Reactive pattern matching for F#

Part of “Variations in F#” research project

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The key theme of the talk

Languages support (overly) rich libraries for encoding concurrent and reactive programs

> In practice, used in *modes* or *design patterns* such as tasks, threads, active objects, etc.

Languages can provide better support for concurrent and reactive programming

We don’t have to commit the language to one specific *mode* or *design pattern*

Agenda

- Background
  - **Asynchronous programming in F#**
- Reactive programming
  - Writing user interface control logic
  - Pattern matching on events
  - Programming with event streams
- Concurrency
  - Pattern matching and concurrency

Computation expressions

Compose expressions in a customized way

```
<builder> { let! arg = function1()
            let! res = function2(arg)
            return res }
```

Meaning is defined by the *<builder>* object

- For example, we could propagate “null” values (aka the “maybe” monad in Haskell)

```
let LoadFirstOrder(customerId) =
   nullable { let! customer = LoadCustomer(customerId)
              let! order = customer.Orders.FirstOrDefault()
              return order }
```

Asynchronous workflows

Writing code that doesn't block threads

```
let http(url:string) =
  async { let req = HttpWebRequest.Create(url)
          let! rsp = req.AsyncGetResponse()
          let reader = new StreamReader(rsp.GetResponseStream())
          return! reader.AsyncReadToEnd() }

let pages = Async.Parallel [ http(url1); http(url2) ]
```

We can use it for various design patterns

- Fork/Join parallelism involving I/O operations
- Active objects communicating via messages

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Reactive programming with *async*

Concurrent *design patterns* using *async*

- » Concurrently executing, communicating agents
- » Using thread pool threads to run computations

Reactive programming design pattern

- » Uses the same language and additional libraries
- » Multiple agents running on a **single thread**
- » Agents mostly wait for events, then **react quickly**

Example: counting clicks

Takes 'int' as an argument and returns 'Async<unit>'

Show t button mouse clicks

Resumes the agent when the event fires

```
let rec loop(count) =
    async {
        let! me = Reactive.AwaitEvent(lbl.MouseDown)
        let add = if me.Button = MouseButtons.Left then 1 else 0
        lbl.Text <- sprintf "Clicks: %d" (count + add)
        return! loop(count + add)
    }
loop(0) |> Async.Start
```

Continue running using 'loop'

This looks like an "aggregation" of events

» Can we make it simpler? Yes, in this particular case…

Example: counting clicks

Modification - let's limit the "clicking rate"

```
let rec loop(count) =
   async {
      let! me = Reactive.AwaitEvent(lbl.MouseDown)
      let add = if me.Button = MouseButtons.Left then 1 else 0
      lbl.Text <- sprintf "Clicks: %d" (count + add)
      let! _ = Reactive.Sleep(1000)
      return! loop(count + add)
   }

loop(0) |> Async.Start
```

Resumes the agent after 1000 milliseconds

How can we describe agents in general?

» Agent is often just a simple state machine!

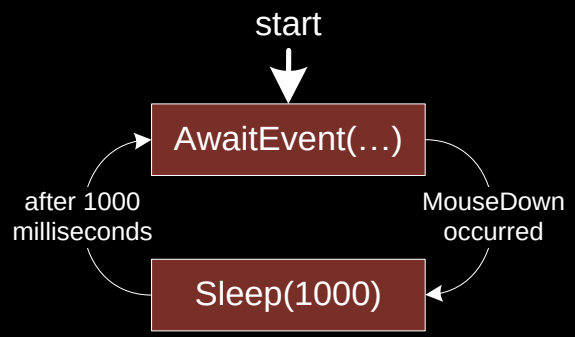
Agents as state machines

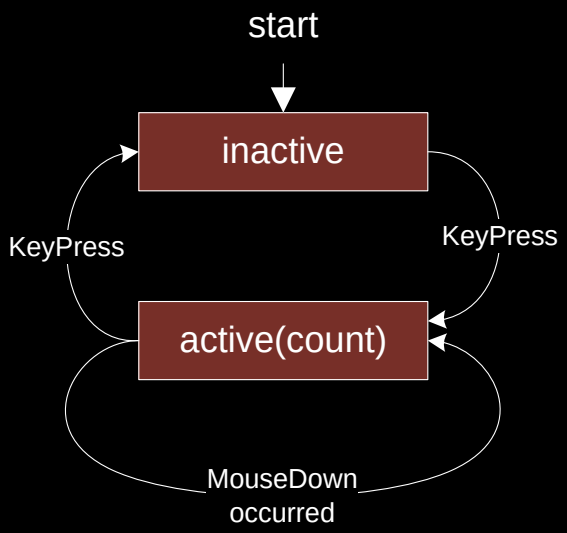
The elements of a state machine

- States and transitions
- In each state, some events can trigger transitions
- We can ignore all other events

We need one more thing…

- Selecting between several possible transitions





Selecting between transitions

Single-parameter *AwaitEvent* isn't sufficient

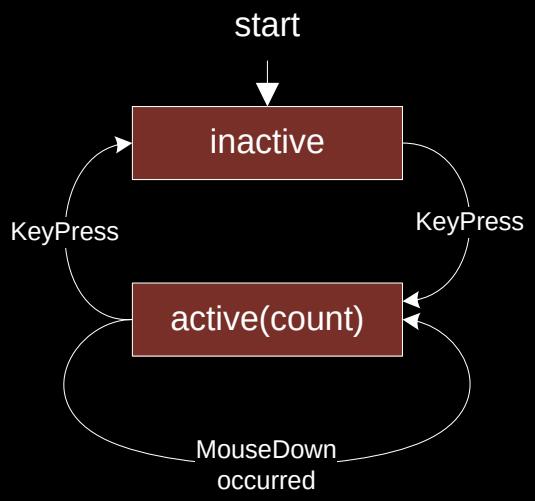
» Select cannot be encoded in our base language

Resume when the first of the events occurs
IEvent<'A> * IEvent<'B> -> Async<Choice<'A * 'B>>

```
let rec active(count) = async {
  let! ev = Async.AwaitEvent(frm.KeyPress, frm.MouseDown)
  match ev with
  | KeyPress(_) ->
      return! inactive()
  | MouseDown() ->
      printfn "count = %d" (count + 1)
      return! active(count + 1) }

and inactive() = async {
  let! me = Async.AwaitEvent(frm.MouseDown)
  return! active(0) }

Async.Start(inactive())
```



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Adding language support for joining

Let’s start with the previous version

```
let rec active(count) = async {
    let! ev = Async.AwaitEvent(frm.KeyPress, frm.MouseDown)
    match! ev with
    | Choice1Of2(_) ->
        return! inactive()
    | Choice2Of2(_) ->
        printfn "count = %d" (count + 1)
        return! active(count + 1) }
```

Computation expression specifies the semantics

- Here: Wait for the first occurrence of an event
- Pattern matching is more expressive than ‘select’

Expressive power of joins

Matching events against *commit patterns*

- » Either commit ("!<*pattern*>") or ignore ("_")
- » Important difference between "!_" and "_"

Filtering – we can specify some pattern

```
match! agent.StateChanged, frm.MouseDown with
| !(Completed res), _ -> printfn "Result: %A" res
| _, !me -> // Process click & continue looping
```

Joining – wait for the first occurrence of each

```
match! frm.MouseDown, frm.MouseUp with
| !md, !mu ->
    printfn "Draw: %A-%A" (md.X, md.Y) (mu.X, mu.Y)
```

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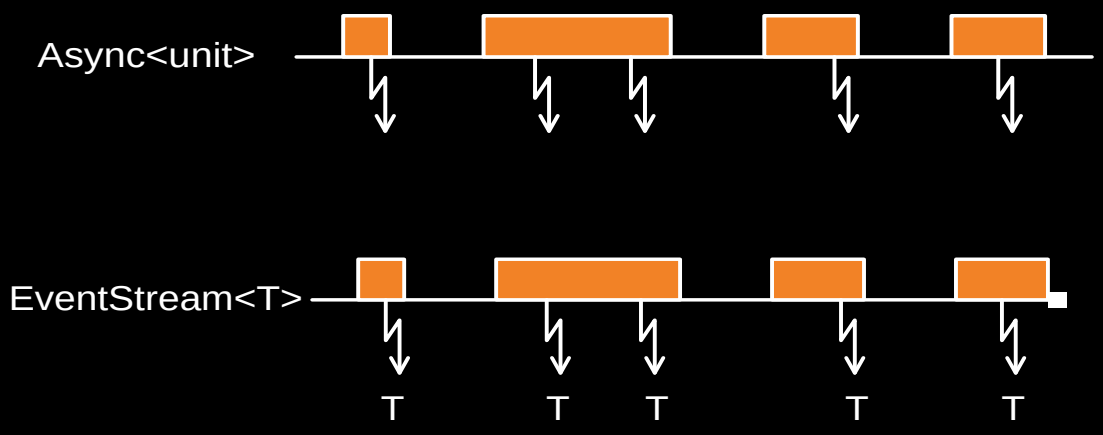
Turning agents into event streams

Agents often perform only event transformations

- » Repeatedly yield values and may eventually end
- » “Event streams” can be elegantly composed



Turning agents into event streams

Agents often perform only event transformations

- » Repeatedly yield values and may eventually end
- » “Event streams” can be elegantly composed

Library support using computation expressions

```
let rec active(count) = eventStream {
    match! frm.Click, frm.KeyPress with
    | !ca, _ -> return! inactive()
    | _, !ka ->
        printfn "count = %d" (count + 1)
        return! active(count + 1) }

inactive().Add(fun n -> printfn "count=%d" n)
```

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Concurrency using Futures

Computation that eventually completes

- » Used for encoding task-based parallelism
- » Similar to *async*, but used for CPU-bound concurrency

```
var f1 = Future.Create(() => {
    /* first computation */
    return result1;
  });
var f2 = Future.Create(() => {
    /* second computation */
    return result2;
  });
UseResults(f1.Value, f2.Value);
```

Synchronization (*join*) point - blocks until both complete

Pattern matching on Futures

What does “match!” mean for Futures?

- “!” pattern: Wait for the computation to complete
- “_” pattern: We don’t need the result to continue

Example: Multiplying all leafs of a binary tree

```
let rec treeProduct(tree) = future {
  match tree with
  | Leaf(num)  -> return num
  | Node(l, r) -> match! treeProduct(l), treeProduct(r) with
                  | pl!, pr! -> return pl * pr }
```

» Joining of futures is a very common task

» Patterns give us additional expressivity

Concurrency using Cω joins

Simple unbounded buffer in Cω

```
public class Buffer {
  public async Put(string s);
  public string Get() & Put(string s) { return s; }
}
```

» Single synchronous method in join pattern

» The caller blocks until the method returns

Joins on channels encoded using "!" patterns:

```
let put = new Channel<_>()
let get = new Channel<ReplyChannel<_>>()
joinActor { while true do
              match! put, get with
              | !v, !chnl -> chnl.Reply(v) } |> Async.Spawn
```

Time for questions & suggestions!

- **Many components could be single threaded**
- **Direct way for encoding state machine is essential**
- **Language features can/should be generally useful**

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For more information:

- Everything is work in progress
- Feel free to ask: tomas@tomasp.net