# Reversible Session-Based Concurrency

## An implementation in Haskell

Folkert de Vries

University of Groningen, The Netherlands,

Supervisors:
Jorge Pérez
Gerard Renardel

Bachelor Symposium 2018
June 26, 2018

# TFP Conference

# Problem

Concurrency is hard

Bridging the gap between theory and practice

# Goal

A functional implementation of the model in the paper
"Causally Consistent Reversible Choreographies" (PPDP 2017)
by Mezzina and Pérez

Our contributions:

- practical validation of theoretical ideas
- a natural connection between reversibility and immutable data structures in pure functional languages
- a step toward reversible concurrent debuggers and failure guiding evaluation

# Core Concepts

- **Reversible** moving backwards through a program
- **Session-Based** sessions and their types
- **Concurrency** calculi for concurrent computation

# Defining Concurrent Computation

# The lambda-calculus

Our favorite model for sequential computation: The lambda calculus

$$
\begin{array}{rll}
M, N ::= & x & \text{Variable} \\
| & (\lambda x.M) & \text{Function definition} \\
| & (M\,N) & \text{Applying a function to an argument}
\end{array}
$$

$\beta$-reduction:

$$(\lambda x.M)\,E \rightarrow (M[x/E])$$

# The pi-calculus

In contrast, the pi-calculus defines

| | |
|---|---|
| $P, Q, R ::= \overline{x}\langle y \rangle.P$ | Send the value $y$ over channel $x$, then run $P$ |
| $\mid x(y).P$ | Receive on channel $x$, bind the result to $y$, then run $P$ |
| $\mid P \mid Q$ | Run $P$ and $Q$ simultaneously |
| $\mid (\nu x)P$ | Create a new channel $x$ and run $P$ |
| $\mid\ !P$ | Repeatedly spawn copies of $P$ |
| $\mid\ 0$ | Terminate the process |
| $\mid\ P + Q$ | (Optionally) Nondeterministic choice |

reduction:

$$\overline{x}\langle z \rangle.P \mid x(y).Q \rightarrow P \mid Q[z/y]$$

# Sessions & Session Types

# Session Types

**Data types** prevent us from making silly mistakes with **data**.

```
> Array(16).join("wat" -1) + " Batman!";
< "NaNNaNNaNNaNNaNNaNNaNNaNNaNNaNNaNNaNNaNNaNNaN Batman!"
```

# Session Types

**Session types** prevent common mistakes in **communication**.

- Send without a receive & receive without a send
- type mismatch between sent and expected value
- Sending/Receiving before you're supposed to
- undesired infinite recursion

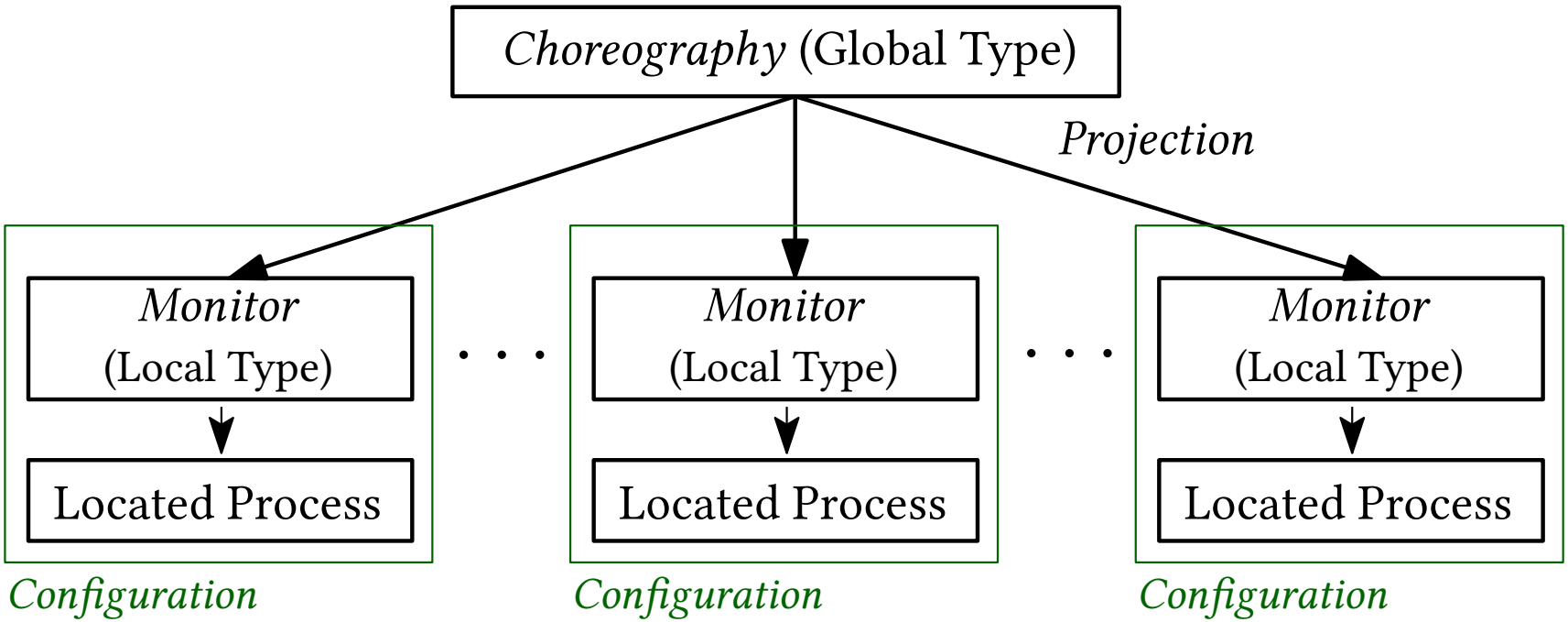
An idea introduced in the late 90s by Honda, Kubo, and Vasconcelos (ESOP 1998), and widely studied ever since.

# Session Types

Global Type

- There is a Transaction between Carol and Bob, a `Bool` is sent.
- There is a Transaction between Alice and Carol, an `Int` is sent.

# Projection


*Choreography* (Global Type)
*Projection*
*Monitor*
(Local Type)
Located Process
*Monitor*
(Local Type)
Located Process
*Monitor*
(Local Type)
Located Process
*Configuration*
*Configuration*
*Configuration*

# Session Types

Global Type

- There is a Transaction between Carol and Bob, a `Bool` is sent.
- There is a Transaction between Alice and Carol, an `Int` is sent.

Local Type (for Carol)

- I will send Bob a `Bool`
- I expect an `Int` from Alice

# Session Types

Global Type

- There is a Transaction between Carol and Bob, a `Bool` is sent.
- There is a Transaction between Alice and Carol, an `Int` is sent.

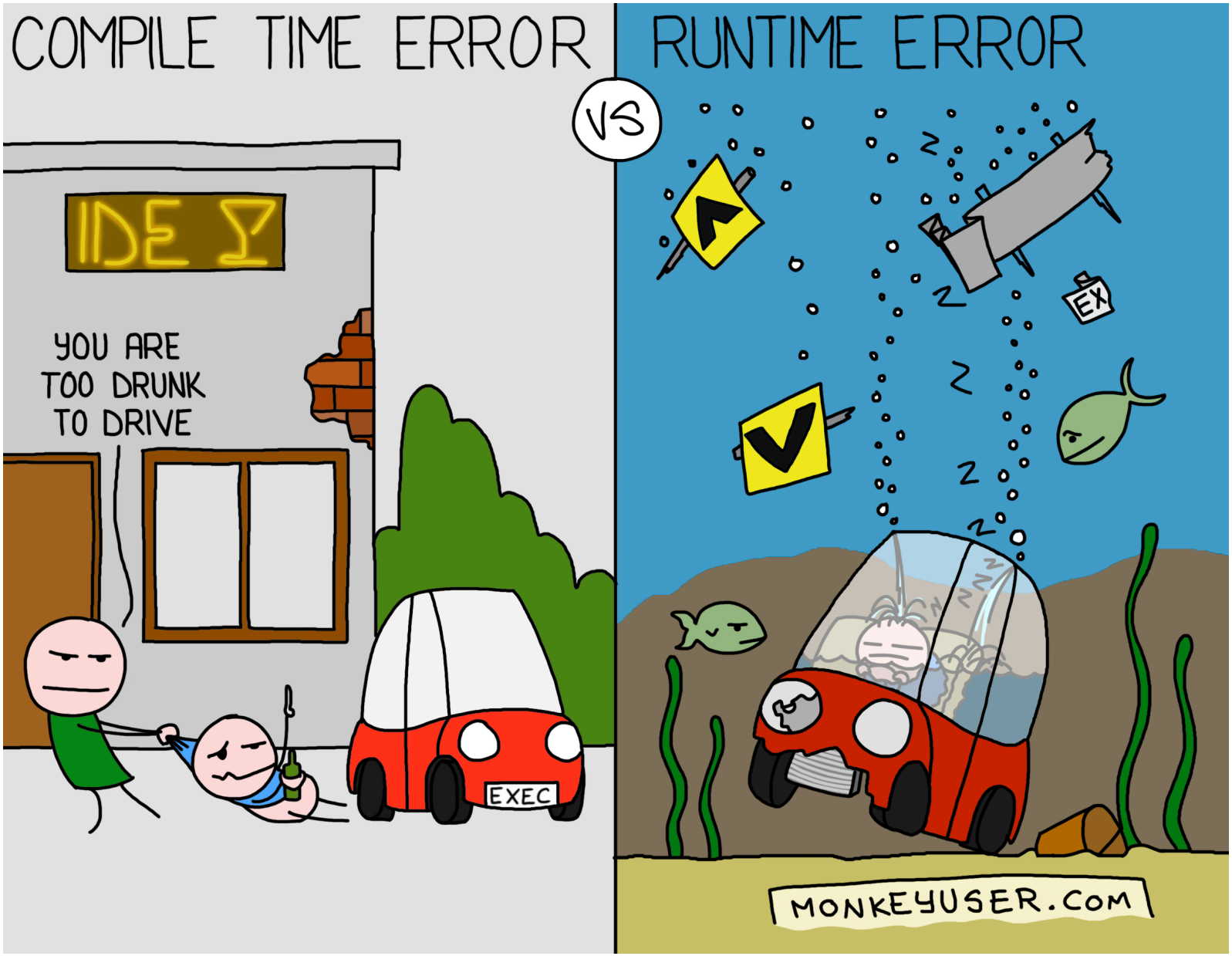
Local Type (for Carol)

- I will send Bob a `Bool`
- I expect an `Int` from Alice

Properties:

- Order: enforced ordering of communication over a channel
- Progress: every sent message is eventually received
- Safety: sent values are typed, there can be no mistmatch

# Session Types: Static vs. Dynamic



# Session Types: Static vs. Dynamic

We will always need dynamic verification of our session types

Because in practice systems are:

- opaque
- written in multiple languages

# Reversibility

# Reversibility

Leave behind a trail of breadcrumbs

So we can always find our way back

# Reversibility

**Causal Consistency**: Reversible steps lead to states that can be reached with forward steps only. No extra new states are introduced.

$$\texttt{backward} \circ \texttt{forward} \approx \texttt{identity}$$

# Implementation

# Implementation

We can define 3 data types

```
-- Our Process Calculus
data Program = ...
-- Our Global Session Type
data GlobalType = ...
-- Our "bread crumbs"
data TypeContext = ...
```

And then implement:

```
type Session a = StateT ExecutionState (Except Error) a
forward  :: Location -> Session ()
backward :: Location -> Session ()
```

# Advantages of a pure functional language

- Algebraic Data Types (Union Types)
  - We can stay close to the theory
  - invalid states are impossible to represent
- Immutability & checked effects
  - Reversibility is easier and testable

# Conclusion

An implementation of reversible, session-based concurrency in Haskell

- Embedding a sophisticated operational semantics in Haskell
- The first functional implementation of a reversible debugger
- https://github.com/folkertdev/reversible-debugger/

Current and future work:

- Graphical interfaces
- Controlled reversibility (checkpoints)

# Questions