
Section 3

— Test Benches —

Administrivia

- **Lab 3:** Report due next Wednesday (10/23) @ 2:30 pm, demo by last OH on Friday (10/25), but expected during your assigned slot.
- **Lab 4:** Report due 10/30, demo by last OH on 11/1



New SystemVerilog Commands

- `always_comb` – higher-level description of more complex combinational behavior.
 - Used to combine multiple assignment statements or express more situational assignments.
- `case/endcase` – describe desired behavior situationally (based on value of expression)
 - Like a switch statement in other languages, but no fall-through and no `break`.
 - Use `default` to cover remaining cases.
- Use `begin` and `end` to group multiple statements together.
 - Like { and } in other languages.
 - e.g., to put multiple statements in one `always_comb` or for one case

Test Benches

Writing a Test Bench

- 1) Start with the module skeleton (`module` / `endmodule`).
 - a) Please use the naming convention of `<module_name>_tb`
- 2) Create signals for all ports of the module you're going to test.
 - a) Suggested to copy-and-paste from module definition, but remove port types (*i.e.*, `input`, `output`).
- 3) Instantiate device under test (`dut` as instance name)
 - a) Port connections: `.<port>(<signal>)` but names match can do `.<port>` as shorthand, or `.*` if all signal names match port names.
- 4) Define test vectors in an `initial` block.
 - a) Needs to end with `$stop`; system task for ModelSim to pause.

Test Vectors for Combinational Logic

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 - Note that our ModelSim setup has all combinational logic delays set to 0.

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- In order to have output values be visible in simulation, need to add arbitrary time delays `#<num>;` (e.g., `#10;`) in-between input changes.
 - Note that our ModelSim setup has all combinational logic delays set to 0.
- Can use “for-loop” to run through all input combinations:

```
for (int i; i < 8; i++) begin
    // set inputs based on i, then time delay
end
```

 - No sequential execution just condenses your code.

Exercise 1

- Write a test bench for the provided `seg7` module from Lecture 3.
 - Be thorough, including all 16 input combinations!

```
module seg7 (bcd, leds);
  input logic [3:0] bcd;
  output logic [6:0] leds;

  always_comb
    case (bcd)
      //           Light: 6543210
      4'b0000: leds = 7'b0111111; // 0
      ... // implementation
      4'b1001: leds = 7'b1101111; // 9
      default: leds = 7'bX;
    endcase
endmodule // seg7
```


Exercise 1 (Solution)

- Instantiate device under test.

```
module seg7_tb ();  
    logic [3:0] bcd;  
    logic [6:0] leds;  
  
    seg7 dut (.bcd(bcd), .leds(leds));  
  
endmodule // seg7_tb
```

Exercise 1 (Solution)

- Instantiate device under test.
 - Alternatively, can use `.*` since our signals match the port names.

```
module seg7_tb ();  
    logic [3:0] bcd;  
    logic [6:0] leds;  
  
    seg7 dut (.*);  
  
endmodule // seg7_tb
```

Exercise 1 (Solution)

- Define `initial` block and add `$stop` system task.

```
module seg7_tb ();
    logic [3:0] bcd;
    logic [6:0] leds;

    seg7 dut (.*);

    int i;
    initial begin

        $stop;
    end
endmodule // seg7_tb
```

Exercise 1 (Solution)

- Test all possible combinations of inputs.

```
module seg7_tb ();  
    ... // signal declarations & dut instantiation  
  
    int i;  
    initial begin  
        for (i = 0; i < 16; i++) begin  
            bcd = i; #20;  
        end  
        $stop;  
    end  
  
endmodule // seg7_tb
```

Exercise 2

- Write a test bench for the `guessing_game` module from Section 2.
 - Be thorough: how many input combinations are there?

```
// Game to check user's 3-bit input guess against a hard-coded  
secret #  
// - SW[2:0] is the guess, KEY[0] is check  
// - LEDR[0] is <, LEDR[1] is ==, LEDR[2] is >  
module guessing_game (  
    output logic [9:0] LEDR,  
    input  logic [3:0] KEY,  
    input  logic [9:0] SW  
);  
  
    ... // implementation  
  
endmodule // guessing_game
```

Exercise 2 (Solution)

- First we declare our simulated port connections.
 - Can copy-and-paste port declarations and remove `input/output`.

```
module guessing_game_tb ();  
    logic [9:0] LEDR;  
    logic [3:0] KEY;  
    logic [9:0] SW;  
  
endmodule // guessing_game_tb
```


Exercise 2 (Solution)

- Instantiate device under test.

```
module guessing_game_tb ();
    logic [9:0] LEDR;
    logic [3:0] KEY;
    logic [9:0] SW;

    guessing_game dut (
        .LEDR(LEDR),
        .KEY(KEY),
        .SW(SW)
    );

endmodule // guessing_game_tb
```

Exercise 2 (Solution)

- Instantiate device under test.
 - Alternatively, can use `.*` since our signals match the port names

```
module guessing_game_tb ();  
    logic [9:0] LEDR;  
    logic [3:0] KEY;  
    logic [9:0] SW;  
  
    guessing_game dut (.*);  
  
endmodule // guessing_game_tb
```

Exercise 2 (Solution)

- Define `initial` block and add `$stop` system task.

```
module guessing_game_tb ();
    logic [9:0] LEDR;
    logic [3:0] KEY;
    logic [9:0] SW;

    guessing_game dut (.*);

    initial begin

        $stop;
    end
endmodule // guessing_game_tb
```

Exercise 2 (Solution)

- Test all possible combinations of inputs.

```
module guessing_game_tb ();
    ... // signal declarations & dut instantiation

    initial begin
        KEY[0] = 1'b1; #10; // KEYS are active low
        for (int i = 0; i < 8; i++) begin
            SW[2:0] = i; KEY[0] = 1'b0; #10; // LEDs should light up
            KEY[0] = 1'b1; #10; // LEDs should be disabled
        end
        $stop;
    end
endmodule // guessing_game_tb
```

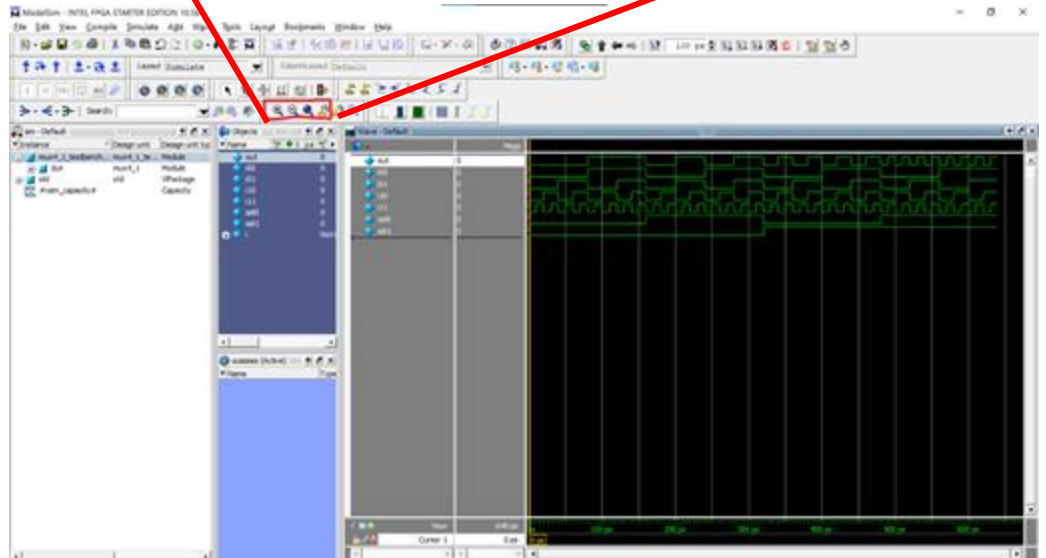
ModelSim Tips & Tricks

Simulation Workflow (Review)




- Double-click `Launch_ModelSim.bat` in the project directory.
- In a text editor, modify `runlab.do` for your project:
 - Add files to compile (modules + test benches).
 - Change which test bench you wish to simulate.
 - Change the waveform script file (`*_wave.do`) – this won't exist at first.
- Execute `do runlab.do` in the *Transcript* pane.
 - Use waveforms to verify/debug logical behavior of your module(s).
- Update waveform script file as desired.
 - Click on different modules in the *sim* pane to access different signals.
 - Drag signals from the *Objects* pane into the *Wave* pane.
 - With the *Wave* pane selected, Ctrl+S to overwrite your waveform script file.

Zoom Tools

- Zoom tools allow you to adjust the amount of the simulation you can view at once as well as the visibility of the signal values.
 - Critical for generating understandable screenshots for your lab reports!

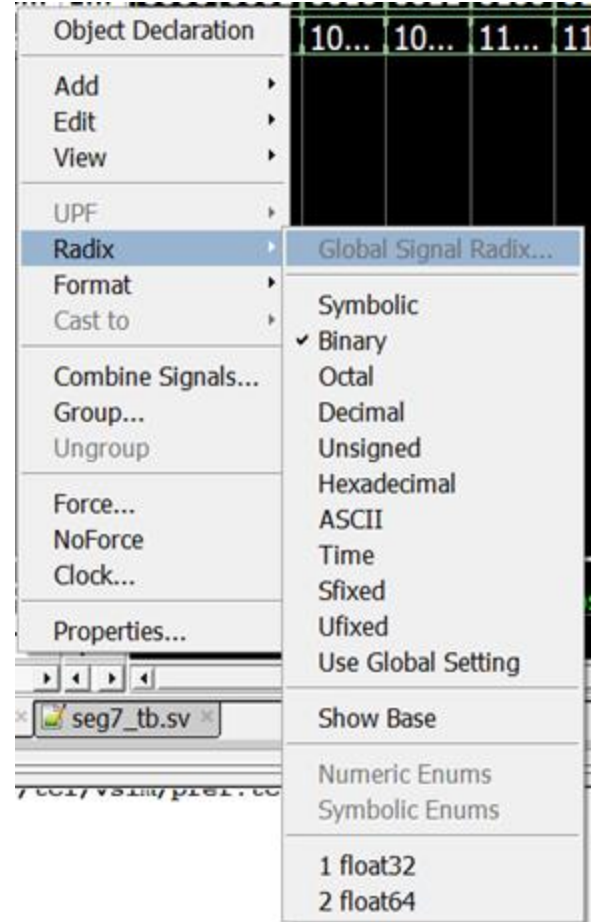


Zoom Tools

- Zoom in/Zoom out 
 - Allows you to change the amount of information shown at once (e.g., 200 ps at a time, 1000 ps at a time).
- Zoom Full 
 - Automatically zooms to show the whole simulation at once.
 - Good for short simulations, not great for longer simulations.
- Zoom In on Active Cursor 
 - Zooms in based on the location of the yellow cursor.

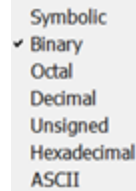
Signal Radix

- Right-click a signal in the Wave pane and use the “Radix” menu to change the display of a signal’s value
 - This does NOT change the actual bits, just how we interpret them!!!
 - Common choices: Binary (default), Unsigned, Decimal (*i.e.*, signed integer), Hexadecimal



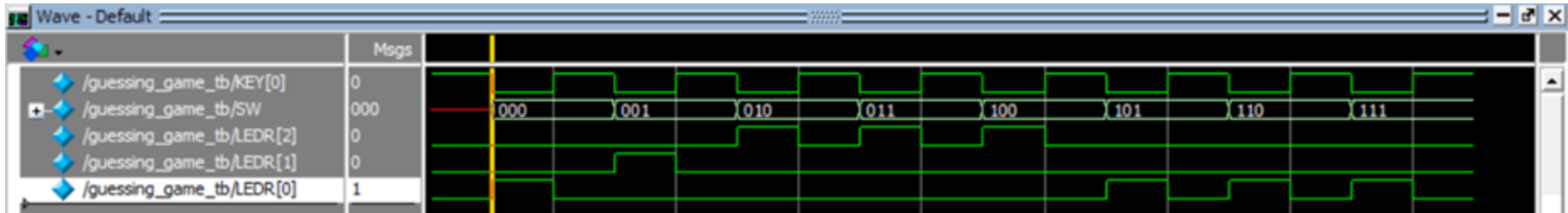
Exercise 3

- Run your `guessing_game` simulation in ModelSim and use it to identify a few input combinations that produce the wrong outputs for *signed* integer interpretation.
 - Tools we just covered: zoom tools and signal radix.



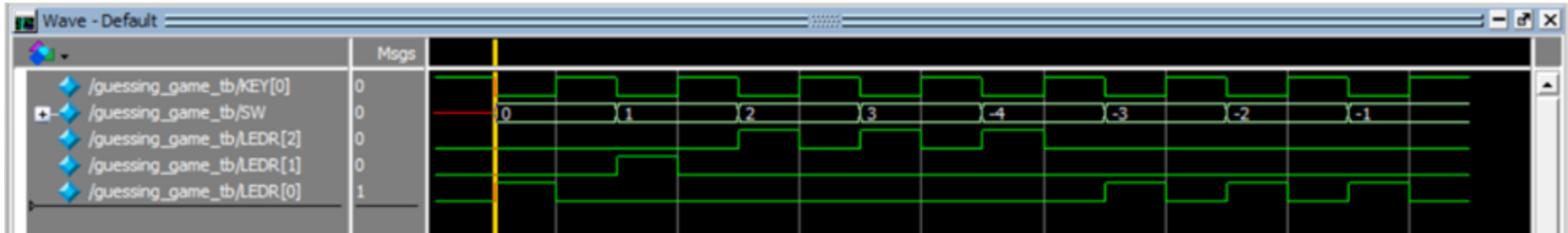
Exercise 3 (Solution)

- By dragging the relevant signals from the Objects window to our Wave window, we get the following waveform:



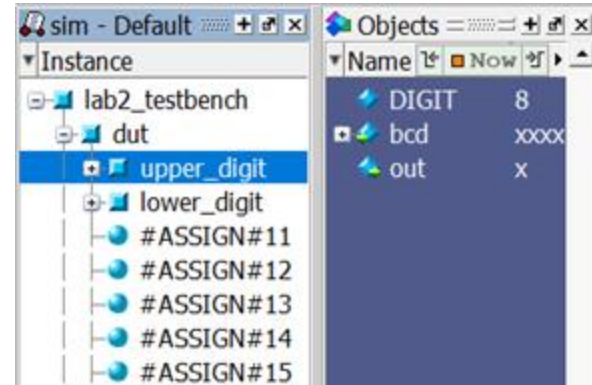
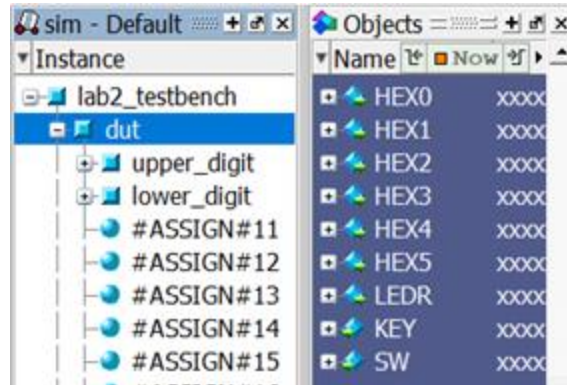
Exercise 3 (Solution)

- Let's make the waveform more interpretable!
 - Since we are interpreting the switch signals as *signed* numbers, we should change the radix to be Decimal.



Internal Signals

- ModelSim lets you add internal signals from any instantiated module to your simulation!
 - Incredibly useful to trace buggy or unexpected values to their source.
 - Click **[+]** next to an instance name to reveal submodules (by instance name).
 - Click the instance name to access different internal signals in the Objects pane:



Exercise 3 (Debugging)

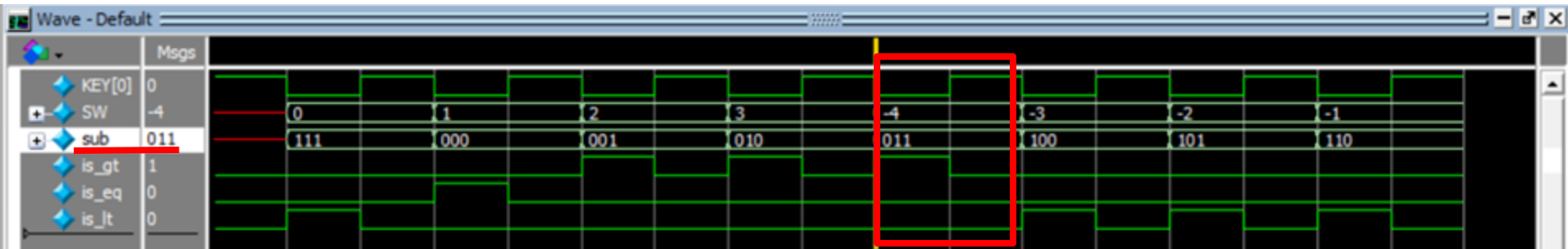
- Our secret num is **1** but our system reports that **-4** is greater...?
 - `LEDR[2:0] = { is_gt&~KEY[0], is_eq&~KEY[0], is_lt&~KEY[0] };`



- Let's investigate further:
 - We know that `is_gt` is an output of the comparator module (instantiated within `dut` as `number_comparator`).
 - Can add `sub` signal from within the comparator module to the waveform!

Exercise 3 (Debugging)

- Let's investigate further:
 - We know that `is_greater_than` is an output of the comparator module (instantiated within `dut`).
 - Can add `sub` signal from within the comparator module to the waveform!




- `-4 - 1` is returning `3'b011` (`-5` can't be represented in 3 bits), so the outputs produce unexpected values!

Lab Reports

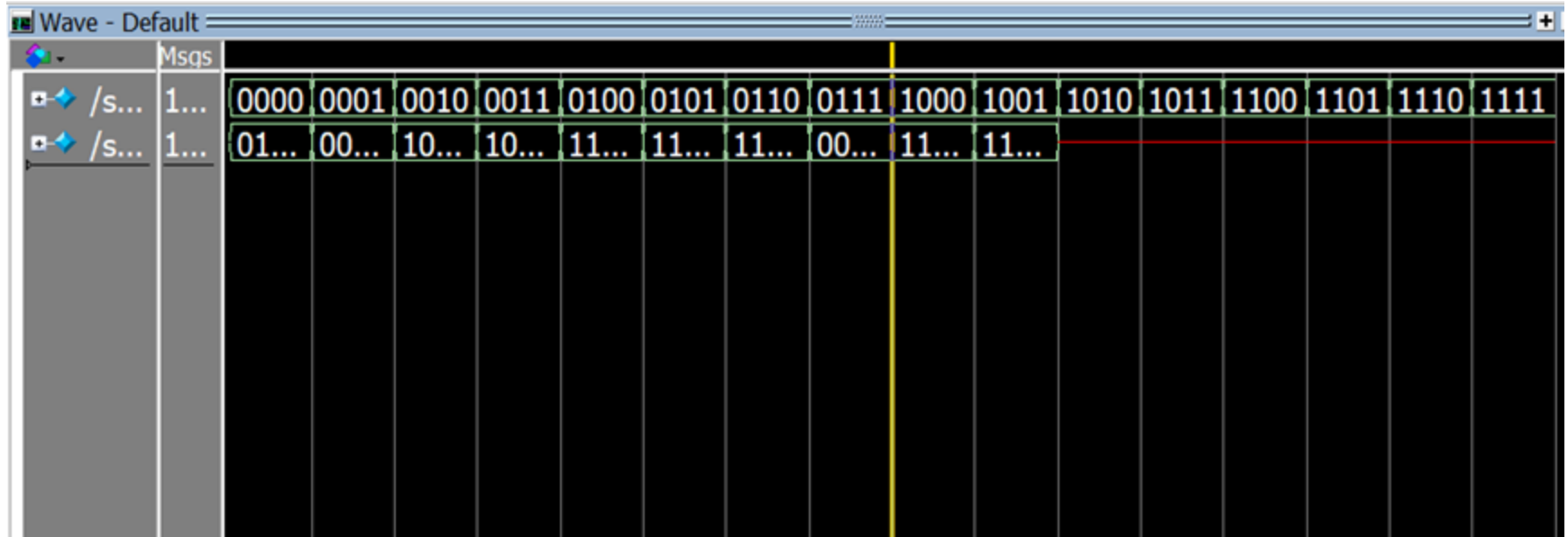
Simulations for Lab Reports

- You are using simulations to **communicate** something to the reader.
 - Usually, “proving” correct behavior of your circuit/system.
 - Difficult to interpret on their own, so accompanying **explanation** is *critical*.
 - Useful both to the grader and to you looking back on this work in the future.

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- You are using simulations to **communicate** something to the reader.
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 - Difficult to interpret on their own, so accompanying **explanation** is *critical*.
 - Useful both to the grader and to you looking back on this work in the future.
- Goals and Tips:
 - All of simulation is included – can be split across multiple images, if needed.
 - Helpful to design test bench to be as concise as possible.
 - Labeling – time (horizontal) axis and all signal names are clearly visible.
 - Can undock  the Wave pane to change window size or can drag vertical divider of Transcript pane up to get time axis label closer to signals.
 - Toggling to **leaf names** shortens signal names.
 - All signal values are visible throughout the simulation.
 - Changing radix can help condense but should make sense in context.

Simulations for Lab Reports (BAD Example)

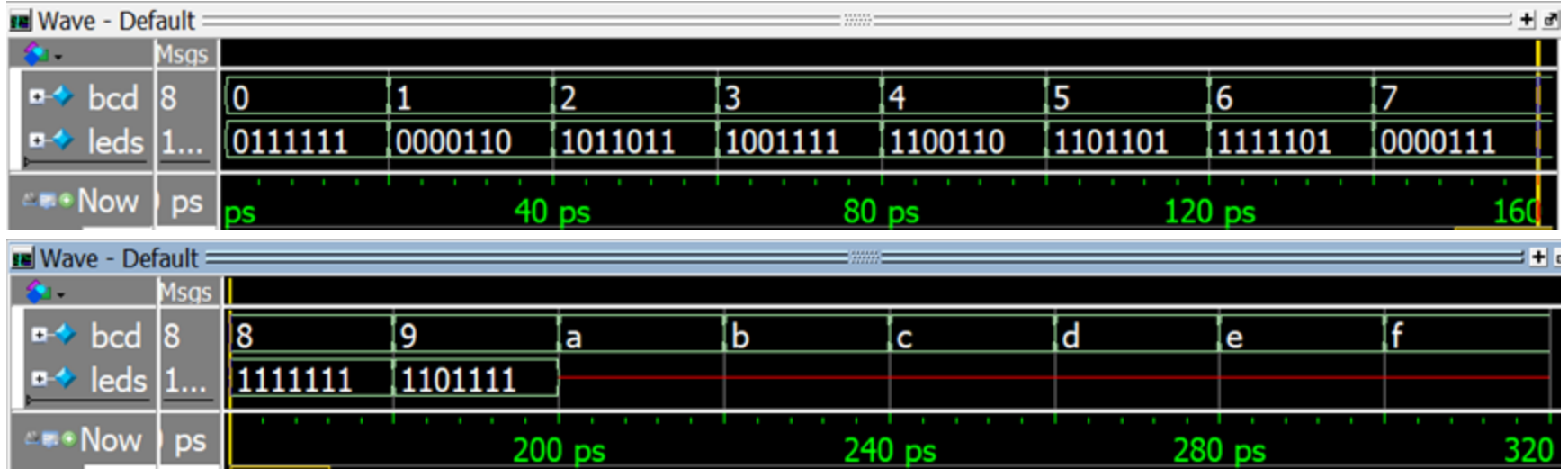


The screenshot shows a logic analyzer window titled "Wave - Default". The main display area is a timing diagram with a black background and white text. The top row of data is highlighted in green and contains the binary sequence: 0000 0001 0010 0011 0100 0101 0110 0111 1000 1001 1010 1011 1100 1101 1110 1111. The second row of data is highlighted in red and contains: 01... 00... 10... 10... 11... 11... 11... 00... 11... 11... followed by several empty columns. A vertical yellow cursor is positioned between the 8th and 9th columns. The left sidebar shows a tree view with two entries labeled "/s..." and "1...".

0000	0001	0010	0011	0100	0101	0110	0111	1000	1001	1010	1011	1100	1101	1110	1111
01...	00...	10...	10...	11...	11...	11...	00...	11...	11...						

- What are we looking at here???

Simulations for Lab Reports (GOOD Example)



- Split across two images to make values of `leds` legible.
- Changed `bcd` radix to hexadecimal: easier to read and matches use case.
 - Decimal would work here, too.
- Can refer to specific times in simulation in explanation now.