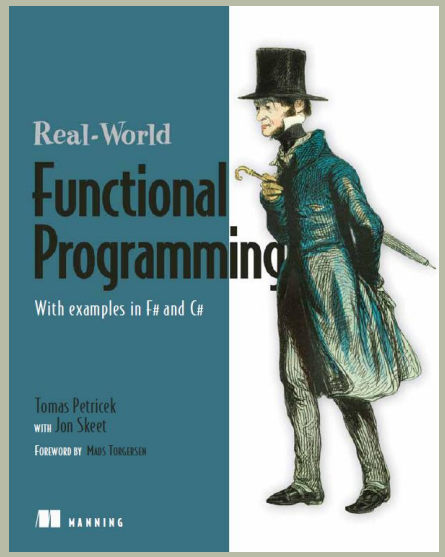
Reactive Programming with F#

Tomáš Petříček

Microsoft C# MVP
http://tomasp.net/blog

A little bit about me…

- Real-World Functional Programming
  - with **Jon Skeet**
  - Today's talk based on some ideas from Chapter 16
- Worked on F# at MSR
  - Internships with Don Syme
  - Web programming and reactive programming in F#
  - Some Visual Studio 2010 IntelliSense



What is this talk about?

- It is not about *concurrent programming*
  - Multiple threads, various programming models
  - **Immutable data** using Tasks or Parallel LINQ
    - We have full control over the control flow
  - **Message passing** using F# `MailboxProcessor`
    - Processors react to received messages
- It is about *reactive programming*
  - Components that react to events in general
    - `MailboxProcessor` is one possible implementation
  - Can be single-threaded – running on GUI thread

Single-threaded reactive programming

- Single-threading makes GUI simple (possible!)
  - Reactive part of the application reacts quickly
  - Expensive work should be done in background
- *Declarative* – **what** to do with received data
  - Define *data-flow* using event combinators

    ⊕ Simple & elegant ⊖ Limited expressivity
- *Imperative* – **how** to react to received data
  - *Define control-flow* using asynchronous workflows
  - ⊖ Write more code ⊕ Easy for difficult tasks

Talk outline

- **Writing reactive GUIs declaratively**
  - Declarative GUI programming in WPF
  - Using F# event combinators
- Writing reactive GUIs imperatively
  - Using the `AwaitObservable` primitive
  - Understanding threading
- Asynchronous programming with events
  - Asynchronous HTTP web requests

Everybody loves declarative style!

- Used by numerous .NET libraries
  - LINQ for specifying queries in C#
  - Specifying layout of user interface in WPF/Silverlight

- Can be used for specifying reactive aspects too!

```
<Button Content="Click me!">
  <i:Interaction.Triggers>
    <i:EventTrigger EventName="Click">
      <ei:CallMethodAction MethodName="Process" (...) />
    </i:EventTrigger>
  </i:Interaction.Triggers>
</Button>
```

Triggered when this event occurs

This action calls specified method

Everybody loves declarative style! (2.)

- Specifying more complex behaviors
  - We can write new Triggers and Actions…
  - For example *Silverlight Experimental Hacks* Library
    - We can specify conditions for triggers

```
<Button Content="Click me!"><i:Interaction.
  <ex:EventTrigger EventName="Click">
    <ex:EventTrigger.Conditions><ex:InvokingConditions>
      <ex:InvokingCondition ElementName="chkAllow"
         Property="Enabled" Value="True" />
    </ex:InvokingConditions></ex:EventTrigger.Conditions>
    <ex:PropertyAction PropertyName="Visible" Value="True" />
  </ex:EventTrigger>
</i:Interaction.Triggers></Button>
```

Triggered only when `chkAllow.Enabled == true`

Displays some control

DEMO

Introducing F# event combinators

Digression: Dynamic invoke in F#

- Access members not known at compile-time
  - Simple version of `dynamic` keyword in C#
  - We can easily define behavior of the operator

```
let (?) (this : Control) (prop : string) : 'T =
  this.FindName(prop) :?> 'T
```

- How does it work?
  - When we write…

```
let ball : Ellipse = this?Ball
```

  - …the compiler treats it as:

```
let ball : Ellipse = (?) this "Ball"
```

More about F# events

- Events in F# are *first-class values*
  - Implement interface type `IEvent<'T>`
  - Events carry values `'T` such as `MouseEventArgs`
  - Can be passed as arguments, returned as results

- We use functions for working with *event values*

```
Event.map    : ('T -> 'R)   -> IEvent<'T> -> IEvent<'R>
Event.filter : ('T -> bool) -> IEvent<'T> -> IEvent<'T>
```

  - Create new event that carries different type of value and is triggered only in some cases
  - `Event.add` registers handler to the final event

Two interesting event combinators

- Merging events with `Event.merge`

```
IEvent<'T> -> IEvent<'T> -> IEvent<'T>
```

  - Triggered whenever first or second event occurs
  - Note that the carried values must have same type

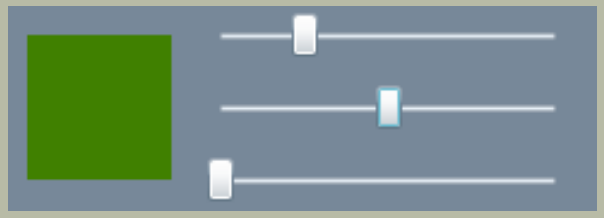
- Creating stateful events with `Event.scan`

```
('St -> 'T -> 'St) -> 'St -> IEvent<'T> -> IEvent<'St>
```

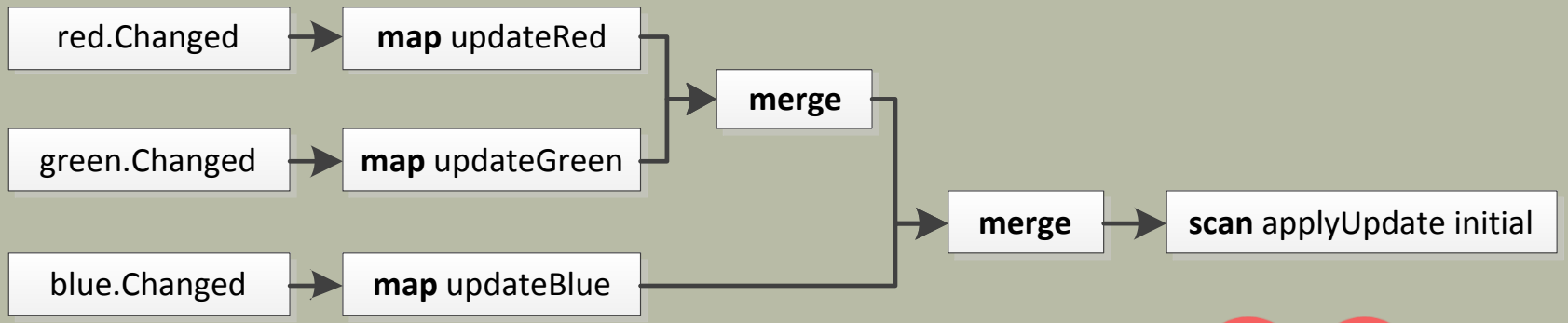
  - State is recalculated each time event occurs
  - Triggered with new state after recalculation

Creating ColorSelector control

- Three sliders for changing color components
- Box shows current color



- Data-flow diagram describes the activity



Diagrams

DEMO

Writing ColorSelector control with F# events

Accessing F# events from C#

- Events in F# are values of type `IEvent<'T>`
  - Enables F# way of working with events
  - Attribute instructs F# to generate .NET event

```
[<CLIEvent>]
member x.ColorChanged = colorChanged
```

- `IEvent<'T>` vs. `IObservable<'T>` in .NET 4.0
  - You can work with both of them from F#
    - Using combinators such as `Observable.map` etc.
  - Observable keeps separate state for each handler
  - Can be confusing if you add/remove handlers

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- **Writing reactive GUIs imperatively**
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- Asynchronous programming with events
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Creating SemaphoreLight control

- **Typical approach** – store state as `int` or enum
  - Imperative code uses mutable fields
  - With event combinators, we use Event.scan
  - Difficult to read – what does state represent?
  - It is hard to see what the transitions are!
- **Better approach** – write workflow that loops between states (points in code)
  - Asynchronous waiting on events causes transitions

DEMO

Writing SemaphoreLight with workflows

Workflows for GUI programming

- `Async.AwaitObservable` operation

```
AwaitObservable : IObservable<'T> -> Async<'T>
```

  - Creates workflow that waits for the first occurrence
    - Currently not part of F# libraries / PowerPack
    - Sometimes, using `IObservable<'T>` is better
    - Works because `IEvent<'T> : IObservable<'T>`

- `Async.StartImmediate` operation
  - Starts the workflow on the **current** (e.g. GUI) thread
  - Callbacks always return to original kind of thread
    - All code in the demo runs on GUI thread as required!

Writing loops using workflows

- Using looping constructs like `while` and `for`

```
let semaphoreStates2() = async {
  while true do
    for current in [ green; orange; red ] do
      let! md = Async.AwaitObservable(this.MouseLeftButtonDown)
      display(current) }
```

"Infinite" loop

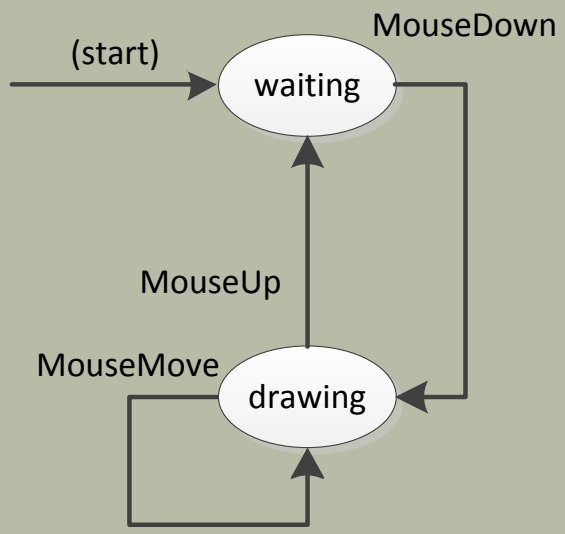
- Functional style – using recursion

```
let rec semaphoreStates() = async {
  for current in [ green; orange; red ] do
    let! md = Async.AwaitObservable(this.MouseLeftButtonDown)
    display(current)
  return! semaphoreStates() }
```

Recursive call written using "do!"

Break: Time for a bit of Art…

Application for drawing rectangles



- Choosing between multiple transitions?
  - `AwaitObservable` taking two events
  - Resume when the first event fires

DEMO

Drawing rectangles in Silverlight

Waiting for multiple events

- Choosing between two (or more) events

```
AwaitObservable : IObservable<'T> * IObservable<'U>
                  -> Async<Choice<'T, 'U>>
```

  - Specify two different transitions from single state
  - Overloads for more events available too

Overload taking two events as parameters

```
let! evt = Async.AwaitObservable
             (main.MouseLeftButtonDown, main.MouseMove)
match evt with
| Choice1Of2(up) ->
    // Left button was clicked
| Choice2Of2(move) ->
    // Mouse cursor moved }
```

Returns `Choice<'T1,'T2>`

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- **Asynchronous programming with events**
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Patterns for asynchronous programming

- Begin/End pattern used by standard libraries

```
let hr = HttpWebRequest.Create("http://...")
let! resp = hr.AsyncGetResponse()
let sr = resp.GetResponseStream()
```

Created from `Begin/EndGetResponse`

- Event-based pattern used more recently

```
let wc = new WebClient()
wc.DownloadStringCompleted.Add(fun res ->
  let string = res.Result )
wc.DownloadStringAsync("http://...")
```

Register handler and then start

- Can we write this using `AwaitObservable`?
  - **Little tricky** – need to attach handler *first*!

Performing asynchronous calls correctly

- Introducing `GuardedAwaitObservable` primitive

```
async {
  let wc = new WebClient()
  let! res =
    Async.GuardedAwaitObservable wc.DownloadStringCompleted
      (fun () -> wc.DownloadStringAsync(new Uri(uri)))
  // (...) }
```

  - Calls a function after attaching event handler
  - We cannot accidentally lose event occurrence

- Mixing asynchronous I/O and GUI code
  - If started from GUI thread, will return to GUI thread
  - We can safely access controls after HTTP request

DEMO

Social rectangle drawing application

Brief summary of the talk

- Reactive code can run on the GUI thread!
- Two programming styles in F#
  - **Declarative** or **data-flow** style
    - Using `Event.scan` combinators
  - **Imperative** or **control-flow** style
    - Using `AwaitEvent` primitive
  - In both cases, we can use diagrams
- Web requests from workflows
  - Both common patterns work

Thanks!

Questions?

References & Links

- **What do you need to run samples?**
  - Samples will be on my blog (below)
  - Get F# and F# PowerPack (http://www.fsharp.net)
  - Get Silverlight Developer tools (F# included!)
    - http://www.silverlight.net/getstarted

- **Blog & contacts**
  - "Real-World Functional Programming"
    - http://functional-programming.net
  - My blog: http://tomasp.net/blog
  - Contact: tomas@tomasp.net