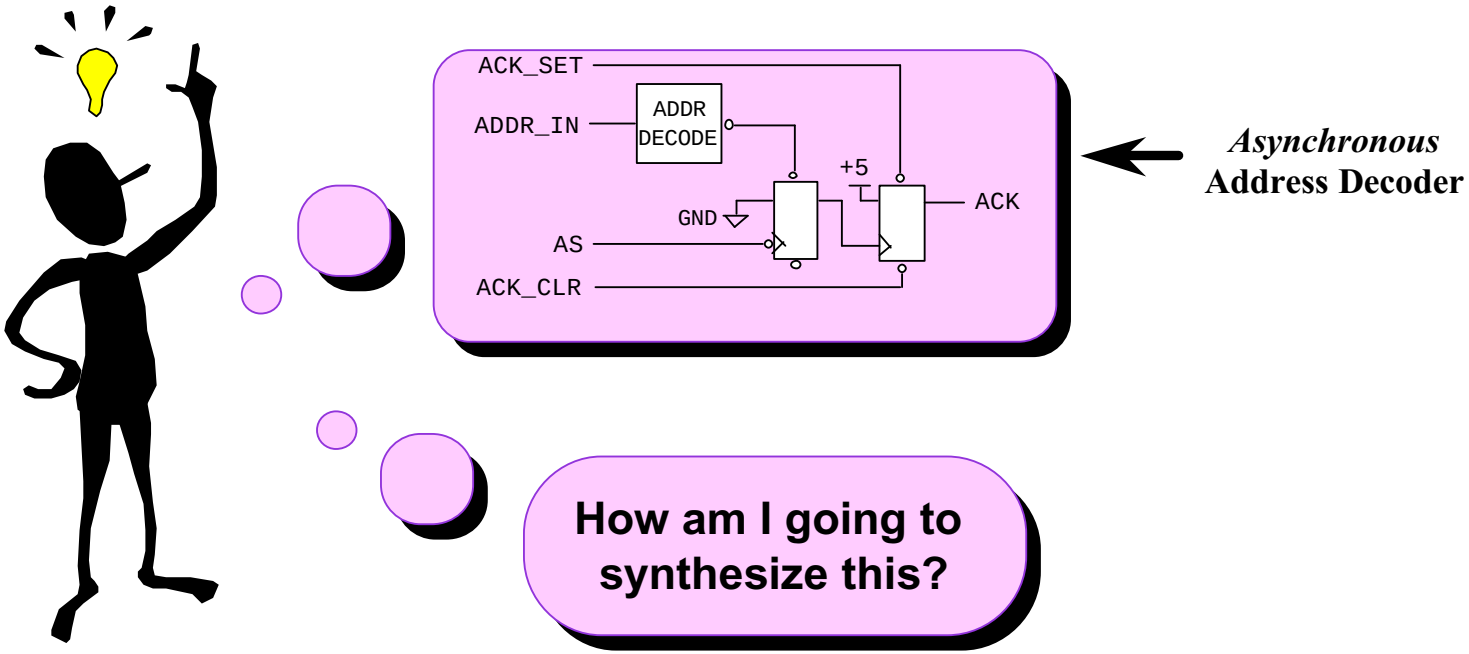
RTL Coding Guidelines
Think Synchronous

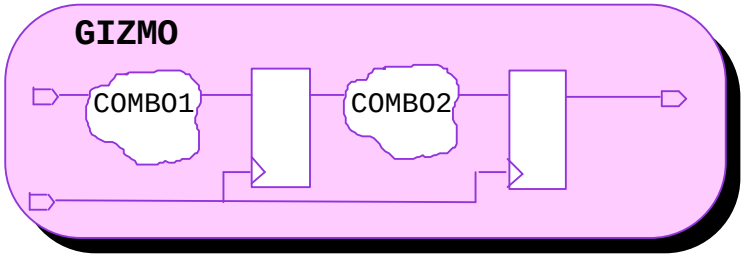
- *Synchronous* designs run smoothly through synthesis, simulation and place-and-route
- Isolate necessary *Asynchronous* logic into separate blocks



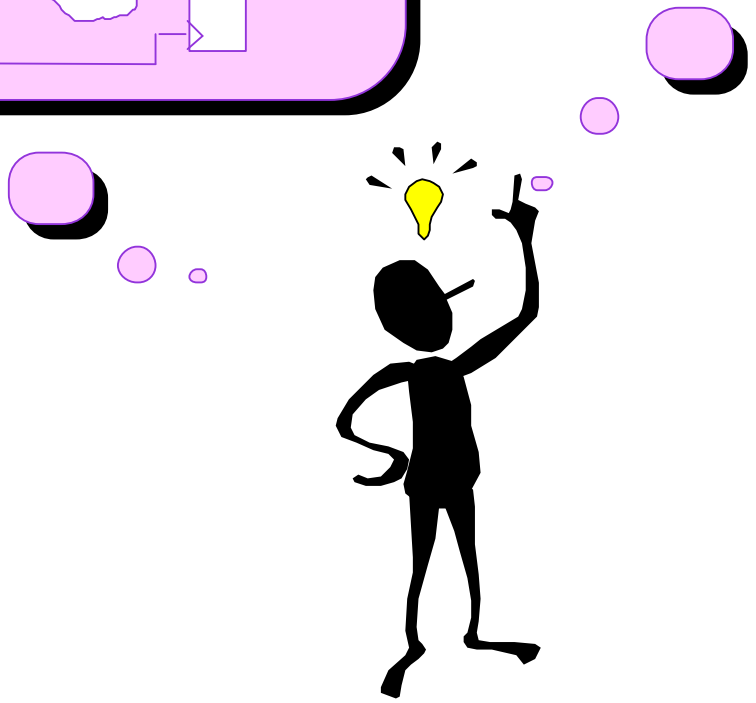
Asynchronous Address Decoder

RTL Coding Guidelines
Think RTL

- **Describe the circuits in terms of its registers and the combinational logic between them**



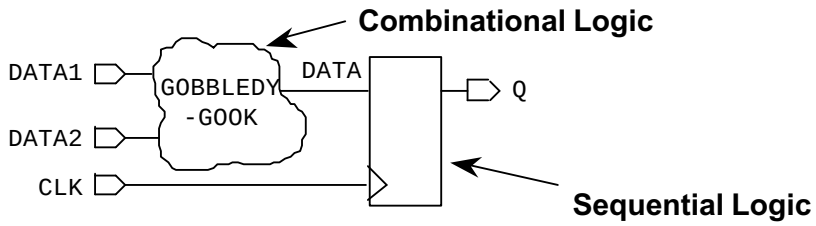

```
module GIZMO (A, CLK, Z);
...
always @(A) begin : COMBO1...
always @(posedge CLK)...
always @(B) begin : COMBO2...
always @(posedge CLK) ...
end module;
```



RTL Coding Guidelines
Separate Combinational from Sequential

- **Follows RTL coding style**
- **Easy to read and self-documenting**

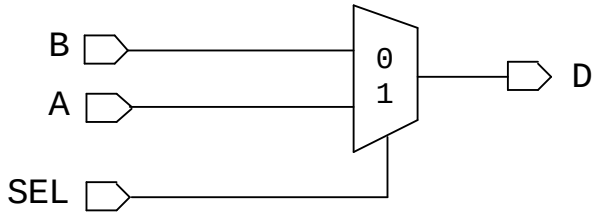
```
module EXAMPLE (DATA1,DATA2,CLK,Q)
input DATA1,DATA2,CLK;
output Q;

reg DATA, Q;
always @(DATA1 or DATA2)
  begin: COMBO
    DATA <= GOBBLEDYGOOK(DATA1,DATA2);
  end

always @(posedge CLK)
  begin: SEQUENTIAL
    Q <= DATA;
  end
endmodule
```



IF Statements

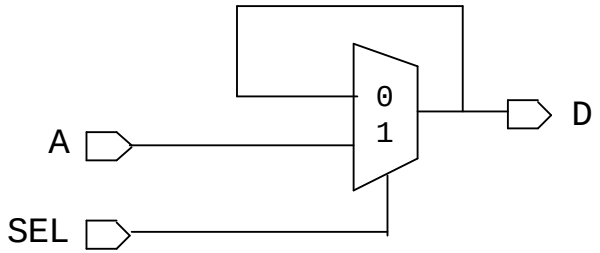
- **IF statements infer multiplexer logic**

```
always @(SEL or A or B)
   if (SEL)
      D <= A;
   else
      D <= B;
```



- **Latches are inferred unless all variables are assigned in all branches**

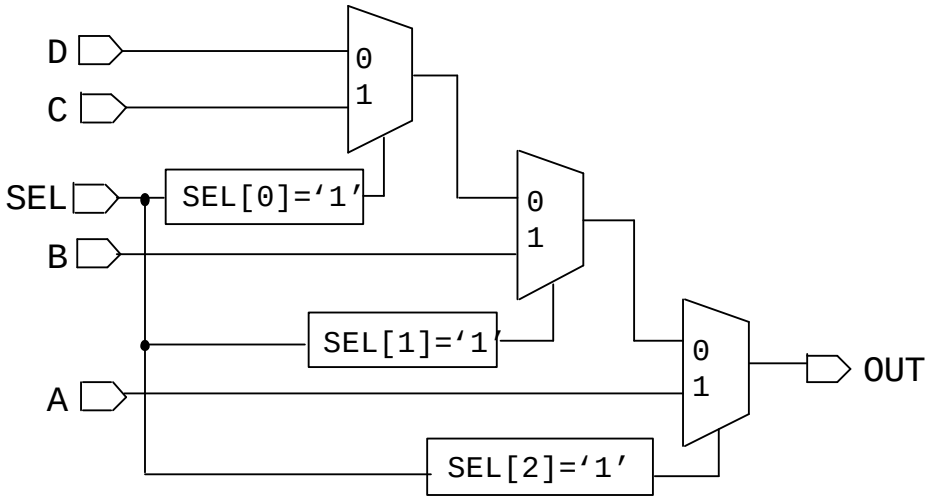
```
always @(SEL or A)
   if (SEL)
      D <= A;
```



IF Statements (cont.)

- **IF-ELSE-IF statements infer priority-encoded multiplexers**

```
always @(SEL or A or B or C or D)
   if (SEL[2] == 1'b1)
      OUT <= A;
   else if (SEL[1] == 1'b1)
      OUT <= B;
   else if (SEL[0] == 1'b1)
      OUT <= C;
   else
      OUT <= D;
```



Long delay from D to OUT

IF Statements (cont.)

- Remove redundant conditions
- Use CASE statements if conditions are mutually exclusive

Don't

```
always @(A or B or C or D or E)
  if (A < B)
    OUT <= C;
  else if (A > B)
    OUT <= D;
  else if (A == B)
    OUT <= E;
```

Do

```
always @(A or B or C or D or E)
  if (A < B)
    OUT <= C;
  else if (A > B)
    OUT <= D;
  else
    OUT <= E;
```

CASE Statements
Verilog Directives

- full_case indicates that all *user-desired* cases have been specified
- Do not use *default* for one-hot encoding

one hot →

```
always @(SEL or A or B or C)
begin
  case (SEL) //synopsys full_case
    3'b001 : OUT <= A;
    3'b010 : OUT <= B;
    3'b100 : OUT <= C;
  endcase
end
```

Does not infer latches

```
always @(SEL or A or B)
begin
  case (SEL)
    3'b001 : OUT <= A;
    3'b010 : OUT <= B;
    3'b100 : OUT <= C;
  endcase
end
```

Infers latches for OUT because not all cases are specified

CASE Statements
Verilog Directives (cont.)

- **parallel_case indicates that all cases listed are mutually exclusive to prevent priority-encoded logic**

```
always @(SEL or A or B or C)
begin
  case (SEL) //synopsys parallel_case
    A : OUT <= 3'b001;
    B : OUT <= 3'b010;
    C : OUT <= 3'b100;
  endcase
end
```

Infers a multiplexer

CASE Statements
"CASE" vs. "IF-ELSE IF"

- Use IF-ELSE for 2-to-1 multiplexers
- Use CASE for n-to-1 multiplexers where n > 2
- Use IF-ELSE IF for priority encoders
- Use CASE with //synopsys parallel_case when conditions are mutually exclusive
- Use CASE with //synopsys full_case when not all conditions are specified
- Use CASE with //synopsys full_case parallel_case for one-hot Finite State Machines (FSMs)

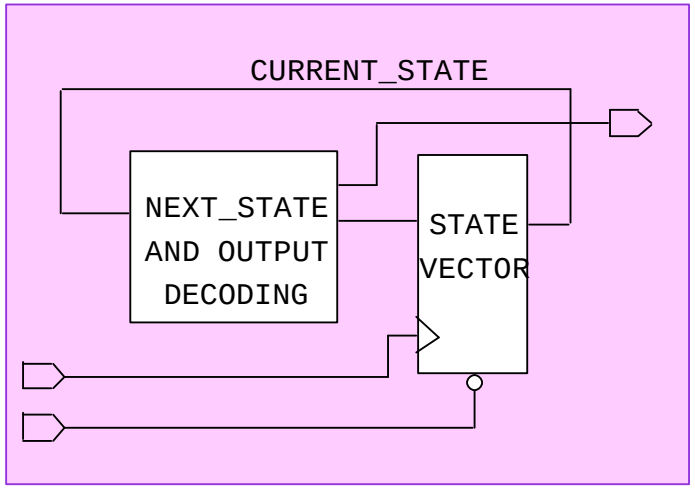
CASE Statements
FSM Encoding

- Use CASE statements to describe FSMs
- Use //synopsys parallel_case to indicate mutual exclusivity
- Use //synopsys full_case when not all possible states are covered (one-hot)
- Do not use *default* unless recovery state is desired

CASE Statements
FSM Encoding (cont.)

```
module EXAMPLE (RESET, CLK, OUT);
input  RESET, CLK;
output  [1:0] OUT;
parameter IDLE=4'b0001, GO=4'b0010, YIELD=4'b0100,
STOP=4'b1000;
reg [3:0] CURRENT_STATE, NEXT_STATE;
always @(CURRENT_STATE)
begin: COMBO
  case (CURRENT_STATE) // synopsys full_case parallel_case
    IDLE: begin NEXT_STATE = GO; OUT <= 2'b01; end
    GO: begin NEXT_STATE = YIELD; OUT <= 2'b11; end
    YIELD: begin NEXT_STATE = STOP; OUT <= 2'b10; end
    STOP: begin NEXT_STATE = IDLE; OUT <= 2'b00; end
  endcase
end
always @(posedge CLK or negedge RESET)
begin: SEQUENTIAL
  if (~RESET)
    CURRENT_STATE <= IDLE;
  else
    CURRENT_STATE <= NEXT_STATE
end
endmodule
```

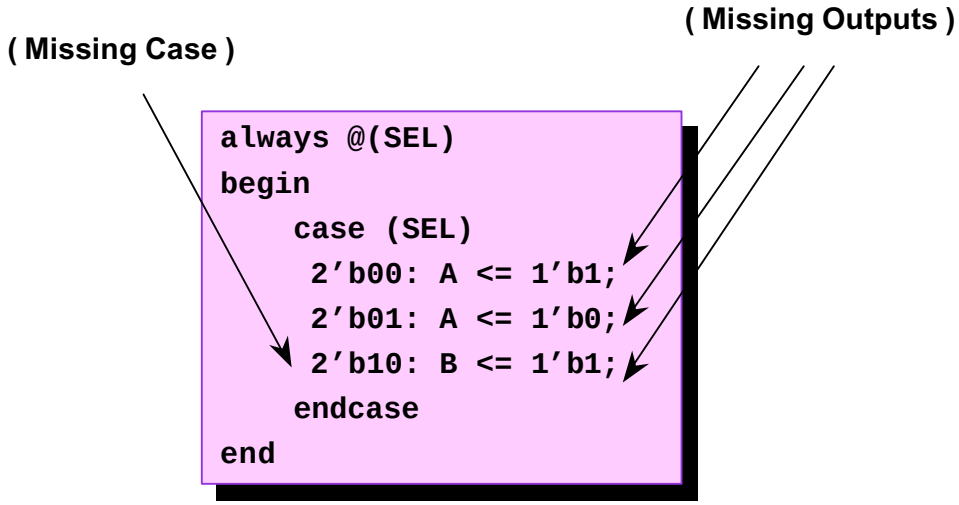
- **Use parameter statements to define state values**
- **Use CASE statements and // synopsys parallel_case full_case to describe FSM**



CASE Statements
Watch for Unintentional Latches

- Completely specify all branches for every case and if statement
- Completely specify all outputs for every case and if statement
- Use //synopsys full_case if all desired cases have been specified

What's wrong with this example?



CASE Statements
Cascade Chain Inference

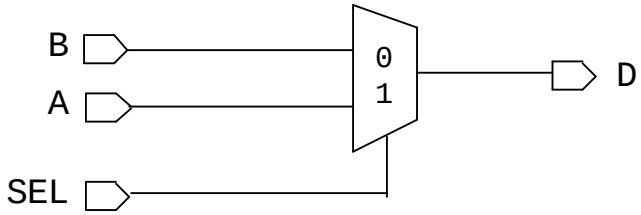
- Using cascade chains improves QoR significantly for multiplexers
- Completely specify all possible cases for cascade chains to be inferred

```
always @(SEL)
begin
    case (SEL)
     3'b000: OUT <= A;
     3'b001: OUT <= B;
     3'b010: OUT <= C;
     3'b011: OUT <= D;
     3'b100: OUT <= E;
     3'b101: OUT <= F;
     3'b110: OUT <= G;
     3'b111: OUT <= H;
    endcase
end
```

Multiplexers

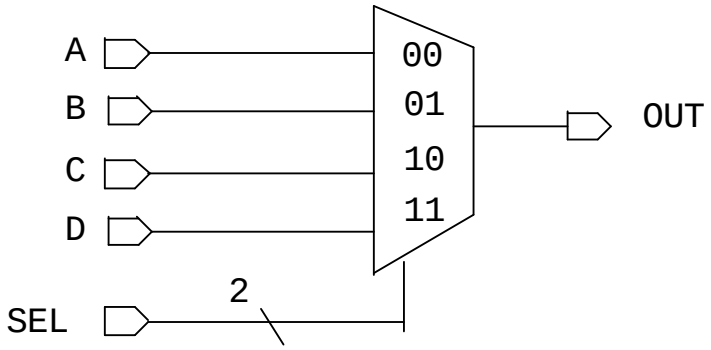
- **Use IF or continuous assignment when select is a single-bit signal**

```
always @(SEL or A or B)
   if (SEL)
      D <= A;
   else
      D <= B;
-----------------------
assign D = SEL ? A : B;
```



- **Use CASE statements when select is a multi-bit bus**

```
always @(SEL or A or B
or C or D)
begin
   case (SEL)
      2'b00 : OUT <= A;
      2'b01 : OUT <= B;
      2'b10 : OUT <= C;
      2'b11 : OUT <= D;
   endcase
end
```



Operators

- **Operators inferred from HDL**
  - Adder, Subtractor, AddSub (+, -), Multiplier (*)
  - Comparators (>, >=, <, <=, ==, !=)
  - Incrementer, Decrementer, IncDec (+1, -1)
- **Example**

```
module add (sum, a, b);
output [15:0] sum;
input [15:0] a, b;

assign sum = a + b + 1'b1;

endmodule
```

Design indicates two adders.

```
module add (sum, a, b);
output [15:0] sum;
input [15:0] a, b;
wire temp;

assign {sum, temp} = {a, 1'b1} + {b, 1'b1};

endmodule
```

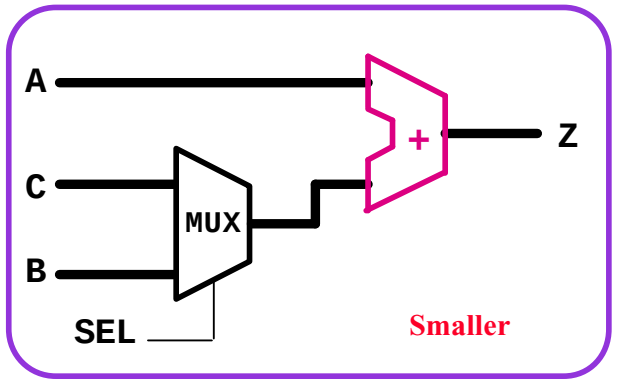
FE infers one adder with carry chain.

Operators
Operator Sharing

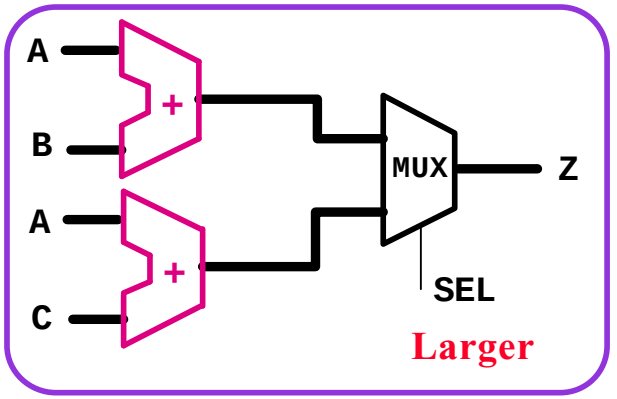
- Operators can be shared within an *always* block by default
- Users can disable sharing

```
always @(SEL or A or
B or C)
begin
    if (SEL)
          Z = A+B;
    else
          Z = A+C;
end
```

With Sharing

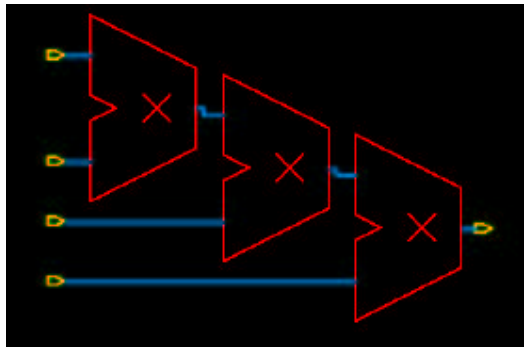


Without Sharing

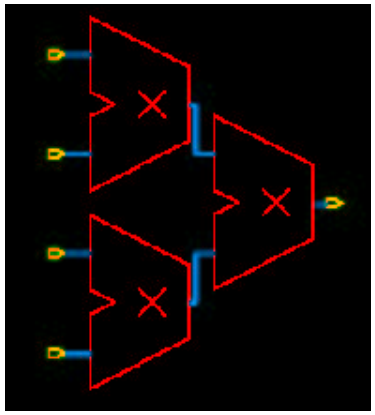


Operators
Operator Balancing

- Use parenthesis to guide synthesis



A*B*C*D



(A*B)*(C*D)