Safe Functional Reactive Programming through Dependent Types

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Reactive Programming

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- Examples: robot controllers, video games, aeroplane control systems...
- Contrast with transformational programs, which take all input at the start of execution and produce all output at the end (e.g. a compiler).

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- Functional Reactive Programming (FRP) differs in that it is very expressive, but lacking in these guarantees.
- This work is about using dependent types to get some of these safety guarantees within FRP (without sacrificing expressiveness).

Outline

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Example

$$\text{RobotController} = \text{SF Sensor ControlValue}$$

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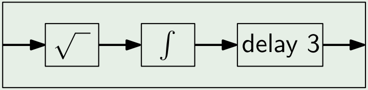
- We compose signal functions to form signal function networks.

Example



Synchronous Data-Flow Networks

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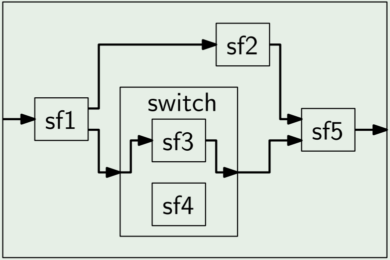

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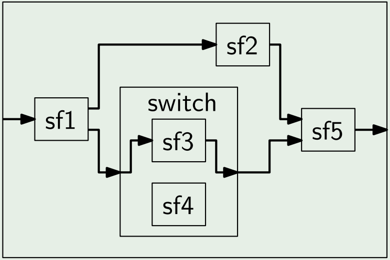

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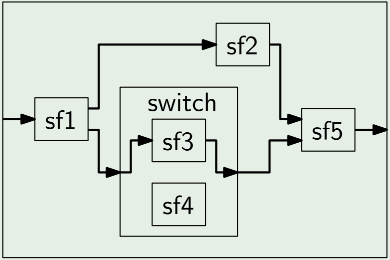

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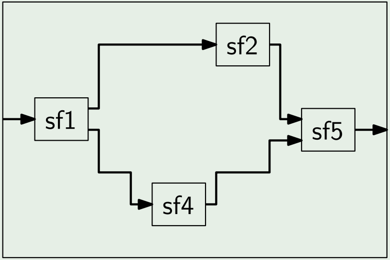

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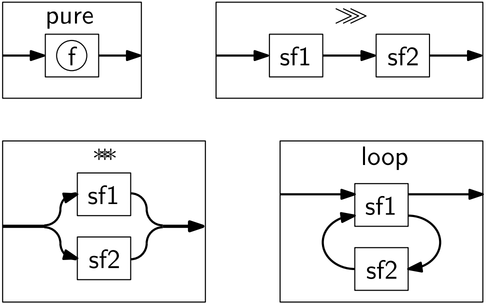
Some Primitive Combinators



$$
\begin{aligned}
\text{pure} &: (a \to b) \to \text{SF } a\ b \\
\_ \ggg \_ &: \text{SF } a\ x \to \text{SF } x\ b \to \text{SF } a\ b \\
\_ *** \_ &: \text{SF } a\ x \to \text{SF } b\ y \to \text{SF } (a, b)\ (x, y) \\
\text{loop} &: \text{SF } (a, x)\ (b, y) \to \text{SF } y\ x \to \text{SF } a\ b
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Example

$$\text{divide} : \mathbb{N} \to (n : \mathbb{N}) \to n > 0 \to \mathbb{N}$$

$$\text{append} : \text{Vector } A\ m \to \text{Vector } A\ n \to \text{Vector } A\ (m+n)$$

$$\text{take} : (m : \mathbb{N}) \to \text{Vector } A\ n \to m \leqslant n \to \text{Vector } A\ m$$

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    - Not yet useable for practical applications.
    - But Agda accepts it, proving the soundness of the type system.
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    - But Agda accepts it, proving the soundness of the type system.
    - (Agda guarantees totality and termination.)
- The rest of the talk will be about one aspect of the type system: ensuring safe feedback loops.

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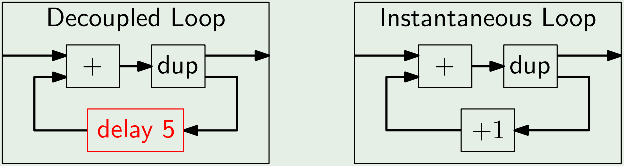

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  - Does not restrict expressiveness.
  - Easy to introduce bugs into programs.
- ...or require explicit use of a specific delay primitive in all recursive (looping) definitions.
  - Can be confirmed as safe by the type checker (conservatively).
  - Limits expressiveness (cannot use dynamic or higher order signal functions for decoupling).

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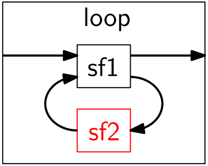

Summary

- FRP and synchronous data-flow languages make a trade-off between expressiveness and safety.
- Dependent types allow us to have FRP with safety guarantees, while retaining dynamic higher-order data-flow.
- An example is tracking decoupledness to prevent instantaneous feedback loops.
- See our paper for further details: `http://www.cs.nott.ac.uk/~nas/icfp09.pdf`