PET-Exchange: A Privacy Enhanced Trading Exchange using Homomorphic Encryption

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Proc. International Conference on Privacy, Security, and Trust (PST), Copenhagen, Denmark, August 2023

Securities exchange

- Trading platforms
- Electronic shift
  - High-frequency trading
- Unfair, unethical, or illegal trading
  - Front running
  - Penny jumping
  - Insider trading

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Insider traders use ETFs to front-run M&A deals, academics say

Research identifies $2.75bn worth of potential 'shadow trades' in US between 2009 and 2021


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Prosecutors charge three investors with insider trading in Trump SPAC deal
By Matt Egan and Kara Scannell, CNN
Updated 12:58 PM EDT, Thu June 29, 2023
Donald Trump's media company owns Truth Social. Investors seeking a merger with his company were charged with insider trading.
New York (CNN) — Federal prosecutors arrested three investors on Thursday on insider trading charges related to a deal to take former President Donald Trump's media business public.

Securities trading

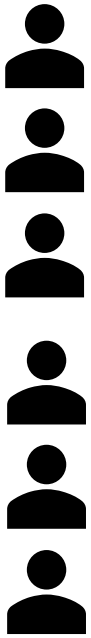
- Transparency in public exchanges
- Dark pools
  - Less transparent, lack of regulation
- Cryptography
  - May prevent unfair practices
- Homomorphic encryption
  - Not trivial due to large overheads

Contributions

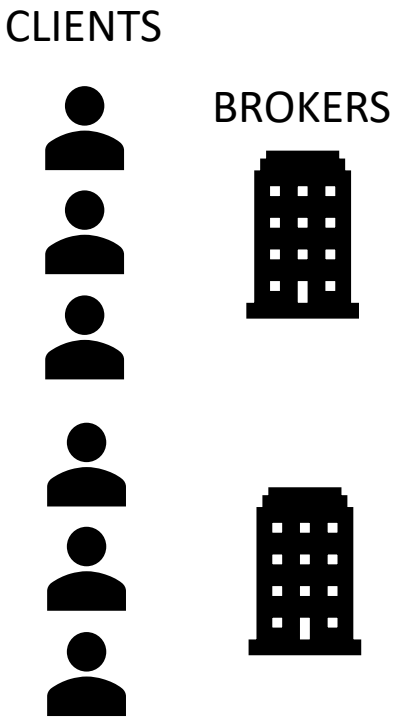
- We present PET-Exchange, a privacy-preserving trading framework using homomorphic encryption for trading securities, partially matching limit orders between multiple buyers and sellers
- Using various conditions and configurations, we provide insights into the most attractive tradeoffs applicable to a wide range of exchanges and use cases
- We provide insights into current performance bottlenecks and validate that we can achieve high accuracy with many decimals of precision

Securities exchange

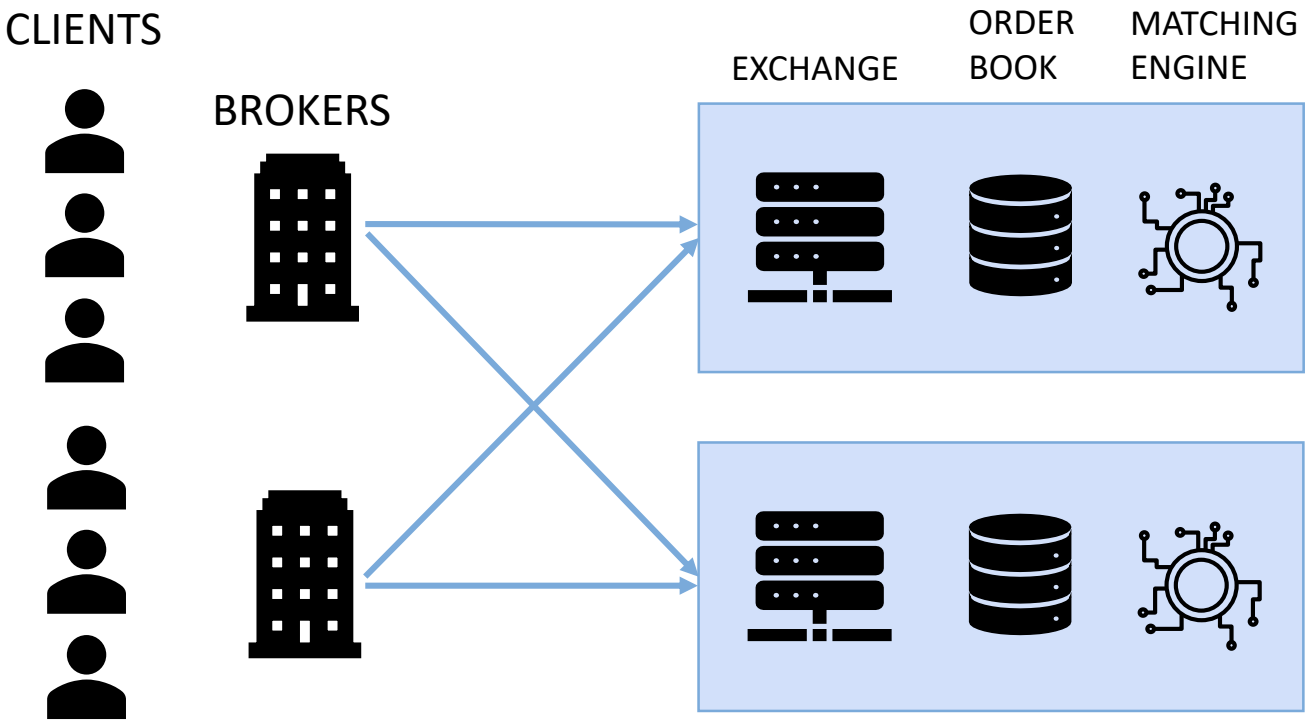
CLIENTS



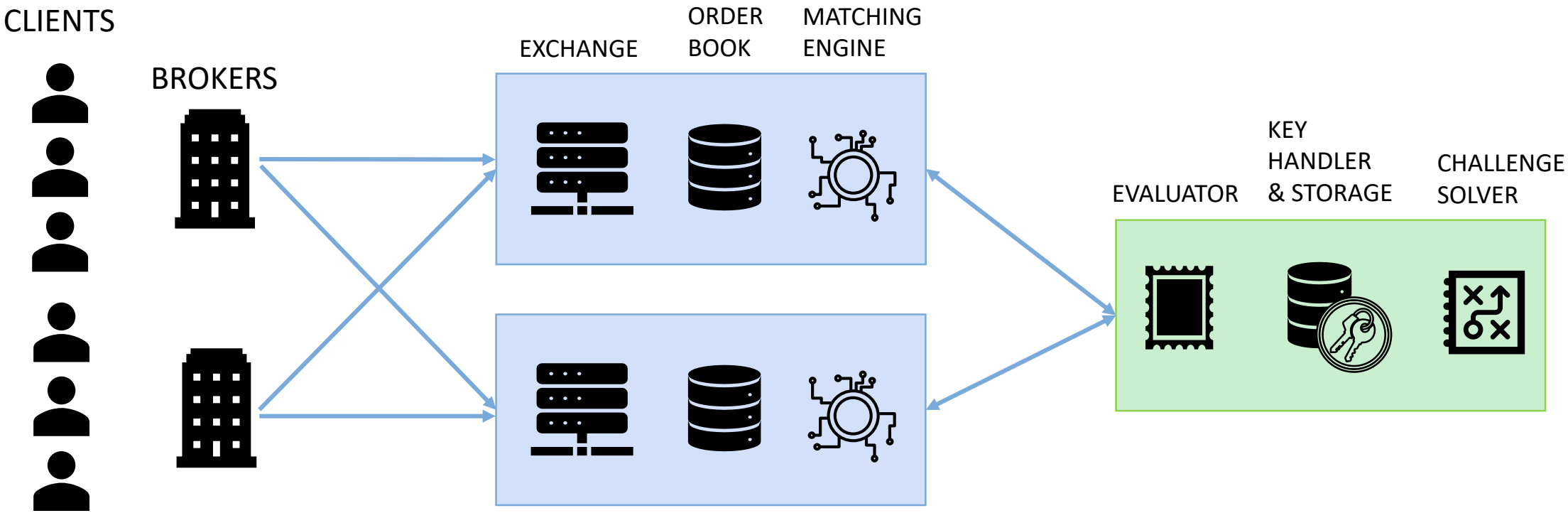
Securities exchange



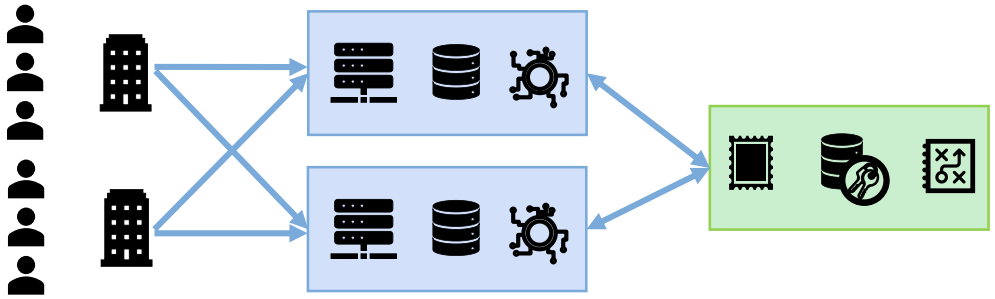
Securities exchange



PET-Exchange

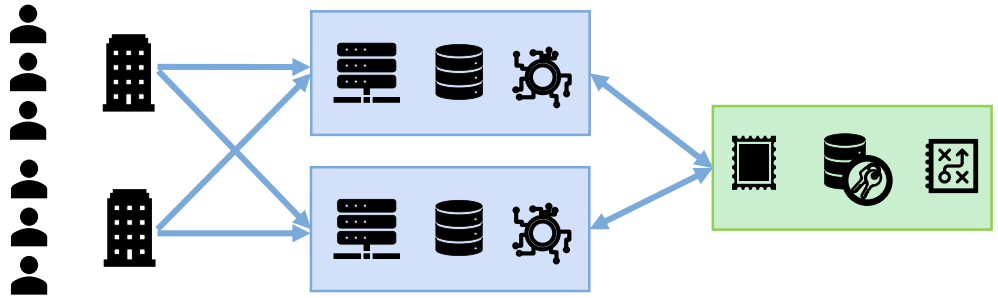


Encrypted order handling



- Order entry
  - Sorted order book
  - Binary search on encrypted orders
- Values cannot be compared directly
  - Local comparison
  - Remote comparison

Encrypted order handling

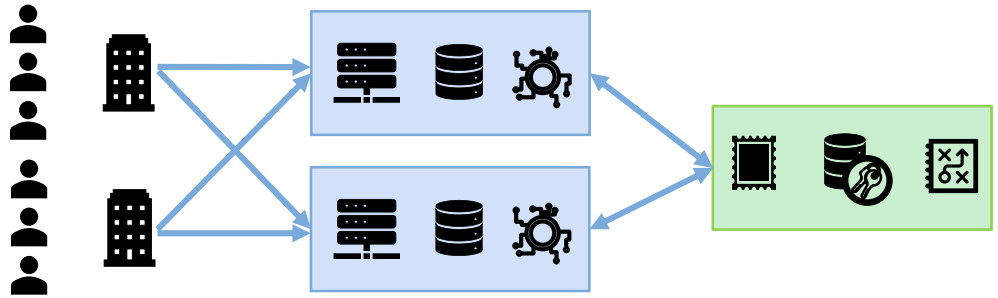


- Local comparison
  - Approximation

$$k = f(\theta^A,\ \theta^B) \approx \begin{cases} 0, & \text{if } \theta^A < \theta^B \\ 0.5, & \text{if } \theta^A = \theta^B \\ 1, & \text{if } \theta^A > \theta^B \end{cases}$$

  - Challenge creation + validation

Encrypted order handling



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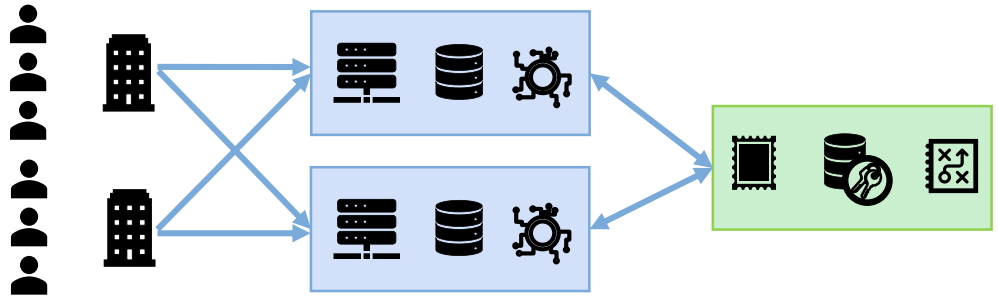
  - Challenge creation + validation
- Remote comparison
  - Padded order values instead of approximation value

Encrypted order handling



- Order matching and execution
  - Local or remote comparison method
  - Homomorphic subtraction to continuously match partially filled orders

Configuration parameters

» CKKS configuration parameters and their overheads

Name	Level	Poly. modulus degree	Security level	E[Order size]	E[Remote challenge size]	E[Local challenge size]
CKKS-11	1	2,048	128	66 KB	66 KB	N/A
CKKS-12	1	4,096	256	130 KB	131 KB	N/A
CKKS-14	6	16,384	128	3.15 MB	3.15 MB	2.10 MB
CKKS-15	6	32,768	256	6.29 MB	6.29 MB	4.19 MB
Plain	N/A	N/A	N/A	0.33 KB	0.18 KB	0.31 KB

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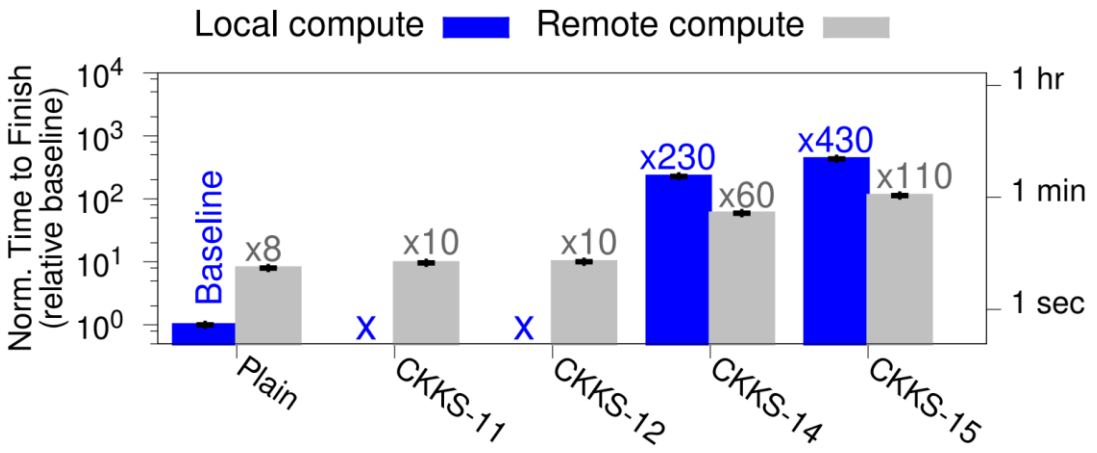
Performance metrics

- Time-to-Finish (TTF)
  - Total runtime for trading session
- Time-to-Match (TTM)
  - Time spent on matching encrypted orders
- Time-to-Insert (TTI)
  - Time spent on inserting encrypted order into order book
- Time-to-Solve-Challenges (TTSC)
  - Time spent on evaluator solving challenges

Evaluation

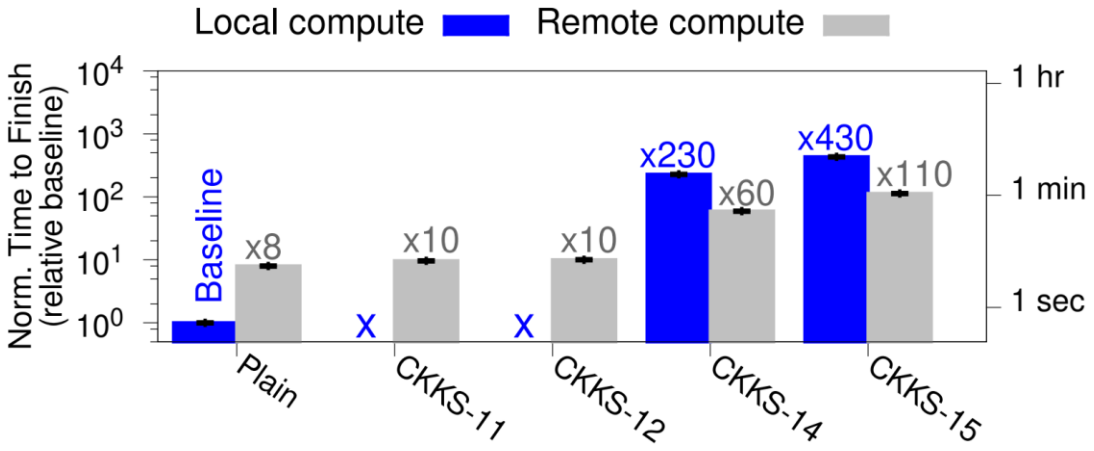
» Increase in time to finish (TTF) relative just doing the non-encrypted (i.e., plain) comparisons locally.

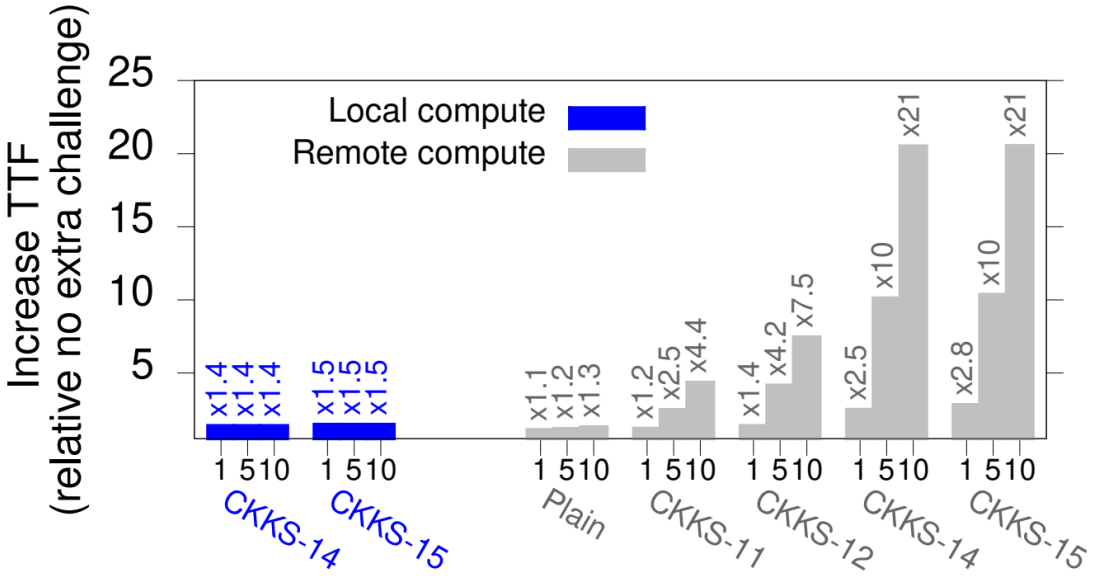


Evaluation

- Increase in time to finish (TTF) relative just doing the non-encrypted (i.e., plain) comparisons locally.

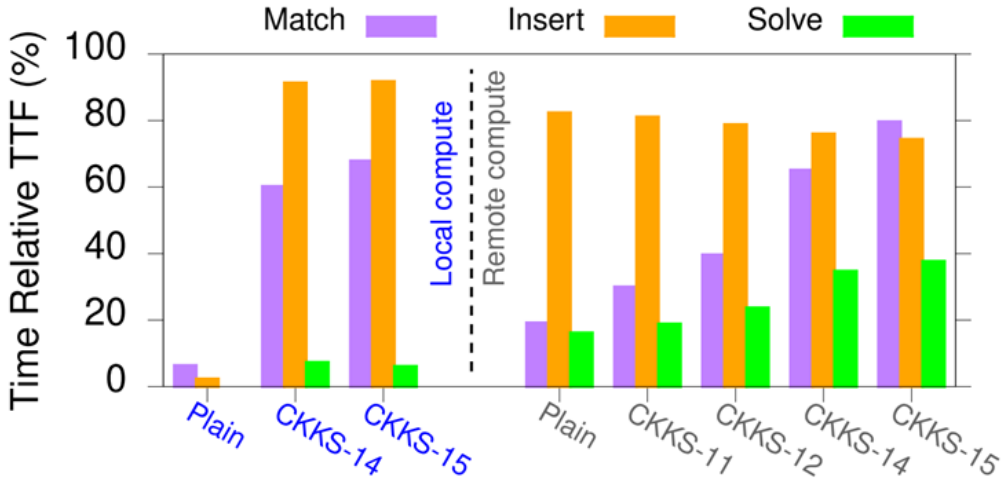
- Increase in time to finish (TTF) when adding N additional challenges to every challenge.



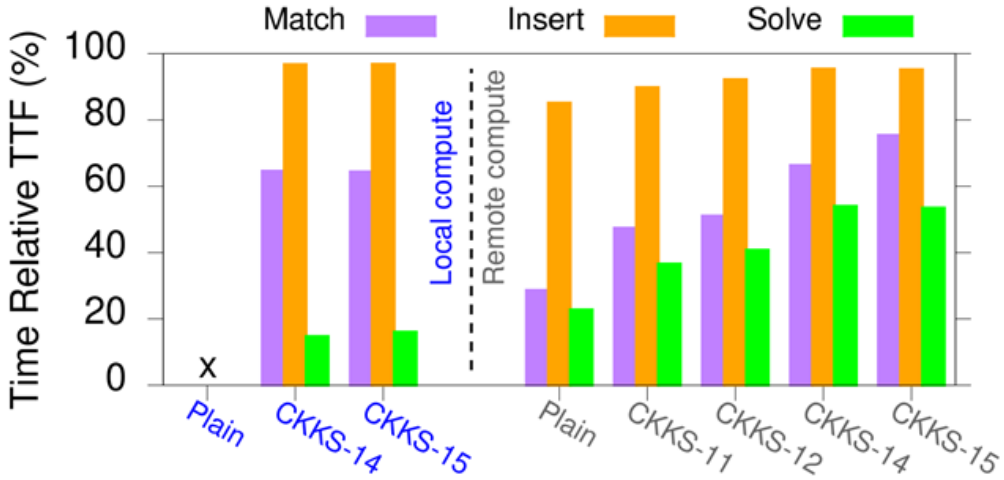


Bottlenecks

» Relative time consumed on different tasks (executed in parallel) relative to the overall time to finish (TTF).



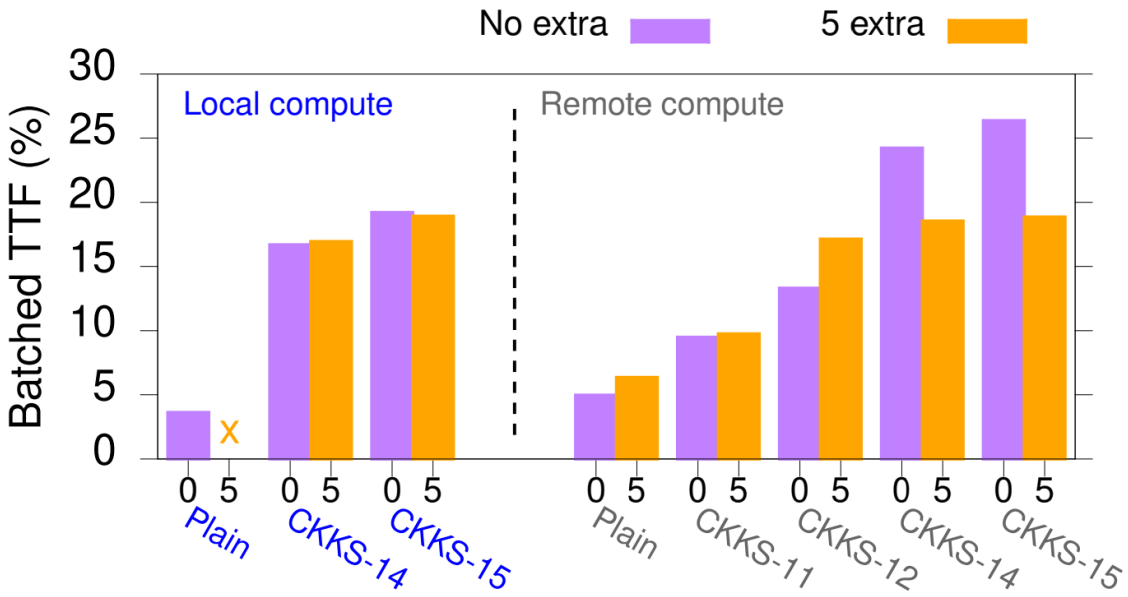
No extra challenges



Five extra challenges per challenge

Batched-based workload

» Relative time to finish (TTF) for batched workload use case compared to the default use case.



Precision and Accuracy

- Operations must be performed with sufficient precision and accuracy

- Average deviation from expected value per configuration and decimal precision

Dec.	Plain	CKKS-11	CKKS-12	CKKS-14	CKKS-15
≤ 8	0	0	0	0	0
9	0	10^{-7}	10^{-5}	10^{-7}	0
10	0	$1.08 \cdot 10^{-6}$	$2.11 \cdot 10^{-8}$	$1.14 \cdot 10^{-8}$	0
11	0	$4.81 \cdot 10^{-8}$	$3.14 \cdot 10^{-8}$	$1.11 \cdot 10^{-8}$	0
12	0	$1.59 \cdot 10^{-6}$	$3.12 \cdot 10^{-8}$	$2.19 \cdot 10^{-9}$	0
13	0	$1.61 \cdot 10^{-8}$	$2.30 \cdot 10^{-8}$	$1.52 \cdot 10^{-9}$	0
14	10^{-11}	$1.11 \cdot 10^{-8}$	$2.83 \cdot 10^{-8}$	$4.44 \cdot 10^{-9}$	10^{-11}
15	10^{-11}	$1.46 \cdot 10^{-8}$	$1.97 \cdot 10^{-8}$	$6.51 \cdot 10^{-9}$	10^{-11}

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Paper is online!

David Hasselquist (david.hasselquist@liu.se)

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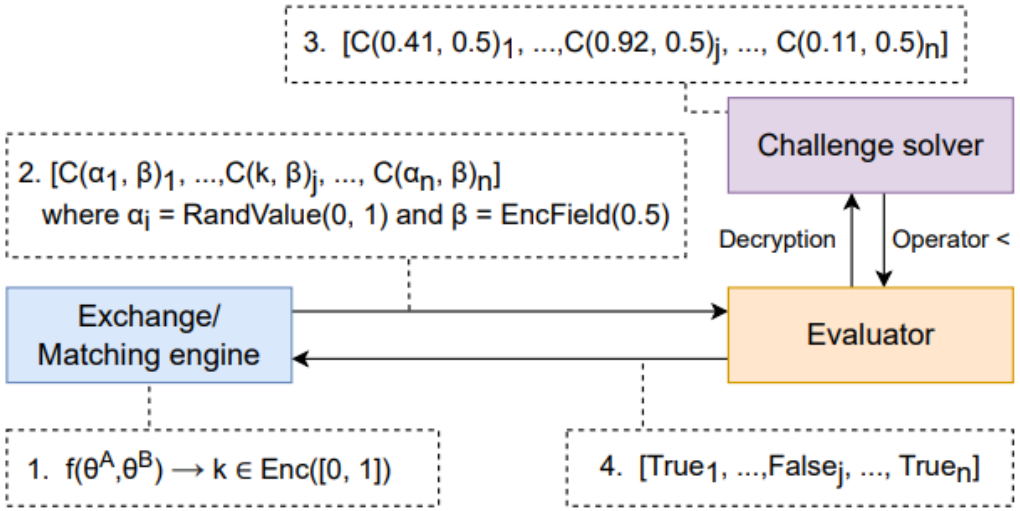
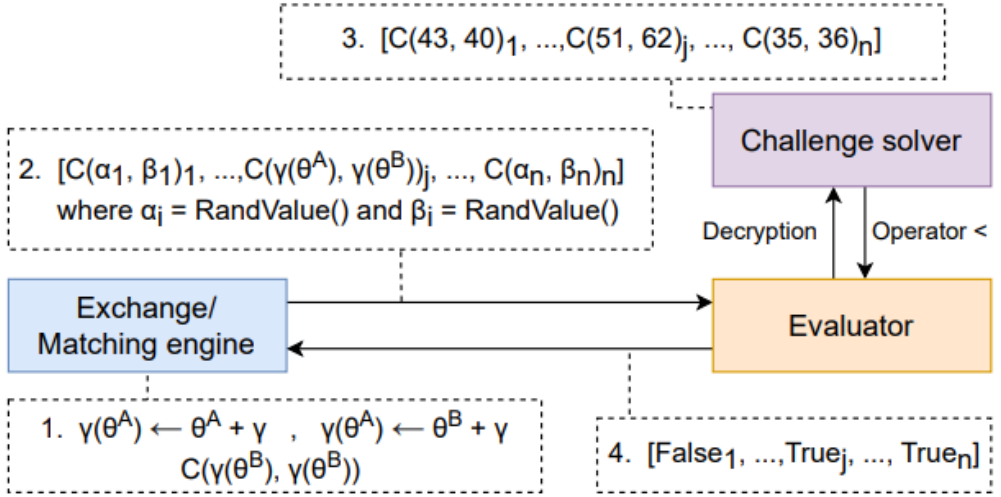
Extra slides

Local vs. remote comparison method



Local comparison



Remote comparison