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Lecture 4: Dynamic System Structure

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Outline

- Describing systems with highly dynamic structure: a generalized `switch`-construct.
- Example: Space Invaders

Highly dynamic system structure?

The basic switch allows one signal function to be replaced by another.

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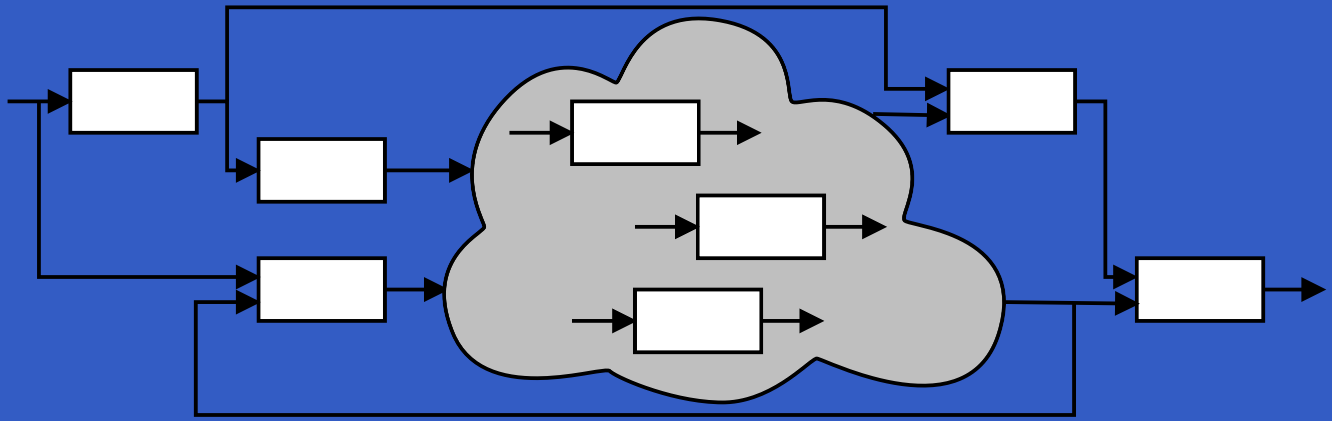
- What about more general structural changes?



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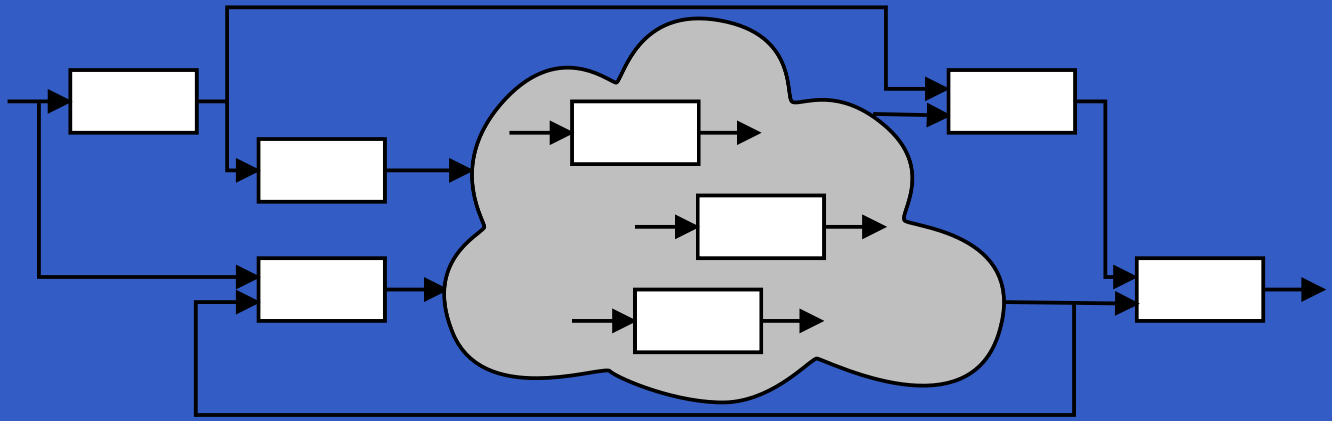


- What about state?

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. . . .

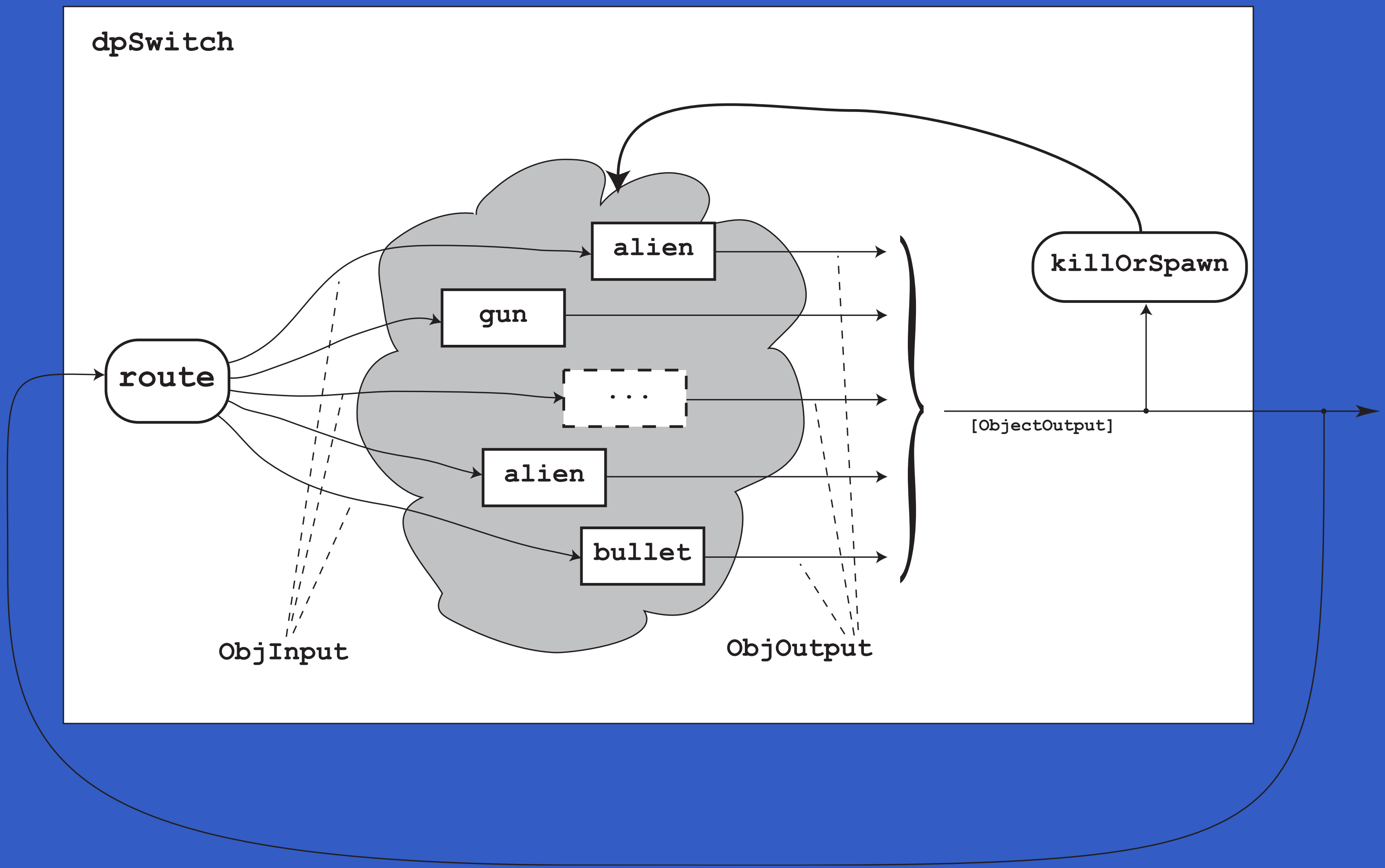
The challenge

George Russel said on the Haskell GUI list:

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

Example: Space Invaders

Overall game structure



Dynamic signal function collections

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- 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.

Dynamic signal function collections

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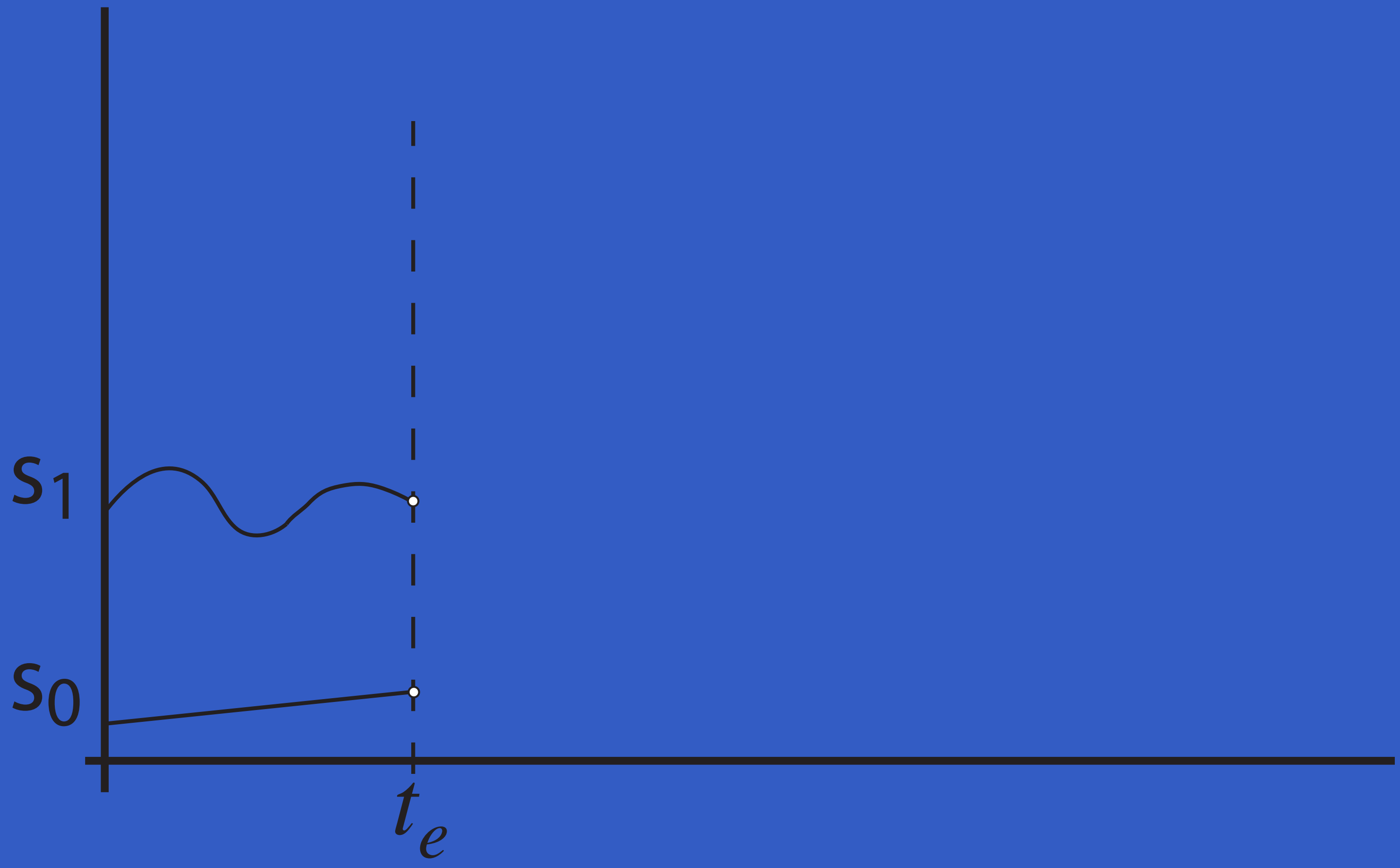
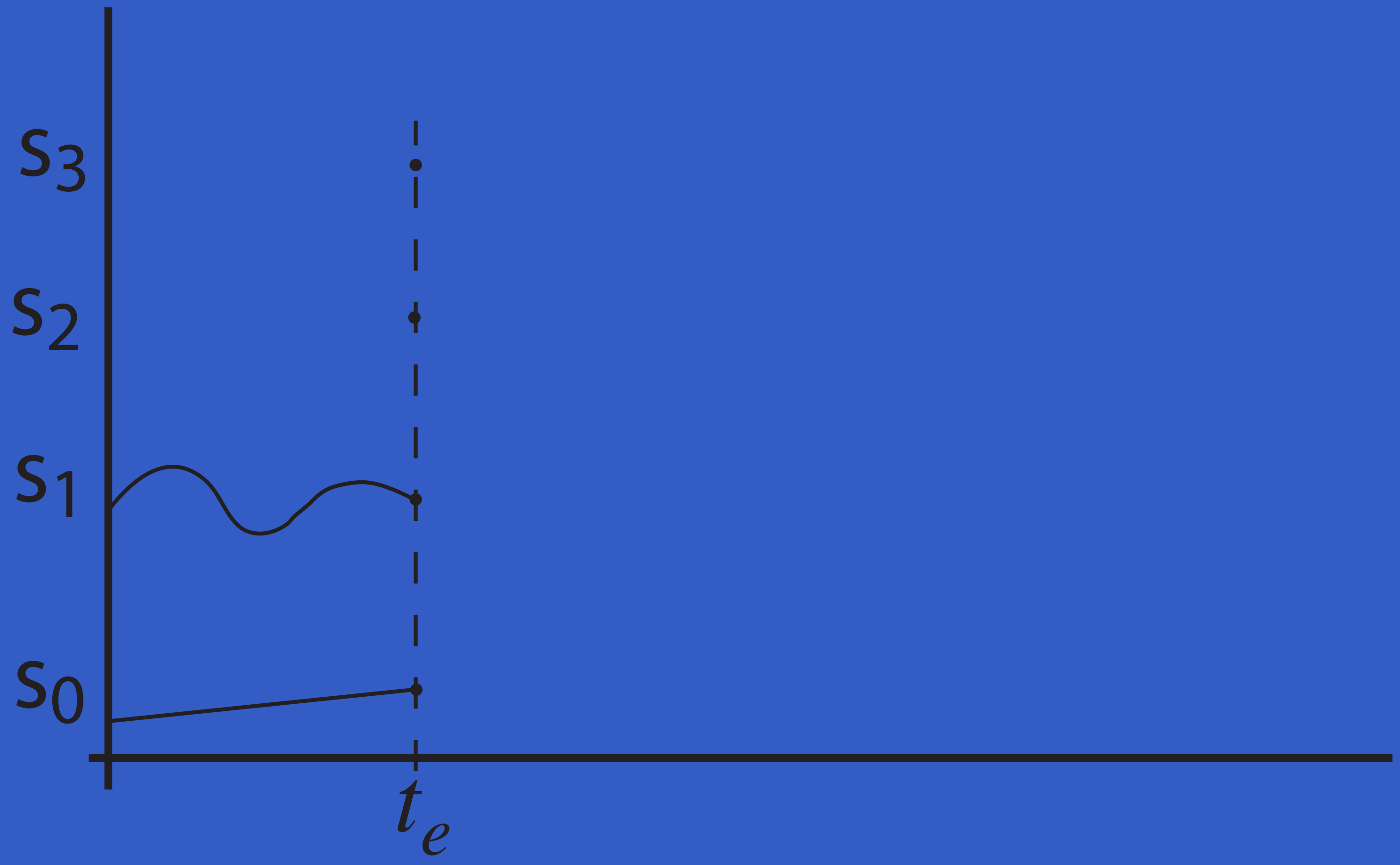


Dynamic signal function collections



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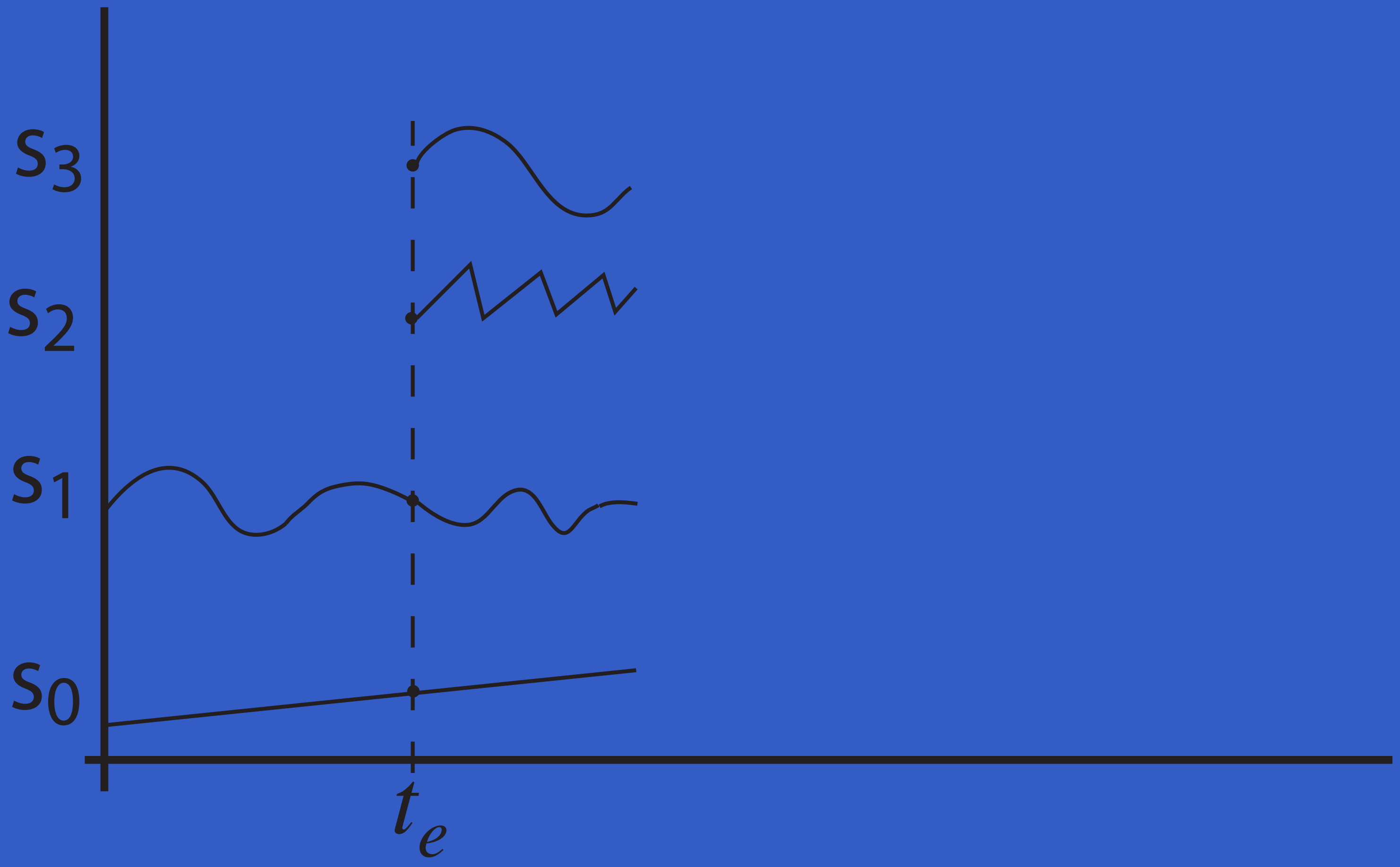

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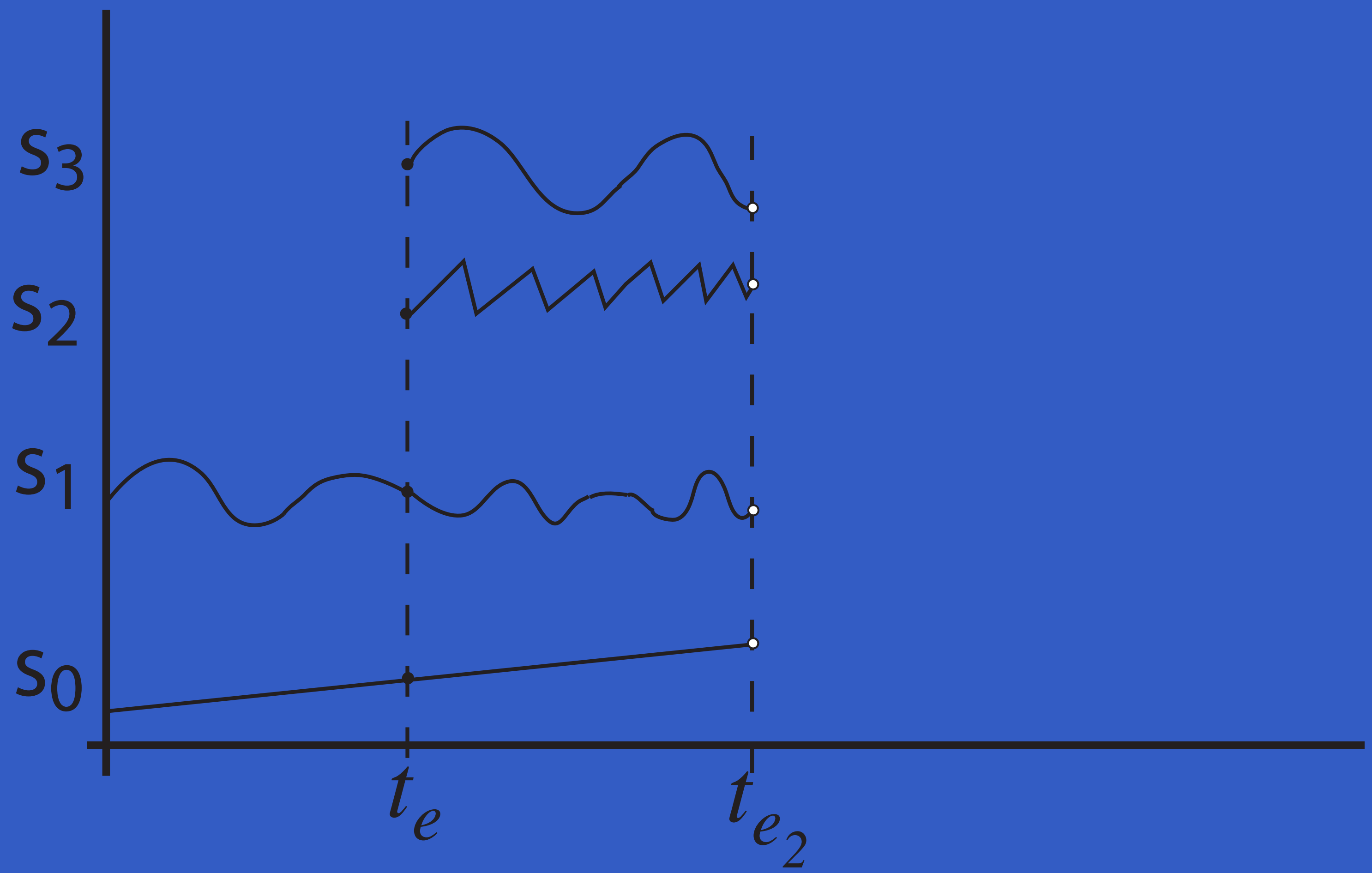

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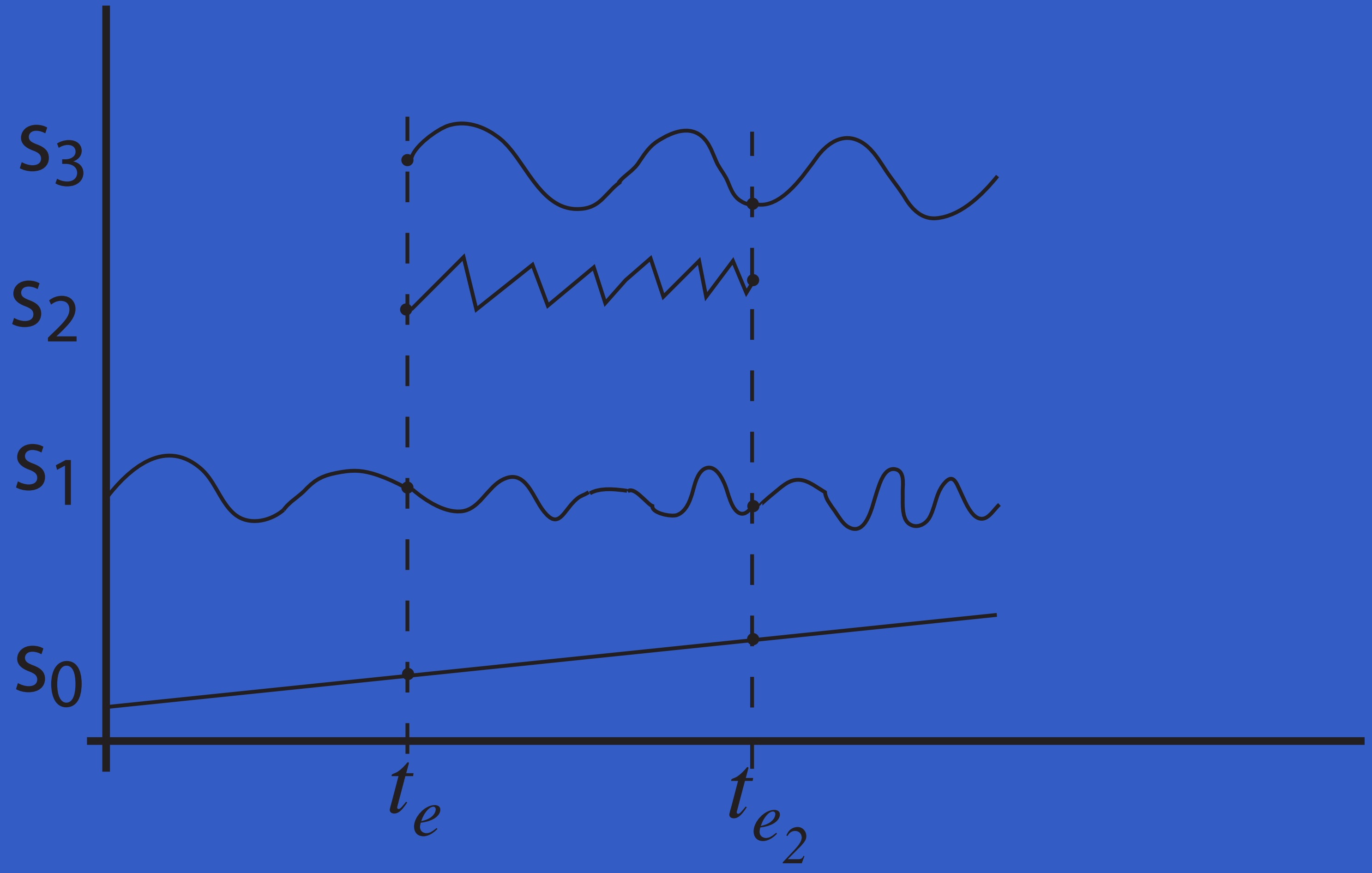

dpSwitch

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)
```

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Routing function

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    -> 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)                        Event source
   -> SF (a, col c) (Event d)
   -> (col (SF b c) -> d -> SF a (col c))
   -> SF a (col c)
```

dpSwitch

Need ability to express:

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```

Function yielding SF to switch into

Routing

Idea:

- The routing function decides which parts of the input to pass to each running signal function instance.

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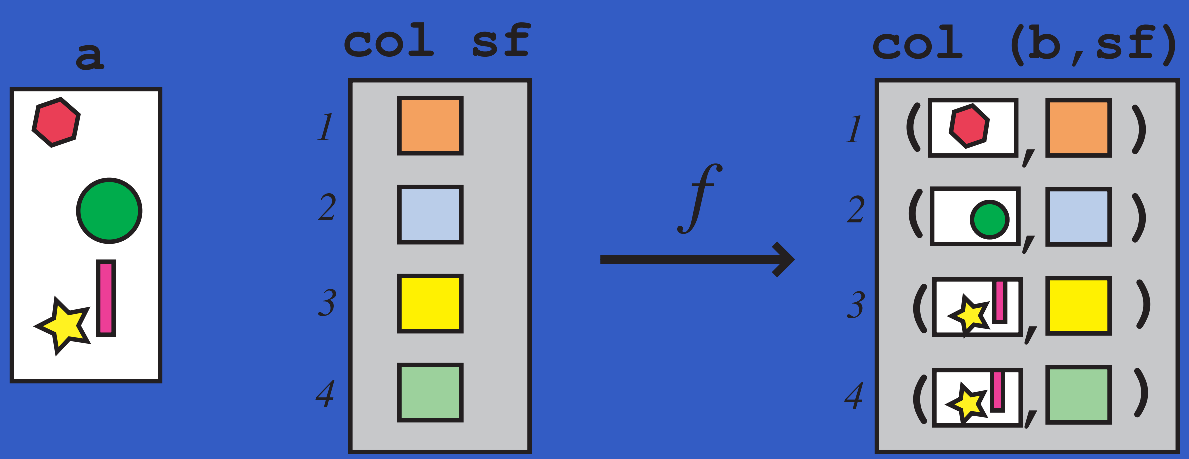
Idea:

- The routing function decides which parts of the input to pass to each running signal function instance.
- It achieves this by pairing a projection of the input with each running instance:



The routing function type

Universal quantification over the collection members:

```
Functor col =>
  (forall sf . (a -> col sf -> col (b,sf)))
```

Collection members thus ***opaque***:

- Ensures only signal function instances from argument can be returned.
- Unfortunately, does not prevent duplication or discarding of signal function instances.

How many different kinds of switches?

There might seem to be quite a few different kinds of switches around:

```
switch, dSwitch, rSwitch,
drSwitch, pSwitch, dpSwitch,
...
```

In fact, they can all easily be defined in terms of, respectively, `switch` or `dSwitch`. But for the parallel (and other ***continuation-based***) switches, an additional notion is needed to provide the capability to freeze signal functions: ***ageing***.

Aging (1)

The primitive `age` continuously makes a frozen, aged, version of its argument signal function available:

```
age :: SF a b -> SF a (b, SF a b)
```

This is used to define the simple continuation-based switched, `kSwitch`:

```
kSwitch ::
    SF a b -> SF (a,b) (Event c)
    -> (SF a b -> c -> SF a b)
    -> SF a b
```

Aging (2)

```
kSwitch :: SF a b -> SF (a,b) (Event c)
           -> (SF a b -> c -> SF a b) -> SF a b
kSwitch sf1 sfe k =
    switch sf (\(c, sf1') -> k sf1' c)
    where
        -- sf :: SF a (b, Event (c, SF a b))
        sf = (identity &&& age sf1)
             >>> arr (\(a, (b, sf1')) ->
                      ((a,b), (b, sf1')))
             >>> first sfe
             >>> arr (\(e, (b, sf1')) ->
                      (b, e `attach` sf1'))
```

Aging (3)

Aging of collections:

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

This can be used to define `pSwitch` and `dpSwitch` in terms of `switch` and `dSwitch`, respectively, in a similar way to `kSwitch`.

Side note: Application of Freezing

The DIVE virtual reality environment (Blom 2009), implemented using an somewhat customised version of Yampa, allows objects in a virtual world to be continuously manipulated in a similar way to a real world.

But in such a setting, how to implement an ***undo*** facility?

DIVE used Yampa's capability to age and freeze signal functions to good effect: whenever a point is reached one might want to return to, just capture the aged signal function representing the system and store it for possible later use.

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'))
```

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)

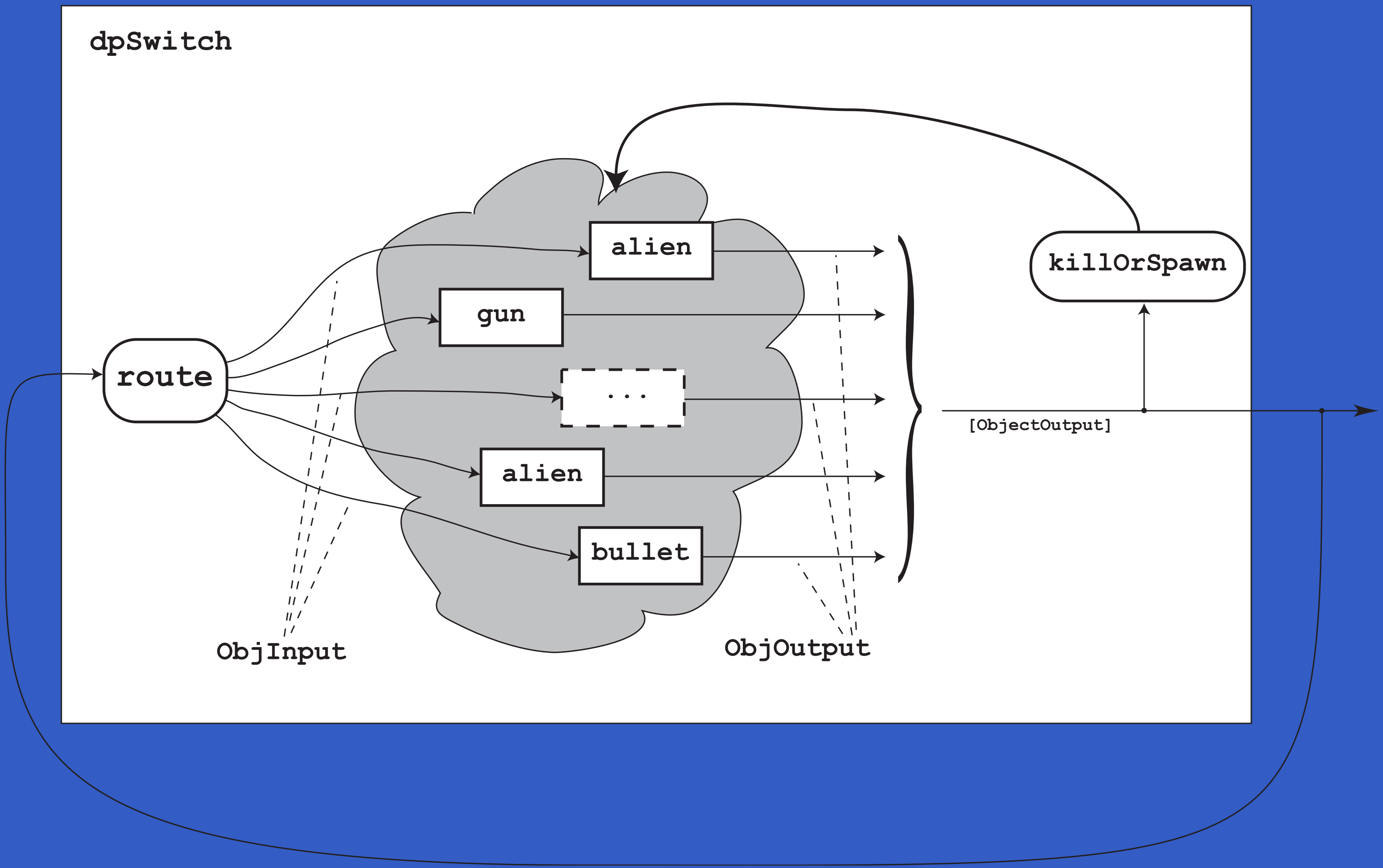
```
...
-- Physics
let a = vector2Polar
            (min alienAccMax
                 (vector2Rho ad))
            h
vp  <- iPre v0      -< v
ffi <- forceField -< (p, vp)
v   <- (v0 ^+^) ^<< impulseIntegral
          -< (gravity ^+^ a, ffi)
p   <- (p0 .+^) ^<< integral -< v
...
```

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
```

Recap: Overall game structure



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 functional 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.
  - Carefully designed to facilitate reuse.
- Yampa allows state to be nicely encapsulated by signal functions:
  - Avoids keeping track of all state globally.
  - Adding more state 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`

Why not imperative, then?

If state is so important, why not stick to imperative/object-oriented programming where we have “state for free”?

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- Advantages of declarative programming retained:
  - High abstraction level.
  - Referential transparency, algebraic laws: formal reasoning ought to be simpler.

Why not imperative, then?

If state is so important, why not stick to imperative/object-oriented programming where we have “state for free”?

- Advantages of declarative programming retained:
  - High abstraction level.
  - Referential transparency, algebraic laws: formal reasoning ought to be simpler.
- Synchronous approach avoids “event-call-back soup”, meaning robust, easy-to-understand semantics.

Elerea

For an entirely different approach to dynamic collections of time-varying entities, see Elerea (Patai 2010):

- Elera has ***first class*** signals, and thus signals can carry collections of signals.
- A signal carrying a collection of signals is turned into a signal carrying a signal of a collection of values.
- A signal if signals is given meaning through a monadic join:

```
join :: S (S a) -> S a
```

Reading (1)

- Henrik Nilsson, Antony Courtney, and John Peterson. Functional reactive programming, continued. In *Proceedings of the 2002 Haskell Workshop*, pp. 51–64, October 2002.
- Antony Courtney and Henrik Nilsson and John Peterson. The Yampa Arcade. In *Proceedings of the 2003 Haskell Workshop*, pp. 7–18, August 2003.

Reading (2)

- Kristopher J. Blom. *Dynamic Interactive Virtual Environments*. PhD Thesis, University of Hamburg, Department of Informatics, 2009
- Gergely Patai. Efficient and Compositional Higher-Order Streams. In *Proceedings of Functional and (Constraint) Logic Programming (WFLP) 2010*, Madrid, Spain, January 2010.