Contextual Metaprogramming for Session Types

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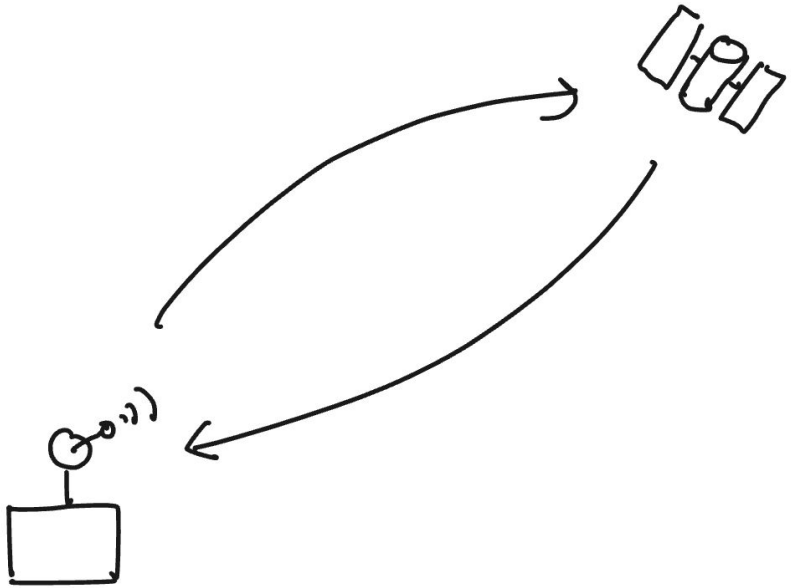
This talk is about...

- Combining two paradigms of type systems
  - **Session Types** for distributed programming
  - **Contextual (Modal) Types** for metaprogramming
- Questions would be
  - Why did we choose this combination?
  - What was technical challenges?

Example: Programming Satellites (1)

Let us consider programming communication between satellites and control rooms



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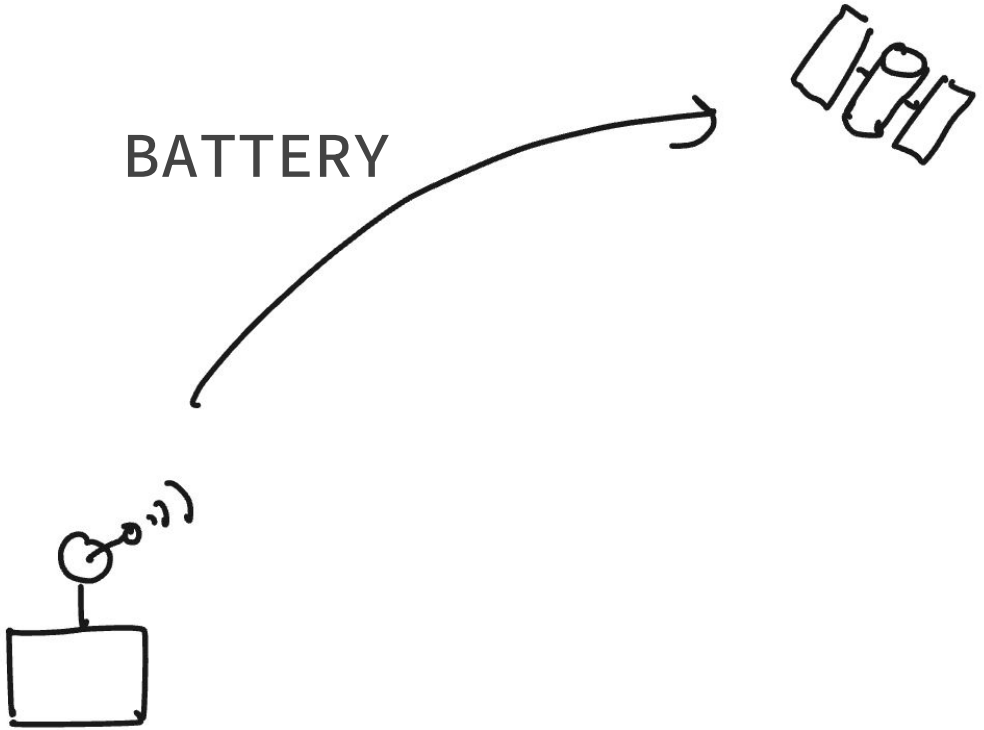

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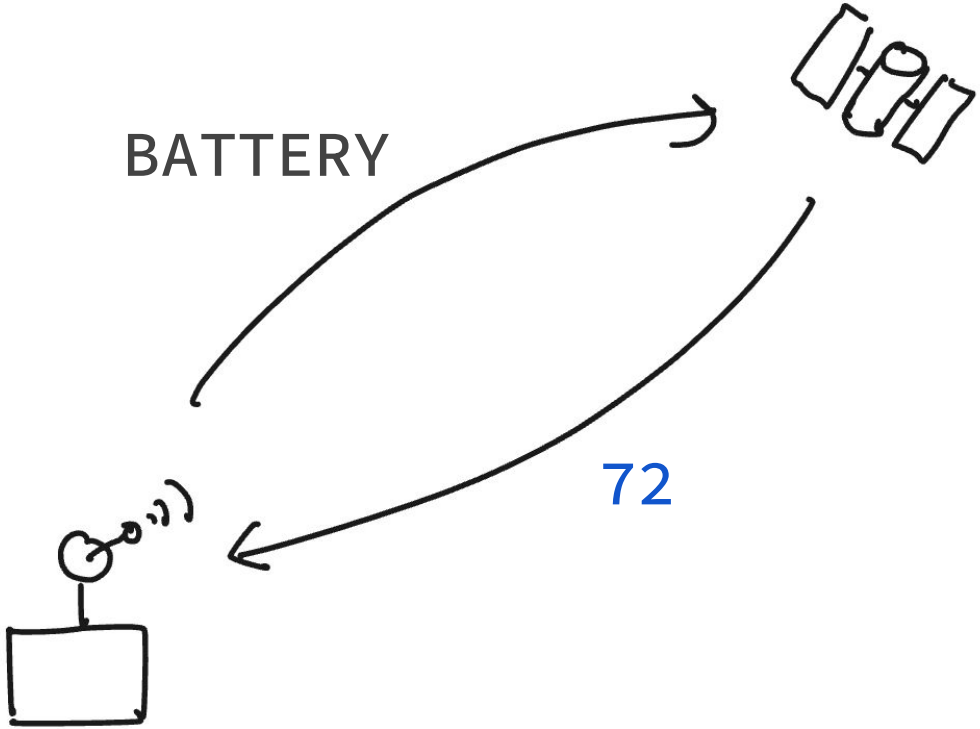

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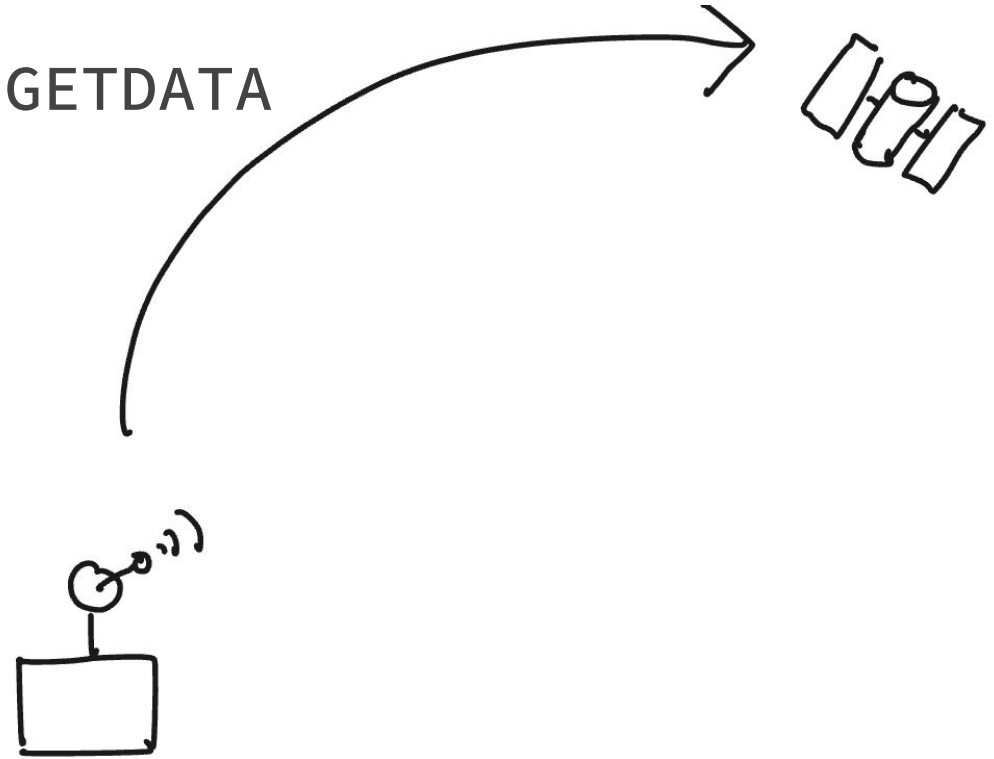

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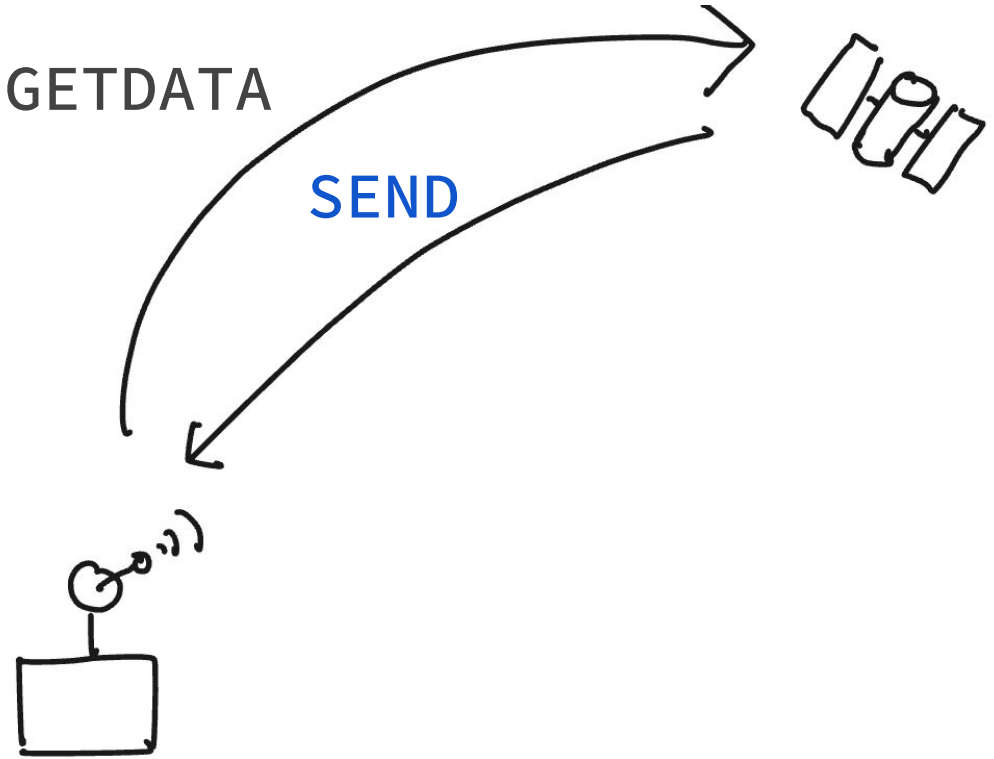

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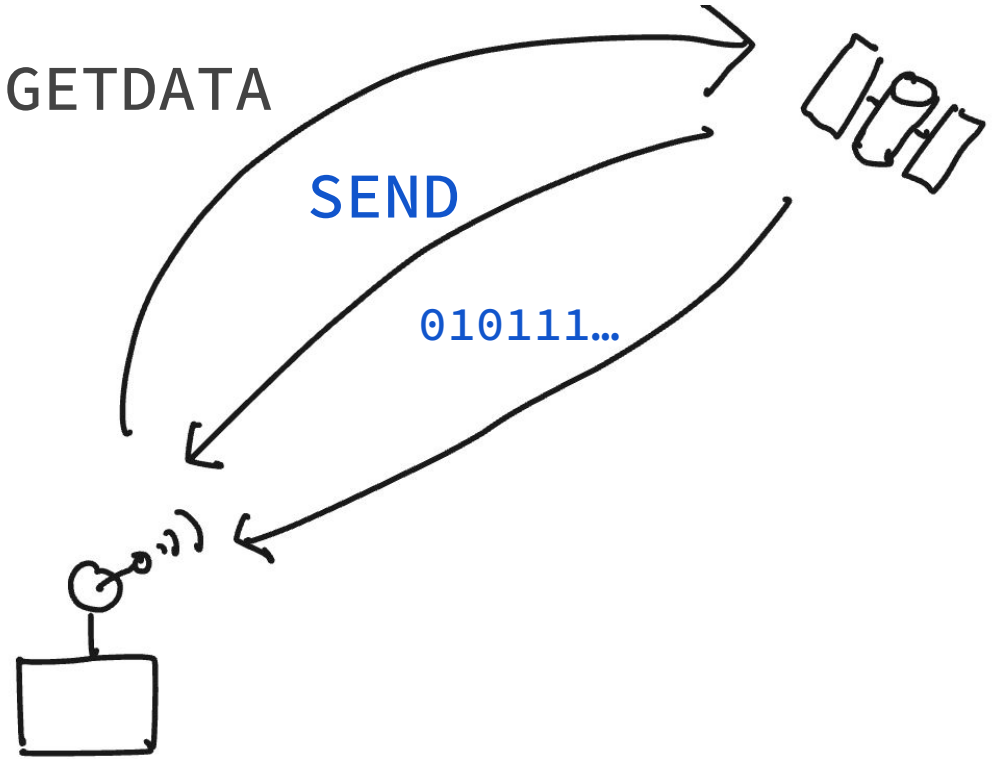

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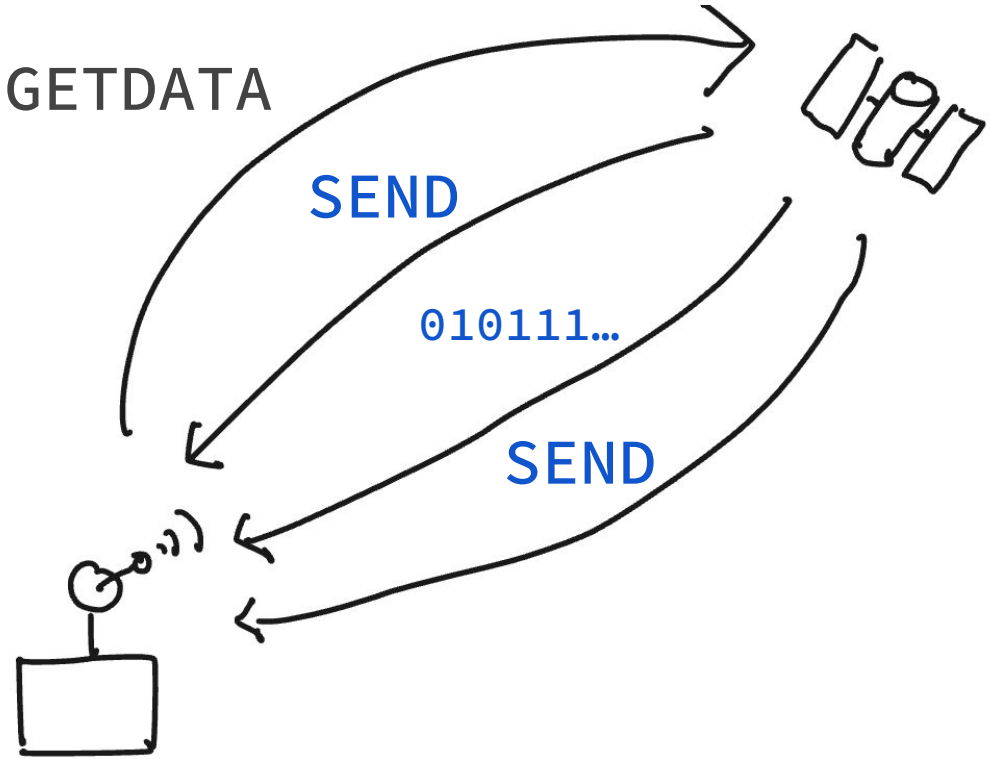

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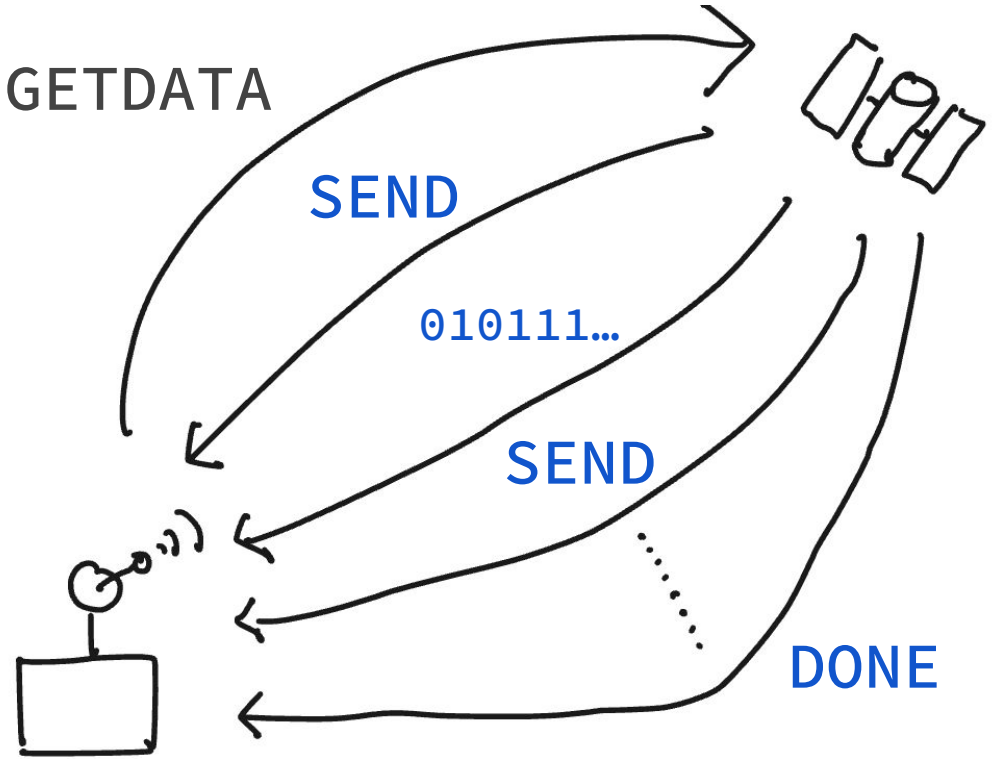

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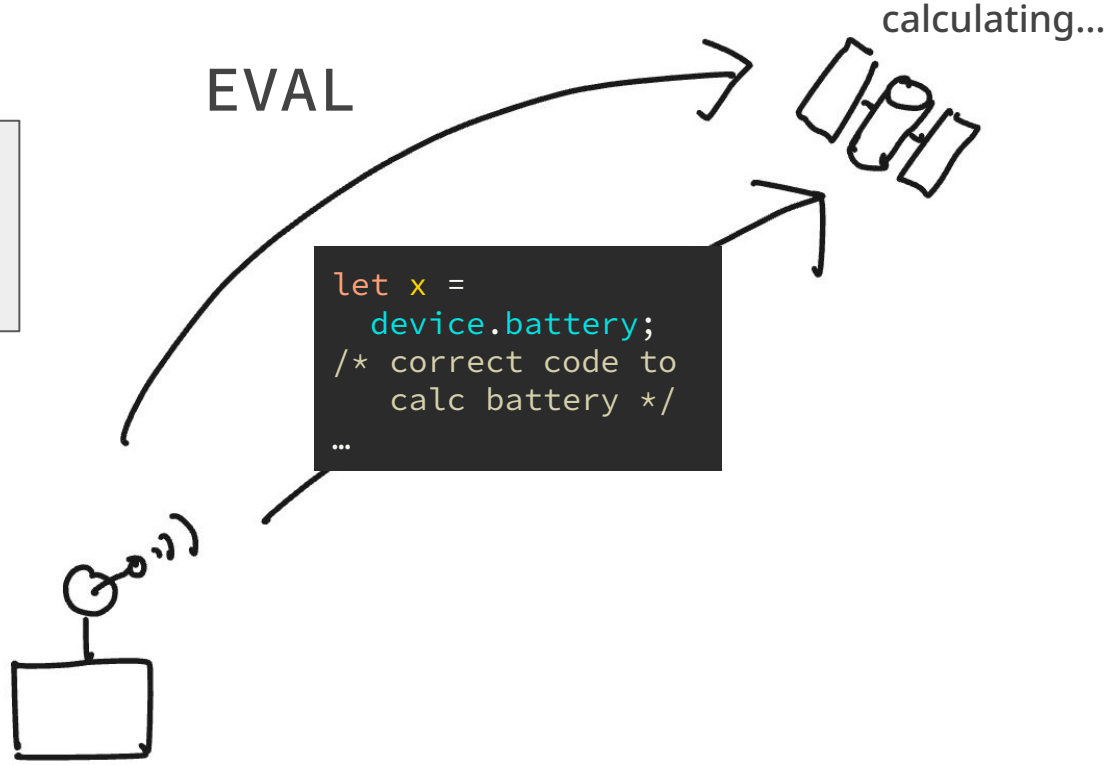

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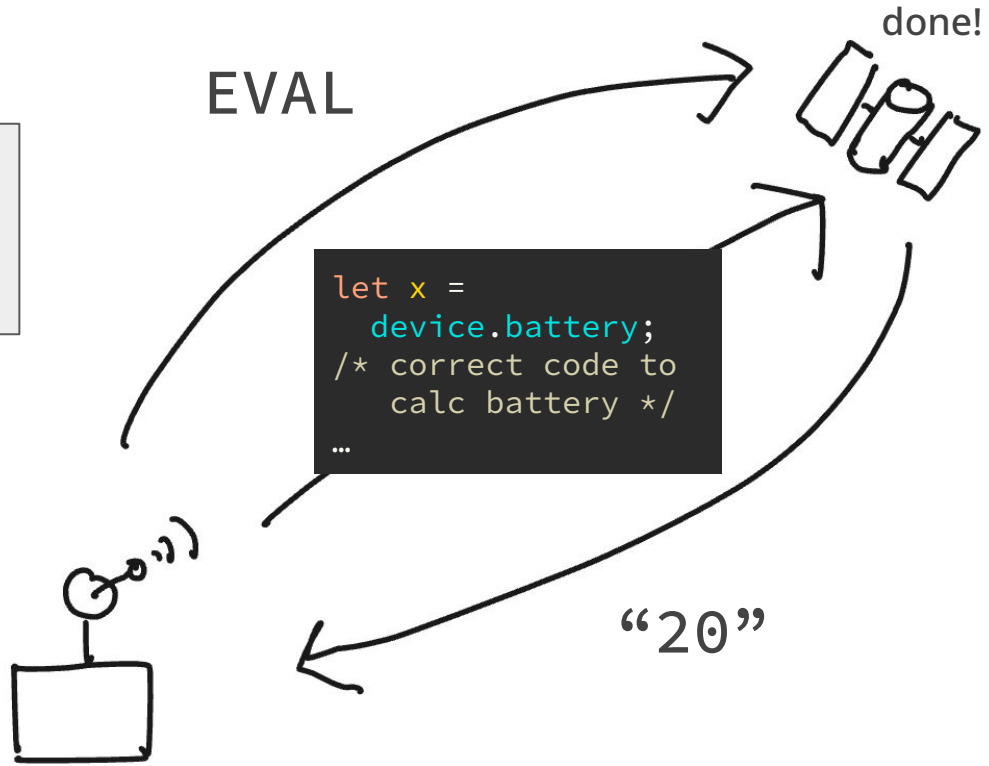

Communication + Metaprogramming is Common

We can observe this pattern in several situations

- Send code to remote devices to run it there
  - e.g. NASA Deep Space 1 **(Search “Lisp in Space”!)**
- Web servers and browsers
  - Server-Side Rendering, Lazy loading, Module Federation, ...
- Volunteer programming (e.g. Folding@Home)
- Hot code reloading

Session Types for Safe Communication

```
type CtrlCh =
rec τ. ⊕{
 BATTERY: ?int.τ,
 GETDATA: rec τ2.
          &{ SEND: ?blob.τ2 ,
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 EVAL: !str.?str.τ
}
```

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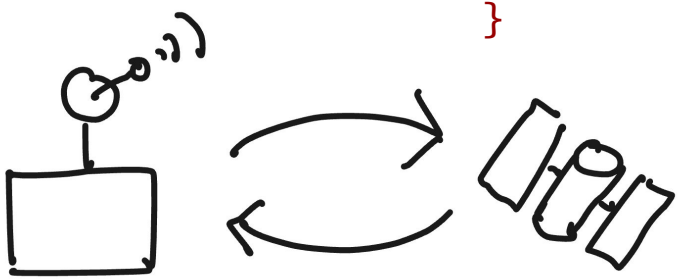

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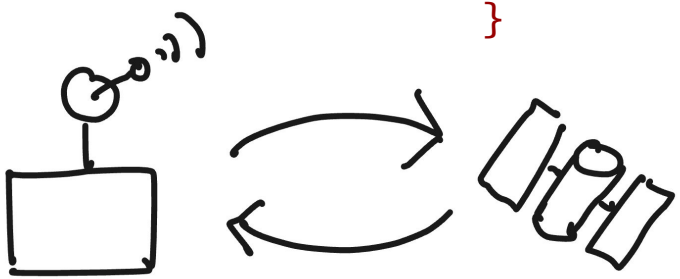

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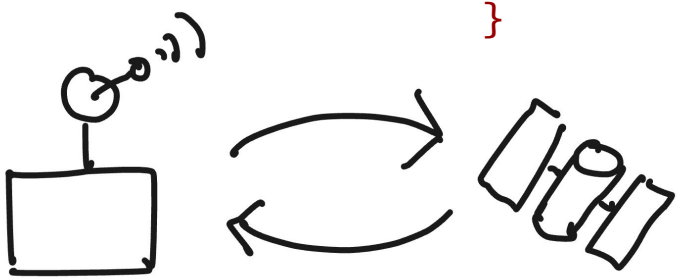

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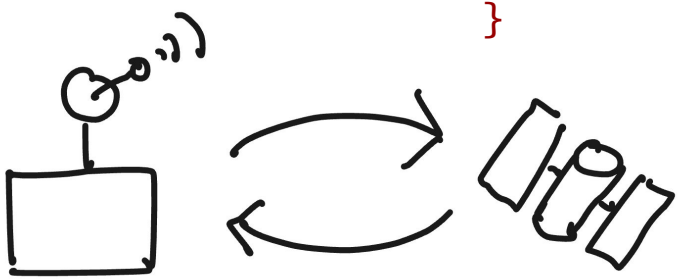

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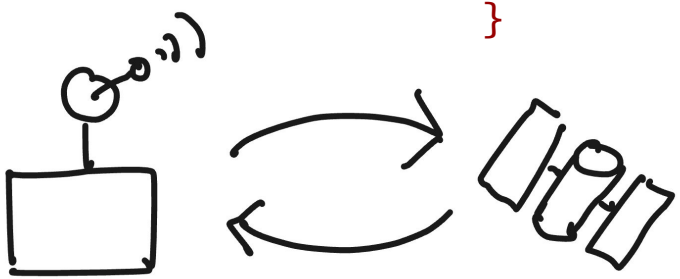

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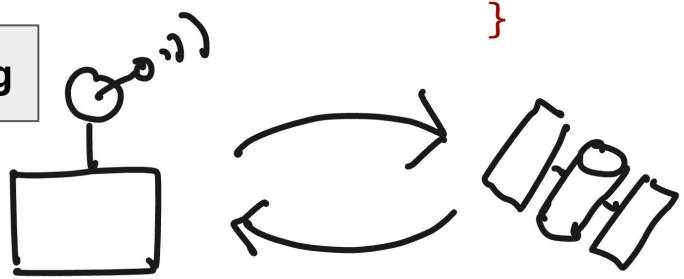
Send string

Possible commands to receive



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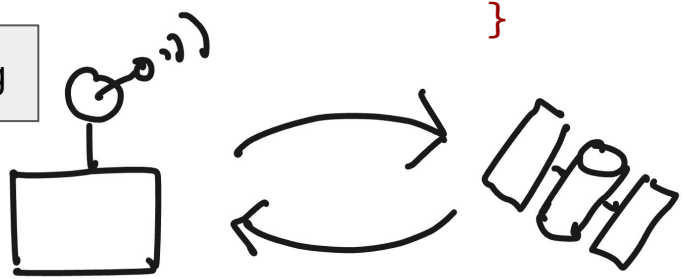
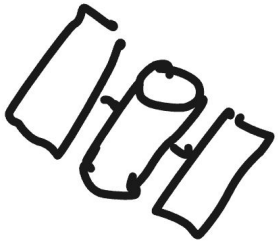


Channels are Linear Resources



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let rec serve(ch: SatelliteCh): unit =
  match ch with
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      let (code, ch) = receive ch in
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Channels must be used exactly once

⇒ **Linear Types**

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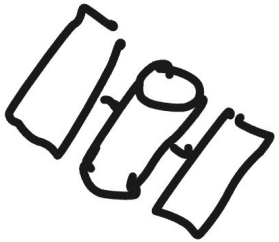

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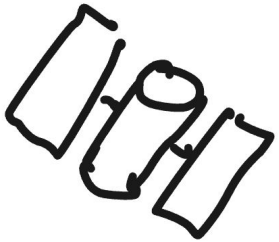

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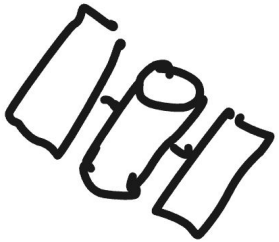

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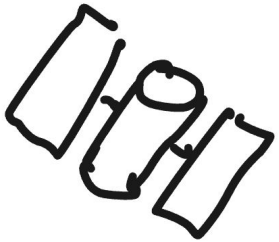

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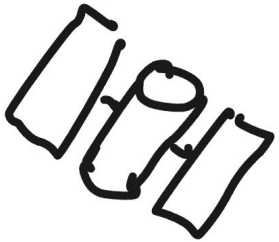

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```

Programs as string

```
…
case EVAL => \ch -> {
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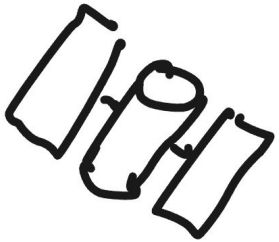
It is dangerous to evaluate code fragments

Contextual Types for Metaprogramming



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type SatelliteCh =
rec τ. &{
 …
 EVAL: ?[Γ⊢str].!str.τ
}
```

Contextual Type
[Nanevski+ 08][Jang+ 22]

```
…
case EVAL => \ch -> {
  let (code, ch) = receive ch in
  let box U = code in
  let ch = send ch U[device,...] in
  serve ch
}
```

Execute code with supplying resources

Resources that a program requires (i.e. *context*)

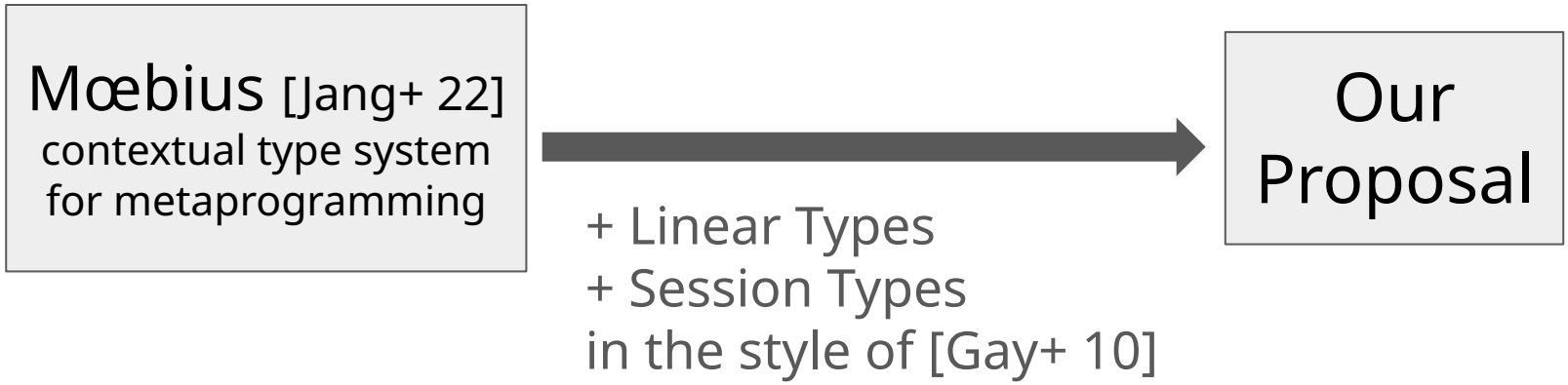
$[\Gamma \vdash str]$

Result of the computation

Example

```
`{x,y. x+y}
:[int,int⊢int]
```

What We Did



We formalized a typed programming language
that provide both session types and contextual types

- Type System
- Operational Semantics

Code is ALWAYS unrestricted resource

We determine linearity of values a la Walker [2005]

```
1000
“some string”
```

Can be copied
⇒ **unrestricted**

```
(ch: CtrlCh)
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Depends on a linear resource ⇒ **linear**

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λch.send ch 1
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```
`{x,ch.send ch x}
```

Our type system enforce that code is closed (= independent from any resources)
⇒ unrestricted

Safety Properties

We confirmed that our proposal satisfies expected safety properties

Theorem 3 (Progress for evaluation)**.** *Let* $\Gamma^S \vdash M : T$*. Then,*

1. M *is a value, or*
2. $M \to N$*, for some* N*, or*
3. M *is of the form* $E[N]$*, for some* E*, with* N *of one of the following forms:* close x, wait x, send $v\ x$, receive x, select $l\ x$, match x with $\{l \to N_l\}^{l \in L}$, new v *or* fork v.

Theorem 4 (Absence of immediate errors)**.** *If* $\vdash P$ *then* P *is not a runtime error.*

Related Work

- Modal types for distributed programs[Jia+04][Murphy+04]
  - Assume simpler communication with multiple processes
- Multi-tier programming
  - e.g., Hop.js[Serrano+16], Links[Cooper+07]
  - Experimental Programming Language Implementations for web applications
- Multi-stage computation
  - We want to evaluate code at runtime
    ⇒ type systems like λ○[Davies17] are not adequate

We are Seeking for Future Directions

Currently, novelty in our proposal seems a bit weak, while we believe that Communication+Metaprogramming have better chemistry...

- Different-Style communications from modal calculi
- Extension towards multi-tier programming
- Staged Semantics in distributed programming

Let us know if you have good idea!

References (1/2)

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