Functional Reactive Programming
for Natural User Interface

“I have no special talents. I am only passionately curious.”
- Albert Einstein

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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](http://tinyurl.com/zzpv9gx)

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“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.”
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

```haskell
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

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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
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 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

\[
\text{fact } n = \text{ product } [1..n]
\]

\[
\text{int fact(int n) }
\]
\[
\text{ int i;}
\]
\[
\text{ int result = 1;}
\]
\[
\text{ for (i = 2; i <= n; ++i) }
\]
\[
\text{ result *= i;}
\]
\[
\text{ return result;}
\]
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

(précise & simple semantics)

define type Time = float
Continuous Time
Discrete Time
Virtual Time
Foundation of FRP - Behavior

(type precise & simple semantics)

```ocaml
type Time = float

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

```plaintext
// 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)
```
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

(type precise & simple semantics)

definitions:

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)
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

\[\text{type } 'a \text{ Behavior} = \text{Behavior of (Time -> 'a)}\]

\[\text{type } 'a \text{ Event} = \text{Event of [Time -> 'a]}\]

Value

Mouse Clicks

Position mouse

Time
“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

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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:

Chains of simple phases - Reactivity

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

and 'a ReactBeh = unit -> 'a Behavior
```
Chains of simple phases

```plaintext
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

```ocaml
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

\[
\begin{align*}
\text{fmap} & : ('a \rightarrow 'a) \rightarrow \text{Behavior} 'a \rightarrow \text{Behavior} 'a \\
\text{pure} & : 'a \rightarrow \text{Behavior} 'a \\
\langle\ast\rangle & : \text{Behavior} ('a \rightarrow 'a) \rightarrow \text{Behavior} 'a \rightarrow \text{Behavior} 'a
\end{align*}
\]

- Less learning and more leverage
- Specifications and laws for “free”
FRP Behavior can compose

```haskell
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`
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> = // ...
type Behavior

// Behavior 'a -> Event<Behavior<'b>> -> Behavior<'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

---

**FRP – Behavior switch**

```plaintext

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
```
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!
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

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