A Brief Introduction to Functional Reactive Programming and Yampa

FoP Away Day 17 January 2007

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Functional Reactive Programming

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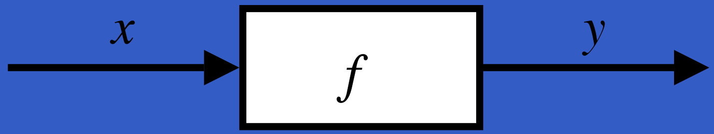
- Umbrella-term for functional approach to programming reactive systems.
- Originated from Functional Reactive Animation (Fran) (Elliott & Hudak).
- Has evolved in a number of directions and into different concrete implementations.
- ***Yampa:*** An FRP implementation in the form of a Haskell ***combinator library***, a.k.a. ***Domain-Specific Embedded Language*** (DSEL).

Signal functions

Key concept: ***functions on signals***.



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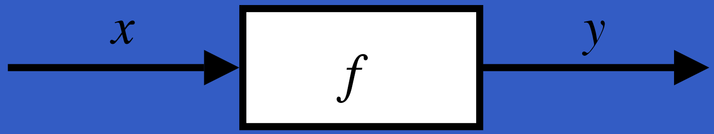

Intuition:

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

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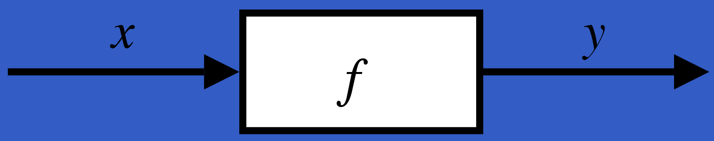

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Additionally, ***causality*** required: output at time t must be determined by input on interval $[0, t]$.

Signal functions and state

Alternative view:

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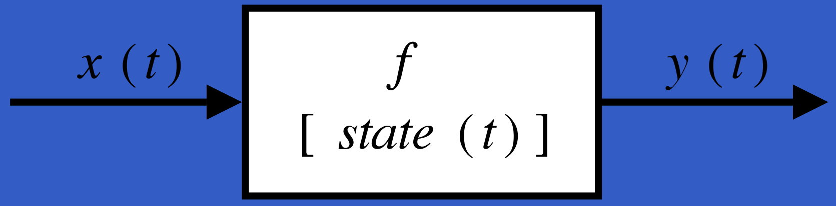
Signal functions can encapsulate ***state***.



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

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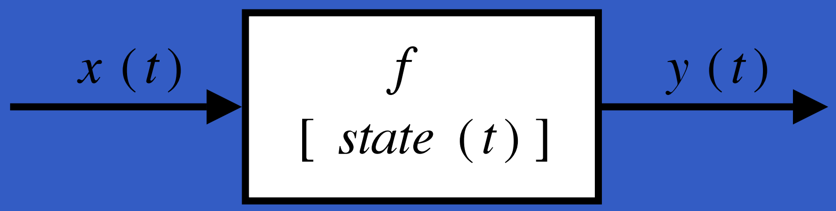

$state(t)$ summarizes input history $x(t')$, $t' \in [0, t]$.

From this perspective, signal functions are:

- ***stateful*** if $y(t)$ depends on $x(t)$ and $state(t)$
- ***stateless*** if $y(t)$ depends only on $x(t)$

Programming with signal functions

In Yampa, systems are described by combining signal functions (forming new signal functions).

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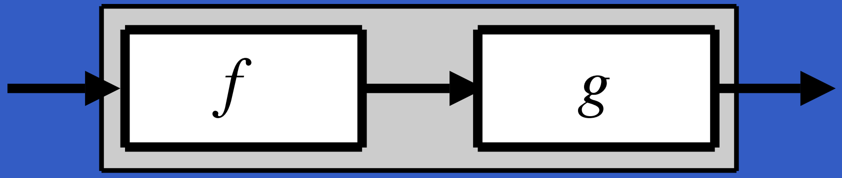
For example, serial composition:



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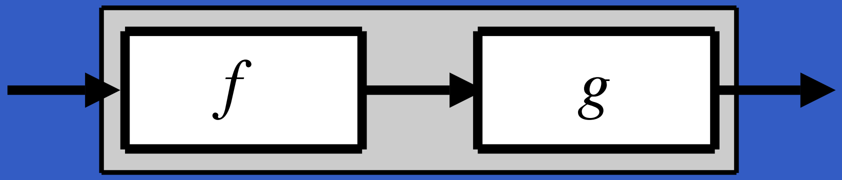
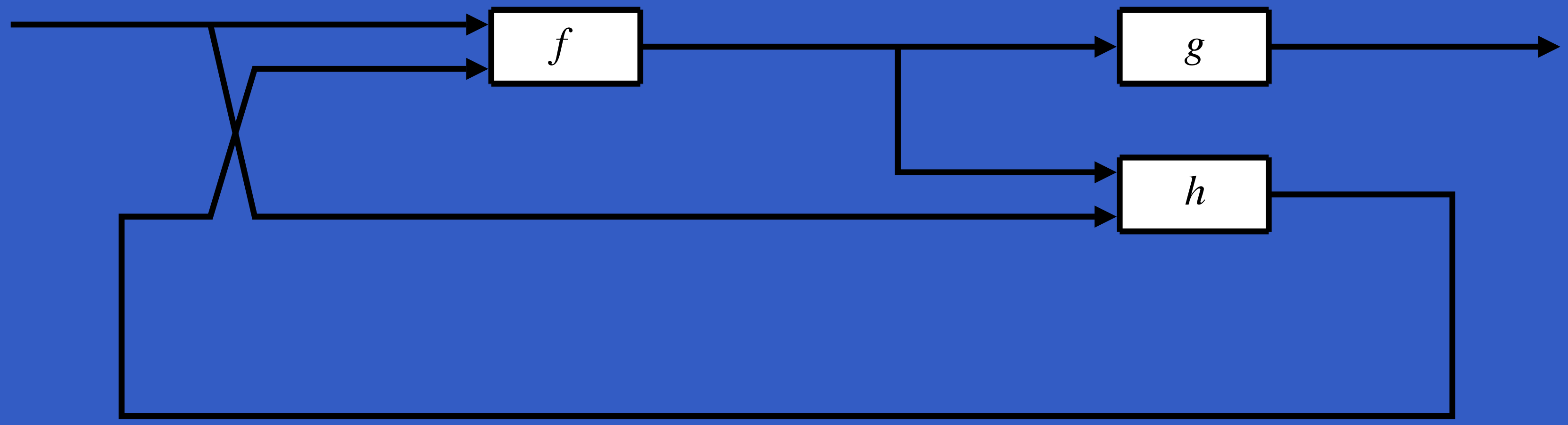


A *combinator* can be defined that captures this idea:

$$(\ggg) :: SF\ a\ b \rightarrow SF\ b\ c \rightarrow SF\ a\ c$$

Programming with signal functions (2)

What about larger networks?
How many combinators are needed?



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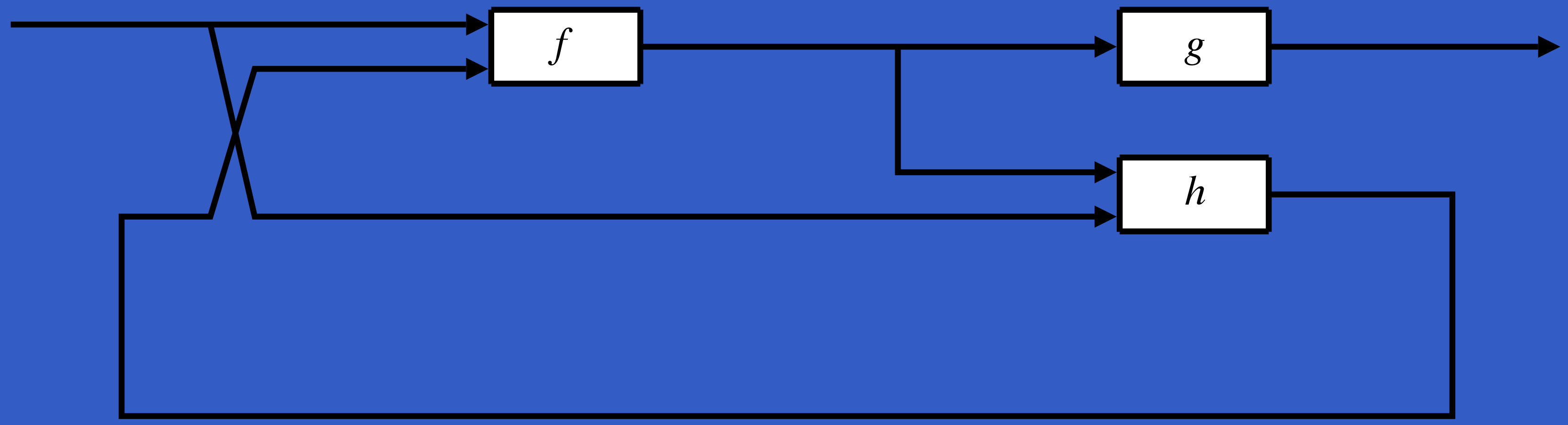
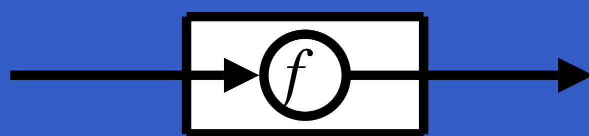


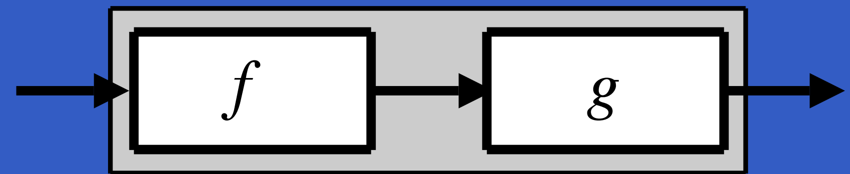
John Hughes's ***Arrow*** framework provides a good answer!

The Arrow framework (1)

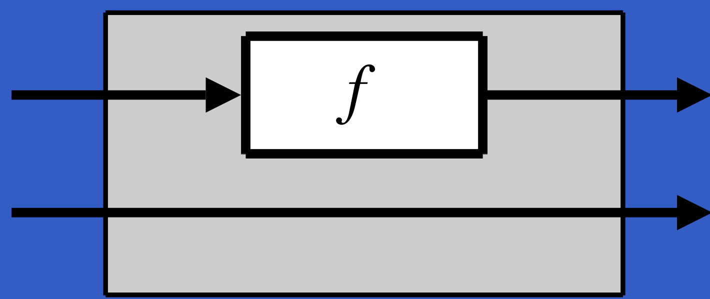
These diagrams convey the general idea:



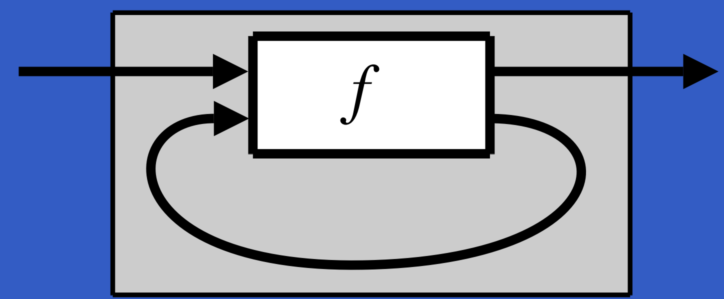
$arr\ f$



$\ggg$



$first\ f$



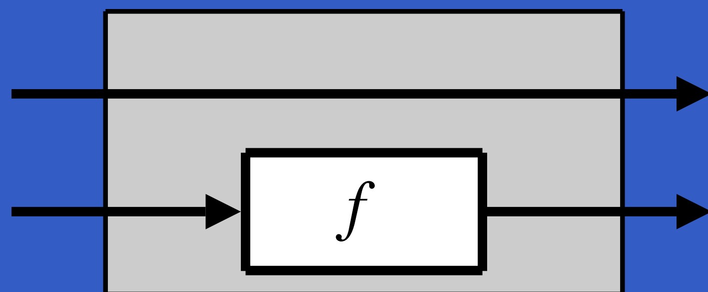
$loop\ f$

$$first :: SF\ a\ b \rightarrow SF\ (a, c)\ (b, c)$$

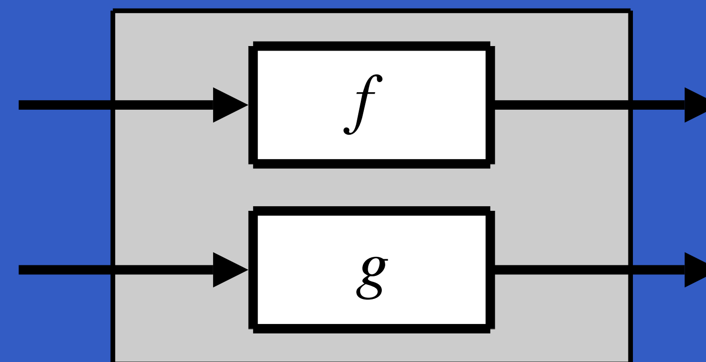
$$loop :: SF\ (a, c)\ (b, c) \rightarrow SF\ a\ b$$

The Arrow framework (2)

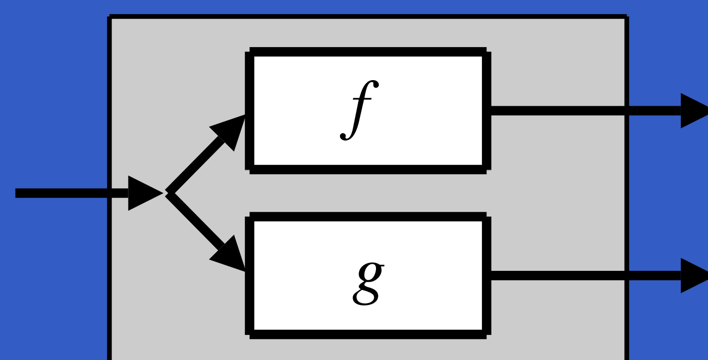
Some derived combinators:



$second\, f$

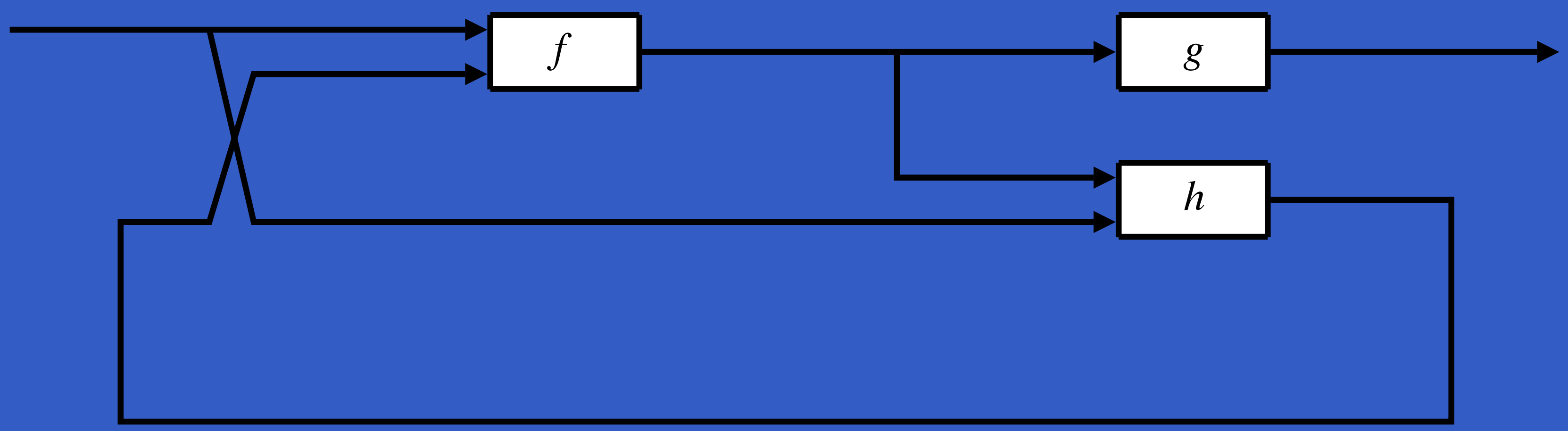


$f \ast\!\ast\!\ast\, g$



$f \,\&\&\&\, g$

Example: Constructing a network



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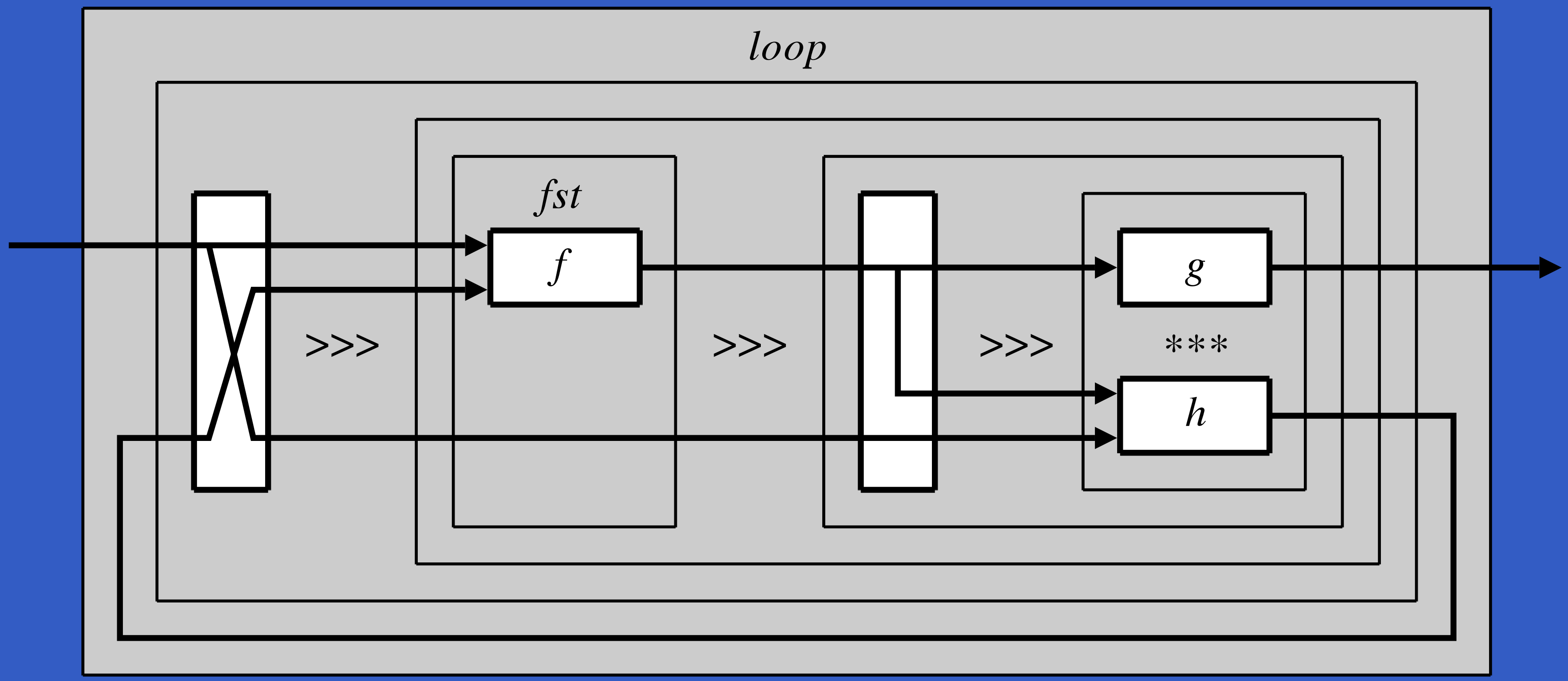

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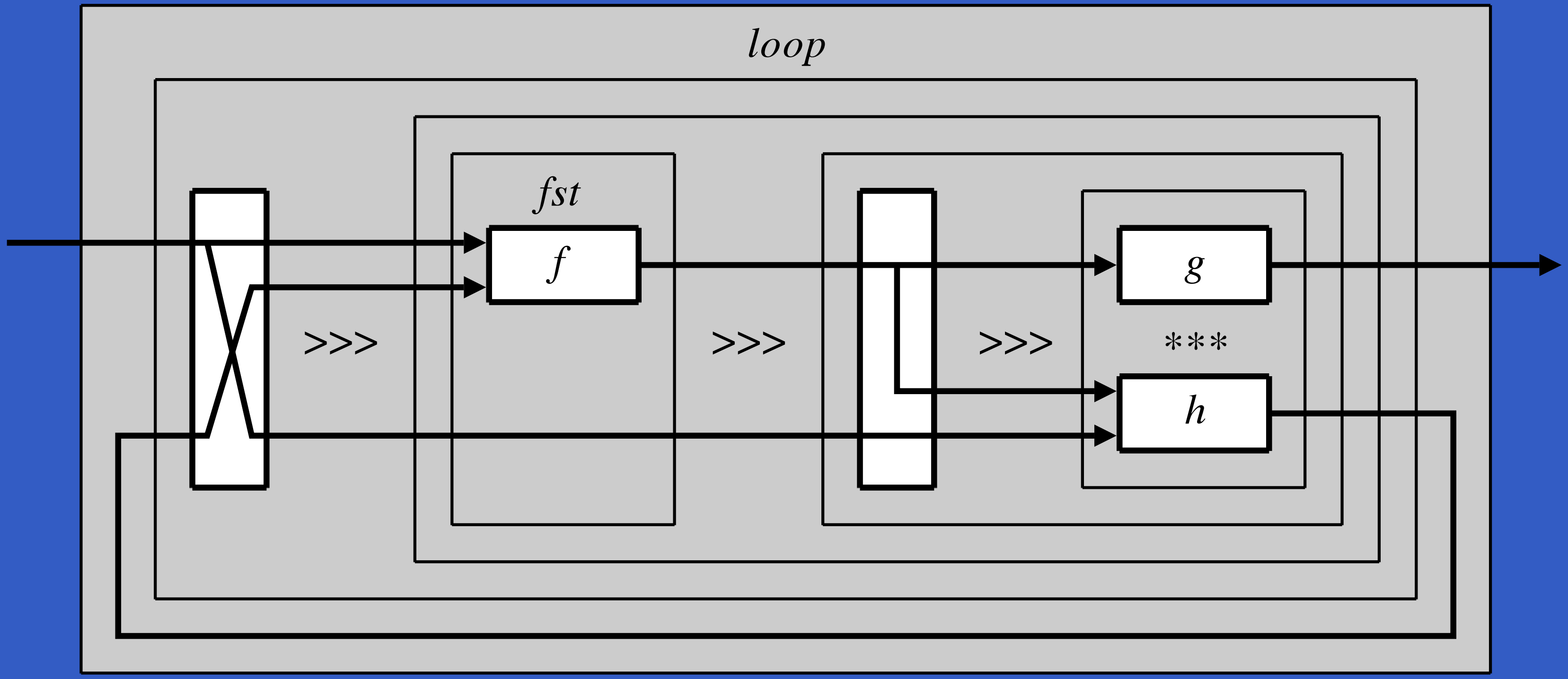
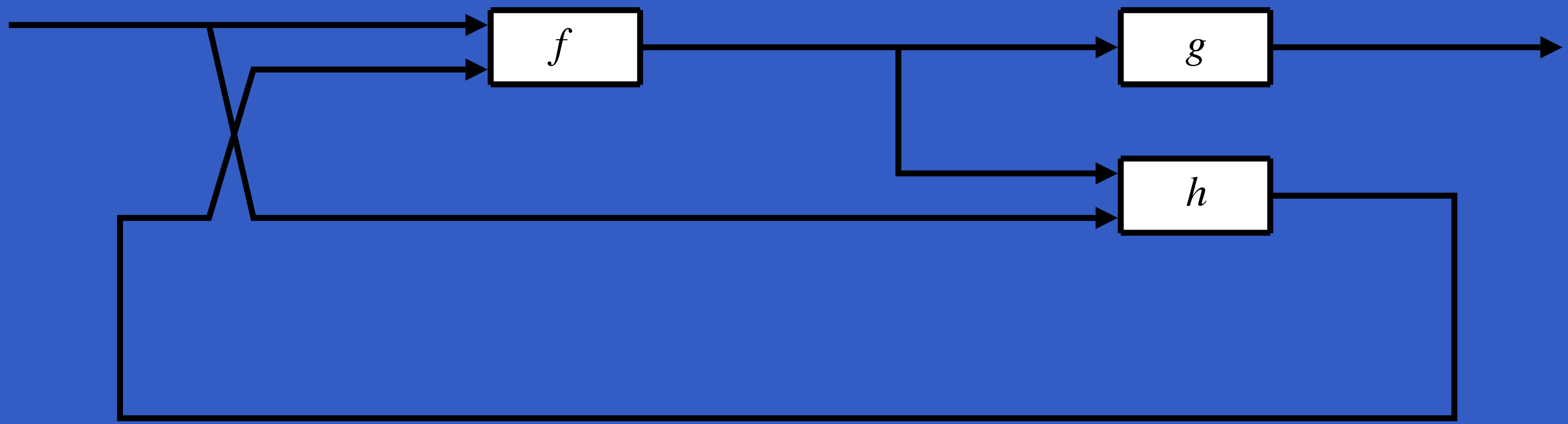


$$
\begin{aligned}
&loop\ (arr\ (\lambda(x, y) \rightarrow ((x, y), x)) \\
&\qquad \ggg (fst\ f \\
&\qquad\qquad \ggg (arr\ (\lambda(x, y) \rightarrow (x, (x, y))) \ggg (g *\!\!*\!\!* h))))
\end{aligned}
$$

The Arrow notation



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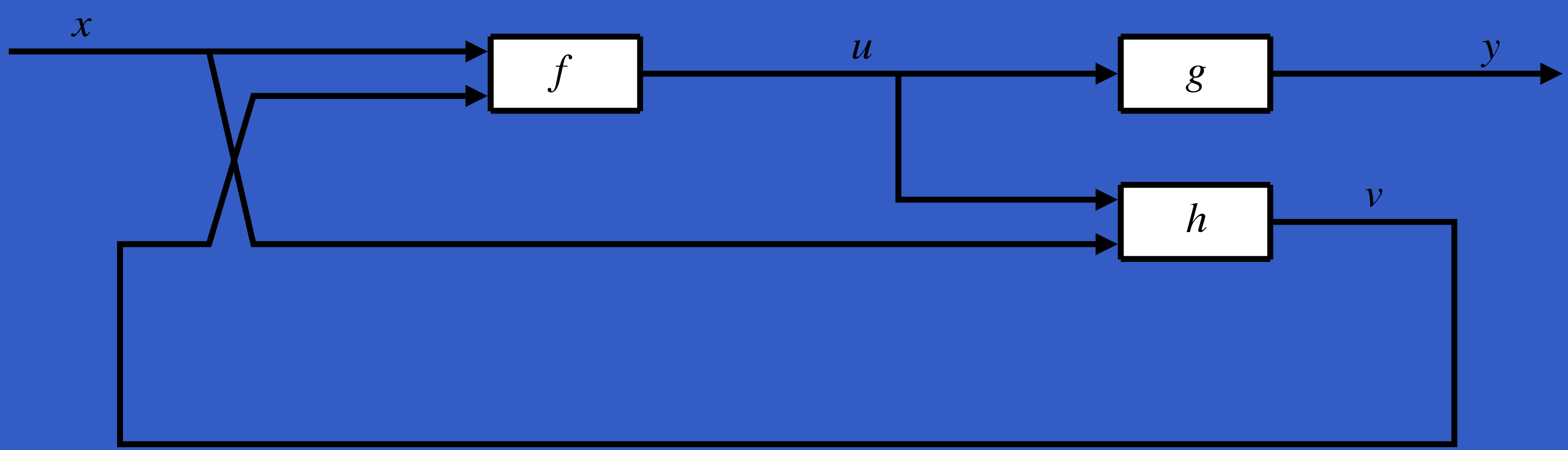

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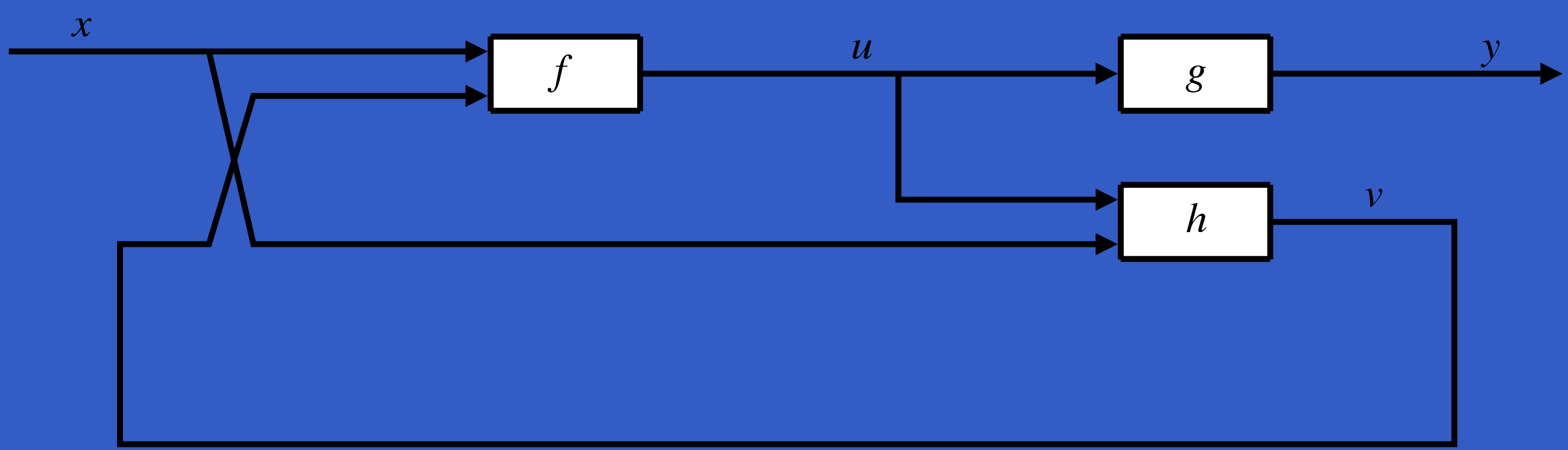

$$
\begin{array}{l}
\textbf{proc}\ x \rightarrow \textbf{do} \\
\quad \textbf{rec} \\
\qquad u \leftarrow f \prec (x, v) \\
\qquad y \leftarrow g \prec u \\
\qquad v \leftarrow h \prec (u, x) \\
\quad returnA \prec y
\end{array}
$$

How does it work?

- Essentially:

$$\textbf{newtype}\ SF\ a\ b =$$
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Note that the system representation in principle is reconstructed at every time step.

Related languages and paradigms

FRP/Yampa related to:

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- Synchronous dataflow languages, like Esterel, Lucid Synchrone.
- Modeling languages, like Simulink, Modelica.

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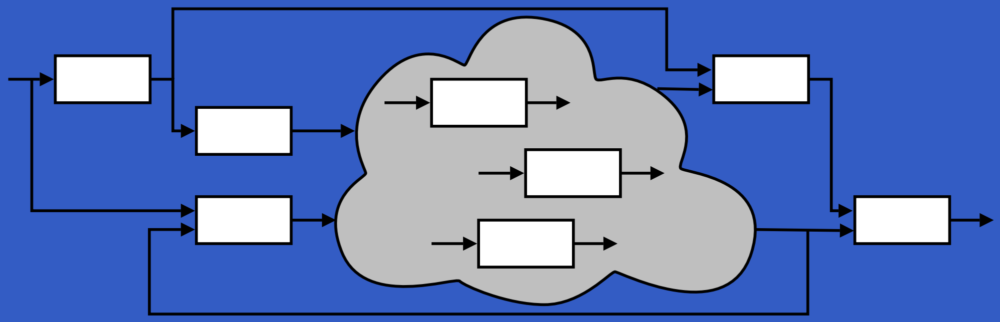
- Supports hybrid (mixed continuous and discrete time) systems: option type $Event$ represents discrete-time signals.
- Supports dynamic system structure through ***switching combinators***:



Example: Space Invaders