Functional Reactive Programming

for Natural User Interface

"I have no special talents. I am only passionately curious."

- Albert Einstein

Riccardo Terrell

lambda DAλS

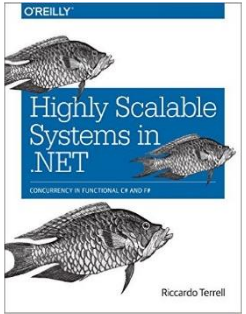
Kraków, 2016

Agenda

- What is Functional Reactive Programming – FRP vs RP
- FRP foundations and motivations
- FRP implemented in F# with Code Samples – Original Paper
- FRP implemented in F# with Code Samples – Modern Paper
- Natural User Interface with Leap Motion in Action

Something about me - Riccardo Terrell

- Originally from Italy, currently - Living/working in Washington DC ~10 years
- +/- 19 years in professional programming
  - C++/VB → Java → .Net C# → Scala → Haskell → C# & F# → ??
- Organizer of the DC F# User Group
- Working @ statmuse
- Polyglot programming believer the mechanism to find the right tool for the job

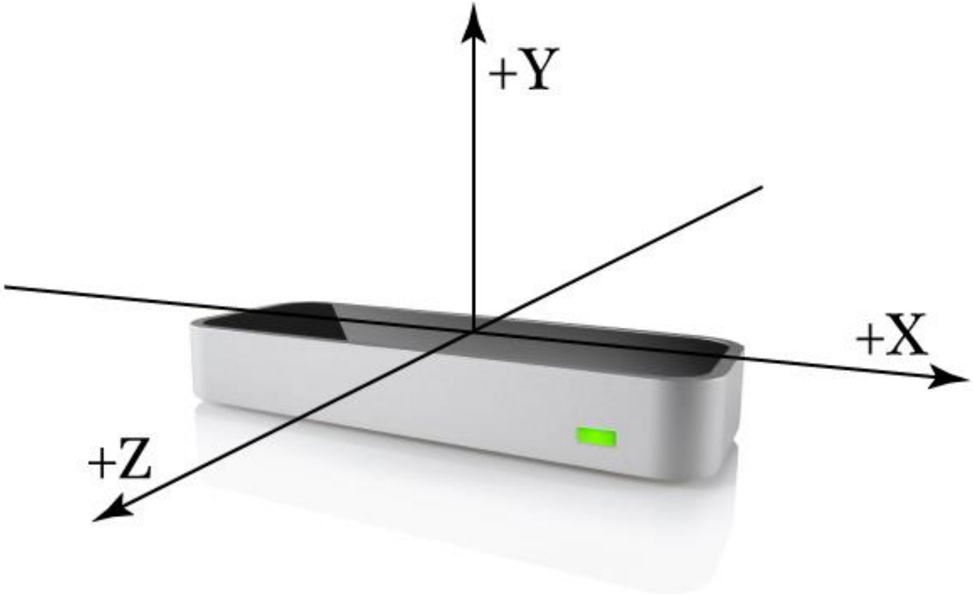


Authoring book on Concurrency adopting the Functional Paradigm in C# & F#

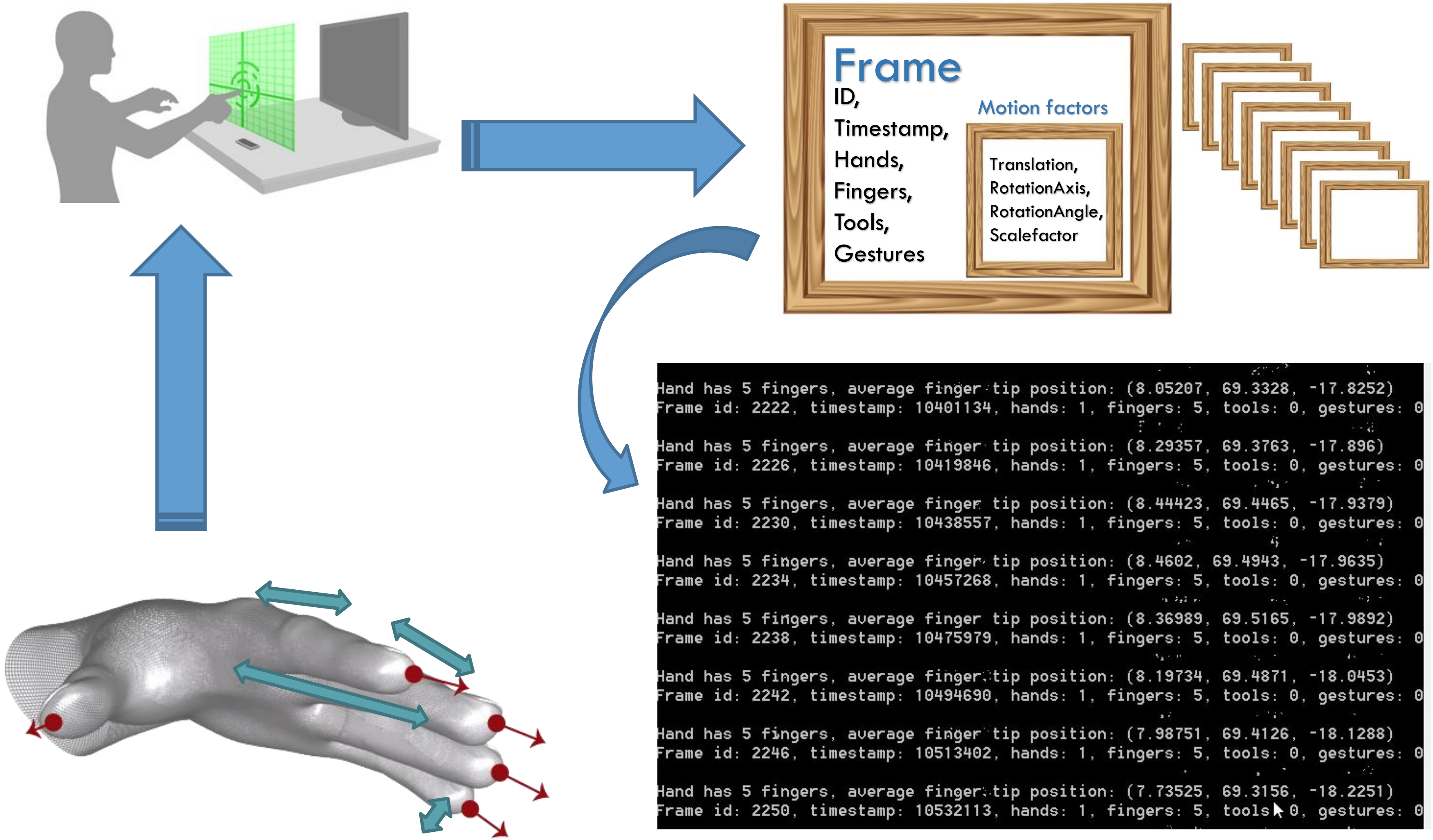
Available for presale: http://tinyurl.com/zzpv9gx

@trikace *rickyterrell.com* *tericcardo@gmail.com*

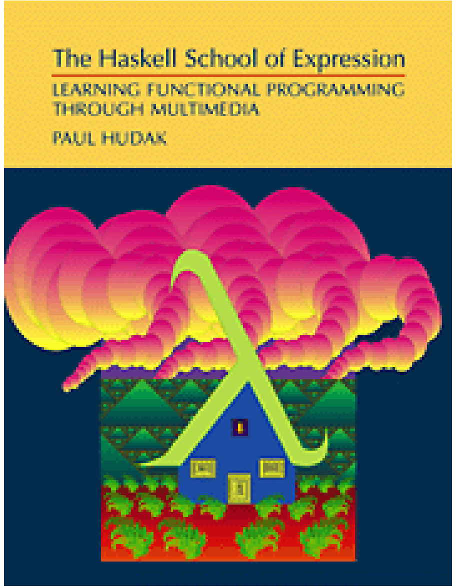
Leap Motion Sensor

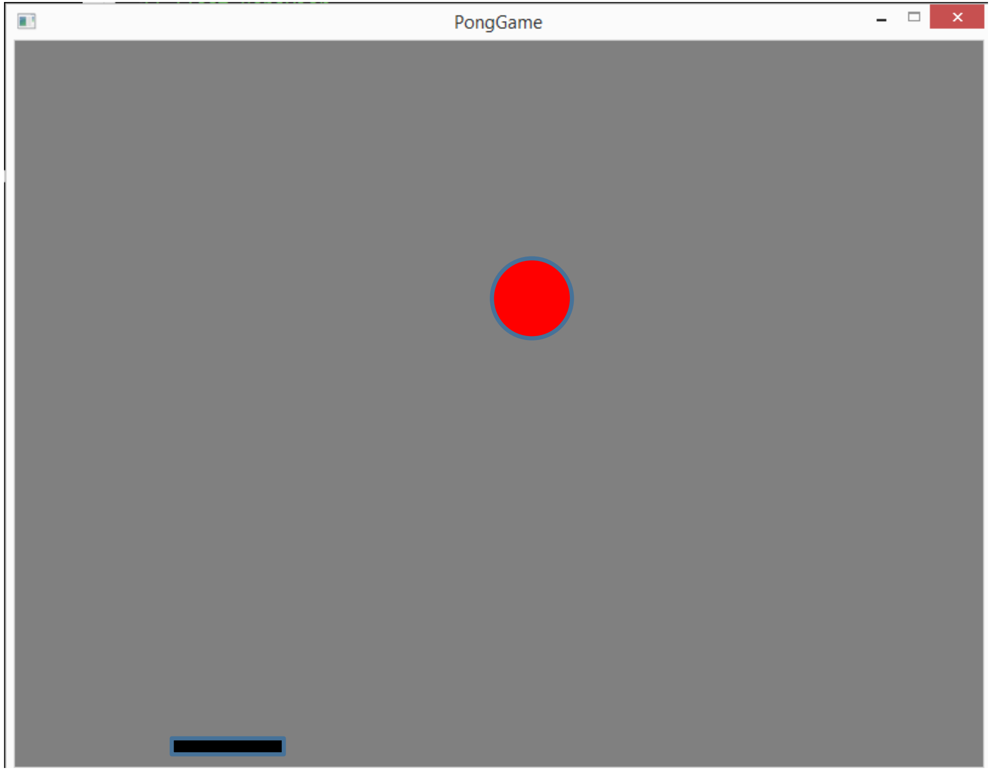


"In just one hand, you have 29 bones, 29 joints, 123 ligaments, 48 nerves, and 30 arteries. That's sophisticated, complicated, and amazing technology (times two). Yet it feels effortless. The Leap Motion Controller has come really close to figuring it all out."


Frame
ID,
Timestamp,
Hands,
Fingers,
Tools,
Gestures
Motion factors
Translation,
RotationAxis,
RotationAngle,
Scalefactor
Hand has 5 fingers, average finger tip position: (8.05207, 69.3328, -17.8252)
Frame id: 2222, timestamp: 10401134, hands: 1, fingers: 5, tools: 0, gestures: 0
Hand has 5 fingers, average finger tip position: (8.29357, 69.3763, -17.896)
Frame id: 2226, timestamp: 10419846, hands: 1, fingers: 5, tools: 0, gestures: 0
Hand has 5 fingers, average finger tip position: (8.44423, 69.4465, -17.9379)
Frame id: 2230, timestamp: 10438557, hands: 1, fingers: 5, tools: 0, gestures: 0
Hand has 5 fingers, average finger tip position: (8.4602, 69.4943, -17.9635)
Frame id: 2234, timestamp: 10457268, hands: 1, fingers: 5, tools: 0, gestures: 0
Hand has 5 fingers, average finger tip position: (8.36989, 69.5165, -17.9892)
Frame id: 2238, timestamp: 10475979, hands: 1, fingers: 5, tools: 0, gestures: 0
Hand has 5 fingers, average finger tip position: (8.19734, 69.4871, -18.0453)
Frame id: 2242, timestamp: 10494690, hands: 1, fingers: 5, tools: 0, gestures: 0
Hand has 5 fingers, average finger tip position: (7.98751, 69.4126, -18.1288)
Frame id: 2246, timestamp: 10513402, hands: 1, fingers: 5, tools: 0, gestures: 0
Hand has 5 fingers, average finger tip position: (7.73525, 69.3156, -18.2251)
Frame id: 2250, timestamp: 10532113, hands: 1, fingers: 5, tools: 0, gestures: 0

Paddle-ball Game with Leap Motion





Functional Reactive Programming

Functional Reactive Programming

- declarative
- functions as values
- side-effects free
- referential transparency
- immutable
- composition

Functional Reactive Programming

```
sample.TweetReceived
    |> Event.filter(fun tweet -> tweet.lang = "en")
    |> Event.choose(fun tweet -> tweet.Text)
    |> Event.map(fun text ->
                 if Set.contains text positive then 1
                 elif Set.contains text negative then -1
                 else 0)
    |> Event.scan (+)
    |> Event.add(fun n -> printfn "Mood=%d" n)
```

Functional Reactive Programming

Composable Dynamic evolving values over time

Functional Reactive ANimation

Functional Reactive Animation

Conal Elliott
Microsoft Research
Graphics Group
conal@microsoft.com

Paul Hudak
Yale University
Dept. of Computer Science
paul.hudak@yale.edu

Abstract

Fran (Functional Reactive Animation) is a collection of data types and functions for composing richly interactive, multimedia animations. The key ideas in Fran are its notions of *behaviors* and *events*. Behaviors are time-varying, reactive values, while events are sets of arbitrarily complex conditions, carrying possibly rich information. Most traditional values can be treated as behaviors, and when images are thus treated, they become animations. Although these no-

- capturing and handling sequences of motion input events, even though motion input is conceptually continuous;
- time slicing to update each time-varying animation parameter, even though these parameters conceptually vary in parallel; and

By allowing programmers to express the "what" of an interactive animation, one can hope to then automate the "how" of its presentation. With this point of view, it should

http://conal.net/papers/icfp97/icfp97.pdf

Functional Reactive Programming adoption

- *Graphical User Interfaces (GUI)*
- *Digital Music*
- *Robotics*
- *Graphical Animation*
- *Sound Synthesis*
- *Virtual Reality Environments*
- *Games*

FRP becomes Main-Stream

FRP has evolved in a number of directions and into different concrete implementations

What is Functional Reactive Programming

“FRP is about handling time-varying values like they were regular values.”

- Haskell Wiki

Functional Reactive Programming is:

- Temporally continuous *(Natural & Composable)*
- Denotative *(Elegant & Rigorous)*

Denotational Semantics

Denotational Semantics map each part of a program to a mathematical object (denotation), which represents the meaning of the program in question.

Consider the definition of a factorial function

```
fact n = product [1..n]
```

```
int fact(int n) {
        int i;
        int result = 1;
        for (i = 2; i <= n; ++i)
            result *= i;
        return result;}
```

Denotational Semantics = Simple Design

Denotational Semantics map each part of a program to a mathematical object (denotation), which represents the meaning of the program in question.

Denotational Semantics properties

- *leads to simple design*
- *emphasizes declarative programming style (What vs How)*
- *uses math to prove a property of a program*
- *proofs that compositionality holds for all building blocks*

Foundation of FRP – Time

(precise & simple semantics)

```
type Time = float
```


Continuous Time
Discrete Time
Virtual Time

Foundation of FRP - Behavior
(precise & simple semantics)

```
type Time = float
```

```
type 'a Behavior = Behavior of (Time -> 'a)
```

Foundation of FRP - Behavior

```
type Time = float
```

```
type 'a Behavior = Behavior of (Time -> 'a)
```

```
// The time itself
let time = Behavior (fun t -> t)

// Behavior constant over time
let conBeh = Behavior (fun _ -> "Hello FRP!")

// Behavior that increase at 2.5 the rate of time
let incrSpeedBeah = Behavior (fun t -> t * 7.5)
```

Behavior API – Original Implementation

```
let  lift0 'a = Behavior 'a

let  lift1 ('a -> 'b) = Behavior 'a -> Behavior 'b

let  lift2 ('a -> 'b -> 'c) =
        Behavior 'a -> Behavior 'b -> Behavior 'c
```

```
let time =  Behavior (fun t -> t)

let time7_5 = lift1 ((*) 7.5) time

let createBehavior f:(Time -> 'a) = (lift1 f) time
```

Foundation of FRP - Event

(precise & simple semantics)

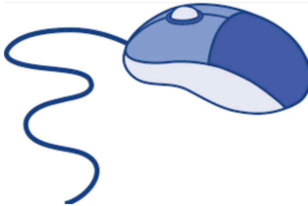
```
type Time = float
```

```
type 'a Behavior = Behavior of (Time -> 'a)
```

```
type 'a Event = Event of [(Time * 'a option)]   - no decreasing time
```

```
// When the Event passes 3 secs increase its speed
let event = Event (fun t -> if (t > 3.) then Some(t*2.5) else None)
```

FRP - Mouse Position



```
Event Based view
MouseMovedEvent (position: Position)
```

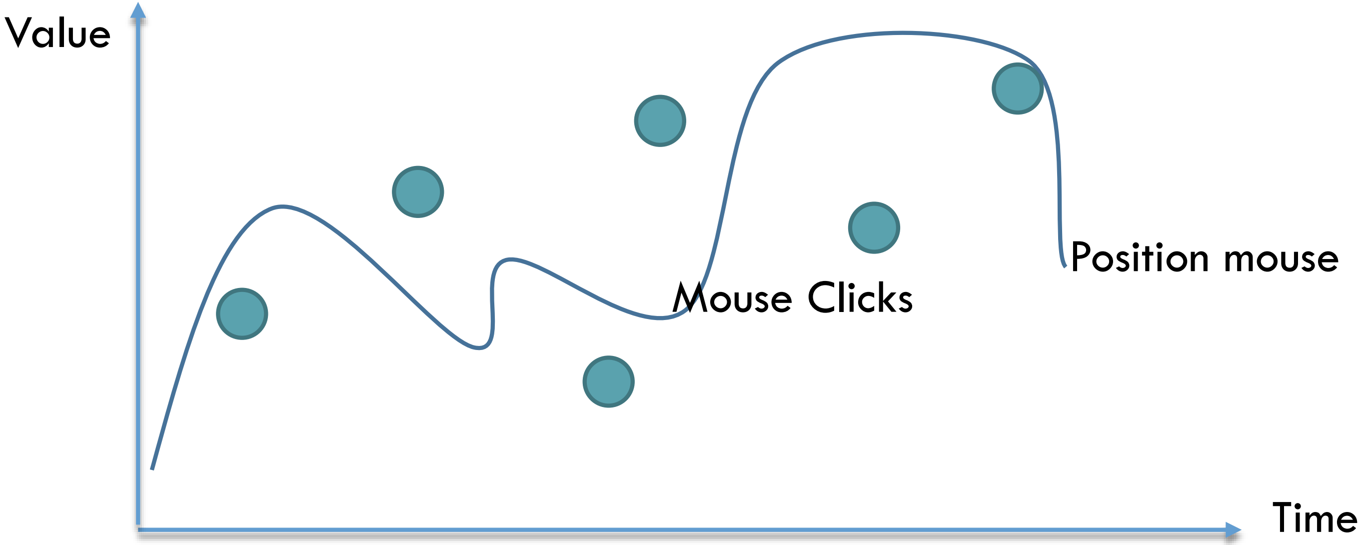

```
FRP view – at any point in time represents the current mouse position
mousePosition = Behavior [Position]

inRectangleBeh(ul: Position , lr:Position) : Behavior [bool] =
        let position = mousePosition()
        Behavior [ul <= position && position <= lr]
```

Foundation of FRP - Behavior

```
type 'a Behavior = Behavior of (Time -> 'a)
```

```
type 'a Event = Event of [Time -> 'a]
```



“So, what is FRP? You could have invented it yourself, start with these ideas:”

http://stackoverflow.com/questions/1028250/what-is-functional-reactive-programming - Conal Elliot

- *Temporal modeling*
  - *Composable Behavior first class values*
- *Event modeling*
  - *Composable Event first class values*
- *Declarative reactivity*
  - *Semantic in terms of temporal composition*
- *Polymorphic media*
  - Set of combinators applicable to any types of time-varying values

Push-Pull Functional Reactive Programming

Push-Pull Functional Reactive Programming

Conal Elliott
LambdaPix
conal@conal.net

Abstract

Functional reactive programming (FRP) has simple and powerful semantics, but has resisted efficient implementation. In particular, most past implementations have used demand-driven sampling, which accommodates FRP's continuous time semantics and fits well with the nature of functional programming. Consequently, values are wastefully recomputed even when inputs don't change, and reaction latency can be as high as the sampling period.

more composable than their finite counterparts, because they can be scaled arbitrarily in time or space, before being clipped to a finite time/space window.

While FRP has simple, pure, and composable semantics, its efficient implementation has not been so simple. In particular, past implementations have used demand-driven (pull) sampling of reactive behaviors, in contrast to the data-driven (push) evaluation typically used for reactive systems, such as GUIs. There are at least two strong reasons for choosing pull over push for FRP:

http://conal.net/papers/push-pull-frp/push-pull-frp.pdf

Chains of simple phases - Reactivity

```
type 'a Behavior =
              Behavior of (Time -> 'a * ReactBeh<'a>))
```

```
and 'a ReactBeh = unit -> 'a Behavior
```

Chains of simple phases

```
type 'a Behavior = Behavior of (Time -> 'a * ReactBeh<'a>)
                 and 'a ReactBeh = unit -> 'a Behavior
```

```
let rec pureBeh value = Behavior(fun time ->
                        (value, fun () -> pureBeh value))
```

```
let rec timeBeh = Behavior(fun time ->
                        (time, fun () -> timeBeh ))
```

Chains of simple phases

```
type 'a Event = Event of
                (Time -> Option<'a> * ReactEvent<'a>)
                and 'a ReactEvent = unit -> 'a Event
```

```
let rec pureEvt value = Event(fun time ->
                (Some(value), fun () -> pureEvt value))
```

FRP Behavior can compose

```
fmap :: ('a -> 'a) -> Behavior 'a -> Behavior 'a
```

```
pure :: ‘a -> Behavior ’a
(<*>) :: Behavior ('a -> 'a) -> Behavior 'a -> Behavior 'a
```

- Less learning and more leverage
- Specifications and laws for “free”

FRP Behavior can compose

```
fmap :: ('a -> 'a) -> Behavior 'a -> Behavior 'a
```

```
pure :: 'a -> Behavior 'a
(<*>) :: Behavior ('a -> 'a) -> Behavior 'a -> Behavior 'a
```

```
type Position = Position of (float*float)

let inRectangleBeh (ul:Position, lr:Position) : bool Behavior =
        pureBeh (fun (position:Position) ->
        if ul <= position && lr <= position then true
        else false) <*> mousePositionBeh // Position Behavior
```

FRP Event API

- never :: 'a Event
- (.|.) :: 'a Event -> 'a Event -> 'a Event
- whenEvent :: bool Behavior -> unit Event
- whileEvent :: bool Behavior -> unit Event
- (.&.) :: ‘a Event -> ’b Event -> (’a * ‘b) Event
- (=>>) :: ‘a Event -> (’a -> ‘b) -> ’b Event

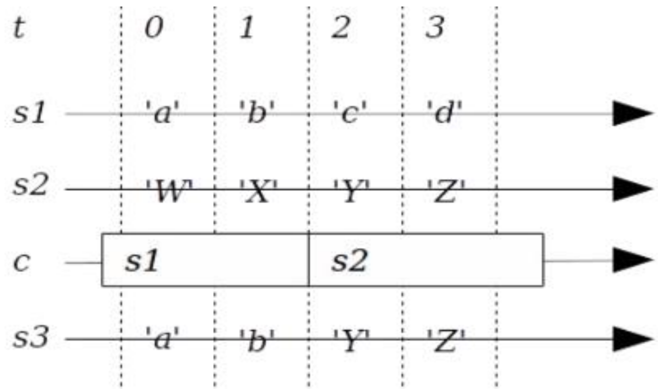
FRP – Combinators

```
type Event ::
// (‘a -> ‘b) -> Event ‘a -> Event ‘b
let map(f : 'a -> 'b) : Event<'b> = // …
// (‘a -> bool) -> Event ‘a
let filter(f : 'a -> bool) : Event<'a> = // …
// (Event ‘a * Event ‘a) -> Event ‘a
let merge(ea : Event<'a>, eb : Event<'a>) : Event<'a> = // …
let (.|.) = merge
// ‘a -> Event<‘a -> ‘a> -> Behavior ‘a
let accum (value:’a) (evt:Event<'a->’a>) : Behavior<'a> = // …
```

FRP – Behavior switch

```
type Behavior
// Behavior ‘a -> Event<Behavior<‘b>> -> Behvavior<‘b>
let switchBeh (beh:Behavior<‘a>) (evt:Event<Behavior<'b>>)
: Behavior<'b> =
```

```
let s1 = MkStream [([0],’a’), ([1], ‘b’), ([2], ‘c’)]
let s2 = MkStream [([0], ‘W’), ([1], ‘X’), ([2], ‘Y’)]
// hold :: ‘a -> ‘a Event -> ‘a Behavior
let c = hold s1 (MkStream[([1], s2)]) [0]
let s3 = Switch c
```



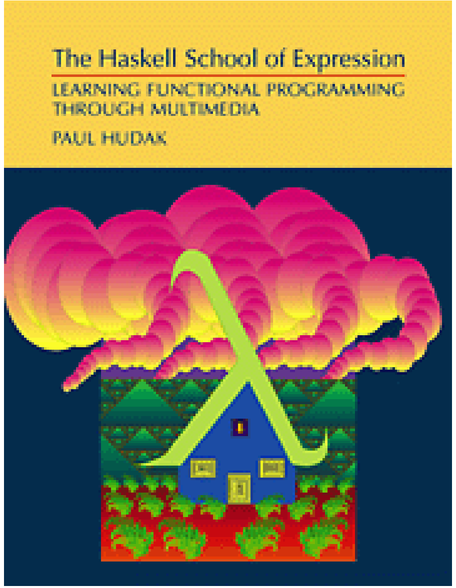

DEMO
Demo

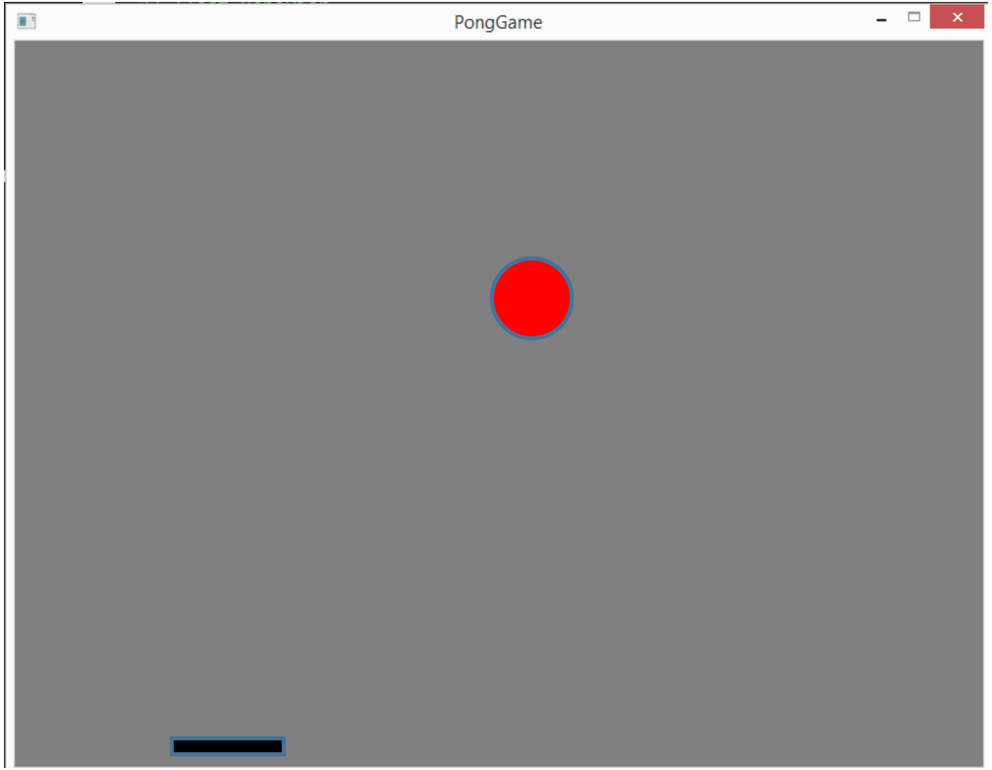
Bank Account

```
type BankAccount() =
    let deposit = Event<int>.newDefault()
    let withdraw = Event<int>.newDefault()
    let bh : Event<int> = merge deposit withdraw
    // Reevaluated for each update
    let bhAcc : Behavior<int> = bh.accum(0, (+))

    member x.Balance with get() = bhAcc.Sample()
    member x.Deposit(amount) = deposit.send(amount)
    member x.Withdraw(amount) = withdraw.send(-amount)
```

Paddle-ball Game with Leap Motion





Summary

- True FRP is about dynamic evolving values over time
  - Precise, simple denotation. (Elegant & rigorous)
  - Continuous time. (Natural & composable)
- Denotational Semantic leads to simpler designs and reusable abstraction
- FRP provide a declarative, composable and elegant programming style for animation, graphic and music (IMO - FRP will influence future NUI studies)
- Build your own FRP!


That's all Folks!
dws4.me

The tools we use have a profound (and devious!) influence on our thinking habits, and, therefore, on our thinking abilities.

-- Edsger Dijkstra

How to reach me

github.com/rikace/Presentations/FRP-NUI

@TRikace

tericcardo@gmail.com