over time
  - Waveform

```
signal s1: std_ulogic := `0`;
```

- Signals may use the assignment symbol := followed by an expression

- The value of the expression will be initial value of the signal
- If no initialisation is provided the signal receives a default value
- VHDL signal types:
  - Integer, real, bit_vector…

Signals and Time

- A concurrent signal assignment statement (CSA)

```
sum <= (x xor y) after 5 ns;
```

- In a more general form:
  - signal <= value expression after time expression;

- In the example

  - if x or y change its value the sum will be assigned the result of the (x xor y) evaluation after 5ns.
- The Time-value pair represents the future value of the signal.
  - Also called transaction.

Multiple Signal Transactions

- It is possible to specify the following:

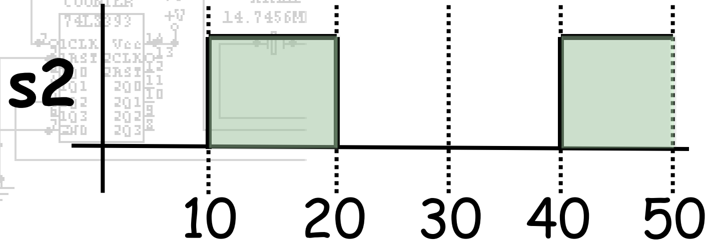
```
s1 <= (x xor y) after 5 ns, (x or y) after 10 ns, (not x) after 10 ns;
```

- After one of the signals changed all three waveform elements will be evaluated and scheduled according to their after specification.
- The simulation keeps an ordered list of all transactions scheduled for a particular signal.
- The scheduled transactions are also known as:
  - Projected output waveform.

Waveform Specification

- The following CSA will generate the following waveform:

```
s2 <= '0','1' after 10 ns, '0' after 20 ns, '1' after 40 ns;
```



Resolved Signals

- In a physical system a wire (signal) has a driver.
- This driver determents the waveform.
- Up the now every signal had one driver only
- But real system have shared signals:
  - Buses
  - Wired logic
- VHDL determines the value of the signal with multiple drivers through a resolution function.

Resolved Type Declaration

- A shared signal must be declared as a resoled type.
- The previous examples used unresolved types:

```
std_ulogic_vector (7 downto 0);
std_ulogic;
```

- The following declaration will make these signal types resolved:

```
std_logic_vector (7 downto 0);
std_logic;
```