Multiparty Session Types and their Applications

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

Nobuko Yoshida

Imperial College London

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

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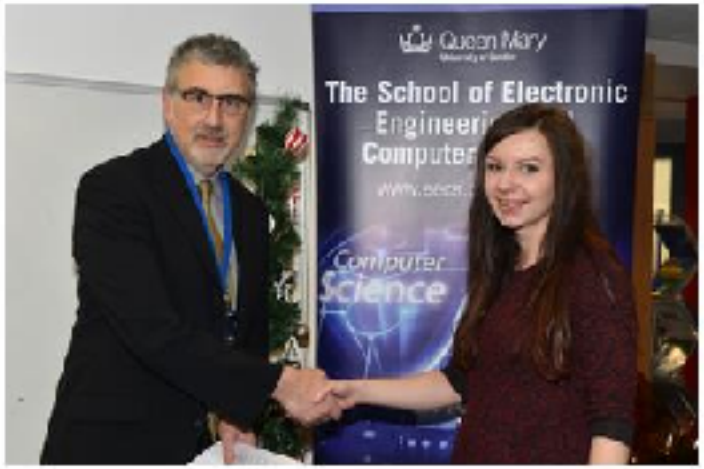
This prize was instituted in 2013 and is awarded annually to one undergraduate student and one postgraduate student in recognition of their achievement in applying the highest quality scientific and engineering principles in the broad area of Distributed Systems. This is the area in which Dr Honda concentrated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

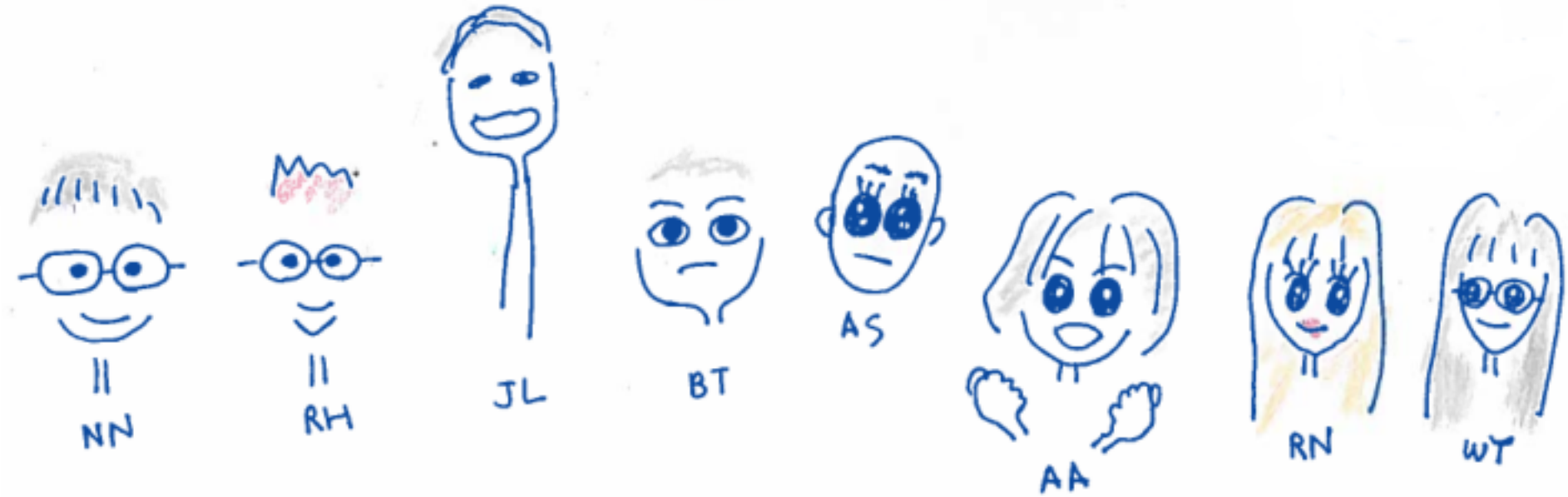
Winners 2013



Ms Anna Pawlicka
2013 winner (Undergraduate) source: QMUL

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

Session Type Mobility Group



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Selected Publications 2015/2016

- **[ECOOP'16]** Alceste Scalas, NY: Lightweight Session Programming in Scala.
- **[CC'16]** Nicholas Ng, NY: Static Deadlock Detection for Concurrent Go by Global Session Graph Synthesis.
- **[FASE'16]** Raymond Hu, NY: Hybrid Session Verification through Endpoint API Generation.
- **[TACAS'16]** Julien Lange, NY: Characteristic Formulae for Session Types.
- **[ESOP'16]** Dimitrios Kouzapas, Jorge A. Pérez, NY: On the Relative Expressiveness of Higher-Order Session Processes.
- **[POPL'16]** Dominic Orchard, NY: Effects as Sessions, Sessions as Effects.
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Session Type Reading List

- Home Page http://mrg.doc.ic.ac.uk/
- [ESOP'98] Language Primitives and Type Disciplines for Structured Communication-based Programming, Honda, Vasconcelos and Kubo
- [SecRet'06] Language Primitives and Type Disciplines for Structured Communication-based Programming Revisited, NY and Vasconcelos, ENTCS.
- [SFM'15] Gentle Introduction to Multiparty Asynchronous Session Types, Coppo et al.
- [COB'14,TGC'13] The Scribble Protocol Language, Honda et al.

- [FMSD'15] Practical interruptible conversations: Distributed dynamic verification with multiparty session types and Python, Demangeon, Honda, Hu, Neykova and NY.
- [FASE'15] Hybrid Session Verification through Endpoint API Generation, Raymond Hu and NY.
- [POPL'15] From communicating machines to graphical choreographies, Lange, Tuosto and NY.
- [CC'16] Static deadlock detection for concurrent go by global session graph synthesis, Ng and NY.

Current: Communication is Ubiquitous

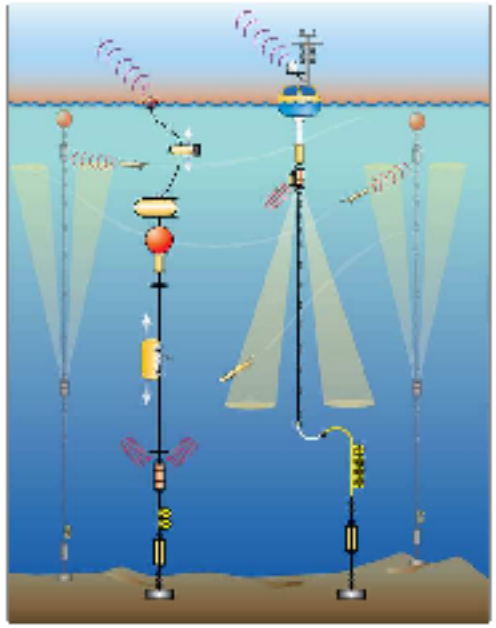
- The way to organise software is increasingly based on communications (Cloud Computing, many cores, message-passing parallel computation, ...)
- Question
  - How to formally abstract/specify/implement/control communications?
  - How to apply mobile processes and their type theories to real distributed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

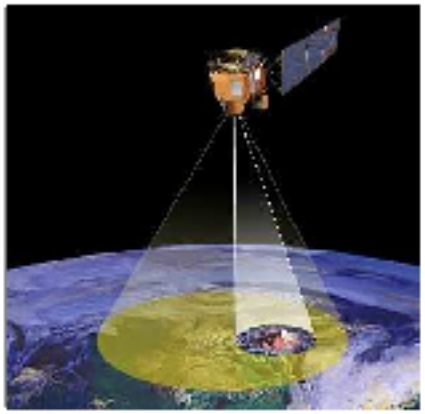
Current: Communication is Ubiquitous

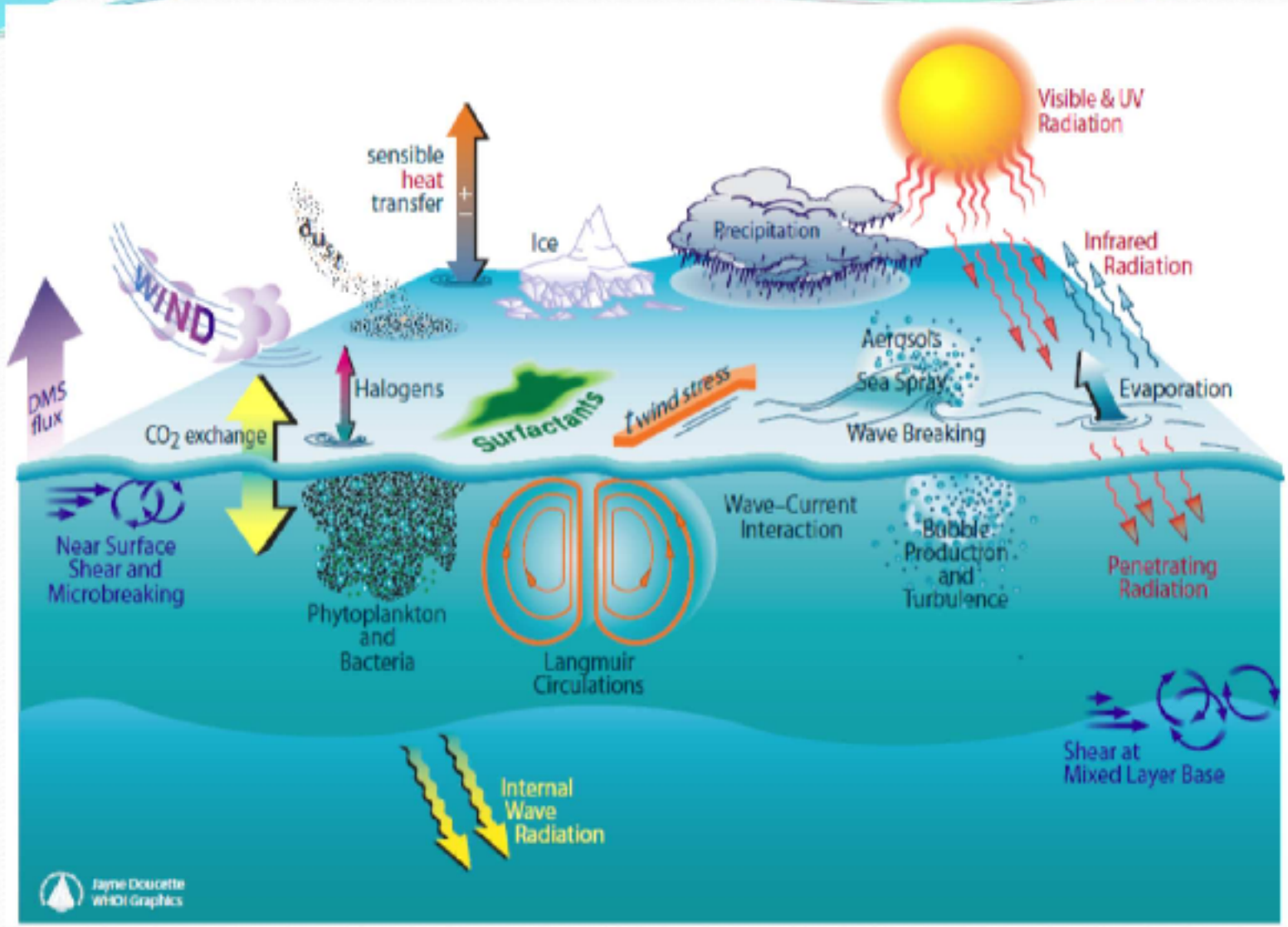
- The way to organise software is increasingly based on communications (Cloud Computing, many cores, message-passing parallel computation, ...)
- Question $\Longrightarrow$ Multiparty session type theory
  - How to formally abstract/specify/implement/control communications?
  - How to apply mobile processes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

Ocean Observatories Initiative

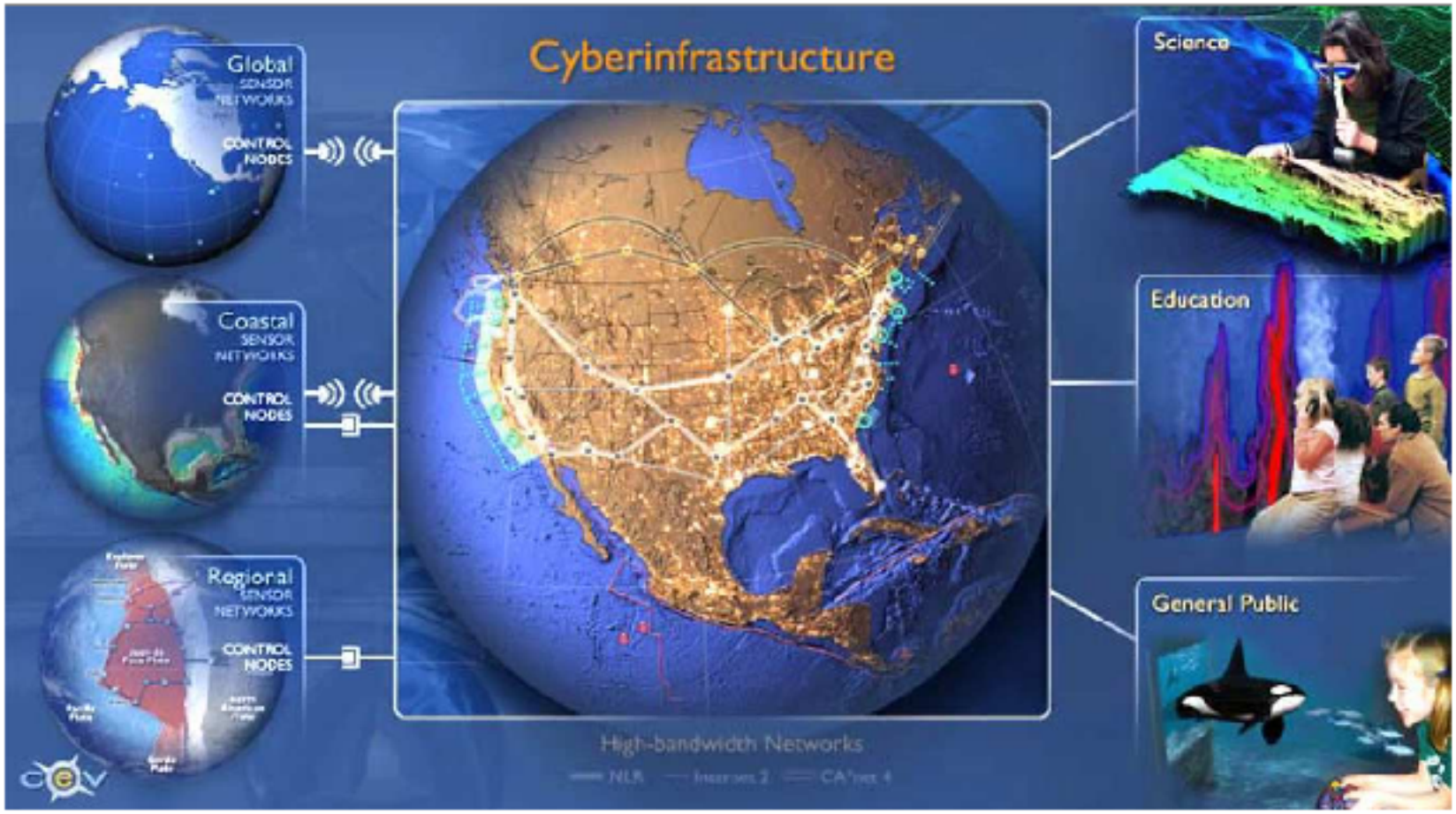
- A NSF project (400M$, 5 Years) to build a cyberinfrastructure for observing oceans around US and beyond.
- Real-time sensor data constantly coming from both off-shore and on-shore (e.g. buoys, submarines, under-water cameras, satellites), transmitted via high-speed networks.

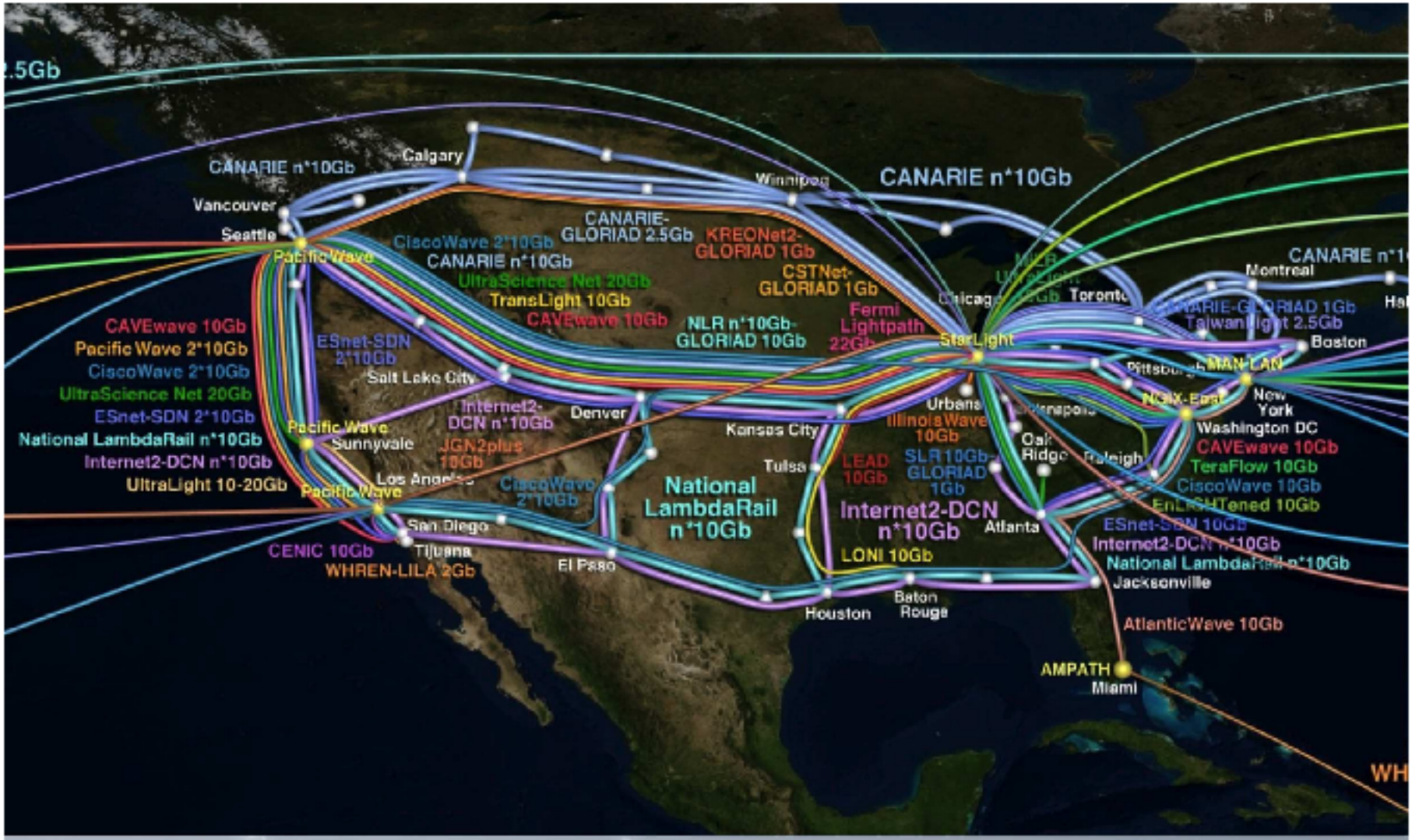





Visible & UV Radiation
sensible heat transfer
Ice
Precipitation
Infrared Radiation
WIND
DMS flux
Aerosols
Sea Spray
Halogens
Surfactants
τwind stress
Evaporation
CO2 exchange
Wave Breaking
Near Surface Shear and Microbreaking
Wave–Current Interaction
Bubble Production and Turbulence
Penetrating Radiation
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 $\pi 4$ 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;
}
```

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⇓

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⇓

Multiparty Session Types [POPL'08]

⇓

Scribble redhat

Dialogue between Industry and Academia

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⇓

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⇓

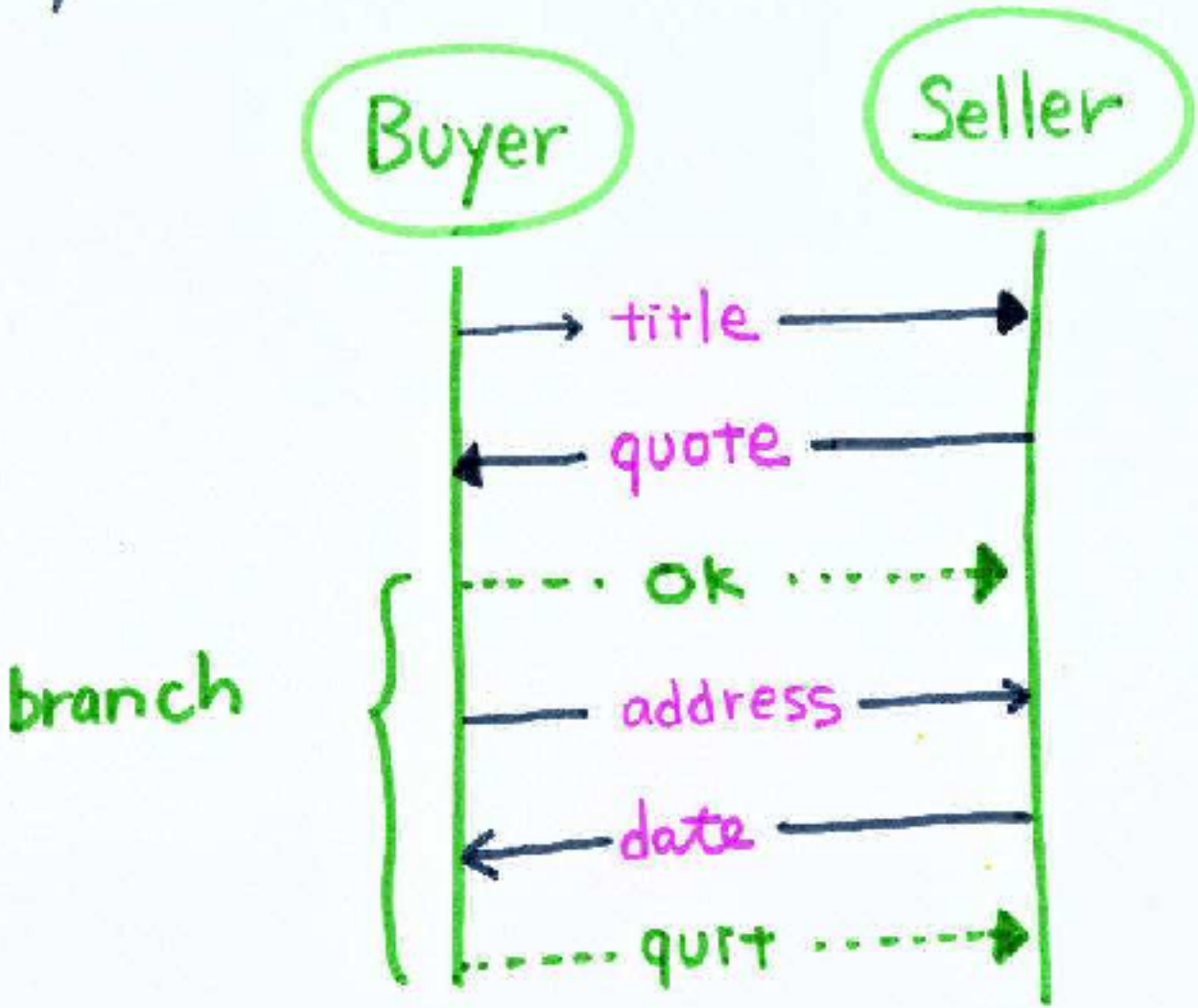
Scribble at π_4 Technology

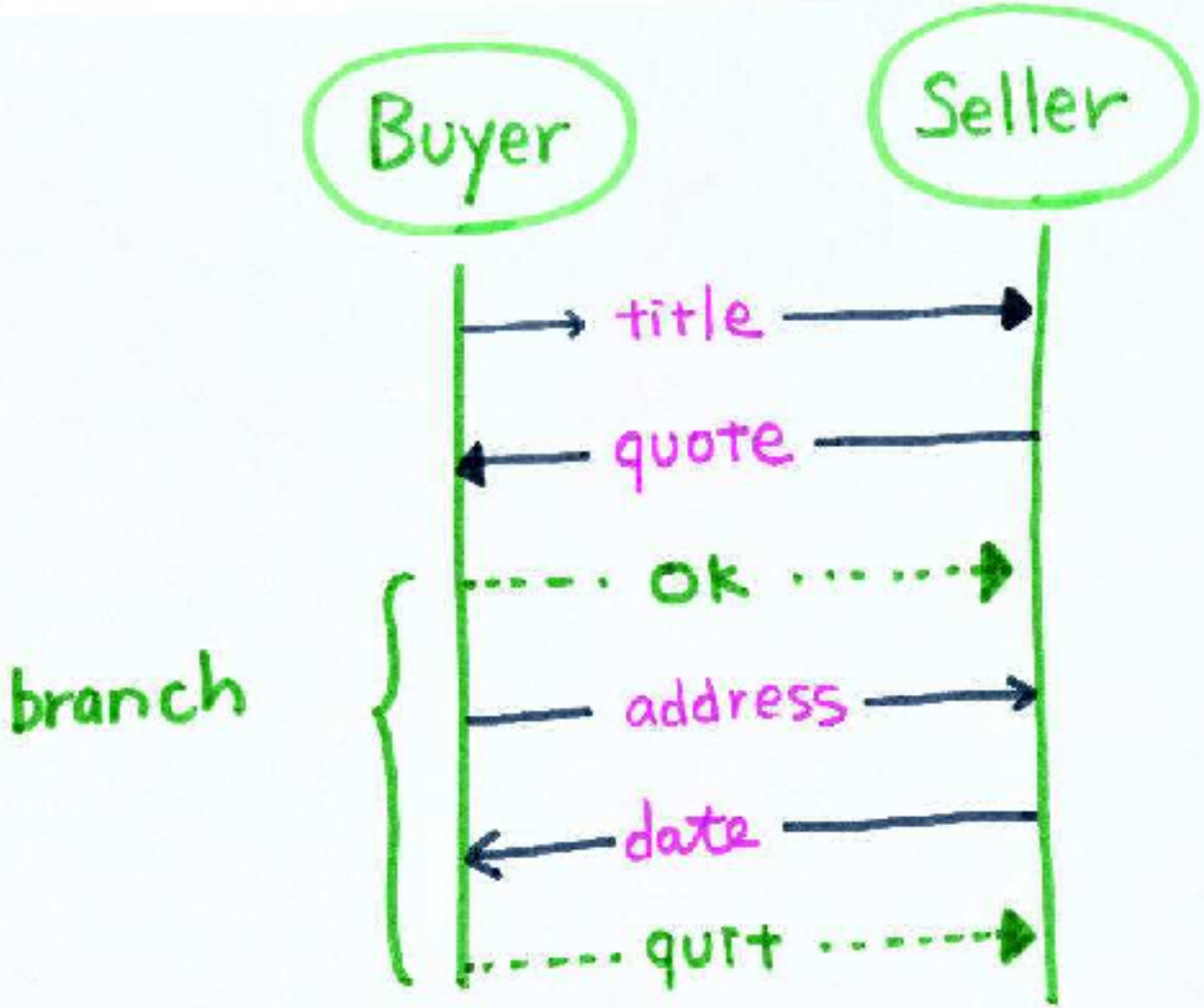
⇓

Multiparty Session Types [POPL'08]

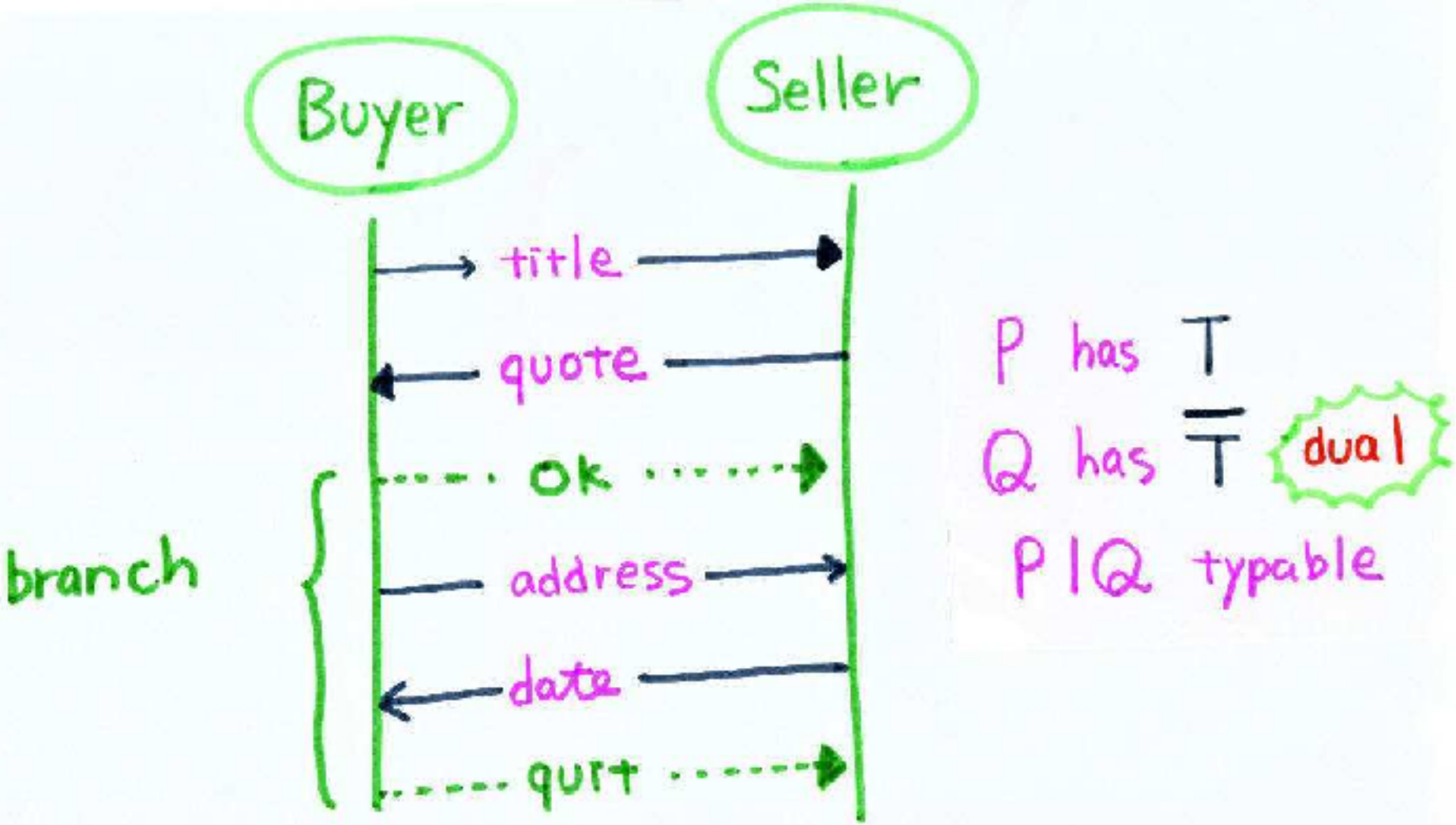
⇓

Binary Session Types : Buyer - Seller Protocol





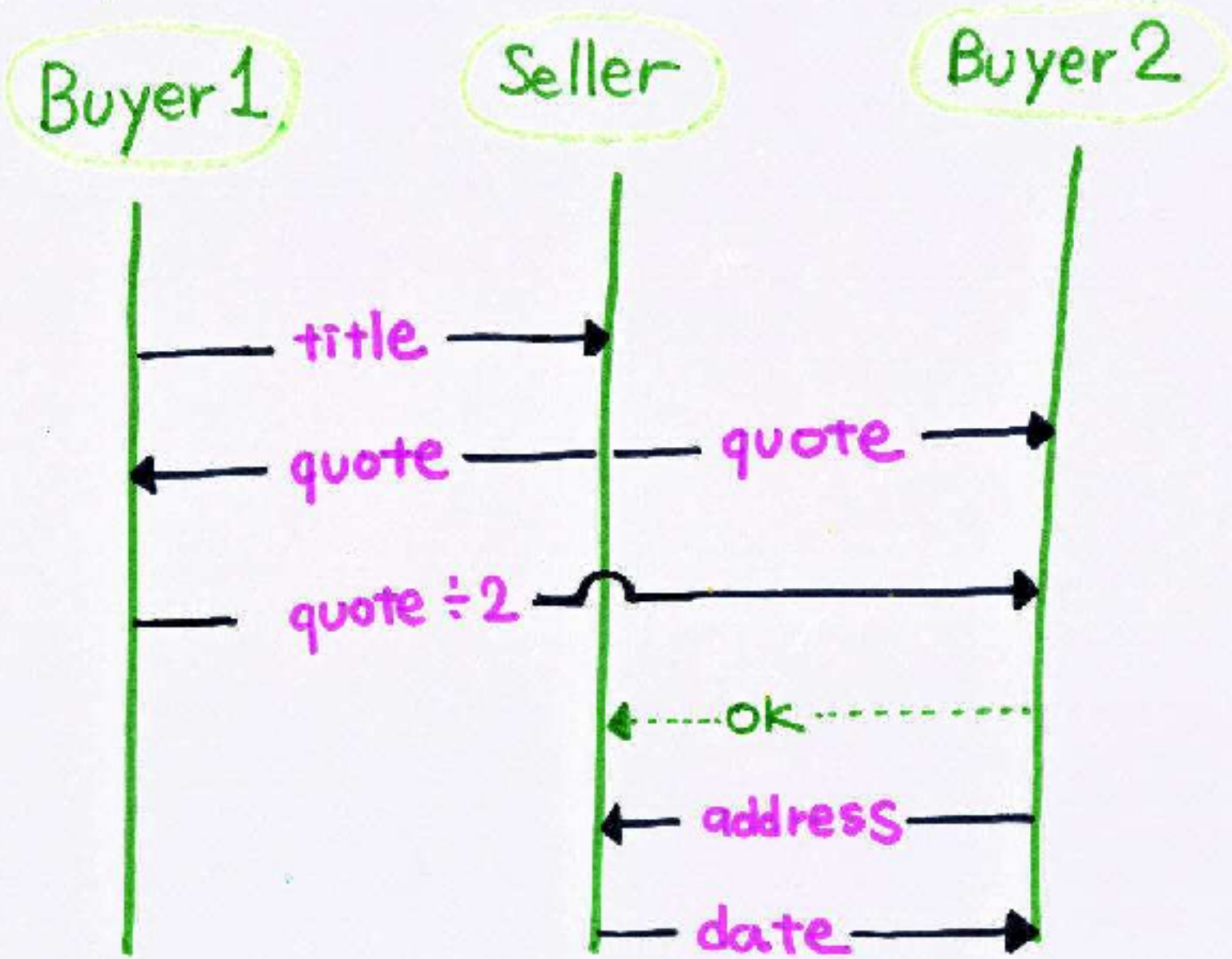
$!\mathrm{String};?\mathrm{Int};\oplus\{\mathrm{ok}:!\mathrm{String};?\mathrm{Date};\mathrm{end},\ \mathrm{quit}:\mathrm{end}\}$

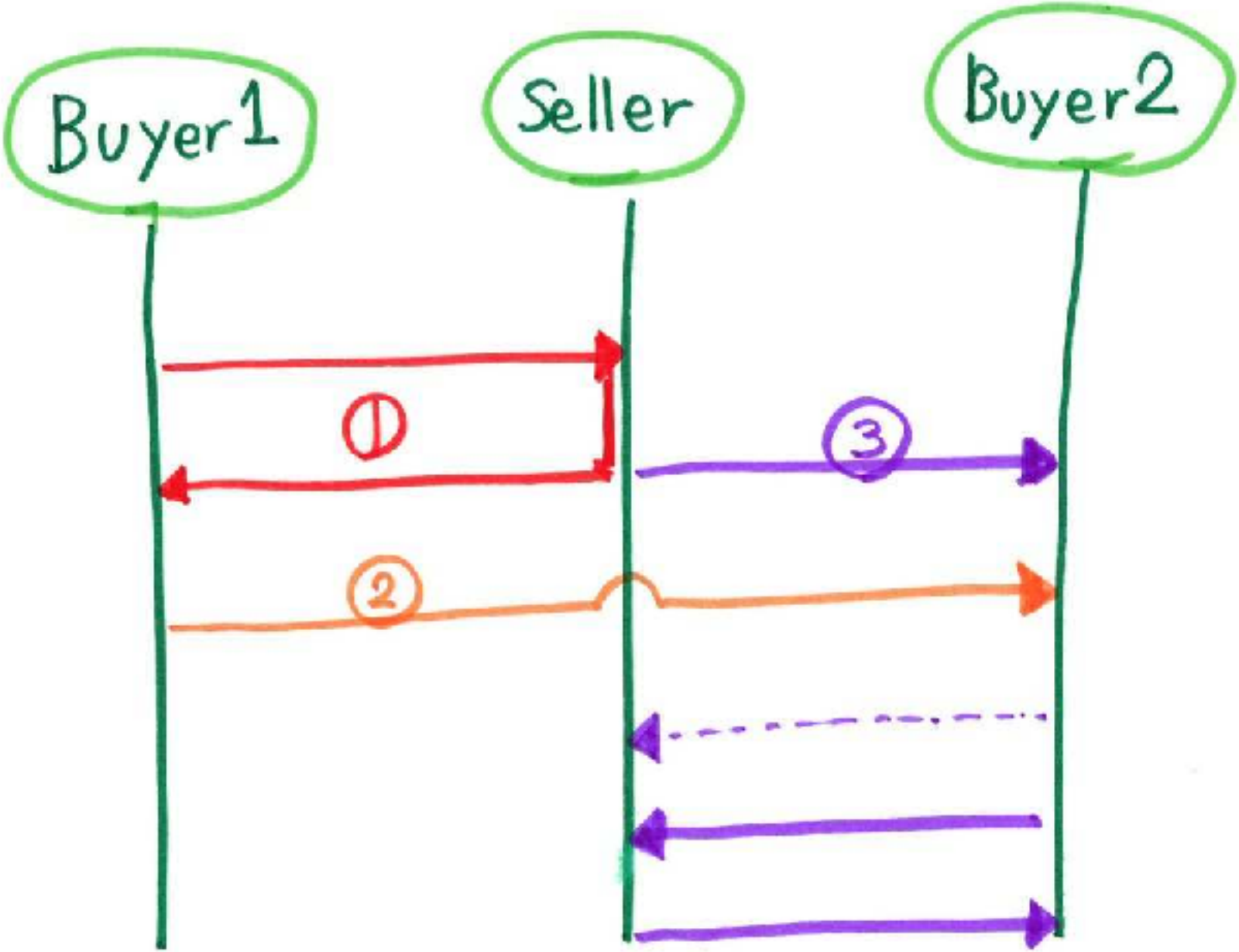


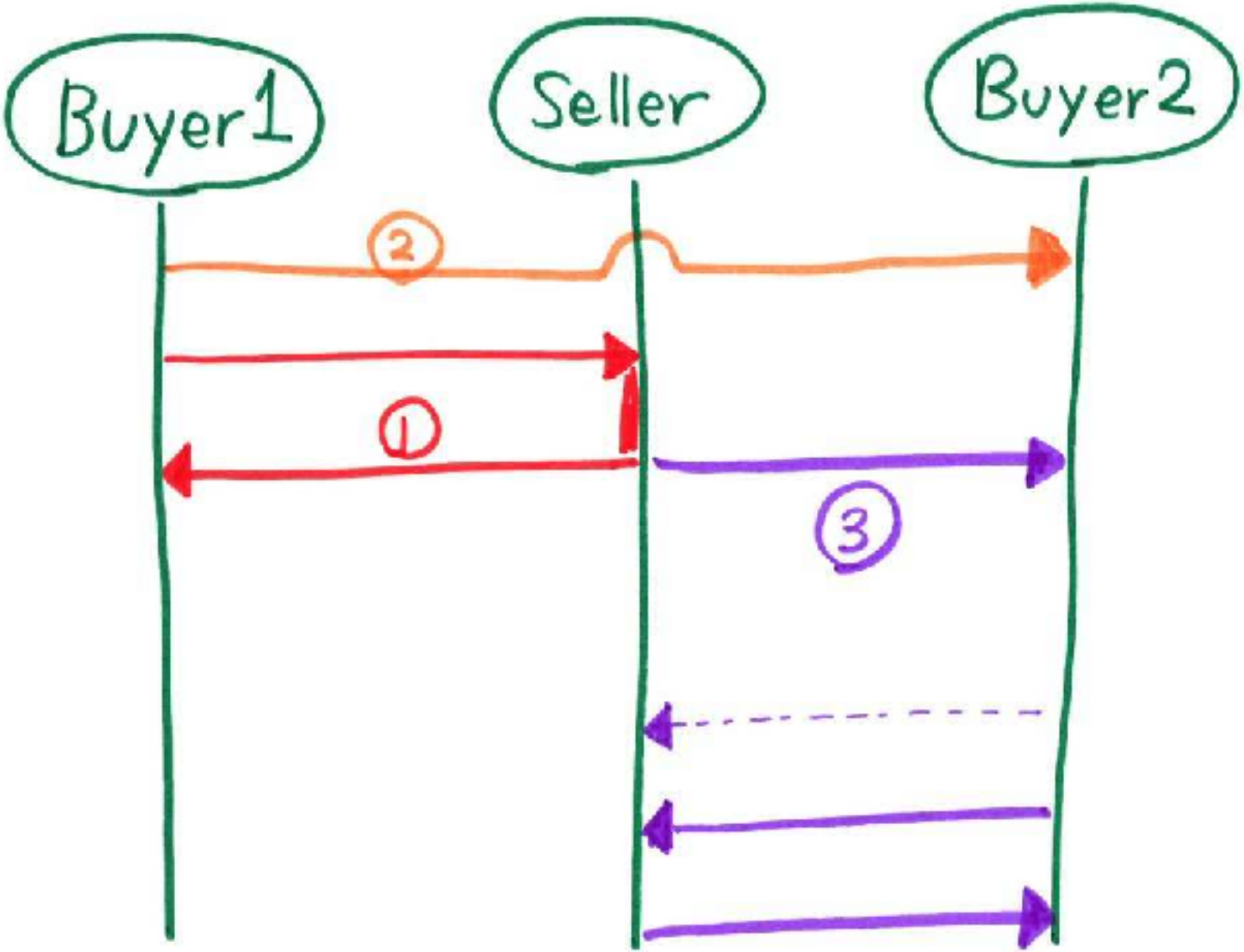
$!\,\mathrm{String}\,;\,?\,\mathrm{Int}\,;\,\oplus\{\mathrm{ok}:!\,\mathrm{String}\,;\,?\,\mathrm{Date}\,;\,\mathrm{end},\ \mathrm{quit}:\mathrm{end}\}$

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

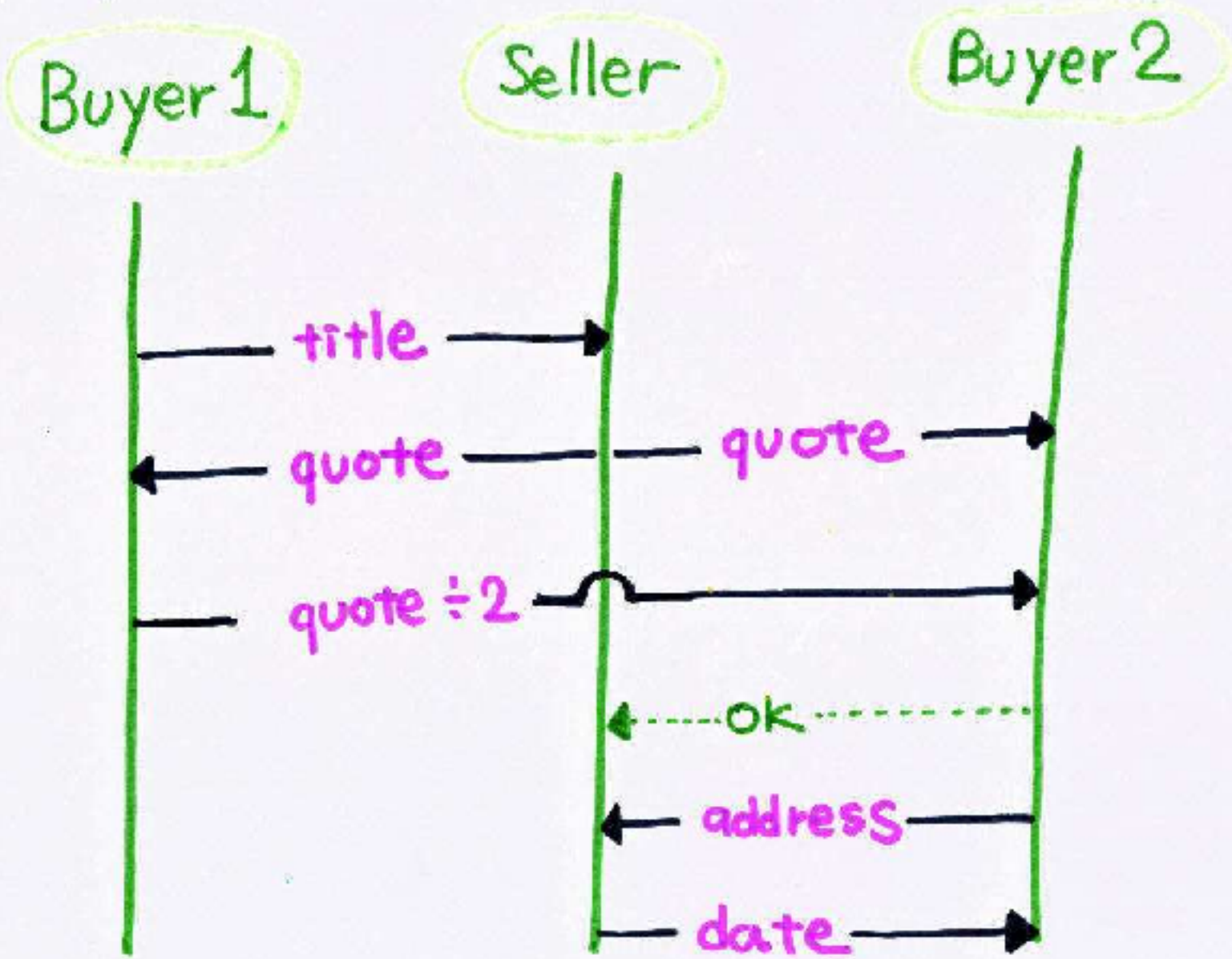
Multiparty Session Types




Buyer1
Seller
Buyer2
①
②
③

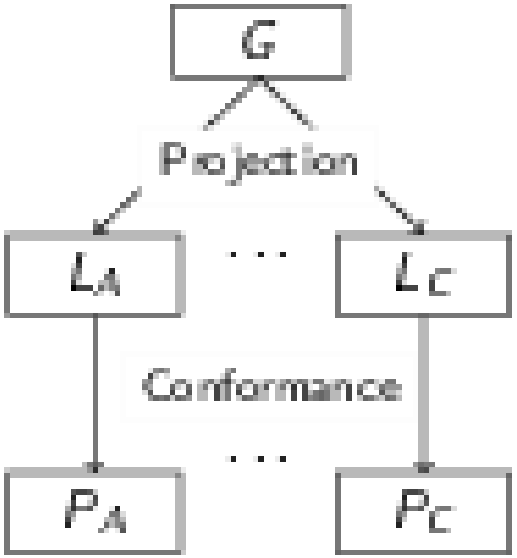

Buyer1
Seller
Buyer2
2
1
3

Multiparty Session Types



Multiparty session types

- Global Types and End Point Projection (Abstract Choreography)
  - Potential errors:
    - Communication mismatch: e.g. receiver is sent an unexpected message
    - Protocol violation: executed interaction does not follow the protocol
    - Deadlock: e.g. all endpoints blocked on input



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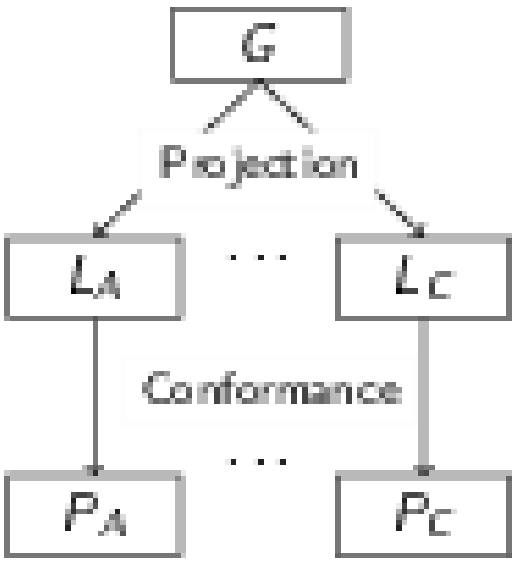

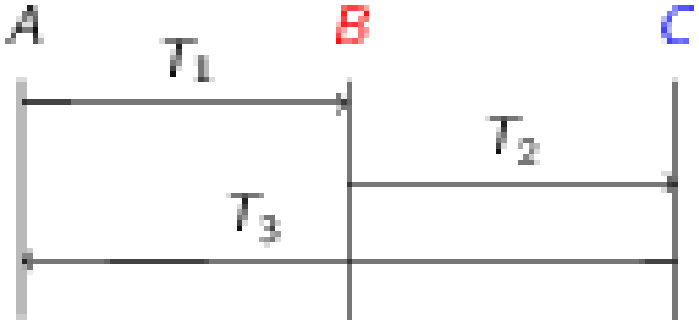

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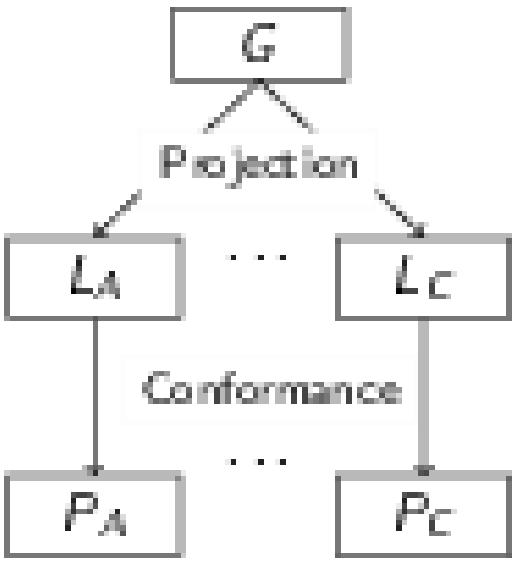

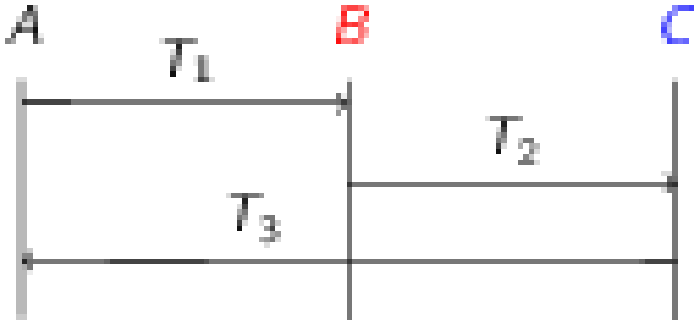

$$G = A \to B : T_1.\ B \to C : T_2.\ C \to A : T_3$$

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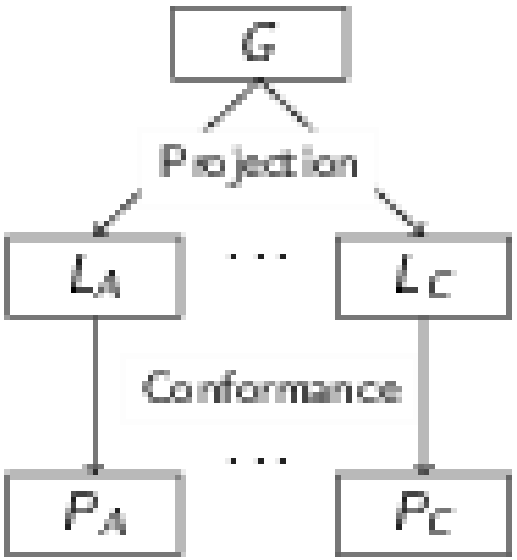

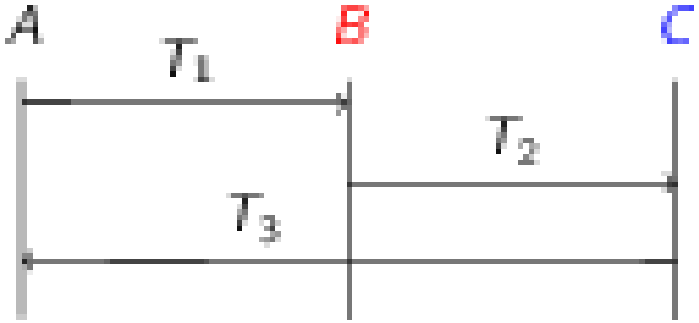

$$G = A \to B : T_1.\ B \to C : T_2.\ C \to A : T_3$$

Projection (Good)

$A : !\langle B, T_1\rangle.?\langle C, T_3\rangle$
$B : ?\langle A, T_1\rangle.!\langle C, T_2\rangle$
$C : ?\langle B, T_2\rangle.!\langle A, T_3\rangle$

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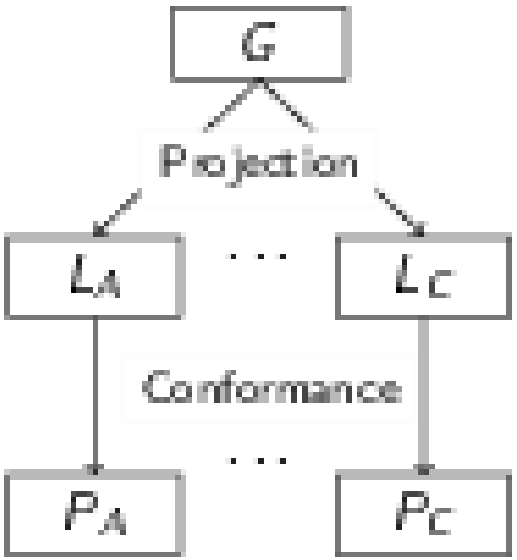
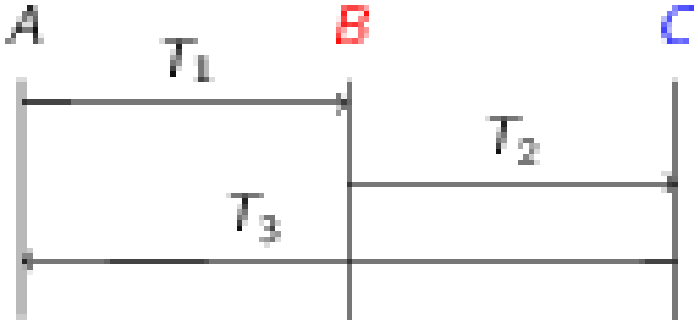




$$G = A \to B : T_1.\ B \to C : T_2.\ C \to A : T_3$$

Projection (Good)

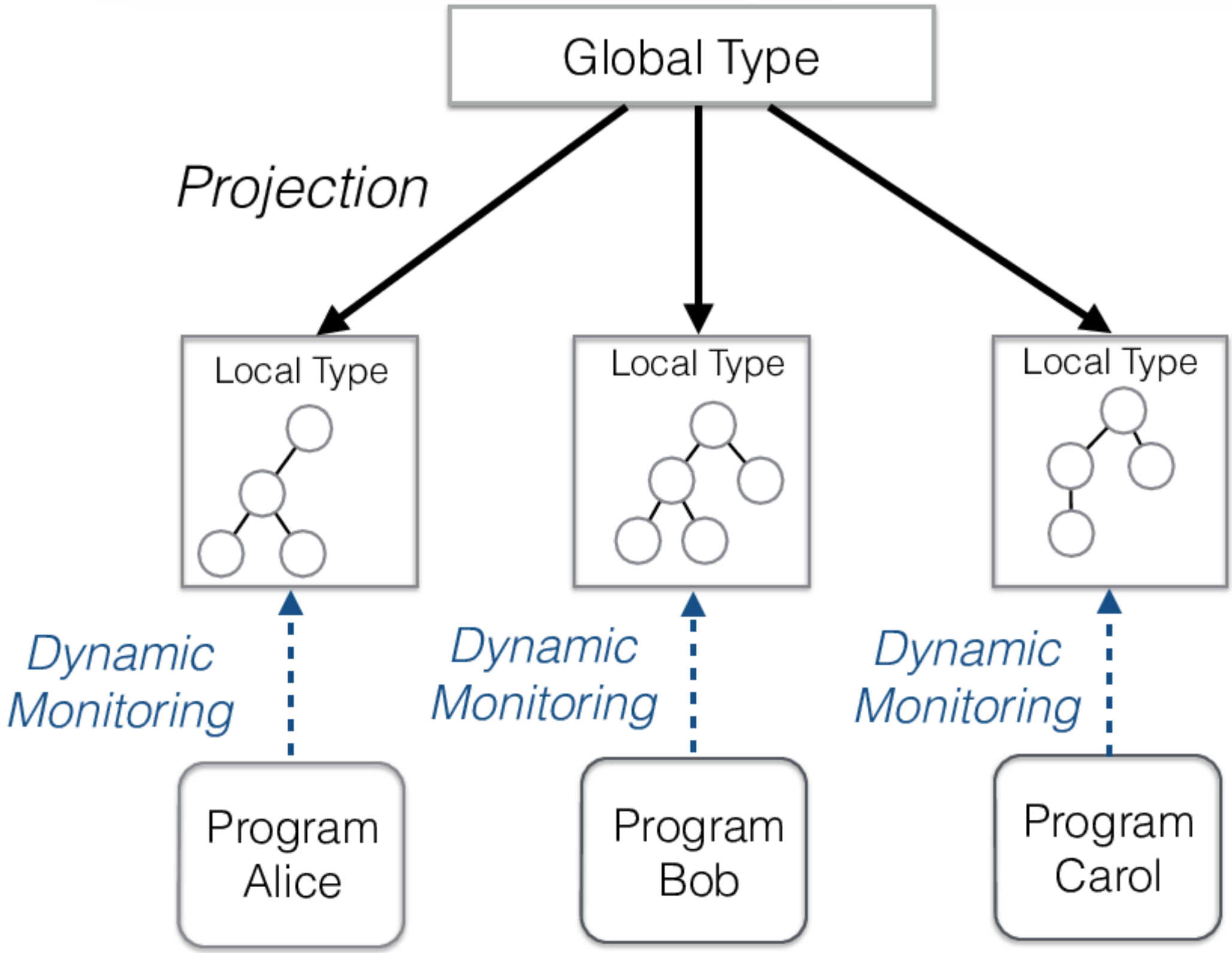
$A : !\langle B, T_1\rangle.?(C, T_3)$
$B : ?(A, T_1).!\langle C, T_2\rangle$
$C : ?(B, T_2).!\langle A, T_3\rangle$

Bad (Deadlock)

$A : ?(C, T_3).!\langle B, T_1\rangle$
$B : ?(A, T_1).!\langle C, T_2\rangle$
$C : ?(B, T_2).!\langle A, T_3\rangle$

Dynamic Monitoring

[RV'13, COORDINATION'14, FMSD'15]



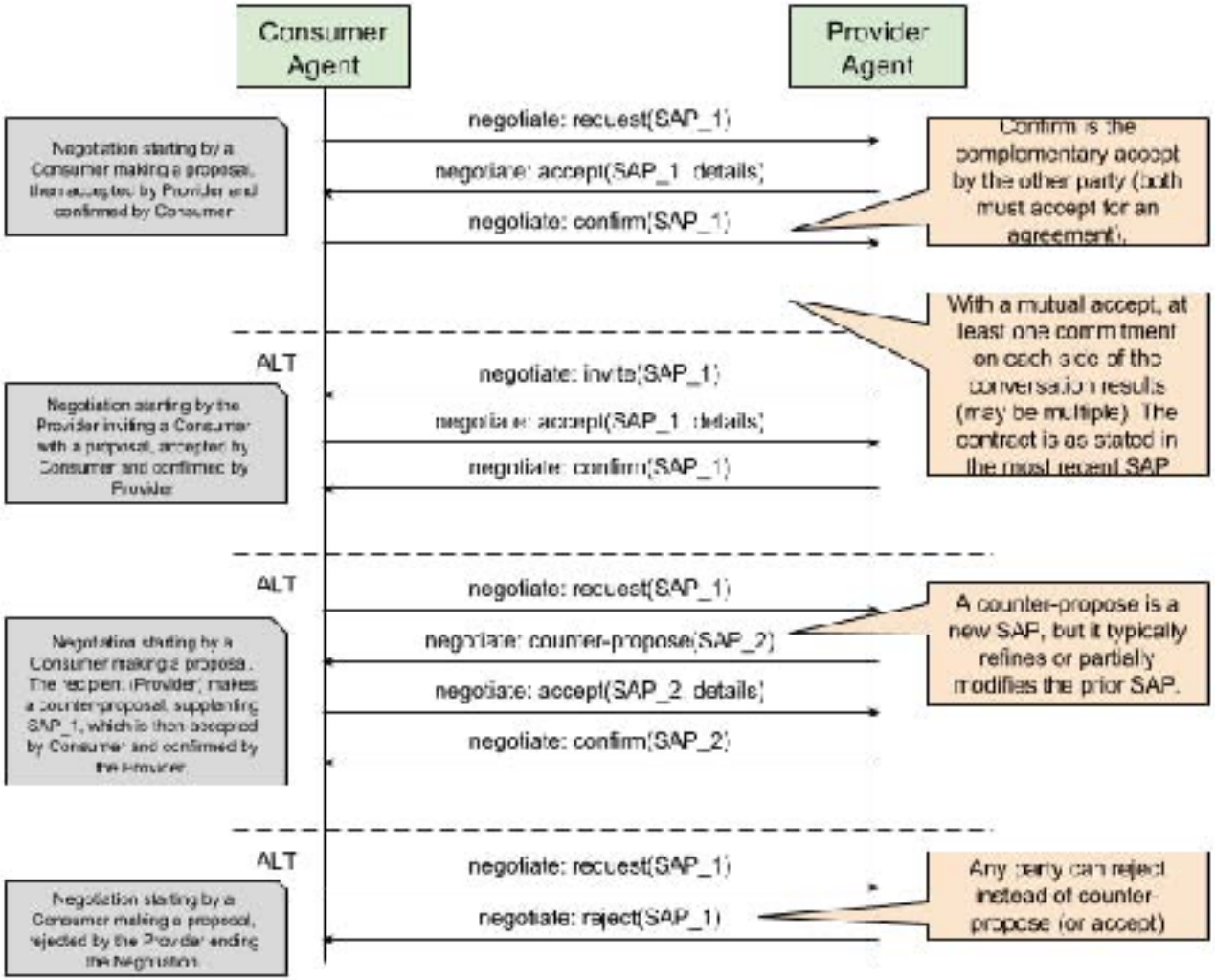
Two Buyer Protocol in Scribble

```
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,
            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;
} } }
```

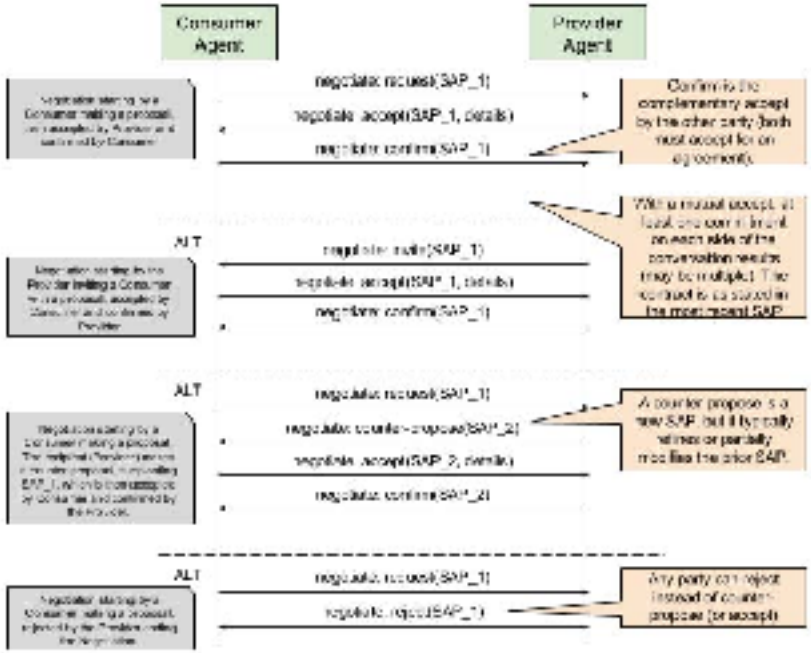
OOI agent negotiation 1/5



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

OOI agent negotiation 2/5

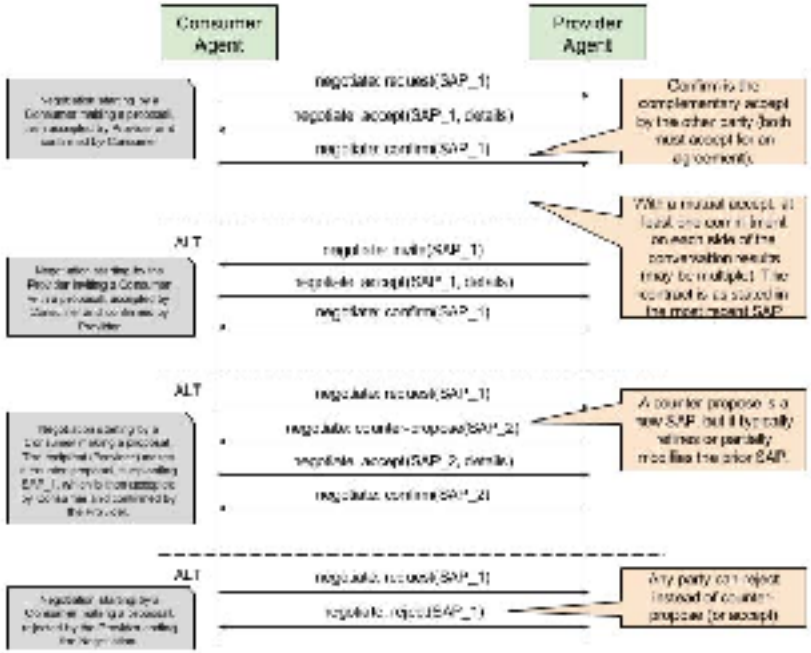
```
type <yml> "SAPDoc1" from "SAPDoc1.yml" as SAP;

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




```
}
```

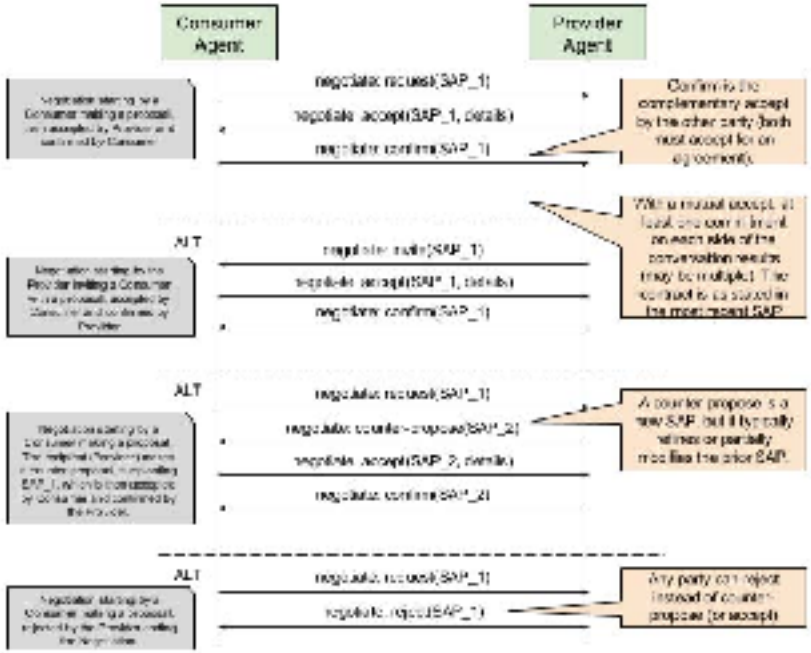
OOI agent negotiation 3/5 (choice)

```
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;

} }
```



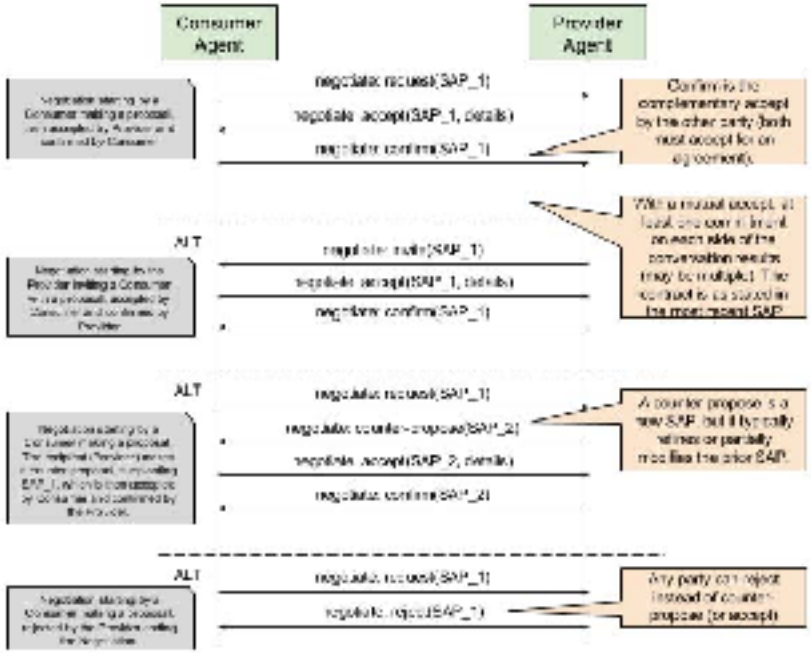
OOI agent negotiation 4/5

```
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;
      }
    }
```

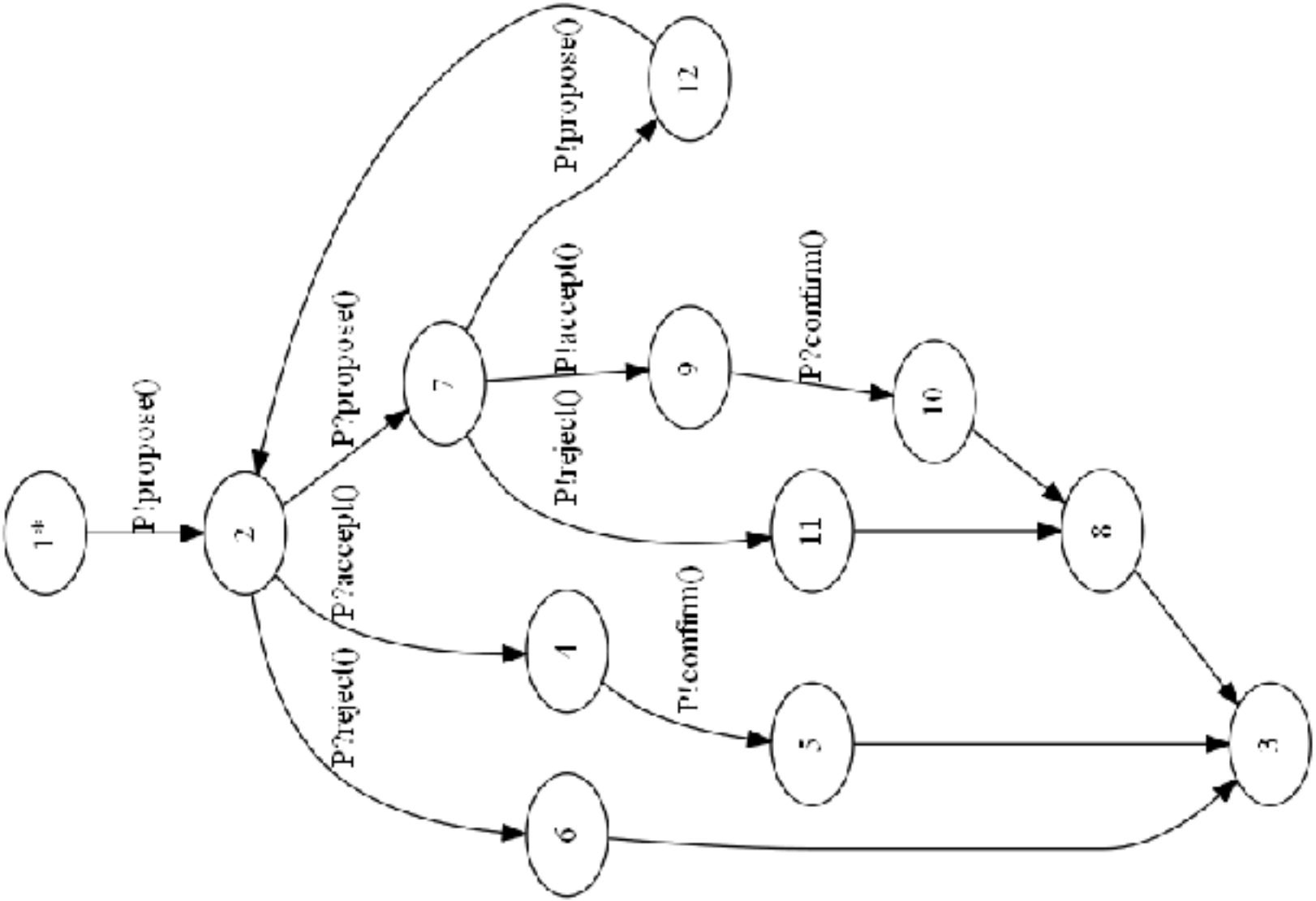


Local protocol projection (Negotiation Consumer)

```
// 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

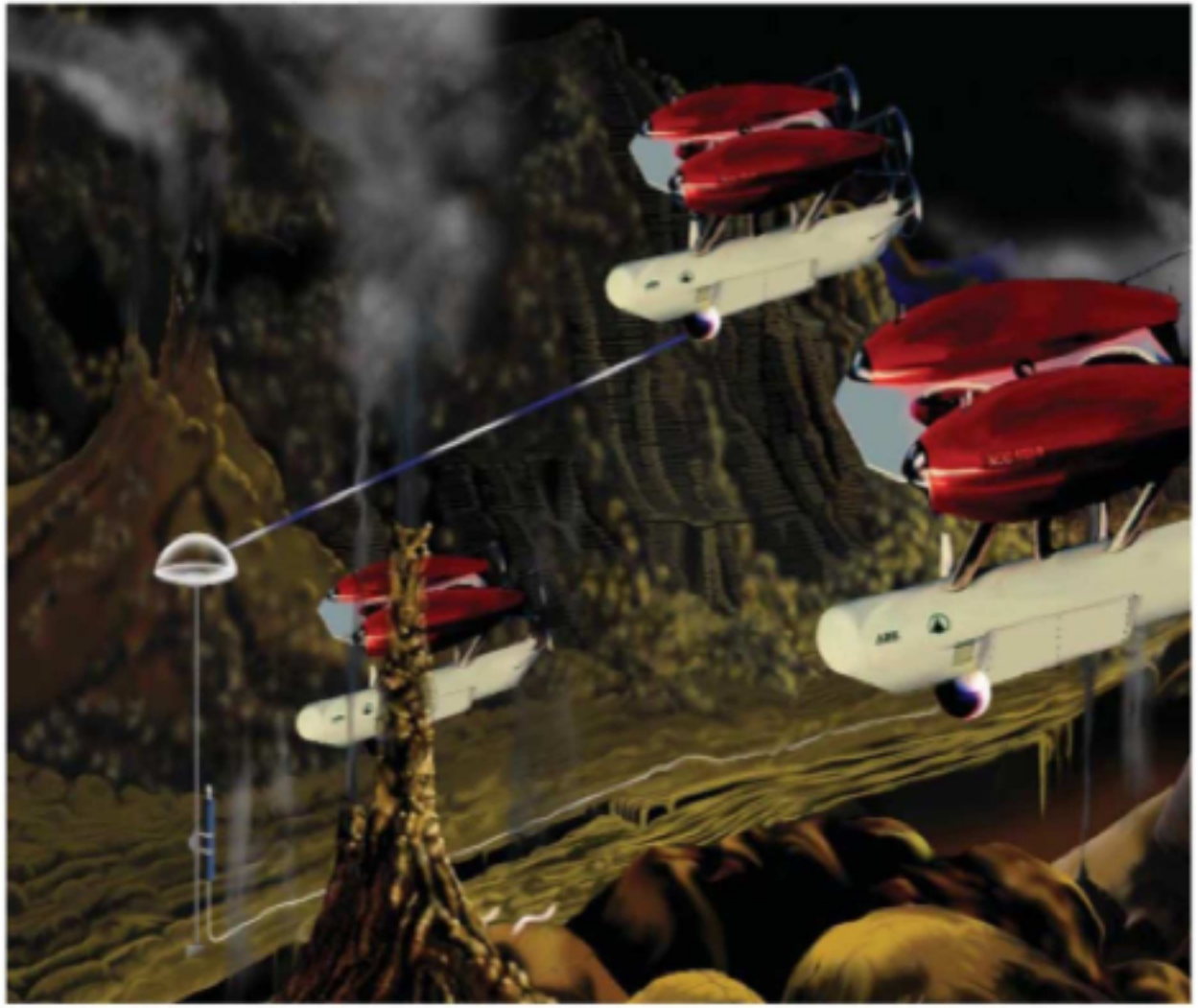


Figure 5: A coordinated set of autonomous underwater vehicles

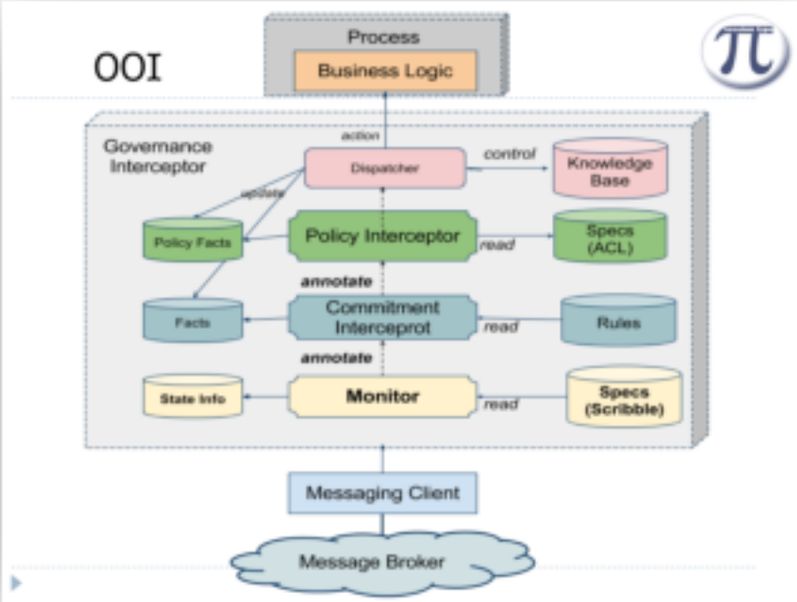
Figure 3: Observatory comprised of ships, aircraft and autonomous vehicles linked to assimilation modeling capabilities on shore

EPSRC
Engineering and Physical Sciences Research Council
EP/N027833/1

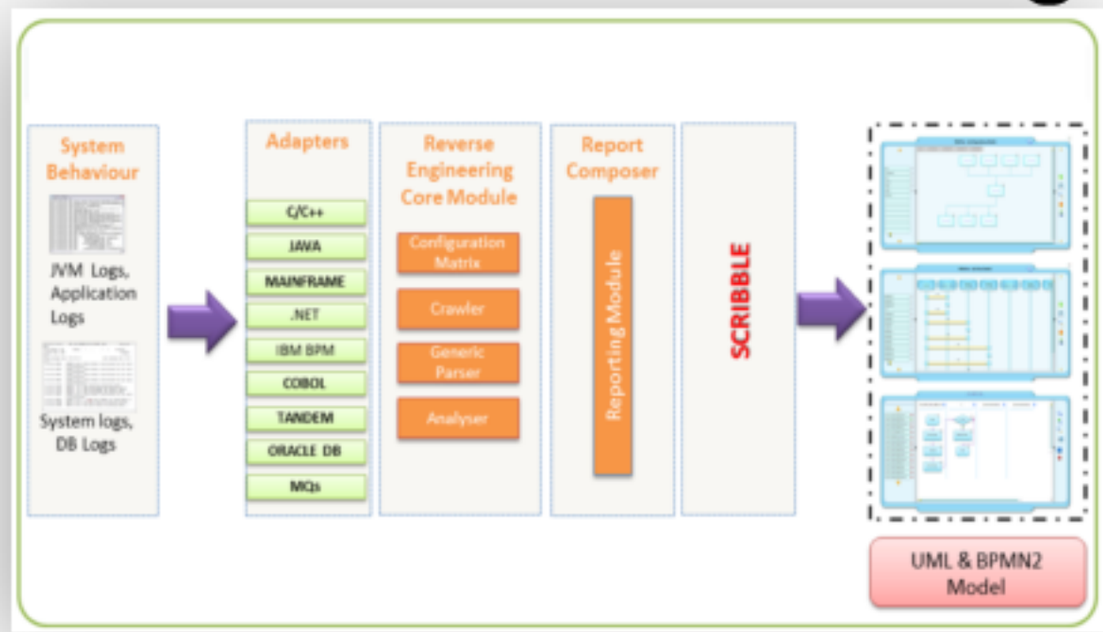
Turtles: Protocol-Based Foundations for Distributed Multiagent Systems

Applications

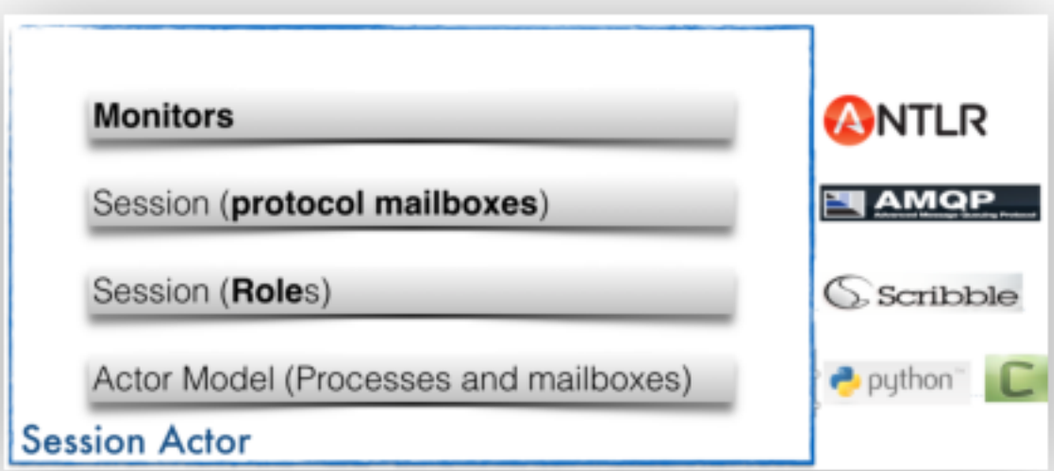
OOI Governance



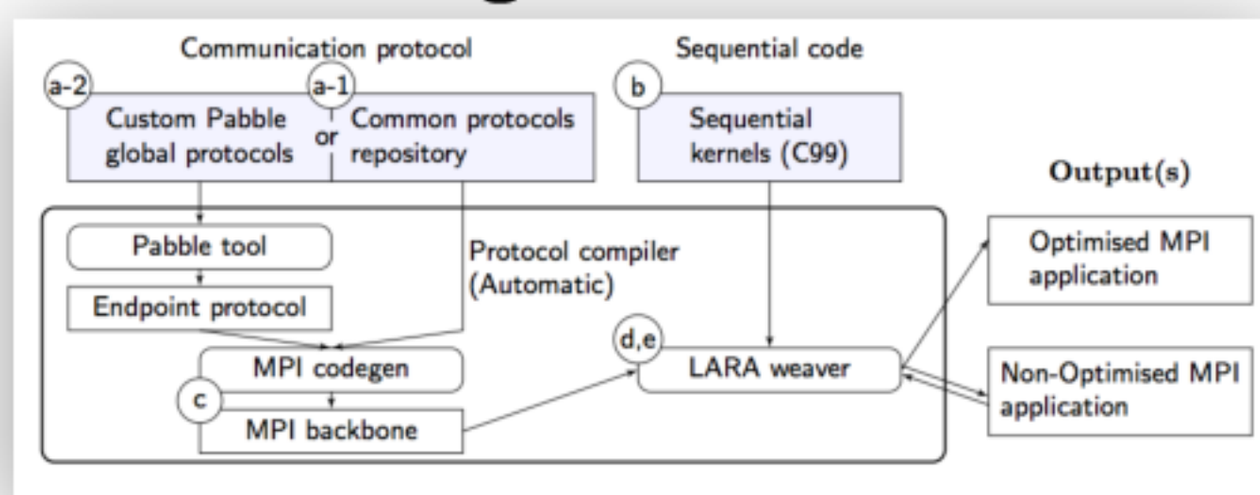
ZDLC: Process Modeling



Protocol Verification

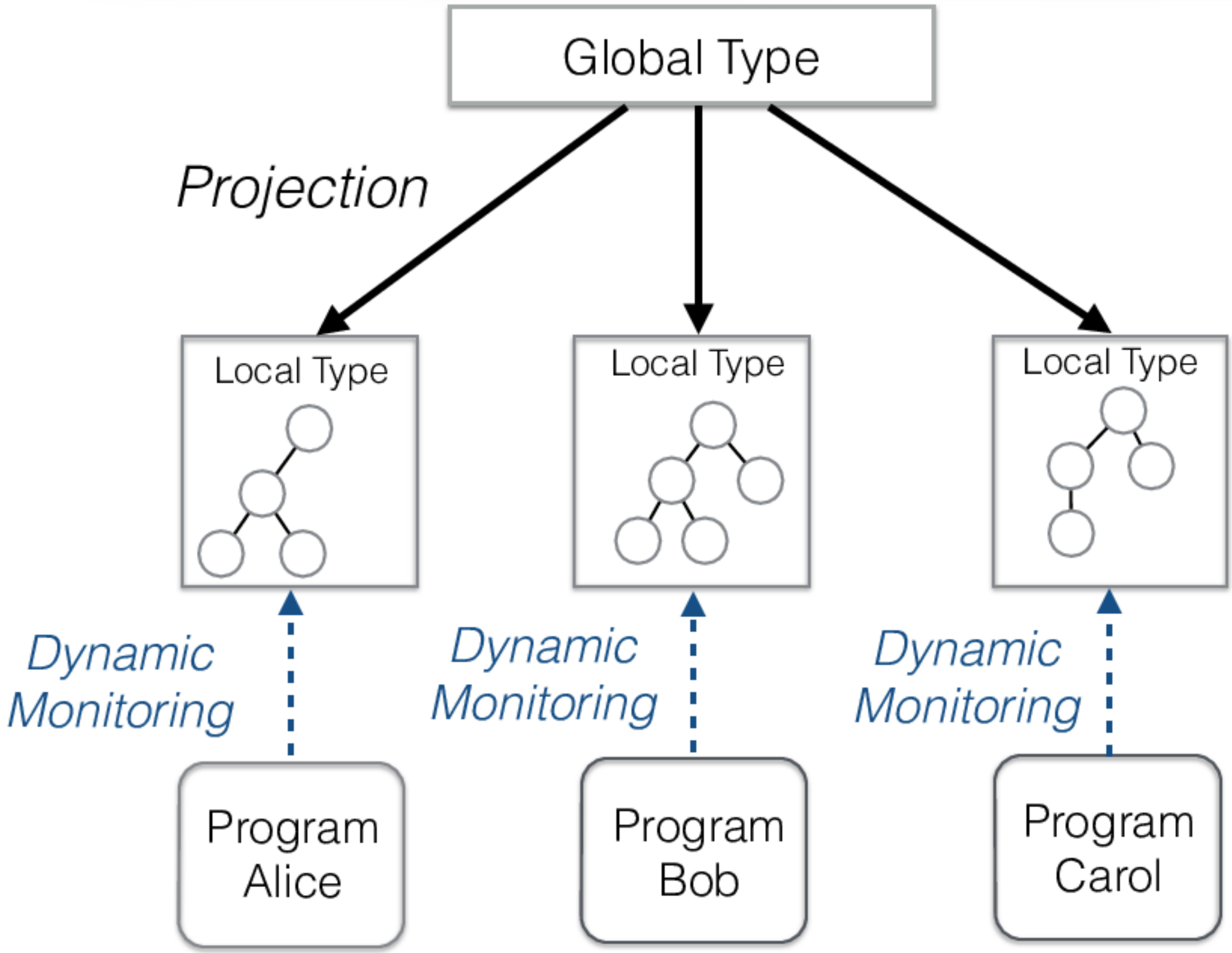


MPI code generations



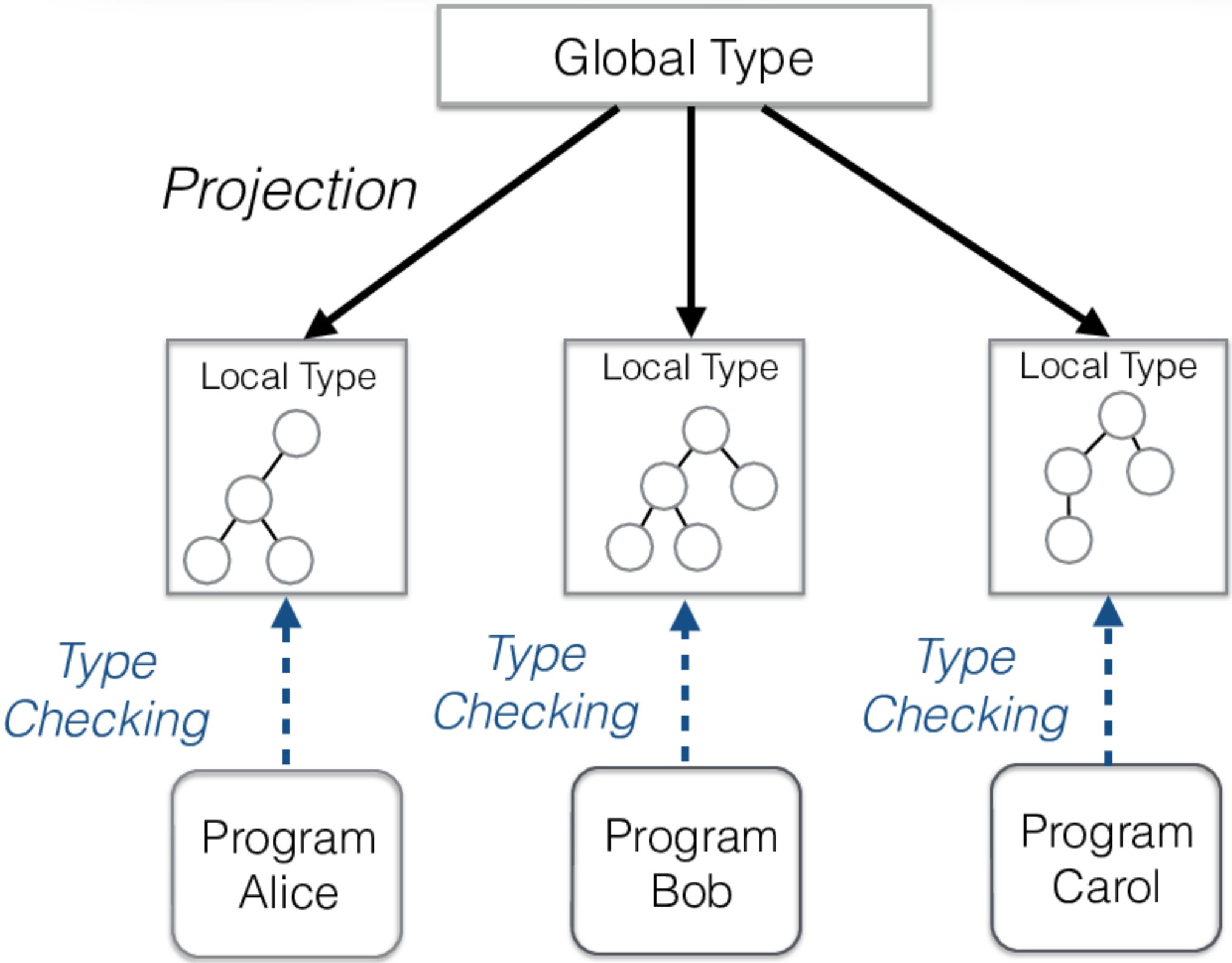
Dynamic Monitoring

[RV'13, COORDINATION'14, FMSD'15]

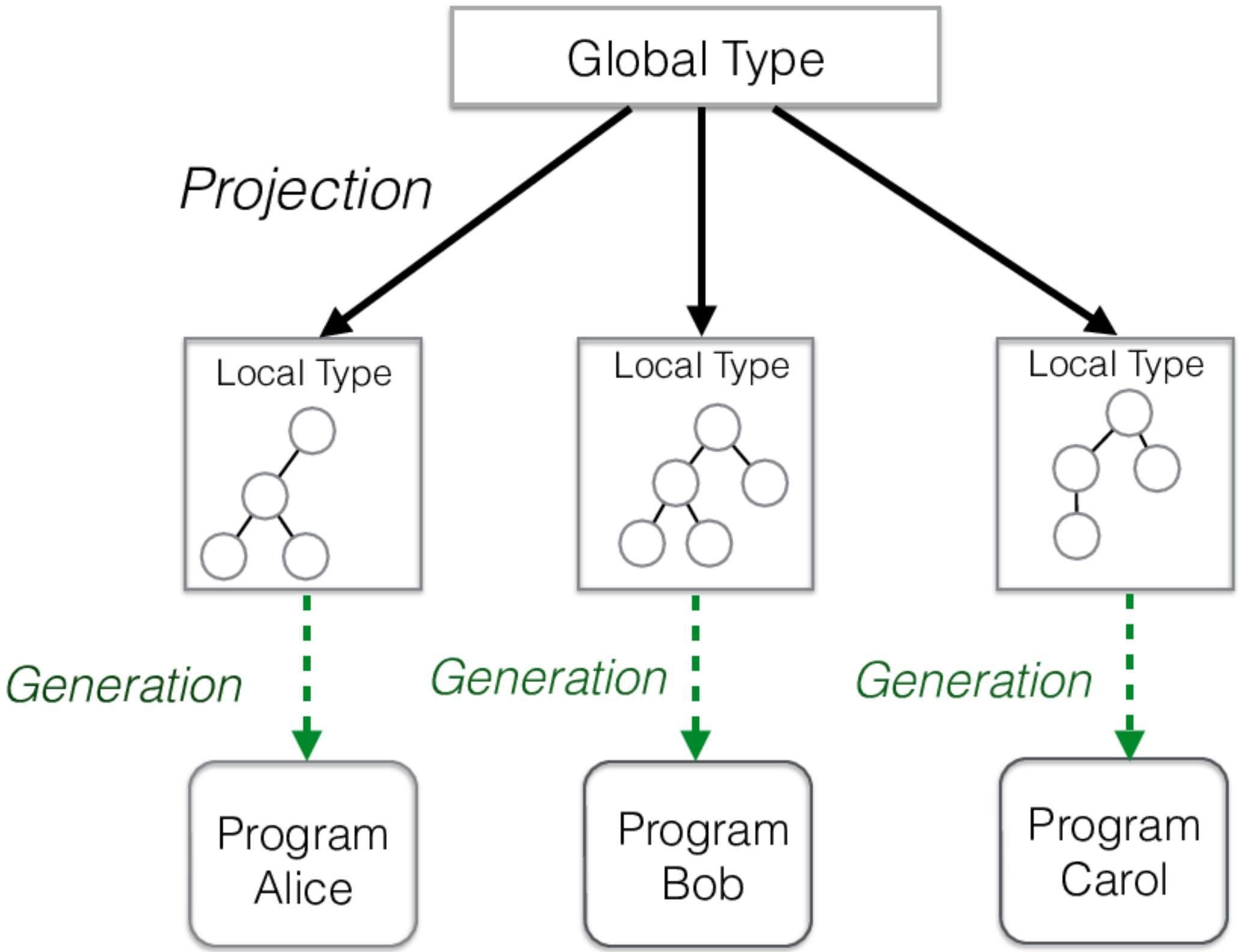


Type Checking

[ECOOP'16, OOPSLA'15, POPL'16]

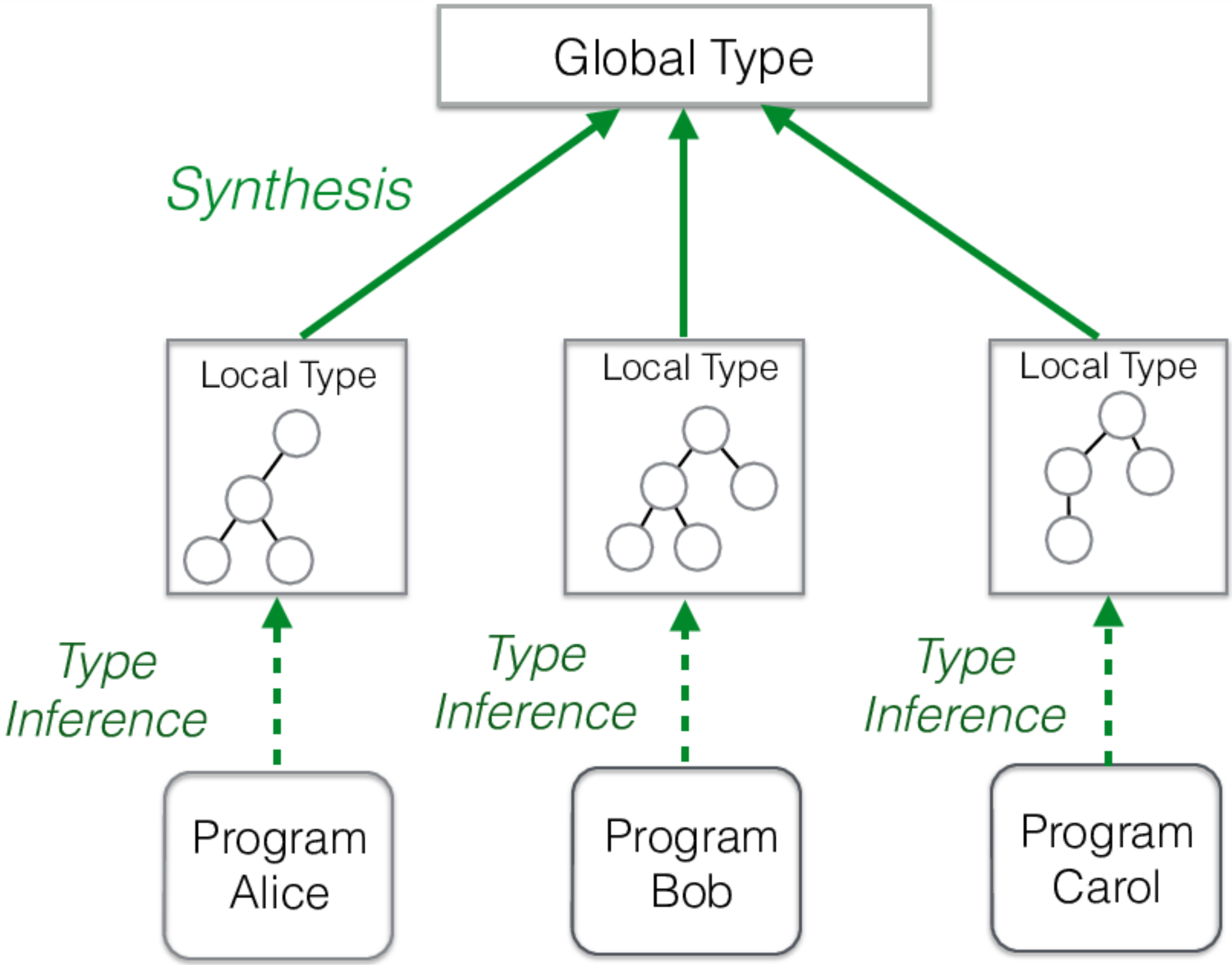


Code Generation [CC'15, FASE'16]



Synthesis

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



Scribble SMTP

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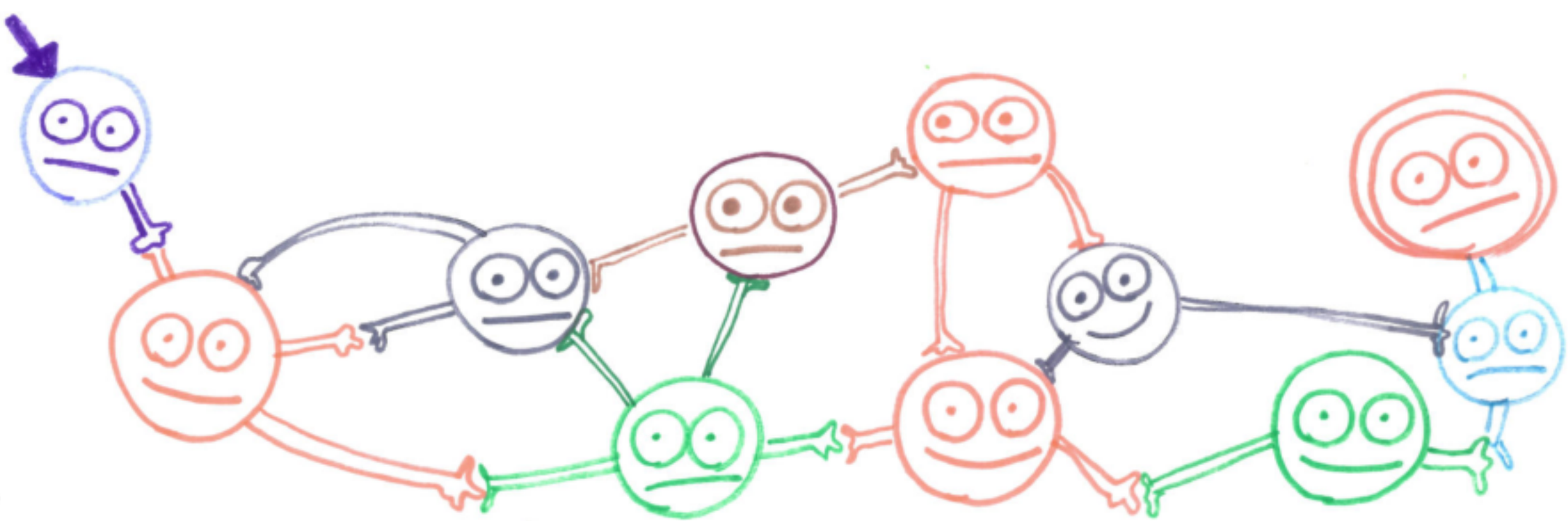
Multiparty Compatibility in Communicating Automata

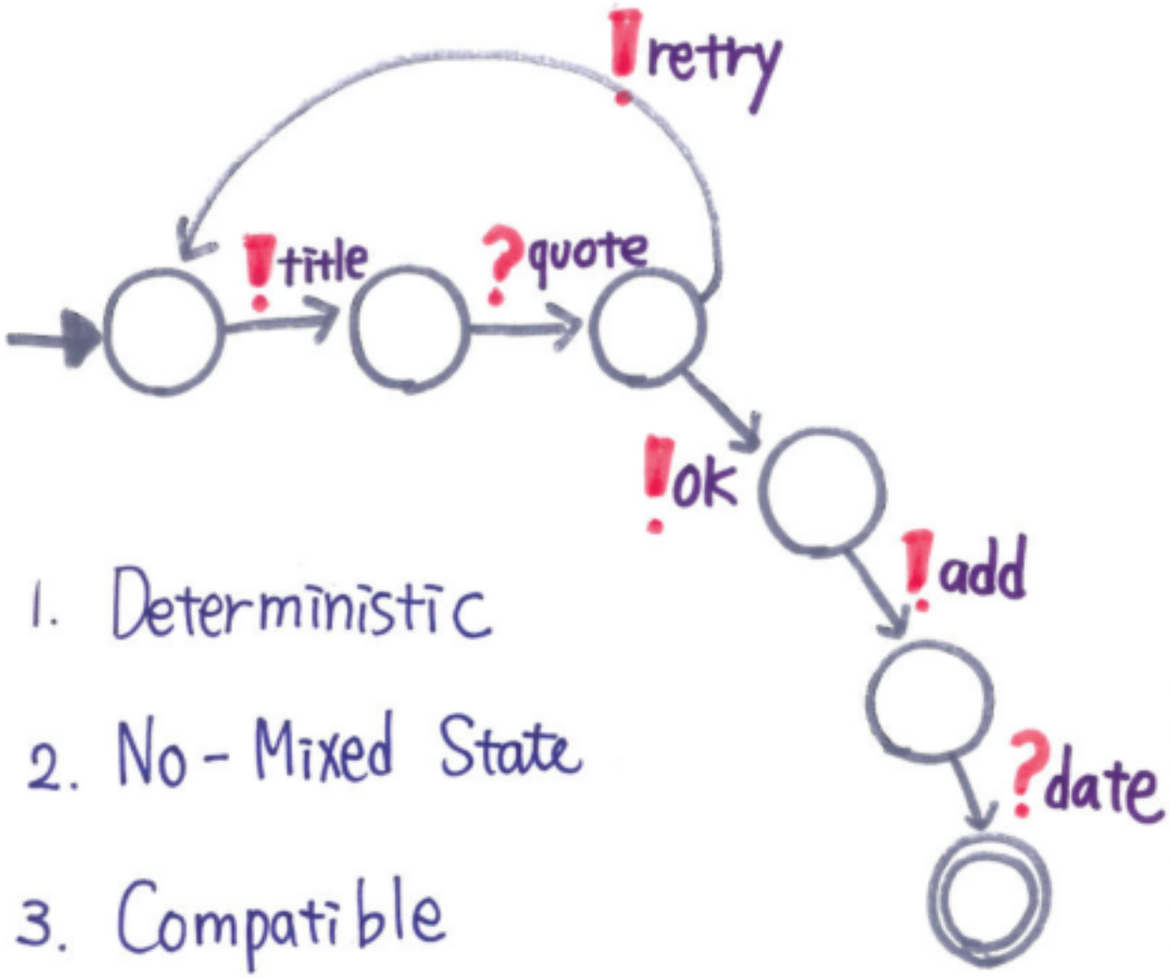
Synthesis and Characterisation of Multiparty Session Types

Nobuko Yoshida

Pierre-Malo Deniélou

ICALP'13





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.

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

Cognizant ZDLC
Zero Deviation Lifecycle

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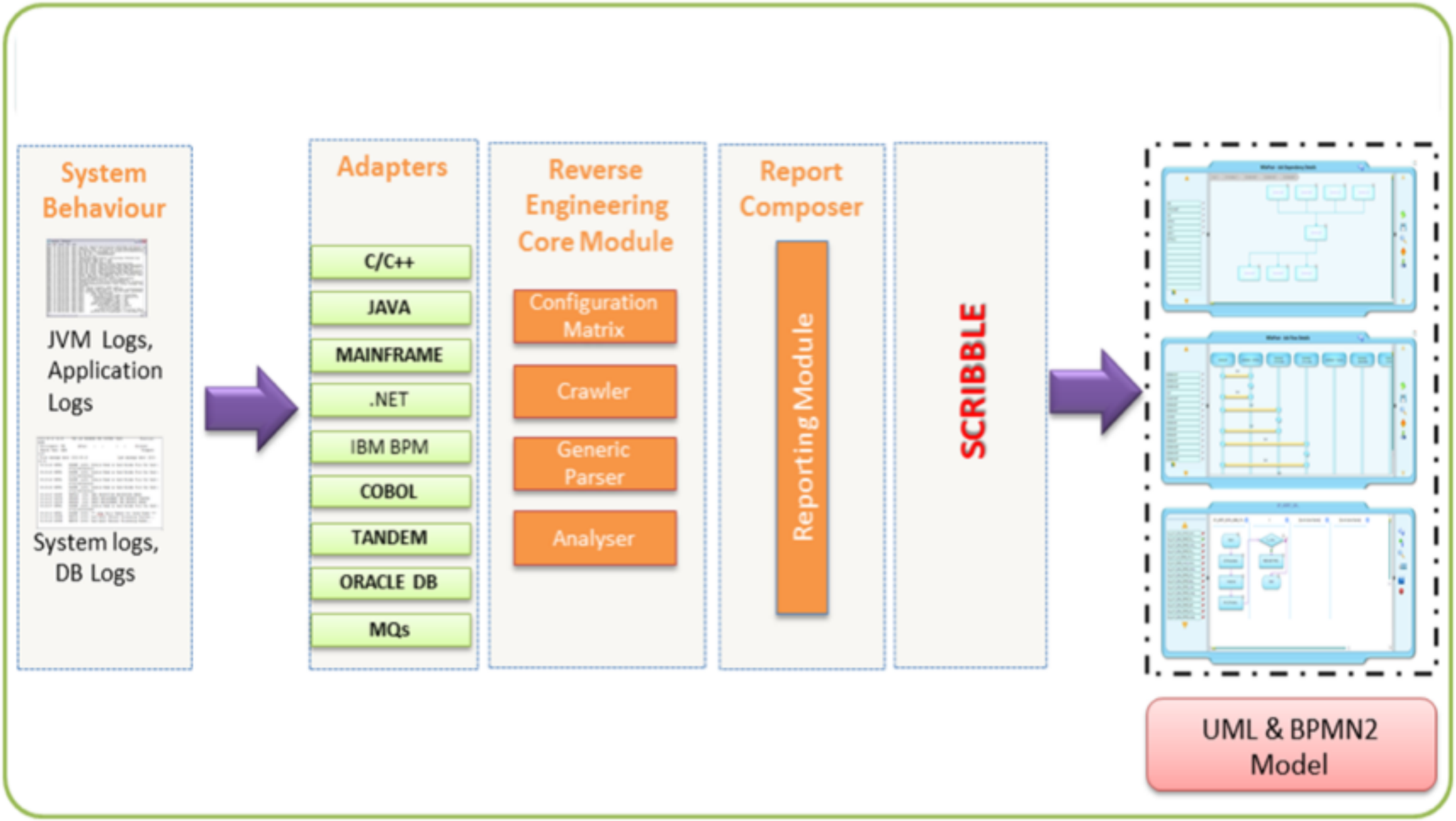
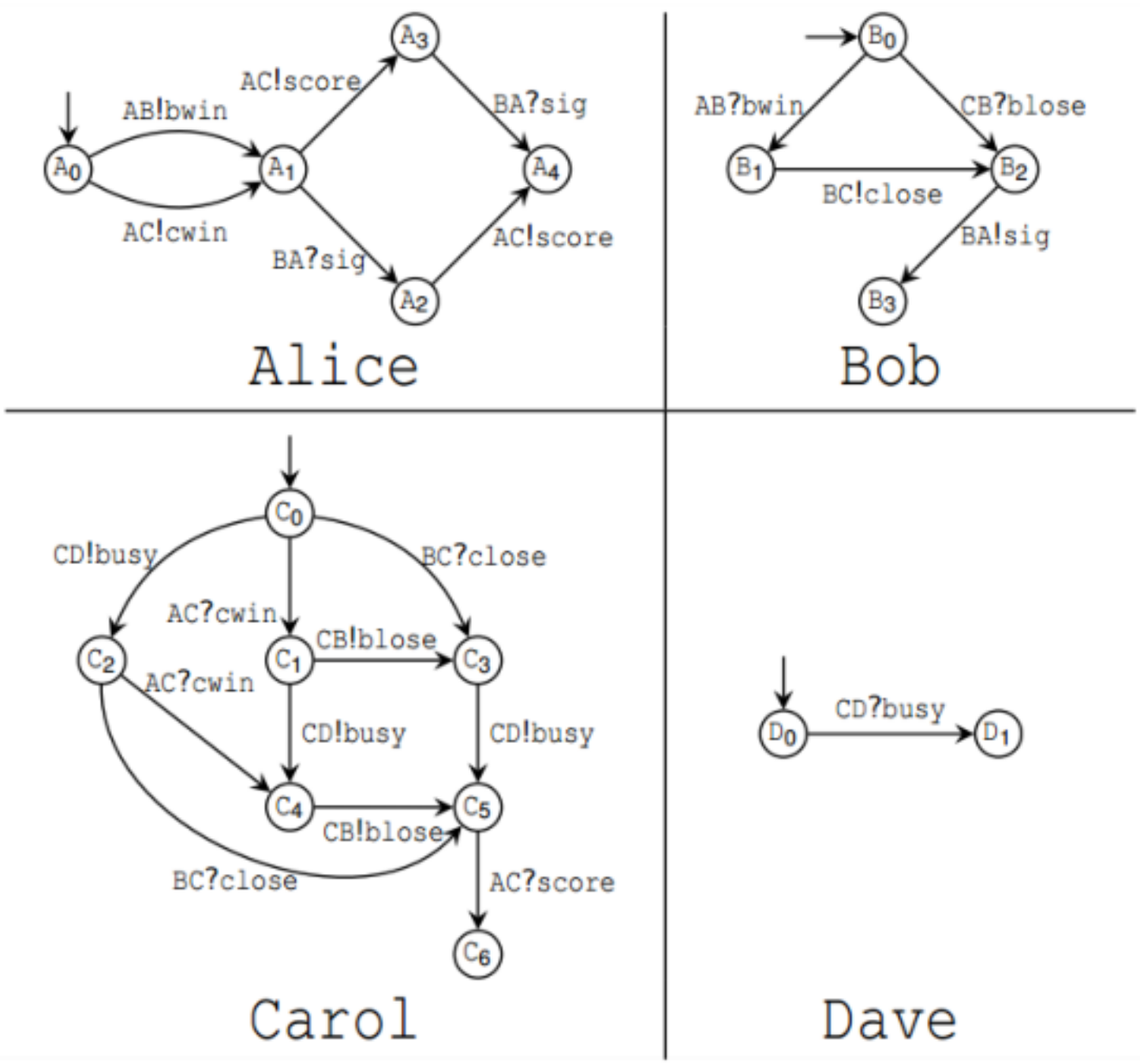
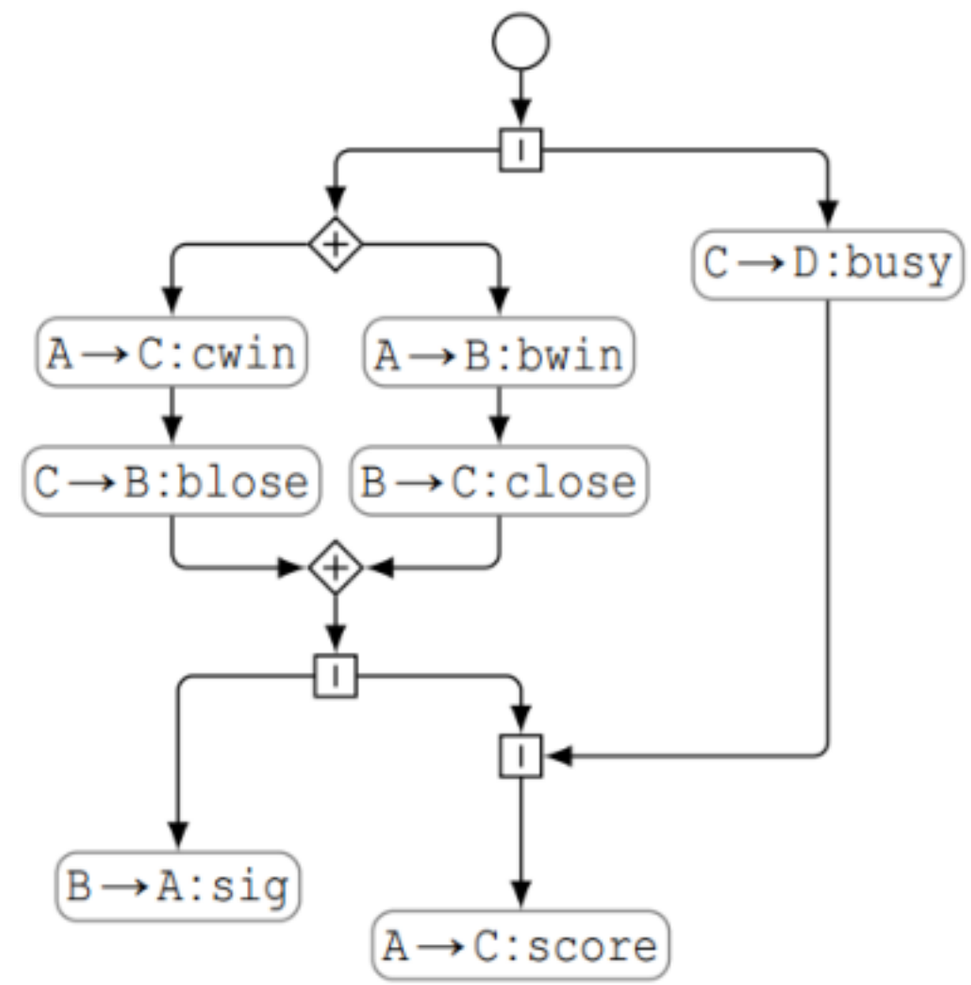
Zero Deviation Life Cycle Platform



From Communicating Machines to Graphical Choreographies [POPL'15, CONCUR'15]

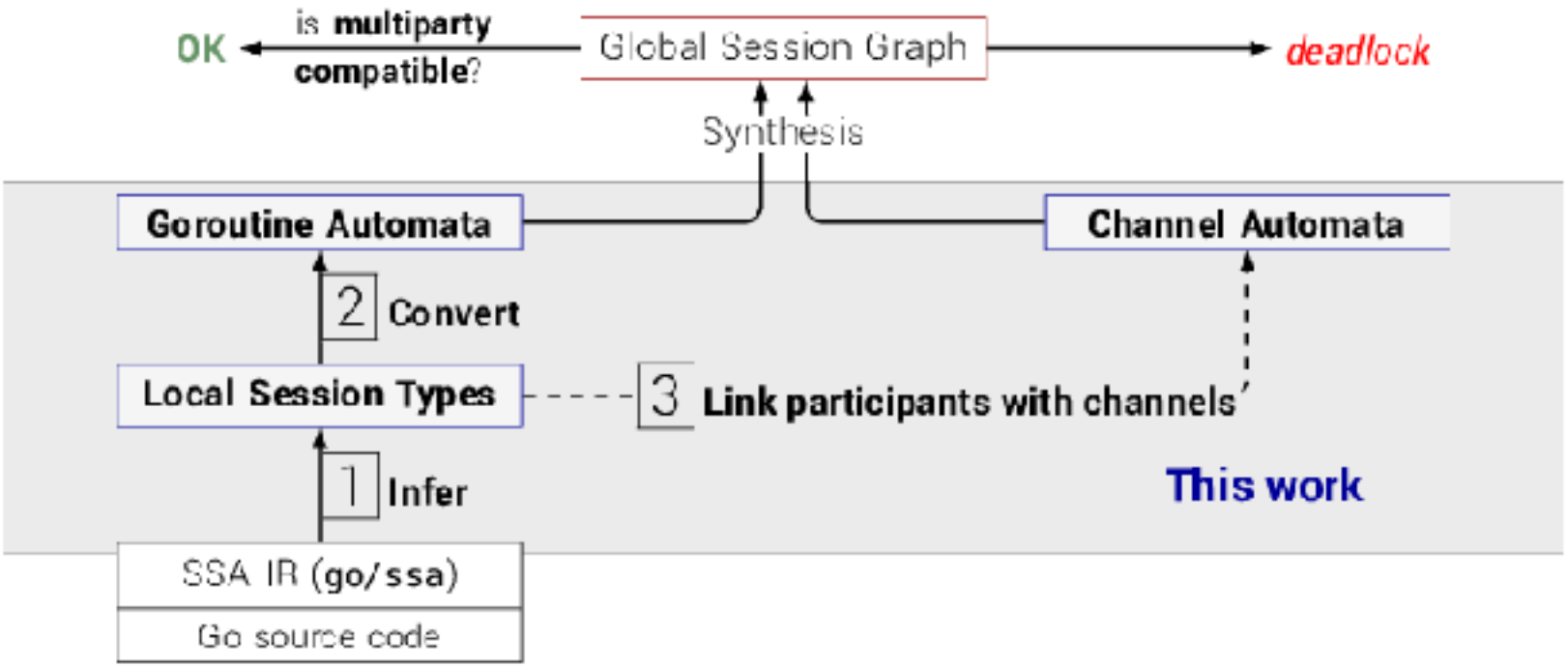




[ESOP'10,ESOP'12,CONCUR'12,CONCUR'14]

Contributions

- Static deadlock detection tool *dingo-hunter*
- Deadlock detection based on session types
- **Infer** session types as Communicating Automata
- **Synthesise** global session graphs from CA

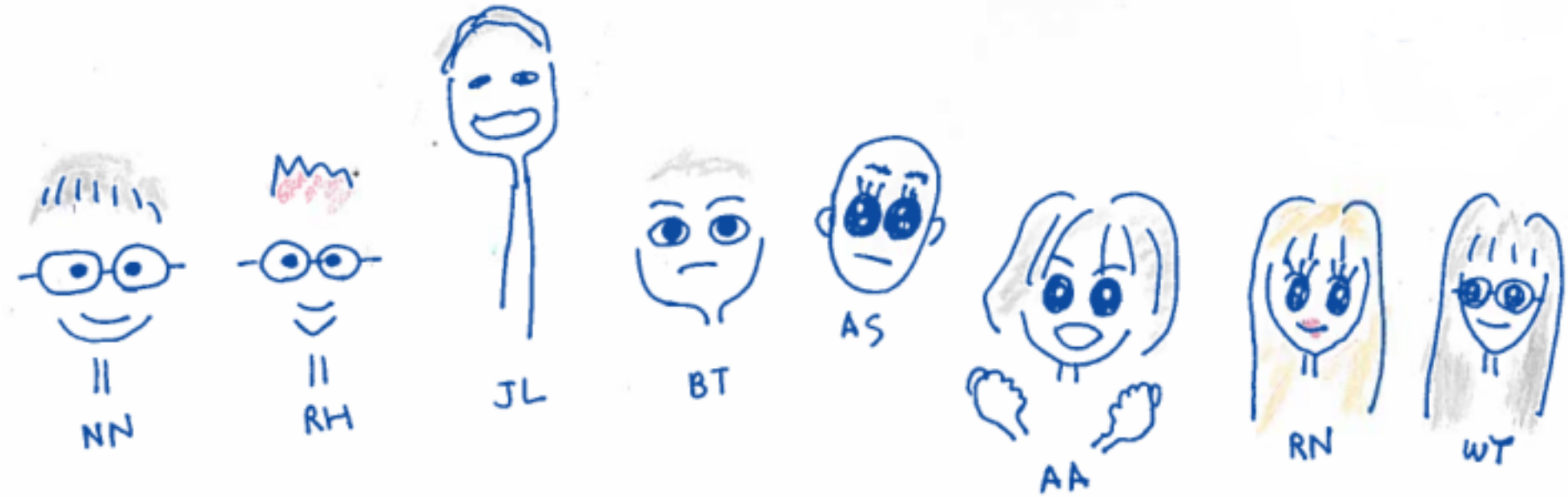


Go and Concurrency

- Developed by Google for multi-core programming
- Concurrency model built on CSP (process calculi)
- Message-passing **communication** over channels

" *Do not communicate by sharing memory; instead, share memory by communicating.* "
-- Effective Go (developer guide)

Session Type Mobility Group



www.mrg.doc.ic.ac.uk