Testers2

towards easy, friendly, fun testing!

CCCC 19

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This talk focuses on **directed testing** strategies

Fundamentally, think **non-synthesizable Verilog**

Assign

- Write (assign) the value of a wire

Delay

- Advances time

Assert

- Assert wire value equal to some reference

PeekPokeTesters currently supports these

Assign => **Poke**

- Write (assign) the value of a wire

Delay => **Step**

- Advances time, by a clock cycle

Assert => **Expect**

- Assert wire value equal to some reference

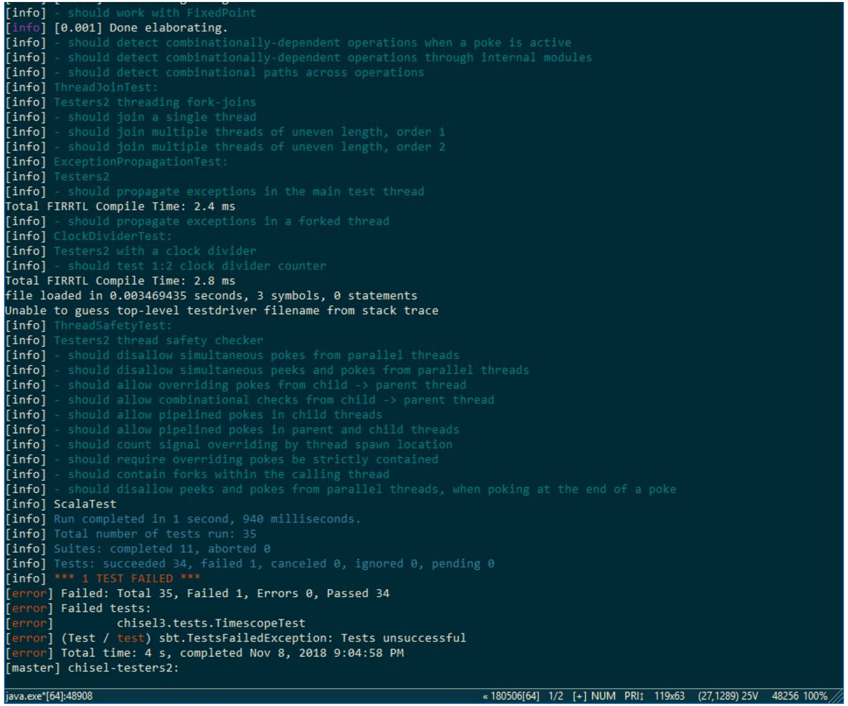
Peek

- Returns the value on a wire as a Scala numeric type

ScalaTest automates test invocation

ScalaTest

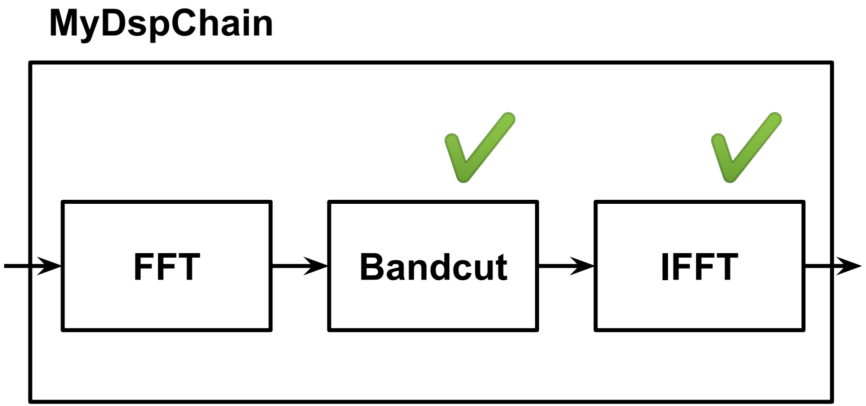
- Unit testing framework for Scala
- Automated test discovery and execution with just `sbt run`



PeekPokeTesters encourages unit testing

Unit testing is beneficial

- Good localization power
- Regressions testing
- Continuous integration
- Documentation



… but PeekPokeTesters doesn’t scale (well)

Need higher-level abstractions for system tests

- a step above peek and poke
- enqueue / dequeue
- stream abstractions

UVM provides for re-use

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```
class simpleadder_transaction
    extends uvm_sequence_item;
  rand bit[1:0] ina;
  rand bit[1:0] inb;
  bit[2:0] out;

  function new(string name = "");
    super.new(name);
  endfunction: new

  `uvm_object_utils_begin(
    simpleadder_transaction)
  `uvm_field_int(ina, UVM_ALL_ON)
    ...
  `uvm_object_utils_end
endclass: simpleadder_transaction
```

https://colorlesscube.com/uvm-guide-for-beginners/ (ch4)

UVM provides for re-use (but not well)

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endclass: simpleadder_transaction
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What do we want?

- Automated regressions
- Easy unit testing
- Scalable to system testing

Writing tests is easy

Minimize test invocation boilerplate

- Default `test()` method encapsulates common default configurations
- Test body inline with test invocation

```
"GCD should work" in {
test(new Gcd) { c =>

  … test body here …

}
}
```

Define basic test APIs on fundamental types

- (data)`.poke(`value`)`
- (data)`.expect(`value`)`
- (clock)`.step()`

```
test{new Gcd) { c =>
  c.in.bits.a.poke(15.U)
  c.in.bits.b.poke(6.U)
  c.clock.step(3)
  c.out.valid.expect(true.B)
  c.out.bits.expect(3.U)
}
```

Allow users to define custom abstractions

Custom Bundles can define test helper:

- (Decoupled)`.enqueue(`data`)`
- (Decoupled)`.dequeueExpect(`data`)`
- … or anything else you want

```
test(new Gcd) { c =>
  c.in.bits.a.poke(15.U)
  c.in.bits.b.poke(6.U)
  c.clock.step(3)
  c.out.valid.expect(true.B)
  c.out.bits.expect(3.U)
  c.out.dequeueExpect(3.U)
}
```

We need some kind of concurrency

FSM / Callbacks

- Similar to writing hardware (i.e., hard)
- Requires writing scaffolding of FSM, in addition to core test logic

Threading

- Fork-join parallelism: multiple threads run in parallel
  - `fork`: create new thread
  - `join`: wait for target thread to finish
- State implicit from by position in code, maintained by infrastructure inbetween
- Low-overhead, better test-logic-to-boilerplate ratio

Wire ownership addresses threading pitfalls

Threading has pitfalls

- What happens of threads conflict with each other?

Intuitively

- Fundamentally unclear who owns what
- But if that were clear, race conditions could be detected and cause errors

<u>**What should happen here?**</u>

```
c.in.poke(1.U)
fork {
  c.in.poke(2.U)
}
fork {
  c.in.poke(3.U)
}
```

Explicit durations are cumbersome

Simple method: user-specified durations

- Test writer must specify directions, adds additional cognitive overhead
- Misses that groups of signals may be related

```
class Decoupled[T] extends Bundle {
  ...
  def enqueue(data: T) {
    this.in.valid.poke(true.B, 1)
    this.in.bits.poke(data, 1)
    this.in.ready.expect(true.B)
    clock.step(1)
  }
}
```

Scoping for boilerplate-free wire ownership

Structured programming inspiration

- Duration 'implicitly' specified by the enclosing scope (block of code)
- Can group multiple pokes together
- Duration obvious visually

```
this.in.valid.poke(false.B)
clock.step(2)
timescope {  // enqueue
  this.in.valid.poke(true.B)
  this.in.bits.poke(data)
  this.in.ready.expect(true.B)
  clock.step(1)
}
```

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this.in.valid.poke(false.B)
clock.step(2)
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  this.in.bits.poke(data)
  this.in.ready.expect(true.B)
  clock.step(1)
}
```

```
clock
in.valid
in.bits
```

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clock.step(2)
timescope {  // enqueue
  this.in.valid.poke(true.B)
  this.in.bits.poke(data)
  this.in.ready.expect(true.B)
  clock.step(1)
}
```

```
clock     1  2
in.valid  F  F
in.bits   x  x
```

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```
this.in.valid.poke(false.B)
clock.step(2)
timescope {   // enqueue
  this.in.valid.poke(true.B)
  this.in.bits.poke(data)
  this.in.ready.expect(true.B)
  clock.step(1)
}

clock      1   2   3
in.valid   F   F   T
in.bits    x   x   D
```

Scoping for boilerplate-free wire ownership

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- Can group multiple pokes together
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```
this.in.valid.poke(false.B)
clock.step(2)
timescope {  // enqueue
  this.in.valid.poke(true.B)
  this.in.bits.poke(data)
  this.in.ready.expect(true.B)
  clock.step(1)
}
```

```
clock     1  2  3  4
in.valid  F  F  T  F
in.bits   x  x  D  x
```

Scoping for boilerplate-free wire ownership

Structured programming inspiration

- Duration 'implicitly' specified by the enclosing scope (block of code)
- Can group multiple pokes together
- Duration obvious visually
- Bonus: being clear about durations is elegant in general, avoids state errors

Rules

- Scopes can take ownership from parents, including parent threads
- Combinational pokes and expects can be checked for reachability

```
this.in.valid.poke(false.B)
clock.step(2)
timescope {  // enqueue
  this.in.valid.poke(true.B)
  this.in.bits.poke(data)
  this.in.ready.expect(true.B)
  clock.step(1)
}
```

clock	1	2	3	4
in.valid	F	F	~~T~~	F
in.bits	x	x	~~D~~	x

Examples

Example: concurrency with shift register

Shifter test abstractions possible

- Multiple "instances" of **`shiftTest`** run concurrently with **`fork`**
- Causality is obvious within each **`shiftTest`**

```
def shiftTest(c: Shift2, v: UInt) {
  timescope {
    c.in.poke(v)
    c.clock.step(1)
  }
  c.clock.step(1)
  c.out.expect(v)
}
test(new Shift2) {
  fork { shiftTest(c, 0.U) }
  c.clock.step(1)
  fork { shiftTest(c, 1.U) }
  ...
}
```

Example: we can build and use libraries

```
class DecoupledSource
  (x: Decoupled, clk: Clock) {
  x.valid.poke(false.B)  // init
  def enqueue(data: T) = timescope{
    x.ready.expect(true.B)
    x.bits.poke(data)
    x.valid.poke(true.B)
    clk.step(1)  // hold for 1 clk
  }
}

class DecoupledSink …
```

```
test(new Gcd) { c =>
  val inSource = new
    DecoupledSource(c.in, clock)
  val outSink = new
    DecoupledSink(c.out, clock)

  inSource.enqueue(
    c.in.Lit(15.U, 6.U))
  outSink.waitForReady()
  outSink.dequeueExpect(3.U)
}
```

Future Work: Integrating Constrained Random

Directed testing is easy, but industry has moved onto constrained-random and coverage-driven

Testers2 provides abstractions, can have constrained random built on top

```
test(new Gcd) { c =>
  ...
  val gcd_in = c.in.randomize(
    0 to 1024)
  val exp_out = calcGcd(
    gcd_in.a, gcd_in.b)

  c.in.enqueue(gcd_in)
  c.out.waitForReady()
  c.out.dequeueExpect(exp_out)
}
```

Recap

tl;dr: encourage unit testing by making writing them **easy** and **painless**

Try the open alpha!
https://github.com/ucb-bar/chisel-testers2
(also available as a managed dependency)

- **Minimize boilerplate** by providing clean, intuitive, minimal interfaces
- **Encourage re-use** by enabling abstraction of test functions
- **Allow concurrency** to enable re-use of sequences with fork-join concurrency
- **Clarify wire ownership** to detect race conditions and avoid nondeterminism
- **Time scopes** establish ownership while minimizing user effort