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CSER 2021

Upending Inversion of Control

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Upending Inversion of Control

Do you practice structured programming?

- Of course you do.
- We were taught to use structured control constructs such as
  - loops
  - ifs
  - sequential composition (one damn thing after another)
- Goto statements are bad
- Subroutines are good
- Global state is bad.

But,

do you practice structured programming
when you are handling events?

Events

- An event is anything a program may need to wait for
  - In a GUI:
    - user actions such as keypresses, mouse actions, button clicks, etc.
  - In distributed or system:
    - incoming requests and responses from clients, servers, and peers.
  - In a concurrent program
    - changes of state
    - messages on internal channels

Example: A use case

A Use case tells a story.

Use case: Greet the user forever

0 The following sequence is repeated forever

0.0 System: Prompts for name
0.1 User: Types in a name and presses “enter”
0.2 System: Greets the user by name

Example: A "console" program

```
proc main()
    loop
        print “What is your name?”
        var name := readLine
        print “Hello ” name “.”
```

The code tells a story. The structure of the story is reflected in the structure of the code.

Narrative structure

The structure of the console program follows the narrative of the use case

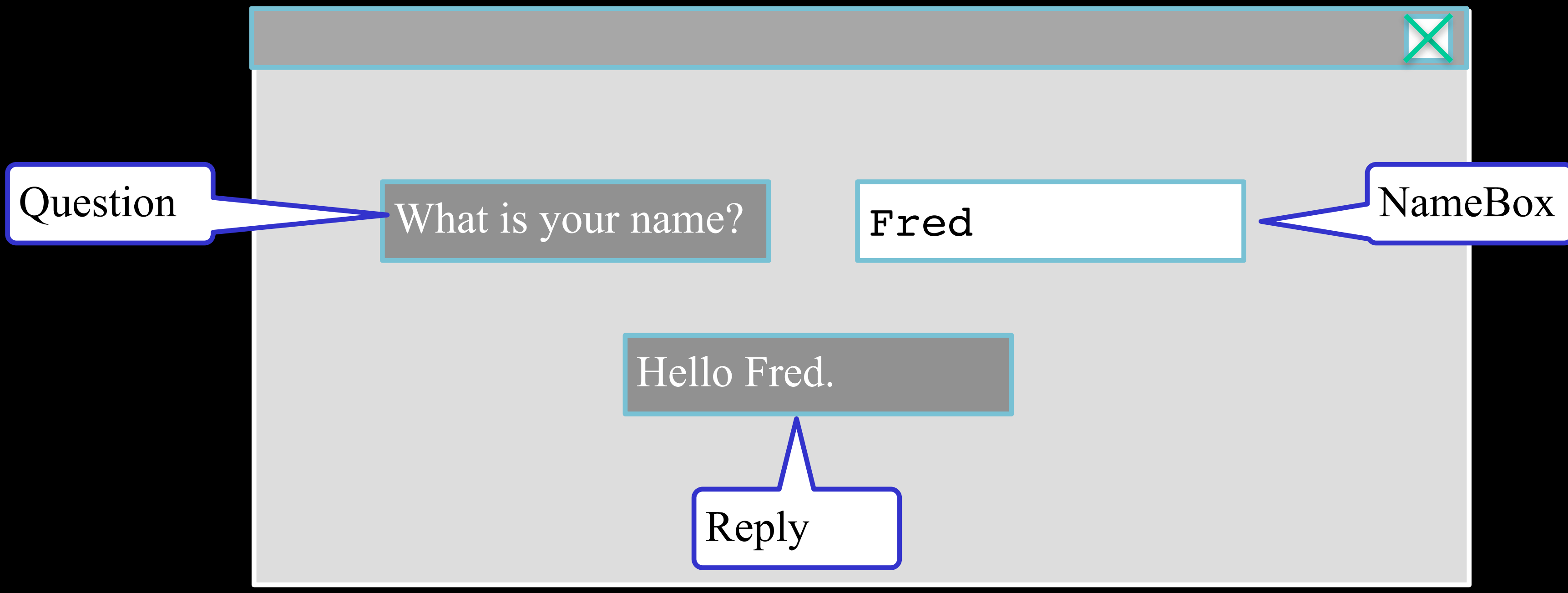
Use case: Greet the user forever

0 The following sequence is repeated forever

- 0.0 System: Prompts for name
- 0.1 User: Types in a name and presses "enter"
- 0.2 System: Greets the user by name

```
proc main()
   loop
      print "What is your
                   name?"
      var name := readLine
      print "Hello " name "."
```

But we want a GUI!



The GUI program

```
var nameBox := new TextField()
var question := new Label( “What is your name” )
var reply := new Label()

proc main()
    nameBox.on( enter, nameBoxHandler )
    show question
    show nameBox
    show reply

proc nameBoxHandler()
    var name := nameBox.contents()
    reply.text := “Hello ” name “.”
```

Event handler. means inversion of control.

Where did the control structure go?

Unstructured

Use case: Greet ...

0 The following sequence is repeated forever

- 0.0 System: Prompts for name
- 0.1 User: Types in a name and presses “enter”
- 0.2 System: Greets the user by name

```
var nameBox := new TextField
var question := new Label( “W
var reply := new Label()

proc main()
   nameBox.on(enter, nameBo
   show question
   show nameBox
   show reply

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   var name := nameBox.conte
   reply.text := “Hello ” name “.”
```

Changing requirements

Use case: Greet the user forever

0 The following sequence is repeated forever

- 0.0 System: Prompts for name
- 0.1 User: Types in a name and presses "enter"
- 0.2 System: Greets the user by name

```
proc main()
    loop
        print “What is your
                        name?”
        var name := readLine
        print “Hello ” name “.”
```

Changing requirements

Use case: Greet the user forever

0 The following sequence is repeated forever

- 0.0 System: Prompts for name
- 0.1 User: Types in a name and presses "enter"
- 0.2 System: Greets the user by name
- 0.3 Wait 1 second

```
proc main()
    loop
        print "What is your
                          name?"
        var name := readLine
        print "Hello " name "."
        pause 1000 ms
```

Changing requirements

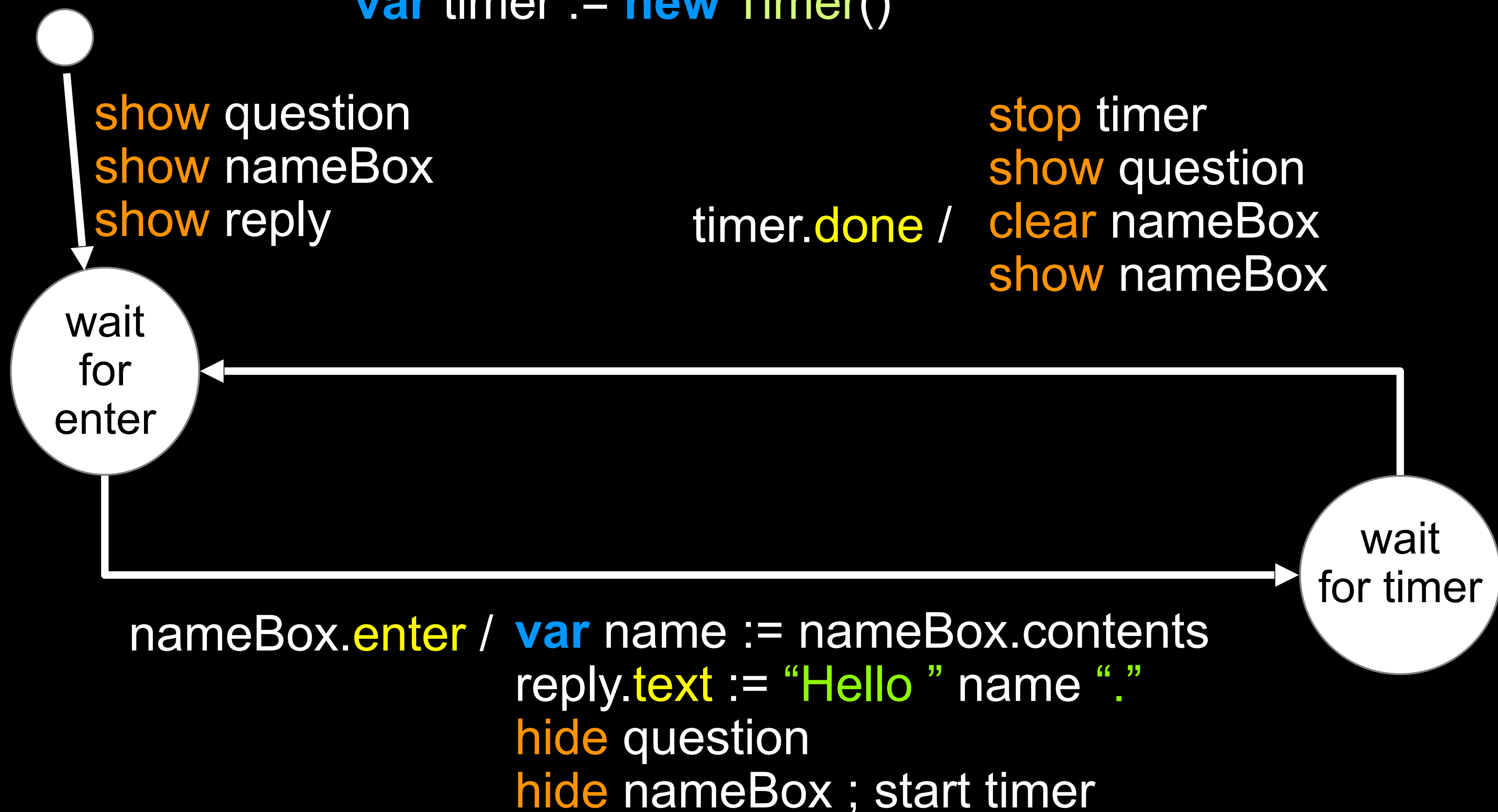
```
var nameBox := new TextField()
var question := new Label( “What is your name” )
var reply := new Label()
var timer := new Timer(1000 ms)

proc main()
    nameBox.on(enter, nameBoxHander)
    timer.on( done, timeHander )
    show question ; show nameBox ; show reply

proc nameBoxHandler()
    var name := nameBox.contents
    reply.text := “Hello ” name “.”
    hide question ; hide nameBox ; start timer

proc timeHandler()
    stop timer ; show question ; clear nameBox ; show nameBox
```

State machines

- Inversion of control programs are state machines
- Unstructured programming all over again
  - But worse
- Where are the states?
  - Our program has two states
  - Where are they in the code?

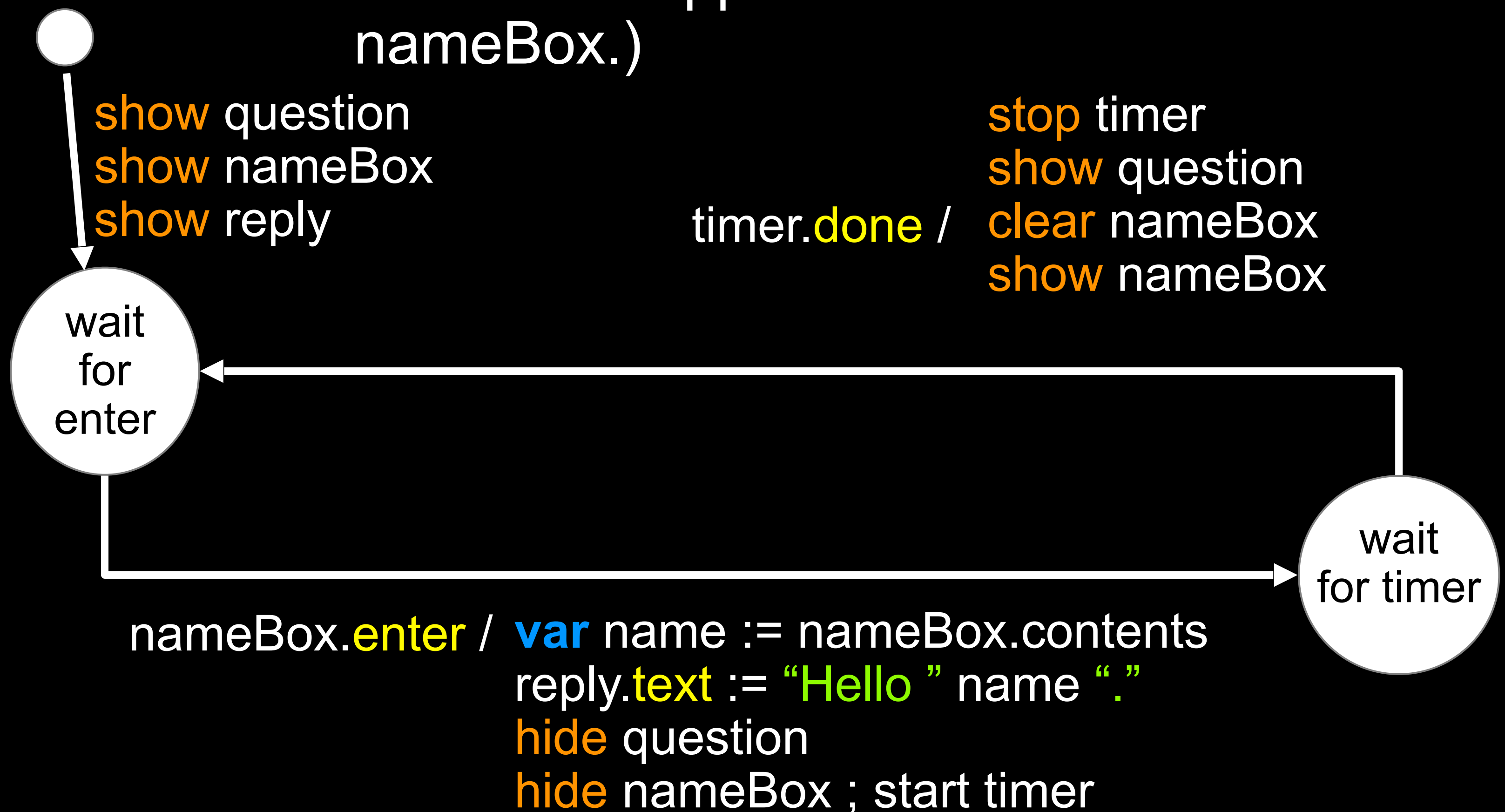
Inv. of control ≃ State machine

```
var nameBox := new TextField()
var question := new Label( “What's your name” )
var reply := new Label()
var timer := new Timer()
```



Inv. of control ≃ State machine

NEAR BUG! What if there is an enter event while the timer is running? (The only reason this won't happen is that I hide the nameBox.)



What I would like

```
var nameBox := new TextField()
var question := new Label( “What's your name” )
var reply := new Label()

proc main()

    show reply

    loop
        clear nameBox
        show nameBox
        show question

        getAndDisplayAnswer
        hide question
        hide nameBox

        pause 1000 ms
```

```
proc getAndDisplayAnswer
        wait for enter on nameBox
        var name := nameBox.contents
        reply.text := “Hello ” name “.”
```

What I would like

```
var nameBox := new TextField()
var question := new Label( “What's your name” )
var reply := new Label()

proc main()

    show reply

    loop
        clear nameBox
        show nameBox
        show question

        getAndDisplayAnswer
        hide question
        hide nameBox

        pause 1000 ms
```

```
proc getAndDisplayAnswer
    wait for enter on nameBox
    var name := nameBox.contents
    reply.text := “Hello ” name “.”
```

state

state

The Problem

How can we write event-driven code in a structured fashion?

The idea

Make a library based on process algebra

- Process algebras
  - extend context-free grammars with
    - interactivity
    - concurrency
    - communication
    - internal and external choice
  - Examples: CSP, CCP, π-calculus, ACP

Take Back Control*

Take Back Control (TBC)

- A library for
  - Asynchronous I/O
  - Cooperative multithreading
  - Event-driven programming in general
- Written in the Haxe language
  - Haxe transpiles to JavaScript, Python, and other languages
- Abstracts away from inversion of control

* I had this name *before* the Brexit "Leave" campaign.

Example

This is code written in Haxe using TBC.

```
static function mainLoop() : Process<Triv> { return
    loop  ( clearText( nameBox ) >
            show( nameBox )  >
            show( question ) >
            getAndDisplayAnswer() >
            hide( question ) >
            hide( nameBox ) >
            pause( 1000 ) ) ; }

static function getAndDisplayAnswer()
: Process<Triv> { return
      await( enter( nameBox ) && getValue( nameBox ) )
      >= hello ; }

static function main() {
    ... create the GUI ...
    mainLoop().run( ) ; }
```

`Process`es

A generic type

`Process<A>`

Each object of type `Process<A>`

- is immutable
- represents a *specification of* behaviour
- has a result type `A`

Processes

When p is a Process<A>

- p.run() starts running the process & returns immediately
- p.go(f, g) similar with continuations
  - f(a) if the run succeeds and
  - g(e) if it fails

```
static function main() {
    ... create the GUI ...
    mainLoop().run( ) ; }
```

Build the view

Build a controller process object

Run the controller

Making `Process` Objects

Some ways to make process objects

- `pause( t )`
  - when run, it waits t milliseconds
  - the result is null
- `exec( f )` is a `Process<A>`
  - when run, it calls closure `f : () -> A`
  - the result is the value of `f()`

Making `Process` Objects

Some ways to make process objects

- `pause( t )`
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Using exec

```
static function clearText( el : InputElement )
  : Process<Triv> {
    return exec( () -> {el.value = ""; null;}  ) ; }
```

Using exec

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static function clearText( el : InputElement )
  : Process<Triv> {
    return exec( () -> {el.value = ""; null;} ) ; }
```

`() -> {el.value = ""; null;}` is a Haxe lambda expression

Using `exec`

```
static function clearText( el : InputElement )
  : Process<Triv> {
    return exec( () -> {el.value = ""; null;}  ) ; }
```

`() -> {el.value = ""; null;}` is a Haxe lambda expression

`show`, `hide`, `getText` and `putText` are similar

Process combinators

Some ways to combine process objects

- `p > q`
  - run `p` and then run `q`.
- `p >= f`
  - run `p` to get a result `a`
  - then run the result of `f(a)`
- `loop( p )` run `p` over and over forever

Process combinators

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Monad inspired by parsing combinators

Our example

```
static function mainLoop() : Process<Triv> {
  return
      loop( clearText( nameBox ) >
            show( nameBox )  >
            show( question ) >
            getAndDisplayAnswer() >
            hide( question ) >
            hide( nameBox ) >
            pause( 1000 )
          ) ;
}
```

Guards represent events

```
static function getAndDisplayAnswer() : Process<Triv> { return
    await( enter( nameBox ) && getValue( nameBox ) ) >= hello ; }

static function hello( name : String ) : Process<Triv> { return
    putText( reply, "Hello "+name ) ; }
```

- `enter( nameBox )`
  - makes a `Guard<js.html.Event>` object representing events
- `getValue( nameBox )`
  - makes a `Process<String>`
- `enter( nameBox ) && getValue( nameBox )`
  - makes a `GuardedProcess<String>` object
- `await( ... )`
  - makes a `Process` from the `GuardedProcess`.
- `await( ... ) >= hello`
  - makes a `Process` that, when run, will update the `reply` label.

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Guards represent events

```
static function getAndDisplayAnswer() : Process<Triv> { return
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- `enter( nameBox ) && getValue( nameBox )`
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- `await( ... )`
  - makes a `Process` from the `GuardedProcess`.
- `await( ... ) >= hello`
  - makes a `Process` that, when run, will update the `reply` label.

Event-driven choice

- Given two guarded processes `gp0` and `gp1`,
  `gp0 || gp1` is also a guarded process
- The first event to happen wins.
- Combining use cases

```
loop ( await(      saveUseCase
                || loadUseCase
                || addItemUseCase
                || deleteItemUseCase )
```

Things I don't have time to show

- Filtering events
- Or-ing events
- Parallel composition `par(p, q)` is a Process object.
  - The two processes are run on the same thread!
- Exception handling
- Loops with exits
- Communication channels – being developed

Similar things

- promises
  - provide some structure ✔
  - not immutable (Promise is not a monad!) ✘
  - handle choice poorly ✘
- async / await
  - do not handle choice ✘
  - part of the language ✘✔
- clojure.core.async
  - similar
  - relies on macros ✘
- actors
  - executions as objects ✘✔
  - only parallel composition ✘
- process algebras
  - same idea ✔
  - implementations? ✘

Conclusion

- TBC an extensible, embedded, domain-specific library supporting
  - Composition: sequential, parallel, choice, looping
  - Abstraction via subroutines and parameters
  - Recursion
- We can write code that
  - is structured and subroutineable
  - corresponds to use cases
  - is easy to understand, modify, and maintain.

Thank you

Read more at

http://sourcephile.blogspot.com/2015/05/

Extending the framework

- You can easily extend the framework by creating your own classes that implement the `Process` interface.
- You just extend class `ProcessA<A>` while overriding method

```
public function go( k : A -> Void ) { … }
```

Implementing the Process Monad

- Each process `p : Process<A>` has a method
  `p.go( k : A -> void )`
- The `go` method initiates the process.
- Its argument specifies what is to be done with the result. `k` is for *k*ontinuation.
- `unit(a).go( k )` means `k(a)`
- `(p >= f).go( k )` means
  `p.go( b -> f(b).go( k ) )`

Implementing the Process Monad

- `exec(f).go( k )` means `k( f() )`
- `pause( t ).go( k )` means
```
        var timer = new Timer( t ) ;
        timer.run = () -> k( null ) ;
        timer.start() ;
```
- E.g. `pause(1000).bind( x->print(42) ).go(k)`

  ≡ (approx.)
```
    var timer = new Timer(1000) ;
    timer.run = () -> (x ->
                         exec( ()->
                               {trace(42);null} )
                       )(null).go(k) ;
    timer.start() ;
```
  ≡
```
    var timer = new Timer(1000) ;
    timer.run = () -> k({trace(42);null}) ;
    timer.start() ;
```

Loops

Define

```
public static function loop<A>( p : Process<A> )
                                          : Process<Triv> {
       return p >= (a -> loop(p)) ; }
```

- [N.B. It looks like an infinite recursion, but it is not! Bind does not call `a -> loop(p)` . It just stores the function in the `Process` object that gets returned. The following definition would not work

```
public static function loop<A>( p : Process<A> )
                                          : Process<Triv> {
       return p > loop(p) ; }
```

This *is* an infinite recursion.]

Extending the framework

- You can create your own class of guards just by extending class `GuardA<E>` while overriding this method
- `public function enable( k : E -> Void ) : Disabler { …`
- The `k` represents the thing to do when the event happens.
- The result is simply an object that can disable the guard.

Event values

- The `&&` operator throws away the underlying event data.
- We can also pipe information from the event to a process.
- If `e` is an `Guard<E>` and `f` is a function in `E -> Process<A>`, then

```
e >> f
```

is a `GuardedProcess<A>`. For example

```
await( e >> unit )
```

is a `Process<E>`.

Event filtering

- If `e` is a `Guard<E>` and `g` is a function in `E -> Bool`, then `e & g` is a `Guard<E>`
- `e & g` ignores events where `g` gives false. For example the `enter( nameBox )` guard is constructed as follows

```
static function enter( el : Element ) : Guard<Event> {

        function isEnterKey( ev : Event ) : Bool {
            var kev = cast(ev, KeyboardEvent) ;
            return kev.code == “Enter” ; }

        return keypress( nameBox ) & isEnterKey ;
  }
```

Implementing await

- Consider
- `await(  g && p || h && q ).go( k )`
- Enables, guard `g`, passing in a continuation that
  - Disables both `g` and `h` and then
  - calls `p.go( k )`
- Also enables guard `h`, passing in a continuation that
  - Disables both `g` and `h` and then
  - calls `q.go( k )`

Exception Handling

- What if there is an exception?
- We can set up an exception handler

  `attempt( p, f )`

  or `attempt(p, f, q)`

  where `f` is a function from exceptions to processes and q is a process to be done regardless.
- E.g.

```
openFile >= (h:Handle) ->
attempt( doStuffWithIt( h ),
         (ex:Dynamic) -> cope(ex),
         closeFile( h ) )
```

- Implementation: I lied earlier. The `go` method actually takes two continuations: One for normal termination and one for exceptional termination.