iCyPhy

Software Design for Cyber-Physical Systems

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Module 2: Motivation for Lingua Franca

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University of California, Berkeley

References

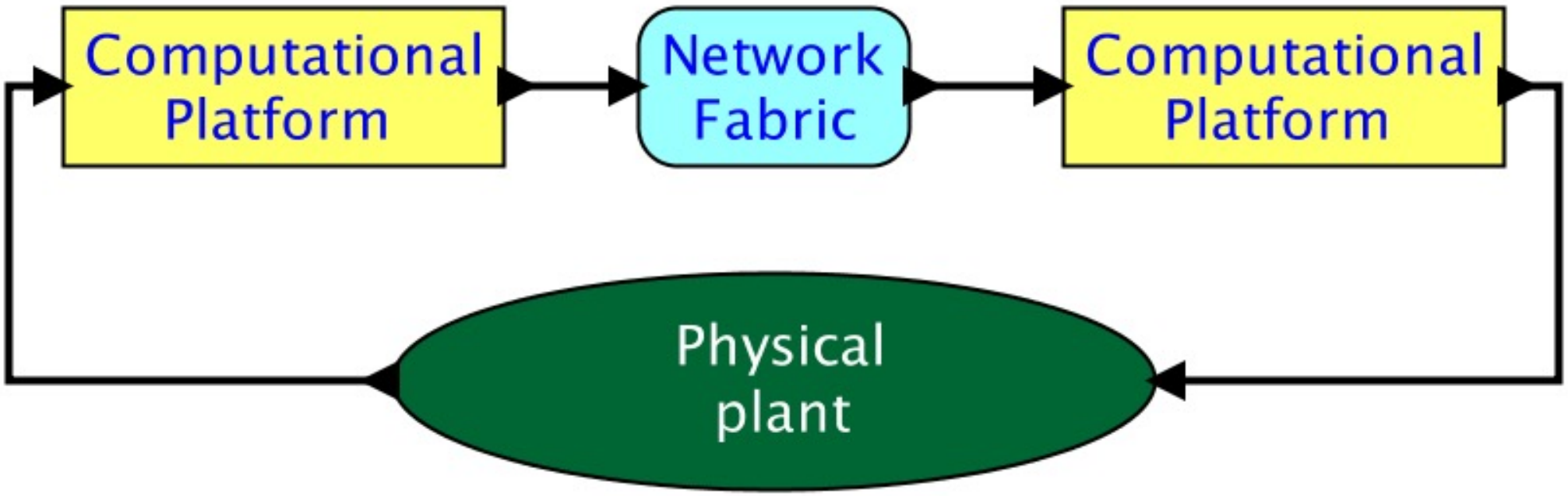
Class website:

https://ptolemy.berkeley.edu/~eal/cps/

Lingua Franca website:

https://lf-lang.org/

Cyber Physical Systems



The major challenge: **Integrating complex subsystems** with adequate **reliability**, **repeatability**, and **testability**.

Popular Techniques

- Publish and Subscribe
  - ROS, MQTT, Azure, Google Cloud
- Actors
  - Akka, Erlang, Orleans, Rebeca, Scala …
- Service-oriented architecture
  - gRPC, Bond, Thrift, …
- Shared memory
  - Linda, pSpaces, …

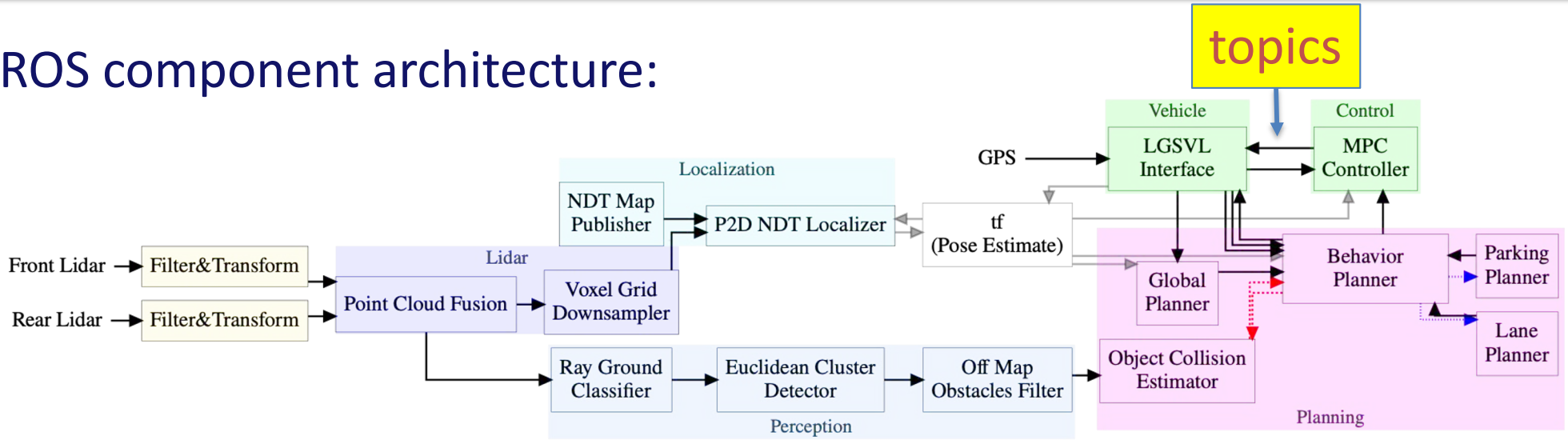
Pub-Sub

- Components **publish** events on **topics**.
- Other components **subscribe** to topics.
- Message **handlers** are invoked in subscribers.
- No ordering guarantees.

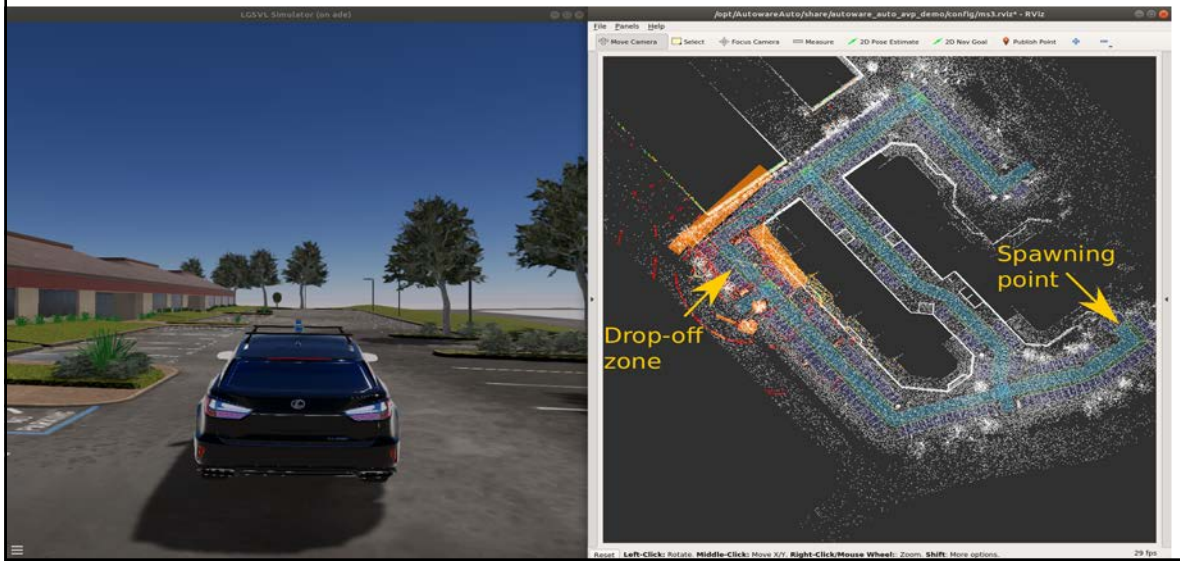
ROS 2 (Robotic Operating System) uses pub-sub built on top of DDS (Data Distribution Service).

A ROS-Based Autonomous Driving Application: Autoware.Auto

ROS component architecture:



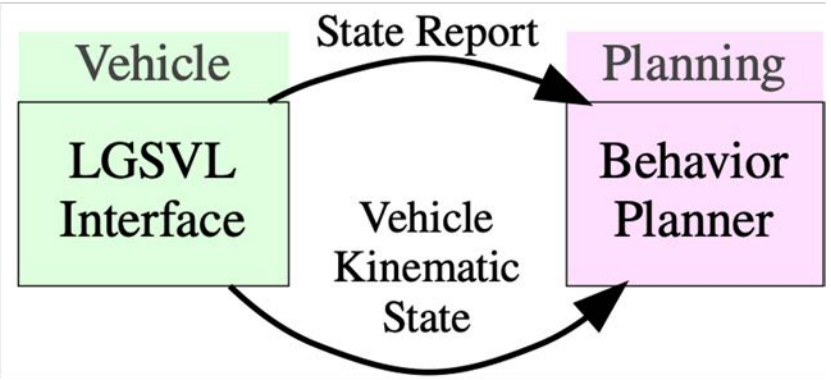
LGSVL simulation of the vehicle:



Soroush Bateni, of UT Dallas, studied this open-source system, which has been deployed on full-size cars.

Out-of-Order Message Handling

- **LGSVL Interface:**
  1. Produce a "forward" gear
  2. Produce a (+) kinematic state
  3. Produce a "reverse" gear
  4. Produce a (-) kinematic state
- **Behavior Planner: What will it see?**
  - 2 -> 1 -> 3 -> 4
  - 1 -> 2 -> 4 -> 3
  - 1 -> 2 -> 3 -> 4
  - 2 -> 1 -> 4 -> 3



Soroush ran 300,000 tests under benign conditions and found occurrences of all four sequences.

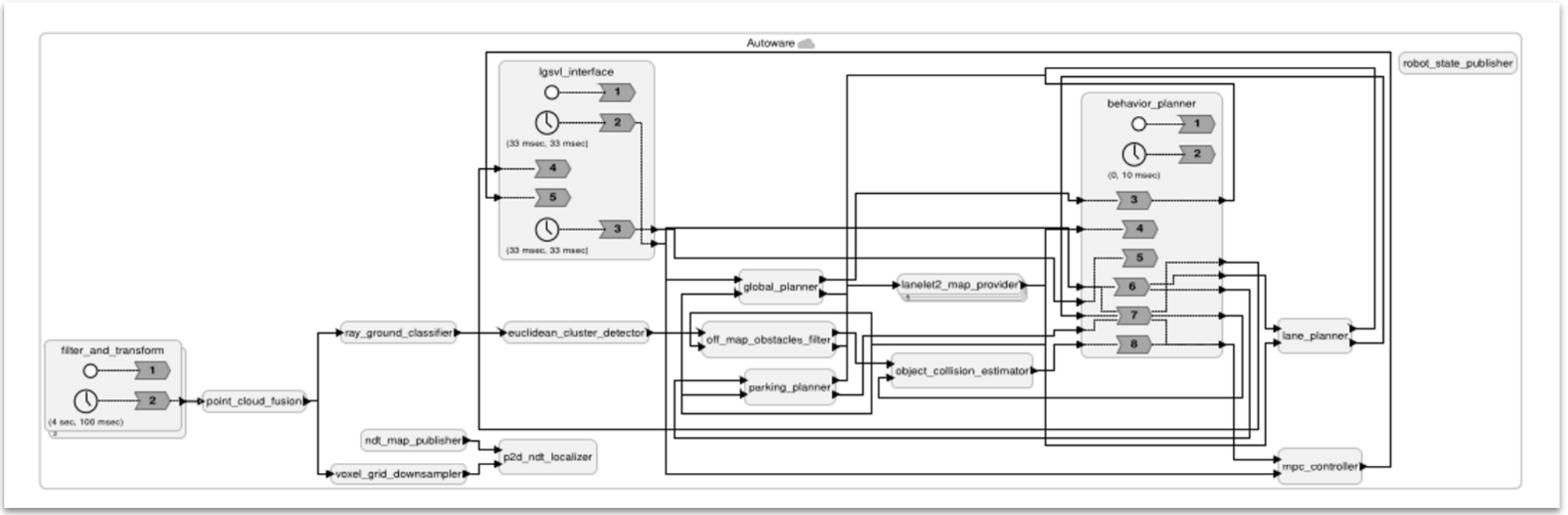
The odd occurrences were rare enough that they are likely to not show up in testing!

Thanks to Soroush Bateni.

Port of Autoware.auto to Lingua Franca

Soroush Bateni

AUTONOMOUS VALET PARKING



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- Publish and Subscribe
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- Actors
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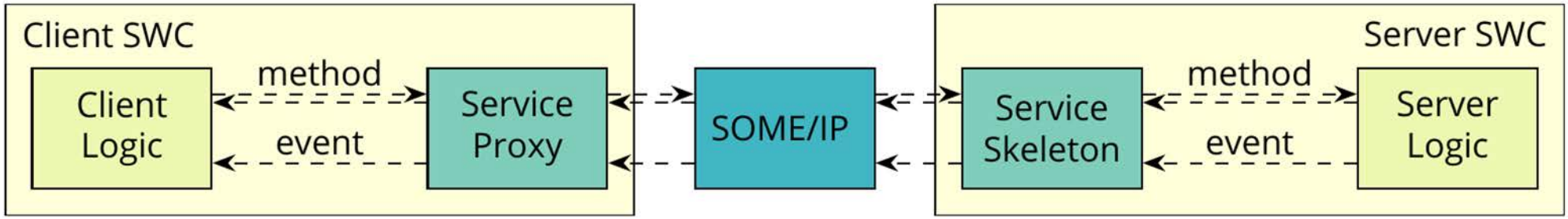
- Service-oriented architecture
  - gRPC, Bond, Thrift, Adaptive AUTOSAR, …
- Shared memory
  - Linda, pSpaces, …

Service-Oriented Architectures

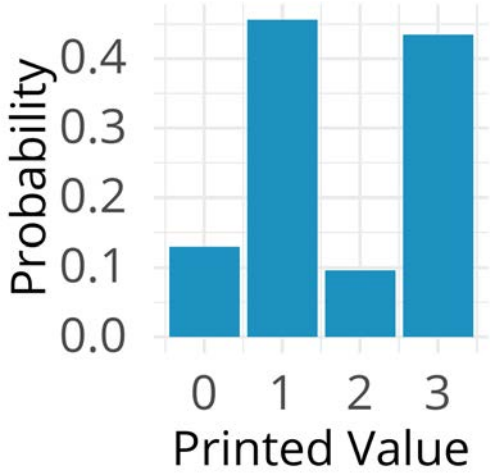
- A **service** is a procedure exposed by a component.
- Components can invoke services on remote components.
- Caller may wait for results (**synchronous**) or retrieve results later (**future**).
- Service invocations are mutually exclusive, but there are no ordering guarantees.

Nondeterminism in SoA



Client Code

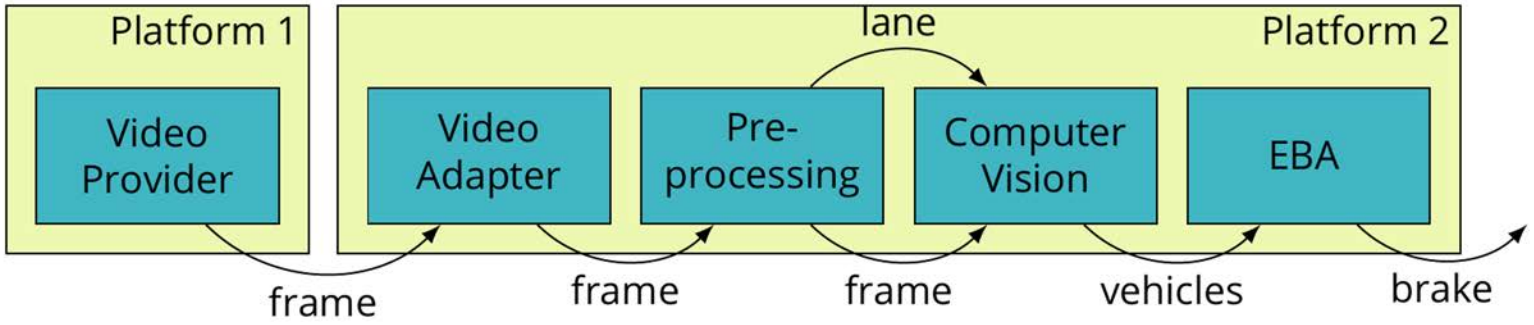
```
1  int main() {
2    s = ServiceProxy();
3
4    s.set_value(1);
5    s.add(2);
6    result = s.get_value();
7
8    std::cout << result.get();
9    return 0;
10 }
```

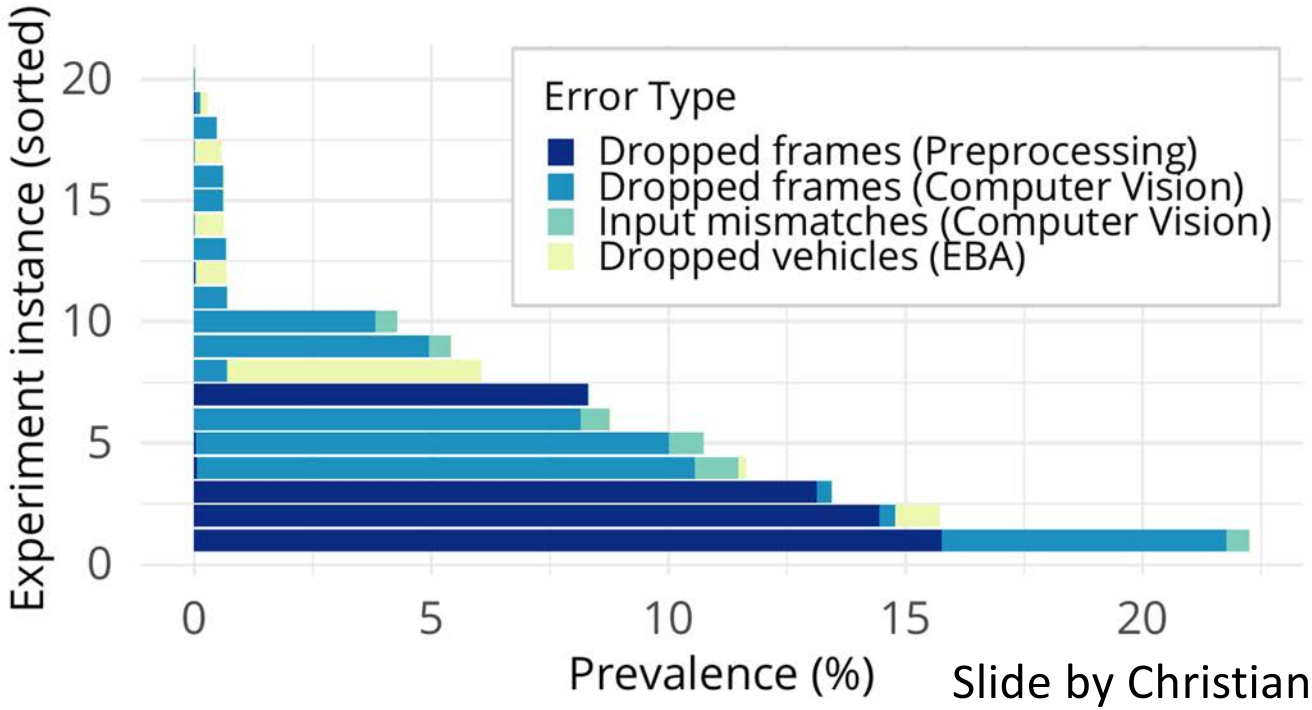


Invocation order on services is not constrained.

Thanks to Christian Menard.

Emergency Brake Assist





Slide by Christian Menard.

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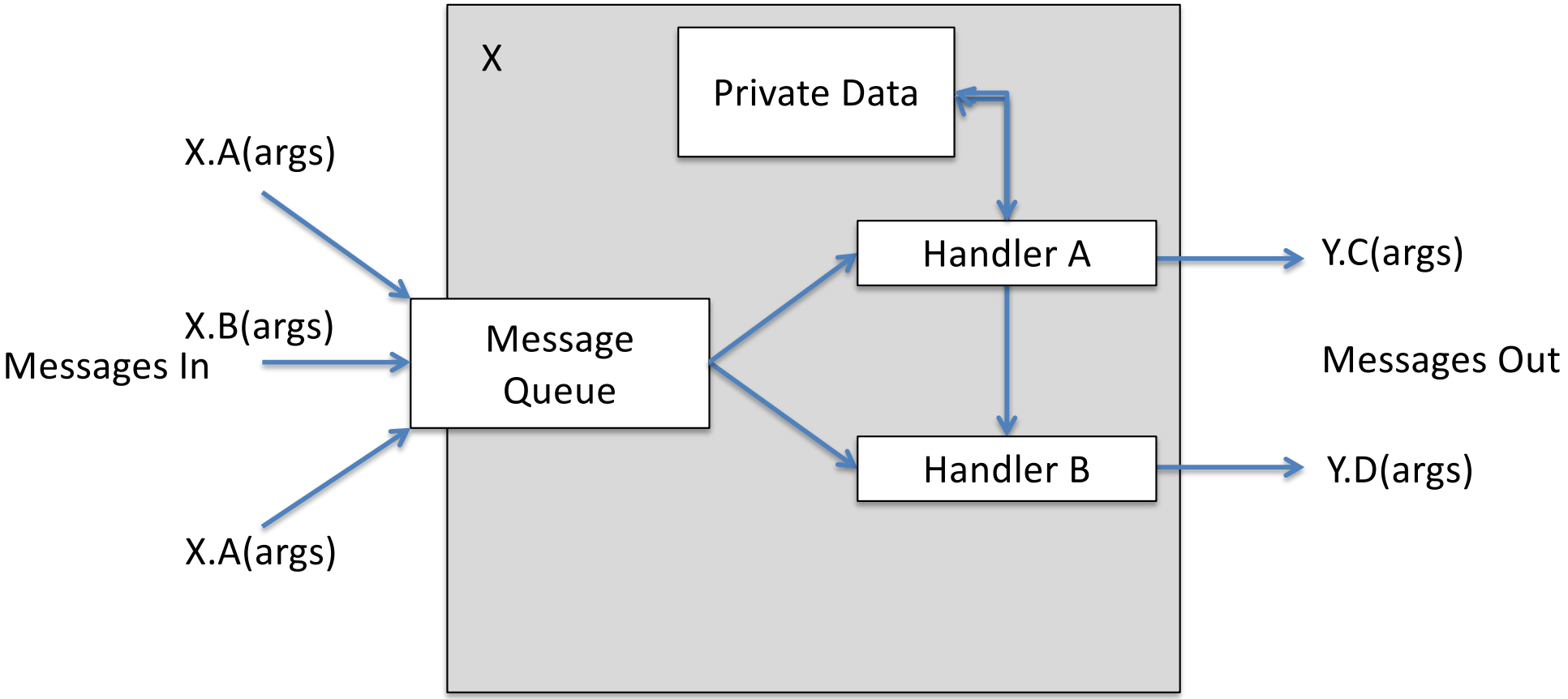
Actors, Loosely

Actors are concurrent objects that communicate by sending each other messages.

Hewitt/Agha Actors

Data + Message Handlers



[Hewitt, 1977] [Agha, 1986, 1990, 1997]

Example

An actor with simple operations on its state:

```
Actor Foo {
   int state = 1;
   handler dbl(){
      state *= 2;
   }
   handler inc(arg){
      state += arg;
      print state;
   }
}
```

Example

An actor that uses actor Foo:

```
Actor Bar {
   handler main(){
      Foo x = new Foo();
      x.dbl();
      x.inc(1);
   }
}
```

Semantics is “send and forget.”

Composition

```
Actor Bar {
   handler main(){
      Foo x = new Foo();
      x.dbl();
      x.inc(1);
   }
}
```

```
Actor Foo {
   int state = 1;
   handler dbl(){
      state *= 2;
   }
   handler inc(arg){
      state += arg;
      print state;
   }
}
```

What is printed?

Pass-Through Actor

Baz: Given an actor of type Foo, send it “double”:

```
Actor Baz {
   handler pass(Foo x){
      x.dbl();
   }
}
```

New Composition

```
Actor Bar {
    handler main(){
        Foo x = new Foo();
        Baz z = new Baz();
        z.pass(x);
        x.inc(1);
    }
}
```

```
Actor Baz {
    handler pass(Foo x){
        x.dbl();
    }
}
```

What is printed?

```
Actor Foo {
    int state = 1;
    handler dbl(){
        state *= 2;
    }
    handler inc(arg){
        state += arg;
        print state;
    }
}
```

Aircraft Door Using Actors

```
Actor Source {
    handler main(){
        x = new Door();
        x.disarm_door();
        x.open_door();
    }
}
```

What assumptions are needed for it to be safe for the open_door handler to open the door?

```
Actor Door {
    handler open_door(){
        …
    }
    handler disarm_door(){
        …
    }
}
```

Aircraft Door Using Actors

```
Actor Source {
    handler main(){
        x = new Door();
        r = new Relay();
        r.check();
        x.open_door();
    }
}
```

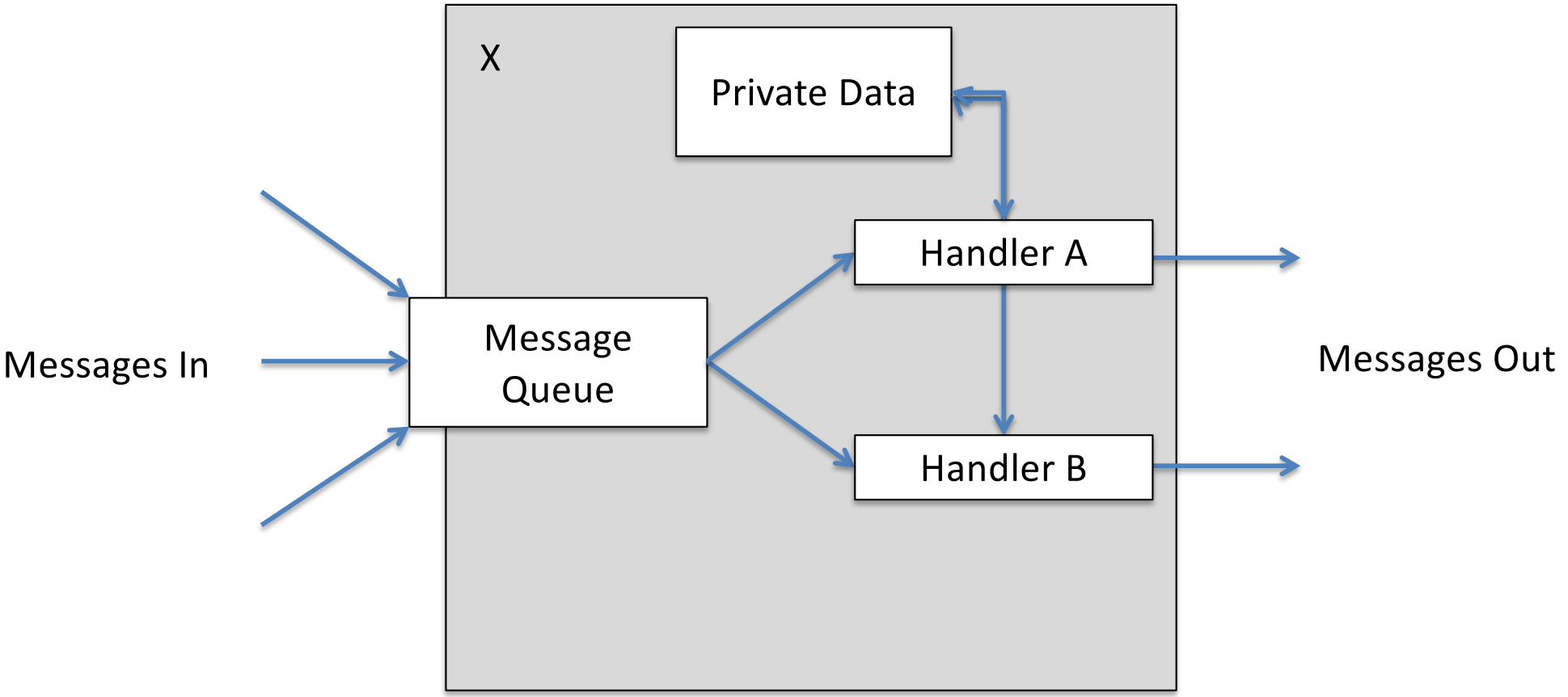
```
Actor Relay {
    handler check(Door x){
        x.disarm_door();
    }
}
```

Now what assumptions are needed for it to be safe for the open_door handler to open the door?

```
Actor Door {
    handler open_door(){
        …
    }
    handler disarm_door(){
        …
    }
}
```

Hewitt/Agha Actors are Not Predictable

Messages are handled in nondeterministic order.



One Solution: Analyze and Use Dependencies

```
Actor Source {
    handler main(){
        x = new Door();
        r = new Relay();
        r.check();
        x.open_door();
    }
}
```

```
Actor Relay {
    handler check(Door x){
        x.disarm_door();
    }
}
```

```
Actor Door {
    handler open_door(){
        …
    }
    handler disarm_door(){
        …
    }
}
```

But how? Where is the dependence graph?

One Solution: Analyze and Use Dependencies

```
Actor Source {
    handler main(){
        x = new Door();
        r = new Relay();
        r.check();
        x.open_door();
    }
}
```

```
Actor Relay {
    handler check(Door x){
        if (something) {
            x.disarm_door();
        }
    }
}
```

```
Actor Door {
    handler open_door(){
        …
    }
    handler disarm_door(){
        …
    }
}
```

And what if the dependence graph is data dependent?

Return to simple, concrete example

```
Actor Bar {
    handler main(){
        Foo x = new Foo();
        Baz z = new Baz();
        z.pass(x);
        x.inc(1);
    }
}
```

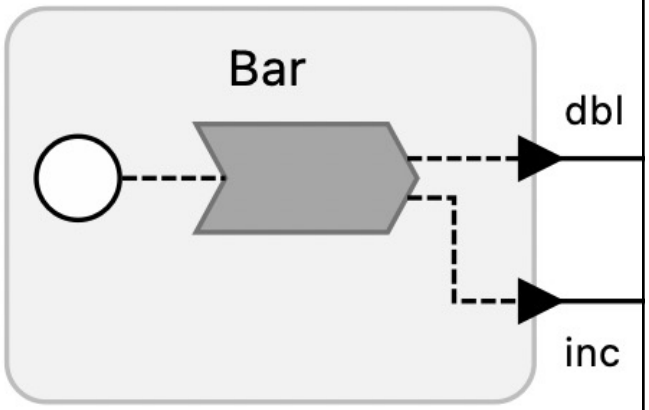
```
Actor Baz {
    handler pass(Foo x){
        x.dbl();
    }
}
```

How to achieve deterministic behavior?

```
Actor Foo {
    int state = 1;
    handler dbl(){
        state *= 2;
    }
    handler inc(arg){
        state += arg;
        print state;
    }
}
```

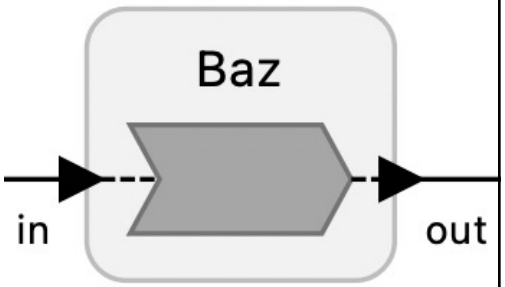
Part 1 of our Solution: Ports

```
reactor Bar {
    output dbl:bool;
    output inc:int;
    reaction(startup) -> dbl, inc {=
        lf_set(dbl, true);
        lf_set(inc, 1);
    =}
}
```



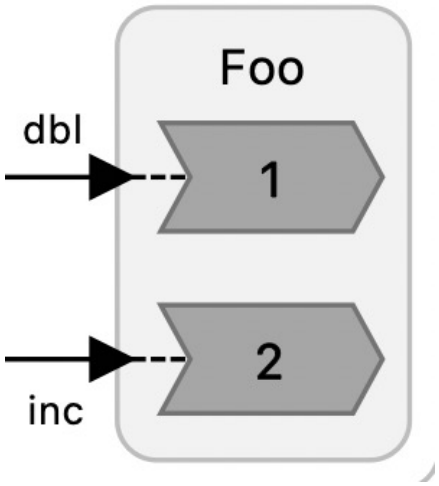
Instead of referring to other actors, an actor refers only to its own ports (and ports of contained reactors).

```
reactor Baz {
    input in:bool;
    output out:bool;
    reaction(in) -> out {=
        lf_set(out, in);
    =}
}
```



Part 1 of our Solution: Ports

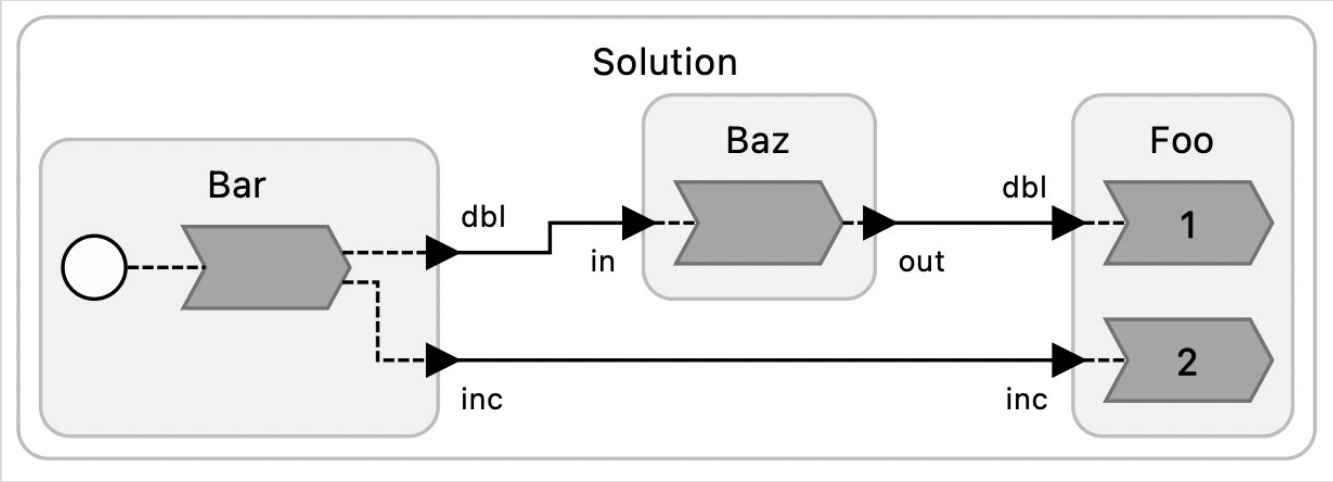
Input ports look like the message handlers of actors.




```
reactor Foo {
    input dbl:bool;
    input inc:int;
    state s:int(1);
    reaction(dbl) {=
        self->s *= 2;
    =}
    reaction(inc) {=
        self->s += inc.value;
    =}
}
```

Part 2 of our Solution: Hierarchy

```
main reactor {
    b = new Bar();
    r = new Baz();
    f = new Foo();
    b.dbl -> r.in;
    r.out -> f.dbl;
    b.inc -> f.inc;
}
```

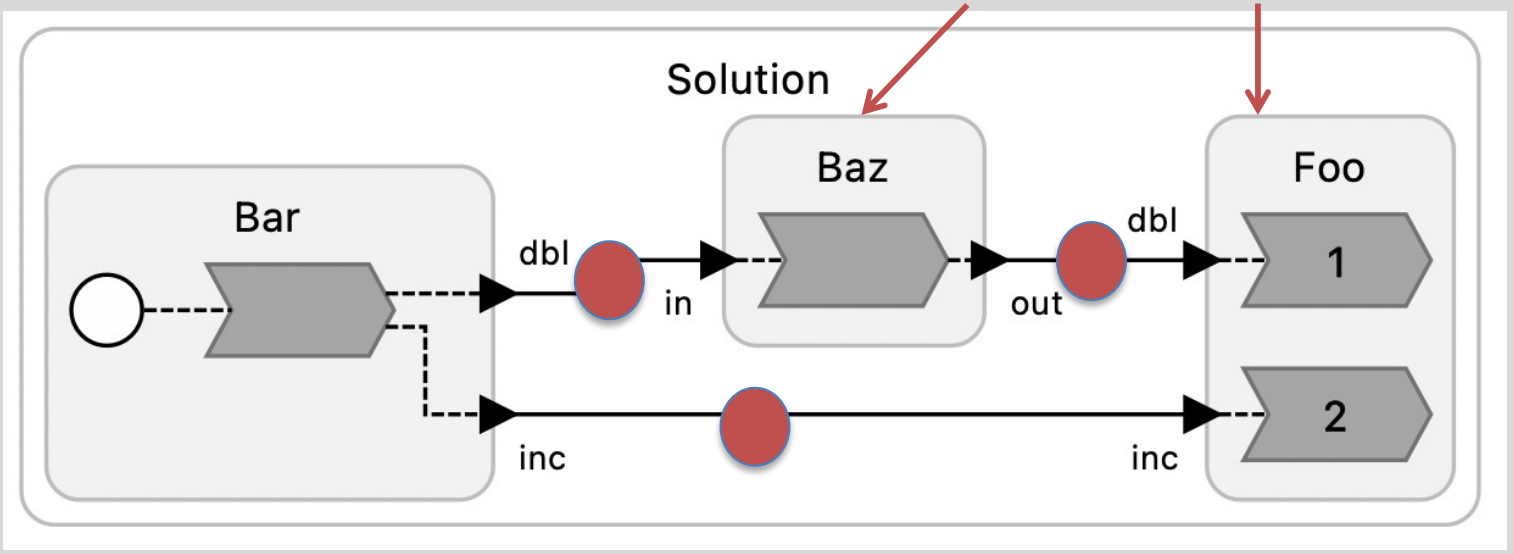


Part 3 of our Solution: Scheduling

```
main reactor Top {
    x = new Foo();
    y = new Bar();
    z = new Baz();
    y.double -> z.in;
    y.increment -> x.increment;
    z.out -> x.double;
}
```

Scheduling becomes especially interesting when production or consumption of messages is data dependent.

Ensure that Baz completes before Foo's handlers are invoked.



The Lingua Franca Team

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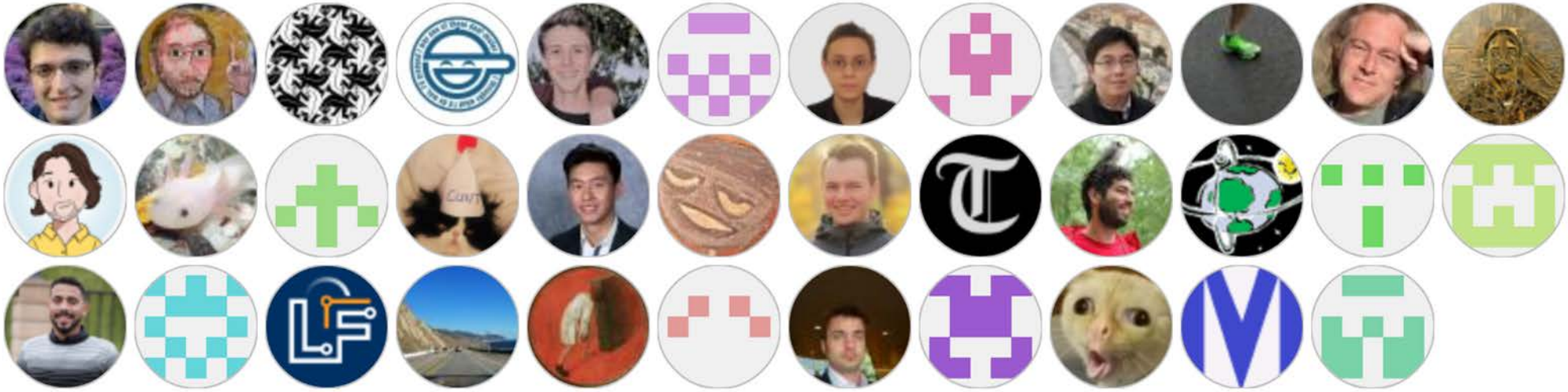

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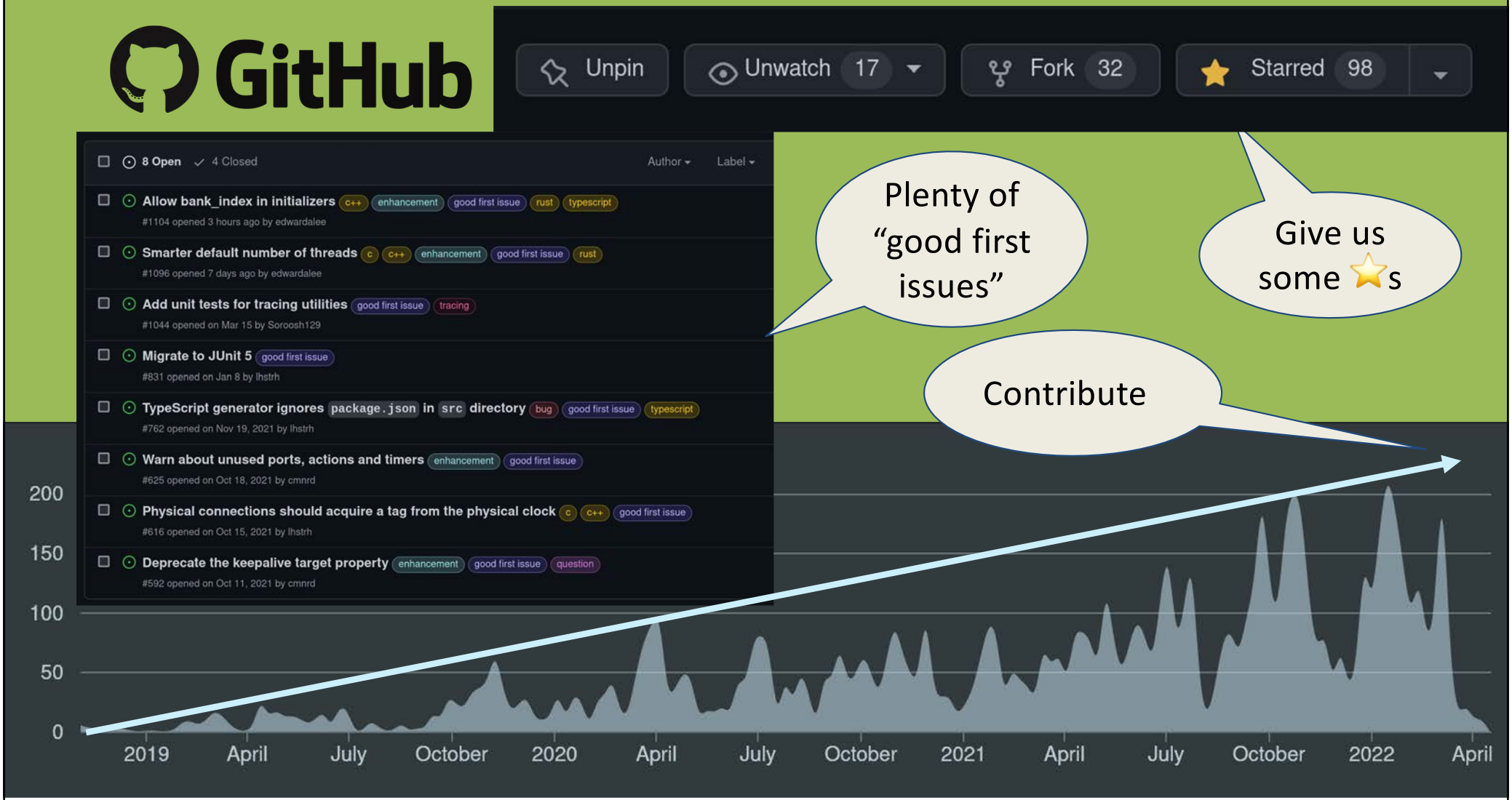
Active, Ongoing Project

https://repo.lf-lang.org



Slack Workspace

I have created a Slack workspace called:

lf-community

You should have gotten an invitation to join it.

Please use it for discussions, questions, and problems with Lingua Franca.

Conclusion

- Pub-Sub, SoA, and Actors are all problematic.
- The problems are solvable (Lingua Franca).