Functional Reactive Programming, Continued

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Functional Reactive Programming

FRP and Yampa:

- FRP: conceptual framework for programming with time-varying entities.
- Yampa (formerly AFRP): an implementation of FRP embedded in Haskell.

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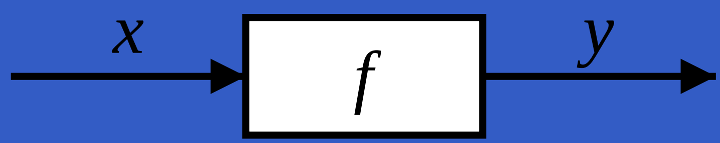
Theme of this talk:

Bringing classical FP ideas like first class continuations to the world of hybrid systems and reactive programming to make structurally dynamic systems possible.

Functional Reactive Programming

Key concept: functions on signals.



Intuition:

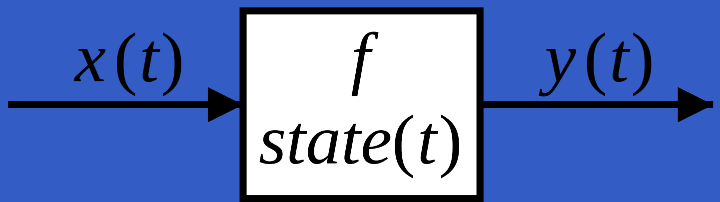
$$\texttt{Signal}\ \alpha = \texttt{Time} \to \alpha$$
$$x :: \texttt{Signal T1}$$
$$y :: \texttt{Signal T2}$$
$$f :: \texttt{Signal T1} \to \texttt{Signal T2}$$

Additionally: ***causality*** requirement.

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 $x(t)$

The Big Picture

Some areas where functions on signals are central:

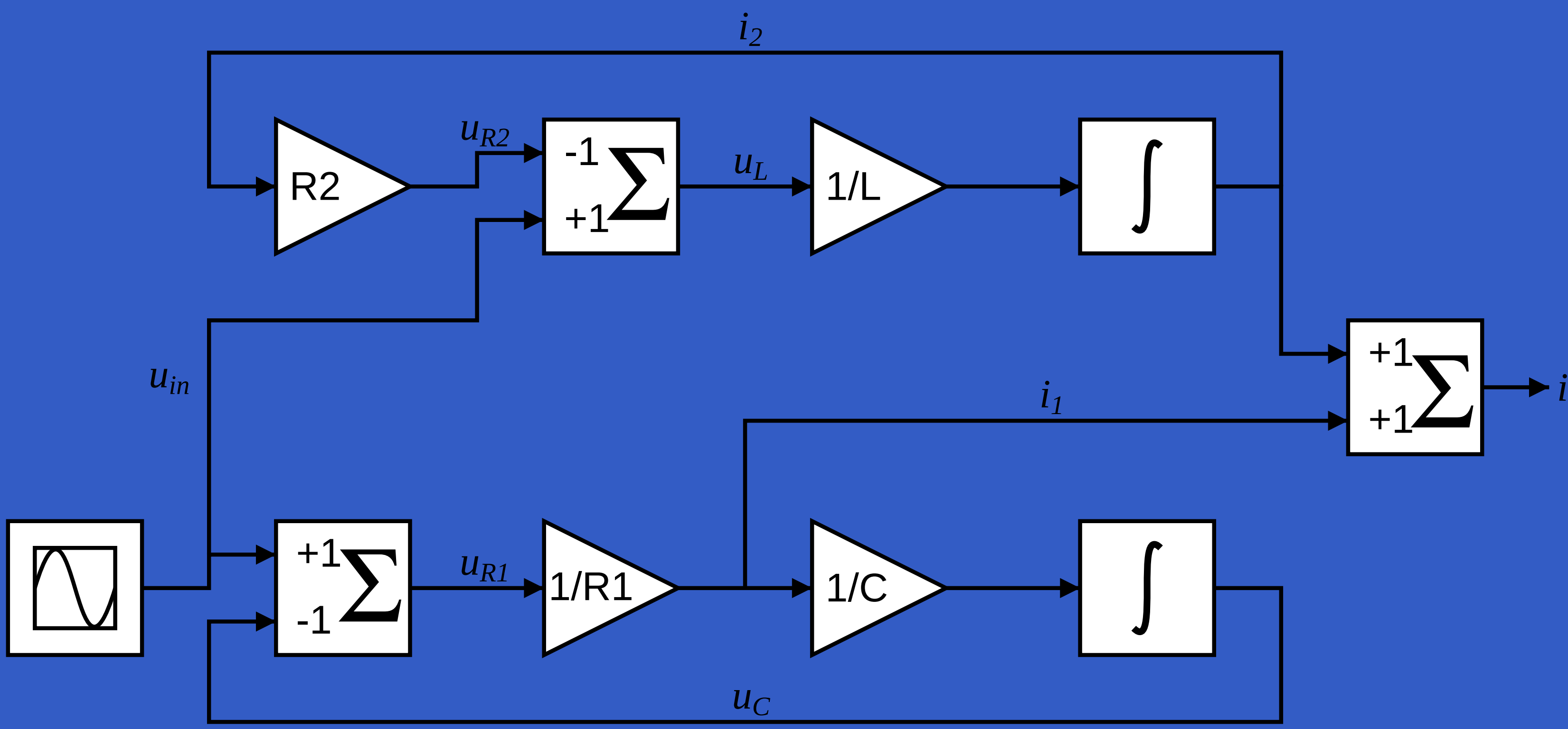
- Modelling and simulation of physical systems
- Hybrid systems
- Reactive systems
- Embedded systems
- Digital Signal Processing
- ...

Related Languages

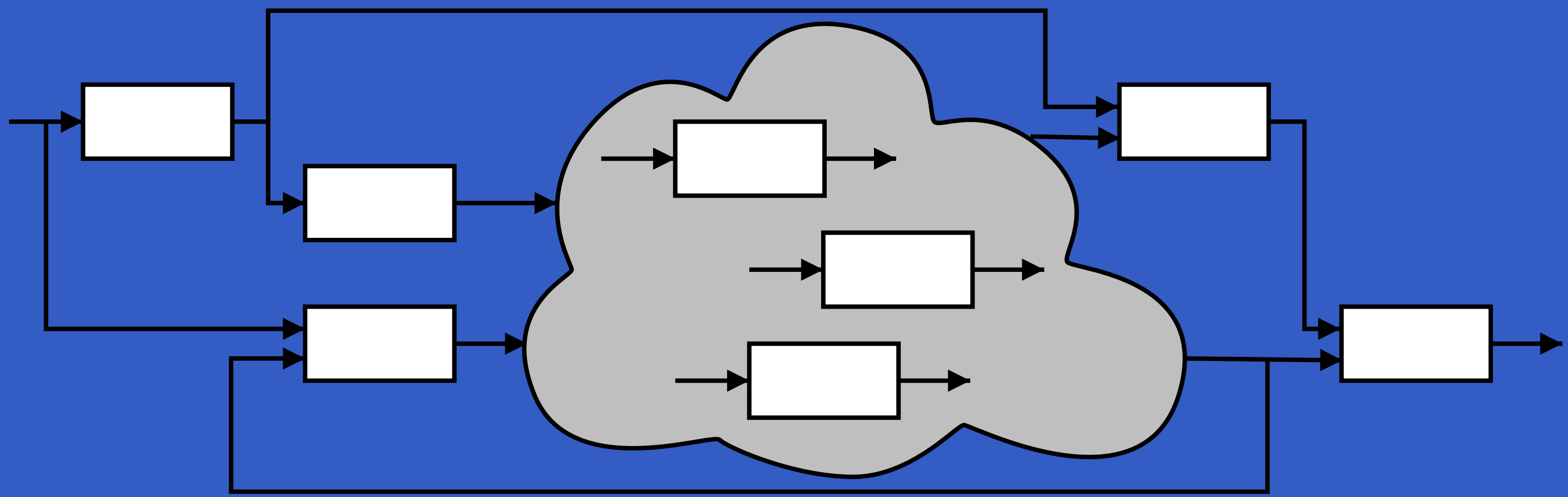
Lots of languages designed around the idea of functions on signals, e.g.:

- Modelling Languages:
  - Simulink
  - Ptolemy II
- Synchronous languages:
  - Esterel
  - Lustre
  - Lucid Synchrone
- . . .

Describing Composite Systems



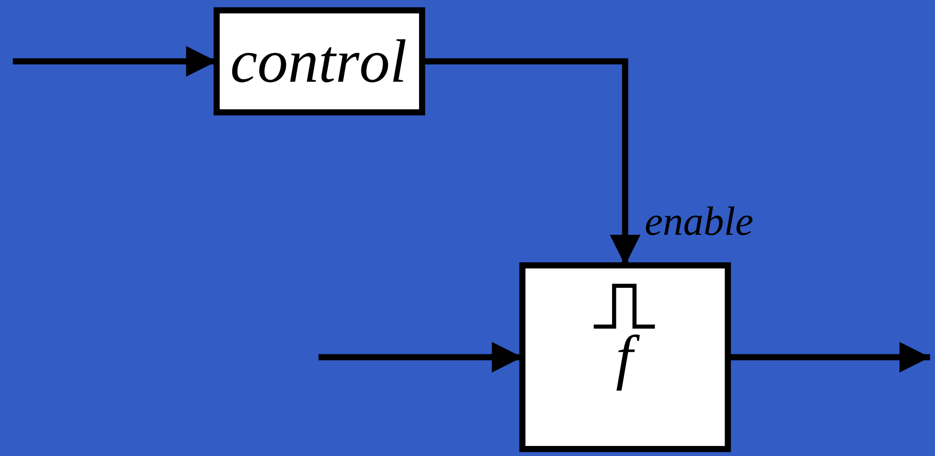
What If System Structure Varies?



- What type of structural changes can be expressed?
- What about state?

Support for Structural Changes

Simulink is fairly typical:



- Blocks can be enabled/disabled dynamically.
- State can be preserved or reset.

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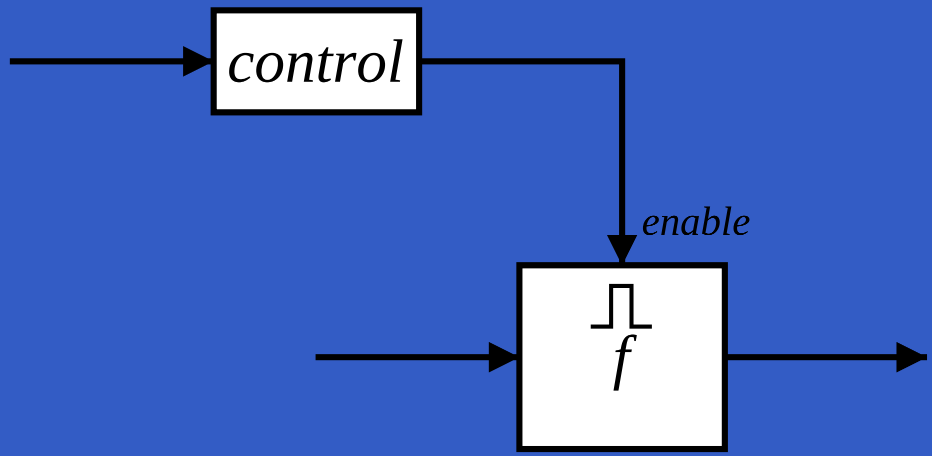

- Blocks can be enabled/disabled dynamically.
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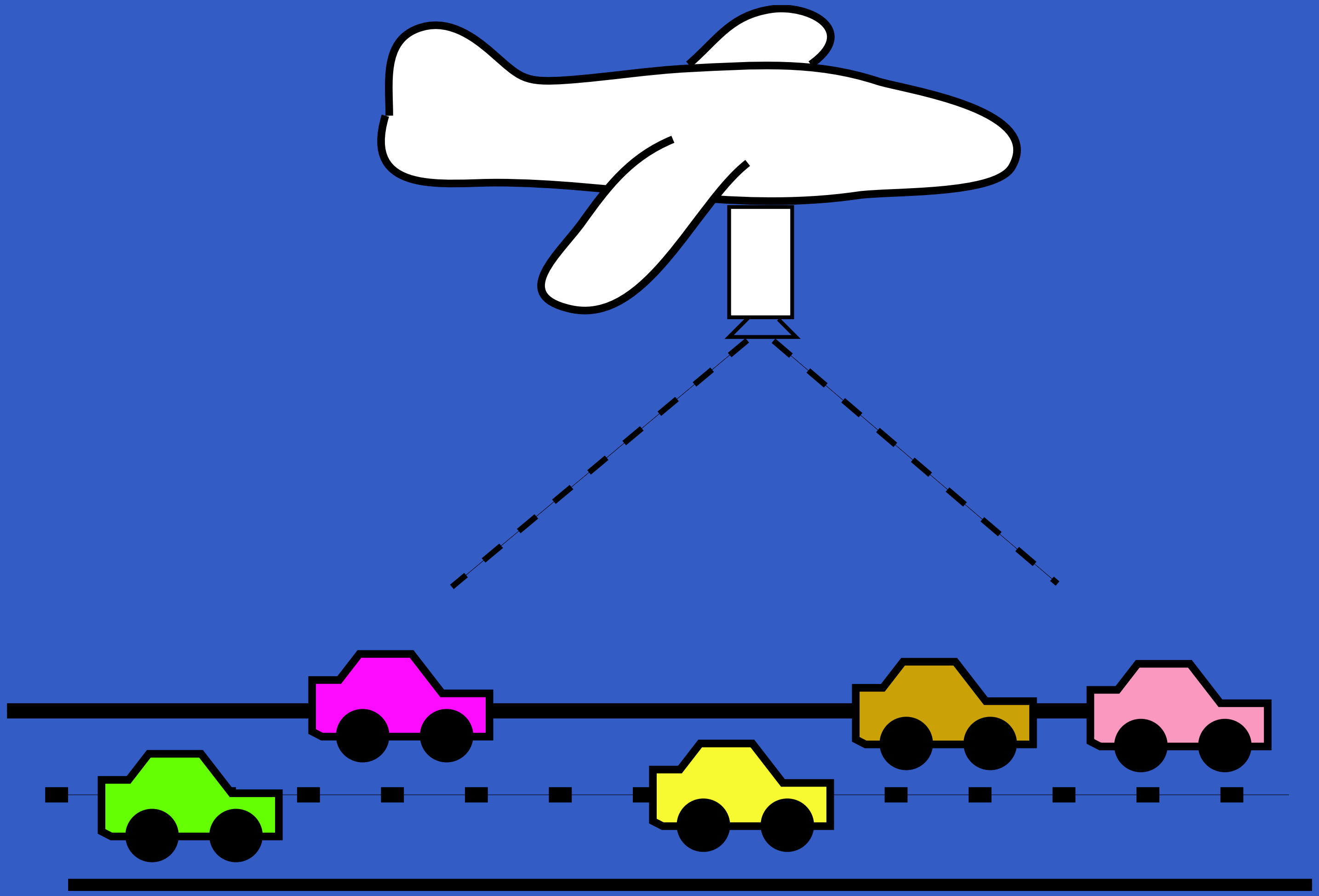
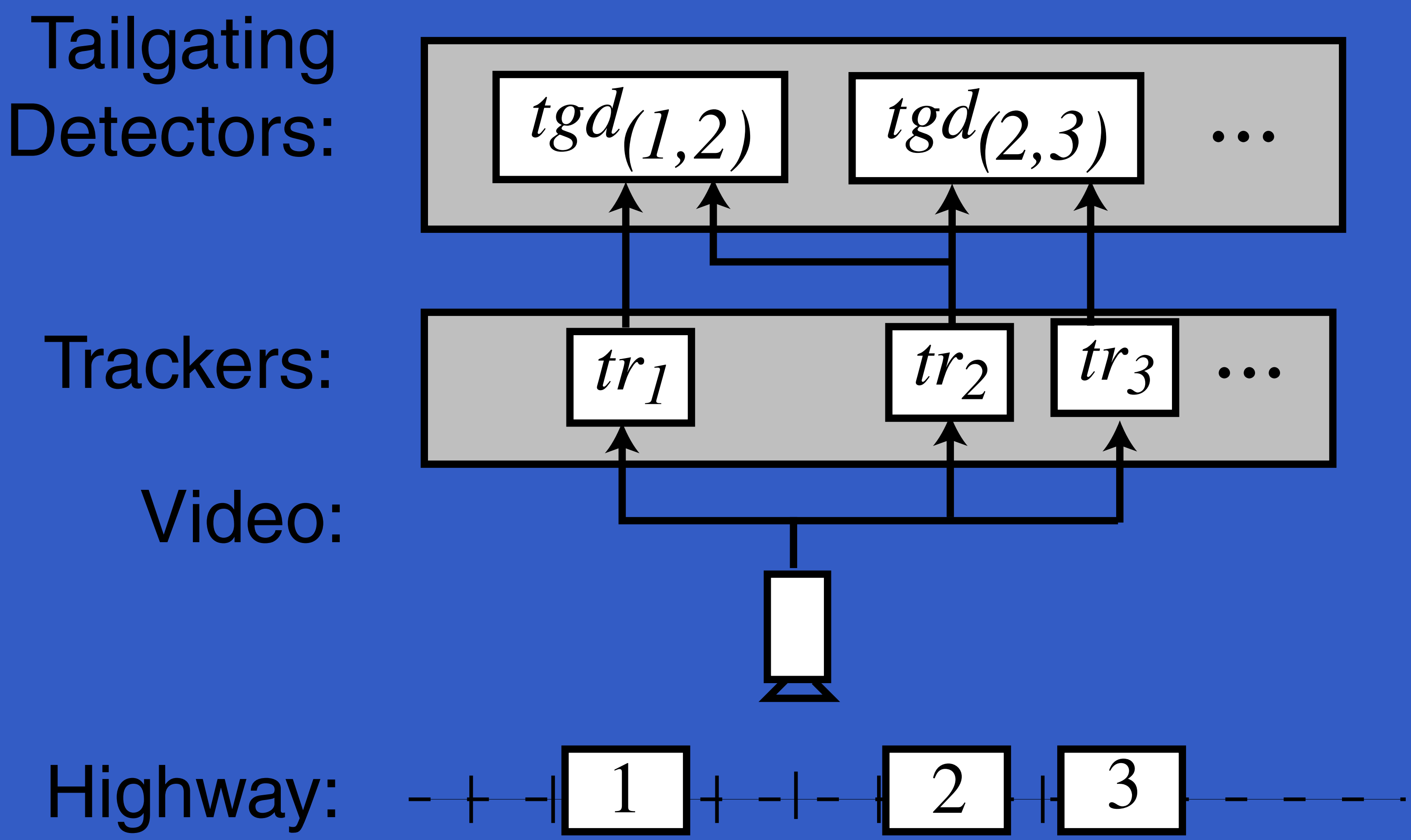
Number of structural configurations fixed.
Blocks cannot be added/deleted dynamically!

Example: Traffic Surveillance



Tailgating detector



Yampa

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- ***Switchers*** “apply” signal functions to signals at some point in time, creating a running signal function instance.

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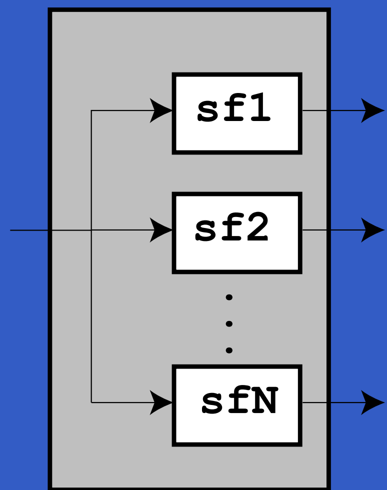
- Signals are ***not*** first class entities.
- ***Switchers*** "apply" signal functions to signals at some point in time, creating a running signal function instance.
- Special combinators to run ***collections*** of signal functions in parallel.

Static Signal Function Collections

The most basic way to form a SF collection:

```
parB :: Functor col =>
        col (SF a b) -> SF a (col b)
```



parB [sf1,sf2,...,sfN]

Can't add or remove SFs from the collection.

Dynamic Signal Function Collections

Idea:

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

```
pSwitchB ::  Functor col =>
     col (SF a b)
    ->  SF (a, col b) (Event c)
    ->  (col (SF a b) -> c -> SF a (col b))
    -> SF a (col b)
```

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```
pSwitchB :: Functor col =>
    col (SF a b)                                    Initial collection
    -> SF (a, col b) (Event c)
    -> (col (SF a b) -> c -> SF a (col b))
    -> SF a (col b)
```

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Event source

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Function yielding SF to switch into

Dynamic Signal Function Collections

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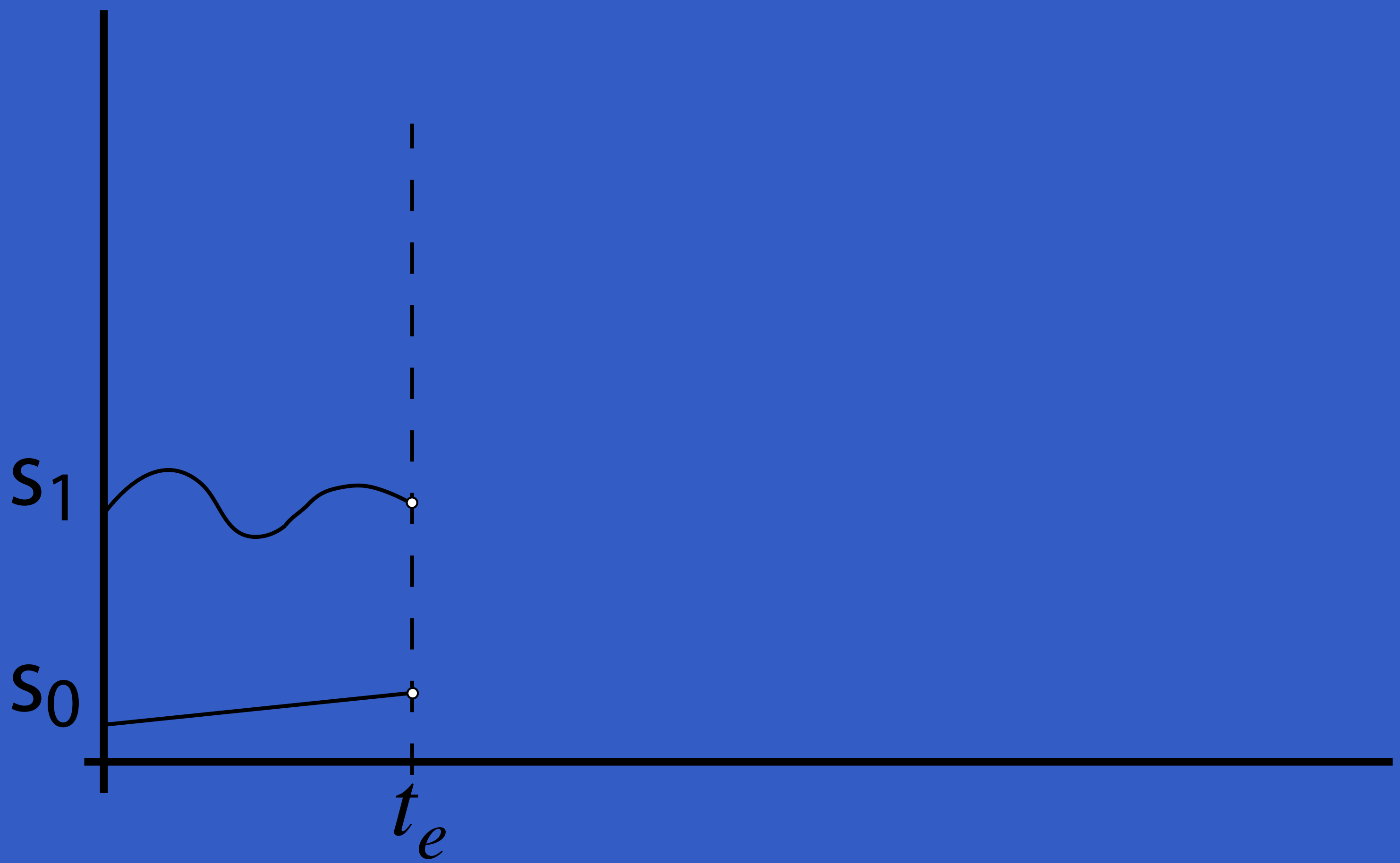
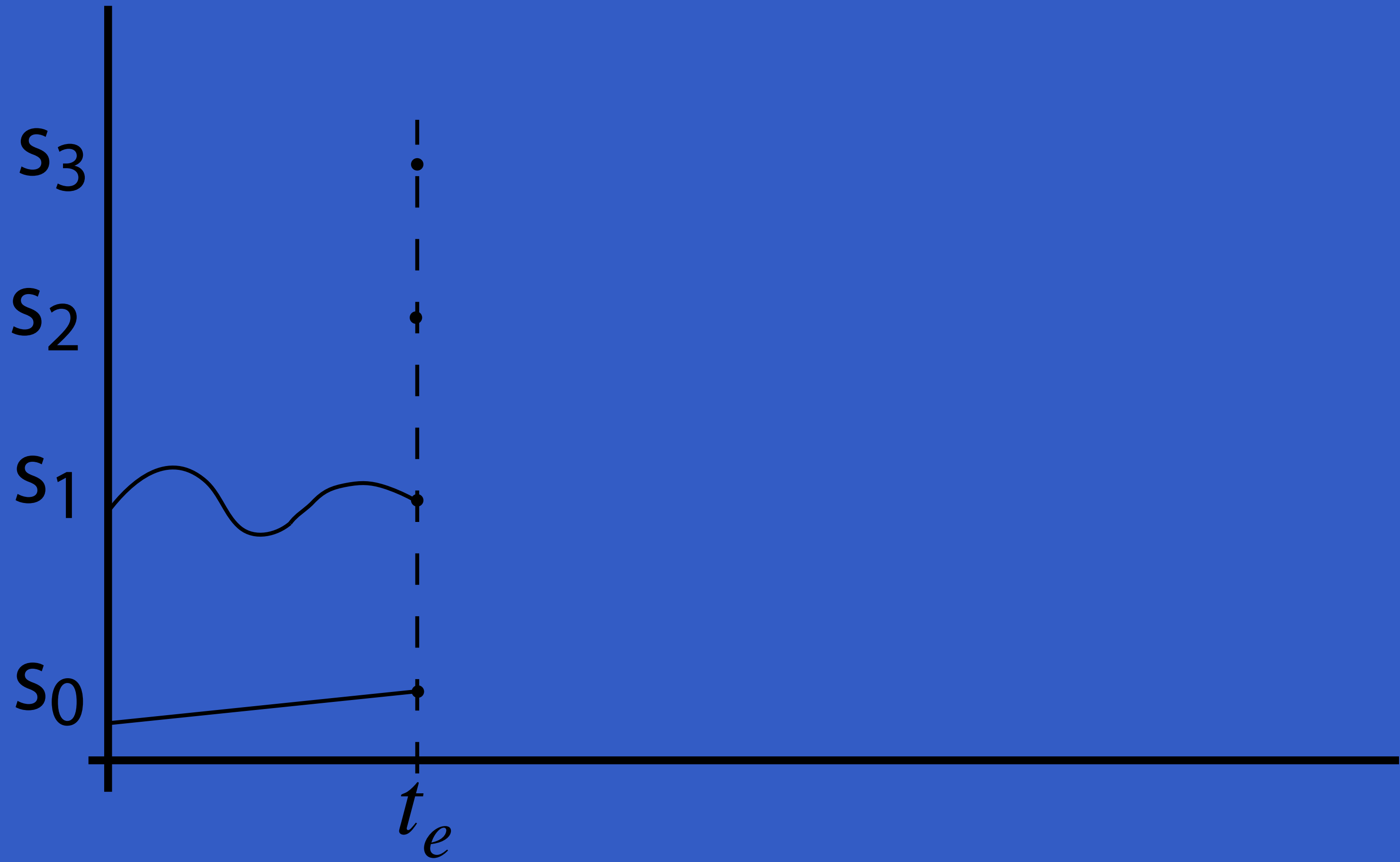


Dynamic Signal Function Collections



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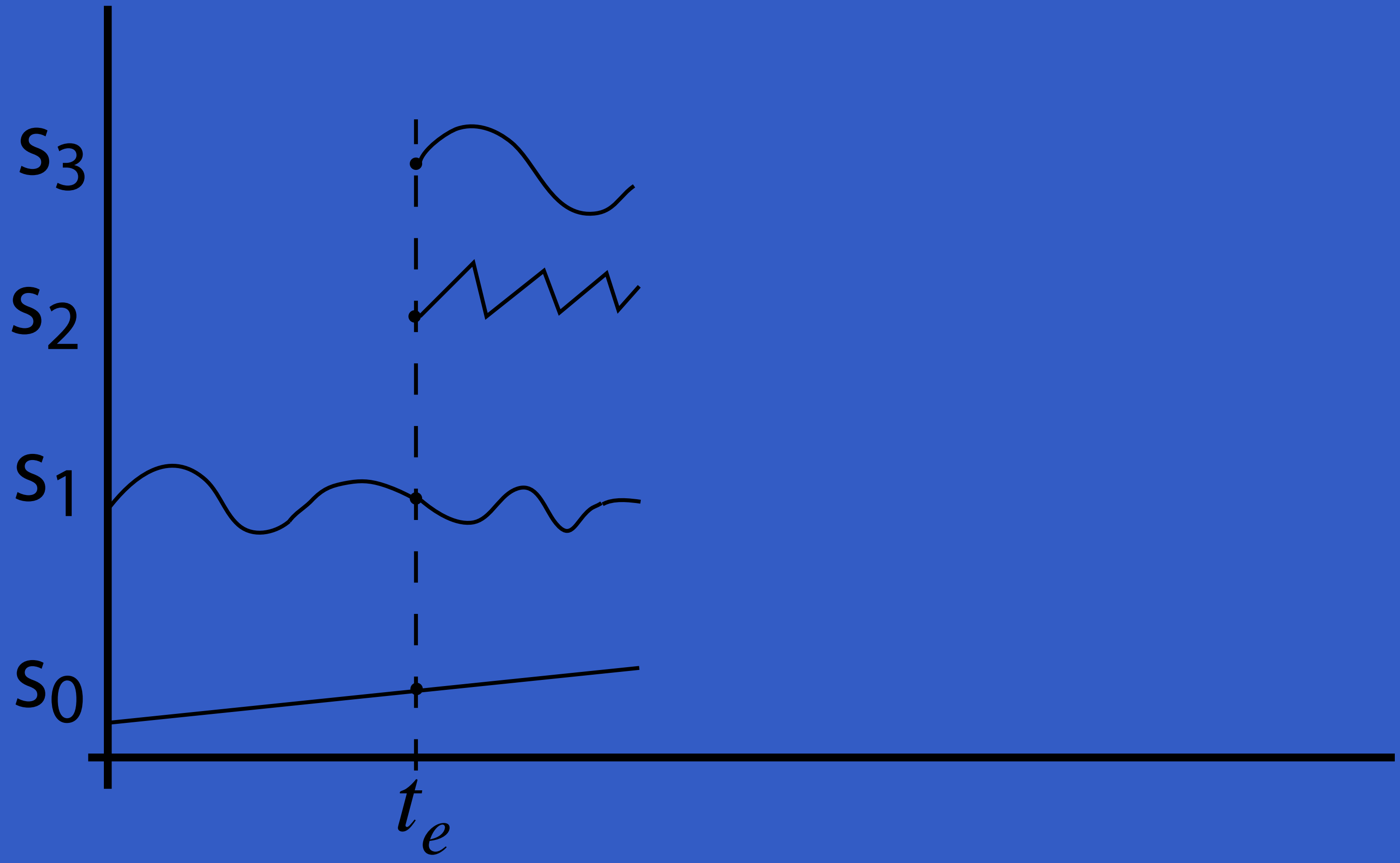

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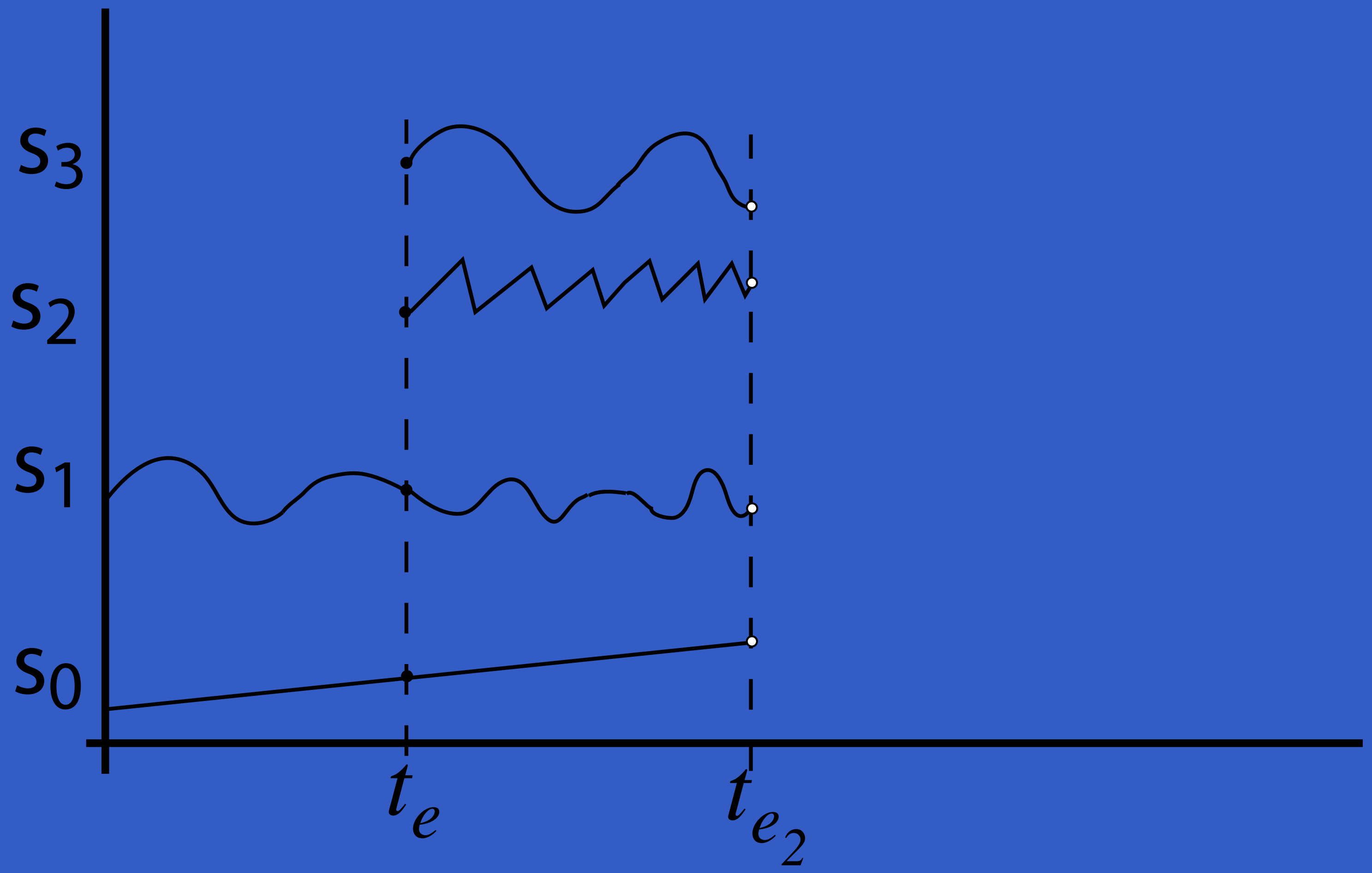
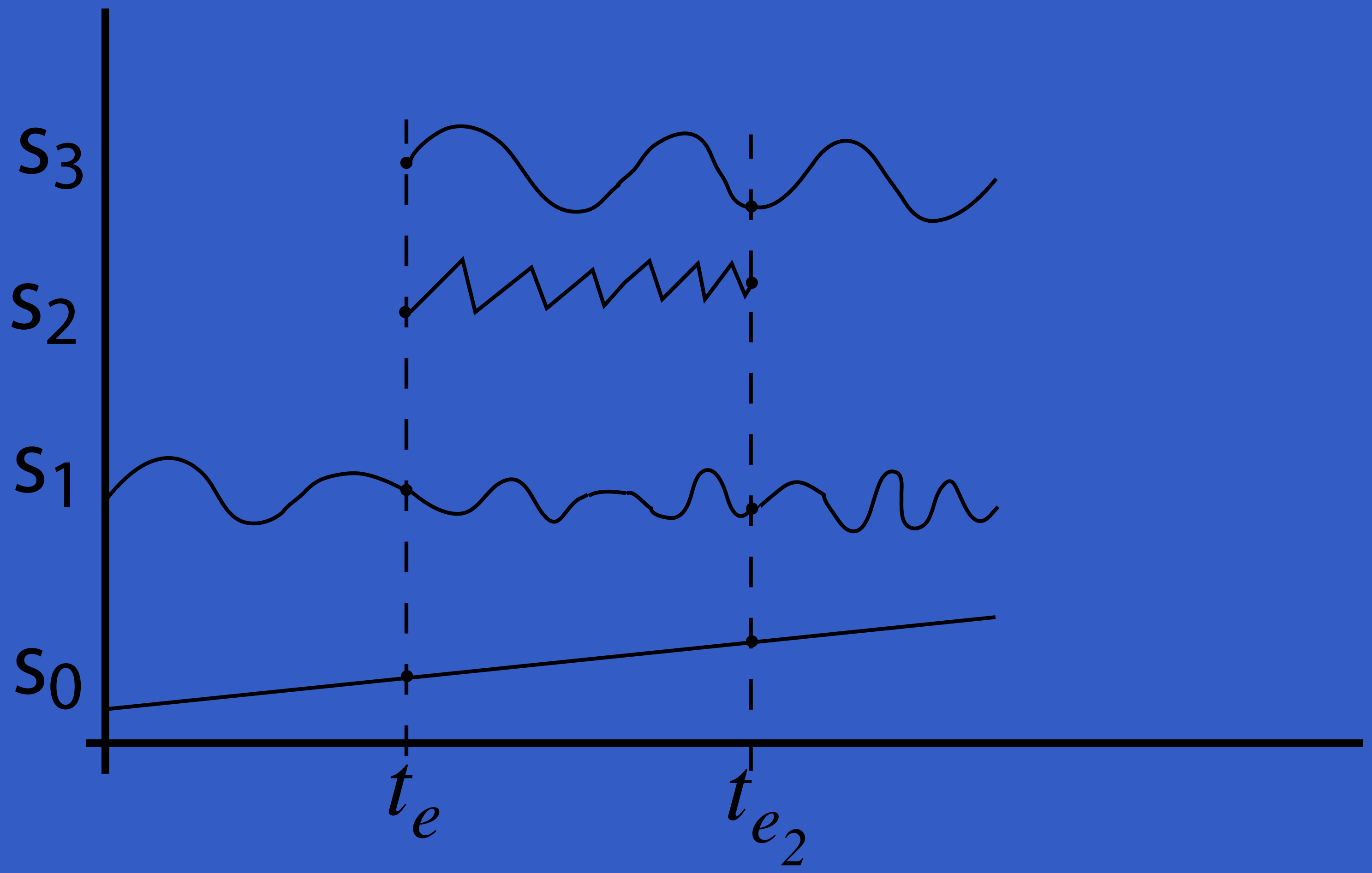
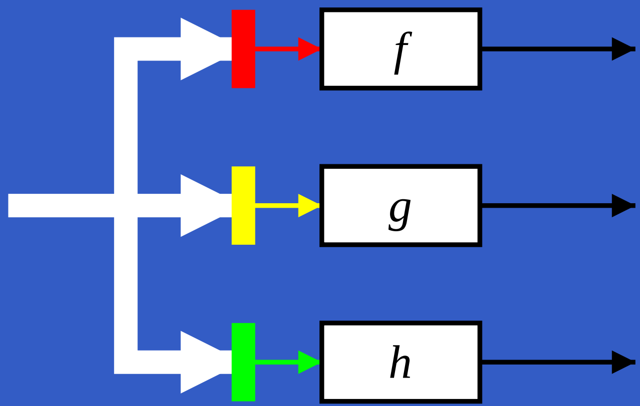


Dynamic Signal Function Collections



Routing (1)

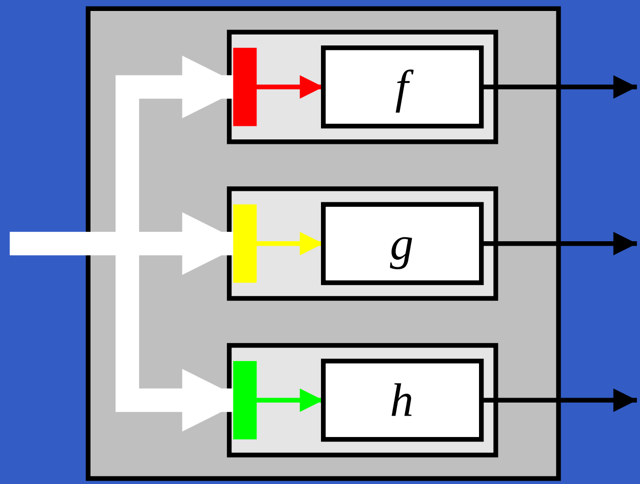
How can flexible communication be achieved?



- Input filtering (+ feedback) is enough.

Routing (1)

How can flexible communication be achieved?



- Input filtering (+ feedback) is enough.
- But composing each actual signal function with a filter is awkward and inflexible.

Routing (2)

Idea:

- Generalized `pSwitch` responsible for routing; obviates need for composition.

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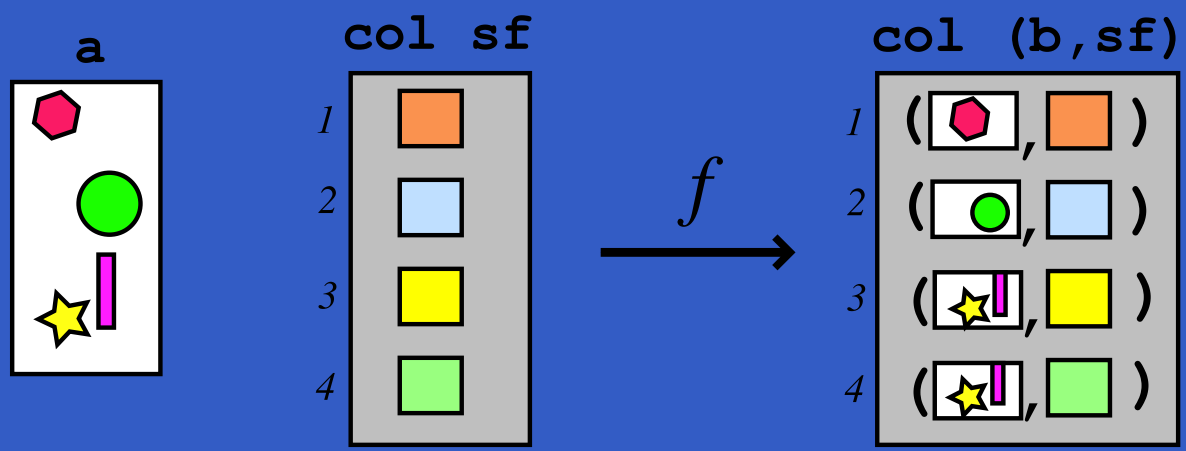
- Generalized `pSwitch` responsible for routing; obviates need for composition.
- Desired routing specified by user-supplied routing function.



pSwitch

```
pSwitch :: 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)
```

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 functions from argument can be returned.
- Unfortunately, does not prevent duplication or discarding of signal functions.

Tailgating Detector: Excerpts

```
type CarTracker = SF (Video, UAVStatus)
                     (Car, Event ())


multiCarTracker ::
    SF (Video, UAVStatus, Event CarTracker)
       [(Id,Car)]
multiCarTracker =
    pSwitch route []
            addOrDelCarTrackers
            (\cts' f ->
                 multiCarTracker (f cts'))
```

Related Work (1)

- First-Order Systems: no dynamic collections
  - Esterel [Berry 92], Lustre [Caspi 87], Lucid Synchrone [Caspi 00], SimuLink, RT-FRP [Wan, Taha, Hudak 01]
- Fudgets [Carlsson and Hallgren 93, 98]
  - Continuation capture with `extractSP`
  - Dynamic Collections with `dynListF`
  - No synchronous bulk update

Related Work (2)

- Fran [Elliott and Hudak 97, Elliott 99]
  - First class ***signals***.
  - But dynamic collections?
- FranTk [Sage 99]
  - Dynamic collections, but only via `IO` monad.

Obtaining Yampa

These ideas have been implemented in Yampa, yielding a very expressive language for reactive programming.

Yampa 0.9 is available from

`http://www.haskell.org/yampa`