Creating the Comparison Sub-Block

Efficient Comparison in the MIPS ALU

For the comparison operations, Set on Less Than (SLT) and Set on Less Than Unsigned (SLTU), we wish to determine whether the input *A* is less than the input *B*. If it is, we set the 32-bit result to *X"00000001"*. If it is not, we set the result to *X"00000000"*.

Let's start by looking at the calculation $A < B$. With a little simple algebra, this expression can be rewritten as $A - B < 0$. If we were to subtract *B* from *A*, then all that would remain is the relatively trivial matter of determining whether the result is less than zero. Instead of a large comparator which will consume a number of gates, we can reuse the single adder with a minimal amount of logic looking at the output.

First, we must make sure that the *Arithmetic* sub-block is performing a subtraction operation. This will occur when *ALUOp(1 DOWNTO 0)* is either "10" or "11". Remember we have two subtraction operations to perform. *SLT* requires a signed subtraction, thus it will be encoded as *ALUOp(1 DOWNTO 0) = "10"*. *SLTU* requires an unsigned subtraction, thus it will be encoded as *ALUOp(1 DOWNTO 0) = "11"*. The remaining two encodings for this sub-block will be undefined.

Now, the question is how do we determine if the result is less than zero based on the four inputs which we have defined to the *Comparison* sub-block: *CarryOut*, *ArithmeticR(31)*, *A(31)*, and *B(31)*.

Let's start with the signed operation. There are four possible combinations of the signs of the inputs: both are positive; both are negative; *A* is positive and *B* is negative; *A* is negative and *B* is positive. When the signs of the inputs are different, our problem is trivial. If *A* is negative and *B* positive, then *A* **must** be less than *B*. Conversely, if *A* is positive and *B* is negative then *A* **can never** be less than *B*. When the inputs have the same sign we need to look at the result of the signed subtraction. Two inputs with the same sign can never cause an overflow in subtraction, so we do not have to concern ourselves with an incorrect answer due to that. If the inputs are of the same sign, then whenever *A* is smaller than *B* the result of subtracting $A - B$ **must** be a negative number. So, if the sign of the result, *SignR*, is negative we have $A < B$, and if it is positive or zero then we have $A \geq B$.

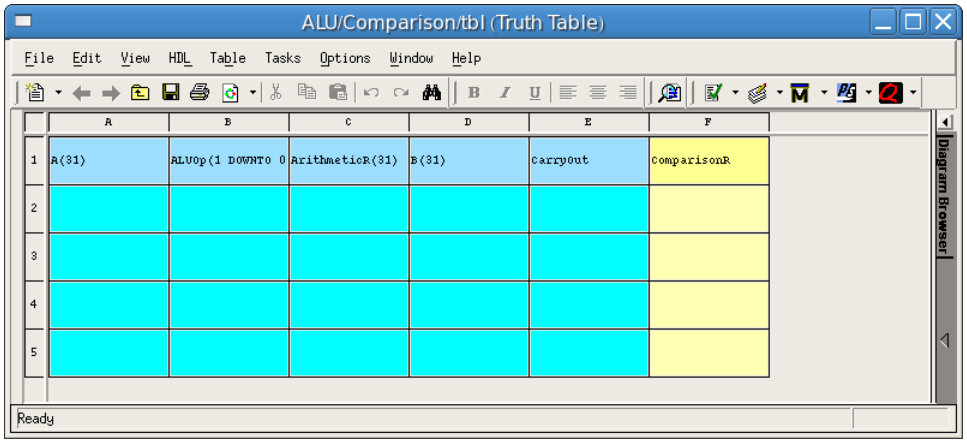
For the unsigned comparison we can have a simple test. Since *A* and *B* are both positive numbers in unsigned representation, subtracting two positive numbers will result in a positive number if $A > B$ or a negative number if $A < B$. However, we cannot represent a negative number with an unsigned integer: if we try we will have an overflow condition. Overflow for unsigned subtraction implies that the result is a negative number (it is impossible to subtract two unsigned numbers and get a result too large to represent). We can test the overflow condition in unsigned subtraction by checking the *CarryOut* from the result. In unsigned addition, the existence of a *CarryOut* indicates overflow when the signal is high. In unsigned subtraction, however, the situation is reversed: *CarryOut* low indicates overflow. Thus, since we are performing unsigned

subtraction in our SLTU, if there is no *CarryOut*, then we had an overflow and *A* - *B* is less than zero and *A* < *B* is true. If there is a *CarryOut*, then *A* - *B* is greater than zero and *A* < *B* is false.

Since we are only concerned with four input bits to determine our output, we will be implementing the *Comparison* sub-block by creating a **Truth Table** view.

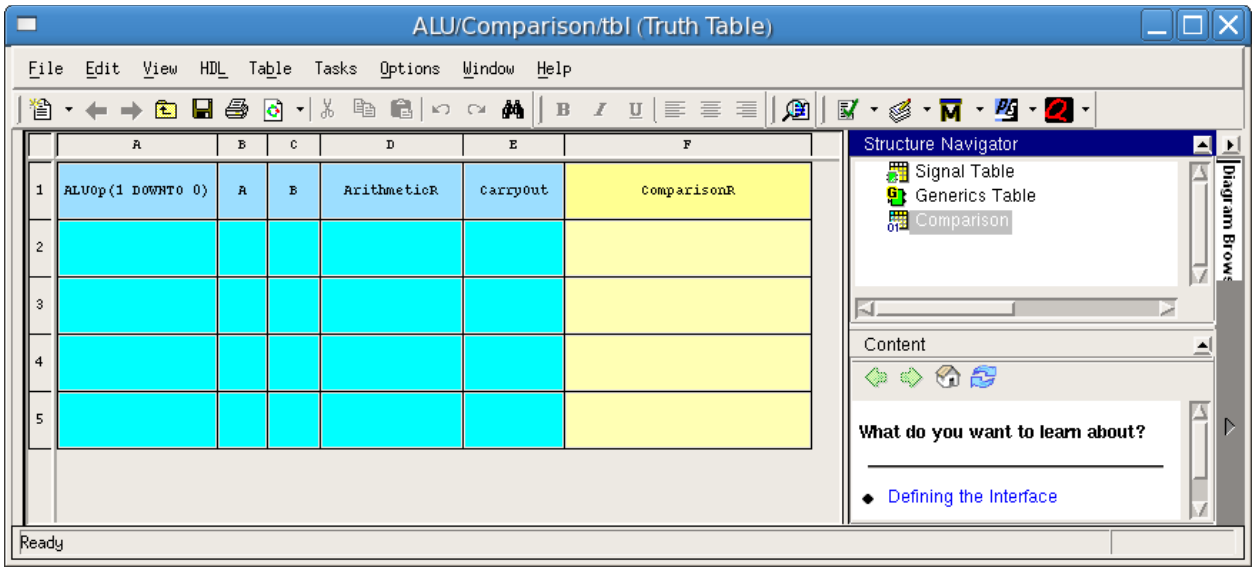
Creating a Truth Table View for the Comparison Sub-Block

First, you need to open a new *Truth Table* view for the *Comparison* sub-block. Do this by opening the *ALU* block diagram, double-click on the *Comparison* sub-block, select the **Graphical View** of **Categories** and select **Truth Table** from the **File Types**. Click the **Next** button and then the **Finish** button. The **Truth Table** view window will appear:

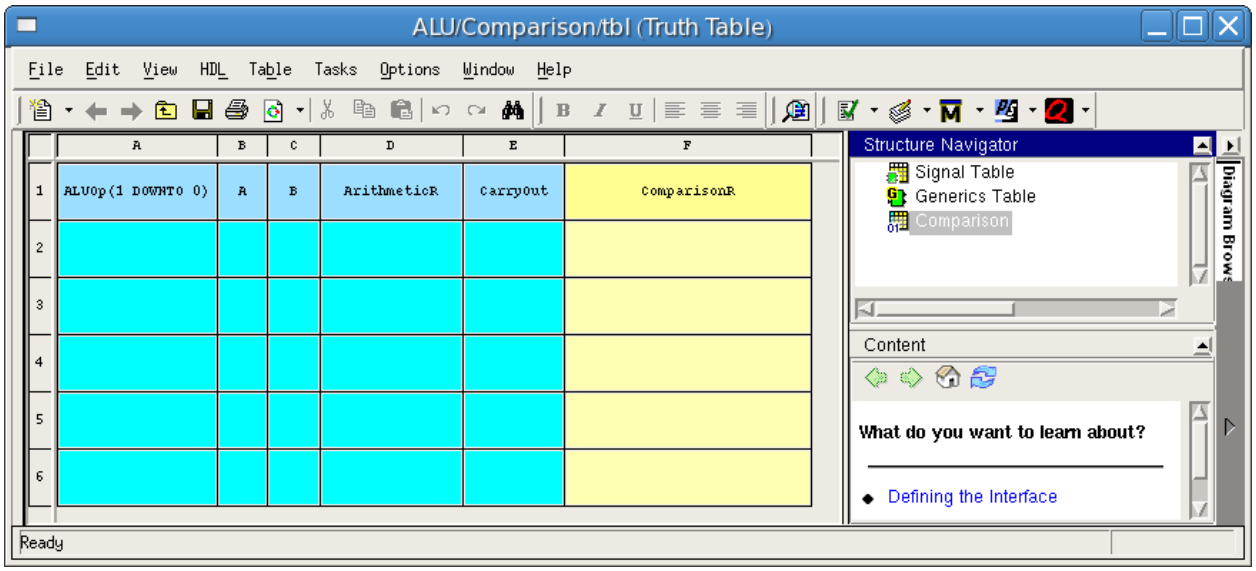


First, reorder the columns in the following order: ALUOp (1 DOWNTO 0), A, B, ArithmeticR, CarryOut and ComparisonR. To reorder the columns, left-click and type in the new value. This is very important to do! Unfortunately, the truth table keeps the name of the signals coming in but sees them differently. Click the **Diagram Browser** at the right of the truth table to observe the **Signal Table**. As you can see from the figure below, *A(31)* is now just *A*. The same applies to ArithmeticR and B.

Return to your Truth Table by clicking on **Comparison**. You may resize the rows and columns of the *Truth Table* by moving the pointer over the lines separating the row and column headers (which are in gray), left-clicking, and dragging to the desired height or width just like in a spreadsheet program. Resize the *A*, *B*, *ArithmeticR*, and *CarryOut* columns so that the signal names just fit. Now make the *ComparisonR* column much larger because it will be holding a 32-bit wide vector. You may also center the data in your rows and columns by selecting all (CTRL + A) and click the **Center** button  . Your view should look something like the figure below:



We will need more than four rows in this *Truth Table*. A row can be added, by right-clicking anywhere over the table and selecting **Add Row** from the pop-up menu. Add one more row so that your table looks like the figure below:



Now we will start to add information to the table. Values are entered by left-clicking on the appropriate cell and typing in the data. *Don't Care* values are specified by leaving a cell empty. Don't care's are useful to shorten the length of the table when a particular entry does not depend on the state of one or more of the inputs. For example, to completely specify the truth table for our design with six bits of input we would need 64 rows but by using don't cares we can reduce that to 5.

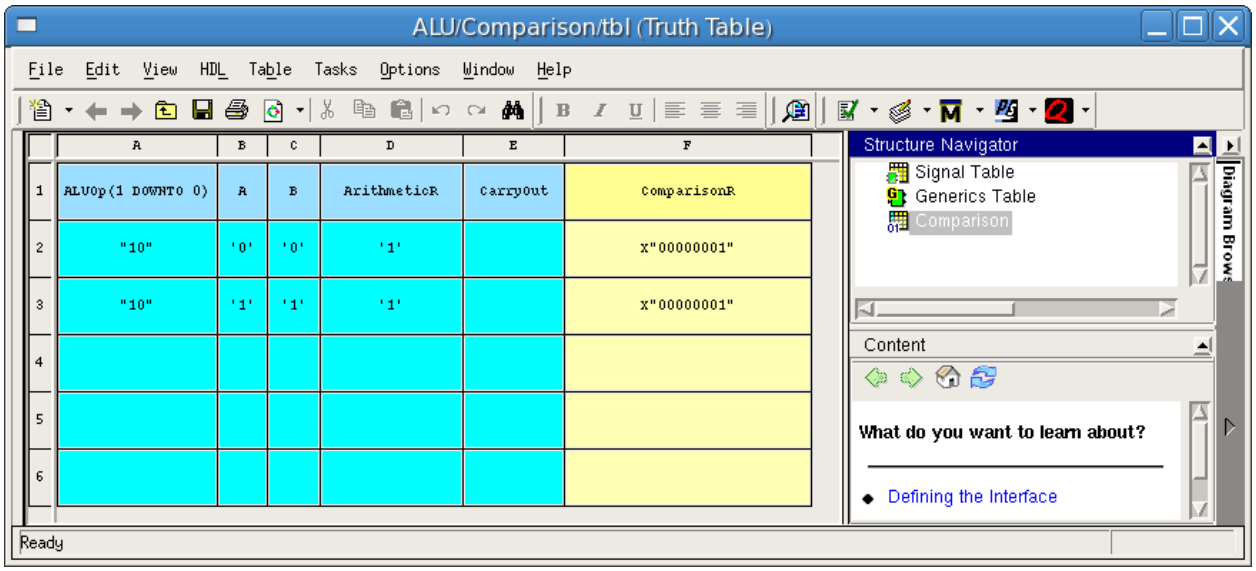
This reduction in the truth table is achieved by a combination of matching only outcomes with a TRUE output(X"00000001") and don't cares for the rest of the input combinations. The one row

of don't cares for a FALSE output(X"00000000") will save the user from 60 rows of unnecessary logic.

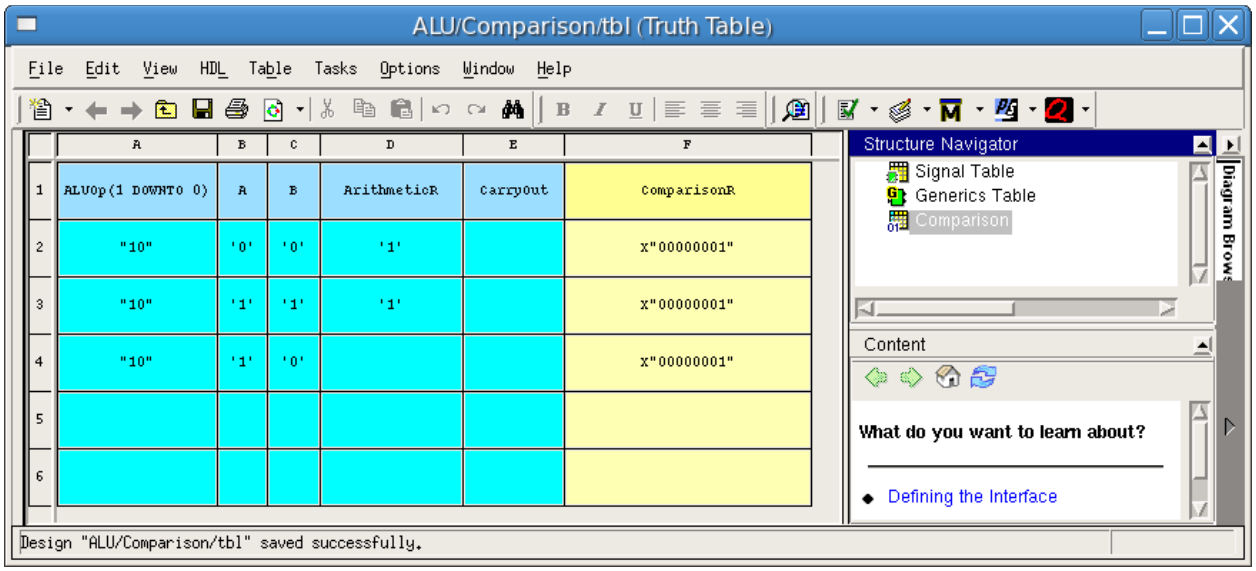
Signed Comparison Operation

Let's start with the signed comparison operation, *SLT*, which is performed when *ALUOp* is equal to "10". Remember from above that there were three possible situations: *A* and *B* have the same sign, *A* is positive and *B* is negative, or *A* is negative and *B* is positive.

Let's start with the case of both inputs having the same sign. This occurs when *A(31) = '0'* and *B(31) = '0'* or *A(31) = '1'* and *B(31) = '1'*. In each case all we need to do is look at the sign of the result, *ArithmeticR(31)*. If *ArithmeticR(31) = '0'* then the result is positive and we want to output FALSE, or X"00000000". We can skip adding this entry into the truth table since it's FALSE. If *ArithmeticR(31) = '1'* then the result is negative and the output is TRUE, or X"00000001". We now have two TRUE possibilities that we can now add to the truth table. Your Truth Table should resemble the figure below:



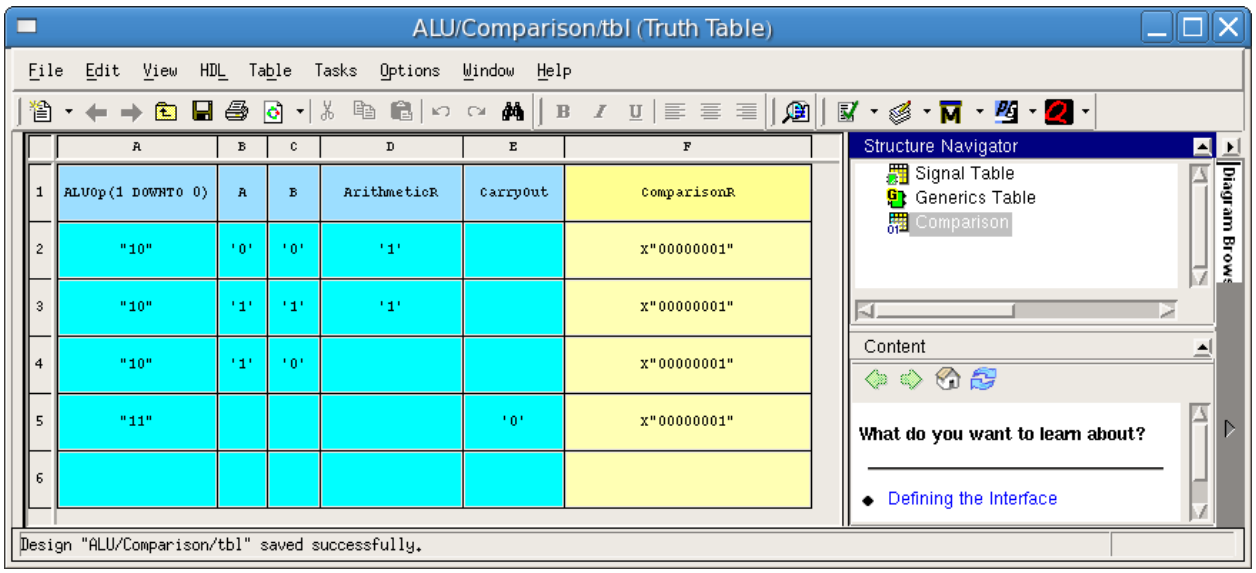
Now we have two cases left. When *A(31) = '0'* and *B(31) = '1'* we have *A* as a positive number and *B* as a negative number, meaning that *A* must be greater than *B* and our result is always going to be false. This means that we don't care what the value of *ArithmeticR(31)* or *CarryOut* is. Conversely, when *A(31) = '1'* and *B(31) = '0'* then *A* is negative and *B* is positive and *A* must be less than *B* so our result is always true. Since we're only adding the TRUE possibilities, we now have one more line to add to the table. Your Truth Table should resemble the figure below:



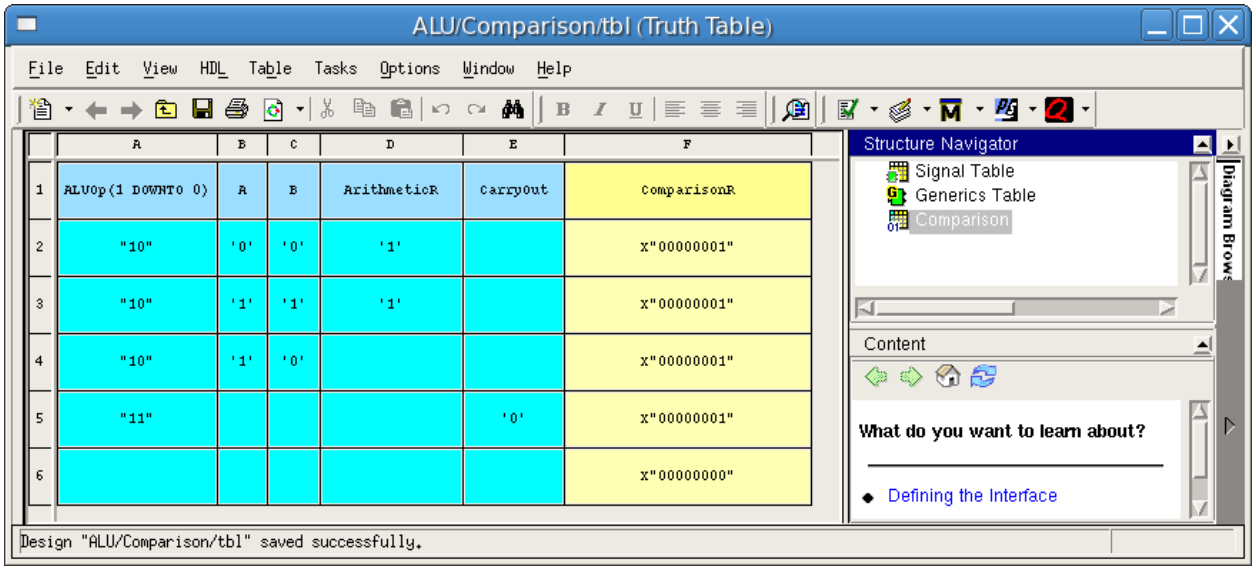
We have now completely specified the behavior of the table for *SLT*, or *ALUOp(1 DOWNTO 0)* = "10".

Unsigned Comparison Operation

We have one line left to fill in in the table which will specify the last 16 cases that correspond to *ALUOp(1 DOWNTO 0)* = "11", or Set on Less than Unsigned. Remember from above that we can test for *A* < *B* unsigned by performing an unsigned subtraction and checking for an overflow indicated by examining carry out from the most significant bit of the adder. So, if we are performing *SLTU* all we need to look at is the *CarryOut* signal. If *CarryOut* = '1', then we did not have overflow, hence *A* - *B* > *0* and we report FALSE. If *CarryOut* = '0', then we have had an overflow and *A* - *B* < *0* so we report TRUE. Our one line of logic has been implemented in the table shown in the figure below:



The last step we have to complete in this table is the *don't care* for any other combination of inputs. This can be done by leaving all inputs blank and setting the output to the FALSE value. Your Truth Table should resemble the figure below:



The *Comparison* sub-block is difficult to fully test in a stand-alone manner due to the fact that it requires the *Arithmetic* sub-block to function correctly. However, it is also a relatively simple sub-block, so we will put off testing its functionality for now and verify that it works correctly when we are simulating the entire *ALU*.

Below is the generated HDL for the Truth Table

```
-- VHDL Entity ALU.Comparison.interface
--
-- Created:
--          by - elenis.student (circe)
--          at - 18:59:03 01/09/07
--
-- Generated by Mentor Graphics' HDL Designer(TM) 2005.3 (Build 75)
--
LIBRARY ieee;
USE ieee.std_logic_1164.all;
USE ieee.std_logic_arith.all;

ENTITY Comparison IS
   PORT(
      A           : IN     std_logic;
      ALUOp       : IN     std_logic_vector (1 DOWNTO 0);
      ArithmeticR : IN     std_logic;
      B           : IN     std_logic;
      CarryOut    : IN     std_logic;
      ComparisonR : OUT    std_logic_vector (31 DOWNTO 0)
   );

-- Declarations

END Comparison ;

--
-- VHDL Architecture ALU.Comparison.tbl
--
-- Created:
--          by - elenis.student (circe)
--          at - 18:59:03 01/09/07
--
-- Generated by Mentor Graphics' HDL Designer(TM) 2005.3 (Build 75)
--
LIBRARY ieee;
USE ieee.std_logic_1164.all;
USE ieee.std_logic_arith.all;
ARCHITECTURE tbl OF Comparison IS

-- Architecture declarations


BEGIN

 ----------------------------------------------------------------
 truth_process_proc: PROCESS(A, ALUOp, ArithmeticR, B, CarryOut)
 ----------------------------------------------------------------
  BEGIN
      -- Block 1
   IF (ALUOp(1 Downto 0) = "10") AND (A = '0') AND (B = '0') AND
        (ArithmeticR = '1') THEN
              ComparisonR <= X"00000001";
   ELSIF (ALUOp(1 Downto 0) = "10") AND (A = '1') AND (B = '1')
```

```
           AND (ArithmeticR = '1') THEN
                    ComparisonR <= X"00000001";
   ELSIF (ALUOp(1 Downto 0) = "10") AND (A = '1') AND (B = '0') THEN
         ComparisonR <= X"00000001";
   ELSIF (ALUOp(1 Downto 0) = "11") AND (CarryOut = '0') THEN
         ComparisonR <= X"00000001";
   ELSE
         ComparisonR <= X"00000000";
   END IF;

 END PROCESS truth_process_proc;

-- Architecture concurrent statements


END tbl;
```

Now that you have finished creating the Comparison sub-blocks, all that is left to complete the *ALU* design is the Mux4Bus32 sub-block.