Time-Lock Puzzles with Efficient Batch Solving

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Bocconi University and MPI-SP

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Time-Lock Puzzles [May93, RSW96]

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- Fast puzzle generation - Time to generate 

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- Puzzle opening takes a long time - The circuit that opens  has depth at least T. Parallelism shouldn't help.

Applications

Applications

Encrypt to the future!

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Sealed Bid Auctions

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Non-Malleable Commitments

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Miner extractable value prevention

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Blockchain front running prevention, fair contract signing, cryptocurrency payments, distributed consensus, more!

Applications - Batch Solving

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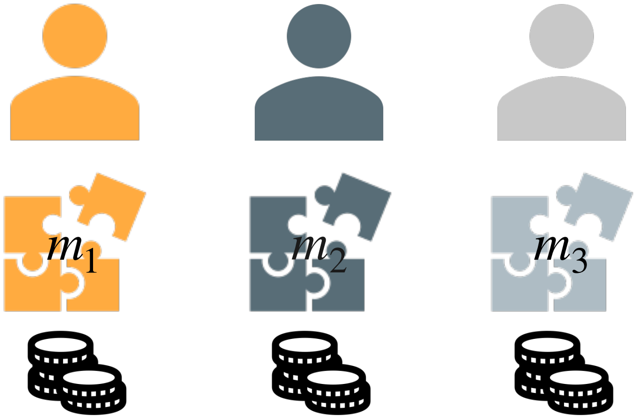
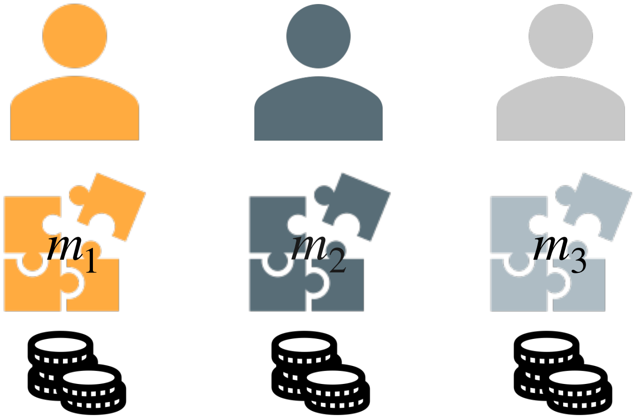


Applications - Batch Solving



Decrypt all transactions!
Solve all puzzles

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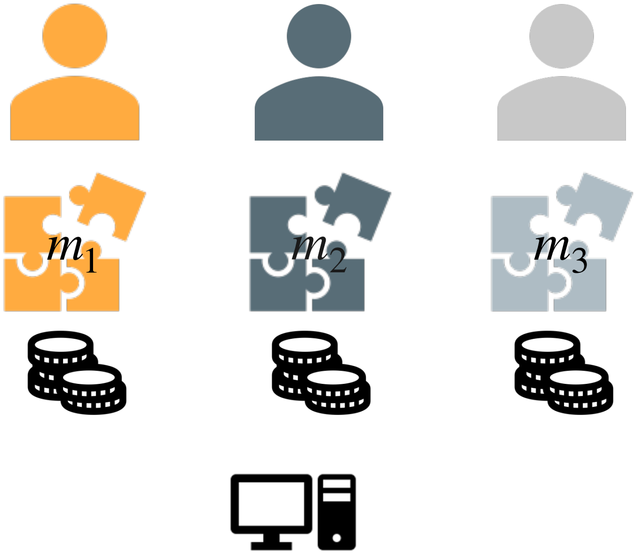

Blockchains, byzantine broadcast

Scalability - Millions of users need solving

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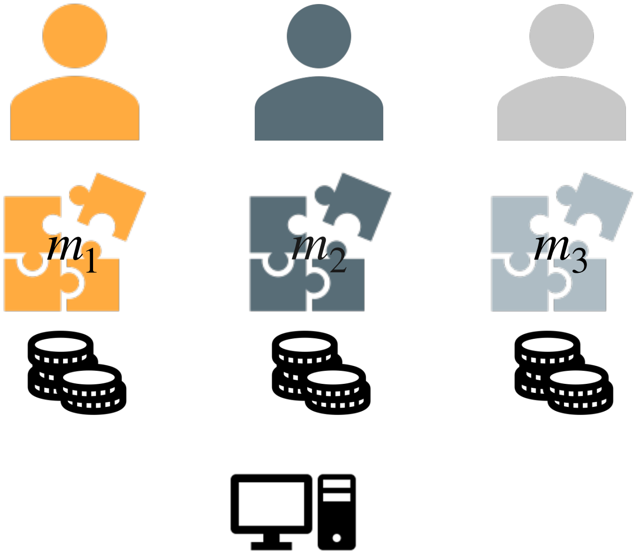
Applications - Batch Solving



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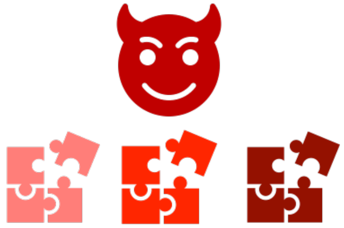

Denial of service attacks

Batching Complexity

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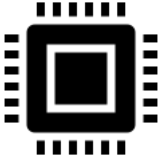

$N \cdot \text{poly}(T)$

Trivial solution

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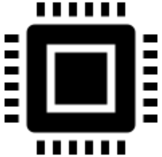

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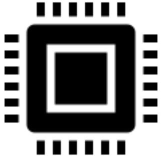

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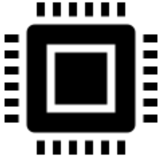

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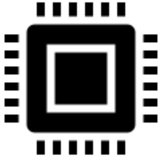

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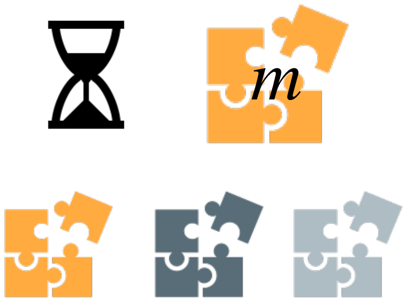
This work

Our Result



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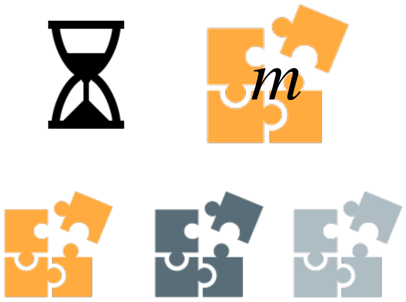

- Generic template for constructing batchable TLPs.

  Only prior solution was based on iO [SLM+23].

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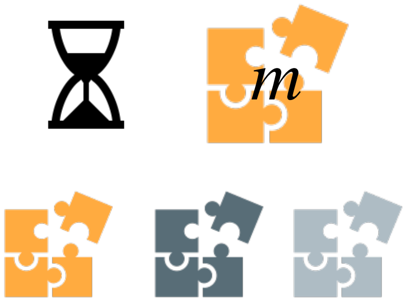

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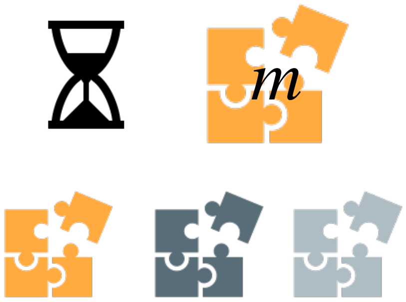

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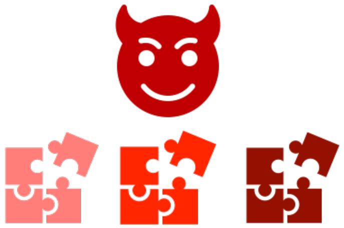
- We give two concrete constructions and an implementation.

- Introduce the notion of rogue batch solving.



Roadmap

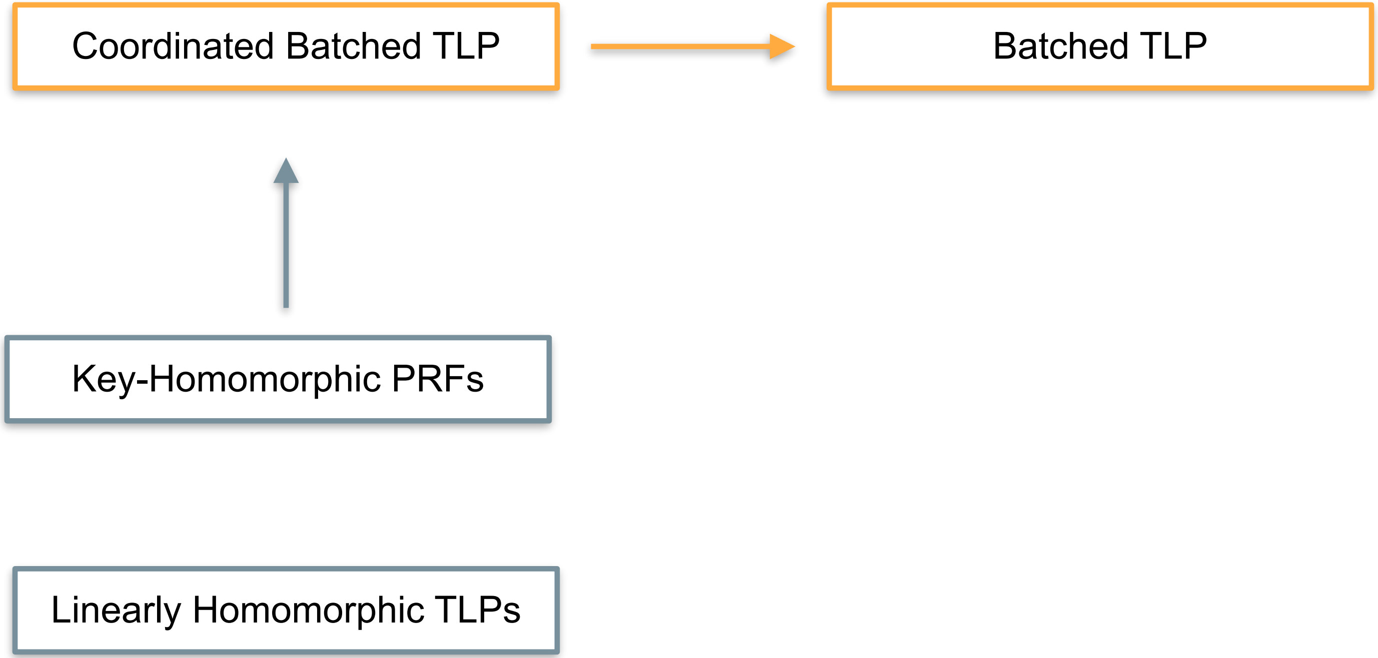
Roadmap

Batched TLP

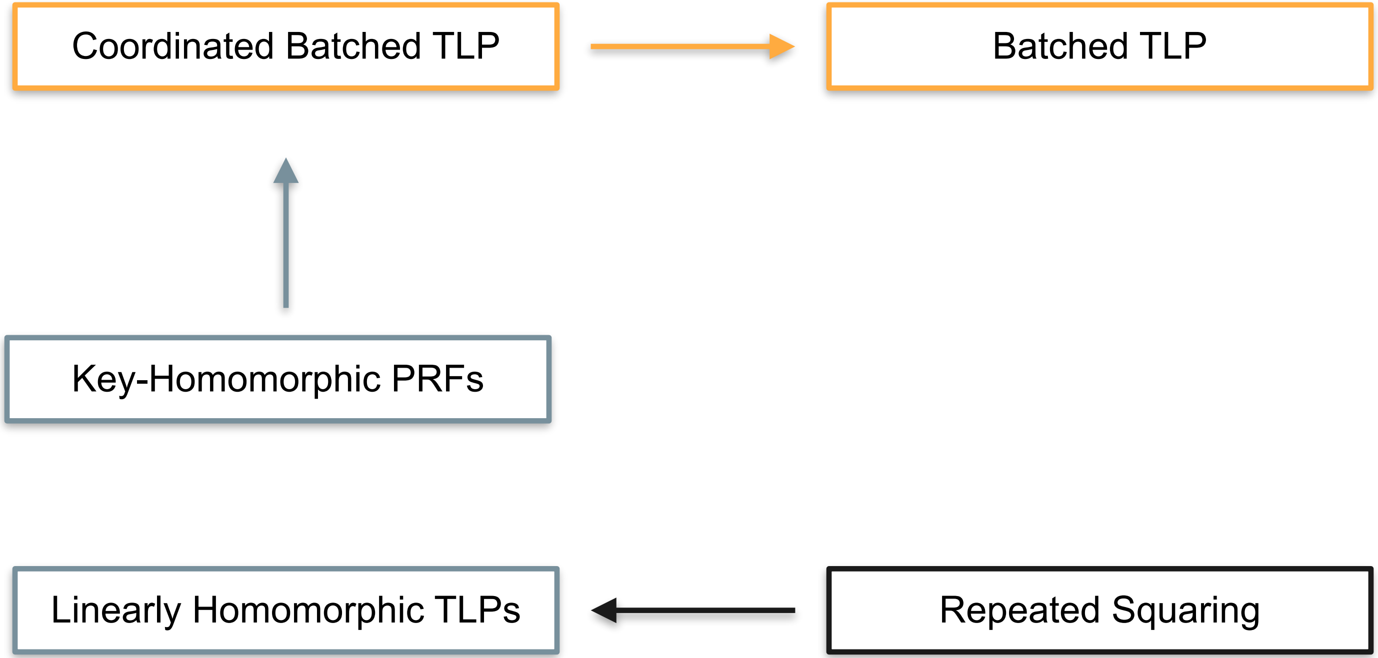
Roadmap

Coordinated Batched TLP → Batched TLP

Roadmap

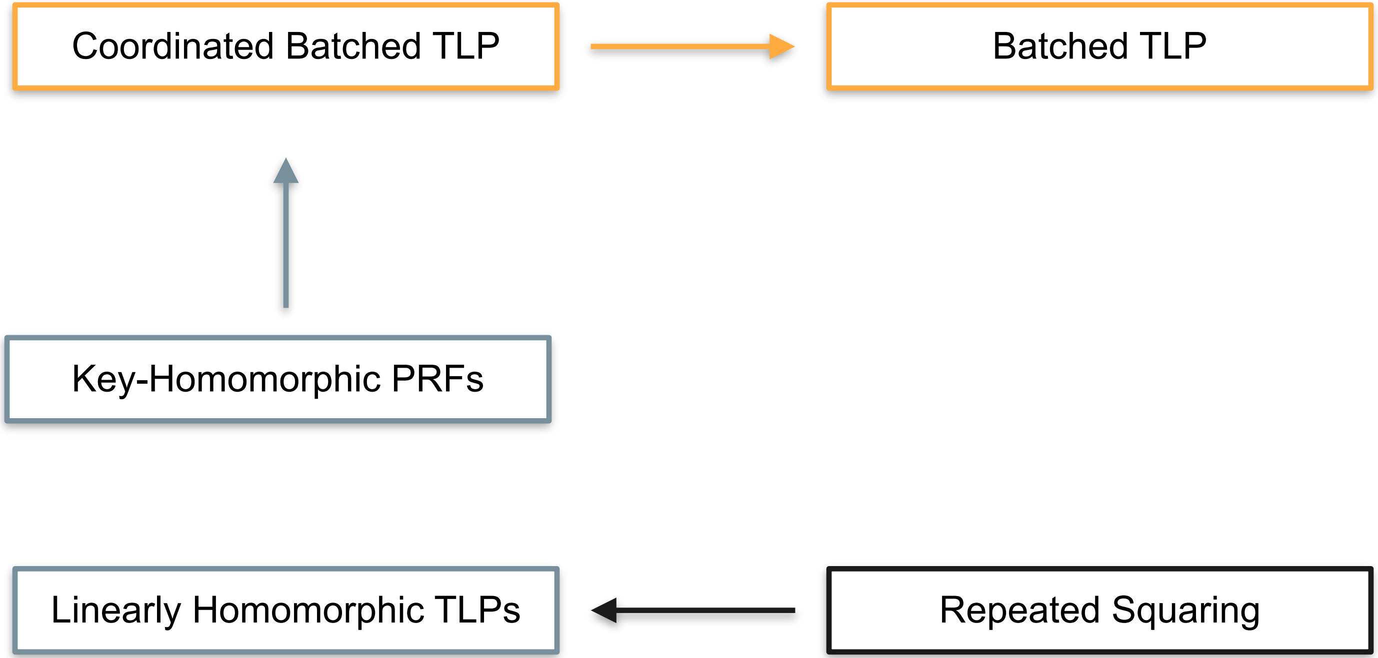

Coordinated Batched TLP
Batched TLP
Key-Homomorphic PRFs
Linearly Homomorphic TLPs

Roadmap



[MT19, TCLM21]

Roadmap



[MT19, TCLM21] $x, x^2, x^4 = (x^2)^2, x^8, \ldots, x^{2^T}$

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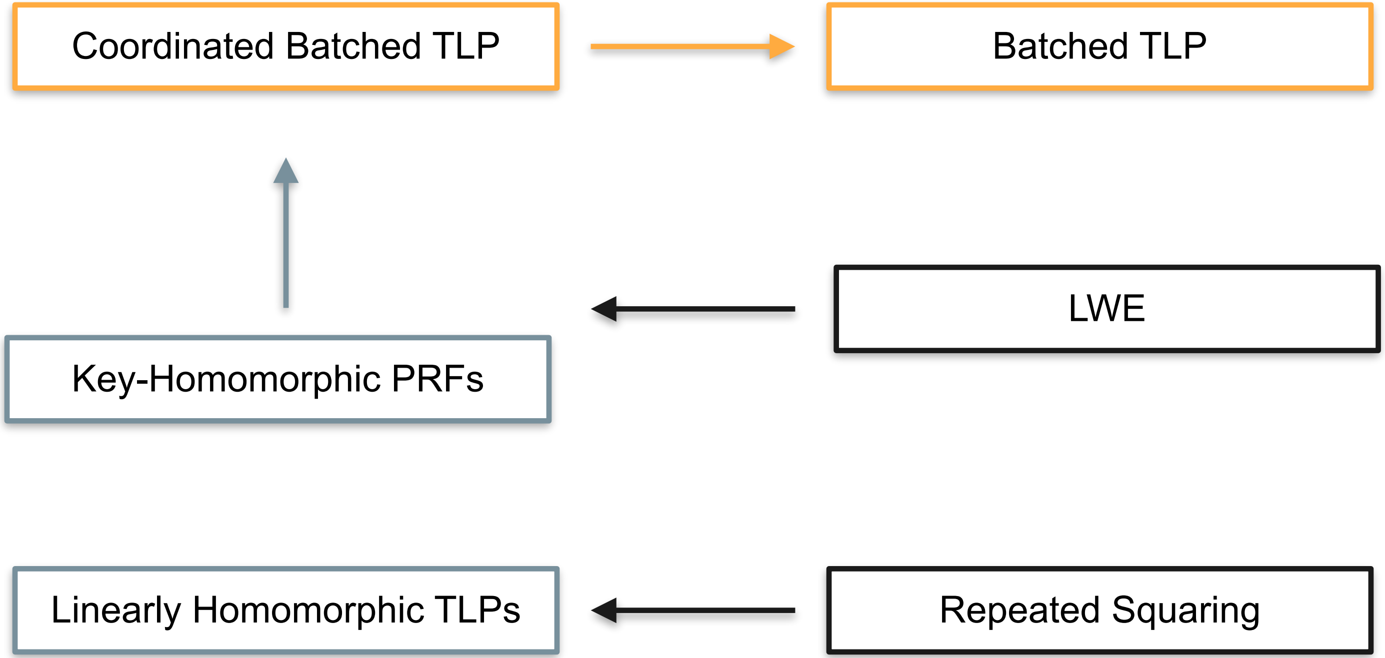

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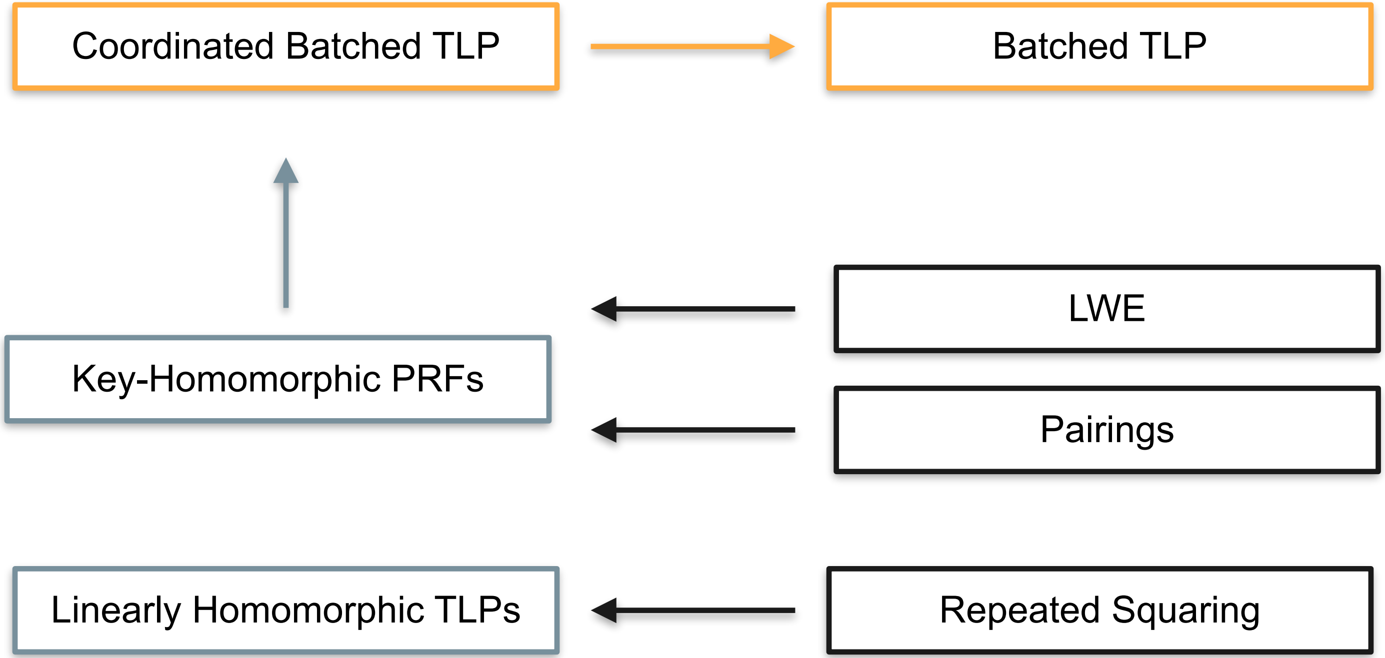

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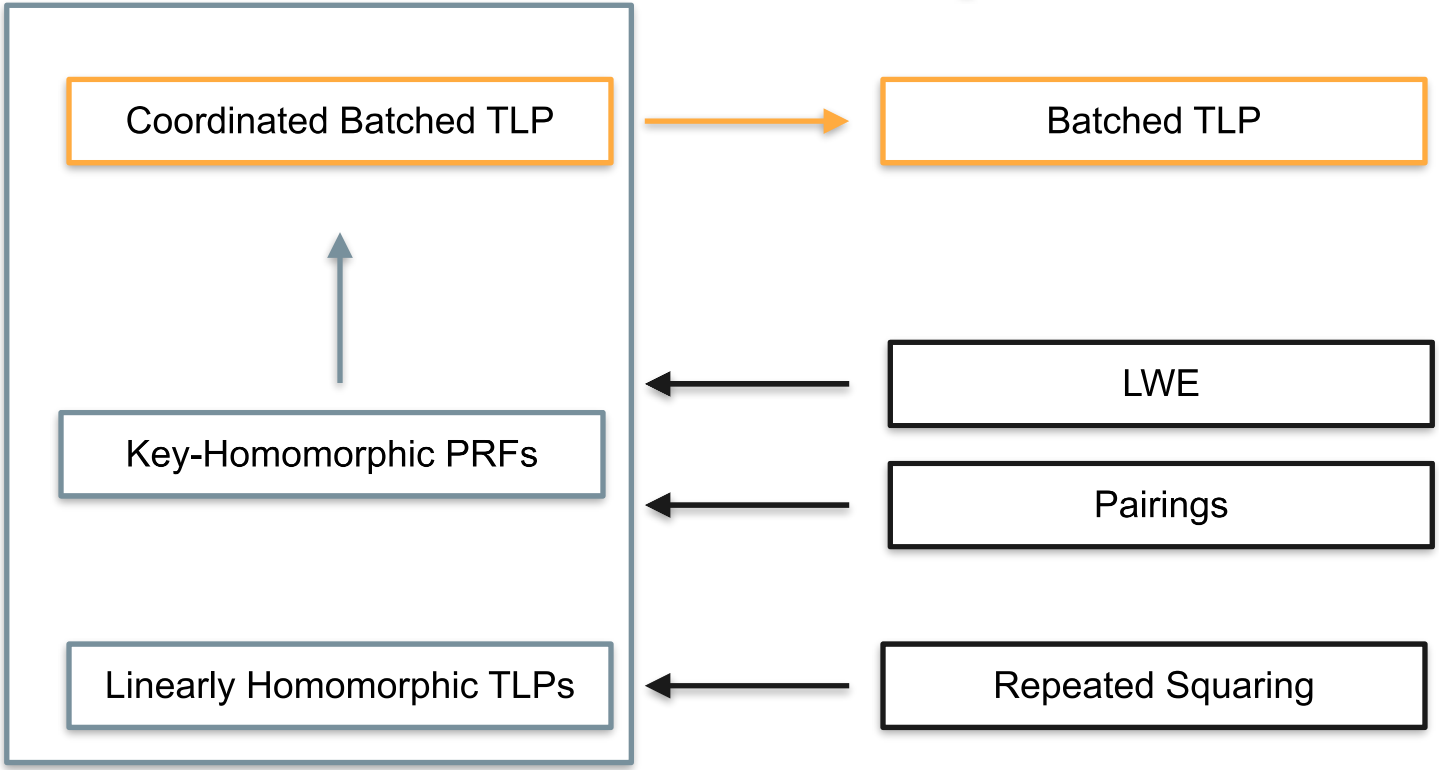

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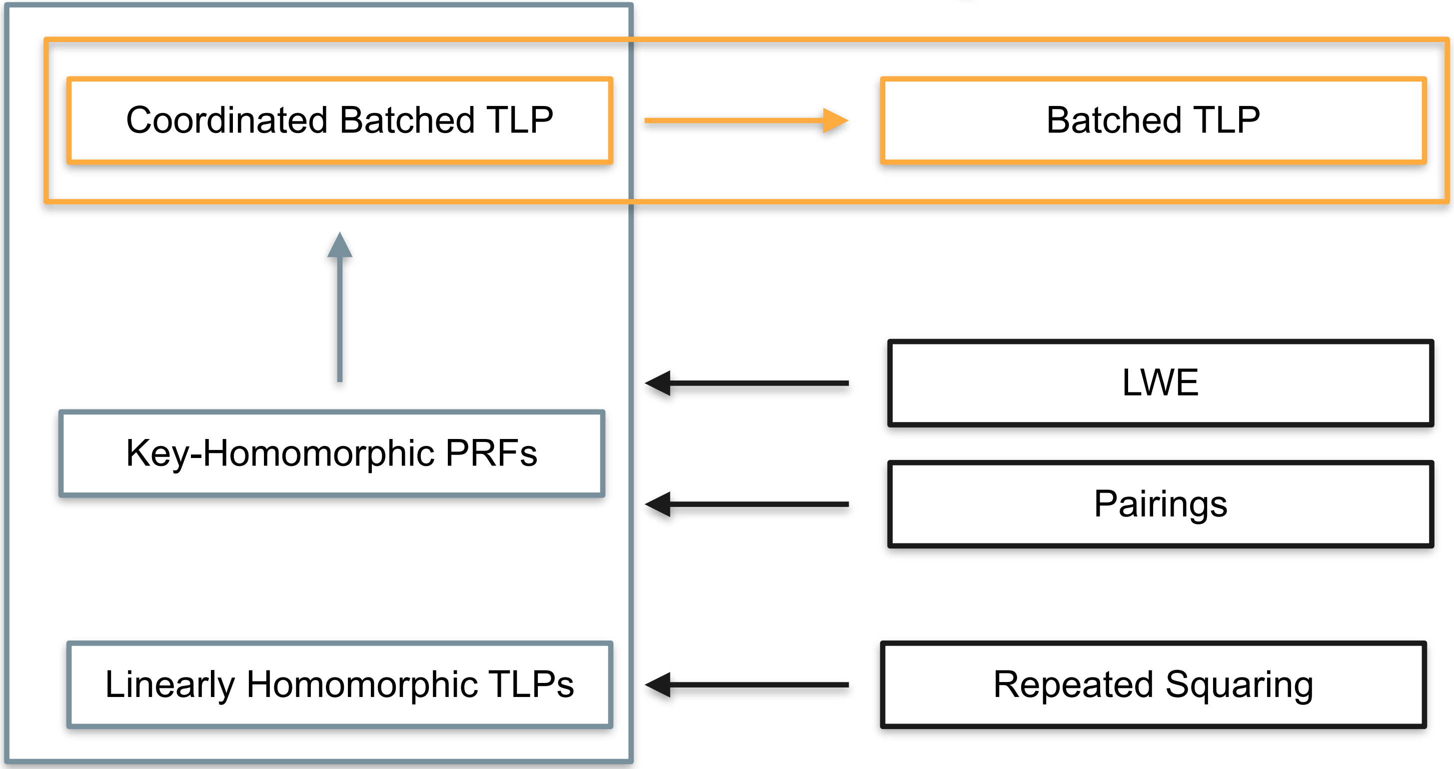

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Linearly Homomorphic TLP

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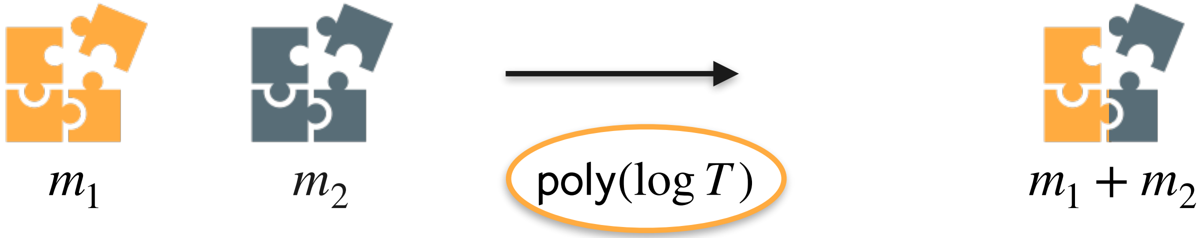
m_1

m_2

Linearly Homomorphic TLP



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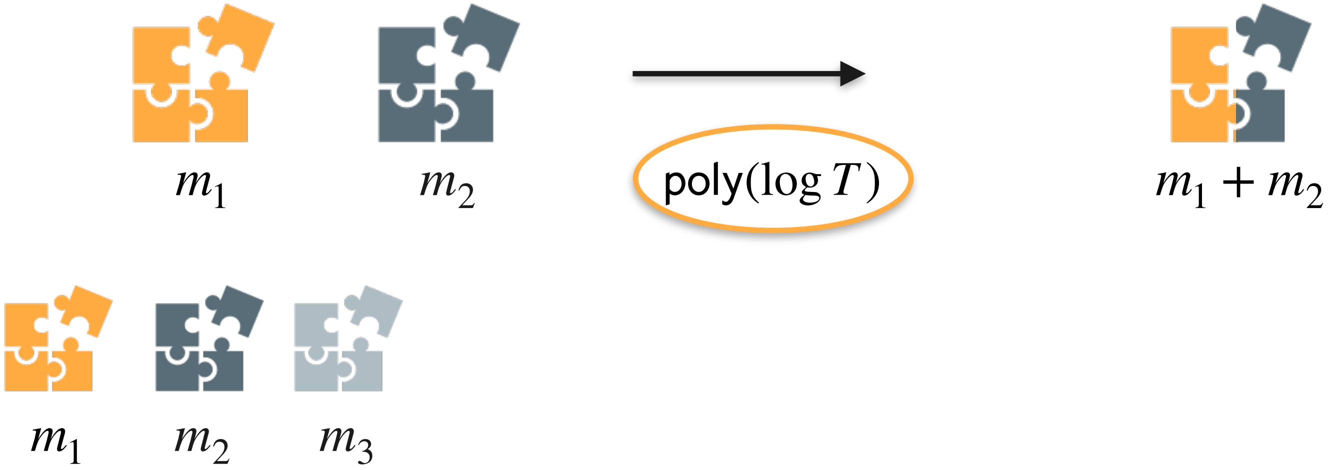

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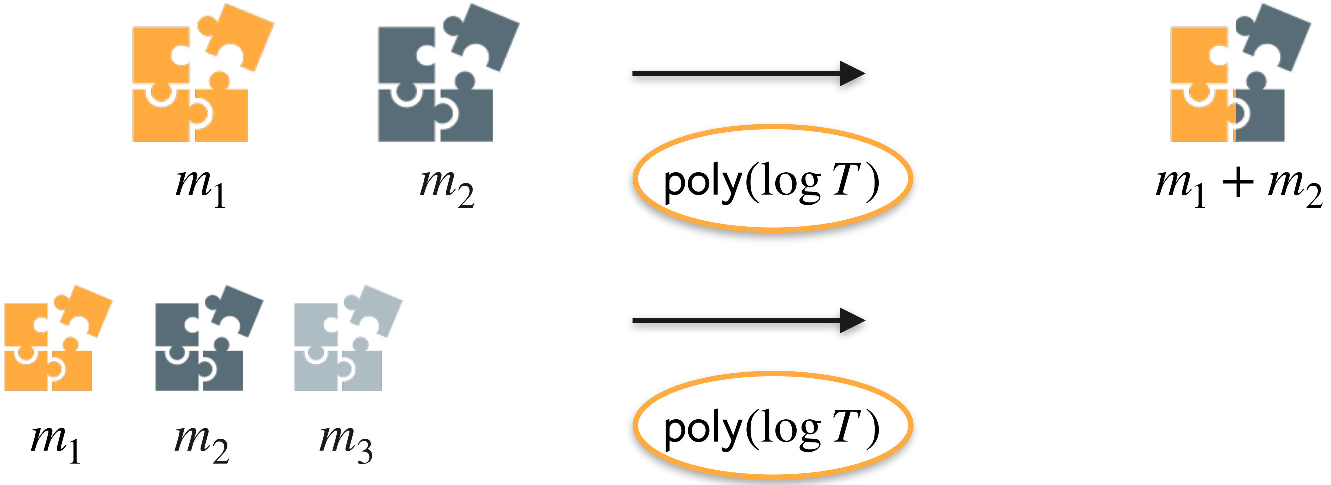

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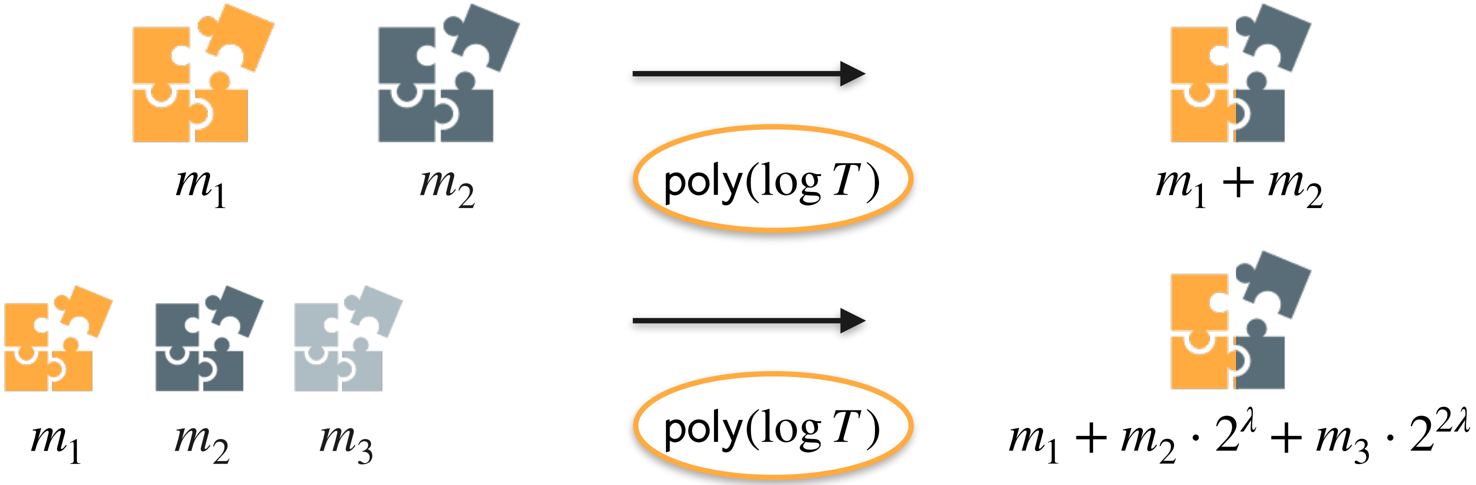

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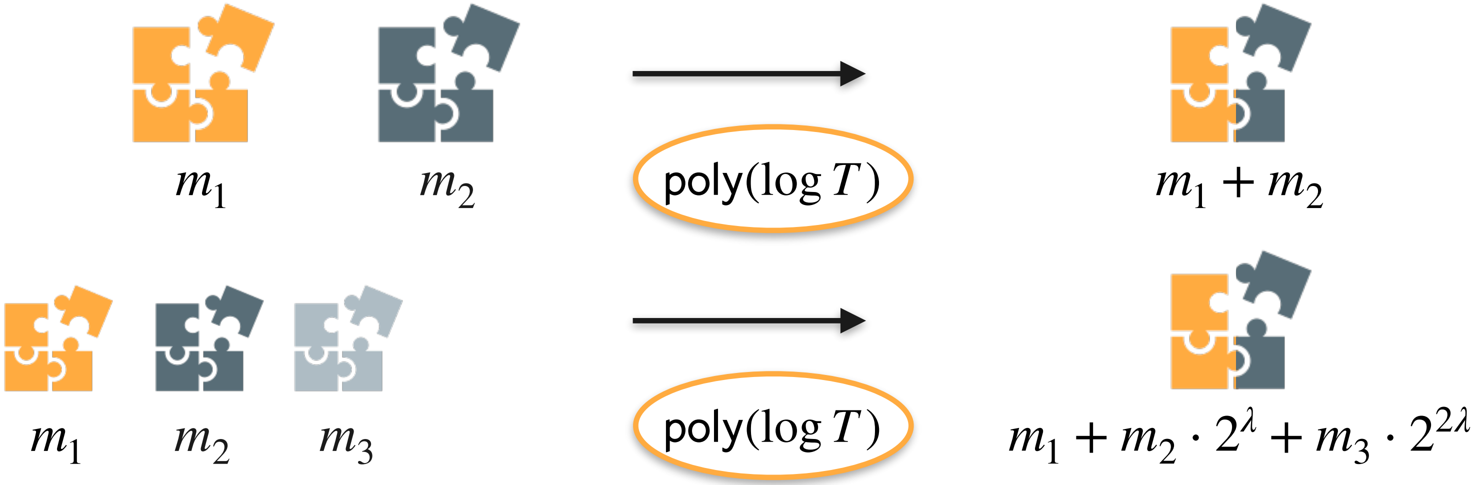
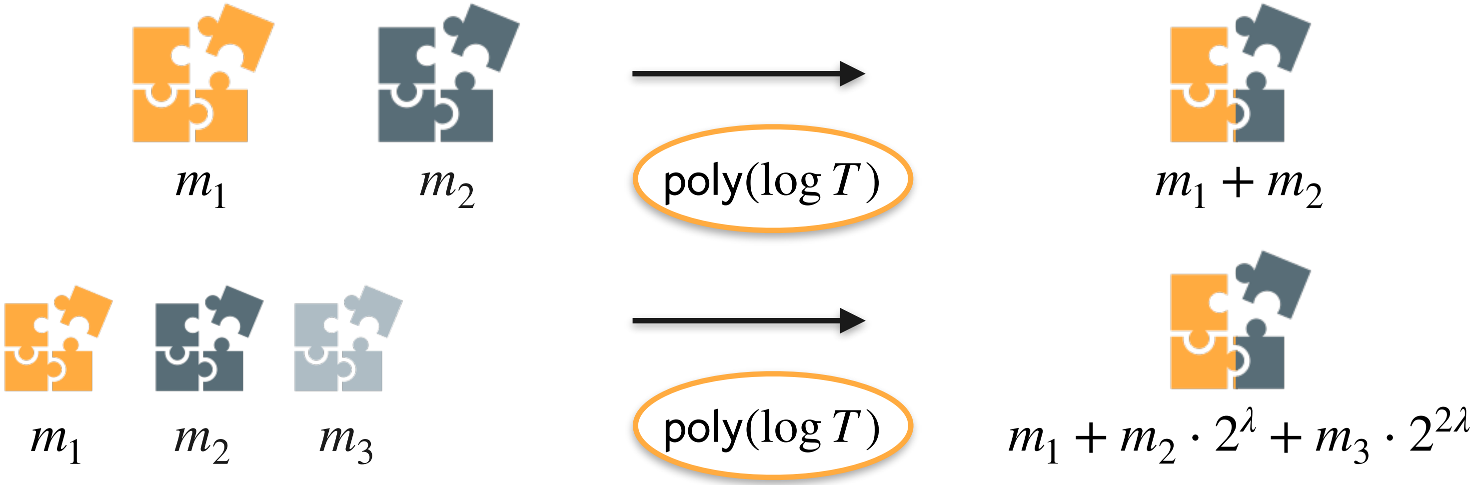


Bounded Batching only

Linearly Homomorphic TLP



Bounded Batching only

Homomorphism over $\{0,1\}^{3\lambda}$

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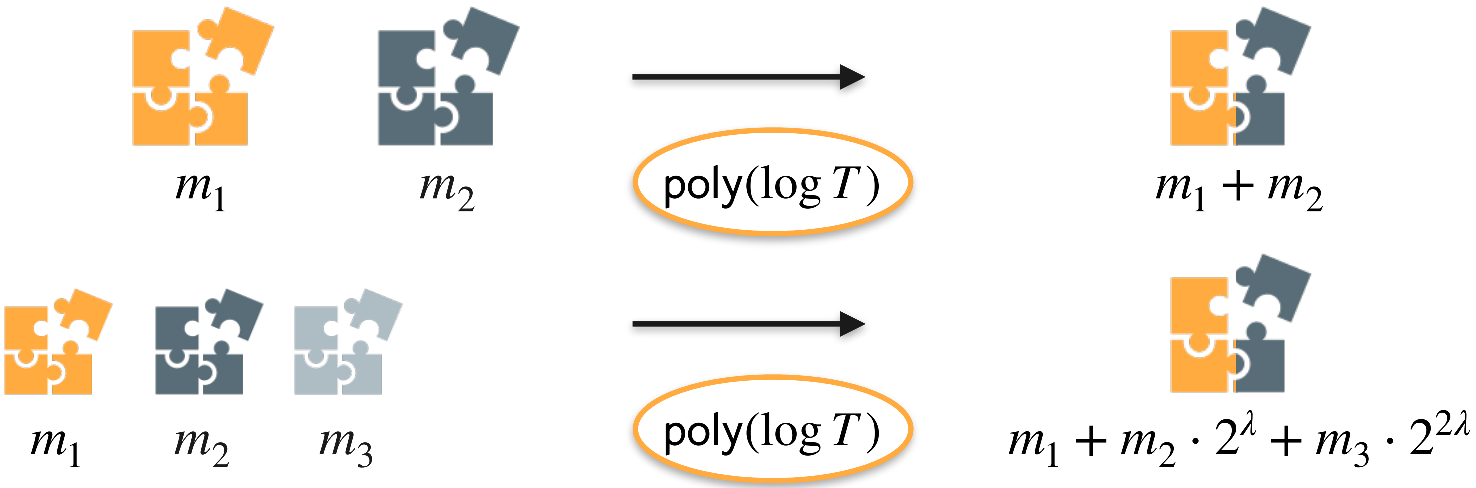

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Homomorphism over $\{0,1\}^{3\lambda}$

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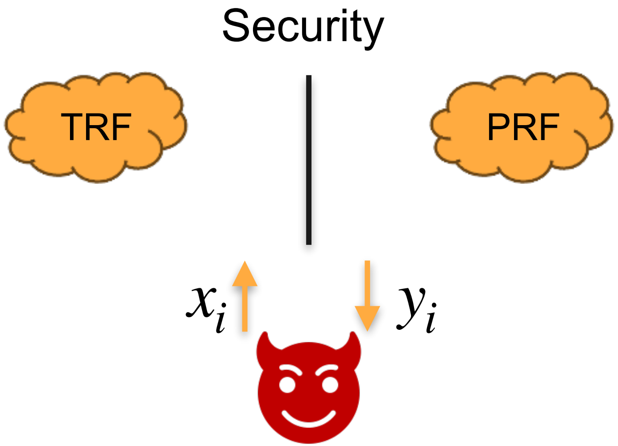

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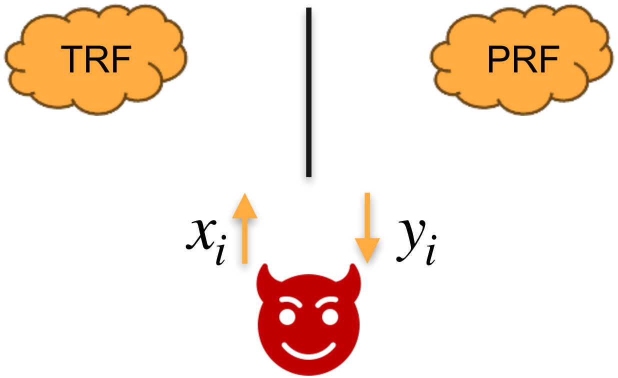
Security



Eval(k_1, x)

Eval(k_2, x)

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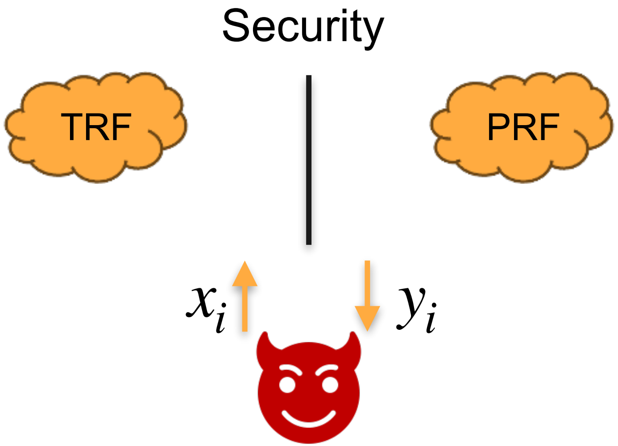

$\mathsf{Eval}(k_1, x)$

$\mathsf{Eval}(k_2, x)$

$\longrightarrow$ $\mathsf{Eval}(k_1 + k_2, x)$

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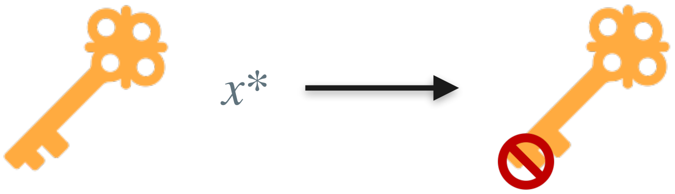

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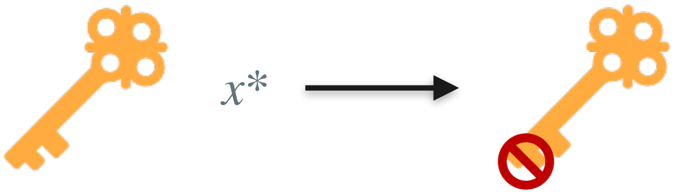
$x \neq x^*$



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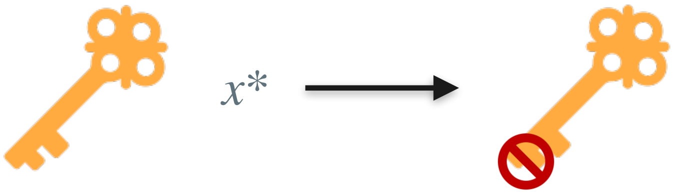

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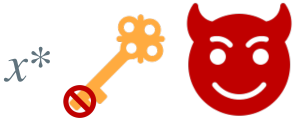
Security

Eval( , x^*) | random



Construction

Construction

Party i

m_i

Construction

Party i

m_i

k_i

$\text{PRF\_Eval}(k_i, i) + m_i$

Construction

Party i

m_i

k_i

$\text{PRF\_Eval}(k_i, i) + m_i$

Puncture k_i at i

Construction

Party i

m_i

k_i

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Puncture k_i at i

m_1 m_2 m_3

Construction

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m_i

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Puncture k_i at i

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Construction

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m_i

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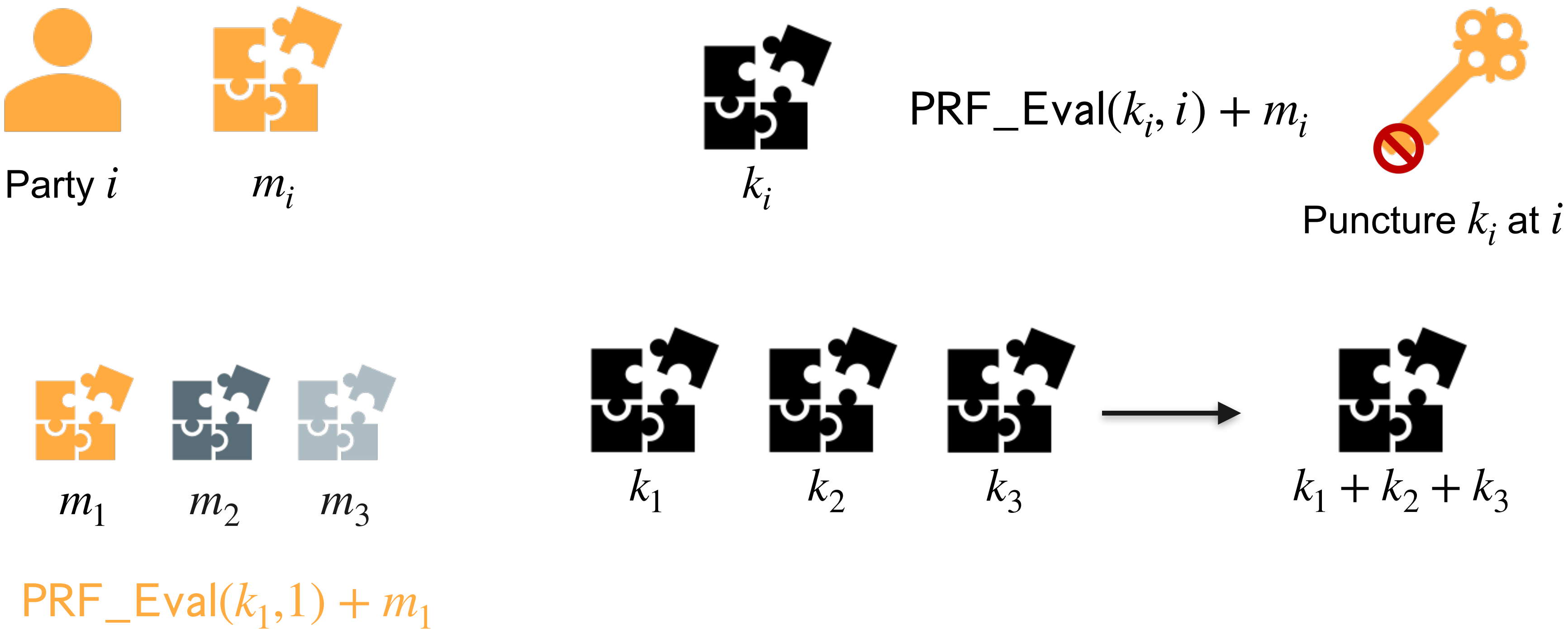
Construction



Construction

Party i

m_i

k_i

PRF_Eval$(k_i, i) + m_i$

Puncture k_i at i

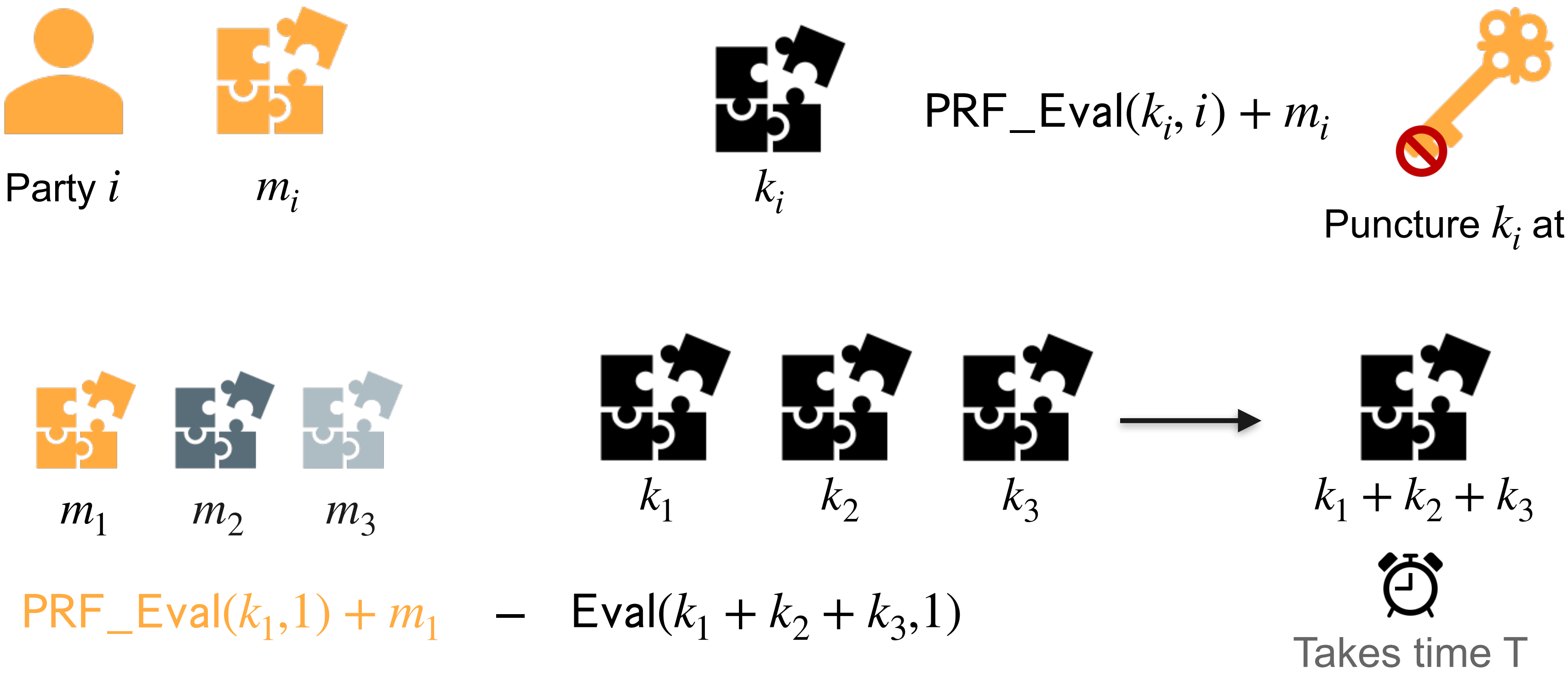
m_1 m_2 m_3

PRF_Eval$(k_1, 1) + m_1$

k_1 k_2 k_3 → $k_1 + k_2 + k_3$

Takes time T

Construction



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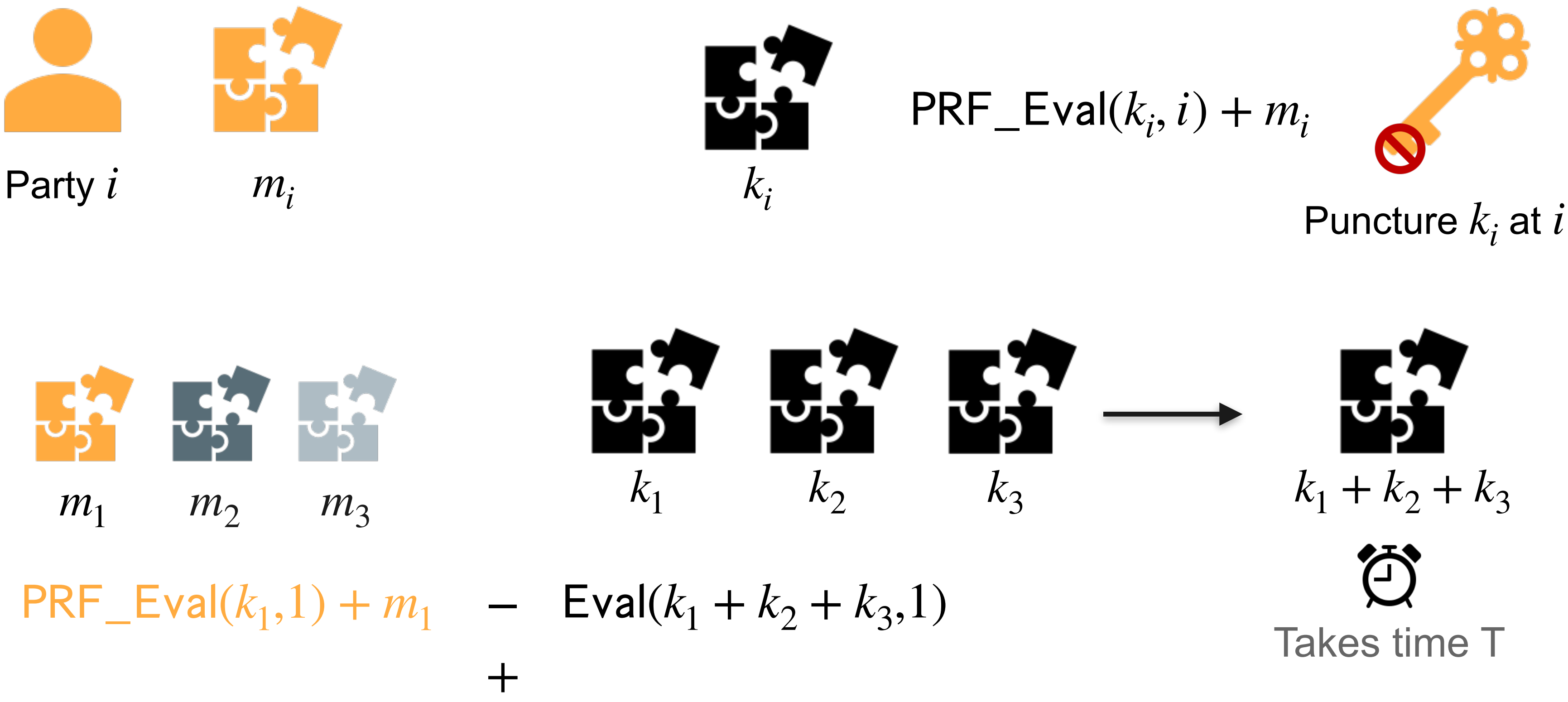

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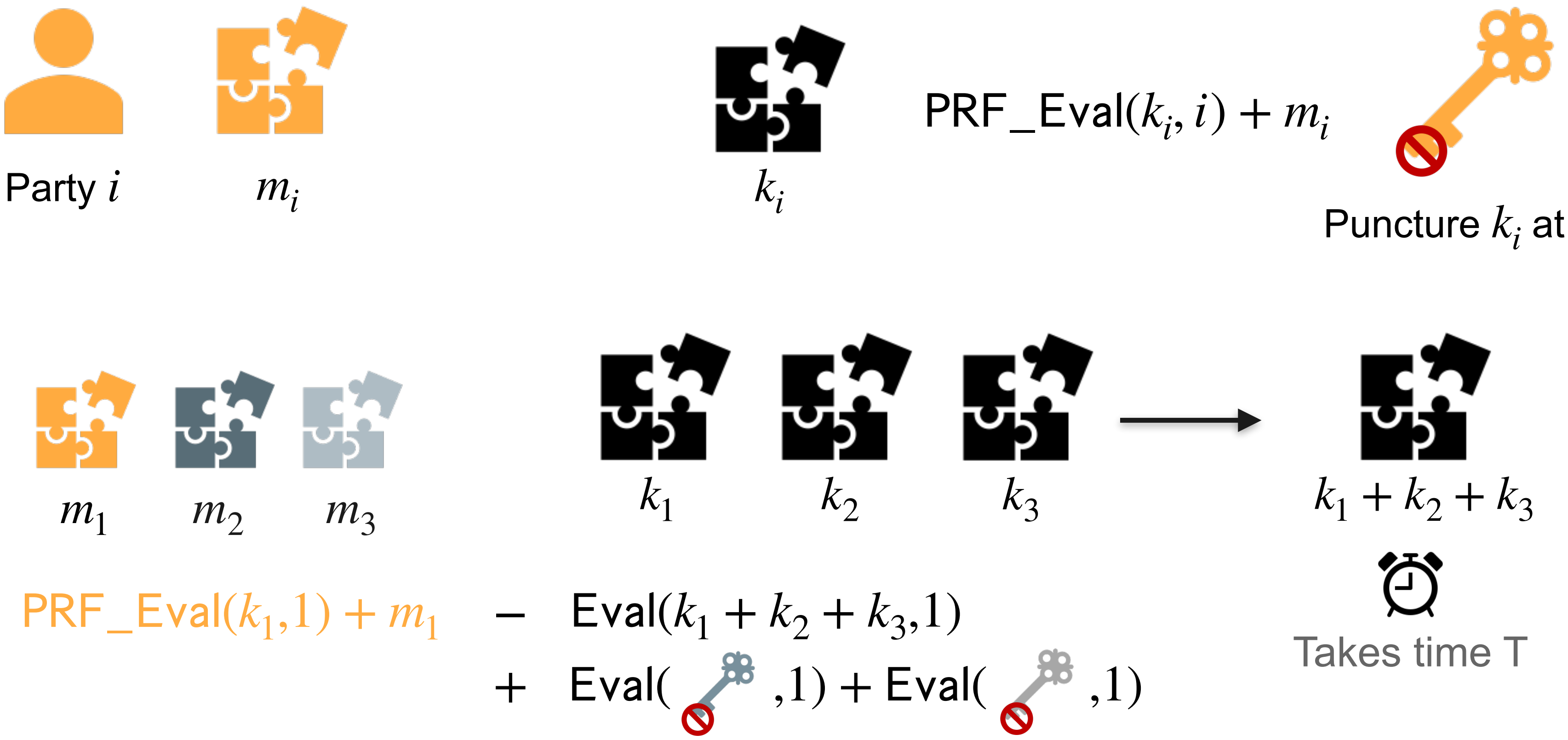
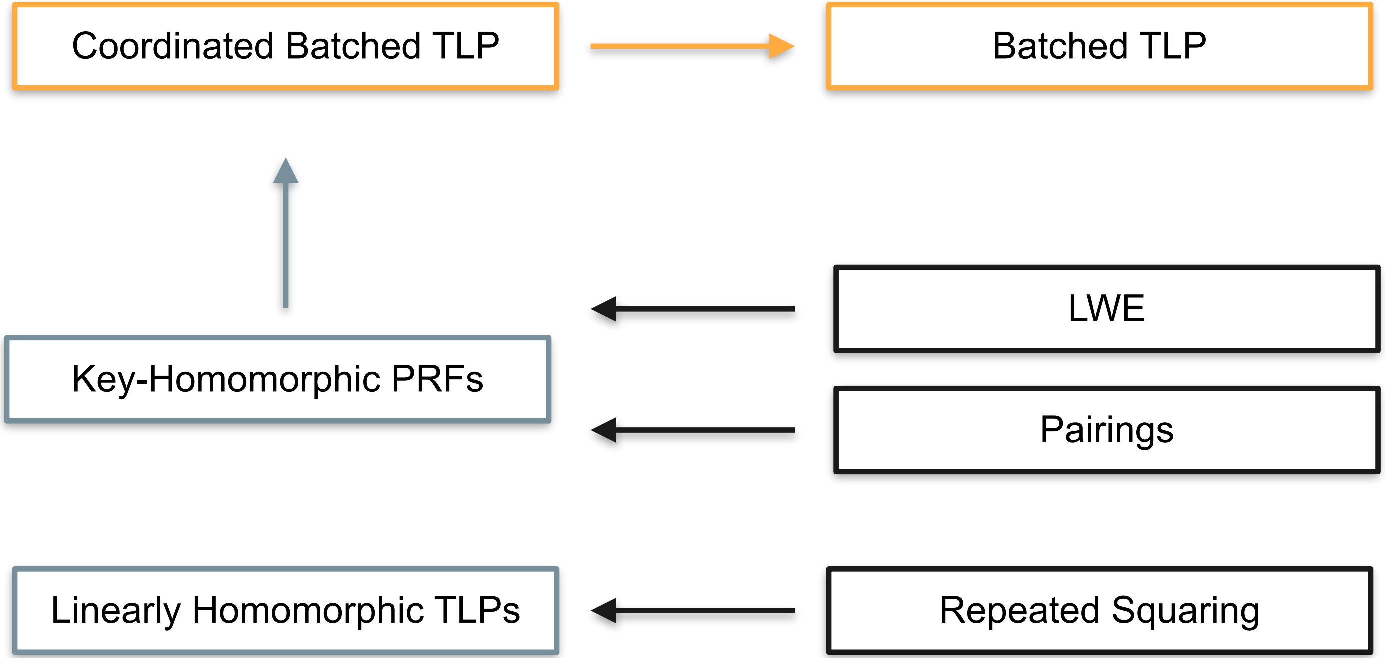


Roadmap



Coordinated Batched TLP
Batched TLP
LWE
Key-Homomorphic PRFs
Pairings
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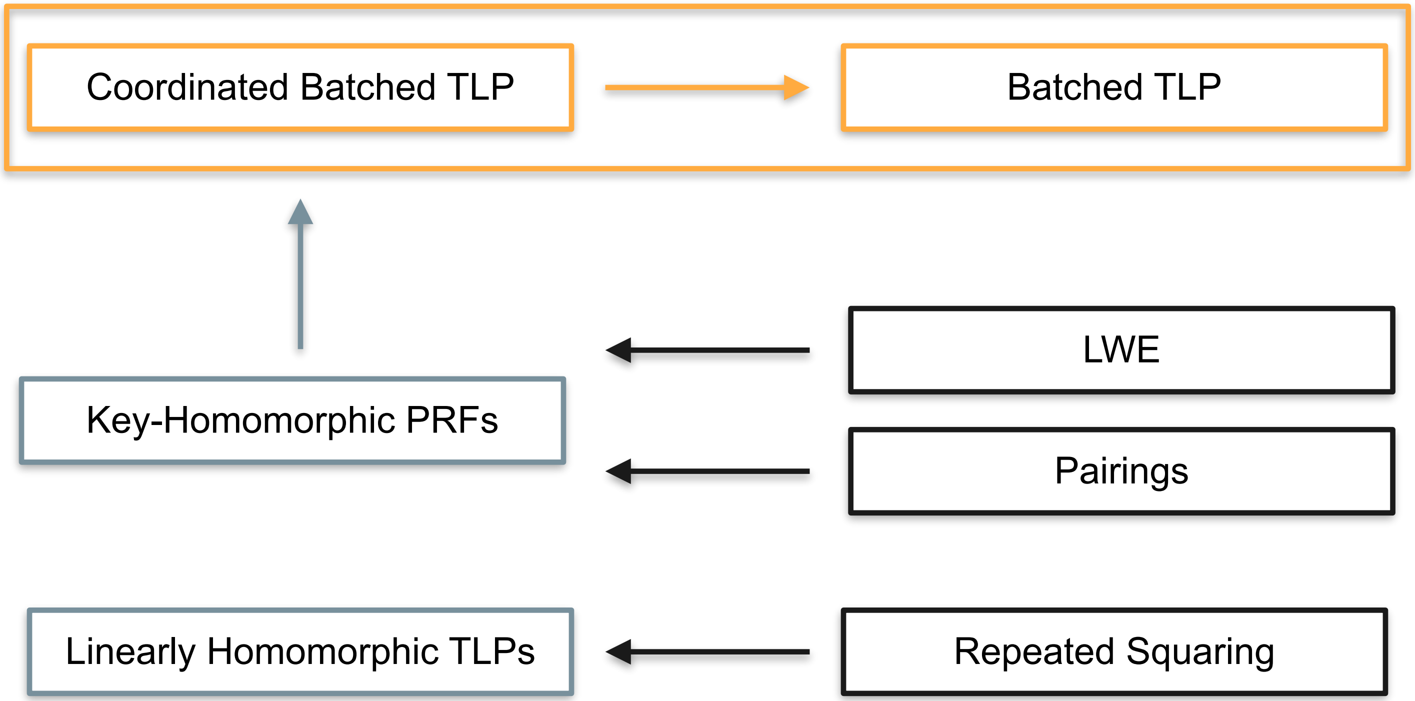
Repeated Squaring

Roadmap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Transformation

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M - 5 - number of users
N - 3 - Batch to at-most 3 puzzles
D - 2 - degree

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Slots

Setup$(1^{\lambda}, T, 1^{4}) \rightarrow$ pp

Users

Transformation

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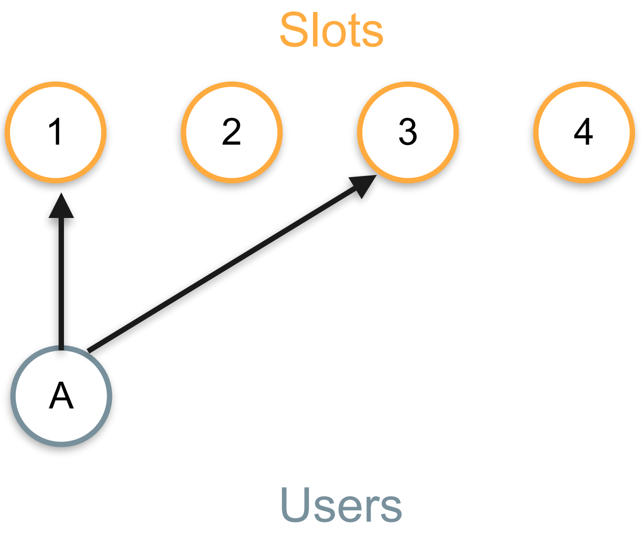
N - 3 - Batch to at-most 3 puzzles
D - 2 - degree

$\text{Setup}(1^\lambda, T, 1^4) \rightarrow \text{pp}$



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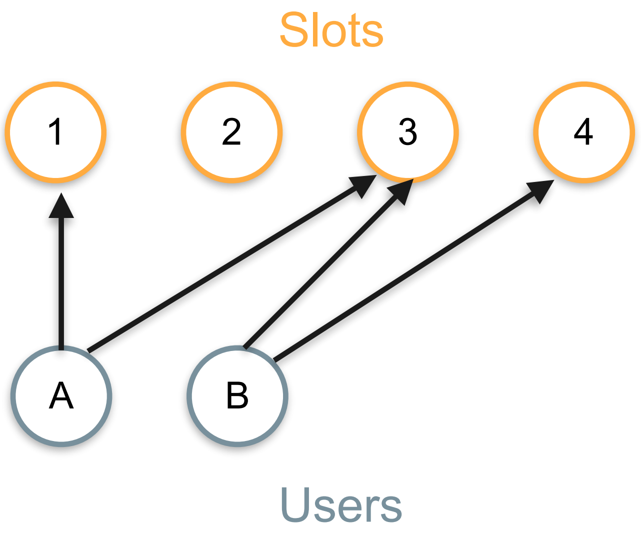

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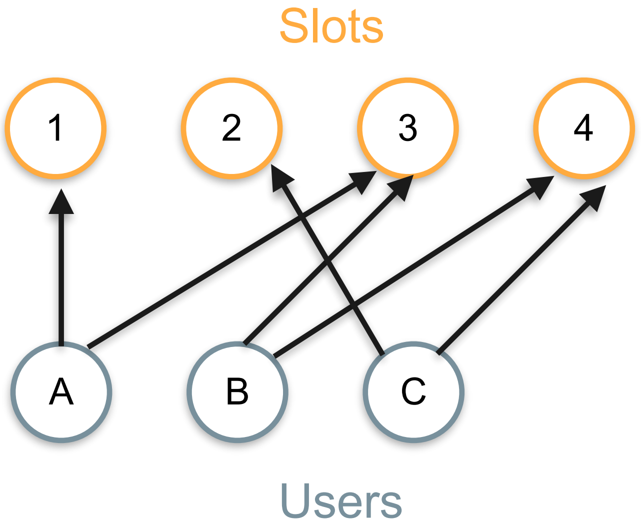

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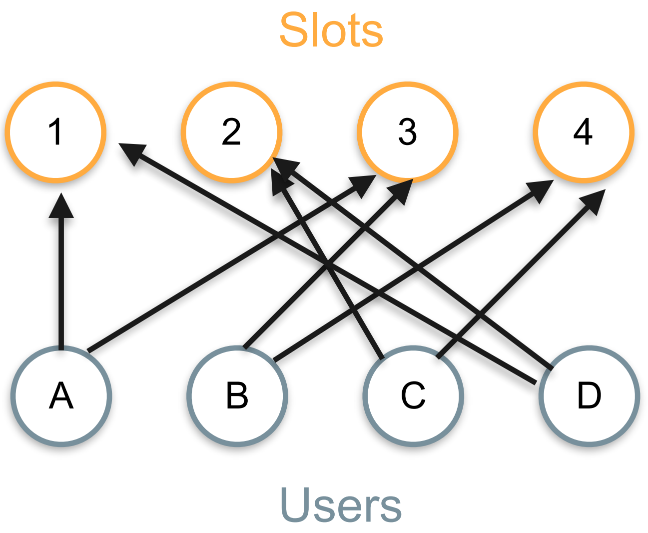

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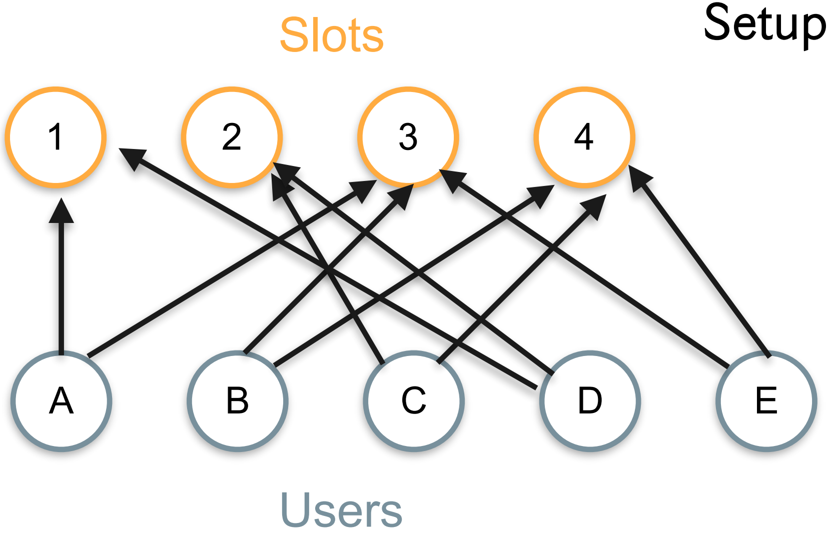

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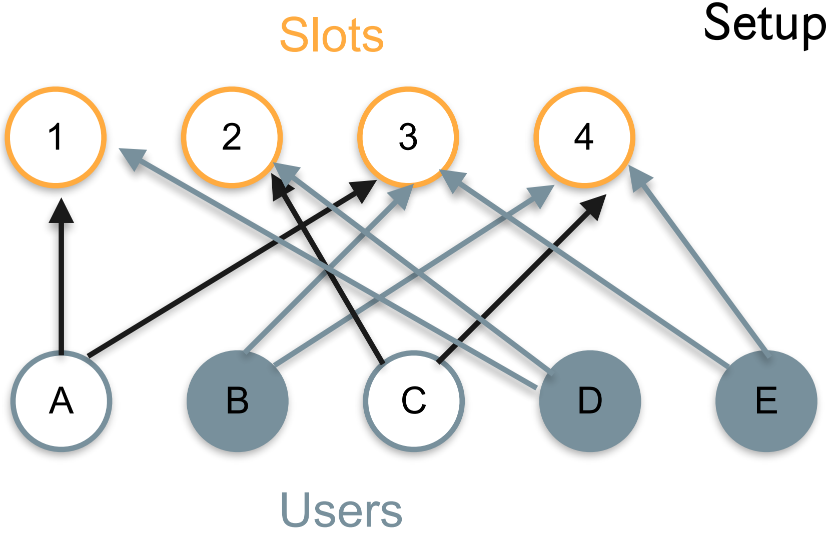

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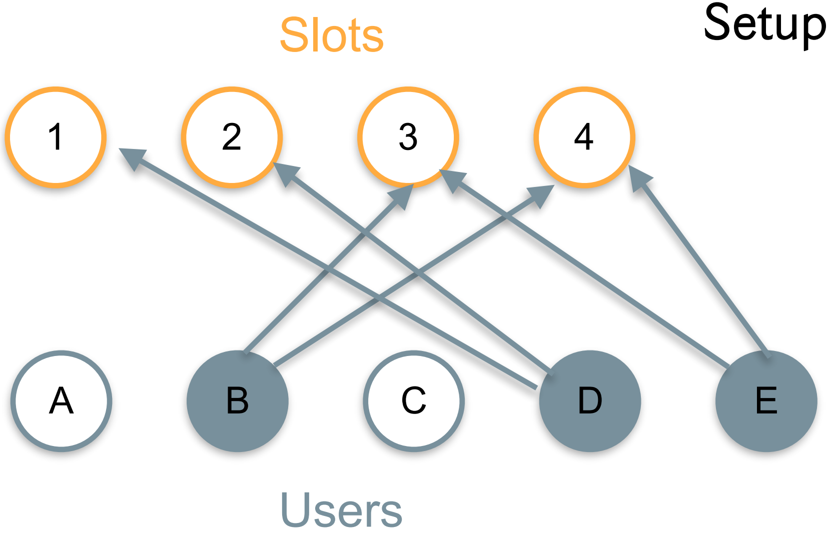

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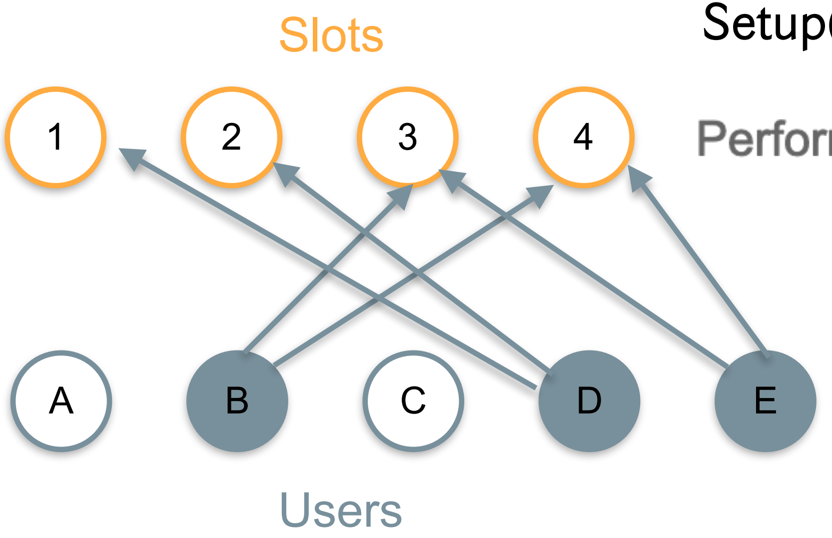
Perform a matching



Transformation

M - 5 - number of users
N - 3 - Batch to at-most 3 puzzles
D - 2 - degree

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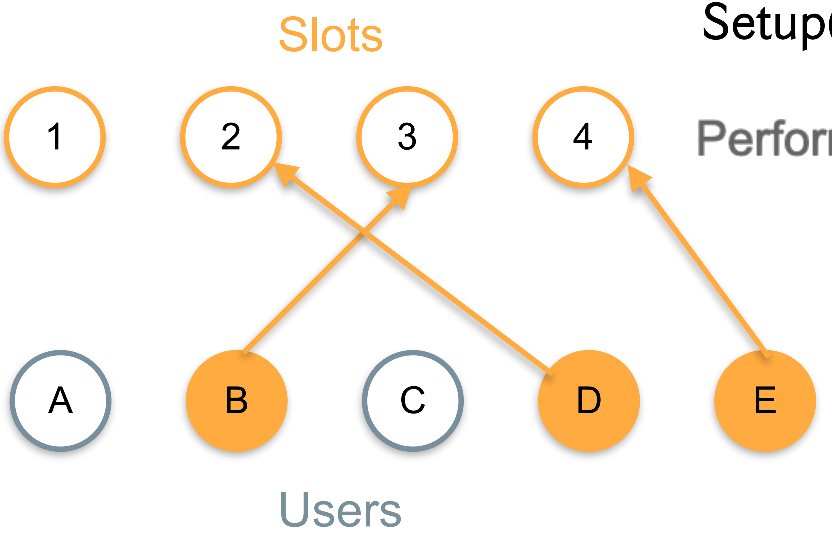

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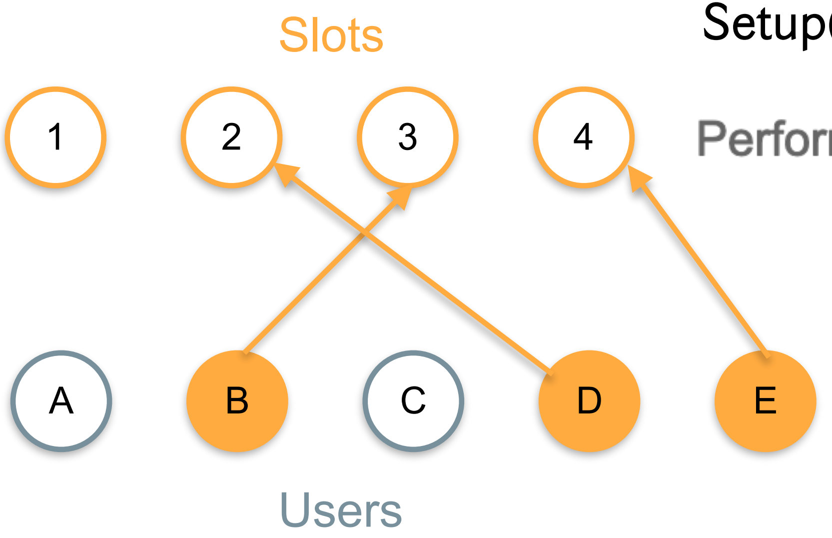


Setup$(1^{\lambda}, T, 1^4) \rightarrow$ pp

Perform a matching

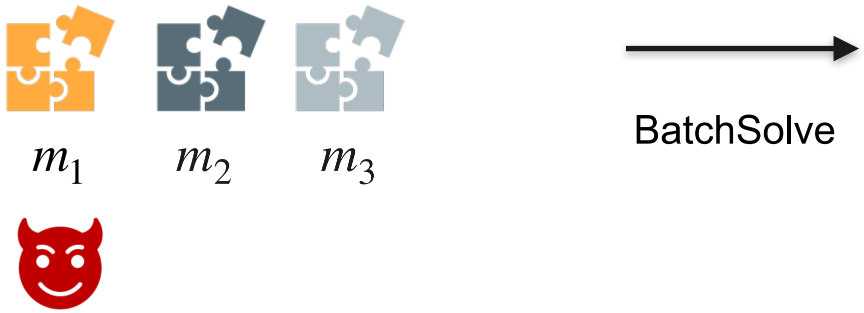
Theorem (informal) - Set slots $\geq 2e \cdot N$, degree $\geq \dfrac{\omega(\log \lambda)}{\log N}$, then we can build an uncoordinated batch TLP.

Rogue puzzles

Rogue puzzles

m_1 m_2 m_3

Rogue puzzles



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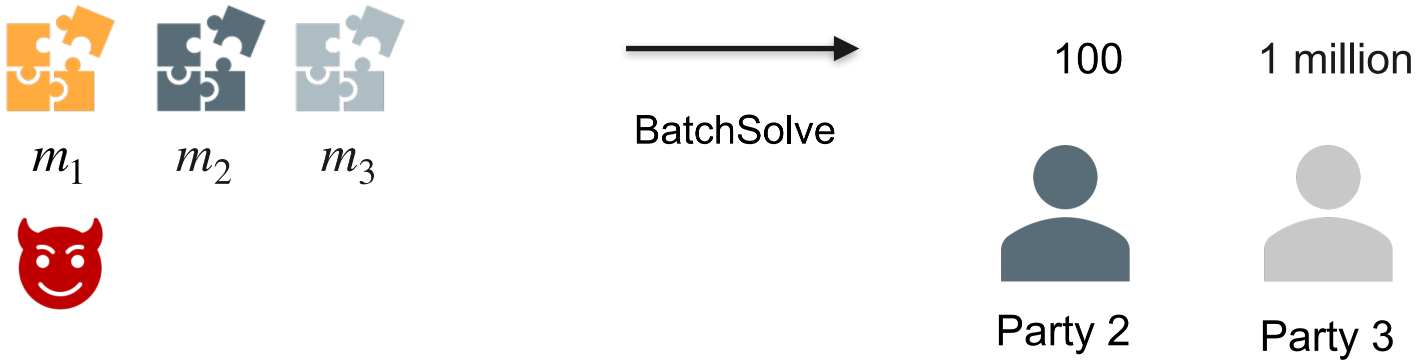

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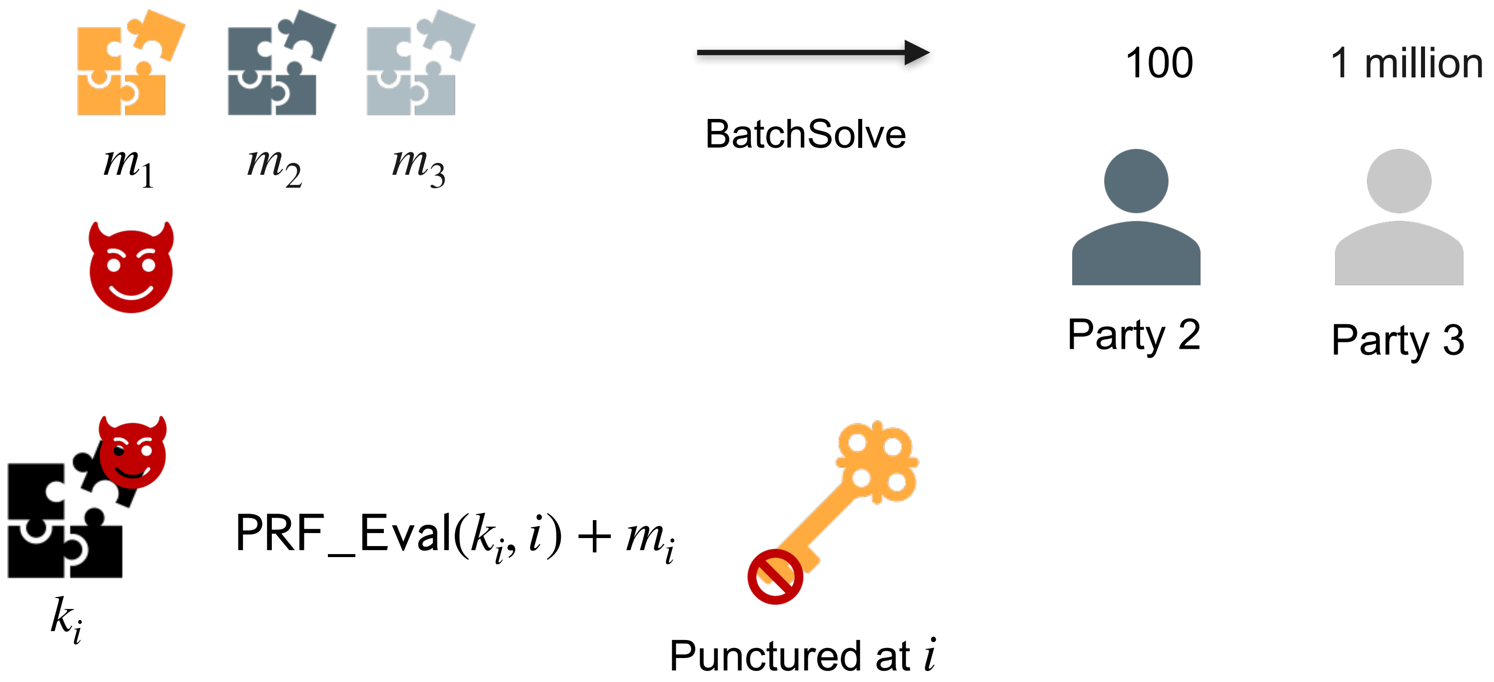

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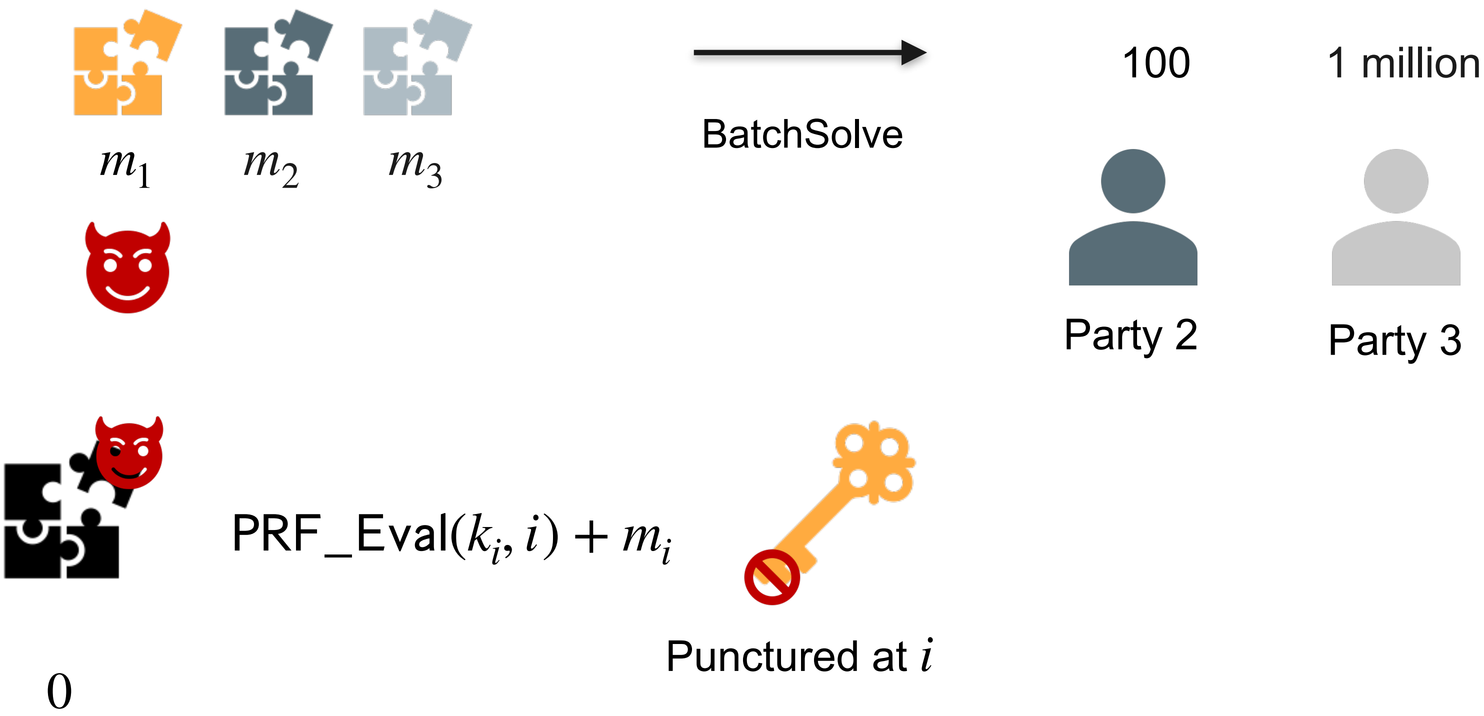

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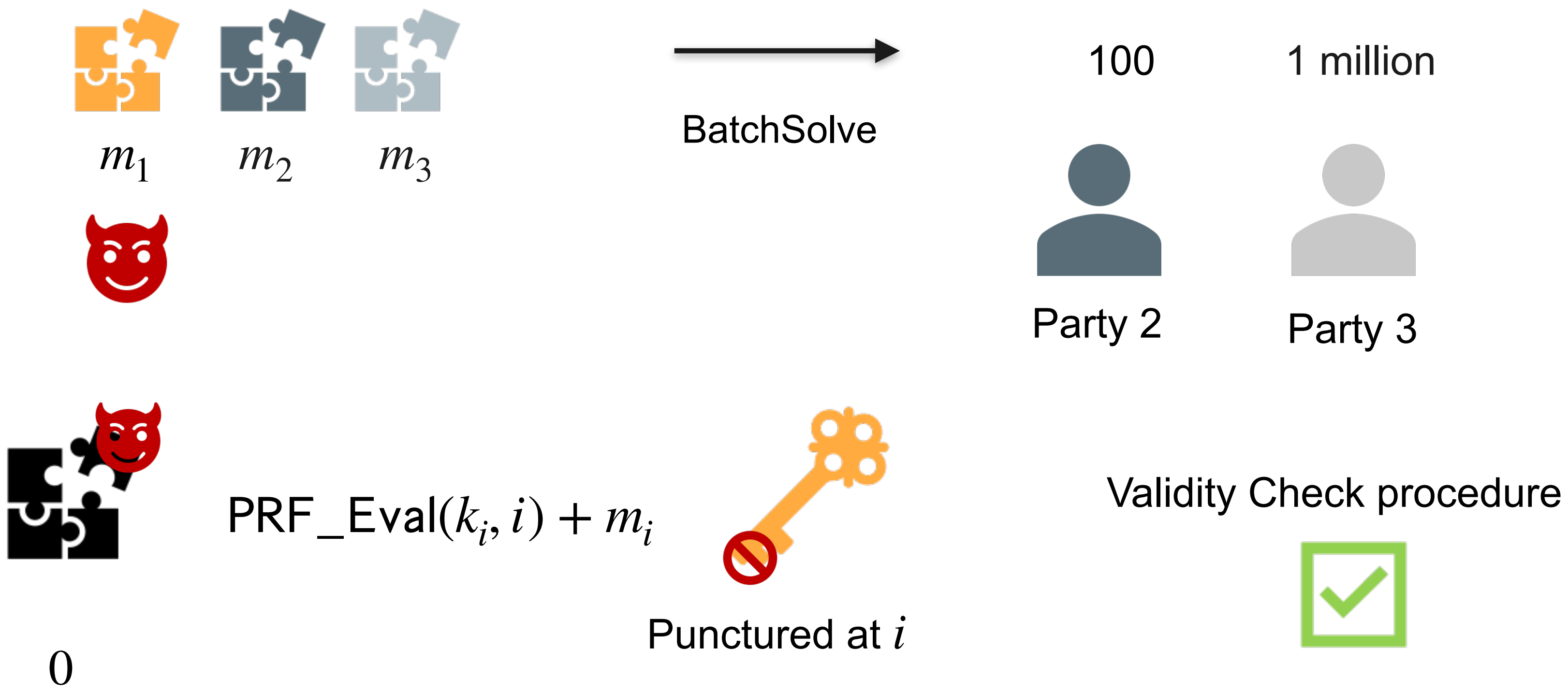

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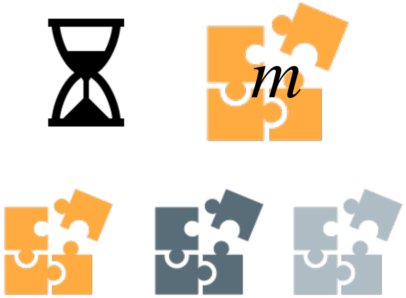
- For T = 50 million computations, and batching 7000 puzzles, the size of a single puzzle is 8 MB trivially, 37 MB using our solution and would be 790 MB using the linearly homomorphic solution.

*the time to do 50 million sequential computations on the test machine is 5 minutes

Conclusion!



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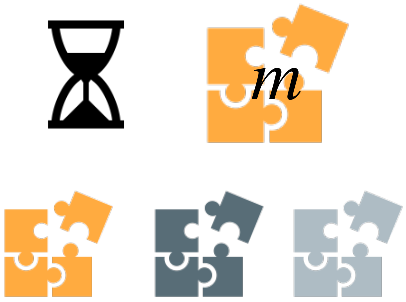

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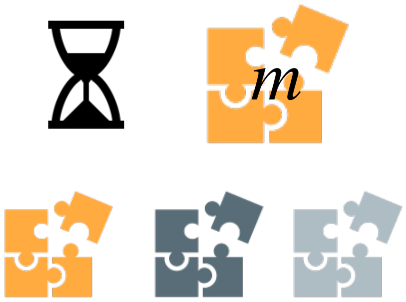

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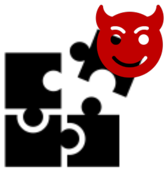

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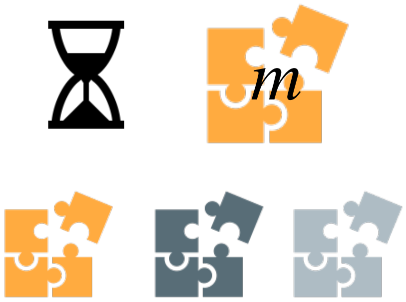

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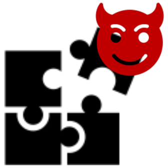

- Give a concrete implementation and numbers.