Idioms for Interaction:
Functional Types, Process Types and Distributed Systems

http://mrg.doc.ic.ac.uk/

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

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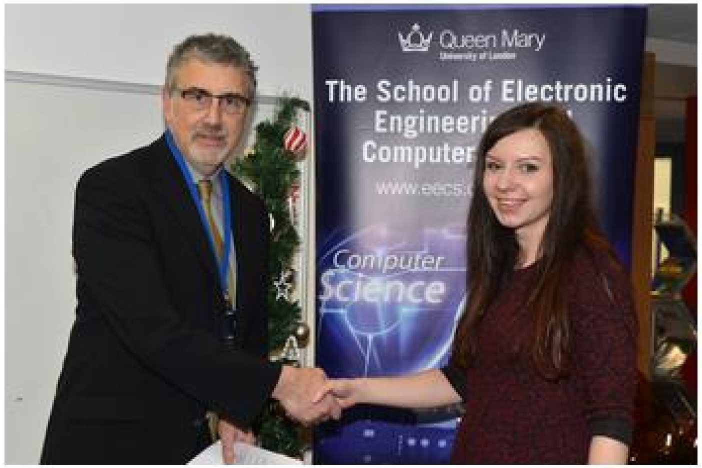
This prize was instituted in 2013 and is awarded annually to one undergraduate student and one postgraduate student in recognition of their achievement in applying the highest quality scientific and engineering principles in the broad area of Distributed Systems. This is the area in which Dr Honda concentrated 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

Outline

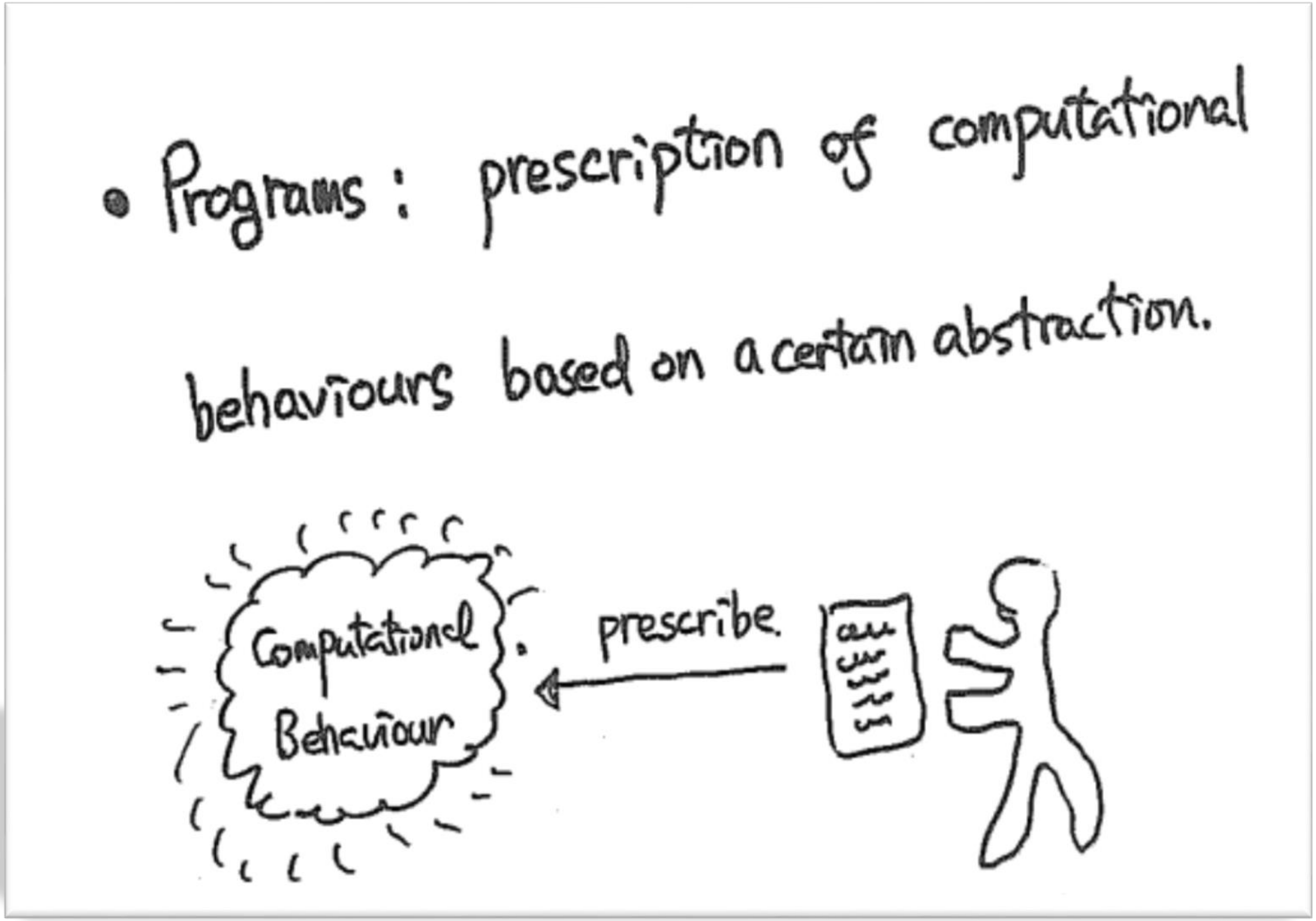
- Idioms for Interaction
- Multiparty Session Types
- Scribble and Applications to a Large-scale Cyberinfrastructure
- Recent Results on Multiparty Session Types

Idioms for Interaction

— Invitation to Hacking in 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.

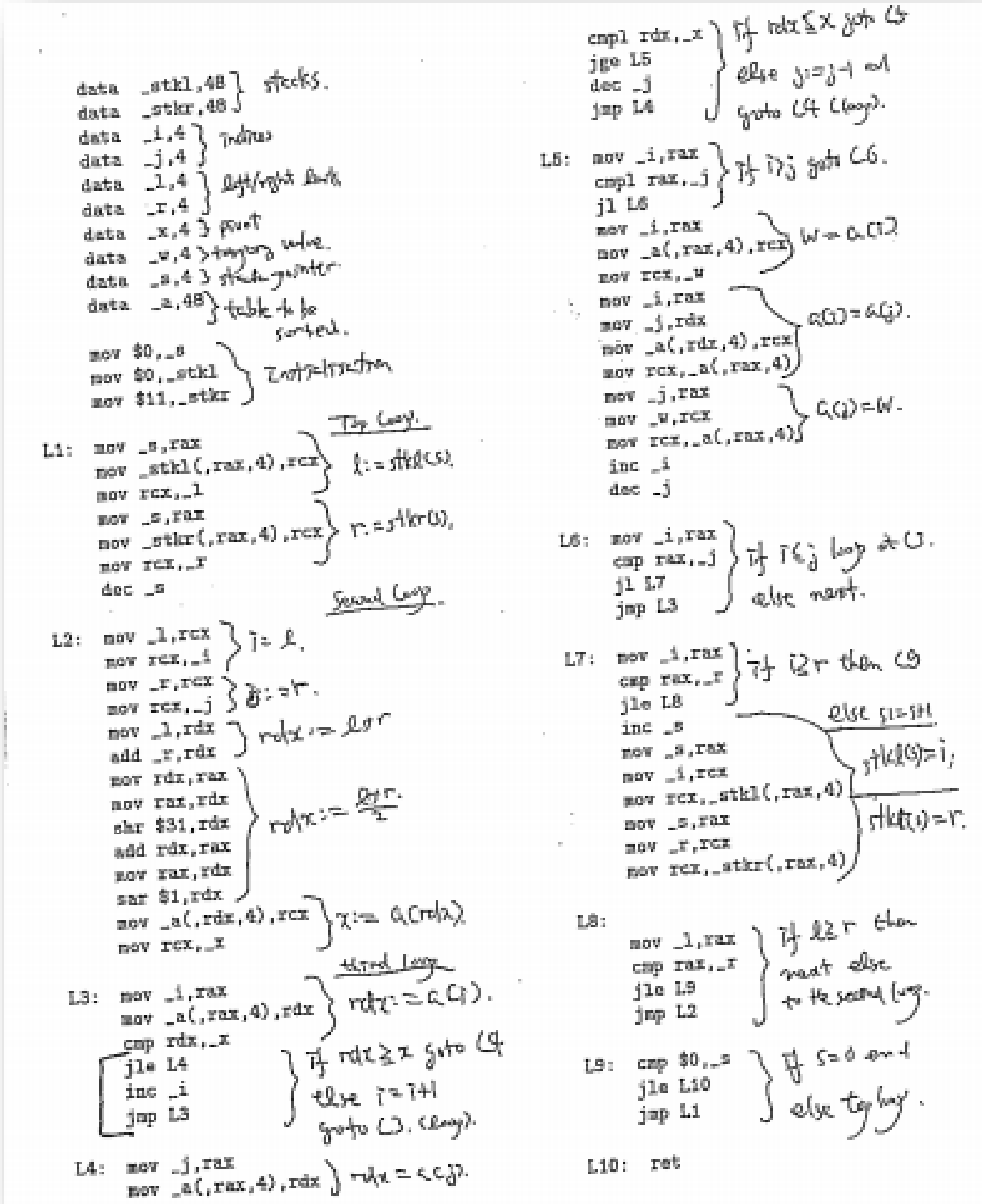
Logical: unification.

- Another element is how we can combine, or structure, these operations:

Imperative: sequential composition, if-then-else, while, procedures, module, ...

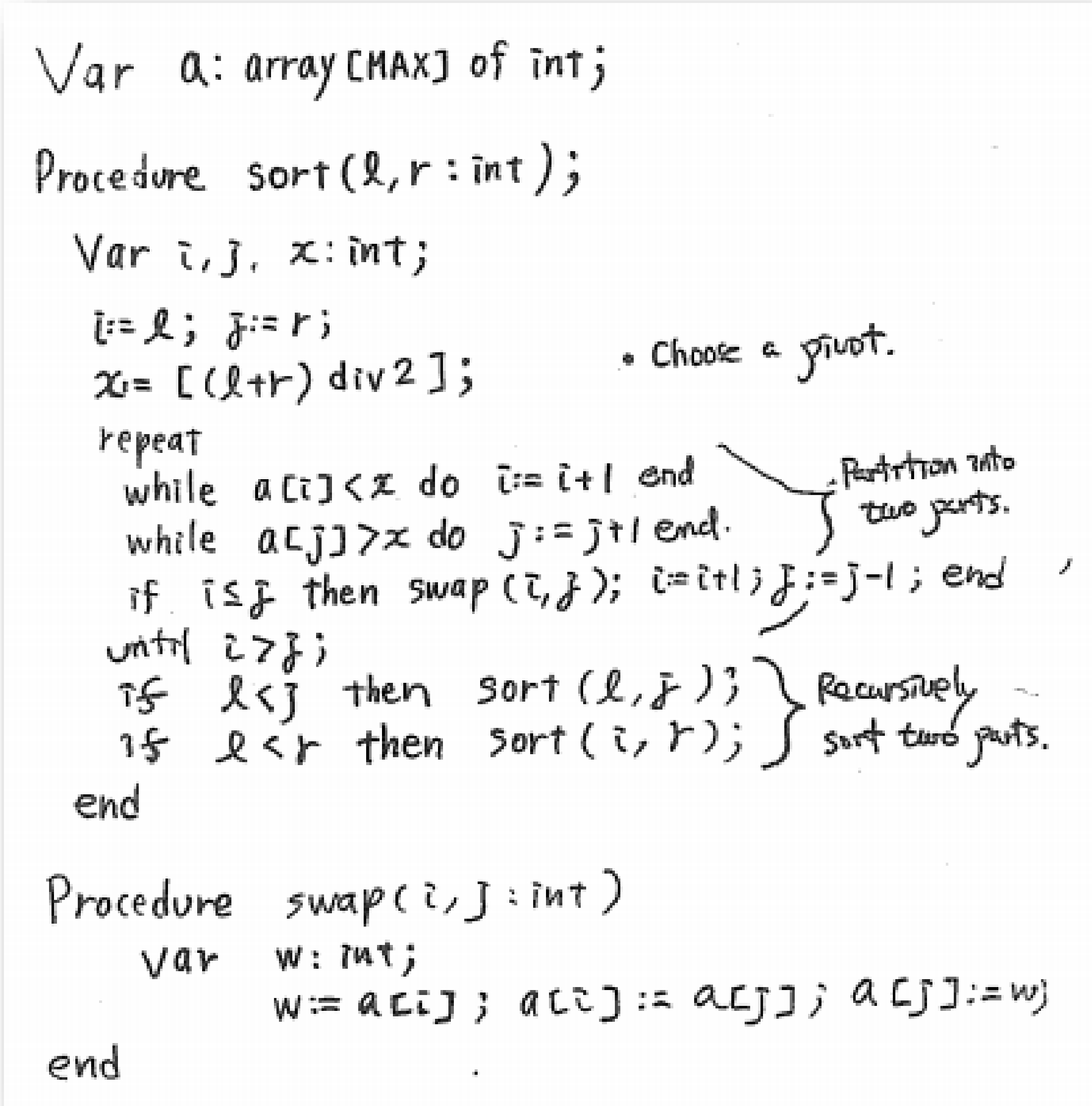
Functional: application, product, union, recursion, modules, ...

UNSTRUCTURED:



```
    data  _stkl,48 } stacks.
    data  _stkr,48 }
    data  _i,4 } indices
    data  _j,4 }
    data  _l,4 } left/right bounds
    data  _r,4 }
    data  _x,4 } pivot
    data  _w,4 } temporary value.
    data  _s,4 } stack pointer
    data  _a,48 } table to be sorted.

    mov $0,_s      }
    mov $0,_stkl   } Initialization
    mov $11,_stkr  }
                                      Top Loop.
L1: mov _s,rax                  }
    mov _stkl(,rax,4),rcx       } l:=stkl(s),
    mov rcx,_l                  }
    mov _s,rax                  }
    mov _stkr(,rax,4),rcx       } r:=stkr(s),
    mov rcx,_r                  }
    dec _s
                                      Second Loop.
L2: mov _l,rcx  } i:=l,
    mov rcx,_i  }
    mov _r,rcx  } j:=r.
    mov rcx,_j  }
    mov _l,rdx  } rdx:=l+r
    add _r,rdx  }
    mov rdx,rax }
    mov rax,rdx }
    shr $31,rdx } rdx:=(l+r)/2
    add rdx,rax }
    mov rax,rdx }
    sar $1,rdx  }
    mov _a(,rdx,4),rcx } x:=a(rdx)
    mov rcx,_x         }
                                      third Loop
L3: mov _i,rax          } rdx:=a(i).
    mov _a(,rax,4),rdx  }
    cmp rdx,_x
    jle L4   } if rdx≥x goto L4
    inc _i   } else i:=i+1
    jmp L3   } goto L3. (loop).

L4: mov _j,rax          } rdx=a(j).
    mov _a(,rax,4),rdx  }
    cmpl rdx,_x  } if rdx≤x goto L5
    jge L5       } else j:=j-1 and
    dec _j       } goto L4 (loop).
    jmp L4       }

L5: mov _i,rax   } if i>j goto L6.
    cmpl rax,_j  }
    jl L6        }
    mov _i,rax              } w=a(i)
    mov _a(,rax,4),rcx      }
    mov rcx,_w              }
    mov _i,rax              } a(i)=a(j).
    mov _j,rdx              }
    mov _a(,rdx,4),rcx      }
    mov rcx,_a(,rax,4)      }
    mov _j,rax              } a(j)=w.
    mov _w,rcx              }
    mov rcx,_a(,rax,4)      }
    inc _i
    dec _j

L6: mov _i,rax  } if i≤j loop at L3.
    cmp rax,_j  } else next.
    jl L7       }
    jmp L3      }

L7: mov _i,rax  } if i≥r then L9
    cmp rax,_r  }
    jle L8      }
    inc _s                  } else s:=s+1
    mov _s,rax              } stkl(s)=i;
    mov _i,rcx              }
    mov rcx,_stkl(,rax,4)   }
    mov _s,rax              } stkr(s)=r.
    mov _r,rcx              }
    mov rcx,_stkr(,rax,4)   }

L8:
    mov _l,rax  } if l≥r then
    cmp rax,_r  } next else
    jle L9      } to the second loop.
    jmp L2      }

L9: cmp $0,_s   } if s=0 end
    jle L10     } else top loop.
    jmp L1      }

L10: ret
```

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    } Partition into
      while a[j]>x do j:=j+1 end.   } 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:

$((\lambda xy.y(xxy))(\lambda xy.y(xxy)))\lambda q.\lambda l.$

$((\lambda x.x(\lambda xy.x))l)(\lambda x.x)$ } if l is nil then nil.

$(((\lambda xy.y(xxy))(\lambda xy.y(xxy))(\lambda c.\lambda xy.x((\lambda x.x(\lambda xy.x))x)y$

$((\lambda xy.\lambda z.z(\lambda xy.y)xy)((\lambda x.x(\lambda xyz.y))x)(c((\lambda x.x(\lambda xyz.z))x)y$ } concat.

$(q(\lambda xy.y(xxy))(\lambda xy.y(xxy))(\lambda f.\lambda px.((\lambda x.x(\lambda xy.x))x)(\lambda x.x)$

$(p((\lambda x.x(\lambda xyz.y))x))((\lambda xy.\lambda z.z(\lambda xy.y)xy)x$

$(f((\lambda x.x(\lambda xyz.z))x)))(f((\lambda x.x(\lambda xyz.z))x)))$ } sort and Filter

$(\lambda y.(((\lambda xy.y(xxy))(\lambda xy.y(xxy)))\lambda f'.\lambda xy.((\lambda x.x\lambda xy.x)y)$ } $(\lambda y.$ LT $y.$ Car

$(\lambda xy.y)(((\lambda x.x\lambda xy.x)x)(\lambda xy.y)(f'((\lambda x.x\lambda xy.y)x)((\lambda x.x\lambda xy.y$

$y((\lambda x.x(\lambda xyz.y))l))((\lambda x.x(\lambda xyz.z))l)$ } cdr l

$((\lambda xy.\lambda z.z(\lambda xy.y)xy)((\lambda x.x(\lambda xyz.y))l)$ } Cons (Car l)

$(q((\lambda xy.y(xxy))(\lambda xy.y(xxy))(\lambda f.\lambda px.((\lambda x.x(\lambda xy.x))x)$

$(\lambda x.x)(p((\lambda x.x(\lambda xyz.y))x))((\lambda xy.\lambda z.z(\lambda xy.y)xy)x$

$(f((\lambda x.x(\lambda xyz.z))x)))(f((\lambda x.x(\lambda xyz.z))x)))$ } sort and Filter

$(\lambda y.((\lambda xy.y(xxy))(\lambda xy.y(xxy)))\lambda f''.\lambda xy.((\lambda x.x\lambda xy.x)x)$

$(((\lambda x.x\lambda xy.x)y)(\lambda xy.x)(\lambda xy.y))$

$(((\lambda x.x\lambda xy.x)y)(\lambda xy.x)(f''((\lambda x.x\lambda xy.y)x)$ } $\lambda y.$ Me y Car l

$((\lambda x.x\lambda xy.y)y)))y((\lambda x.x(\lambda xyz.y))l))((\lambda x.x(\lambda xyz.z))l)))))$. } Cdr l

Quicksort with combinators:

Y (λf. λl.

  (Isnil l)

  (Concat (f Filter (λy. LT y (Car l))
                              (Cdr l))

      (Cons (Car l)
          (f Filter (λy. ME y
                                  (Car l)
                              (Cdr l)))))

I = λx.x T = λxy.x F = λxy.y Y = (λxy.y(xxy))(λxy.y(xxy))

Cons = λxy.λz.zFxy Isnil = λx.xT

Car = λx.x(λxyz.y) Cdr = λx.x(λxyz.z)

Concat = Y (λc.λxy.x (Isnil x) y (Cons (Car x)(c (Cdr x) y)

Filter = Y(λf.λpx.(Isnil x) I (p (Car x)) (Cons x (Filter (Cdr x)))
                                        (Filter (Cdr x))

Iszero = λx.xT Pred = λx.xF

LT = Y (λf.λxy.(Iszero y) F ((Iszero x) T (f (Pred x)(Pred y

ME = Y (λf.λxy.(Iszero x)((Iszero y) I F)((Iszero y)(T) y))
f (Pred x)(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

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

$\pi \quad P ::= \Sigma \pi_i.P_i \mid P|Q \mid (\nu x)P \mid !P \mid 0.$

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

λ in π

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

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

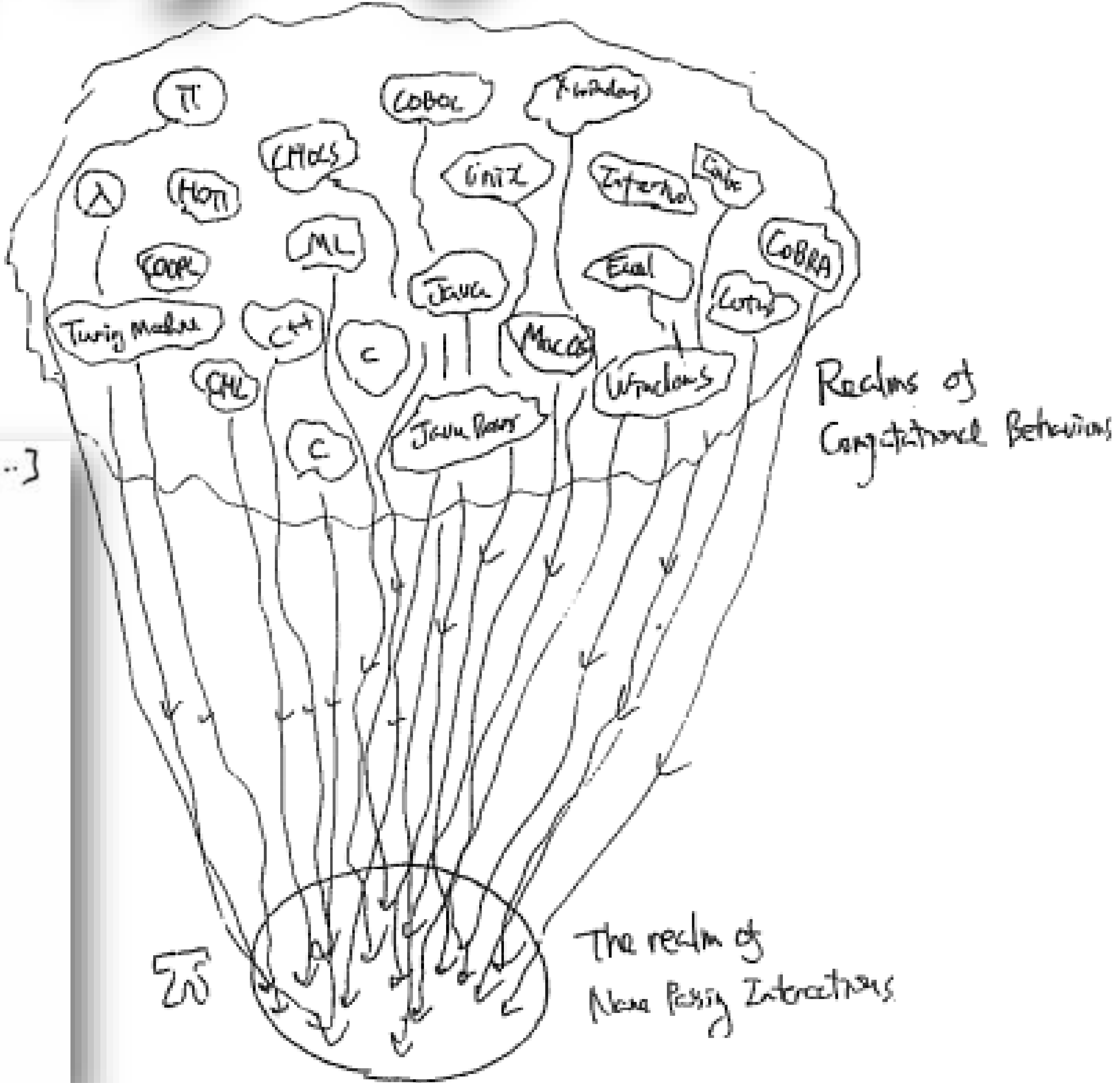
$$[\![MN]\!]_u \stackrel{\text{def}}{=} (\nu f x)\left([\![M]\!]_f \mid \bar{f}\langle x u \rangle \mid [\![x = N]\!]\right)$$

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 [HY94]
- 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

with operation:

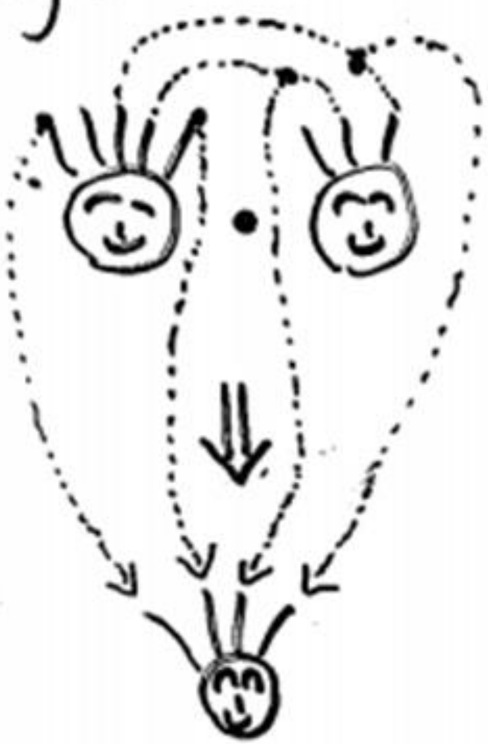
function application.

$$\begin{cases} f:\alpha\Rightarrow\beta \bullet e:\alpha = f\bullet e : \beta. \\ \text{else undefined.} \end{cases}$$

Process Types

- When it comes to processes, composition becomes:

e.g.



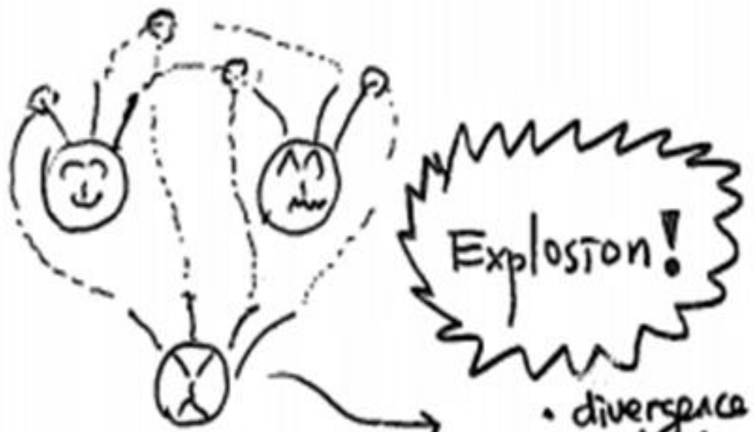
3 + 5

⇓

8

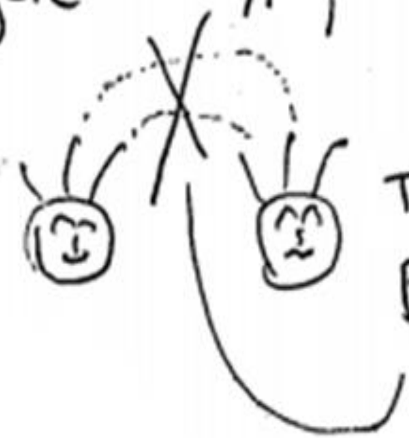
$P \bullet_\delta \delta \longmapsto_\tau \sigma$

- But some composition is dangerous!



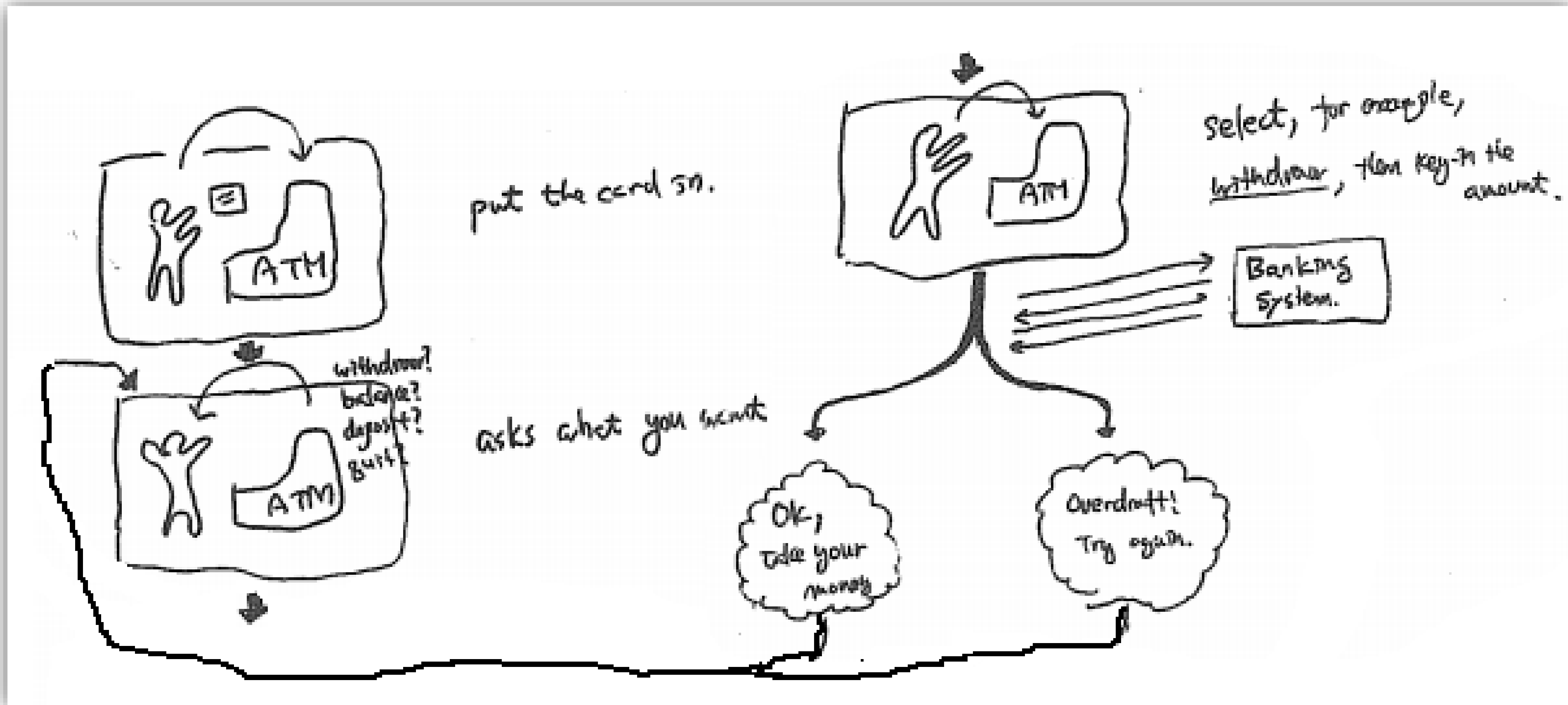
- divergence
- deadlock
- run-time error
- ⋮

- Therefore we type processes,



The connection is prohibited

Implementing ATM



Implementing ATM

```
ATM(cb) ≝

z.⟨z⟩:: z?ID; [?wd; ?X;                       * ↔ user.
          b̄⟨w⟩:: w!wt; !ID; !X;                * ↔ bank.
            [?ok;                              *  :
               z!ok; !X; ATM⟨cb⟩,              * ↔ user
             ?overdraft:                       * ↔ bank
               z!over; ATM⟨cb⟩],               * ↔ user.
        ?bal;                                  * ↔ user
          b̄⟨w⟩:: w!bal; ?X;                    * ↔ bank
               z!X; ATM⟨cb⟩]
```

ENCODING

[illegible]

Current: Communication is Ubiquitous

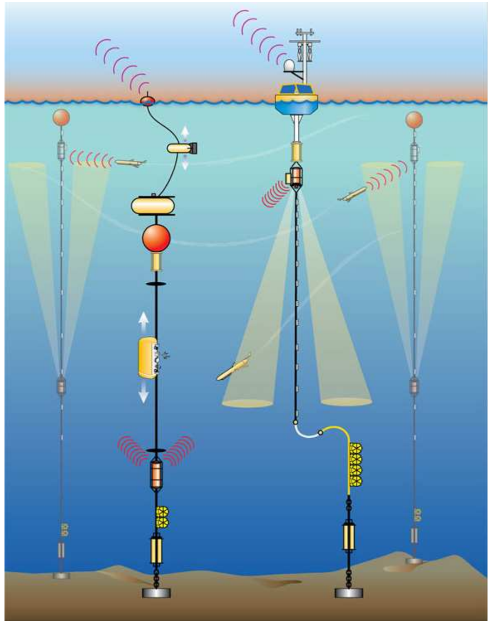
- The way to organise software is increasingly based on communications (Cloud Computing, many cores, message-passing parallel computation, ...)
- Question
  - How to formally abstract/specify/implement/control communications?
  - How to apply mobile processes and their type theories to real distributed applications and programming languages?

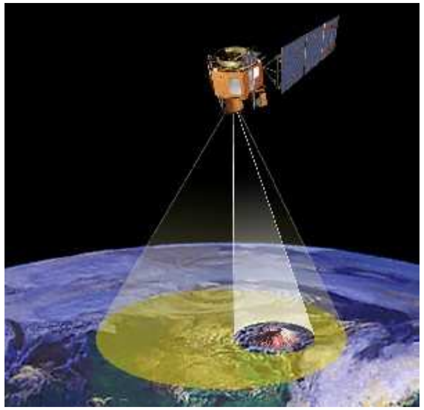
Current: Communication is Ubiquitous

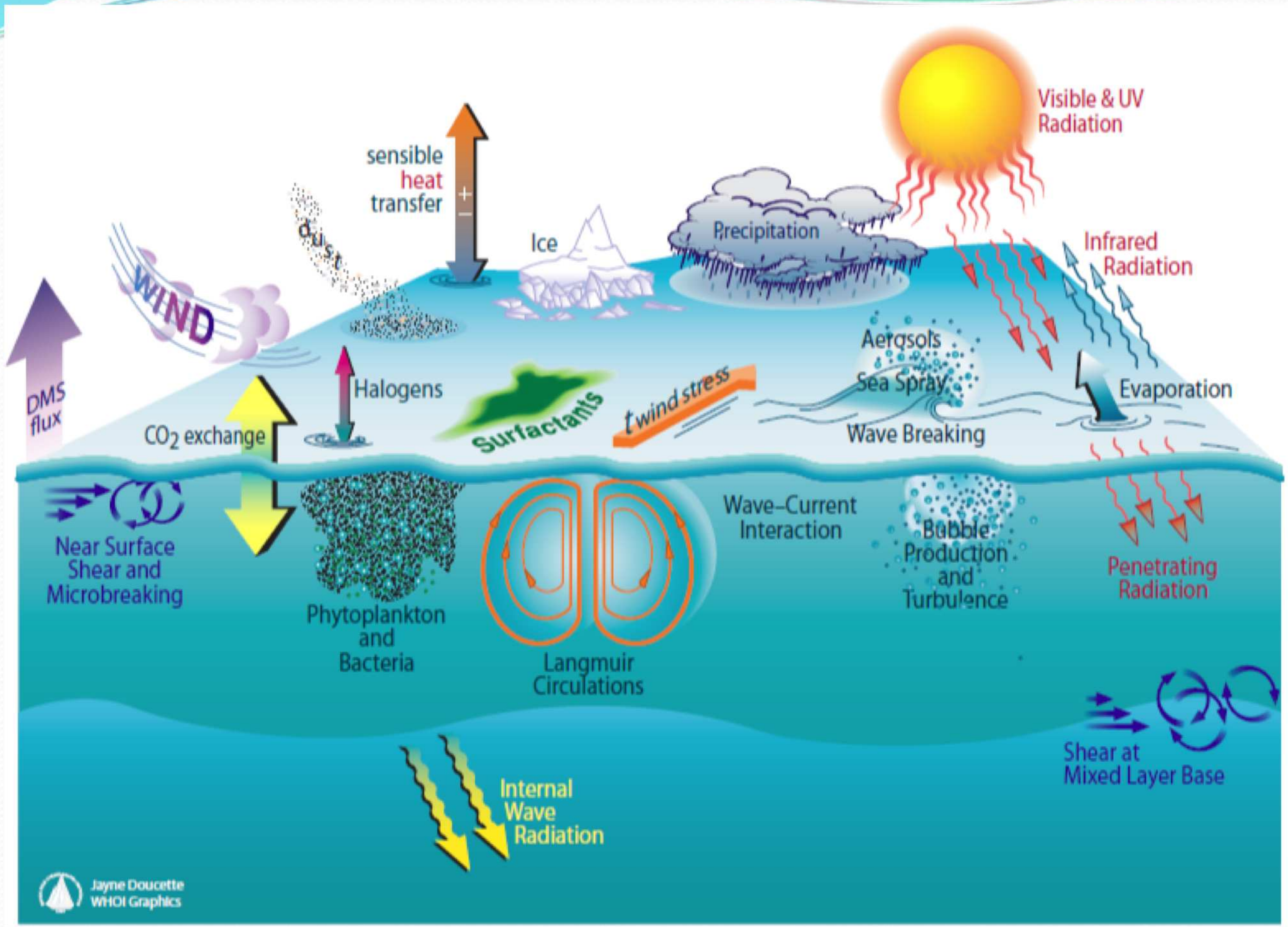
- The way to organise software is increasingly based on communications (Cloud Computing, many cores, message-passing parallel computation, ...)
- Question $\Longrightarrow$ Multiparty session type theory
  - How to formally abstract/specify/implement/control communications?
  - How to apply mobile processes and their type theories to real distributed applications and programming languages?
    $\Longrightarrow$ large-scale cyberinfrastructure for e-Science

Ocean Observatories Initiative

- A NSF project (400M$, 5 Years) to build a cyberinfrastructure for observing oceans around US and beyond.
- Real-time sensor data constantly coming from both off-shore and on-shore (e.g. buoys, submarines, under-water cameras, satellites), transmitted via high-speed networks.

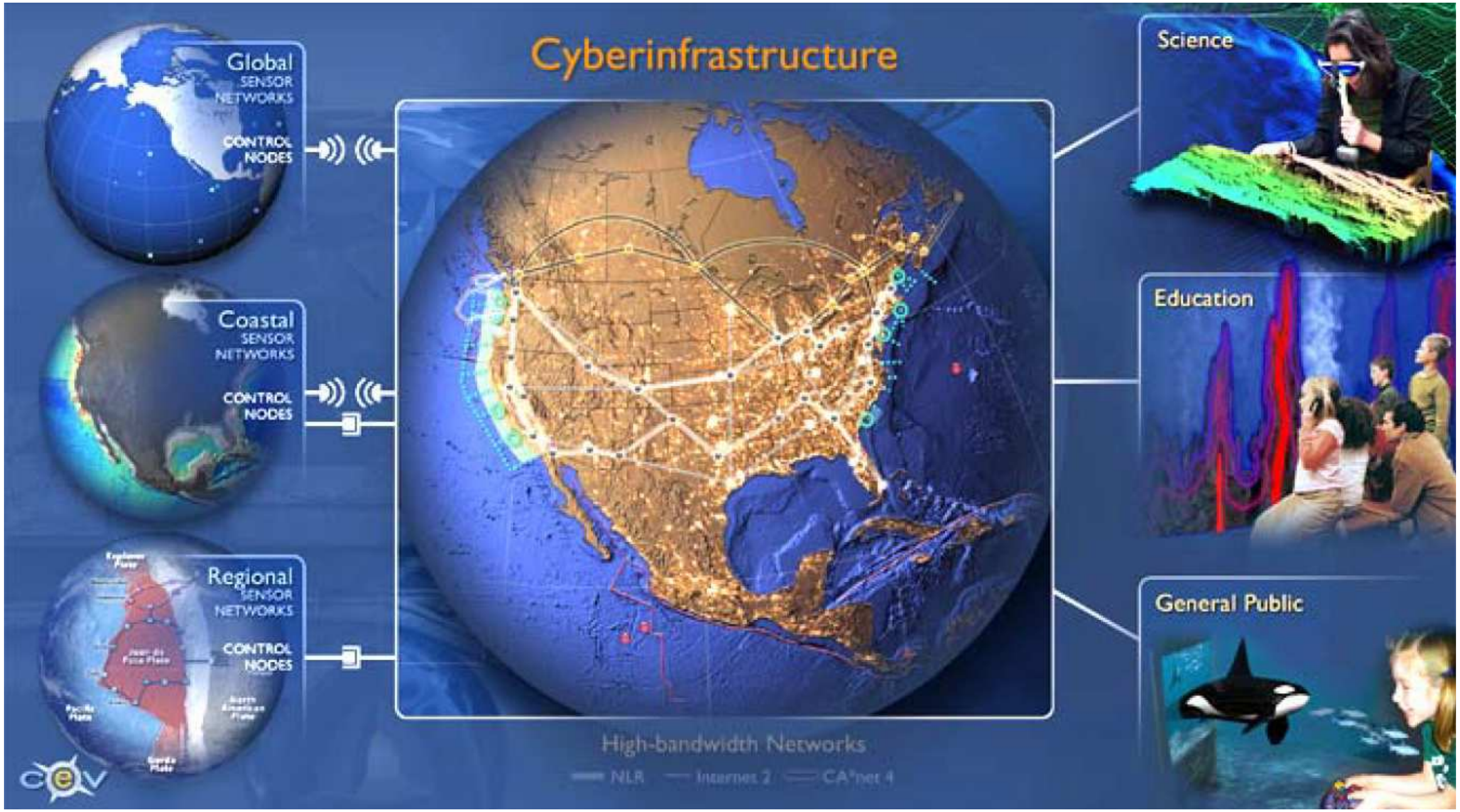


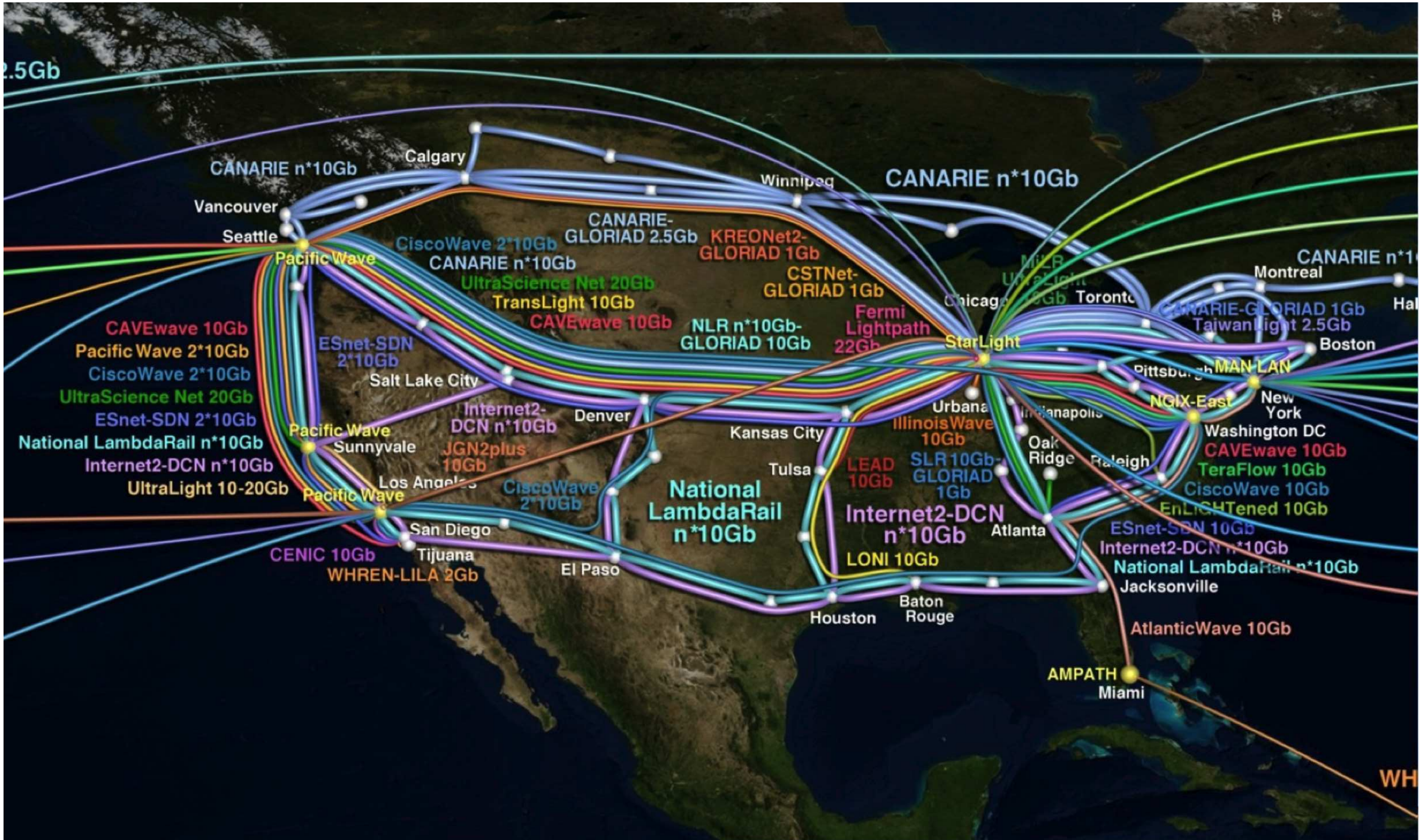




sensible
heat
transfer
Visible & UV
Radiation
dust
Ice
Precipitation
Infrared
Radiation
WIND
Aerosols
Sea Spray
DMS
flux
Halogens
Surfactants
τ wind stress
Evaporation
CO2 exchange
Wave Breaking
Wave–Current
Interaction
Near Surface
Shear and
Microbreaking
Bubble
Production
and
Turbulence
Penetrating
Radiation
Phytoplankton
and
Bacteria
Langmuir
Circulations
Shear at
Mixed Layer Base
Internal
Wave
Radiation
Jayne Doucette
WHOI Graphics

Ocean Observatories Initiative





Ocean Observatories Initiative

Challenges

- The need to specify, catalogue, program, implement and manage *multiparty message passing protocols*.
- Communication assurance
  - Correct message ordering and synchronisation
  - Deadlock-freedom, progress and liveness
  - Dynamic message monitoring and recovery
  - Logical constraints on message values
- Shared and used over a long-term period (e.g. 30 years in OOI).

Why Multiparty Session Types?

- Robin Milner (2002): *Types are the leaven of computer programming; they make it digestible.*

  $\Longrightarrow$ Can describe communication protocols as *types*

  $\Longrightarrow$ Can be materialised as *new communications programming languages* and *tool chains*.

- *Scalable* automatic verifications (deadlock-freedom, safety and liveness) without *state-space explosion problems* (*polynomial time complexity*).

- Extendable to *logical verifications* and flexible *dynamic monitoring*.

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 π4 Technology

Pi calculus versus Petri nets: Let us eat "humble pie" rather than further inflate the "Pi hype"

W.M.P. van der Aalst

Abstract. In the context of *Web Service Composition Languages* (WS-CLs) there is on ongoing debate on the best foundation for *Process-Aware Information Systems* (PAISs): *Petri nets* or *Pi calculus*. Example of PAISs are Workflow Management (WFM), Business Process Management (BPM), Business-to-Business (B2B), Customer Relationship Management (CRM), Enterprise Resource Planning (ERP) systems. Clearly, the web-service paradigm will change the architecture of these systems dramatically. Therefore, triggered by industry standards such as SOAP, WSDL, UDDI, etc., standards are being proposed for orchestrating web services. Examples of such WSCLs are BPEL4WS, BPML, WSFL, WSCI, and XLANG. In the debate on Petri nets versus Pi calculus many players in the "WSCL marketplace" are using demagogic arguments not based

Petri-Pi Working Group led by R. Milner and W.M.P van der Aalst started in 2003

Beginning: Petri-Pi

From: Robin Milner

Date: Wed, February 11, 2004 1:02 pm

Steve

Thanks for that. I believe the pi-calculus team ought to be able to do something with it -- you seem to be taking it in that direction already.

Nobuko, Kohei: I thought we ought to try to model use-cases in pi-calculus, with copious explanations in natural language, aiming at seeing how various concepts like role, transaction, .. would be modelled in pi. I am hoping to try this one when I get time; you might like to try too, and see if we agree!

Robin

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;
        }
    }
}
```

Dr Gary Brown (Pi4 Tech) in 2007

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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$\Downarrow$

Scribble at π4 Technology

$\Downarrow$

Multiparty Session Types [POPL'08]

$\Downarrow$

Dialogue between Industry and Academia

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$\Downarrow$

Formalisation of W3C WS-CDL [ESOP'07]

$\Downarrow$

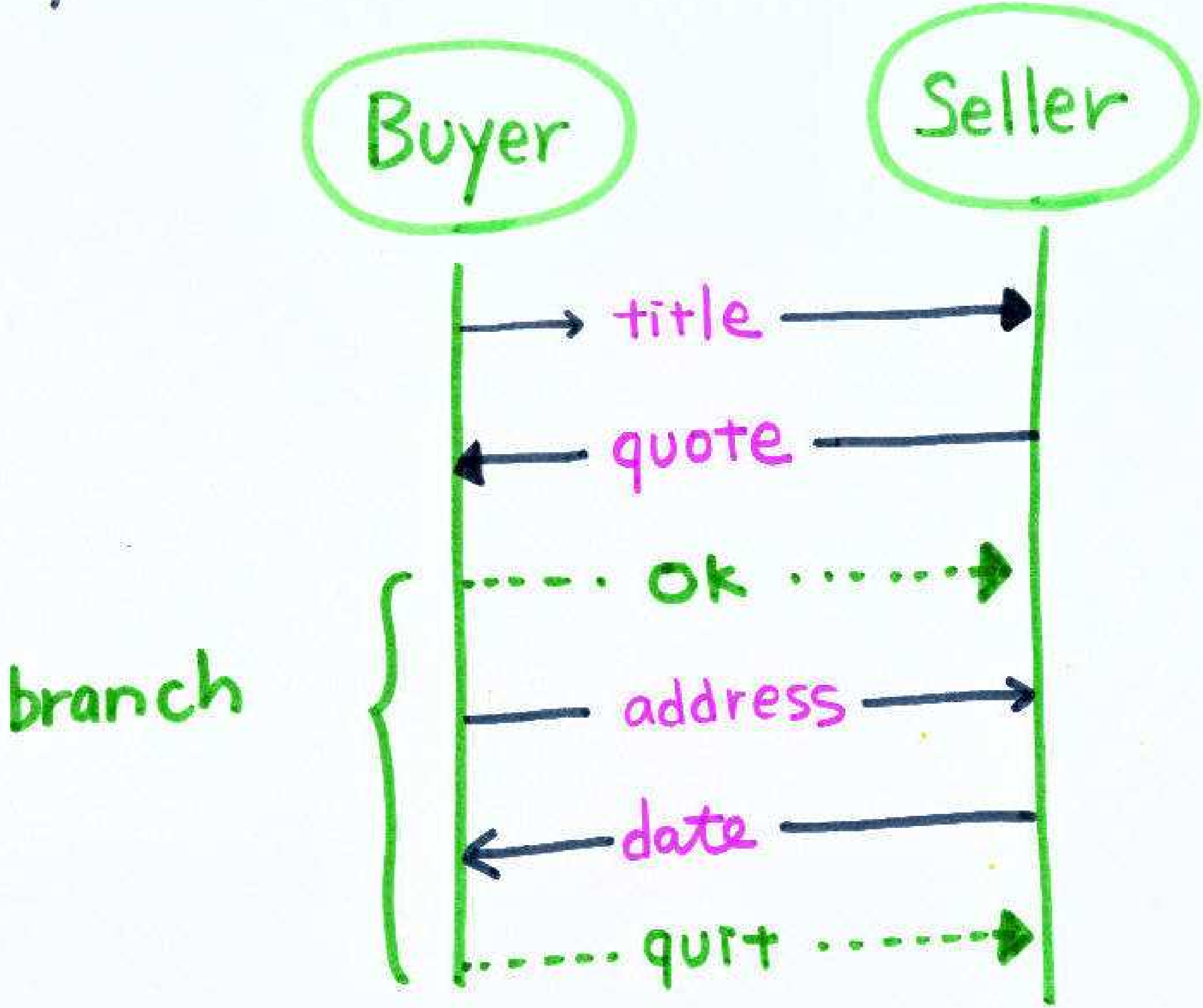
Scribble at π4 Technology

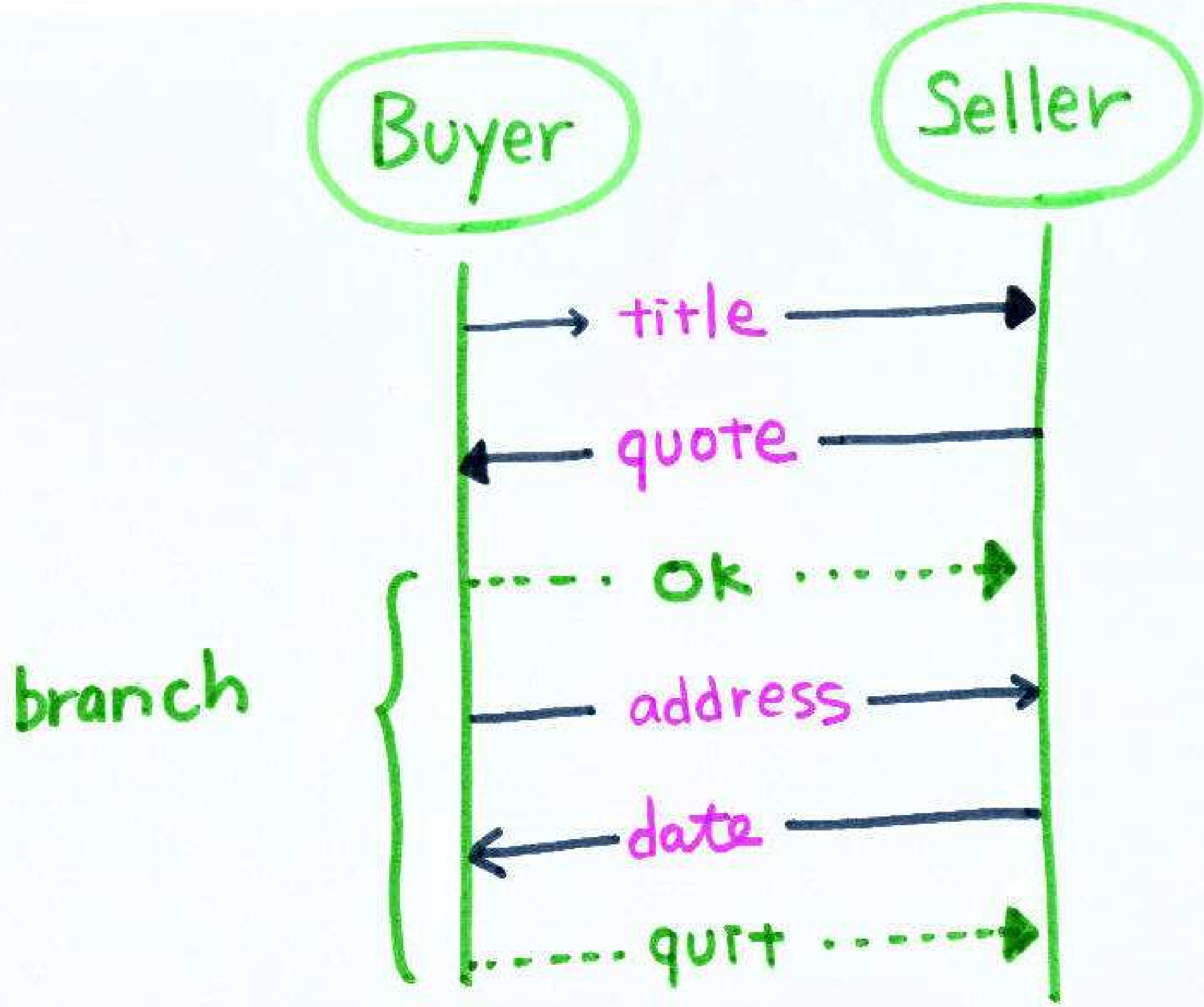
$\Downarrow$

Multiparty Session Types [POPL'08]

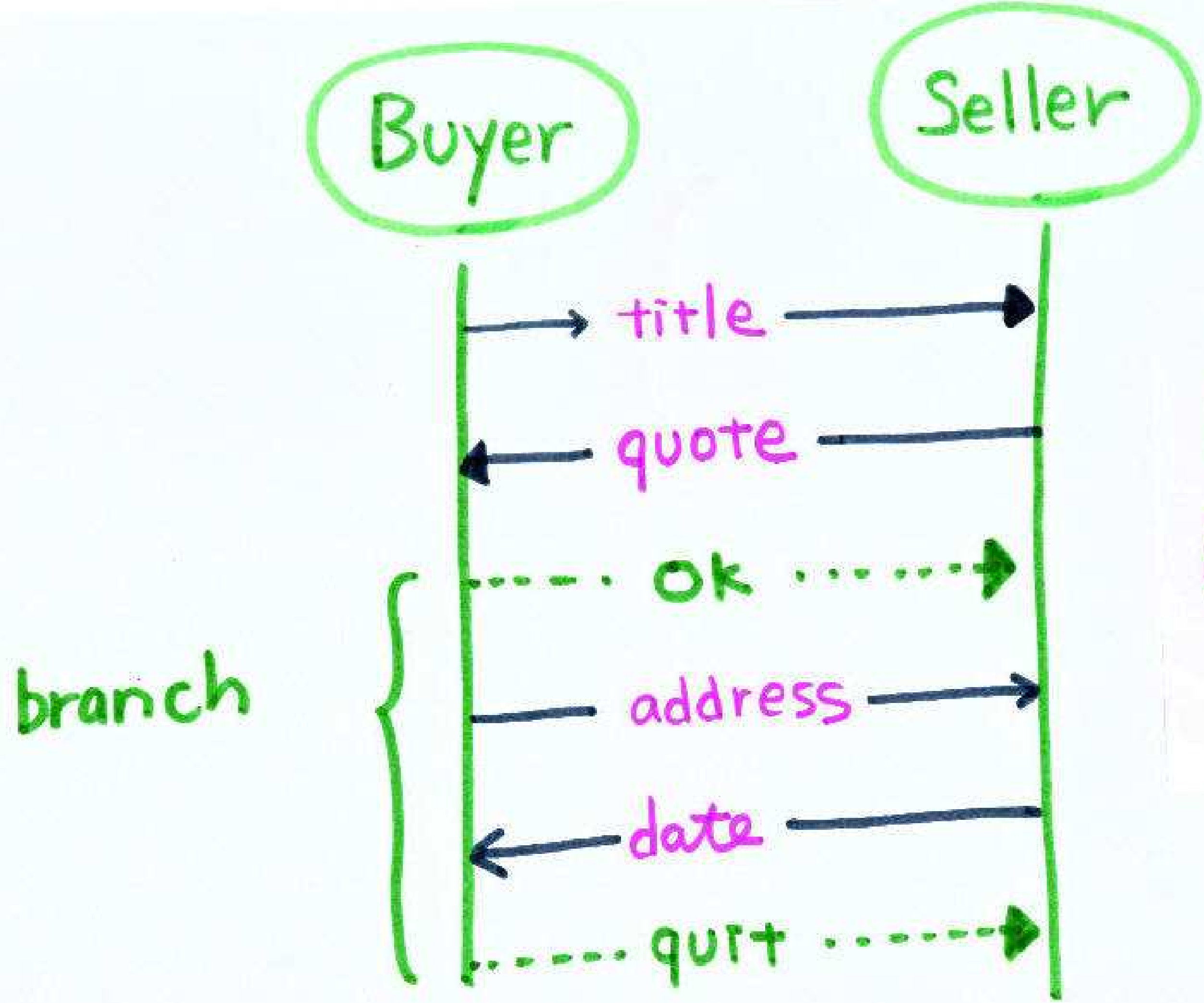
$\Downarrow$

Binary Session Types : Buyer - Seller Protocol





$!\,\mathrm{String}\,;\,?\,\mathrm{Int}\,;\ \oplus\{\mathrm{ok}:\,!\mathrm{String}\,;\,?\mathrm{Date}\,;\mathrm{end},\ \mathrm{quit}:\mathrm{end}\}$



P has T

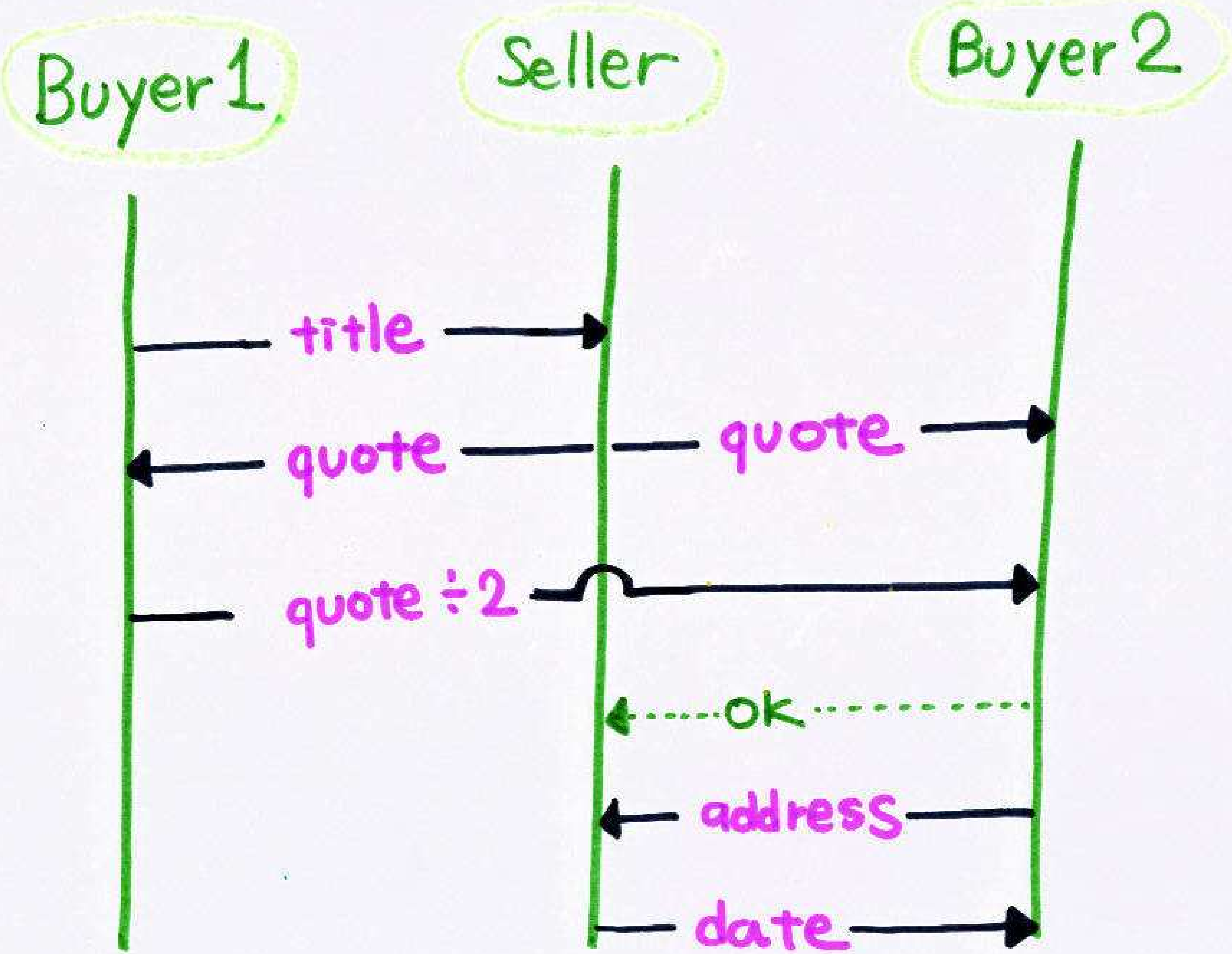
Q has $\overline{T}$ dual

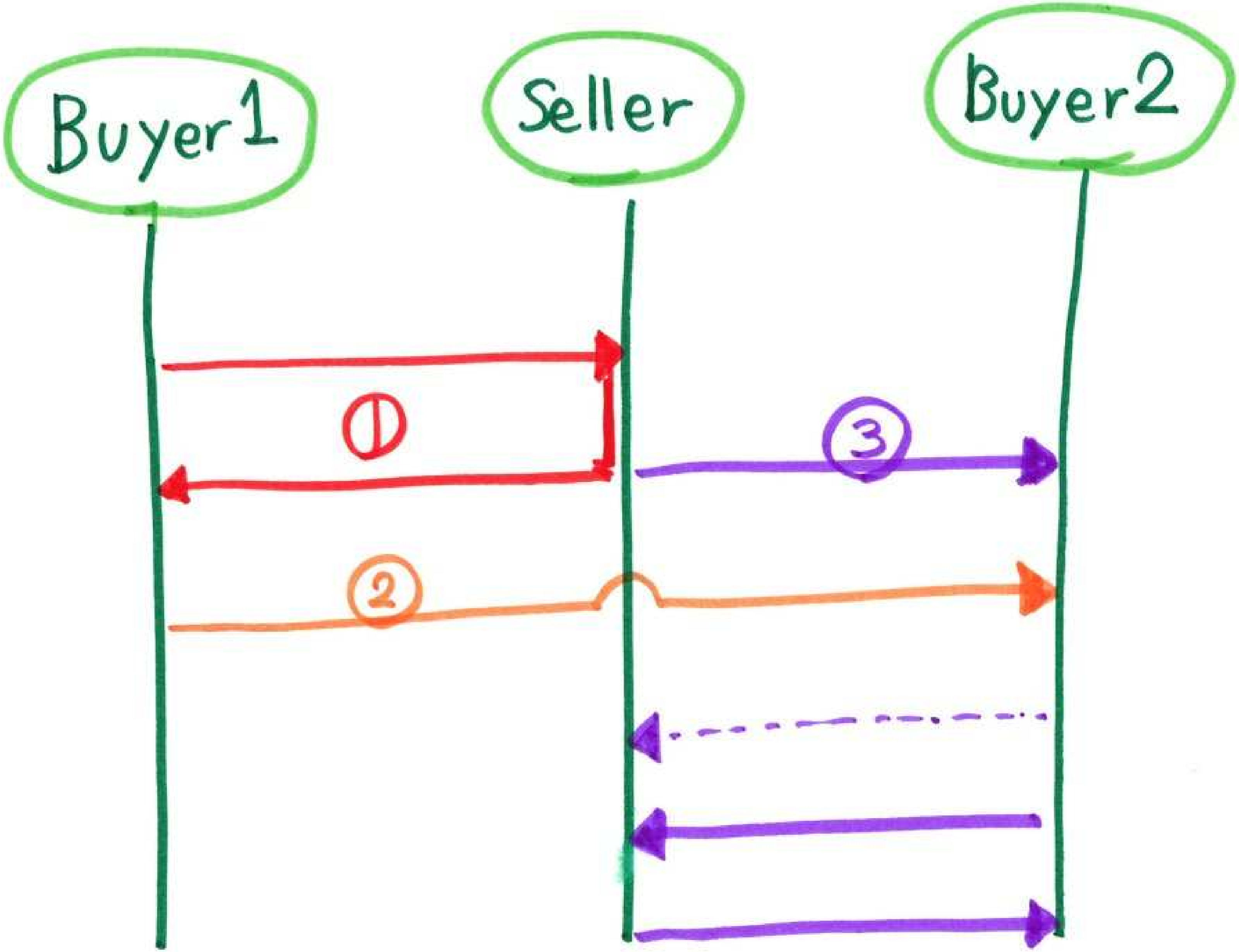
P | Q typable

$$!\,\mathrm{String}\,;\,?\,\mathrm{Int}\,;\,\oplus\{\mathrm{ok}:\,!\mathrm{String};\,?\mathrm{Date};\mathrm{end},\ \mathrm{quit}:\mathrm{end}\}$$

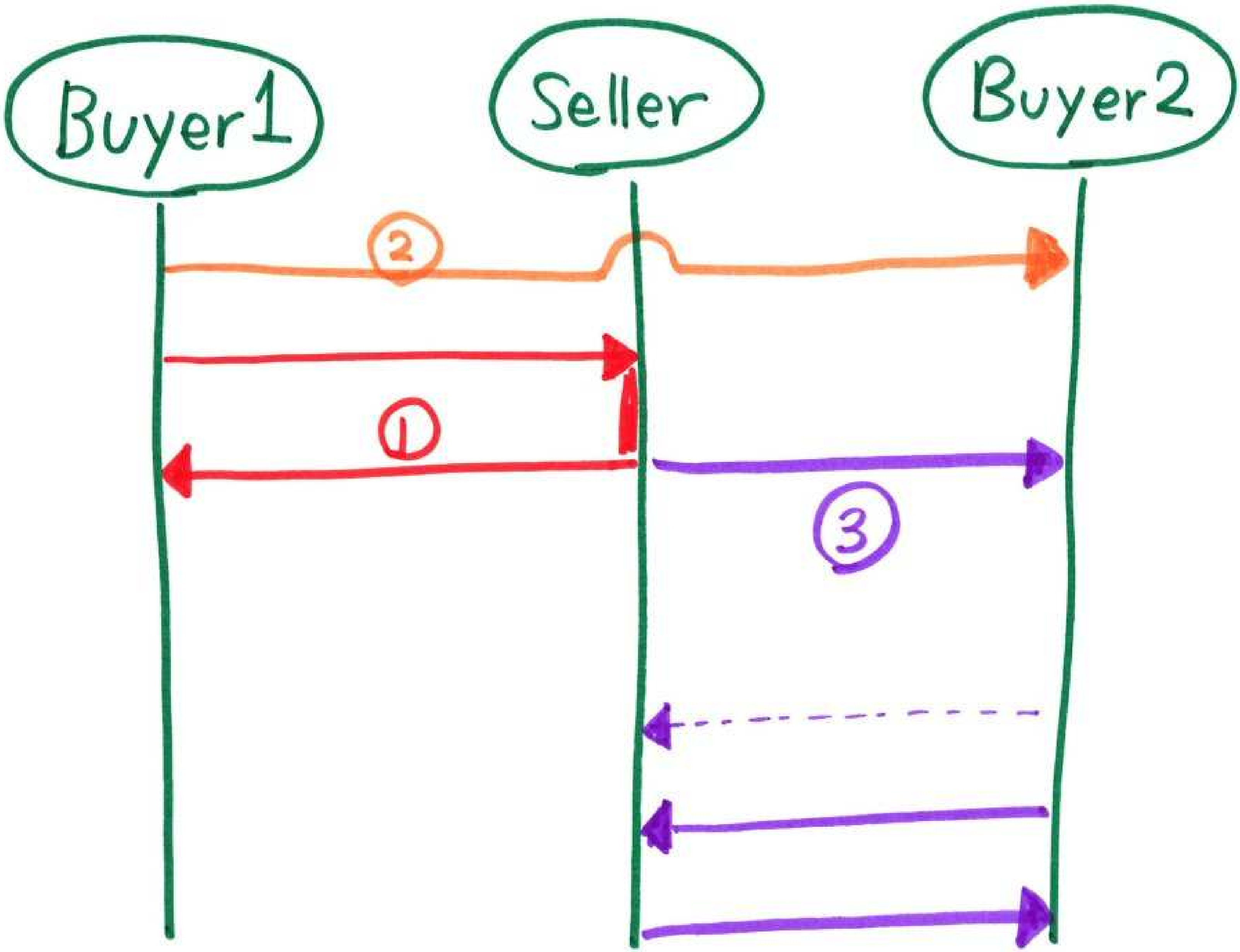
dual $?\,\mathrm{String}\,;\,!\,\mathrm{Int}\,;\,\&\{\mathrm{ok}:\,?\mathrm{String};\,!\mathrm{Date};\mathrm{end},\ \mathrm{quit}:\mathrm{end}\}$

Multiparty Session Types



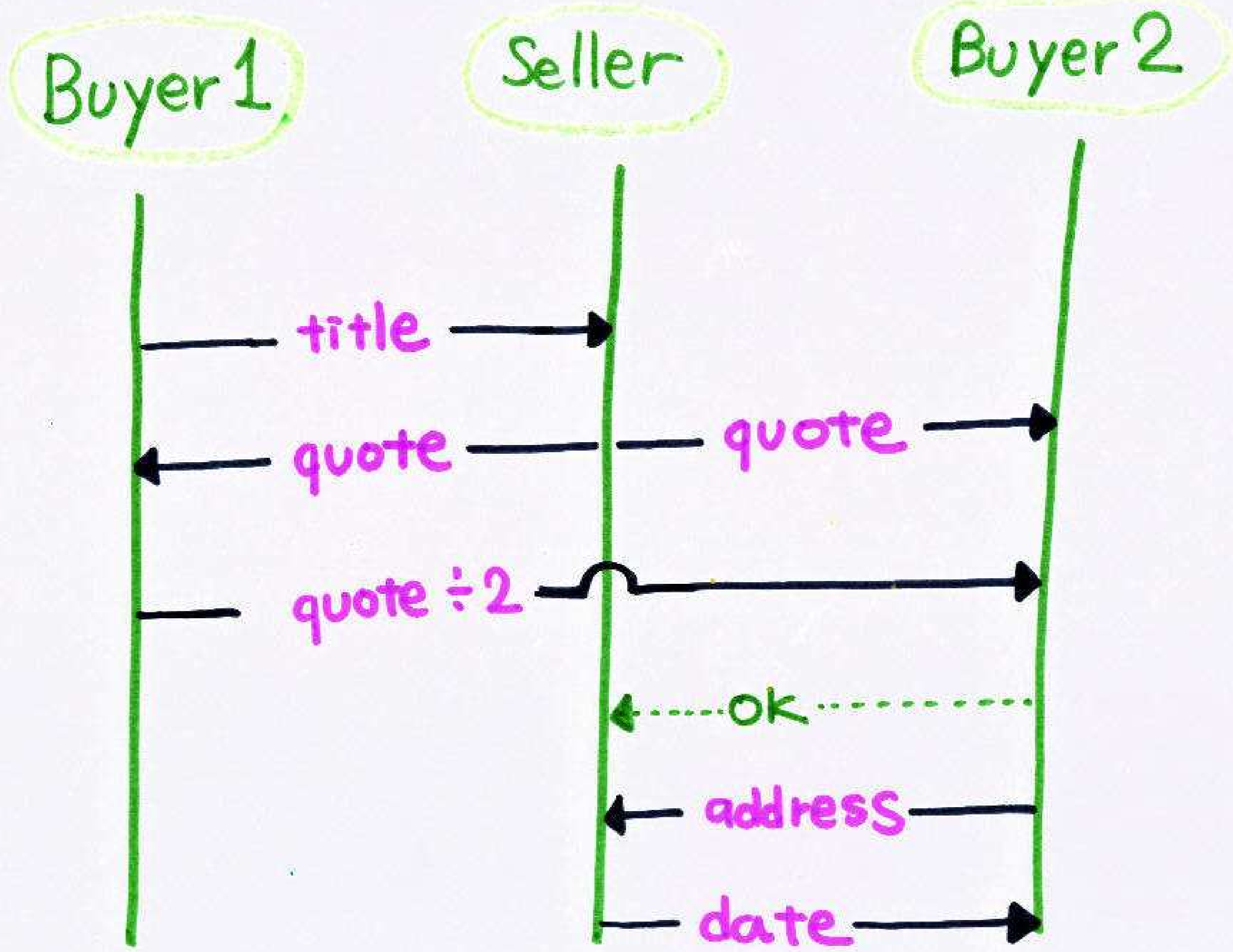


Buyer1
Seller
Buyer2
1
3
2

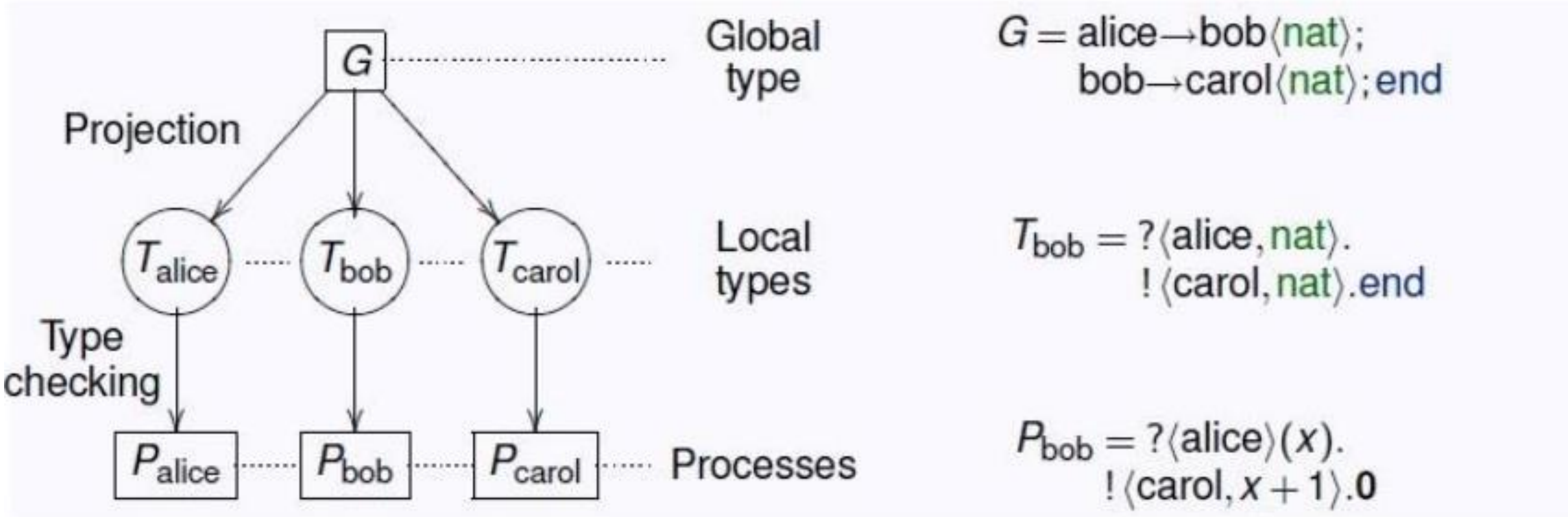


Buyer1
Seller
Buyer2
2
1
3

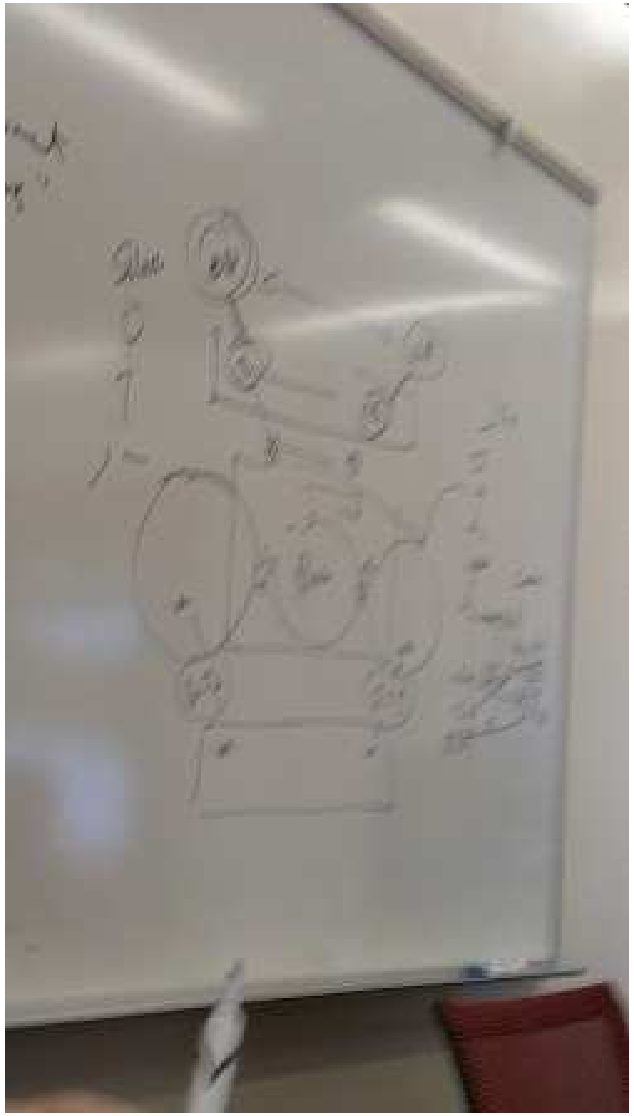
Multiparty Session Types



Session Types Overview



- Properties
  - Communication safety (no communication mismatch)
  - Communication fidelity (the communication follow the protocol)
  - Progress (no deadlock/stuck in a session)



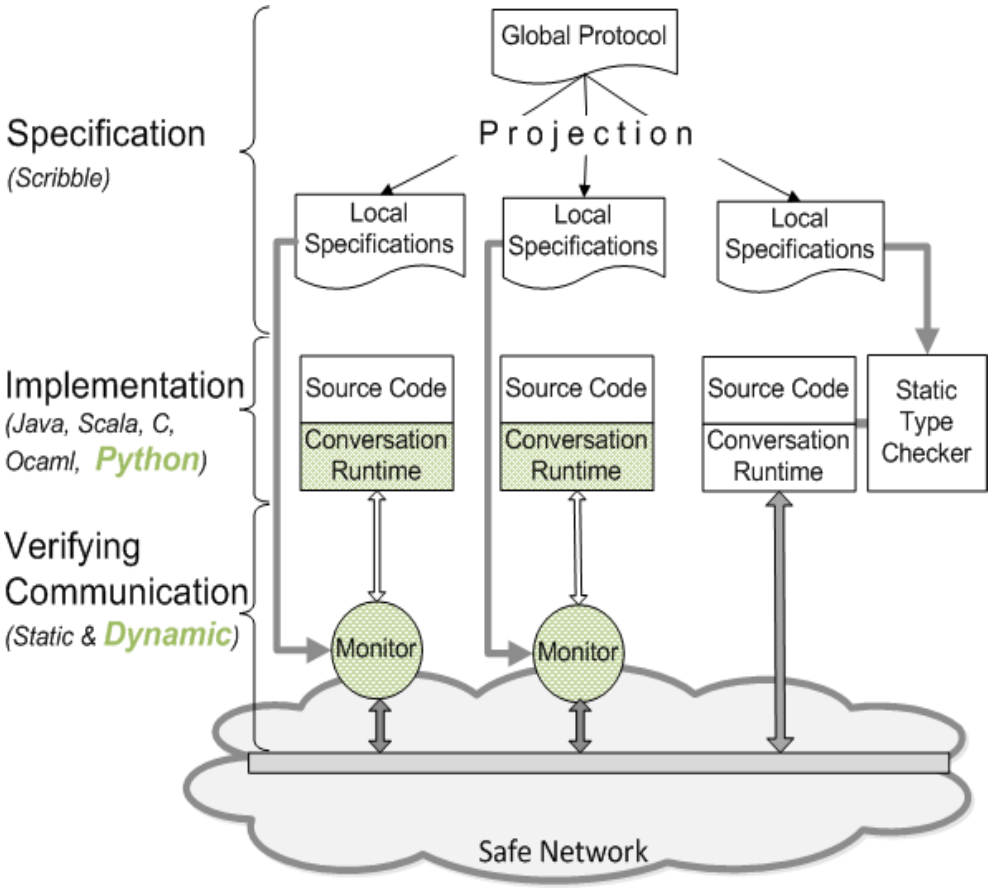
Evolution Of MPST

- Binary Session Types [THK98, HVK98]
- Multiparty Session Types [POPL'08]
- A Theory of Design-by-Contract for Distributed Multiparty Interactions [Concur'11]
- Multiparty Session Types Meet Communicating Automata [ESOP'12, ICALP'13]
- Network Monitoring through Multiparty Session Types [FMOODS'13]

- SPY: Local Verification of Global Protocols [RV'13]
- Distributed Runtime Verification with Session Types and Python [RV'13]

Session Types for Runtime Verification

- Methodology
  - Developers design protocols in a dedicated language - Scribble
  - Well-fomedness is checked by Scribble tools
  - Protocols are projected into local types
  - Local types generate monitors



www.scribble.org

Scribble

Fork me on GitHub

What is Scribble?

Scribble is a language to describe application-level protocols among communicating systems. A protocol represents an agreement on how participating systems interact with each other. Without a protocol, it is hard to do meaningful interaction: participants simply cannot communicate effectively, since they do not know when to expect the other parties to send data, or whether the other party is ready to receive data.

However, having a description of a protocol has further benefits. It enables verification to ensure that the protocol can be implemented without resulting in unintended consequences, such as deadlocks.

Find out more ...

Language Guide | Tools | Specification | Forum

An example

```
module examples;

global protocol HelloWorld(role Me, role World) {
	hello(Greetings) from Me to World;
	choice at World {
		hello(GoodMorning) from World to Me;
	} or {
		hello(GoodAfternoon) from World to Me;
	}
}
```

A very simply example, but this illustrates the basic syntax for a hello world interaction, where a party performing the role Me sends a message of type *Greetings* to another party performing the role 'World', who subsequently makes a decision which determines which path of the choice will be followed, resulting in a *GoodMorning* or *GoodAfternoon* message being exchanged.

Describe

Scribble is a language for describing multiparty protocols

Verify

Scribble has a theoretical foundation, based on the Pi Calculus and Session Types, to ensure that protocols

Project

Endpoint projection is the term used for identifying the

Implement

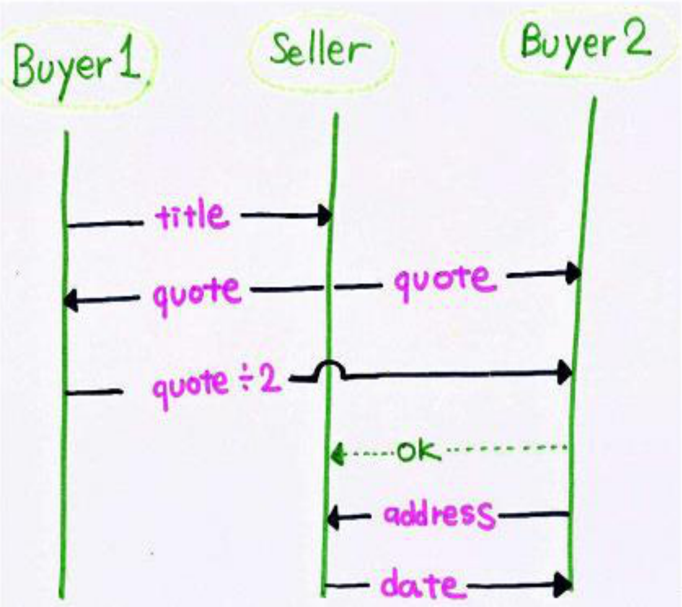
Various options exist, including (a) using the endpoint projection for a role to generate a skeleton code, (b)

Monitor

Use the endpoint projection for roles defined within a

Two Buyer Protocol in Scribble

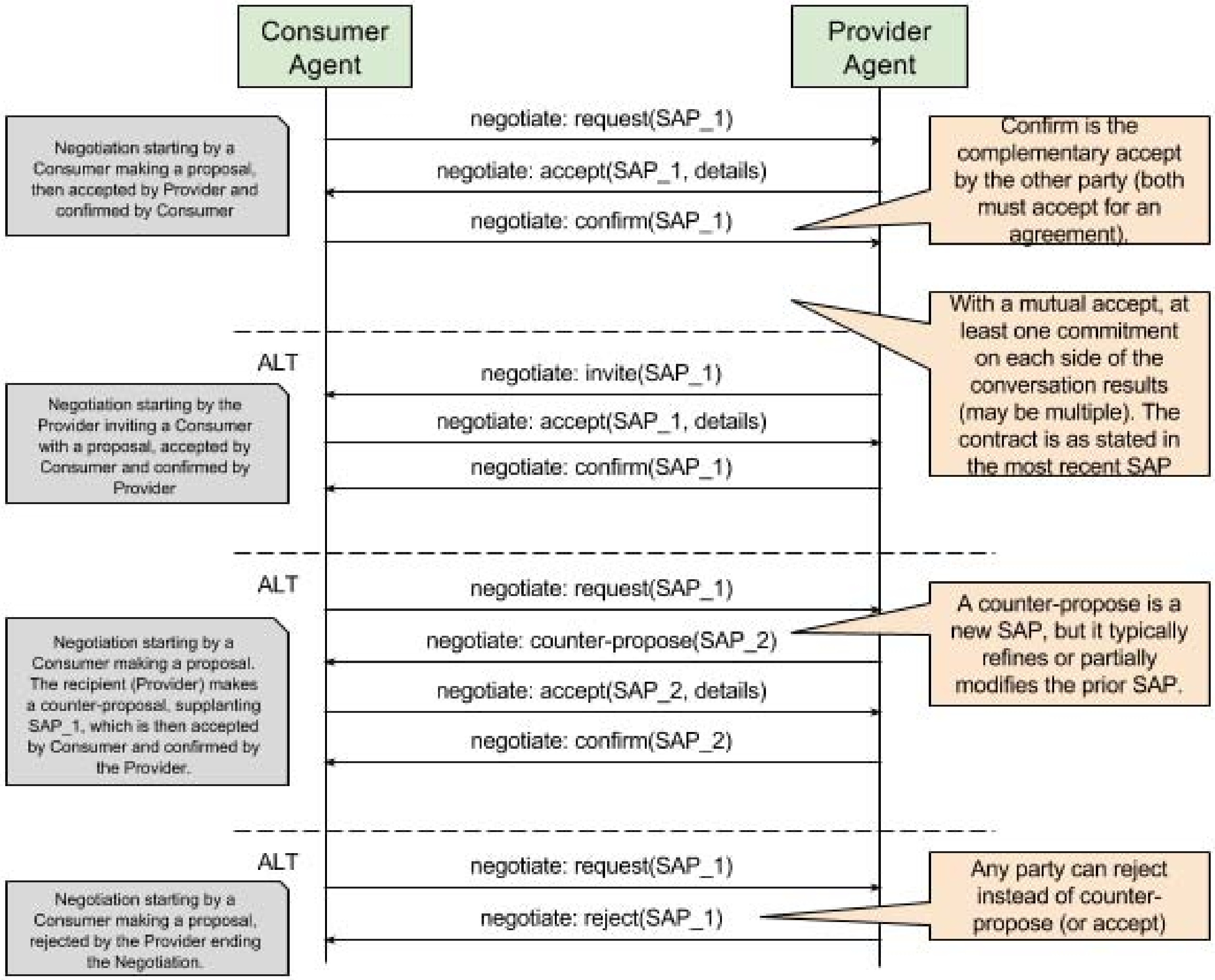
```
module Bookstore;

type <java> "java.lang.Integer" from "rt.jar" as Integer;
type <java> "java.lang.String" from "rt.jar" as String;

global protocol TwoBuyers(role A, role B, role S) {
    title(String) from A to S;
    quote(Integer) from S to A, B;
    rec LOOP {
        share(Integer) from A to B;
        choice at B {
            accept(address:String) from B to A, S;
            date(String) from S to B;
        } or {
            retry() from B to A, S;
            continue LOOP;
        } or {
            quit() from B to A, S;
}   }   }
```



Buyer: A local projection

```
module Bookstore_TwoBuyers_A;

type <java> "java.lang.Integer" from "rt.jar" as Integer;
type <java> "java.lang.String" from "rt.jar" as String;

local protocol TwoBuyers_A at A(role A, role B, role S) {
 title(String) to S;
 quote(Integer) from S;
 rec LOOP {
  share(Integer) to B;
  choice at B {
   accept(address:String) from B;
  } or {
   retry() from B;
   continue LOOP;
  } or {
   quit() from B;
} } }
```

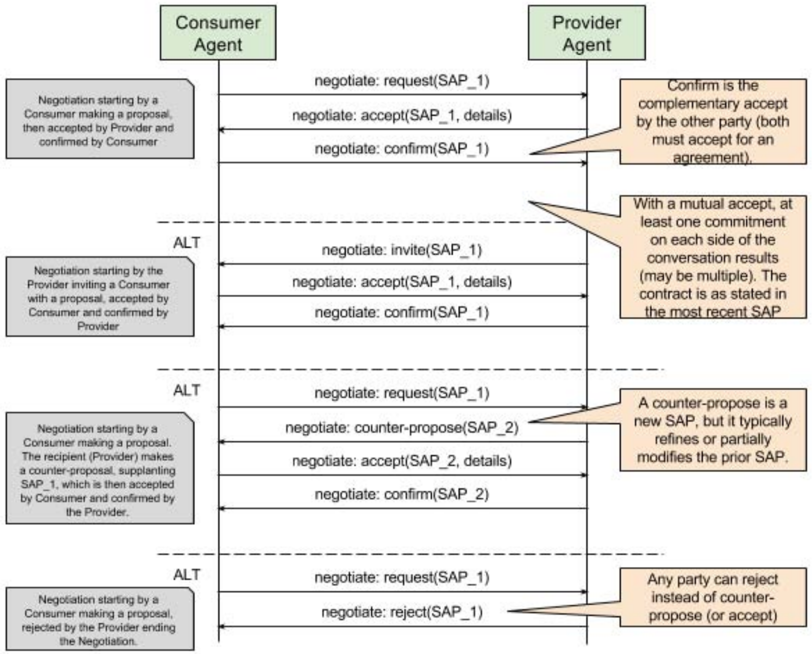
OOI agent negotiation 1/5



- https://confluence.oceanobservatories.org/display/syseng/CIAD+COI+OV+Negotiate+Protocol

OOI agent negotiation 2/5

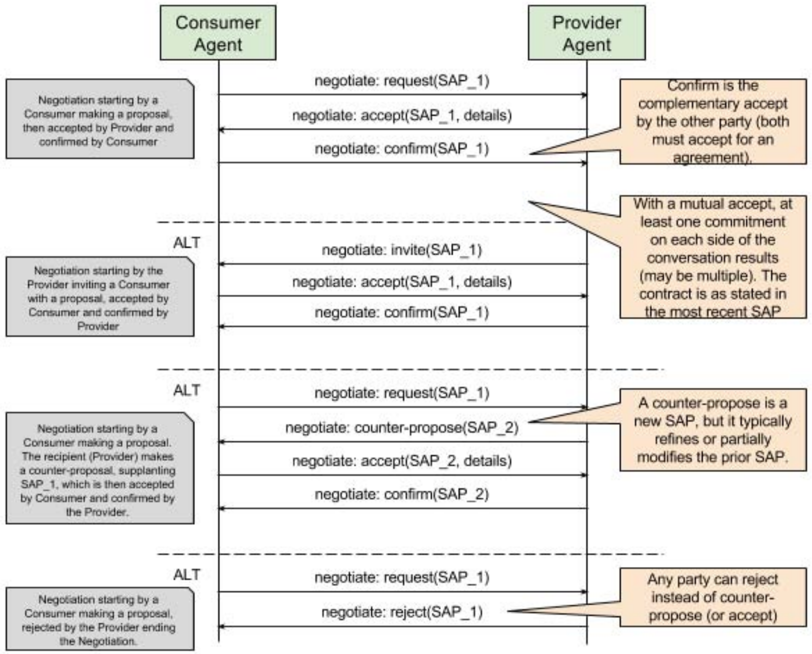
```
type <yml> "SAPDoc1" from "SAPDoc1.yml" as SAP;

global protocol Negotiate(role Consumer as C, role Producer as P) {
```




```
}
```

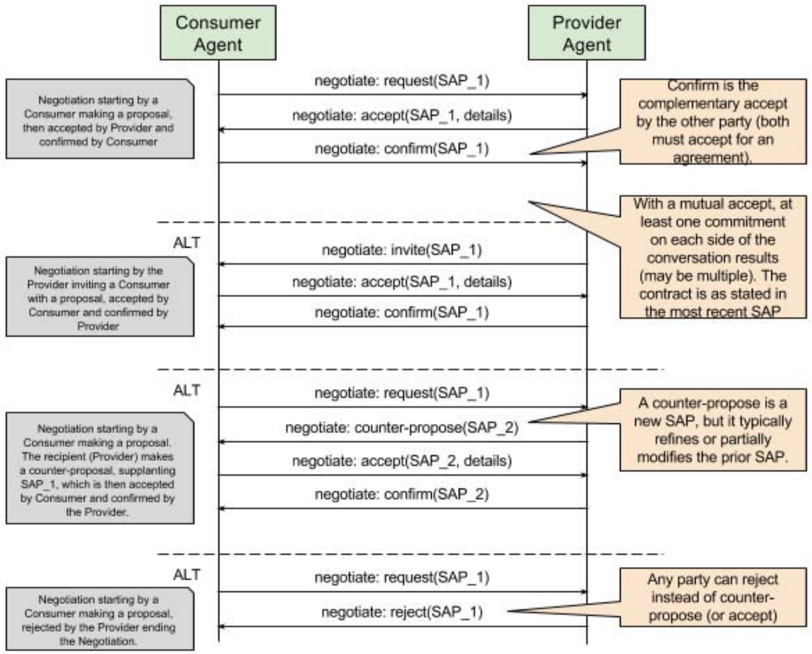
OOI agent negotiation 3/5 (choice)

```
type <yml> "SAPDoc1" from "SAPDoc1.yml" as SAP;

global protocol Negotiate(role Consumer as C, role Producer as P) {
  propose(SAP) from C to P;

    choice at P {
      accept() from P to C;
      confirm() from C to P;
    } or {
      reject() from P to C;
    } or {
      propose(SAP) from P to C;

} }
```



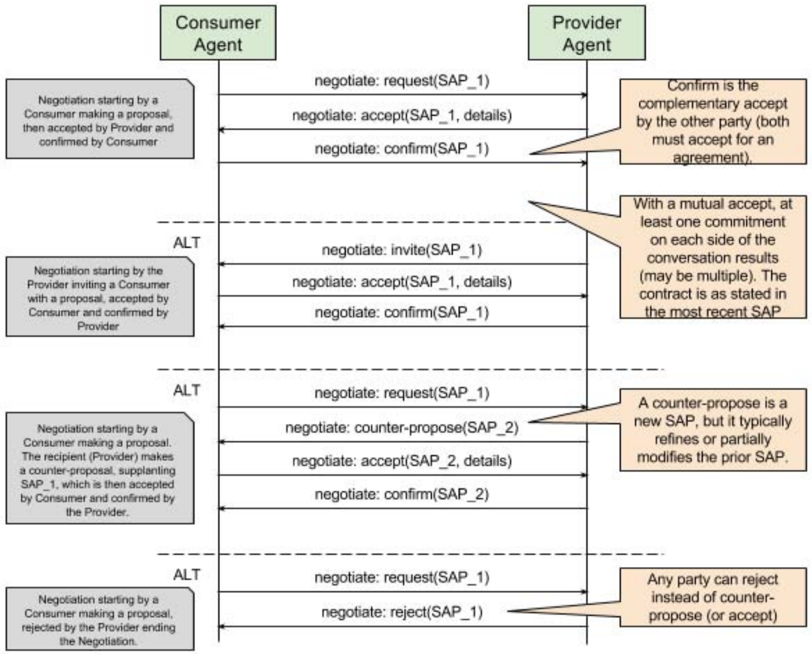
OOI agent negotiation 4/5

```
type <yml> "SAPDoc1" from "SAPDoc1.yml" as SAP;

global protocol Negotiate(role Consumer as C, role Producer as P) {
  propose(SAP) from C to P;

    choice at P {
      accept() from P to C;
      confirm() from C to P;
    } or {
      reject() from P to C;
    } or {
      propose(SAP) from P to C;
      choice at C {
        accept() from C to P;
        confirm() from P to C;
      } or {
        reject() from C to P;
      } or {
        propose(SAP) from C to P;

} } }
```



OOI agent negotiation 5/5 (recursion)

```
type <yml> "SAPDoc1" from "SAPDoc1.yml" as SAP;

global protocol Negotiate(role Consumer as C, role Producer as P) {
  propose(SAP) from C to P;
  rec X {
    choice at P {
      accept() from P to C;
      confirm() from C to P;
    } or {
      reject() from P to C;
    } or {
      propose(SAP) from P to C;
      choice at C {
        accept() from C to P;
        confirm() from P to C;
      } or {
        reject() from C to P;
      } or {
        propose(SAP) from C to P;
        continue X;
      }
    }
```

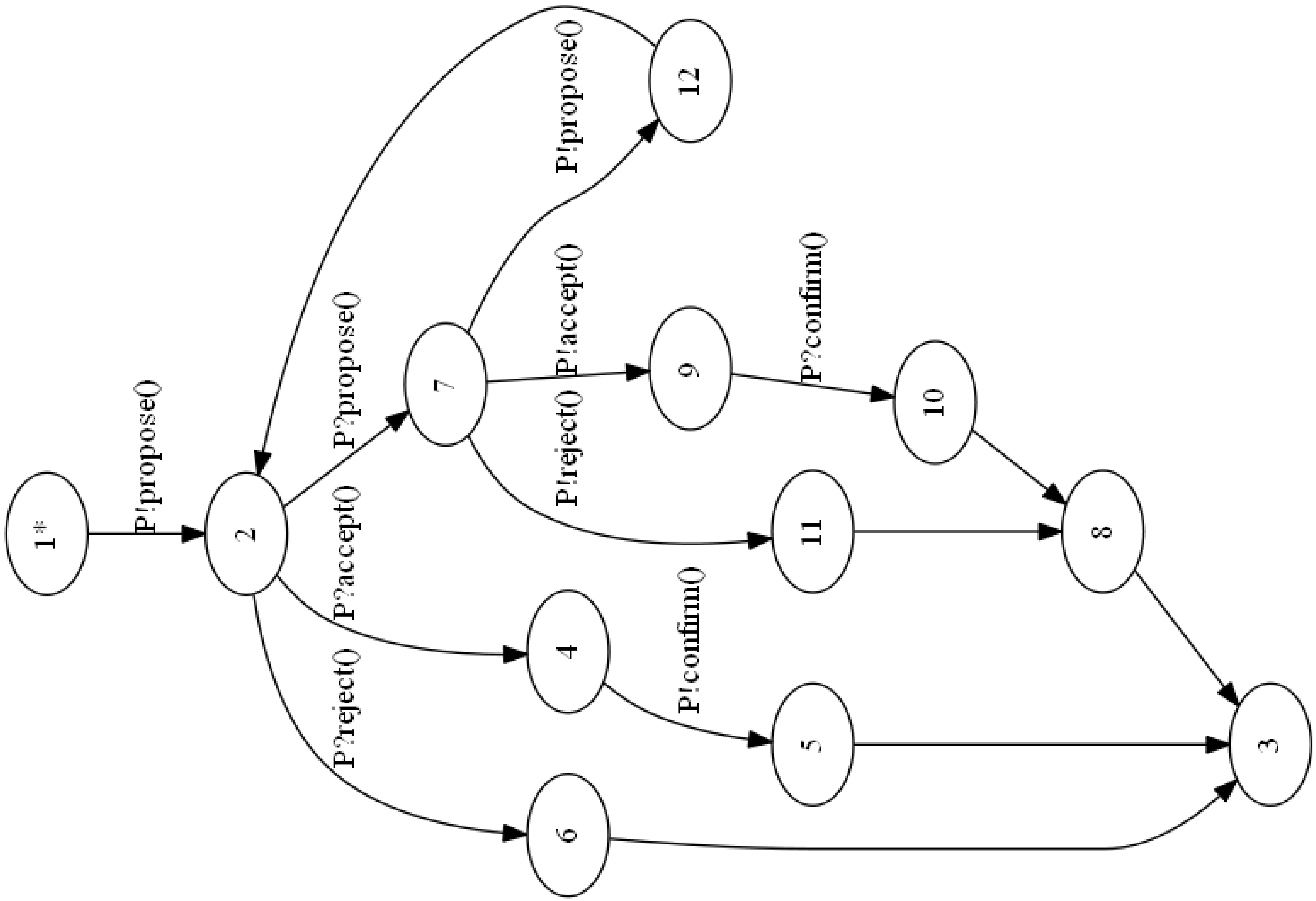


Local protocol projection (Negotiation Consumer)

```
// Global
propose(SAP) from C to P;
rec START {
  choice at P {
    accept() from P to C;
    confirm() from C to P;
  } or {
    reject() from P to C;
  } or {
    propose(SAP) from P to C;
    choice at C {
      accept() from C to P;
      confirm() from P to C;
    } or {
      reject() from C to P;
    } or {
      propose(SAP) from C to P;
      continue START;
} } }
```

```
// Projection for Consumer
propose(SAP) to P;
rec START {
  choice at P {
    accept() from P;
    confirm() to P;
  } or {
    reject() from P;
  } or {
    propose(SAP) from P;
    choice at C {
      accept() to P;
      confirm() from P;
    } or {
      reject() to P;
    } or {
      propose(SAP) to P;
      continue START;
} } }
```

FSM generation (Negotiation Consumer)



Scribble Community

- Webpage:
  - www.scribble.org
- GitHub:
  - https://github.com/scribble
- Tutorial:
  - www.doc.ic.ac.uk/~rhu/scribble/tutorial.html
- Specification (0.3)
  - www.doc.ic.ac.uk/~rhu/scribble/langref.html

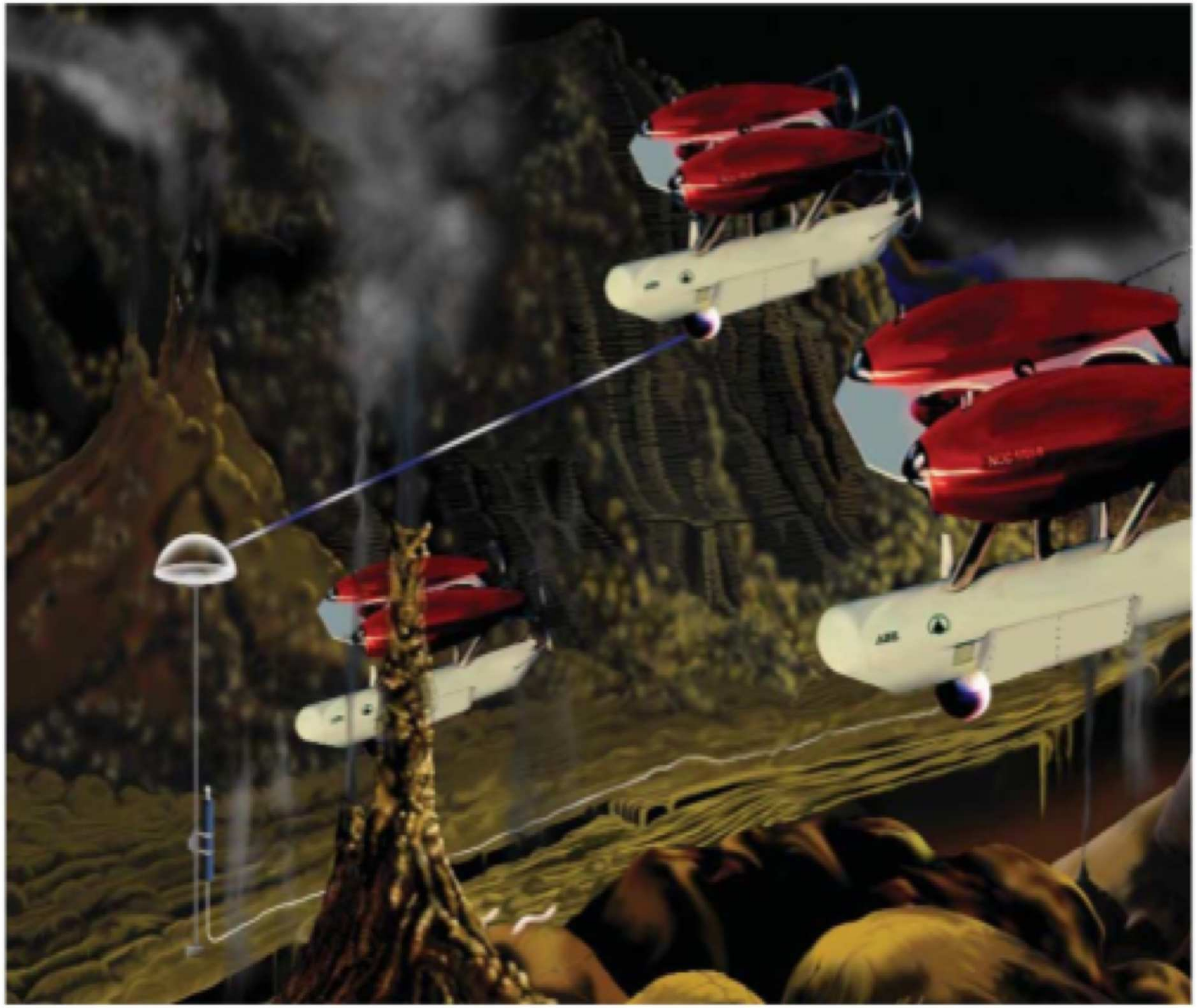


Figure 5: A coordinated set of autonomous underwater vehicles

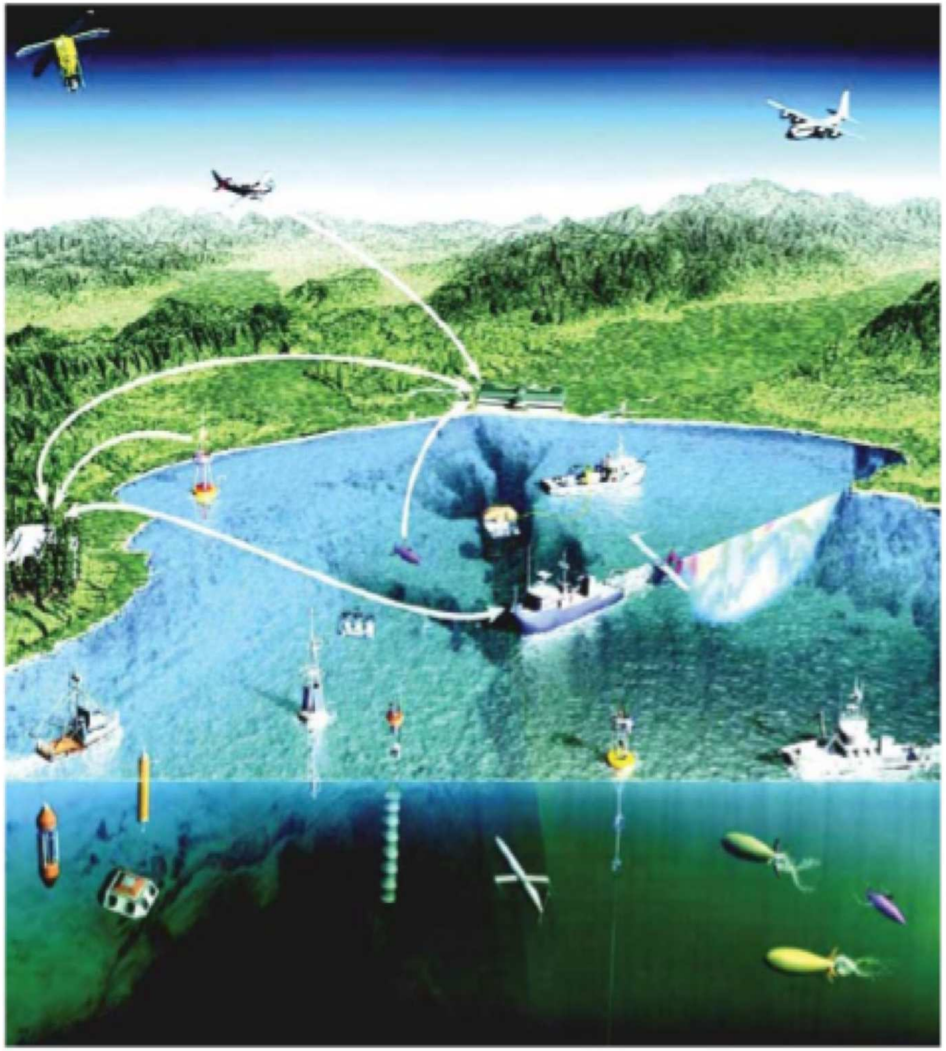
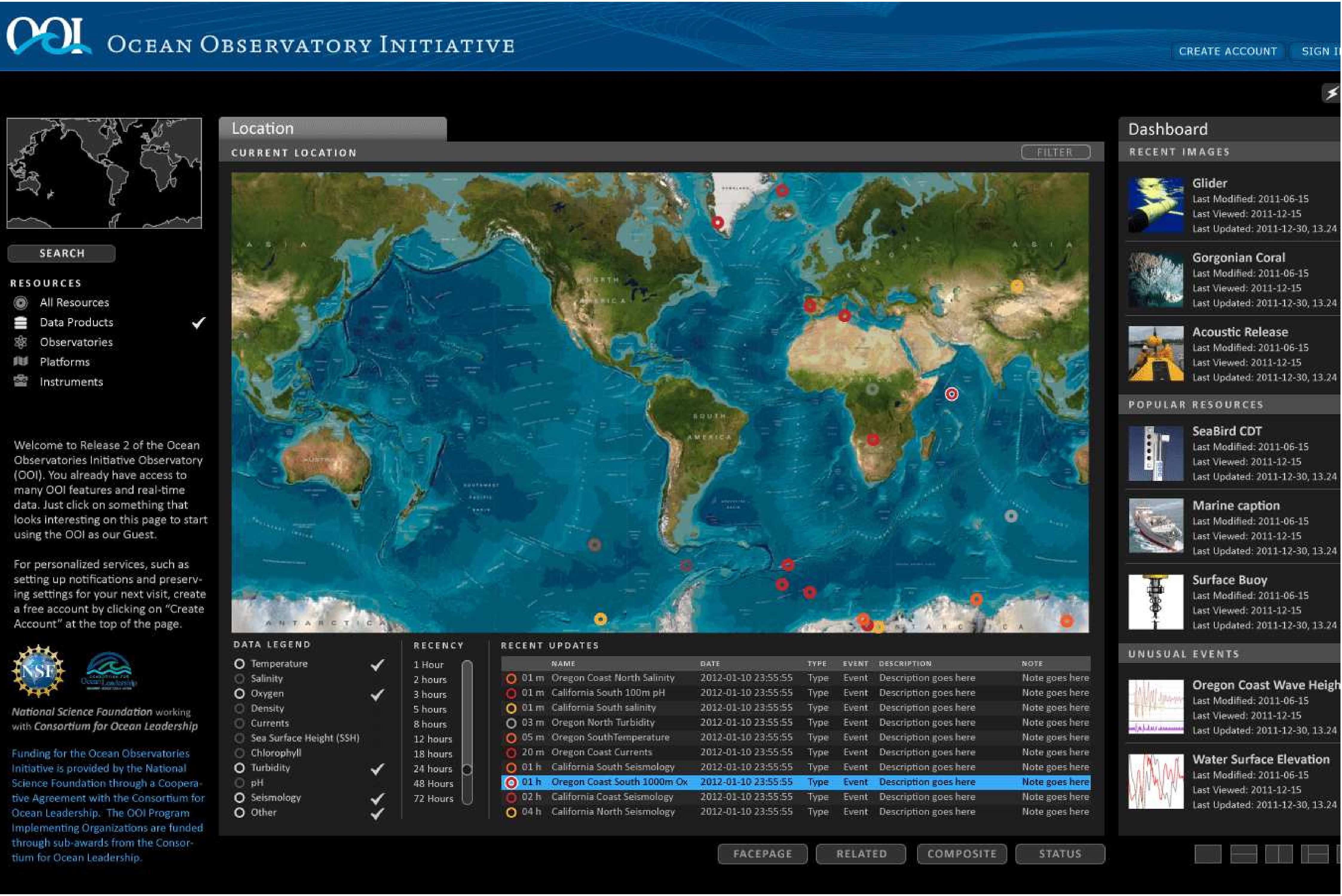


Figure 3: Observatory comprised of ships, aircraft and autonomous vehicles linked to assimilation modeling capabilities on shore



OCEAN OBSERVATORY INITIATIVE
CREATE ACCOUNT
SIGN I
SEARCH
RESOURCES
All Resources
Data Products
Observatories
Platforms
Instruments
Welcome to Release 2 of the Ocean Observatories Initiative Observatory (OOI). You already have access to many OOI features and real-time data. Just click on something that looks interesting on this page to start using the OOI as our Guest.
For personalized services, such as setting up notifications and preserving settings for your next visit, create a free account by clicking on "Create Account" at the top of the page.
National Science Foundation working with Consortium for Ocean Leadership
Funding for the Ocean Observatories Initiative is provided by the National Science Foundation through a Cooperative Agreement with the Consortium for Ocean Leadership. The OOI Program Implementing Organizations are funded through sub-awards from the Consortium for Ocean Leadership.
Location
CURRENT LOCATION
FILTER
ASIA
NORTH AMERICA
SOUTH AMERICA
EUROPE
ANTARCTICA
DATA LEGEND
Temperature
Salinity
Oxygen
Density
Currents
Sea Surface Height (SSH)
Chlorophyll
Turbidity
pH
Seismology
Other
RECENCY
1 Hour
2 hours
3 hours
5 hours
8 hours
12 hours
18 hours
24 hours
48 Hours
72 Hours
RECENT UPDATES
NAME DATE TYPE EVENT DESCRIPTION NOTE
01 m Oregon Coast North Salinity 2012-01-10 23:55:55 Type Event Description goes here Note goes here
01 m California South 100m pH 2012-01-10 23:55:55 Type Event Description goes here Note goes here
01 m California South salinity 2012-01-10 23:55:55 Type Event Description goes here Note goes here
03 m Oregon North Turbidity 2012-01-10 23:55:55 Type Event Description goes here Note goes here
05 m Oregon SouthTemperature 2012-01-10 23:55:55 Type Event Description goes here Note goes here
20 m Oregon Coast Currents 2012-01-10 23:55:55 Type Event Description goes here Note goes here
01 h California South Seismology 2012-01-10 23:55:55 Type Event Description goes here Note goes here
01 h Oregon Coast South 1000m Ox 2012-01-10 23:55:55 Type Event Description goes here Note goes here
02 h California Coast Seismology 2012-01-10 23:55:55 Type Event Description goes here Note goes here
04 h California North Seismology 2012-01-10 23:55:55 Type Event Description goes here Note goes here
FACEPAGE
RELATED
COMPOSITE
STATUS
Dashboard
RECENT IMAGES
Glider
Last Modified: 2011-06-15
Last Viewed: 2011-12-15
Last Updated: 2011-12-30, 13.24
Gorgonian Coral
Last Modified: 2011-06-15
Last Viewed: 2011-12-15
Last Updated: 2011-12-30, 13.24
Acoustic Release
Last Modified: 2011-06-15
Last Viewed: 2011-12-15
Last Updated: 2011-12-30, 13.24
POPULAR RESOURCES
SeaBird CDT
Last Modified: 2011-06-15
Last Viewed: 2011-12-15
Last Updated: 2011-12-30, 13.24
Marine caption
Last Modified: 2011-06-15
Last Viewed: 2011-12-15
Last Updated: 2011-12-30, 13.24
Surface Buoy
Last Modified: 2011-06-15
Last Viewed: 2011-12-15
Last Updated: 2011-12-30, 13.24
UNUSUAL EVENTS
Oregon Coast Wave Heigh
Last Modified: 2011-06-15
Last Viewed: 2011-12-15
Last Updated: 2011-12-30, 13.24
Water Surface Elevation
Last Modified: 2011-06-15
Last Viewed: 2011-12-15
Last Updated: 2011-12-30, 13.24

Multiparty Session Type Theory

- Multiparty Asynchronous Session Types [POPL'08]
- Progress
  - Global Progress in Dynamically Interleaved Multiparty Sessions [CONCUR'08], [Math. Struct. Comp. Sci.]
  - Inference of Progress Typing [Coordination'13]
- Asynchronous Optimisations and Resource Analysis
  - Global Principal Typing in Partially Commutative Asynchronous Sessions [ESOP'09]
  - Buffered Communication Analysis in Distributed Multiparty Sessions [CONCUR'10]

- Logics
  - Design-by-Contract for Distributed Multiparty Interactions [CONCUR'10]
  - Specifying Stateful Asynchronous Properties for Distributed Programs [CONCUR'12]
  - Multiparty, Multi-session Logic [TGC'12]
- Extensions of Multiparty Session Types
  - Multiparty Symmetric Sum Types [Express'10]
  - Parameterised Multiparty Session Types [FoSSaCs'10, LMCS]
  - Global Escape in Multiparty Sessions [FSTTCS'10] [Math. Struct. Comp. Sci.]
  - Dynamic Multirole Session Types [POPL'11]
  - Nested Multiparty Sessions [CONCUR'12]
  - Timed Multiparty Session Types [CONCUR'14]

- Dynamic Monitoring
  - Asynchronous Distributed Monitoring for Multiparty Session Enforcement [TGC'11]
  - Monitoring Networks through Multiparty Sessions [FORTE'13]
- Automata Theories
  - Multiparty Session Automata [ESOP'12]
  - Synthesis in Communicating Automata [ICALP'13]
- Petri Nets
  - Multiparty Session Nets [TGC'14]
- Typed Behavioural Theories
  - Governed Session Semantics [CONCUR'13]
- Choreography Languages
  - Compositional Choreographies [CONCUR'13]

Language and Implementations

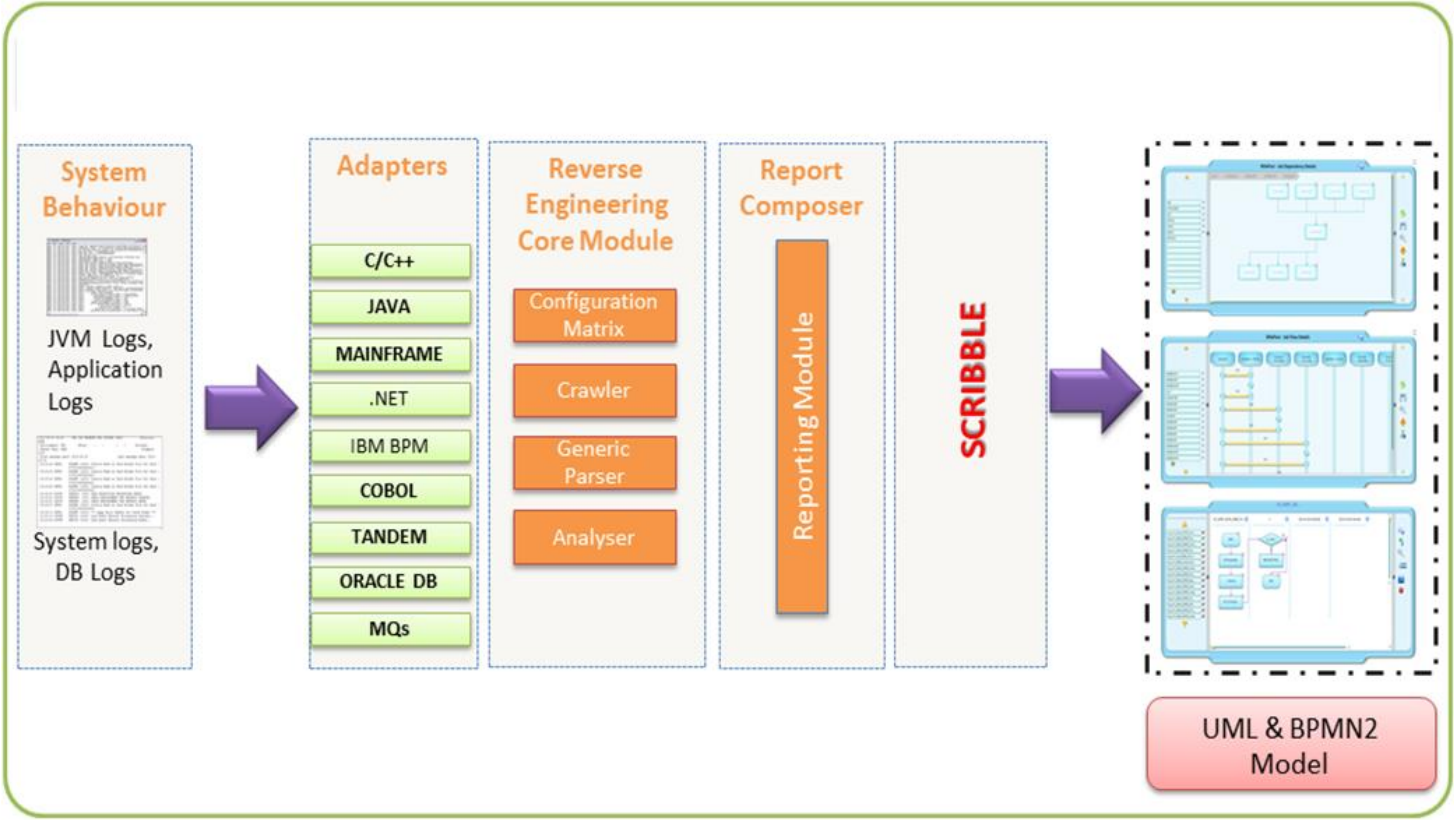
- Carrying out large-scale experiences with OOI, Pivotal, Red Hat, Congnizant, UNIFI, TrustCare
  - JBoss SCRIBBLE [ICDCIT'10, COB'12] and SAVARA projects
- High-performance computing

  Session Java [ECOOP'08,ECOOP'10,Coordination'11]

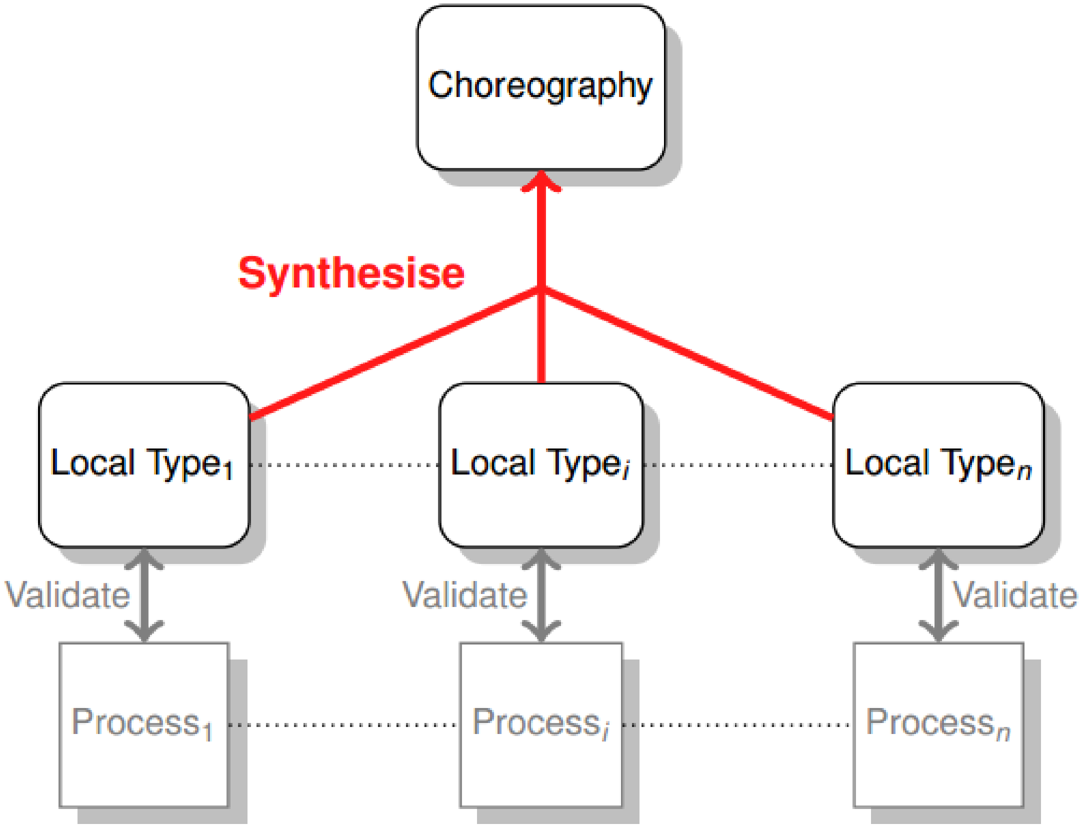
  $\Longrightarrow$ Session C & MPI [TOOLS'12][Hearts'12][EuroMPI'12][PDP'14]
- Multiparty session languages Ocaml, Java, C, Python, Scala, Jolie
  - Trustworthy Pervasive Healthcare Services via Multiparty Session Types [FHIES'12]
  - Practical interruptible conversations: Distributed dynamic verification with session types and Python [RV'13]
  - Multiparty Session Actors [Coordination'14]

http://www.zdlc.co/faq/

Zero Deviation Life Cycle Platform

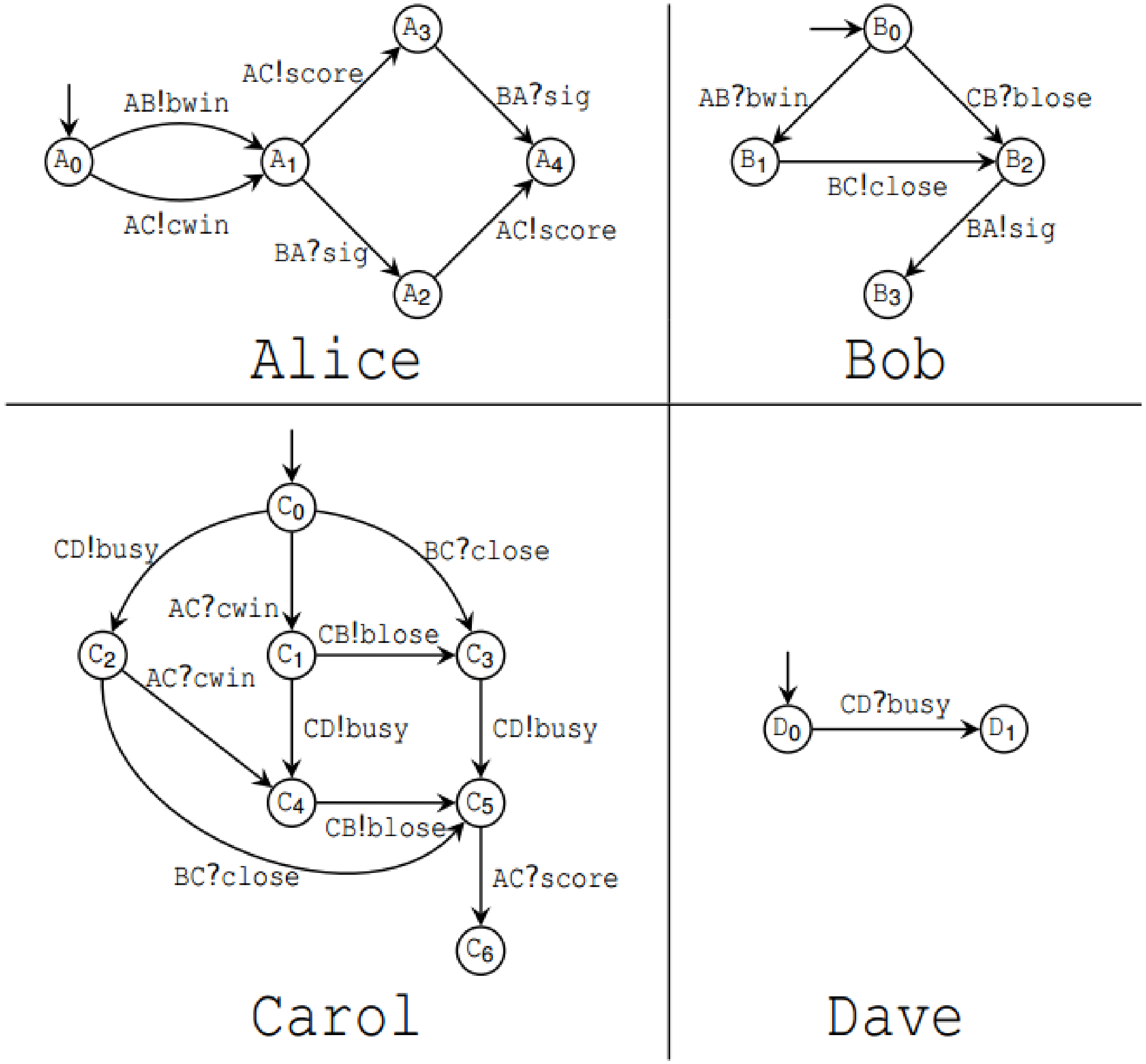


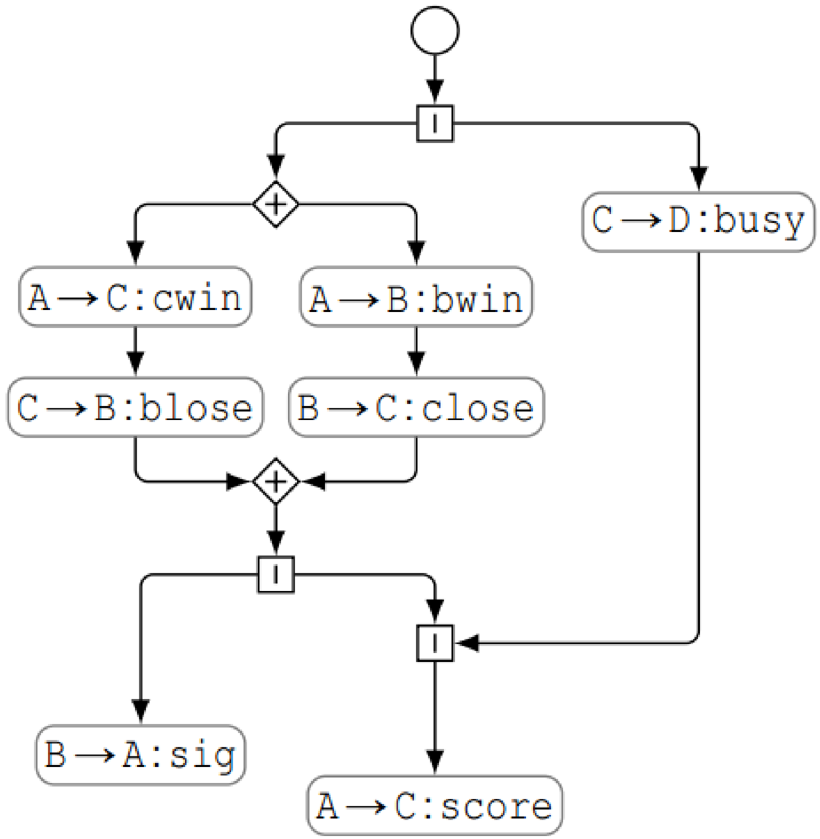
Synthesis of Graphical Choreographies 1/2



- Multiparty Session Types top-down approach (cf. POPL'08 & ESOP'12)
- Not applicable without *a priori knowledge* of a choreography
- Synthesise a choreography from a set of local specifications
- Concretely: from *Communicating Finite-State Machines* to *Global Graphs*

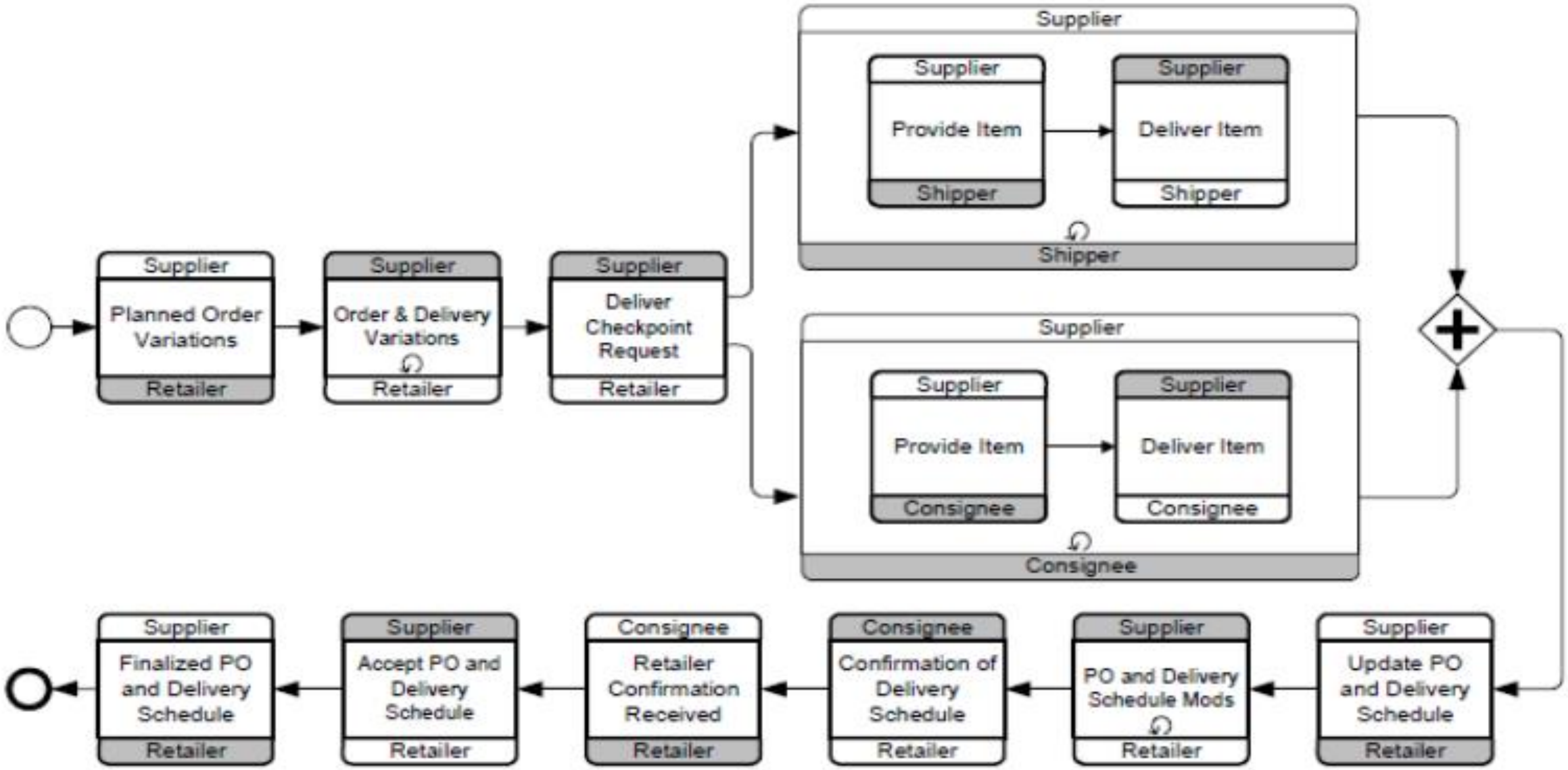
Synthesis of Graphical Choreographies 2/2





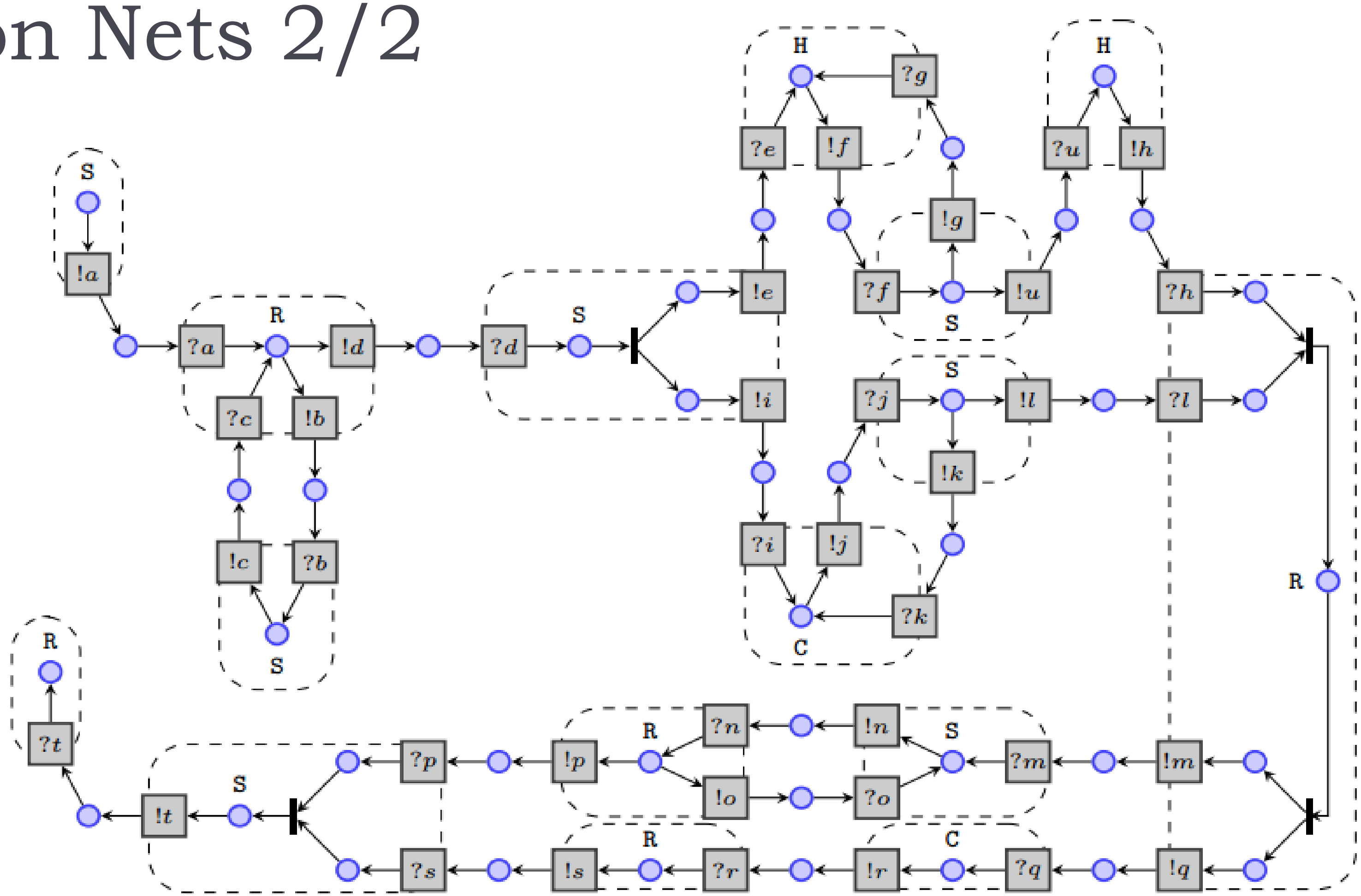
Session Nets 1/2

Graphical global specification based on Petri Nets that cannot be directly represented in the MPST linear syntax



An application of the Petri Nets token dynamics to a conformance validation

Session Nets 2/2



$$
\begin{aligned}
g = \{&a \mapsto \texttt{Planned}, b \mapsto \texttt{Order}, c \mapsto \texttt{OrderEnd}, d \mapsto \texttt{Checkpoint}, e \mapsto \texttt{Provide},\\
&f \mapsto \texttt{Deliver}, g \mapsto \texttt{Provide}, h \mapsto \texttt{Update}_1, i \mapsto \texttt{Provide}, j \mapsto \texttt{Deliver}, k \mapsto \texttt{Provide},\\
&l \mapsto \texttt{Update}_2, m \mapsto \texttt{PO}, n \mapsto \texttt{POAck}, o \mapsto \texttt{PO}, p \mapsto \texttt{Accept}_1, q \mapsto \texttt{Confirmation},\\
&r \mapsto \texttt{Retailer}, s \mapsto \texttt{Accept}_2, t \mapsto \texttt{Finalized}, u \mapsto \texttt{ProvideEnd}\}
\end{aligned}
$$

A rare cluster of qualities

From the team of OOI CI:

Kohei has lead us deep into the nature of communication and processing. His esthetics, precision and enthusiasm for our mutual pursuit of formal Session (Conversation) Types and specifically for our OOI collaboration to realize this vision in very concrete terms were, as penned by Henry James, lessons in seeing the nuances of both beauty and craft, through a rare cluster of qualities - curiosity, patience and perception; all at the perfect pitch of passion and expression.