Session TYPES

AS A

Descriptive π Tool

for Distributed PROTOCOL

Nobuko Yoshida & Raymond Hu

25th Oct 2017

The Kohei Honda Prize for Distributed Systems Queen Mary, University of London

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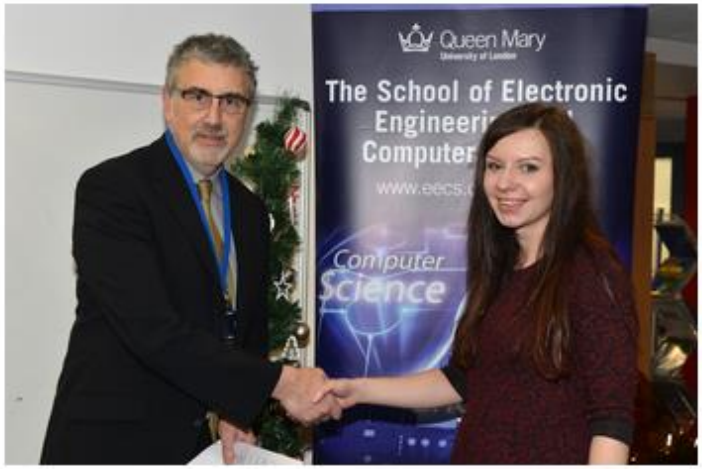
This prize was instituted in 2013 and is awarded annually to one undergraduate student and one postgraduate student in recognition of their achievement in applying the highest quality scientific and engineering principles in the broad area of Distributed Systems. This is the area in which Dr Honda concentrated most of his teaching, and it is also the area in which he conducted his research. Its primary funding comes from a donation from his family, who wished to commemorate Dr Honda in this way. Additional funding has come from Dr Honda's own ETAPS Award. This prize is sponsored by Springer Verlag, and awarded annually by the ETAPS committee in recognition of an individual's research contribution. Dr Honda received the first such award posthumously, and the awarding panel expressed a wish that the funding be used to supplement this prize fund. The laudation for this award, written by Dr Honda's colleague, Prof Vladimiro Sassone is included later.

About Dr Honda

Kohei Honda was born and lived the first part of his life in Japan. Like many scientists he was fascinated by the idea of finding basic explanatory theories, like the physicists looking for grand unified theories of the universe. Kohei, though, was passionately interested in finding the right basic explanatory theory for the process of computation. Most academics agree that the basic theory

Winners 2013



Ms Anna Pawlicka
2013 winner (Undergraduate) source: QMUL

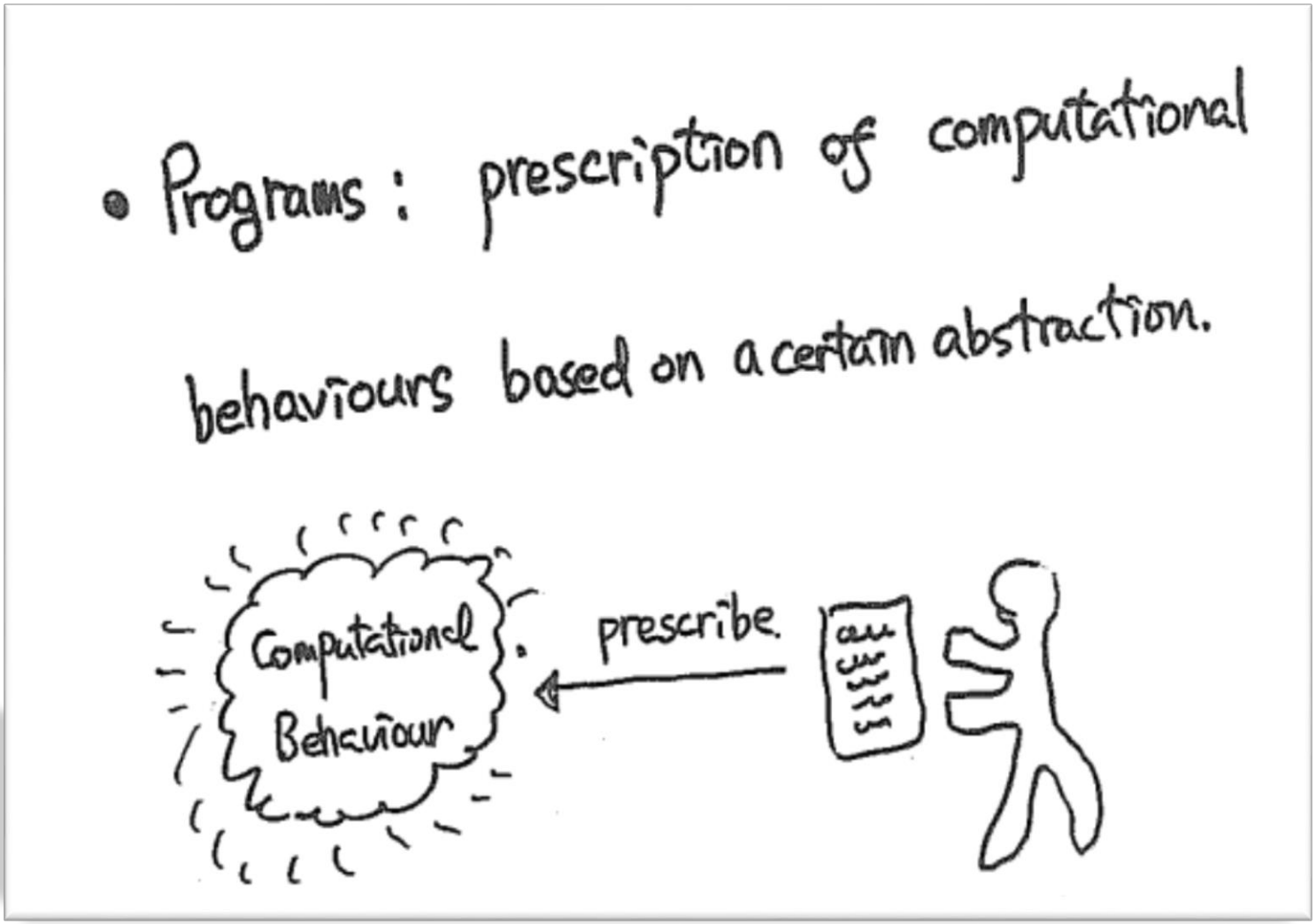
Mr. Valdmir Negacevshi
2013 winner (Postgraduate) source: QMUL

Idioms for Interaction

—Invitation to Hacking on π-calculus—

Programming languages are tools which offer frameworks of abstraction for such activities – promoting or limiting them

- *Imperative*
- *Functional*
- *Logical*



On Programs and Programming

- The most fundamental element of a PL

  in this context is a set of operations

  it is based on:

  Imperative: assignment, jump.

  Functional: β-reduction.

  Logical: unification.

- Another element is how we can combine,

  or structure, these operations:

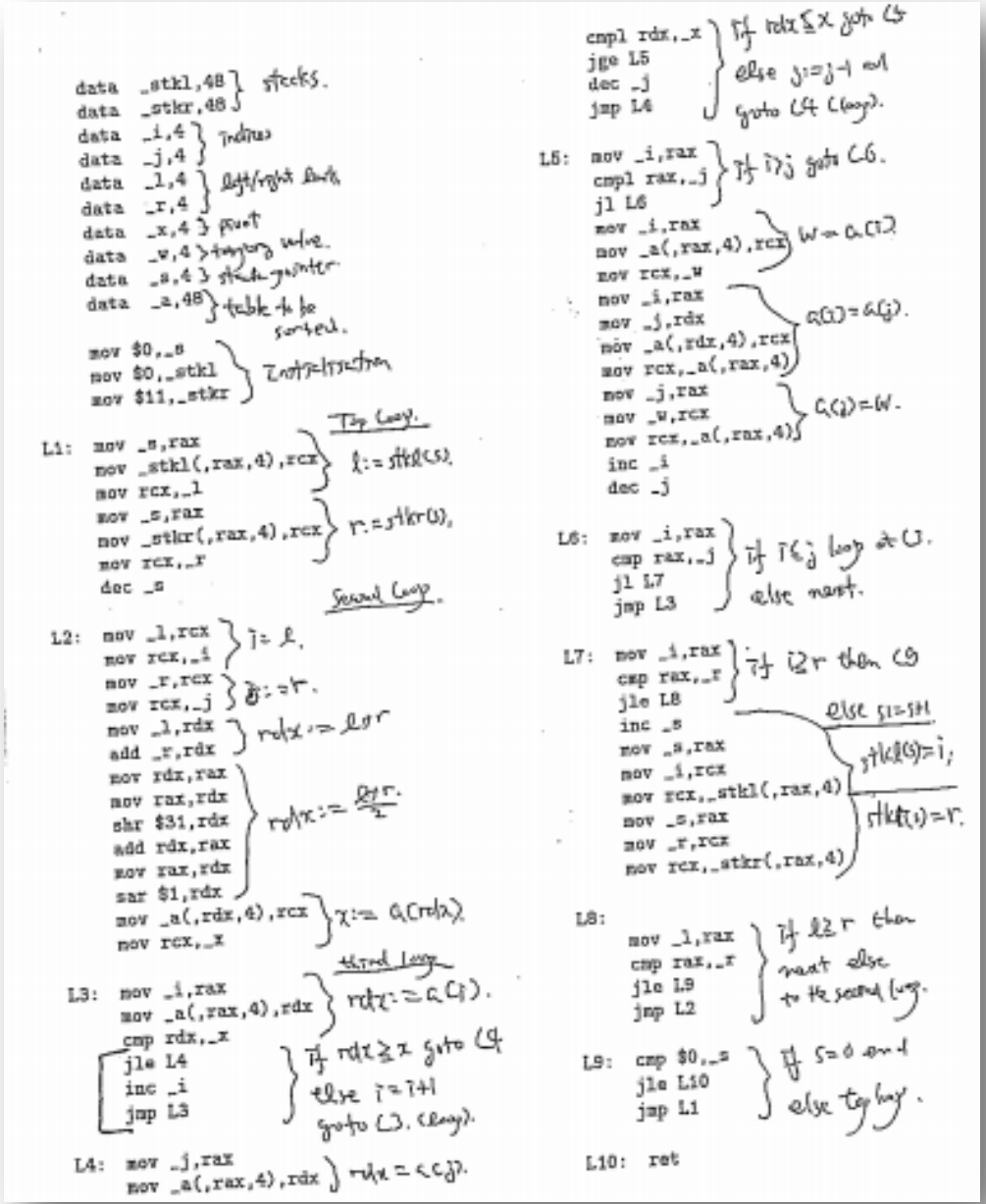
  Imperative: sequential composition, if-then-else,

  while, procedures, modules, ...

  Functional: application, product, union,

  recursion, modules, ...

UNSTRUCTURED:



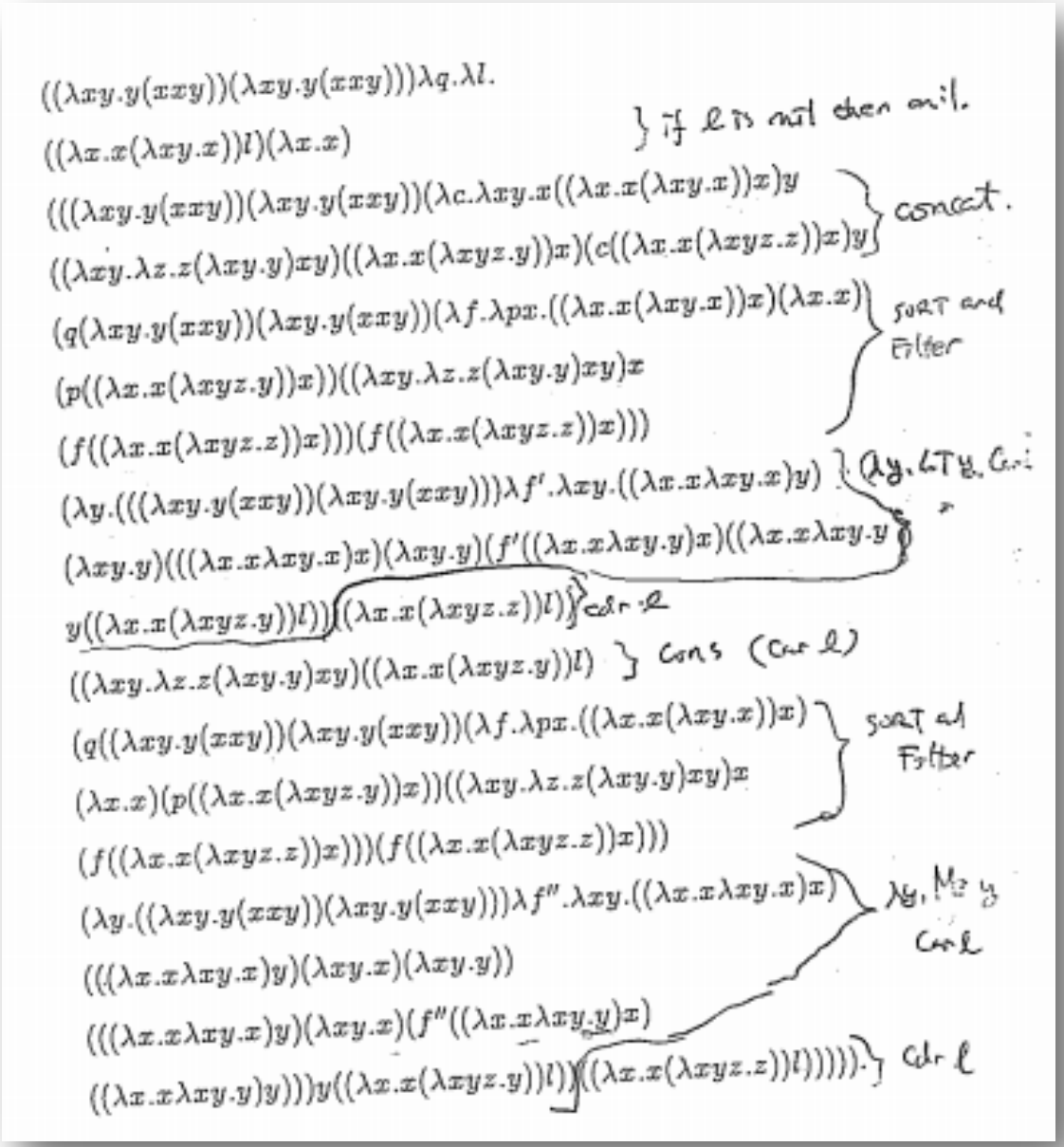
STRUCTURED:

```
Var a: array[MAX] of int;

Procedure sort(l,r: int);
  Var i,j, x: int;
  i:= l; j:= r;
  x:= [(l+r) div 2];          • Choose a pivot.
  repeat
    while a[i]<x do i:= i+1 end
    while a[j]>x do j:= j+1 end.     } Partition into two parts.
    if i≤j then swap(i,j); i:=i+1; j:=j-1; end
  until i>j;
  if l<j then sort(l,j);      } Recursively
  if l<r then sort(i,r);      } sort two parts.
end

Procedure swap(i,j: int)
    var w: int;
        w:= a[i]; a[i]:= a[j]; a[j]:= w;
end
```

Quicksort in pure lambda:



Quicksort with combinators:

$$Y(\lambda f.\ \lambda l.\ (\text{Isnil } l)\ (\text{Concat } (f\ \text{Filter } (\lambda y.\ LT\ y\ (\text{Car } l))\ (\text{Cdr } l))\ (\text{Cons } (\text{Car } l)\ (f\ \text{Filter } (\lambda y.\ \text{Me } y\ (\text{Car } l)\ (\text{Cdr } l))))))$$

$I = \lambda x.x \quad T = \lambda xy.x \quad F = \lambda xy.y \quad Y = (\lambda xy.y(xxy))(\lambda xy.y(xxy))$

$\text{Cons} = \lambda xy.\lambda z.zFxy \quad \text{Isnil} = \lambda x.xT$

$\text{Car} = \lambda x.x(\lambda xyz.y) \quad \text{Cdr} = \lambda x.x(\lambda xyz.z)$

$\text{Concat} = Y(\lambda c.\lambda xy.x\ (\text{Isnil } x)\ y\ (\text{Cons } (\text{Car } x)\ (c\ (\text{Cdr } x)\ y)))$

$\text{Filter} = Y(\lambda f.\lambda px.(\text{Isnil } x)\ I\ (p\ (\text{Car } x))\ (\text{Cons } x\ (\text{Filter Cdr } x))\ (\text{Filter } (\text{Cdr } x)))$

$\text{Iszero} = \lambda x.xT \quad \text{Pred} = \lambda x.xF$

$LT = Y(\lambda f.\lambda xy.(\text{Iszero } y)\ F\ ((\text{Iszero } x)\ T\ (f\ (\text{Pred } x)\ (\text{Pred } y))))$

$ME = Y(\lambda f.\lambda xy.(\text{Iszero } x)\ ((\text{Iszero } y)\ I\ F)\ ((\text{Iszero } y)\ (T)\ (f\ (\text{Pred } x)\ (\text{Pred } y))))$

Quicksort in ML:

```
fun qs nil:int list = nil
  | qs (x::r) = let val small =
                          filter (fn y => y<x) r
                    and large =
                          filter (fn y => y>=x) r
                in qs small @ [x] @ qs large
                end

fun filter p nil = nil
  | filter p (x::r) =
      if p x then x:: filter p r
             else filter p r
```

The π-calculus as a Descriptive Tool

λ $\quad M ::= x \mid \lambda x.M \mid MN$

π $\quad P ::= \sum \pi_i.P_i \mid P|Q \mid (\nu x)P \mid !P \mid \emptyset.$

with $\quad \pi ::= x(\tilde{y}) \mid \bar{x}\langle \tilde{y} \rangle.$

λ in π

$[\![x]\!]_u \stackrel{\text{def}}{=} \bar{x}\langle u \rangle.$

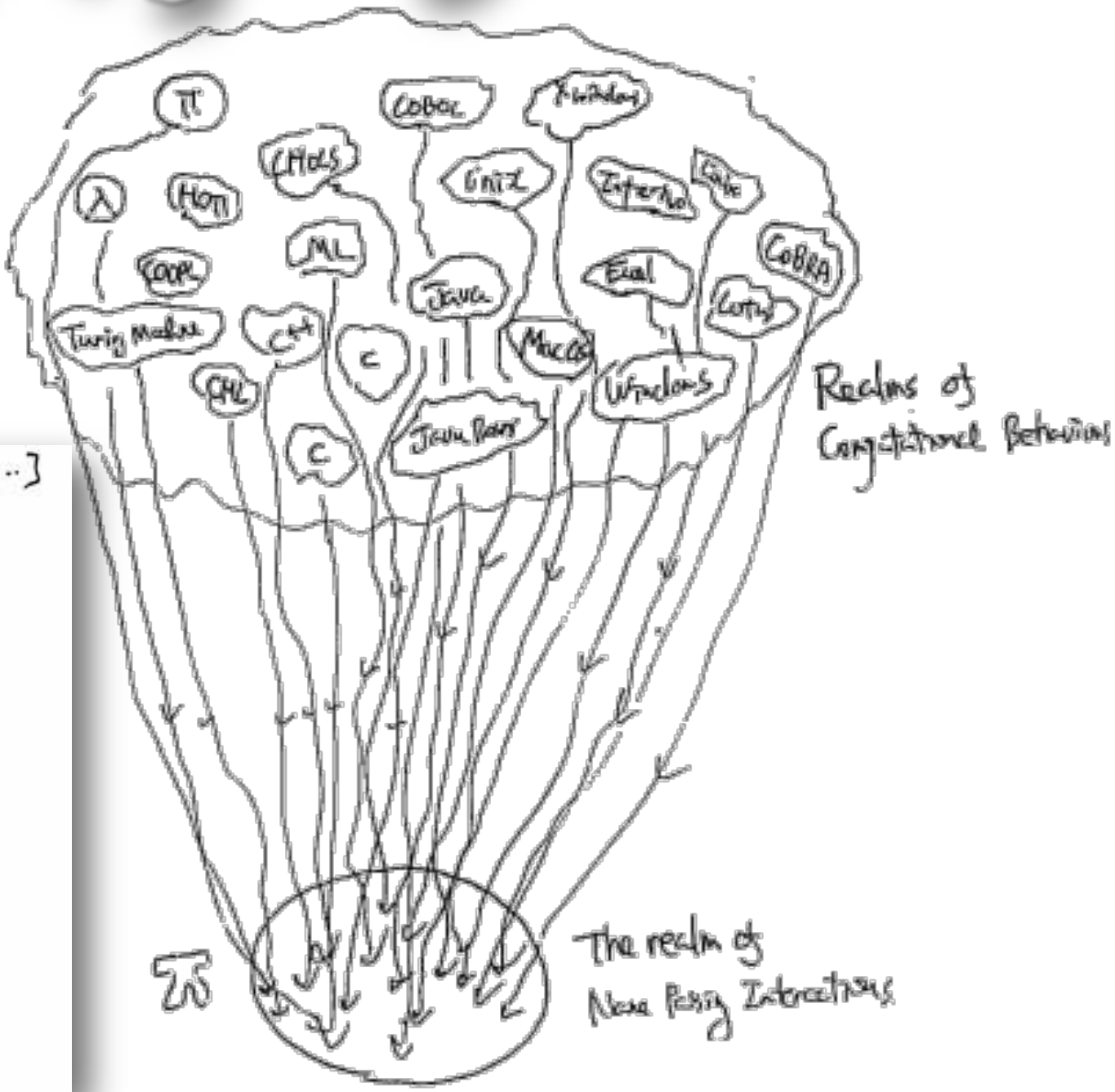
$[\![\lambda x.M]\!]_u \stackrel{\text{def}}{=} u(x u').[\![M]\!]_{u'}.$

$[\![MN]\!]_u \stackrel{\text{def}}{=} (\nu f x)\left([\![M]\!]_f \mid \bar{f}\langle x u \rangle \mid [\![x=N]\!]\right)$

with $[\![x=N]\!] \stackrel{\text{def}}{=} !x(u').[\![N]\!]_{u'}.$

* Examples of Representable Computation.

- λ-calculus [MPW89, Milner90, Milner92, ...]
- Concurrent Object [Walker91]
- ω-order term passing [Sangiorgi 92]
- Various data structures [Milner 92, ...]
- Proof Nets [Bellin and Scott 93]
- Arbitrary "constant" interaction [HYS4]
- strategies on Games [HO95]

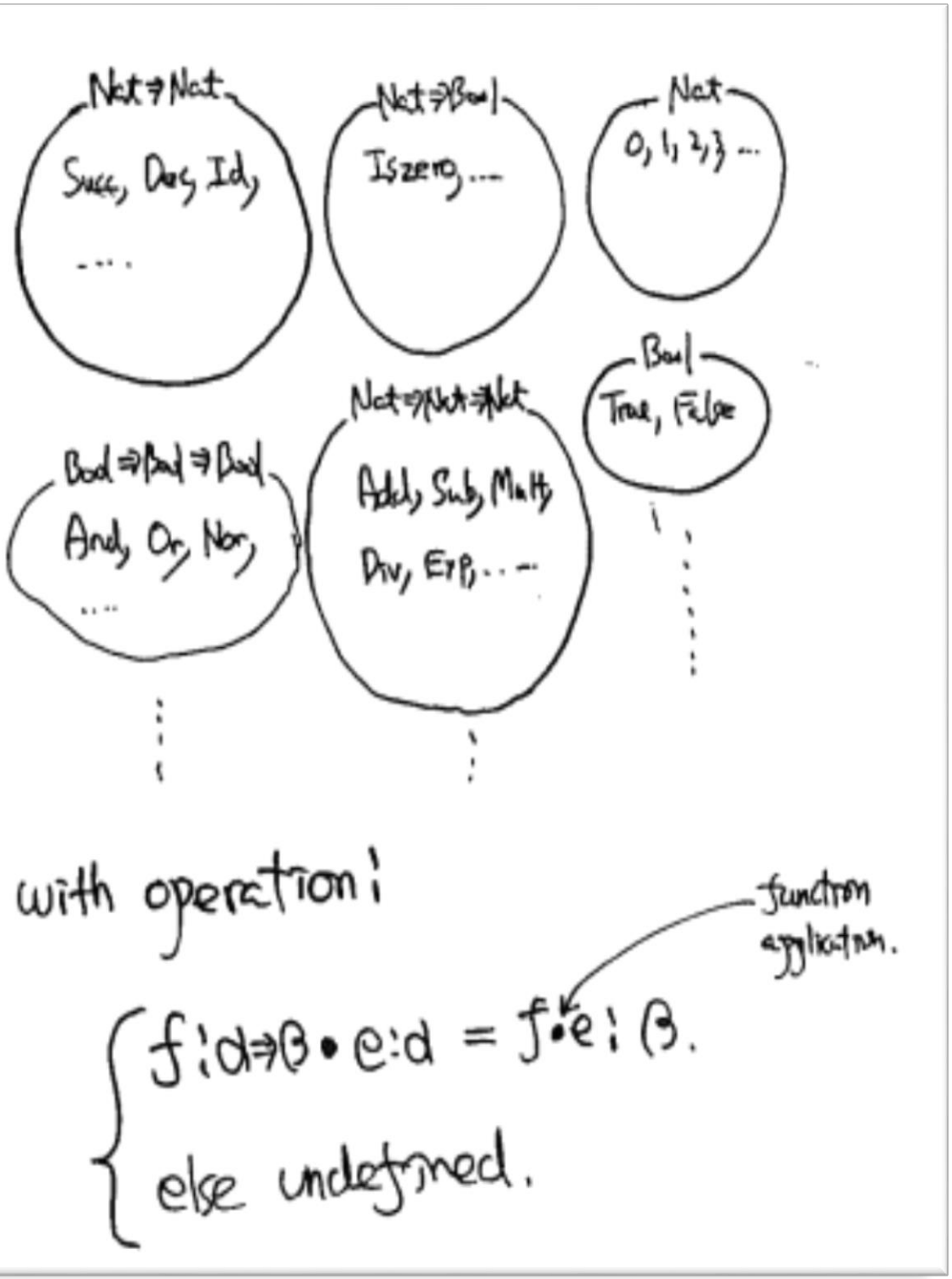


The Role of Types in π-calculus

- (classification) How can we classify name-passing interactive behaviours, i.e. behaviours representable in π-calculus? What classes ("types") of behaviours can we find in the calculus?

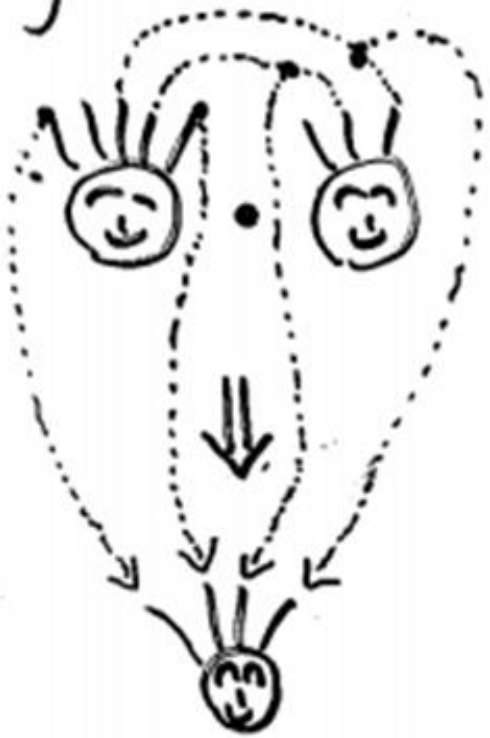
- (safety) Is this program/system in the safe (or correct, relevant, ...) classes of behaviours? Can the safety be preserved compositionally?

Functional Types



Process Types

- When it comes to processes, composition becomes:



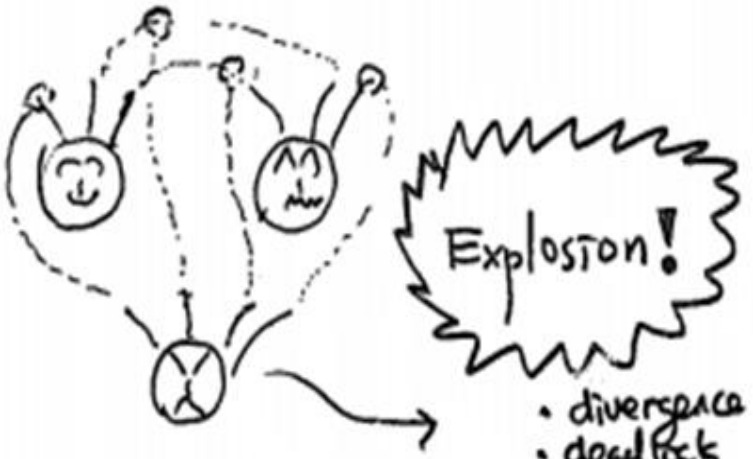
cf.

3 + 5

8

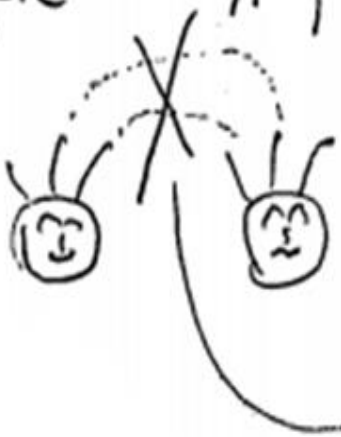
$P \bullet_\delta \delta \longmapsto_\tau \delta$

- But some composition is dangerous!



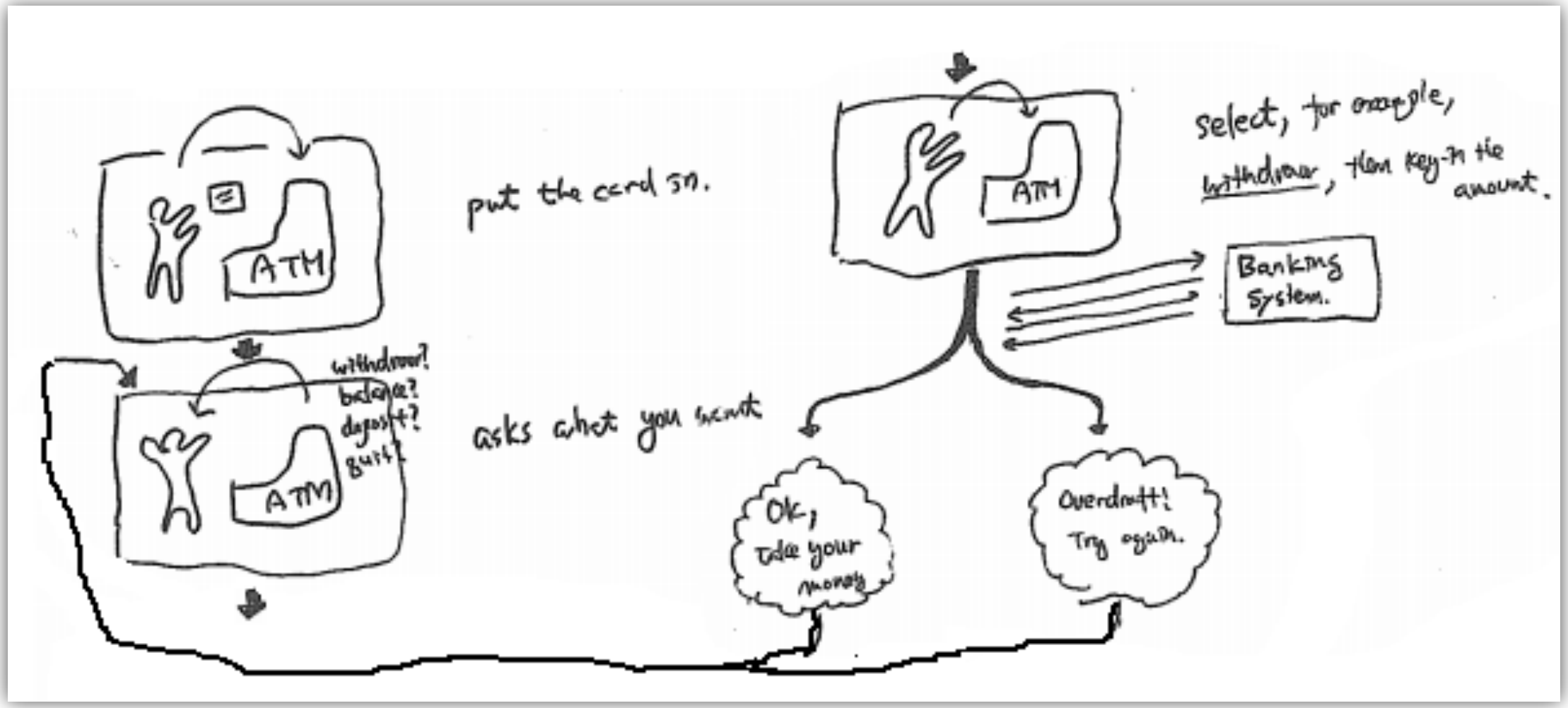
- divergence
- deadlock
- run-time error
- ⋮

- Therefore we type processes,



The connection is prohibited

Implementing ATM

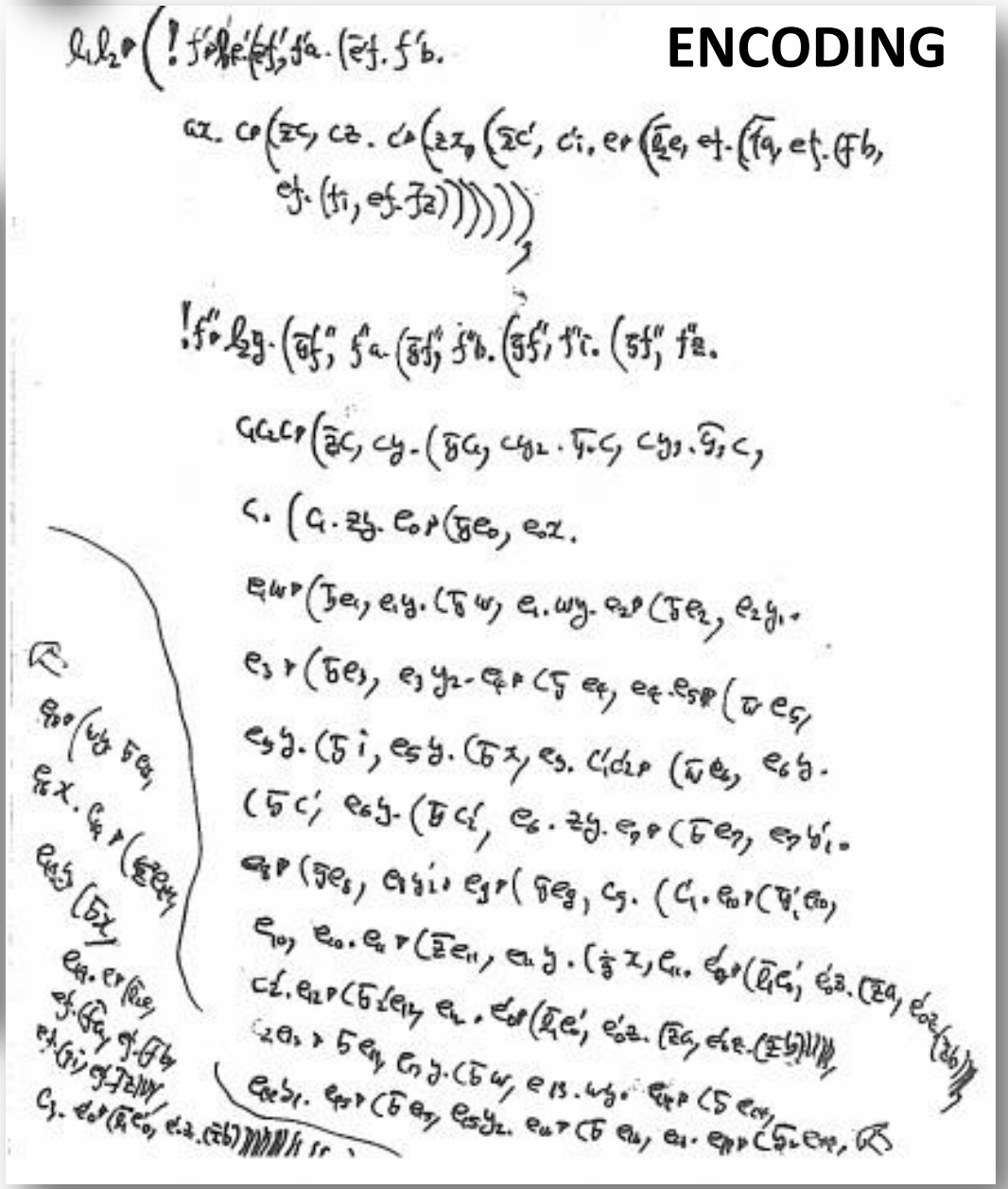


Implementing ATM

$ATM(cb) \stackrel{def}{=}$

```
ATM<z>:: z?ID; [?wd; ?X;                          * ↔user.
        b<w>:: w!wt; !ID; !X;                     * ↔bank.
          [?ok:                                   *  :
            z!ok; !X; ATM(cb),                    * ↔user
           ?overdraft:                            * ↔bank
            z!over; ATM(cb)],                     * ↔user.
        ?bd;                                      * ↔user
          b<w>:: w!bd; ?X;                        * ↔bank
            z!X; ATM<cb>]
```

ENCODING



Dialogue between Industry and Academia

Binary Session Types [PARL'94, ESOP'98]

$\Downarrow$

Milner, Honda and Yoshida joined W3C WS-CDL (2002)

$\Downarrow$

Formalisation of W3C WS-CDL [ESOP'07]

$\Downarrow$

Scribble at $\pi 4$ Technology

CDL Equivalent

- Basic example:

```
package HelloWorld {
    roleType YouRole, WorldRole;
    participantType You{YouRole}, World{WorldRole};
    relationshipType YouWorldRel between YouRole and WorldRole;
    channelType WorldChannelType with roleType WorldRole;

    choreography Main {
        WorldChannelType worldChannel;

        interaction operation=hello from=YouRole to=WorldRole
                relationship=YouWorldRel channel=worldChannel {
            request messageType=Hello;
        }
    }
}
```

Scribble Protocol

- *"Scribbling is necessary for architects, either physical or computing, since all great ideas of architectural construction come from that unconscious moment, when you do not realise what it is, when there is no concrete shape, only a whisper which is not a whisper, an image which is not an image, somehow it starts to urge you in your mind, in so small a voice but how persistent it is, at that point you start scribbling" - Kohei Honda 2007*

- Basic example:

```
protocol HelloWorld {
    role You, World;
    Hello from You to World;
}
```

Dialogue between Industry and Academia

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⇓

Multiparty Session Types [POPL'08]

⇓

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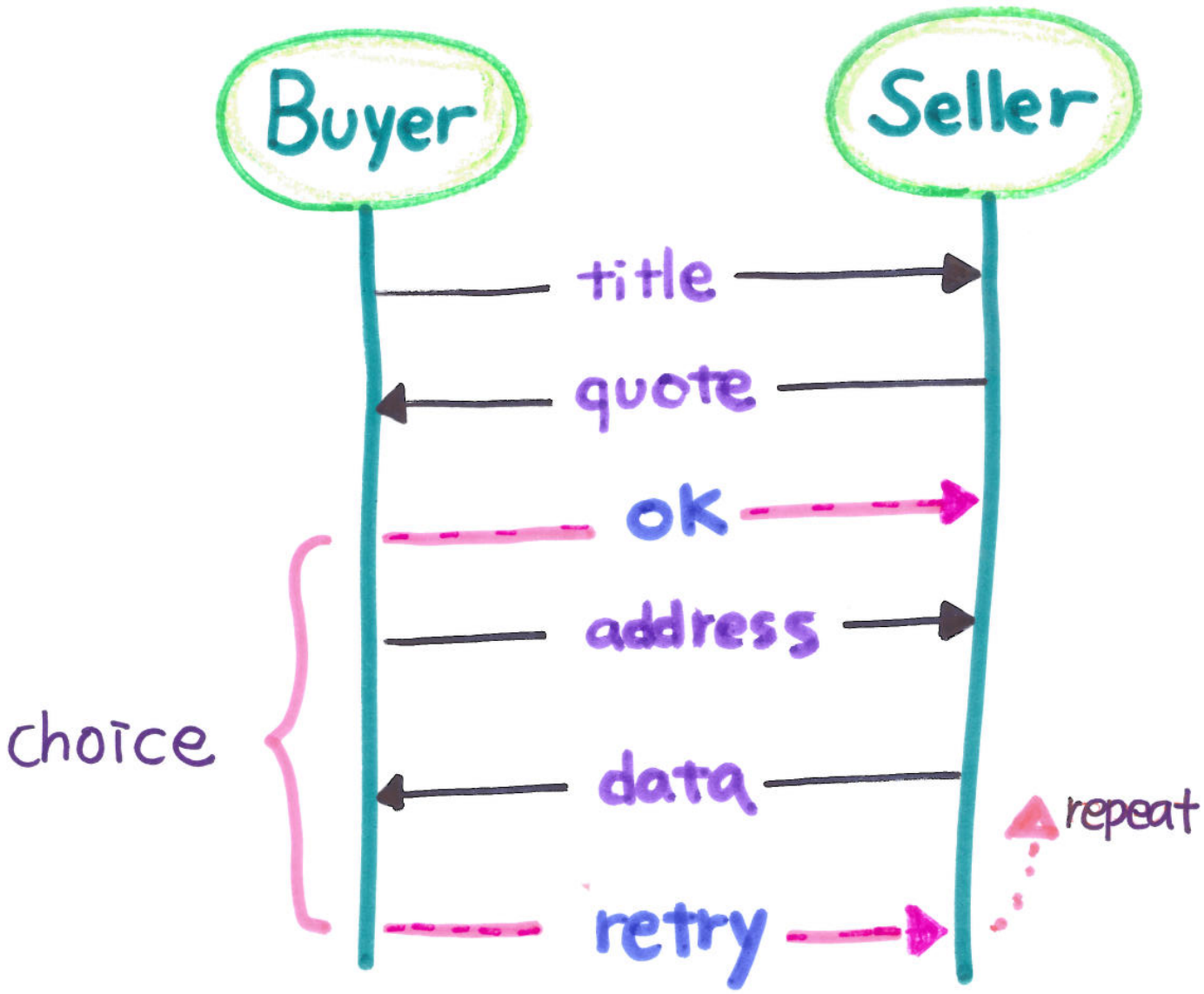
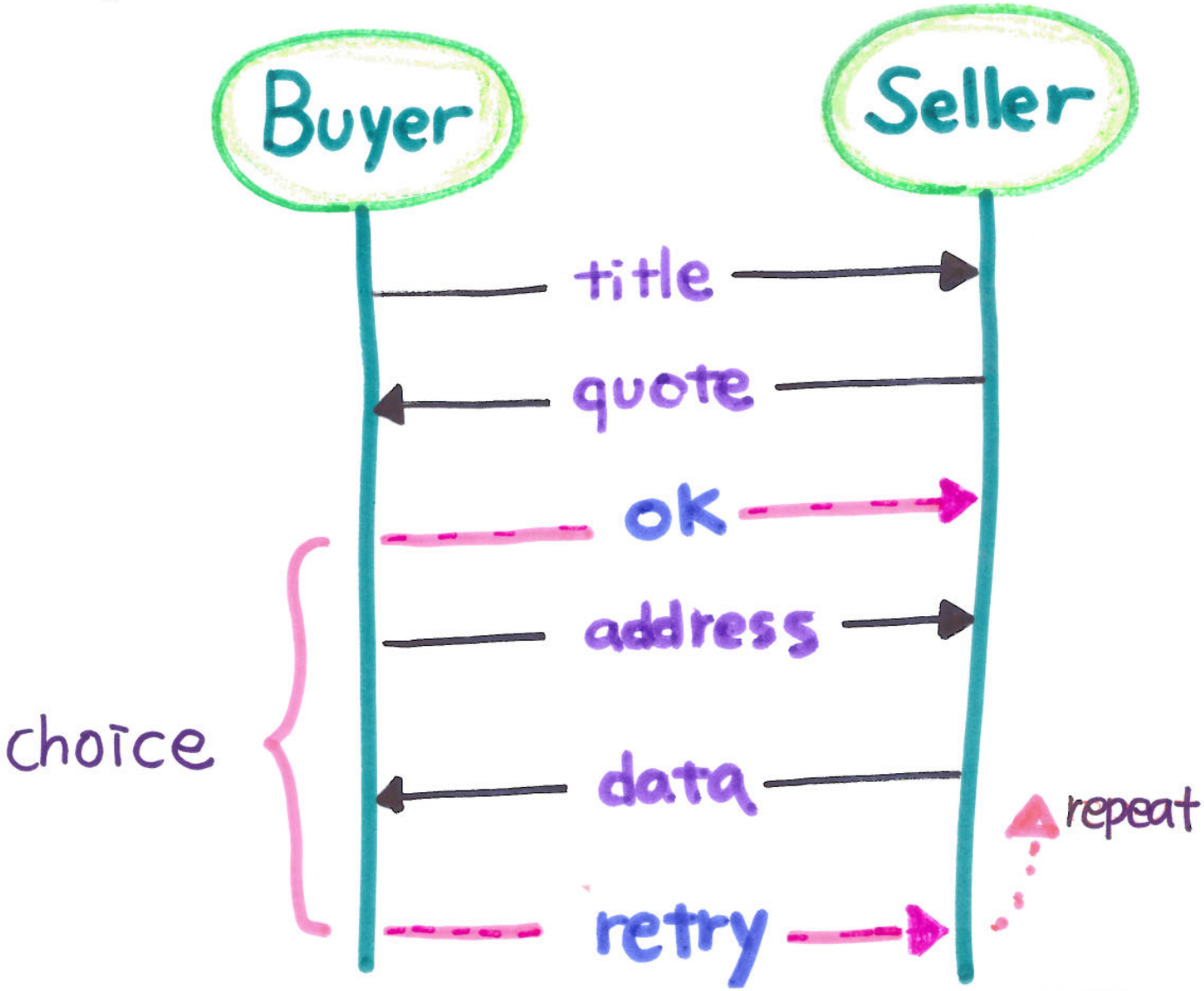
Multiparty Session Types [POPL'08]

⇓

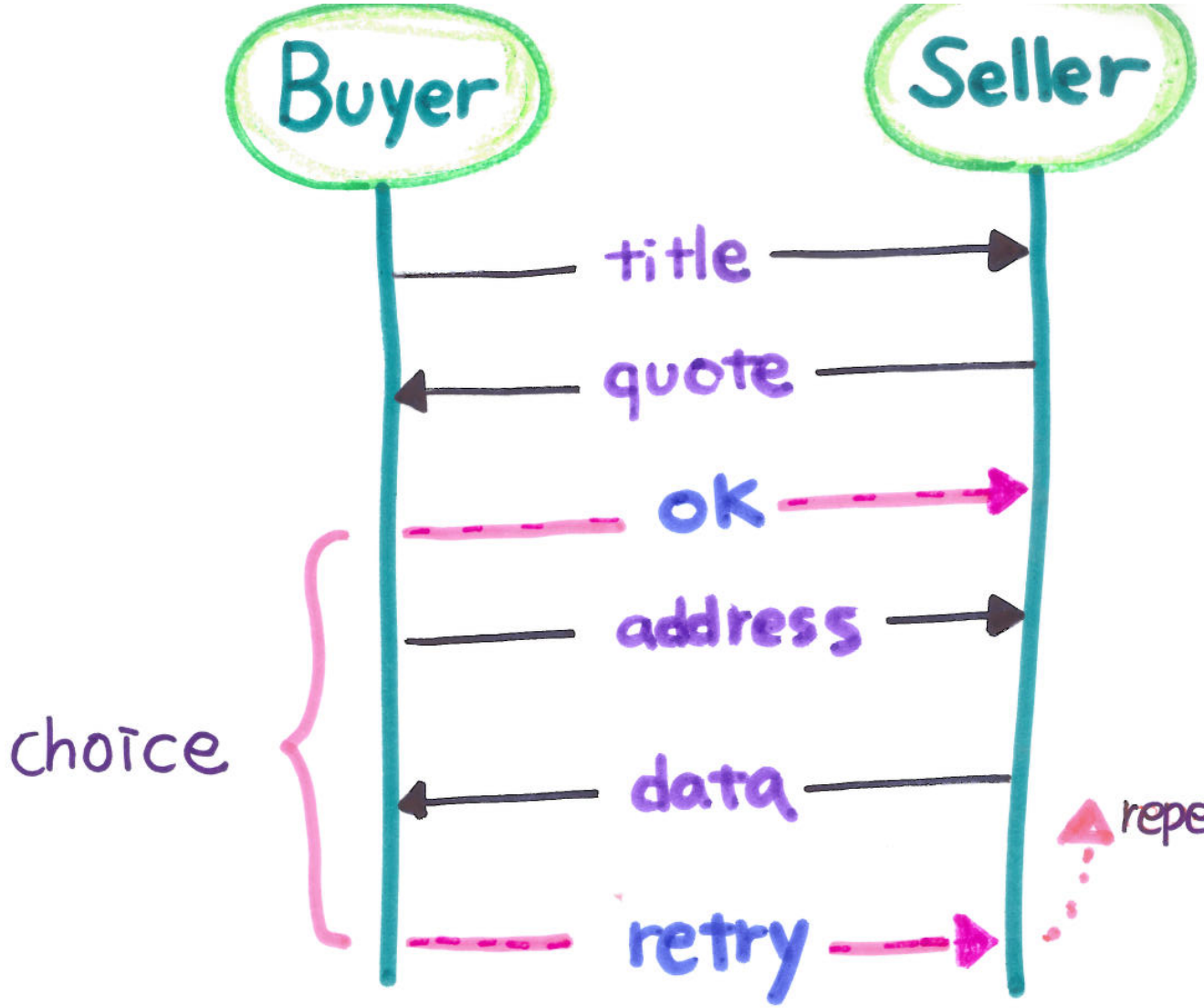
Binary Session Types: Buyer - Seller Protocol



Binary Session Types: Buyer - Seller Protocol



μt. ! Title ; ? Quote ; ! { ok : ! Add ; ? Date , retry : t }



P has T

Q has $\overline{T}$

dual

P | Q typable

$\mu t.!\ \text{Title}\ ;?\ \text{Quote}\ ;!\ \{\text{ok}:!\ \text{Add}\ ;?\ \text{Date}\ ,\ \text{retry}:t\}$

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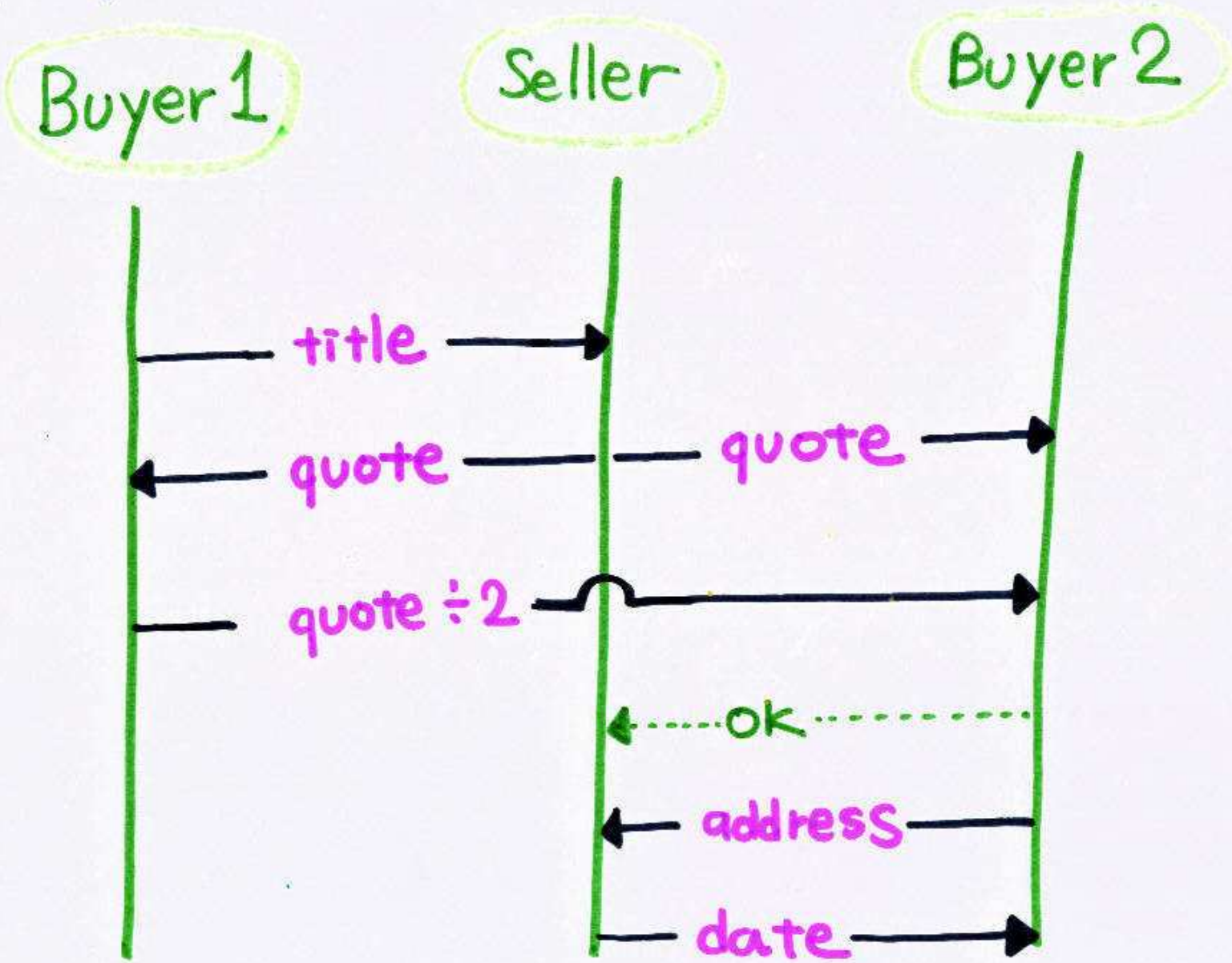
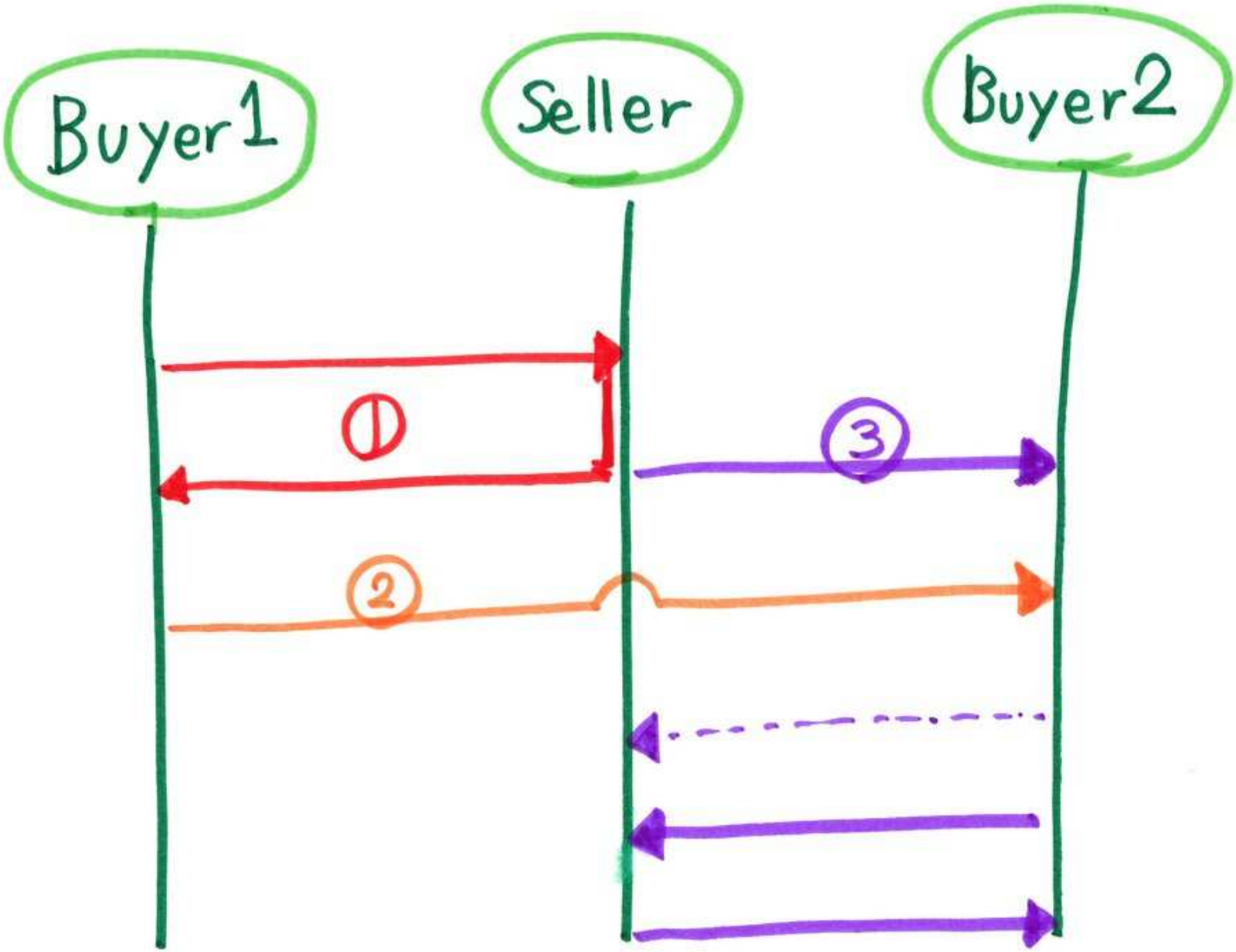
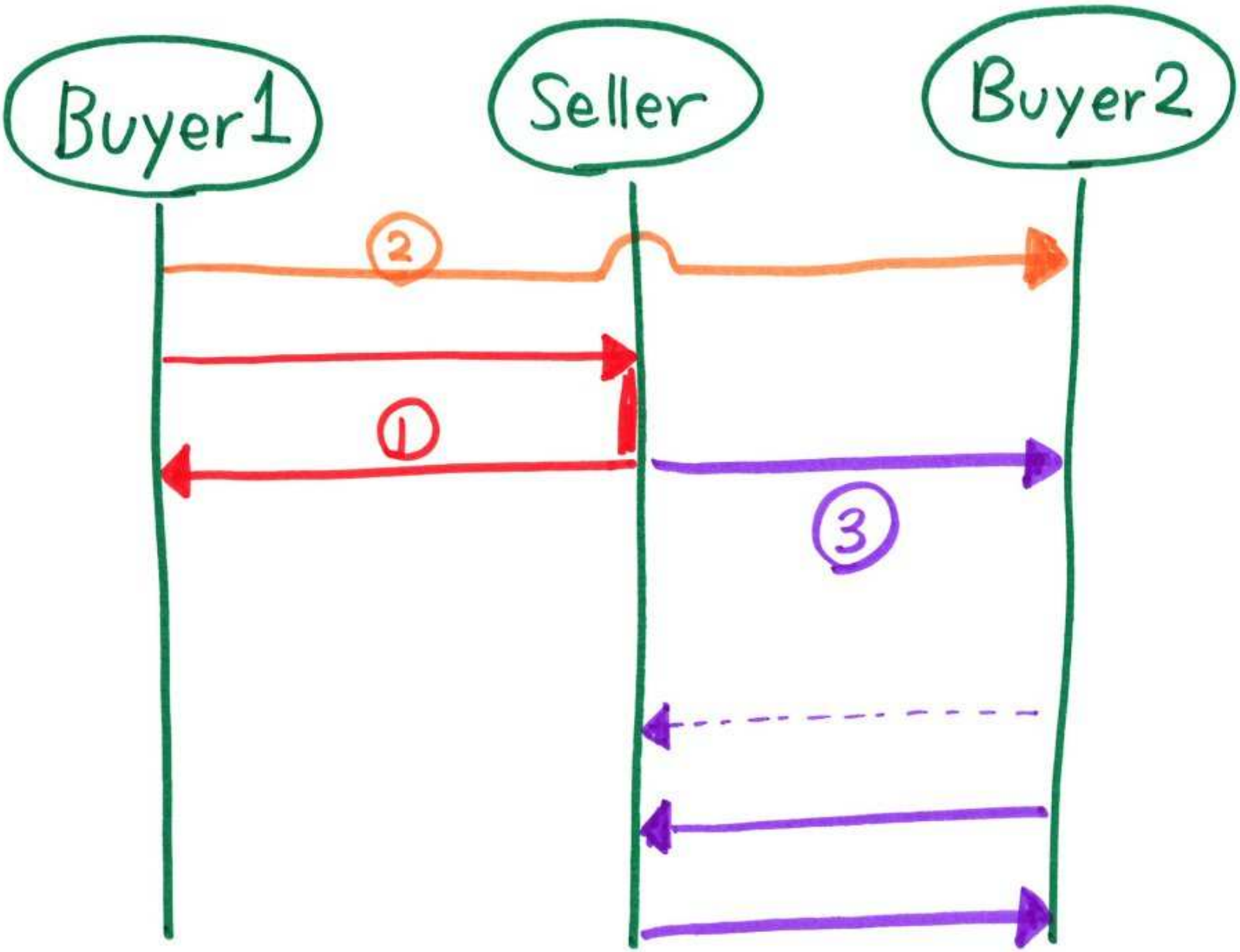
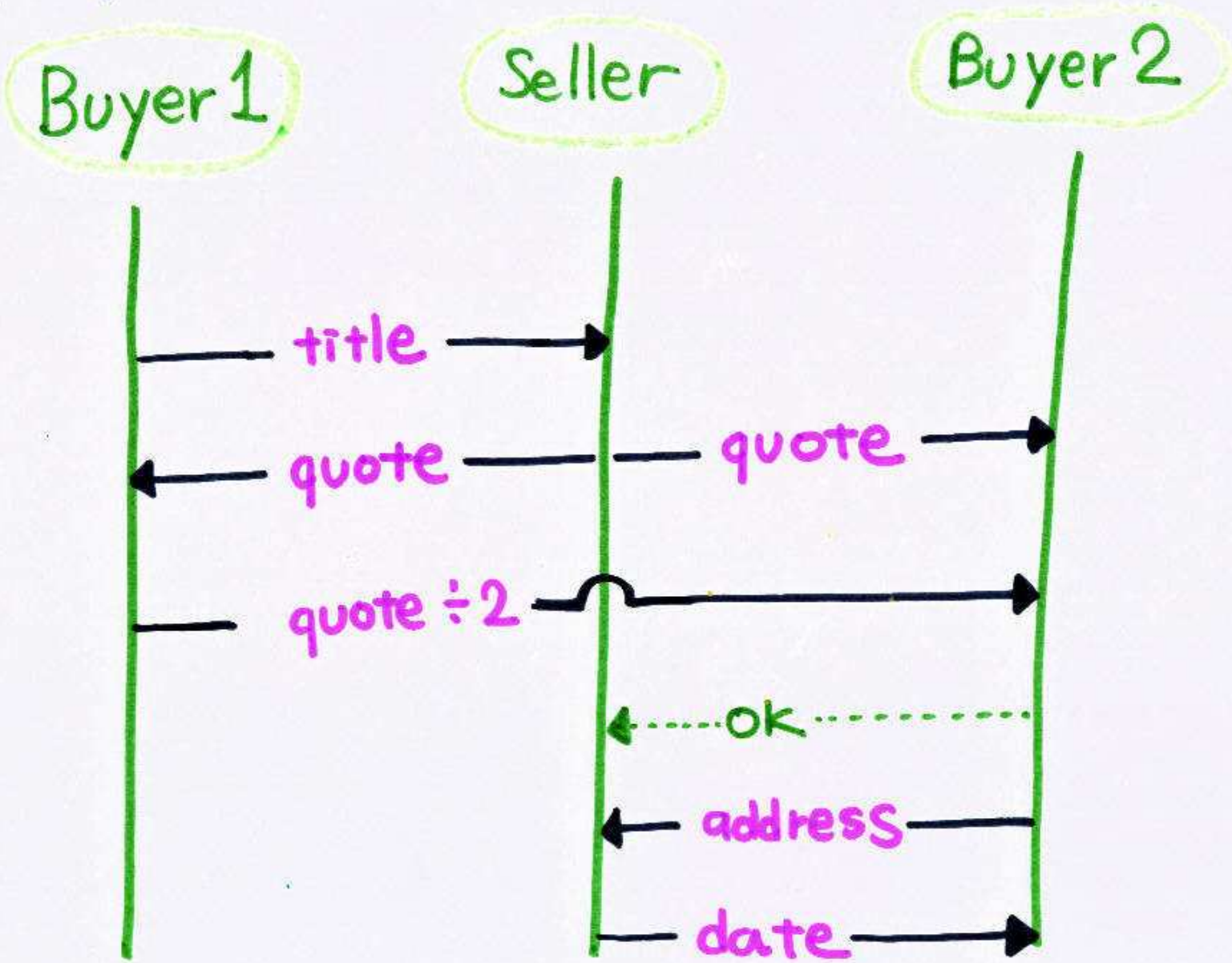
Multiparty Session Types

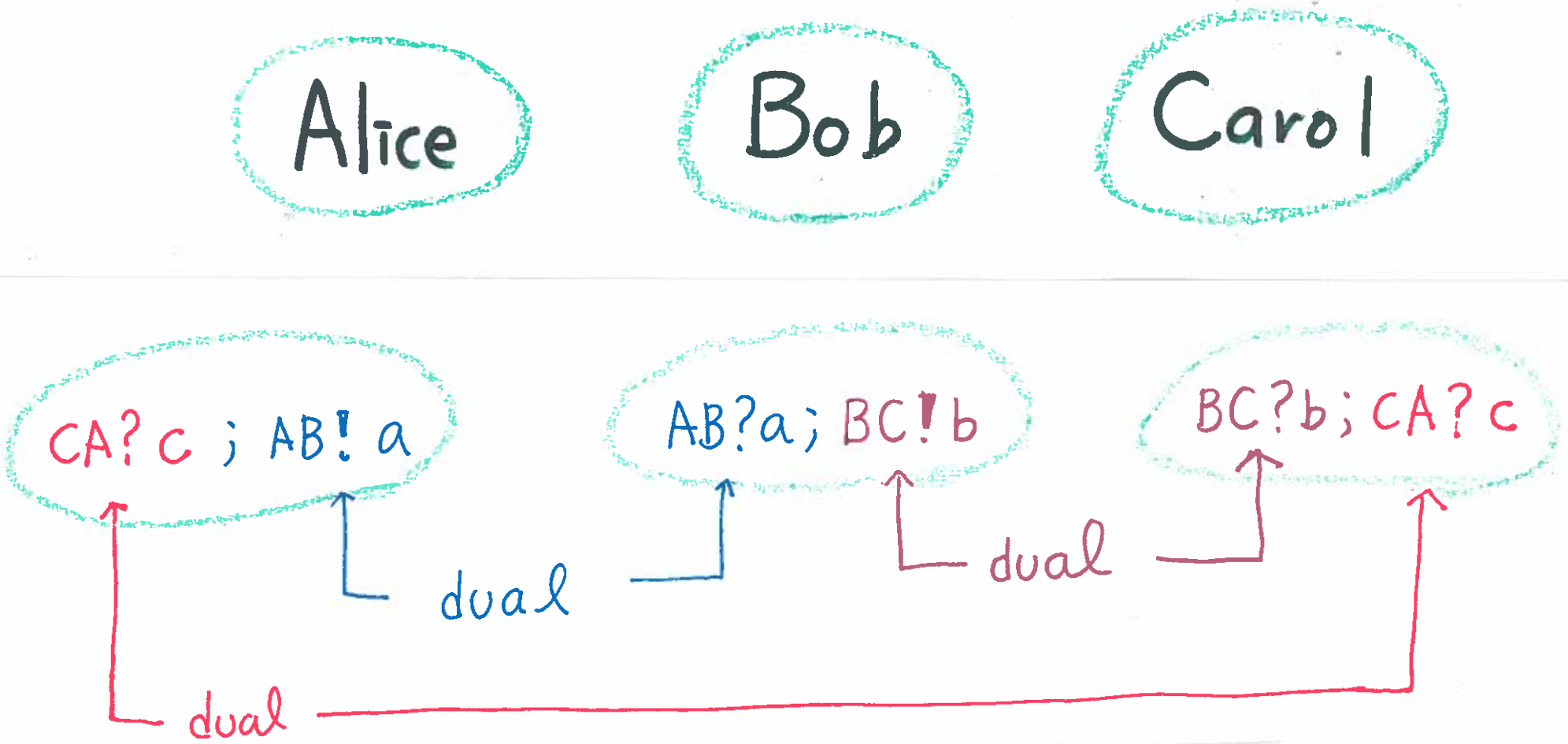



Buyer1
Seller
Buyer2
1
3
2


Buyer1
Seller
Buyer2
2
1
3

Multiparty Session Types



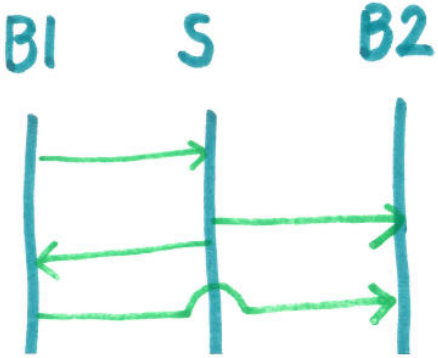


3 dual pairs

If you use binary Session Types ....

Deadlock!

Multiparty Session Types [Honda, Yoshida, Carbone 2008]



G

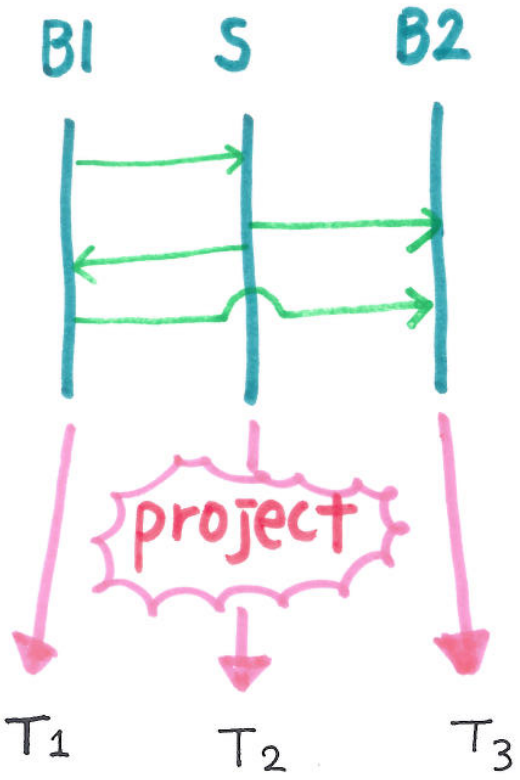
B1 → S Int.

S → B2 Char

STEP 1

Write Global Type

Multiparty Session Types [Honda, Yoshida, Carbone 2008]



G

$B1 \rightarrow S$ Int.

$S \rightarrow B2$ Char

T

$B_1?$ Int. $B_2!$ Char

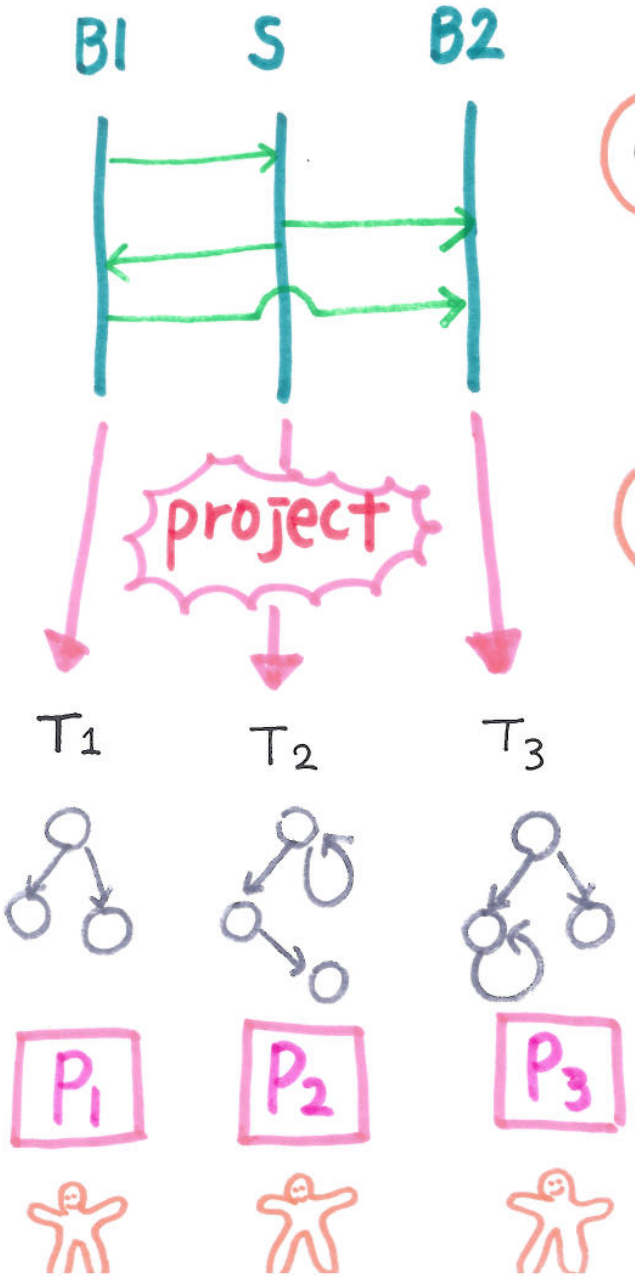
STEP 1

Write Global Type

STEP 2

Project to Local Types

Multiparty Session Types [Honda, Yoshida, Carbone 2008]



G $B1 \rightarrow S$ Int.
$S \rightarrow B2$ Char

T $B_1?\text{Int}.\ B_2!\text{Char}$

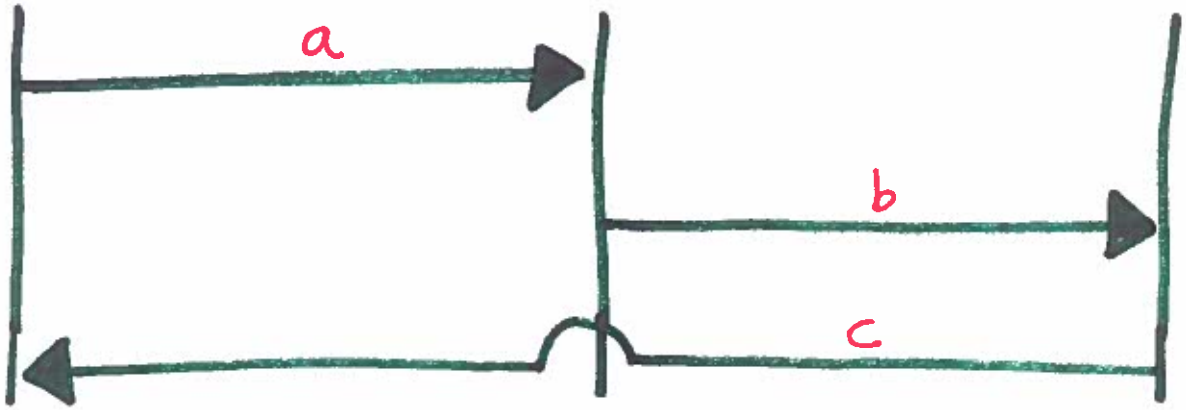
P $B_1?(x).\ B_2!\langle\text{"apple"}\rangle$

STEP 1
Write Global Type

STEP 2
Project to Local Type

STEP 3
- Static Check
- Generate Code
- Run-time check

Alice Bob Carol



Global Type

Projection

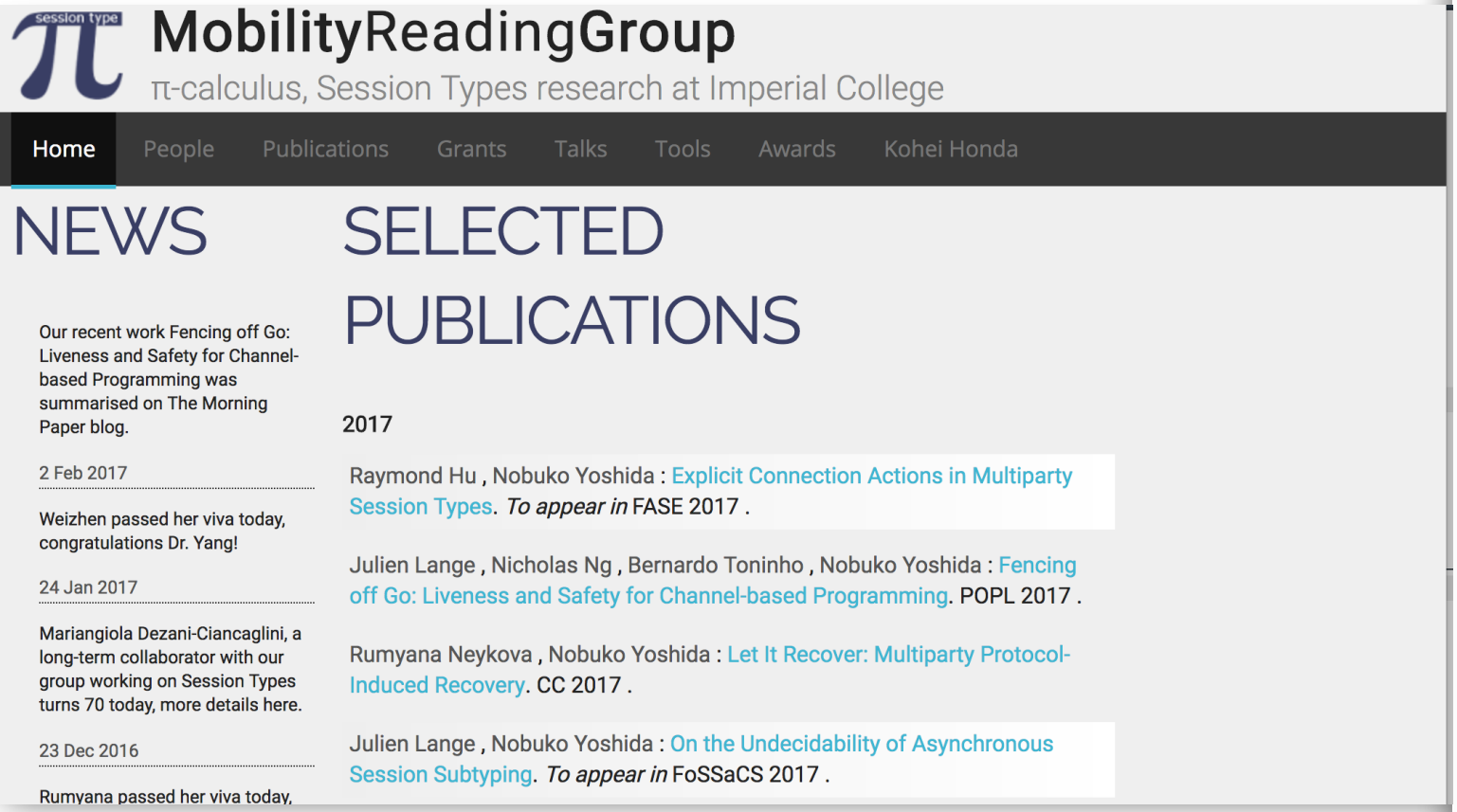
Alice AB!a; CA?c

Bob AB?a; BC!b

Carol BC?b; CA!c;

LOCAL TYPES

Us ∈ Mobility Research Group



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Selected Publications 2016/2017

- **[ECOOP'17]** Alceste Scala, Raymond Hu, Ornela Darda, NY: A Linear Decomposition of Multiparty Sessions for Safe Distributed Programming..
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Relationship with Communicating AUTOMATA

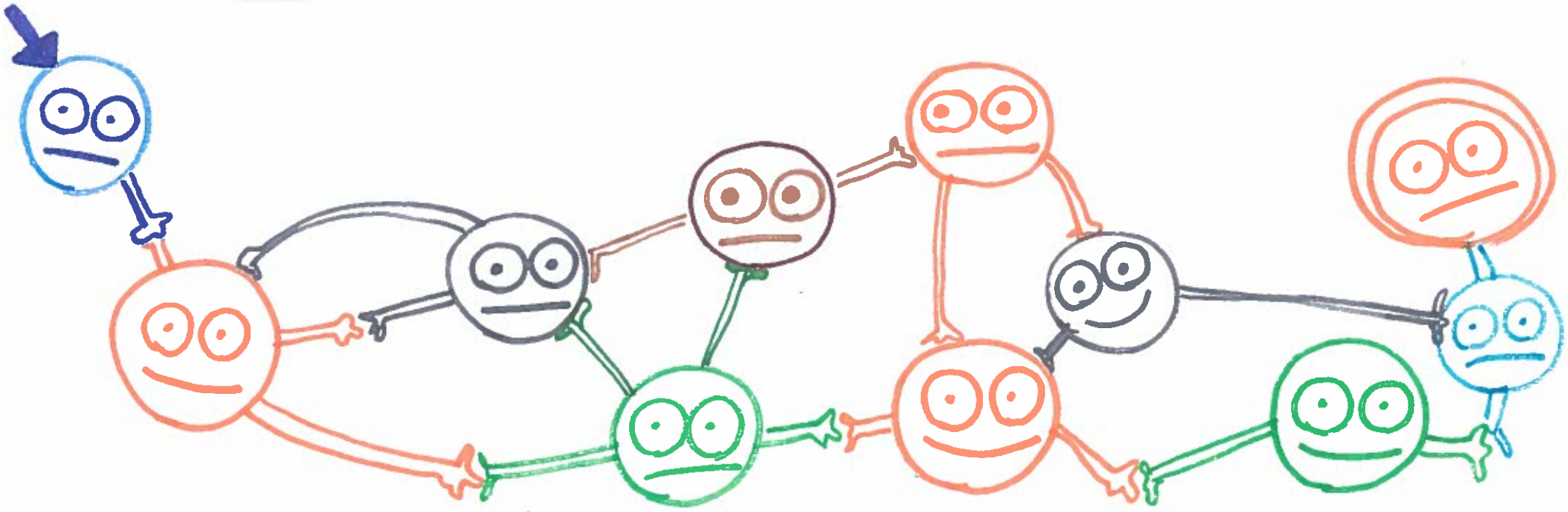
ESOP 12
ICALP 13
Characterisation
Synthesis

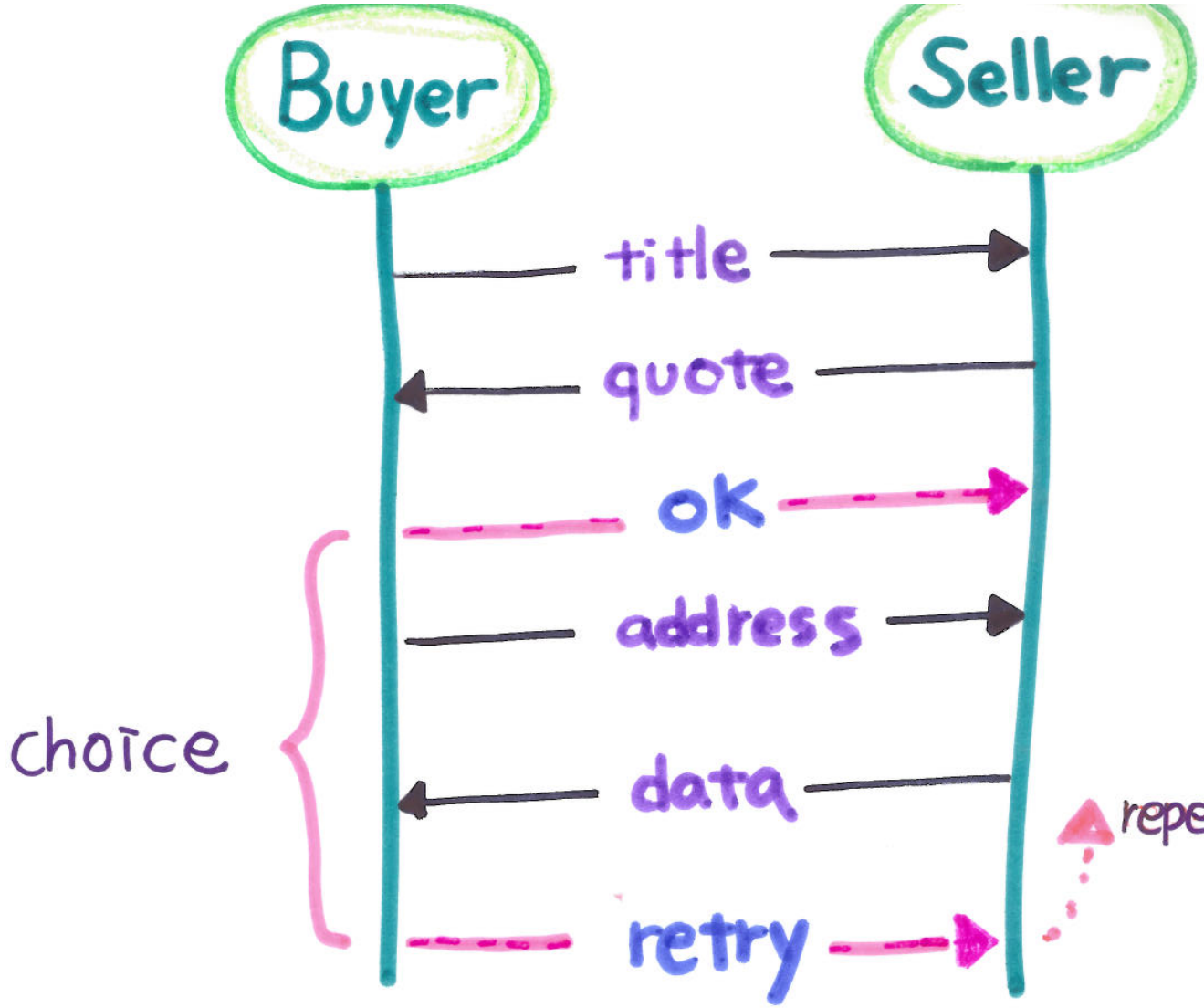
CONCUR 15
Timed Automata

POPL 15
Graphical Synthesis

TACAS 16
Subtyping + Model-checking

FOSSACS17
Undecidability





P has T

Q has $\overline{T}$

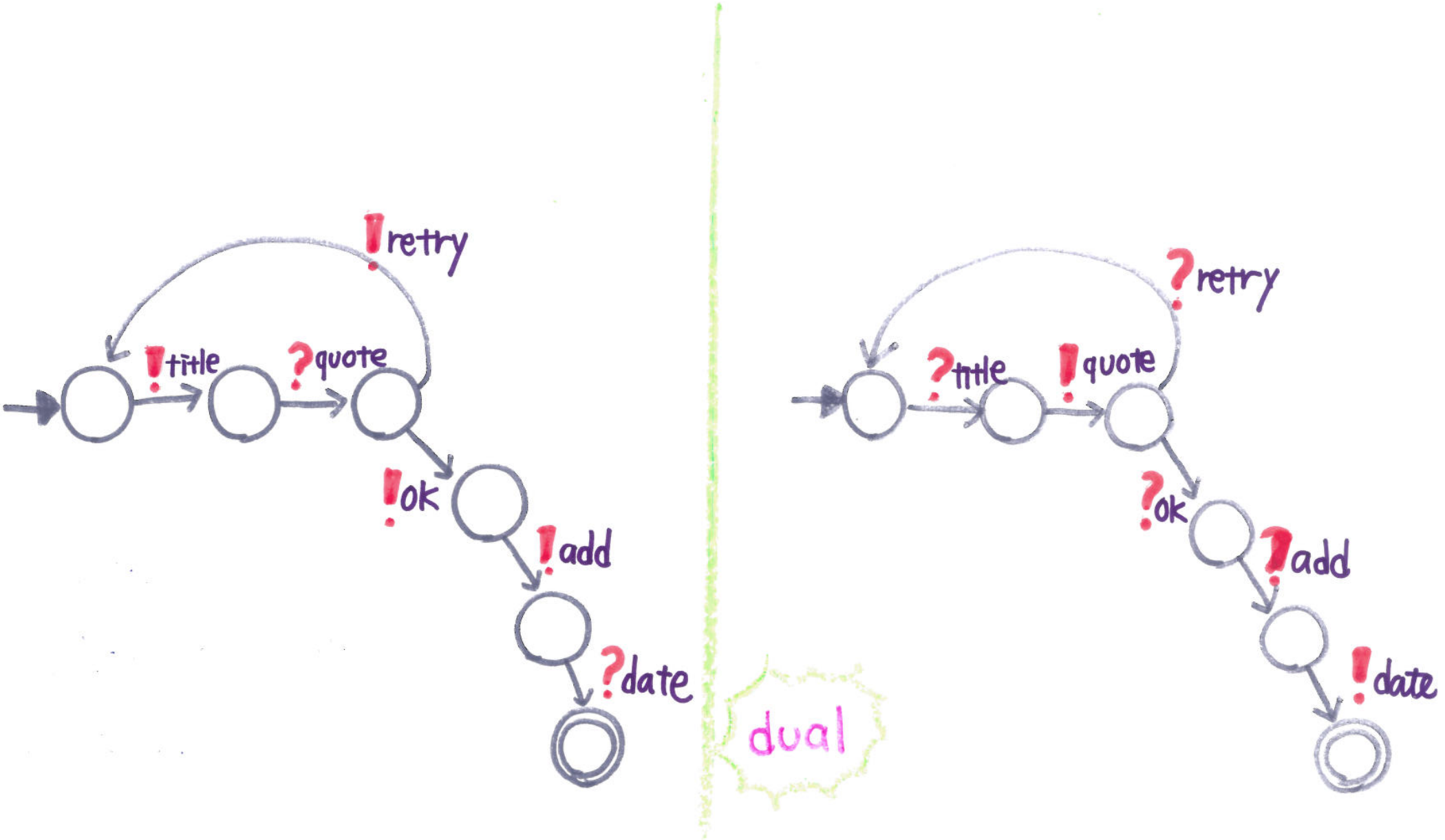
dual

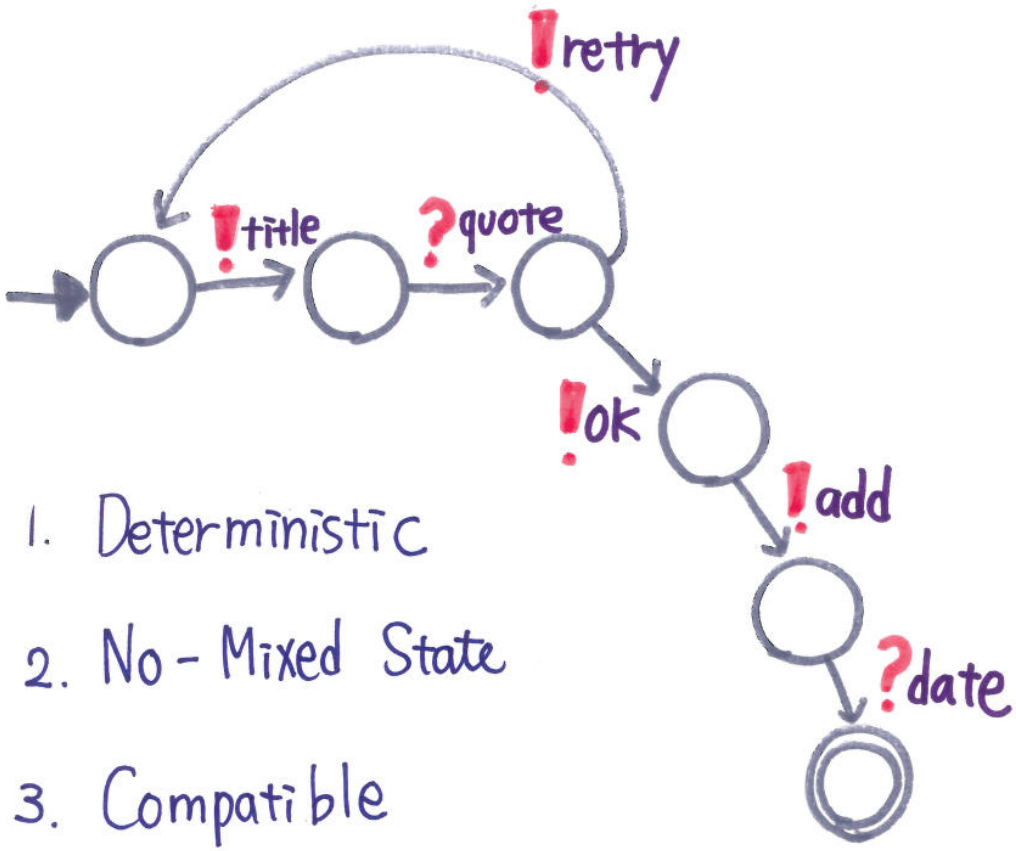
P | Q typable

$\mu t.!\ \text{Title}\ ;?\ \text{Quote}\ ;!\ \{\text{ok}:!\ \text{Add}\ ;?\ \text{Date}\ ,\ \text{retry}:t\}$

$\mu t.?\ \text{Title}\ ;!\ \text{Quote}\ ;?\ \{\text{ok}:?\ \text{Add}\ ;!\ \text{Date}\ ,\ \text{retry}:t\}$

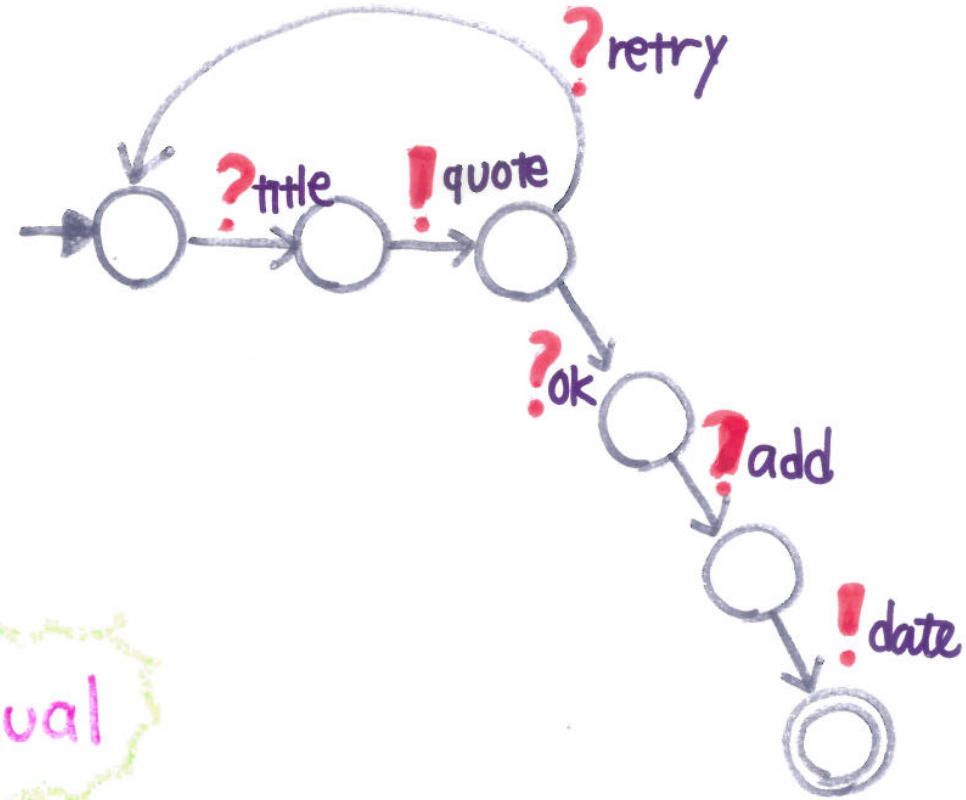
Communicating Automata [1980s]





1. Deterministic
2. No-Mixed State
3. Compatible

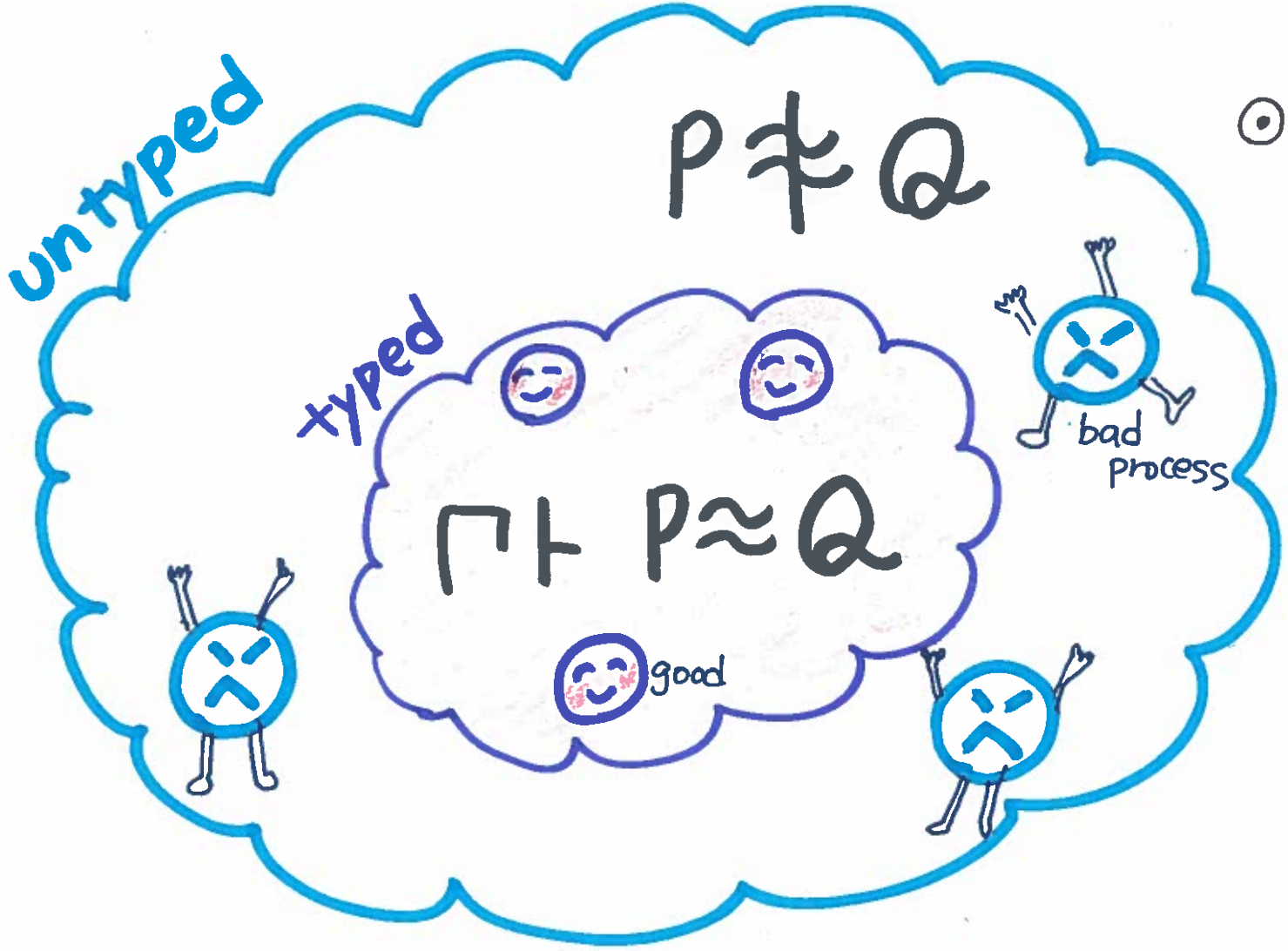
dual



[Gouda et al 1986] Two compatible machines without mixed states which are deterministic satisfy deadlock-freedom.

Typed Semantics in π 1991→

IO-subtyping, Linear types, Secure Information Flow, ...



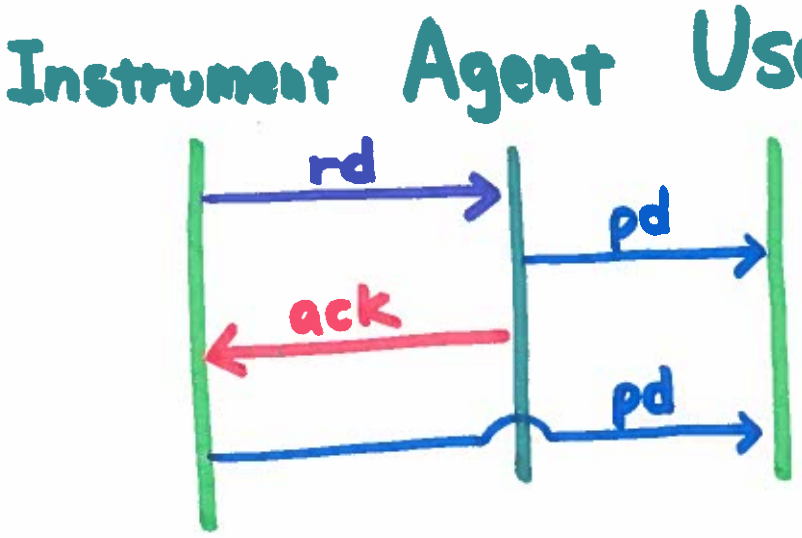
- ⊙ Correctness of Encoding
- ⊙ Limit environment Γ
  ⇒ Equate more processes
- ⊙ Compositional

GLOBALLY GOVERNED SESSION SEMANTICS

Dmitrios Kouzapas
Glasgow

Nobuko Yoshida
Imperial college London

Usecase : UC.R2.13 "Acquire Data from Instrument" from Ocean Observatories Initiative (OOI)



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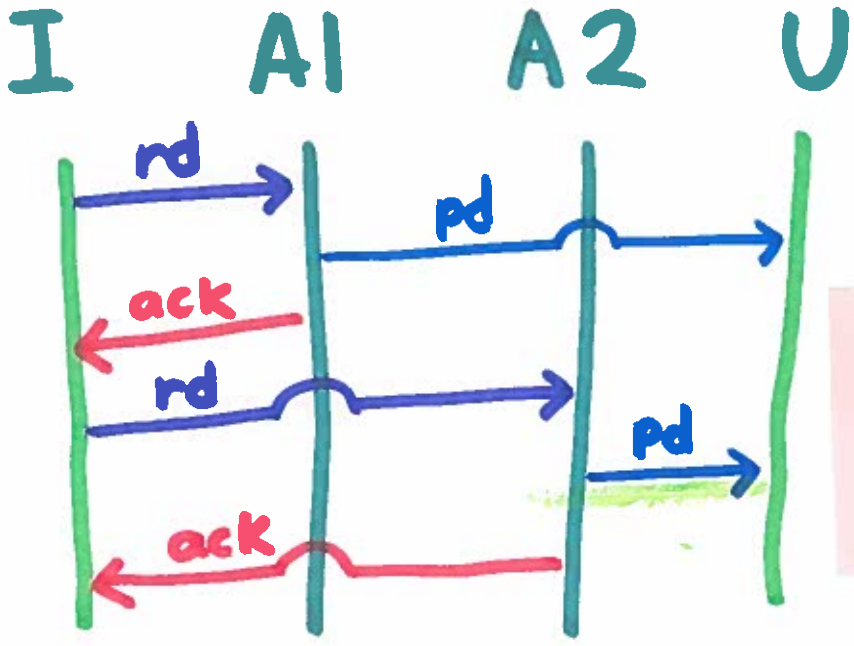
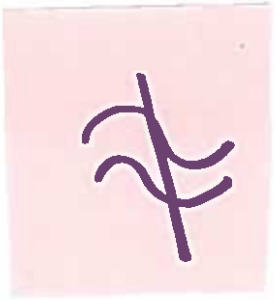
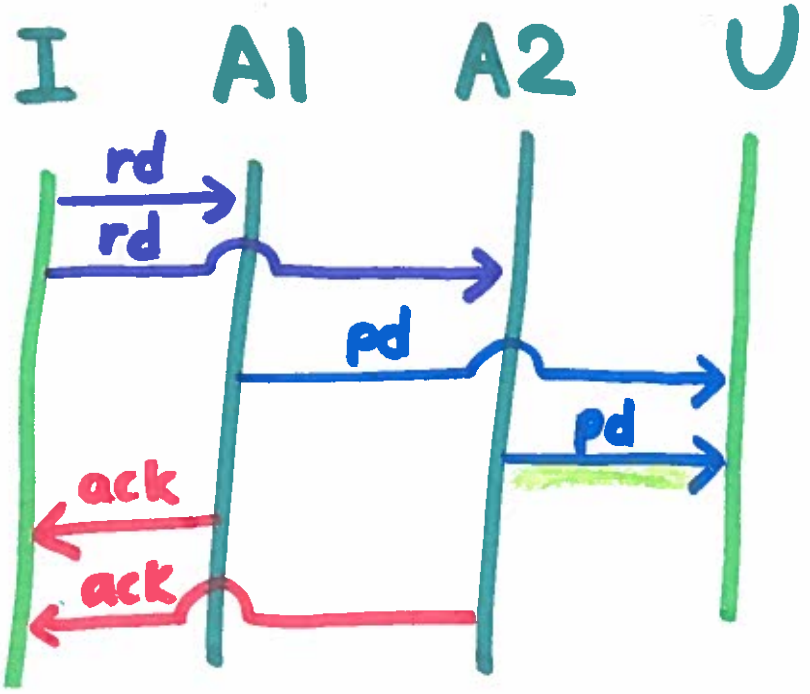
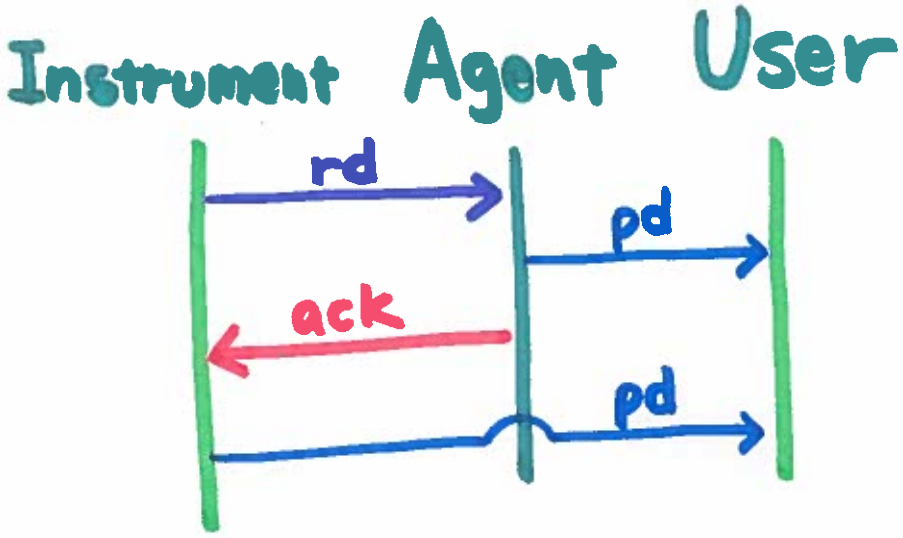
A2 → U: <pd>.
end



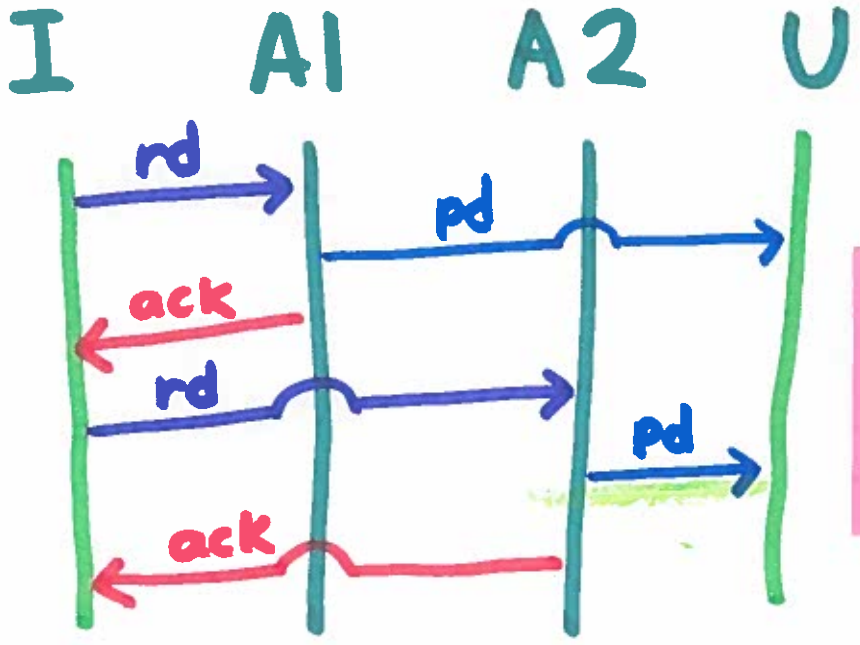




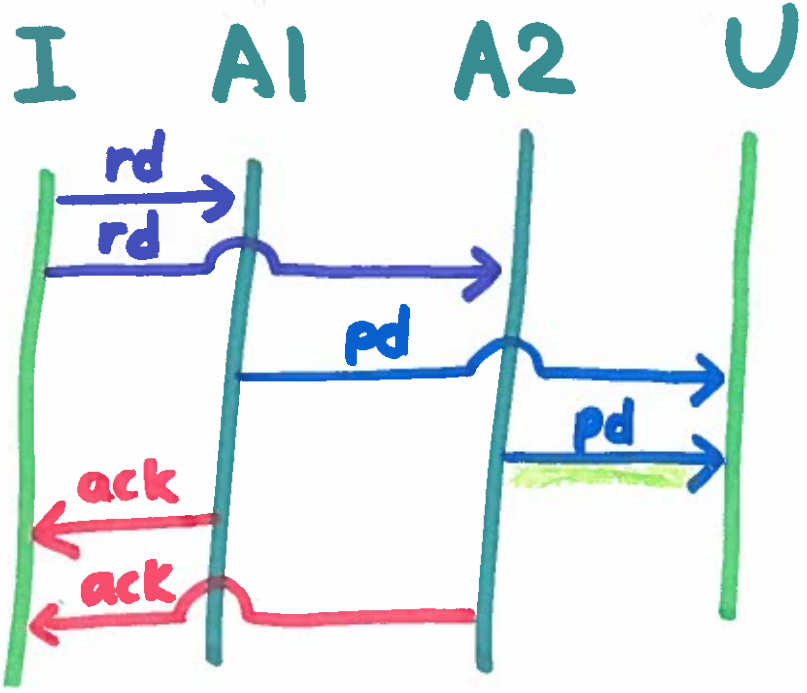
Usecase : UC.R2.13 "Acquire Data from Instrument" from Ocean Observatories Initiative (OOI)



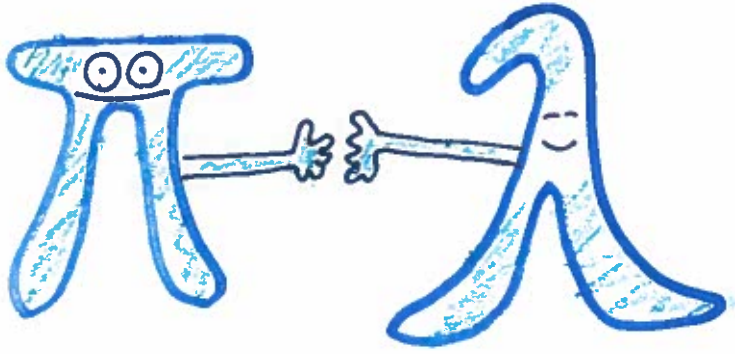
A1 → U : ⟨pd⟩.
A2 → U : ⟨pd⟩.
end



≈g



HOπ and TYPES

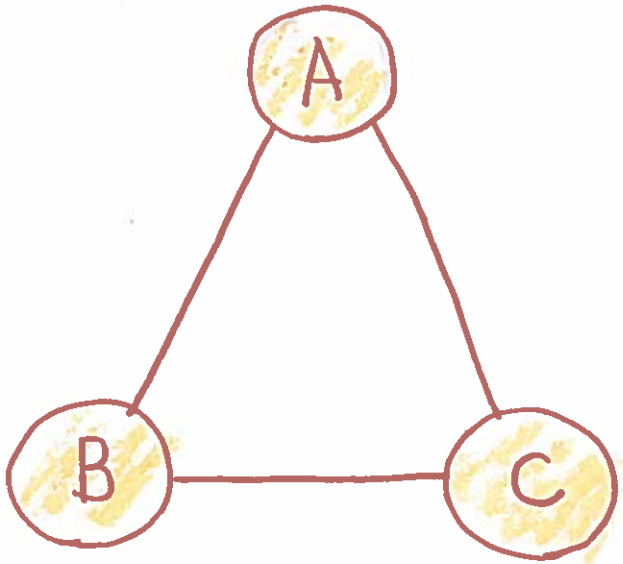


CONCUR 16 Characteristic Bisimulations

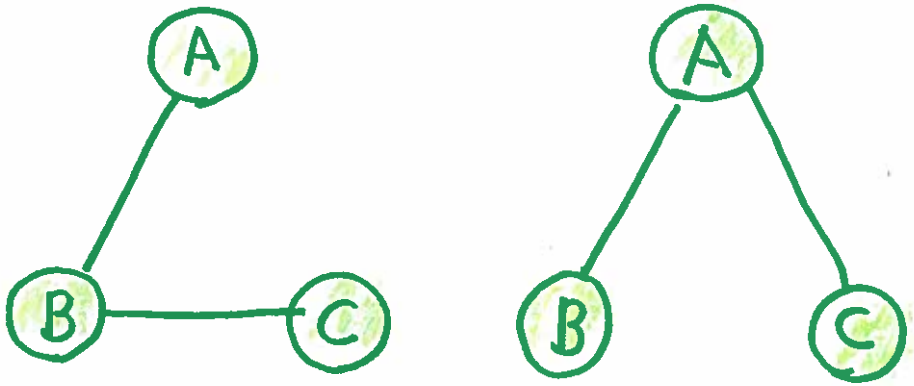
ESOP 16 Expressiveness

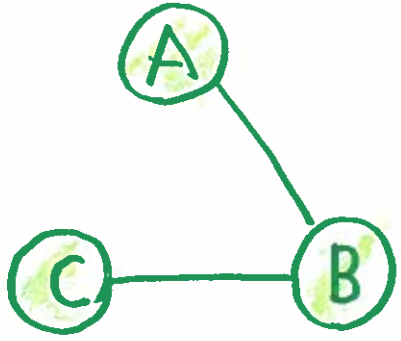
ACTA INFORMATICA

Interconnectability of Session Logical Processes



Multi Party

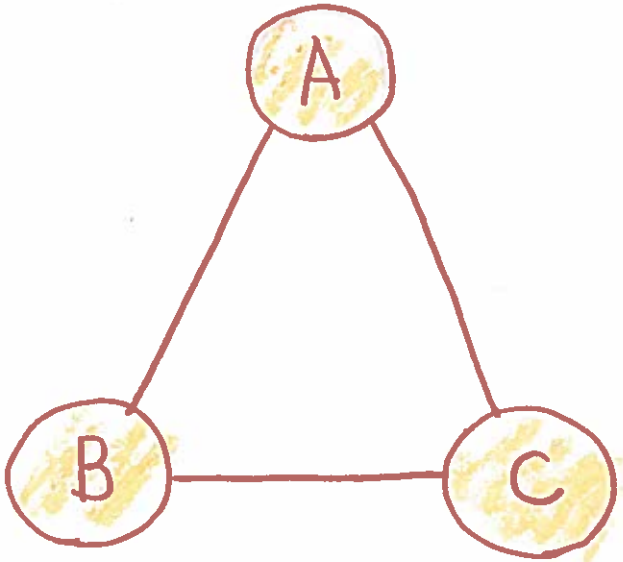




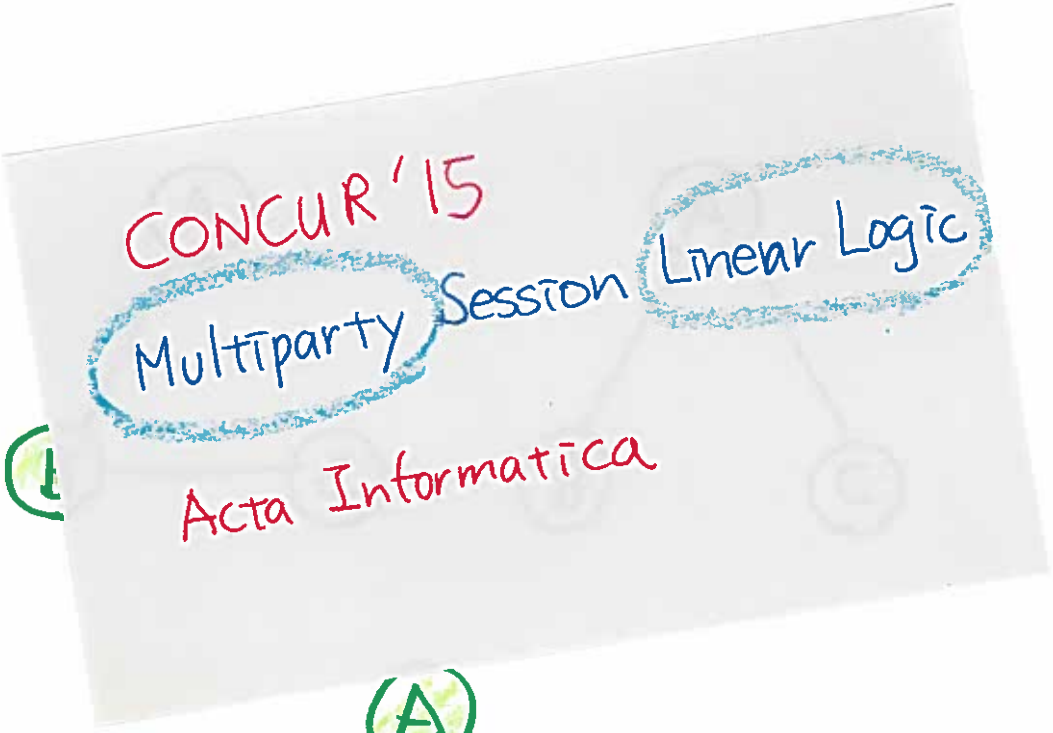
Linear Logical Session

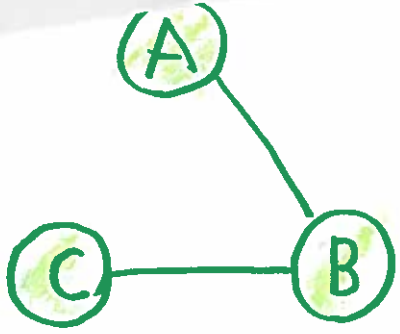
cf. [1995] Specification Structures and Proposition as Types

Interconnectability of Session Logical Processes



Multi Party





Linear Logical Session

cf. [1995] Specification Structures and Proposition as Types

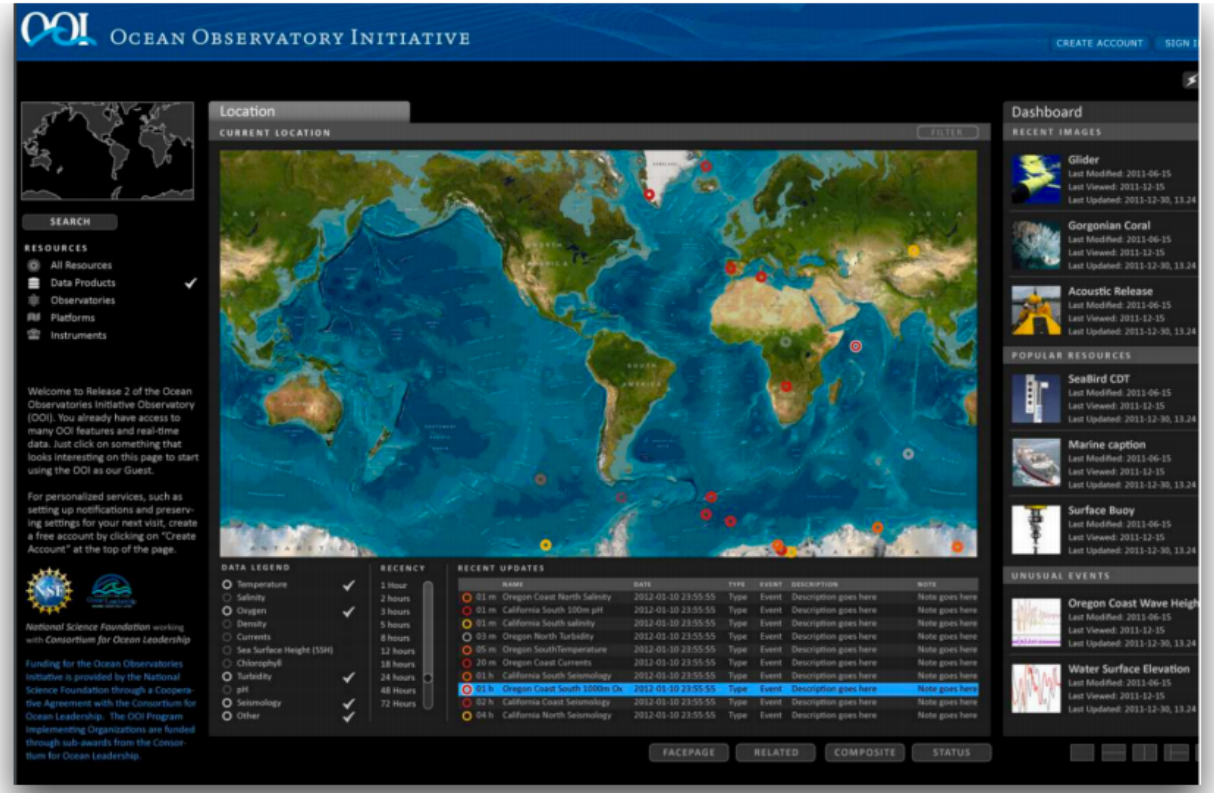
www.scribble.org

Online tool : http://scribble.doc.ic.ac.uk/

```
1  module examples;
2
3  global protocol HelloWorld(role Me, role World) {
4    hello() from Me to World;
5    choice at World {
6      goodMorning1() from World to Me;
7    } or {
8      goodMorning1() from World to Me;
9    }
10 }
11
```

Load a sample | Check | Protocol: examples.HelloWorld | Role: Me | Project | Generate Graph

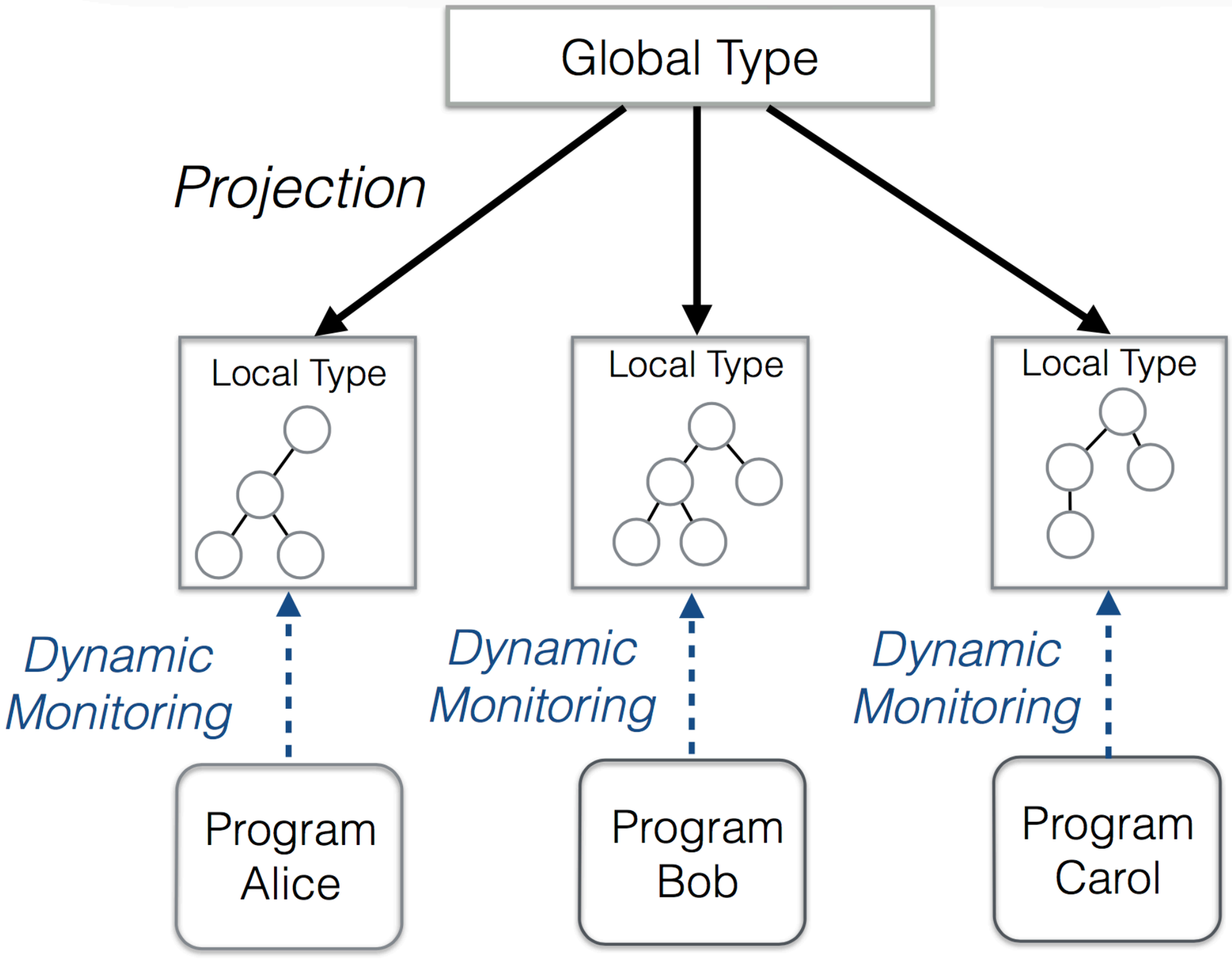
OOI Collaboration



- **TCS'16:** Monitoring Networks through Multiparty Session Types. Laura Bocchi , Tzu-Chun Chen , Romain Demangeon , Kohei Honda , Nobuko Yoshida
- **LMCS'16**: Multiparty Session Actors. Rumyana Neykova, Nobuko Yoshida
- **FMSD'15:** Practical interruptible conversations: Distributed dynamic verification with multiparty session types and Python. Romain Demangeon , Kohei Honda , Raymond Hu , Rumyana Neykova , Nobuko Yoshida
- **TGC'13:** The Scribble Protocol Language. Nobuko Yoshida , Raymond Hu , Rumyana Neykova , Nicholas Ng

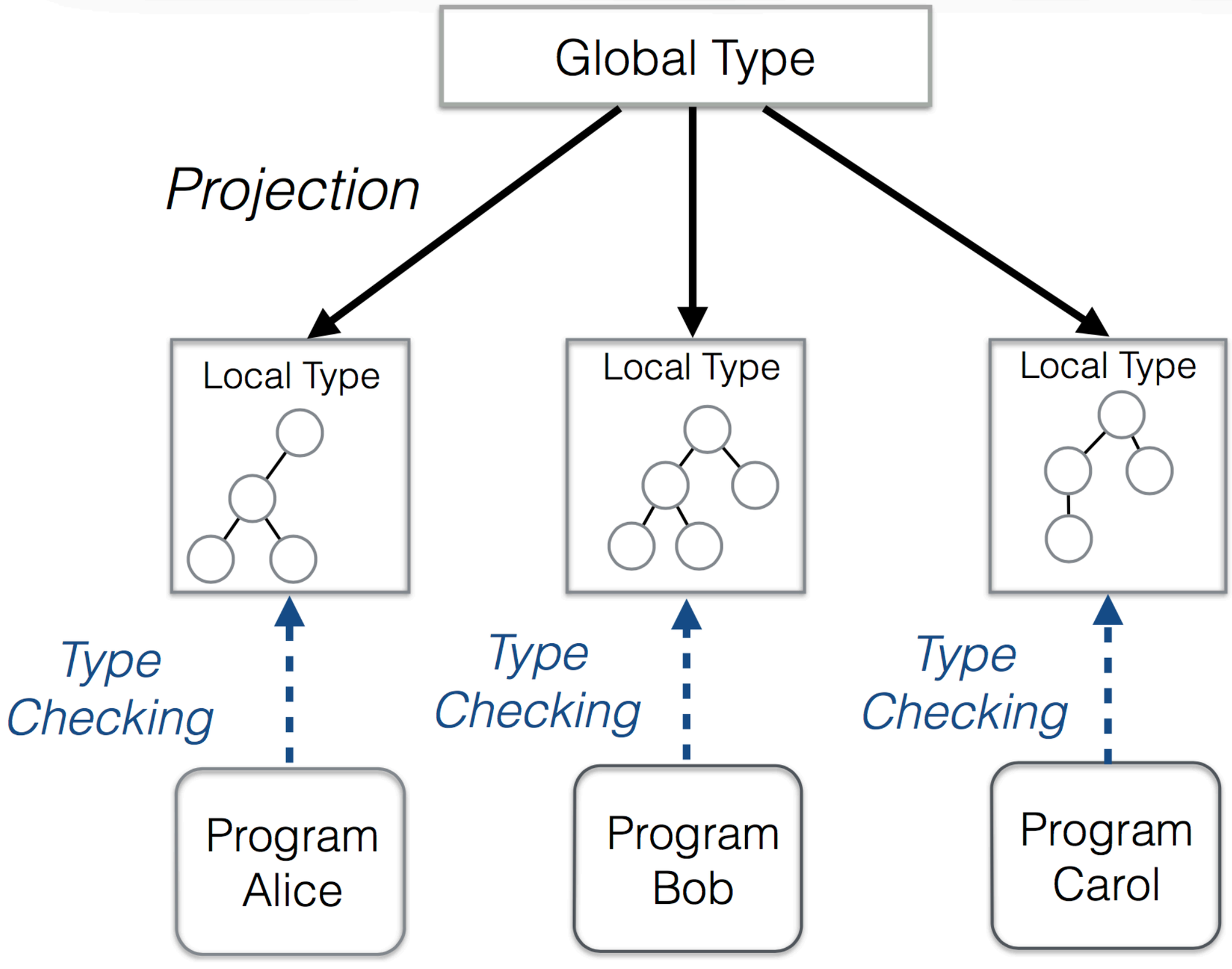
Dynamic Monitoring

[RV'13, COORDINATION'14, FMSD'15, LMCS'17, CC'17]



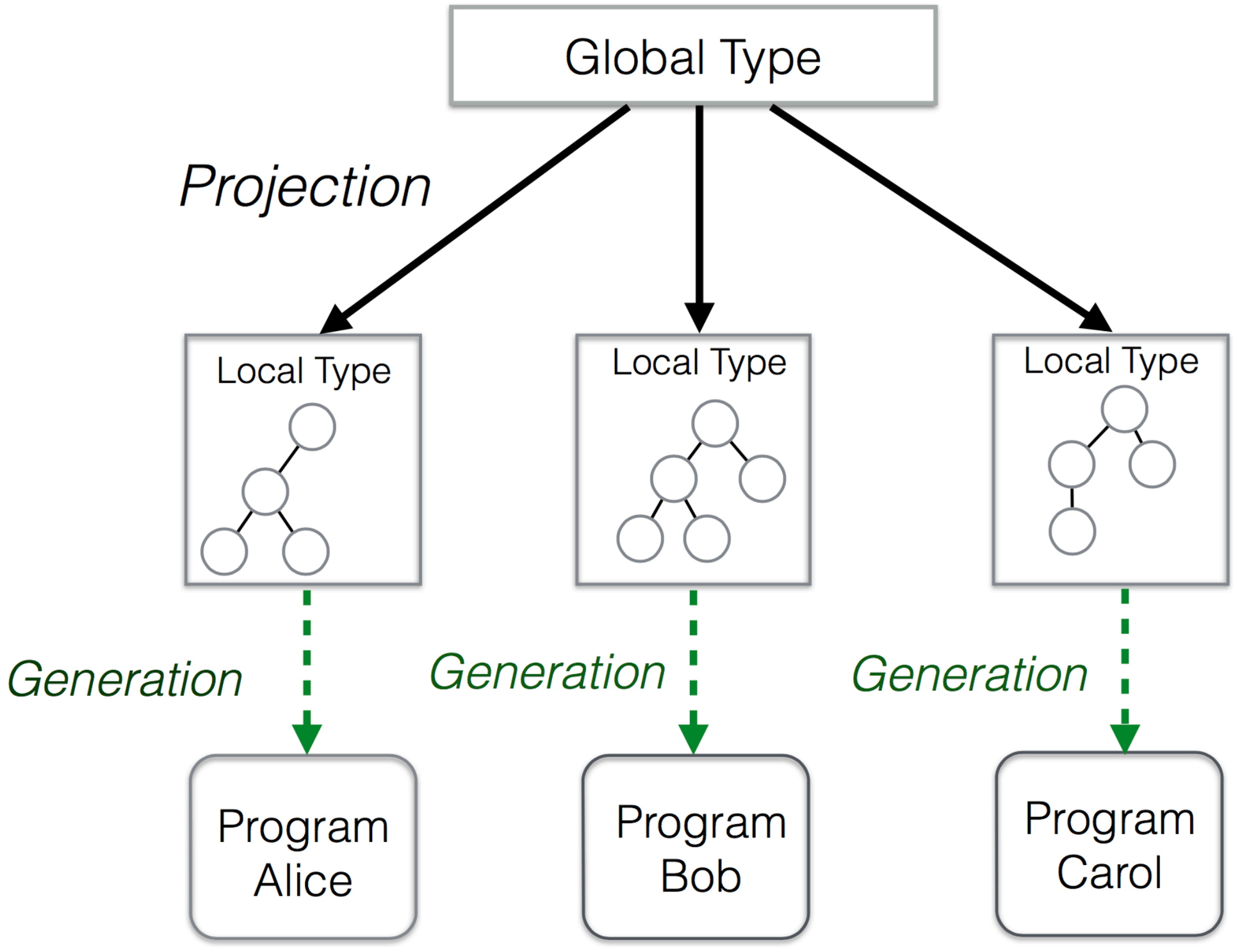
Type Checking

[OOPSLA'15, ECOOP'16, ECOOP'17, COORDINATION'17]



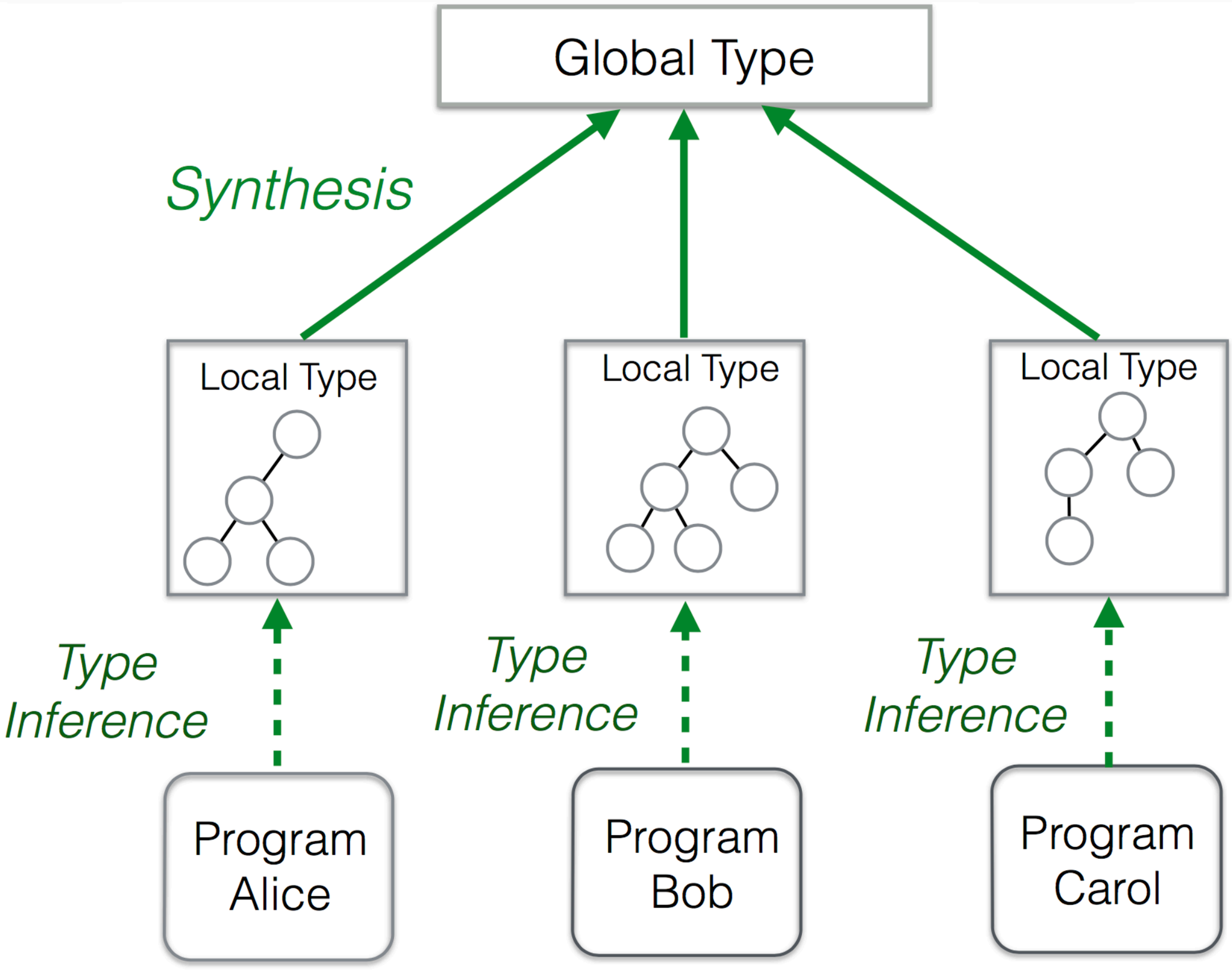
Code Generation

[CC'15, FASE'16, FASE'17]



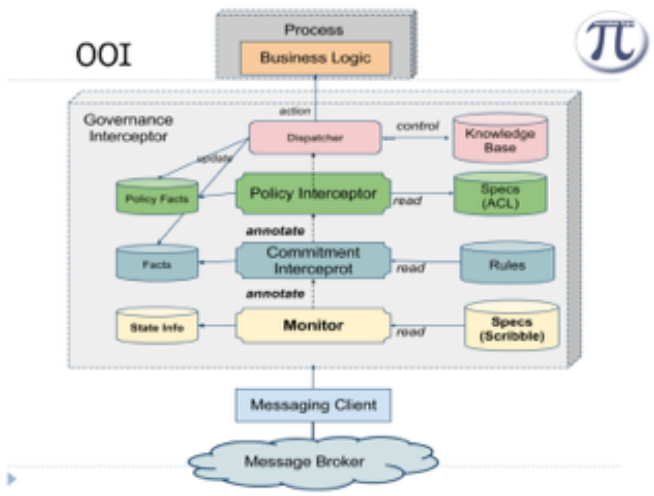
Synthesis

[ICALP'13, POPL'15, CONCUR'15, TACAS'16, CC'16]

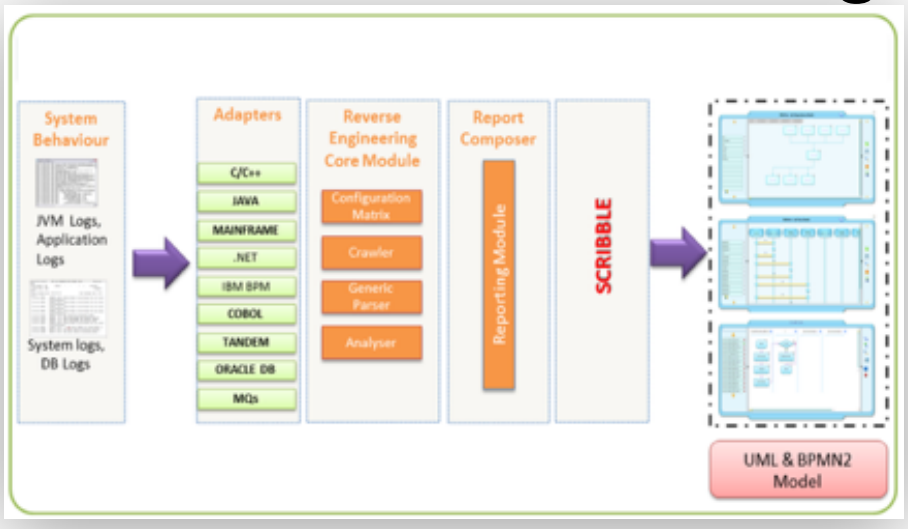


Session Type based Tools

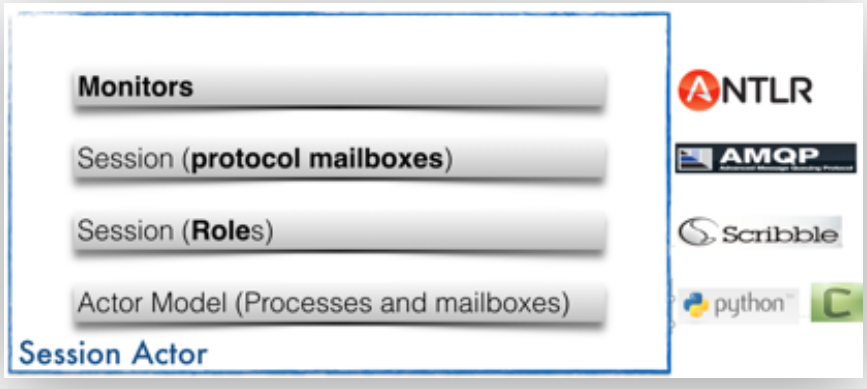
OOI Governance



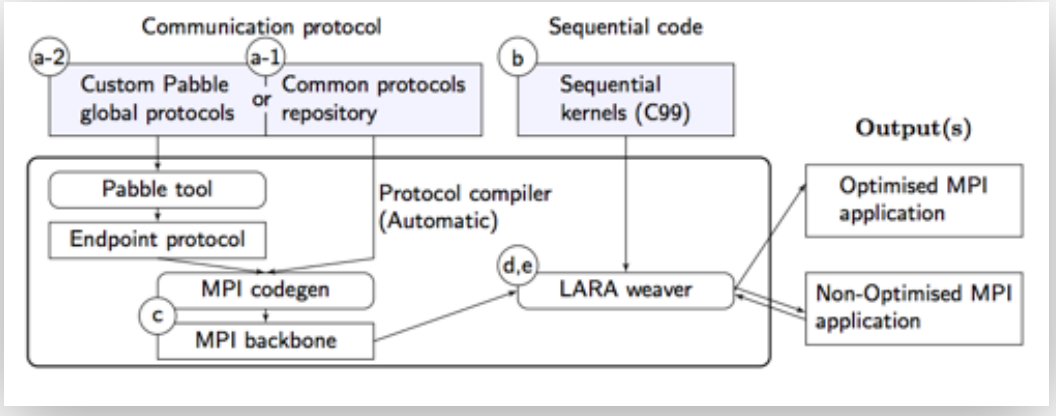
ZDLC: Process Modeling



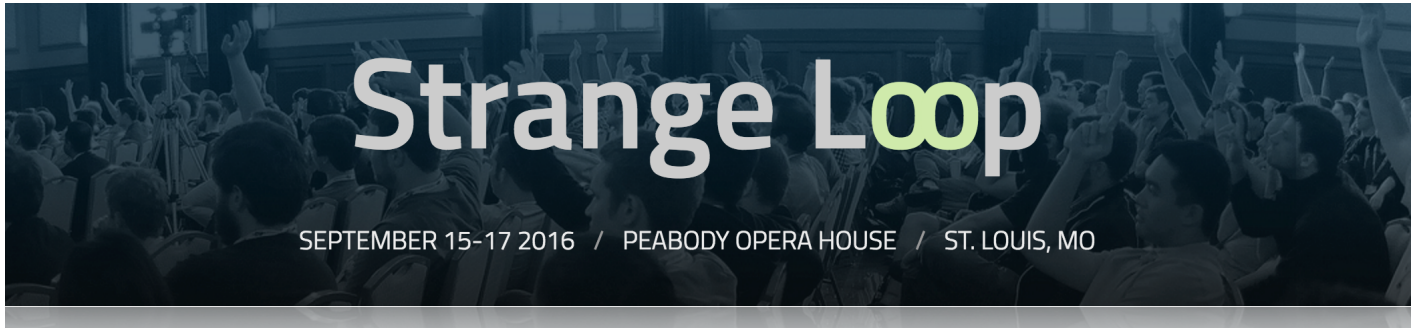
Actor Verification



MPI code generations



Interactions with Industries



Adam Bowen @adamnbowen · Sep 15
I didn't even know that session types existed an hour ago, but thanks to Nobuko Yoshida's great talk at **#pwlconf**, I want to learn more.

Nobuko Yoshida
Imperial College, London

DoC researcher to speak at Golang UK conference

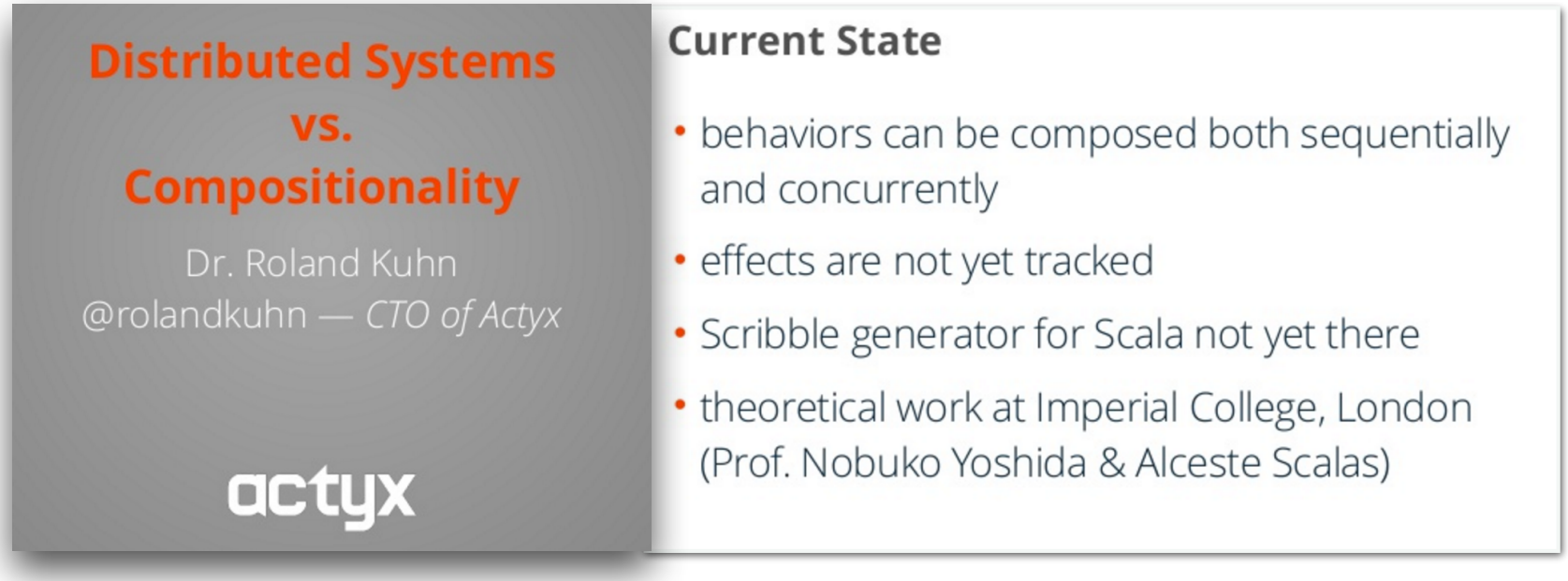
by Vicky Kapogianni
20 July 2016

DoC researcher to speak at industry-focused Golang UK conference on results of concurrency research

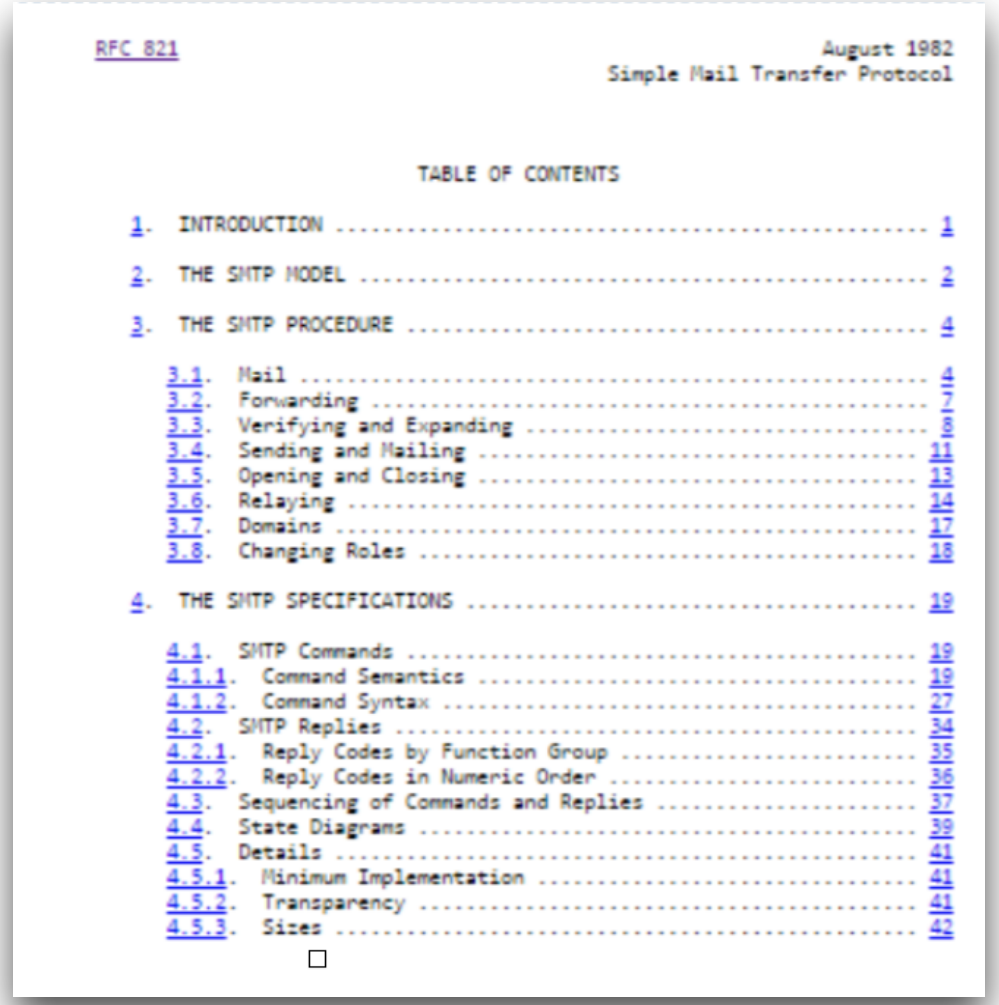
Click here to add content

.@nicholascwng rocking on @GolangUKconf about static deadlock detection in #golang #gouk16

Interactions with Industries



Java API Generation [FASE'16]



RFC 821 August 1982
Simple Mail Transfer Protocol

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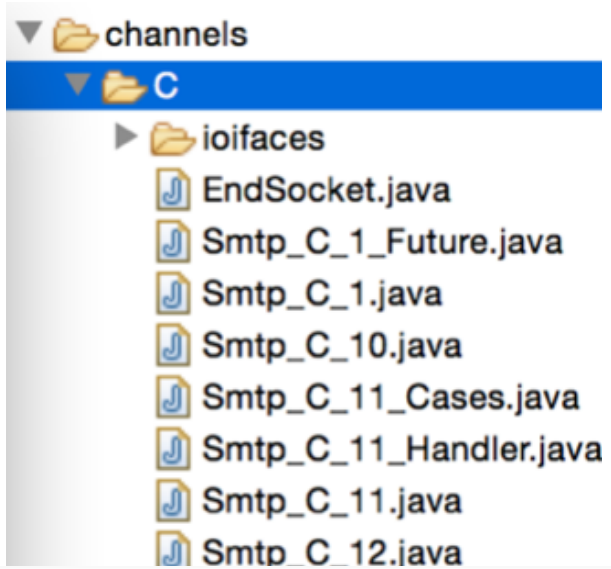



```
.send(Smtp.S, new DataLine("Session
.send(Smtp.S, new EndOfData())
.receive(Smtp.S, Smtp._250, new Buf
.s
```

send(S role, Mail m) : Smtp_C_11 - Smtp_C_10
send(S role, Quit m) : EndSocket - Smtp_C_10

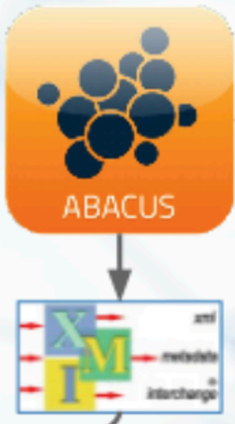
Scribble – Proving a distributed design

Estafet

Innovate | Deliver | Transform

1. All design work takes place in ABACUS, DCC's enterprise architecture tool. This can export standard XMI files (an open standard for UML5)

2. XMI is converted into OpenTracing format for consumption by managed service



7. Generate exception report and send back to DCC

3. OpenTracing files are combined to build a model in Scribble

4. Model holds *types* rather than *instances* to understand behaviour

5. Scribble compiler identifies inconsistency, change & design flaws

6. Issues highlighted graphically in Eclipse

www.estafet.com

Estafet Managed Service