Imperial College London

Session Types and their Applications

Code Mesh November 5th/6th 2020 Nobuko Yoshida

Session types serve as both **theoretical** and **engineering foundations** of **communication-centred programming languages and systems** and **software**, so that the society can use **safe** **concurrent systems** and **distributed services.**

Communications are Ubiquitous

- Increasingly, **communications** are the way to organise software and systems.
- Industry trend – programming languages with **explicit message-passing primitives.**

microservices






Problems: Ambiguity

- Protocol descriptions are **ambiguous**
- **SMTP: simple mail transfer protocol**
  - They are written in English, often very long

RFC 821 August 1982
Simple Mail Transfer Protocol

TABLE OF CONTENTS

Problems: Ambiguity

- Protocol descriptions are **ambiguous**
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3.1. MAIL

There are three steps to SMTP mail transactions. The transaction is started with a MAIL command which gives the sender identification. A series of one or more RCPT commands follows giving the receiver information. Then a DATA command gives the mail data. And finally, the end of mail data indicator confirms the transaction.

The first step in the procedure is the MAIL command. The <reverse-path> contains the source mailbox.

MAIL <SP> FROM:<reverse-path> <CRLF>

This command tells the SMTP-receiver that a new mail transaction is starting and to reset all its state tables and buffers, including any recipients or mail data. It gives the reverse-path which can be used to report errors. If accepted, the receiver-SMTP returns a 250 OK reply.

The <reverse-path> can contain more than just a mailbox. The <reverse-path> is a reverse source routing list of hosts and source mailbox. The first host in the <reverse-path> should be the host sending this command.

The second step in the procedure is the RCPT command.

RCPT <SP> TO:<forward-path> <CRLF>

This command gives a forward-path identifying one recipient. If accepted, the receiver-SMTP returns a 250 OK reply, and stores the forward-path. If the recipient is unknown the receiver-SMTP returns a 550 Failure reply. This second step of the procedure can be repeated any number of times.

Problems: Concurrency Bugs

- Communications increase **concurrency bugs**
  - Survey of 4K users [golang.org]
  - Analysis of 6 large software systems [ASPLOS 19]

deadlock

channel errors

More than a half of concurrency bugs in Go are caused by communications.

The Go Gopher

Problems: Concurrency Bugs

- Communications increase **concurrency bugs**
  - Survey of 4k users **[golang.org]**
  - Analysis of 6 large software systems **[ASPLOS 19]**

More than a half of concurrency bugs in Go are caused by communications.

Session Types

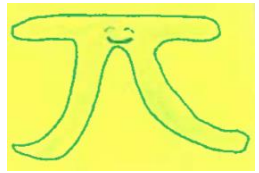
- Prevent concurrency bugs.
- Can abstract, implement and manage communications as **Protocols.**
- **Clean, Cheap** and **Retrofittable.**

Why Session Types, Why Now?

Significant academic and industry interests via fundamental breakthroughs

Milner, Honda, NY

Binary Session Types — ESOP'98



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Joined W3C Standardization — 2002

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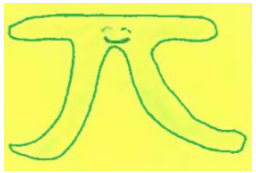

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Multiparty Session Types — POPL' 08

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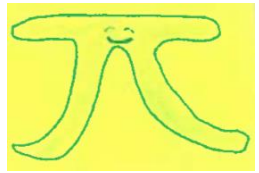

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Multiparty Session Types — POPL' 08

largest open source company in the world

Red Hat

Scribble

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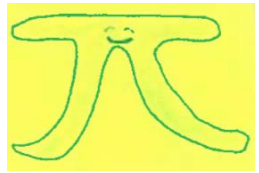

Joined W3C Standardization — 2002

Multiparty Session Types — POPL' 08

25M US$ large cyber infrastructures

OCEAN OBSERVATORIES INITIATIVE

Red Hat

Scribble

middleware standardisations

AMQP Advanced Message Queuing Protocol

RabbitMQ Messaging that just works

Why Session Types, Why Now?

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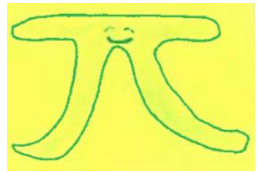

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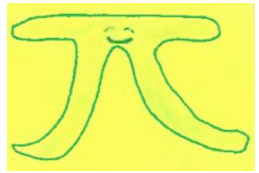
ETAPS Test Time Award 2019

Binary Session Types — ESOP'98



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POPL Influential Paper Award 2018

Multiparty Session Types — POPL' 08

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Why Session Types, Why Now?

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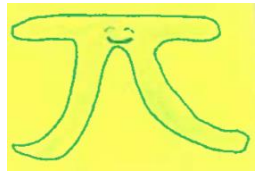
ETAPS Test Time Award 2019

PLDI'19, ICSE'18, CC'18, CAV'19
POPL'19, POPL'19, POPL'19,
ECOOP'19, ESOP'19, ESOP'18
CONCUR'19, FOSSACS'19,
LICS'18, FOSSACS'18

POPL Influential Paper Award 2018

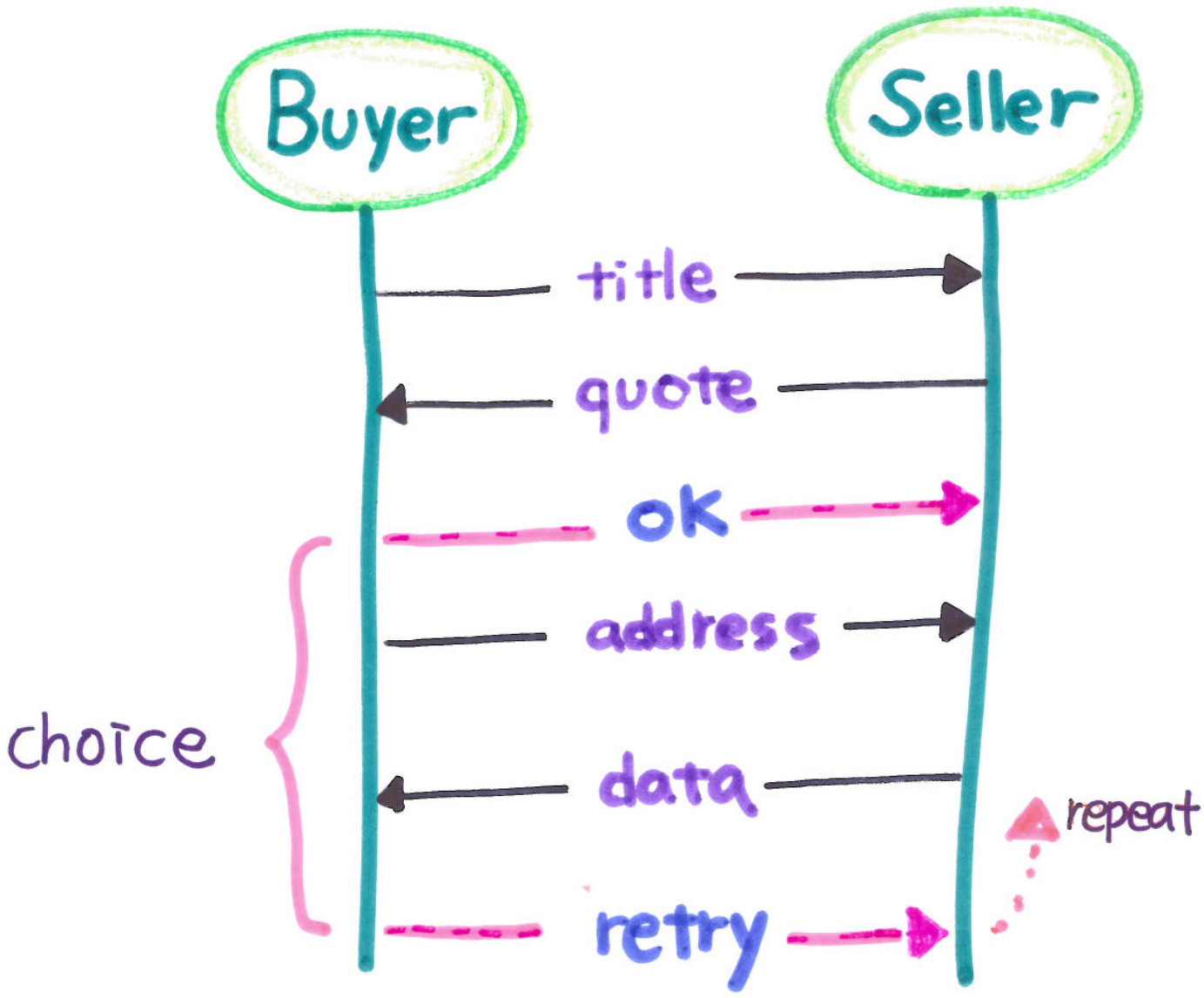
Binary Session Types — ESOP'98



Joined W3C Standardization — 2002

Multiparty Session Types — POPL' 08

Binary Session Types: Buyer - Seller Protocol



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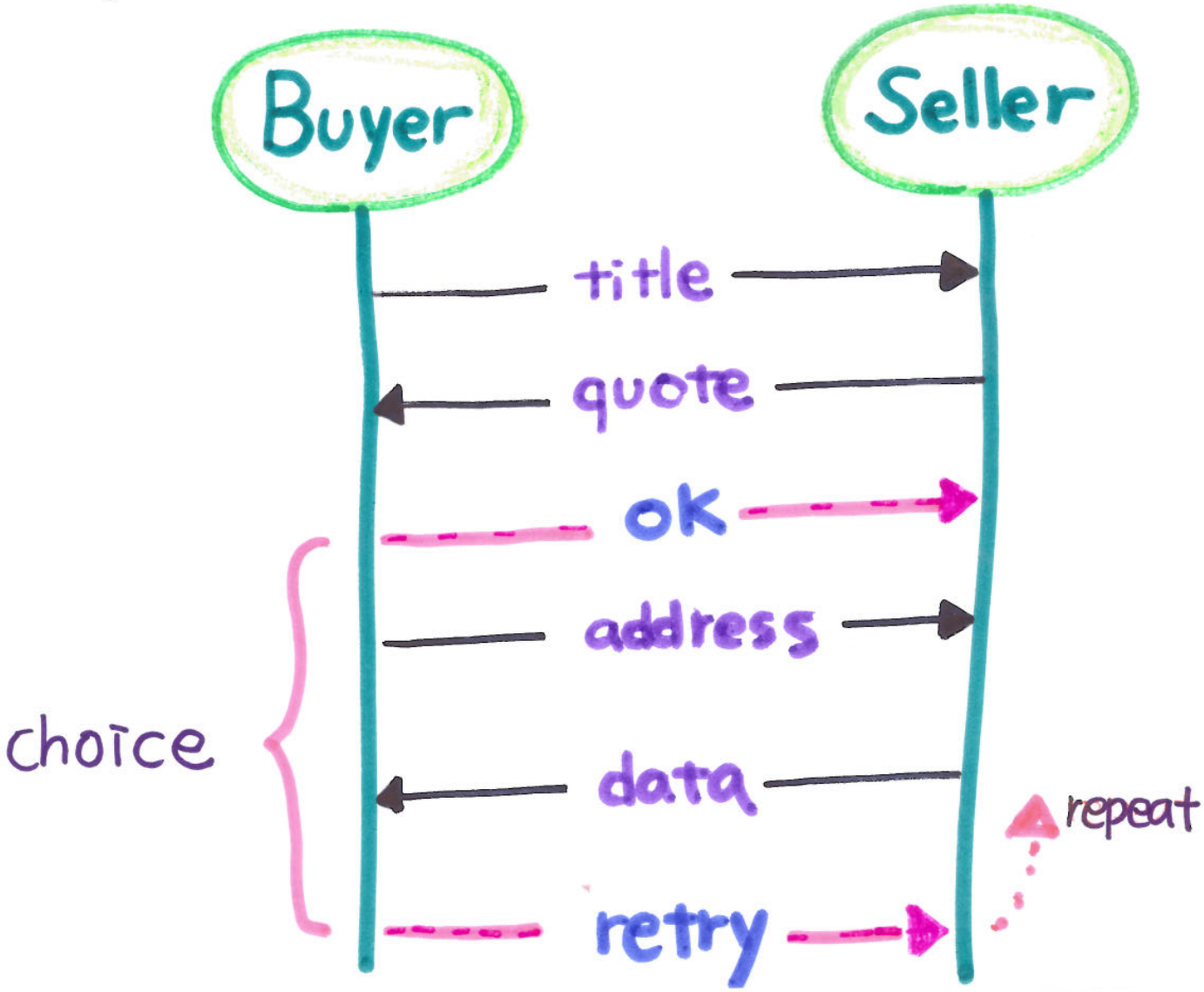

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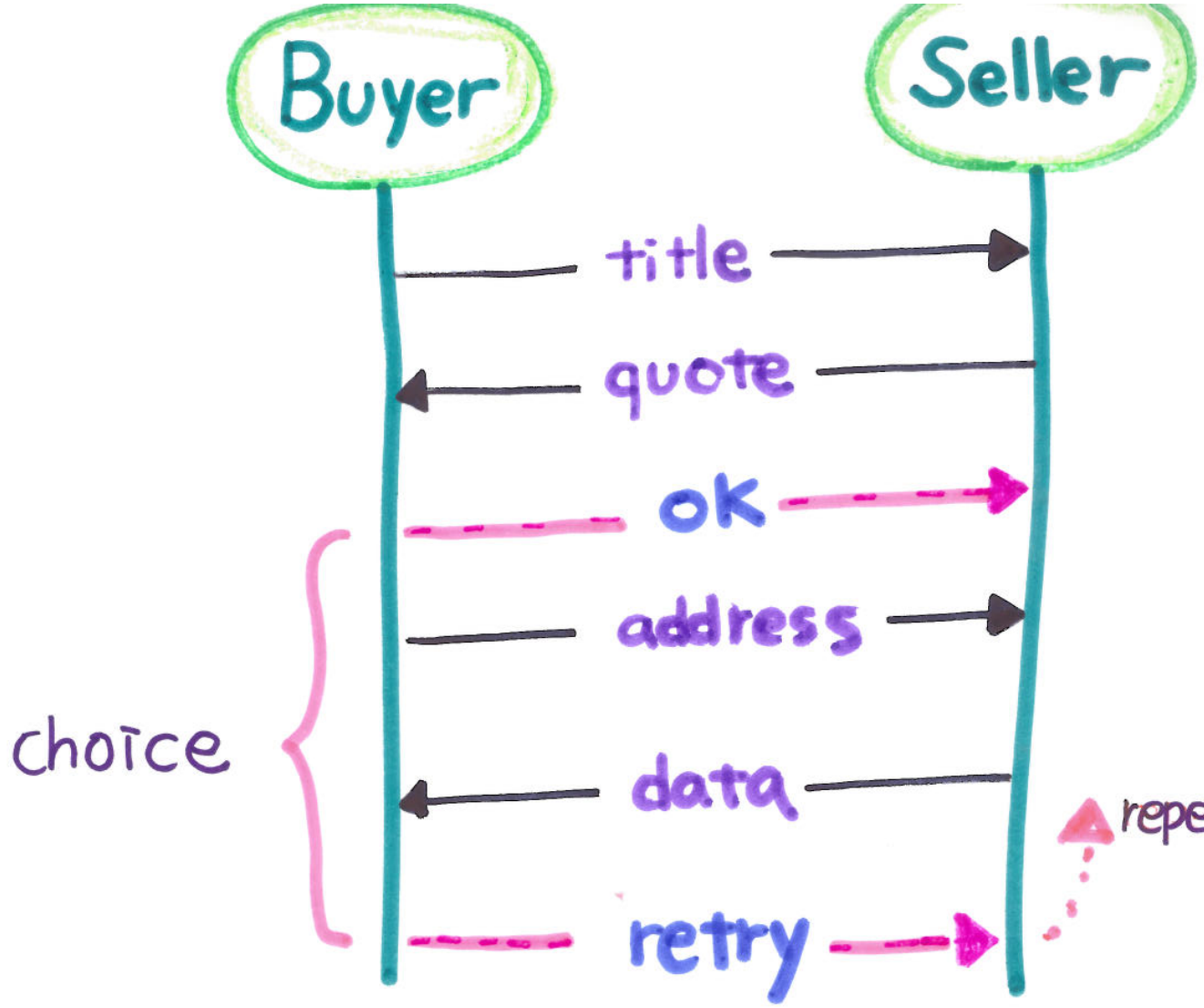

P has T

Q has $\overline{T}$

dual

P | Q typable

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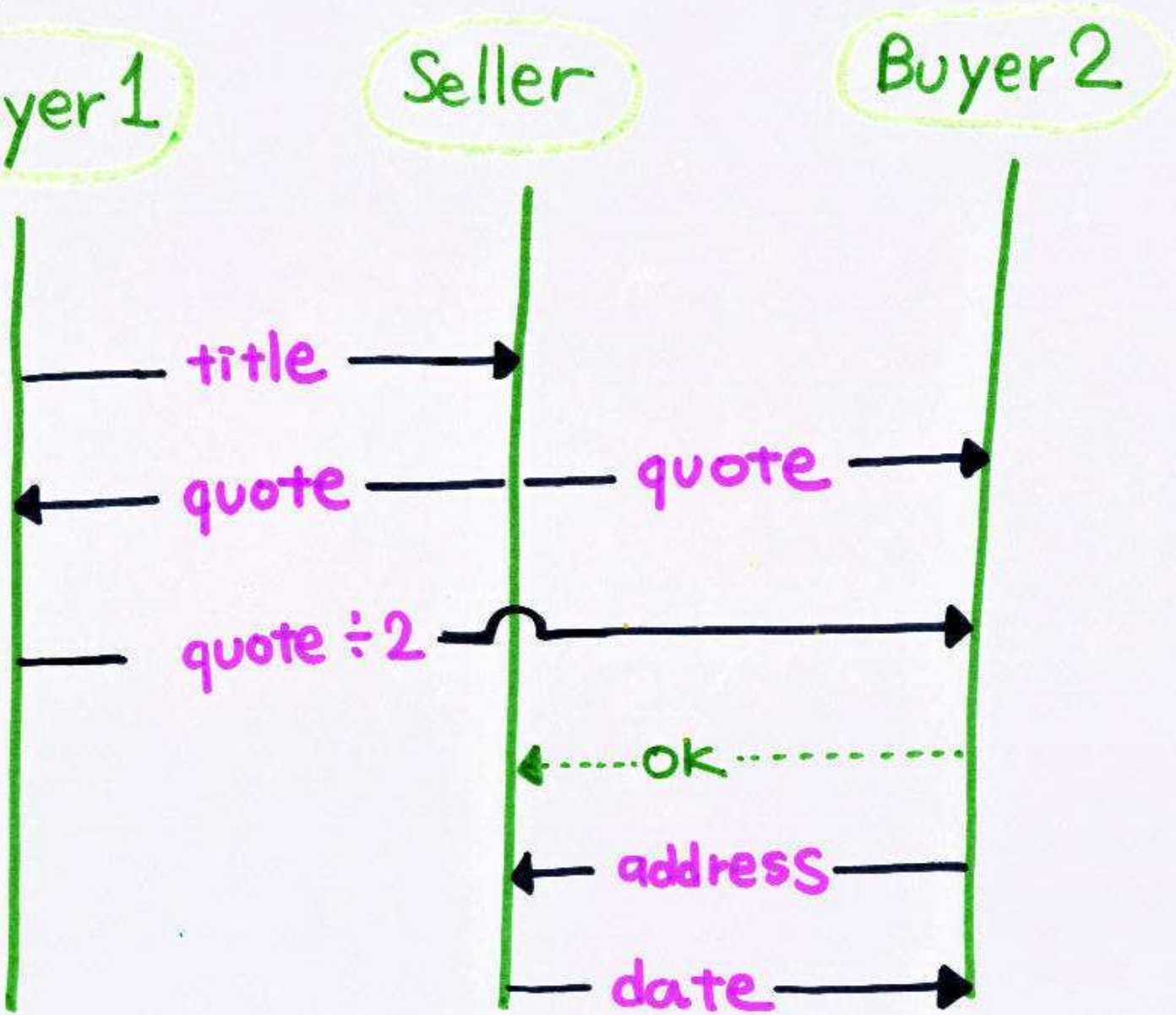
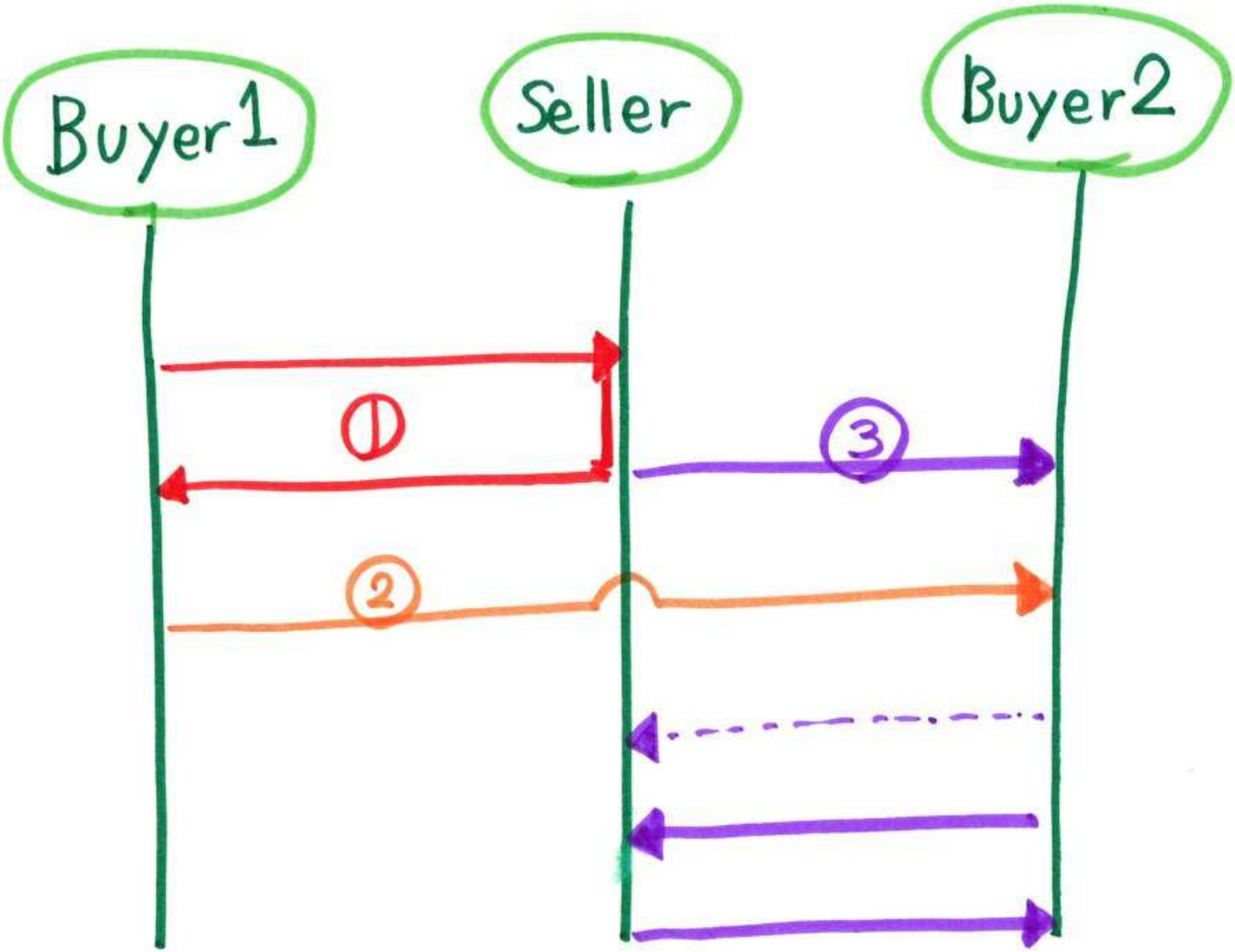
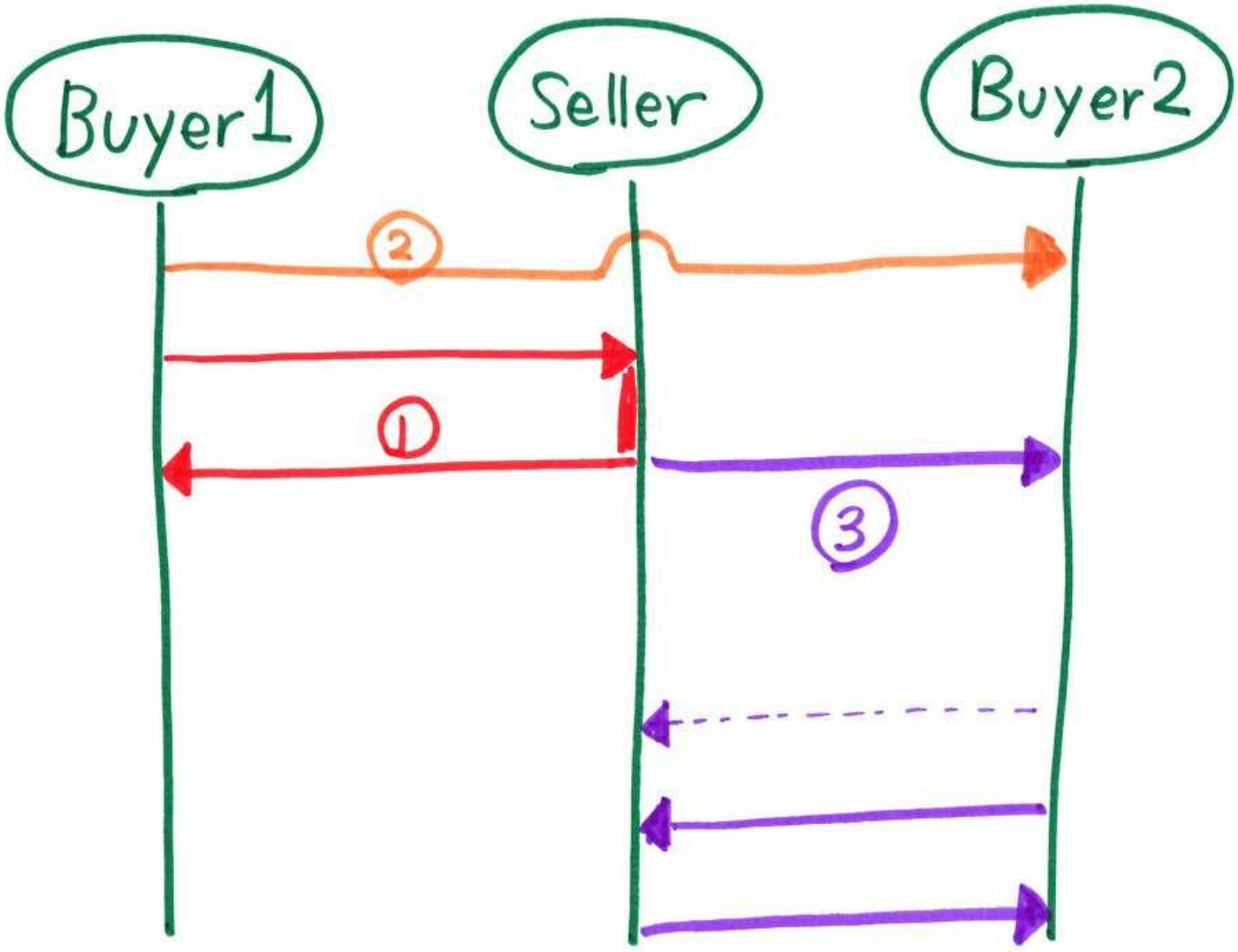
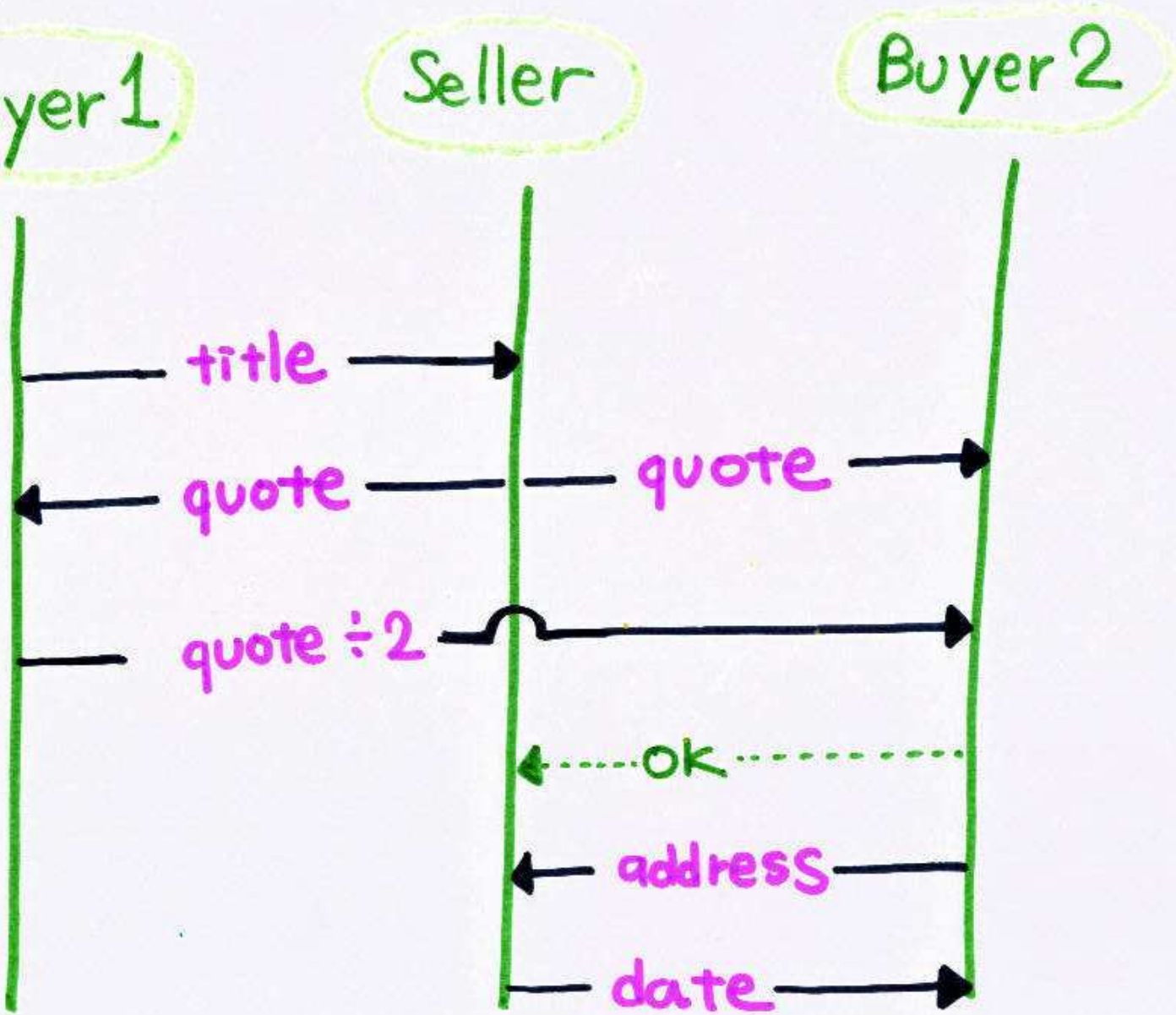
Multiparty Session Types

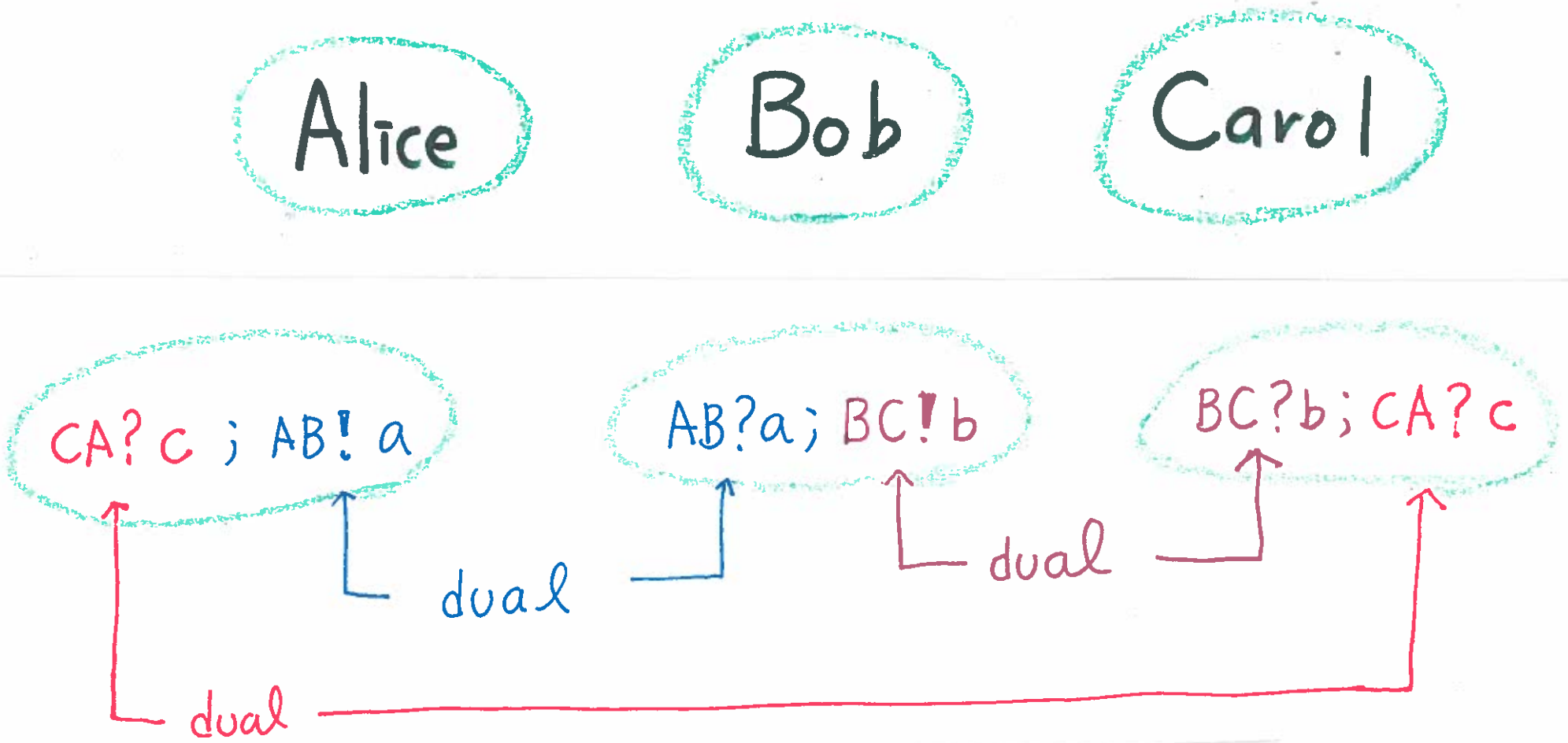



Buyer1
Seller
Buyer2
1
3
2


Buyer1
Seller
Buyer2
2
1
3

Multiparty Session Types



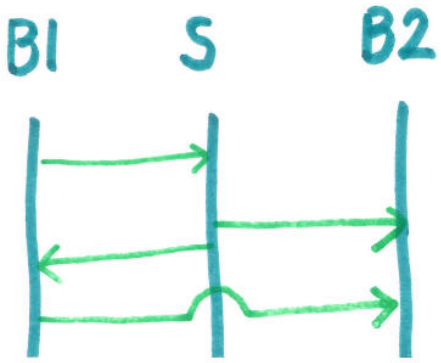


3 dual pairs

If you use binary Session Types ....

Deadlock!

Multiparty Session Types [Honda, Yoshida, Carbone 2008]



G

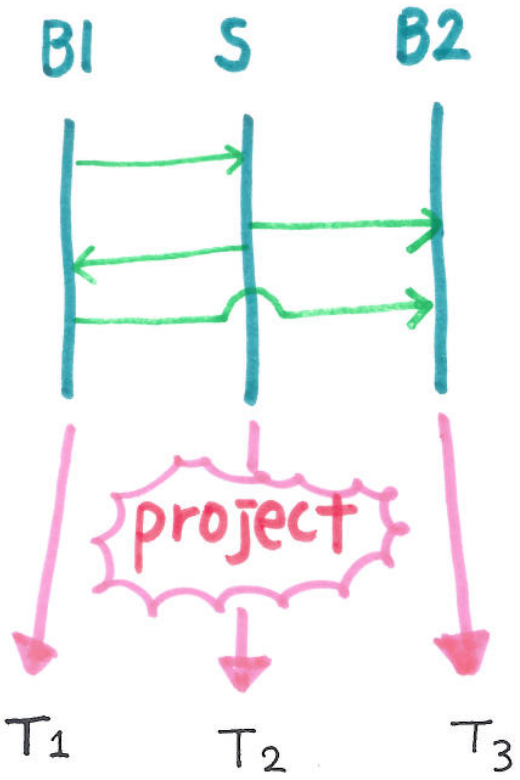
B1 → S Int.

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

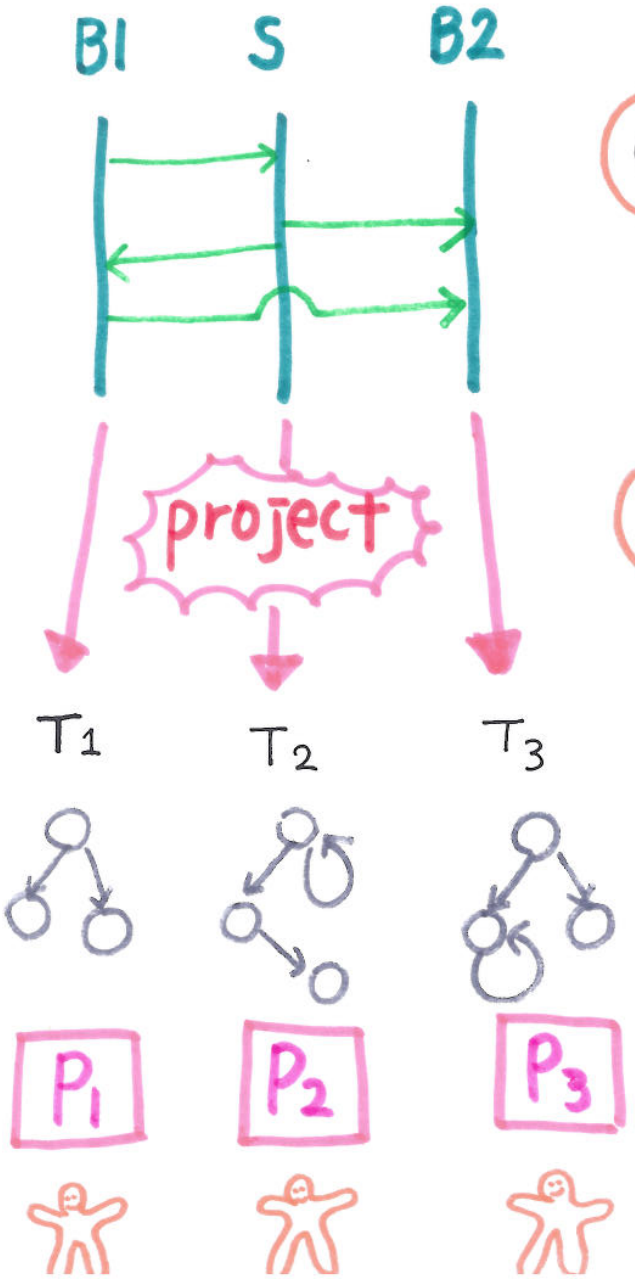
STEP 1

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

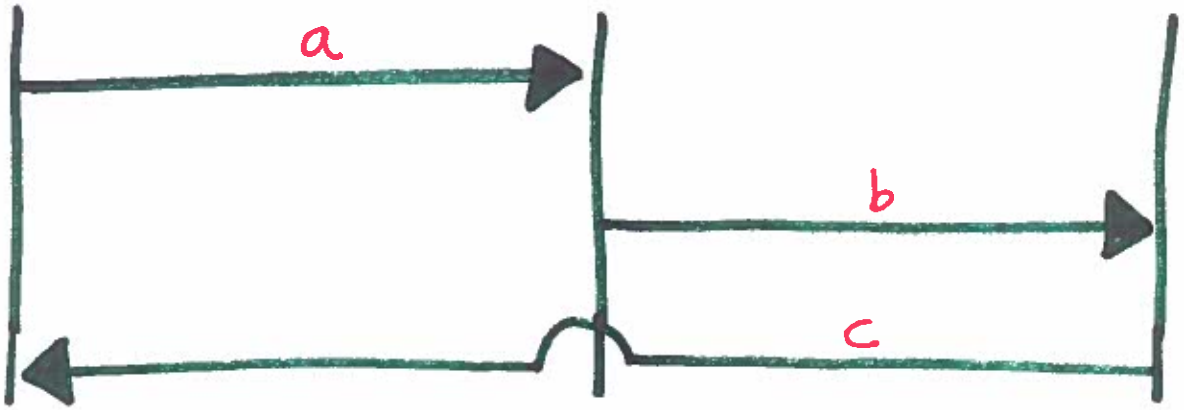
STEP 2
Project to Local Type

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

Alice

Bob

Carol



Global Type

Projection

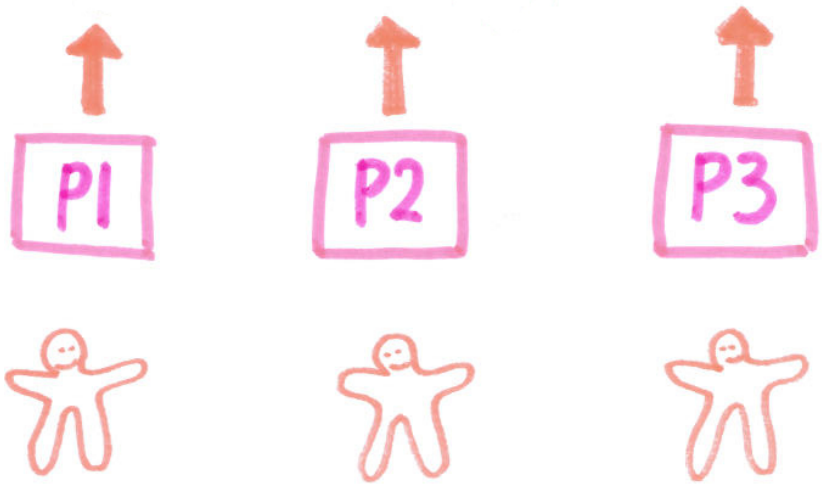
Alice AB!a; CA?c

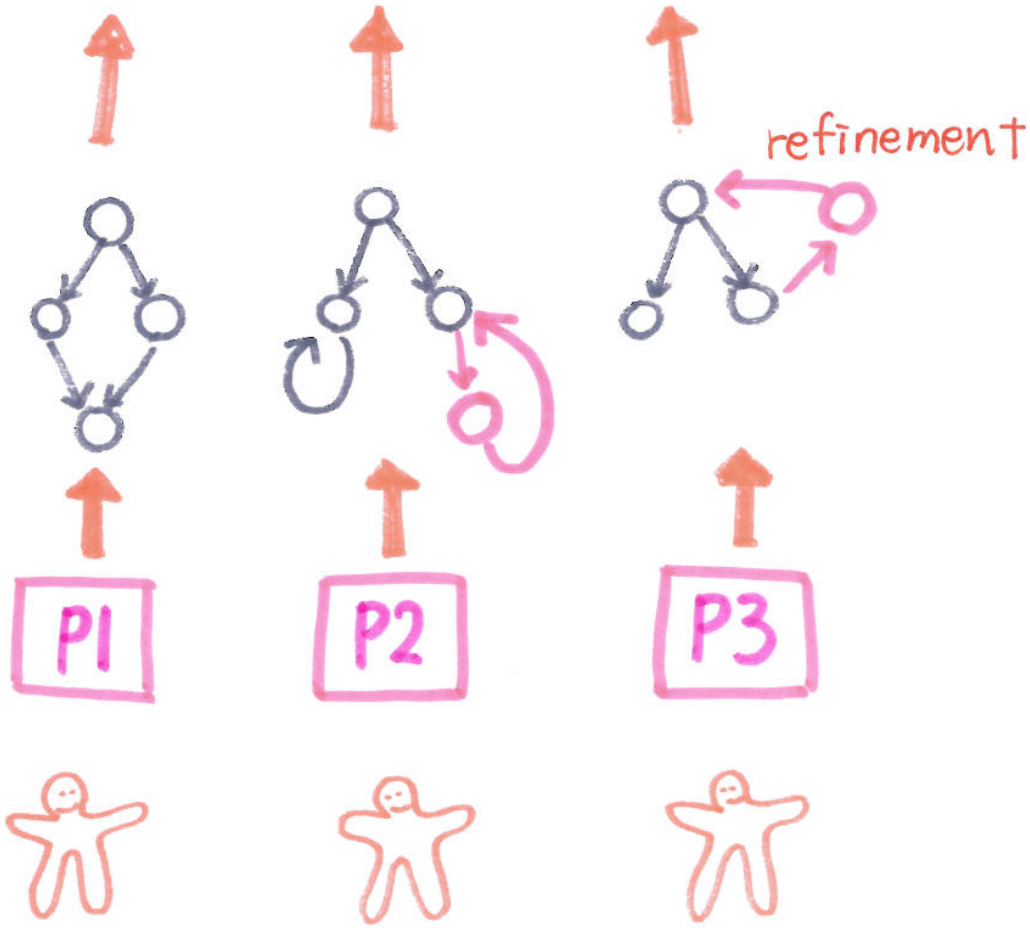
Bob AB?a; BC!b

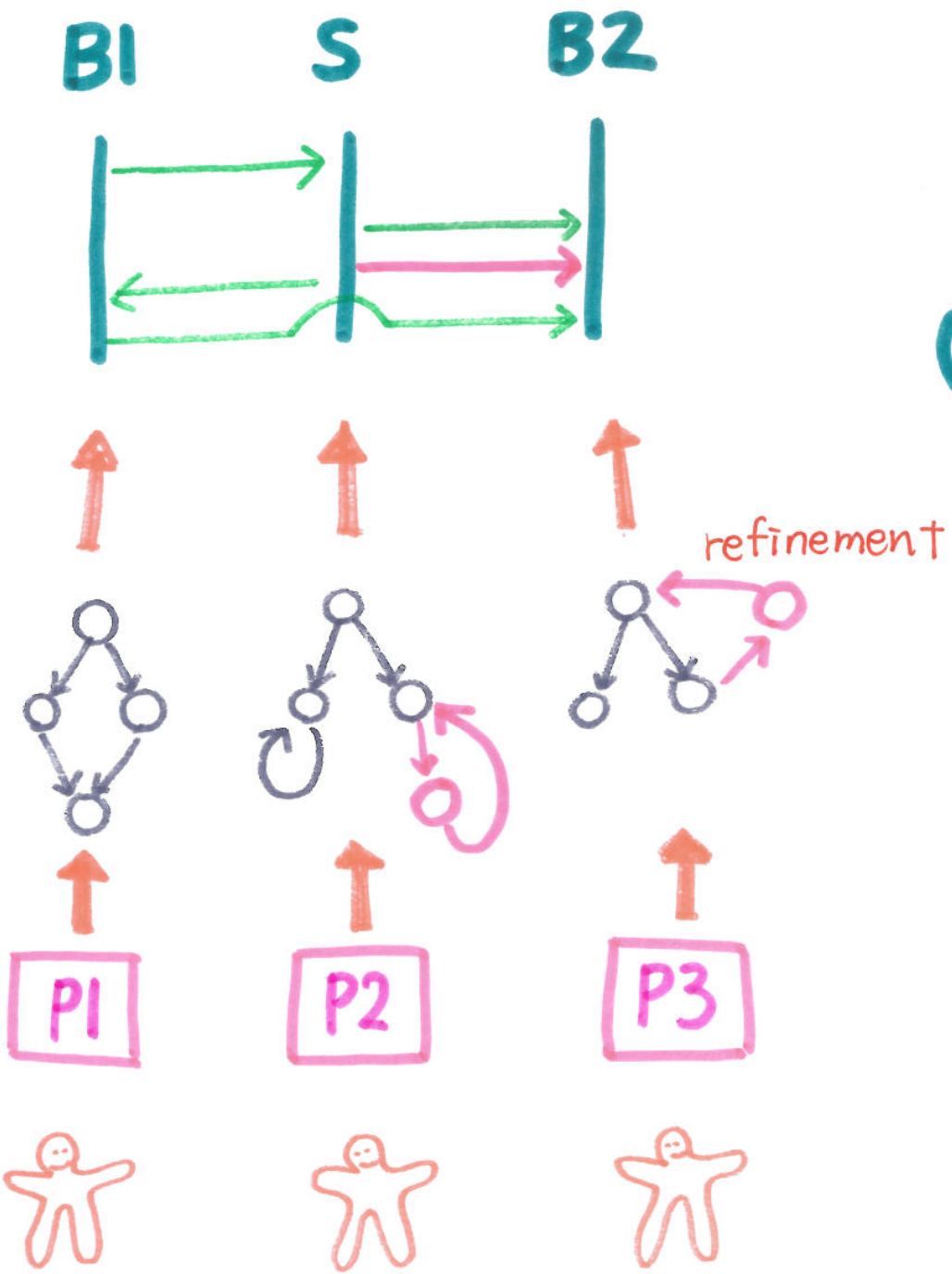
Carol BC?b; CA!c;

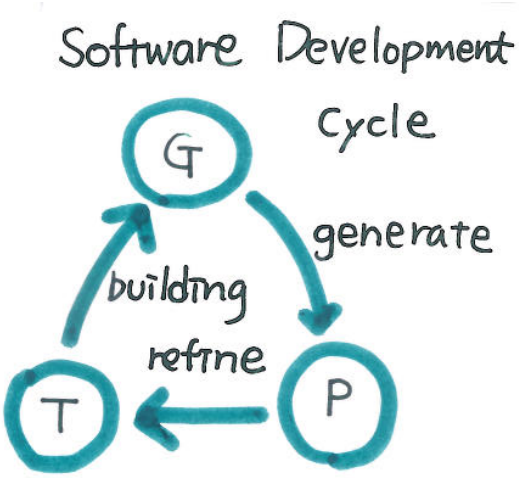
LOCAL TYPES

NO Deadlock


P1
P2
P3


refinement
P1
P2
P3



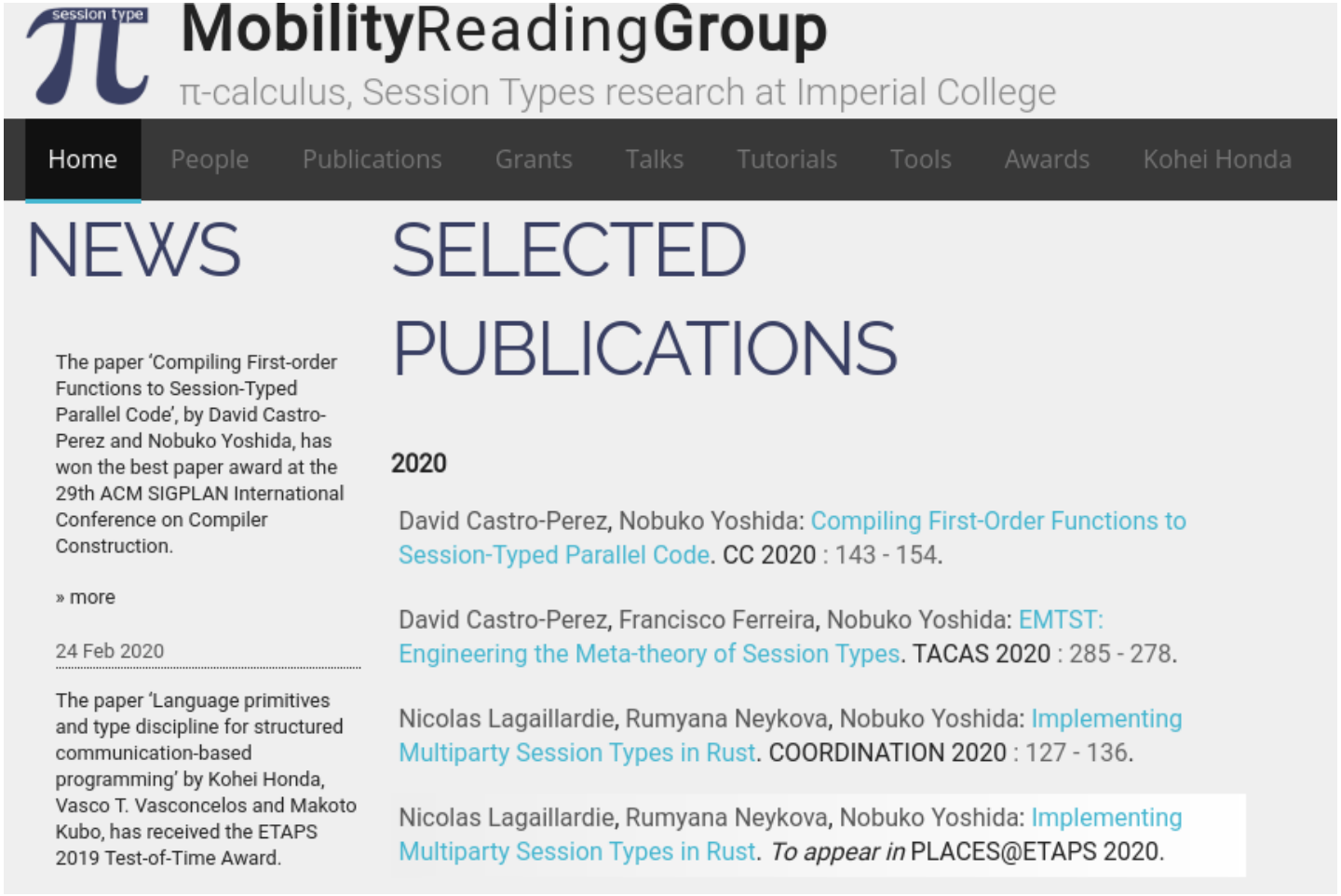


- Optimisation
- refinement
- Inference
- Testing

The Mobility Reading Group at Imperial College

Our research group is **specialised in π-calculus** and **session types** — both **theory** and **applications**

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



- **TACAS'20**: **Coq Mechanisation**. EMTST: Engineering the Meta-theory of Session Types. David Castro-Perez, Francisco Ferreira and NY
- **ESOP'20**: **Theory**. Exploring Type-Level Bisimilarity towards More Expressive Multiparty Session Types, Sung-Shik Jongmans and NY
- **CC'20**: **Parallel Programming** (**Best Paper Award**) Compiling First-Order Functions to Session-Typed Parallel Code, David Castro-Perez and NY
- **ECOOP'20**: **Go Language**. Static Race Detection and Mutex Safety and Liveness for Go Programs, Julia Gabet and NY
- **ECOOP'20**: **OCaml**. Multiparty Session Programming with Global Protocol Combinators, Keigo Imai, Rumyana Neykova, NY and Shoji Yuen
- **OOPSLA'20**: **Cost Analysis using Multiparty Session Types**. CAMP: Cost-Aware Multiparty Session Protocol, David Castro-Perez and NY
- **OOPSLA'20**: **Go Language**. Featherweight Go, Robert Griesemer and Raymond Hu and Wen Kokke and Julien Lange and Ian Lance Taylor and Bernardo Toninho and Philip Wadler and NY.
- **OOPSLA'20**: **Robotics**. Multiparty Motion Coordination: From Choreographies to Robotics Programs, Rupak Majumdar, NY and Damien Zufferey.
- **OOPSLA'20**: **F⋆**. Statically Verified Refinements for Multiparty Protocols, Fangyi Zhou, Francisco Ferreira, Raymond Hu, Rumyana Neykova and NY

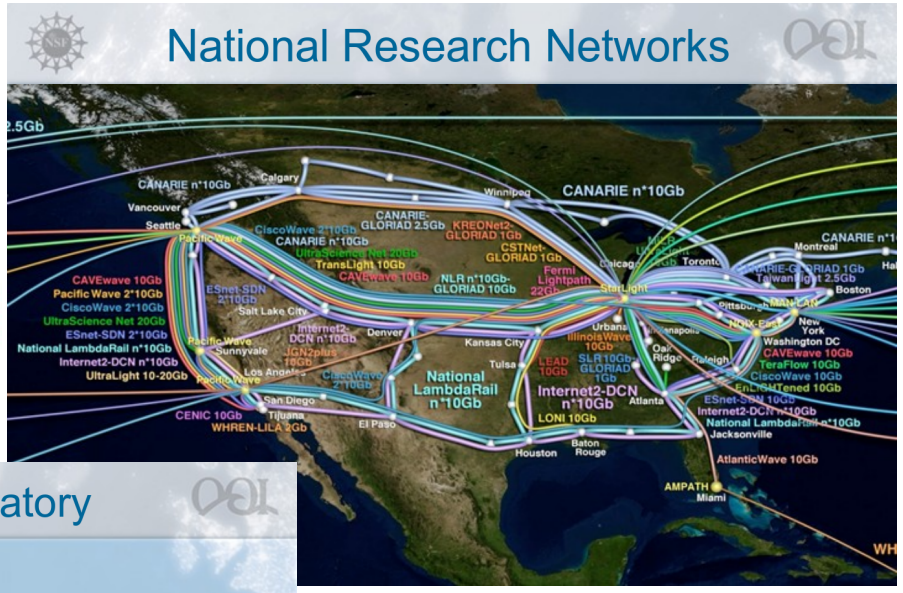
Case study (I): Network Protocols with Scribble

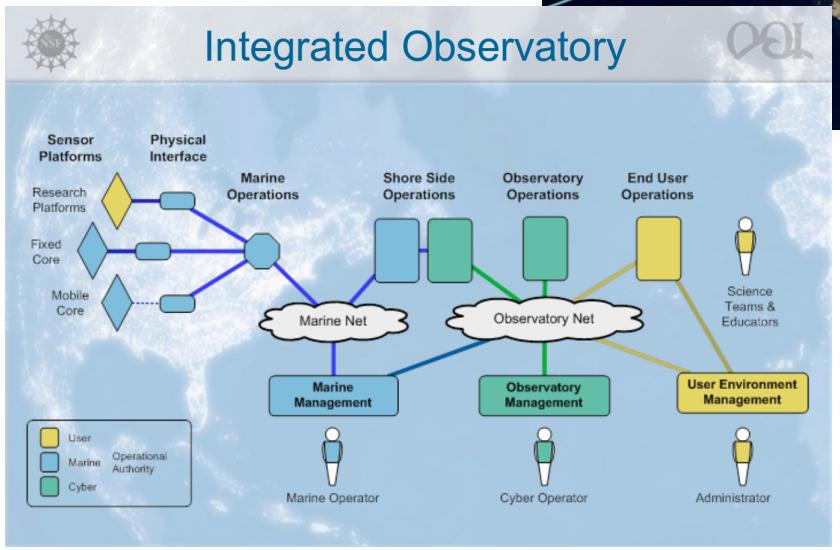
DEMO:

Scribble and **RFC 5321**
("Simple" Mail Transfer Protocol)

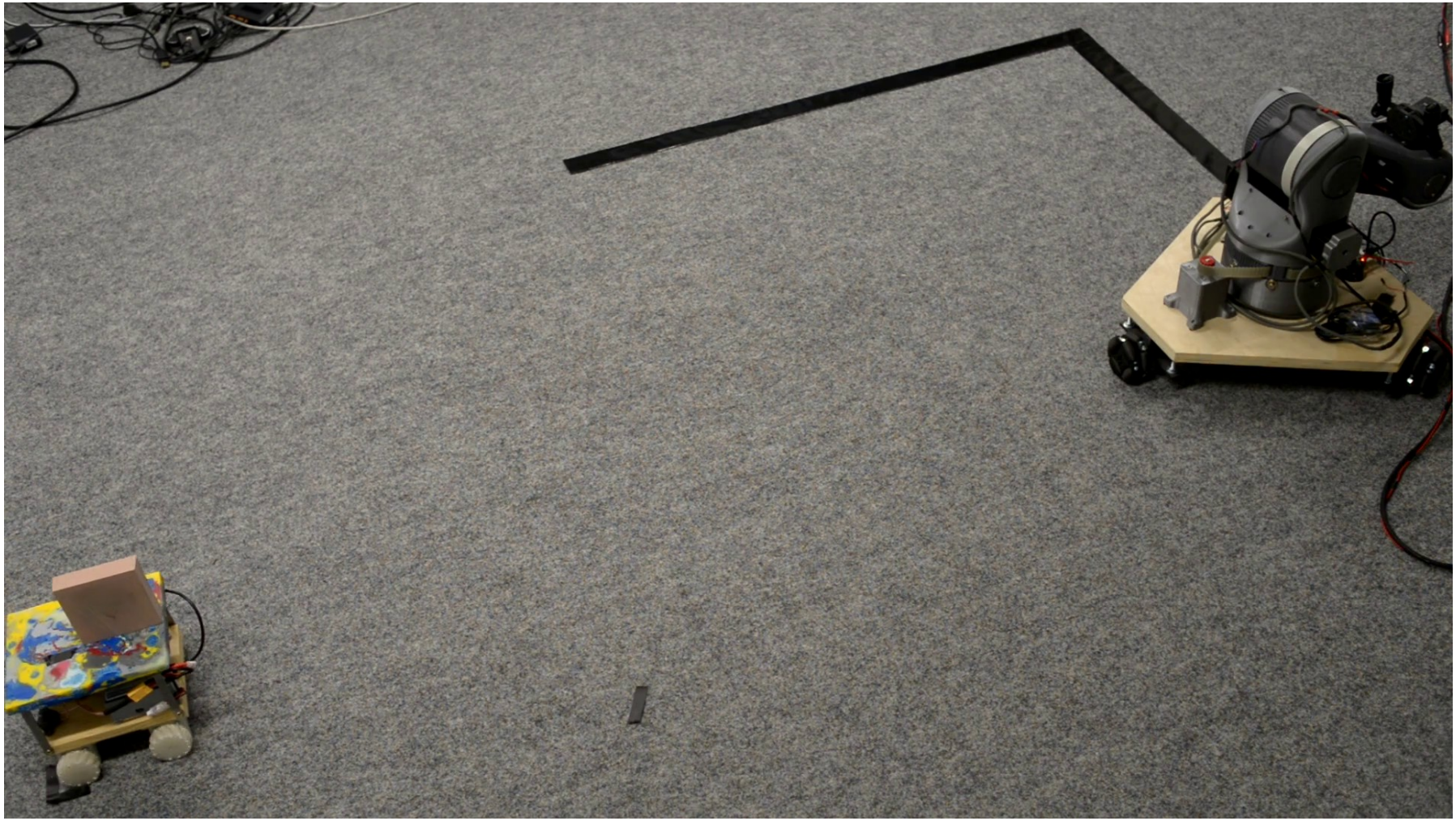
Case study (II): Ocean Observatories Initiative

Collaboration: use session types on top of OOI network to **guarantee global safety**





Case study (III): Motion Session Types for Robotics Interactions [ECOOP'19,OOPSLA'20]



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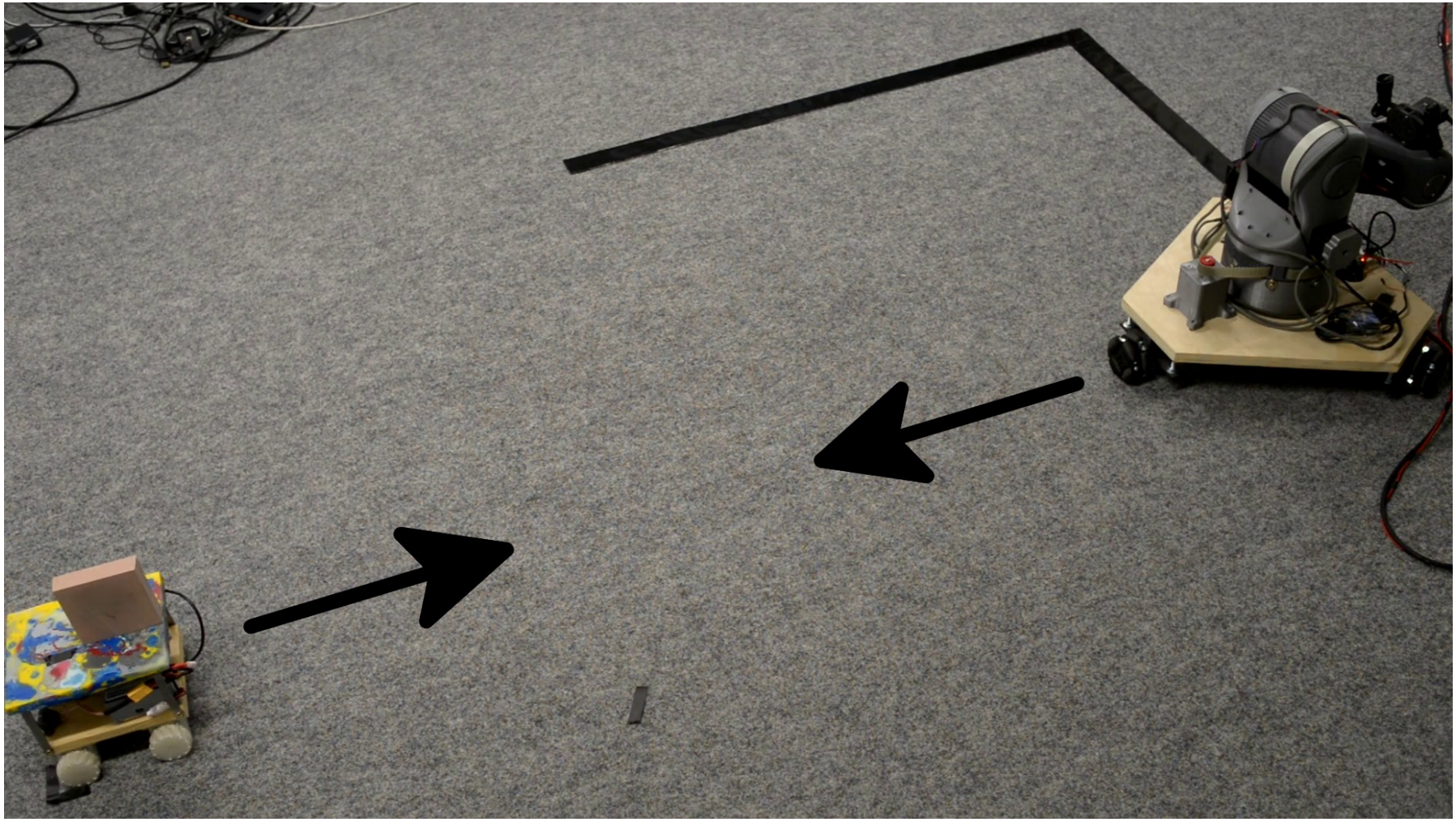

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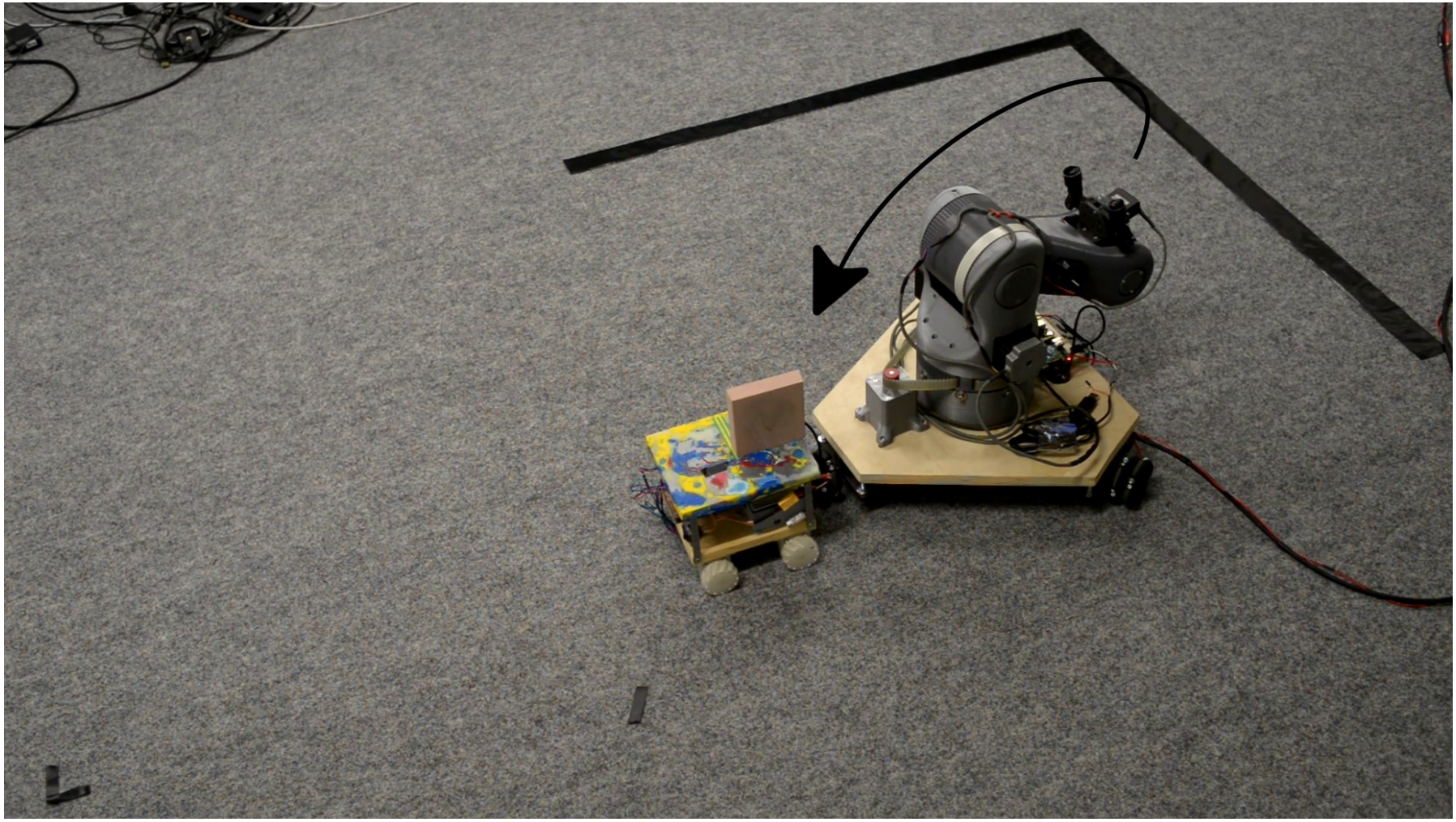

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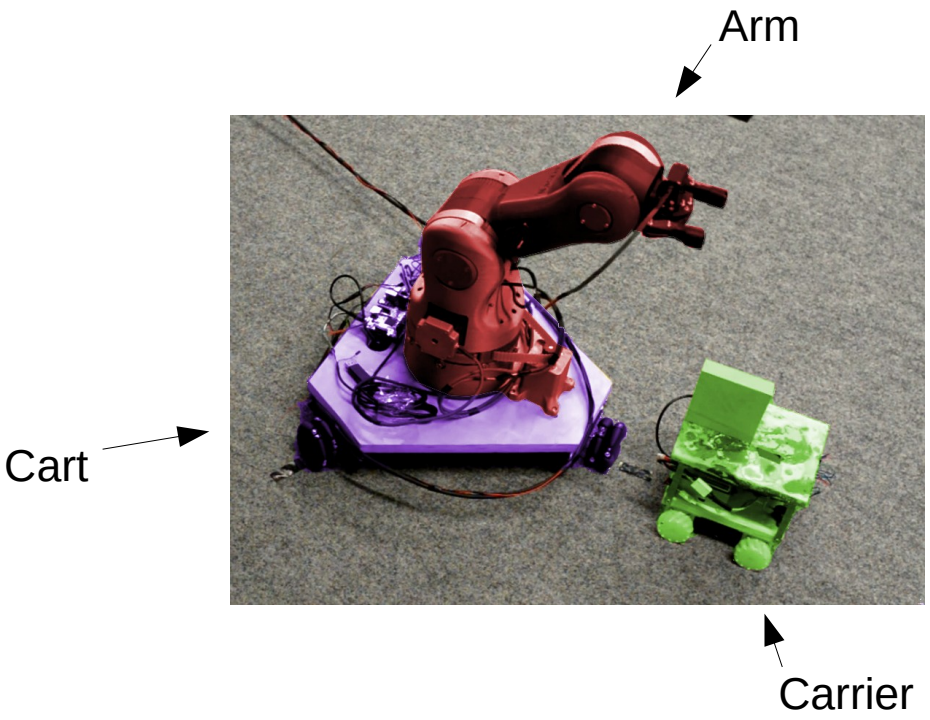
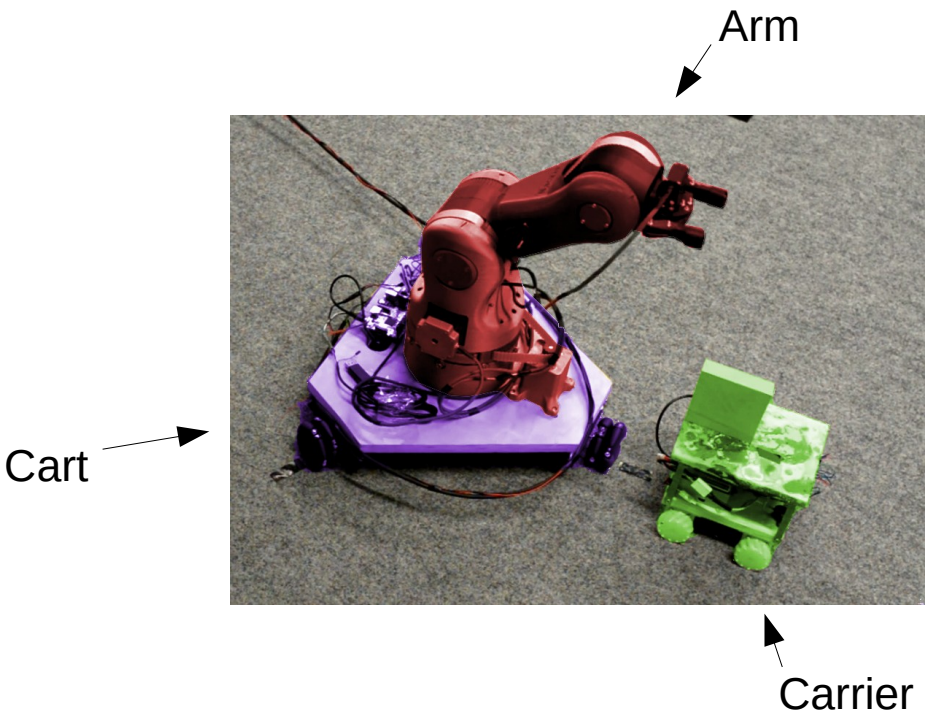
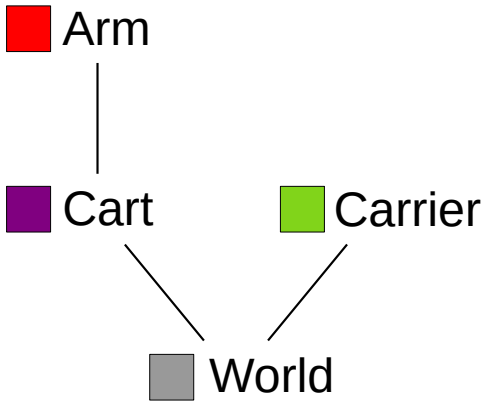


Cart & Arm:

Two robots attached together that act as "one" robot (communication)

Case study (III): Motion Session Types for Robotics Interactions [ECOOP'19,OOPSLA'20]





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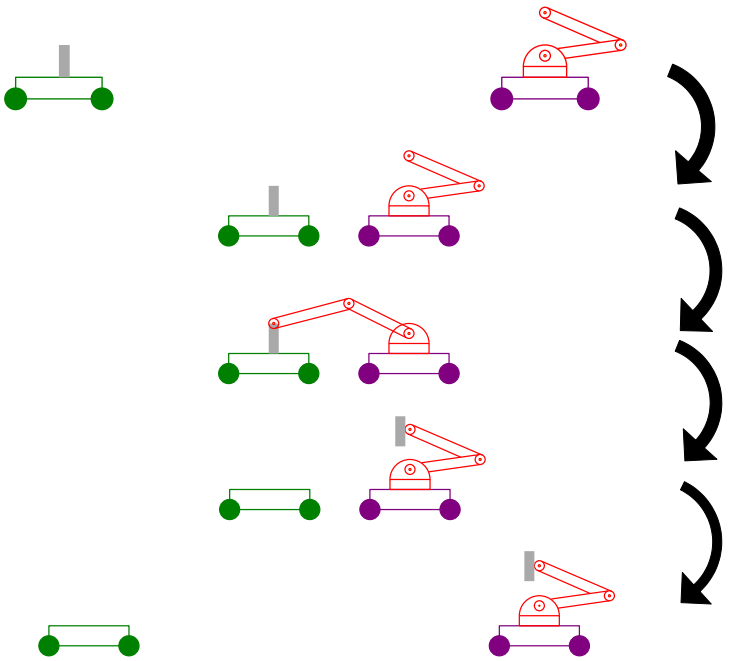


$\mathsf{Cart} \to \mathsf{Arm} : \mathit{fold}(\mathtt{unit}).\mathsf{dt}\langle \mathsf{Cart} : \mathsf{idle}, \mathsf{Carrier} : \mathsf{idle}, \mathsf{Arm} : \mathsf{fold}\rangle.$

$\mathsf{Arm} \to \mathsf{Cart} : \mathit{ok}(\mathtt{unit}).\mathsf{Cart} \to \mathsf{Carrier} : \mathit{ok}(\mathtt{unit}).$

$\mathsf{dt}\langle \mathsf{Cart} : \mathsf{move}, \mathsf{Carrier} : \mathsf{move}, \mathsf{Arm} : \mathsf{idle}\rangle.$

$\mathsf{Carrier} \to \mathsf{Cart} : \mathit{ok}(\mathtt{unit}).\mathsf{Cart} \to \mathsf{Arm} : \mathit{grab}(\mathtt{unit}).$

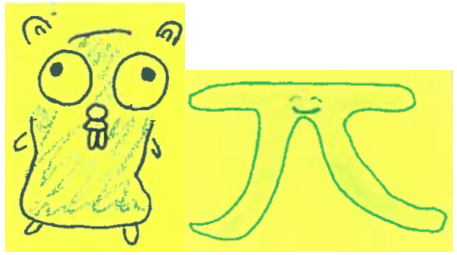
$\mathsf{dt}\langle \mathsf{Cart} : \mathsf{idle}, \mathsf{Carrier} : \mathsf{idle}, \mathsf{Arm} : \mathsf{grip}\rangle.$

$\mathsf{Arm} \to \mathsf{Cart} : \mathit{ok}(\mathtt{unit}).\mathsf{Cart} \to \mathsf{Carrier} : \mathit{ok}(\mathtt{unit}).$

$\mathsf{dt}\langle \mathsf{Cart} : \mathsf{move}, \mathsf{Carrier} : \mathsf{move}, \mathsf{Arm} : \mathsf{idle}\rangle.$

$\mathsf{Cart} \to \mathsf{Arm} : \mathit{done}(\mathtt{unit}).\mathsf{Cart} \to \mathsf{Carrier} : \mathit{done}(\mathtt{unit}).\mathtt{end}$

Case Study IV Golang research



Go is a popular industrial systems language developed by **Google** (5th GitHub language). Go's design is inspired by **CSP**, but more akin to **the π-calculus**.

Our MRG group has several research projects involving **Go**:

- Static verification framework for **Go** [**CC'16**,**POPL'17**, **ICSE'18**,**ECOOP'20**].
- Distributed programming in **Go** based on MPST [**POPL'19**]
- Introducing **polymorphism** in **Go**, in collaboration with Google [**OOPSLA'20**].

Case Study IV Golang research

Robert Griesemer

Ian Lance Taylor

I want to thank you and your team for all the type theory work on Go so far – it really helped clarify our understanding to a massive degree. So thanks! (Robert Griesemer)

Conclusion

Session types allow to:

1. **formalise protocols** for concurrent/distributed systems
2. **verify concurrent and distributed programs** at **compile-time**
3. and also **implement automatic run-time monitoring**

This leads to two main uses:

- spot **protocol violations** and **deadlocks** at **compile-time**
- and detect and **report protocol violations** at **run-time**

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

. . . and get in touch for enquiries and a **reading list**!
(**n.yoshida@imperial.ac.uk**)

Questions?