Mitigating Read Amplification with Dynamic Block Size Control in HBase

바닥까지 파보는! HBase random read 성능 개선기

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3. HBase read amplification – 정의 및 원인 분석
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5. Evaluation – 벤치마킹 및 적용 효과
6. Conclusion - 마무리

1. Background

배경소개

AIDA

ADVANCED INTERFACE
FOR DATA & AI

CUVE C3 CQuery Logiss AiSuite Hades Deathnote

- 저장
- 유통

1.1 네이버 데이터 저장 플랫폼: CUVE

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*Deview 2017 : HBase 기반 검색 데이터 저장소

HBase 기반의
범용적인
대규모
분산 데이터 저장소

1.1 네이버 데이터 저장 플랫폼: CUVE

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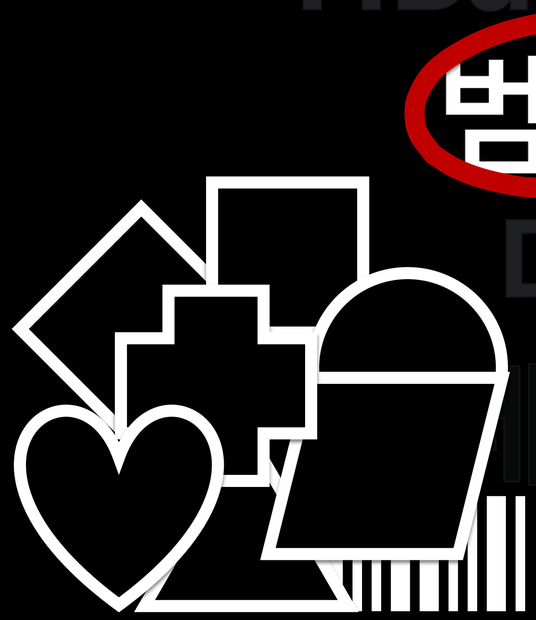
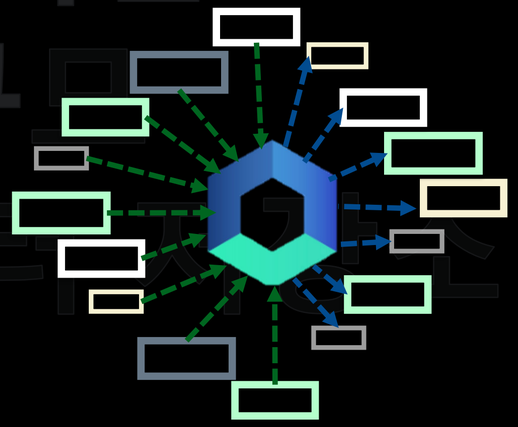
HBase 기반의
범용적인
대규모
데이터저장소



다양한 데이터



다양한 사용자

1.2 데이터의 다양성

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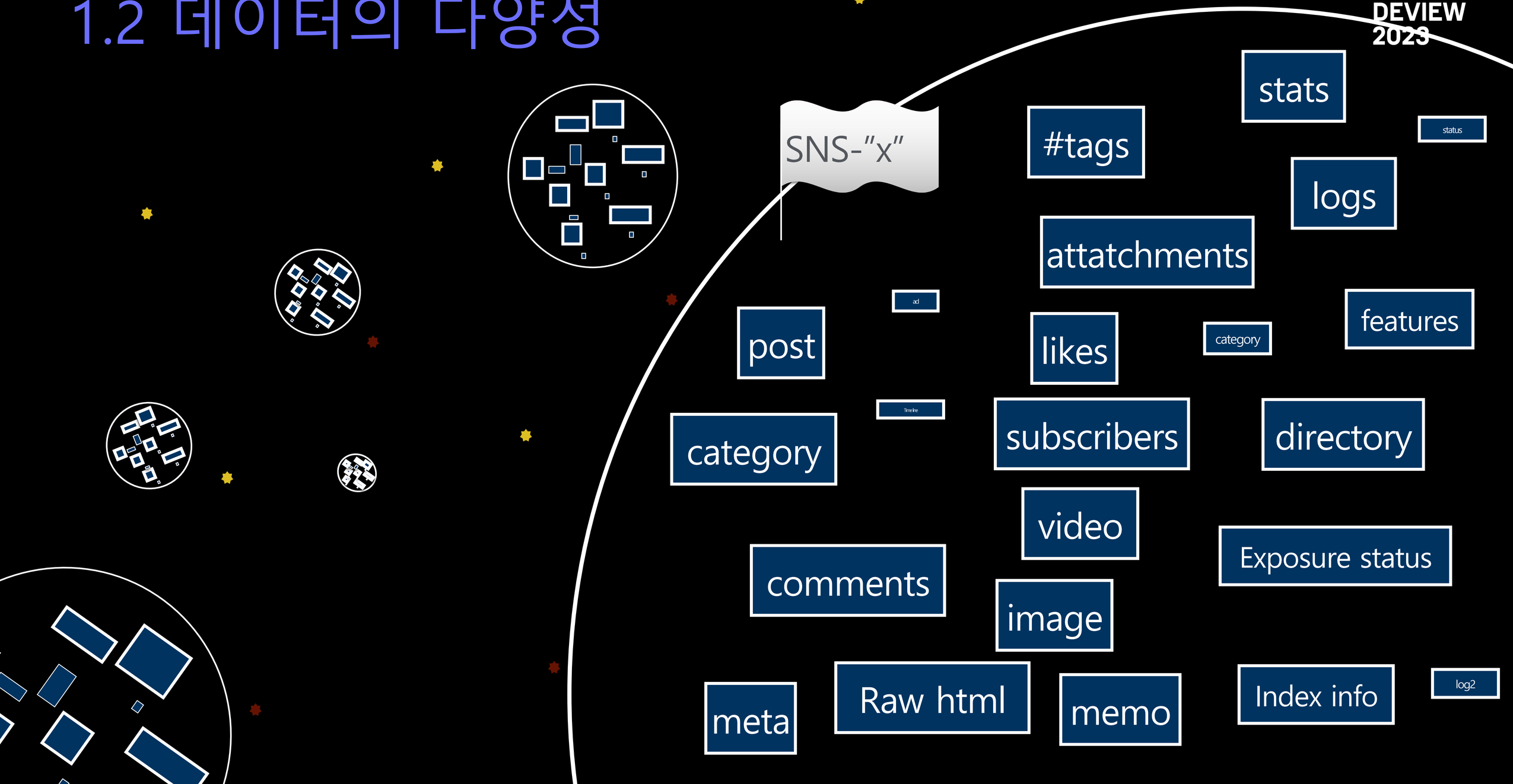

1.2 데이터의 다양성

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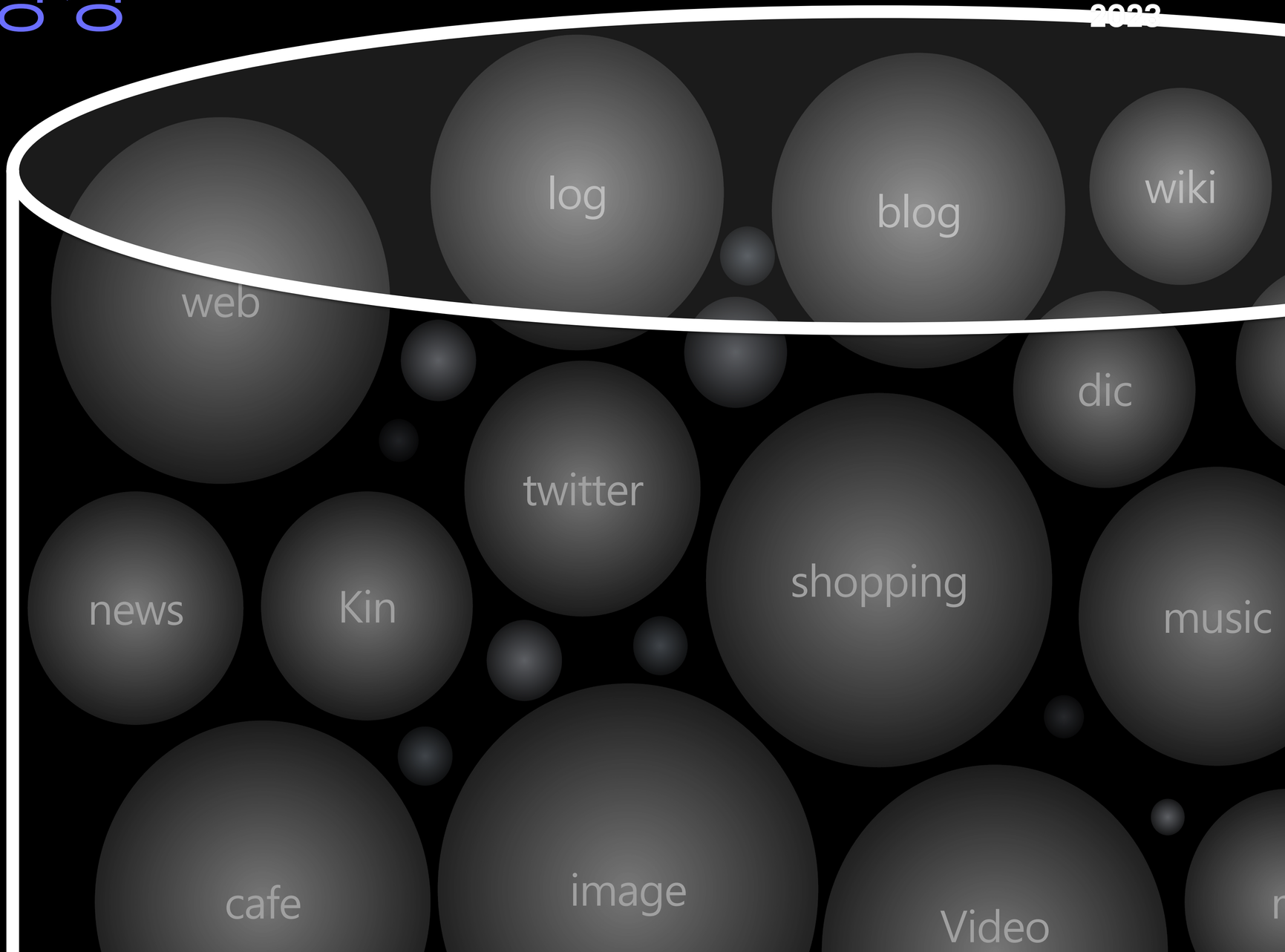

1.3 입출력 패턴의 다양성

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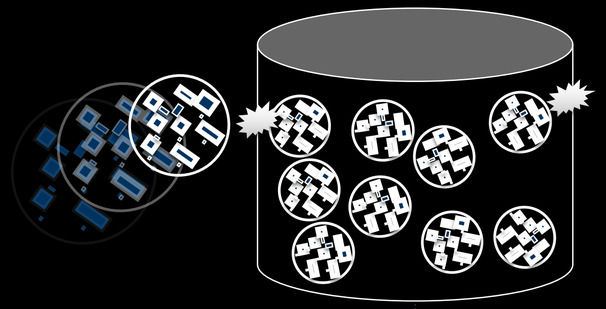
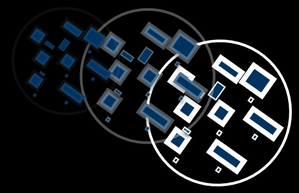


입력 패턴

- Read intensive vs Write intensive
- Timeline data vs non-time series
- Bulk update, Force update
- Update policy

  (del&create, partial, Immutable …)
- Migrations

…



출력 패턴

- Streaming
- Full-dump
- Random get
- Time-range scan
- Scan with filter
- Meta-only
- Prefix scan
- Secondary Index search

Deview 2015 : Hbase consistent 2ndary indexing

1.4 HBase와 저장소

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대규모

Deview 2021 : 네이버 최대의 데이터 저장소 운영기

- Scalability
- performance

범용성

- Schema-less
- Hadoop-eco friendly

Image : https://hbase.apache.org/

2. 데이터 다양성

- 효율성과 공존하기

2.1 효율적인 클러스터 운영

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Data

사용
패턴

Image : https://unsplash.com/ko/%EC%82%AC%EC%A7%84/yny2UwDVo08

2.1 효율적인 클러스터 운영

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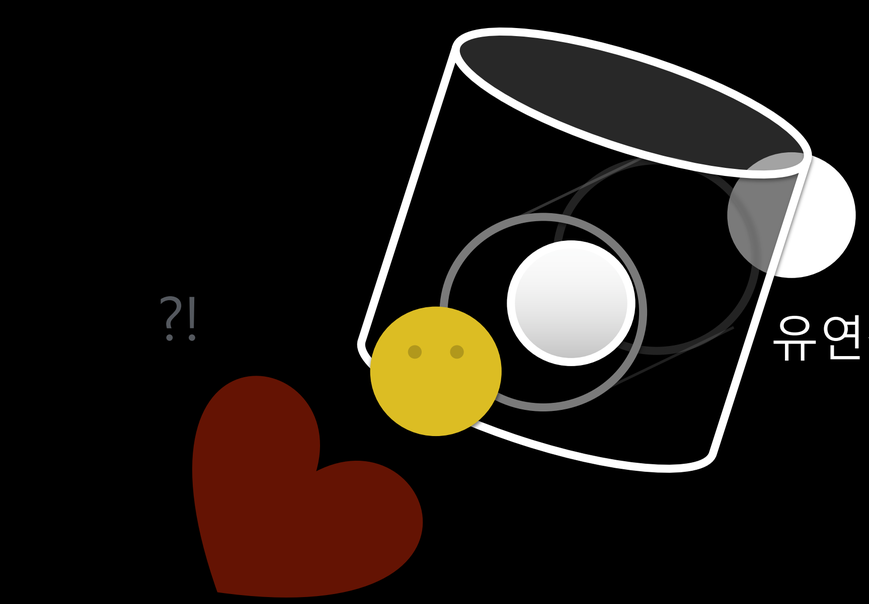

유연성의 결여

안정성 😟
효율성 ☹️

다양성에 의한 비효율

2.2 해결방안1 : 제약

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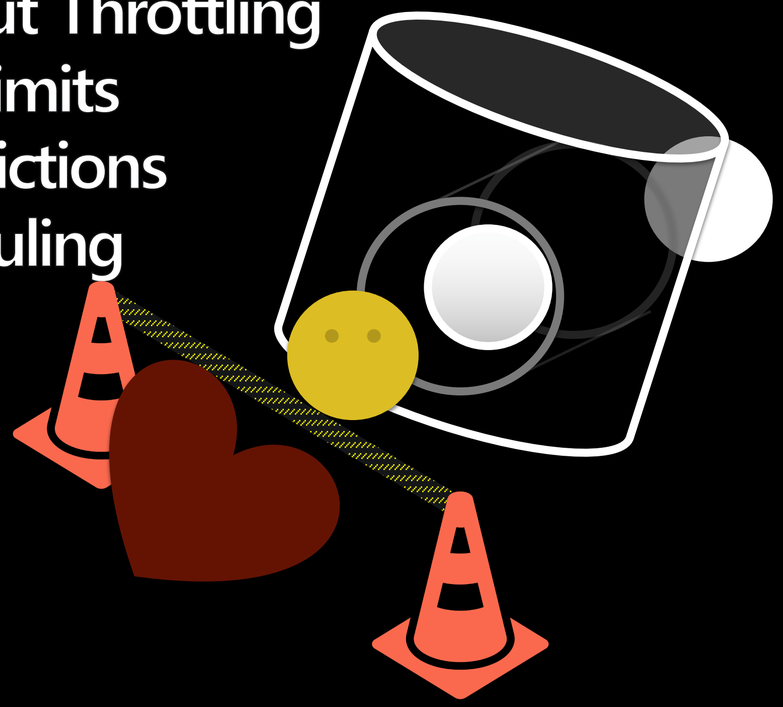
제약

- Throughput Throttling
- Resource limits
- Data Restrictions
- Job Scheduling



안정성 😀
효율성 😉

사용성 😥
범용성 ☹️

2.3 해결방안2 : Multi-clustered storage

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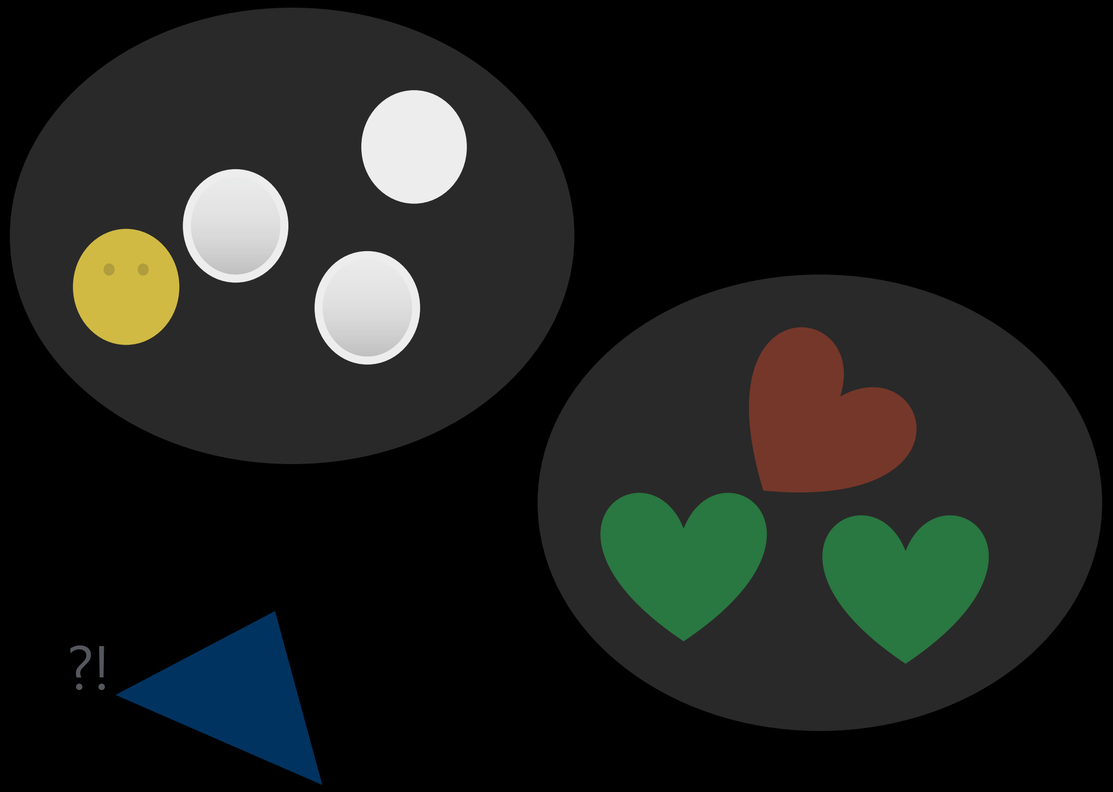
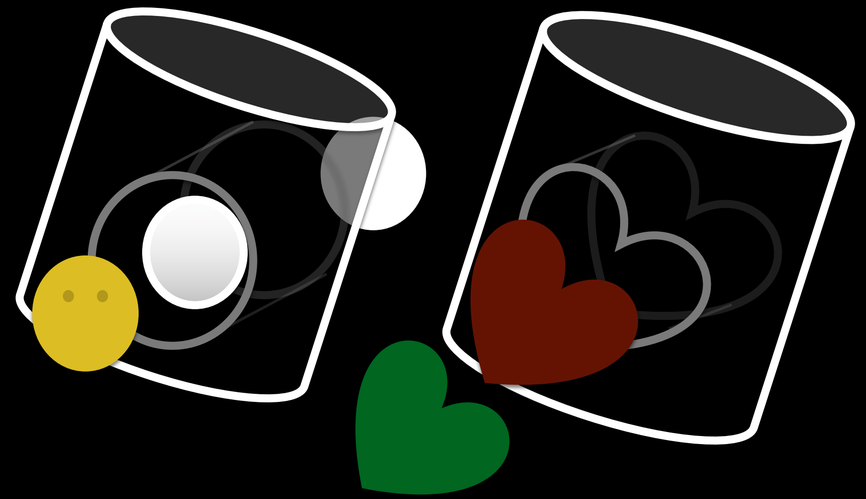


확실히 다른 데이터와 사용 패턴을
일정 수준 이상의 규모로 모아



클러스터를 구분하고 각각의 데이터에 맞게 최적화

2.3 해결방안2 : Multi-clustered storage

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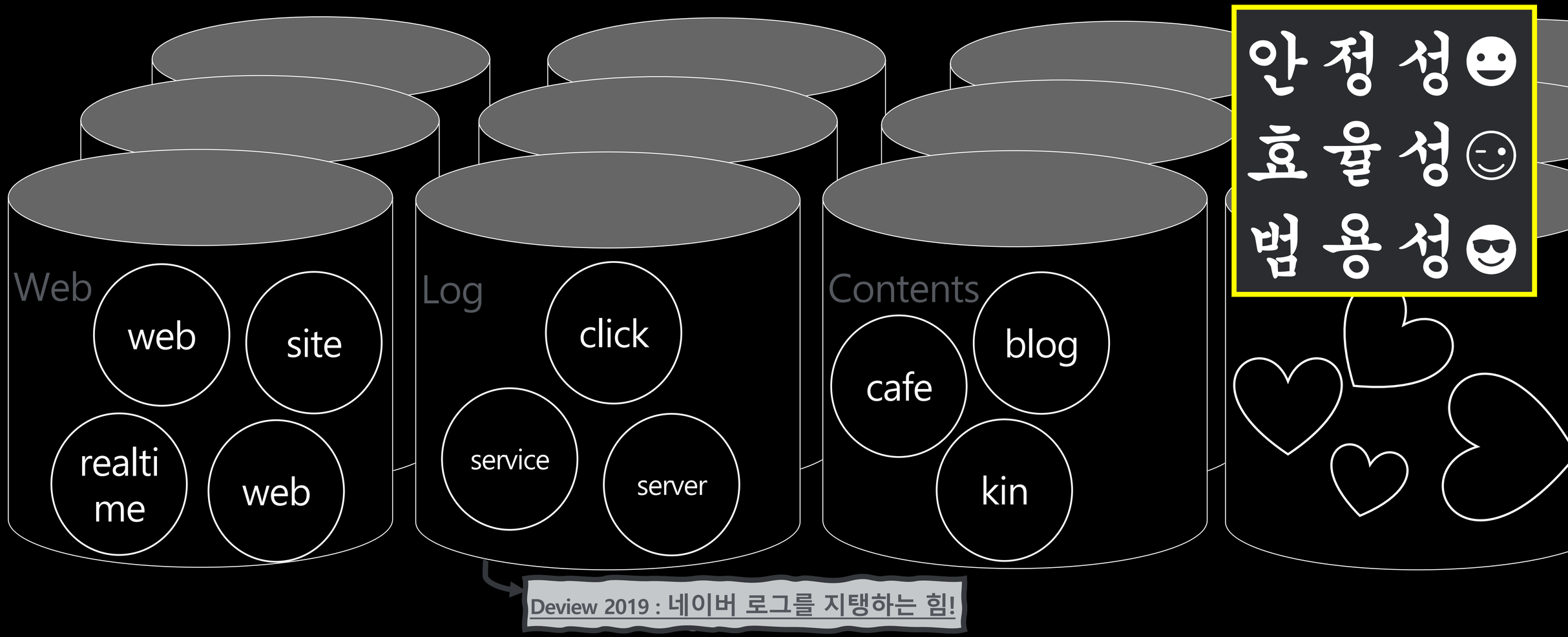

2.3 multi-clustering의 비용

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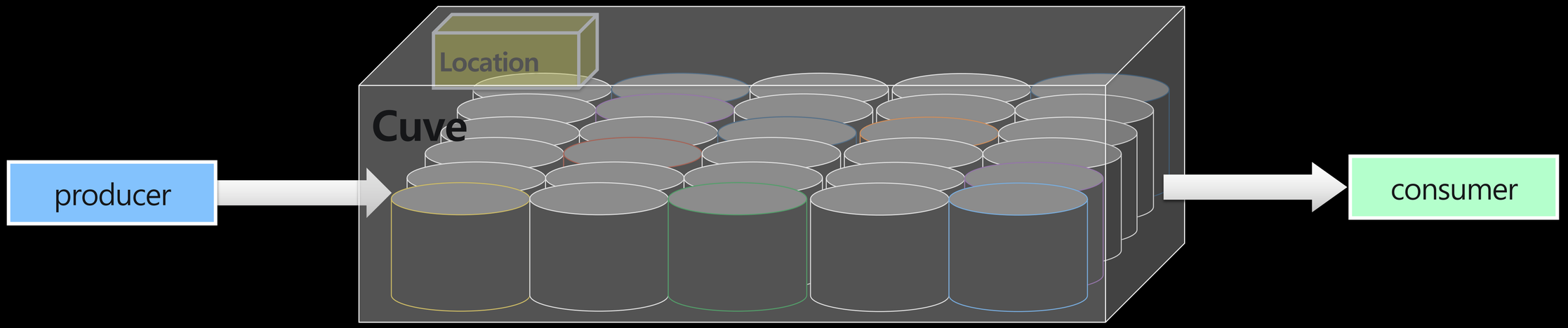
- one-cluster환경과 동일한 통합된 사용 경험을 제공
- 규모가 늘어날 수록 복잡도 또한 증가

사용성 ☺

개발/운영비용 😟



2.3 multi-clustering의 비용

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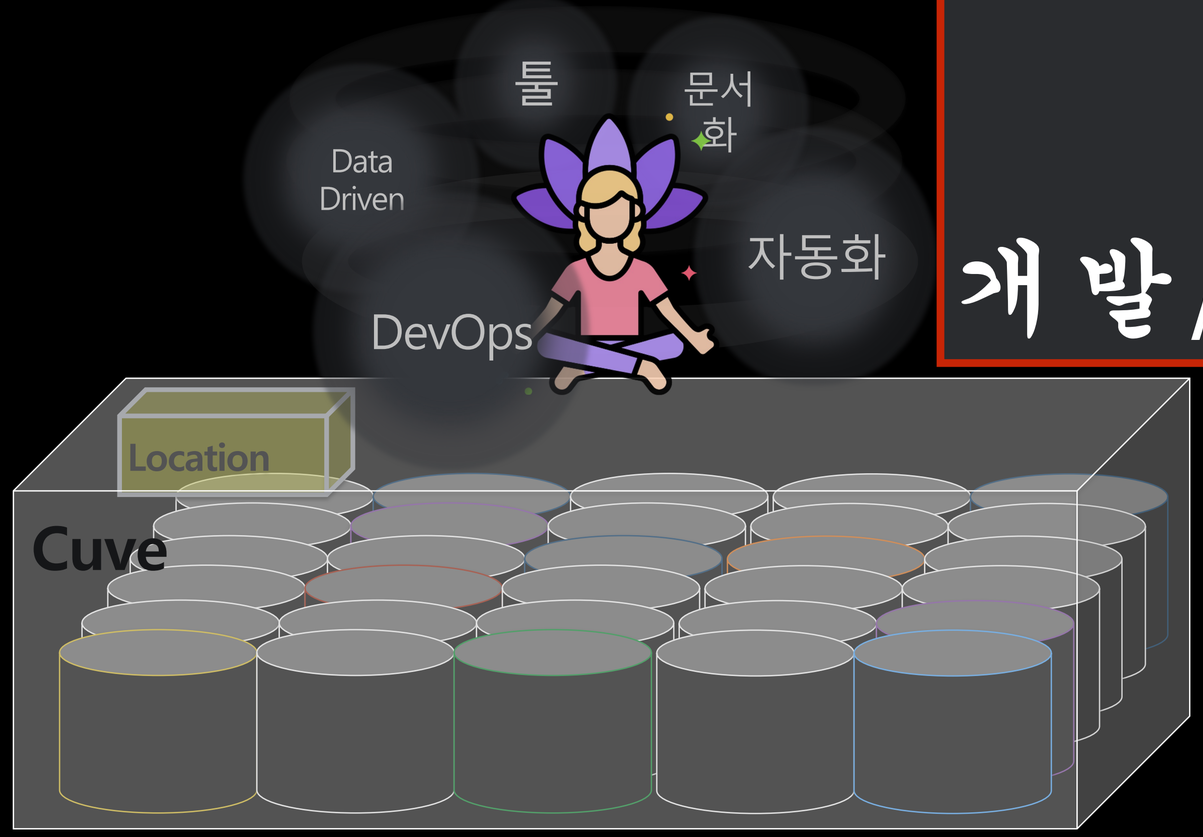
상이한 여러 클러스터들을 원활하게 운영해야 함

안정성 😈
효율성 😊
범용성 😎
사용성 😀

확장성 ☹️
지속성 😈
개발/운영비용 😣



2.4 해결방안3 : HBase 데이터 유연성 개선

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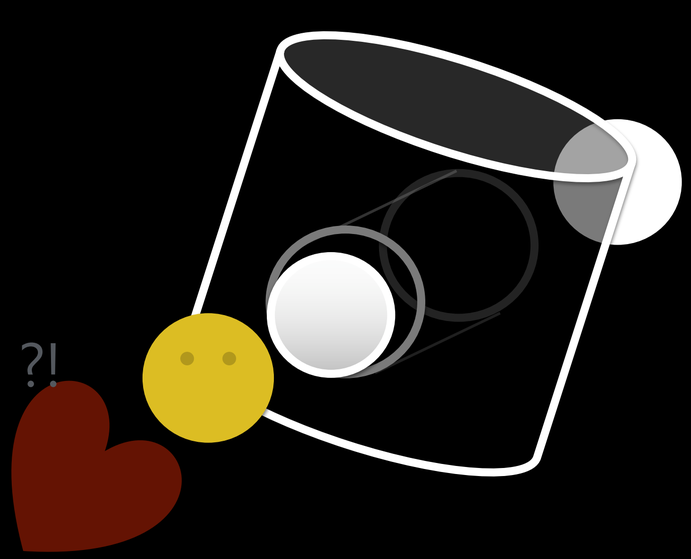
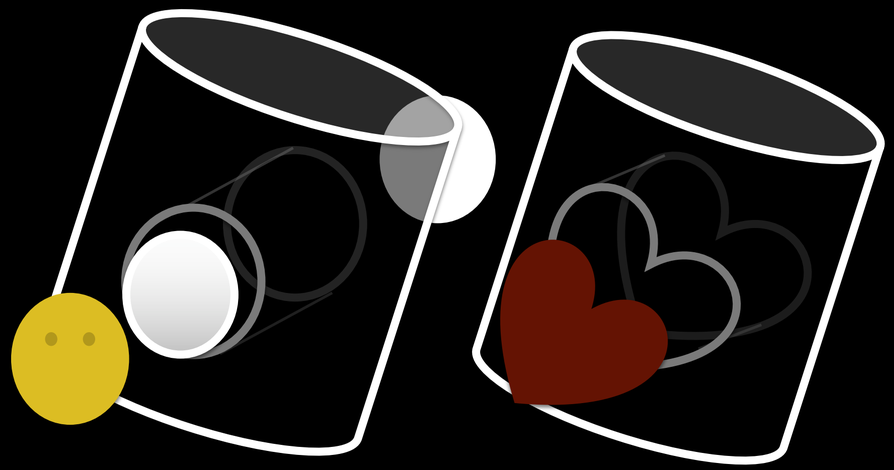
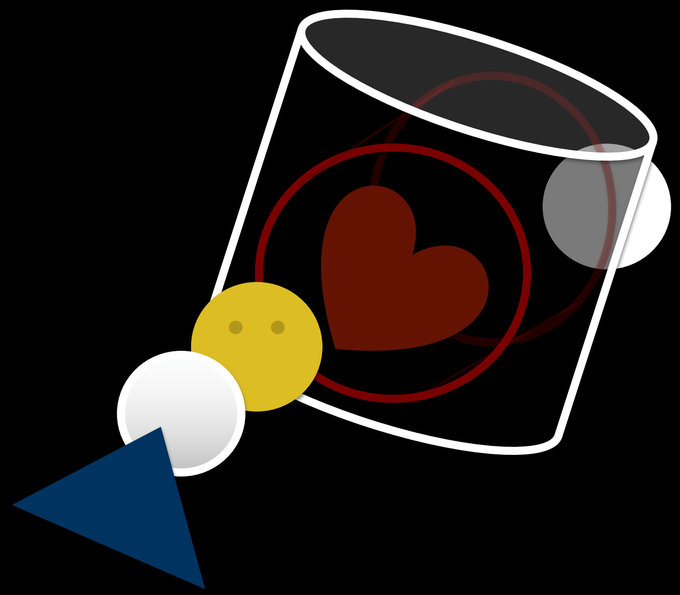


제약



multi-clustering



유연성 개선

2.4 해결방안3 : HBase 데이터 유연성 개선

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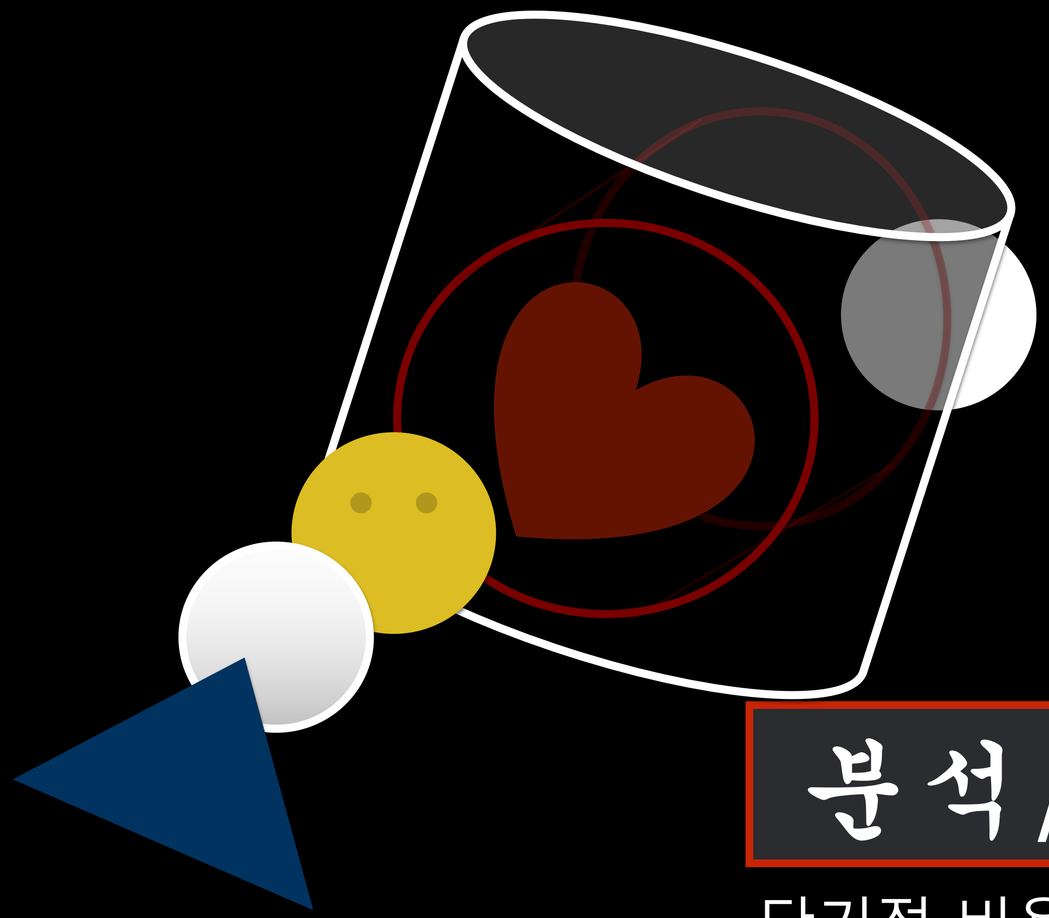
안정성
효율성
범용성
사용성
확장성
지속성

장기적 효과



분석/개발비용

단기적 비용

2.5 HBase random read amplification

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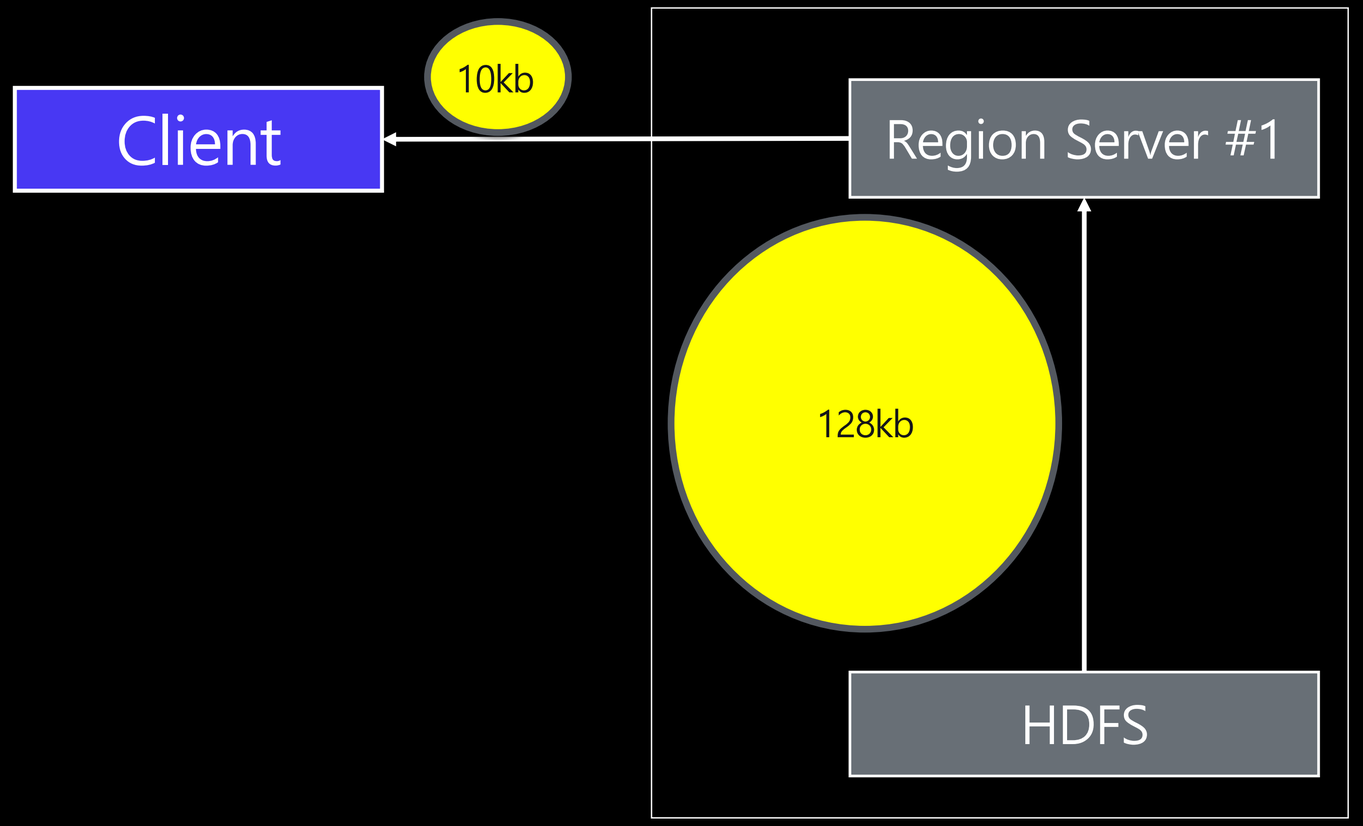
HBase의 random read 과정에서

Client가 실제 쿼리한 data size 보다

증폭된 hdfs read 요청,

그 결과로 과도한 disk IO 사용



3. HBase read amplification

HBase의 read amplification 원인 분석

3.1 HBase read amplification:

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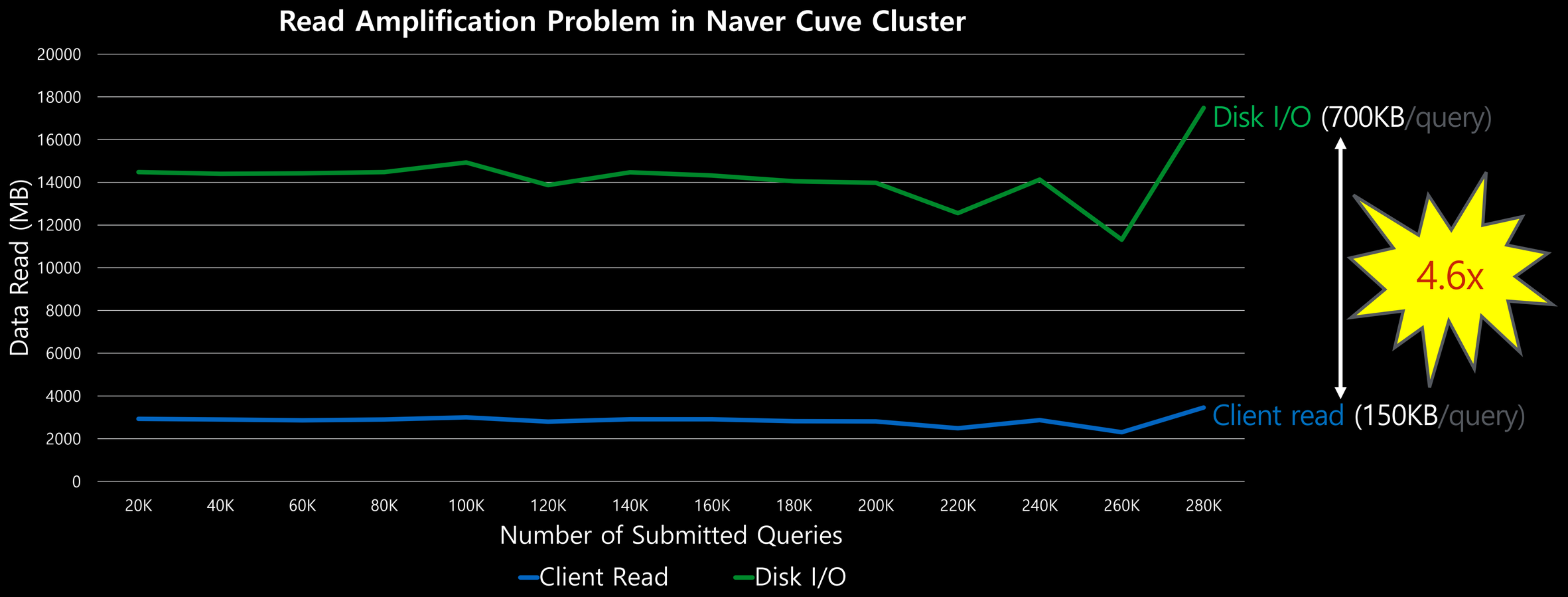

3.1 HBase read amplification:

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1. Multi File Access Amplification
2. Granularity Mismatch Amplification
3. Cache Pollution

3.2 Multi File Access Amplification: Write Process

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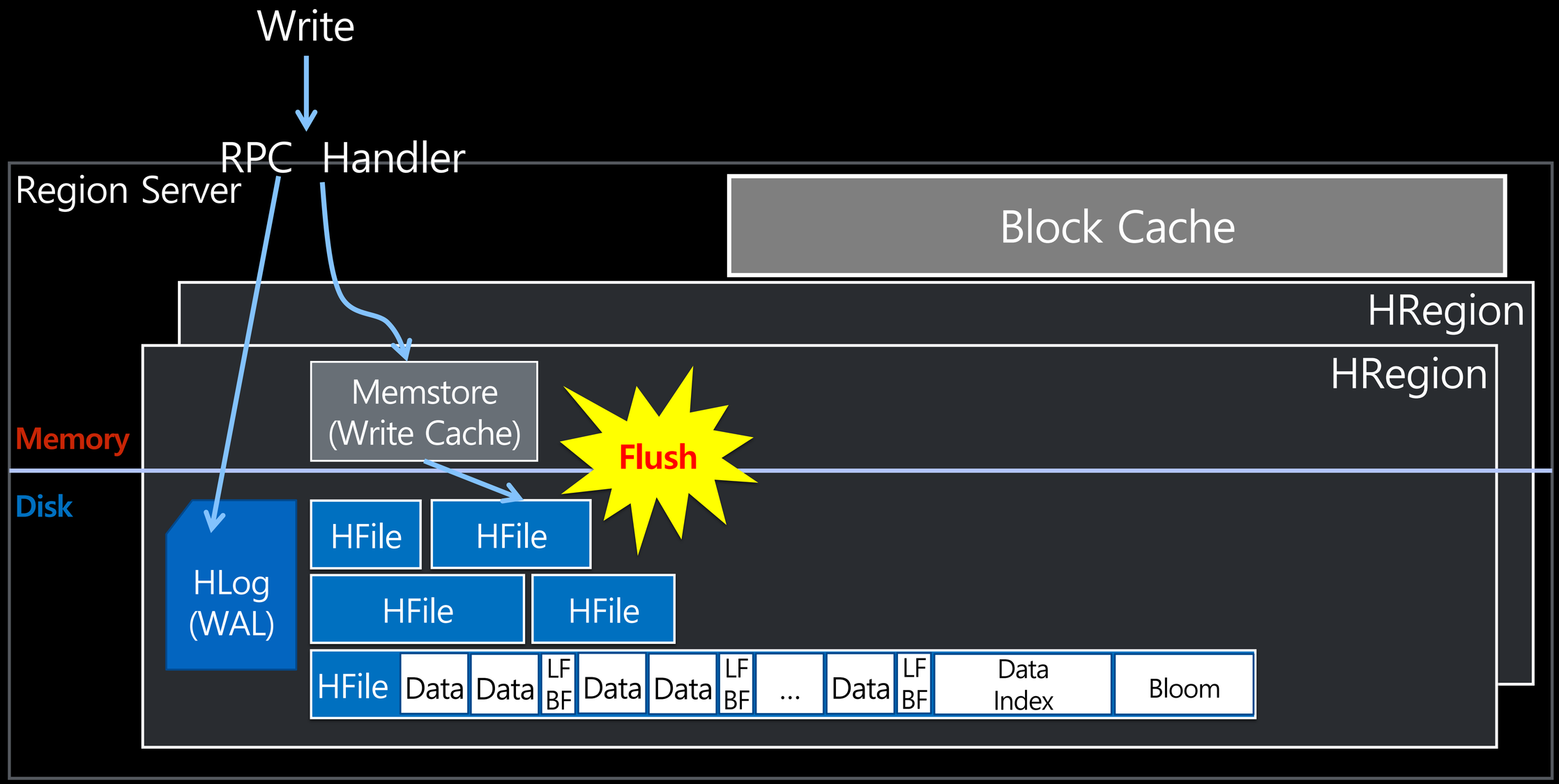

3.2 Multi File Access Amplification: Validation

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HBase Key Structure

Row Key	Column Family	Column Qualifier	Time Stamp

Client  RPC Handler  Scanner (**Initialization**)

3 stages of scanner initialization

- Region Scanner Initialization
- Store Scanner Initialization
- Store File Scanner Initialization

3.2 Multi File Access Amplification: Read Process

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HBase Key Structure

Row Key	Column Family	Column Qualifier	Time Stamp

Client ⟷ RPC Handler ⟷ **Region Scanner Initialization**

3.2 Multi File Access Amplification: Read Process

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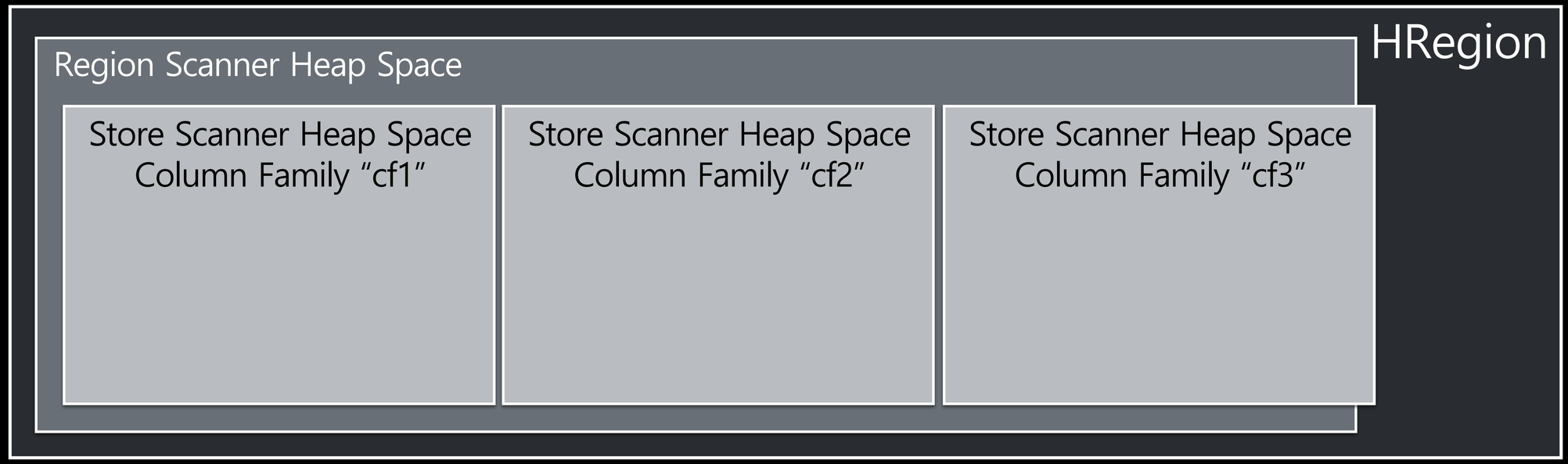
HBase Key Structure

Row Key	Column Family	Column Qualifier	Time Stamp

Client ⟷ RPC Handler ⟷ **Store Scanner Initialization**



3.2 Multi File Access Amplification: Read Process

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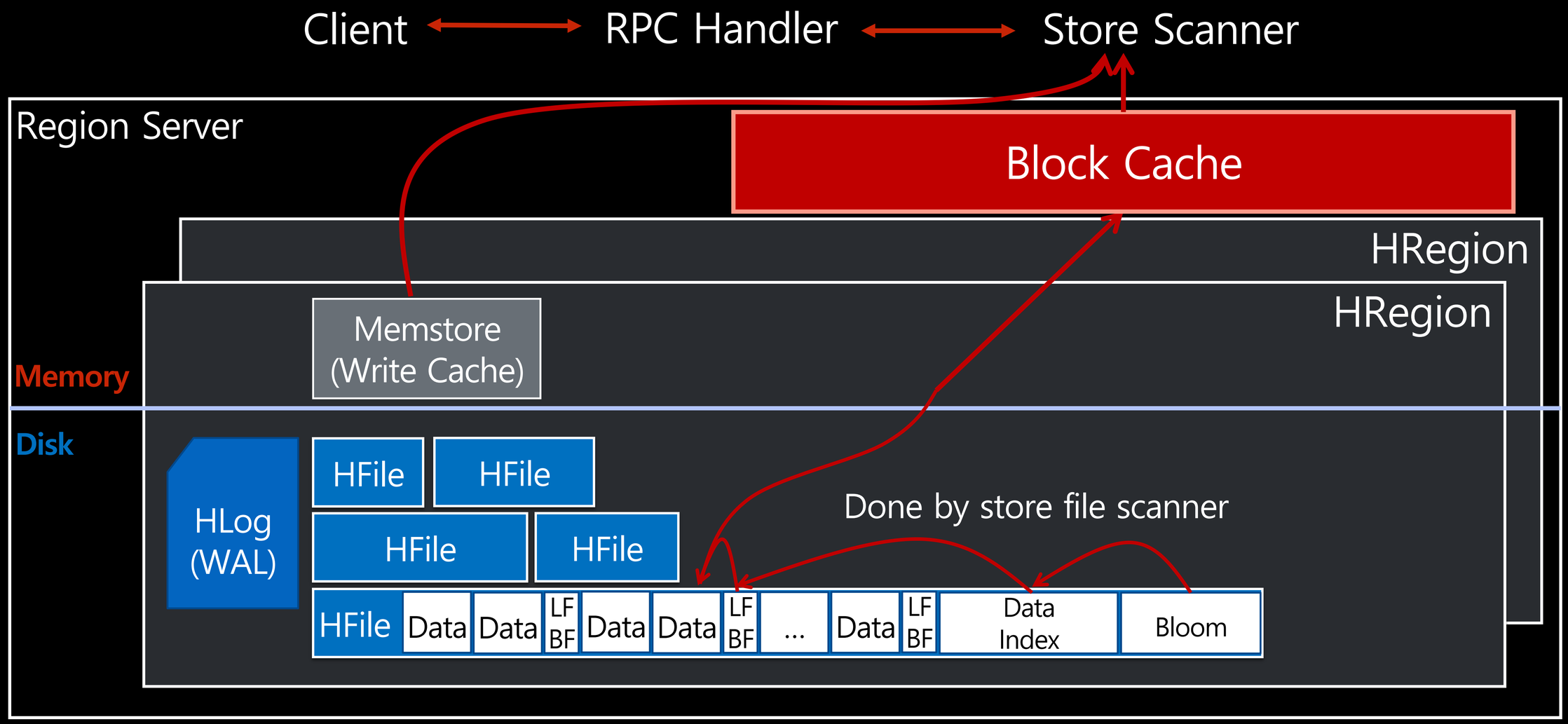

3.2 Multi File Access Amplification: Read Process

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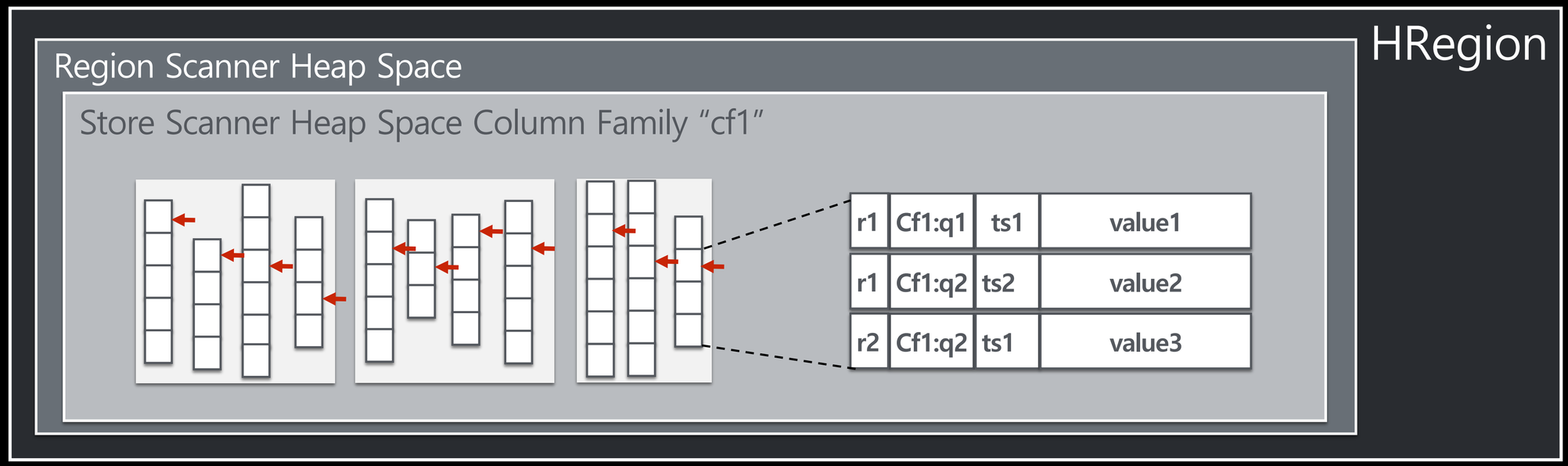
HBase Key Structure

Row Key	Column Family	Column Qualifier	Time Stamp

Client ⟷ RPC Handler ⟷ **Initialization Terminate**



3.2 Multi File Access Amplification: Validation

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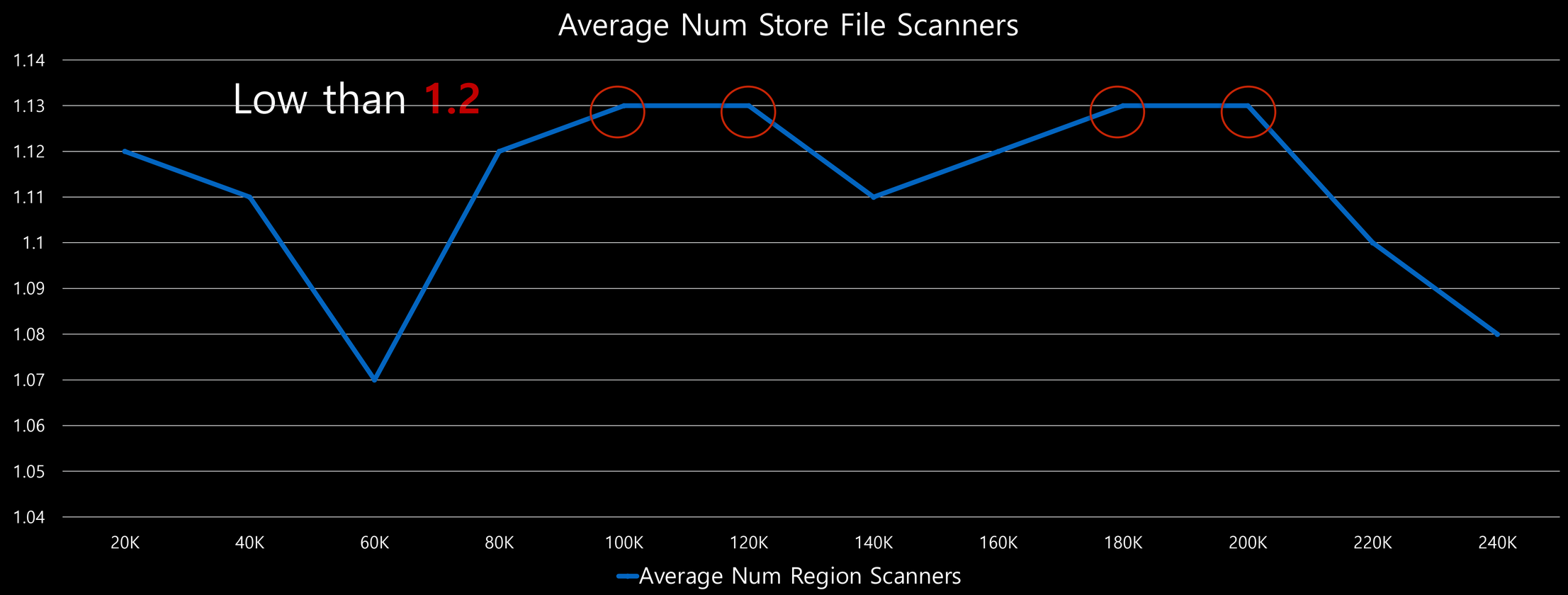

3.2 Multi File Access Amplification:
Compaction을 통한 HFile의 감소

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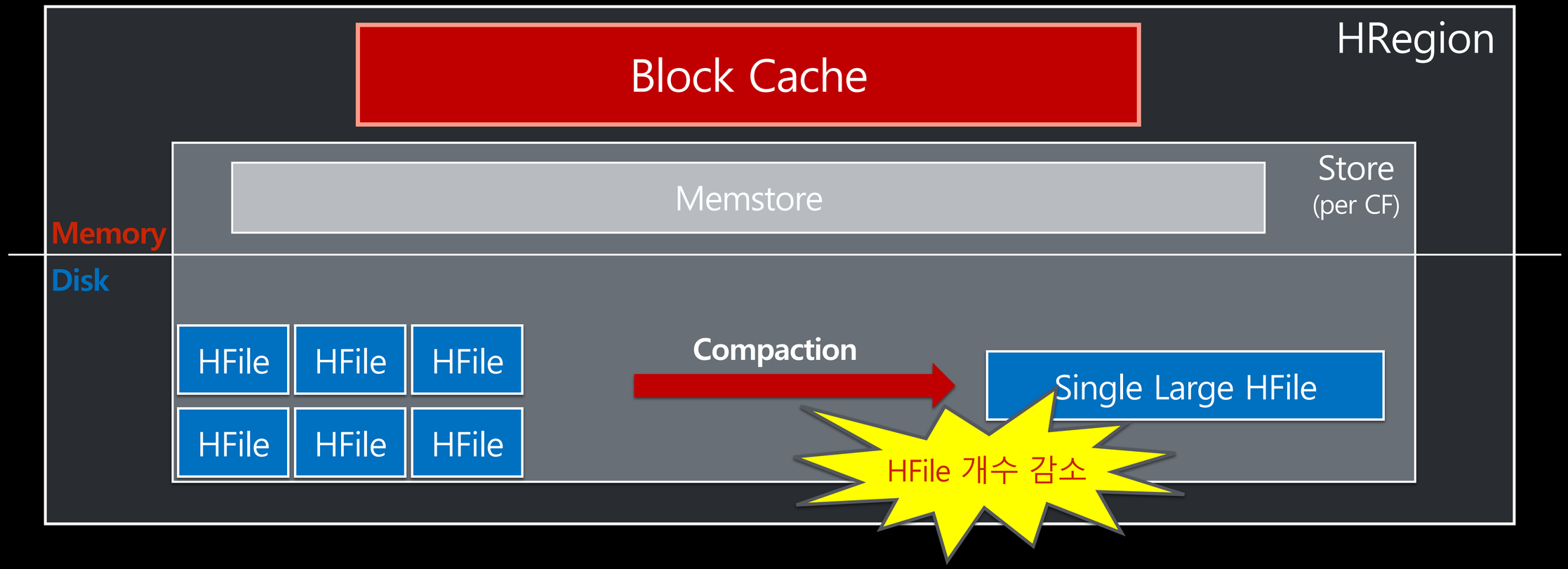
Compaction: 여러 개의 HFile의 하나의 HFile로 rewrite하는 과정



3.2 Multi File Access Amplification:
Bloom Filter로 인해 접근하는 HFile수 감소

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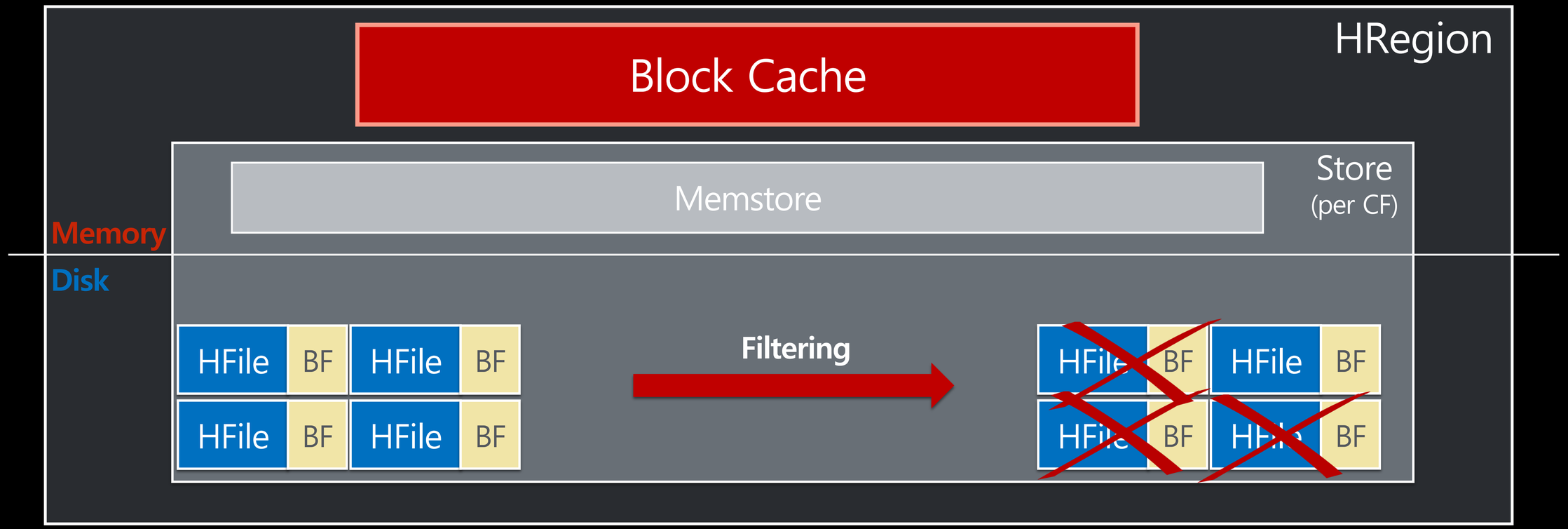
Bloom Filter:



3.2 Multi File Access Amplification: if?

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1. Check Compaction Status: compaction throughput, compaction thread...
2. Check Flush Status: memstore size, flush threshold size...
3. Check Bloom Filtering Status: bloom filter type, bloom filter size...

3.3 HBase read amplification:

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1. ~~Multi File Access Amplification~~
2. Granularity Mismatch Amplification
3. Cache Pollution

3.3 Granularity Mismatch Amplification

: Application request data size differ from I/O data size

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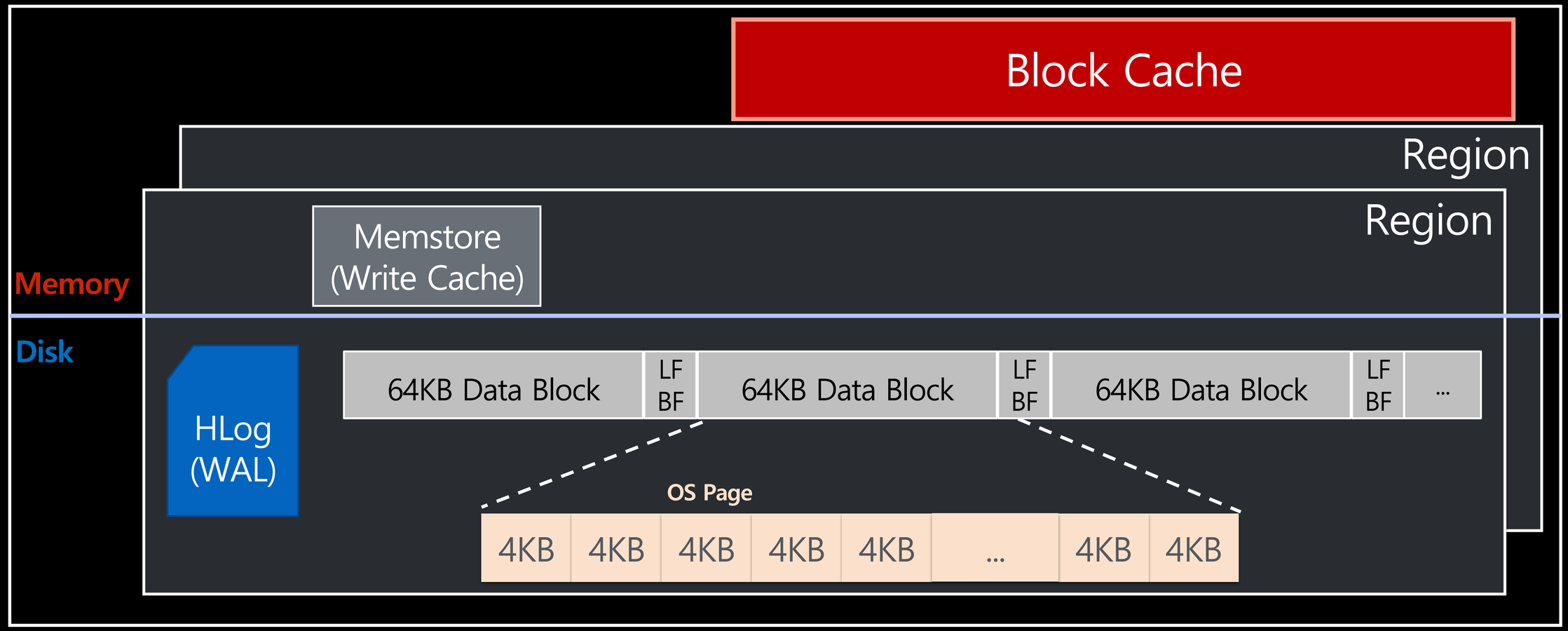

3.3 Granularity Mismatch Amplification

: Application request data size differ from I/O data size

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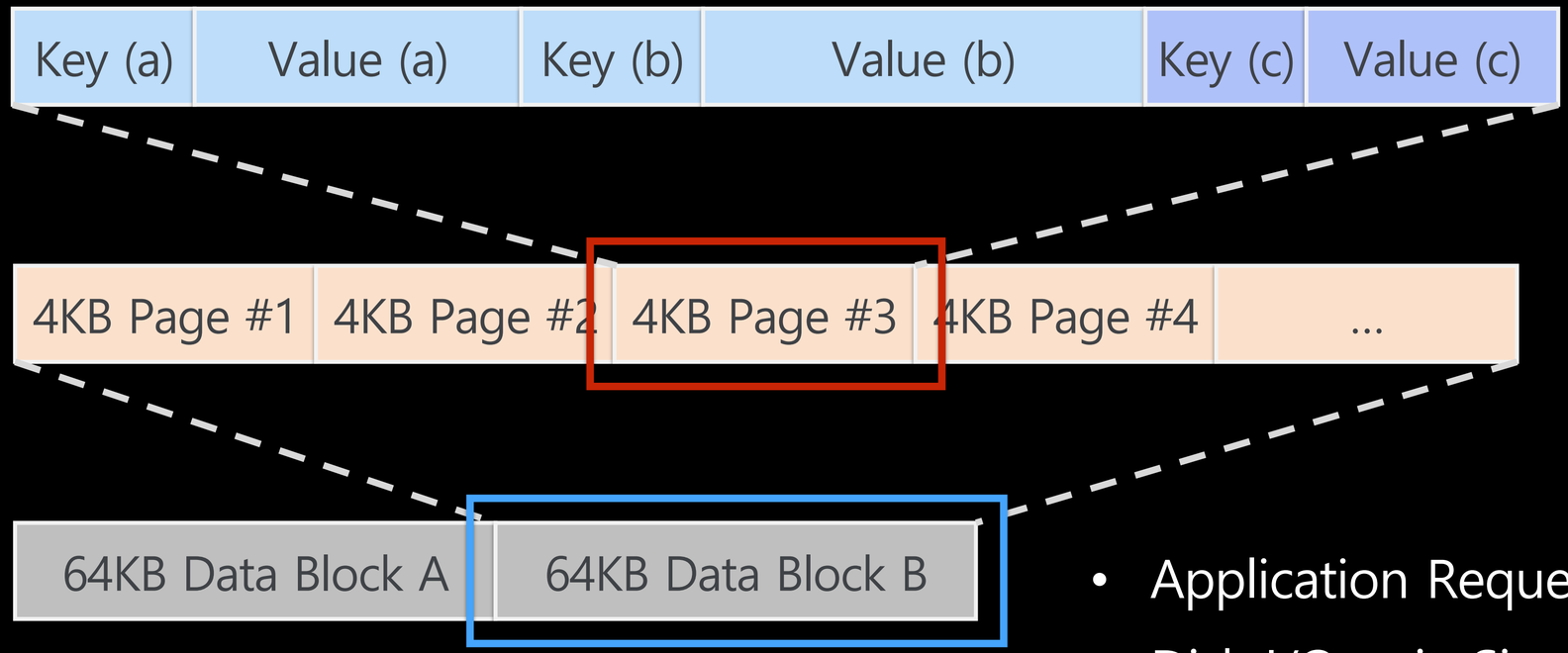

- Application Request: Single OS Page (4KB Page #3)
- Disk I/O unit: Single Data Block (64KB Data Block B)
- Theoretically, **16x** amplification occur

3.4 HBase read amplification:

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1. ~~Multi File Access Amplification~~
2. Granularity Mismatch Amplification
3. Cache Pollution

3.4 Cache Pollution Problem

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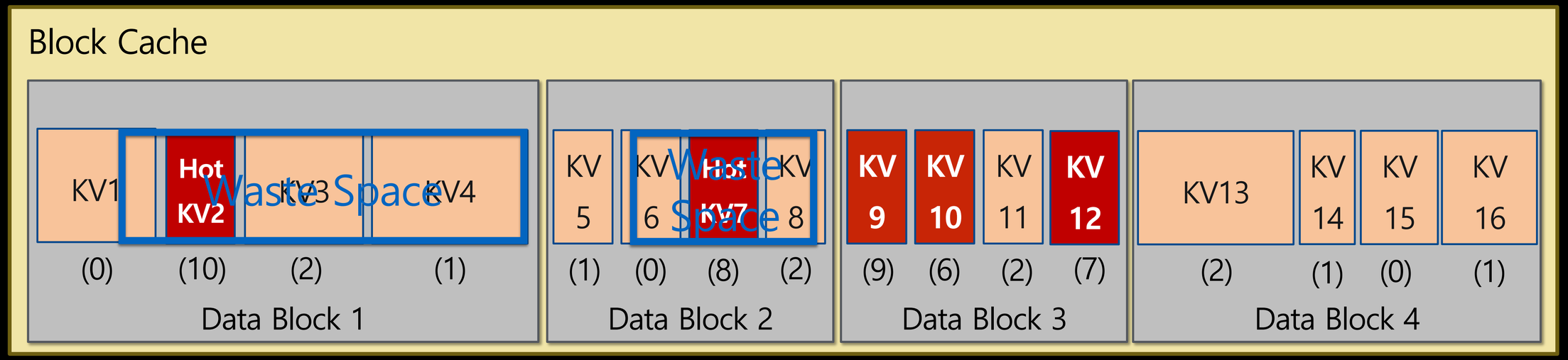
Data Block unit LRU Replacement



3.4 Cache Pollution Problem

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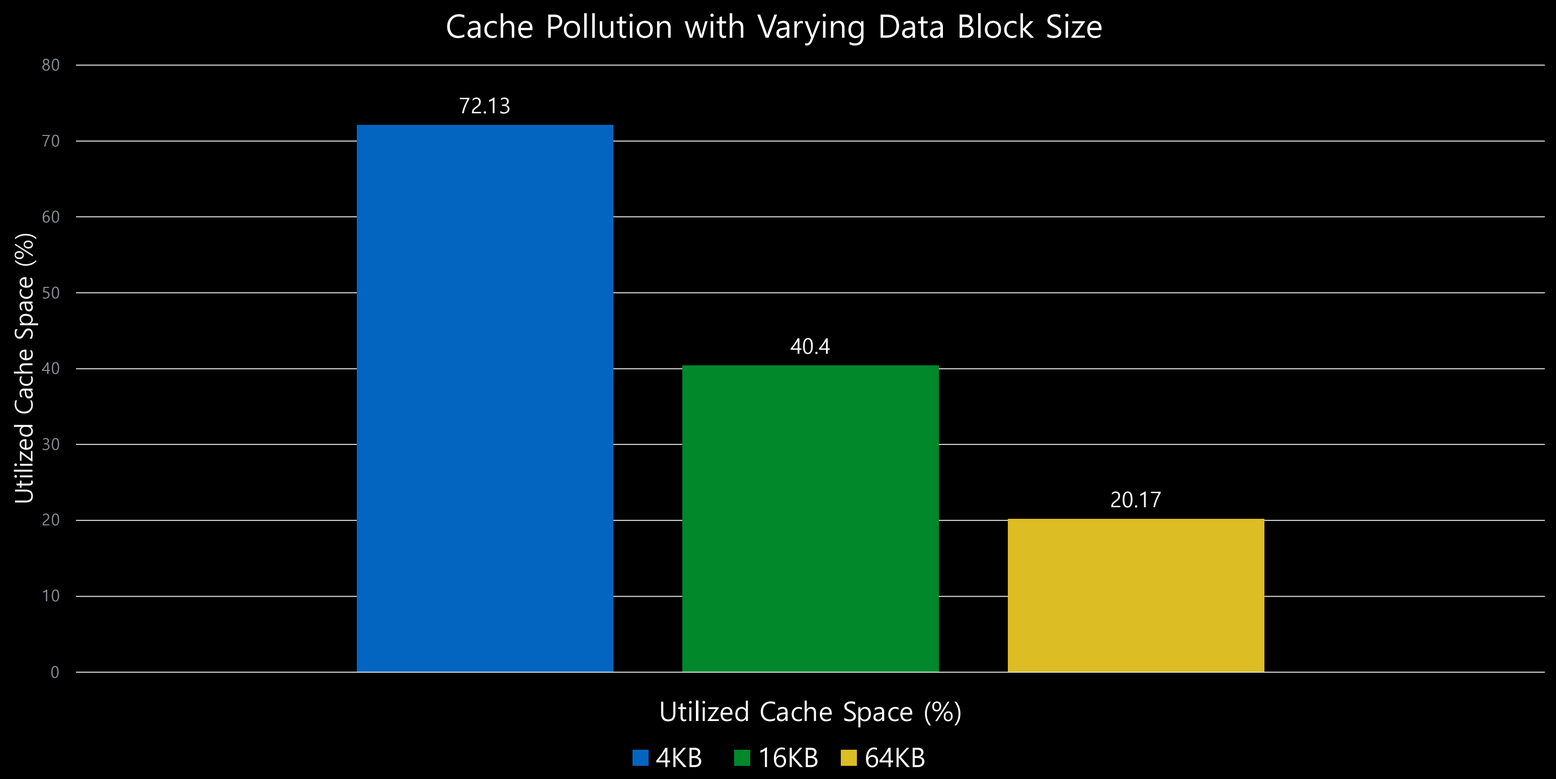

- 4KB Data Block: 72.13%
- 16KB Data Block: 40.4%
- 64KB Data Block: 20.17%

64KB Data Block = 72.03% under utilization than 4KB Data Block

3.5 Naïve solution: Small Data Block Size

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1. Decrease space locality

- Low space locality leads frequent random read
- Frequent random read increase the number of disk seek operation

2. Increase block encoding cost

- Decrease Block encoding & compression efficiency

3.5 Naïve solution: Small Data Block Size

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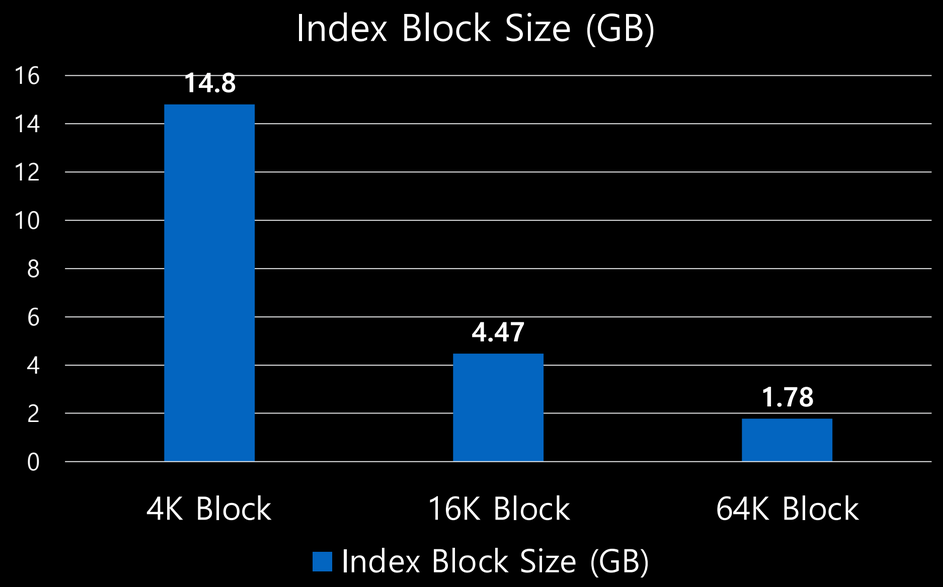
3. Index Block size grow



- 4KB Data Block Index size = **14.8 GB** (per RS)
- 64KB Data Block Index size = **1.78 GB** (per RS)
- 4KB DB Index size = **8.3** X 64KB DB Index size

3.5 Naïve solution: 적절한 크기의 data block?

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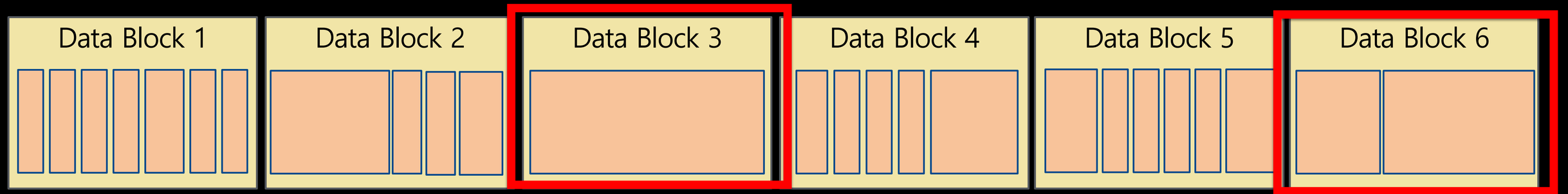
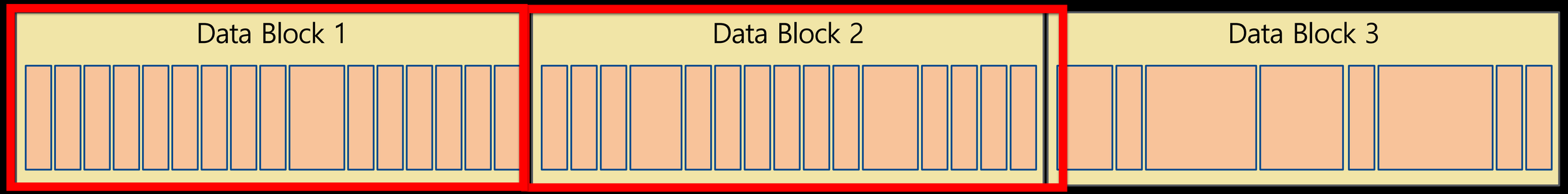
Case of small data block size



Case of big data block size



3.6 New Approach

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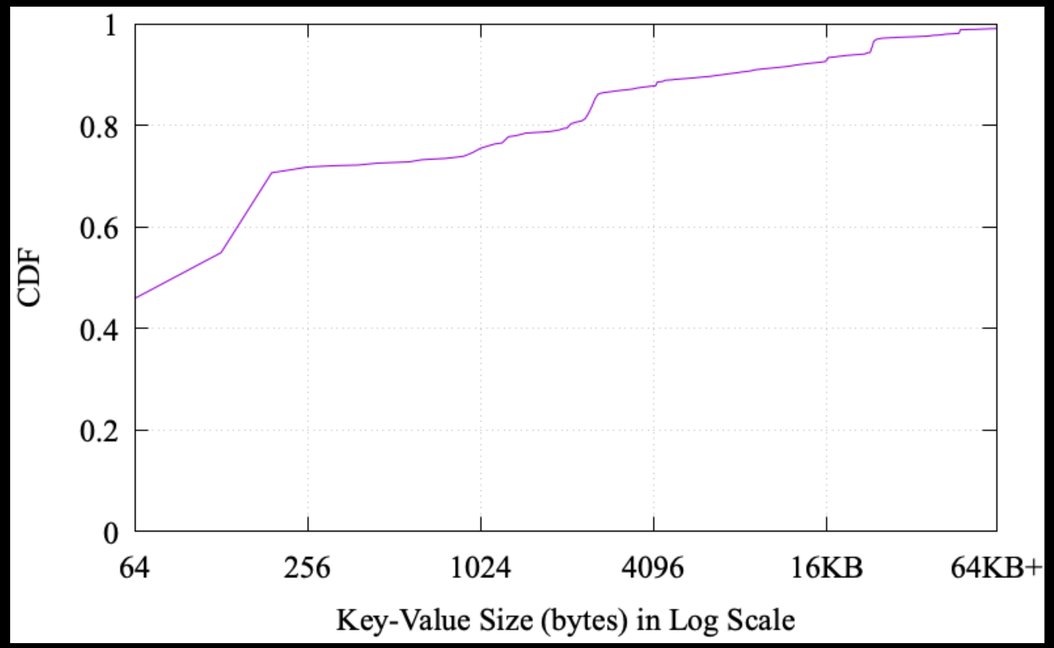

Figure: Data Block Size Distribution in Naver's HBase Cluster

Various key-value size in Naver Cuve cluster's

- 80% of key-values smaller than 4KB
- 10% of key-values larger than 16KB

Fixed-size data block cannot handle various size of KV

- Small KV benefit from small size data block
- Large KV benefit from large size data block

4. Solution

HBase 개선 방안

4.1 Solution 1: Dynamic Variable Block Size Control

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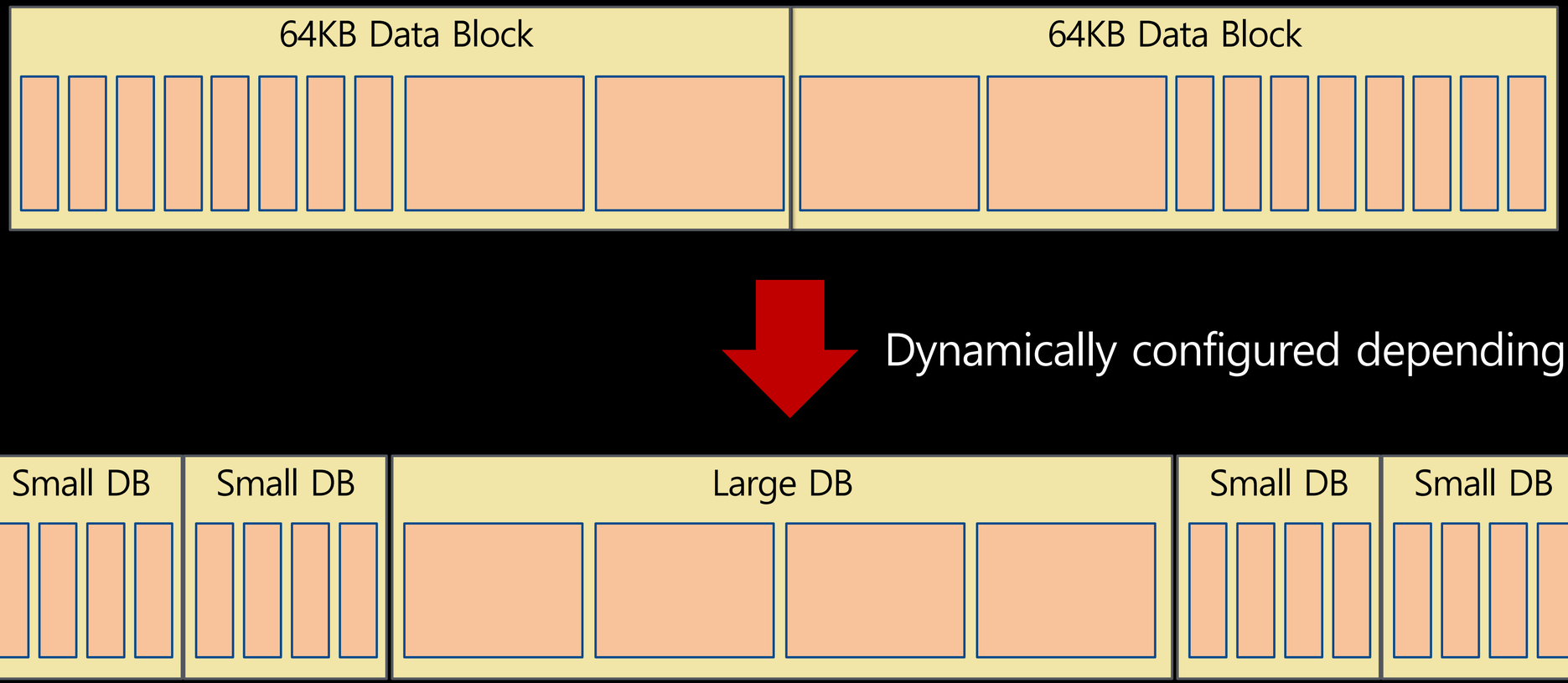

4.1 Solution 1: Dynamic Variable Block Size Control

Idea: Dynamically configured depending on KV Size

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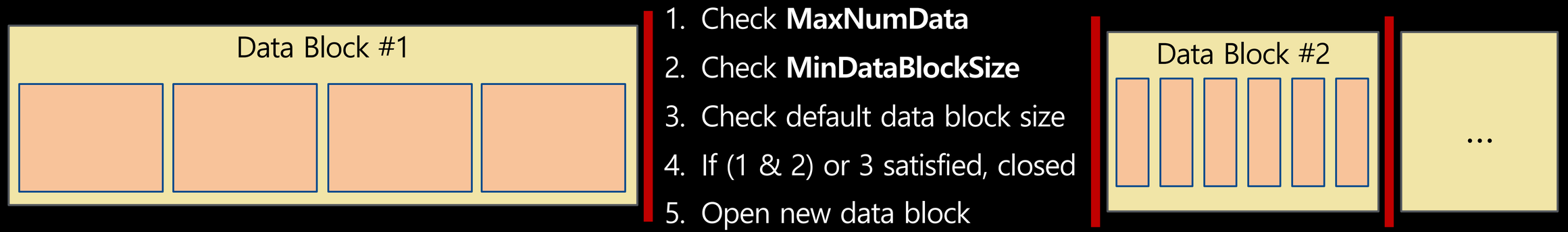
Add two more condition in vanilla HBase

- **MaxNumData:** Upper bound of Key-Value entry in single data block :
  - To store small Key-Value in small data block to mitigate read amplification problem
- **MinDataBlockSize:** Lower bound of data block size
  - Keep the data blocks from getting too small to get benefit from spatial locality



4.1 Solution 1: Dynamic Variable Block Size Control

Idea: Dynamically configured depending on KV Size

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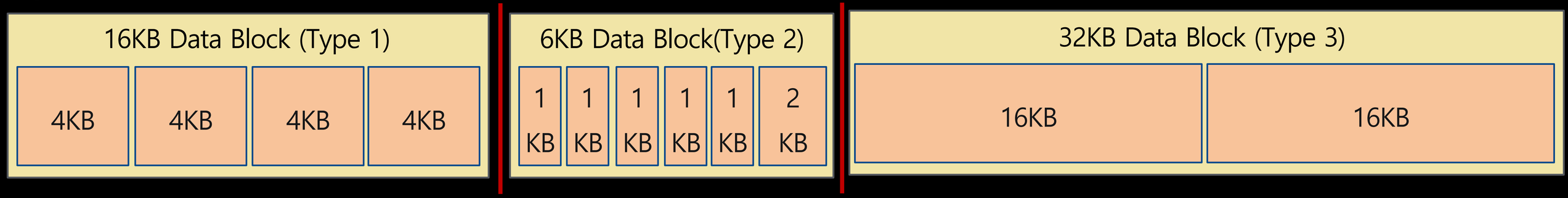
e.g., MaxNumData=4, MinDataBlockSize=6KB, Default Data Block Size=32KB



Data Block Type

1. Type 1: Closed by MaxNumData Condition
2. Type 2: Closed by MinDataBlockSize Condition
3. Type 3: Closed by Default Data Block Size

4.2 Solution 2: KV Cache

Idea: Promoting hot KV based on space utilization

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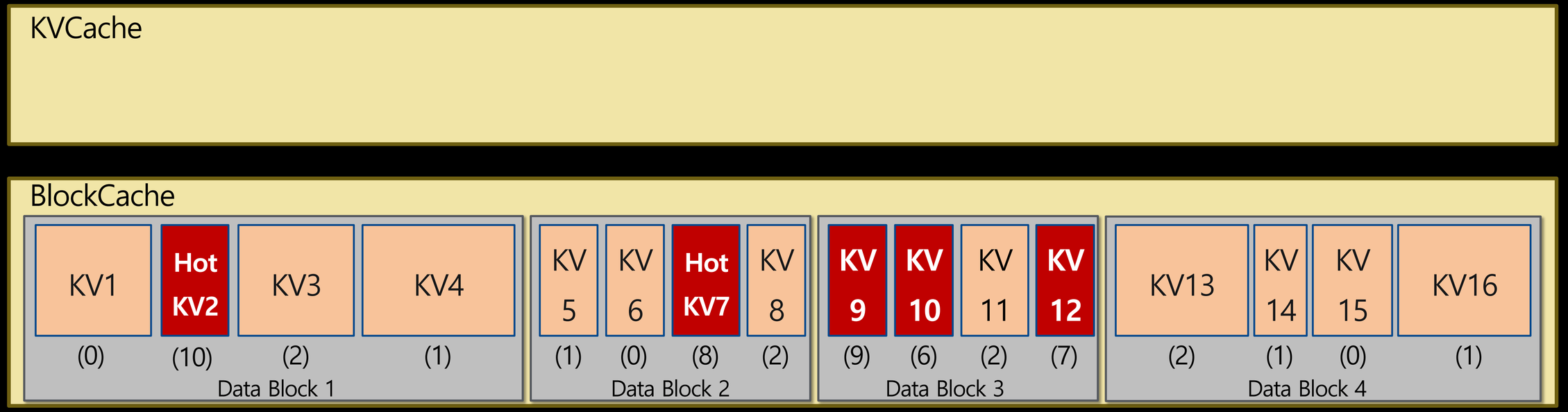

- KV2 and KV7 are promoted to KVCache due to **low cache space utilization**
- KV9, KV10 and KV12 are not promoted to KVCache due to **high cache space utilization**

4.2 Solution 2: KV Cache

Idea: Promoting hot KV based on space utilization

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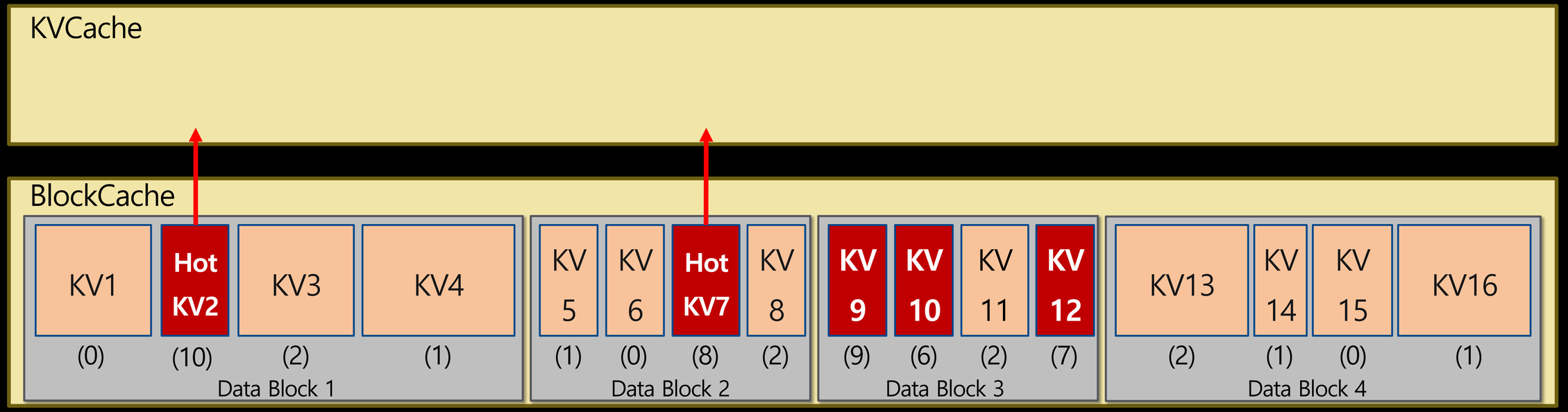

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4.2 Solution 2: KV Cache

Idea: Promoting hot KV based on space utilization

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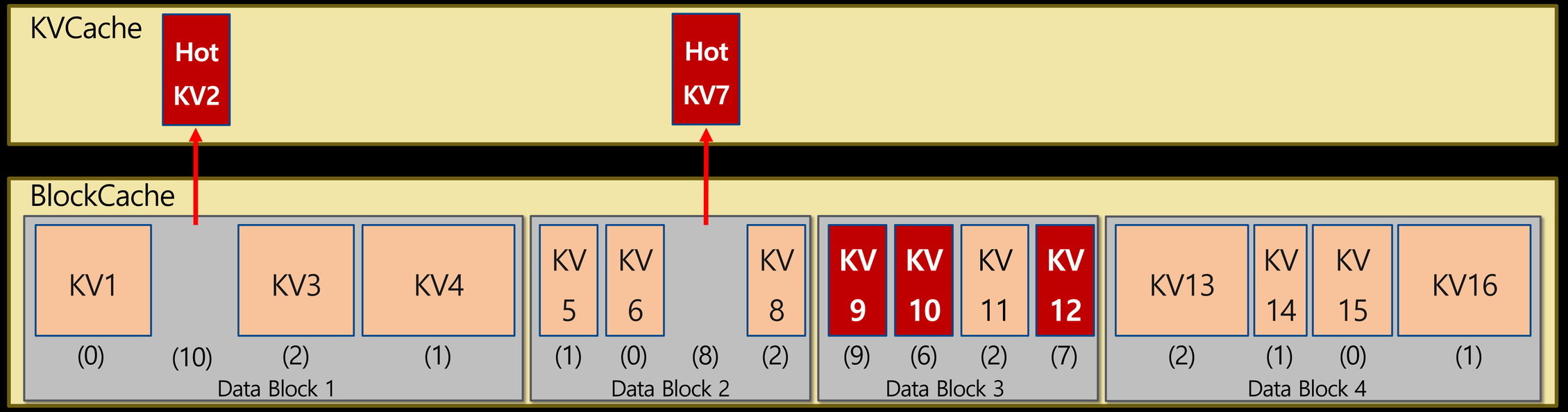

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4.2 Solution 2: KV Cache

Idea: Promoting hot KV based on space utilization

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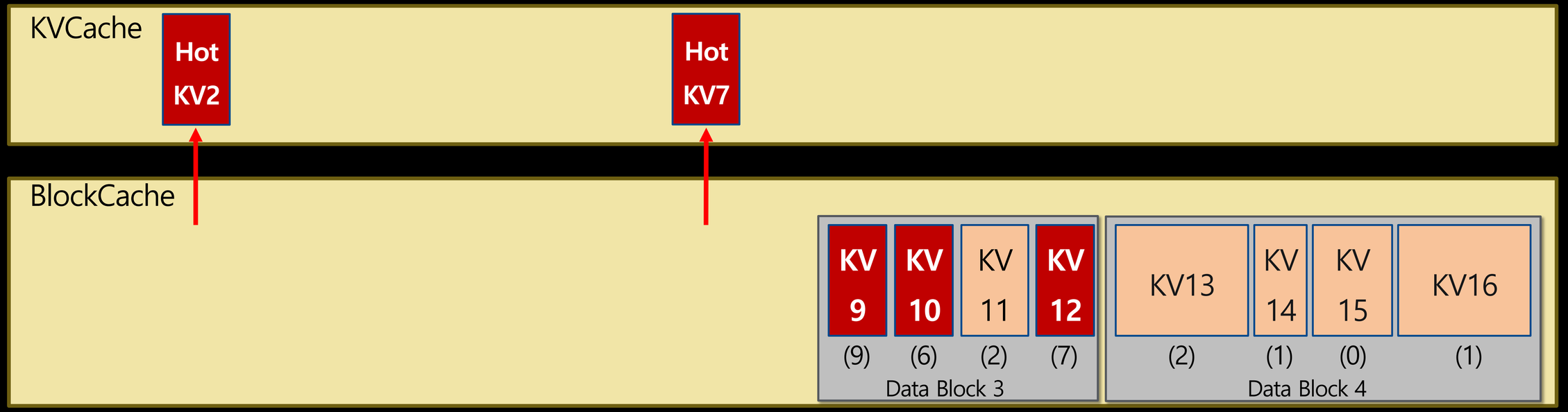

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4.2 Solution 2: KV Cache

Idea: Promoting hot KV based on space utilization

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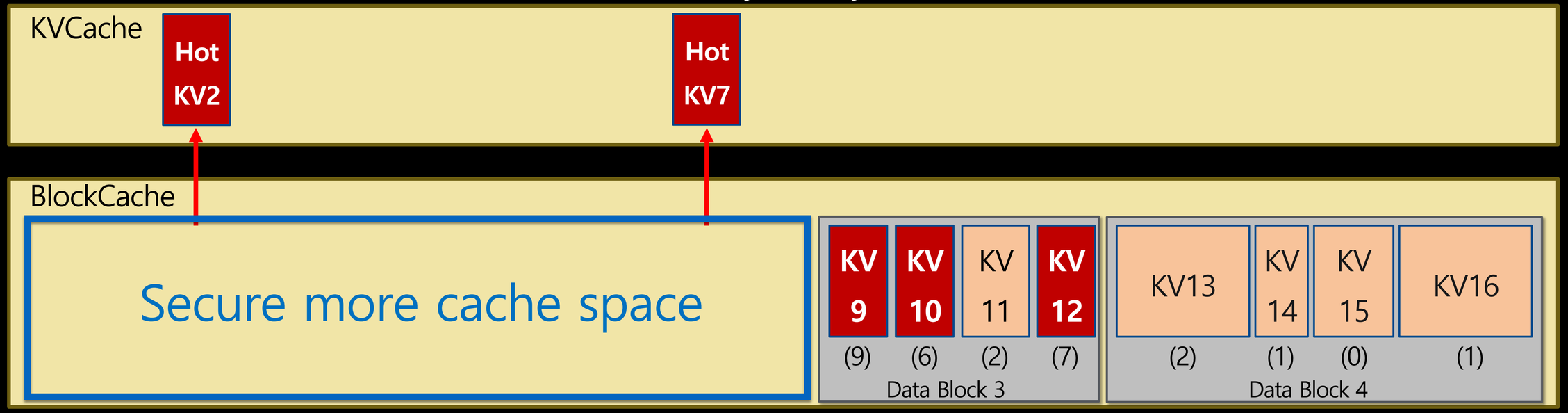
$$Promotion\ Threshold = Access\ Count[key\ entry] > Mean + Standard\ Deviation$$



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4.2 Solution 2: KV Cache

Cache Replacement Policy

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Replacement Matric in KVCache

- **Last Access Time :** Due to promotion from Block Cache
- **Number of Access :** Due to relative access frequency of neighboring key-values
- **Key-Value Size :** Due to various key-value size

Replacement Formula

$$W = \frac{Normalized\ Access\ Frequency^{f}}{Data\ Size^{d} \times (Current\ Time\ - Last\ Access\ Time)}$$

5. Evaluation

벤치 마킹 및 적용 효과

5.1 Evaluation 용어 설명

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- Synthetic Workload CBMG (Customer Behavior Model Graph)
- Modeling workload based on spatial-temporal customer behavior
- Apply CBMG workload in CUVE based on URL similarity

- Read Amplification Factor
- Application Request #Page / IO Request #Page
- RAF proportional to Granularity Mismatch Amplification

5.1 CUVE: CBMG Benchmark : Read Amplification Factor

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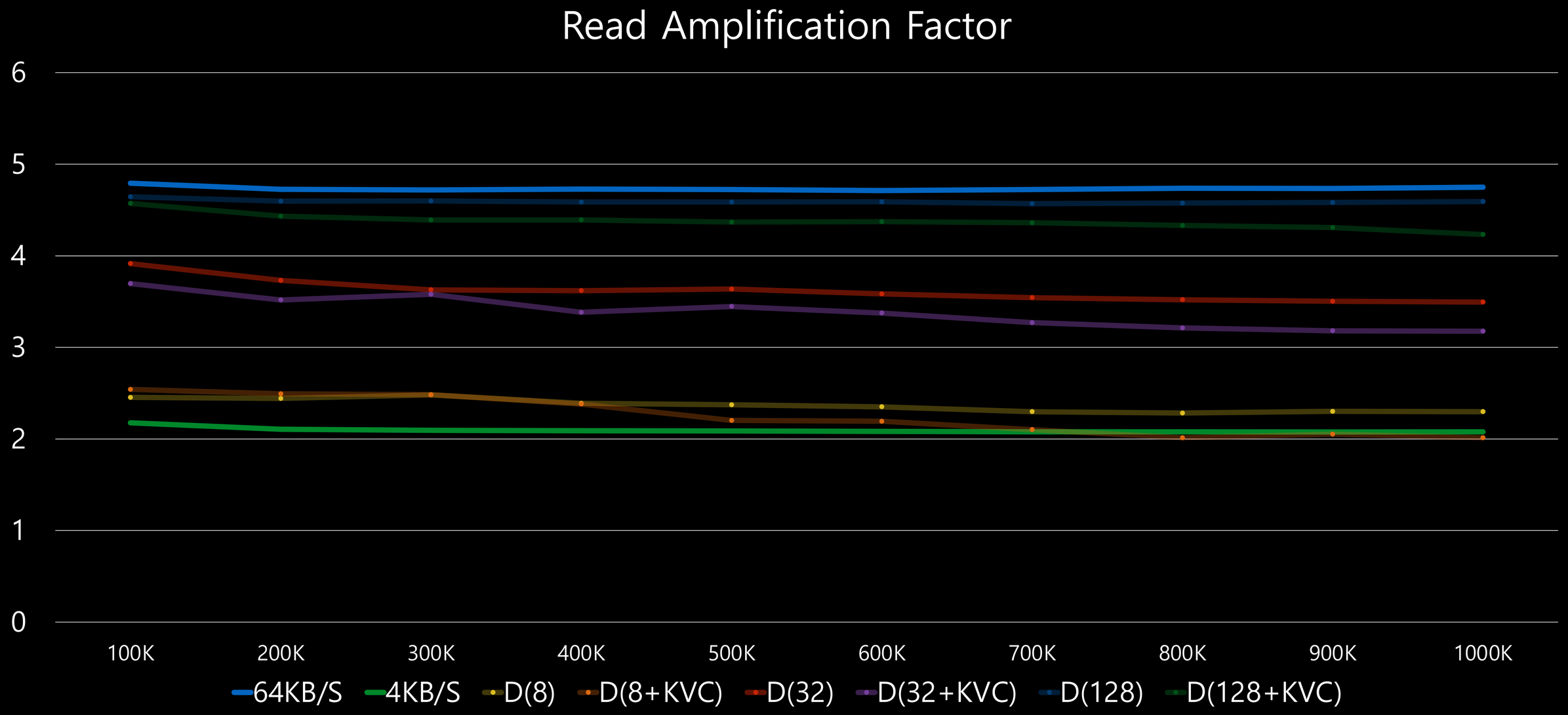

5.2 CUVE: CBMG Benchmark :

Cache Hit Ratio & Throughput

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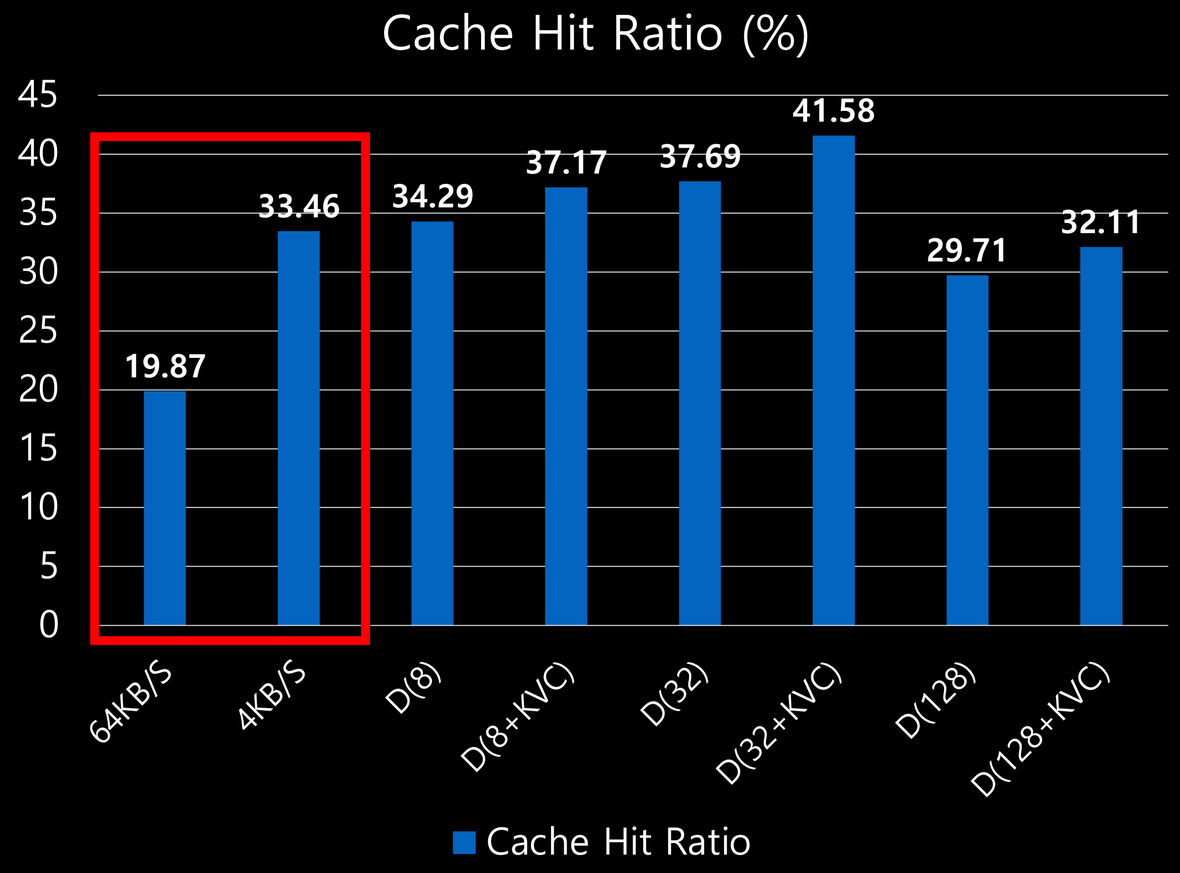

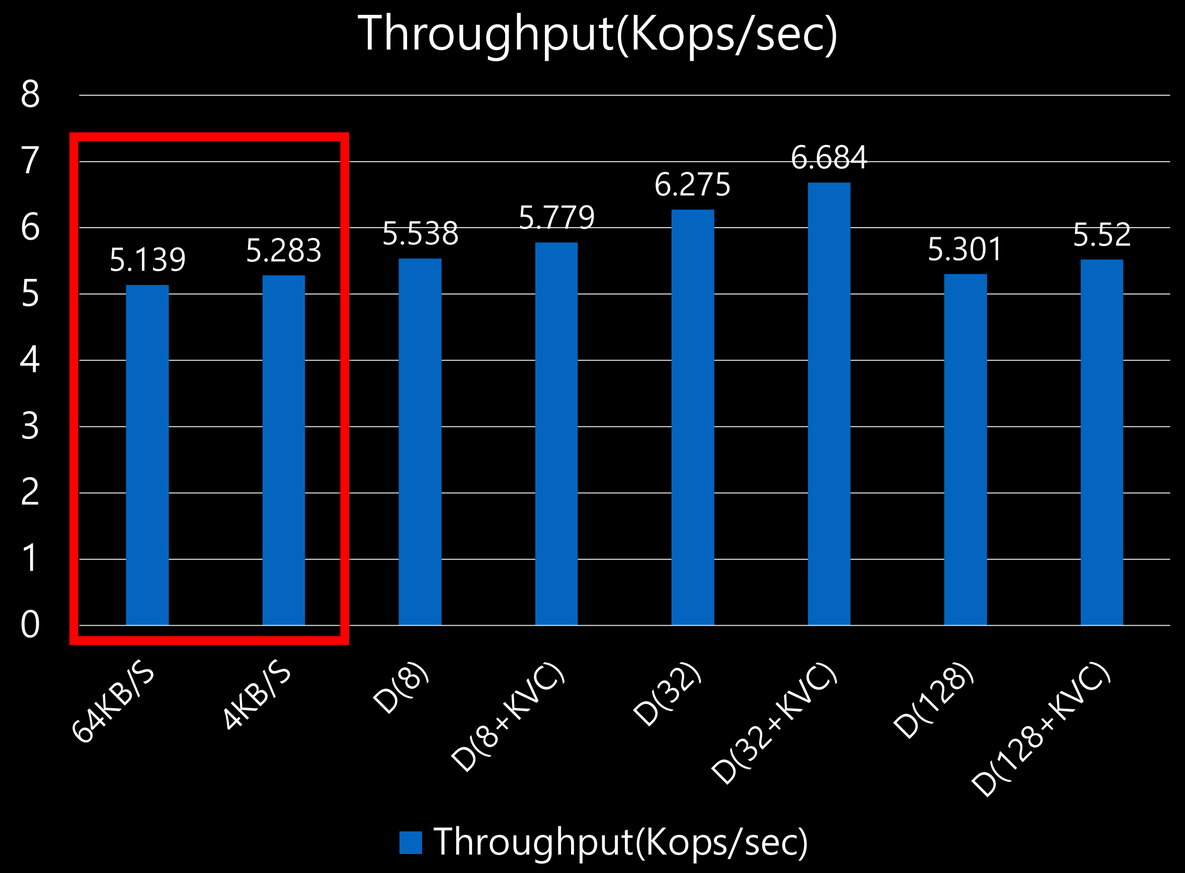

5.1 CUVE: CBMG Benchmark : Read Amplification Factor

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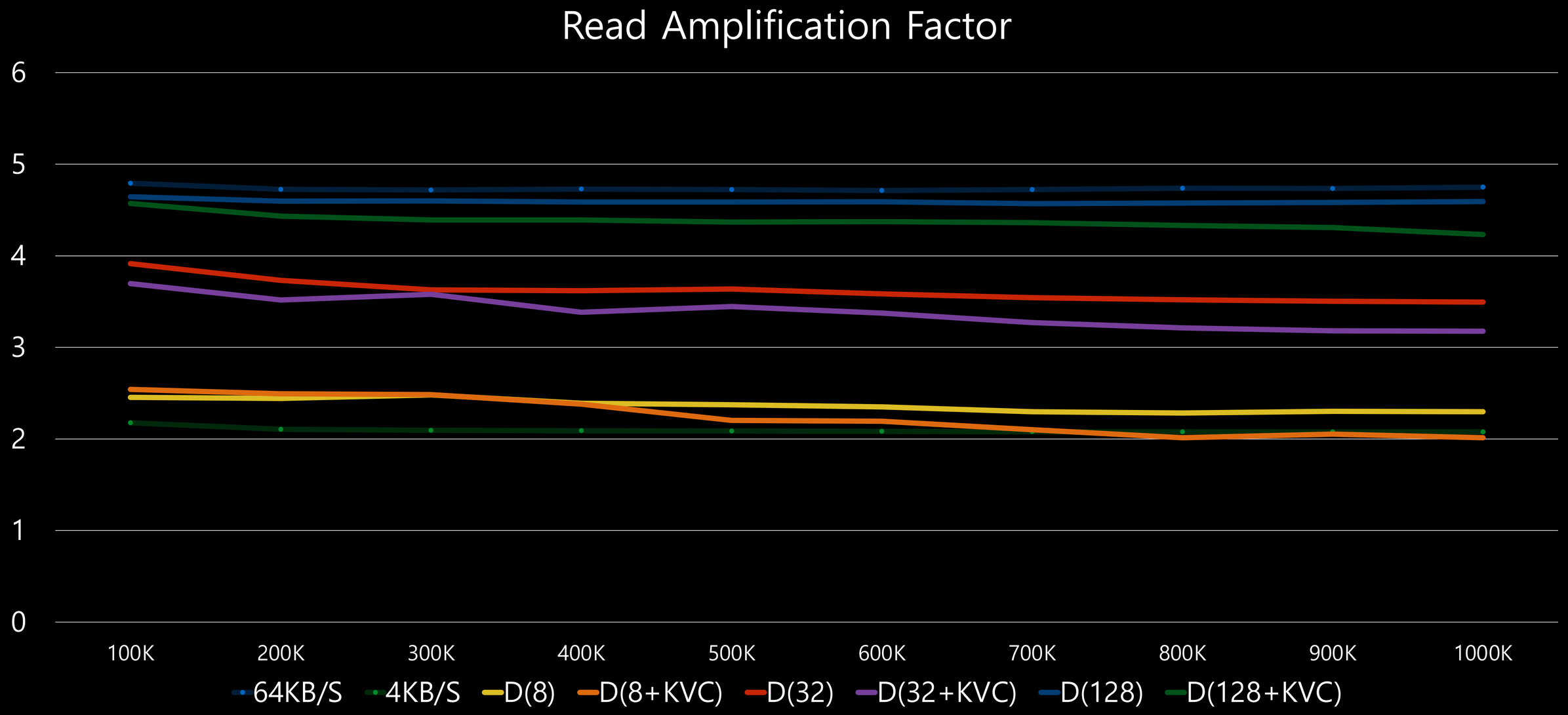

5.2 CUVE: CBMG Benchmark :

Cache Hit Ratio & Throughput

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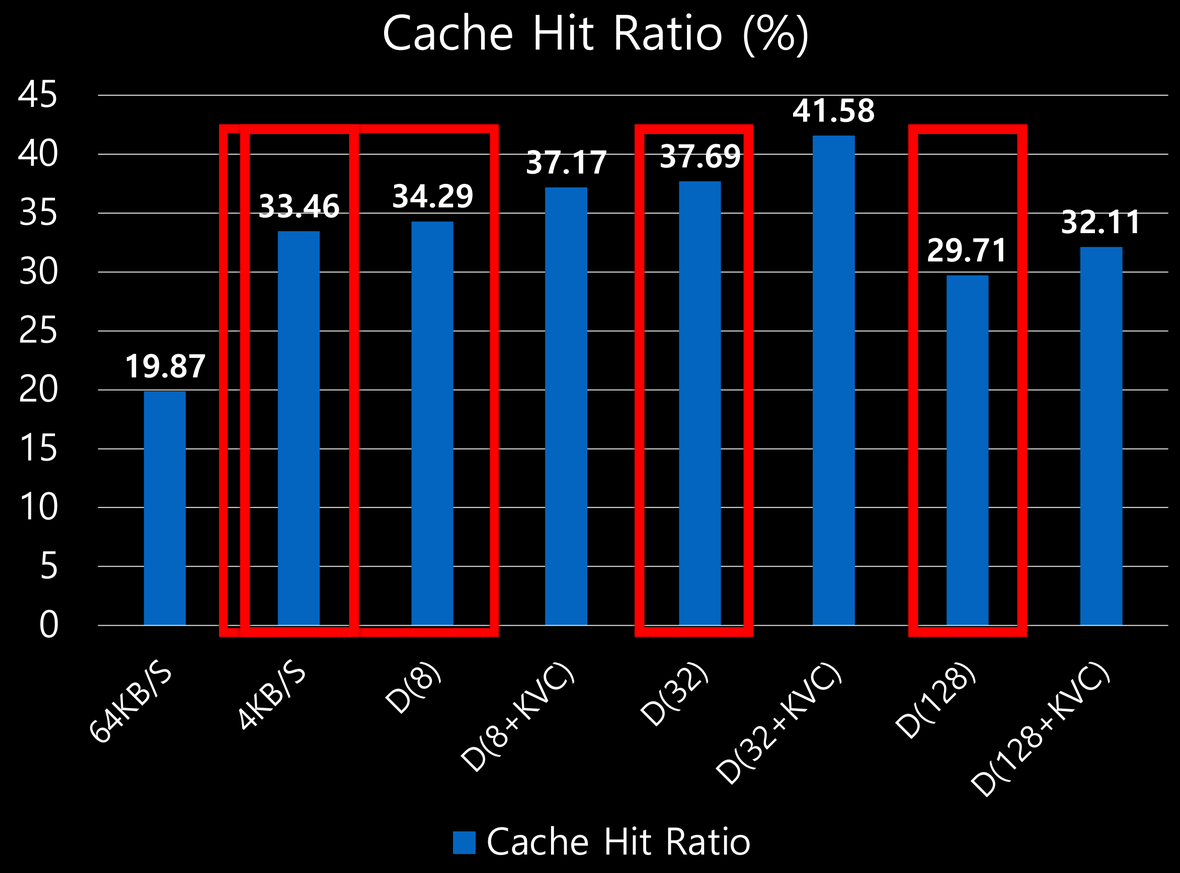

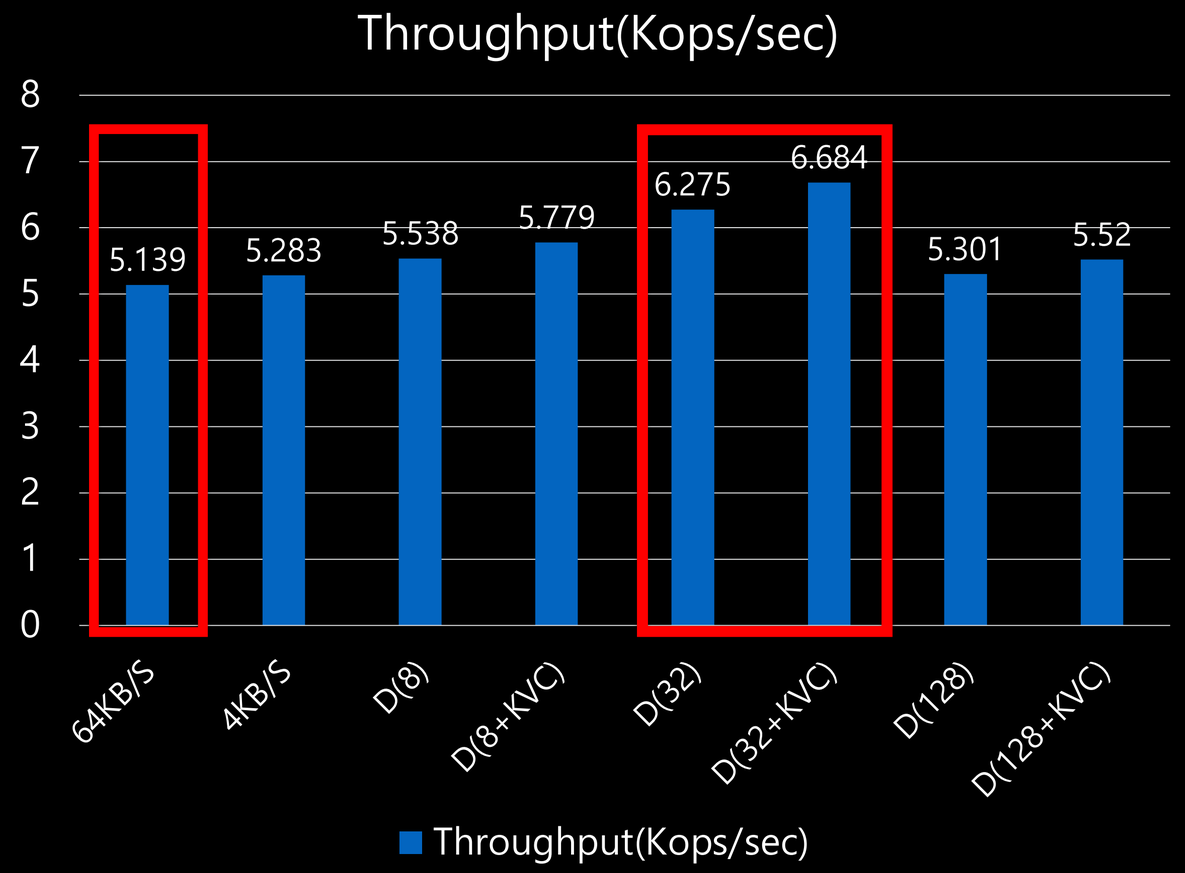

6. Conclusion
마무리

6 Conclusion

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Using 64KB Data block in Vanilla HBase:

- Granularity Mismatch Problem -> Unnecessary Disk I/O
- Cache Pollution Problem -> Degrade Cache Utilization

Using 4KB Data block in Vanilla HBase:

- Frequent small random read -> Disk seek overhead
- Increasing the size of index blocks -> Disk I/O for read index block

6 Conclusion

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Solution 1: **Dynamic Variable Block Size Control**

- ❑ Reduce unnecessary Disk I/O for small Key-Value
- ❑ Increase spatial locality for large Key-Value

Solution 2: **Fine-grained KV Cache**

- ❑ Increase cache efficiency for prevent frequent small random read
- ❑ Increase cache utilization in large data block

Q & A

Thank You