

ENGR 210 / CSCI B441
“Digital Design”

Flip Flops + Sequential Logic

Andrew Lukefahr

Course Website

fangs-bootcamp.github.io

Write that down!

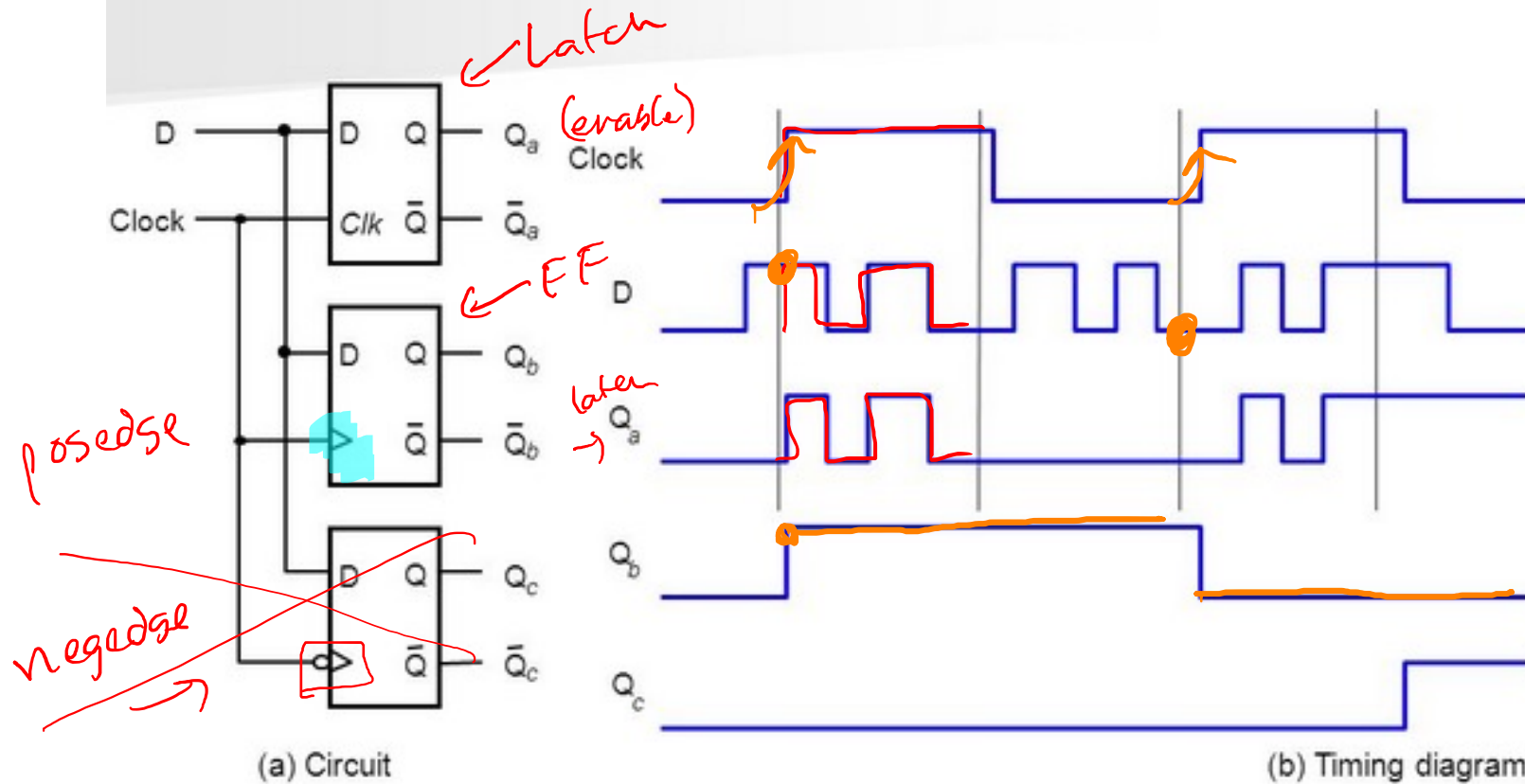
Announcements

- P2: You should be done.
- P3: You should be done.
- P4: Up and ready.

D Latch versus D Flip-Flop

Latch → output follows input (D) when enable (clk) is high

FF → ~~not~~ output follows input only on rising edge of enable (clk)



Comparison of level-sensitive and edge-triggered devices

Defaults

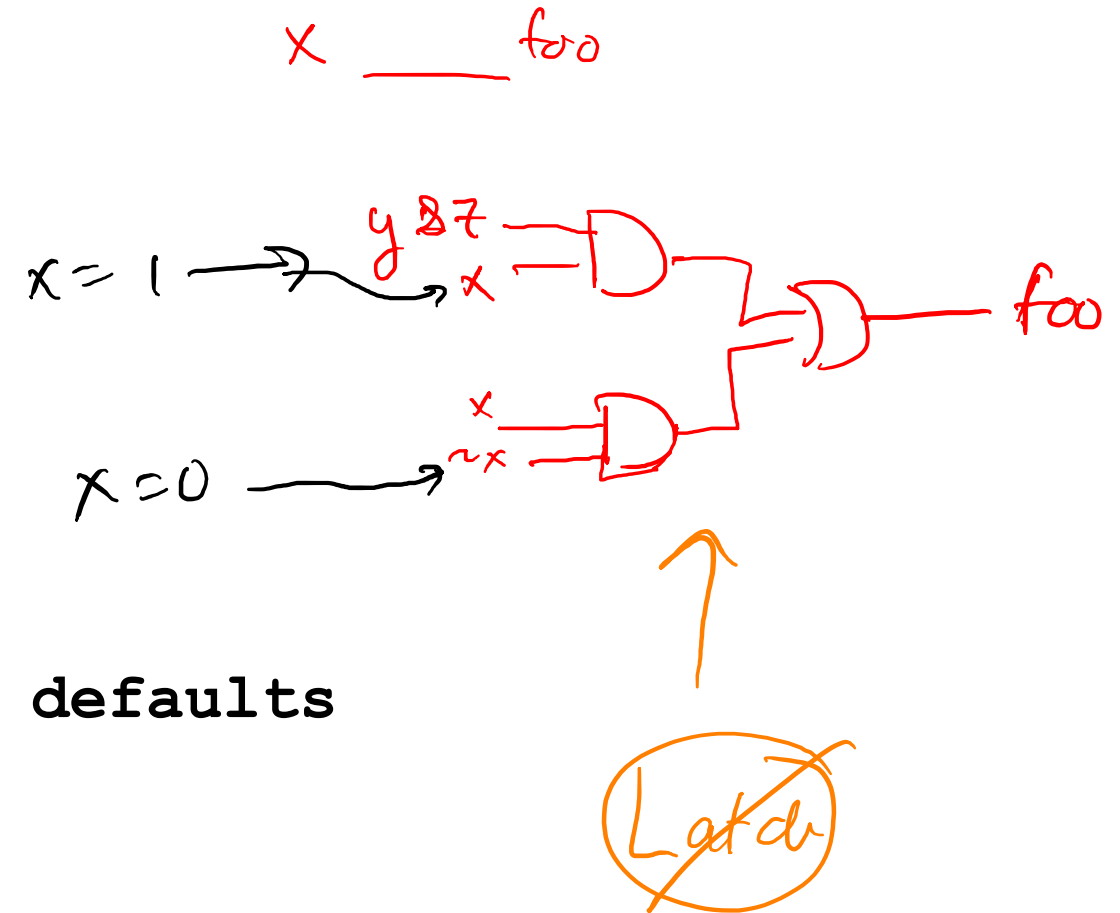
```
wire x,y,z;  
logic foo, bar ;
```

```
always_comb begin
```

```
    foo = x; bar = x; //good: defaults
```

```
    if (x) foo = y & z; //  
    if (x) bar = y | z ; //
```

```
end
```



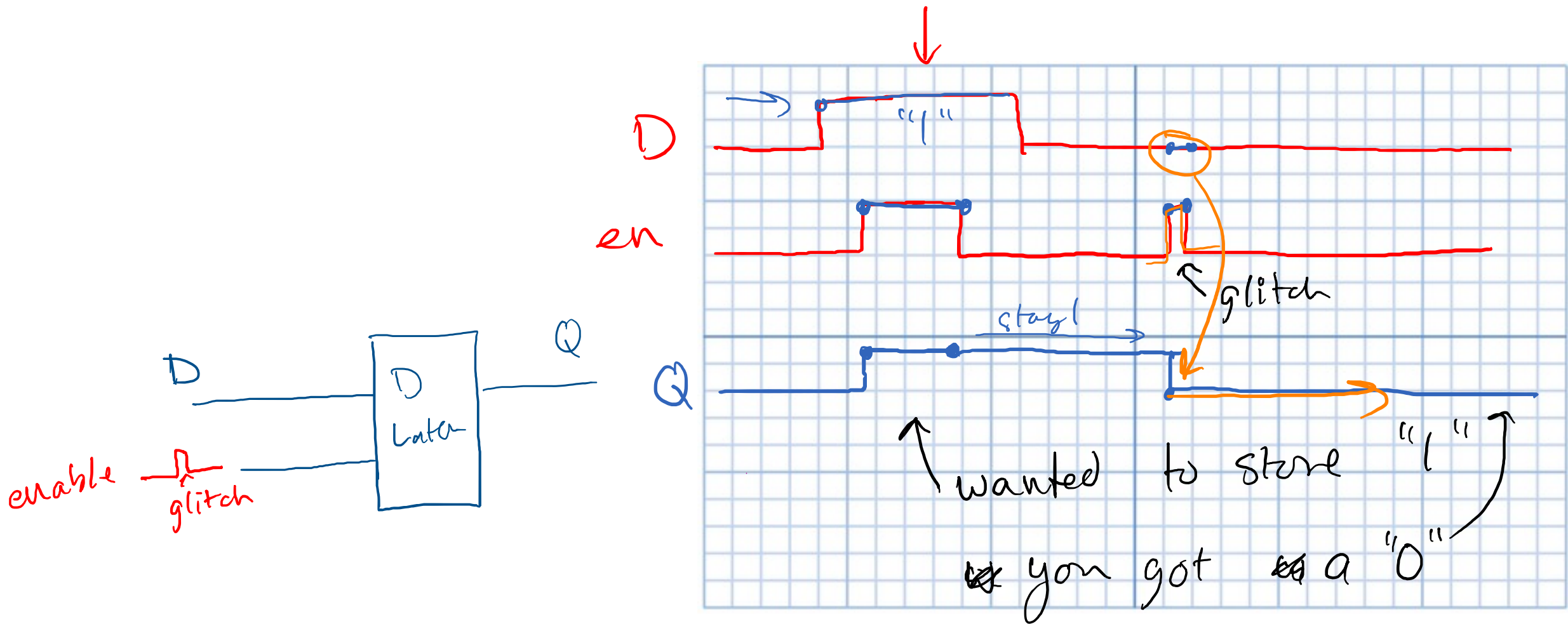
What if $x == 0$? $foo = bar = x$!

Always specify defaults for `always_comb`!

"Warnings: Inferrius Later"

Always specify
defaults for
always_comb!

Glitches on D-Latches



Flip-Flop in Verilog

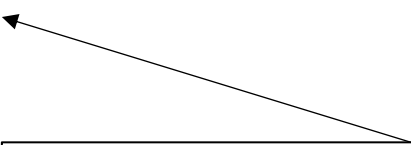
```
module d_ff (  
    input          d,    //data  
    input          clk,  //clock  
    output logic q      //output register  
);  
  
    always_ff @( posedge clk )  
    begin  
        q <= d; //non-blocking assign  
    end  
  
endmodule
```


BLOCKING (=) FOR
`always_comb`

NON-BLOCKING (<=) for
`always_ff`

What's the initial value for a DFF?

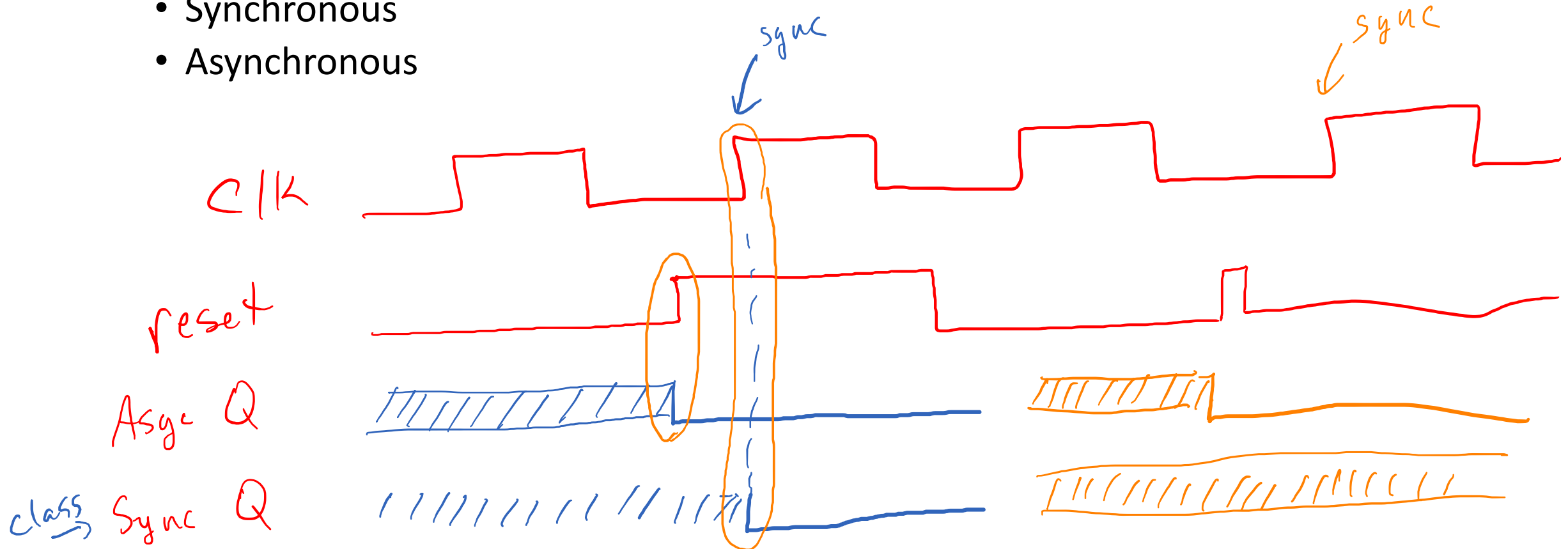
```
module d_ff (  
    input d,          //data  
    input clk,        //clock  
    output logic q     //output  
);  
  
    always_ff @( posedge clk )  
    begin  
        q <= d; //non-blocking assign  
    end  
endmodule
```



What is q before first posedge clk?

D-FF's with Reset

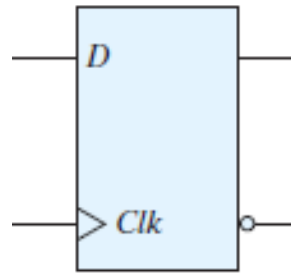
- Two different ways to build in a reset
 - Synchronous
 - Asynchronous



D-FF's with Reset

- Two different ways to build in a reset
 - Synchronous
 - Asynchronous
- We always use synchronous resets for this class!

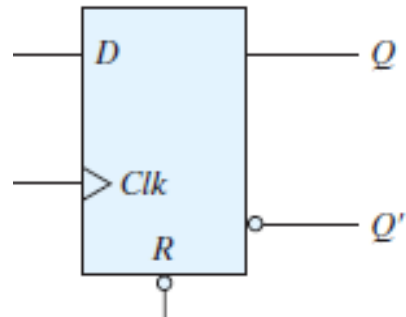
Verilog models of D flip-flop



Edge triggered D flip-flop:

```
logic Q;  
always_ff @ (posedge clk)  
    Q <= D;
```

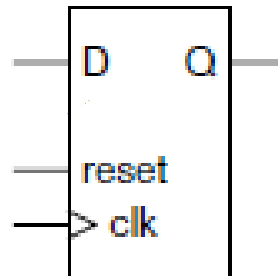
↖ No reset
FF



Edge triggered, asynchronous reset D flip-flop:

```
logic Q;  
always_ff @ (posedge clk, negedge rst)  
    if (~rst) Q <= 1'b0; //asynch. reset  
    else Q <= D;
```

↖ Not
used
in
class



Edge triggered, synchronous reset, clock enable D flip-flop: ↖

```
logic Q;  
always_ff @ (posedge clk)  
    ↗ if (reset) Q <= 1'b0; // synch. reset  
    else Q <= d;
```

DFF with Synchronous Reset

```
module d_ff (
    input d,                //data
    input clk,              //clock
    input rst,              //reset
    output logic q          //output
);

    always_ff @( posedge clk )
    begin
        if (rst) q <= 'h0; //reset case
        else      q <= d; //non-reset case
    end

endmodule
```

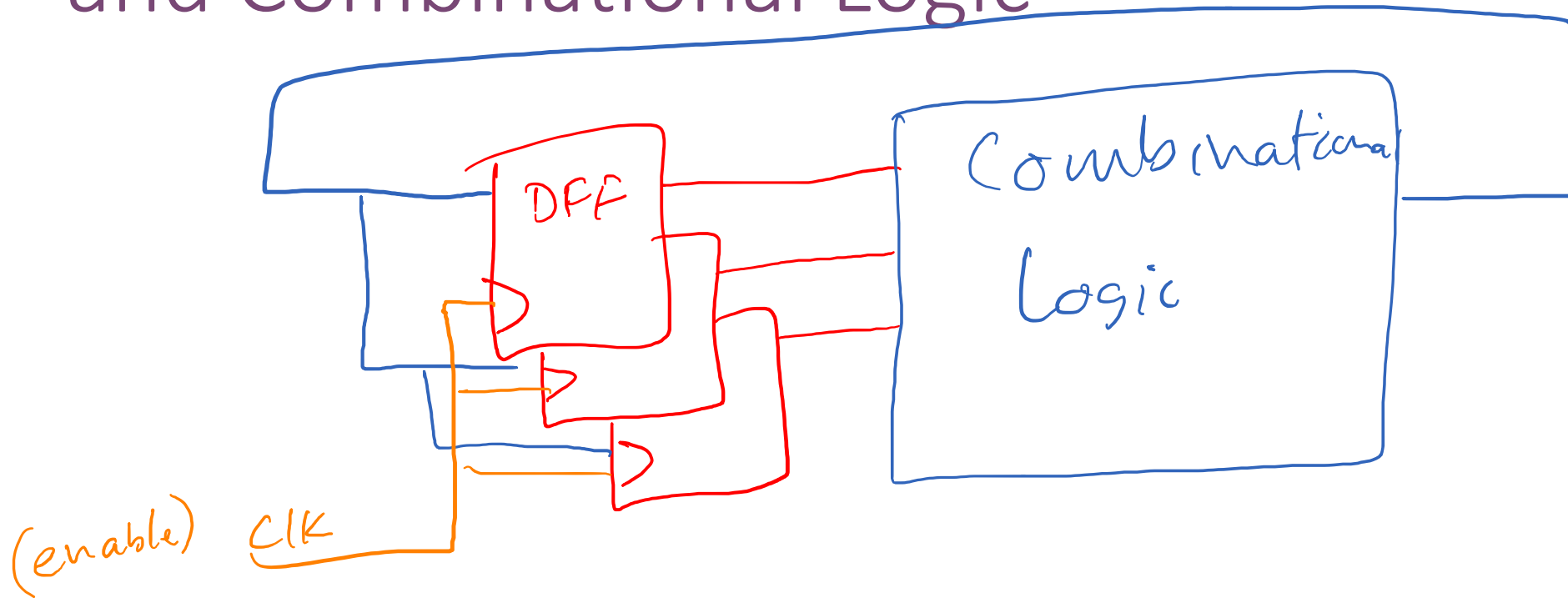
What does this do?

```
module mystery(  
    input          clk,    //clock  
    input          rst,    //reset  
    output logic   out     //output  
);  
  
    logic [3:0] Q;  
    logic [3:0] sum;  
  
    always_ff @( posedge clk ) // <- sequential logic  
    begin  
        if (rst) Q <= 4'h0;  
        else    Q <= sum;    //non-blocking  
    end  
  
    always_comb begin // <- combinational logic  
        sum = Q + 4'h1; //blocking  
        out = sum[3];  
    end  
  
endmodule
```

What does this do?

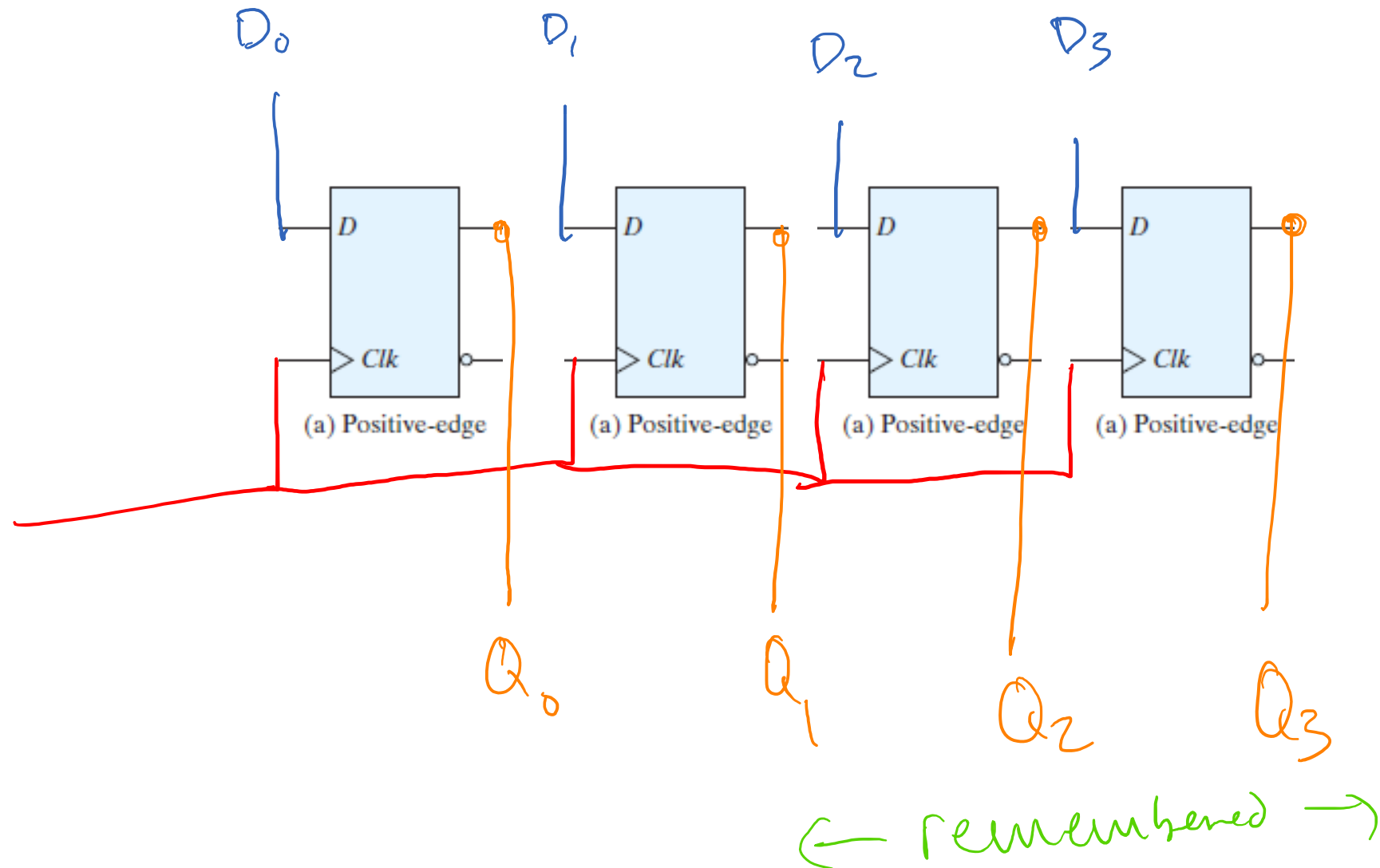
```
module counter(  
    input          clk,    //clock  
    input          rst,    //reset  
    output logic   out     //output  
);  
  
    logic [3:0] Q;  
    logic [3:0] sum;  
  
    always_ff @( posedge clk ) // <- sequential logic  
    begin  
        if (rst) Q <= 4'h0;  
        else     Q <= sum;      //non-blocking  
    end  
  
    always_comb begin // <- combinational logic  
        sum = Q + 4'h1; //blocking  
        out = sum[3];  
    end  
  
endmodule
```


Sequential Logic uses both Flip-Flops and Combinational Logic



Registers

Switches



4-bit Register in Verilog

```
module d_ff (
    input          d,    //data
    input          clk,  //clock
    input          rst,  //reset
    output logic   q     //output
);

    always_ff @( posedge clk )
    begin
        if (rst) q <= 'h0; //reset case
        else    q <= d; //non-reset case
    end

endmodule
```

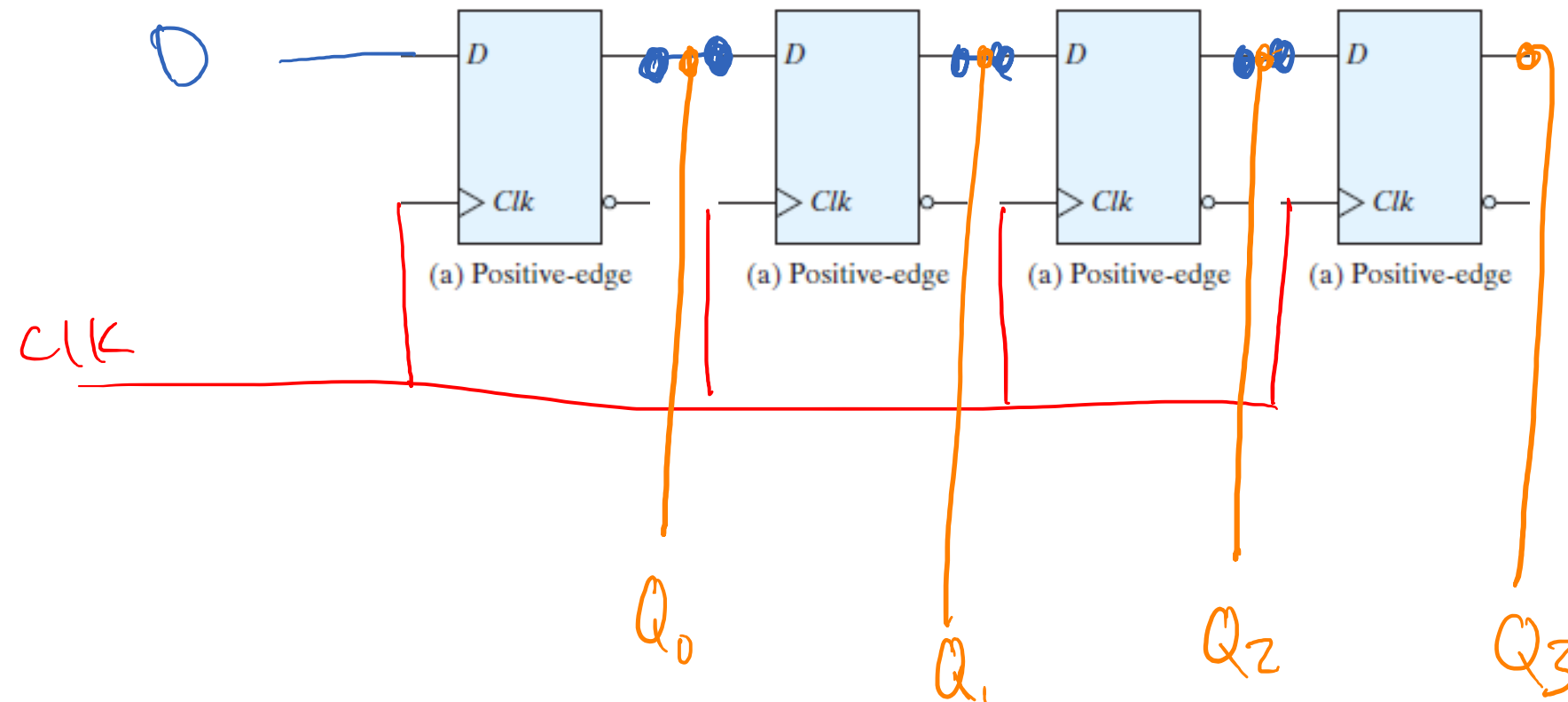
4-bit Register in Verilog

```
module d_ff (
    input          [3:0] d,  //data
    input          clk, //clock
    input          rst, //reset
    output logic [3:0] q  //output
);

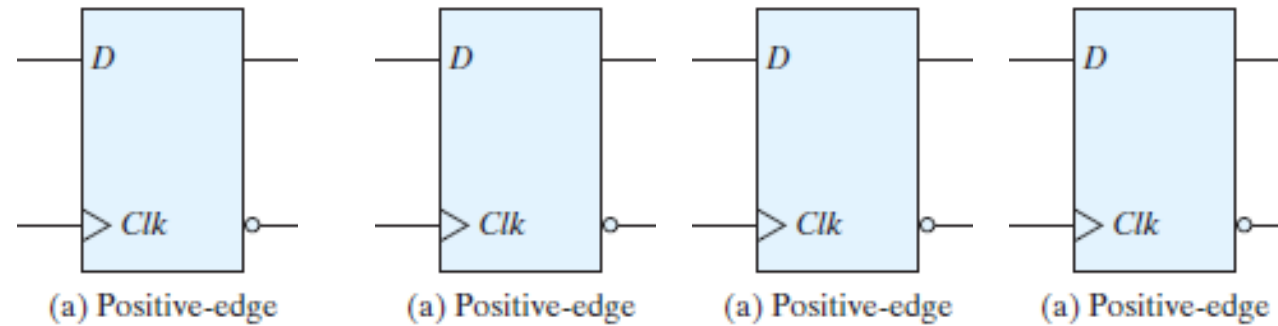
    always_ff @( posedge clk )
    begin
        if (rst) q <= 'h0; //reset case
        else    q <= d; //non-reset case
    end

endmodule
```

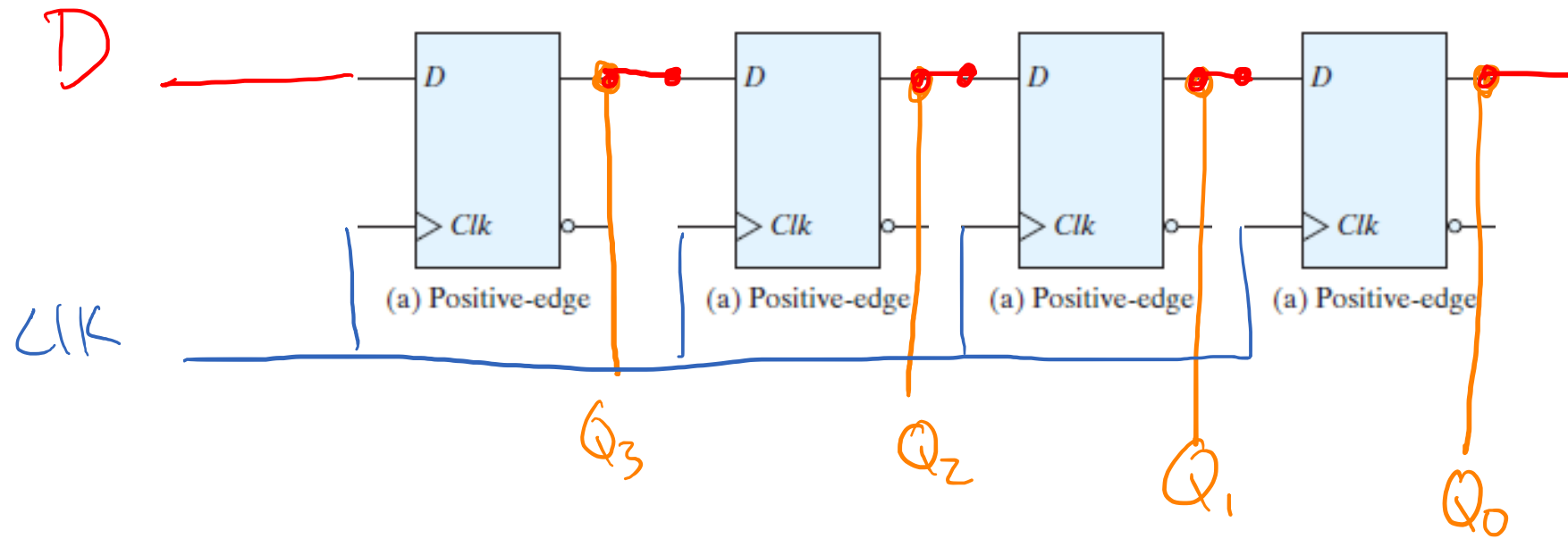
D Flip-Flops as Shift Registers



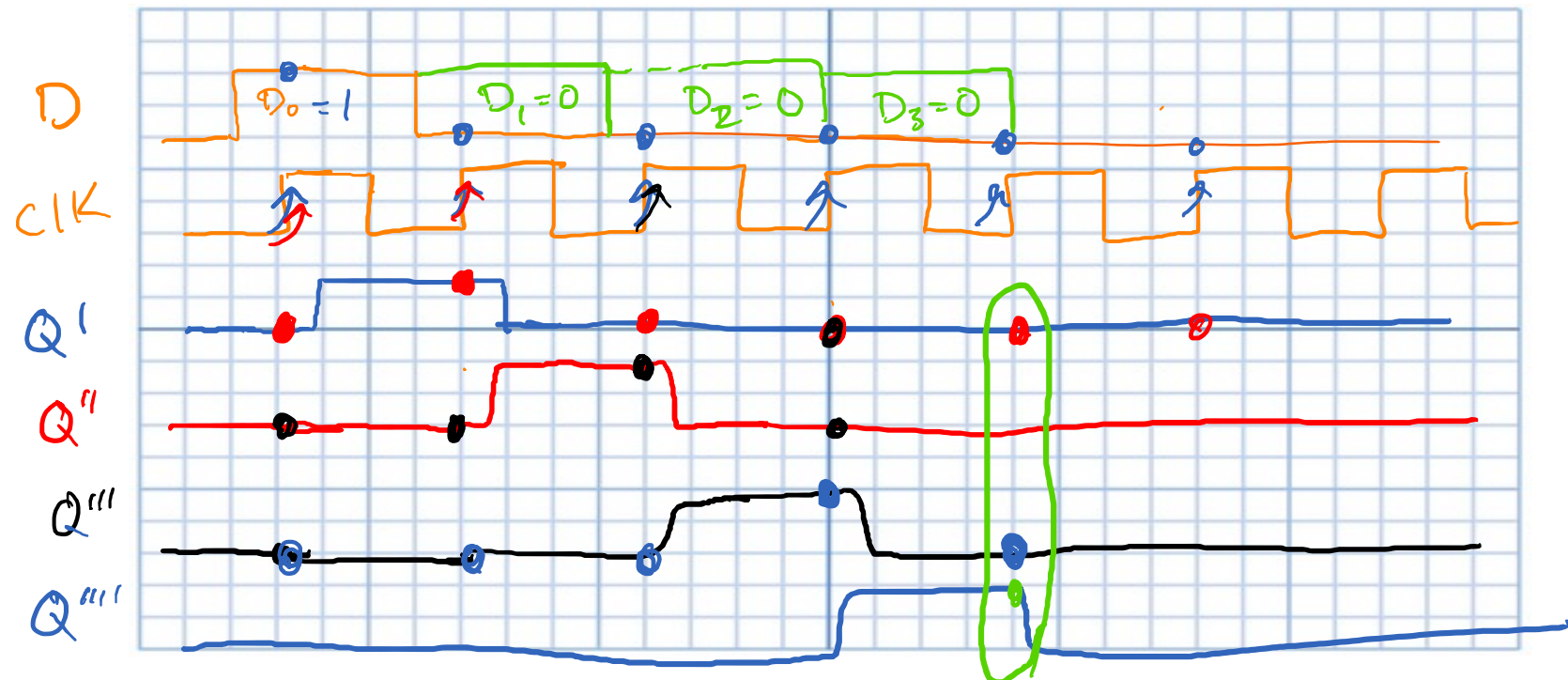
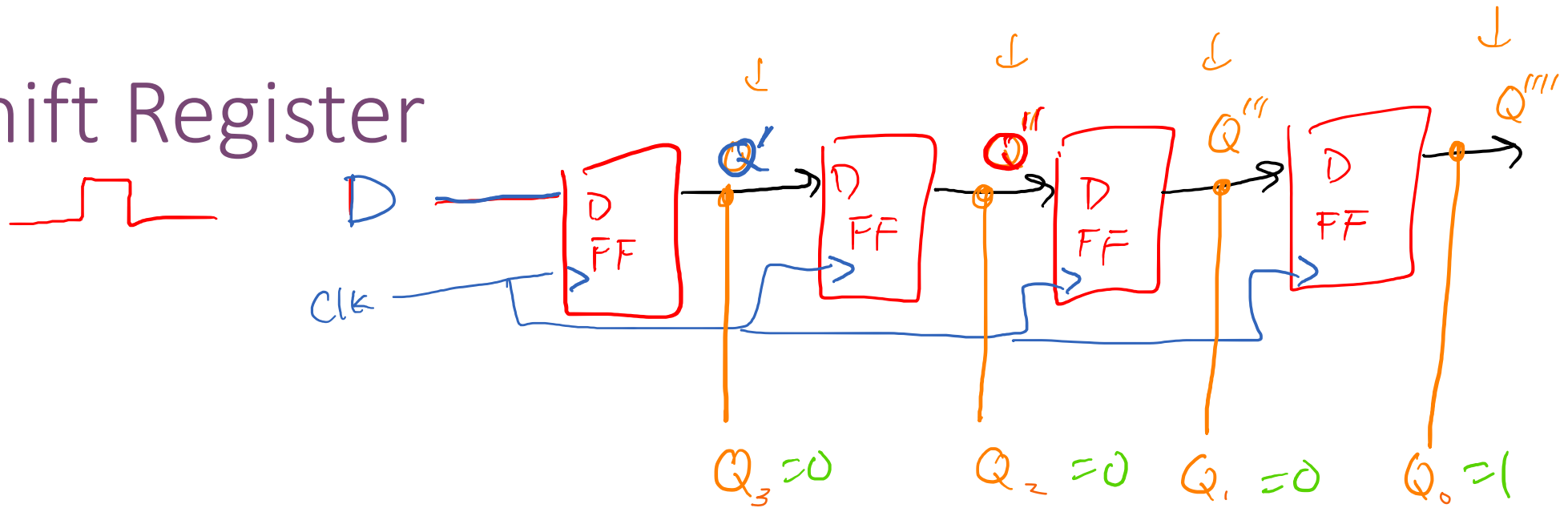
D Flip-Flops as Shift Registers



D Flip-Flops as Shift Registers

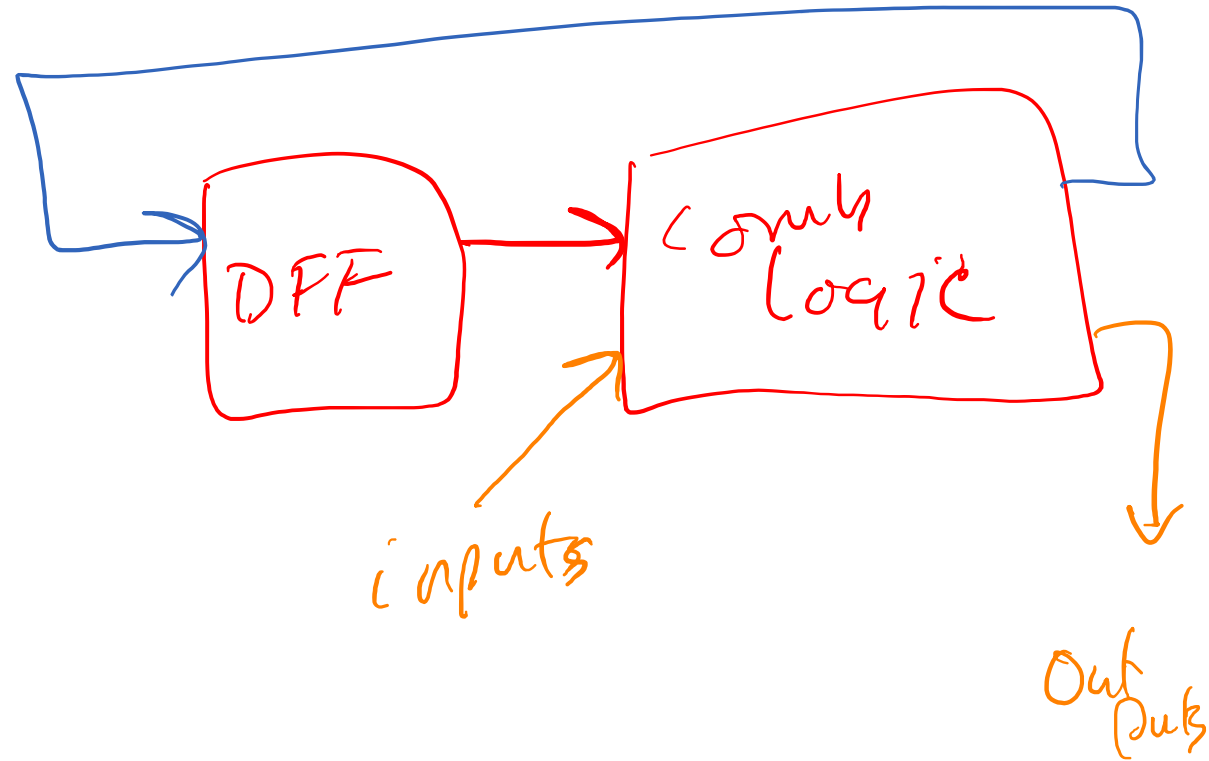


Shift Register



Shift-Register in Verilog

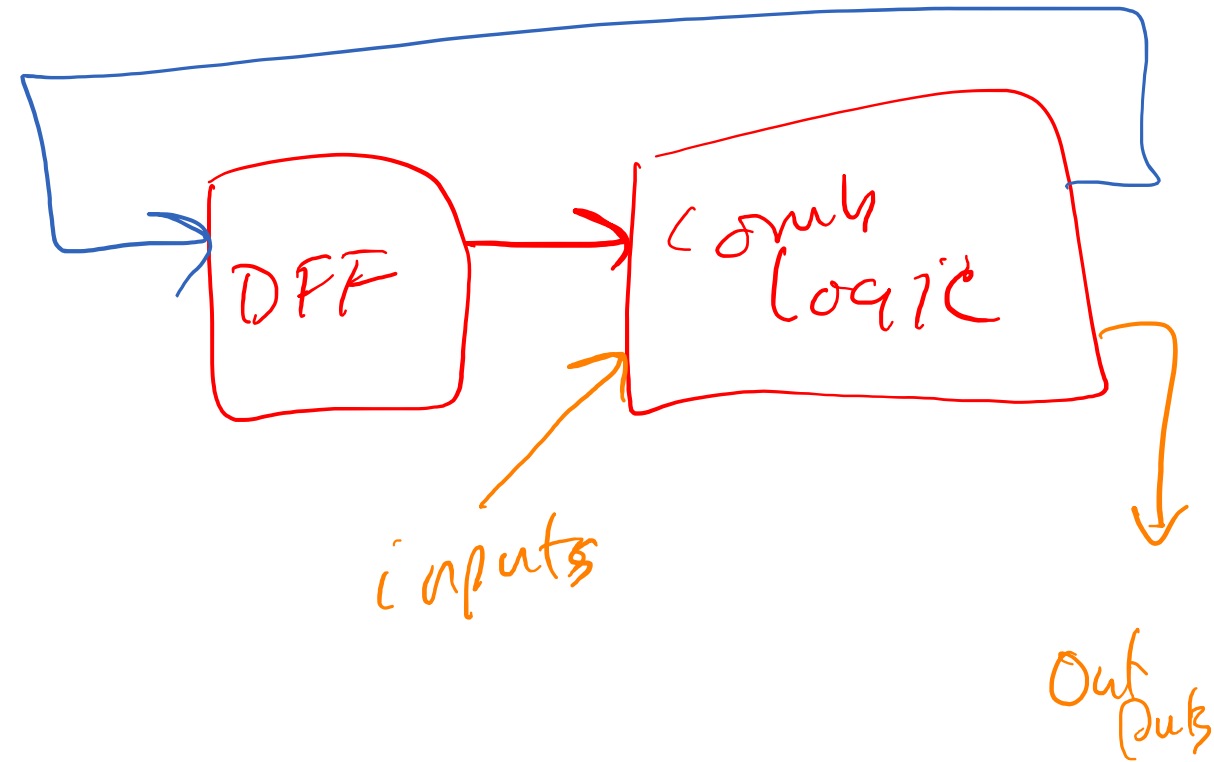
```
module shift_register (  
    input clk, rst, D,  
    output [3:0] Q );
```



```
endmodule
```

Shift-Register in Verilog

```
module shift_register (  
    input clk, rst, D,  
    output [3:0] Q );  
  
    logic [3:0] dff;  
    logic [3:0] next_dff;  
  
    always_ff(@posedge clk) begin  
        if (rst) dff <= 4'h0;  
        else     dff <= next_dff;  
    end  
  
    always_comb  
        next_dff = { dff[2:0], D};  
  
    assign Q = dff;  
  
endmodule
```



Shift-Register in Verilog

```

module shift_register (
    input clk, rst, D,
    output [3:0] Q );

    logic [3:0] dff;
    logic [3:0] next_dff;

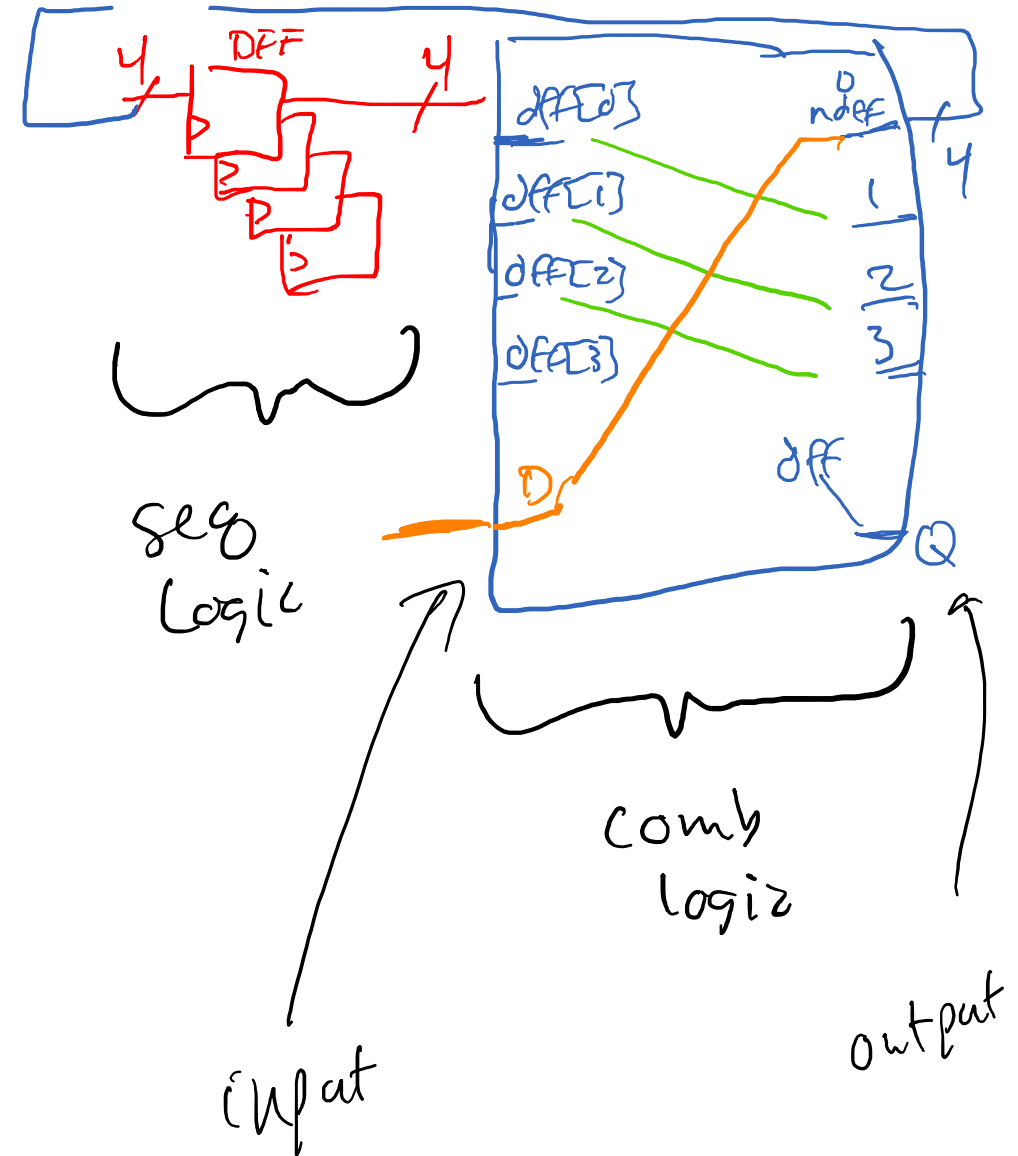
    always_ff(@posedge clk) begin
        if (rst) dff <= 4'h0;
        else     dff <= next_dff;
    end

    always_comb
        next_dff = { dff[2:0], D};

    assign Q = dff;

endmodule

```



Inputs can affect output or state

```
module counter(  
    input clk, rst  
    input          out_fast, //faster output  
    output logic   out      //output  
);  
    logic [3:0] Q;  
    logic [3:0] sum;  
  
    always_ff @( posedge clk ) begin  
        if (rst) Q <= 4'h0;  
        else    Q <= sum;  
    end  
  
    always_comb begin  
        sum = Q + 4'h1;  
        out = sum[3];  
    end  
  
endmodule
```

```

module counter(
    input clk, rst
    input out_fast, //faster output
    output logic out //output
);
    logic [3:0] Q;
    logic [3:0] sum;

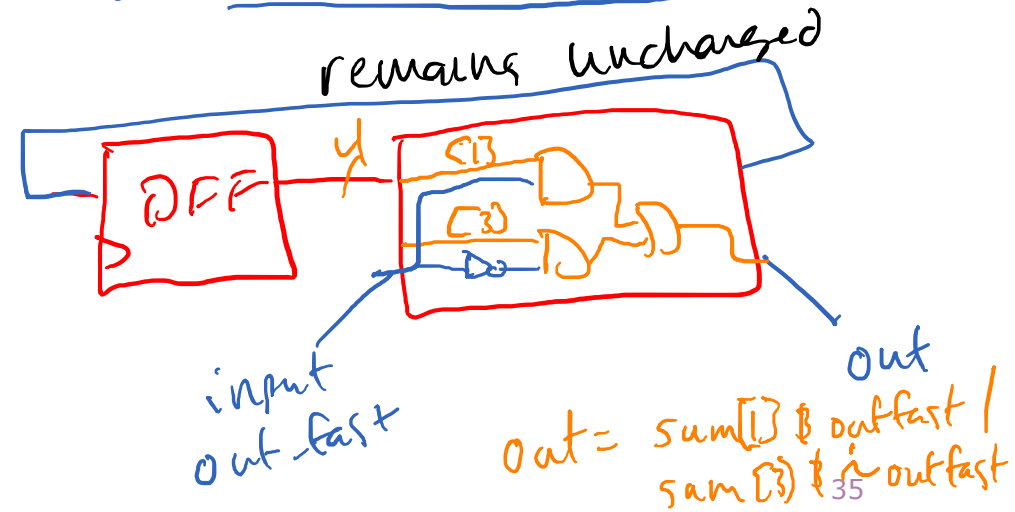
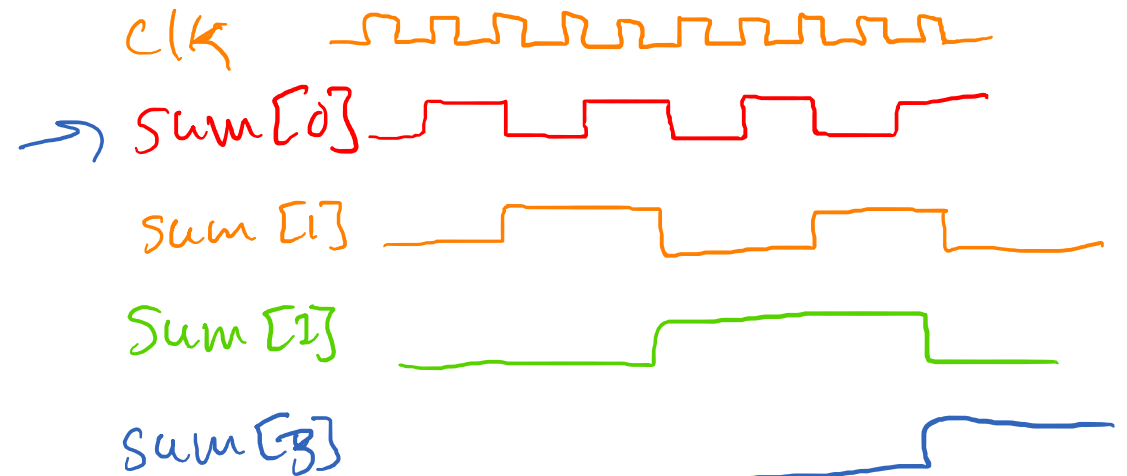
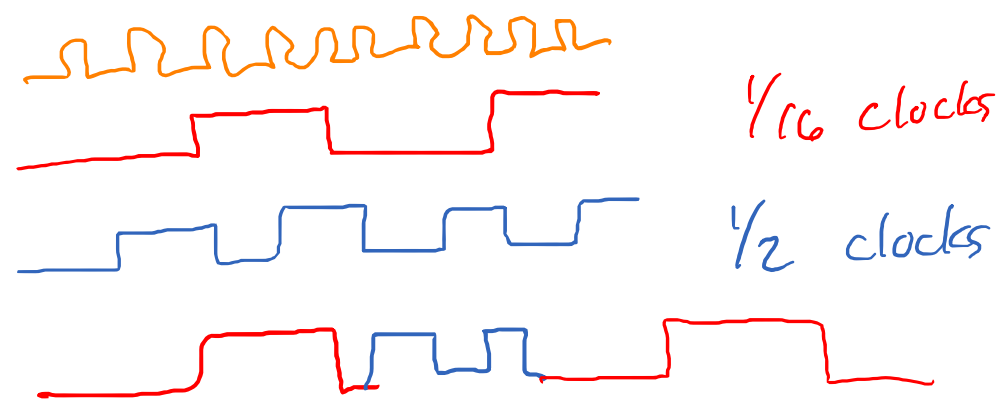
    always_ff @( posedge clk ) begin
        if (rst) Q <= 4'h0;
        else Q <= sum;
    end

    always_comb begin
        sum = Q + 4'h1;
        ✓ out = sum[3]; //default
        ✓ if (out_fast) out = sum[1];
    end
endmodule

```

out_fast=0

out_fast=1




```

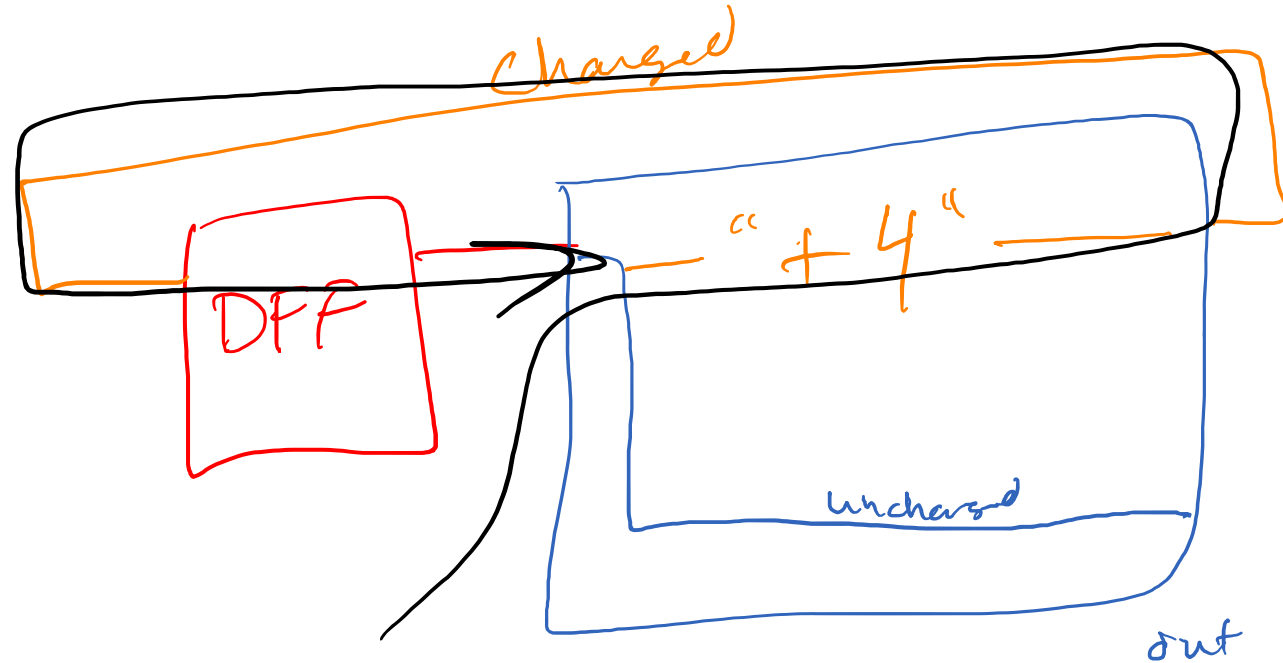
module counter(
    input clk, rst
    input          out_fast, //faster output
    output logic   out       //output
);
    logic [3:0] Q;
    logic [4:0] sum;

    always_ff @( posedge clk ) begin
        if (rst) Q <= 4'h0;
        else    Q <= sum;
    end

    always_comb begin
        sum = Q + 4'h1;
        out = sum[3];
        ↪ if (out_fast) sum = {0,Q} + 5'h4;
    end

endmodule

```



Next Time

- Finite State Machines (FSMs)