High-Throughput Secure Three-Party Computation for Malicious Adversaries and an Honest Majority

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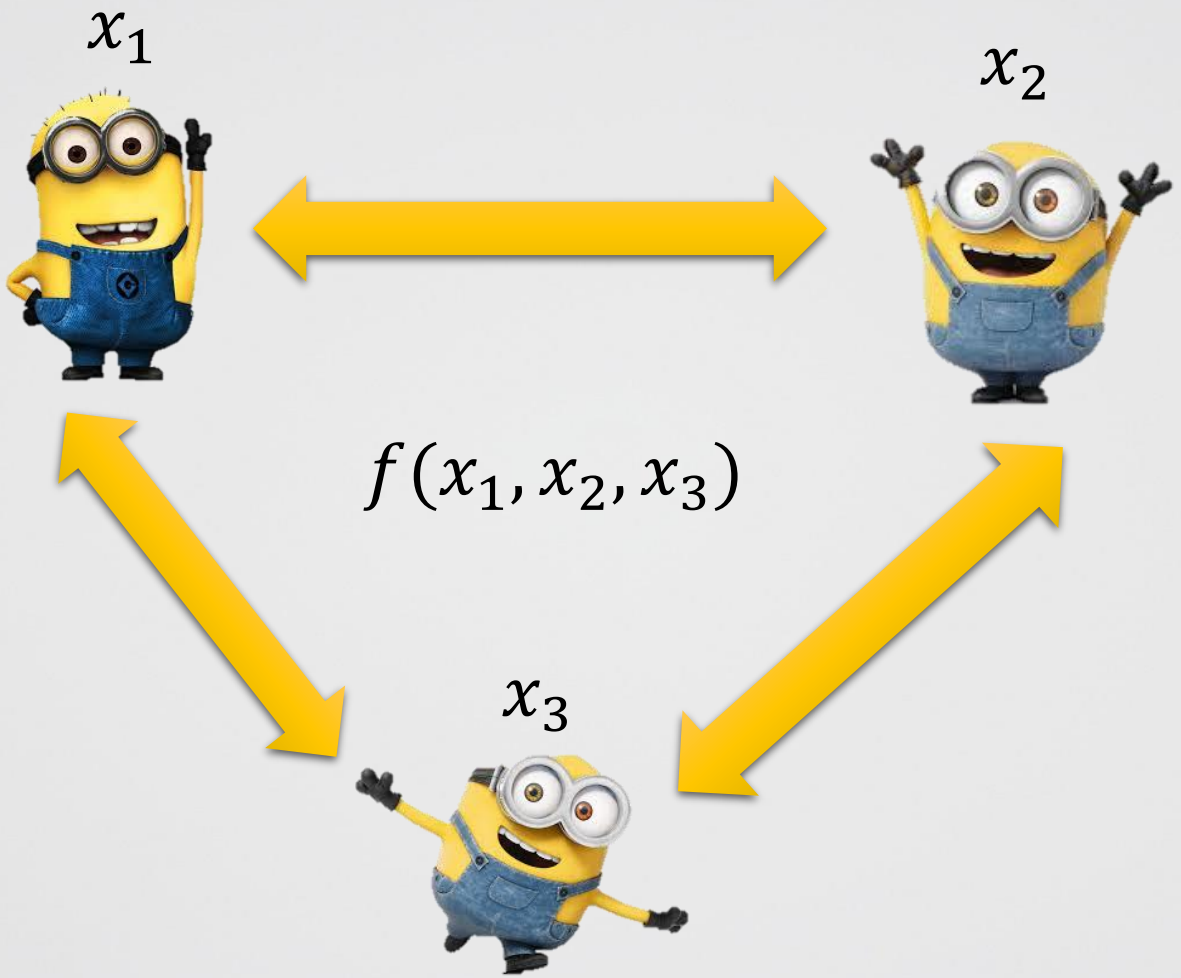
Eurocrypt 2017

BIU Center for Research in Applied Cryptography and Cyber Security

Secure Three-Party Computation with an Honest Majority



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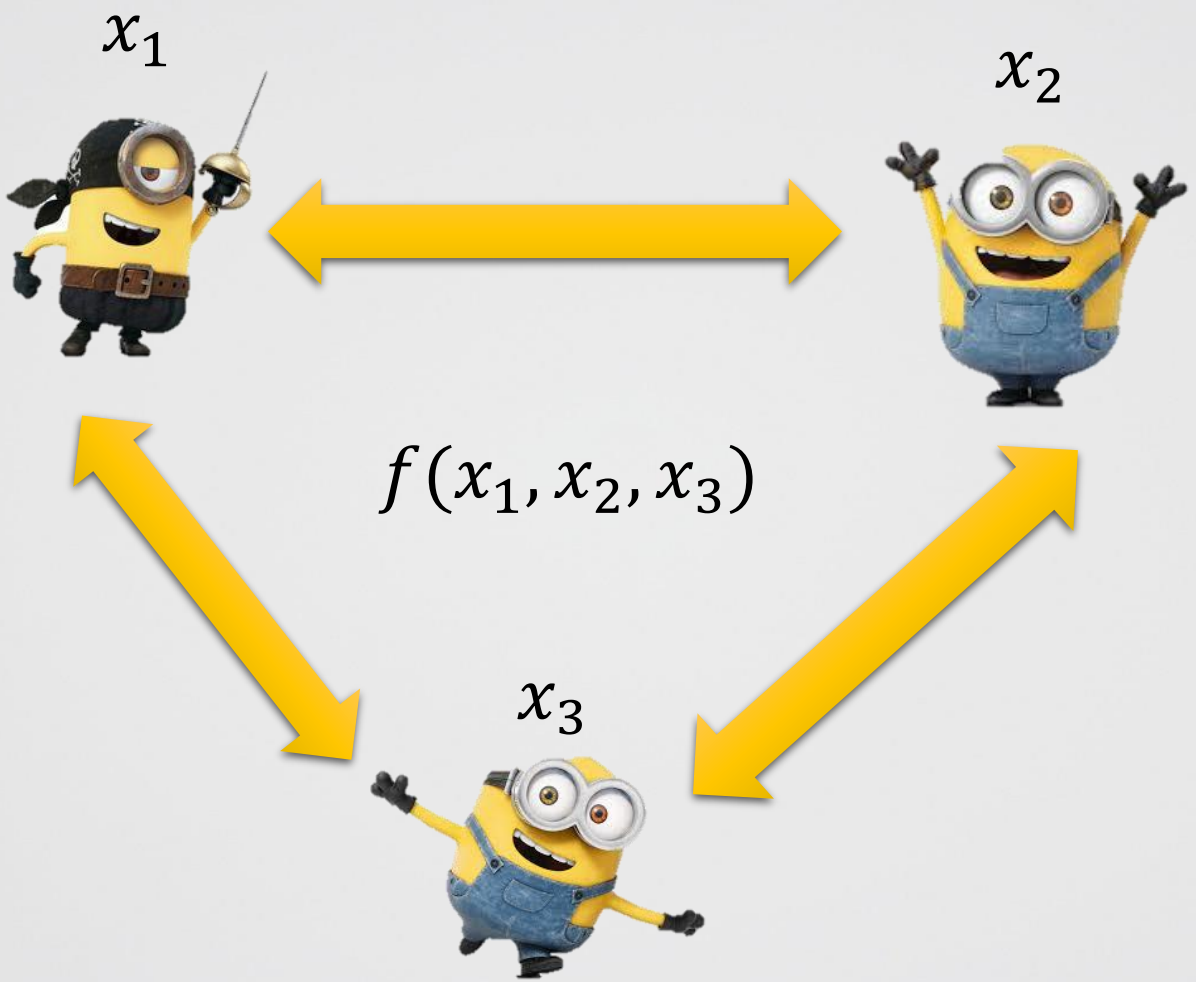

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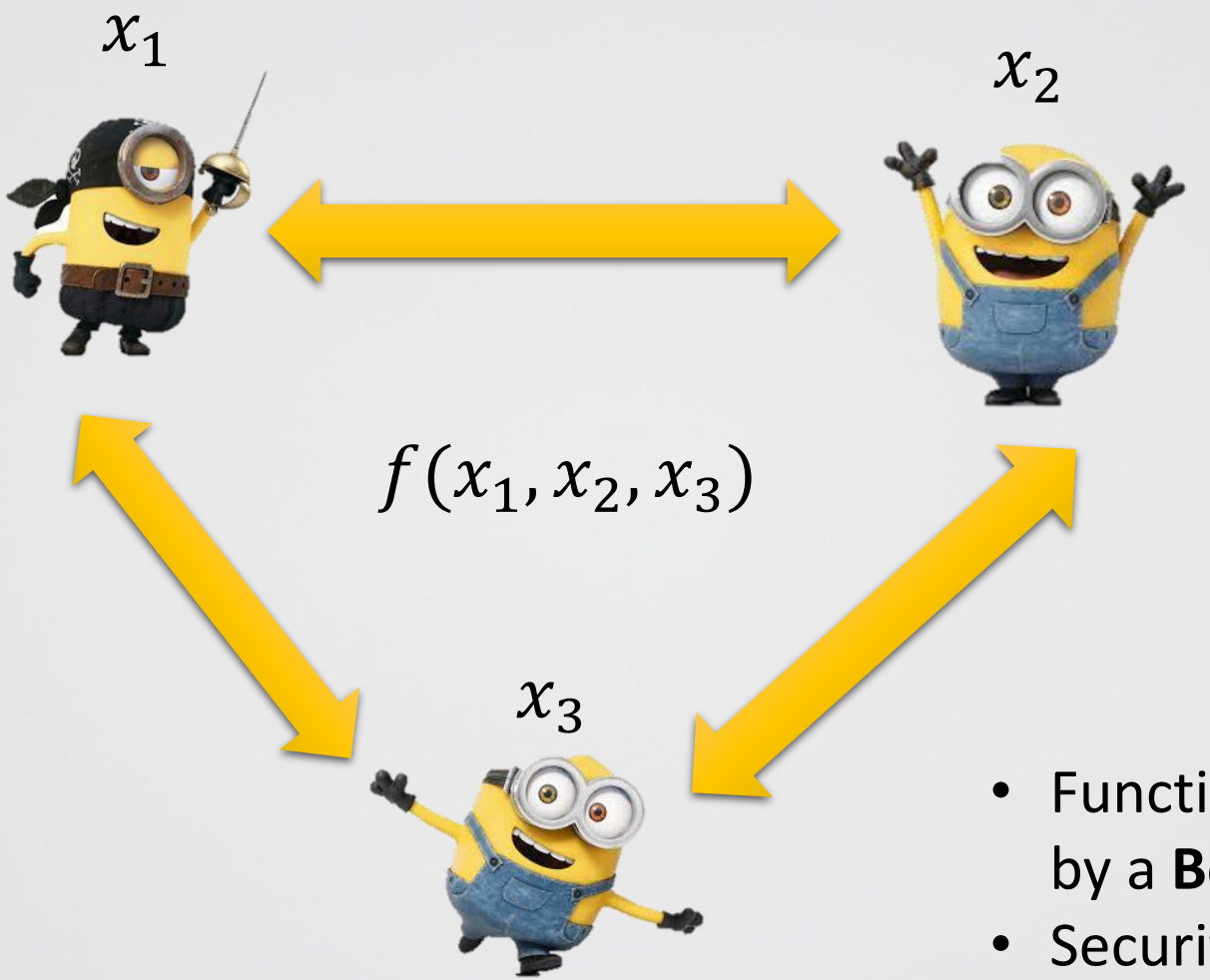

- Functionality is represented by a **Boolean circuit**
- Security with **abort**

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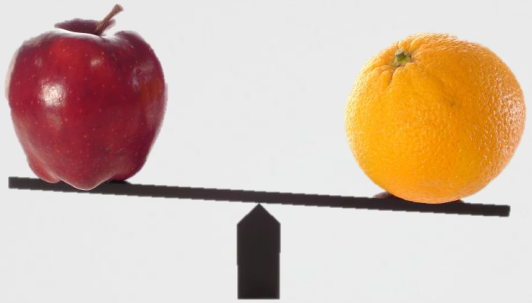

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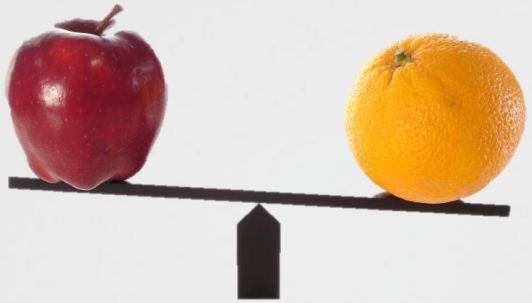

How much time it takes to compute a function?

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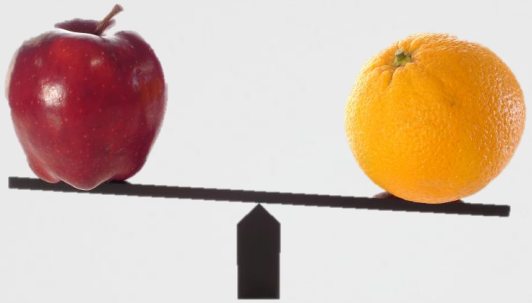

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Latency

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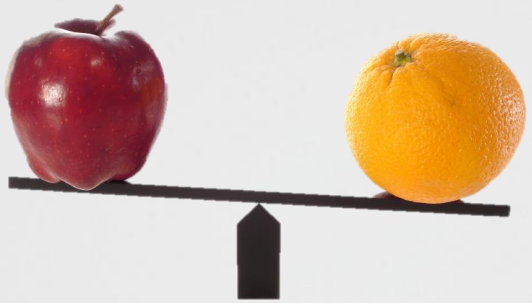

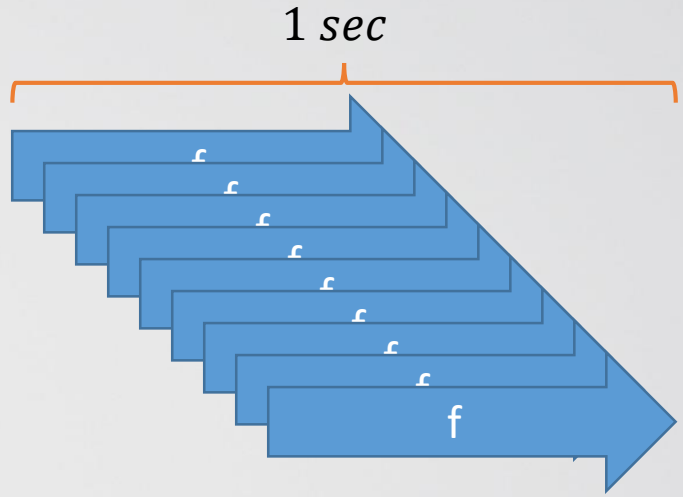

How many functions can we compute in one sec?

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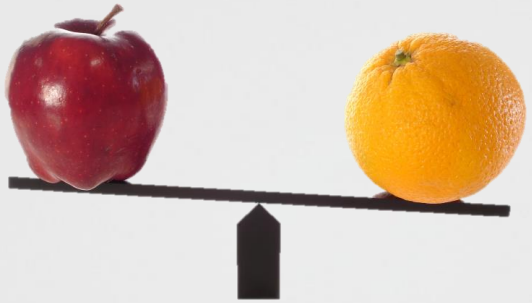

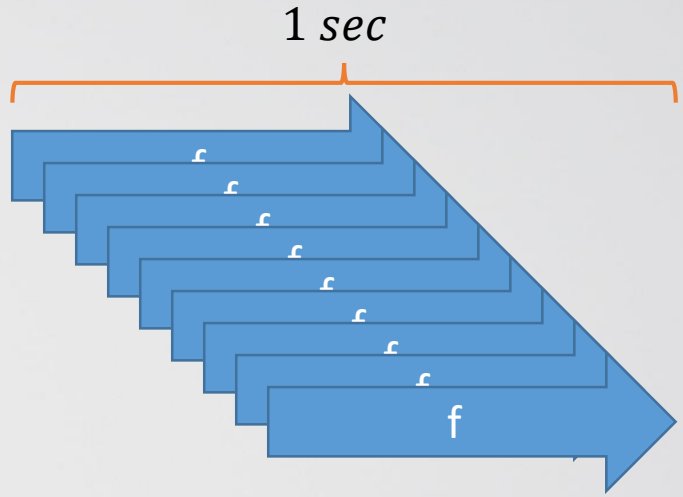

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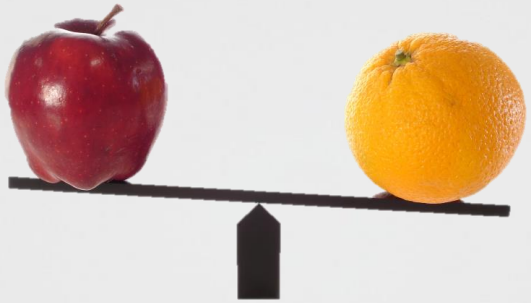
Throughput

Low Latency vs. High-Throughput

Low Latency

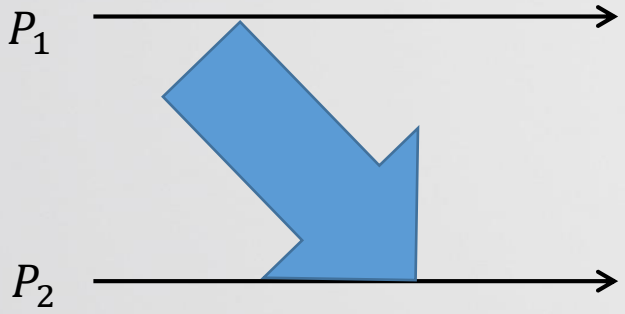
High-Throughput



Low Latency vs. High-Throughput

Low Latency

- Constant rounds of communication



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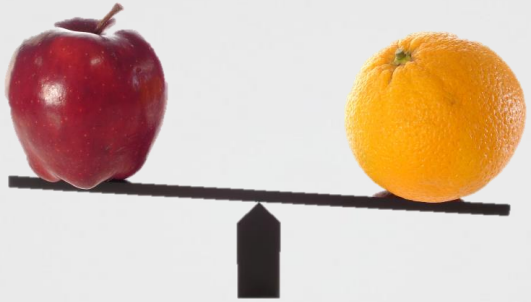

"the garbled-circuit approach"

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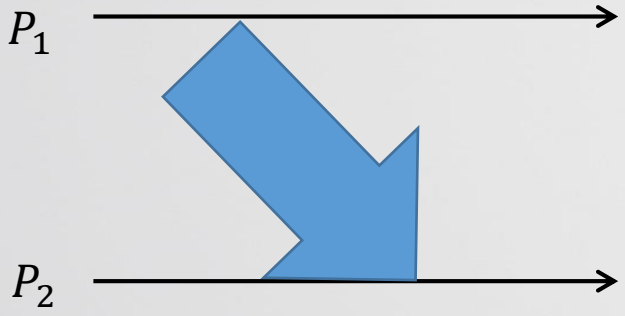

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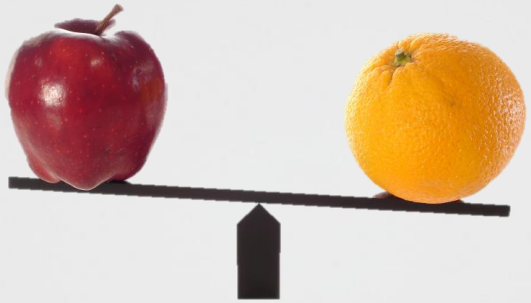
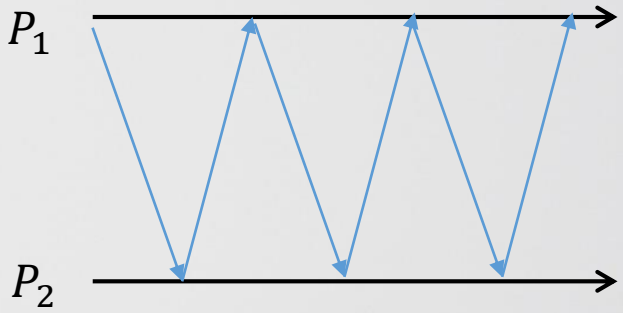


High-Throughput

- Low bandwidth
- Simple Computations



"the secret-sharing approach"

Low Latency vs. High-Throughput

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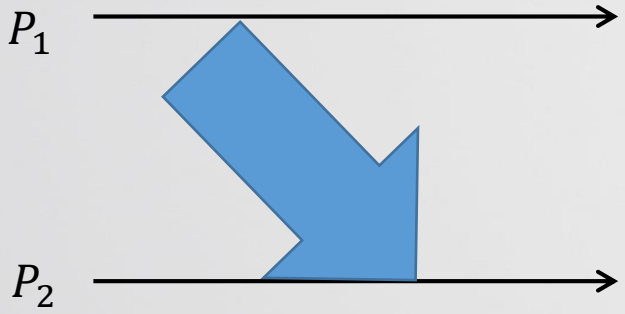

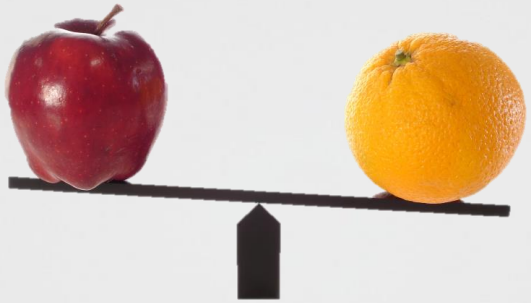

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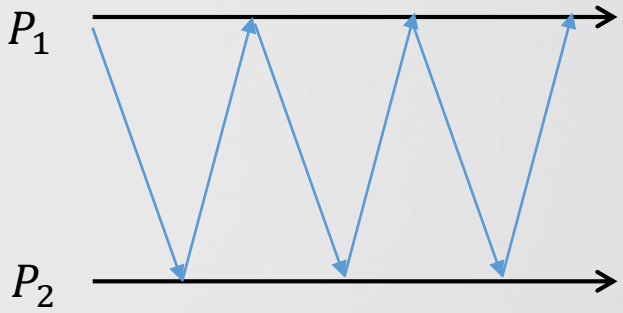

"the secret-sharing approach"

The Starting Point: The Semi-honest protocol of [AFLNO16]

- Based on replicated secret sharing
- Requires **1 bit of communication** sent by each party per AND gate.
- Speed: compute over 7 billion AND gates per second
  - Concretely, over 1,300,000 AES operations per second

From Semi-Honest to Malicious adversary

- Sharing the inputs
- Emulating the circuit
- Output Reconstruction

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How to force the corrupted party to share its inputs “correctly”?

How to verify AND gates were computed correctly?

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Verification of AND Gates

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Sub-protocol "triple verification without opening"

Communication: <u>2 bits per each party</u>

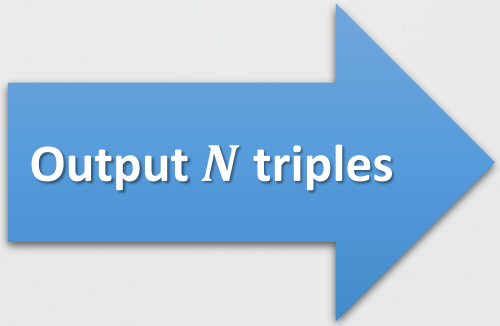
The Protocol

On-line protocol

1. Share the inputs
2. Run the Semi-honest protocol
3. Verify all ANDs gates
4. Reconstruct Output

3 bits per AND gate

The Protocol



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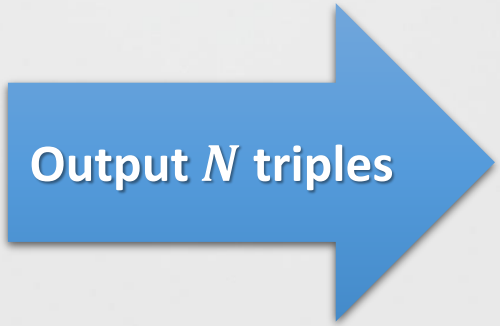

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The Protocol

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Output N triples

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- $[a], [b]$ are generated without any interaction!
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How to verify that the triple is valid?

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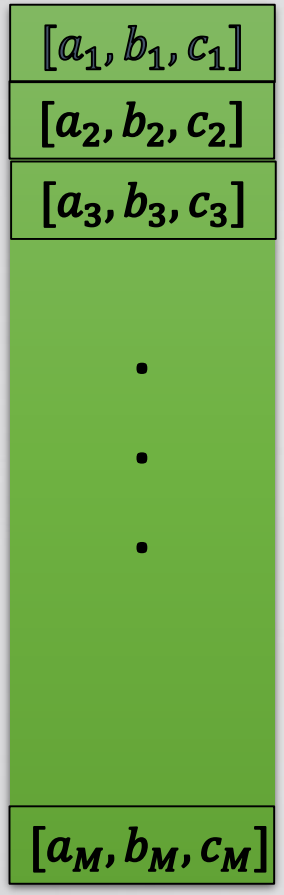

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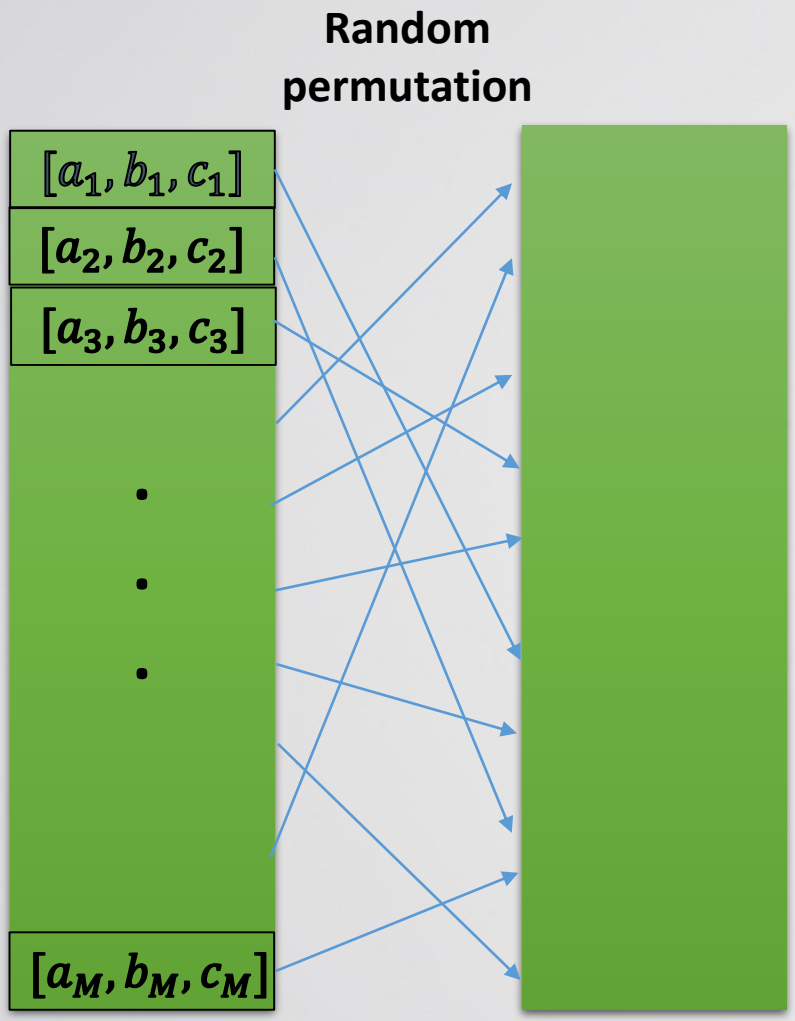

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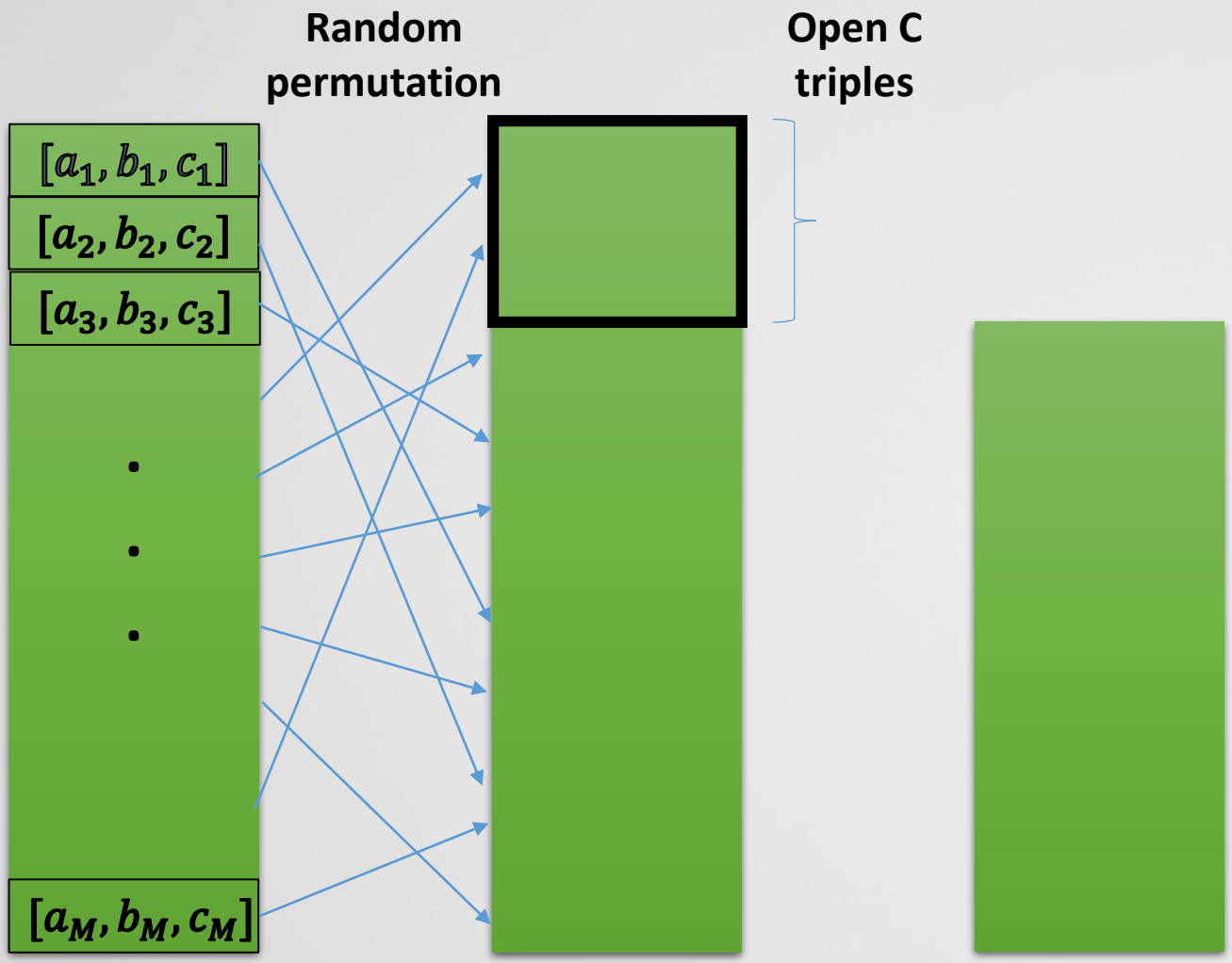

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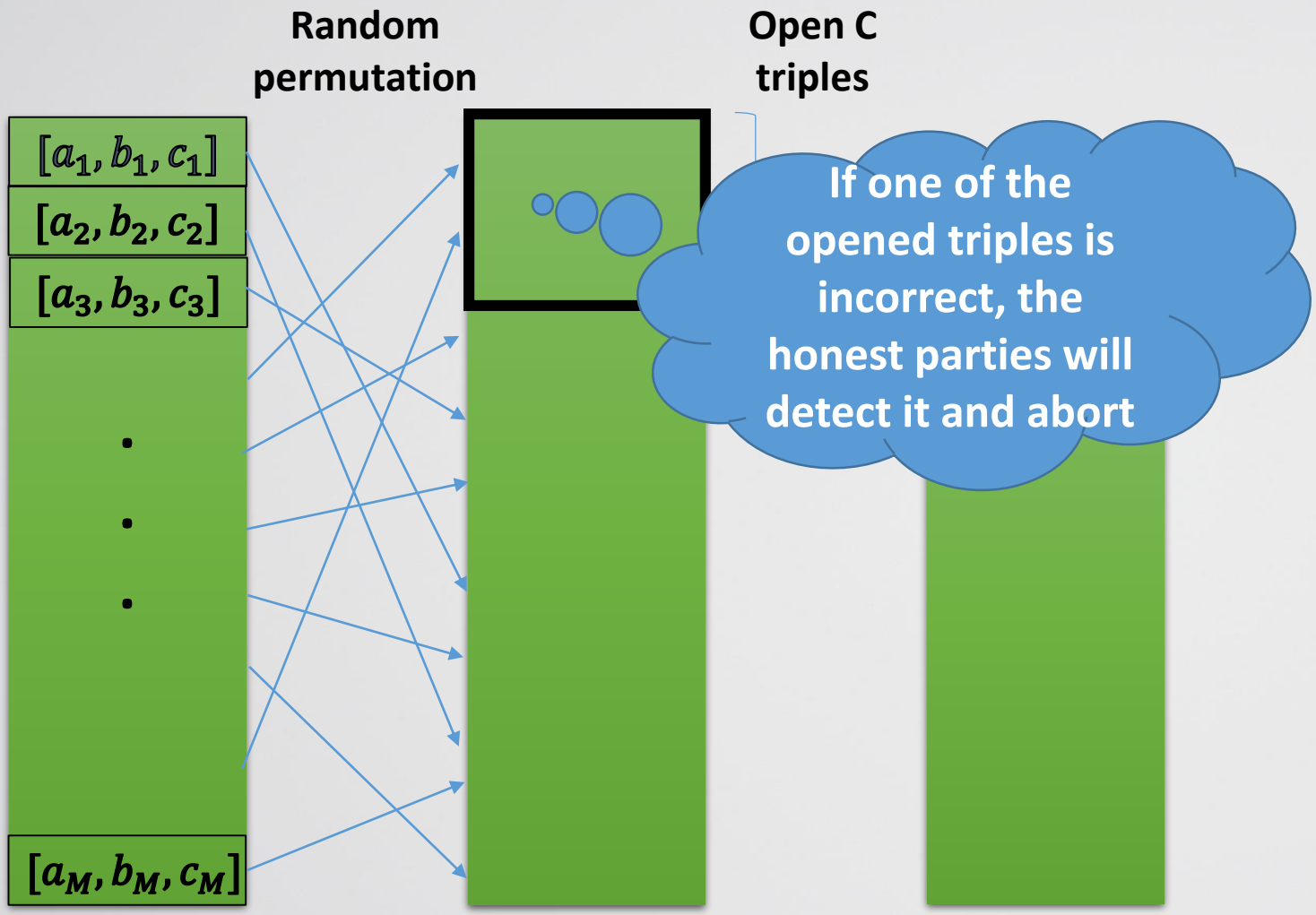

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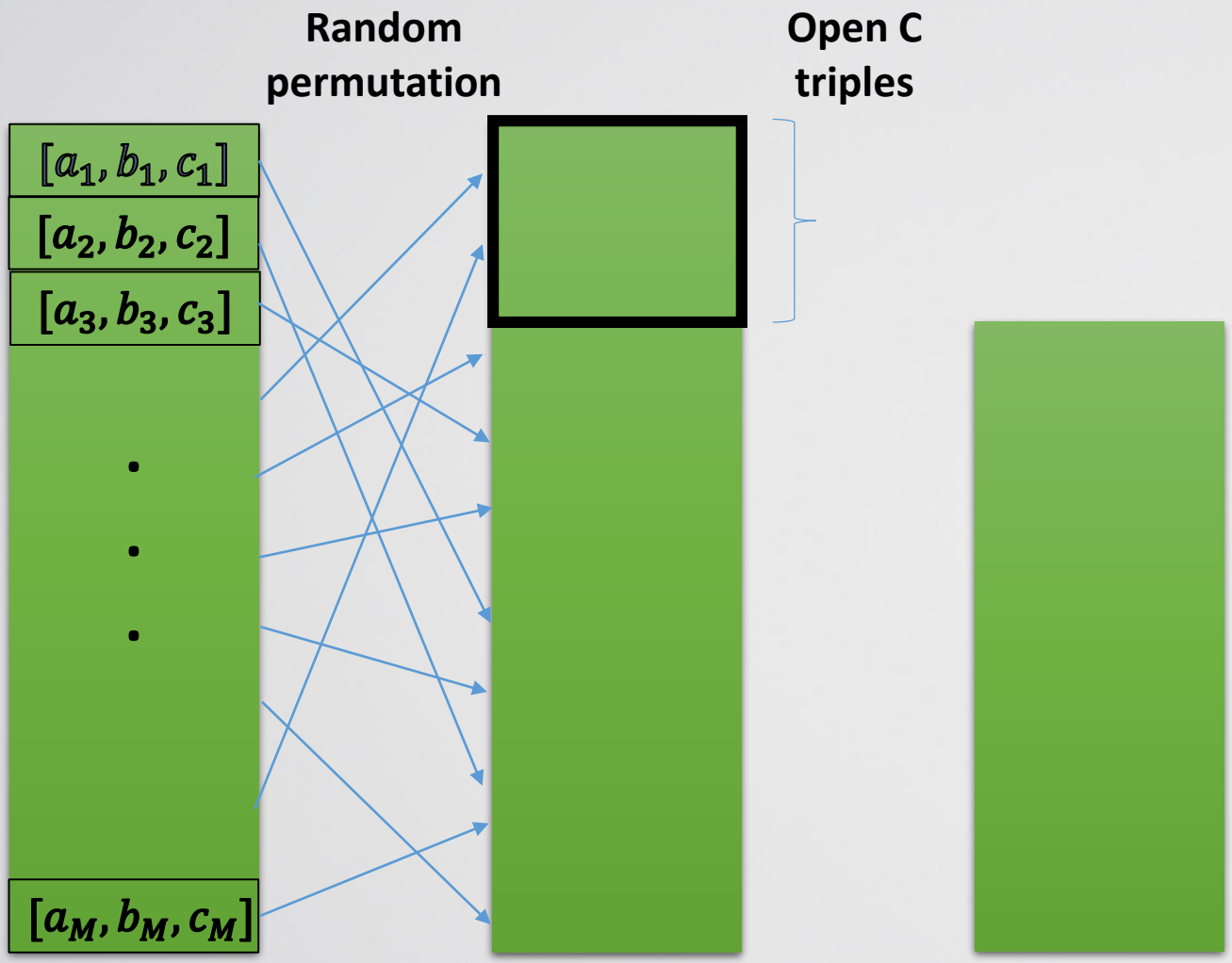

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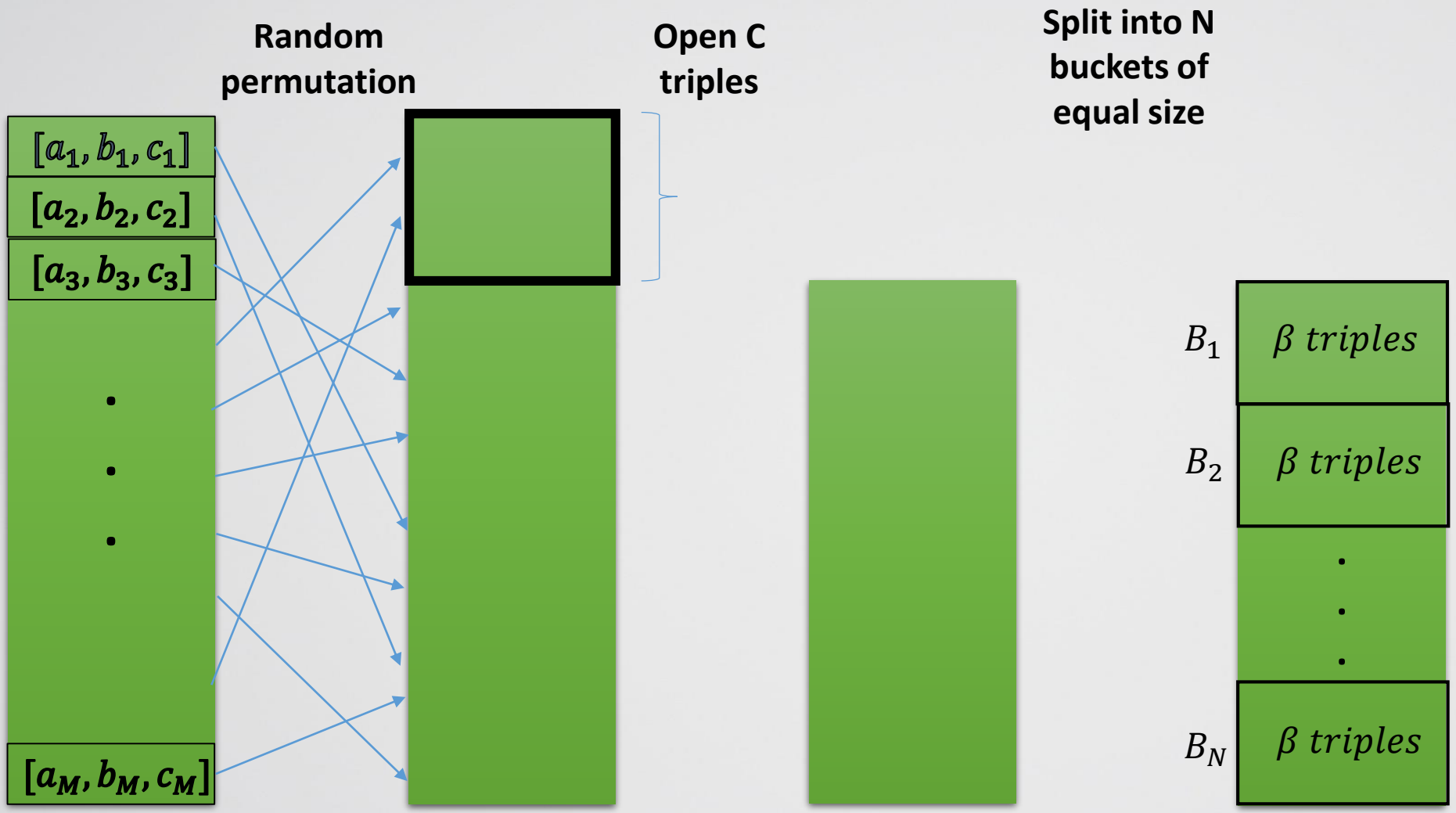

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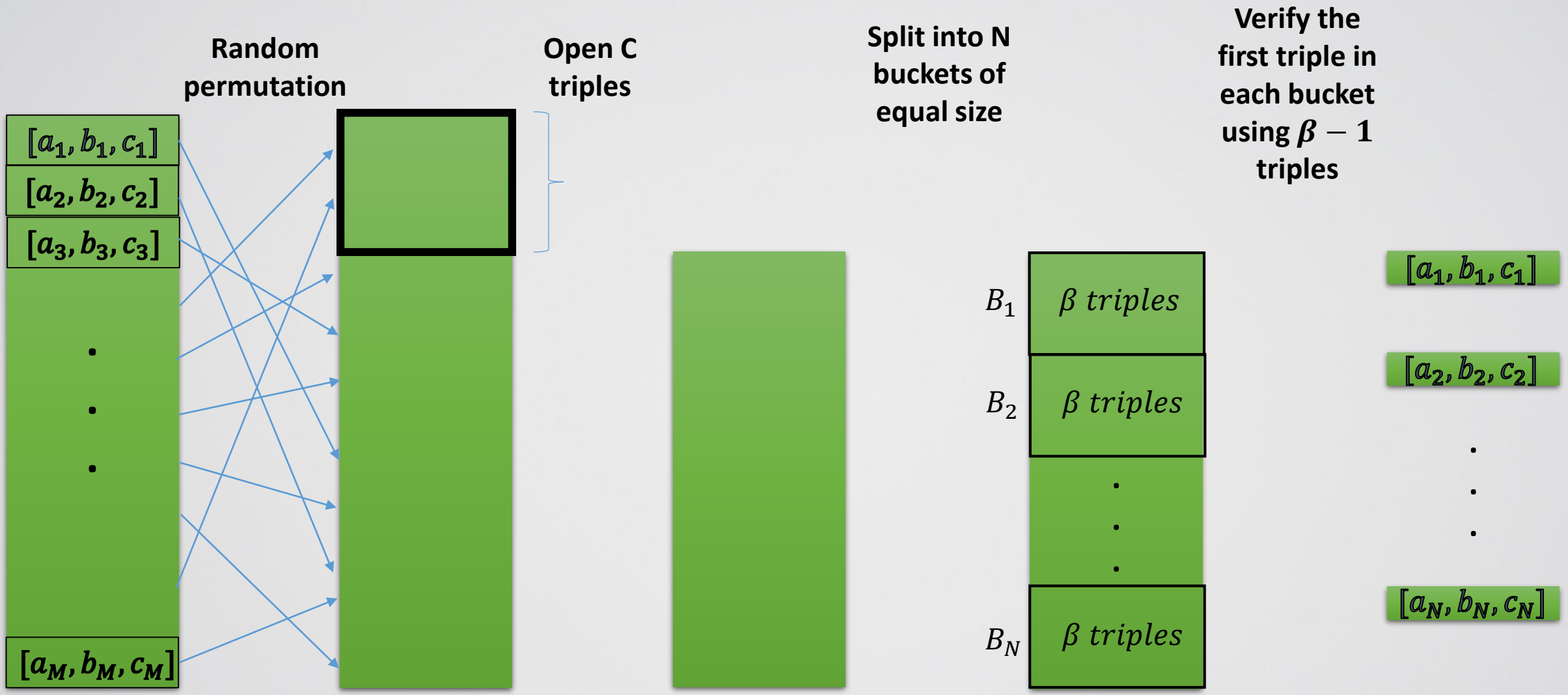

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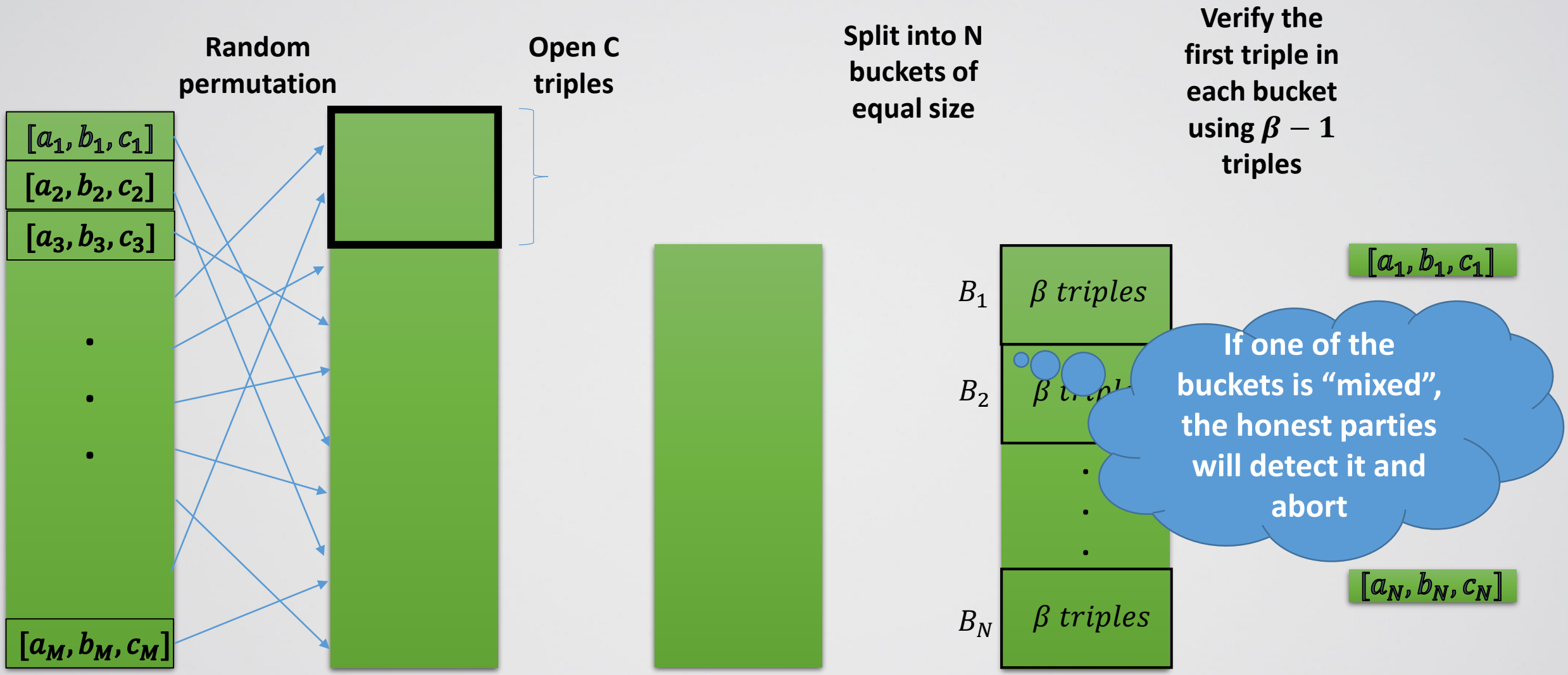

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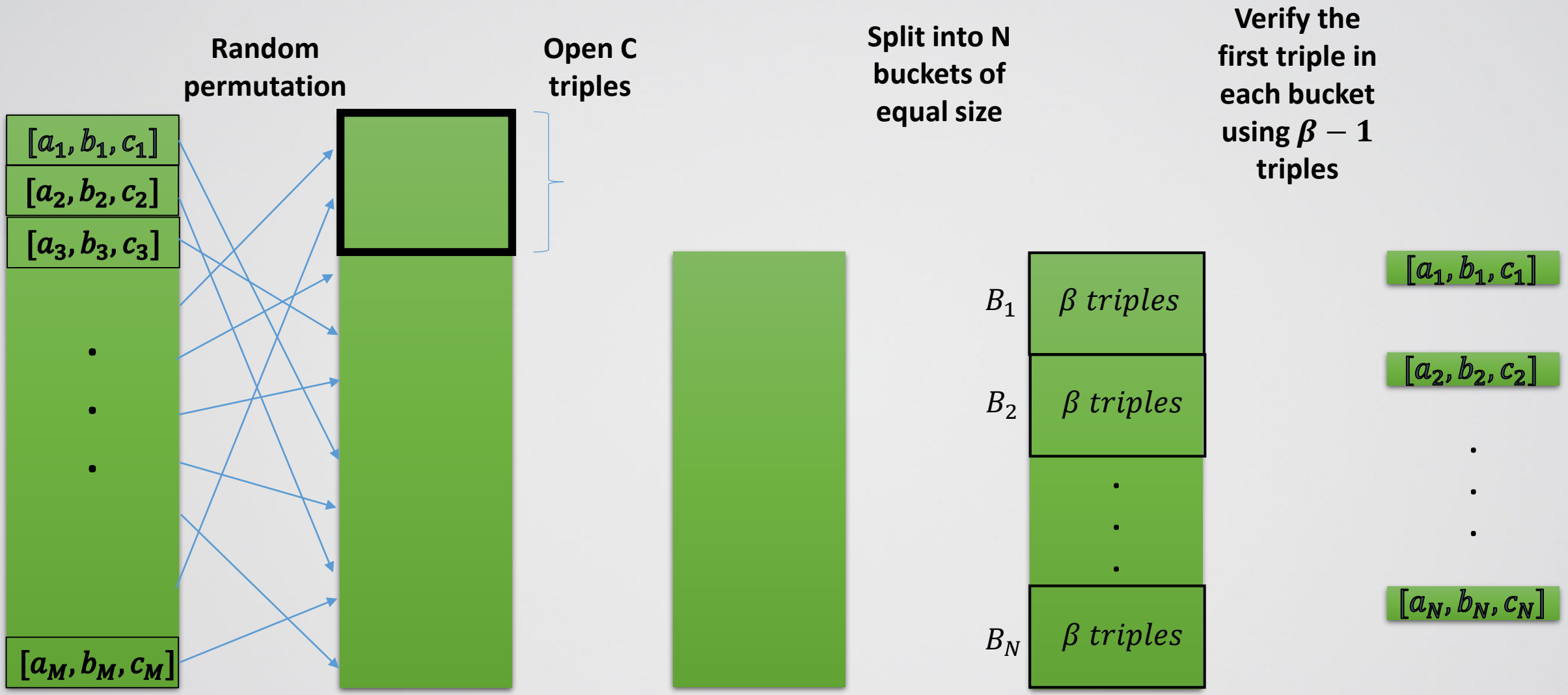

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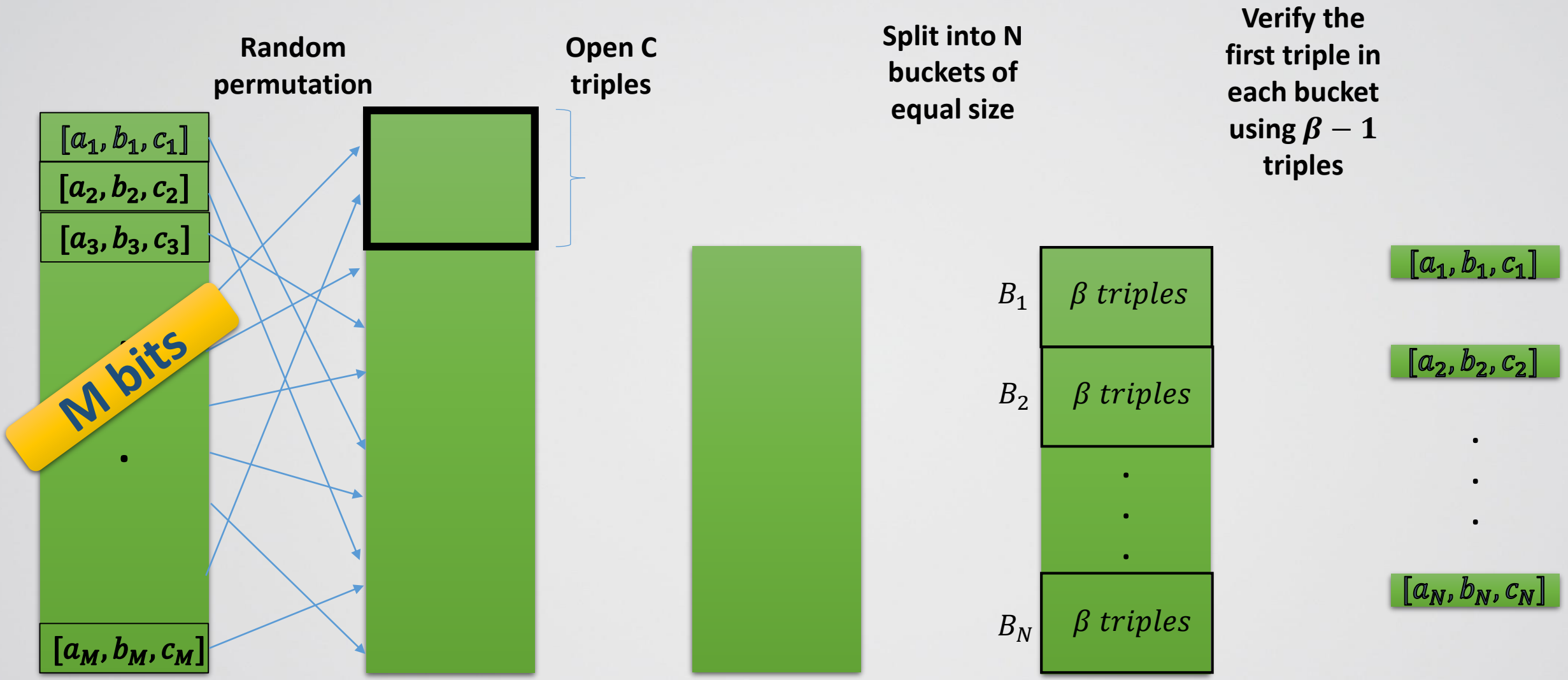

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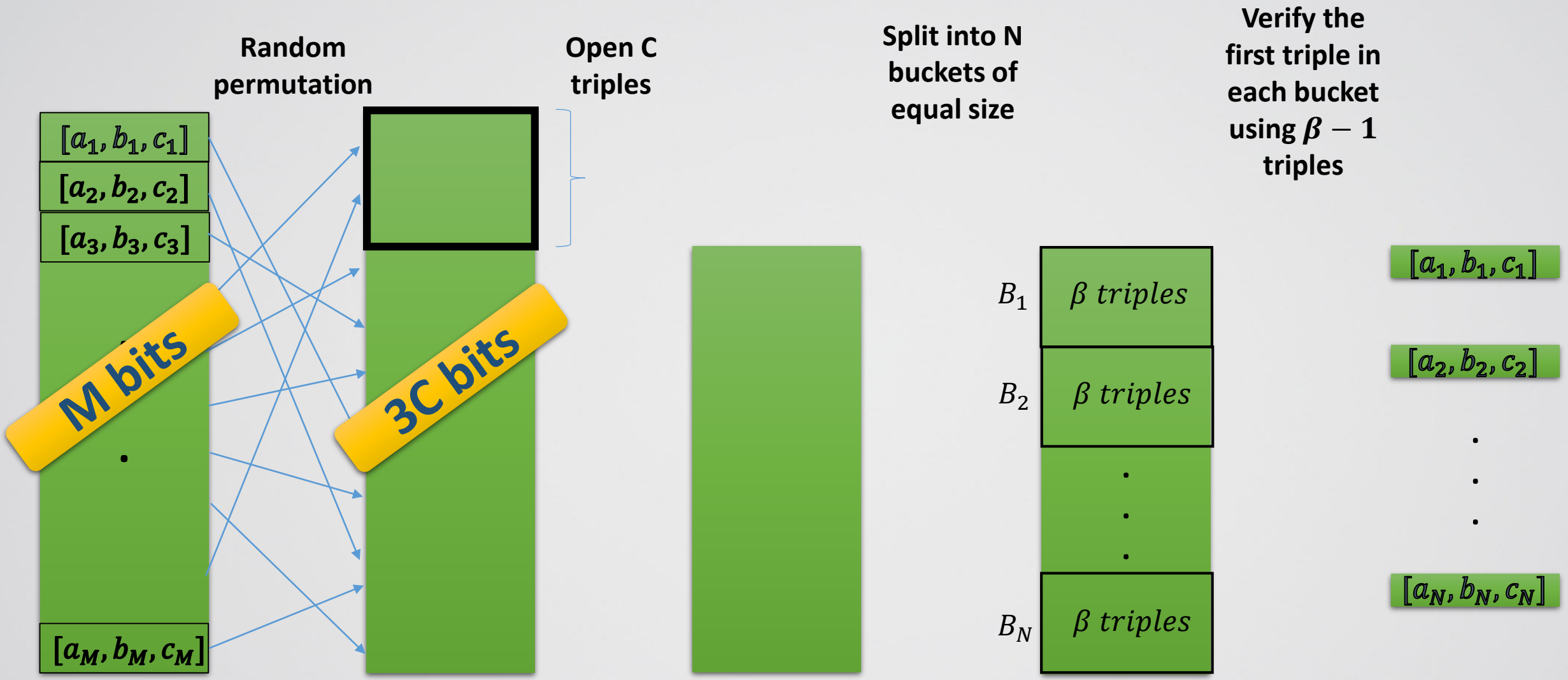

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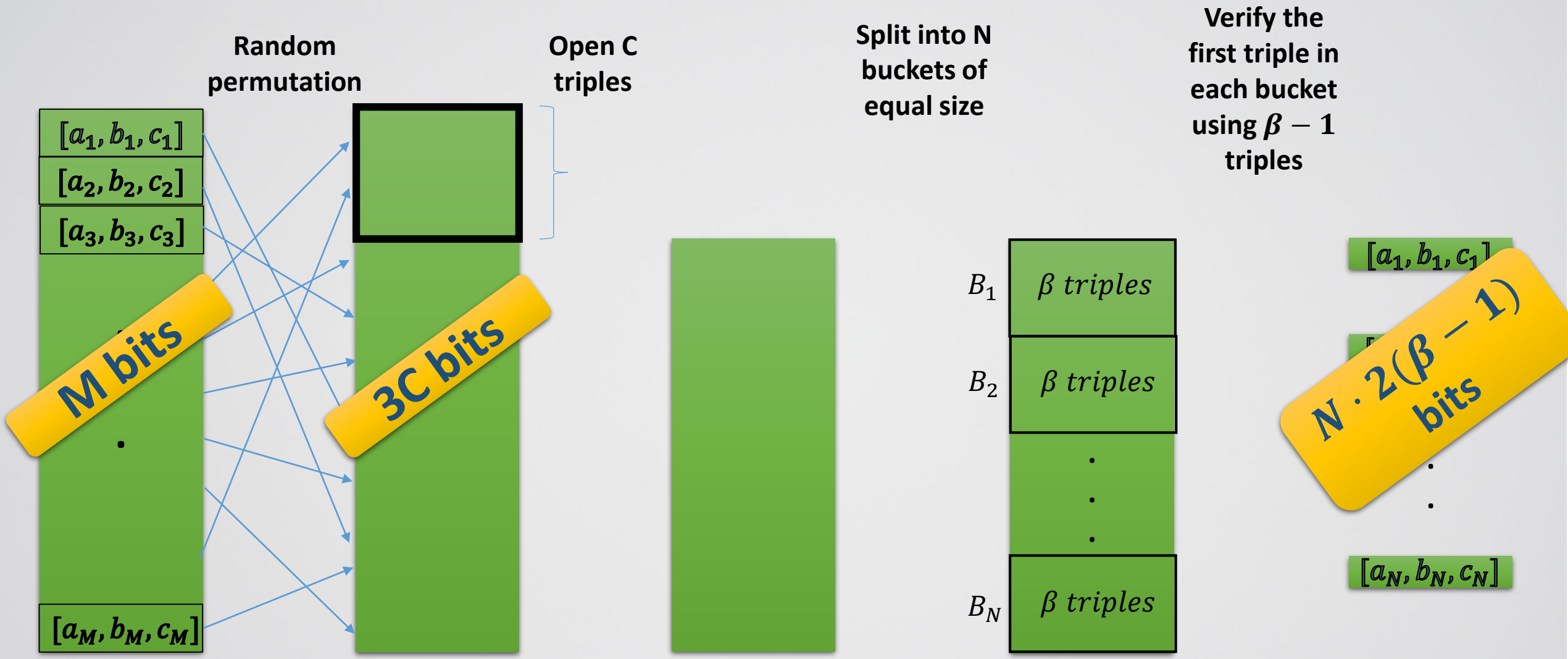

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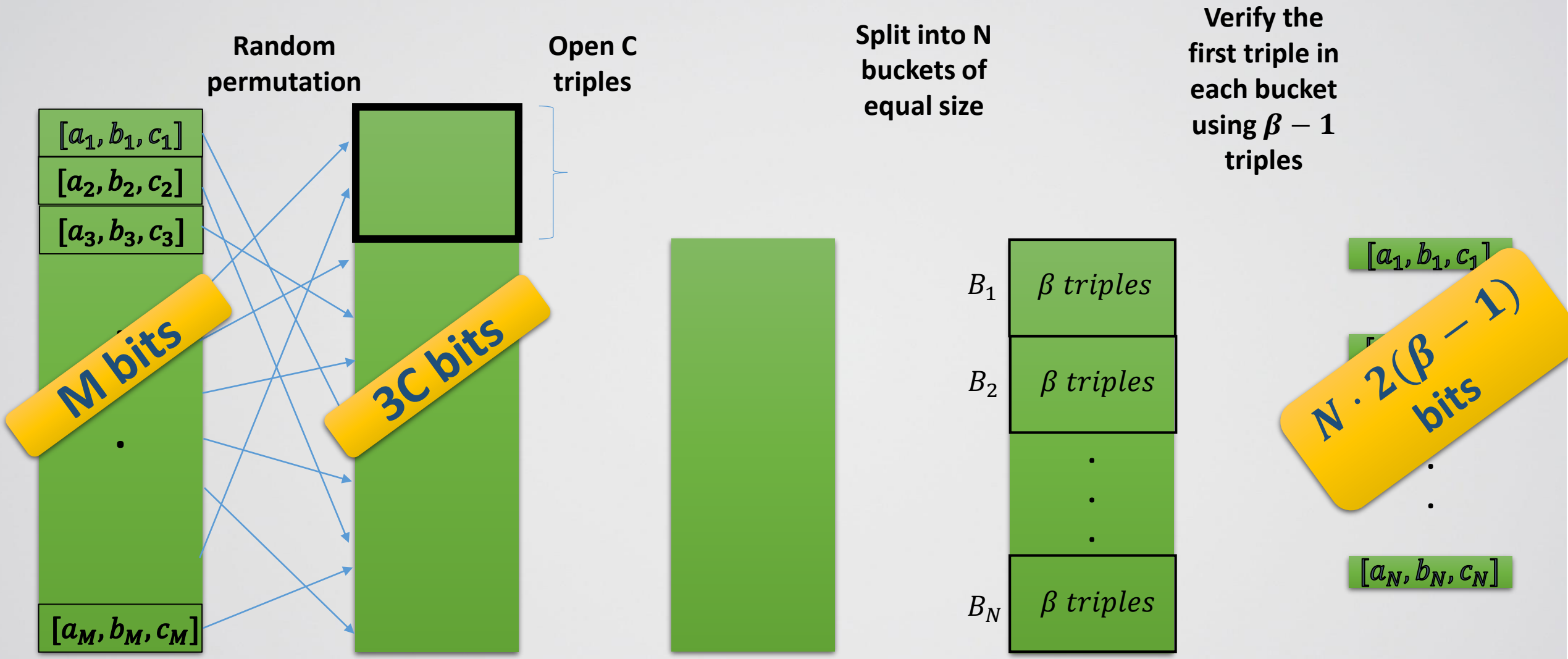

Overall: $M + 3C + 2N(\beta - 1) = N(3\beta - 2) + 4C$ bits

The Balls & Buckets Game

Cost of the pre-processing: $N(3\beta - 2) + 2C$

$\underline{ame(A, N, B, C)}$

1. chooses $N\beta + C$ balls, where each ball can be **bad** or **good**

1.

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CC balls, where each ball can be bad or good

1. The adversary A chooses $N\beta + C$ balls, where each ball can be **bad** or **good**
2. chooses $N\beta + C$ balls, where each ball can be **bad** or **good**

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1. C balls are randomly chosen and opened.
   - If a bad ball was opened – the adversary loses

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<u>The goal</u>: Given a statistical parameter σ and number of triples N to generate, find β, C of minimal size such that:

$$Pr[A\ wins] \leq 2^{-\sigma}$$

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	Tiny OT	Our Work
β	4	3
C	65,536	3
$M = N\beta + C$	4,259,840	3,154,731

$$N = 2^{20}, \sigma = 40$$

Summary & Efficiency

Parameters: $N = 2^{20}, \beta = 3, C = 3$

Pre-processing protocol

1. Generate $N\beta + C$ triples
2. Open C triples
3. Split into buckets and use $\beta - 1$ triples to verify one triple

7 bits per AND gate

Output N triples

On-line protocol

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3 bits per AND gate

Efficiency Comparison

	Communication (bits)	Number of AES Computations
MRZ[15]	85N	3N
Our protocol	10N	N/5

N = number of AND gates

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Three-party with honest majority at the cost of semi-honest Yao

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More Improvements & Implementation

"Optimized Honest-Majority MPC for Malicious Adversaries – Breaking the 1-Billion-Gate Barrier" *(To appear in IEEE S&P 2017)*

- Reduction of communication from 10 bits to 7 bits only!
  - This is achieved by better combinatorics that allows to use a bucket of size 2 (instead of 3)
- Cache-efficient shuffling
- Implementation
  - Basic implementation: **503,766,615 AND gates/sec**
  - With optimizations: **1,152,751,967 AND gates/sec**

THANK-YOU!

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