

# Learn RISC-V CPU Implementation and **BSV**

(**BSV**: a High-Level Hardware Design Language)

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L9: **BSV**: Finite State Machines/StmtFSM



# Reminders

Please git clone: [https://github.com/rsnikhil/Learn\\_Bluespec\\_and\\_RISCV\\_Design](https://github.com/rsnikhil/Learn_Bluespec_and_RISCV_Design)  
(git pull for latest version). Repository structure:

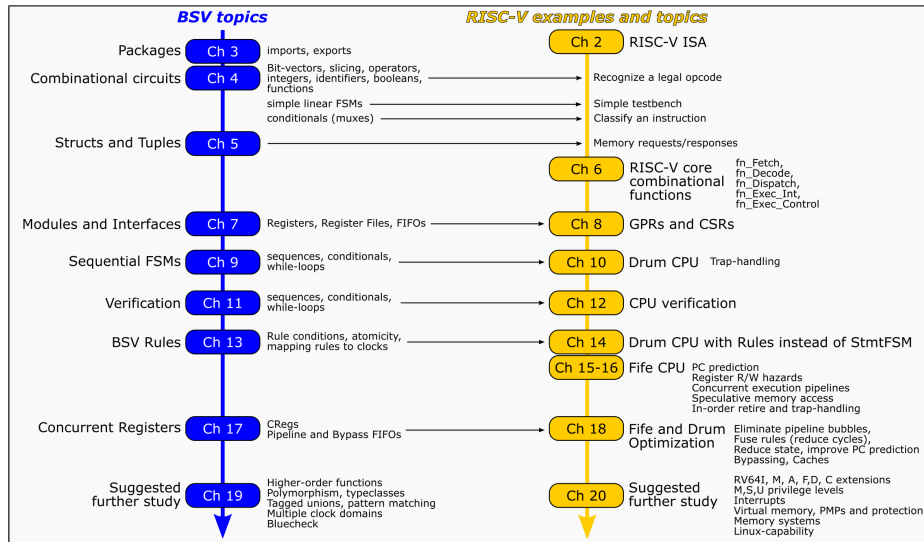
```
./Book_BLang_RISCV.pdf
  Slides/
    Slides_01_Intro.pdf
    Slides_02_ISA.pdf
    ...
  Exercises/
    Ex-03-A-Hello-World/
    Ex-03-B-Top-and-DUT/
    ...
  Code/
    src_Top/
    src_Drum/
    src_Fife/
    src_Common/
    ...
  Doc/Installing_bsc_Verilator_etc.{adoc,html}
```

- Slides and Exercise are numbered in sync with book Chapter numbers.
- For Exercises, please see Appendix E of the book. Some (not all) exercises have associated code in the Exercises/ directory.

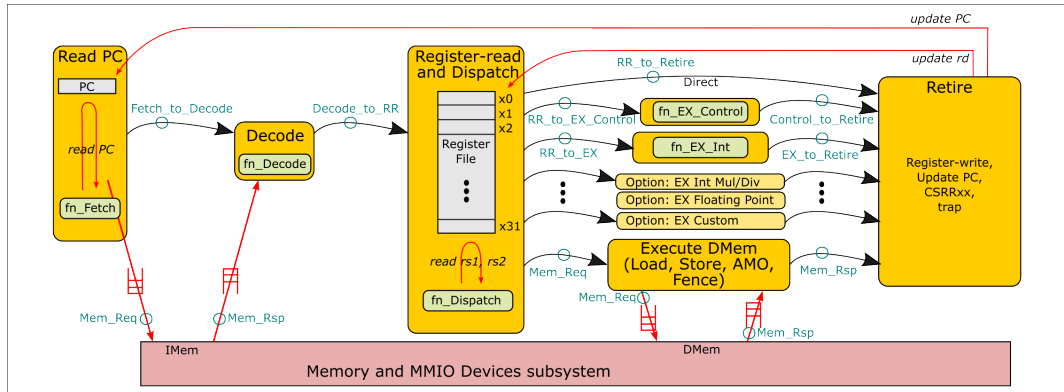
To compile and run the code for exercises, Drum and Fife, please make sure you have installed:

- bsc compiler (see <https://github.com/B-Lang-org/bsc>)
- Verilator compiler (see <https://www.verilator.org/>)

# Chapter Roadmap



# Flow of information between stages in Drum and Fife

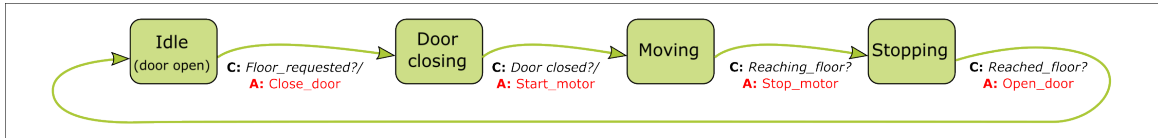


# Classical Finite State Machines (FSMs): Bubble-and-Arrow diagrams

An FSM is a *process*, a behavior that evolves over time.

A classical notation for describing/specifying FSMs is the bubble-and-arrow diagram.

Here is a (greatly over-simplified) FSM spec for controlling an elevator:

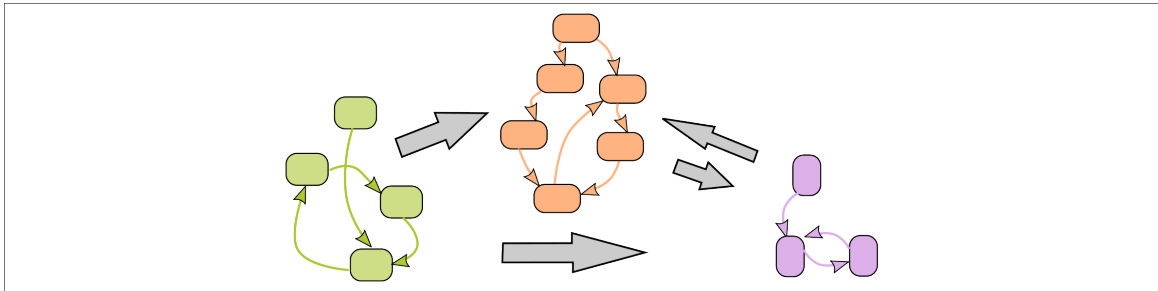


Each state of the process is depicted by a bubble. Each arrow depicts a transition to another state enabled by a condition (C:) and performing an action (A:).

The RISC-V instruction-execution flow diagram can be interpreted as an FSM bubble-and-arrow diagram, and implemented that way. This is exactly what Drum is.

# Sequential vs. Concurrent FSMs

Most hardware systems (except for extremely simple ones) are best viewed as *communicating, concurrent FSMs*:



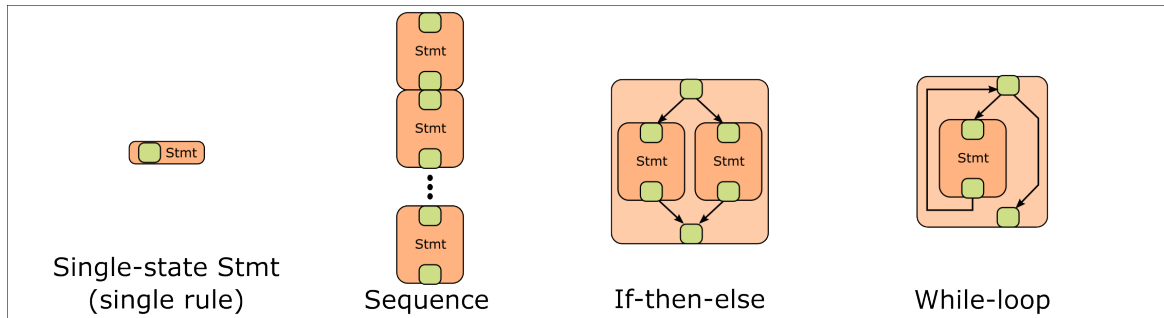
Multiple FSMs communicate with each other (*via* registers, register files, FIFOs, ...).

*Note:* theoretically multiple FSMS are equivalent to a single FSM, but the size of such a single-FSM description can be MUCH larger. This is because we have to describe all possible combinations of states where when one FSM is in state  $A_j$  and another FSM is simultaneously in state  $B_k$ .

# BSV: StmtFSM: sub-language for specifying structured FSMs

StmtFSM is a sub-language in **BSV** for specifying structured FSMs.

- We start with an expression of type **Action**.
- Then, we *compose* larger FSMs from smaller FSMs using sequencing, if-then-else and while-loop constructs.



Each construct produces an expression of type **Stmt**.

# BSV: A single-state FSM

Example:

```
seq
  action
    rg_pc <= rg_pc + 4;           // Assignment to a register
    f_F_to_D.deq;                // Dequeue a fifo
    f_D_to_RR.enq (v);           // Enqueue into a fifo
    $display ("Hello, World!");  // Print something (in simulation only)
  endaction
endseq
```

The seq-endseq construct is an expression of type Stmt.

All actions in an action-endaction block take place *simultaneously* and *instantaneously*, no matter the textual order in which they are written.

(In hardware, all their ENABLE signals are asserted simultaneously, and they are all performed on the next clock signal.)



# BSV: Action-blocks can contain name-bindings

Example:

```
action
  Bit #(XLEN) next_pc = rg_pc + 4;
  rg_pc <= next_pc;
  $display ("Next PC is %08h", next_pc);
  ...
  let y <- pop_o (to_FIFOF_0 (f_mem_rsps));
  ...
  $display ("mem_rsp is ", fshow (y));
endaction
```

# BSV: Linear Sequence flows

```
seq
  ... Action or Stmt ...
  ... Action or Stmt ...
  ...
  ... Action or Stmt ...
endseq
```

*Note:* A sequence of  $n$  actions may not complete in  $n$  clocks.

Actions execute according to usual **BSV** semantics—an action may implicitly stall (be paused) until all the methods it invokes are READY.

Library-provided actions to explicitly pause an FSM:

```
seq
  ...
  await (... Bool expr ...)      // pause until some condition
  delay (... numeric expr ...)   // pause for n cycles
  ...
endseq
```

# BSV: Conditional and loop flows

Conditional flows:

```
if (... Bool expr ...)  
  ... Action or Stmt ...  
else  
  ... Action or Stmt ...
```

Note: “if (b) ... else ...” is used in **BSV** in two different ways:

- In computation, where they represent hardware MUXes (multiplexers)
- In StmtFSM, where they represent alternative temporal FSM flows

But there is no ambiguity, because these are distinct contexts.

Loop flows:

```
while (... Bool expr ...)  
  ... Action or Stmt ...
```

# BSV: Instantiating an FSM from a Stmt specification

```
mkAutoFSM (... argument expression of type Stmt ...);
```

- This statement occurs inside a module, along with other sub-module instantiations.
- This statement instantiates a sub-module whose behaviour is specified by the `Stmt`
- The FSM starts running as soon as the system comes out of reset.
- If the FSM reaches its end state, it executes a `$finish()` to stop simulation.

Note:

- (It may not reach the end state if it has an infinite while-loop.)
- (It may not reach the end state if some action gets stuck, e.g., trying to dequeue an empty FIFO.)

# BSV: StmtFSM final comments

- StmtFSM is frequently used in testbenches for sequentially producing test stimulus and sequentially consuming outputs (although, in Drum, we also use it in the design).
- StmtFSM can only express *structured* processes (composed by nesting seq-endseq, if, while).  
For more complex flows, and more fine-grain concurrency, we can directly use **BSV Rules** (e.g., we do this in Fife).  
[See also “Section 9.11 Historical Note about Structured Programming” for connections to modern software programming languages.]
- There are more ways to create Stmt's; see *bsc* library document.
- There are more module-constructors (than mkAutoFSM); see *bsc* library document.

End