Senate

A Maliciously Secure MPC Platform for Collaborative Analytics

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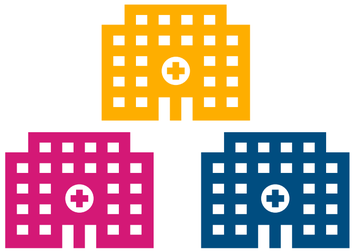
[1] UC Berkeley [2] Opaque Systems [3] VMware Research

USENIX Security 2021

Rich collaborative analytics on shared data



Medical studies

Financial services

Online advertising

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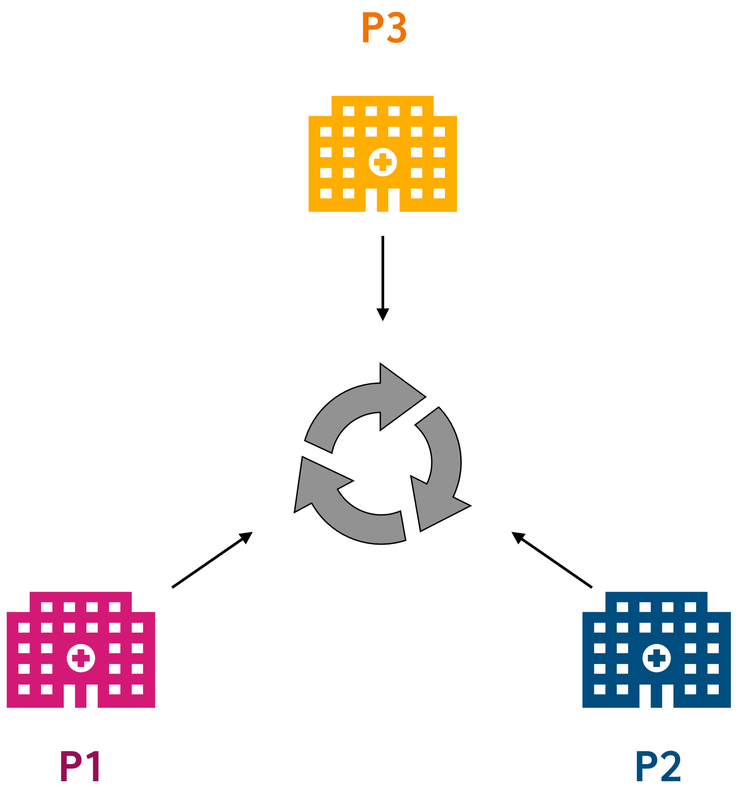


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SELECT diagnosis, COUNT (*) count
FROM patients|P1 U patients|P2 U patients|P3
WHERE has_cdiff = 'True'
GROUP BY diagnosis ORDER BY count LIMIT 10
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Example query: Disease comorbidity

[Bater+17]

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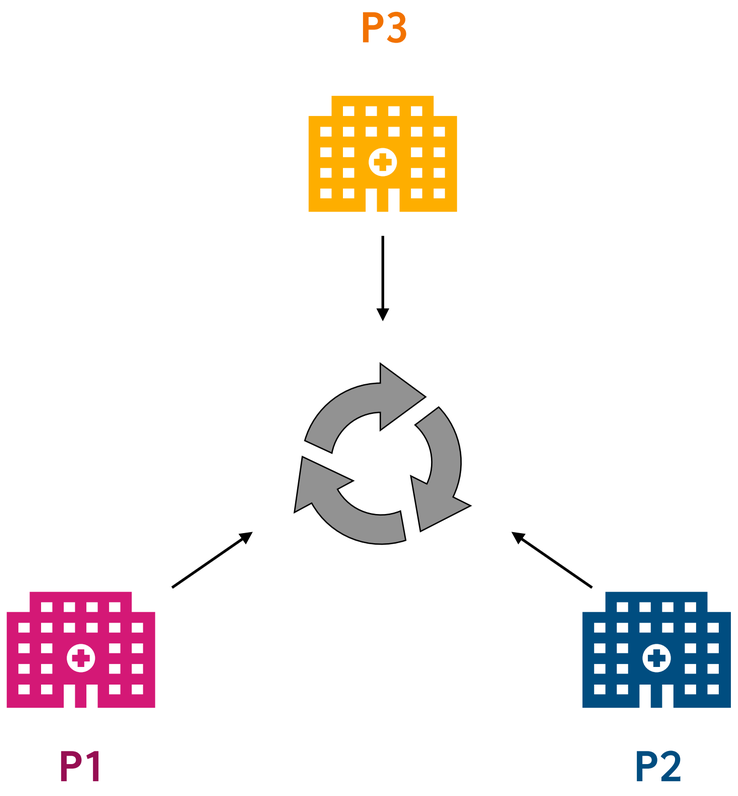


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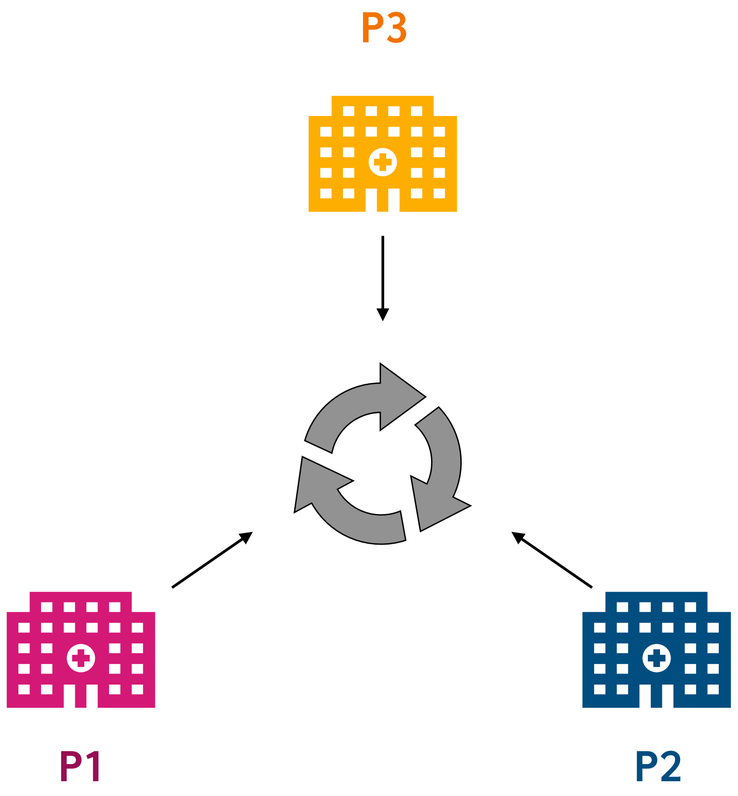


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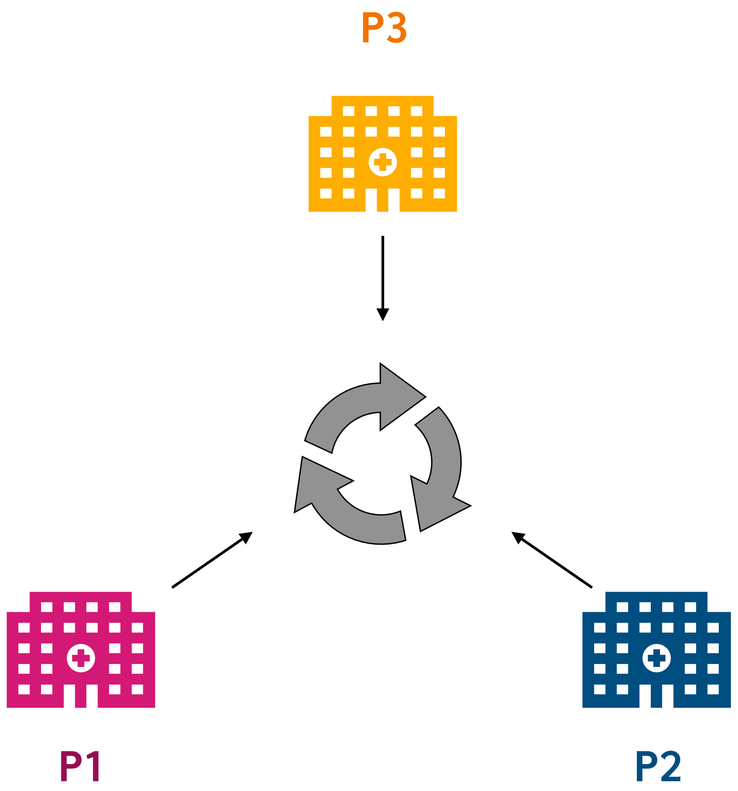


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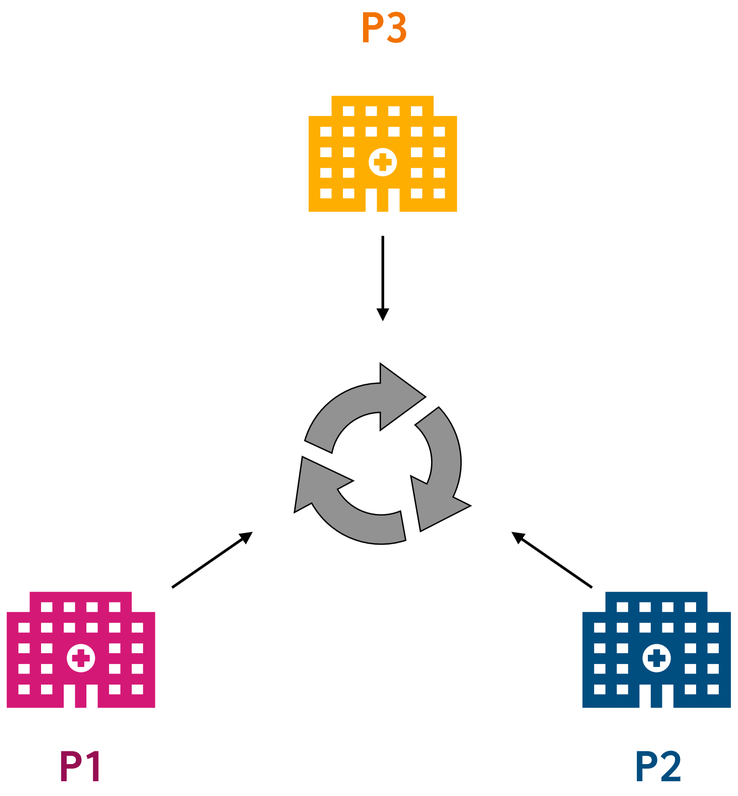


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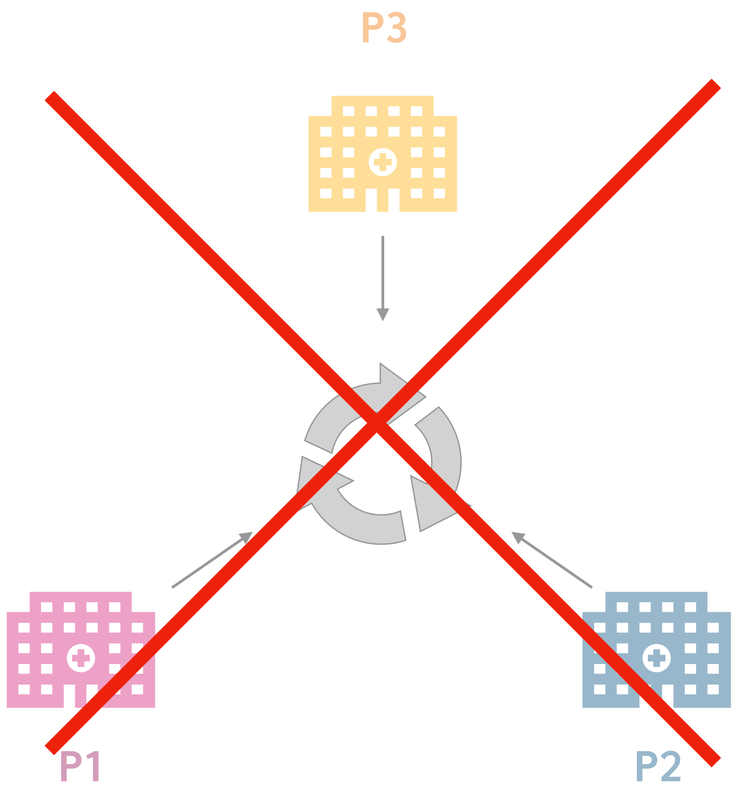


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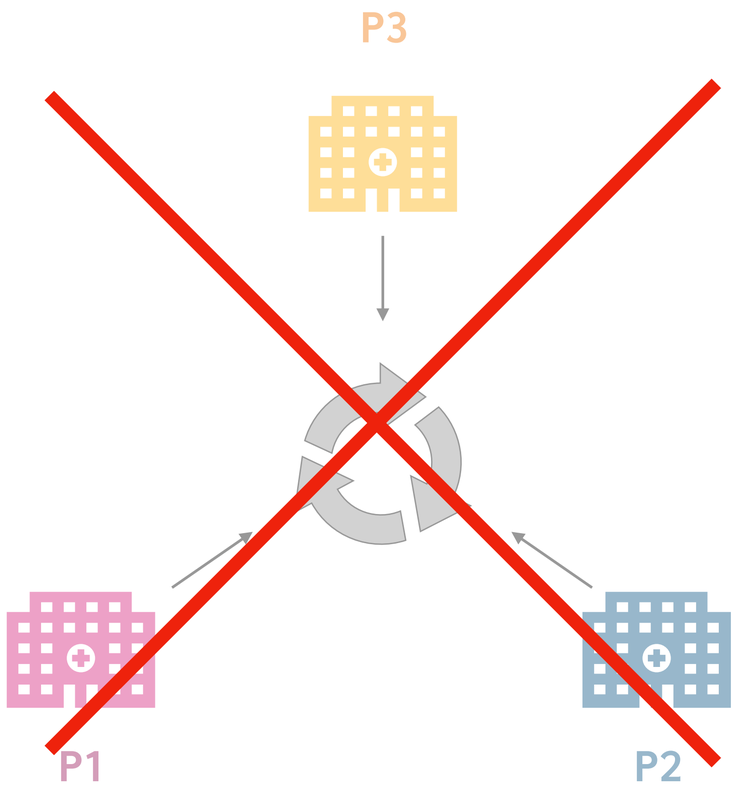
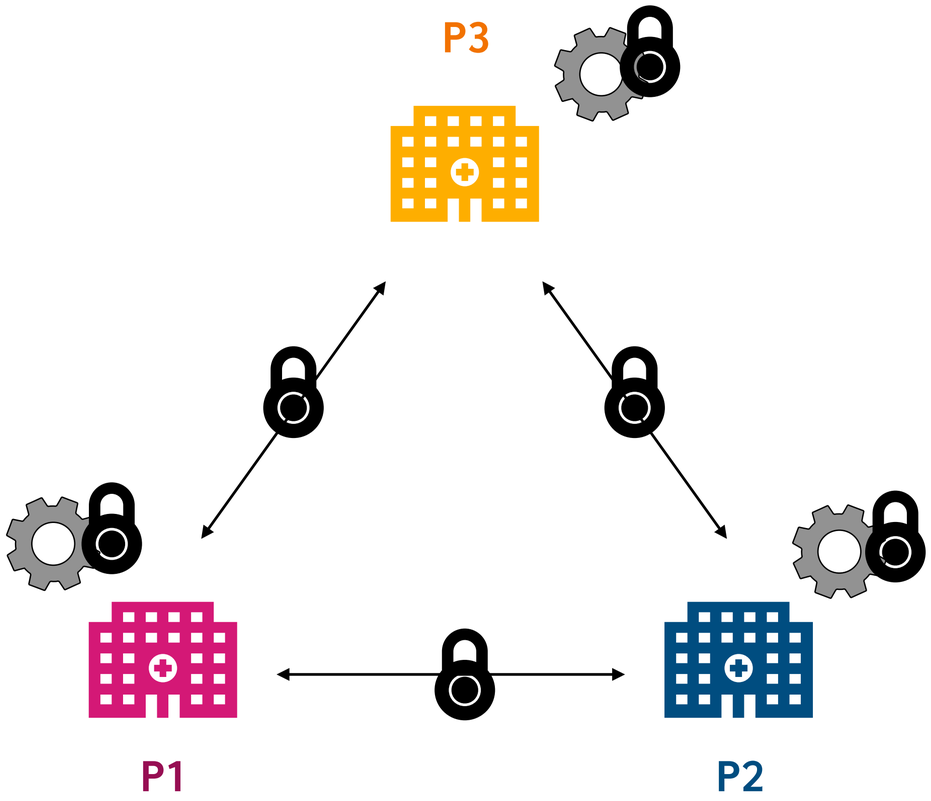


- Privacy concerns
- Laws and regulations
- Business competition

Secure multiparty computation (MPC)

[Yao82, GMW87, BGW88]



- Enables parties to share and compute on encrypted data

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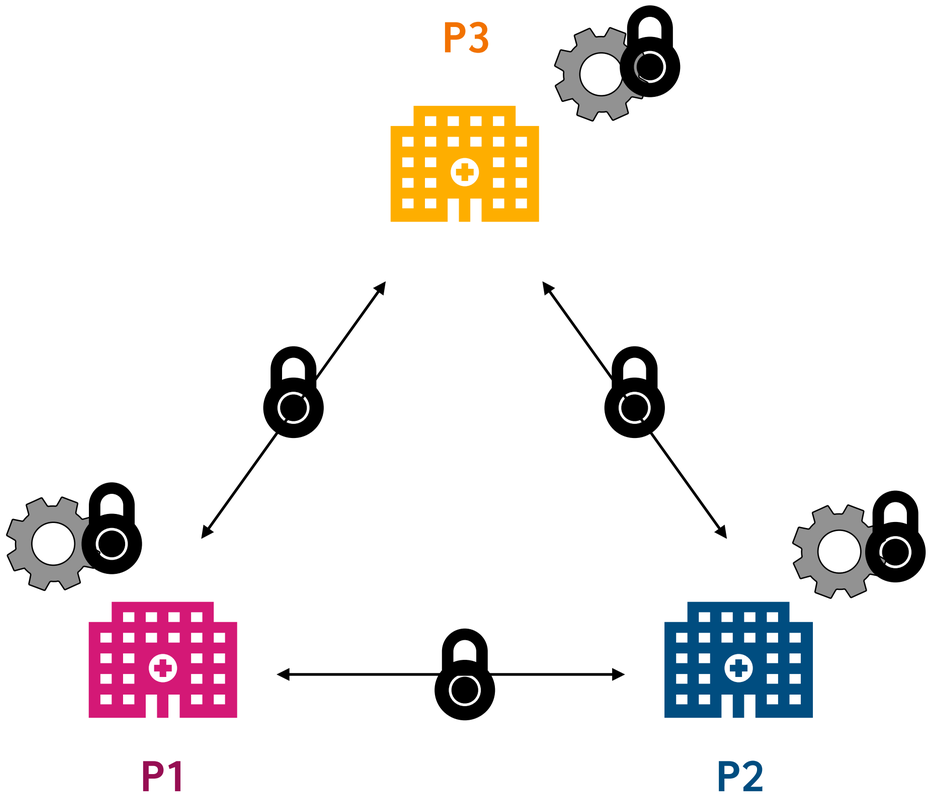
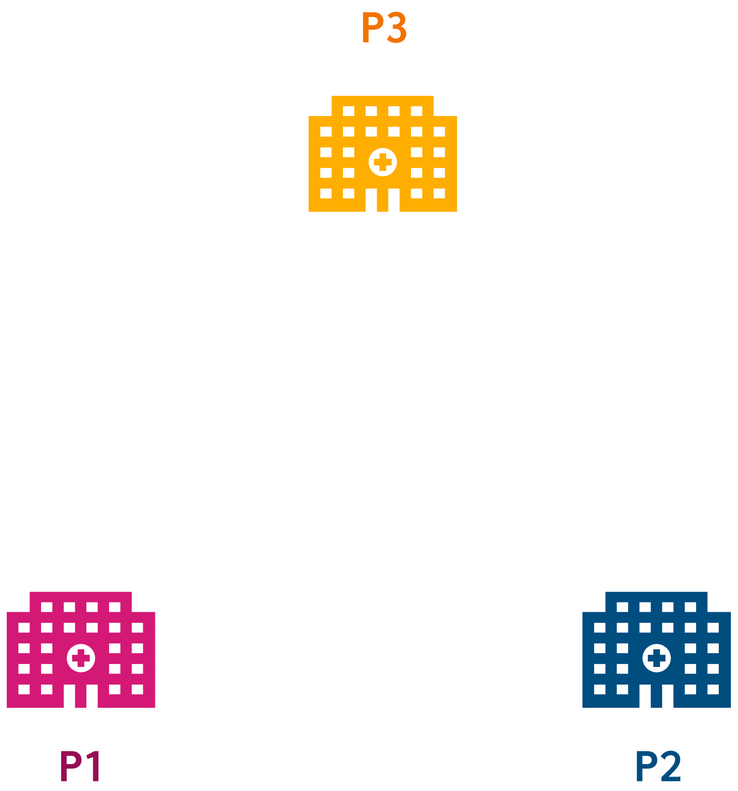


- Enables parties to share and compute on encrypted data
- No party learns any party's input beyond the final result

Threat model & Desired security guarantees



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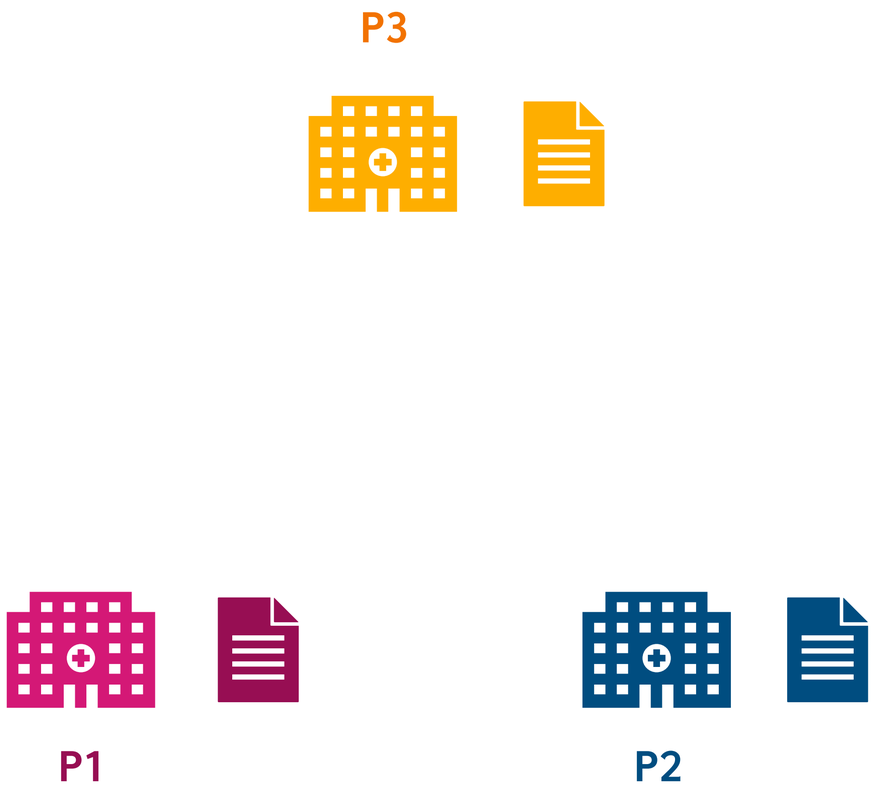
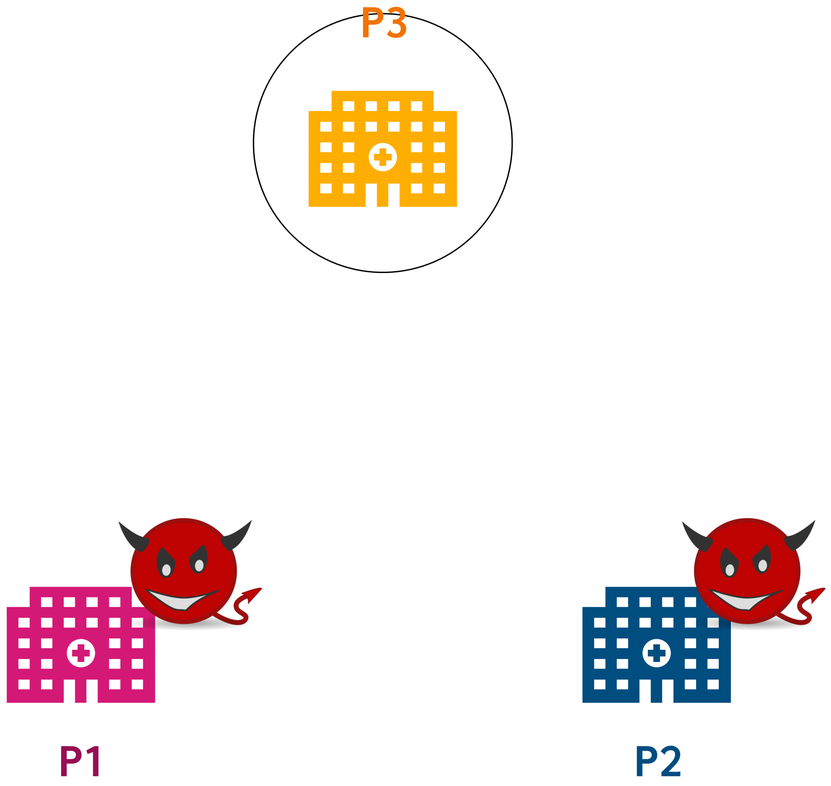


- All parties can provide arbitrary input

Threat model & Desired security guarantees



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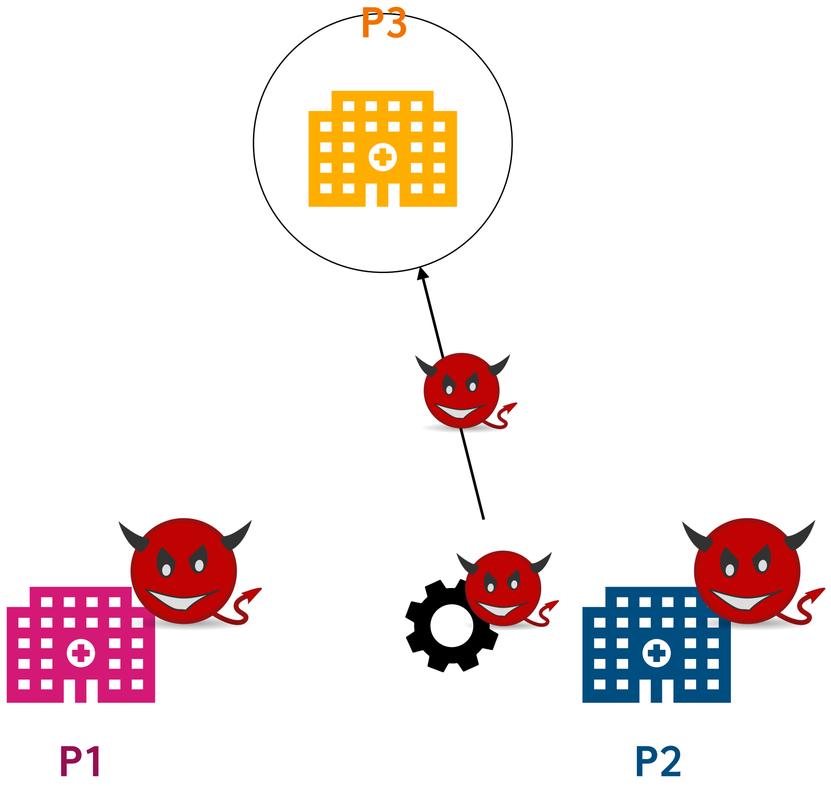
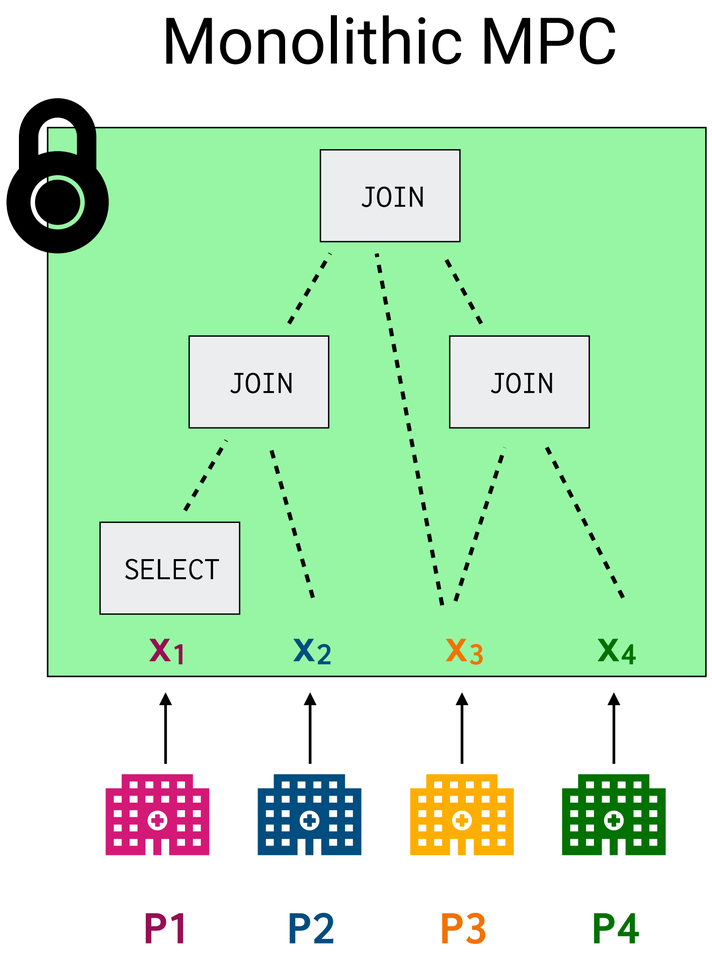


- All parties can provide arbitrary input
- Protocol should be secure even if all other parties collude (dishonest majority)
- Protocol should be secure even if the adversary deviates from the protocol (malicious security)

Current state of the art: Monolithic circuits

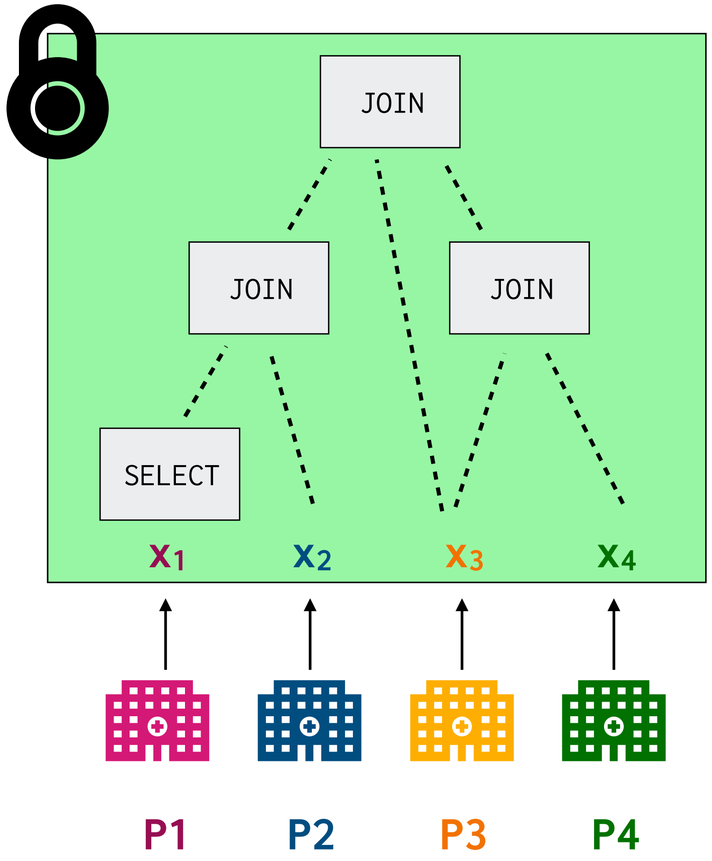
e.g. [WRK17]



All parties need to execute a *monolithic* cryptographic computation *together* to evaluate the desired function

Can we “decompose” monolithic MPC?

Monolithic MPC



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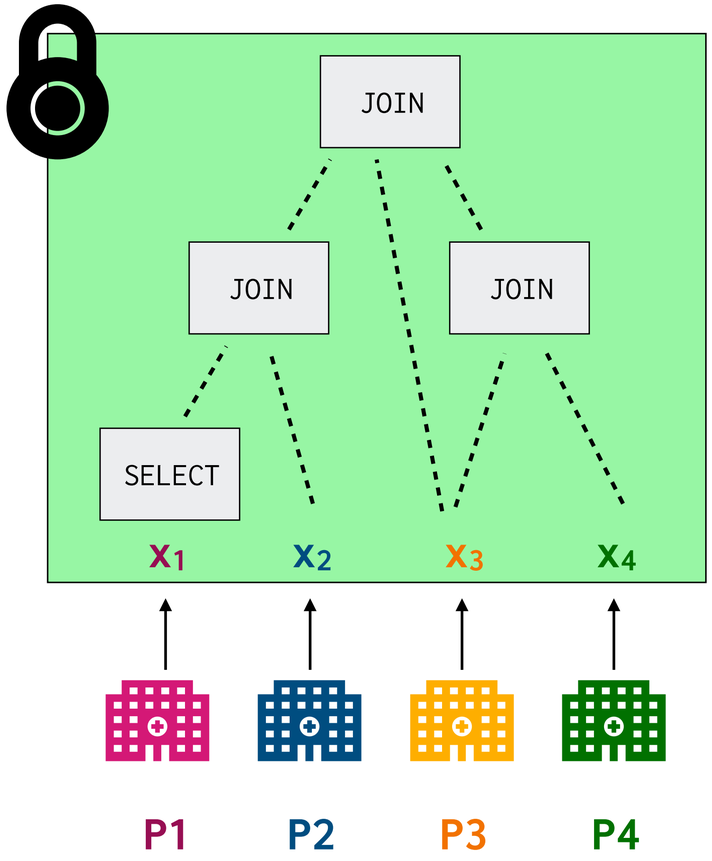
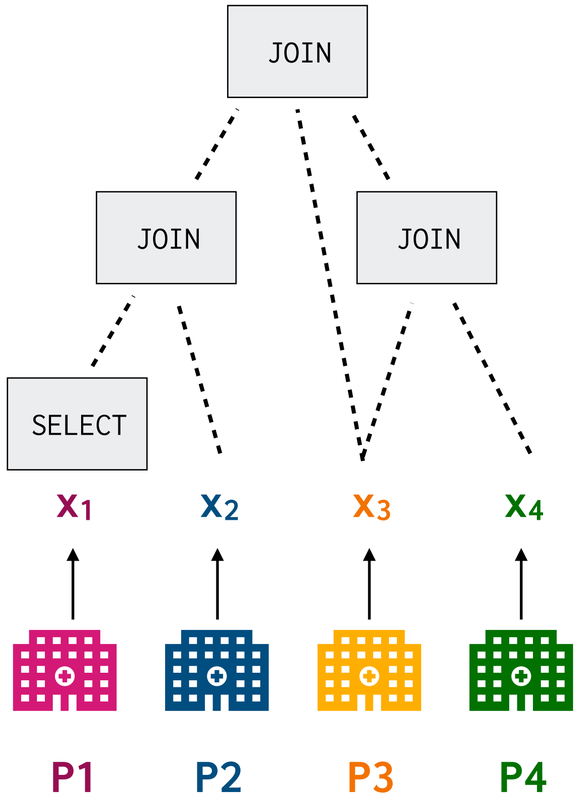


Plaintext execution



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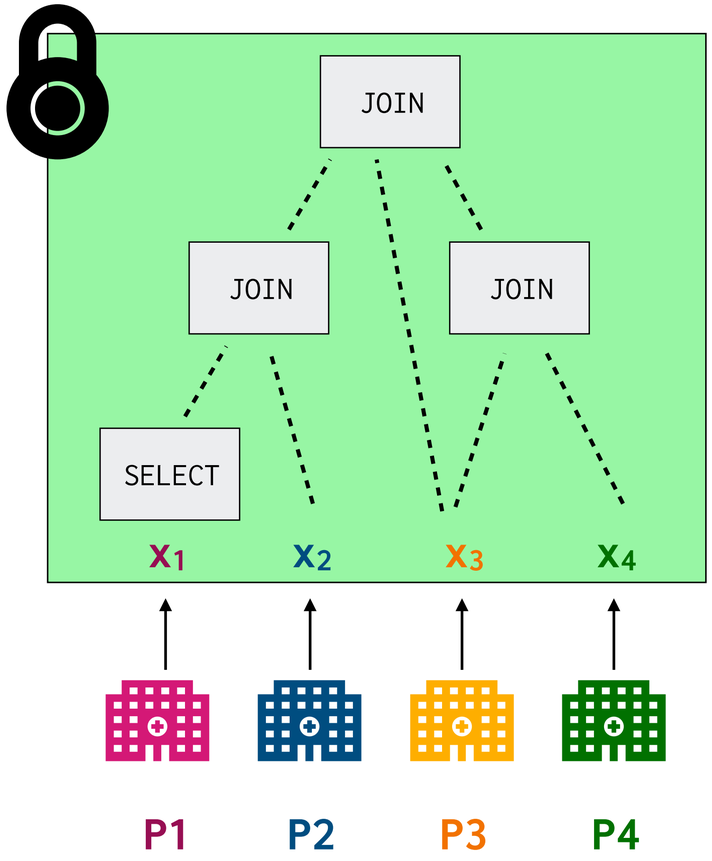

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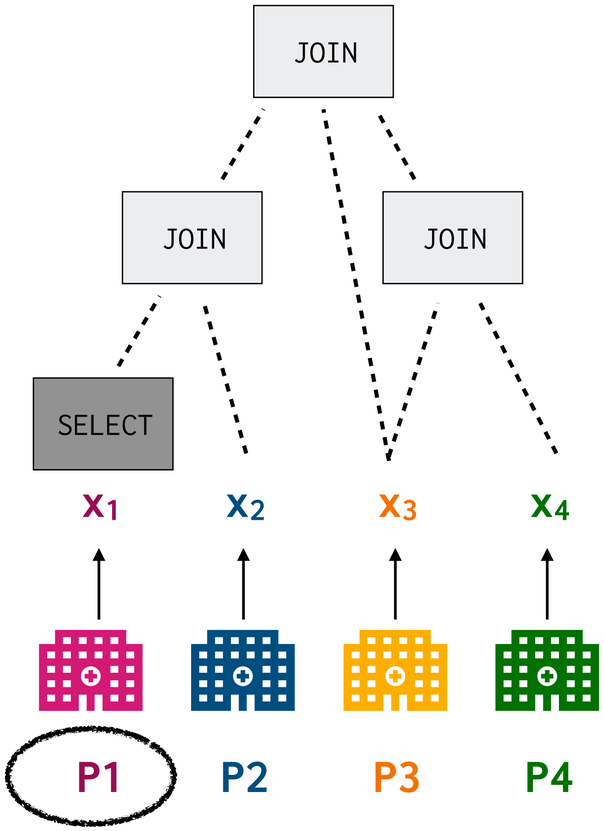

Local operation

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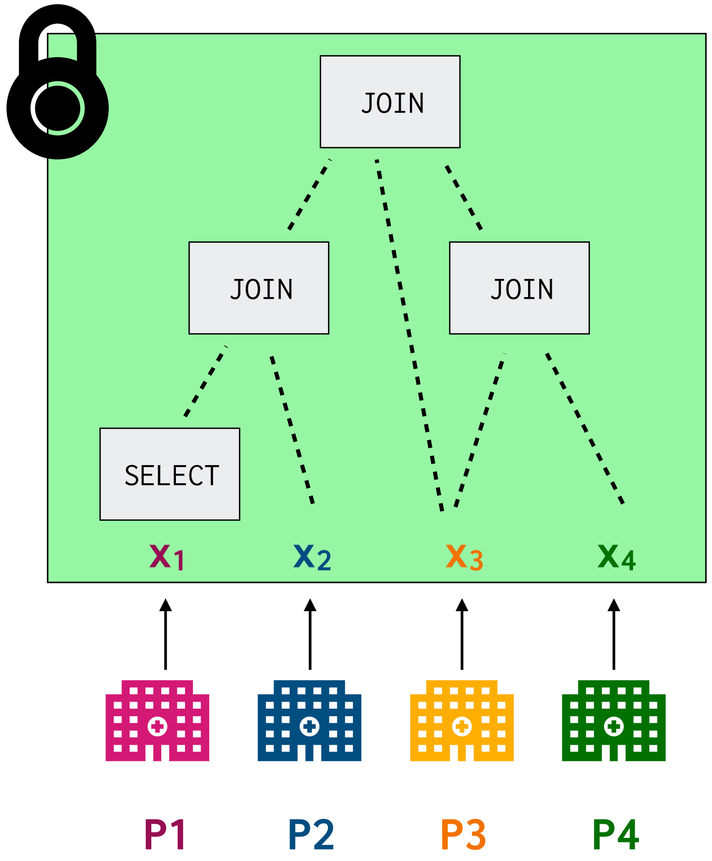

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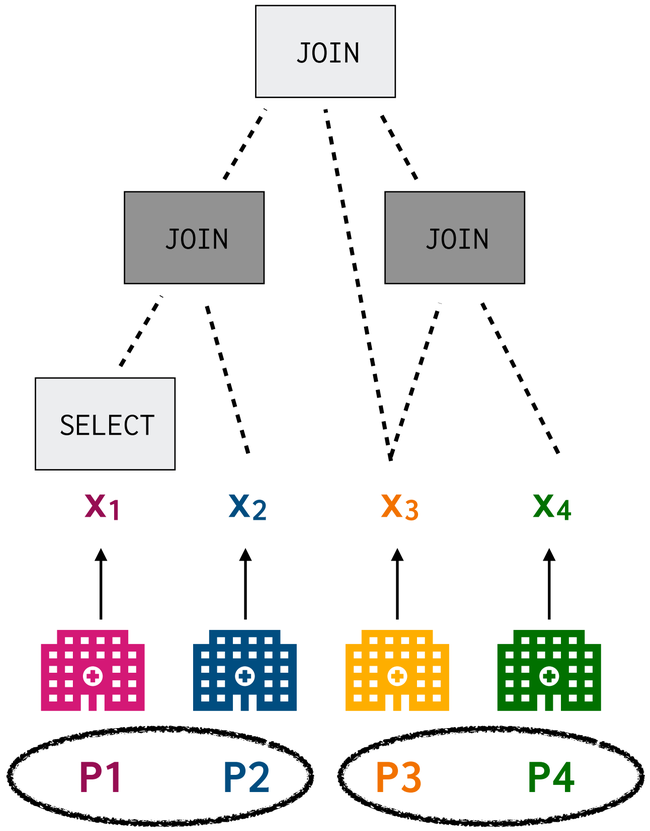

Parallel operations

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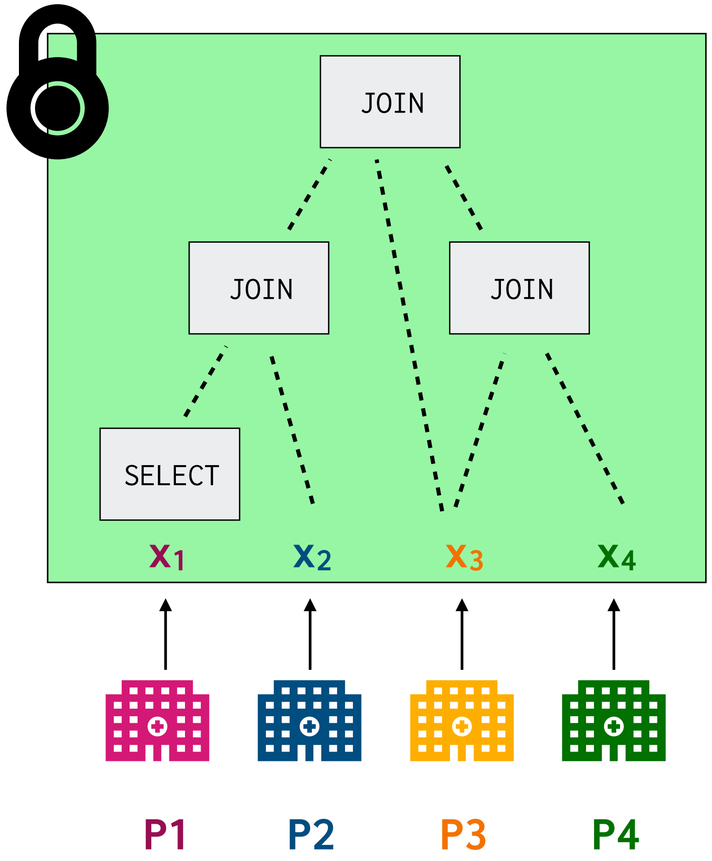

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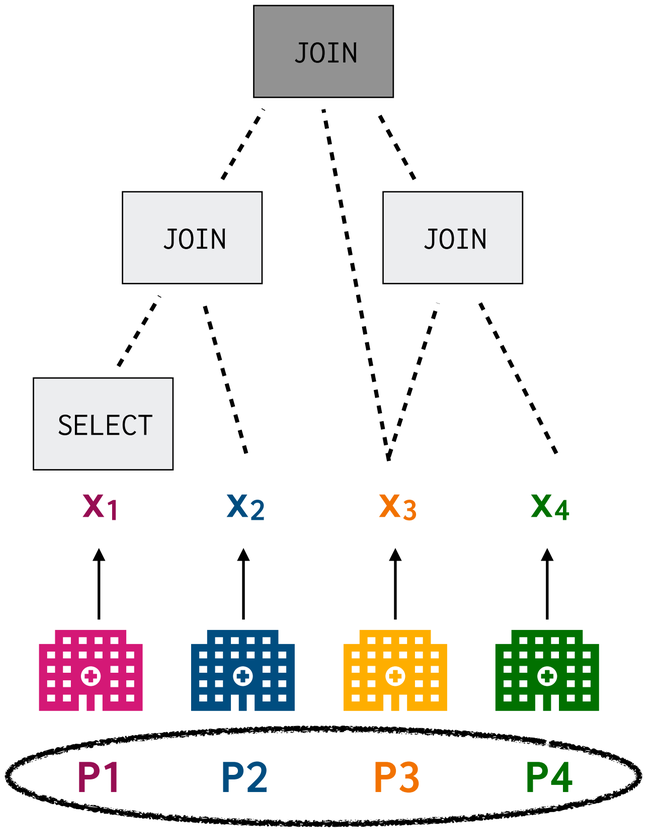

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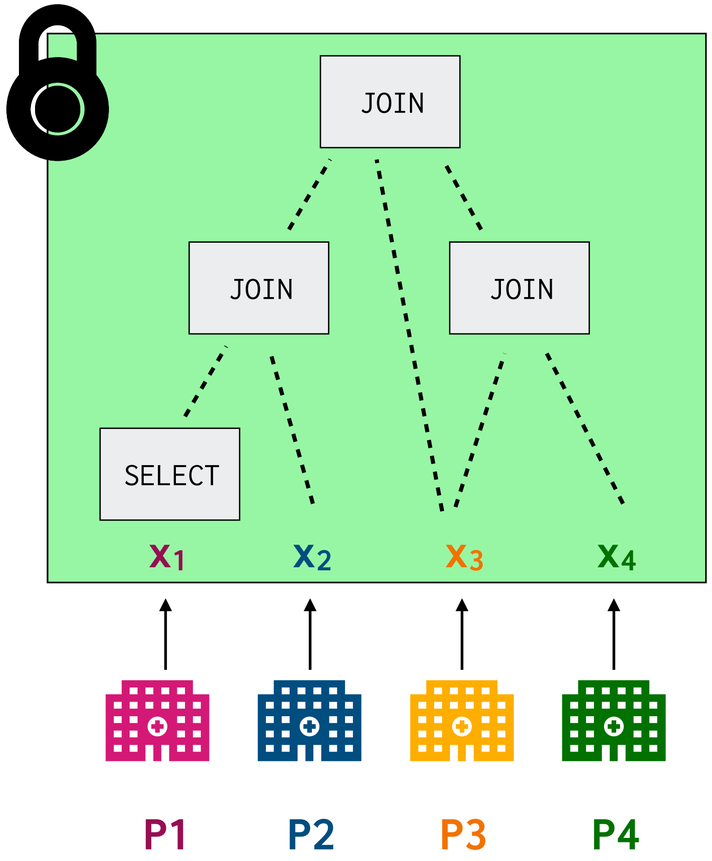

Drawbacks

- No parallelism across parties

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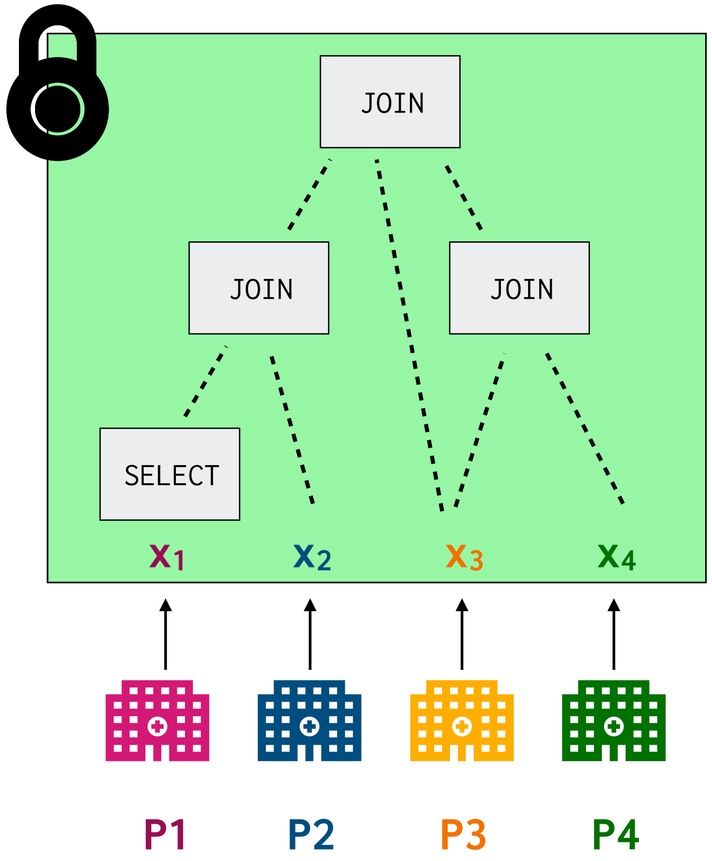

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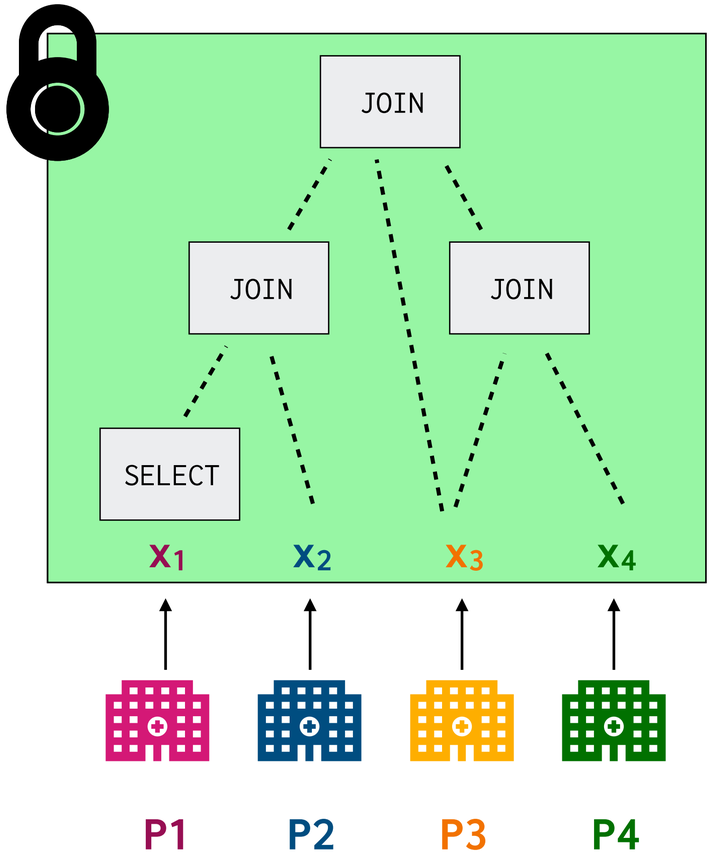

Drawbacks

- No parallelism across parties
- No local plaintext computation
- *All* parties jointly execute *every* sub-computation, even if it doesn’t directly involve their input

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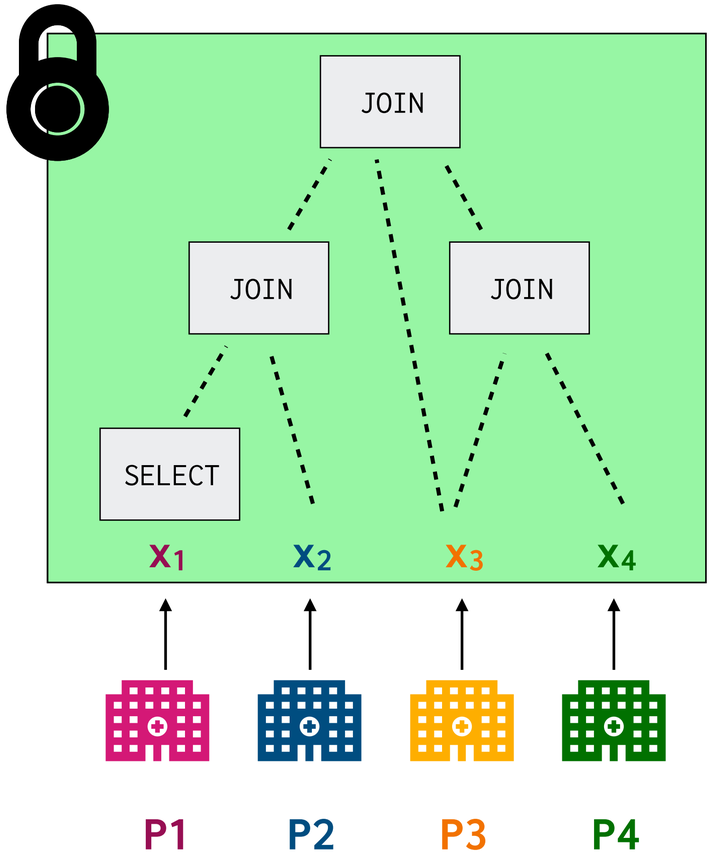
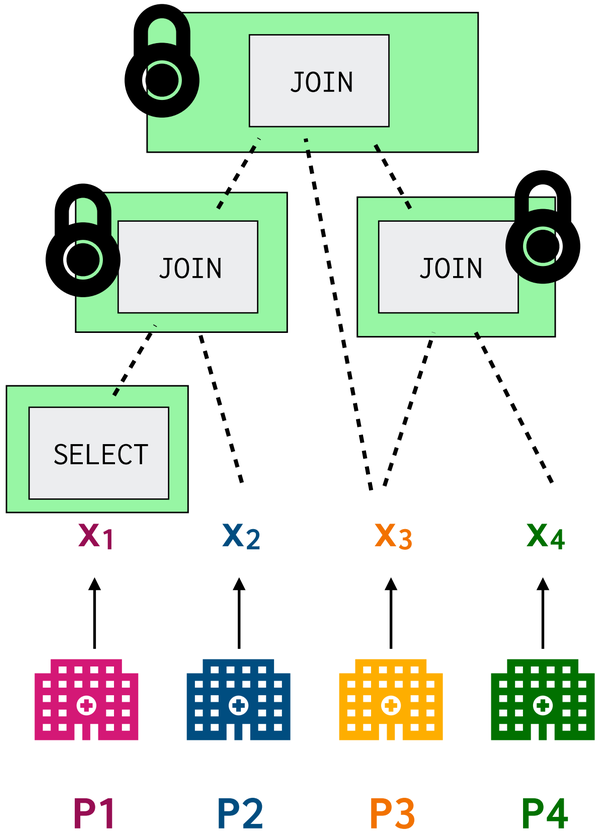


How to decompose without compromising security?

Challenges in MPC decomposition

Strawman MPC decomposition



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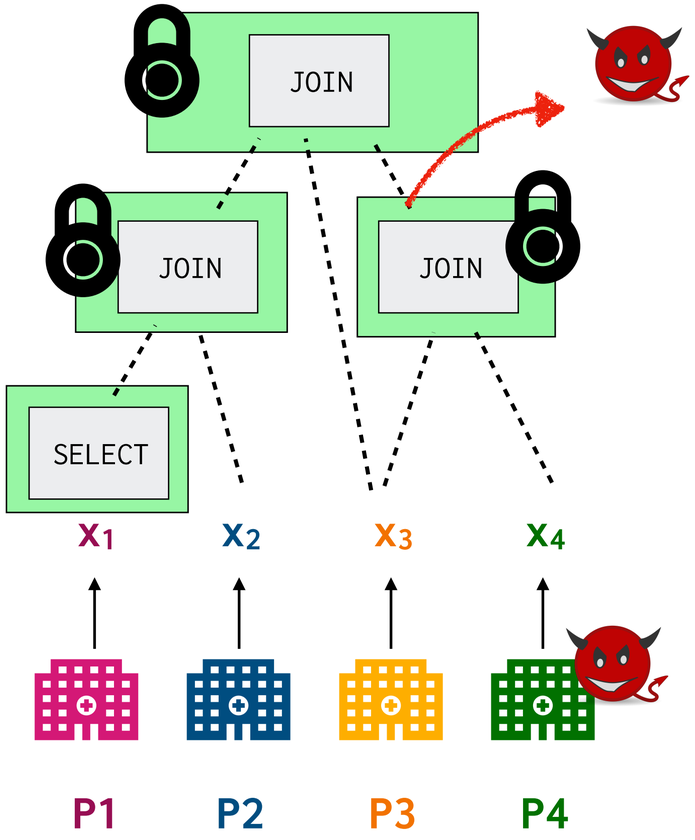

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1. Decomposition reveals intermediate results to the adversary

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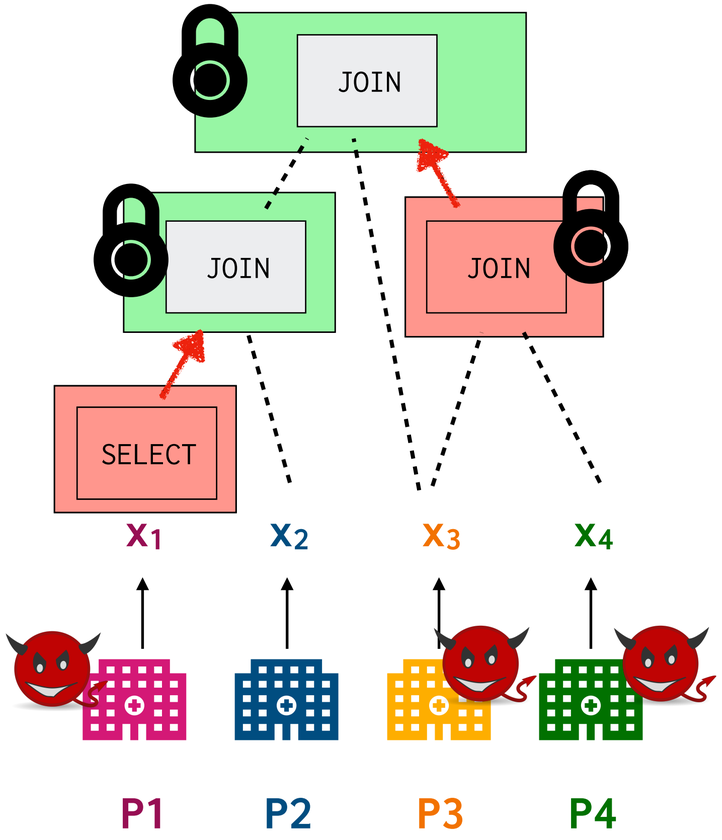

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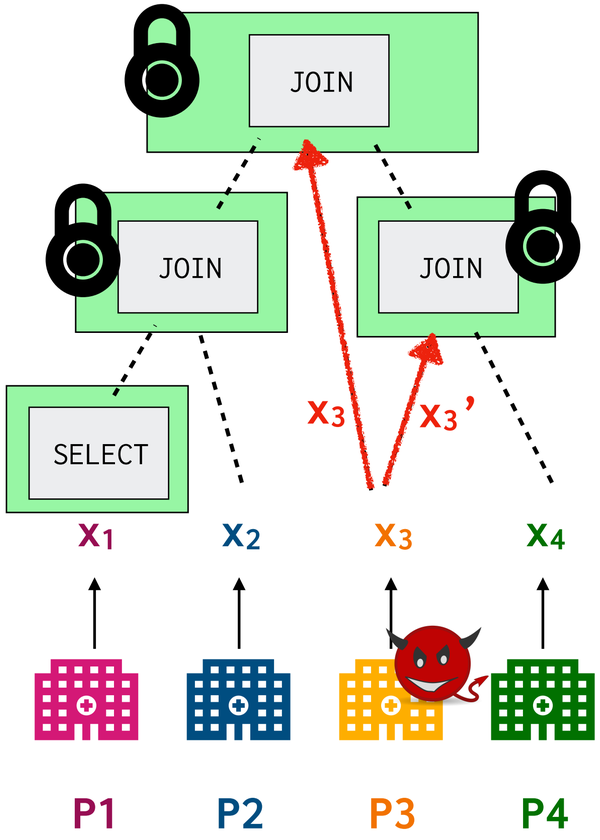

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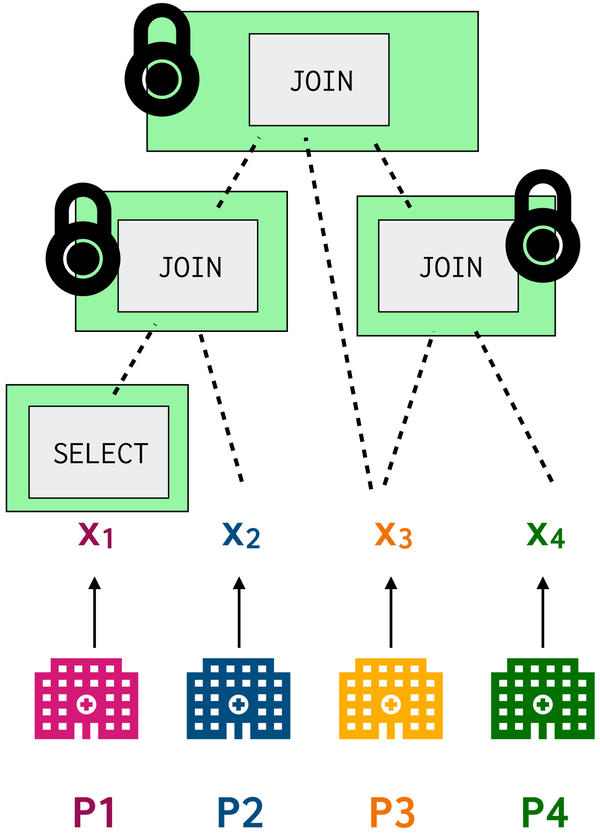
Key technique: Secure MPC decomposition

Senate's MPC protocol



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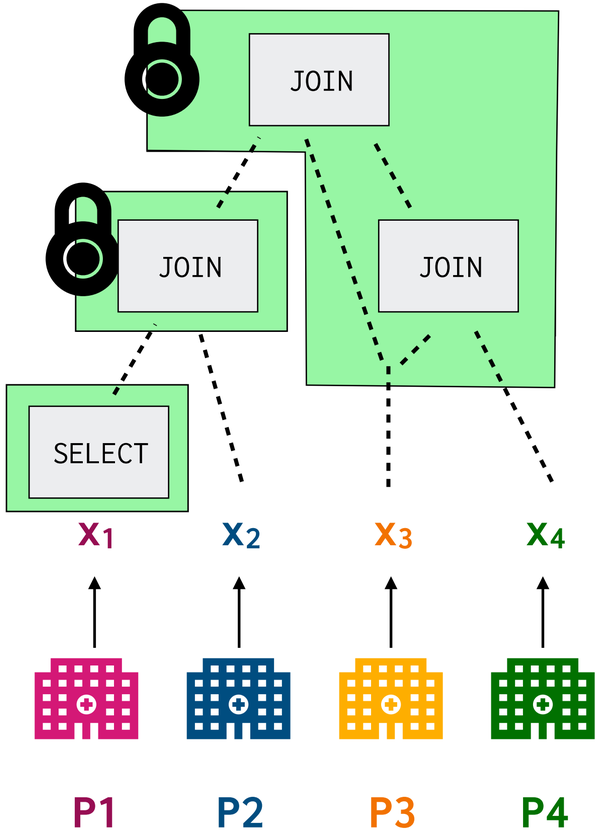

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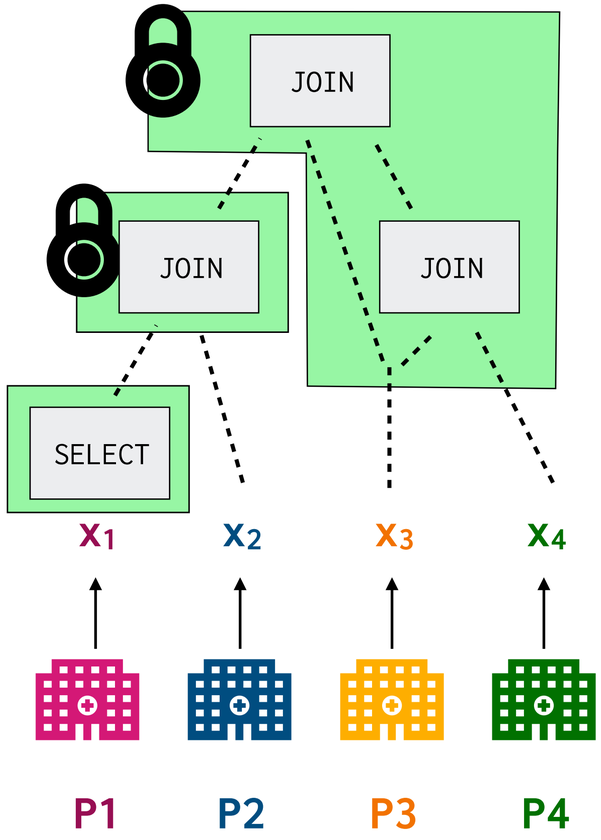

Secure MPC decomposition even in the presence of malicious adversaries

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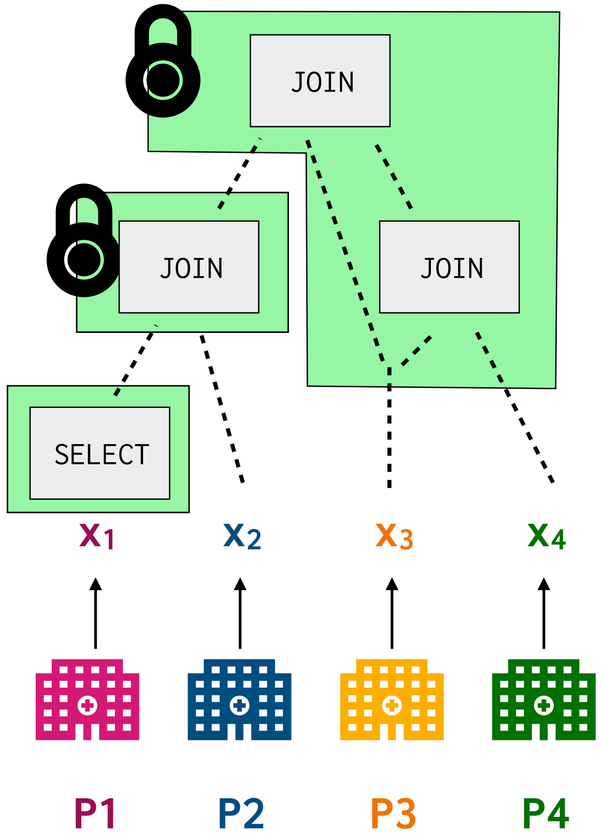

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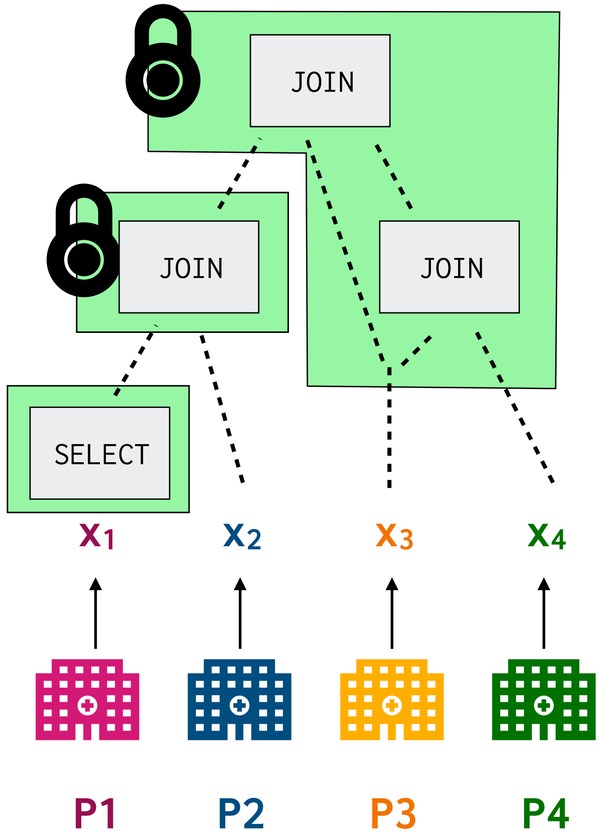

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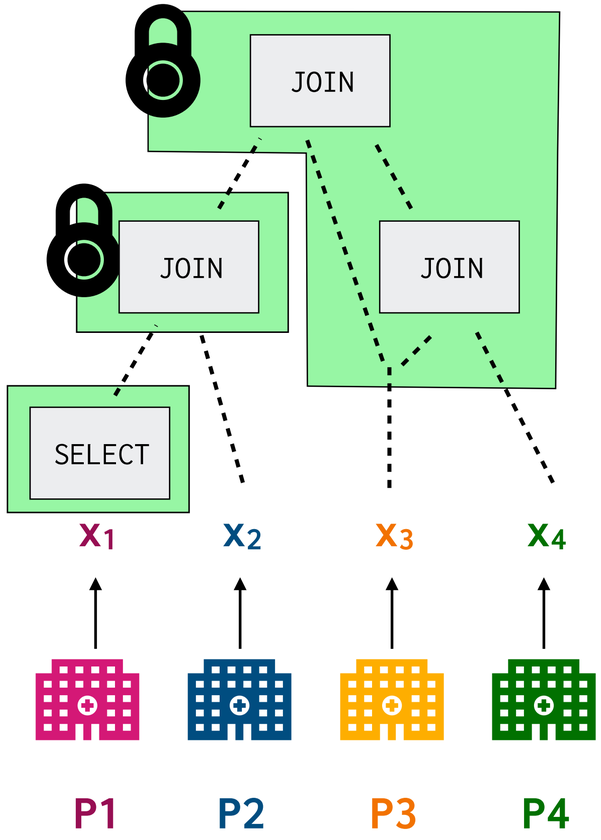

Secure MPC decomposition even in the presence of malicious adversaries

- Enables local computation
- Sub-computations involving different parties can proceed in parallel
- Sub-computations involve only required subset of parties

Senate’s contributions

Secure MPC decomposition protocol

- *Solders* sub-computations together for security of intermediate inputs
- Enforces integrity of sub-computations
- Formalizes class of *admissible* decompositions

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- New Boolean circuit primitives for multiparty operations: *m*-SI, *m*-SU, *m*-Sort, Verifiers
- Realizing SQL operators using the circuit primitives: joins, group by, order by, filters

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- New algorithms for planning the representation and execution of SQL queries
- Cost model for determining the optimal decomposition

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See paper

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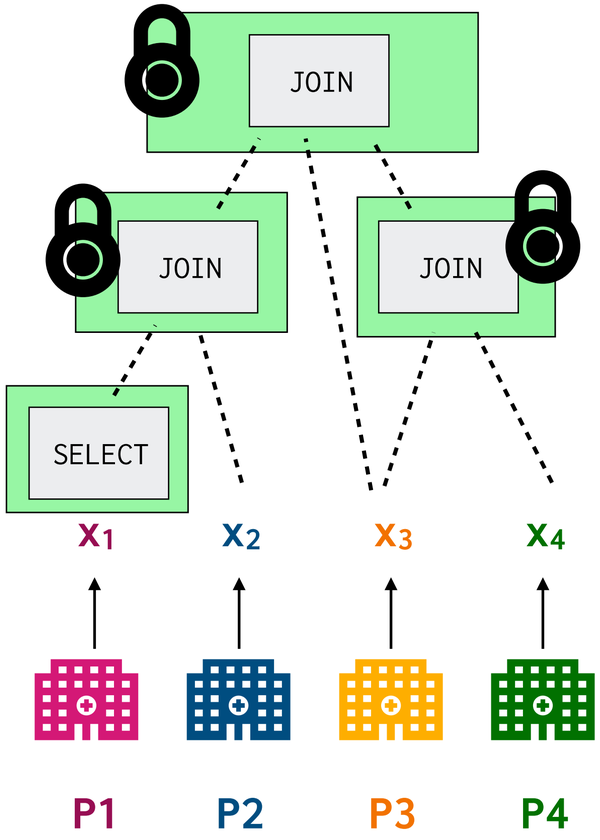

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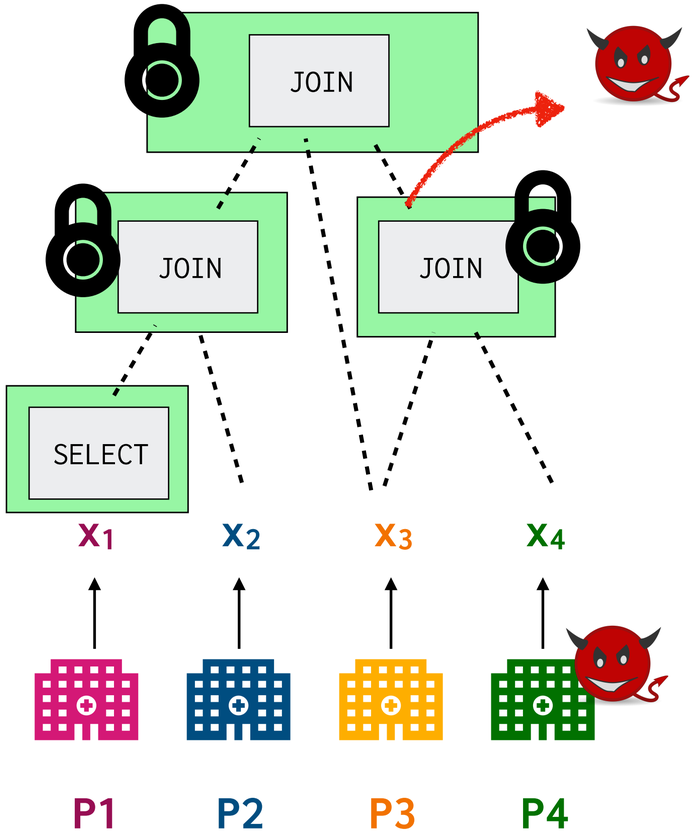

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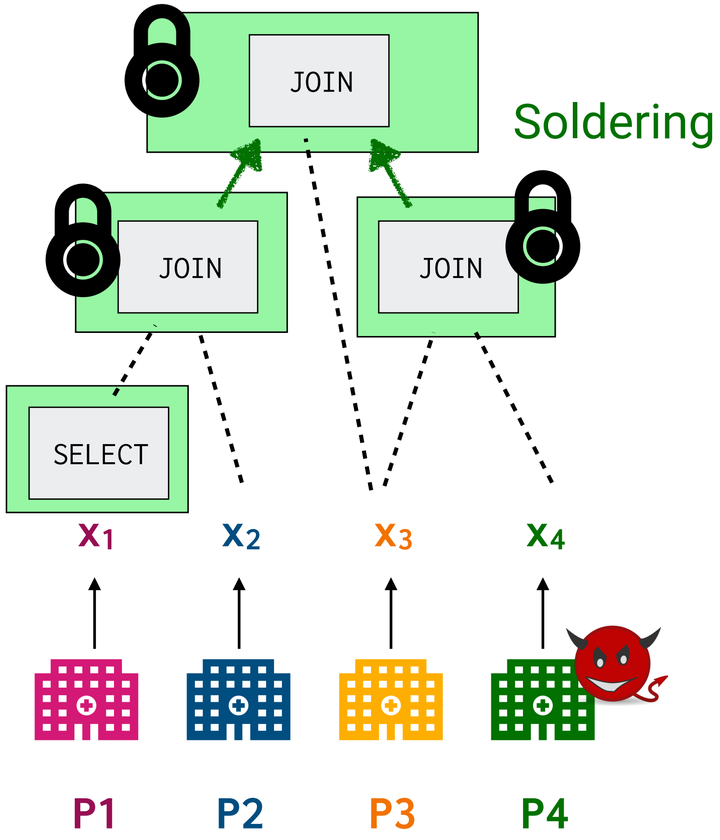

Key technique:

- New lightweight “soldering” technique for WRK [WRK17] circuits that masks intermediate values

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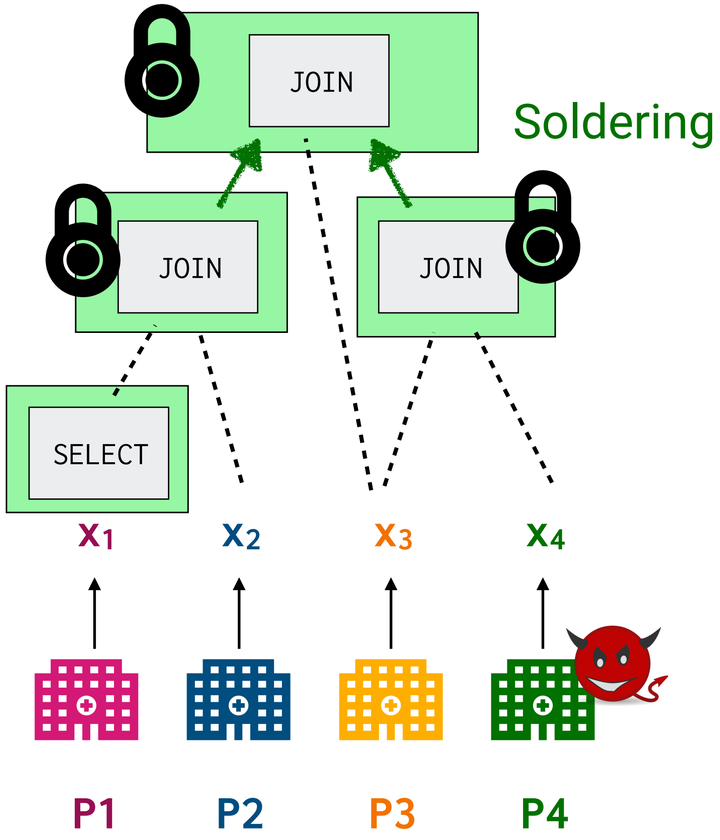
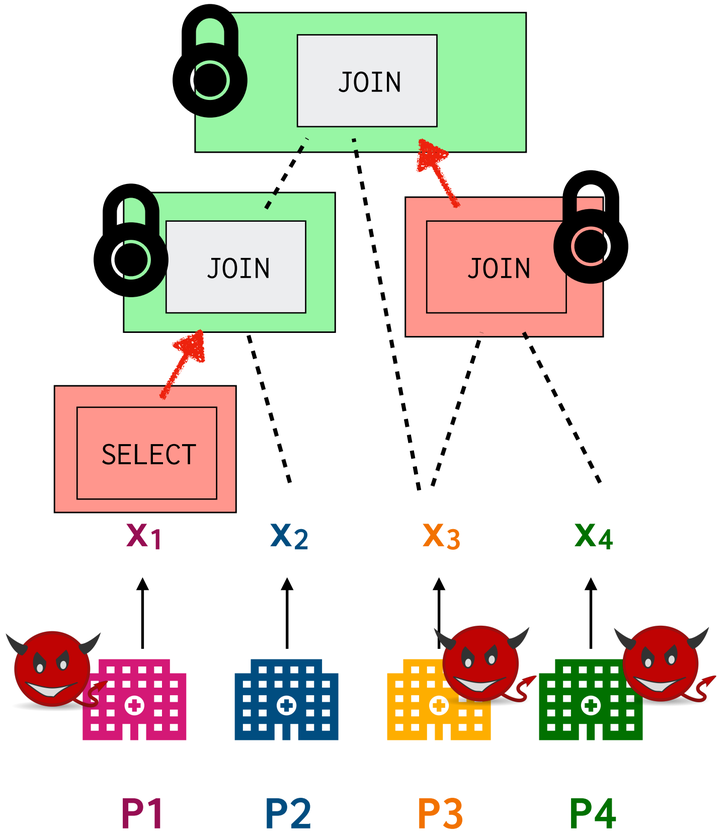


Key technique:

- New lightweight “soldering” technique for WRK [WRK17] circuits that masks intermediate values
- Set of parties in first circuit can be a subset of second

❷ Ensuring validity of intermediate inputs



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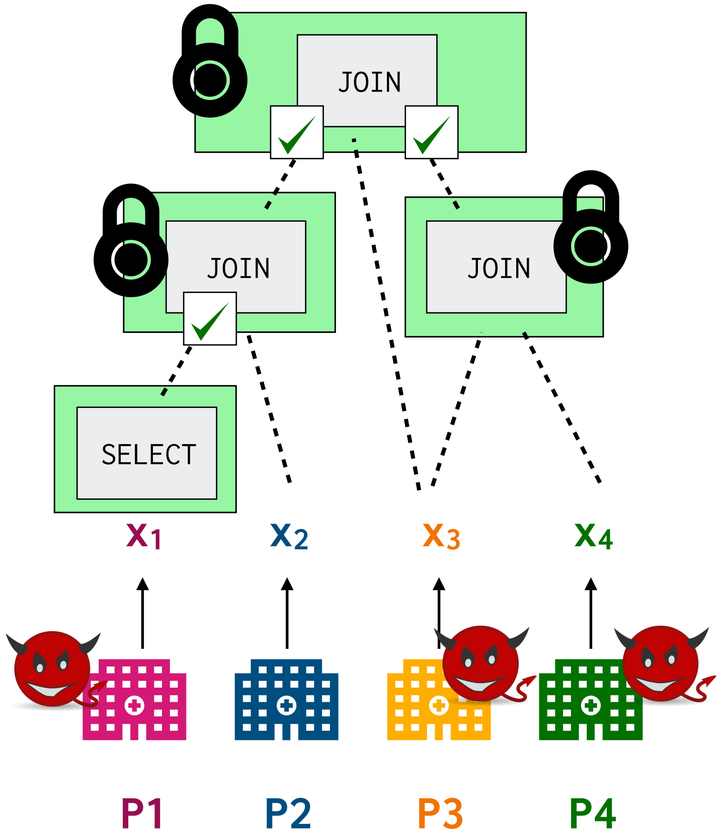

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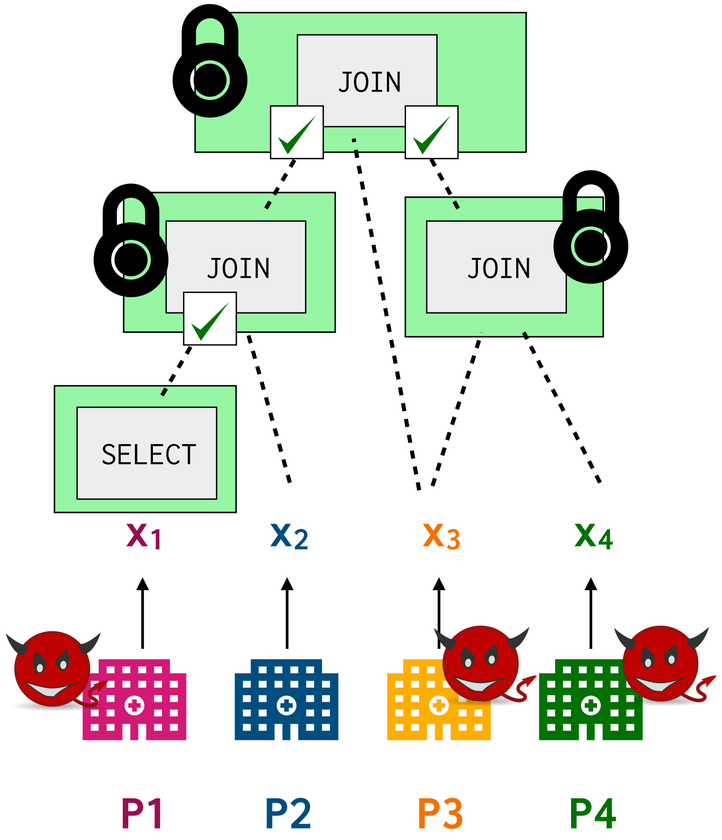
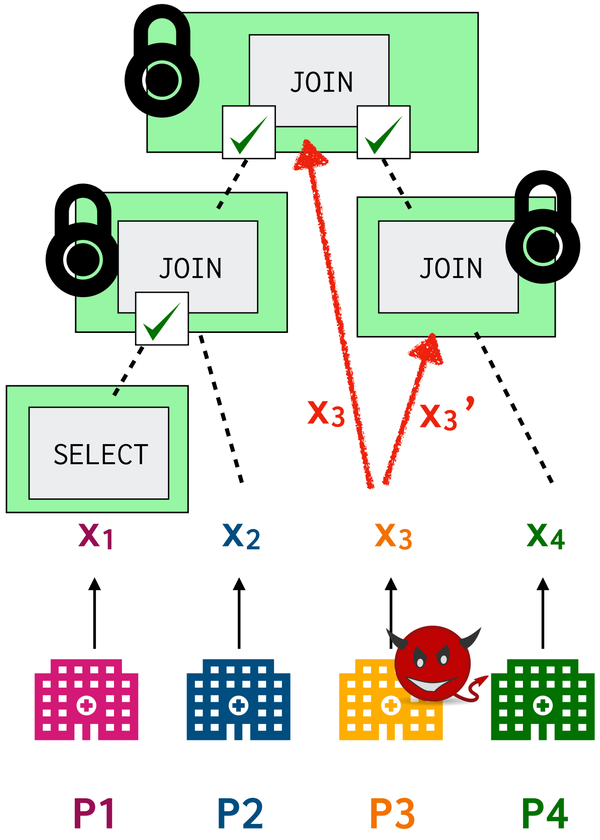


Key technique:

- Parent circuit verifies the validity ☑ of intermediate inputs
- Formalize the class of *admissible* decompositions — every sub-computation must be easily *invertible*

③ Ensuring consistency of inputs



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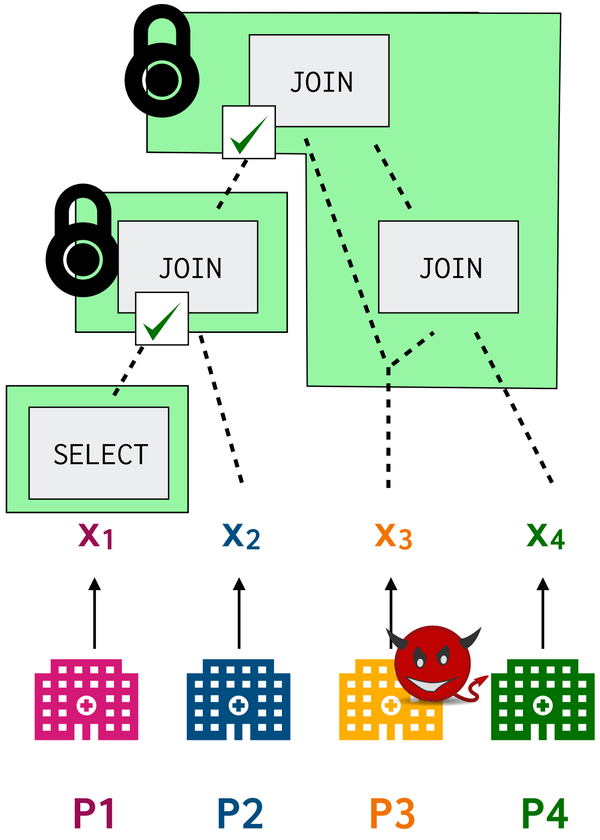

Key technique:

- Restrict admissible decompositions to trees and not graphs

Evaluation Highlights

Performance on TPC-H analytics benchmark

[http://www.tpc.org/tpch/]

Industry standard benchmark for analytics queries

- Comprises a rich set of 22 complex queries on data split across 8 tables
- No notion of multiple “parties”, so we assume one table per party

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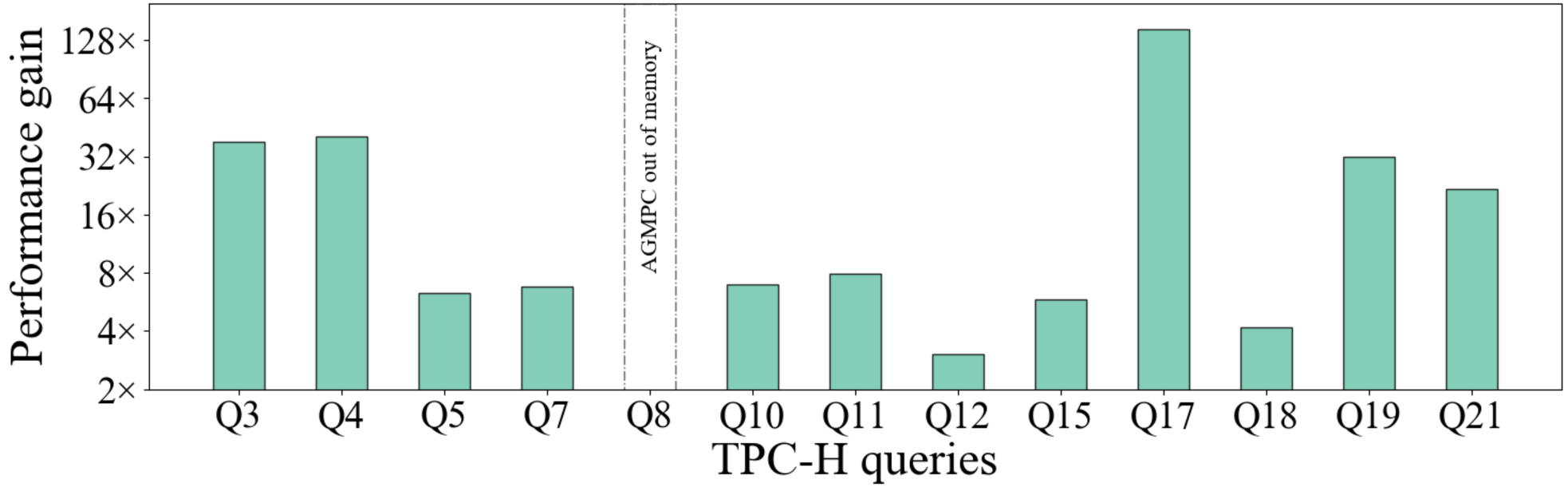
Methodology

- r5.12x large AWS instances in LAN and WAN settings
- Baseline: AGMPC framework (implements monolithic WRK)

[https://github.com/emp-toolkit/emp-agmpc] [WRK17]

Performance on TPC-H analytics benchmark

Senate supports 13 of 22 queries, up to 145x faster than the baseline



Summary

Senate is an MPC platform for securely executing collaborative analytical queries in the presence of malicious adversaries

Improves performance over the state of the art by up to 145x:

- Protocol for secure MPC decomposition
- Efficient query planning and execution algorithms based on a cost model

Summary

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Thanks!

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