Towards Mailbox Typing for Erlang

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Common protocol errors (unexpected request)

```
id_server() →
  receive
    {init, N} → id_server_loop(N)
  end.

id_server_loop(N) →
  receive
    {get, Client} →
      Client ! {id, N},
      id_server_loop(N + 1);
    {init, _} → error
  end.
```

```
client() →

  % Create server process.
  Server = spawn {id_server, []},

  % Initialize server.
  Server ! {init, 5},
  Server ! {init, 5}, ✗
  Server ! {get, self},
  receive
    {id, Id} → print Id
  end.
```

Common protocol errors (omitted reply)

```
id_server() →
  receive
    {init, N} → id_server_loop(N)
  end.

id_server_loop(N) →
  receive
    {get, Client} →
      Client ! {id, N},
      id_server_loop(N + 1);
    {init, _} → error
  end.
```

```
client() →

  % Create server process.
  Server = spawn {id_server, []},

  % Initialize server.
  Server ! {init, 5},

  Server ! {get, self},
  receive
    {id, Id} → print Id
  end.
```

Common protocol errors (self-deadlock)

```
id_server() →
  receive
    {init, N} → id_server_loop(N)
  end.

id_server_loop(N) →
  receive
    {get, Client} →
      Client ! {id, N},
      id_server_loop(N + 1);
    {init, _} → error
  end.
```

```
client() →

  % Create server process.
  Server = spawn {id_server, []},

  % Initialize server.
  Server ! {init, 5},

  Server ! {get, self},
  receive
    {id, Id} → print Id
  end.
```

```
  receive
    {id, Id} → print Id
  end,
  Server ! {get, self}.
```

✗

Common protocol errors (unsupported request)

```
id_server() →
  receive
    {init, N} → id_server_loop(N)
  end.

id_server_loop(N) →
  receive
    {get, Client} →
      Client ! {id, N},
      id_server_loop(N + 1);
    {init, _} → error
  end.
```

```
client() →

  % Create server process.
  Server = spawn {id_server, []},

  % Initialize server.
  Server ! {init, 5},

  Server ! {get, self},  ✗
  receive
    {id, Id} → print Id
  end.
```

Our wish-list to catch protocol errors

Static

Early error detection

Avoids defensive code

Annotated code

Self-contained information

Documents code

Compatible with other tools

Lightweight

Fast execution

Usable during development

Scalable

Applicable to large code bases

Current error-detection tool landscape

Lightweight ↔ Full-blown

Dialyzer (static typing)	Mailbox typing (behavioural typing)	Concuerror (systematic testing)
✓ Code annotations	✓ Code annotations	✗ Relies on test suites
✓ Scalable	✓ Scalable	✗ Less scalable
✗ Not for concurrency	✓ Targets concurrency	✓ Targets concurrency
✓ Detects errors early	✓ Detects errors early	✗ Detects errors late
✗ Less precise	✗ Less precise	✓ More precise

Mailbox types for unordered interactions

Behavioural typing capturing **process interaction** (De'Liguoro & Padovani '18)

Mailboxes: **first-class** entities with a **type**

Type = Capability + pattern

!*P* Messages that **must** be sent

?*P* Messages that mailbox **can** contain

Many writer, one reader

! reference is **sharable**

? reference is **not sharable**

Pattern = commutative regular expression

Invariant on the mailbox contents

Captures **out-of-order** message deposits

Captures **selective** message reception

Receive one `init` and zero or more `get` messages ⇒ `?"init.get*"`

Send one `id` message ⇒ `!"id"`

Receive zero or more `get` and one `init` message ⇒ `?"init.get*"`

Aim: sends and receives must **balance out**

Challenge 1: Instantiating mailbox types to a PL

Process calculus

Shows a snapshot in a **system state**

Names declared **statically** upfront

Names remain **constant**

Programming language

Specifies what is to be **executed**

Names introduced via **reduction**

Names can be **aliased**

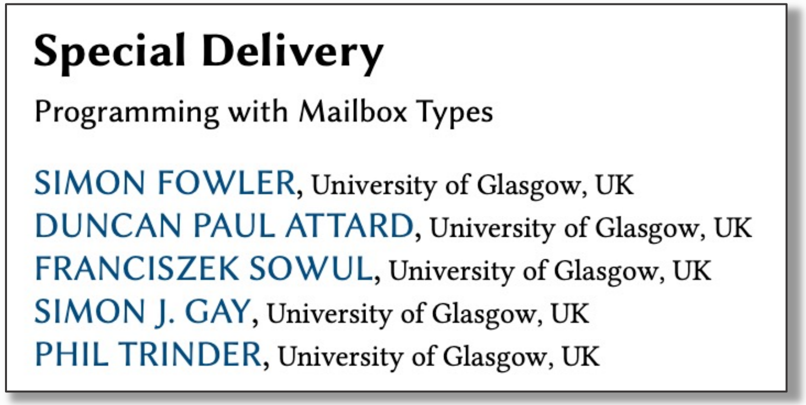
Difficulties

Sequenced expressions, nested evaluation contexts

Using names **many times** to **send**, but **once** to **receive**

Solution 1: Programming with mailbox types

ICFP'23



Special Delivery

Programming with Mailbox Types

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Mailbox types for a core PL calculus: **Pat**

Declarative type system

Corresponding **algorithmic** type system

OCaml type checker for **Pat**

Sufficiently **expressive**

Fast execution

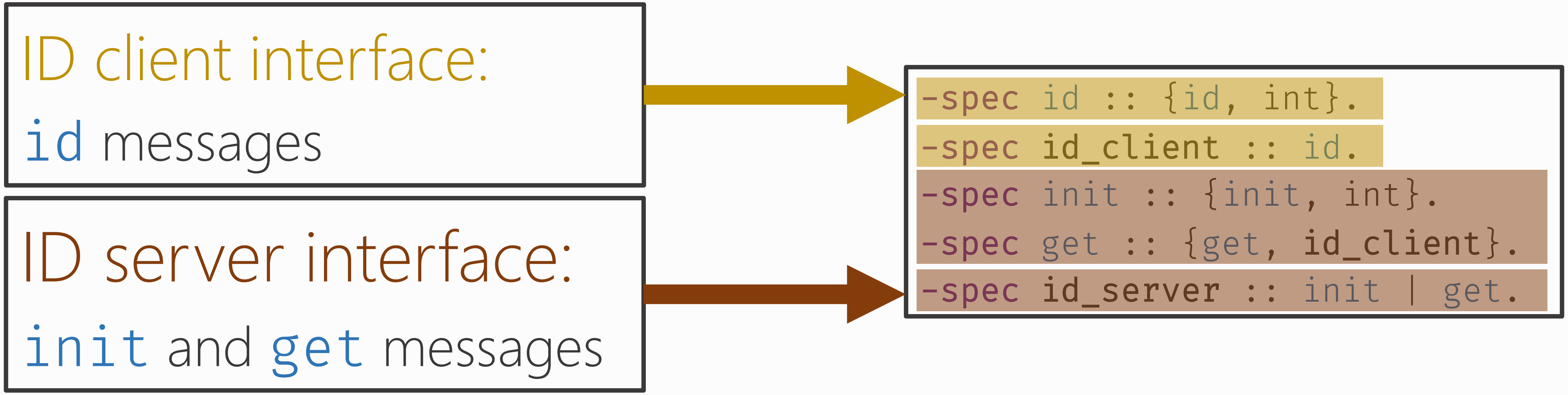
Challenge 2: Applying mailbox typing to Erlang

First-class mailboxes	Erlang mailboxes
Explicitly created and freed	**Tied** to the lifecycle of processes
Process can own **many mailboxes**	Processes own **one mailbox**
Mailbox **needed** for receiving	Mailbox **implicit** when receiving
Mailbox has a **precise type**	Mailbox is **untyped**

Interface = isolates mailbox type + state

A **set of messages** that a mailbox can **receive**

Annotates process functions: `-new` or `-use`



ID client interface:

`id` messages

ID server interface:

`init` and `get` messages

```
-spec id :: {id, int}.
-spec id_client :: id.
-spec init :: {init, int}.
-spec get :: {get, id_client}.
-spec id_server :: init | get.
```

```
-new id_server.
-spec id_server() ⟶ unit.
id_server() ⟶
  assert("init.get*"),
  receive
    {init, N} ⟶ id_server_loop(N)
  end.

-use id_server.
-spec id_server_loop(int) ⟶ unit.
id_server_loop(N) ⟶
  assert("get*"),
  receive
    {get, Client} ⟶
      Client ! {id, N},
      id_server_loop(N + 1)
  end.
```

Logical `id_server` mailbox

Thread `id_server` mailbox through

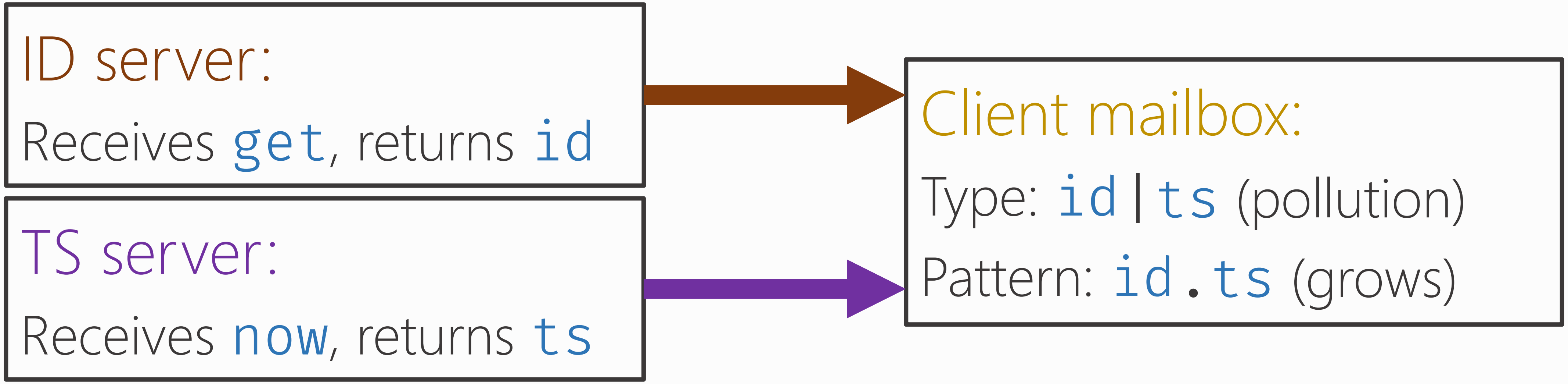
```
-new id_client.
-spec client() ⟶ unit.
client() ⟶
  Server = spawn {id_server, []},

  Server ! {init, 5},
  Server ! {get, self},
  assert("id"),
  receive
    {id, Id} ⟶ print Id
  end.
```

Logical `id_client` mailbox

Remove defensive error-handling code `{init, _} ⟶ error`

Limitations with typing one monolithic mailbox



ID server:

Receives `get`, returns `id`

TS server:

Receives `now`, returns `ts`

Client mailbox:

Type: `id`|`ts` (pollution)

Pattern: `id.ts` (grows)

Does **not delineate** conceptually unrelated messages

Tracking mailbox state can quickly become **intractable**

```
-spec id_rpc(id_server) → int.
id_rpc(To) →
  To ! {get, self},
  assert(“id”),
  assert(“id.ts”),
  receive
    {id, Id} → Id
  end.

-spec ts_asy(ts_server) → unit.
ts_asy(To) → To ! {now, self}.

-spec ts_get() → int.
ts_get() →
  assert(“ts”),
  receive
    {ts, Ts} → Ts
  end.
```

Pattern grows

Reasoning not local

```
-spec id_server :: init | get.
-spec ts_server :: now.
-spec client :: id | ts.
```

Type pollution

Patterns depends on order of function invocations

```
-new client.
-spec client() → unit.
client() →
  IdServer = spawn {id_server, …
  TsServer = spawn {ts_server, …

  ts_asy(TsServer), %Async.
  print(IdServer),
  id_rpc(IdServer), %Sync.
  print(TsServer),
  print ts_get().
```

Mailbox types: induce **structured communication**

Organising the Erlang mailbox logically

Gives a **projected view** of an otherwise monolithic mailbox

Isolates message types

Minimises type pollution

Types are more precise

Isolates mailbox state

Patterns are localised

Reasoning becomes compositional

```
-new id_client.
-spec id_rpc(id_server) → int.
id_rpc(To) →
  To ! {get, self},
  assert("id"),
  receive
    {id, Id} → Id
  end.

-spec ts_asy(ts_server) → unit.
ts_asy(To) → To ! {now, self}.

-spec ts_get() → int.
ts_get() →
  assert("ts"),
  receive
    {ts, Ts} → Ts
  end.
```

Logical id_client mailbox

Local reasoning

```
-spec id_server :: init | get.
-spec ts_server :: now.
-spec id_client :: id.
-spec ts_client :: ts.
```

Two interfaces

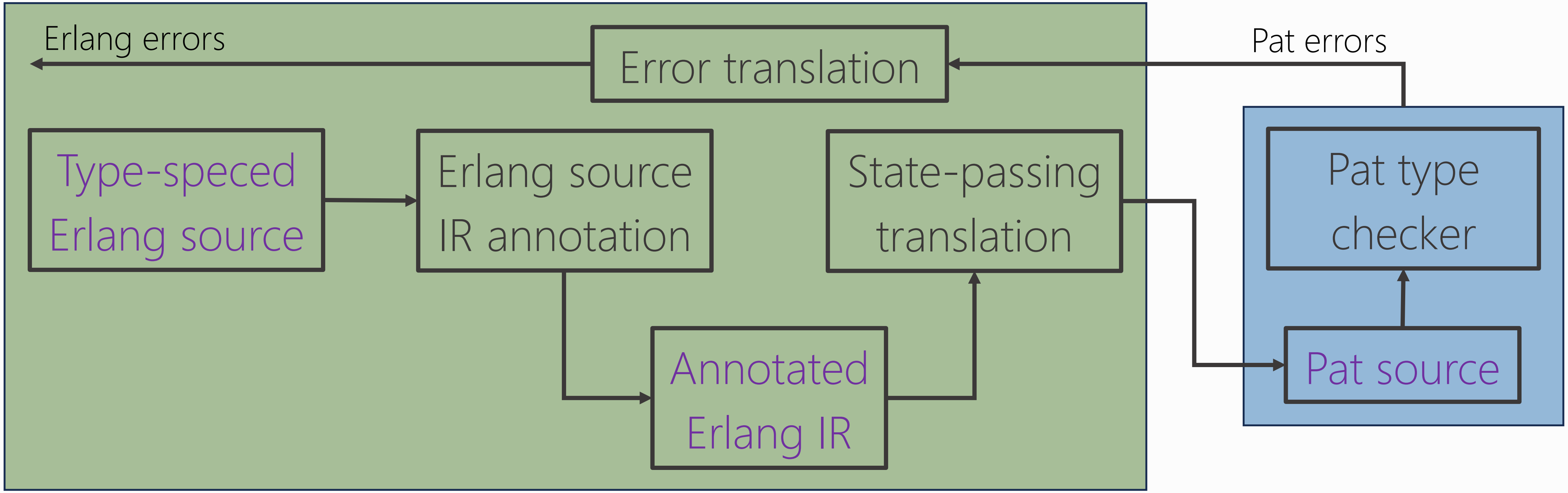
```
-new ts_client.
-spec client() → unit.
client() →
  IdServer = spawn {id_server, …
  TsServer = spawn {ts_server, …

  ts_asy(TsServer), % Async.
  print id_rpc(IdServer), % Sync.
  print ts_get().
```

Logical ts_client mailbox

Isolated mailboxes

Towards mailbox typing for Erlang



Status summary

In progress

Design with Erlang typespecs

Annotated Erlang IR

Refinement of Pat

Formalised **IR** ⟶ **Pat** translation

Next

Implement **IR** ⟶ **Pat** translation

Implement error translation

Formalise **Erlang** ⟶ **IR** translation

Implement **Erlang** ⟶ **IR** translation

Why mailbox typing?

Actors

Type the **mailbox contents**, not the process interactions

Fits **asynchrony**: out-of-order mailbox reading and writing

Fits **asymmetric** interaction: many writers, one reader paradigm

Erlang

Overlay a structure on top of a monolithic mailbox

Document communication between processes