

Session types

An Introduction

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Data types

One of the **most successful concepts** in computer science

Data types describe the **intended usage** of data

```
int x = 1;  
int y = 2;  
int z = x + y; // Correct :)
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Allow to **document code** and **spot errors at compile-time**

```
public int add(int a, int b) { ... }  
  
int x = add(1, 2)    // Correct :)  
int y = add(1, "Hi!") // Does not compile :)
```

Data types (cont'd)

```
public int add(int a, int b) { ... }
```

From this definition, we can tell that:

1. add takes two integers a, b
2. it does *something*, possibly **using** a, b
 - ▶ and if a,b are used, they are **only used as integers**
3. finally, it returns an integer

What about communicating systems?

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2. it can **use s to send/receive data** to/from the server
3. it returns nothing

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But **what messages are sent/received?**

And **in what order?**

Does client really **implement the intended protocol?**

What could possibly go wrong?



Client

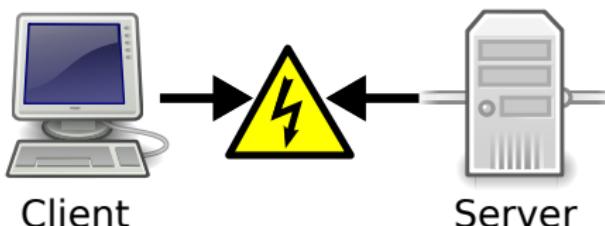


Server

E.g., consider a very simple protocol:

1. a **client** sends two integers to a **server**
2. then, the **server** answers with a boolean

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1. a **client** sends two integers to a **server**
2. then, the **server** answers with a boolean

If one of the two does not correctly implement its part of the protocol, we can encounter **various run-time errors**:

- ▶ **mismatching inputs/outputs** X
- ▶ **deadlocks** X

From data types to session types

A **session type** formalises a **protocol** as a **structured sequence of communications**

- ▶ unlike data types, session types focus on **communication**

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From the **client viewpoint**, the **session type** is:

Session = **send(int).send(int).receive(bool)**

Session types enforce channel usage

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With session types, a client looks like:

```
public void client(Session s) { ... }
```

... where s is a **communication channel** of type “Session”

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The type determines the **intended usage of s**: i.e., if the code compiles, then client uses s to **send two integers**, and then **receive a boolean**

Session types and duality

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What about the **server**? Its view of the protocol is **dual**:

Session = **receive(int).receive(int).send(bool)**

... and correspondingly, its code uses a dual type:

```
public void server(Session s) { ... }
```

Session-typed interactions never go wrong



Client



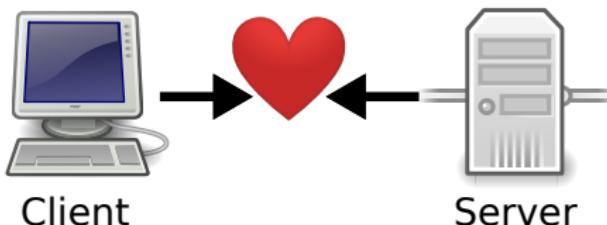
Server

Now, at **compile time**, we can verify that **client** and **server** implement **dual sessions types**...

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Session-typed interactions never go wrong



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Session = `send(int).send(int).receive(bool)`

Session = `receive(int).receive(int).send(bool)`

... and this guarantees **correct interaction at run-time**:

- ▶ **communication safety** — no mismatching input/output ✓
- ▶ **progress** — no deadlocks ✓

Session types in theory...



In this course, you will learn the **basic theory of session types**...

- ▶ i.e., their use in the π -calculus

Session types in theory... and practice



+



In this course, you will learn the **basic theory of session types**...

- ▶ i.e., their use in the π -calculus

... and experiment with **practical applications in Scala**

- ▶ using a tool called **Scribble** —

<https://github.com/scribble/scribble-java>

<https://nuscr.dev/nuscr/>

<https://github.com/nuscr/nuscr>

Data types
oo

Concurrent systems
oo

Session types
oooo

Applications
o●

Research
ooooo

Student projects
oo

Conclusion
o

DEMO:

Scribble and RFC 5321 (“Simple” Mail Transfer Protocol)

The Mobility Reading Group at Oxford

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

<https://mrg.cs.ox.ac.uk/>

The screenshot shows the homepage of the MobilityReadingGroup website. The header features a large blue π symbol with the text "session type" above it, followed by the text "MobilityReadingGroup" and "π-calculus, Session Types research at the University of Oxford". A navigation bar below includes links for Home (which is highlighted in blue), People, Publications, Grants, Talks, Tutorials, Tools, Awards, and Kohei Honda.

NEWS

23 Jun 2023

The paper 'Rollback Recovery in Session Based Programming', by Claudio Antares Mezzina, Francesco Tiezzi and Nobuko Yoshida, has won the best paper award at the 25th International Conference on Coordination Models and Languages (Coordination 2023).

» more

22 Mar 2022

MEng student, Zak Cutner, awarded Microsoft Prize and Distinguished Project award.

6 Aug 2021

Nobuko Yoshida, with Francisco

SELECTED PUBLICATIONS

2023

Romain Demangeon, Nobuko Yoshida: [Causal Computational Complexity of Distributed Processes](#). IC 2023 : 104998.

Adam D. Barwell, Ping Hou, Nobuko Yoshida, Fangyi Zhou: [Designing Asynchronous Multiparty Protocols With Crash Stop Failures](#). *To appear in ECOOP*.

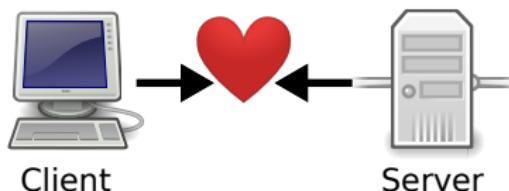
David Castro-Perez, Nobuko Yoshida: [Dynamic Updatable Multiparty Session Types](#). *To appear in ECOOP*.

Lorenzo Gheri, Nobuko Yoshida: [Hybrid Multiparty Session Types: Compositionality for Protocol Specification through Endpoint Projection](#). *To appear in OOPSLA 2023*.

From client-server...

Session types can formalise **complex client-server protocols...**

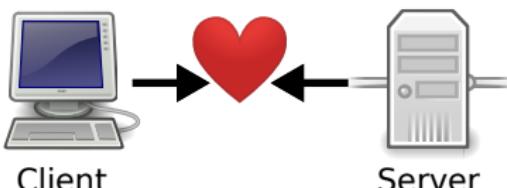
- ▶ SMTP
- ▶ HTTP
- ▶ POP3
- ▶ ...



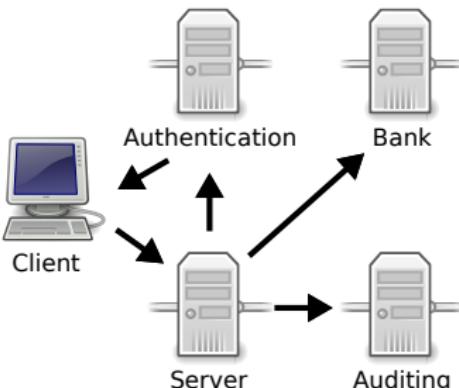
From client-server... to multiparty protocols

Session types can formalise **complex client-server protocols...**

- ▶ SMTP
- ▶ HTTP
- ▶ POP3
- ▶ ...



... and also extend to **multiparty protocols**



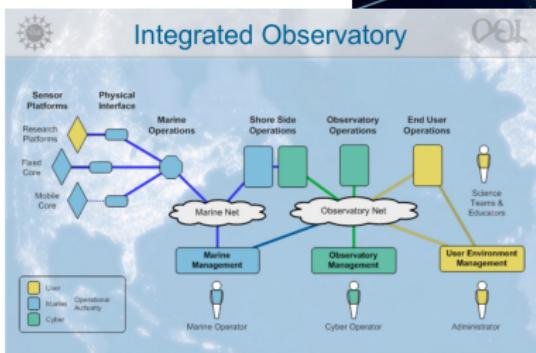
Other programming languages

(Elements of) the session types theory have been **implemented in many languages**, e.g.:

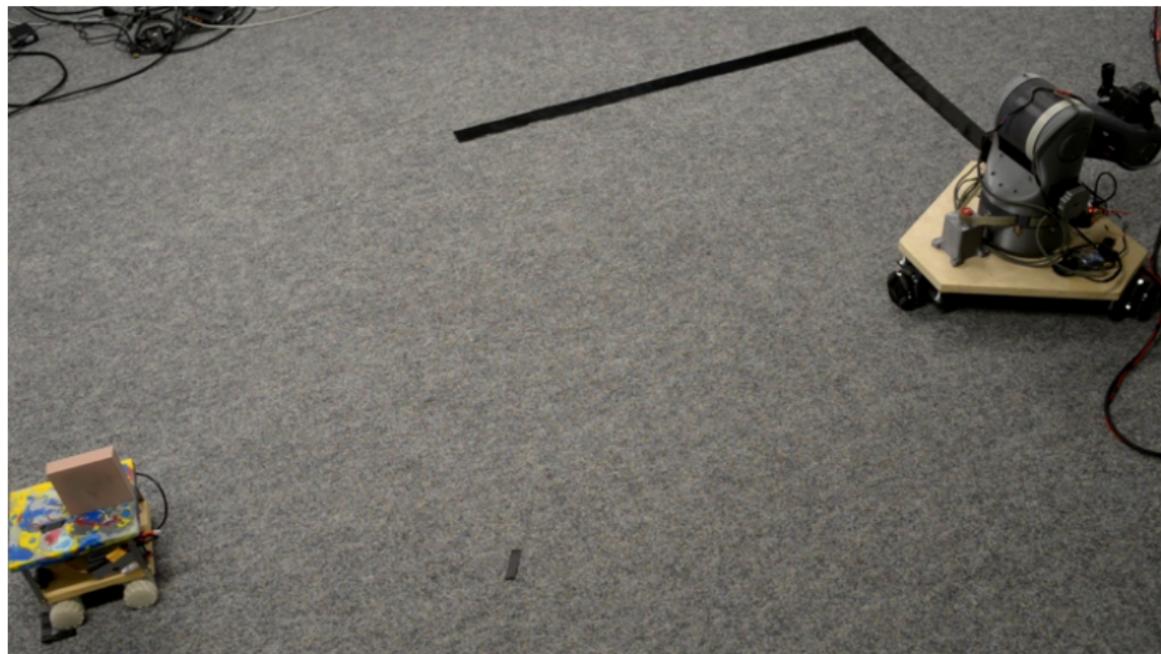


Case study (I): Ocean Observatories Initiative

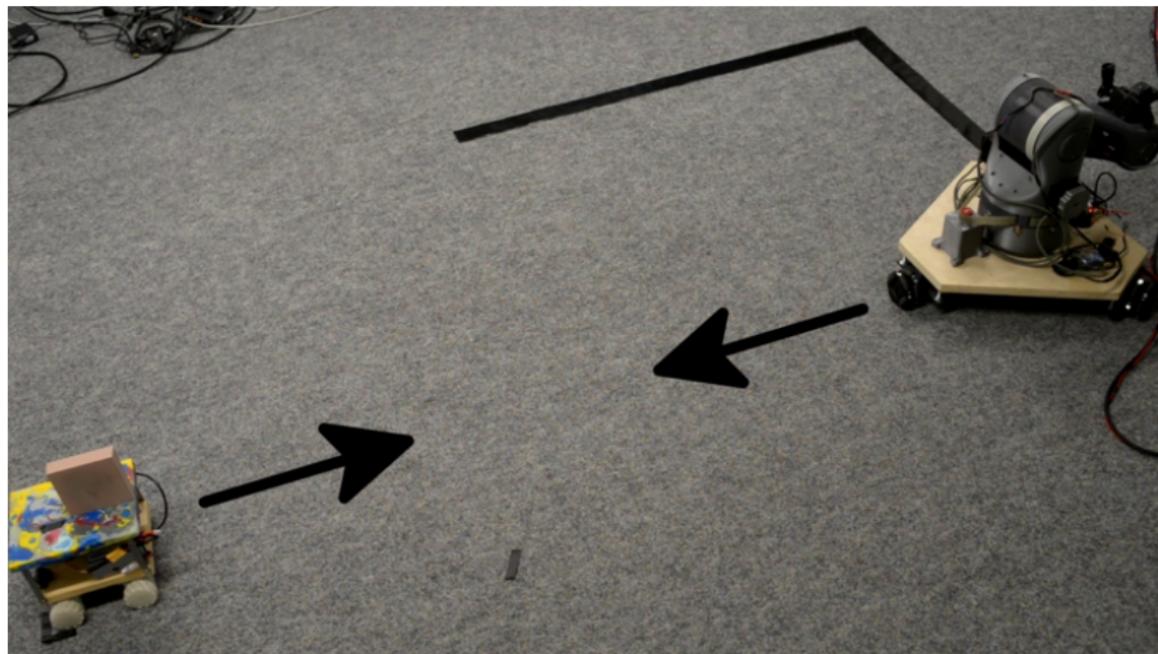
Collaboration: use session types on top of OOI network to guarantee global safety



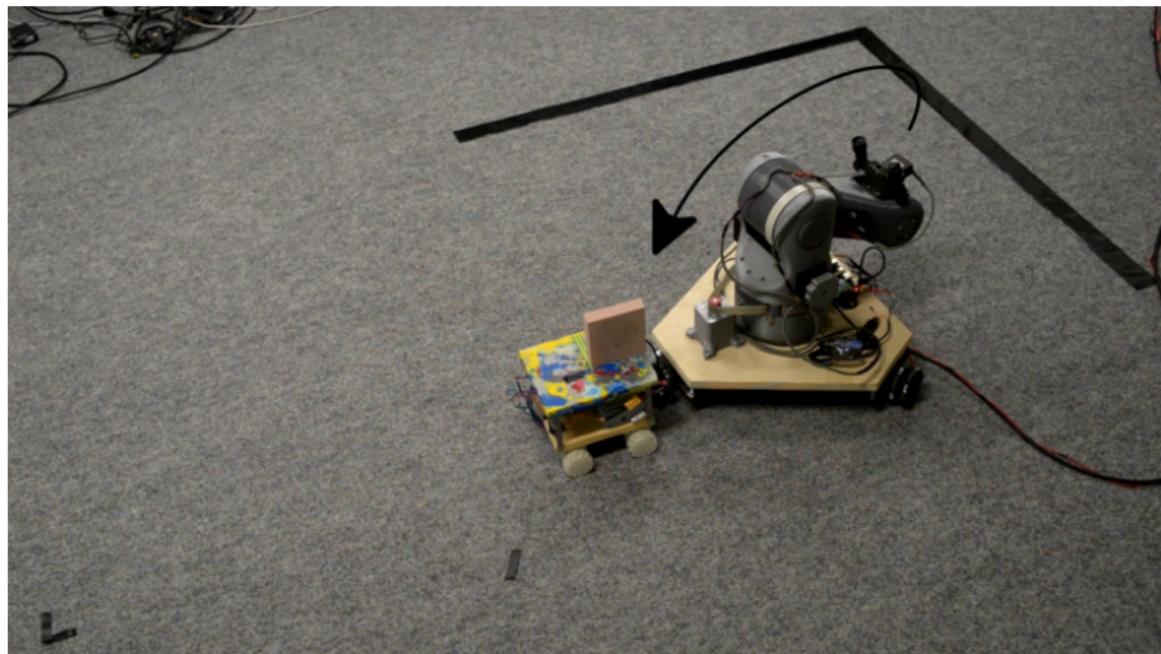
Case study (II): Motion Session Types for Robotics Interactions



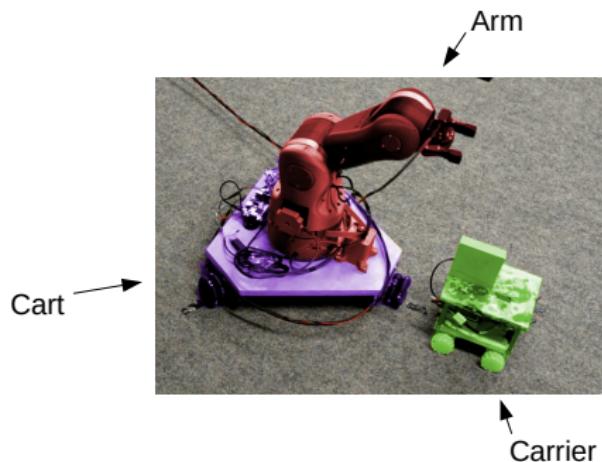
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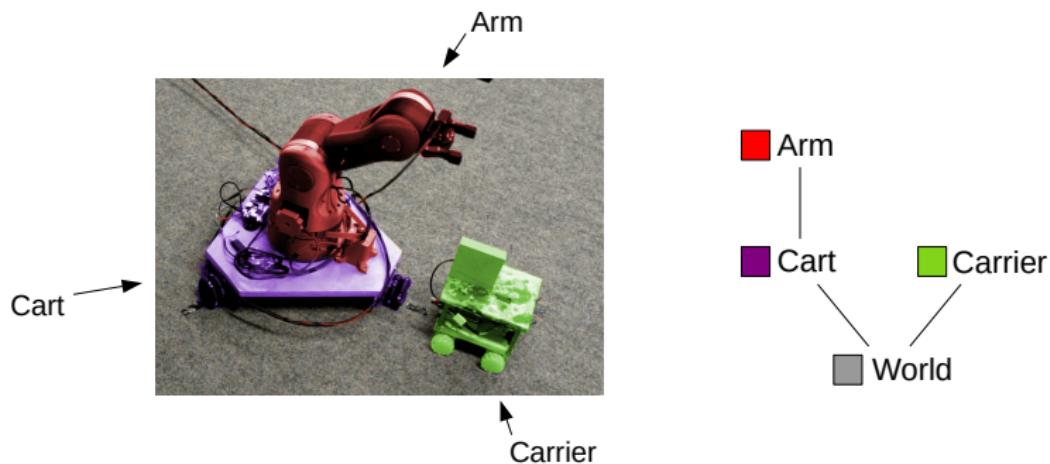
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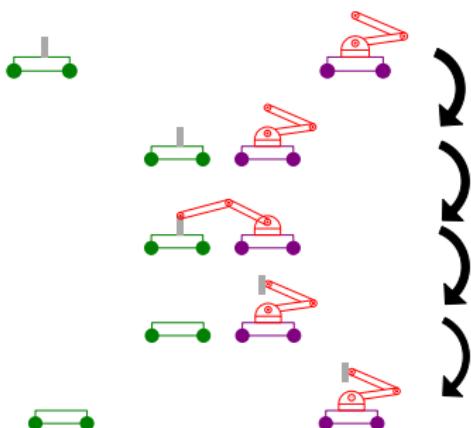
Cart & Arm:

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

Case study (II): Motion Session Types for Robotics Interactions



Case study (II): Motion Session Types for Robotics Interactions



Cart → Arm : fold(unit).dt(Cart : idle, Carrier : idle, Arm : fold).
Arm → Cart : ok(unit).Cart → Carrier : ok(unit).
dt<Cart : move, Carrier : move, Arm : idle>.
Carrier → Cart : ok(unit).Cart → Arm : grab(unit).
dt<Cart : idle, Carrier : idle, Arm : grip>.
Arm → Cart : ok(unit).Cart → Carrier : ok(unit).
dt<Cart : move, Carrier : move, Arm : idle>.
Cart → Arm : done(unit).Cart → Carrier : done(unit).end

Recent Student Projects

Looking for **student projects** or **PhDs**? Here are some from previous years:

- ▶ Complexity Analyses of Multiparty Session Types
 - ▶ Published at **POPL'25**
- ▶ Implementing Flexible Multiparty Session Types in **TypeScript**
 - ▶ Published at **ECOOP'22**
- ▶ Implementing Asynchronous Multiparty Session Types in **Rust**
 - ▶ Published at **PPoPP'22**
- ▶ Safe Session Web Programming in **TypeScript**
 - ▶ Published at **CC'21**
- ▶ Efficient runtime for concurrent programs in **Dotty / Scala 3**
 - ▶ Published at **PLDI'19**
- ▶ Session type providers in **F#**
 - ▶ Published at **CC'18**

Student Project Topics

Looking for **research topics** from this course? Here are some of our proposed topics:

- ▶ Integration of session types with various programming languages: e.g. **Scala**, **Rust**, **Go**, **Haskell**, **OCaml**, **TypeScript**, **F#**, **PureScript**, ...
- ▶ Applications of session types for **cyberphysical systems**, **robotics** and **cyber security**.
- ▶ ... and we are **open to suggestions!**

We are looking for **MSC project and PhD students**.

Conclusion

Session types allow to:

1. **formalise protocols** for concurrent/distributed systems
2. **verify concurrent 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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For papers and more info, visit:

<https://mrg.cs.ox.ac.uk/>

... and get in touch for enquiries and research topics!

Questions?