Specification and analysis of communication protocols

Emilio Tuosto @ GSSI

20-24 April
and
4-7 May, 2026
Dipartimento di Informatica, Pisa

Logistics

Logistics

- Click or scan  for the web page; timetable

April 2026	May 2026
20 : 14.00-16.00	4 : 14.00-16.00
21 : 16.00-18.00	5 : 16.00-18.00
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- Choreographic models
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- Adding join patterns to actors
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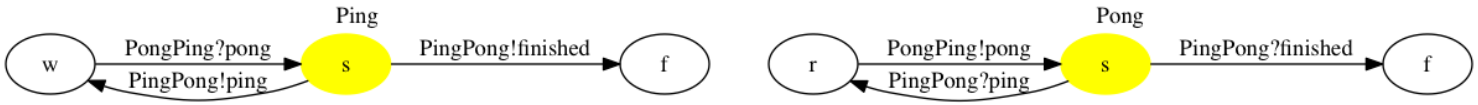

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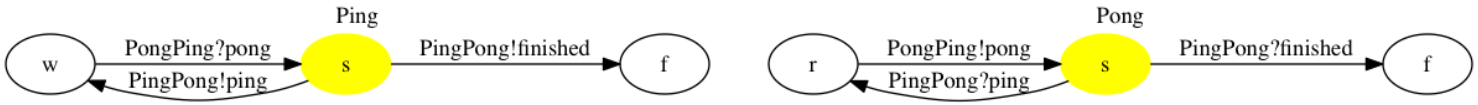

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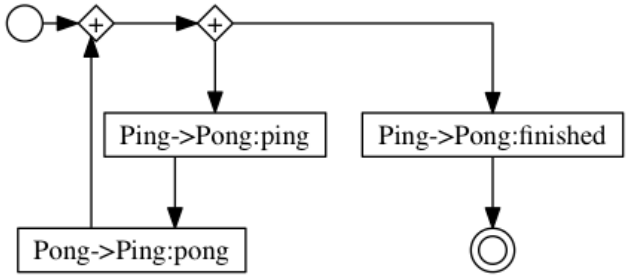

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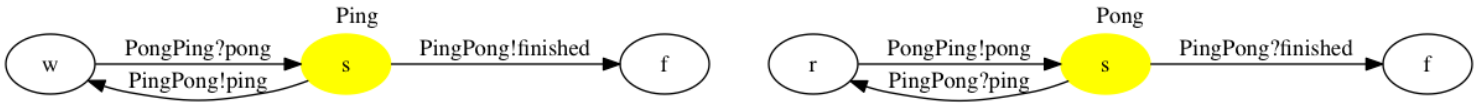

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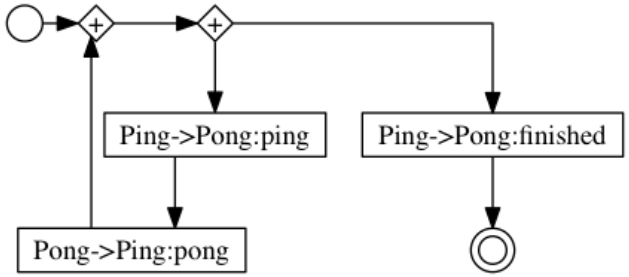

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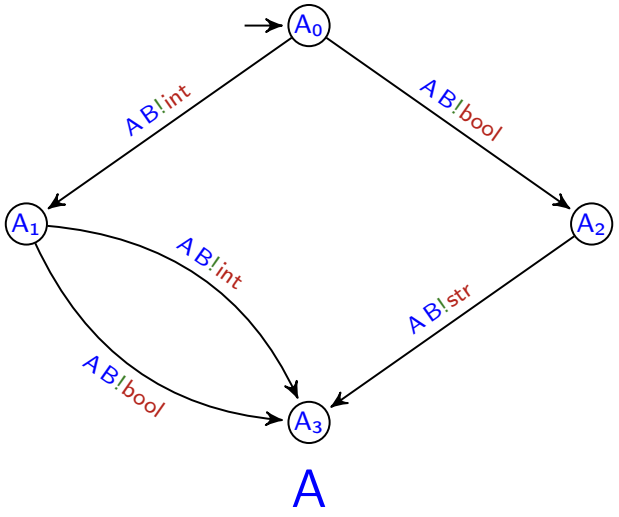
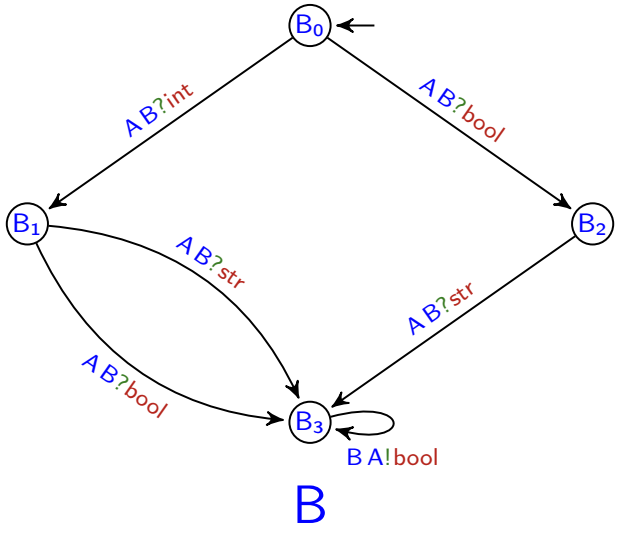
Research direction

How do we extract such models from code or documentation?

Our first formal model...informally

Communicating systems





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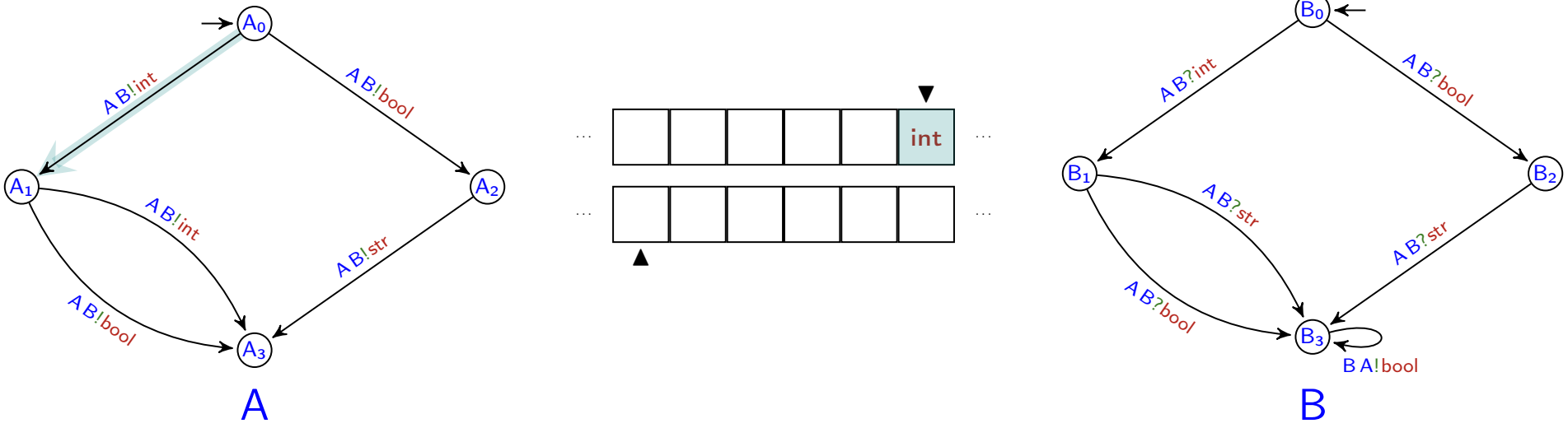

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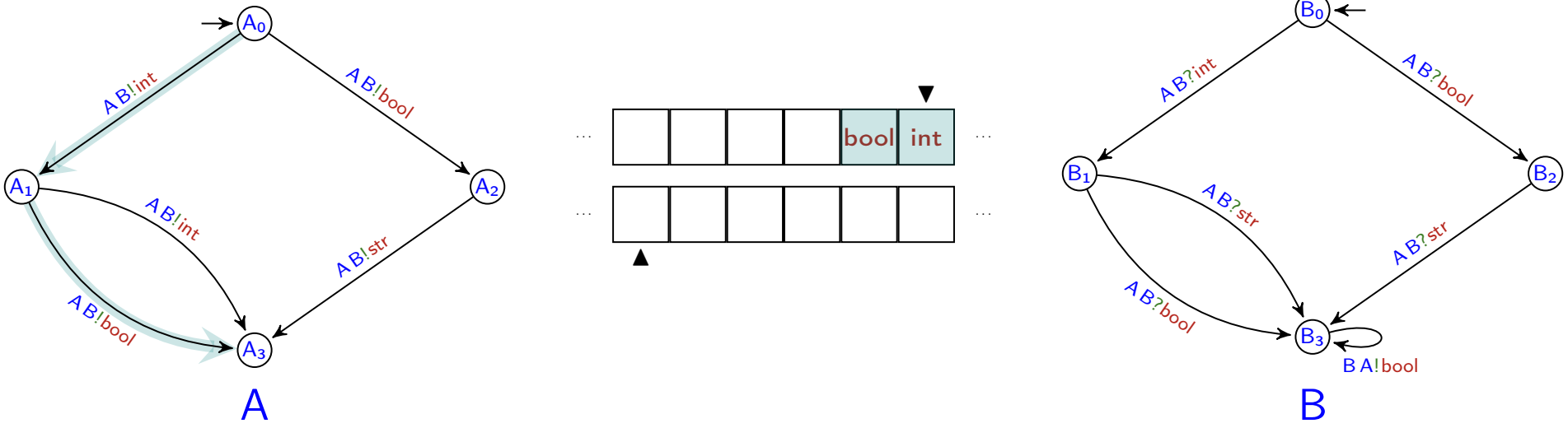

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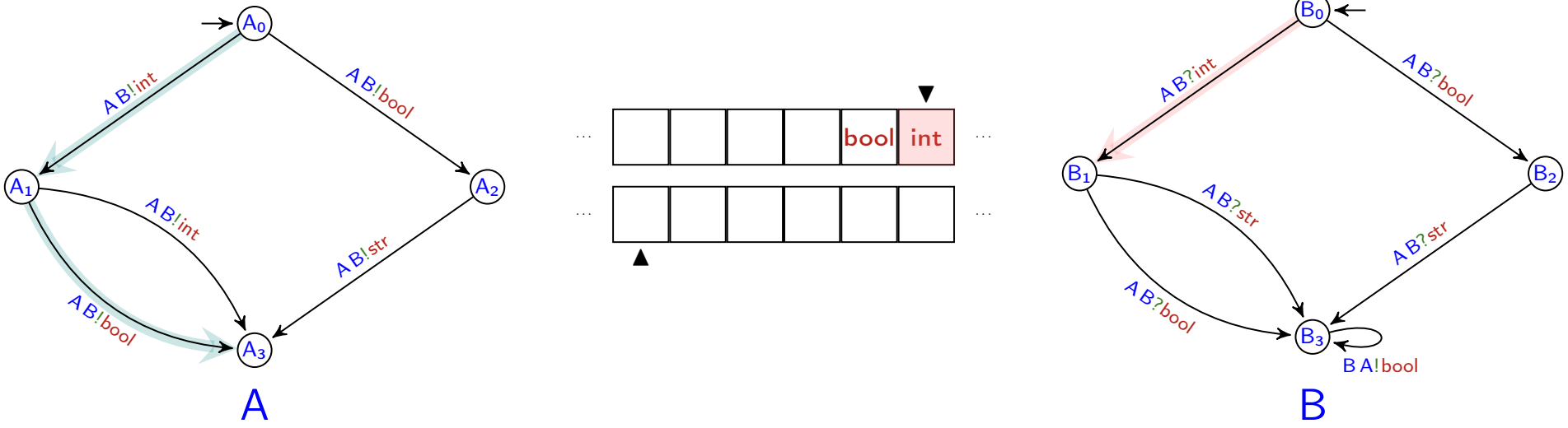

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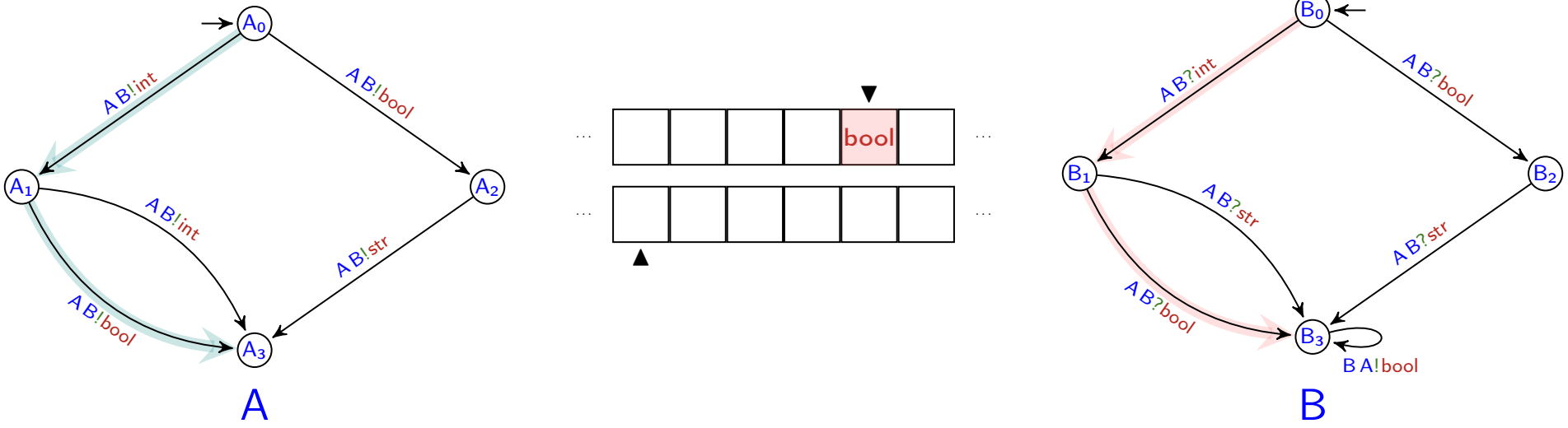

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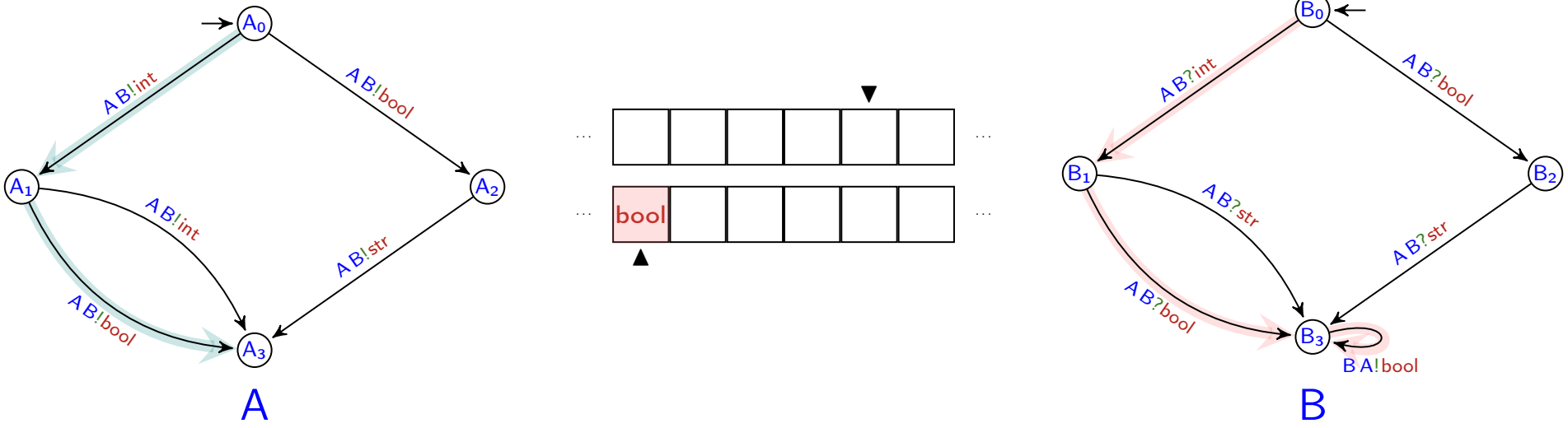

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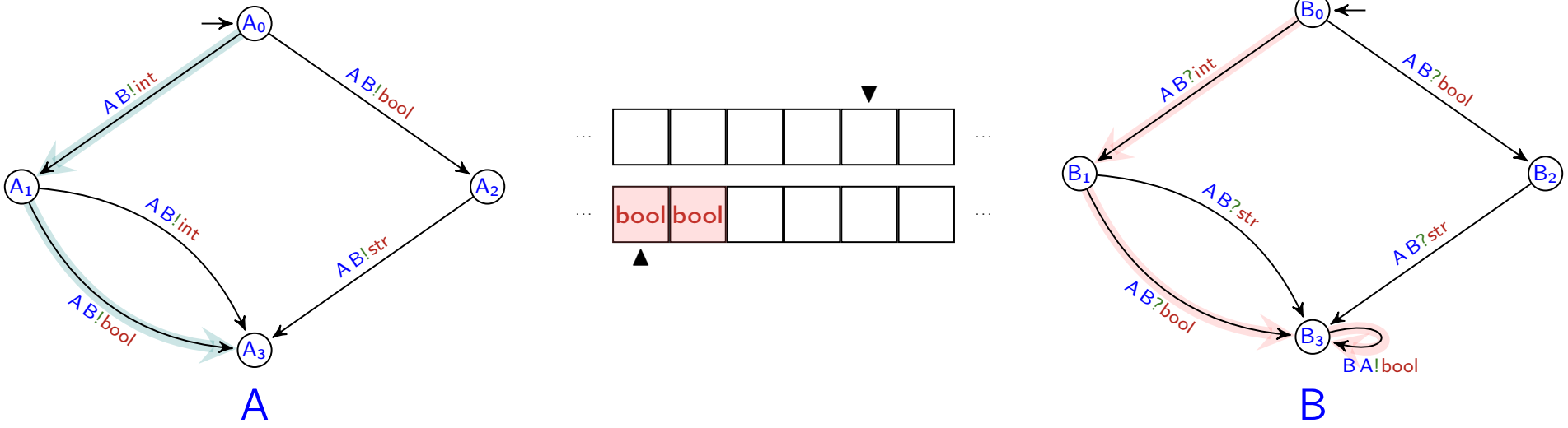

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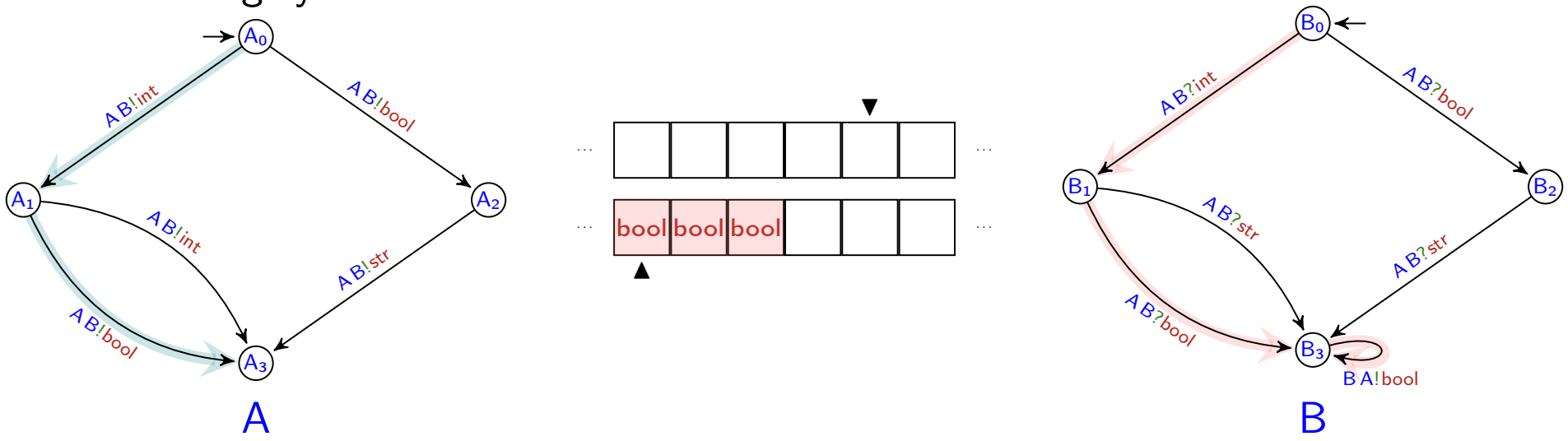

- a communicating finite-state machine (CFSM) is an FSA whose transitions are input/output actions executed by a single participant and whose states are all accepting
- a communicating system is a finite map assigning to a participant A a CFSM executing communications of A

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Exercise:

Find the bugs (there're at least 2!)

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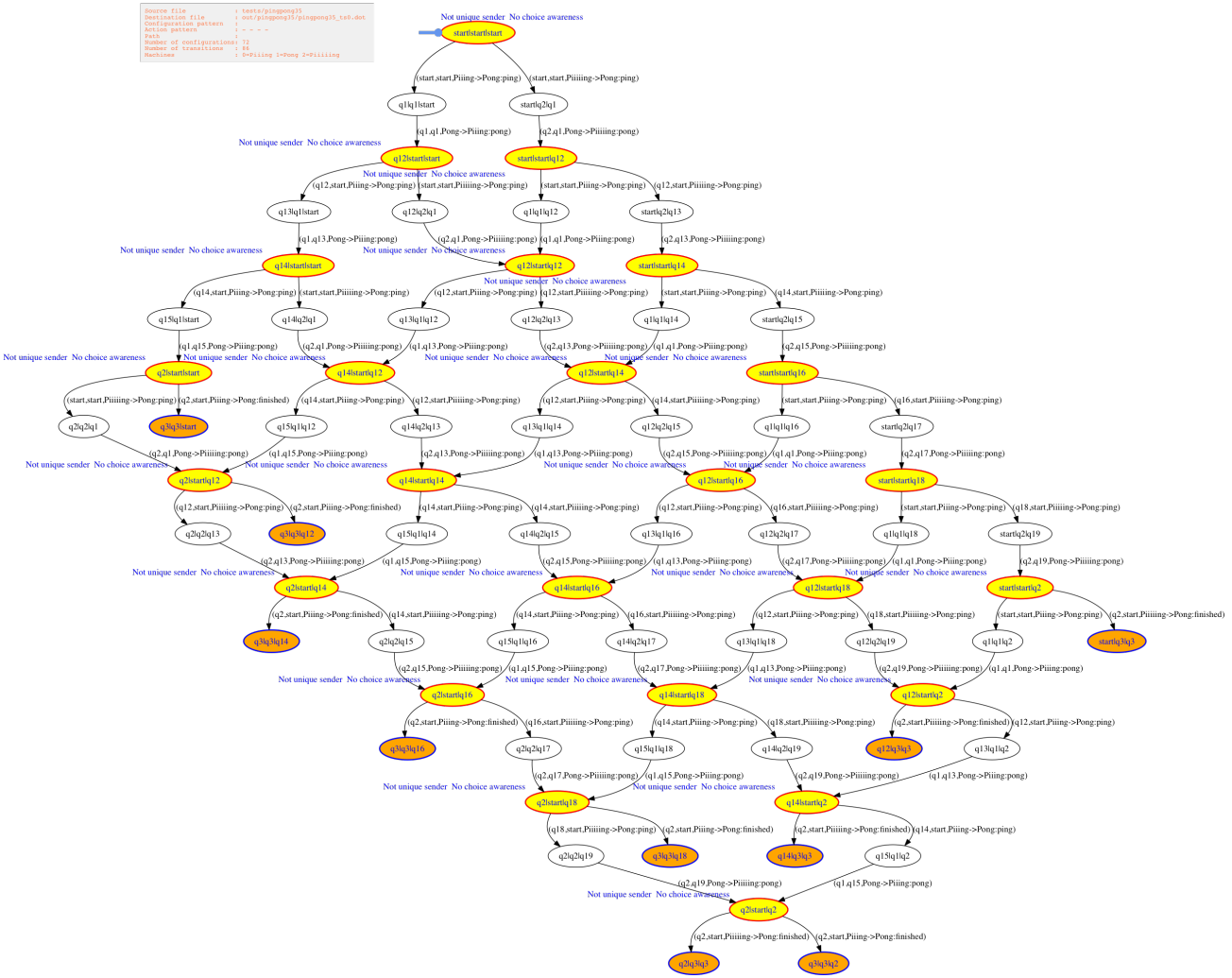

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```
Source file              : tests/pingpong35
Destination file         : out/pingpong35/pingpong35_ts0.dot
Configuration pattern    :
Action pattern           : - - - -
Path                     :
Number of configurations: 72
Number of transitions    : 86
Machines                 : 0=Piiing 1=Pong 2=Piiiiing
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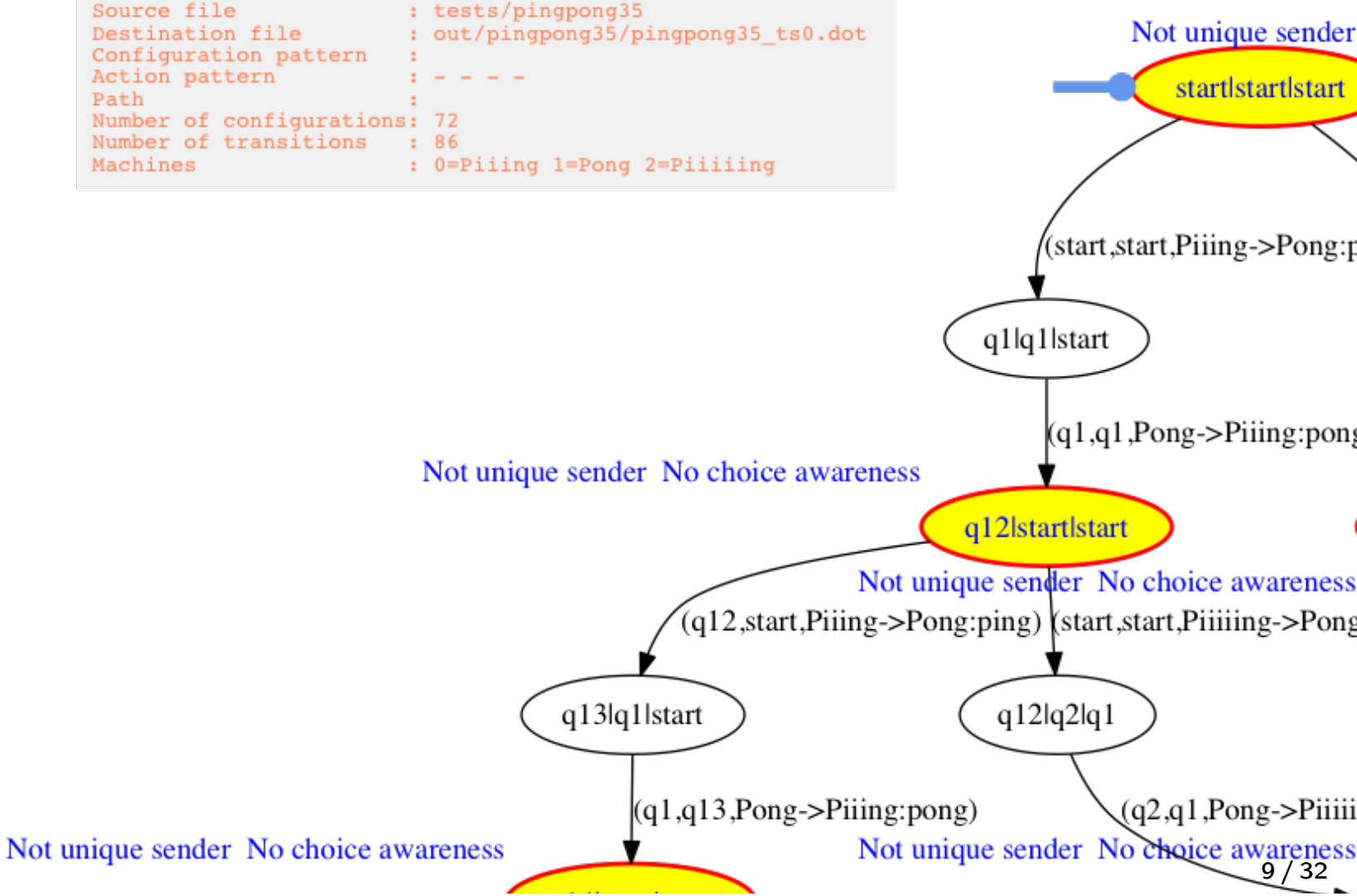

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  - code is formal!
  - the other addends should be formal too!

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Fundamental limitations

Distributed consensus

Distributed sharing
Security & coordination
Computer-assisted collaborative work
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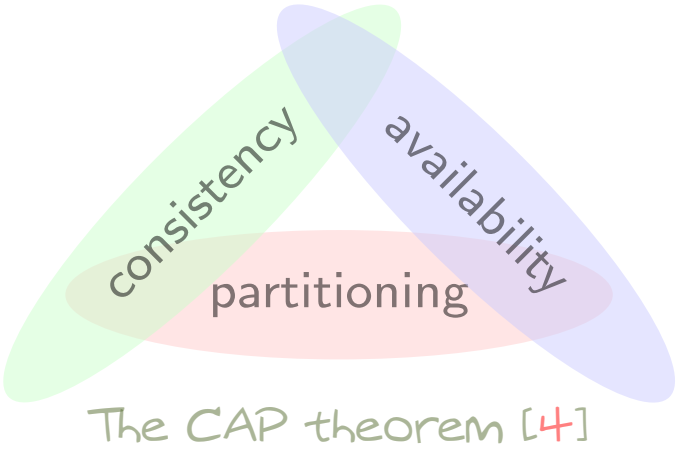
Fundamental limitations



The CAP theorem [4]

Distributed consensus

Distributed sharing
Security & coordination
Computer-assisted collaborative work
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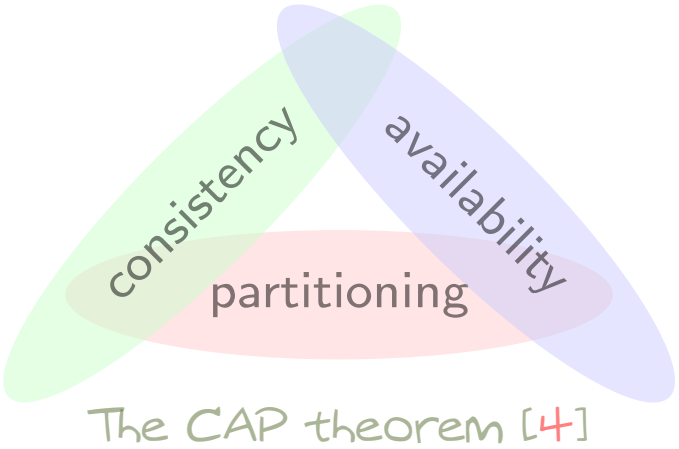
With some "solutions"

- Centralisation points (not that appealing)

Fundamental limitations



The CAP theorem [4]

Distributed consensus

Distributed sharing
Security & coordination
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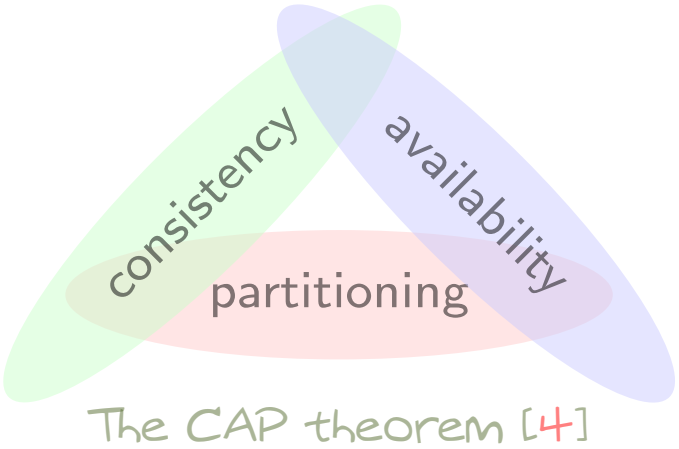

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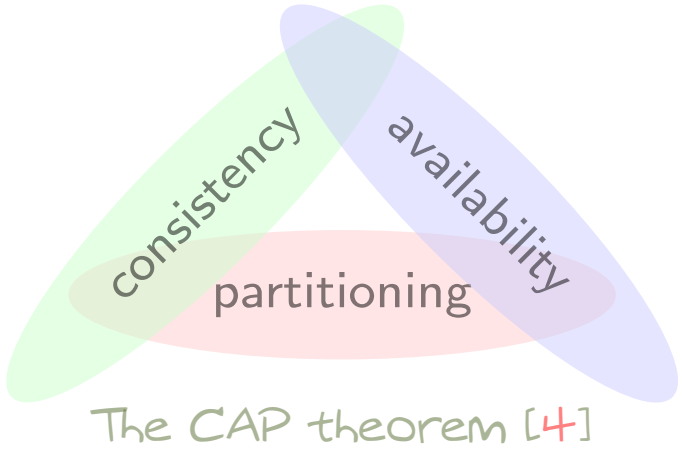

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Main design principles / programming styles for the coordination of distributed components:

- orchestration
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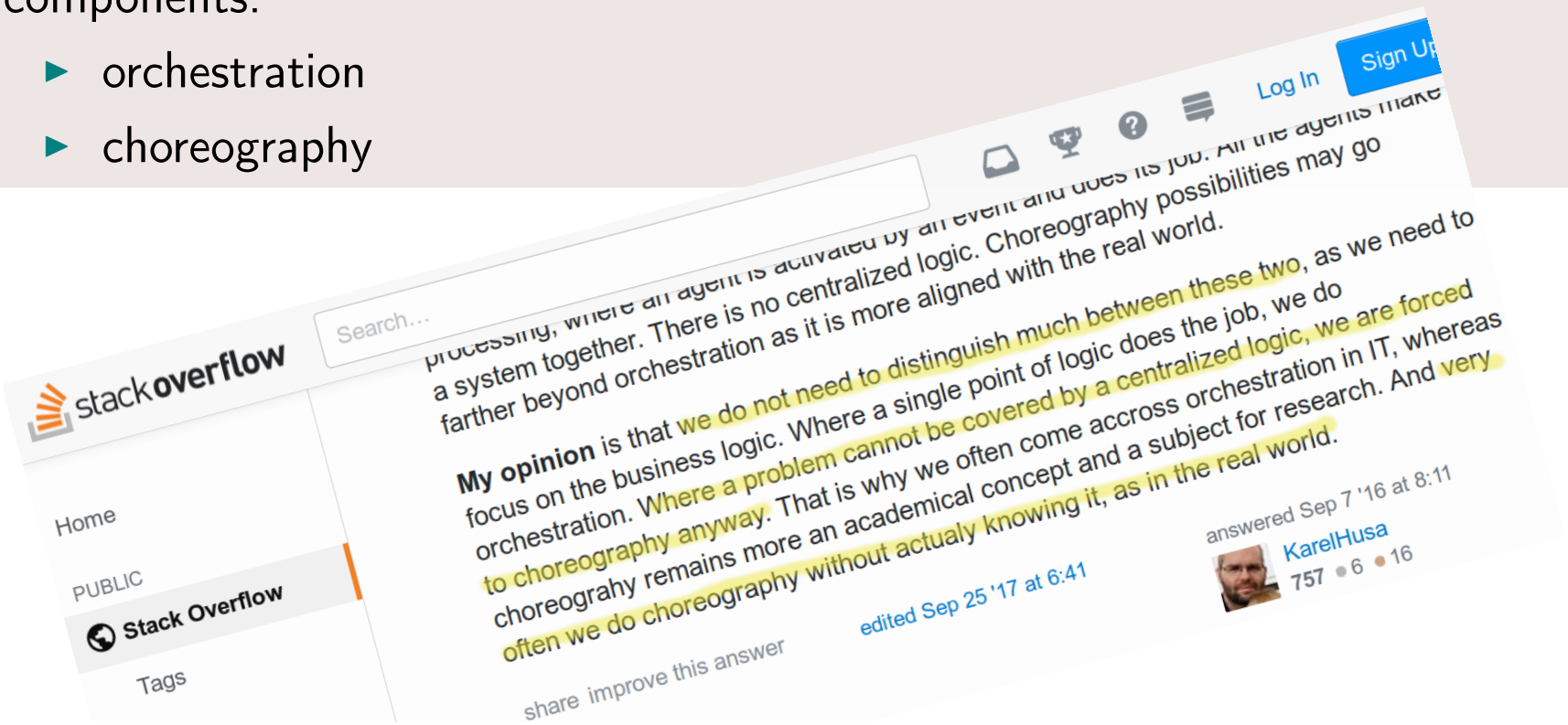

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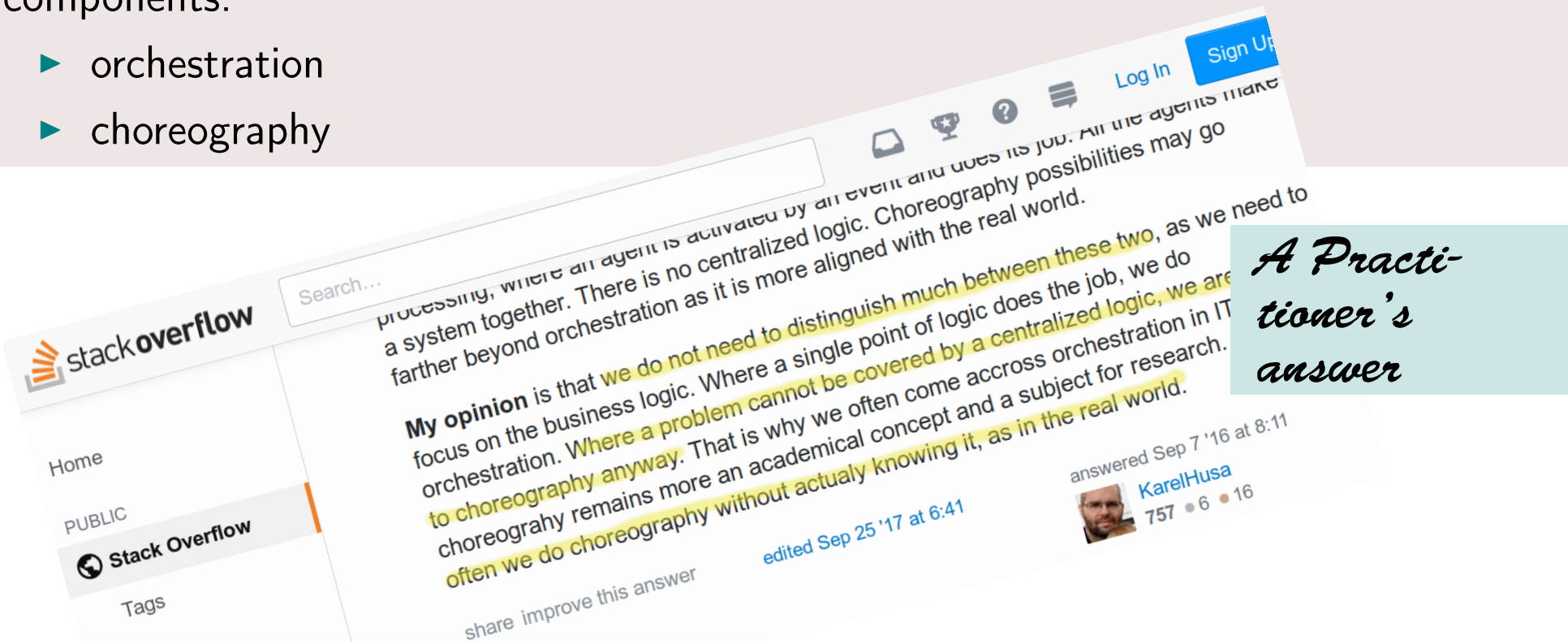


A Practitioner's answer

A rich research context

Many open problems

- Compositionality / Modularity
- Specs of Self-⋆ systems
- Data-driven systems
- Fault-tolerance
- Security
- ...

Many research teams

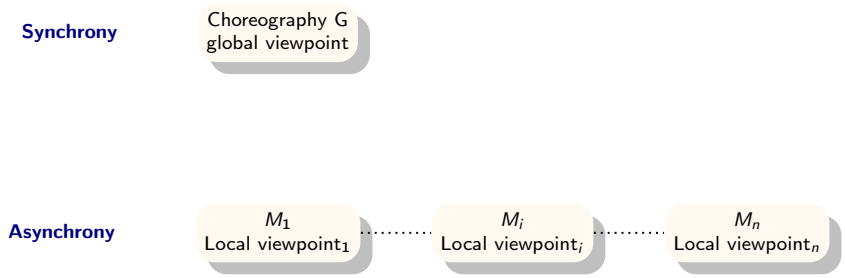
- Denmark
- Italy
- Germany
- Serbia
- Portugal
- Argentina
- Japan
- UK (including Scotland ☺)
- USA

– A first choreographic model –

"Top-down"

Quoting W3C [8]

"Using the Web Services Choreography specification, a contract containing a global definition of the common ordering conditions and constraints under which messages are exchanged, is produced that describes, from a global viewpoint [...] observable behaviour of all the parties involved. Each party can then use the global definition to build and test solutions that conform to it. The global specification is in turn realised by combination of the resulting local systems [...]"



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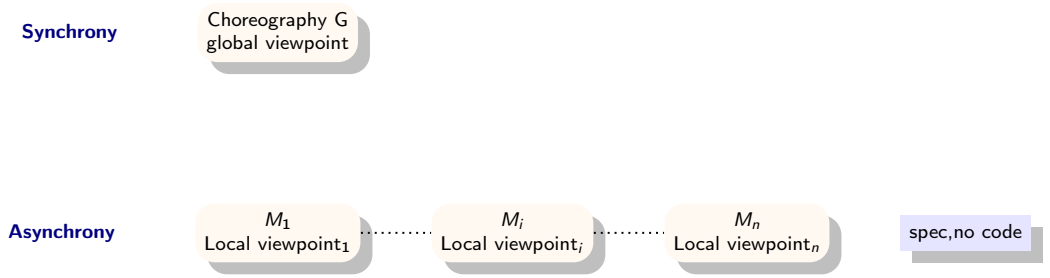

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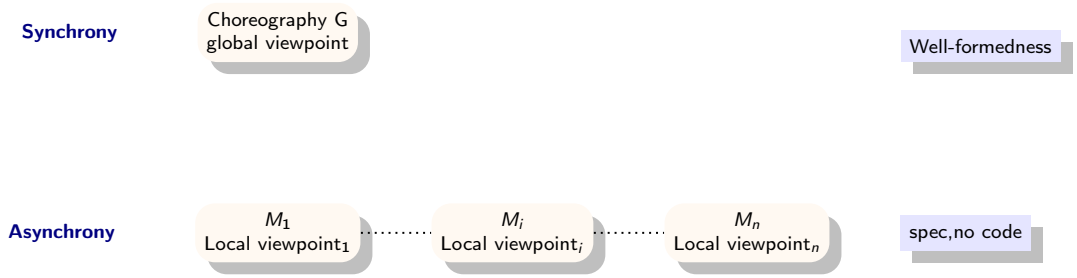

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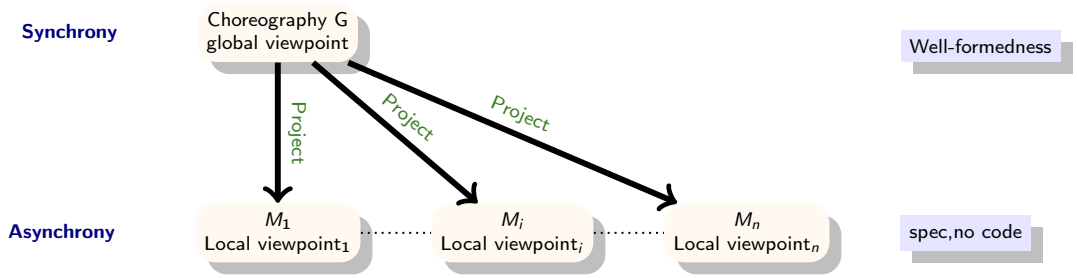

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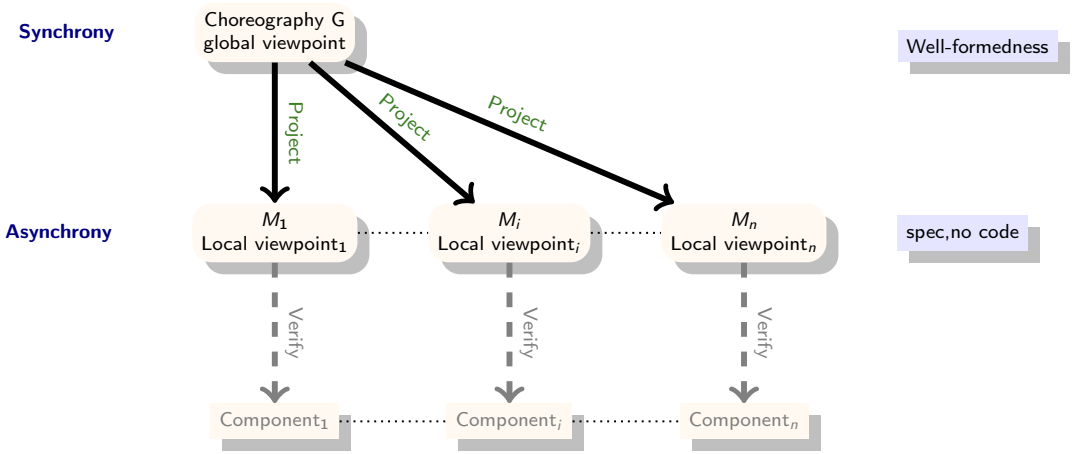
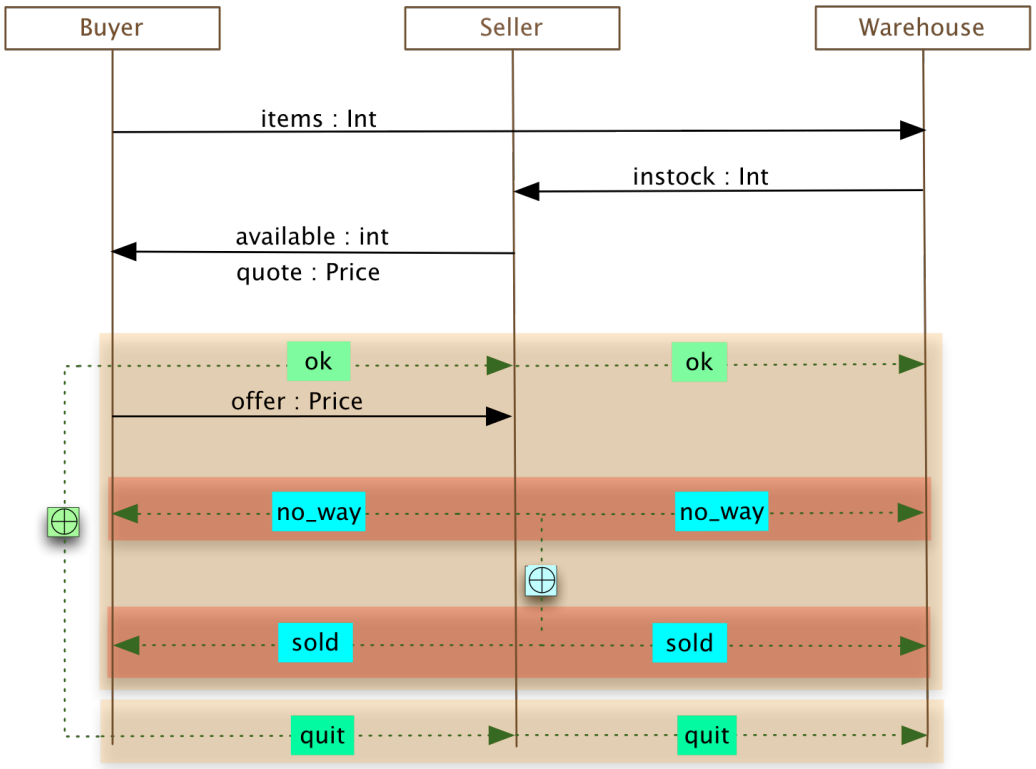
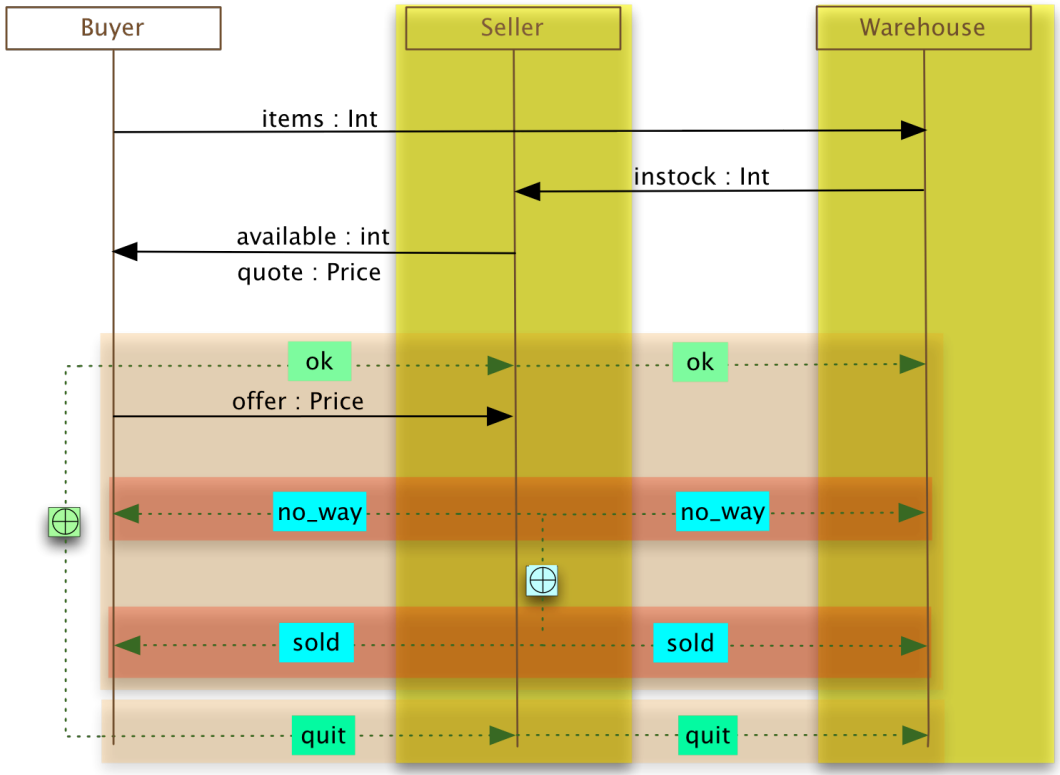


An intuitive account...



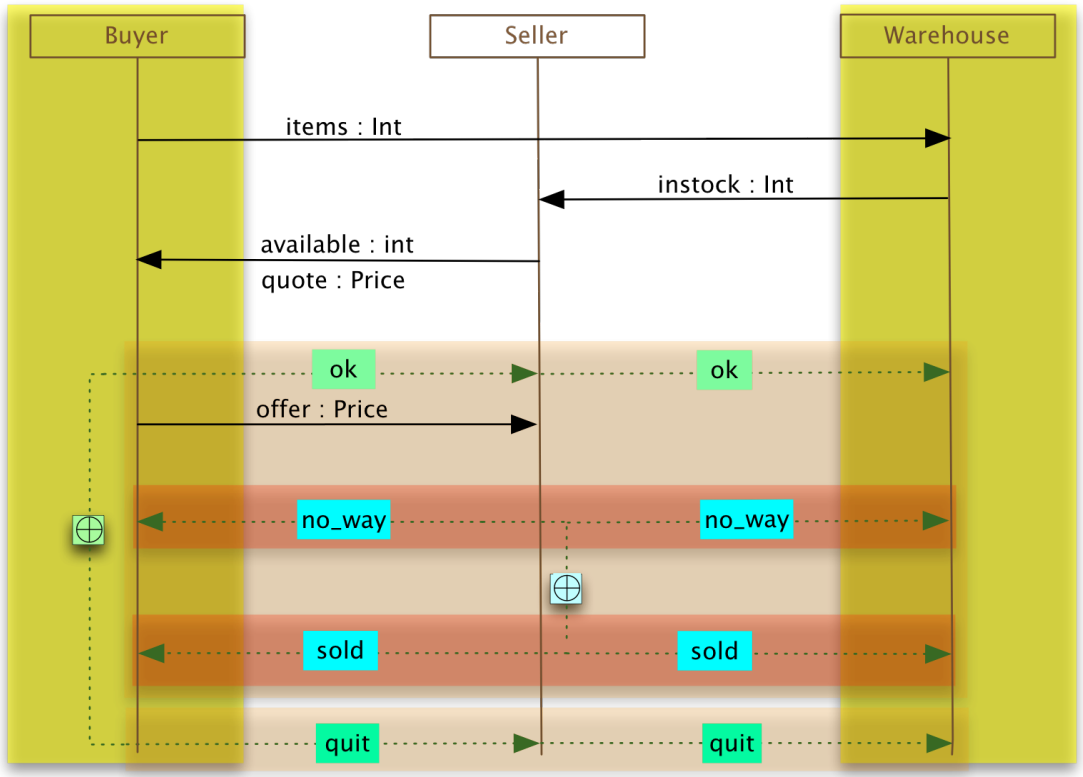
Global viewpoint

An intuitive account...



Projecting on buyer

An intuitive account...



Projecting on seller

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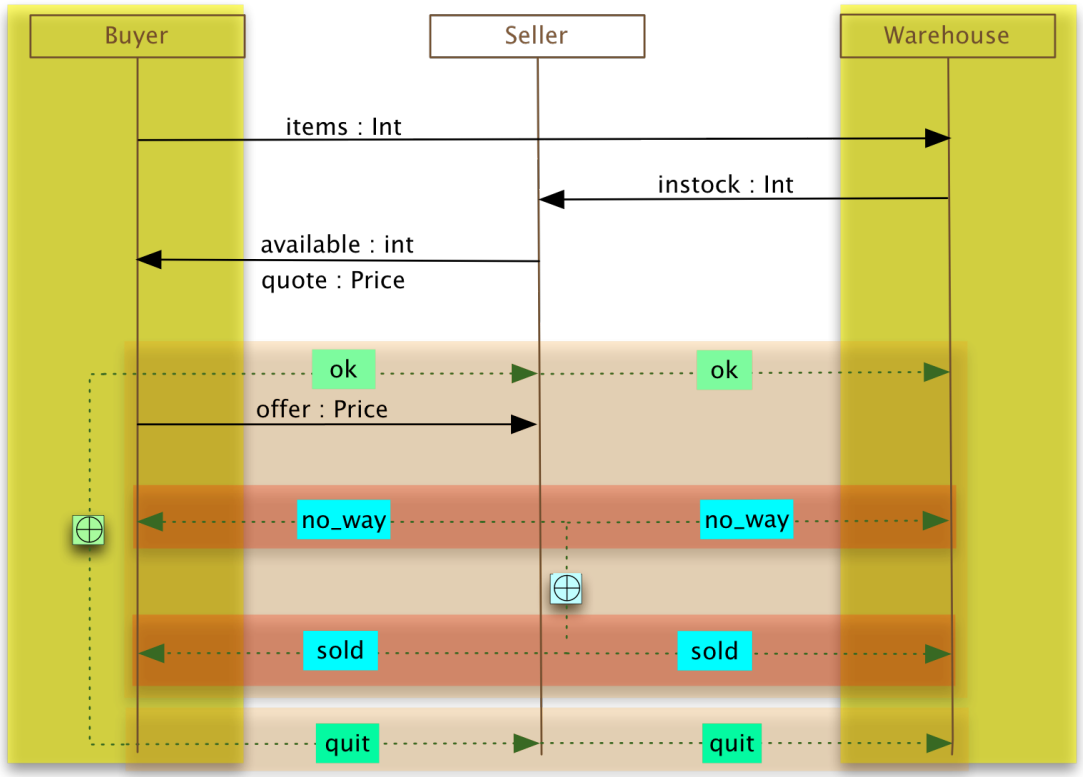

Life is harder...recall the bugs of pingpong

Projecting on seller

Global views...a bit more formally

G-choreographies [10, 6]

$$\mathsf{G}, \mathsf{G}' \ ::= \ \circledcirc \ \mid \ \mathsf{A} \to \mathsf{B} : \mathsf{m} \ \mid \ \mathsf{G} \mid \mathsf{G}' \ \mid \ \mathsf{G}; \mathsf{G}' \ \mid \ \mathsf{G} + \mathsf{G}' \ \mid \ *\mathsf{G}$$

i.e., regular expressions (on an alphabet of interactions) with parallel composition

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G-choreographies [10, 6]

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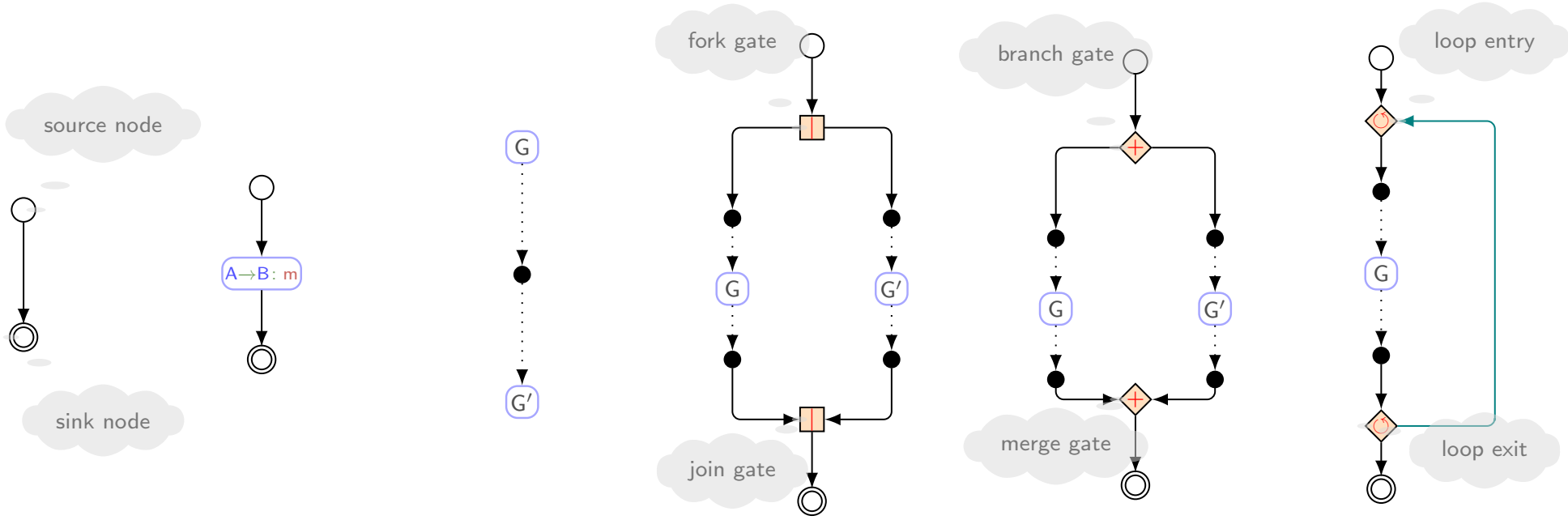

empty | interaction | sequential | parallel | branch | iteration

Global views' semantics as pomsets

A **pomset** on a set $\mathcal{E}$ of **events** is (an isomorphism class of) a **labelled partially-order** $(\mathcal{E}, \lambda, \leq)$, with

- $\lambda : \mathcal{E} \to \mathcal{L}$ a labelling function
- $\leq \quad \subseteq \quad \mathcal{E} \times \mathcal{E}$ reflexive, anti-symmetric, transitive

Our basic ingredients:

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Our basic ingredients:

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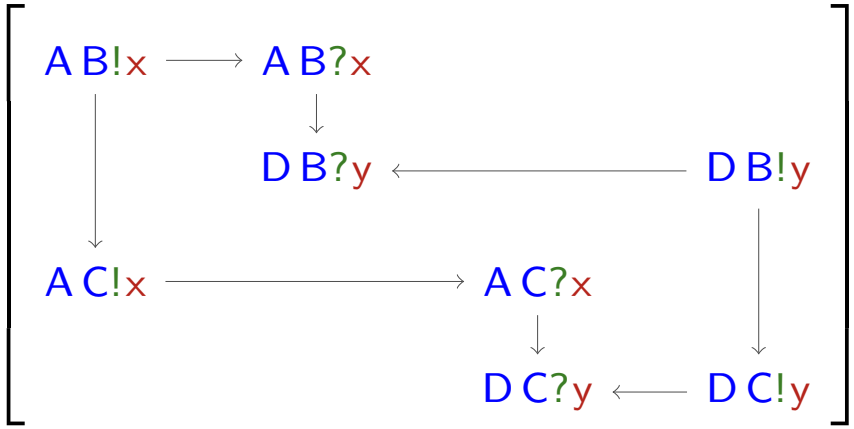
- a set $\mathcal{P}$ of **participants' identities**,
- a set $\mathcal{C} = \mathcal{P} \times \mathcal{P} \setminus \{(\mathsf{A}, \mathsf{A}) \mid \mathsf{A} \in \mathcal{P}\}$ of **channels**

Communication events: $\mathcal{E} = \mathcal{E}^! \cup \mathcal{E}^?$ where

$$\mathcal{E}^! = \mathcal{C} \times \{!\} \times \mathcal{M}$$
$$\mathcal{E}^? = \mathcal{C} \times \{?\} \times \mathcal{M}$$

A simple pomset of communication events



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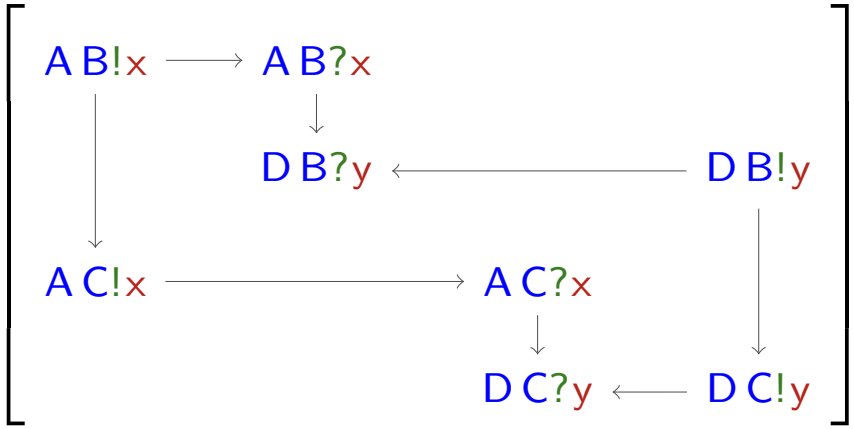

Exercise

Find a g-choreography that corresponds to the pomset on the left.
Another unfair question!

Pomsets semantics of g-choreographies

We define $[\![\ ]\!] : \mathsf{G} \mapsto$ set of pomsets as[1]

$$[\![\circledcirc]\!] = \{\epsilon\}$$

$$[\![\mathsf{A}\to\mathsf{B}:\ \mathsf{m}]\!] = \{[\mathsf{A}\,\mathsf{B}!\mathsf{m} \to \mathsf{A}\,\mathsf{B}?\mathsf{m}]\}$$

$$[\![\mathsf{G} \mid \mathsf{G}']\!] = \{[\text{disjoint union of } r \text{ and } r'] \mid (r, r') \in [\![\mathsf{G}]\!] \times [\![\mathsf{G}']\!]\}$$

$$[\![\mathsf{G}; \mathsf{G}']\!] = \begin{cases} \bigcup_{(r,r')\in[\![\mathsf{G}]\!]\times[\![\mathsf{G}']\!]} \{\mathsf{seq}(r, r')\} & \text{if } \forall (r, r') \in [\![\mathsf{G}]\!] \times [\![\mathsf{G}']\!] : \ ws(r, r') \\ \text{undef} & \text{otherwise} \end{cases}$$

$$[\![\mathsf{G} + \mathsf{G}']\!] = \begin{cases} [\![\mathsf{G}]\!] \cup [\![\mathsf{G}']\!] & \text{if } wb(\mathsf{G}, \mathsf{G}') \\ \text{undef} & \text{otherwise} \end{cases}$$

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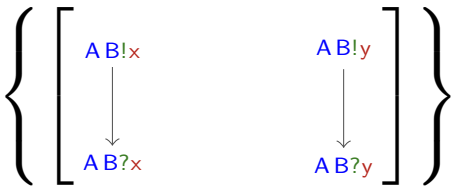
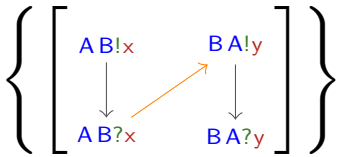
[1] Assuming single-threadness.

Some simple examples

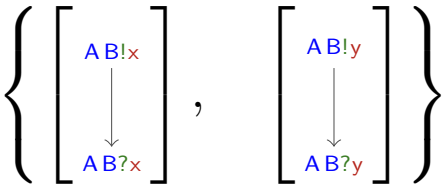
$A \to B : x \mid A \to B : y$



$A \to B : x;\ B \to A : y$



$A \to B : x + A \to B : y$



Exercise

Now you can check your answer to the exercise on slide 20.

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