SpinalHDL

An alternative to standard HDL

Summary

- Why a new language
- Language introduction / dissection / comparison
- Examples (a lot)

Why a new language

- Because of current HDL :
  - Verbosity, endless wiring, copy paste
  - Wire level, can’t define abstractions
  - Broken features
    - Can’t parameterize records/struct
    - Can’t define record’s elements directions individually
    - SystemVerilog interface
    - No hardware «meta-description» capabilities
  - They were initially designed for simulation
  - Heavy legacy

Language introduction

- Open source , started in december 2014
- Focus on only on RTL
- Compatibility/interoperability is fine
  - It generate VHDL/Verilog files
  - It can integrate VHDL/Verilog IP as blackbox
- Abstraction level :
  - Start at the same level than VHDL
  - Finish between VHDL and HLS
  - The user can create new abstraction levels

Language dissection

- Spinal language is «integrated» in Scala
  - You can use all the Scala syntax / library
  - Scala IDE are helpfull and free
  - Object oriented and functional paradigms
- 2 layers
  - Core : Low level RTL
  - Lib : High level RTL, based on the Core layer
- How it work
  1. Use Spinal syntax to describe your RTL,
  2. Run Scala,
  3. VHDL/Verilog is generated.

At this point it's very important :

- To be open minded
- To forget pessimism as there is no logic overhead in the generated code.
- Not to be disturbed by the fact that Spinal HDL is only a RTL language. That's not a problem.
- Not to be afraid by the fact that you will have to simulate/synthesize a VHDL/Verilog file, while the specification is written in Spinal. That too isn't a problem.

Justification :

- There is many good verification solutions for the generated VHDL/Verilog (SystemVerilog, Formal verification, cocotb)
- The component hierarchy and all names are preserved durring the VHDL/Verilog generation. This make the navigation between the Scala code and the generated one easy.

A simple component

```
class MyComponent extends Component {
  val io = new Bundle {
    val a      = in  Bool
    val output = out Bool
  }

  io.output := io.a
}
```

Combinatorial, Latch/Loop

```
class MyComponent extends Component {
  val io = new Bundle {
    val a      = in  Bool
    val b      = in  Bool
    val c      = in  Bool
    val output = out Bool
  }

  io.output := (io.a & io.b) | (!io.c)
}
```

```
class MyComponent extends Component {
  //...
  io.output := io.a | io.output //Latch/Loop detected, not allowed
}
```

Signals

```
class MyComponent extends Component {
  val io = new Bundle {
    val a      = in  Bool
    val b      = in  Bool
    val c      = in  Bool
    val output = out Bool
  }
  val a_and_b = Bool
  a_and_b := io.a & io.b
  val not_c = !io.c
  io.output := a_and_b | not_c
}
```

Generated VHDL

```scala
class MyComponent extends Component {
 val io = new Bundle {
  val a      = in  Bool
  val b      = in  Bool
  val c      = in  Bool
  val output = out Bool
 }
 val a_and_b = io.a & io.b
 val not_c = !io.c
 io.output := a_and_b | not_c
}
```

```vhdl
entity MyComponent is
 port(
  io_a : in std_logic;
  io_b : in std_logic;
  io_c : in std_logic;
  io_output : out std_logic
 );
end MyComponent;

architecture arch of MyComponent is
 signal a_and_b : std_logic;
 signal not_c : std_logic;
begin
 io_output <= (a_and_b or not_c);
 a_and_b <= (io_a and io_b);
 not_c <= (not io_c);
end arch;
```

Registers

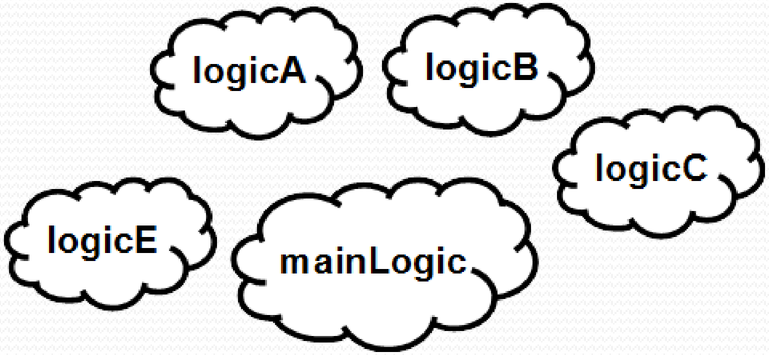
```
class MyComponent extends Component {
  val io = new Bundle {
    val a = in Bool
  }

  val reg1 = Reg(Bool)
  val reg2 = Reg(Bool) init(False)
  val reg3 = RegInit(False)
  val reg4 = RegNext(io.a)
}
```

ClockDomains

```
class MyTopLevel extends Component {
  val io = new Bundle {
    val coreClk = in Bool
    val coreReset = in Bool
  }

  val coreClockDomain = ClockDomain(
    clock  = io.coreClk,
    reset  = io.coreReset,
    config = ClockDomainConfig(
      clockEdge        = RISING,
      resetKind        = ASYNC,
      resetActiveLevel = HIGH
    )
  )

  val coreArea = new ClockingArea(coreClockDomain) {
    val myCoreClockedRegister = Reg(UInt(4 bit))
    //...
  }
}
```

Organize things

```scala
class UartCtrlTx extends Component {
  val io = new Bundle {
    // io definition
  }
  val timer = new Area {
    // emit a pulse that is used as time reference
    // in the state machine
  }
  val stateMachine = new Area {
    // some logic
  }
}
```



Unify logic and FF

```
val mySignal  = Bool
val myRegister   = Reg(UInt(4 bit))
val myRegisterWithInit = Reg(UInt(4 bit)) init(3)

mySignal := False
when(???){
  mySignal := True
  myRegister := myRegister + 1
}
```

No more component binding

```
architecture arch of something is
  signal sub_condA : std_logic;
  signal sub_condB : std_logic;
  signal sub_result : std_logic;

  component SubComponent
    port(condA  : in std_logic;
         condB  : in std_logic;
         result : in std_logic);
  end component;
begin
  sub : SubComponent
    port map (condA  => sub_condA
              condB  => sub_condB
              result => sub_result);
end arch;
```

```
class TopComponent extends Component{
  val sub = new SubComponent
}
```

Component instance

```
class MySubComponent extends Component{
 val io = new Bundle {
  val subIn  = in  Bool
  val subOut = out Bool
 }
 ...
}

class MyComponent extends Component {
 val io = new Bundle {
  val a      = in  Bool
  val b      = in  Bool
  val output = out Bool
 }

 val compInstance = new MySubComponent

 compInstance.io.subIn := io.a
 io.output :=  compInstance.io.subOut | io.b
}
```

Uint, Vec, When

```
class MyComponent extends Component
{
 val io = new Bundle {
  val conds  = in  Vec(Bool,2)
  val output = out UInt(4 bits)
 }

 when(io.conds(0)){
  io.output := 2
  when(io.conds(1)){
   io.output := 1
  }
 } otherwise {
  io.output := 0
 }
}
```

Enum, Area, switch

```
object MyEnum extends SpinalEnum {
 val state0, state1, anotherState = newElement
}

abstract class MyComponent extends Component {
 val logicOfA = new Area {
  val flag  = Bool
  val logic = Bool
 }

 val fsm = new Area {
  val state = Reg(MyEnum()) init (MyEnum.state0)
  switch(state) {
   is(MyEnum.state0) {
    when(logicOfA.flag) {
     state := MyEnum.state1
    }
   }
   default {
   }
  }
 }
}
```

For, Variable, Generics

```
class CarryAdder(size: Int) extends Component {
  val io = new Bundle {
    val a      = in UInt (size bits)
    val b      = in UInt (size bits)
    val result = out UInt (size bits)
  }

  var c = False
  for (i <- 0 until size) {
    val a = io.a(i)
    val b = io.b(i)

    io.result(i) := a ^ b ^ c
    c \= (a & b) | (a & c) | (b & c);
  }
}
```

Bundle, Generics, Vec, Packing

```
case class Color(channelWidth : Int) extends Bundle{
  val r = UInt(channelWidth bit)
  val g = UInt(channelWidth bit)
  val b = UInt(channelWidth bit)
}

class MyColorSelector(sourceCount : Int,channelWidth: Int) extends Component {
  val io = new Bundle {
    val sel     = in  UInt(log2Up(sourceCount) bits)
    val sources = in  Vec(Color(channelWidth), sourceCount)
    val result  = out Bits (3*channelWidth bit)
  }

  val selectedSource = io.sources(io.sel)
  io.result := toBits(selectedSource)
}
```

Memory

```scala
//Memory of 1024 Bool
val mem = Mem(Bool, 1024)

//Write it
mem(5) := True

//Read it
val read0 = mem.readAsync(4)
val read1 = mem.readSync(6)
```

Less scope limitations

```
val valid = Bool
val regA = Reg(UInt(4 bit))

def doSomething(value : Int) = {
  valid := True
  regA := value
}

when(???){
  doSomething(4)
}
```

Function, User utils (1)

```
case class Color(channelWidth: Int) extends Bundle {
  val r = UInt(channelWidth bit)
  val g = UInt(channelWidth bit)
  val b = UInt(channelWidth bit)

  def +(that: Color): Color = {
    val result = cloneOf(this)
    result.r := this.r + that.r
    result.g := this.g + that.g
    result.b := this.b + that.b

    return result
  }
}
```

Function, User utils (2)

```
class MyColorSumming(sourceCount: Int, channelWidth: Int) extends Component {
  val io = new Bundle {
    val sources = in Vec(sourceCount, Color(channelWidth))
    val result = out(Color(channelWidth))
  }

  var sum = io.sources(0)
  for (i <- 1 until sourceCount) {
    sum \= sum + io.sources(i)
  }
  io.result := sum

  // But you can do all this stuff by this way, balanced is bonus :
  // io.result := io.sources.reduceBalancedSpinal(_ + _)
}
```

Basic abstractions

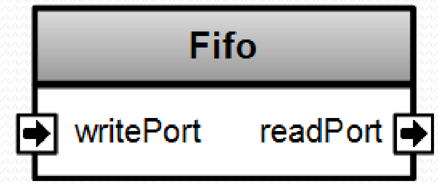
```
val timeout = Timeout(1000)
when(timeout){    //implicit conversion to Bool
  timeout.clear() //Clear the flag and the internal counter
}

//Create a counter of 10 states (0 to 9)
val counter = Counter(10)
counter.clear()     //When called it reset the counter. It's not a flag
counter.increment()  //When called it increment the counter. It's not a flag
counter.value       //current value
counter.valueNext   //Next value
counter.willOverflow  //Flag that indicate if the counter overflow this cycle
when(counter === 5){ }  //counter is implicitly its value
```

Flow, Stream

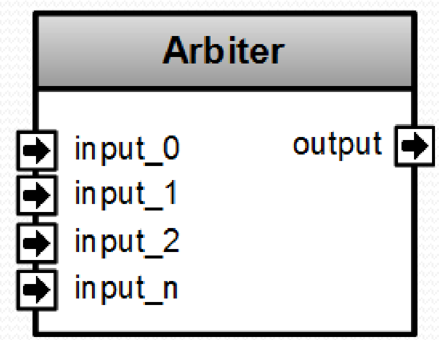
```
case class Flow[T <: Data](dataType: T) extends Bundle {
  val valid   = Bool
  val data: T = cloneOf(dataType)
}

case class Stream[T <: Data](dataType: T) extends Bundle {
  val valid   = Bool
  val ready   = Bool
  val data: T = cloneOf(dataType)
  // some logic
}

val myStreamOfRGB= Stream(RGB(8,8,8))
```

Stream components

```
class Fifo[T <: Data](dataType: T, depth: Int) extends Component {
  val io = new Bundle {
    val writePort = slave Stream (dataType)
    val readPort  = master Stream (dataType)
  }
  //...
}
```

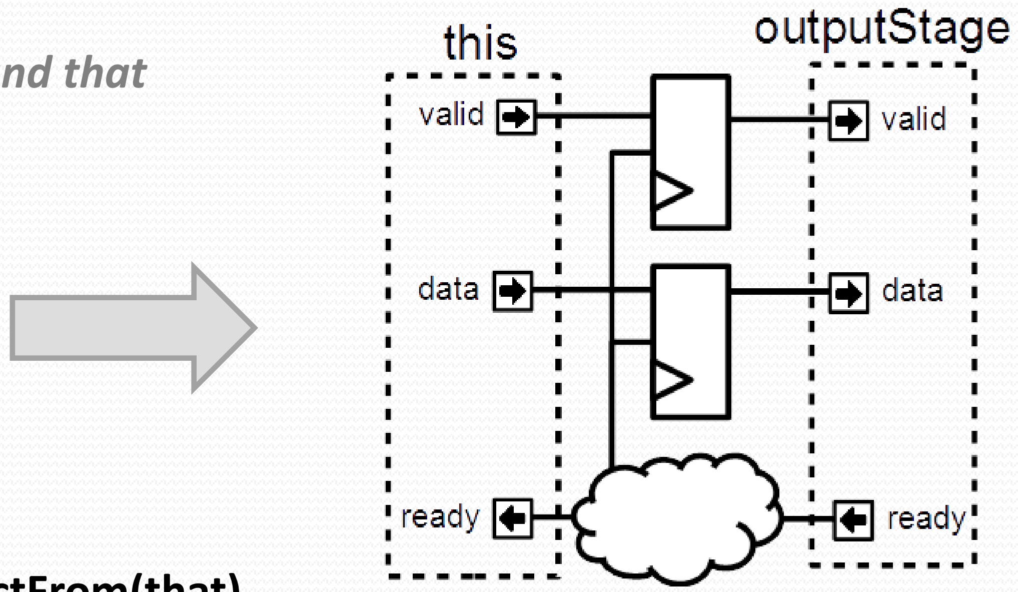



```
class Arbiter[T <: Data](dataType: T, portCount: Int) extends Component {
  val io = new Bundle {
    val inputs  = Vec(slave(Stream(dataType)), portCount)
    val output = master(Stream(dataType))
  }
  //...
}
```



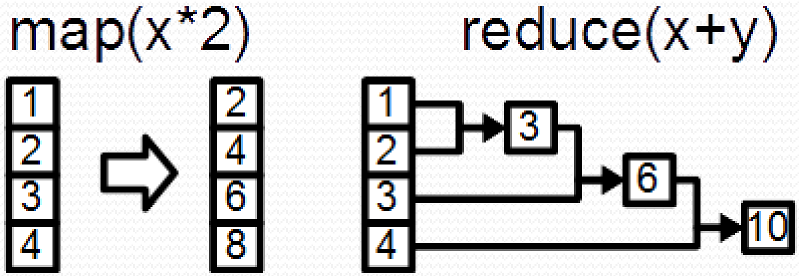
Stream functions

```
case class Stream[T <: Data](dataType: T) extends Bundle {
 // ...
 def connectFrom(that: Stream[T]) = {
   // some connections between this and that
 }
 def m2sPipe(): Stream[T] = {
   val outputStage = cloneOf(this)
   val validReg = RegInit(False)
   val dataReg = Reg(dataType)
   // some logic
   return outputStage
 }
 def << (that: Stream[T]) = this.connectFrom(that)
 def <-< (that: Stream[T]) = this << that.m2sPipe()
}

val myStreamA,myStreamB = Stream(UInt(8 bit))
myStreamA <-< myStreamB
```



Functional programming

```
Case class LineTag extends Bundle {
  val valid = Bool
  val address = UInt(32 bit)
  val dirty = Bool

  def hit(targetAddress : UInt) : Bool = valid && address === targetAddress
}

val lineTags = Vec(LineTag(), 8)
val lineHits = lineTags.map(lineTag => lineTag.hit(targetAddress))
val lineHitValid = lineHits.reduce((a,b) => a || b)
val lineHitIndex = OHToUInt(lineHits)
```



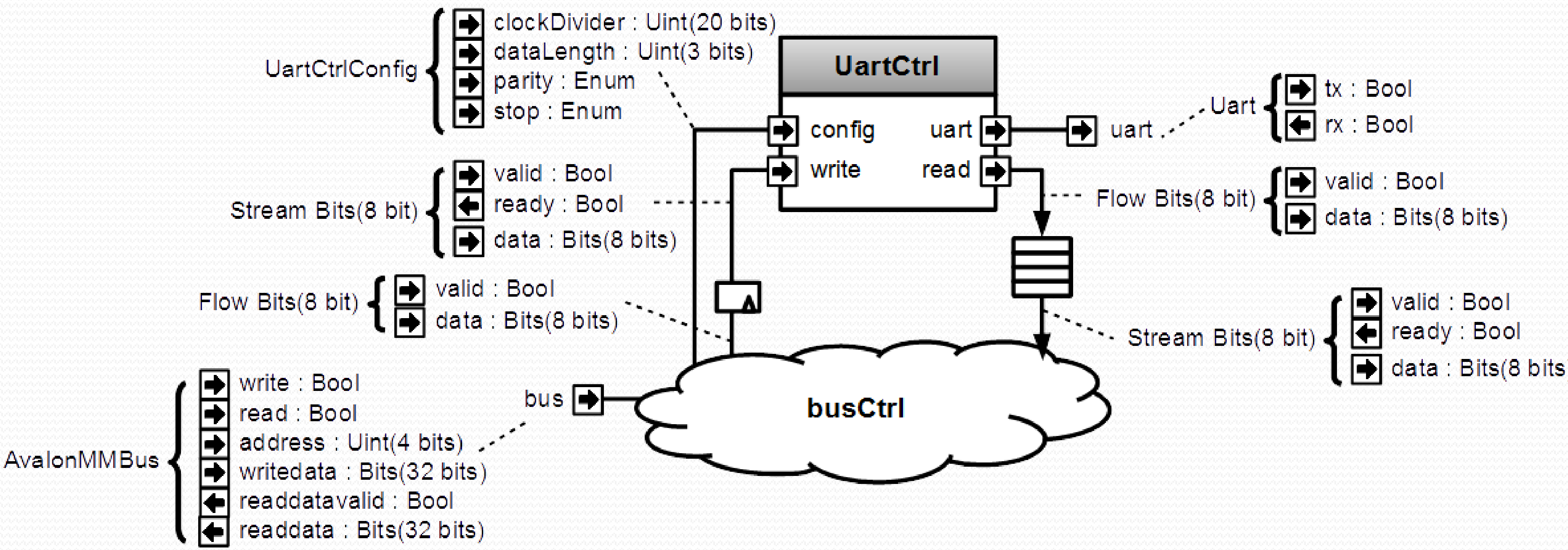
Scala is here to help you

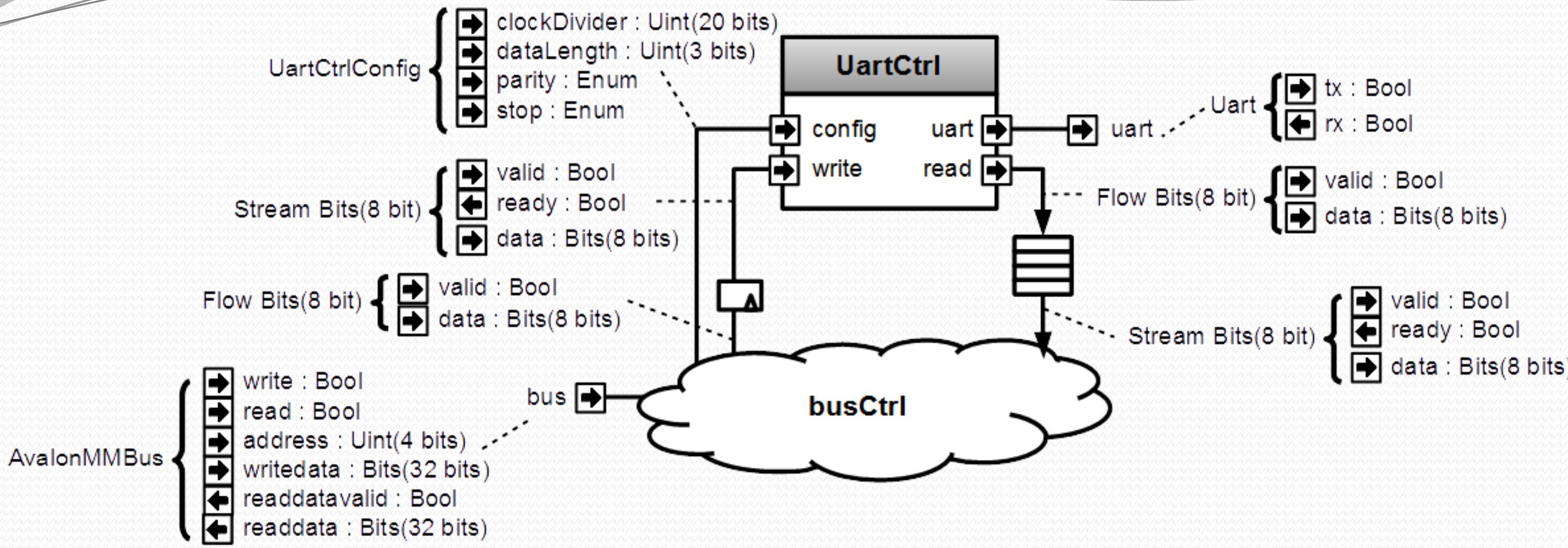
```
class SinusGenerator(resolutionWidth : Int,sampleCount : Int) extends Component {
  val io = new Bundle {
    val sin = out SInt (resolutionWidth bits)
  }

  def sinTable = (0 until sampleCount).map(sampleIndex => {
    val sinValue = Math.sin(2 * Math.PI * sampleIndex / sampleCount)
    S((sinValue * ((1 << resolutionWidth) / 2 - 1)).toInt, resolutionWidth bits)
  })

  val rom    = Mem(SInt(resolutionWidth bit), initialContent = sinTable)
  val phase = CounterFreeRun(sampleCount)
  val sin      = rom.readSync(phase)
}
```

Netlist analyser / Latency analysis

```
class MyComponentWithLatencyAssert extends Component {
  val io = new Bundle {
    val slavePort  = slave Stream (UInt(8 bits))
    val masterPort = master Stream (UInt(8 bits))
  }

 //These 3 line are equivalent to io.slavePort.queue(16) >/-> io.masterPort
  val fifo = new StreamFifo((UInt(8 bits)),16)
  fifo.io.push << io.slavePort
  fifo.io.pop >/-> io.masterPort

  assert(3 == latencyAnalysis(io.slavePort.data,io.masterPort.data))
  assert(2 == latencyAnalysis(io.masterPort.ready,io.slavePort.ready))
}
```

Meta-hardware description





Name	Type	Access	Address	Description
clockDivider	UInt	RW	0	Set the UartCtrl clock divider
frame	UartCtrlFrameConfig	RW	4	Set the dataLength, the parity and the stop bit configuration
writeCmd	Bits	W	8	Send a write command to the UartCtrl
writeBusy	Bool	R	8	Bit 0 => zero when a new writeCmd could be sent
read	Bits ## Bool	R	12	Bit 0 => read data valid Bit 8 downto 1 => read data

```scala
class AvalonUartCtrl(uartCtrlConfig : UartCtrlGenerics, rxFifoDepth : Int) extends Component{
 val io = new Bundle{
  val bus =  slave(AvalonMM(AvalonMMUartCtrl.getAvalonMMConfig))
  val uart = master(Uart())
 }

 val uartCtrl = new UartCtrl(uartCtrlConfig)
 io.uart <> uartCtrl.io.uart

 val busCtrl = AvalonMMSlaveFactory(io.bus)

 //Make clockDivider register
 busCtrl.driveAndRead(uartCtrl.io.config.clockDivider, address = 0)

 //Make frame register
 busCtrl.driveAndRead(uartCtrl.io.config.frame, address = 4)

 //Make writeCmd register
 val writeFlow = busCtrl.createAndDriveFlow(Bits(uartCtrlConfig.dataWidthMax bits), address = 8)
 writeFlow.toStream.stage() >> uartCtrl.io.write

 //Make writeBusy register
 busCtrl.read(uartCtrl.io.write.valid, address = 8)

 //Make read register
 busCtrl.readStreamNonBlocking(uartCtrl.io.read.toStream.queue(rxFifoDepth), address = 12)
}
```

About Scala

- Free Scala IDE (eclipse, intelij)
  - Highlight syntax error
  - Renaming flexibility
  - Intelligent auto completion
  - Code’s structure overview
  - Navigation tools
- Allow you to extend the language
- Provide many libraries

It work perfectly on FPGA

- RISCV CPU, 5 stages, 1.15 DMIPS/Mhz
  - MUL/DIV
  - Instruction/Data cache
  - Interrupts
  - JTAG debugging
- Avalon/APB UART
- Avalon VGA
- Pipelined and multi-core fractal accelerator

?

Component instance

```
class MySubComponent extends Component{
  val io = new Bundle {
    val subIn  = in  Bool
    val subOut = out Bool
  }
  ...
}

class MyComponent extends Component {
  val io = new Bundle {
    val a      = in  Bool
    val b      = in  Bool
    val output = out Bool
  }

  val compInstance = new MySubComponent

  compInstance.io.subIn := io.a
  io.output :=  compInstance.io.subOut | io.b
}
```

Flow, Stream, Fragment

```scala
case class Flow[T <: Data](dataType: T) extends Bundle {
  val valid   = Bool
  val data: T = cloneOf(dataType)
  //..
}

case class Stream[T <: Data](dataType: T) extends Bundle {
  val valid   = Bool
  val ready   = Bool
  val data: T = cloneOf(dataType)
  //..
}

case class Fragment[T <: Data](dataType: T) extends Bundle {
  val last    = Bool
  val data: T = cloneOf(dataType)
  //..
}
```

Stream functions

```
val cond = Bool
val inPort = Stream(Bits(32 bit))
val outPort = Stream(Bits(32 bit))

outPort << inPort
outPort <-< inPort
outPort </< inPort
outPort <-/< inPort
val haltedPort = inPort.haltWhen(cond)
val filteredPort = inPort.throwWhen(inPort.data === 0)
val outPortWithMsb = inPort.translateWith(inPort.data.msb)

val mem = Mem(Bool, 1024)
val memReadCmd = Stream(UInt(10 bit))
val memReadPort = mem.streamReadSync(memReadCmd, memReadCmd.data)
memReadPort.valid //arbitration
memReadPort.ready //arbitration
memReadPort.data.value //Readed value
memReadPort.data.linked //Linked value (memReadCmd.data)
```

Flow of Fragment example

```
case class LogicAnalyserConfig() extends Bundle{
  val trigger = new Bundle{
    val delay = UInt(32 bit)
    //...
  }
  val logger = new Bundle{
    val samplesLeftAfterTrigger = UInt(8 bit)
    //...
  }
}

class LogicAnalyser extends Component {
  val io = new Bundle {
    val cfgPort = slave Flow Fragment(Bits(8 bit))
  }
  val waitTrigger = io.cfgPort filterHeader (0x01) toRegOf (Bool) init (False)
  val userTrigger = io.cfgPort pulseOn (0x02)
  val configs     = io.cfgPort filterHeader (0x0F) toRegOf(LogicAnalyserConfig())
}
```

Generator, Logic Analyser

```
val logicAnalyser = LogicAnalyserBuilder()
  .setSampleCount(256)
  .exTrigger(somewhere.inThe.hierarchy.trigger)
  .probe(somewhere.inThe.hierarchy.signalA)
  .probe(somewhere.inThe.hierarchy.signalB)
  .probe(somewhere.signalC)
  .build

val uartCtrl = new UartCtrl()
uartCtrl.read >> logicAnalyser.io.slavePort
uartCtrl.write << logicAnalyser.io.masterPort
```