Read as Needed:
Building WiSER, a Flash-Optimized Search Engine

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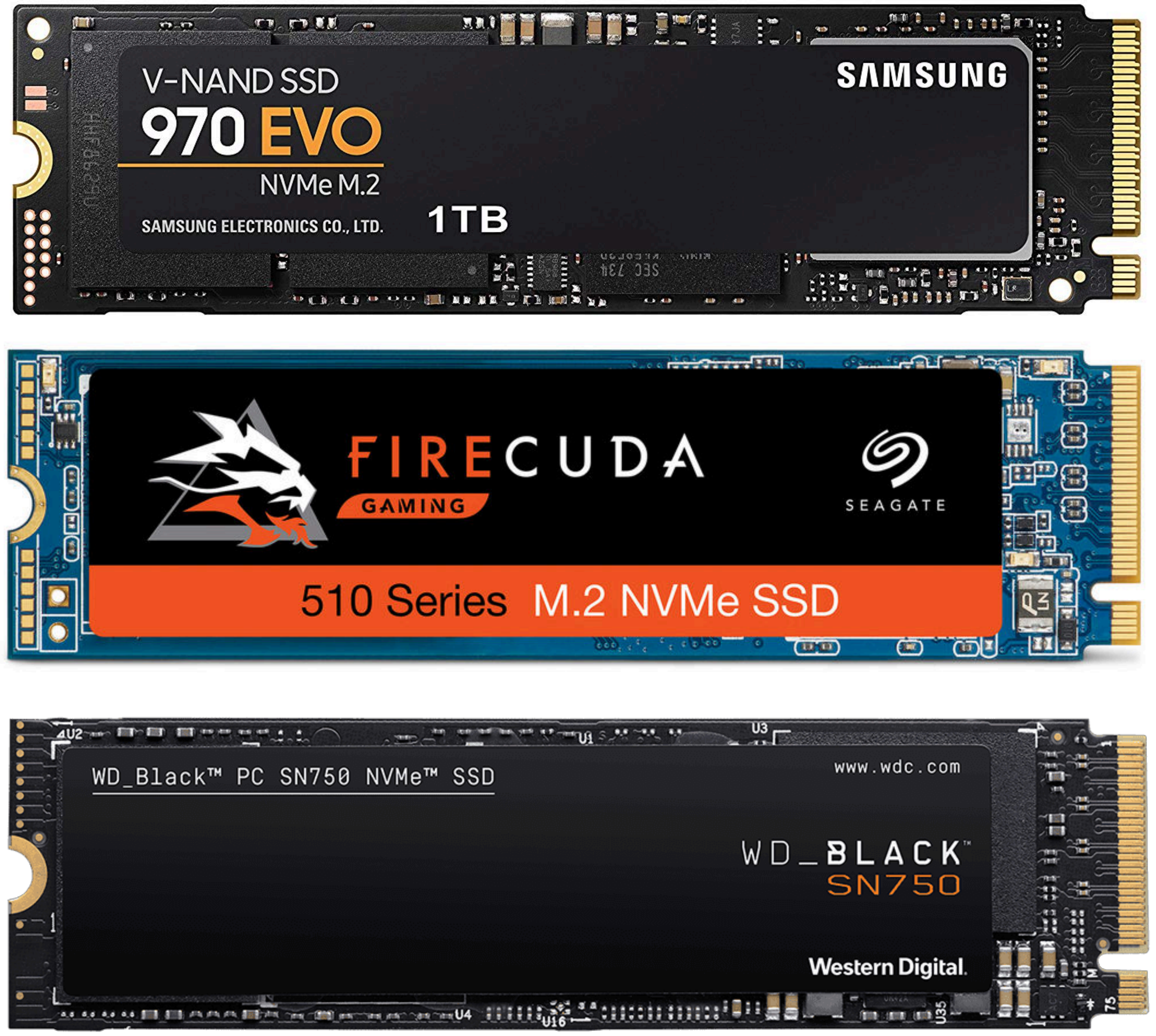
SSDs are Fast



...

- Sequential read: 3.5GB/s
- Random read: 500,000 IOPS
- 0.17 dollar/GB

Not an endorsement for any brand

Many applications/systems have been optimized for SSDs

Key-value stores

- RocksDb, Wisckey, …

Graph stores

- FlashGraph, Mosaic, …

File systems

- SFS, F2FS, …

…

Search engines are overlooked

Search engines are important and widely used

DB-Engines Ranking

Feb 2020	DBMS
1.	Oracle
2.	MySQL
3.	Microsoft SQL Server
4.	PostgreSQL
5.	MongoDB
6.	IBM Db2
7.	Elasticsearch
8.	Redis
9.	Microsoft Access
10.	SQLite

- Wikipedia
- Github
- Uber
- ...

Search engines are challenging for storage systems

Low data latency

- queries are interactive

High data throughput

- engines retrieve info from a large amount of data

High scalability

- data grows over time

Just use more RAM?

RAM is critical in existing search engines

- "your RAM will limit all other resources"

— an Elasticsearch user

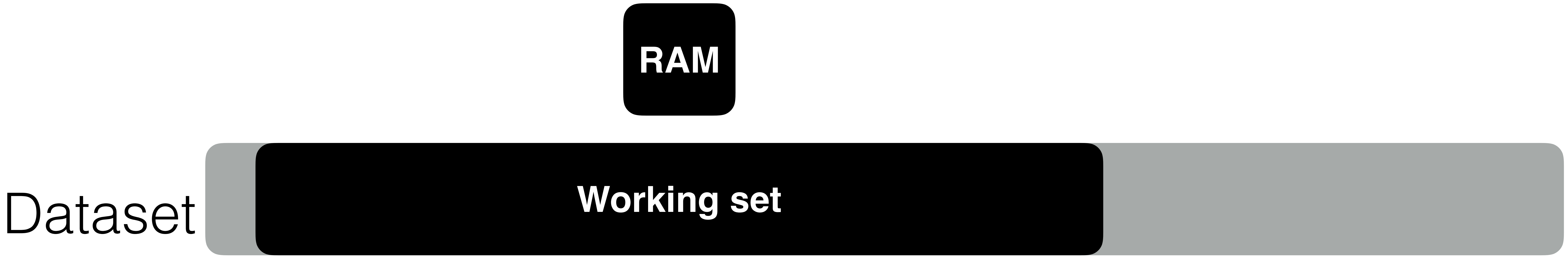
OK at small scale

- total cost is low

Cost prohibitive at large scale

- data grows fast
- may waste bandwidth: rarely read and process 100GB/s

Can search engines perform well with a small memory and a fast SSD?



Yes

Built an engine that performs well on small memory

- could outperform other engine with entire dataset in memory

Our philosophy: read as needed

- use small memory
- read data from SSDs as needed
- do not attempt to cache data in memory
- attempt to read data from SSDs efficiently

SSDs have high read bandwidth and IOPS

- read an entire drive (1TB) in 5 minutes
- higher bandwidth is possible with RAID

Computation/network is more likely to be the bottleneck

To optimize a read-as-needed system, we must:

Reduce read amplification

- SSD bandwidth is still limited

Hide I/O latency

- SSD latency is still high

Use large requests to improve device efficiency

- SSDs favor large requests

We apply four techniques to build a read-as-needed search engine

1. **Grouping data by term**
   - reduce read amplification
   - use large requests
2. **Two-way Cost-aware Bloom Filters**
   - reduce read amplification
3. **Adaptive Prefetching**
   - hide I/O latency
4. **Trade Disk Space for I/O**
   - reduce read amplificationm

Our Contributions

Four techniques to improve search engine performance

- small memory, large dataset, fast SSDs

An open-source flash-optimized search engine from scratch (WiSER)

- 11,000 lines of C++

A benchmark for evaluating search engines

- based on Wikipedia
- a variety of queries for stressing the system

Better performance than the state-of-the-art Elasticsearch

- increase end-to-end query throughput by up to 2.7x
- reduce end-to-end latency by up to 16x

Outline

Overview

Techniques

Evaluation

Final Thoughts

Techniques

1. Cross-stage Data Grouping
2. Two-way Cost-aware Bloom Filters
3. Adaptive Prefetching
4. Trade Disk Space for I/O

Guided by the Wikipedia dataset

Techniques

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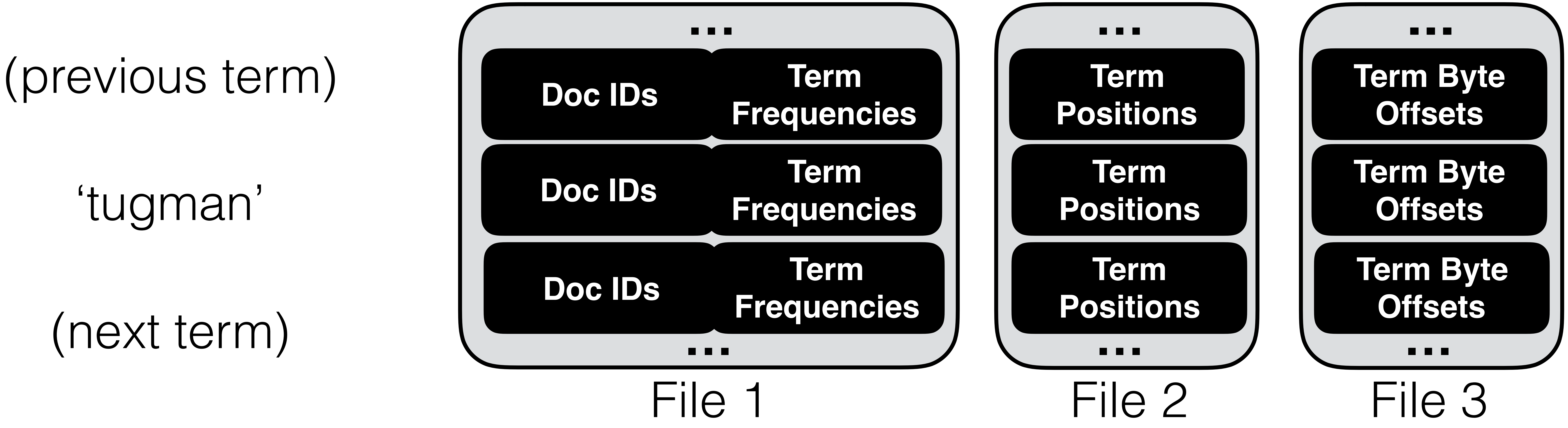
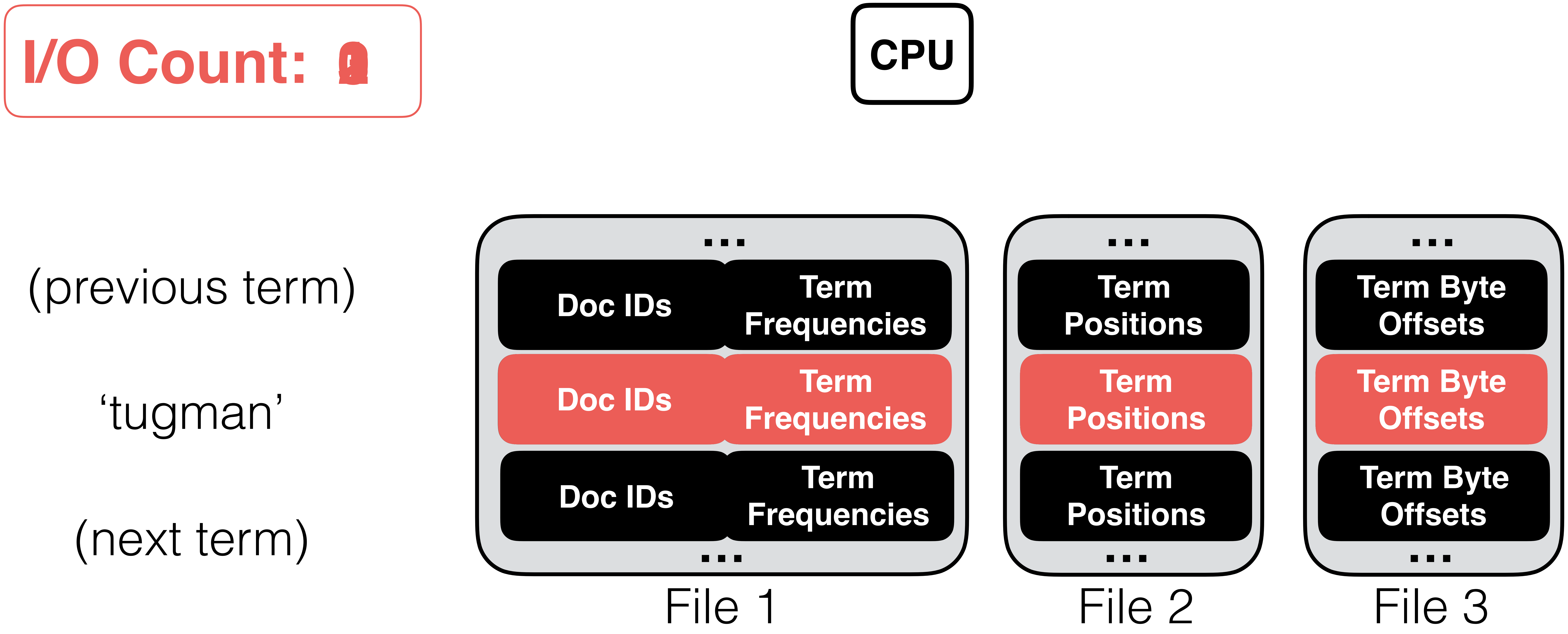
Background: stages of a search query

Data in Elasticsearch is grouped by stage



How much I/O is needed for ‘tugman’?



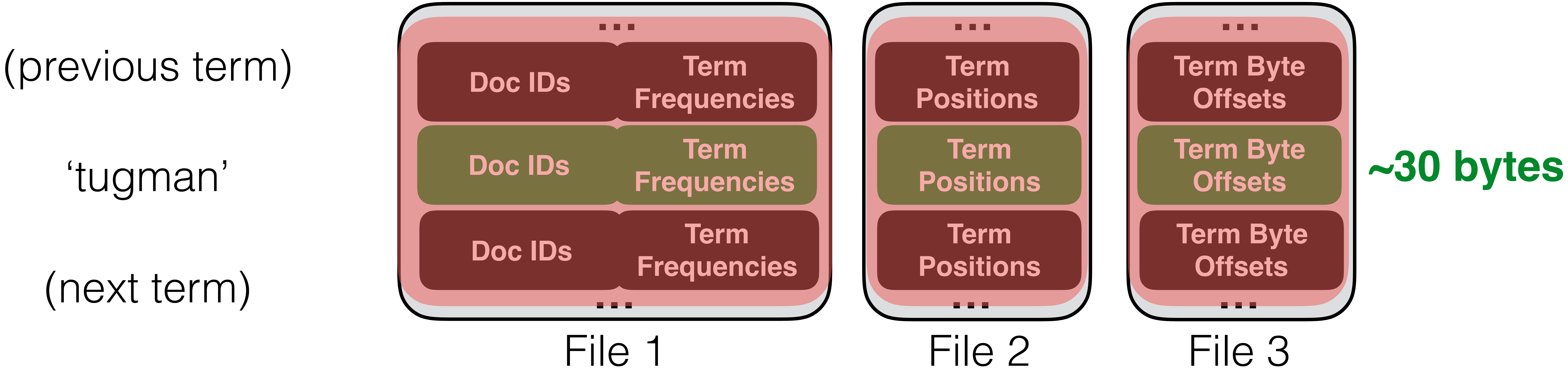
Transferred data is often wasted

I/O Count: 3, Size: 12 KB

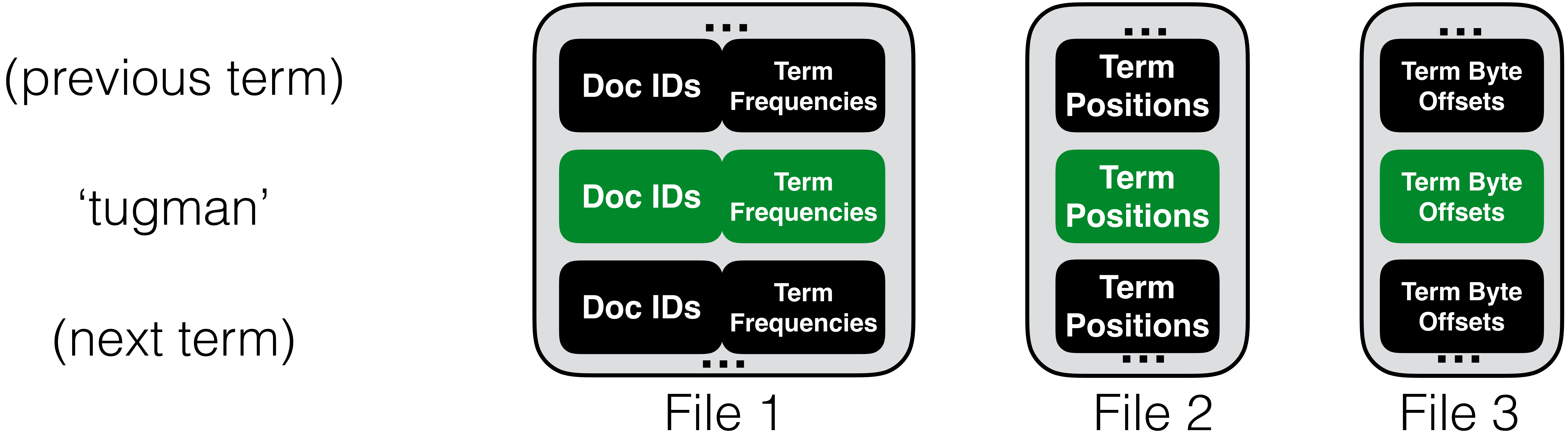
Data of ‘tugman’ can fit in 4KB

Small term is common

- 99% of Wikipedia terms can fit in 4 KB



WiSER groups data by term



WiSER groups data by term

How much I/O does WiSER need for ‘tugman’?

I/O Count: 0

Reduce I/O by up to 3x

CPU

Techniques

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Background: phrase queries offer high accuracy

Search “united AND states”

Search **phrase** “united states”

The **United States** president…

The spokesman of **united** airlines **states** that…

Background: phrase queries offer high accuracy

But demand a lot more data

Term	Position	Position
united	2,X,X,X,X,X,X…	4,X,X,X,X,X,X…
states	3,X,X,X,X,X,X…	6,X,X,X,X,X,X…

Our **United States** president…

The spokesman of **united** airlines **states** that…

Tried regular Bloom filters, it doesn't work…

WiSER adds two Bloom filters to enable "two-way" filtering

Term	bloom filter **before**	bloom filter **after**	**Position**
united	our	states	2
states	united	president	3
united	of	airline	4
states	airlines	that	6

Our **United States** president…

The spokesman of **united** airlines **states** that…

Check if "united states" is a phrase in a document by:

1. Checking if "states" is in "united".after
2. Or, checking if "united" is in "states".before.

Why adding two filters?

WiSER dynamically chooses the smaller filter for filtering (two-way)

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Check if 'states' is after 'united'

600 KB > 500 KB + 50 KB

	600 KB	600 KB	500 KB
united	Filters.before	Filters.after	Positions

	60KB	60KB	50KB
states	Filters before	Filters after	Positions

Check if 'united' is before 'states'

60 KB < 500 KB + 50 KB

WiSER only uses filters when it can reduce I/O (cost-aware)

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Check if ‘states’ is after ‘united’

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Not worth it

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Elasticsearch relies on the OS to prefetching…

WiSER adaptively prefetches frequently-used data to hide I/O latency

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Techniques

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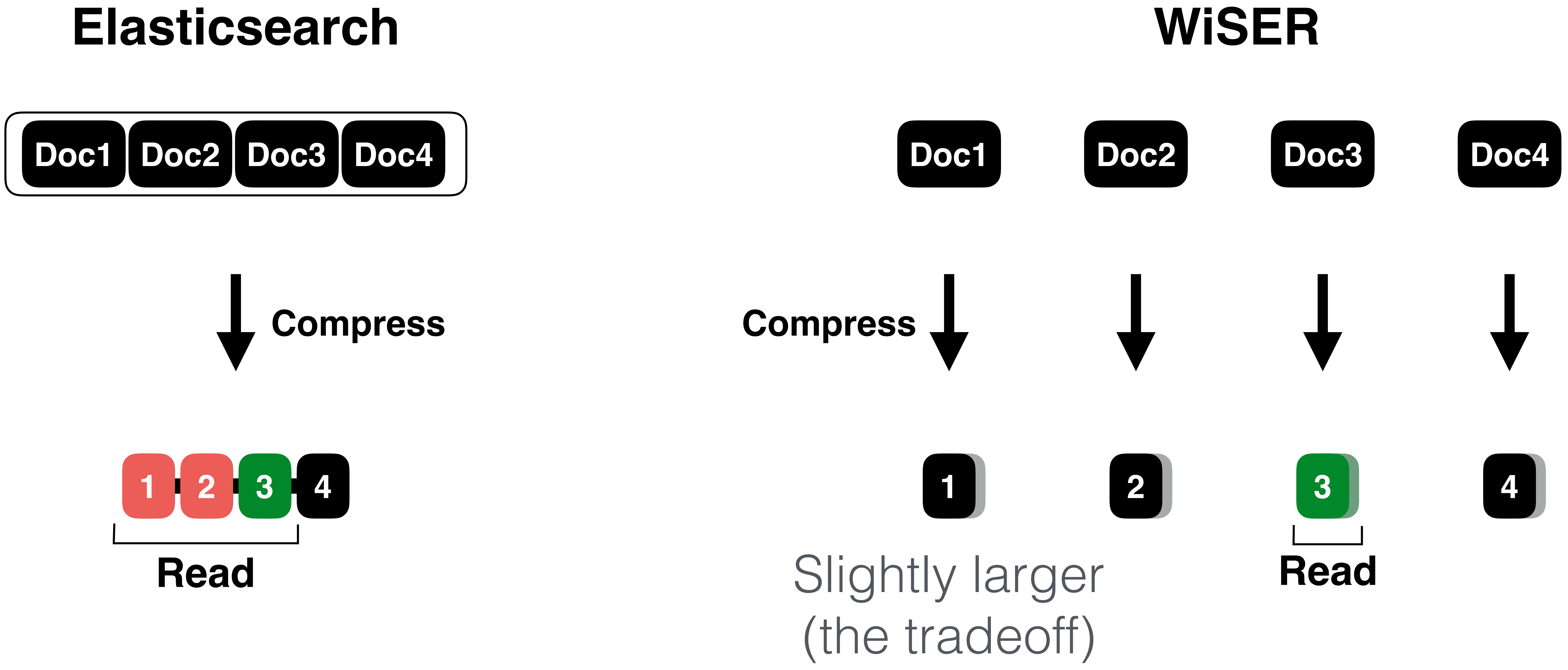
WiSER compresses documents individually to reduce read amplification



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Evaluate with *WSBench*

Dataset: Wikipedia

- 6 million documents, 6 million terms, 18GB

Queries

- single term queries, “and” queries, “phrase” queries, real queries
- vary term popularities in wikipedia

Machine

- 16 cores
- NVMe SSD: peak read 2 GB/s, 200,000 IOPS
- Linux container with 512-MB RAM
  - how well each search engine can scale up to large working sets that do not fit in main memory?

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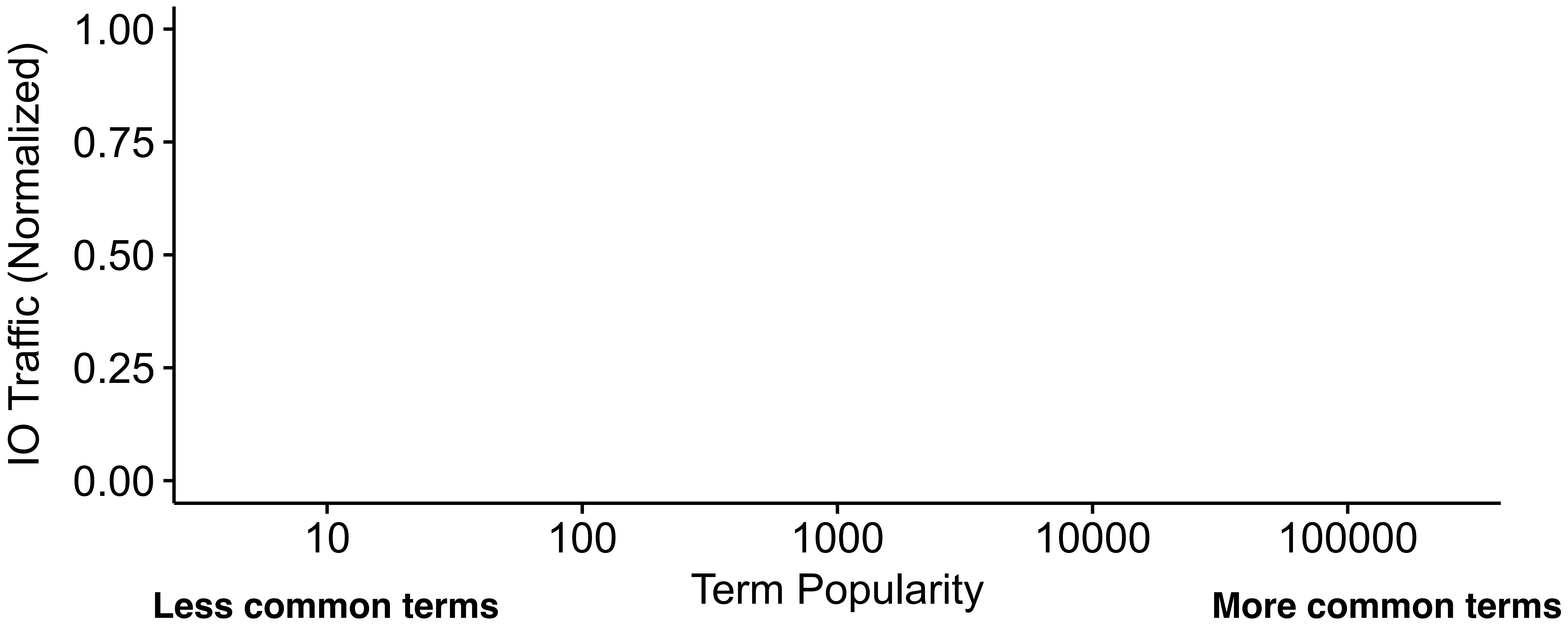

(single term query)

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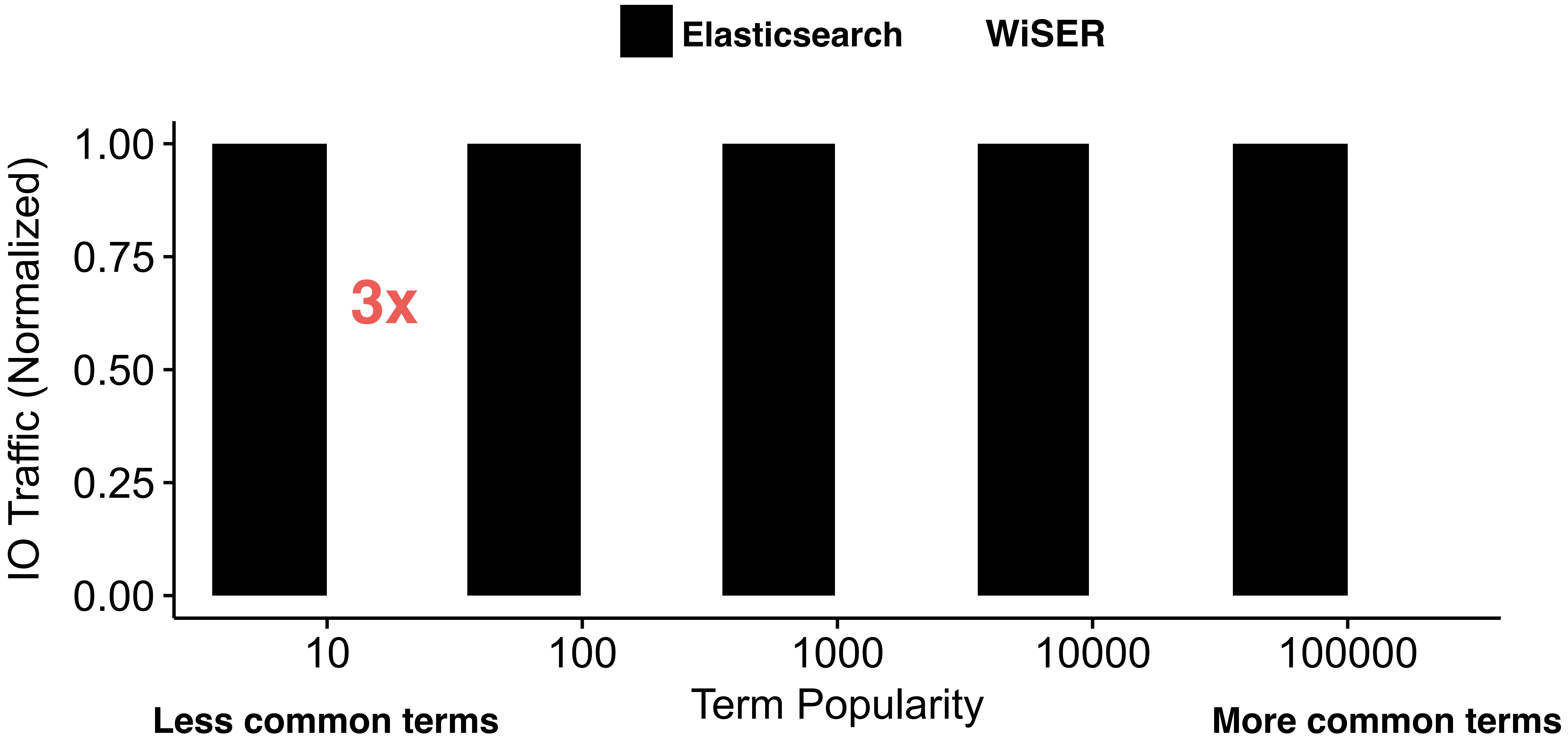

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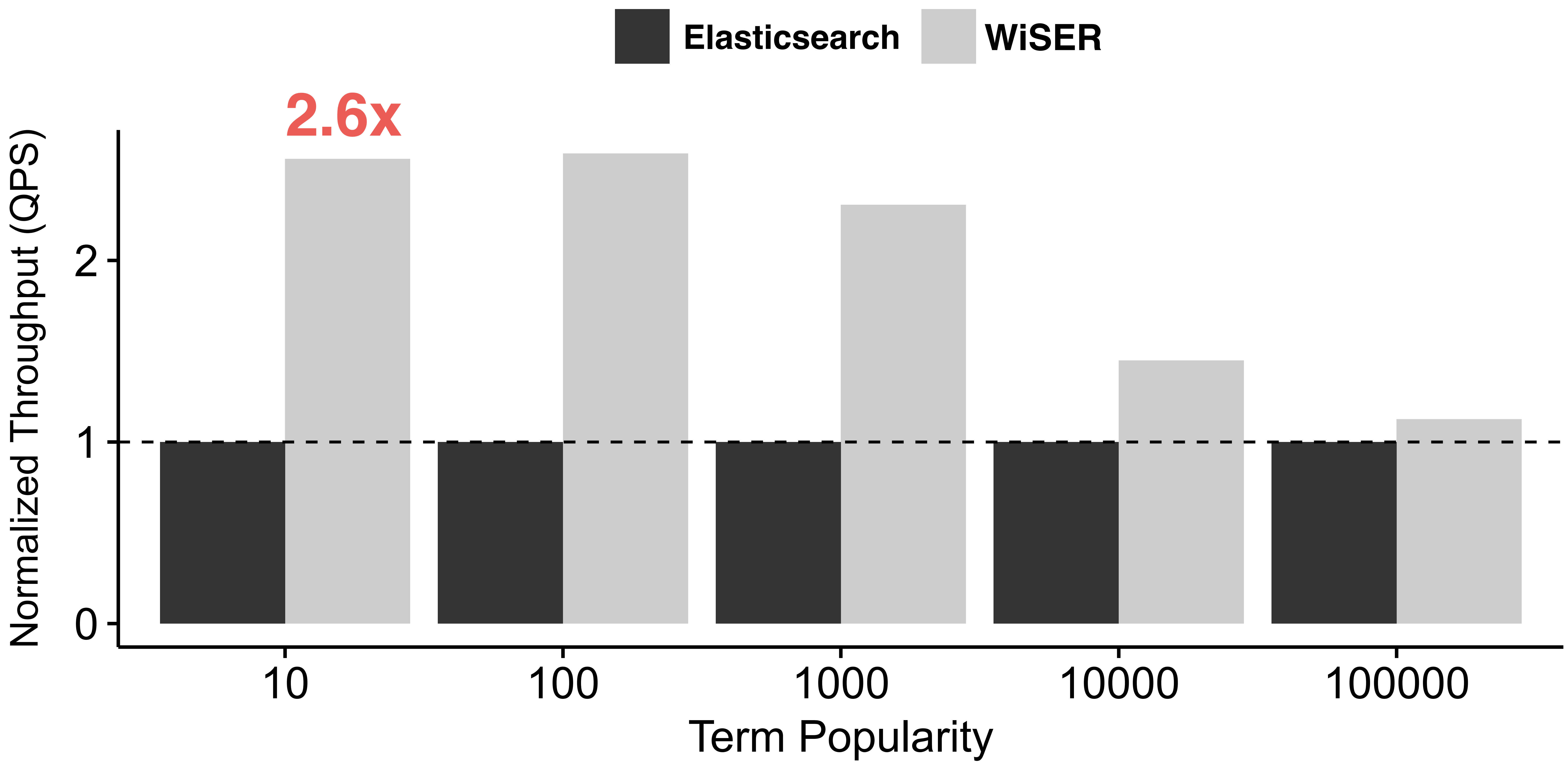

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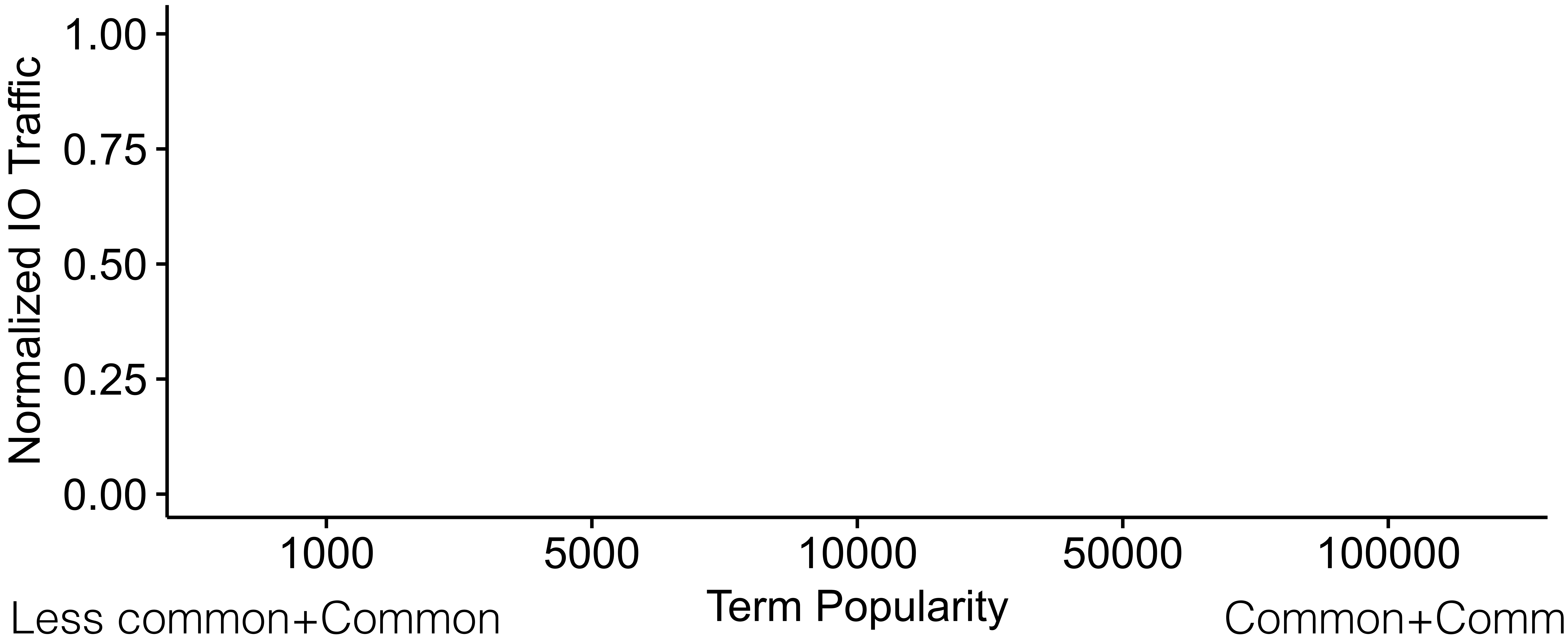

Less common+Common

Common+Common

(phrase query)

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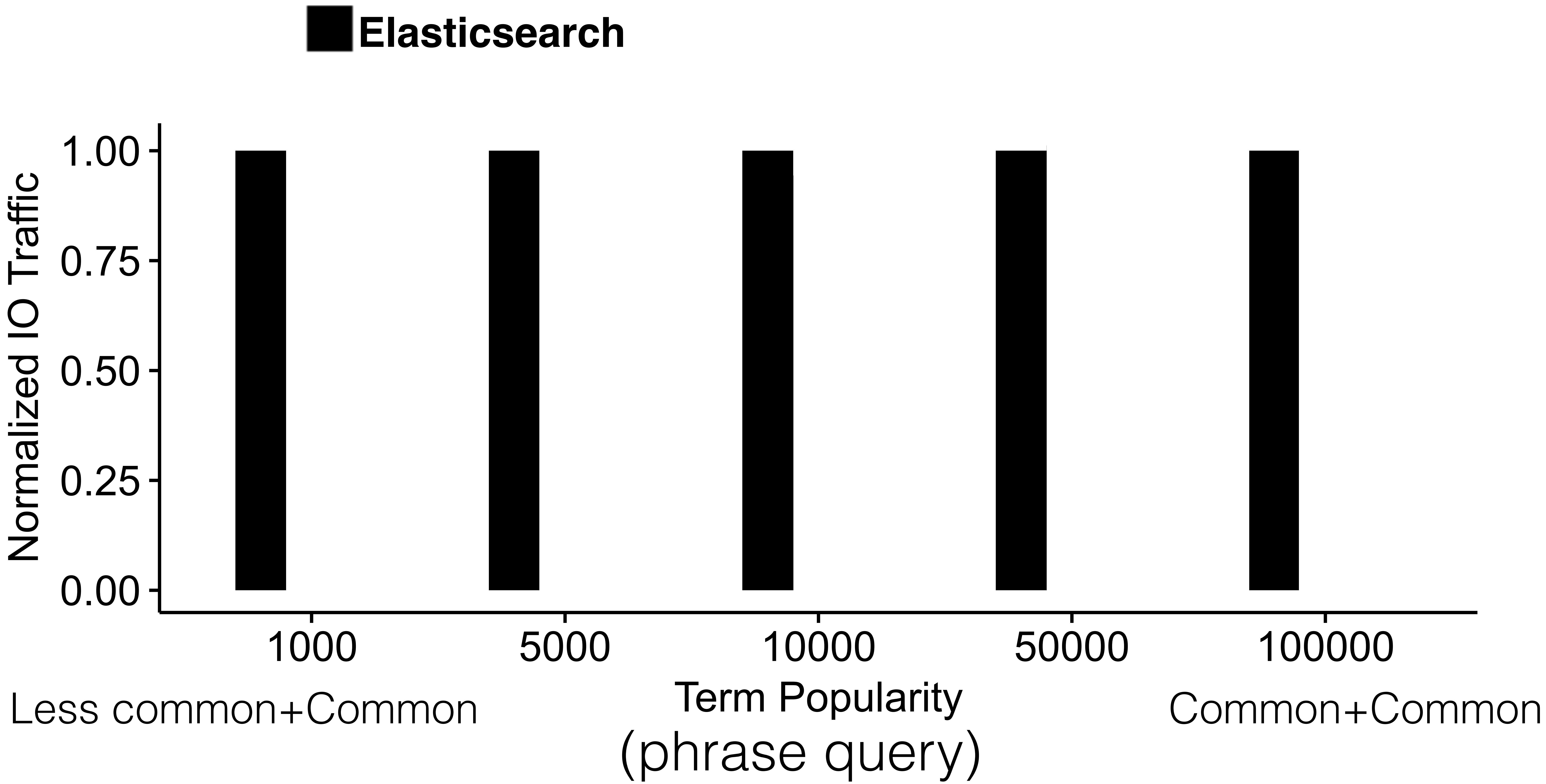

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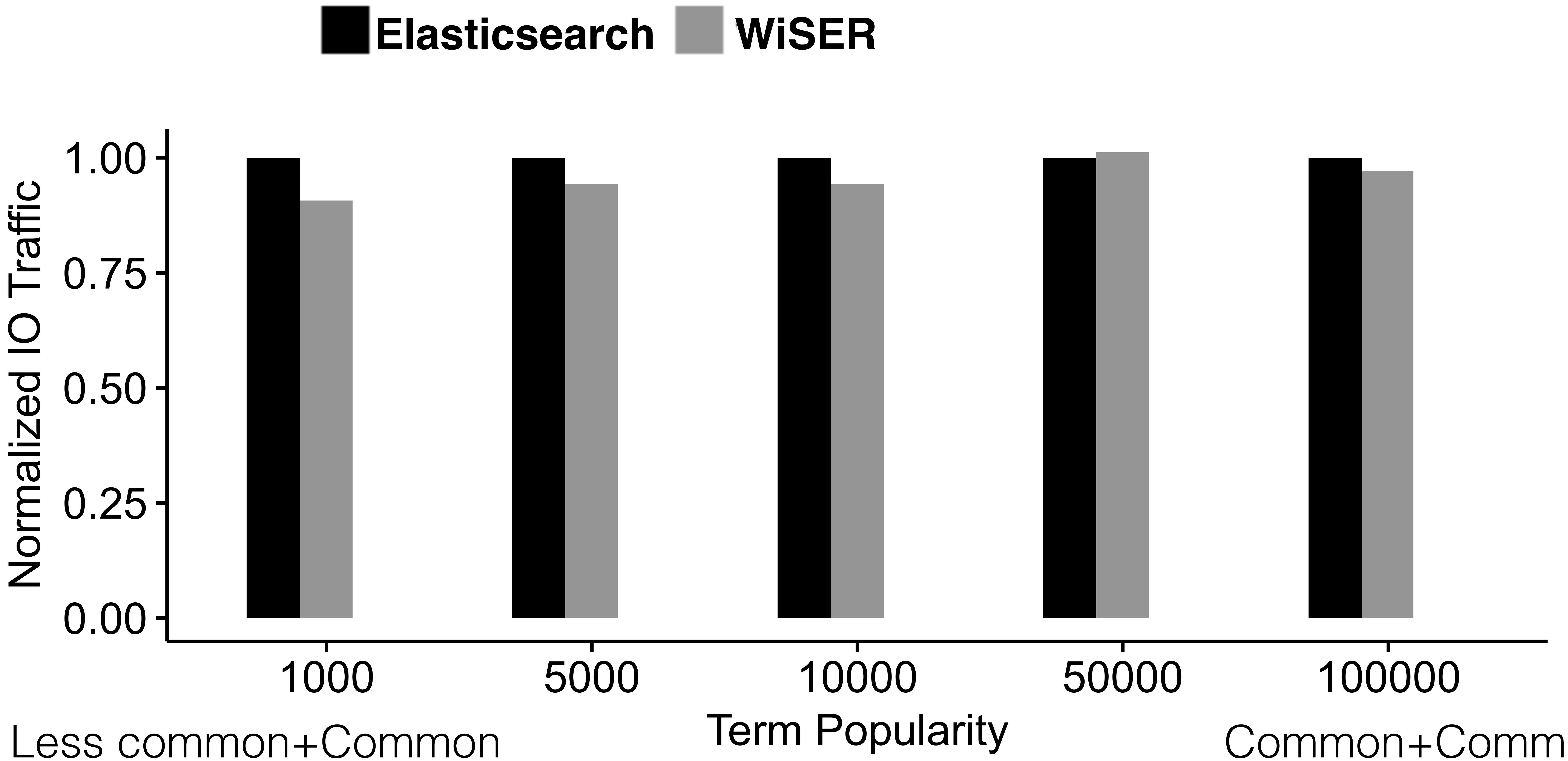

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(phrase query)

Common+Common

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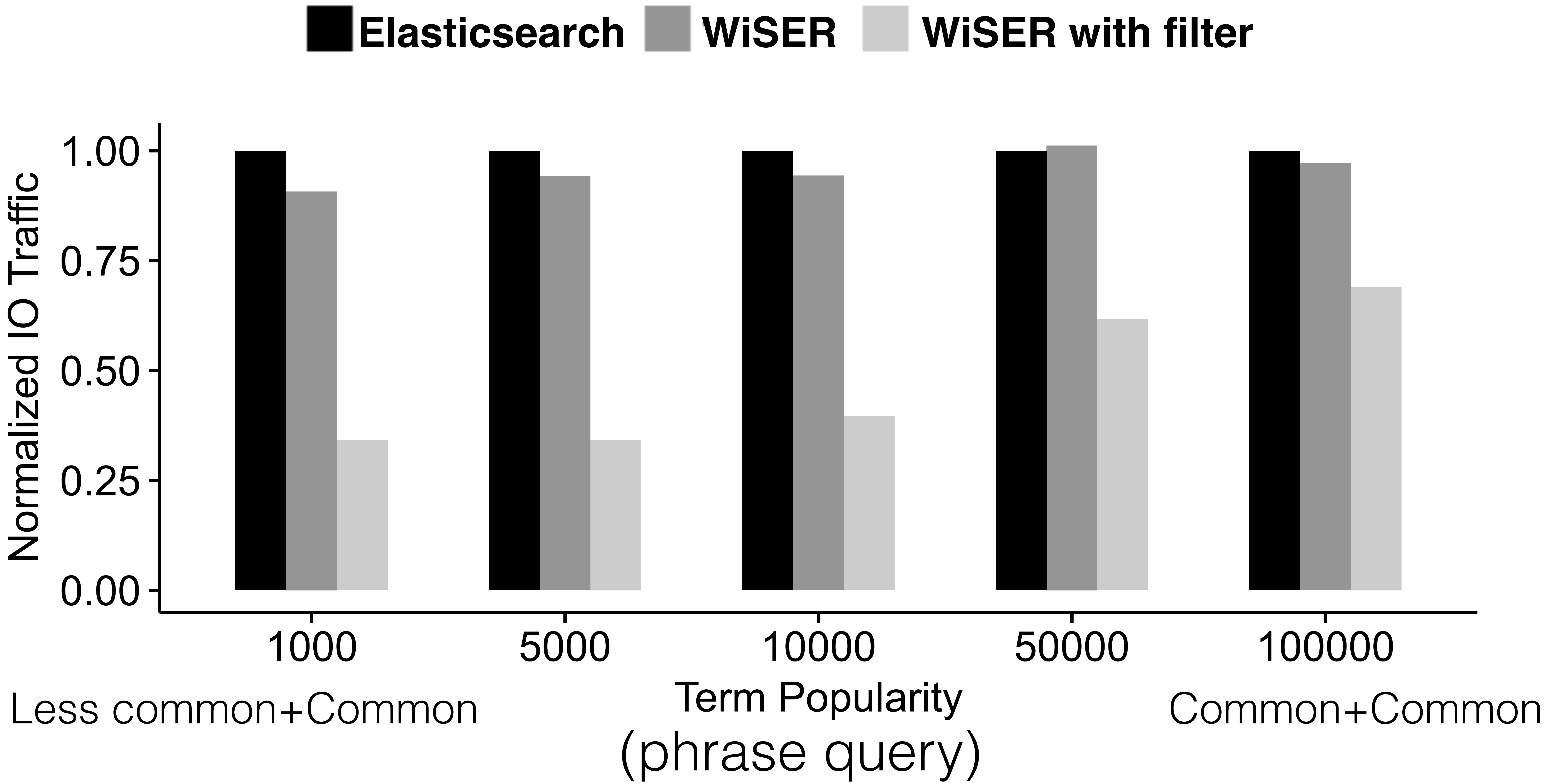

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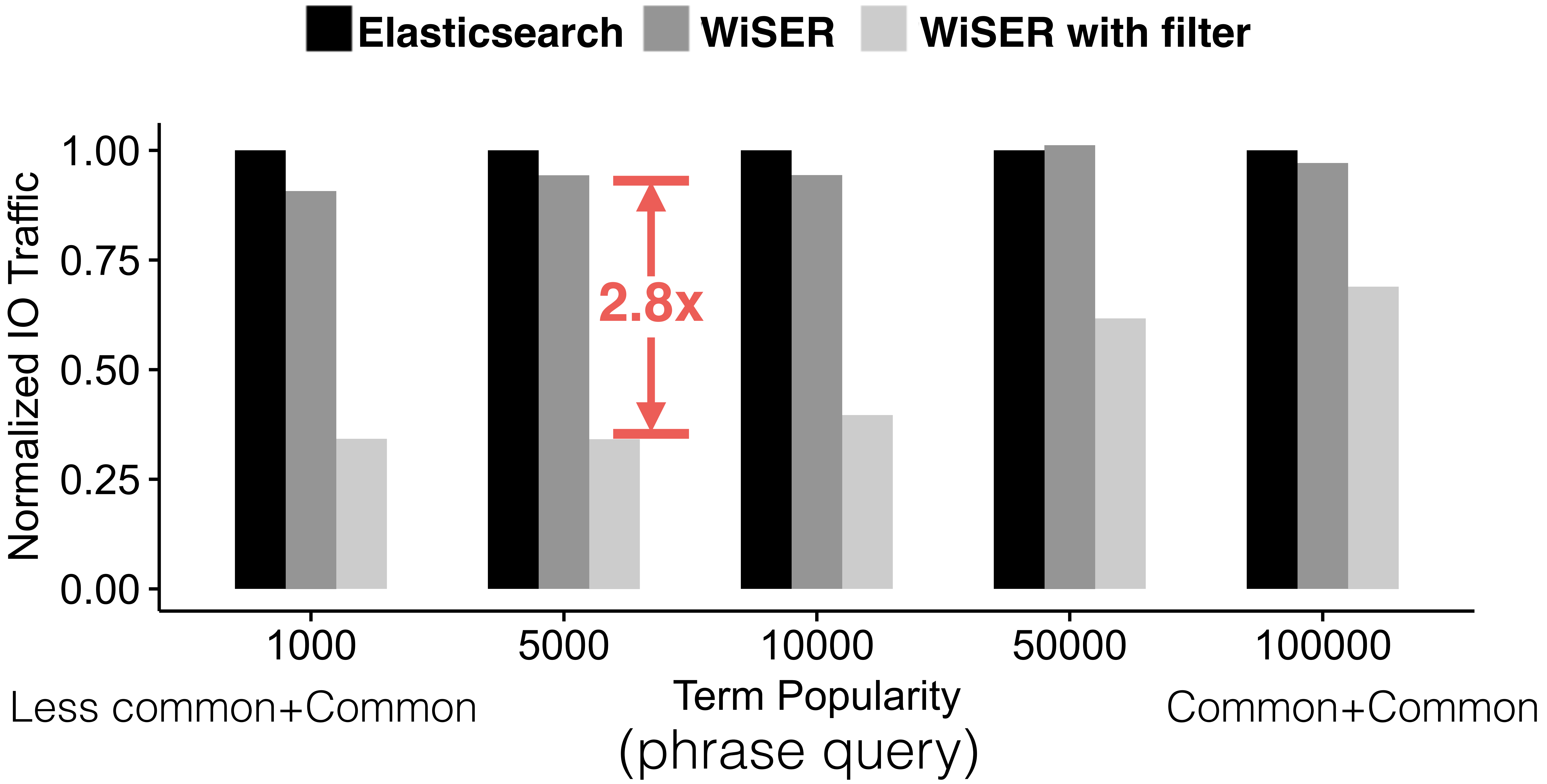

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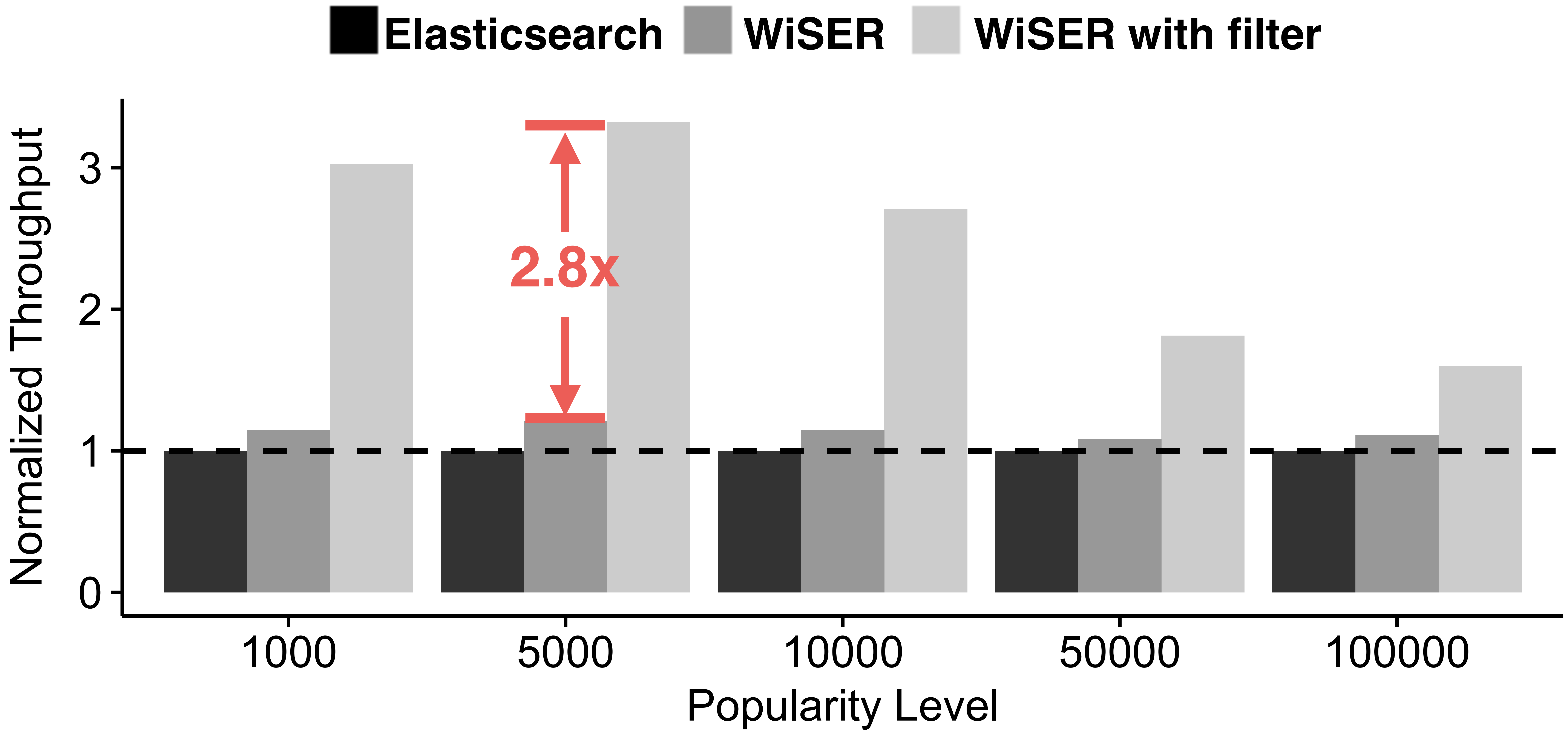
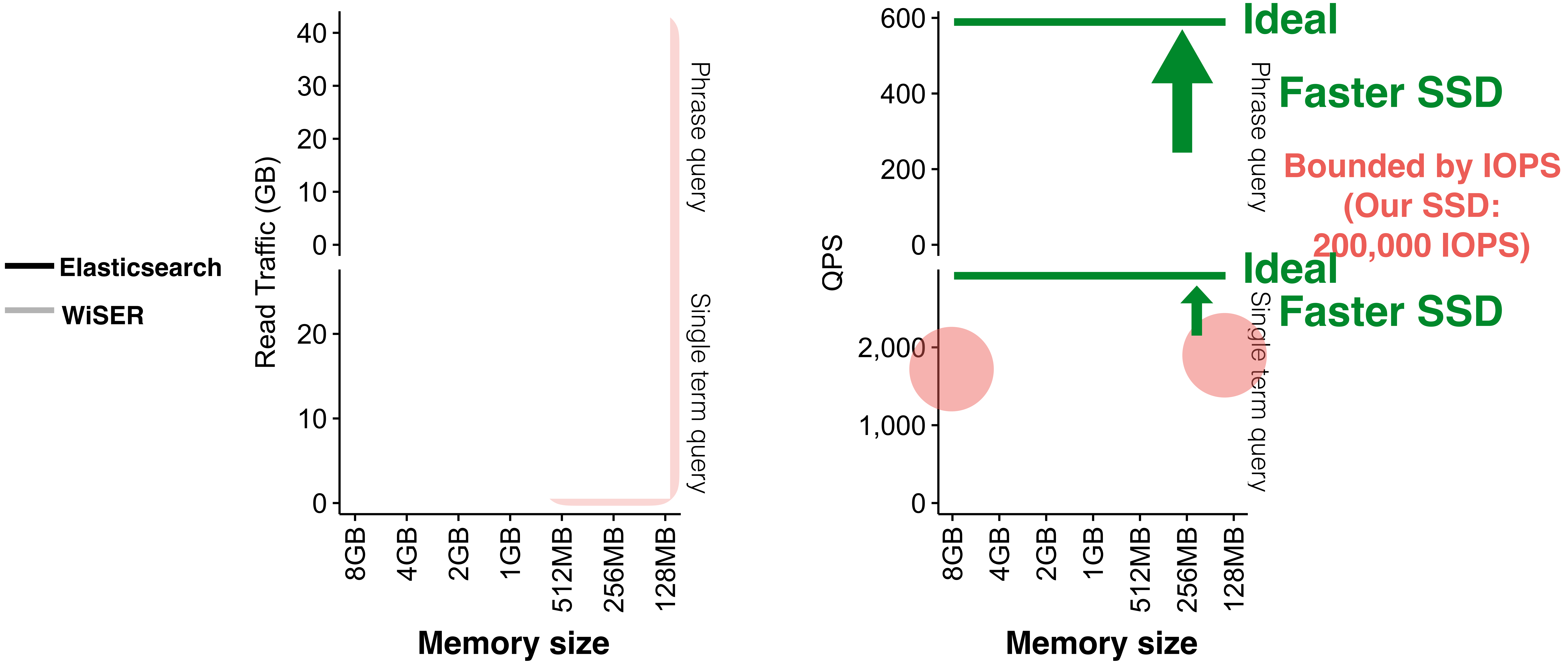


How does small-memory performance compare with larger-memory performance?



More results are in the paper…

Final Thoughts

Does your application really need large cache/RAM?

Will your application works just fine if it reads data as needed from fast SSDs?

Q & A

Ask as Needed