SubScript:

Extending Scala with the Algebra of Communicating Processes

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Overview

- Programming is Still Hard
- **Algebra of Communicating Processes**
- **SubScript** Now
  - Examples: GUI controllers
  - Implementation
  - Demonstration
- **SubScript** when Ready
  - Features
  - Challenges
  - Dataflow Programming, ...
- Conclusion

Programming is Still Hard

Mainstream programming languages: **imperative**

- good in **batch** processing
- not good in **parsing**, **concurrency**, **event handling**
- Java threads & event handlers are data
  - boring boilerplate code
  - error-prone: non-responsive GUIs
    - **GUI** thread
    - **background** threads
    - **event** handlers
    - enabling/disabling widgets
- Callback Hell

Neglected idioms

- Non-imperative choice: **BNF**, **YACC**
- Data flow: **Unix** pipes
- Process Algebra: **ACP**

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

$$
\begin{aligned}
x+y &= y+x \\
(x+y)+z &= x+(y+z) \\
x+x &= x \\
(x+y)\cdot z &= x\cdot z+y\cdot z \\
(x\cdot y)\cdot z &= x\cdot(y\cdot z)
\end{aligned}
$$

$$
\begin{aligned}
0+x &= x \\
0\cdot x &= 0 \\
1\cdot x &= x \\
x\cdot 1 &= x
\end{aligned}
$$

$$
\begin{aligned}
(x+1)\cdot y &= x\cdot y + 1\cdot y \\
&= x\cdot y + y
\end{aligned}
$$

Algebra of Communicating Processes - 3

$$
\begin{aligned}
(x+y)/z &= x/z + y/z \\
a \cdot x / y &= a \cdot (x/y) + y \\
0 / x &= x \\
1 / x &= 1
\end{aligned}
$$

$$x \parallel y = x \between y + y \between x + x \mid y$$

Algebra of Communicating Processes - 3a

Oops - (0+1)/z rewrote to both z+1 and 1. Repaired using guards:

$$
\begin{aligned}
(x+y)/\ z &= \ is0(x+y)\cdot z \\
&\quad + not0(x)\cdot x/z \\
&\quad + not0(y)\cdot y/z \\
a\cdot x\ /\ y &= \ a\cdot(x/y)\ +\ y \\
0\ /\ x &= \ x \\
1\ /\ x &= \ 1 \\
\\
is0(x+y) &= is0(x)\cdot is0(y) \\
is0(a\cdot x) &= 0 \\
is0(0) &= 1 \\
is0(1) &= 0 \\
not0(x) &= is0(is0(x))
\end{aligned}
$$

Algebra of Communicating Processes - 4

Less known than CSP, CCS

Specification & Verification

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

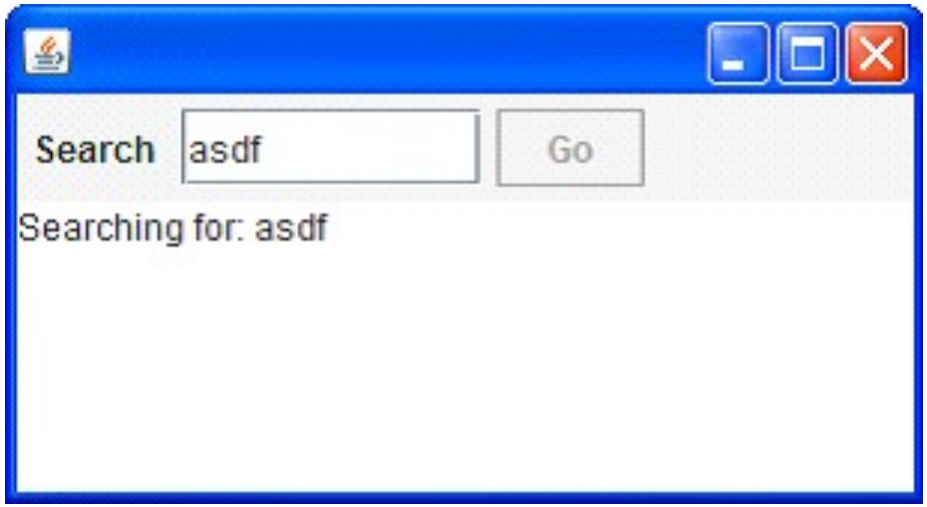
Strengths

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

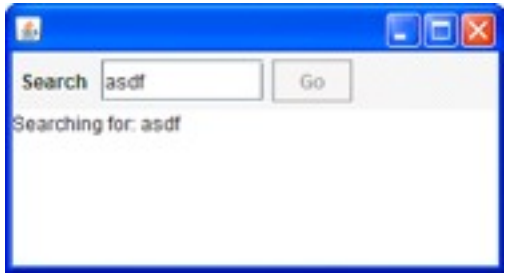
ACP Language Extensions

- 1980: Jan van den Bos - **Input Tool Model**
- 1988-2011: AvD - **Scriptic**
  - Pascal, Modula-2, C, C++, Java
- 2011-...: AvD - **SubScript**
  - Scala
  - JavaScript, ... (?)
- Application Areas
  - GUI Controllers
  - Text Parsers
  - Discrete Event Simulation
  - Dataflow Programming (?)
  - Parallel Processing (?)

GUI application - 1

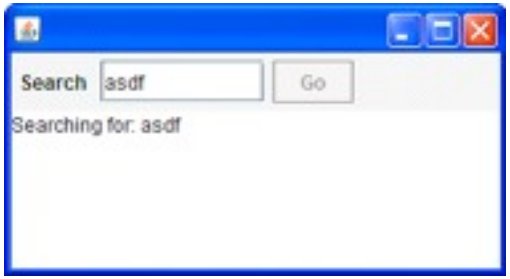


- Input Field
- Search Button
- Searching for…
- Results



GUI application - 2

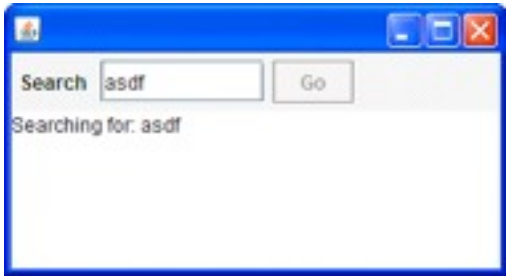
```
val searchButton = new Button("Go”) {
  reactions.+= {
    case ButtonClicked(b) =>
      enabled = false
      outputTA.text = "Starting search...”
      new Thread(new Runnable {
       def run() {
        Thread.sleep(3000)
        SwingUtilities.invokeLater(new Runnable{
          def run() {outputTA.text="Search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

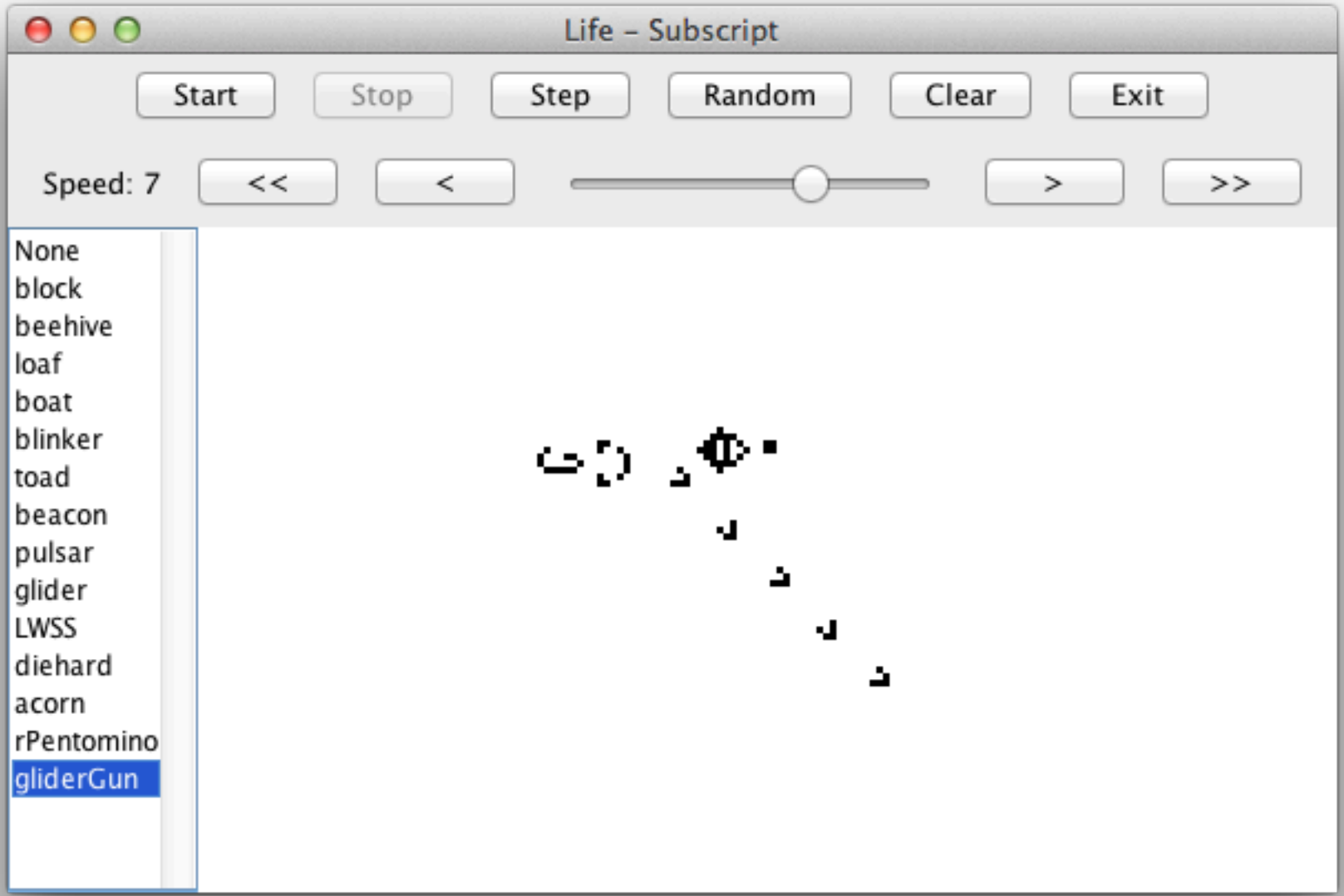
GUI application - 5

- 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} ...
```

Game of Life - 1



Game of Life - 2

```
   live           = ||  boardControl mouseInput speedControl doExit

  boardControl    = ...; (..singleStep) multiStep || clear || randomize

   doExit         = exitCommand var r=false @gui:{r=areYouSure} while(!r)

  randomizeCommand = randomizeButton + 'r'
      clearCommand =     clearButton + 'c'
       stepCommand =      stepButton + ' '
       exitCommand =      exitButton + windowClosing,top
 multiStepStartCmd =     startButton + Key.Enter
  multiStepStopCmd =      stopButton + Key.Enter

  do1Step         = {*board.calculateGeneration*} @gui: {!board.validate!}

  randomize       =   randomizeCommand @gui: {!board.doRandomize()!}
  clear           =       clearCommand @gui: {!board.doClear      !}
  singleStep      =        stepCommand do1Step
   multiStep      = multiStepStartCmd; ...do1Step {*sleep*}
                  / multiStepStopCmd
```

Game of Life - 3

```
speedControl     = ...; speedKeyInput+speedButtonInput+speedSliderInput

setSpeed(s: Int) = @gui: {!setSpeedValue(s)!}

speedKeyInput    = times(10)
                 + val c = chr(pass_up1+'0') key(c)
                   setSpeed(digit2Speed(c))

speedButtonInput = if (speed>minSpeed) speedDec
                 + if (speed<maxSpeed) speedInc

speedDec         = minSpeedButton setSpeed,minSpeed
                 +   slowerButton setSpeed(speed-1)
speedInc         = maxSpeedButton setSpeed,maxSpeed
                 +   fasterButton setSpeed(speed+1)

speedSliderInput = speedSlider setSpeed,speedSlider.value
```

Game of Life - 4

```
mouseInput     = (mouseClickInput & mouseDragInput)
               /  doubleClick
                  (mouseMoveInput / doubleClick {!resetLastMousePos!}); ...

mouseClickInput  = var p:java.awt.Point=null
                 ; var doubleClickTimeout=false
                   mouseSingleClick, board, p?
                   {! resetLastMousePos !}
                   ( {*sleep_ms(220); doubleClickTimeout=true*}
                   / mouseDoubleClick, board, p? )
                   while (!doubleClickTimeout)
                 ; {! handleMouseSingleClick(p) !}
                 ; ...

 mouseMoveInput  = mouseMoves(    board,(e:MouseEvent)=>handleMove(e.point))
 mouseDragInput  = mouseDraggings(board,(e:MouseEvent)=>handleDrag(e.point))
                 / (mouse_Released  {!resetLastMousePos!})
                 ; ...
```

Implementation

- 50% done, communication due
- Branch of Scalac

```
script a = b;{c}   ⟹
```

```
def _a = _script('a) {
  _seq(_call{here=>_b}, _normal{here=>c})
}
```

  - lines: scanner 100, parser 1000, typer 200
- Virtual Machine
  - lines: 2000
  - static script trees
  - dynamic Call Graph
- Swing event handling scripts
  - lines: 260
- Graphical Debugger
  - lines: 550 (10 in SubScript)

Debugger built using **SubScript**

```
live = {* awaitMessageBeingHandled *}
        if (shouldStep)
        (  @gui: {!updateDisplay!} stepCommand
        || if (autoCheckBox.isChecked) waitForStep
        )
        { messageBeingHandled=false }
        ...
     || exit


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

SubScript Features - 1

"Scripts" – process refinements as class members

- Called like methods from Scala
  - with a ScriptExecutor as extra parameter
- Call other scripts
- Parameters: in, out?, constrained, forcing

Formal Constrained	`implicit key(c??: Char) = …`		
Actual Calls	**Output**	**Constrained**	**Forcing**
Conventional	`key(c?)`	`key(c? if? c.isDigt)`	`key('1')`
No parentheses	`key,c?`	`key,c? if? c.isDigt`	`key,'1'`
Using `implicit`	`c?`	`c? if? c.isDigt`	`'1'`

SubScript Features - 2

ACP Atomic Actions ~ Scala Code {…} start/end

{ … }	Normal
{? … ?}	Unsure
{! … !}	Immediate
{* … *}	New thread
@gui: { … }	GUI thread
@dbThread: { … }	DB thread
@reactor: {. … .}	Event handler
@reactor: {... … ...}	Event handler, permanent
@startTime: { … }	Simulation time + real time
@processor=2: {* … *}	Processor assignment
@priority=2: {* … *}	Priority
@chance=0.5: { … }	Probability

SubScript Features - 3

N-ary operator	Meaning
; ws	Sequence
+	Choice
&	Normal parallel
|	Or-parallel (weak)
&&	And-parallel
||	Or-parallel
==>	Network/pipe
/	Disrupt
%/	Interrupt

Unary operator	Meaning
x*	Process launch

Construct	Meaning
here	Current position
@ … :	Annotation
if-else	
match	
try-catch-finally	
for	
while	
break	
...	while(true)
..	Both ... and .
.	Optional break
(-), (+), (+-)	Neutral: 0, 1-like

SubScript Features - 4

Process Communication

Definitions: *Shared Scripts*	
`send(i:Int), receive(j??:Int) = {j=i}`	
`send(i:Int), receive(i??: _ ) = {}`	
`ch<-(i:Int),  ch->(i??:Int) = {}`	
`ch<-->(i??:Int)  = {}`	
`  <-->(i??:Int)  = {}`	
`  <==>(i??:Int)  = {}`	
Usage: *Multicalls*	
`  send(10) & receive(i?)`	Output param
`  send(10) & receive(10)`	Forcing
`  ch<-(10) &  ch->(10)`	Channel
`  <-10  &  ->i?`	Nameless
`  *<-10  ;  ->i?`	Asynchronous send

Data Flow Programming - 1

```
def copy(in: File, out: File): Unit = {
  val  inStream = new  FileInputStream(in)
  val outStream = new FileOutputStream(out)
  val eof = false
  while (!eof) {
    val b = inStream.read()
    if (b==-1) eof=true else outStream.write(b)
  }
   inStream.close()
  outStream.close()
}
```

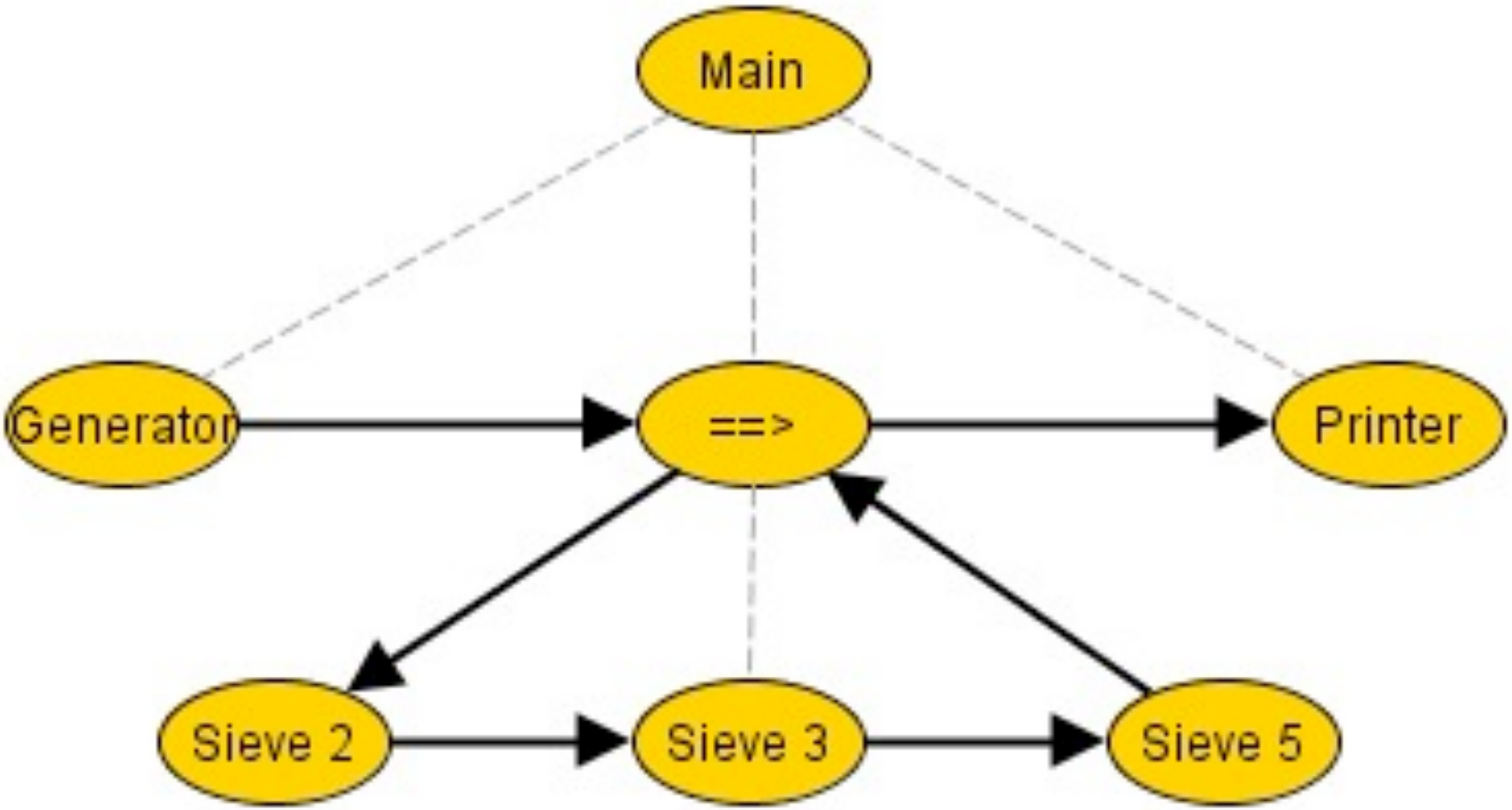
Data Flow Programming - 2

```
fileCopier(in:File, out:File)   =   reader(in) ==> writer(out)

reader(f:File)   = val inStream = new FileInputStream(f);
                   val b = inStream.read()  <=b   while (b!=-1);
                   inStream.close()

writer(f:File)   = val outStream = new FileOutputStream(f);
                   =>i?: Int   while (i != -1)    outStream.write(i);
                   outStream.close()

   <==>(i:Int)  = {}
```

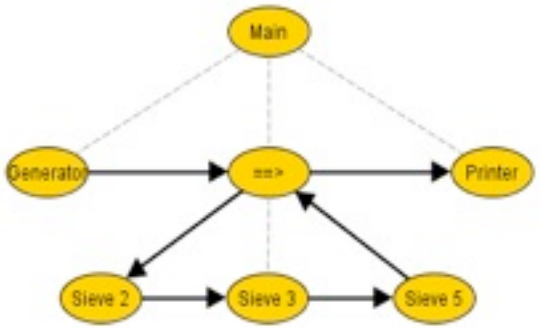
Data Flow Programming - 3

```
fileCopier  (in:File, out:File) = reader(in) ==> writer(out)

fileCrFilter(in:File, out:File) = reader(in) ==> crFilter ==> writer(out)


                    crFilter  =  =>c?:Int  if(c!='\r') <=c  ...
```

Sieve of Eratosthenes - 1



Sieve of Eratosthenes - 2




```
main = generator(2,1000000)
                ==> (..==>sieve)
    ==>{toPrint}==> printer

generator(s,e) = for(i<-s to e) <=i

sieve          =   =>p:Int?    @toPrint:<=p;
                 ..=>i:Int? if (i%p!=0) <=i

printer        = ..=>i:Int? println,i

<==>(i:Int)    = {}
```

Challenges

- **Implementation**: compiler, vm, debugger
- **Unit tests**
- **vms** for simulations, parallel execution, ...
- New features
  - **process lambdas**
  - **disambiguation**
  - **return values**
- Documentation, papers, ...

Challenge: Process Lambdas

- Henk Goeman 1989: (Self) Applicative Communicating Processes
- Robin Milner 1989: **π**-calculus

```
poisson(t:Int, s:()=>script) = {duration=rndNegExp(t)} s* ...
customerGenerator            = poisson,10, <customer.live>
```

Challenge: Disambiguation

```
  a b  +  a c
..a b  ;  a c
```

```
  a b  ||  a c
```

```
  a b  |+|  a c
..a b  |;|  a c
```

Challenge: Return Values

- YACC

```
expr   : expr PLUS term  { $$ = $1 + $3; }
       |           term  { $$ = $1; }
;
term   : term MUL factor { $$ = $1 * $3; }
       |          factor { $$ = $1; }
;
factor : LPAR expr RPAR  { $$ = $2; }
       | NUMBER          { $$ = $1; }
;
```

- SubScript (?)

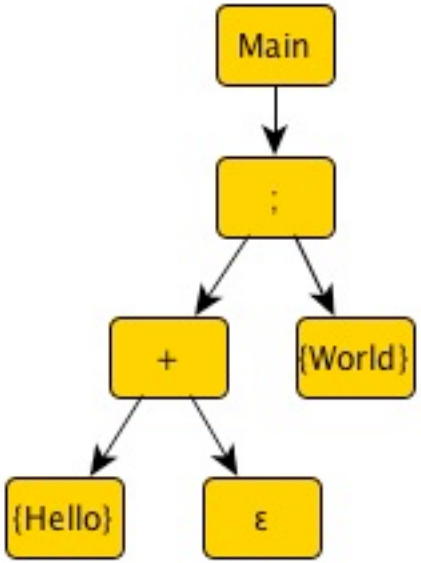
```
expr  : Int =       term  ^^{$ += _} .. "+"
term  : Int = {^1^}; factor^^{$ *= _} .. "*"
factor: Int = number^ + "(" expr^ ")"
number: Int = @expectNumber: {? acceptNumber ?}
```

Conclusion

- Easy and efficient programming
- Support in Scalac branch
- Simple implementation: 5000 lines
- Still much to do and to discover
- Open Source:
  subscript-lang.org
  github.com/AndreVanDelft/scala
- **Help** is **welcome**
  - Participate!
- Hands-on workshop

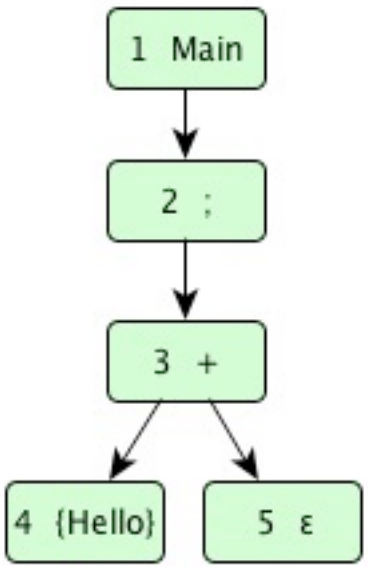
The End

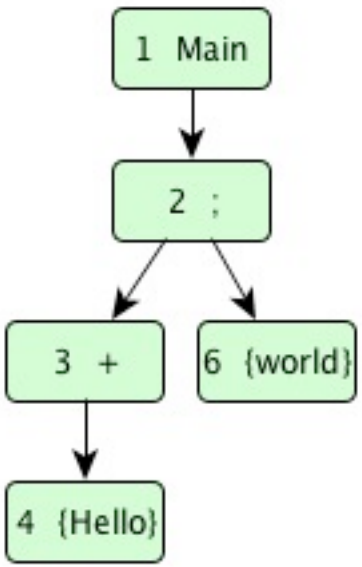
- Spare Slides next

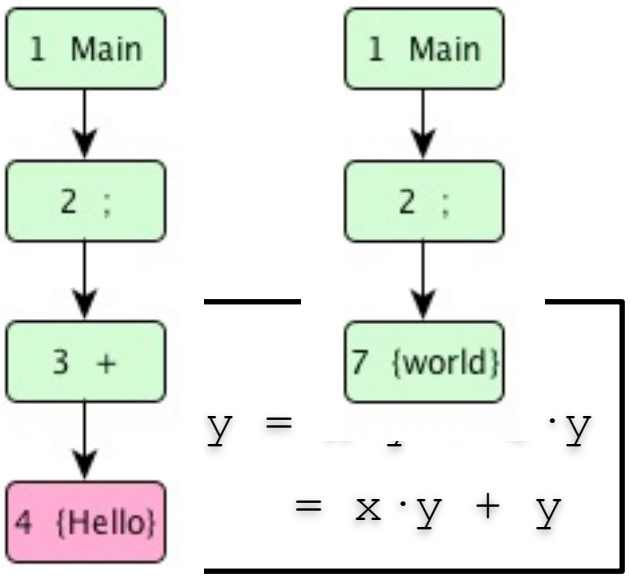


Templates & Call Graphs

```
{Hello}+ε; {World}
```







Experience - 1

- **Scriptic**: **Java** based predecessor
- In production since 2010
- Analyse technical documentation
- Input: **ODF** ~ **XML** Stream
- **Fun** to use mixture of grammar and 'normal' code
- Parser expectations to scanner

```
implicit text(s??: String) = @expect(here,  TextToken(_s): {?accept(here)?}
implicit number(n??:  Int) = @expect(here,NumberToken(_n): {?accept(here)?}
```

Experience - 2

Low level scripts

```
implicit text(s??: String) = @expect(here,  TextToken(_s): {?accept(here)?}
implicit number(n??:  Int) = @expect(here,NumberToken(_n): {?accept(here)?}
```

```
anyText        = s?: String
anyLine        = anyText endOfLine

someEmptyLines = ..endOfLine
someLines      = ..anyLine
```

Experience - 3

For-usage

```
tableRow(ss: String*) = startRow; for(s<-ss) cell(s); endRow
```

```
oneOf(r?: String, ss: String*) = for(s<-ss) + s {! r=s !}
```

Experience - 4

If-usage

```
footnoteRef(n?: Int) = "(" n? ")"


footnote(n?: Int,
         s?: String) =  if (fnFormat==NUMBER_DOT) (n? ".")
                        else (footnoteRef,n? "-")
                        s?
                        endOfLine
```

Experience - 5

Grammar ambiguity

```
var s: String
var n: Int

startCell s? endCell  +  startCell n? endCell
startCell s? endCell  ||  startCell n? endCell
startCell s? endCell |+| startCell n? endCell
```

```
xmlTag(t: XMLTag),.. = @expect(here, t) {?accept(here)?}
```