A Rehabilitation of Message-Passing Concurrency

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PWLConf 2018, St. Louis

A Paper I Love

- *Types for Dyadic Interaction*, Kohei Honda, CONCUR 1993
- With some newer developments
  - *Session Types as Intuitionistic Linear Propositions*, Luís Caires & Pf., CONCUR 2010
  - *Manifest Sharing with Session Types*, Stephanie Balzer & Pf., ICFP 2017

Types for Dyadic Interaction*

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Abstract

We formulate a typed formalism for concurrency where types denote freely composable structure of dyadic interaction in the symmetric scheme. The resulting calculus is a typed reconstruction of name passing process calculi. Systems with both the explicit and implicit typing disciplines, where types form a simple hierarchy of types, are presented, which are proved to be in accordance with each other. A typed variant of bisimilarity is formulated and it is shown that typed β-equality has a clean embedding in the bisimilarity. Name reference structure induced by the simple hierarchy of types is studied, which fully characterises the typable terms in the set of untyped terms. It turns out that the name reference structure results in the deadlock-free property for a subset of terms with a certain regular structure, showing behavioural significance of the simple type discipline.

The Activity of Programming

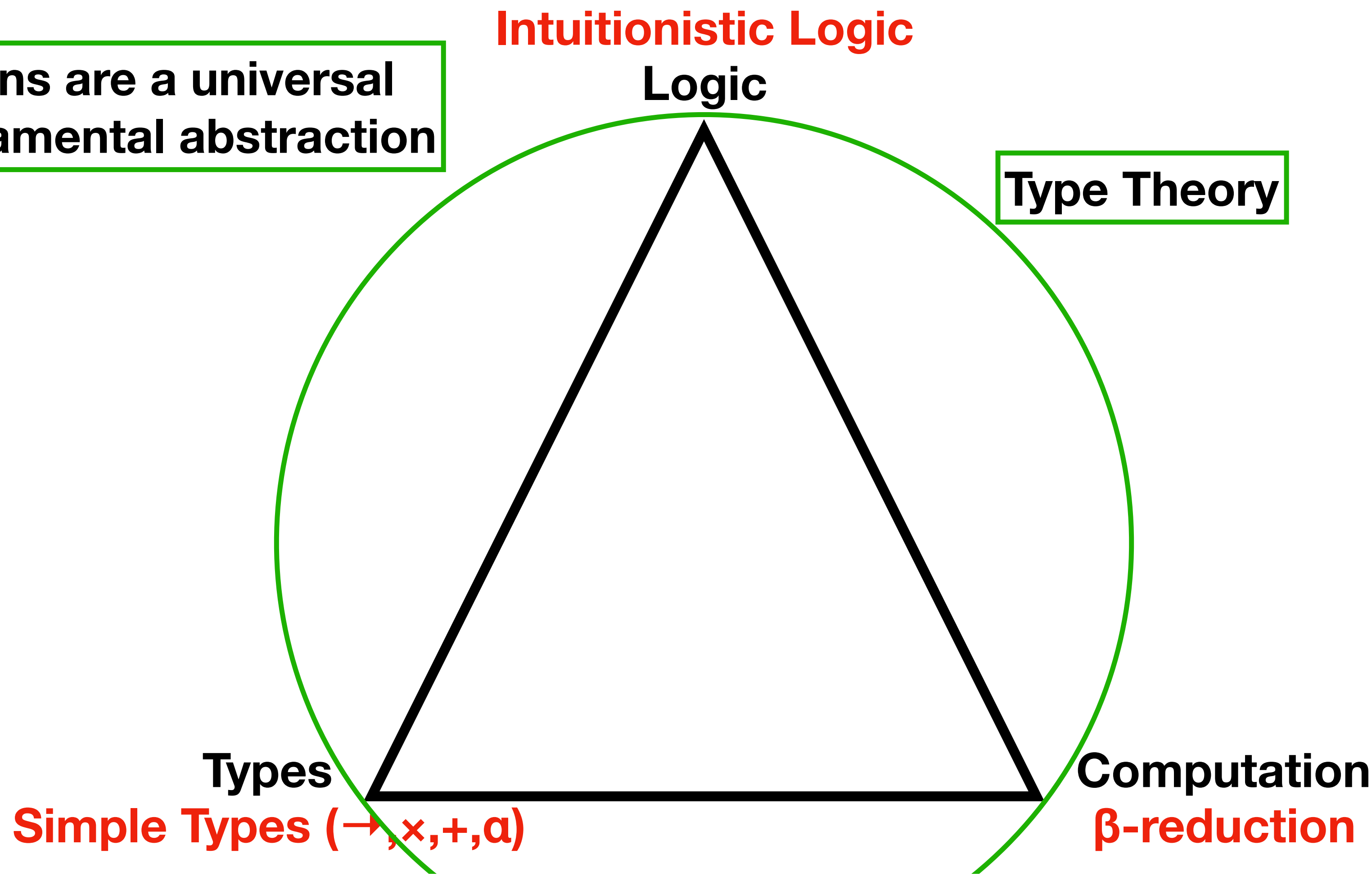
- Every programmer, all the time, reasons
  - Operationally (how)
  - Logically (what)
- The effectiveness of a programming language depends critically on
  - How programs execute
  - What they achieve
  - Which reasoning principles connect the operational and logical meaning of a program

```
sort(A);
x = A[0];
```

```
hd(sort(A))
```

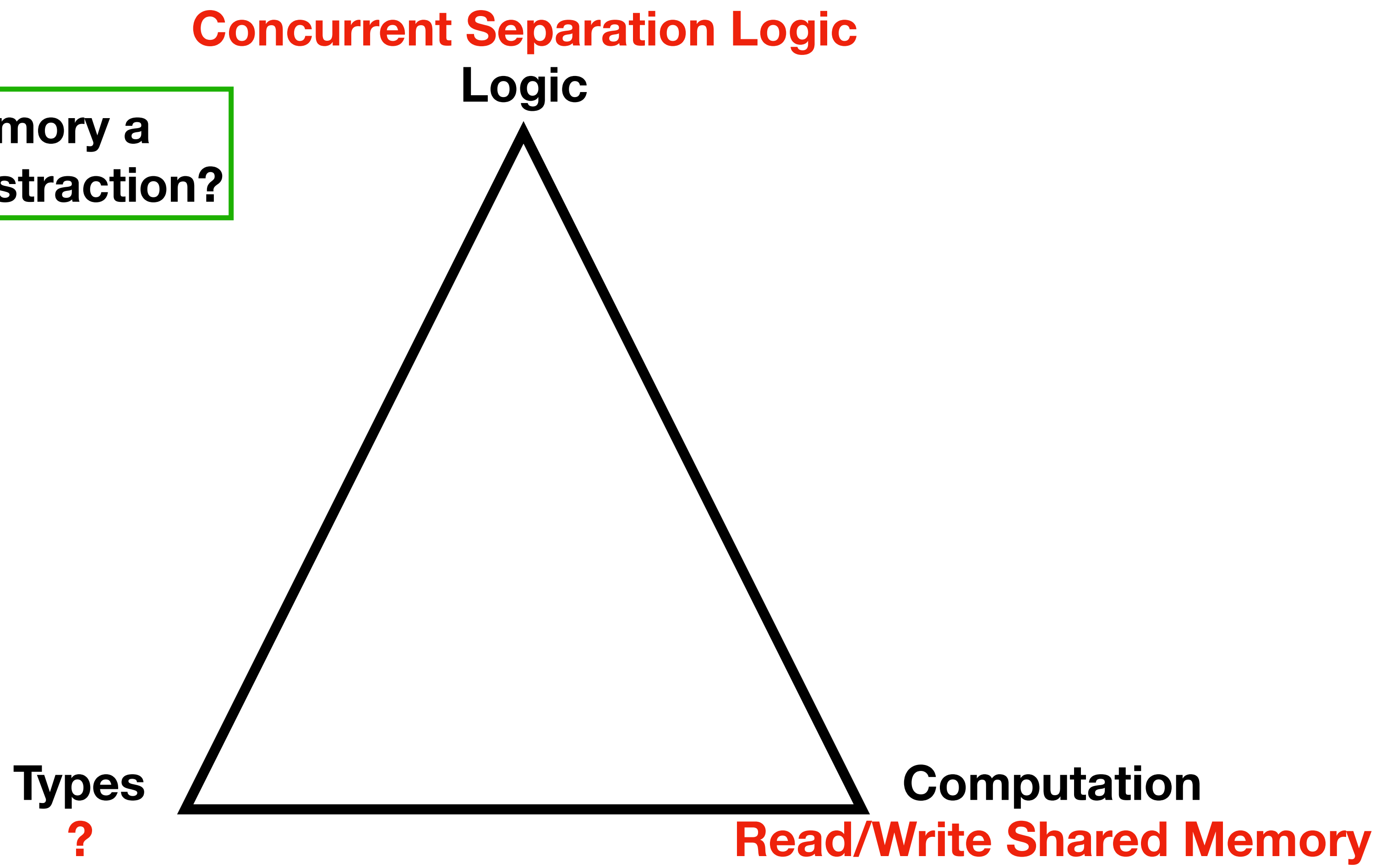
Why is Functional Programming So Effective?

Functions are a universal and fundamental abstraction

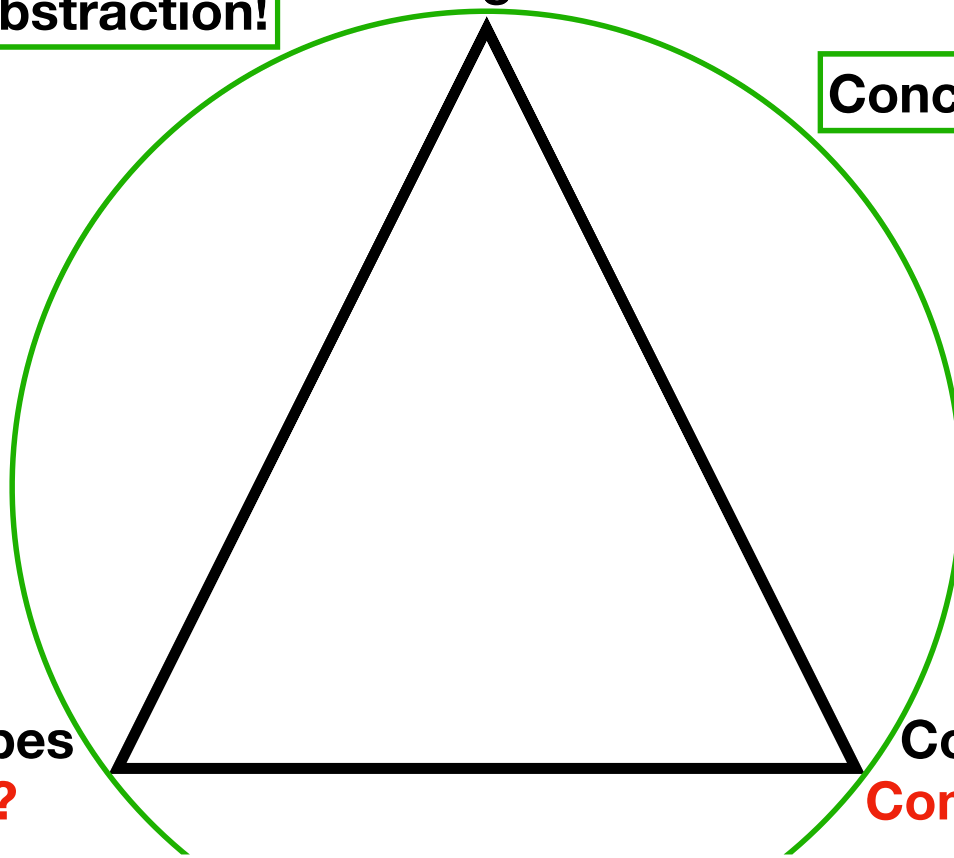


What about Concurrency?

Is Shared Memory a Fundamental Abstraction?



What about Concurrency?

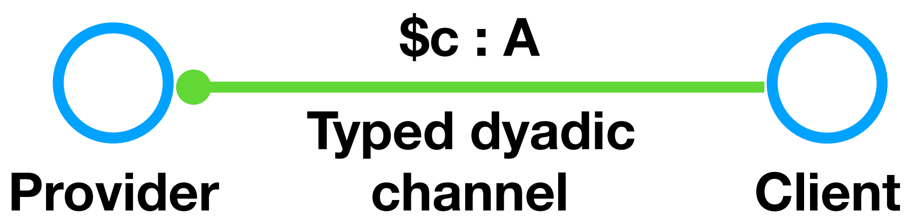


There is Hope

Do not communicate by sharing memory; instead, share memory by communicating.
—Effective Go

- Previous talk!
- From the language point of view: Go
  - Goroutines (threads/processes) as a fundamental abstraction
  - Channels (`chan T`) as a fundamental abstraction
- Connection to logic is missing
- Types are not expressive enough

Example: A Store (Stack or Queue)



- Protocol
  - Client: ins; x; *recurse…*

Client's choice (external)

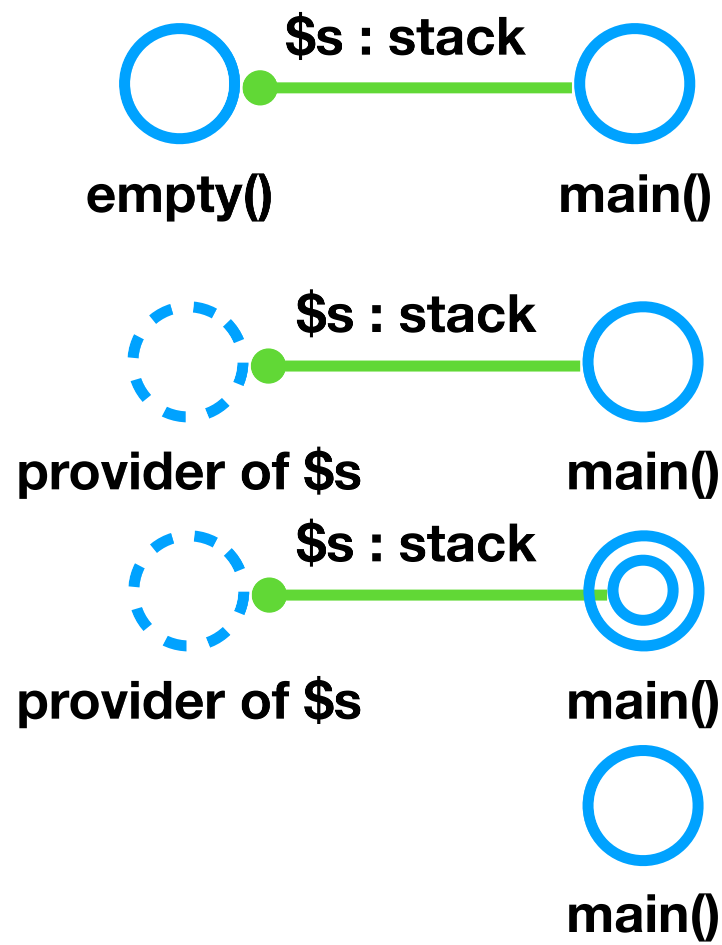
  - Client: del
    - Provider: none; close.

Provider's choice (internal)

    - Provider: some; x; *recurse…*
- Protocol should be expressed by a type!

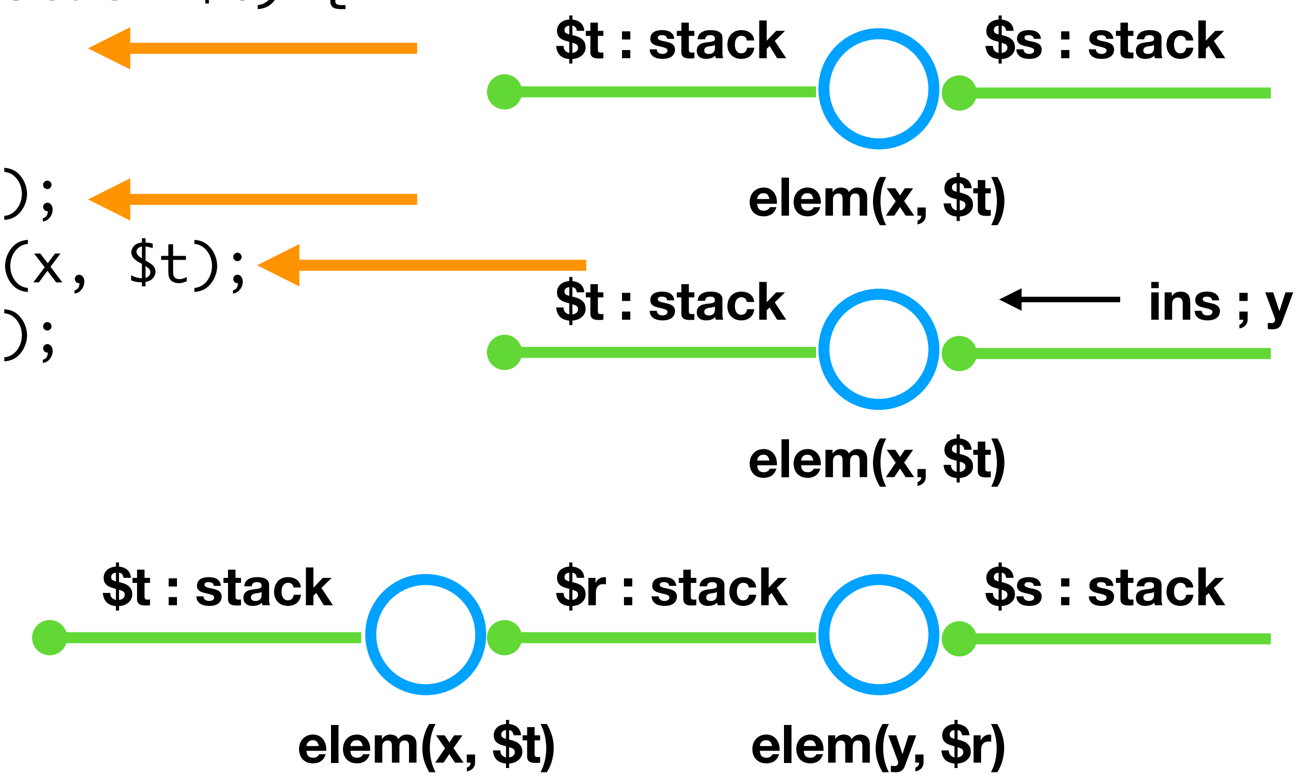
A Simple Client, in CC0

```
int main() {
  int n = 10;
  stack $s = empty();
  for (int i = 0; i < n; i++) {
    $s.ins; send($s, i);
  }
  print_stack($s);
  return 0;
}
```



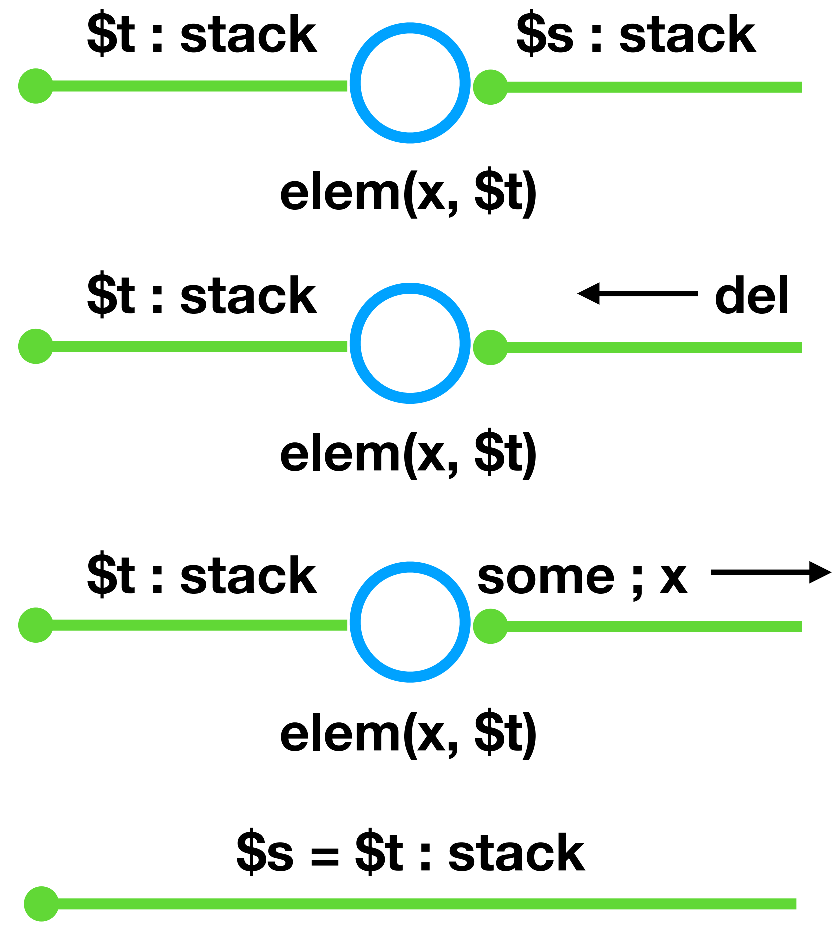
A Simple Provider, in CC0

```
stack $s elem(int x, stack $t) {
  switch ($s) {
    case ins: {
      int y = recv($s);
      stack $r = elem(x, $t);
      $s = elem(y, $r);
    }
    case del: {
      $s.some;
      send($s, x);
      $s = $t;
    }
  }
}
```

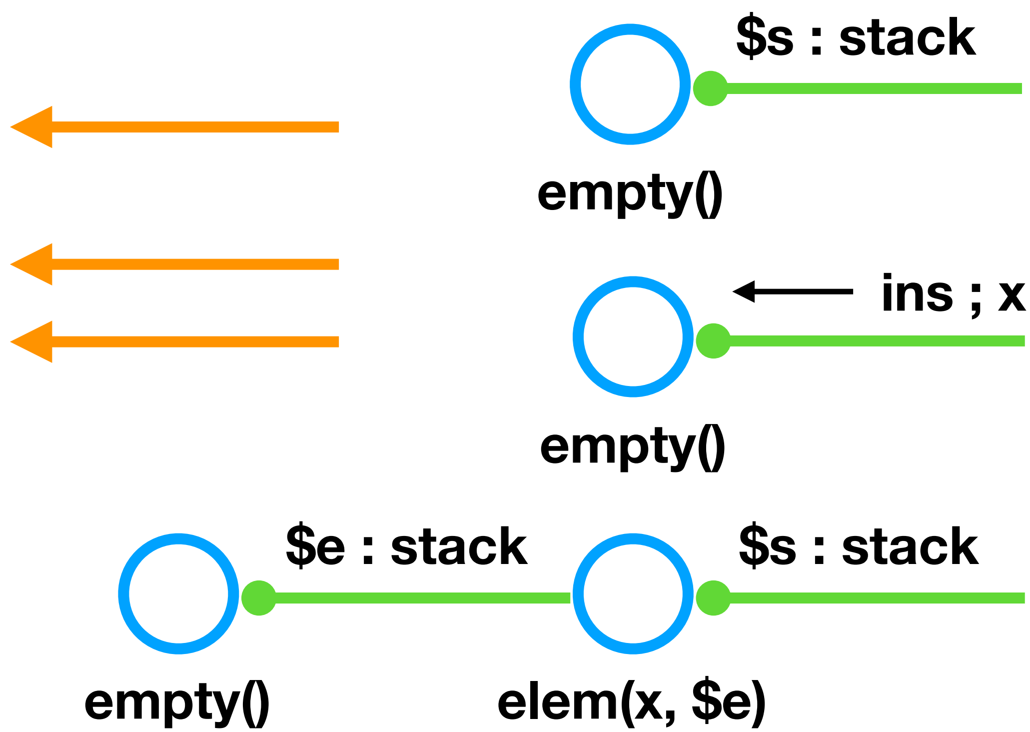


```
stack $s elem(int x, stack $t) {
  switch ($s) {
    case ins: {
      int y = recv($s);
      stack $r = elem(x, $t);
      $s = elem(y, $r);
    }
    case del: {
      $s.some;
      send($s, x);
      $s = $t;
    }
  }
}
```

Forwarding (or *channel identification*) is not part of the π-calculus



```
stack $s empty() {
  switch ($s) {
    case ins: {
      int x = recv($s);
      stack $e = empty();
      $s = elem(x, $e);
    }
    case del: {
      $s.none;
      close($s);
    }
  }
}
```



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      $s.none;
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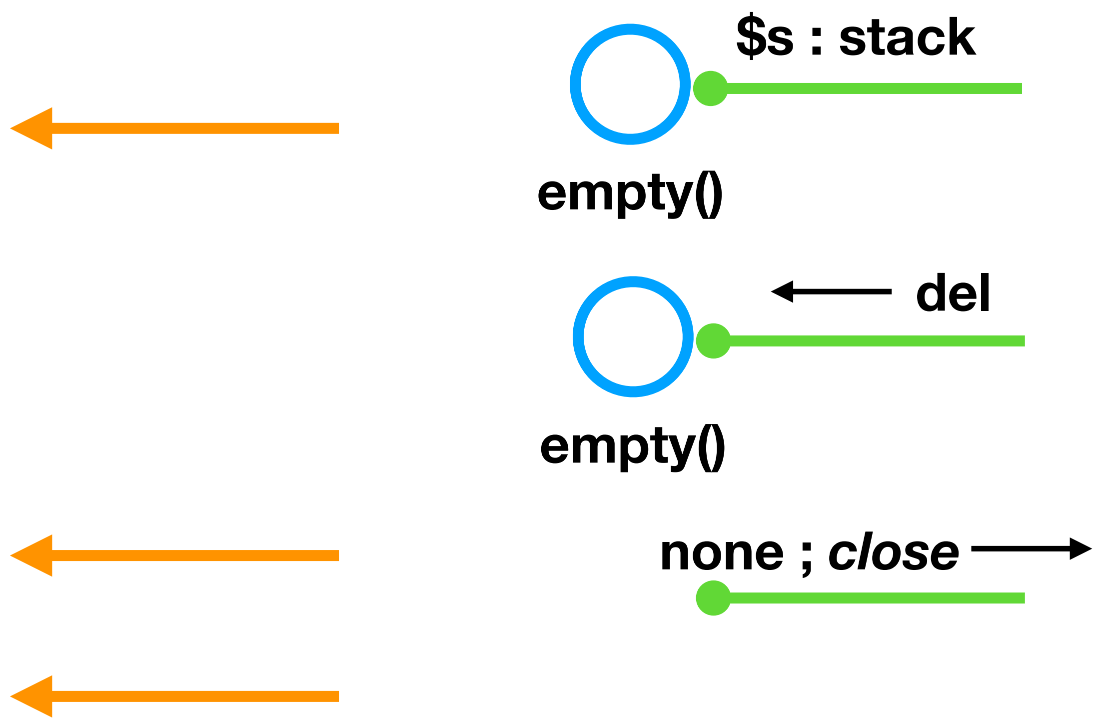
    }
  }
}
```



Summary So Far

- Processes provide one channel and are clients to other channels
- Spawning a process “returns” a fresh channel $c, with two endpoints
  - New process provides $c
  - Spawning process is client of $c
- Processes can terminate by forwarding
- Communication is bidirectional
  - Processes send and receive labels or integers

Typing Channels

- Channel types should encode protocol of communication
  - Provider and client must execute complementary actions
- External choice: Provider branches on label / Client sends label
- Internal choice: Provider sends label / Client branches on label
- Termination: Provider terminates / Client waits for termination
- Basic data: sending or receiving atomic values

Session Types, Abstractly

		Type	Provider action	Continuation
A	$::=$	$\&\{\ell : A_\ell\}_{\ell \in L}$	receive some $k \in L$	A_k
	$\mid$	$\oplus\{\ell : A_\ell\}_{\ell \in L}$	send some $k \in L$	A_k
	$\mid$	$A \multimap B$	receive channel $c : A$	B
	$\mid$	$A \otimes B$	send channel $c : A$	B
	$\mid$	$\mathbf{1}$	terminate	*none*
	$\mid$	$\forall x{:}\tau.\, A$	receive $v : \tau$	$[v/x]A$
	$\mid$	$\exists x{:}\tau.\, A$	send $v : \tau$	$[v/x]A$

$$\boxed{\begin{aligned} stack_A = \&\{\ & \mathsf{ins} : A \multimap stack_A, \\ & \mathsf{del} : \oplus\{\ \mathsf{none} : \mathbf{1}, \\ & \qquad\qquad \mathsf{some} : A \otimes stack_A\ \}\ \} \end{aligned}}$$

Types as Propositions

- These types are exactly the propositions of linear logic, except ‘!’
- An instance of the Curry-Howard correspondence
    - Typing rules correspond to sequent calculus inference rules
    - Programs correspond to process expressions
    - Communication corresponds to cut reduction

Session Typing Judgments

channels used by P

$$\underbrace{x_1 : A_1, \ldots, x_n : A_n}_{\Gamma} \vdash P :: (x : A)$$

channel provided by P

Configuration $\Omega ::= (P_1 \mid \cdots \mid P_n)$

Configuration Typing $\Gamma \models \Omega :: \Gamma'$

channels used by Ω **channels provided by Ω**

Theoretical Properties

- Without recursive types and processes
  - Session fidelity (Preservation) $\text{If } \Gamma \models \Omega :: \Gamma' \text{ and } \Omega \mapsto \Omega' \text{ then } \Gamma \models \Omega :: \Omega'$
  - Deadlock freedom $\text{If } \Gamma \models \Omega :: \Gamma' \text{ then } \Omega \textit{ poised} \text{ or } \Omega \mapsto \Omega' \text{ for some } \Omega'$
  - Termination $\text{If } \Gamma \vdash \Omega :: \Gamma' \text{ then } \Omega \mapsto^* \Omega' \text{ for } \Omega' \textit{ poised}$
- With recursion
  - Session fidelity (Preservation)
  - Deadlock freedom

Ω is *poised* if all processes in Ω attempt to communicate along a channel in the external interface

Mode of Communication

- Both synchronous and asynchronous communication can be supported
- Asynchronous: messages still must appear in order (for session fidelity)
  - Synchronization via polarization of the types
- Synchronous: messages can be coded via one-action processes
- Asynchronous seems to be the right default
  - Closer to reasonable implementation
  - Generalizes to channels with multiple endpoints

Session Types, in CC0

```
choice stack_req {
  <?int ; ?choice stack_req> ins;
  <!choice stack_response>   del;
};

choice stack_response {
  < >                        none;
  <!int ; ?choice stack_req> some;
};

typedef <?choice stack_req> stack;
```

? = receive
! = send
; = sequence of interaction
<…> session type

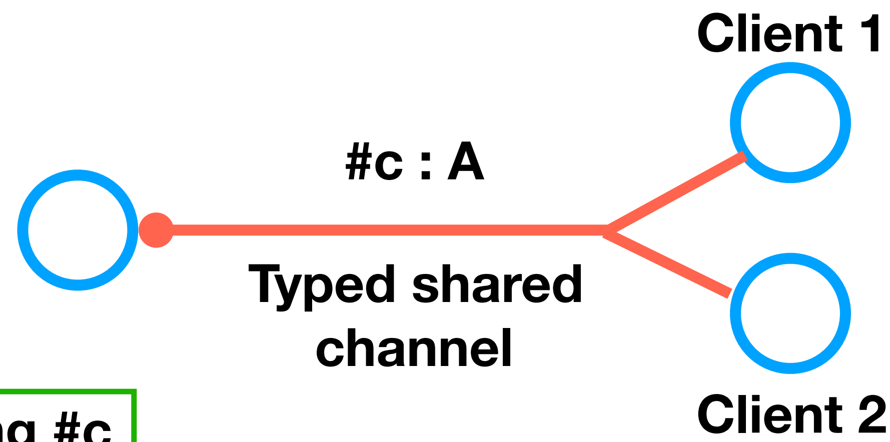
Tracing the Type-Checker

```
stack $s elem(int x, stack $t) {
  switch ($s) {
    case ins: {                % $s : <?int ; stack> -| $t : stack
      int y = recv($s);        % $s : stack          -| $t : stack
      stack $r = elem(x, $t);  % $s : stack          -| $r : stack
      $s = elem(y, $r);
    }
    case del: {                % $s : <!choice stack_response> -| …
      $s.some;                 % $s : <!int ; stack> -| $t : stack
      send($s, x);             % $s : stack          -| $t : stack
      $s = $t;
    }
  }
}
```

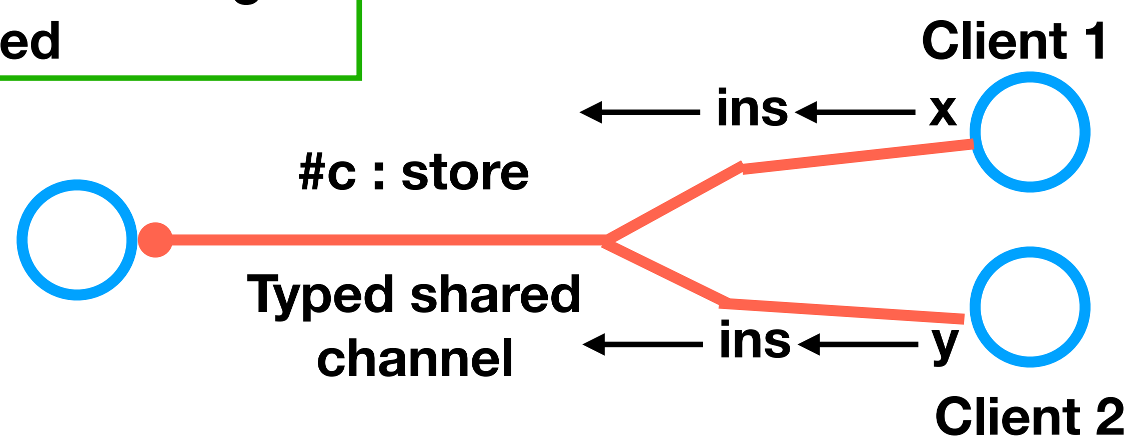
Tracing the Type-Checker

```
stack $s empty() {
  switch ($s) {
    case ins: {               % $s : <?int ; stack> -| .
      int x = recv($s);       % $s : stack          -| .
      stack $e = empty();     % $s : stack          -| $e : stack
      $s = elem(x, $e);
    }
    case del: {               % $s : <!stack_response> -| .
      $s.none;                % $s : < >               -| .
      close($s);
    }
  }
}
```

The Problem with Sharing



If both clients can freely interact along #c session fidelity will be violated



Linear and Shared Channels

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	$\mid$	$\exists x{:}\tau.\, A$	send $v : \tau$	$[v/x]A$
	$\mid$	$\downarrow S$	detach from client	S
S	$::=$	$\uparrow A$	accept client	A

$$!A \triangleq \downarrow\uparrow A$$

A Shared Queue

$$\begin{aligned} queue_A = {\uparrow}\&\{\ & \mathsf{ins} : A \multimap {\downarrow} queue_A, \\ & \mathsf{del} : \oplus\{\ \mathsf{none} : {\downarrow} queue_A, \\ & \qquad\quad\ \ \mathsf{some} : A \otimes {\downarrow} queue_A\ \}\ \} \end{aligned}$$

The section ↑…↓ describes a *critical region*

Types must be *equisynchronizing* (released at the same type they are acquired to guarantee session fidelity)

Certain deadlocks can now arise

Sharing and critical regions are manifest in the type!

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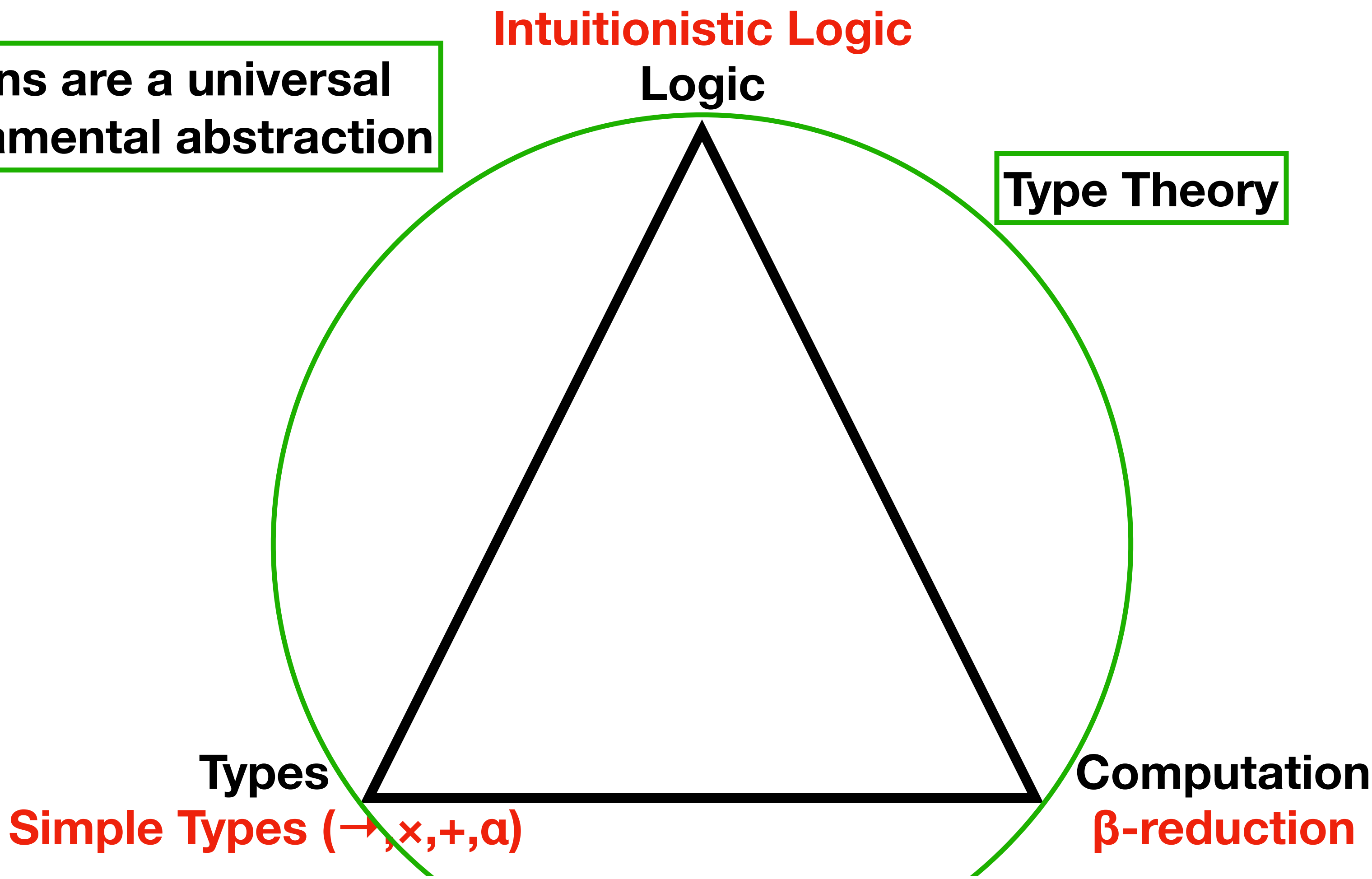

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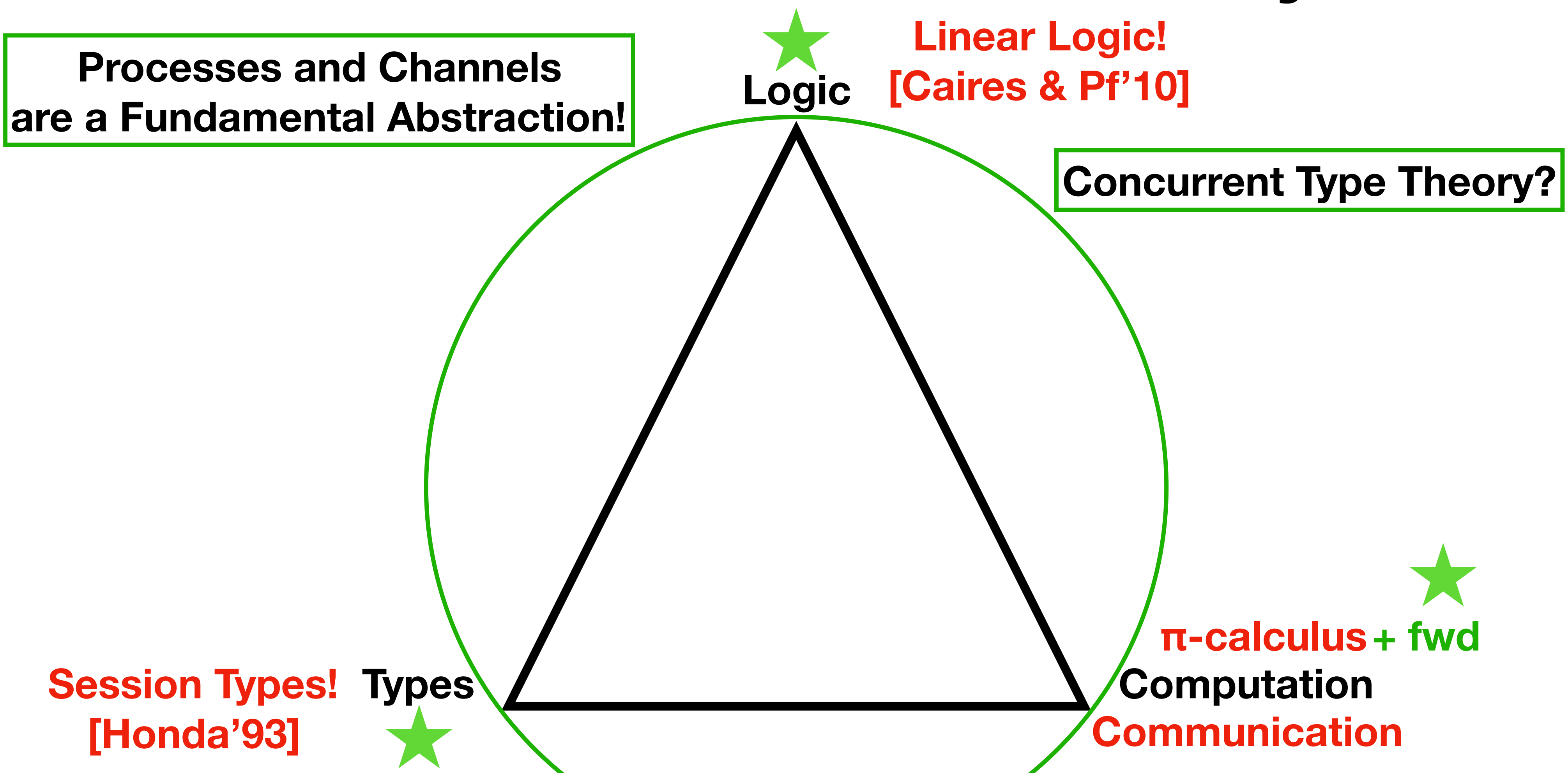

Session Types at Present

- Scribble — www.scribble.org — multiparty session types
- ABCD project — groups.inf.ed.ac.uk/abcd/ — Simon Gay, Nobuko Yoshida, Philip Wadler
- At CMU — SILL (functional), CC0 (imperative), RSILL (time and work)
- Thanks to my collaborators: Coşku Acay, Stephanie Balzer, Luís Caires, William Chargin, Ankush Das, Henry DeYoung, Anna Gommerstadt, Dennis Griffith, Jan Hoffmann, Limin Jia, Jorge Pérez, Rokhini Prabhu, Klaas Pruiksma, Miguel Silva, Mário Florido, Bernardo Toninho, Max Willsey

A Paper I Love

- *Types for Dyadic Interaction*, Kohei Honda, CONCUR 1993

Kohei Honda, 1959—2012

Types for Dyadic Interaction*

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We formulate a typed formalism for concurrency where types denote freely composable structure of dyadic interaction in the symmetric scheme. The resulting calculus is a typed reconstruction of name passing process calculi. Systems with both the explicit and implicit typing disciplines, where types form a simple hierarchy of types, are presented, which are proved to be in accordance with each other. A typed variant of bisimilarity is formulated and it is shown that typed β-equality has a clean embedding in the bisimilarity. Name reference structure induced by the simple hierarchy of types is studied, which fully characterises the typable terms in the set of untyped terms. It turns out that the name reference structure results in the deadlock-free property for a subset of terms with a certain regular structure, showing behavioural significance of the simple type discipline.