The Yampa Arcade

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Functional Reactive Programming

Functional Reactive Programming (FRP)

- Framework for reactive programming in a functional setting
- Systems described by composing ***signal functions***: functions mapping ***signals*** to ***signals***
- Originated from Functional Reactive Animation (Fran) (Elliott & Hudak)

Yampa is our latest implementation of FRP.

The Challenge

George Russel said on the Haskell GUI list:

> “I have to say I’m very sceptical about things like Fruit which rely on reactive animation, ever since I set our students an exercise implementing a simple space-invaders game in such a system, and had no end of a job producing an example solution. . . .

The Challenge

George Russel said on the Haskell GUI list:

> . . . Things like getting an alien spaceship to move slowly downward, moving randomly to the left and right, and bouncing off the walls, turned out to be a major headache. Also I think I had to use ‘error’ to get the message out to the outside world that the aliens had won. . . .

The Challenge

George Russel said on the Haskell GUI list:

> My suspicion is that reactive animation works very nicely for the examples constructed by reactive animation folk, but not for my examples."

What was wrong?

Possible reasons for George Russel’s reaction:

- Original reactive animation systems like Fran and FAL lacked crucial features
  Yampa attempts to address this [Haskell Workshop ’02]
- Not many examples of good FRP code around
  The present paper attempts to address that

This talk

This talk tries to convey that FRP/Yampa

- is a reasonable approach for this kind of applications
- has some unique advantages over other approaches

The Game

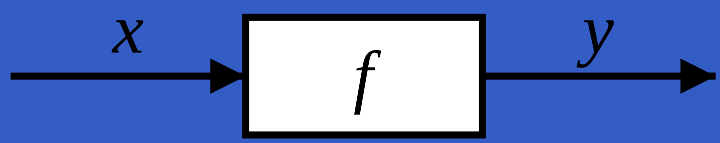
Yampa

Our most recent FRP implementation is called ***Yampa***:

- Embedding in Haskell; i.e. a Haskell library.
- Arrows used as the basic structuring framework.
- Advanced switching constructs allows for description of systems with highly dynamic structure.

Signal Functions

Key concept: functions on signals.



Intuition:

$$\texttt{Signal}\ \alpha \approx \texttt{Time} \rightarrow \alpha$$
$$x :: \texttt{Signal T1}$$
$$y :: \texttt{Signal T2}$$
$$f :: \texttt{Signal T1} \rightarrow \texttt{Signal T2}$$

Additionally: ***causality*** requirement.

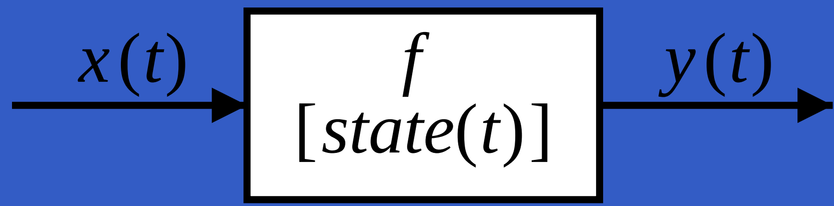
Signal Functions in Yampa

- Signal Functions are ***first class entities***.
  Intuition: $\texttt{SF}\ \alpha\ \beta \approx \texttt{Signal}\ \alpha \rightarrow \texttt{Signal}\ \beta$
- Signals are ***not*** first class entities: they only exist indirectly through signal functions.
- The strict separation between signals and signal functions distinguishes Yampa from earlier FRP implementations.

Signal Functions and State

Alternative view:

Functions on signals can encapsulate state.



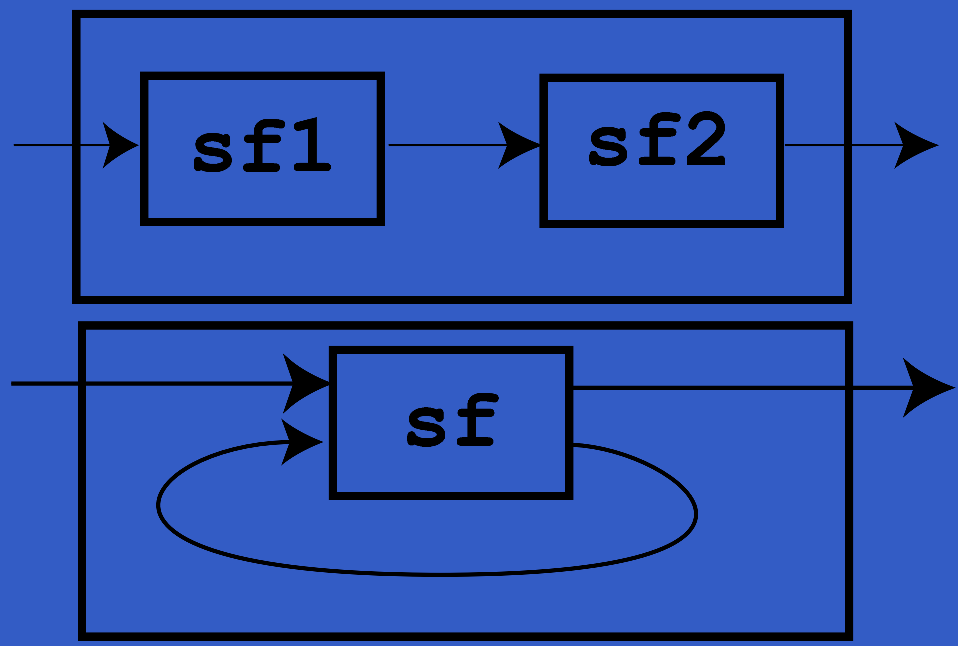
$state(t)$ summarizes input history $x(t')$, $t' \in [0, t]$.

Functions on signals are either:

- ***Stateful***: $y(t)$ depends on $x(t)$ and $state(t)$
- ***Stateless***: $y(t)$ depends only on $x(t)$

Describing Systems

Systems are described by combining signal functions into more complex signal functions:



Yampa and Arrows

Yampa uses John Hughes' ***arrow*** framework.
Core Signal Function combinators:

- `arr :: (a -> b) -> SF a b`
- `>>> :: SF a b -> SF b c -> SF a c`
- `first :: SF a b -> SF (a,c) (b,c)`
- `loop :: SF (a,c) (b,c) -> SF a b`

Enough to express any conceivable "wiring".

The Arrow Syntactic Sugar

Using the basic combinators directly is often very cumbersome. Ross Paterson's syntactic sugar for arrows provides a convenient alternative:

```
proc pat -> do [ rec ]
    pat1 <- sfexp1 -< exp1
    pat2 <- sfexp2 -< exp2
    ...
    patn <- sfexpn -< expn
    returnA -< exp
```

Also: `let` pat `=` exp $\equiv$ pat `-< arr id -<` exp

Describing the Alien Behavior (1)

```
type Object = SF ObjInput ObjOutput

alien :: RandomGen g =>
  g -> Position2 -> Velocity -> Object
alien g p0 vyd = proc oi -> do
  rec
    -- Pick a desired horizontal position
    rx   <- noiseR (xMin, xMax) g -< ()
    smpl <- occasionally g 5 ()   -< ()
    xd   <- hold (point2X p0) -< smpl `tag` rx
    ...
```

Describing the Alien Behavior (2)

```
...
-- Controller
let axd = 5 * (xd - point2X p)
          - 3 * (vector2X v)
    ayd = 20 * (vyd - (vector2Y v))
    ad  = vector2 axd ayd
    h   = vector2Theta ad
...
```

Describing the Alien Behavior (3)

```
...
-- Physics
let a = vector2Polar
            (min alienAccMax
                 (vector2Rho ad))
            h
vp  <- iPre v0     -< v
ffi <- forceField -< (p, vp)
v   <- (v0 ^+^) ^<< impulseIntegral
      -< (gravity ^+^ a, ffi)
p   <- (p0 .+^) ^<< integral -< v
...
```

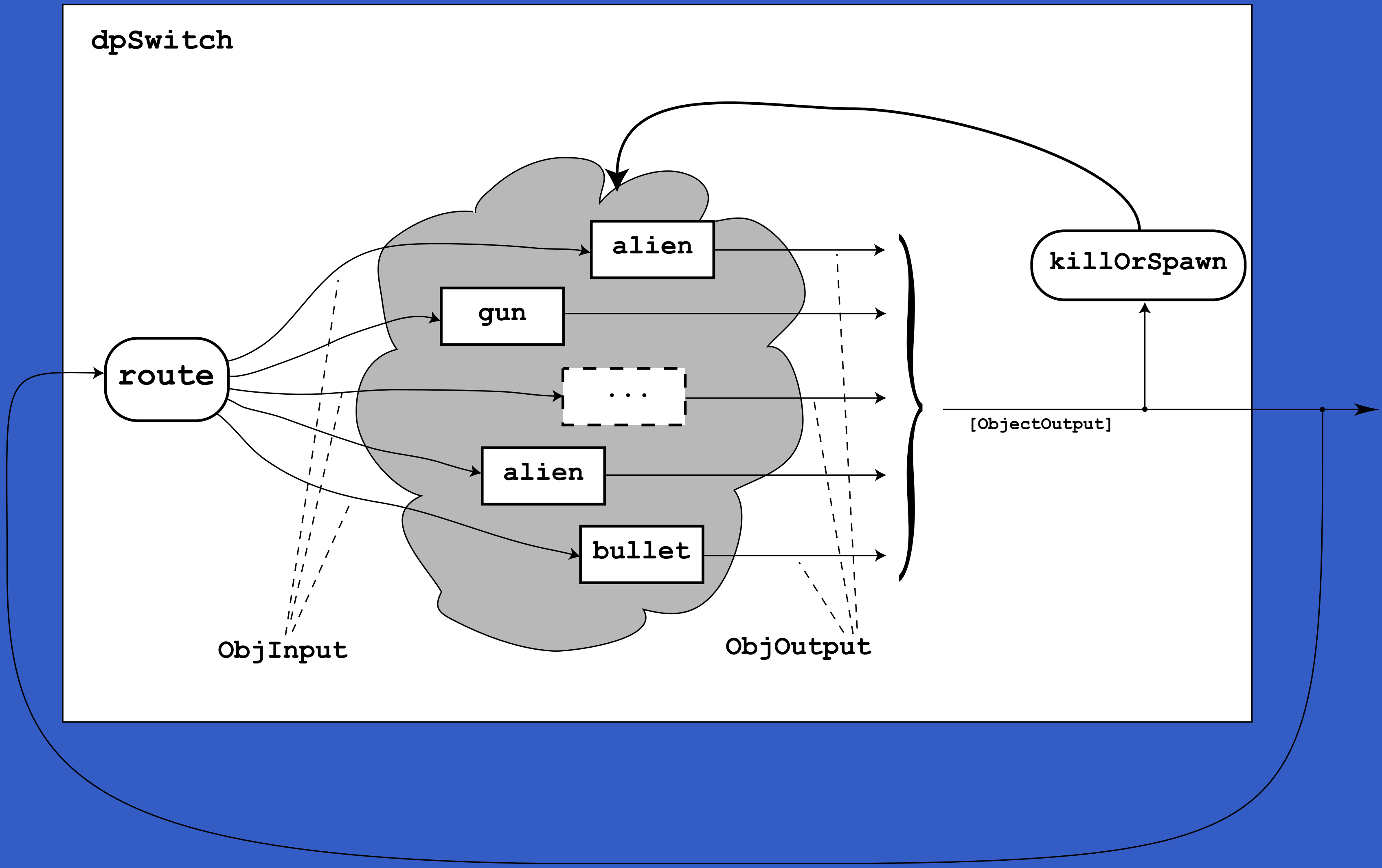
Describing the Alien Behavior (4)

```
    ...
    -- Shields
    sl  <- shield -< oiHit oi
    die <- edge   -< sl <= 0

  returnA -< ObjOutput
                ooObsObjState = oosAlien p h v,
                ooKillReq     = die,
                ooSpawnReq    = noEvent

  where
    v0 = zeroVector
```

Overall Game Structure



Dynamic Signal Function Collections

Idea:

- Switch over ***collections*** of signal functions.
- On event, “freeze” running signal functions into collection of signal function ***continuations***, preserving encapsulated ***state***.
- Modify collection as needed and switch back in.

dpSwitch

Need ability to express:

- How input routed to each signal function.
- When collection changes shape.
- How collection changes shape.

```
dpSwitch ::  Functor col =>
   (forall sf .  (a -> col sf -> col (b,sf)))
   ->  col (SF b c)
   ->  SF (a, col c) (Event d)
   ->  (col (SF b c) -> d -> SF a (col c))
   -> SF a (col c)
```

dpSwitch

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```
dpSwitch ::  Functor col =>
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    ->  (col (SF b c) -> d -> SF a (col c))
    -> SF a (col c)
```

Routing function

dpSwitch

Need ability to express:

- How input routed to each signal function.
- When collection changes shape.
- How collection changes shape.

```
dpSwitch ::  Functor col =>
    (forall sf .  (a -> col sf -> col (b,sf)))
   -> col (SF b c)
   ->  SF (a, col c) (Event d)
   ->  (col (SF b c) -> d -> SF a (col c))
   -> SF a (col c)
```

Initial collection

dpSwitch

Need ability to express:

- How input routed to each signal function.
- When collection changes shape.
- How collection changes shape.

```
dpSwitch ::  Functor col =>
    (forall sf .  (a -> col sf -> col (b,sf)))
   ->  col (SF b c)
   -> SF (a, col c) (Event d)
   ->  (col (SF b c) -> d -> SF a (col c))
   -> SF a (col c)
```

Event source

dpSwitch

Need ability to express:

- How input routed to each signal function.
- When collection changes shape.
- How collection changes shape.

```
dpSwitch ::  Functor col =>
    (forall sf .  (a -> col sf -> col (b,sf)))
   ->  col (SF b c)      Function yielding SF to switch into
   ->  SF (a, col c) (Event d)
   ->  (col (SF b c) -> d -> SF a (col c))
   -> SF a (col c)
```

The Game Core

```
gameCore :: IL Object
            -> SF (GameInput, IL ObjOutput)
                  (IL ObjOutput)
gameCore objs =
  dpSwitch route
           objs
           (arr killOrSpawn >>> notYet)
           (\sfs' f -> gameCore (f sfs'))
```

Closing the Feedback Loop (1)

```
game :: RandomGen g =>
  g -> Int -> Velocity -> Score ->
  SF GameInput ((Int, [ObsObjState]),
                Event (Either Score Score))
game g nAliens vydAlien score0 = proc gi -> do
  rec
    oos <- gameCore objs0 -< (gi, oos)
  score    <- accumHold score0
                   -< aliensDied oos
  gameOver <- edge -< alienLanded oos
  newRound <- edge -< noAliensLeft oos
  ...
```

Closing the Feedback Loop (2)

```
...
returnA -< ((score,
             map ooObsObjState
                 (elemsIL oos)),
            (newRound `tag` (Left score))
            `lMerge` (gameOver
                      `tag` (Right score)))
where
  objs0 =
    listToIL
      (gun (Point2 0 50)
       : mkAliens g (xMin+d) 900 nAliens)
```

Other approaches?

Transition function operating on world model with explicit state (e.g. Asteroids by Lüth):

- Model snapshot of world with ***all*** state components.
- Transition function takes input and current world snapshot to output and the next world snapshot.

One could also use this technique ***within*** Yampa to avoid switching over dynamic collections.

Why use Yampa, then?

- Yampa provides a lot of functionality for programming with time-varying values:
  - captures common patterns
  - packaged in a way that makes reuse very easy
- Yampa allows state to be nicely encapsulated by signal functions:
  - avoids keeping track of all state globally
  - adding more state is easy and usually does not imply any major changes to type or code structure

State in `alien`

Each of the following signal functions used in `alien` encapsulate state:

- `noiseR`
- `occasionally`
- `hold`
- `iPre`
- `forceField`
- `impulseIntegral`
- `integral`
- `shield`
- `edge`

Drawbacks of Yampa?

- Choosing the right switch can be tricky.
- Subtle issues concerning when to use e.g. `iPre`, `notYet`.
- Syntax could be improved (with specialized pre-processor).