Synchronisability and Communicating Session Automata

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(Joint work with Benedikt Bollig, Cinzia Di Giusto, Alain Finkel, Laetitia Laversa, Etienne Lozes, and Nobuko Yoshida)

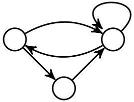
STARDUST Meeting
Glasgow 2023

Communicating Automata

Distributed processes

- each process is a finite state machine

P_i :



Communicating Automata

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- fixed number

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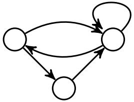

$P_1, \ldots, P_n$

Communicating Automata

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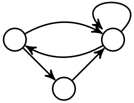
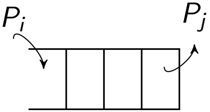


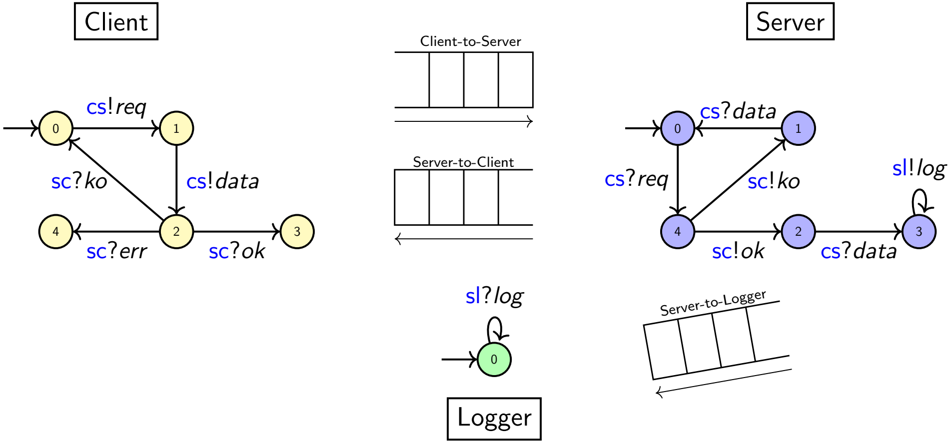
- fixed number

$P_1, \ldots, P_n$

- communicate using queues (perfect, peer-to-peer)



Client-Server-Logger protocol [1]



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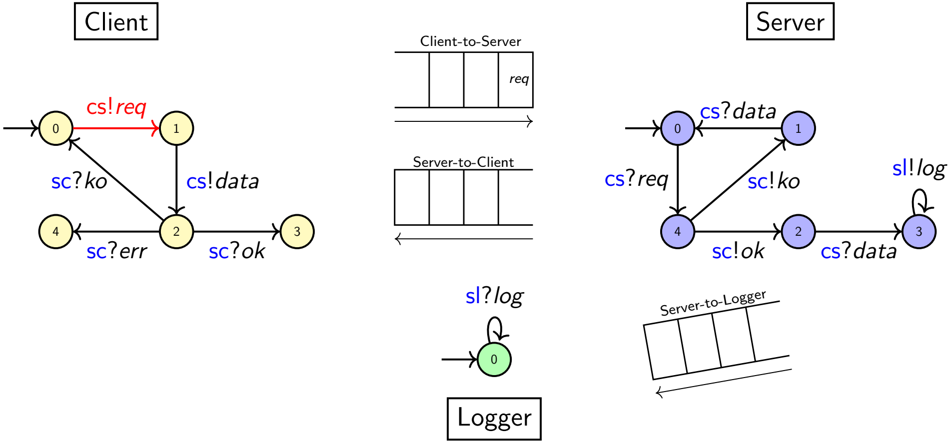

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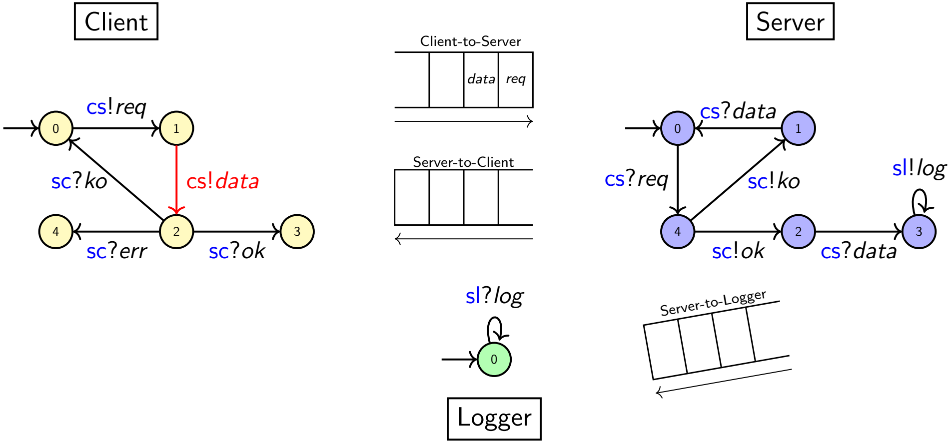

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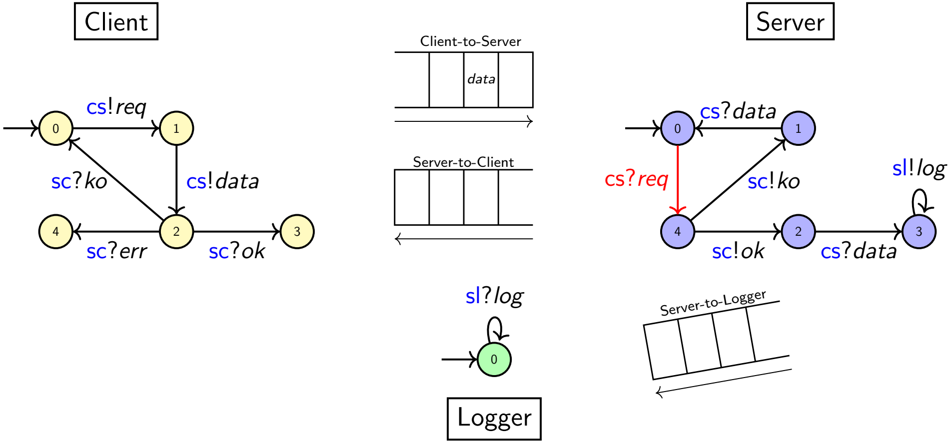

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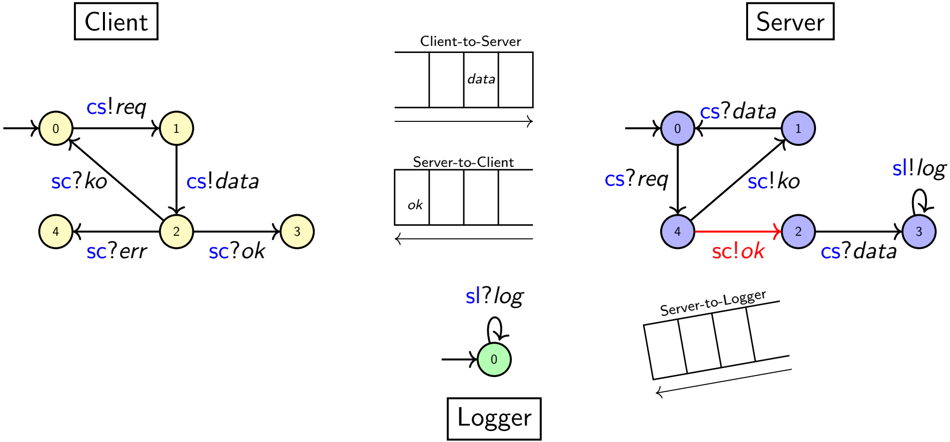

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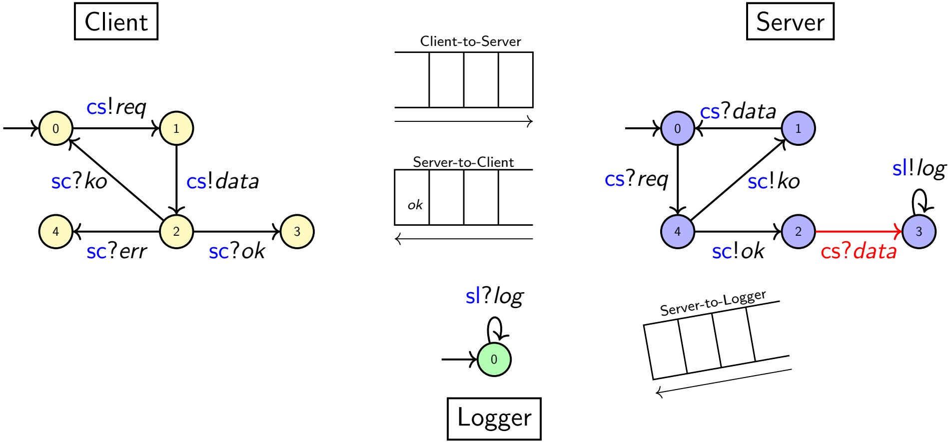

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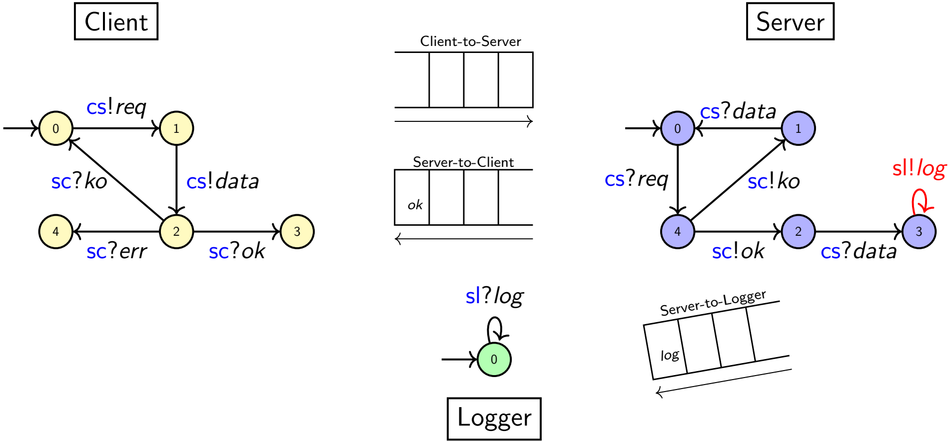

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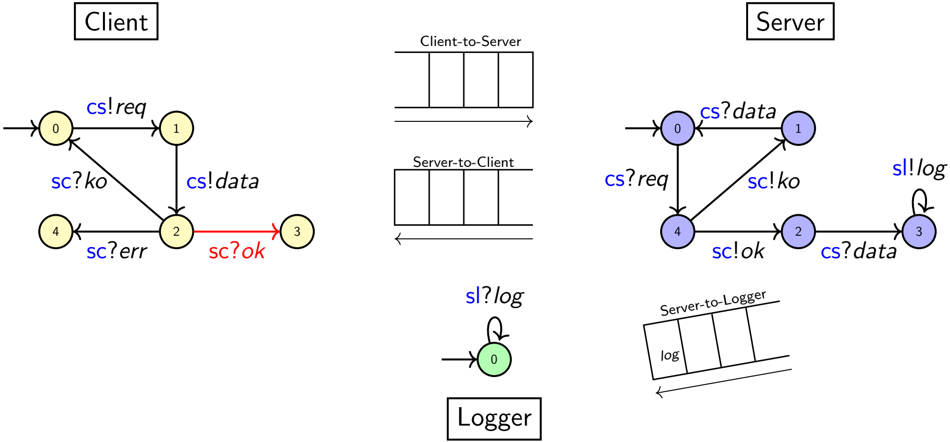

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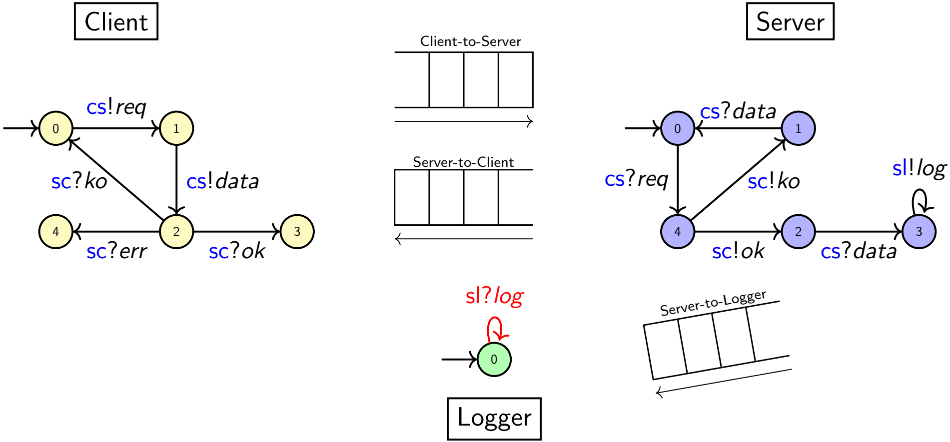

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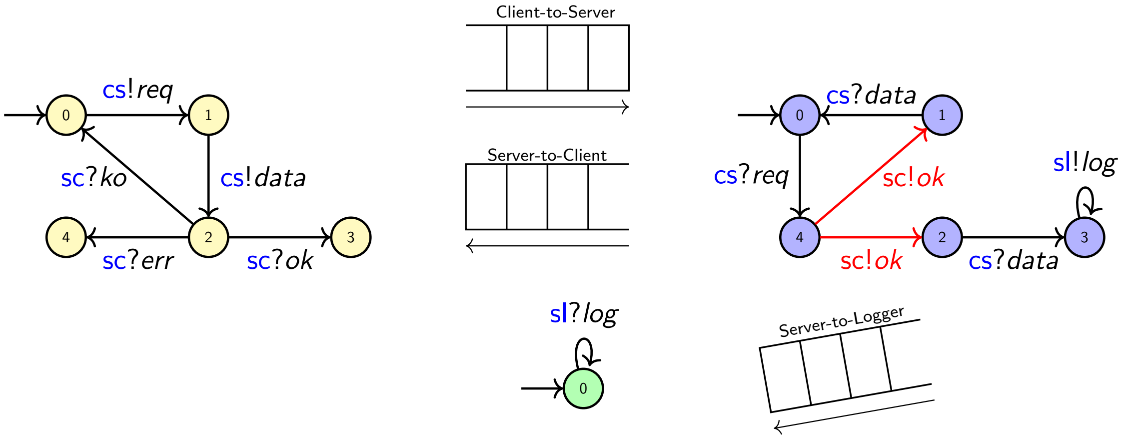
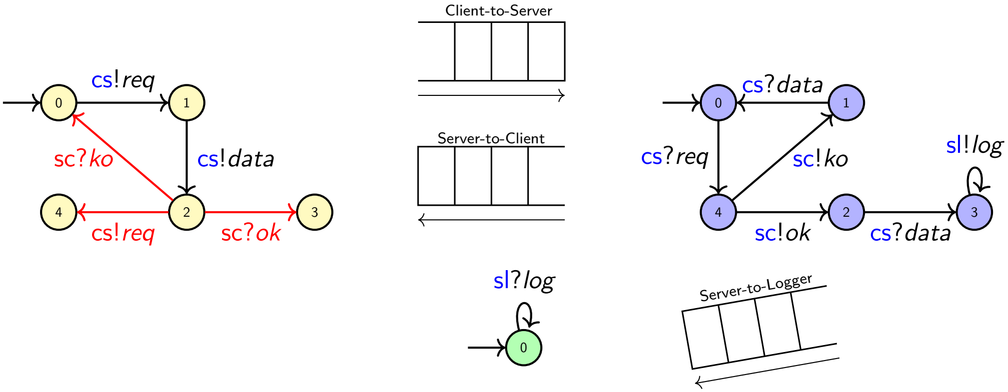
Communicating *Session* Automata

- Deterministic



Communicating *Session* Automata

- Deterministic
- No mixed states



Boundedness

Boundedness Problem

Is there a bound on the size of the queues for all runs?

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UNDECIDABLE for general communicating automata [2]

[2] Brand and Zafiropulo, *On communicating finite-state machines*, 1983

Boundedness

Underapproximations

- Restrict to k-bounded channels.

Boundedness

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Underapproximations

- Restrict to k-bounded channels. Too restricting!
- Every unbounded execution is equivalent to a bounded execution.

Message Sequence Charts

- A graphical way to represent executions

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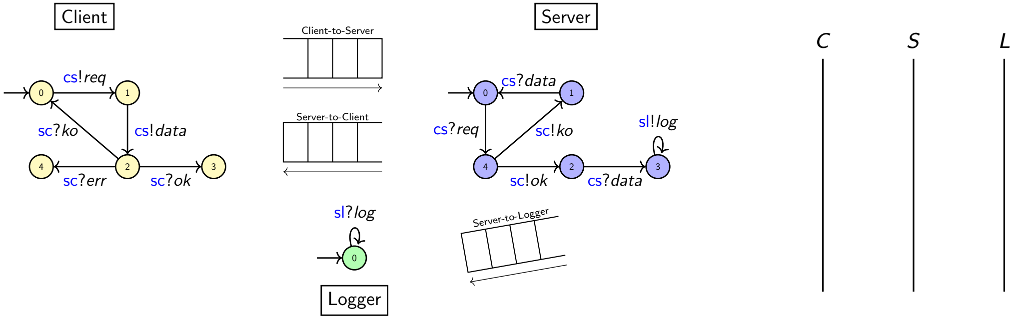

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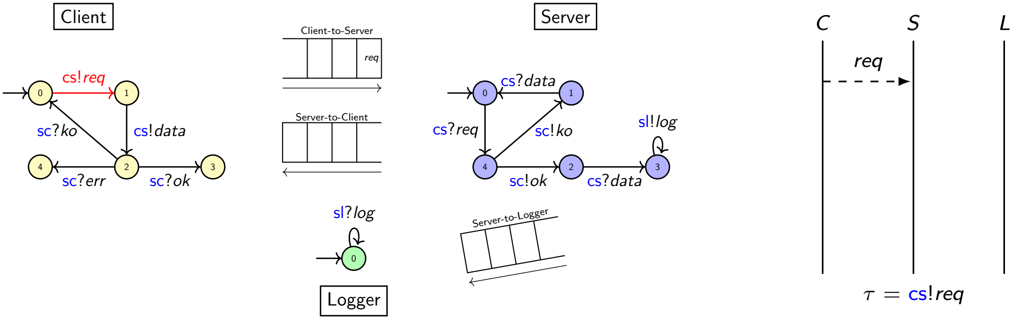

$\tau = \text{cs}!req$

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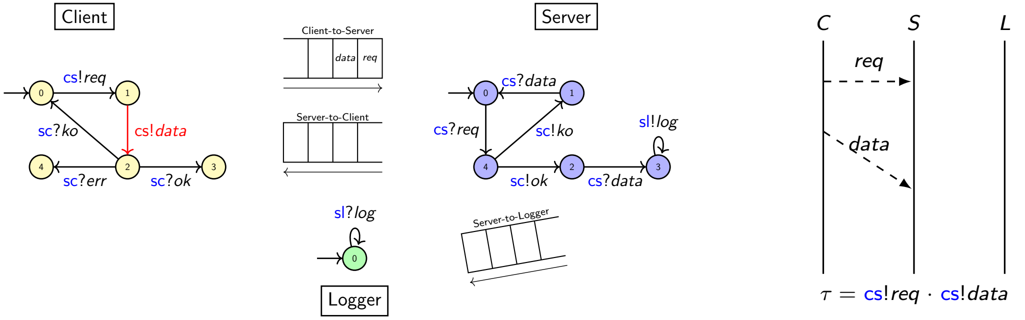

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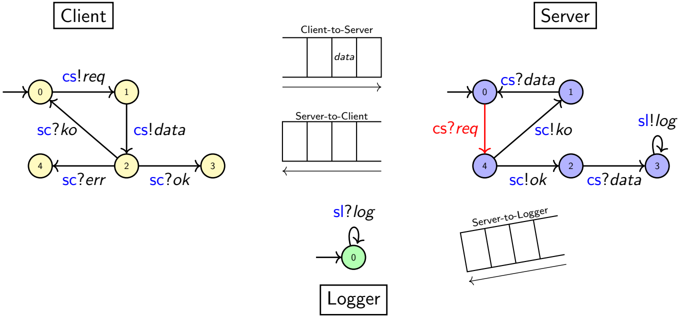

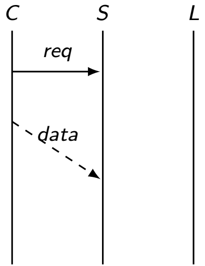

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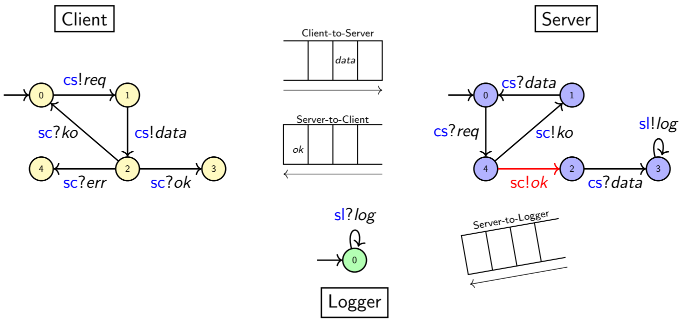

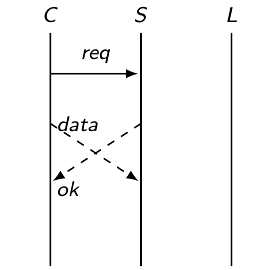

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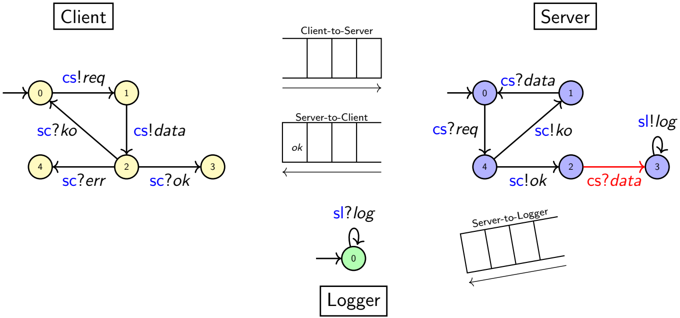

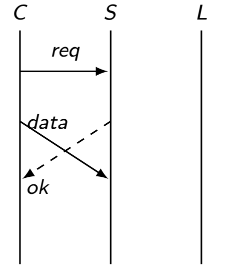

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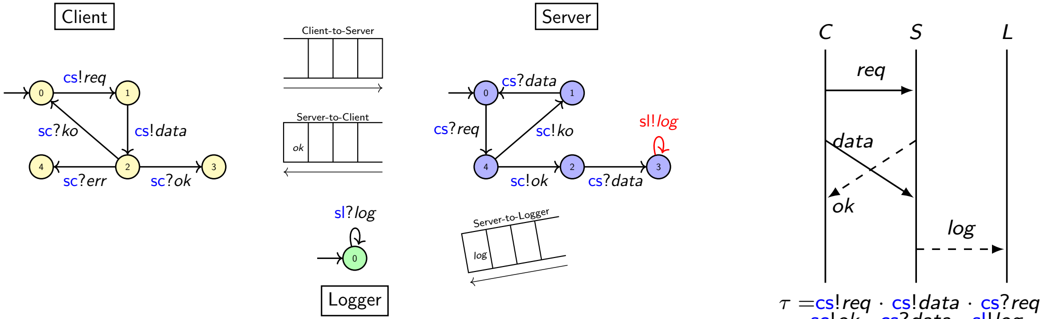

$\tau =$ cs!*req* · cs!*data* · cs?*req* · sc!*ok* · cs?*data* · sl!*log*

Synchronisability

- *existentially k-bounded* systems [2] [3] - all accepting executions re-ordered to a k-bounded execution.

[2] Lohrey and Muscholl, *Bounded MSC communication*, 2002

[3] Genest et al., *A Kleene theorem for a class of communicating automata with effective algorithms*, 2004

Synchronisability

- *existentially k-bounded* systems [2] [3]
- *synchronisable systems* [4] - send projection equivalent to rendezvous.

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Synchronisability

- *existentially k-bounded* systems [2] [3]
- *synchronisable systems* [4]
- *k-synchronisable systems* [5] - if every MSC admits a linearisation that can be divided into "blocks" of at most k messages.

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Synchronisability

- *existentially k-bounded* systems [2] [3]
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- *k-synchronisable systems* [5]
- *k-exhaustive systems* [6] - whenever a send action is enabled, it can be fired within a k-bounded execution

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Weakly k-synchronous MSCs

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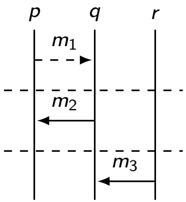

MSO definability

Condition 1

The set of MSCs are MSO-definable.

MSO definability

First-order variables

MSO Logic

- $x \to y$ — x precedes y in the process order
- $x \lhd y$ — x and y are matched send-receive events
- $\lambda(x) = a$ — x has the label a
- $x = y$ — Second-order variable
- $\exists x.\phi$ — there is an event x such that ϕ
- $\exists X.\phi$ — there is a unary relation X such that ϕ holds
- $\phi \vee \phi$, $\neg\phi$, $x \in X$, etc.

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Second-order variable

$matched(x) = \exists y. x \lhd y$ indicates that x is a matched send.

Special tree width

Condition 2

The set of MSCs have bounded special tree-width.

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- Adam-Eve play the *decomposition game*.
- Eve "colours" some events on the MSC, removes edges between coloured events.
- Adam chooses one of the resulting connected components.
- Bounded special tree-width k if Eve can win (colour all vertices) with $k+1$ colours.

Crucial observation

Theorem

Let $\mathcal{C}$ be a class of MSCs. If $\mathcal{C}$ is MSO-definable and STW-bounded class, the following problem is decidable: Given a communicating system S, do we have $L(S) \subseteq \mathcal{C}$?

Crucial observation

Theorem

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- Synchronisability for an STW-bounded class $\xrightarrow{\text{reduces to}}$ *bounded model-checking*
- Bounded model-checking $\rightarrow$ known to be decidable [7]

[7] Bollig and Gastin, *Non-sequential theory of distributed systems*, 2019

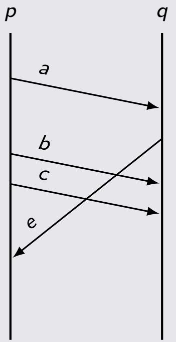
Applying the framework to k-weakly synchronous MSCs

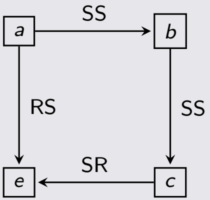
Result

The set of k-weakly synchronous MSCs are MSO-definable.

Applying the framework to k-weakly synchronous MSCs

Conflict graph





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Result

The set of weakly synchronous MSCs are MSO-definable.

Graphical characterisation of weakly synchronous MSCs

- No RS edge along any cycle
- At most k vertices in any SCC

MSO definable!

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Result

The set of weakly synchronous MSCs has bounded STW.

- Eve's strategy - isolate each exchange, then remove message pairs
- Uses at most $4n + 1$ colours

What if the channels are not perfect?

We can assume various sources of unreliability in the channels like:

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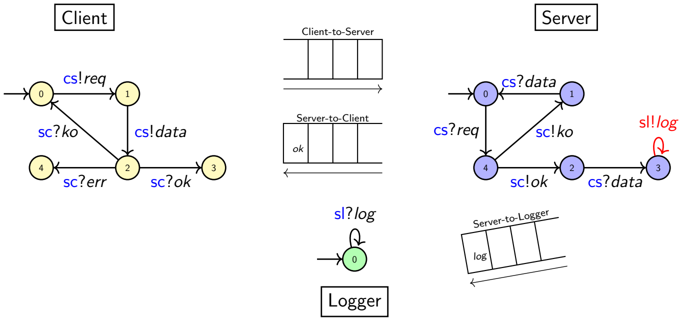

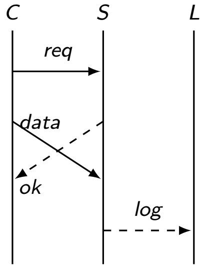

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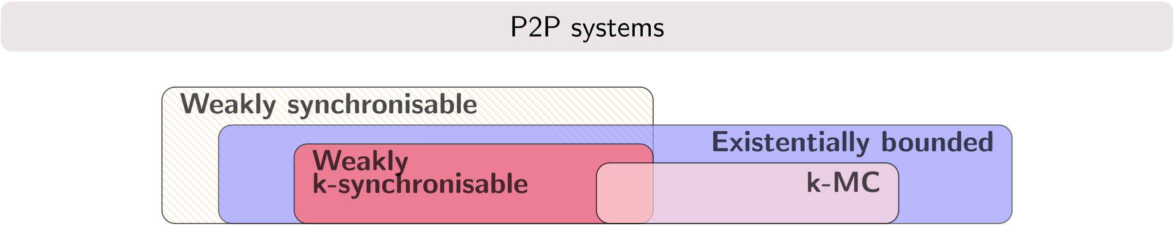
Comparison of classes



Contributions and Perspectives

- Unifying framework for various notions of synchronisability.[8]
- Applicable to both mailbox and p2p communications.
- LCPDL for better complexity.

[8] Bollig et al. *A Unifying Framework for Deciding Synchronisability*, 2021

Contributions and Perspectives

- How can we modify these notions to retain their decidability in the presence of errors?
- Given an unreliable automaton, can we modify it to retain membership?
- Can we use ideas like completely specified protocols to always have information during errors?

Thank you!

Questions?

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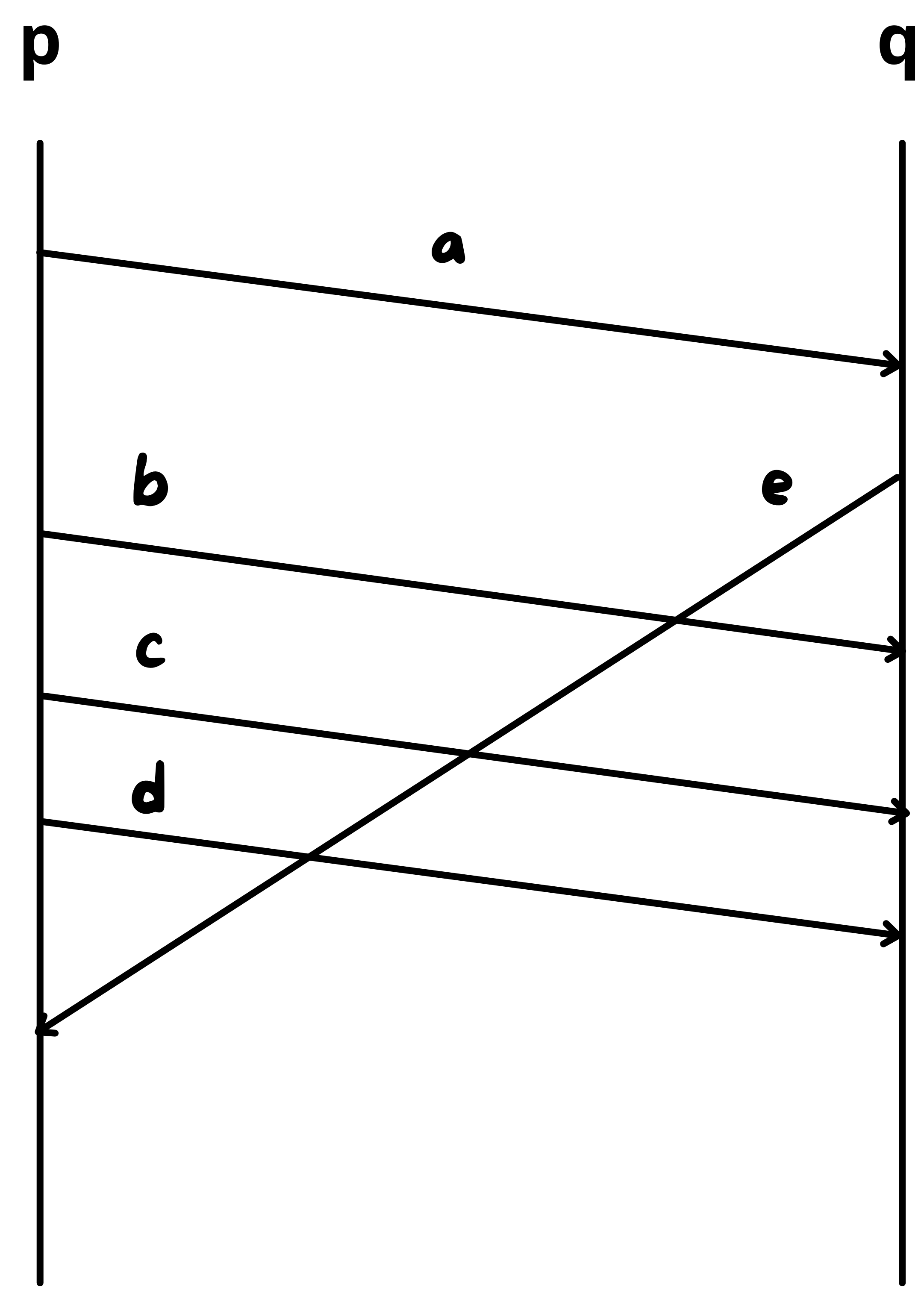

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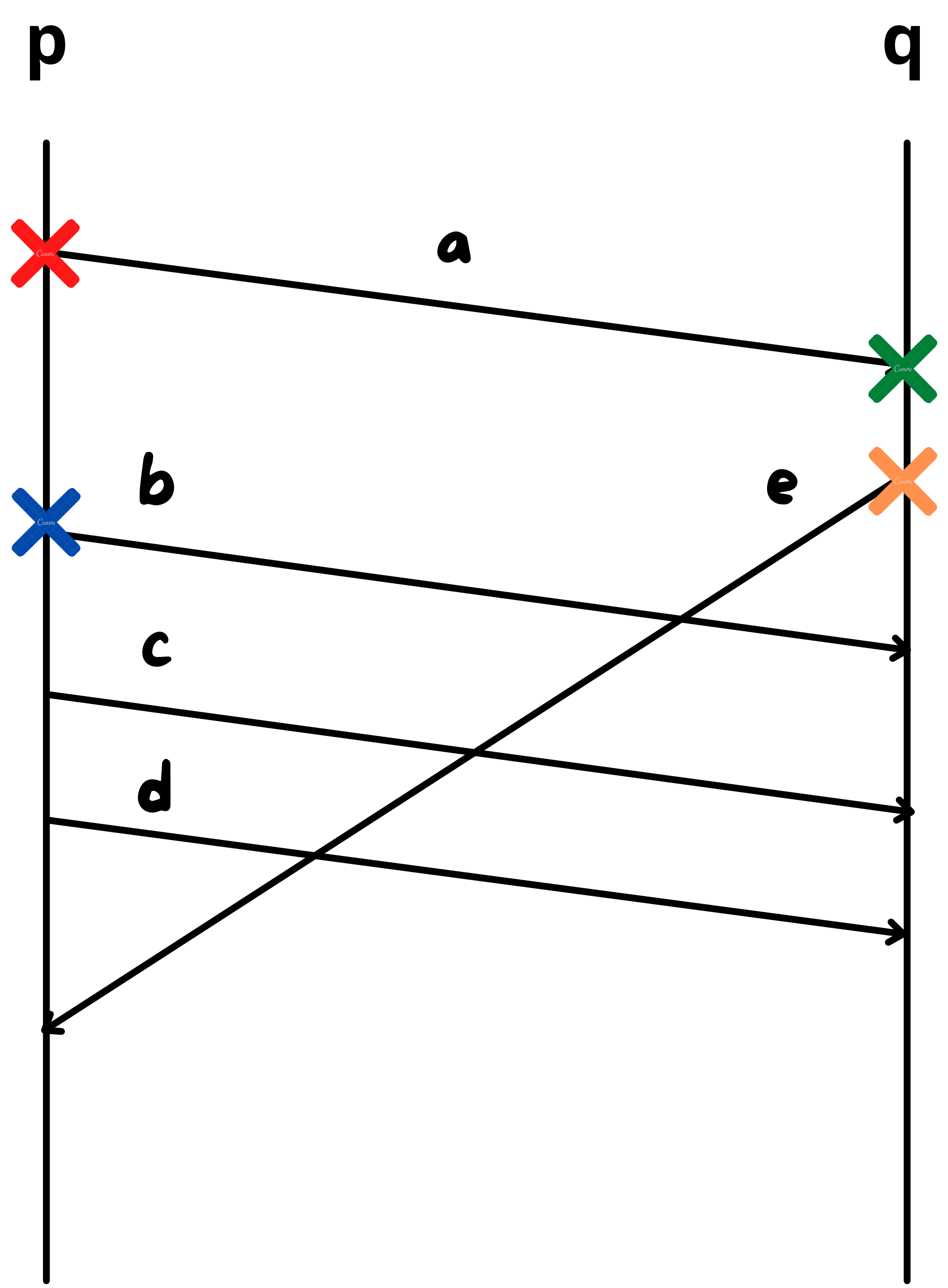
Eve's turn



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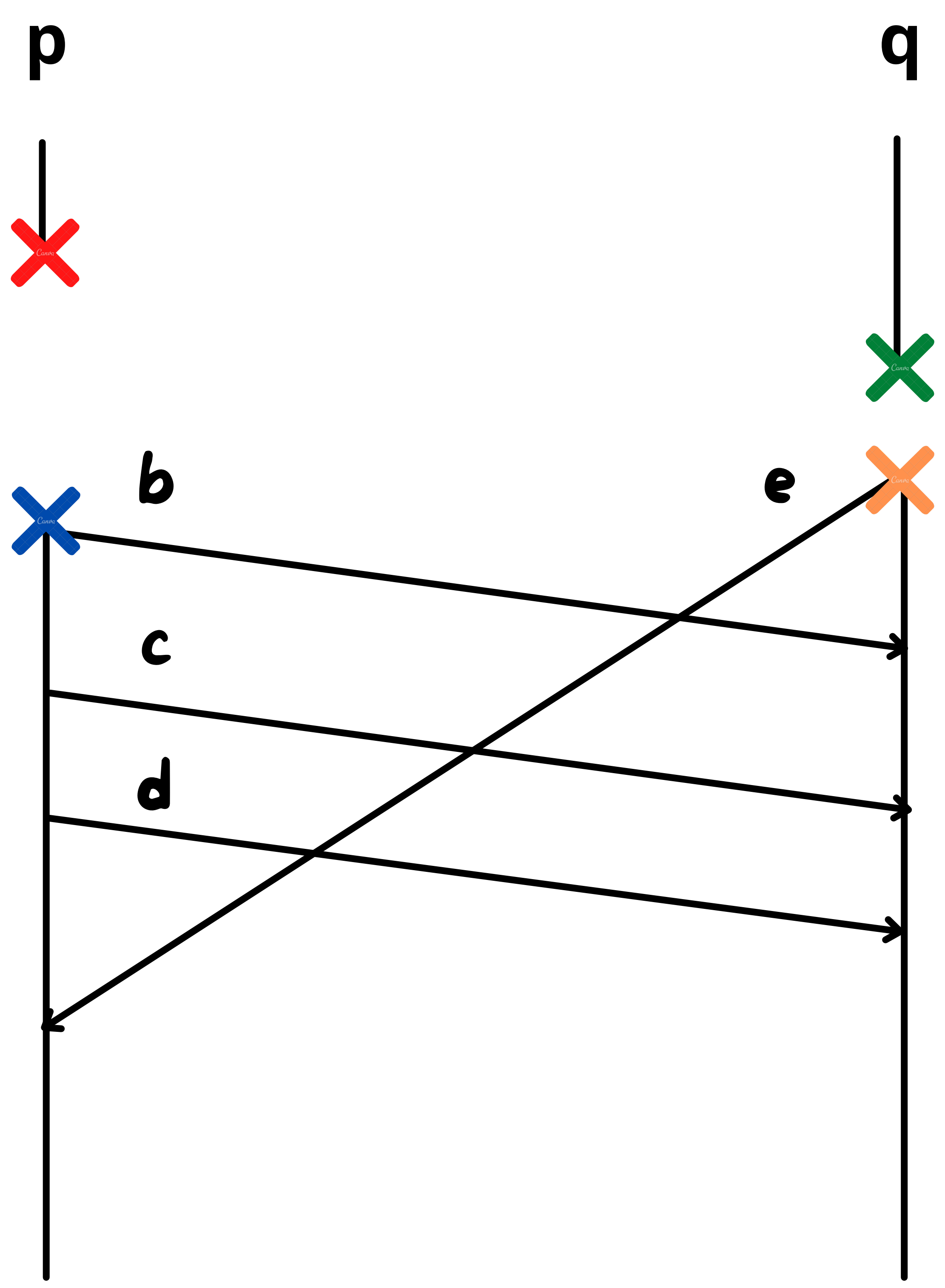

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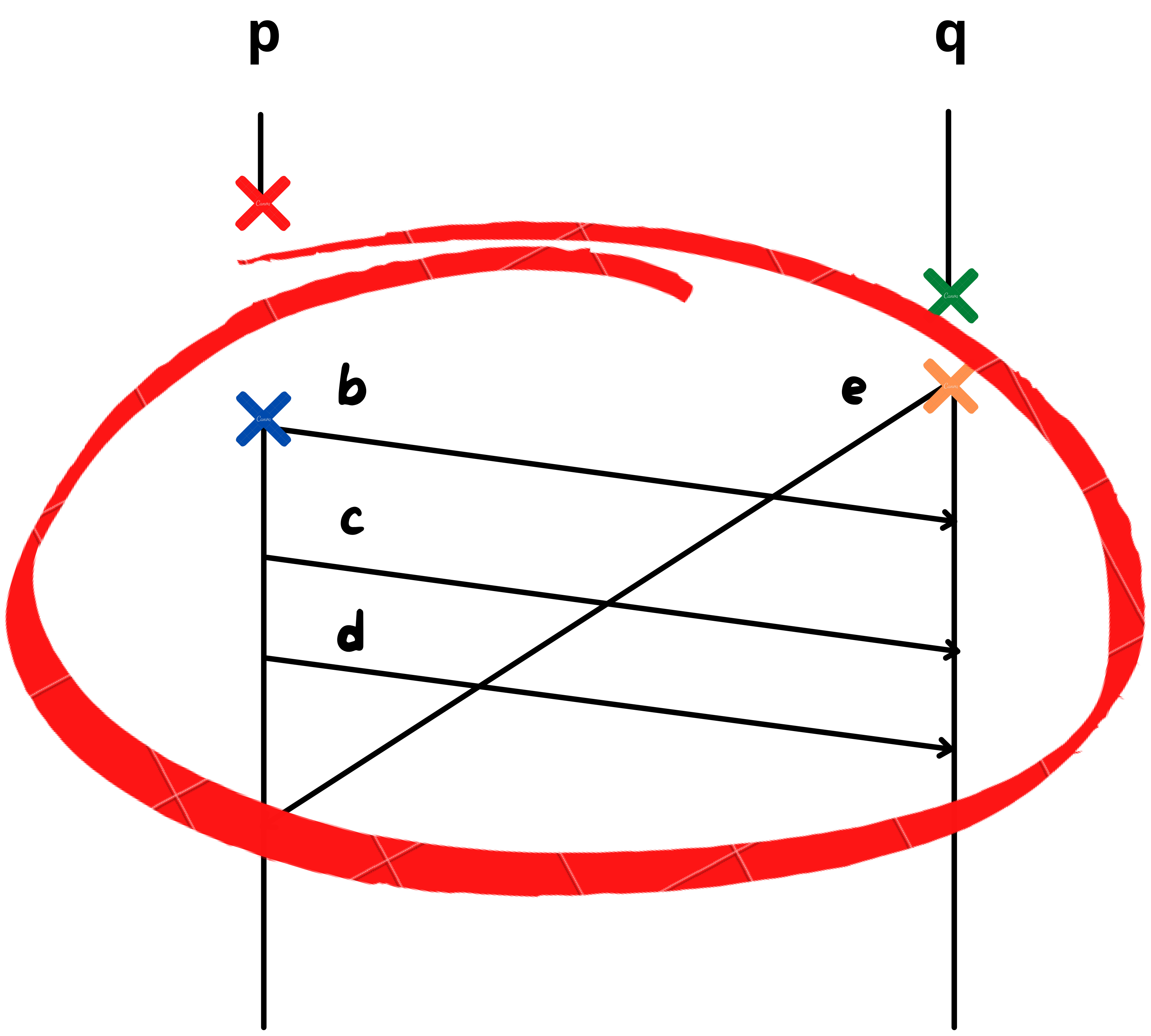

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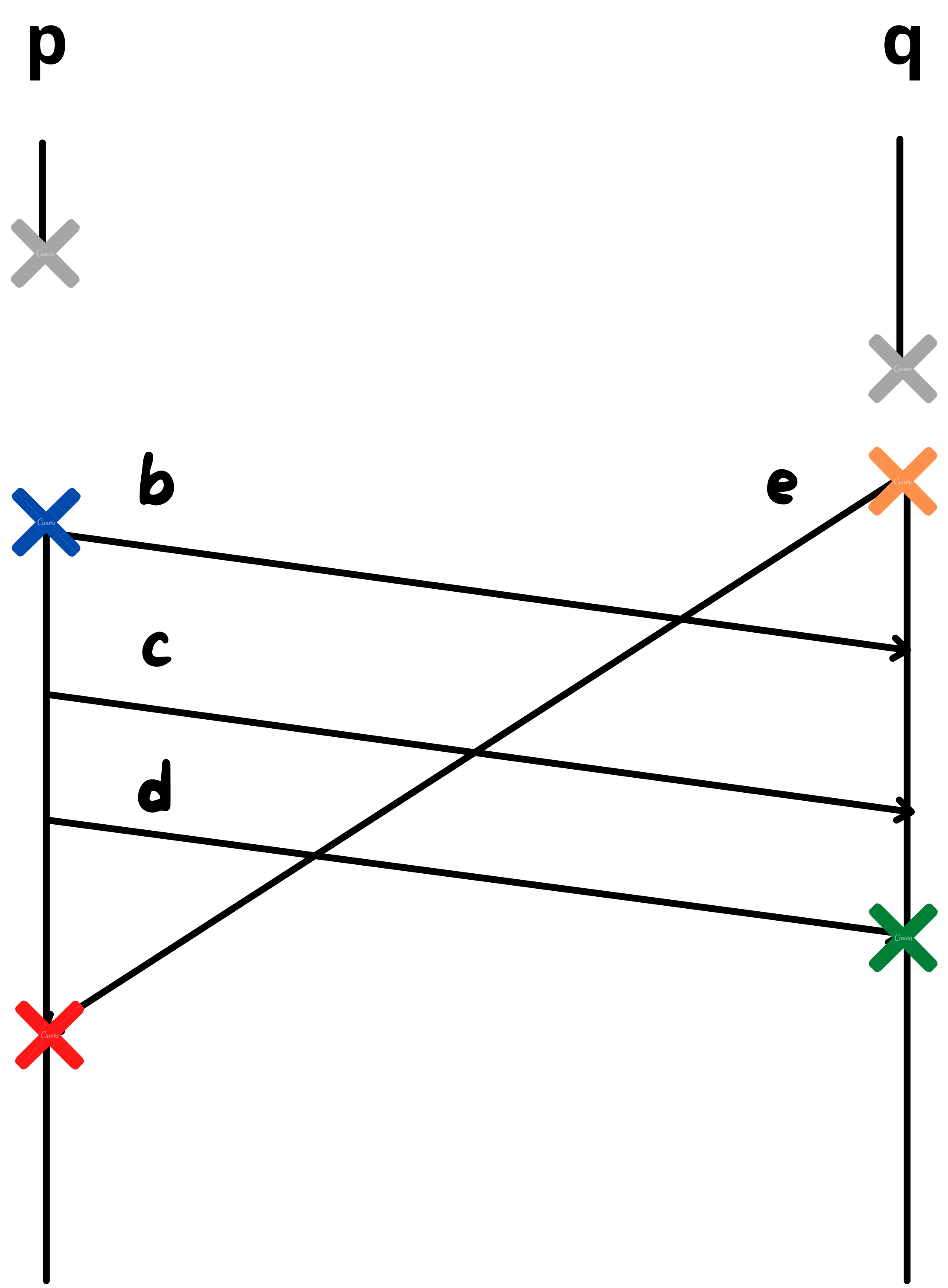

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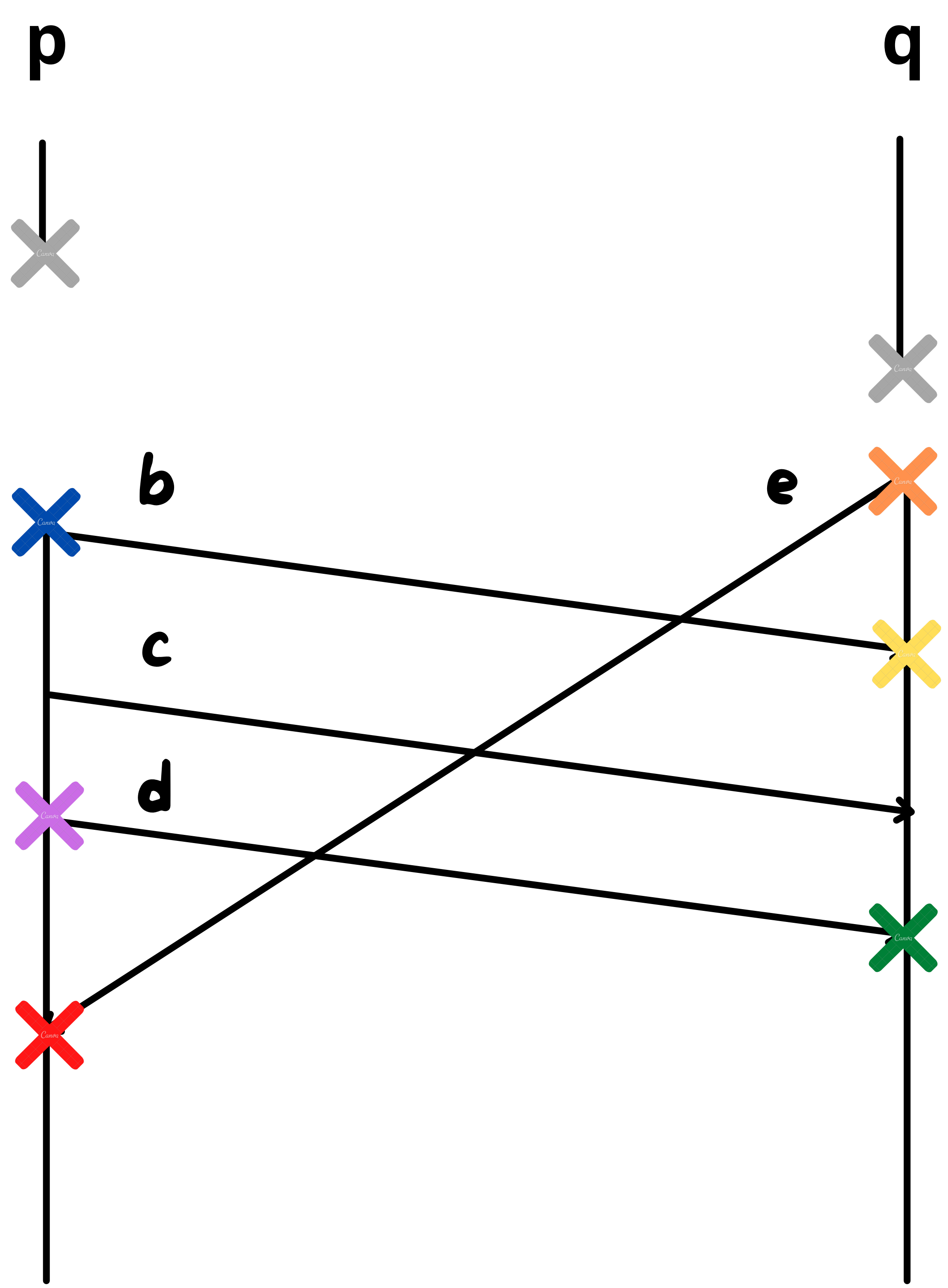

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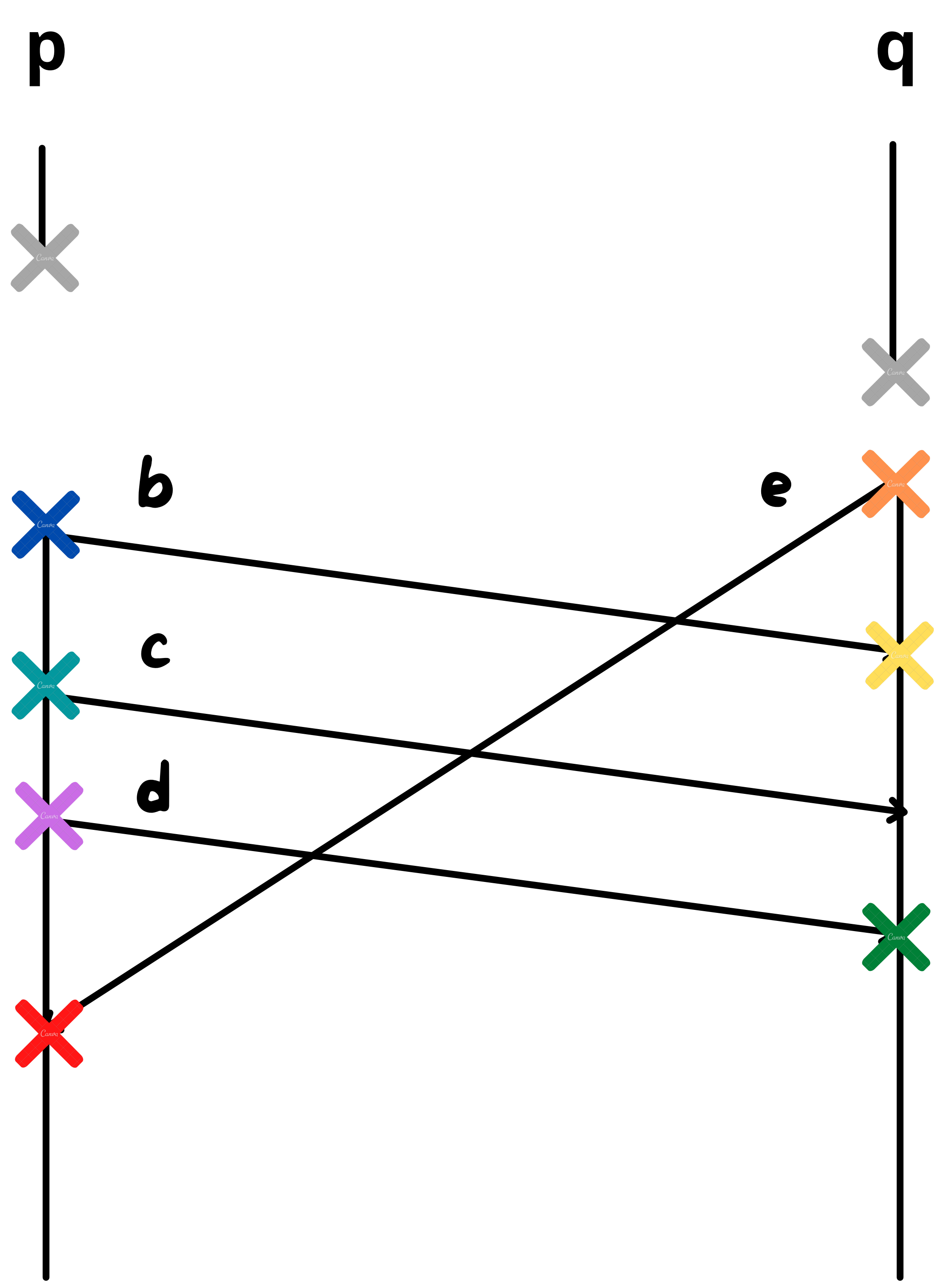

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