Lightweight Session Programming in Scala

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Troubles with session programming

Consider a simple **"greeting" client/server session protocol**:

1. the client can ask to **greet** someone, or **quit**
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- describe the protocol **informally**
- develop *ad hoc* **protocol APIs** to avoid **protocol violations**
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Impact on **software evolution and maintenance**

Lightweight Session Programming in Scala

This talk: we show how in **Scala** + `lchannels` we can write:

```
def client(c: Out[Start]): Unit = {
  if (Random.nextBoolean()) {
    val c2 = c !! Greet("Alice")_

    c2 ? {
      case m @ Hello(name) => client(m.cont)
      case Bye(name)       => ()
    }
  } else {
    c ! Quit()
  }
}
```

. . . with a **clear theoretical basis**, giving a **general API** with **static protocol checks** and **message transport abstraction**

Scala

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- **Declaration-site variance**
- **Case classes** for OO pattern matching

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```
sealed abstract class Pet
case class Cat(name: String)   extends Pet
case class Dog(name: String)   extends Pet
```

```
def says(pet: Pet) = {
  pet match {
    case Cat(name) => name + " says: meoow"
    case Dog(name) => name + " says: woof"
  }
}
```

Session types

Consider again our **"greeting" client/server session protocol**:

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We can **formalise** the **client** viewpoint as a **session type** for the **session** π**-calculus**: (Honda *et al.*, 1993, 1994, 1998, ...)

$$S_h = \mu_X.\left(\begin{array}{l} !\mathtt{Greet}(\mathsf{String}).\left(\begin{array}{l} ?\mathtt{Hello}(\mathsf{String}).X \\ \& \\ ?\mathtt{Bye}(\mathsf{String}).\mathbf{end} \end{array} \right) \\ \oplus \\ !\mathtt{Quit}.\mathbf{end} \end{array} \right)$$

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From theory to practice

Desiderata:

- find a **formal link** between **Scala types** and **session types**
- represent **sessions** in a language **without session primitives**
  - **lightweight**: no language extensions, minimal dependencies

Inspiration (from concurrency theory):

- **encoding of session types into linear types for π-calculus**

  (Dardha, Giachino & Sangiorgi, PPDP'12)

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Result: **Lightweight Session Programming in Scala**

Session vs. linear types (in pseudo-Scala)

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}
```

"Linear Scala"

```
def client(c: LinOutChannel[?]): Unit = {
  if (...) {
    val (c2in, c2out) = createLinChannels[?]()
    c.send( Greet("Alice", c2out) )
    c2in.receive match {
      case Hello(name, c3out) => client(c3out)
      case Bye(name)          => ()
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  } else {
    c.send( Quit() )
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Goals:

- define and implement linear in/out channels
- instantiate the "?" type parameter
- automate continuation channel creation

lchannels: **interface**

```
abstract class In[+A] {

  def receive(implicit d: Duration): A





}

abstract class Out[-A] {

  def send(msg: A): Unit


}
```

API offers **typed** send/receive

- with **runtime checks** for **linear use** and **error handling**

Note **input/output co/contra-variance**

lchannels: **interface**

```
abstract class In[+A] {

  def receive(implicit d: Duration): A


  def ?[B](f: A => B)(implicit d: Duration): B = {
    f(receive)
  }
}

abstract class Out[-A] {

  def send(msg: A): Unit
  def !(msg: A)                              = send(msg)

}
```

API offers **typed** `send`/`receive`, plus **syntactic sugar**

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lchannels: interface

```
abstract class In[+A] {
  def future: Future[A]
  def receive(implicit d: Duration): A = {
    Await.result[A](future, d)
  }
  def ?[B](f: A => B)(implicit d: Duration): B = {
    f(receive)
  }
}

abstract class Out[-A] {
  def promise[B <: A]: Promise[B] // Impl. must be constant
  def send(msg: A): Unit     = promise.success(msg)
  def !(msg: A)                          = send(msg)

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  def promise[B <: A]: Promise[B] // Impl. must be constant
  def send(msg: A): Unit     = promise.success(msg)
  def !(msg: A)                                = send(msg)
  def create[B](): (In[B], Out[B]) // Used to continue a session
}
```

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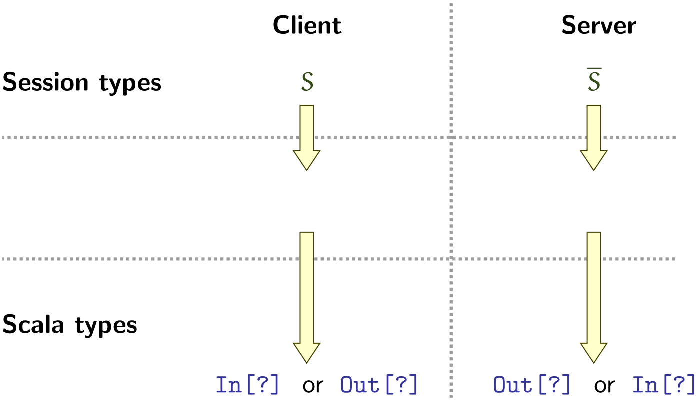
Session programming = In[·]/Out[·] + CPS protocols

How do we **instantiate the** In[·]/Out[·] **type parameters**?



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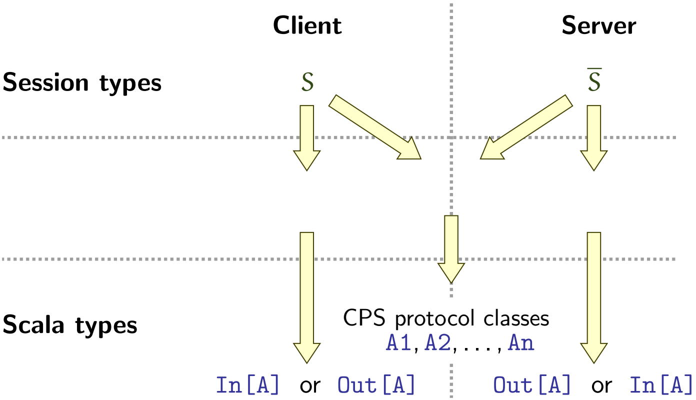

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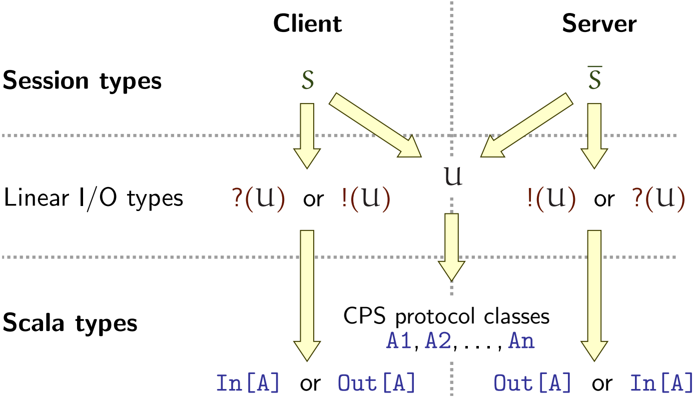

Programming with `lchannels` (I)

$$S_h = \mu_X.\Big(\mathbf{!}\texttt{Greet}(\mathsf{String}).\big(\mathbf{?}\texttt{Hello}(\mathsf{String}).X \;\&\; \mathbf{?}\texttt{Bye}(\mathsf{String}).\mathbf{end}\big) \oplus \mathbf{!}\texttt{Quit}.\mathbf{end}\Big)$$

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$\text{prot}\langle\!\langle S_h \rangle\!\rangle_{\mathcal{N}}$ =

```
// Top-level internal choice
case class Greet(p: String)
case class Quit(p: Unit)

// Inner external choice
case class Hello(p: String)
case class Bye(p: String)
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case class Greet(p: String)                          extends Start
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Goals:

- define and implement linear in/out channels ✓
- instantiate the "?" type parameter ✓
- automate continuation channel creation ✗

The "create-send-continue" pattern

We can observe that `In`/`Out` channel pairs are usually created for **continuing a session after sending a message**

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Let us **add the !! method** to Out[·]:

```
abstract class Out[-A] {
  ...
  def !![B](h: Out[B] => A): In[B] = {
    val (cin, cout) = this.create[A]()  // Create...
    this ! h(cout)                      // ...send...
    cin                                 // ...continue
  }

  def !![B](h: In[B] => A): Out[B] = {
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Scala + lchannels

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Demo

Run-time and compile-time checks

Well-typed output / int. choice	**Compile-time**
Exhaustive input / ext. choice	**Compile-time**

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Double use of linear input endp.	**Run-time**
"Forgotten" output	**Run-time** **(timeout on input side)**
"Forgotten" input	**Unchecked**

Formal properties

Theorem *(Preservation of duality)*.

$\langle\!\langle \overline{S} \rangle\!\rangle_{\mathcal{N}} = \overline{\langle\!\langle S \rangle\!\rangle_{\mathcal{N}}}$ (where $\overline{\texttt{In[A]}} = \texttt{Out[A]}$ and $\overline{\texttt{Out[A]}} = \texttt{In[A]}$).

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Theorem *(Dual session types have the same CPS protocol classes).*

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$\mathsf{prot}\langle\langle S \rangle\rangle_{\mathcal{N}} = \mathsf{prot}\langle\langle \overline{S} \rangle\rangle_{\mathcal{N}}$.

Theorem *(Scala subtyping implies session subtyping).*
For all $S, \mathcal{N}$:

- if $\langle\langle S \rangle\rangle_{\mathcal{N}} = \texttt{In[A]}$ and $\texttt{B} <: \texttt{In[A]}$, then $\exists S', \mathcal{N}'$ such that $\texttt{B} = \langle\langle S' \rangle\rangle_{\mathcal{N}'}$ and $S' \leqslant S$;
- if $\langle\langle S \rangle\rangle_{\mathcal{N}} = \texttt{Out[A]}$ and $\texttt{Out[A]} <: \texttt{B}$, then $\exists S', \mathcal{N}'$ such that $\texttt{B} = \langle\langle S' \rangle\rangle_{\mathcal{N}'}$ and $S \leqslant S'$.

Conclusions

We presented a **lightweight integration of session types in Scala** based on a **formal link** between CPS protocols and session types

We leveraged **standard Scala features** (from its type system and library) with a **thin abstraction layer** (`lchannels`)

- low **cognitive overhead**, **integration** and **maintenance** costs
- naturally supported by **modern IDEs** (e.g. **Eclipse**)

We validated our session-types-based programming approach with **case studies** (from literature and industry) and **benchmarks**

Ongoing and future work

Automatic generation of CPS protocol classes
from session types, using **Scala macros**

- *B. Joseph. "Session Metaprogramming in Scala". MSc Thesis, 2016*

Extension to **multiparty session types**, using **Scribble**

- A. Scalas, O. Dardha, R. Hu, N. Yoshida.
  "A Linear Decomposition of Multiparty Sessions for Safe Distributed Programming".
  To appear at ECOOP 2017.

Ongoing and future work

Automatic generation of CPS protocol classes
from session types, using **Scala macros**

- *B. Joseph. "Session Metaprogramming in Scala". MSc Thesis, 2016*

Extension to **multiparty session types**, using **Scribble**

- A. Scalas, O. Dardha, R. Hu, N. Yoshida.
  "A Linear Decomposition of Multiparty Sessions for Safe Distributed Programming".
  To appear at ECOOP 2017.

Generalise the approach to other frameworks beyond `lchannels`, and study its properties.
Natural candidates: **Akka Typed**, **Reactors.IO**

Investigate other programming languages. Possible candidate:
C# (declaration-site variance and FP features)

Try `lchannels` and Scribble!

http://alcestes.github.io/lchannels

http://scribble.org

ECOOP 2016

ECOOP 2017