Functional Reactive Programming (Elm)

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Seminarium: Zaawansowane programowanie funkcyjne

13.05.2015

Bibliography

Evan Czaplicki
Elm: Concurrent FRP for functional GUIs, 2012

Evan Czaplicki
Controlling Time and Space: understanding the many formulations of FRP, 2014.

About FRP

Placeholder for FRP definition.

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It's not easy to find a definition of FRP. It's even harder to find a meaningful one.

What I consider as FRP

A way to:

- express time varying values in a declarative way

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- express time varying values in a declarative way
- react to real world events in structured manner

GUI programming is not easy

```
$("#target" ).click(function() {
  ...
});

$("#target" ).blur(function() {
  ...
});

$( "#target" ).mousemove(function( event ) {
  ...
});
```

Base building block - a signal

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When combined with pureness and immutability, it produces clean and simple reactive code. It's an escape hatch from callback hell. Or event listener hell.

Simple signals

Examples

- `Mouse.position`
- `Windows.dimensions`
- `Time.every Time.second`
- `Time.fps 60`

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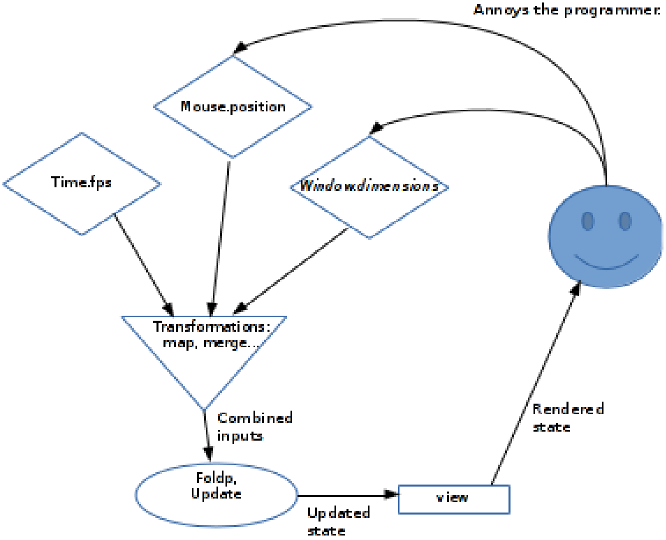
Signals in Elm are your program's connection to the 'real world'. Elm's signals are discrete, not continuous. They are completely event-driven.

Signal graph



Elm crash course

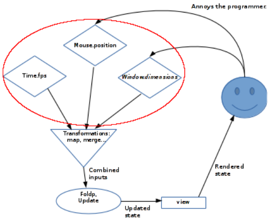
Goal: sketch an implementation of a simple snake game. It will:

- show how a typical Elm program looks like
- familiarize us with signals

We'll visit all parts of the diagram from the previous slide in order of their execution.

Program inputs

```
keys = Mouse.arrows
timer = Time.fps 10
```



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```
keys : Signal { x:Int, y:Int }
* '{ x = 0, y = 0 }' no arrows.
* '{ x =-1, y = 0 }' left arrow.
* '{ x = 1, y = 1 }' up and right arrows.
* '{ x = 0, y =-1 }' down, left, and right arrows.
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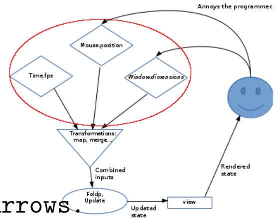

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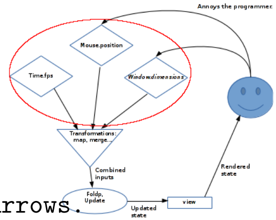

What we want to get is:

```
type Direction = Up | Down | Left | Right
pressedKey : Signal Maybe Direction
```

Mapping signals

Transforming record to single direction is straightforward:

```
direction dir =
  if | (dir.x==1) && (dir.y==0) → Just Right
     | (dir.x== -1) && (dir.y==0) → Just Left
     | (dir.x==0) && (dir.y==1) → Just Up
     | (dir.x==0) && (dir.y== -1) → Just Down
     | otherwise → Nothing
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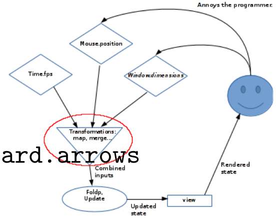
And
we'll use a handy and well-known function:

```
map : (a -> b) -> Signal a -> Signal b

pressedKey : Signal Maybe Direction
pressedKey = Signal.map direction Keyboard.arrows
```



Merging signals

So we have two sources of input, and want to update the state basing on them:

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  Signal a → Signal b → Signal c

Signal.map2 (,) pressedKey timer
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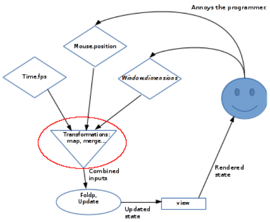

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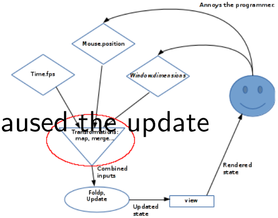
But... We lose the way to distinguish what caused the update = TurboSnake.



Merging signals

Solution: union type.

```
type Update = Arrows (Maybe Direction) | Timer Float
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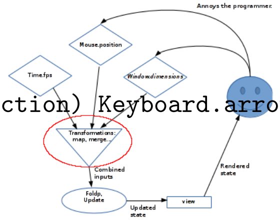
```

timer and pressedKey become:

```
timer : Signal Update
timer = Signal.map Timer Time.fps

pressedKey : Signal Update
pressedKey = Signal.map (Arrows << direction) Keyboard.arrows
```

(<<) is just a function composition.



Merging signals

Still having two signals and no means to *merge* them? Merge to the rescue!

`merge : Signal a` $\rightarrow$ `Signal a` $\rightarrow$ `Signal a`

Merge interleaves two given signals producing merged one.

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merge : Signal a → Signal a → Signal a
```

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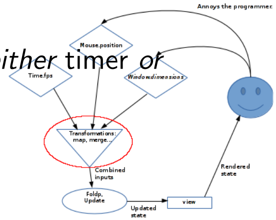
```
inputs : Signal Update
inputs = Signal.merge timer pressedKey
```

This signal carries the most recent update, *either* timer *or* keyboard update.



Folding signals

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We must *fold from the past*:

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foldp : (a → state → state) →
  state → Signal a → Signal state
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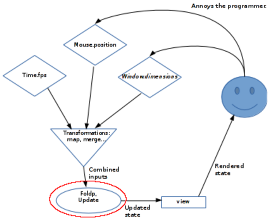

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Simple example:

```
clickCount : Signal Int
clickCount =
foldp (λclick total → total + 1) 0 Mouse.clicks
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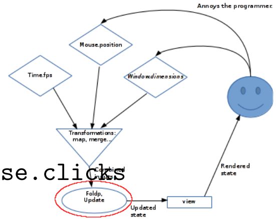

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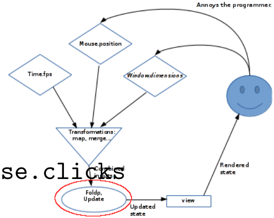


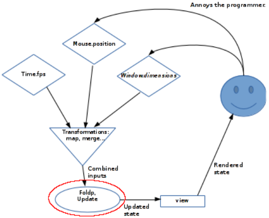
Real life (snake) example:

```
loop = Signal.foldp update initialState inputs
```

What is a state?

State is just a value. A record, that encompasses whole state of application.

```
type alias Model =
    { snake : Snake,
      direction : Direction,
      pressedKey : Maybe Direction,
      gameOver : Bool,
      fruit : Maybe Position,
      seed : Random.Seed
    }
```




```
type alias Snake =
  { body : Queue.Queue Position,
    head : Position
  }
```

Time for lamentation

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‘But hey, one global state? Where’s the modularity? ‘
Nothing prevents you from dividing model into smaller submodels, dividing inputs into subinputs, update into subupdates.

The upside is, whole knowledge about the program is concentrated in one place.

Update and below

```
loop : Signal Model
loop = Signal.foldp update initialState inputs

inputs : Signal Update

initialState : Model

foldp : (a → state → state) →
  state → Signal a → Signal state
```

The type of foldp requires, that:

```
update : Update → Model → Model
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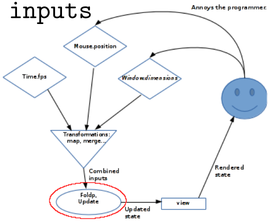

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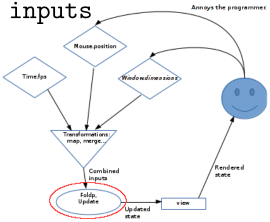

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Function? What about the signals? FRP? Anything?

For the curious

Game logic doesn't contain any signals! We just get the inputs and previous state, and feed it to pure function for a new state. Unfortunately, that implies, that it's not really interesting for us.

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Game logic doesn't contain any signals! We just get the inputs and previous state, and feed it to pure function for a new state. Unfortunately, that implies, that it's not really interesting for us. But... Here's the code:

```
update : Update → Model → Model
update u state =
  if state.gameOver
    then state
    else
      case u of
      Timer _ → state |> updateFruit >> updateDirection >>
updateSnake >> updateGameOver
      Arrows a → updatePressedKey a state
```

Main (view)

```
main : Signal Element
```

Element is an Elm representation of HTML element to display. We close the loop - after reacting to user input (declaratively), we produce the output (also declaratively).

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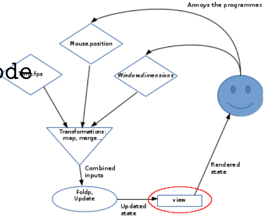
```
main = Signal.map2 view Window.dimensions loop
```

```
view : (Int, Int) → Model → Element
view (w',h') state = magical elm view code
```



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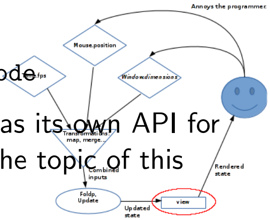
View code is interesting on its own, as Elm has its own API for drawing things on HTML page, but it's not the topic of this presentation.



Typical program overview

A typical Elm program consists of:

- a model
- a view
- inputs - signals are mainly here
- state update logic

It's not forced in any way, but it emerges naturally from the way Elm is structured.

Elm is not the end of FRP

There are many implementations of FRP available. They can be roughly categorized:

- first order FRP (Elm is here!)
- higher order FRP (Fran)
- asynchronous data flow (FRP libraries in imperative languages)
- arrowized FRP (Netwire, brrrr...)

First order FRP

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- Hot swapping
- Time travel debugging

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We can create new signals, delete signals, reconnect them in different ways at runtime.

```
join :Signal (Signal a) → Signal a
```

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clickCount = count Mouse.clicks
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True: Click, click. False: Click, Click. True: what is the value now?
Because `count Mouse.clicks = clickCount`, the value must be 4.

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True: Click, click. False: Click, Click. True: what is the value now? Because `count Mouse.clicks = clickCount`, the value must be 4. Imagine a program running for a year without restarting, where suddenly such signal is switched on.

Problem and solution

Switching the signal on (creating a new signal) may need looking back through whole history. That means, memory usage grows linearly over time.

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- program architecture *might* get messier

Asynchronous data flow

Examples: ReactiveCocoa, ReactiveExtensions, bacon.js

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If your FRP is in imperative language, it probably falls into this category.

How does it avoid the problem?

Asynchronous data flow is FRP for imperative languages. There is no requirement, that two same expressions yield same values. When we create new signal, we just start counting from zero.

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Asynchronous data flow is FRP for imperative languages. There is no requirement, that two same expressions yield same values. When we create new signal, we just start counting from zero. Another problem is what to do with signals, which is no one listening to. Some libraries (for example ReactiveExtensions) provide a distinction to hot and cold signals. The first always update, the second just stop.

Arrowized FRP

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AFRP can be embedded in first order FRP as a library. In Elm it's Automaton.

Elm's automaton API

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pure : (a → b) → Automaton a b
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state : s → (a → s → s) → Automaton a s
```

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state : s → (a → s → s) → Automaton a s

count : Automaton a Int
count = state 0 (λa total → total + 1)
```

What gives...

An automaton can have state, that gets updated every time it receives input. When you switch the automaton of the signal graph, it doesn't receive any input, so its state doesn't change. That eliminates the lookback problem.

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In general, when you build program in 'standard' Elm, the main building block are still functions, signal are somewhere at the top. When using Arrowized FRP, whole logic is expressed in terms of signals.

The tour is over

Questions?