Reactive Programming with Algebra

André van Delft
Anatoliy Kmetyuk

Amsterdam.Scala meetup	2 December 2014
Java/Scala Lab, Odessa	6 December 2014
Scala Exchange, London	9 December 2014

Overview

- Introduction
  - Programming is Still Hard
  - Some History
  - Algebra of Communicating Processes
- SubScript
  - Example application
  - Debugger demo
- Dataflow
  - Twitter Client
  - SubScript Actors
- Conclusion

Programming is Still Hard

Mainstream programming languages: imperative

- good in batch processing
- not good in parsing, concurrency, event handling
- Callback Hell

Neglected idioms

- Non-imperative choice: BNF, YACC
- Data flow: Unix pipes

Math!

Algebra can be easy and fun

Area	Objects	Operations	Rules
Numbers	0, 1, ..., x, y, ...	$+ \quad \cdot \quad - \quad /$	$x+y = y+x$
Logic	F, T, x, y, ...	$\vee \quad \wedge \quad \neg$	$x \vee y = y \vee x$
Processes	0, 1, a, b,..., x, y, ...	$+ \quad \cdot \quad \& \quad \mid \quad \&\& \quad \| \quad /$	$x+y = y+x$

Some History

1955	Stephen Kleene	~~> regular expressions, *
	Noam Chomsky	~~> language grammars
1960	John Backus & Peter Naur	~~> BNF
	Tony Brooker	~~> Compiler Compiler
1971	Hans Bekič	~~> Algebra of Processes
1973	Stephen Johnson	~~> YACC
1974	Nico Habermann & Roy Campbell	~~> Path Expressions
1978	Tony Hoare	~~> Communicating Sequential Processes (CSP)
1980	Robin Milner	~~> Calculus of Communicating Systems (CCS)
1982	Jan Bergstra & Jan Willem Klop	~~> Algebra of Communicating Processes (ACP)
1989	Robin Milner	~~> Pi-Calculus
	Henk Goeman	~~> Self-applicative Processes

Algebra of Communicating Processes - 1

Bergstra & Klop, Amsterdam, 1982 - ...

ACP ~ Boolean Algebra

+ choice
· sequence
0 deadlock
1 empty process

atomic actions a,b,…
parallelism
communication
disruption, interruption
time, space, probabilities
money
...

Algebra of Communicating Processes - 2

Less known than CSP, CCS

Specification & Verification

- Communication Protocols
- Production Plants
- Railways
- Coins and Coffee Machines
- Money and Economy

Strengths

- Familiar syntax
- Precise semantics
- Reasoning by term rewriting
- Events as actions

Algebra of Communicating Processes - 3

$$x+y = y+x$$
$$(x+y)+z = x+(y+z)$$
$$x+x = x$$
$$(x+y)\cdot z = x\cdot z+y\cdot z$$
$$(x\cdot y)\cdot z = x\cdot(y\cdot z)$$

$$0+x = x$$
$$0\cdot x = 0$$
$$1\cdot x = x$$
$$x\cdot 1 = x$$

$$(x+1)\cdot y = x\cdot y + 1\cdot y$$
$$= x\cdot y + y$$

Algebra of Communicating Processes - 4

$$x \parallel y = x \mathbin{⌊\!⌊} y + y \mathbin{⌊\!⌊} x + x | y$$

$$(x+y) \mathbin{⌊\!⌊} z = \ldots$$

$$a \cdot x \mathbin{⌊\!⌊} y = \ldots$$

$$1 \mathbin{⌊\!⌊} x = \ldots$$

$$0 \mathbin{⌊\!⌊} x = \ldots$$

$$(x+y) | z = \ldots$$

$$\ldots = \ldots$$

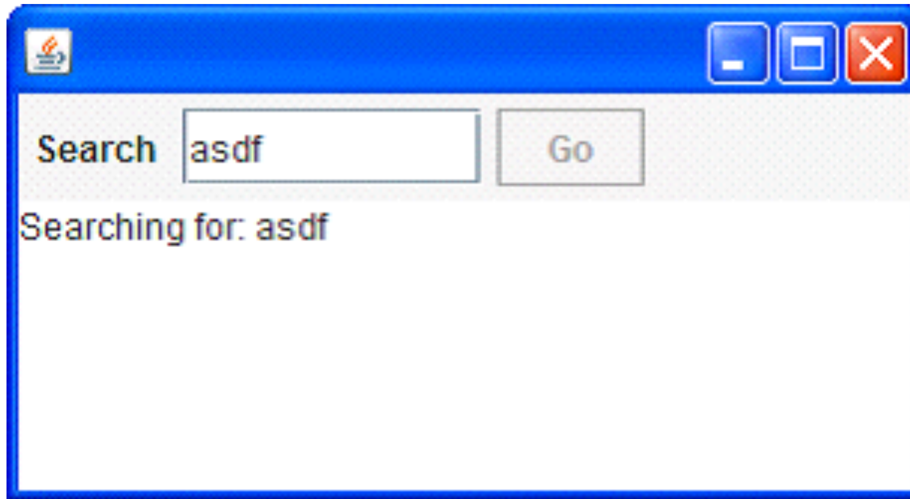
ACP Language Extensions

- 1980: Jan van den Bos - Input Tool Model [Pascal, Modula-2]
- 1988-2011: AvD - Scriptic [Pascal, Modula-2, C, C++, Java]
- 1994: Jan Bergstra & Paul Klint - Toolbus
- 2011-...: AvD - SubScript [Scala, JavaScript (?)]

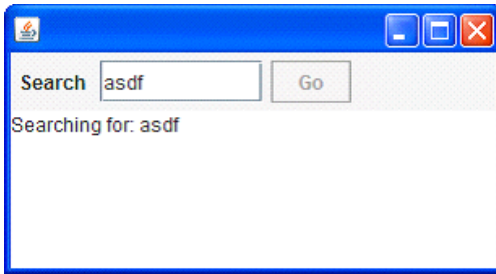
Application Areas:

- GUI Controllers
- Text Parsers
- Discrete Event Simulation
- Reactive, Actors, Dataflow

GUI application - 1

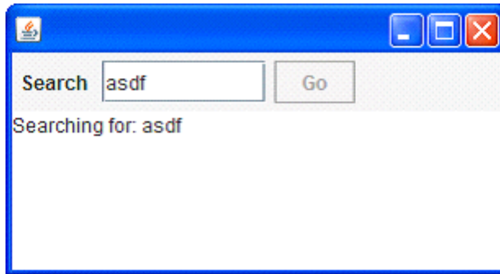


- Input Field
- Search Button
- Searching for…
- Results



GUI application - 2

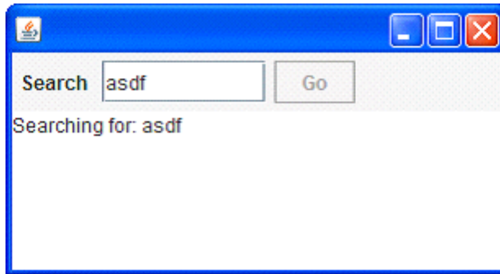
```
val searchButton = new Button("Go”) {
  reactions.+= {
    case ButtonClicked(b) =>
      enabled = false
      outputTA.text = "Starting search...”
      new Thread(new Runnable {
       def run() {
        Thread.sleep(3000)
        SwingUtilities.invokeLater(new Runnable{
          def run() {outputTA.text="Search ready”
                     enabled = true
        }})
      }}).start
  }
}
```



GUI application - 3

```
live =        searchButton
       @gui: {outputTA.text="Starting search.."}
             {* Thread.sleep(3000) *}
       @gui: {outputTA.text="Search ready"}
             ...
```

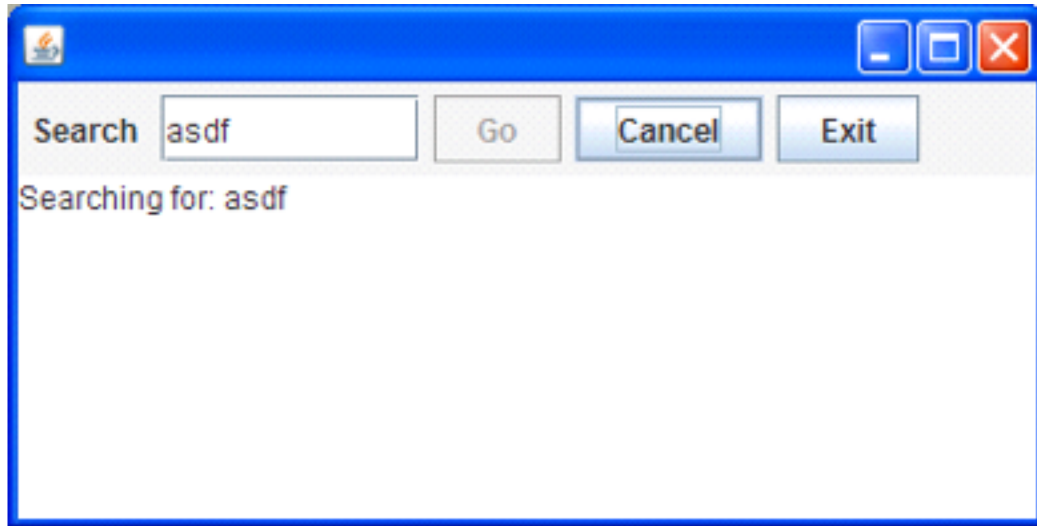
- Sequence operator: white space and `;`
- `gui`: code executor for
- `SwingUtilities.InvokeLater`+`InvokeAndWait`
- `{* ... *}`: by executor for `new Thread`

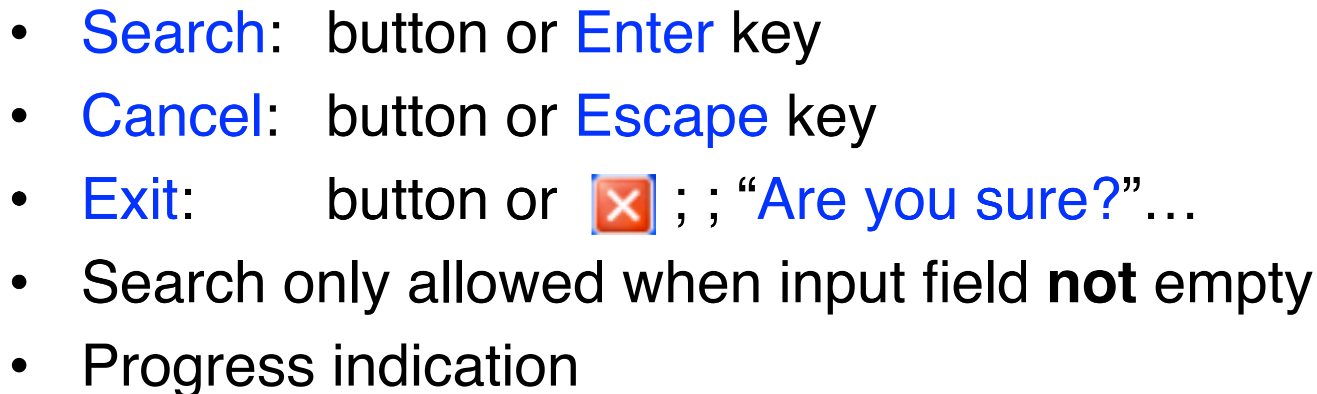


GUI application - 4

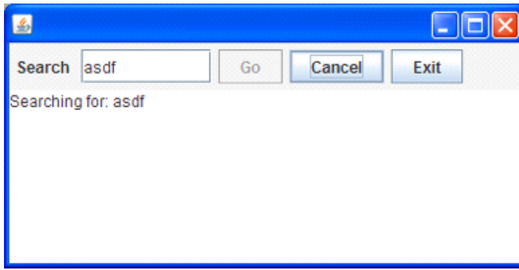
```
live              = searchSequence...

searchSequence    = searchCommand
                    showSearchingText
                    searchInDatabase
                    showSearchResults

searchCommand     = searchButton
showSearchingText = @gui: {outputTA.text = "…"}
showSearchResults = @gui: {outputTA.text = "…"}
searchInDatabase  = {* Thread.sleep(3000) *}
```

GUI application - 5





- Search: button or Enter key
- Cancel: button or Escape key
- Exit: button or ☒ ; ; “Are you sure?”…
- Search only allowed when input field **not** empty
- Progress indication



GUI application - 6

```
live              = searchSequence... || exit

searchCommand     = searchButton + Key.Enter
cancelCommand     = cancelButton + Key.Escape
exitCommand       =   exitButton + windowClosing
exit              =   exitCommand @gui: while(!areYouSure)
cancelSearch      = cancelCommand @gui: showCanceledText

searchSequence    = searchGuard searchCommand;
                    showSearchingText
                    searchInDatabase
                    showSearchResults / cancelSearch

searchGuard       = if(!searchTF.text.isEmpty) . anyEvent(searchTF) ...

searchInDatabase  = {*Thread.sleep(3000)*} || progressMonitor
progressMonitor   = {*Thread.sleep( 250)*}
                    @gui:{searchTF.text+=here.pass} ...
```

SubScript Features

"Scripts" – process refinements as class members

```
script a = b; {c}
```

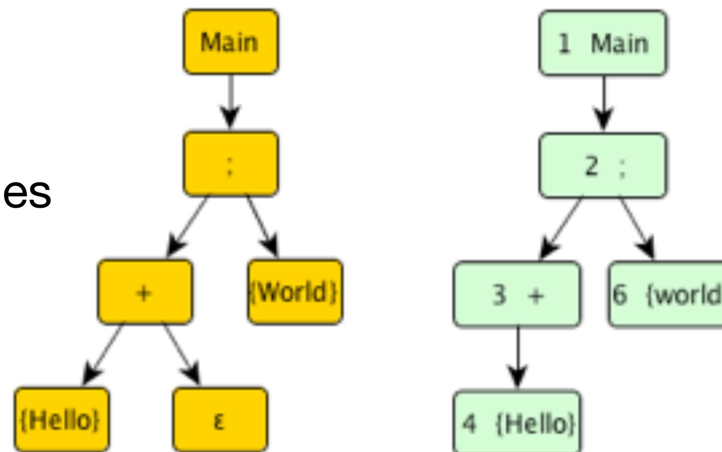
- Much like methods: override, implicit, named args, varargs, ...
- Invoked from Scala: `_execute(a, aScriptExecutor)`
  Default executor: `_execute(a)`
- Body: process expression
  Operators: `+ ; & | && || /` ...
  Operands: script call, code fragment, if, while, ...
- Output parameters: ?, ...
- Shared scripts:
  `script send,receive = {}`

Implementation - 1

- Branch of Scalac: 1300 lines (scanner + parser + typer)

```
script Main = ({Hello} + ε); {World}

import subscript.DSL._
def Main = _script('Main) {
                _seq(_alt(_normal{here=>Hello}, _empty),
                          _normal{here=>World}          )
           }
```

- Virtual Machine: 2000 lines
  - static script trees
  - dynamic Call Graph



- Swing event handling scripts: 260 lines
- Graphical Debugger: 550 lines (10 in SubScript)

Debugger - 1

Subscript Graphical Debugger

Step | Auto | Exit

Step:
- Act
- Dea
- Cnt
- AAS
- AAE
- Scs
- Brk
- Exc
- Idle

Log:
- Act
- Dea
- Cnt
- AAS
- AAE
- Scs
- Brk
- Exc
- Idle

main
;
{} {}

```
** 14   Continuation 4 ; 13        AASt
++ 22        AAEnded 3 main
>> 22        AAEnded 3 main
++ 23        AAEnded 2 call
>> 23        AAEnded 2 call
++ 24        AAEnded 1 **
>> 24        AAEnded 1 **
>> 19        Success 5 {}
++ 25        Success 4 ;
```

```
25        Success 4 ;
```

```
20   Deactivation 5 {}
14   Continuation 4 ; 13        AAStart
```

1 **
2 call
3 main
4 ; — AA Started, AA Ended
Success
5 {} S

Debugger - 2

built using SubScript

```
live          = stepping || exit

stepping      = {* awaitMessageBeingHandled(true) *}
                if shouldStep then (
                   @gui: {! updateDisplay !}
                   stepCommand || if autoCheckBox.selected then sleepStepTimeout
                )
                { messageBeingHandled(false) }
                ...

    exit          = exitCommand
                    var     isSure = false
                    @gui: { isSure = confirmExit }
                    while (!isSure)

exitCommand = exitButton + windowClosing
```

One-time Dataflow - 1

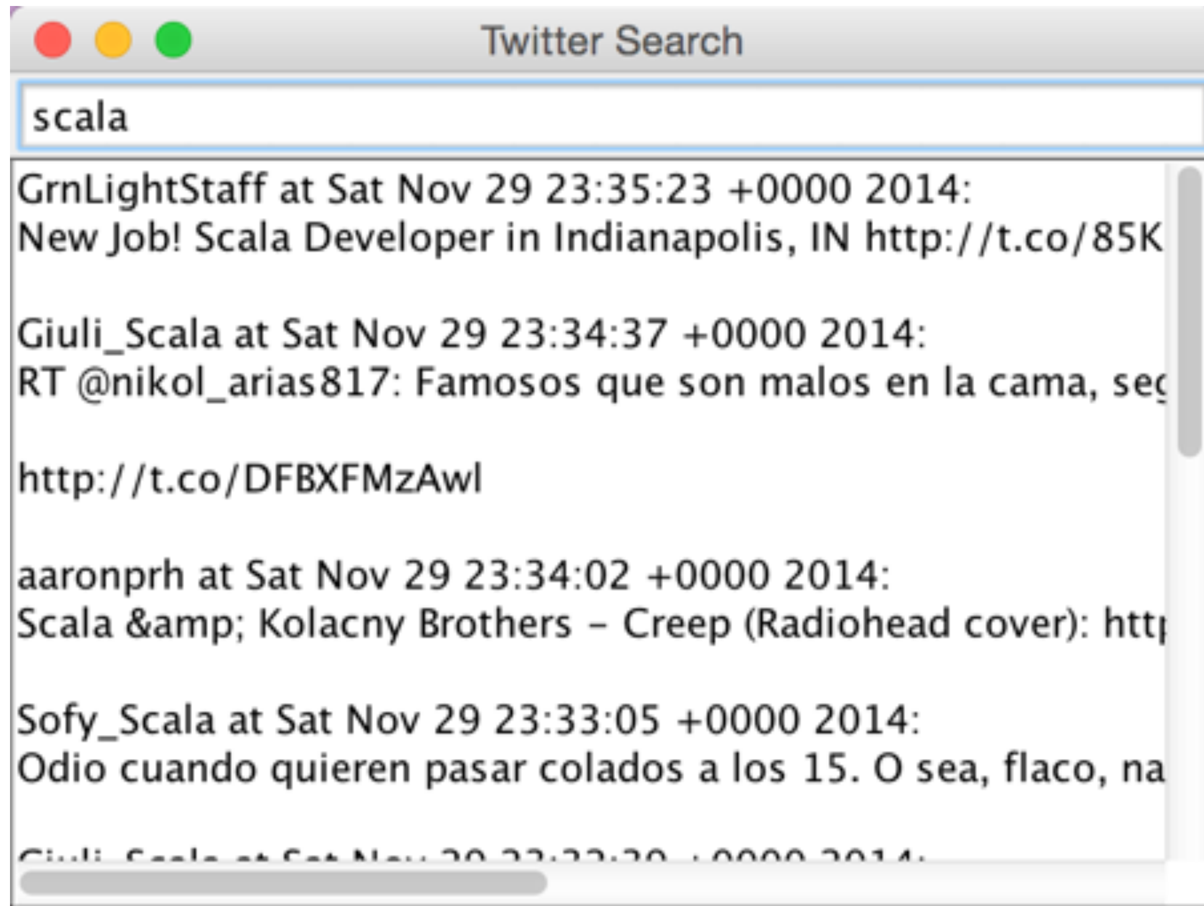
```
exit     = exitCommand
           var     isSure = false
           @gui: { isSure = confirmExit }
           while (!isSure)

exit     = exitCommand  @gui:confirmExit ~~> while(!_)
```

- Script result type `script confirmExit:Boolean = ...`
- Result values `$success`
  `confirmExit^`
  `confirmExit^$1`

- Script Lambda's `b:Boolean => [while(!b)]` `while(!_)`
- `x~~>y` definition `do_flowTo([x^],[y^])`

```
do_flowTo[T,U](s:script[T],t:T=>script[U]): U = s^$1 then t($1)^
```

Example: Twitter Search Client - 1



Example: Twitter Search Client - 2

```
trait Controller {
  val view: View
  def start(): Unit
  val twitter      = Twitter()
  val tweetsCount  = 10
  val keyTypeDelay = 500 // to prevent exceeding Twitter API calls limit
  def clearView    = view.main(Array())
  def searchTweets = twitter.search(view.searchField.text, tweetsCount)
  def updateTweetsView(ts:Seq[Tweet]) = view.setTweets(ts)
}


class SubScriptController(val view: View) extends Controller {
  def start() = _execute(_live())

  script..
    live         = clearView; mainSequence/..

    mainSequence = anyEvent(view.searchField)
                   {* Thread sleep keyTypeDelay *}
                   {*searchTweets*} ~~> @gui:updateTweetsView
}
```

Example: Twitter Search Client - 3

```
live         = clearView; mainSequence/..

mainSequence = anyEvent(view.searchField)
               {* Thread sleep keyTypeDelay *}
               {* searchTweets *} ~~> @gui:updateTweetsView
```

Work in progress:

```
live         = clearView; mainSequence...
searchTweets = {* script.$success =
                   twitter.search(view.searchField.text,tweetsCount) *}

mainSequence = anyEvent(view.searchField)
               {* Thread sleep keyTypeDelay *}
               searchTweets
               ~~> ts:Any ==>
                   @gui:updateTweetsView(ts.asInstanceOf[Seq[Tweet]]))
```

Example: Twitter Search Client - 3

```
live          = clearView; mainSequence/..

mainSequence = anyEvent(view.searchField)
               {* Thread sleep keyTypeDelay *}
               {* searchTweets *} ~~> @gui:updateTweetsView
```

```
class PureController(val view: View) extends Controller with Reactor {

  def start() = {initialize; bindInputCallback}

  def bindInputCallback = {
    listenTo(view.searchField.keys)

    val fWait   = InterruptableFuture {Thread sleep keyTypeDelay}
    val fSearch = InterruptableFuture {searchTweets}

   reactions += {case _      => fWait   .execute()
      .flatMap  {case _      => fSearch.execute()}
      .onSuccess{case tweets => Swing.onEDT{view.setTweets(tweets)}}
} } }
```

Example: Twitter Search Client - 3

```
live          = clearView; mainSequence/..

mainSequence = anyEvent(view.searchField)
               {* Thread sleep keyTypeDelay *}
               {* searchTweets *} ~~> @gui:updateTweetsView
```

```
implicit script future2script[T](f:Future[T]): Script[T]
= @{f onComplete {case Success(t) => $success = t; there.execute
                  case Failure(t) => $failure = t; there.fail  }
    f.execute()
   }:
   {. .}  // "there"
```

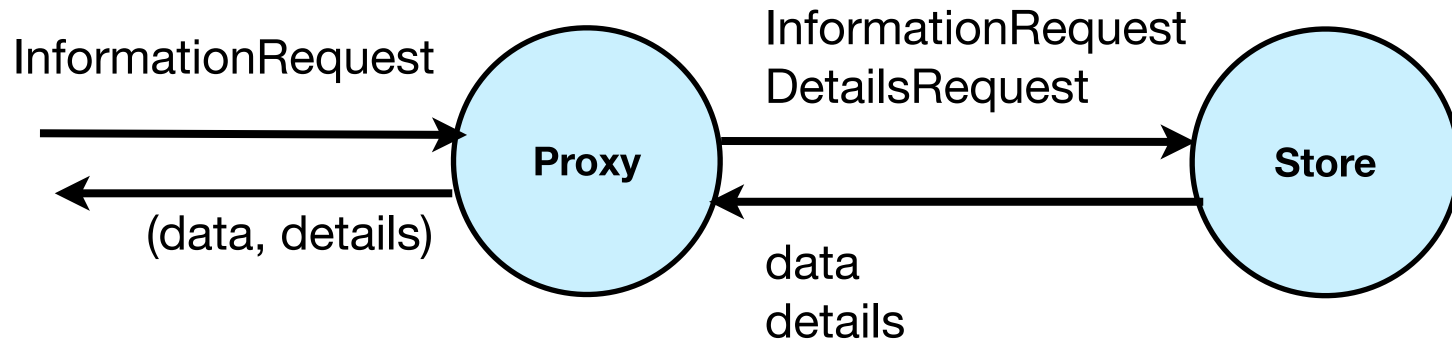
```
mainSequence = anyEvent(view.searchField)
               fWait ~~> fTweets ~~> @gui:updateTweetsView
```

SubScript Actors: Ping Pong

```
class Ping(another: ActorRef) extends Actor {

  override def receive: PartialFunction[Any,Unit] = {case _ =>}

     another ! "Hello"
     another ! "Hello"
     another ! "Terminal"
}
```

```
class Pong extends SubScriptActor {

  implicit script str2rec(s:String) = << s >>

  script ..
    live = "Hello" ... || "Terminal" ; {println("Over")}
}
```

SubScript Actors: DataStore - 1




```
class DataStore extends Actor {

  def receive = {
    case InformationRequest(name) => sender ! getData    (name)
    case DetailsRequest     (data) => sender ! getDetails(data)
  }

}
```

SubScript Actors: DataStore - 2

```
class DataProxy(dataStore: ActorRef) extends Actor {

  def waitingForRequest = {
    case req: InformationRequest =>
      dataStore ! req
      context become waitingForData(sender)
  }

  def waitingForData(requester: ActorRef) = {
    case data: Data =>
      dataStore ! DetailsRequest(data)
      context become waitingForDetails(requester, data)
  }

  def waitingForDetails(requester: ActorRef, data: Data) = {
    case details: Details =>
      requester ! (data, details)
      context become waitingForRequest
  }
}
```

SubScript Actors: DataStore - 3

```
class DataProxy(dataStore: ActorRef) extends SubScriptActor {

  script live = << req: InformationRequest
                 => dataStore ! req
                ==>
                    var response: (Data, Details) = null
                    << data: Data
                    => dataStore ! DetailsRequest(data)
                   ==>
                       << details:Details ==> response = (data,details) >>
                    >>
                    {sender ! response}
                 >>
                 ...
}
```

SubScript Actors: DataStore - 4

```
class DataProxy(dataStore: ActorRef) extends SubScriptActor {

  script live =
    << req: InformationRequest ==> {dataStore ? req}
                   ~~data:Data~~> {dataStore ? DetailsRequest(data)}
             ~~details:Details~~> {  sender  ! (data, details)}
    >>
    ...
}
```

```
  script live =
    << req: InformationRequest
   ==> {dataStore ? req}
   ~~> v:Any ==> ( val data    = v.asInstanceOf[Data]
                   {dataStore ? DetailsRequest(data)}
   ~~> w:Any ==> ( val details = w.asInstanceOf[Details]
                   {  sender  ! (data, details)}
                 ))
    >>
    ...
```

SubScript Actors: Shorthand Notations

```
<< case a1: T1 => b1 ==> s1
   case a2: T2 => b2 ==> s2
   ...
   case an: Tn => bn ==> sn >>
```

```
<< case a1: T1 => b1
   case a2: T2 => b2
   ...
   case an: Tn => bn >>
```

```
<< case a1: T1
   case a2: T2
   ...
   case an: Tn >>
```

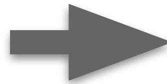
```
<< case a: T => b ==> s >>

     << a: T => b ==> s >>

     << a: T => b >>

     << a: T  >>

     << 10 >>
```

SubScript Actors: Implementation - 1

```
trait SubScriptActor extends Actor {
  private val callHandlers = ListBuffer[PartialFunction[Any, Unit]]()

  def _live(): ScriptNode[Any]
  private def script terminate = Terminator.block
  private def script die       = {if (context ne null) context stop self}

  override def aroundPreStart() {
   runner.launch( [ live || terminate ; die ] )
   super.aroundPreStart()
  }

  override def aroundReceive(receive: Actor.Receive, msg: Any) {
    ...
    callHandlers.collectFirst {
      case handler if handler isDefinedAt msg => handler(msg) } match {
        case None     => super.aroundReceive( receive         , msg)
        case Some(_) => super.aroundReceive({case _: Any =>}, msg)
  } }
 ...
}
```

SubScript Actors: Implementation - 2

```
<< case a1: T1 => b1 ==> s1
   case a2: T2 => b2 ==>
   ...
   case an: Tn => bn ==> sn >>
```



```
r$(case a1: T1 => b1; [s1]
   case a2: T2 => b2; null
   ...
   case an: Tn => bn; [sn])
```

```
trait SubScriptActor extends Actor {
  ...
  script r$(handler: PartialFunction[Any, ScriptNode[Any]]) =

    var s:ScriptNode[Any]=null
    @{val handlerWithAA = handler andThen {hr => {s = hr; there.eventHappened}}
                          synchronized {callHandlers += handlerWithAA}
      there.onDeactivate {synchronized {callHandlers -= handlerWithAA}}
    }:
    {. .}
    if s != null then s
}
```

Conclusion

- Easy and efficient programming
- Simple implementation: 5000 lines, 50%
  - VM + Scalac branch
  - Move to SugarScala & Macro's
- Still much to do and to discover
- Open Source:
  subscript-lang.org
  github.com/AndreVanDelft/scala
- Help is welcome
  Participate!

The End

- Spare Slides next