Updatable Learned Index with Precise Positions
Experiment

Wu J, Zhang Y, Chen S, et al., **2021 VLDB**

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Contents

1. Introduction

1) Motivation

Problems with LIPP

- Not tolerate errors
- Create child nodes when conflict occurs (conflict-based structural modification)
- The more conflicts → the higher height of tree → **space amplification**
- Violates the space efficient principle of learned index

Goal

- Analyze the impact of space amplification due to conflicts
- <u>Try to solve it</u>

\+ Also, analyze the performance of range query

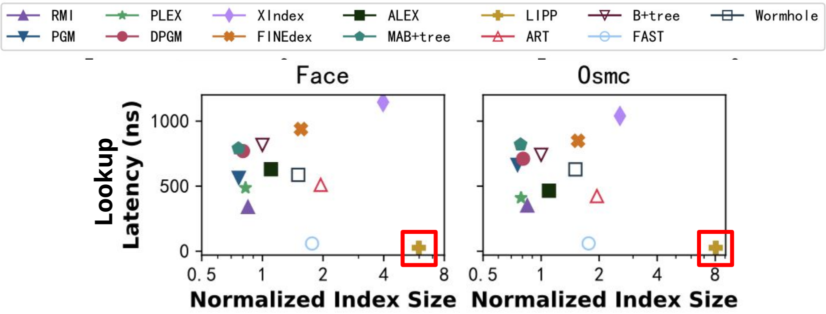


Figure 1: Trade-off of performance and normalized index size.

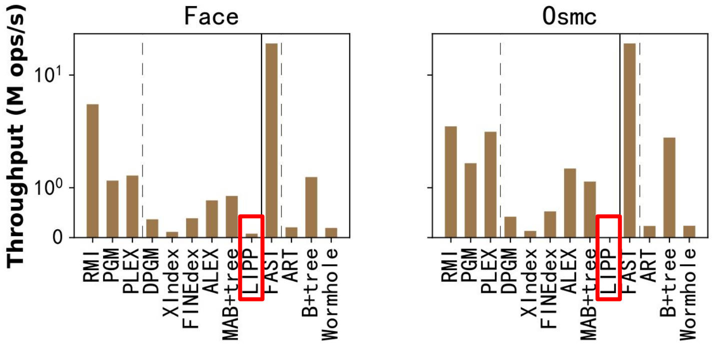


Figure 2: Throughput of range queries.

1. Introduction

Node Utilization: Proportion of non-null entries.

2) Observe with a focus on Utilization

Most nodes have less than 30% of all entries

→ There exists upper bound

$$T_{\mathcal{M}} = \max_{l \in [0, L-1]} |\{k \in \mathcal{K} | \mathcal{M}(k) == l\}|$$

We observe that there exists an upper bound for the minimum $T_{\mathcal{M}}$, i.e. $\exists \mathcal{M}, T_{\mathcal{M}} \leq \lceil \frac{N}{3} \rceil$ where N is the number of keys in $\mathcal{K}$, i.e. $N = |\mathcal{K}|$. However, the $\lceil \frac{N}{3} \rceil$ may not be the tightest upper bound in many cases. Thus, our goal is to find a best model $\mathcal{M} = A\mathcal{G}(k) + b$ with the minimum conflict degree $T_{\mathcal{M}}$.

We think that **TM** will be an important factor of space amplification

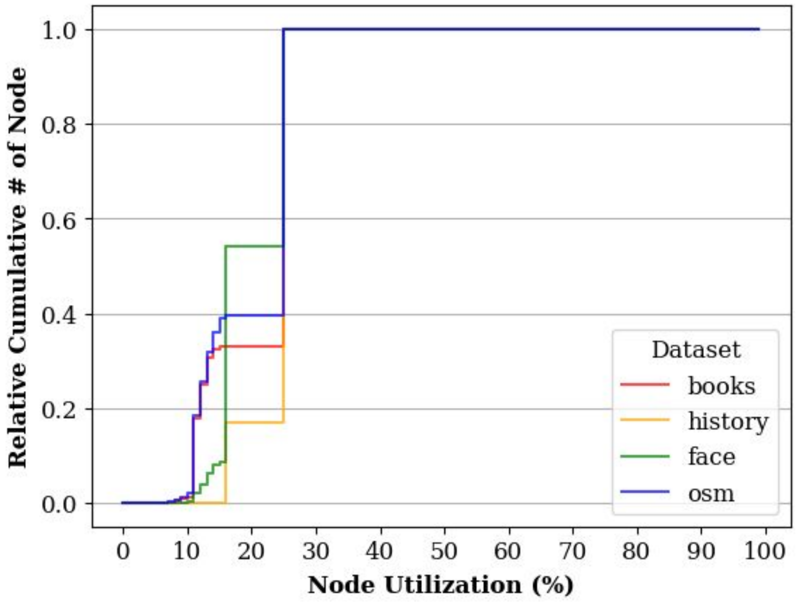


Figure 3: Node utilization CDF

1. Introduction

$$T_{\mathcal{M}} = \max_{l \in [0, L-1]} |\{k \in \mathcal{K} | \mathcal{M}(k) == l\}|$$

3) Parameters of LIPP

- We said that our observation, node utilization upper-bound, is caused by TM, but it is not true

- We found that the factor of affecting to utilization is fill factor(initial node size, gap count)

- We assume that controlling this factor will change performance and index size

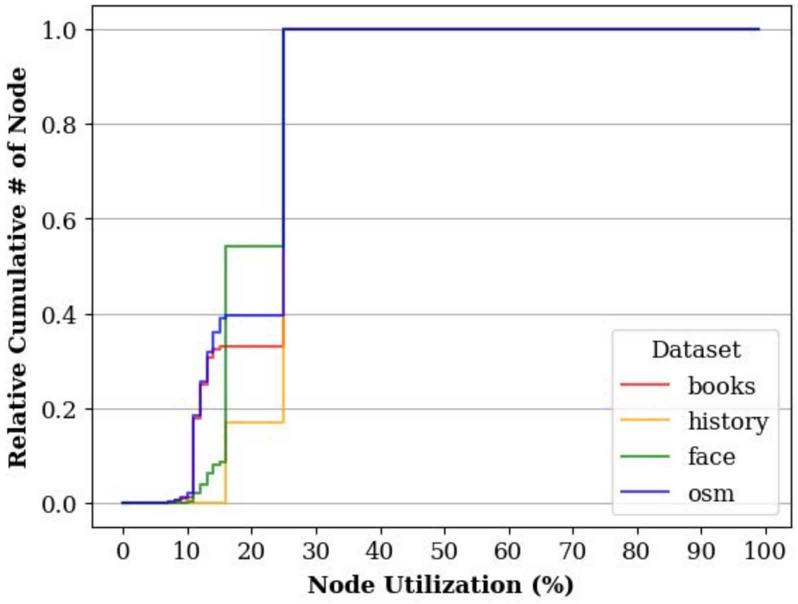


Figure 3: Node utilization CDF

1. Introduction

Fill factor: How many fill space when given new keys, inverse of utilization
e.g., if fill factor is 2, node utilization is 1/2

4) To do Works

1. A sensitivity analysis into updatable learned index structure
   - Node utilization management policy: ***fill factor***
   - Model: simple linear regression vs kernelized linear regression
   - Conflict resolving: shifting vs chaining
   - SMO(Structural modification operation): cost-benefit(fanout tree) vs conflict-proportion

1. Introduction

4) To do Works

2. Performance comparison between ALEX and LIPP through size
   - Need understanding of fill factor(parameter) each indexes

3. Which techniques are appropriate when considering performance versus space?
   - Create a new index based on that analysis
     - + Conflict resolving : error-controlled approach (shift-chain hybrid)
     - + Concurrency-friendly : semi-ordered

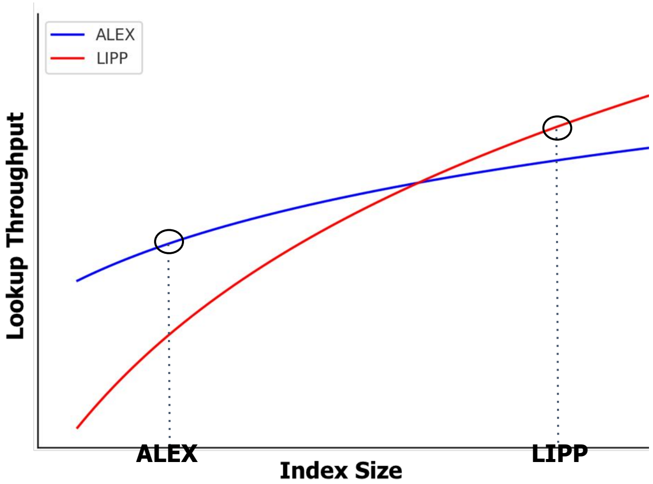


Figure 4: Expected lookup throughput according to size.

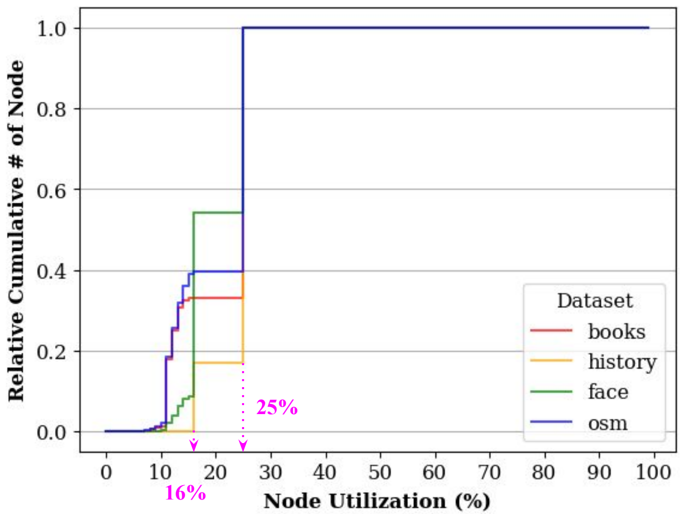
2. Observations

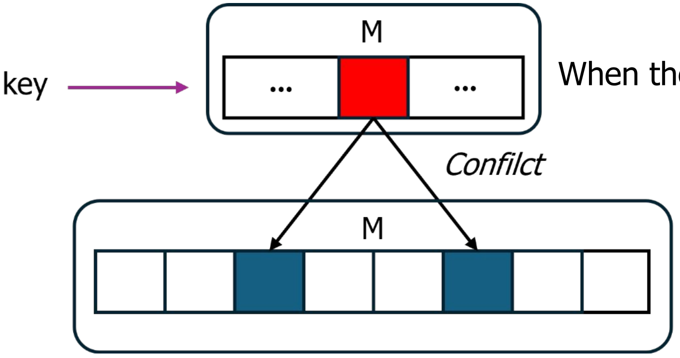
1-1) Node Utilization

Node size set when

(1) Build tree at first (bulk load)

(2) Rebuild (adjust)





When the entry is already ***Data*** type

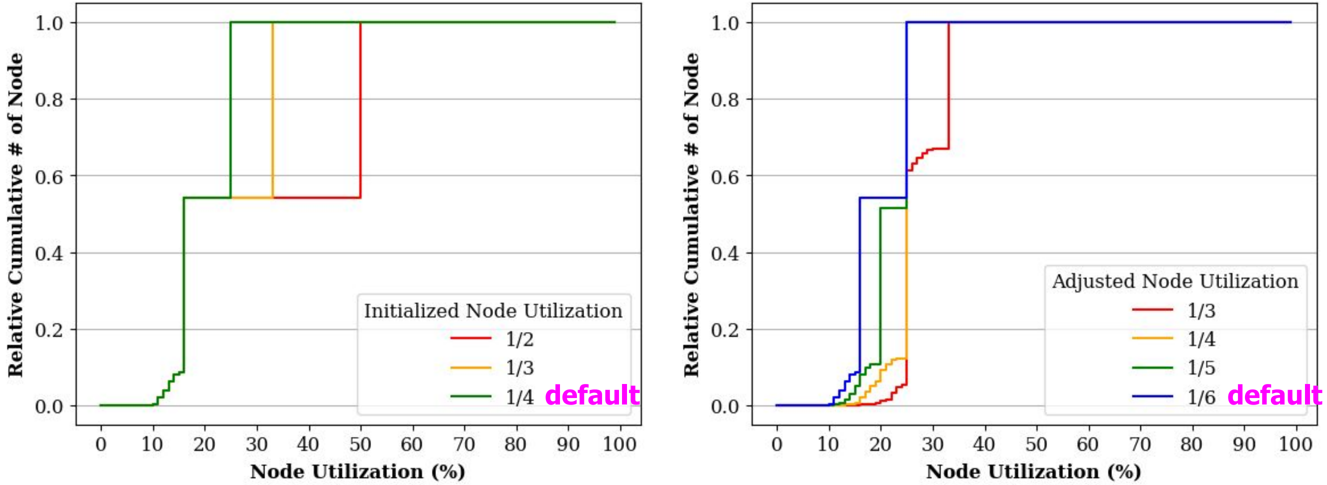
→ Utilization: 2/8 (initial node size) = 25%

Figure 5: Making "Node" type entry when conflict

2. Observations

Observed after bulk load **100M** keys
Dataset: **Face (1.6GB)**

1-2) Node Utilization CDF



- The initial node size greater, the utilization lower
- The gap size greater, the utilization lower

2. Observations

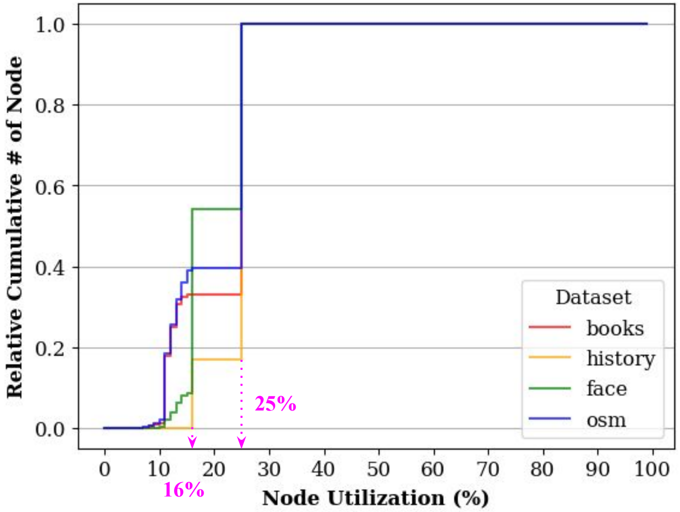
2) Static Gap Count

- It is important to determine **the array length of new node**, because of trade-off between performance and space consumption

- When new node is first created, gaps are hard-coded with **1,2,5** depending on the keys size
    - 1, size ≥ 1_000_000
    - 2, size ≥ 100_000
    - 5, default

- Almost all nodes have a count lower than 100_000, which means that on average, <u>⅙ utilized</u>

- It has low hotness

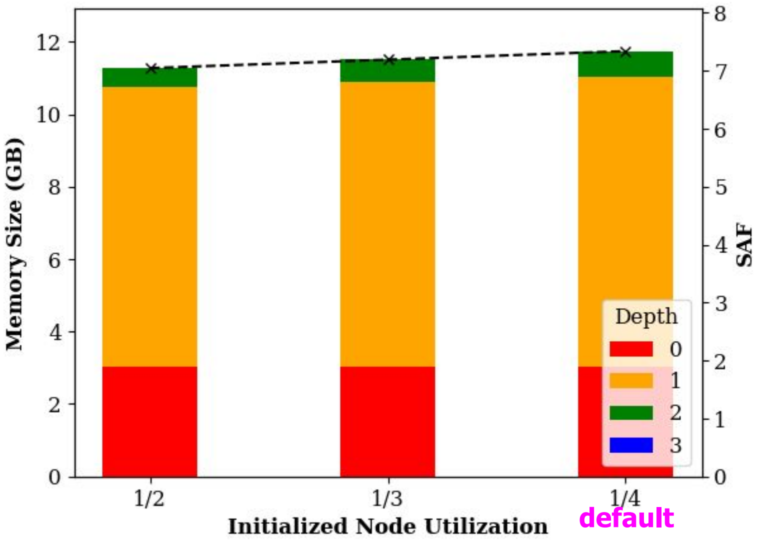


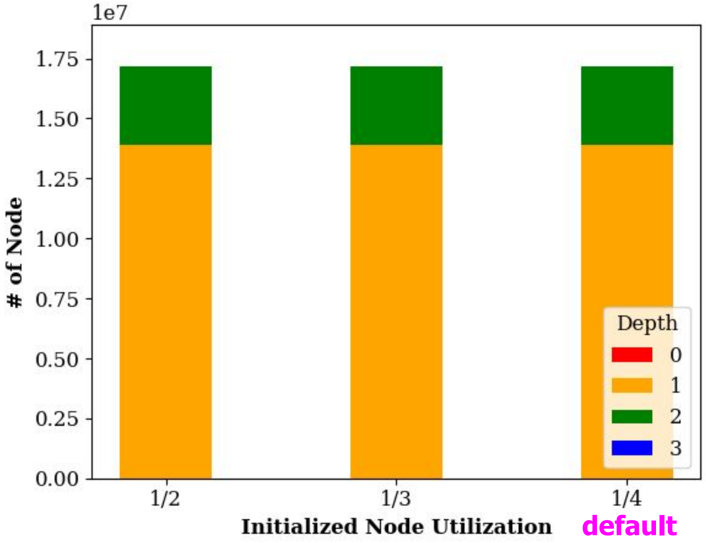

```
const int BUILD_GAP_CNT = compute_gap_count(size);

node->is_two = 0;
node->build_size = size;
node->size = size;
node->fixed = 0;
node->num_inserts = node->num_insert_to_data = 0;

{
    const int L = size * static_cast<int>(BUILD_GAP_CNT + 1);
node->num_items = L;
```

2. Observations

Observed after bulk load **100M** keys
Dataset: **Face (1.6GB)**

3) Root Node Size (Initial Node Size)



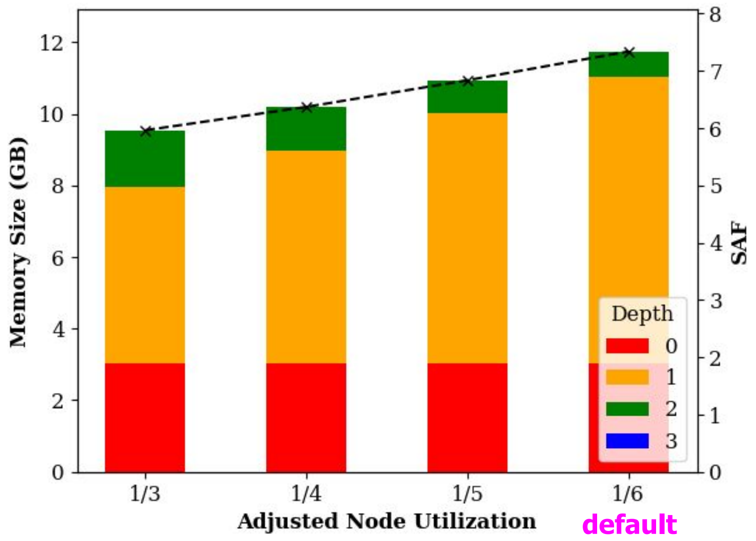


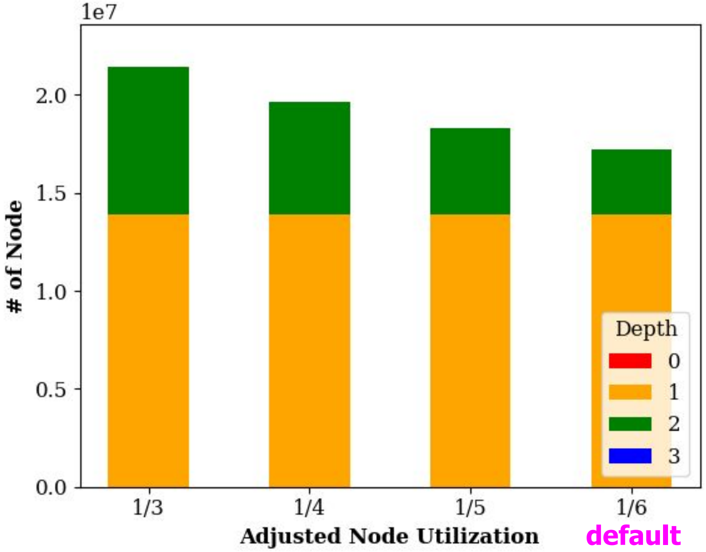
- Root node takes up a significant percentage of the total index size
- Initial node size doesn't have much impact on overall size
- Large number of nodes, but small percentage of size (MBs)

2. Observations

Observed after bulk load **100M** keys
Dataset: **Face**

3) Root Node Size (Gap Count)

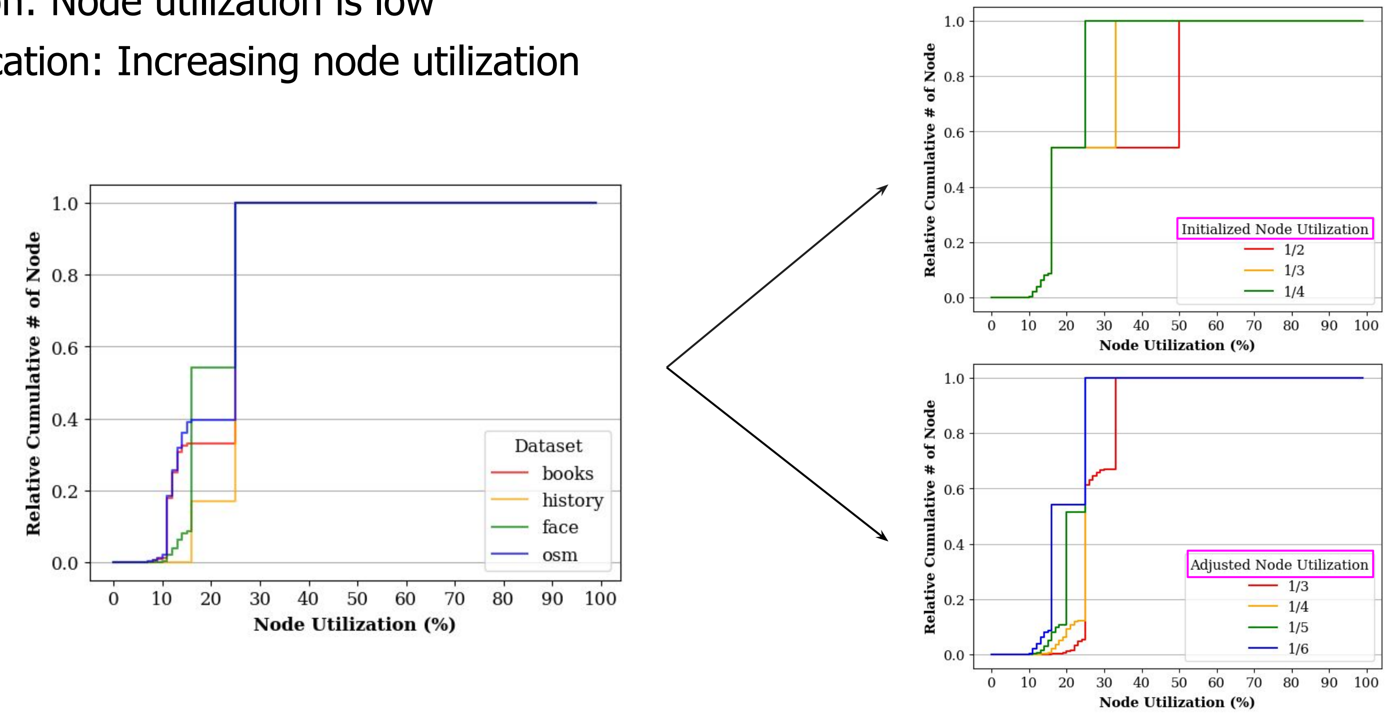




- Gap count has more impact than initial node size, but not primarily
- There may be some other factors (e.g., α, β, FMCD …)

3. Hypothesis

- Hypothesis: The cause of LIPP's SAF may be <u>array management policy</u> (node utilization)
- Reason: Node utilization is low
- Verification: Increasing node utilization

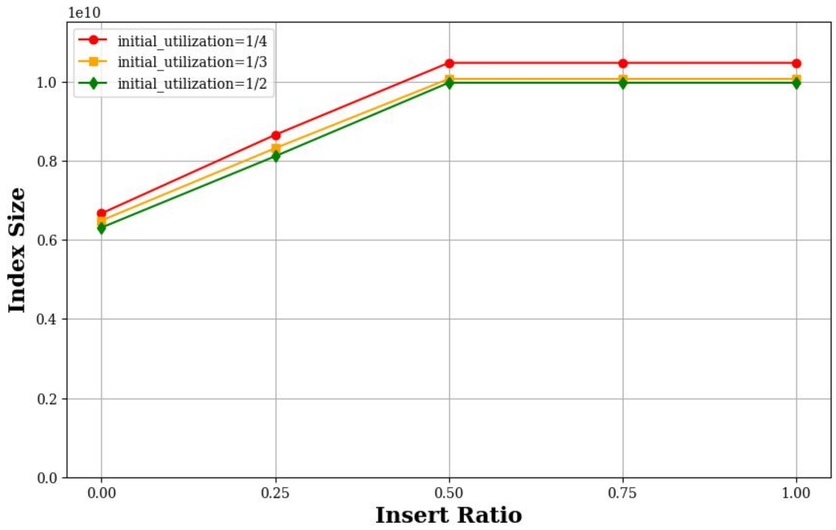


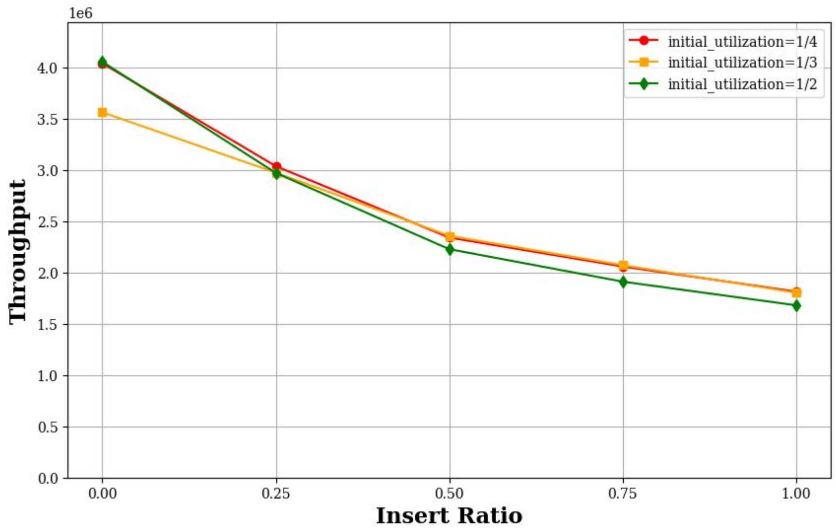
4. Experiments

Observed after bulk load **100M** keys
Dataset: **Face**

Goal : Impact of lipp's array utilization policy (initial node size)

Observation. The **initial node size** has little effect on index size and read-write performance



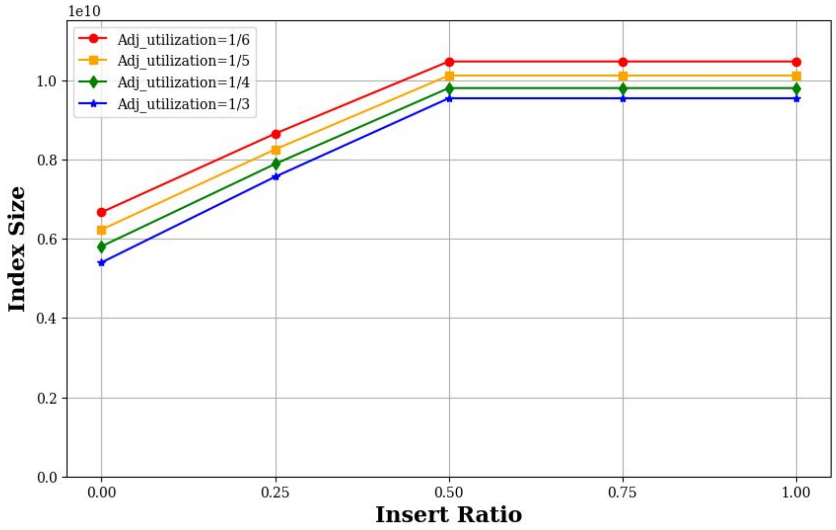


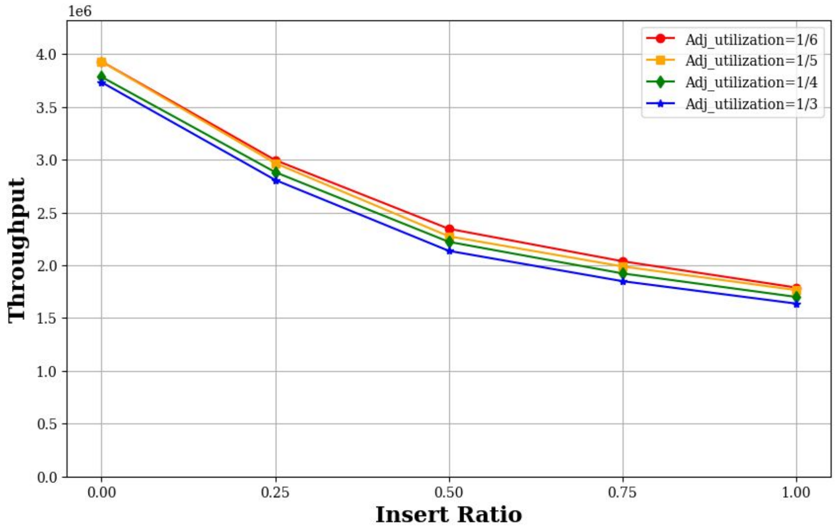
4. Experiments

Observed after bulk load **100M** keys
Dataset: **Face**

Goal : Impact of Lipp's array utilization policy (gap count)

Observation. The **gap count** has a greater impact than the initial node size, but it is not the main cause





5. Conclusion & Question

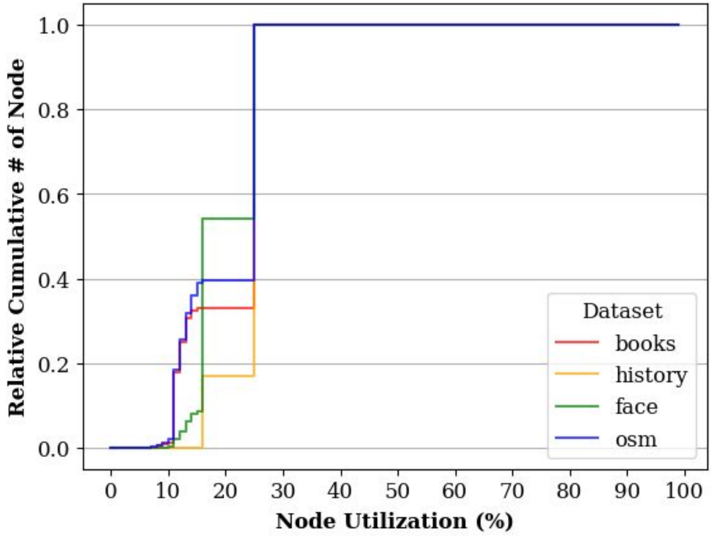
Experiment conclusion:

- Array management policy was not the main cause of Space Amplification (SAF)

Question: No nodes exceed initial node utilization (25%)

- If fill factor is the problem, 3/8 should also exist!
- But, node with a utilization rate of 3/8 is not observed

→ Probably FMCD, conflict issue or something…



6. Future work

1. A sensitivity analysis into updatable learned index structure
- **Current Hypothesis: Array management policy**
    - **fill factor: initial node size, gap_count**
- **New Hypothesis (Expectation)**
    - **rebuilding condition: α, β**
    - **training model: FMCD**
- **Model : simple linear regression vs kernelized linear regression**
- Conflict resolving : shifting vs chaining
- SMO (Structural modification operation) : cost-benefit (fanout tree) vs rebuilding

$$\frac{n.element\_num}{n.build\_num} \geq \beta \quad \beta \text{ is set to 2 by default}$$

$$\frac{n.conflict\_num}{n.element\_num - n.build\_num} \geq \alpha \quad \text{we set the threshold } \alpha = 0.1$$

2. Performance comparison between ALEX and LIPP through size
- Need understanding of fill factor parameter each indexes

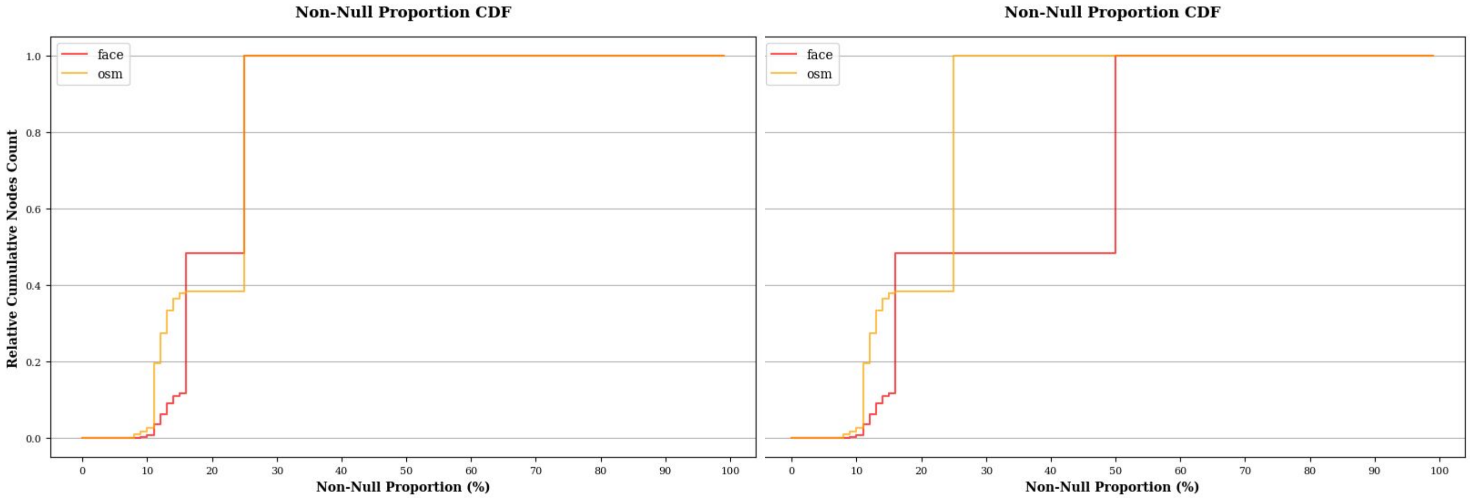
3. Which techniques are appropriate when considering performance versus space?
- Create a new index based on that analysis
+ Conflict resolving : error-controlled approach (shift-chain hybrid)
+ Concurrency-friendly : semi-ordered

Q&A

Thank you!

2. Observation

3) Ro



4. New? Hypothesis

- Adjustment trigger

  1) fill factor

  2) conflict num

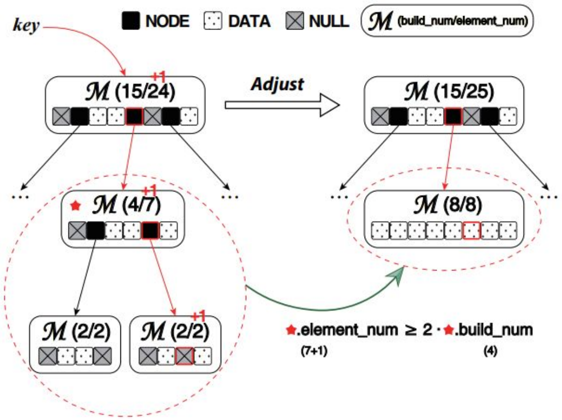


Figure 4: Node Adjustment

- This is because we are considering the utilization of the sub-tree, not the node
- When β is 2, the actual utilization may be much less than 50%

$$\frac{n.element\_num}{n.build\_num} \geq \beta \quad \beta \text{ is set to 2 by default}$$

$$\frac{n.conflict\_num}{n.element\_num - n.build\_num} \geq \alpha \quad \text{we set the threshold } \alpha = 0.1$$

1. Summary

Motivation

Poor understanding of Updatable Learned Index (LIPP)

→ Additional studying: Array Size Policy, Rebuilding Process, FMCD

Analysis of relationship between **index size** and **performance**

→ Between LIPP and ALEX, which structure is more suitable for a learned index?

+ Error-Controlled Approach, Range Query, Semi-Ordered

1.1. Adjustment Strategy

When to Adjust

1. Insert key(s)

2. Update and check statistics of nodes in the traversal path

3. Trigger adjustment on a chosen node when certain conditions are satisfied
   a. $\frac{n.element\_num}{n.build\_num} \geq \beta$ β is set to 2 by default
   b. $\frac{n.conflict\_num}{n.element\_num - n.build\_num} \geq \alpha$ we set the threshold $\alpha = 0.1$

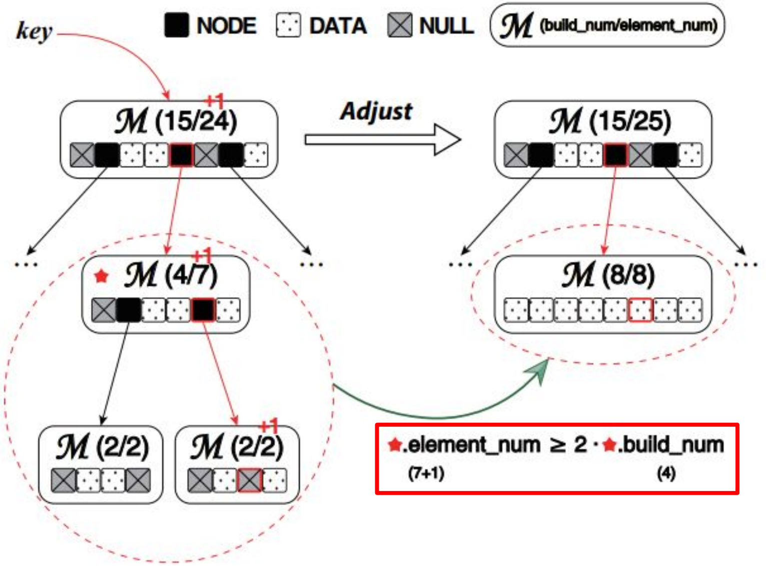


Figure 4: Node Adjustment

1.1. Adjustment Strategy

How to Adjust

1. Collect all elements(keys) in the subtree rooted at node by sequential traversal

2. Build a partial tree on the elements

3. Update the pointer of the original node to point of the new node(tree)

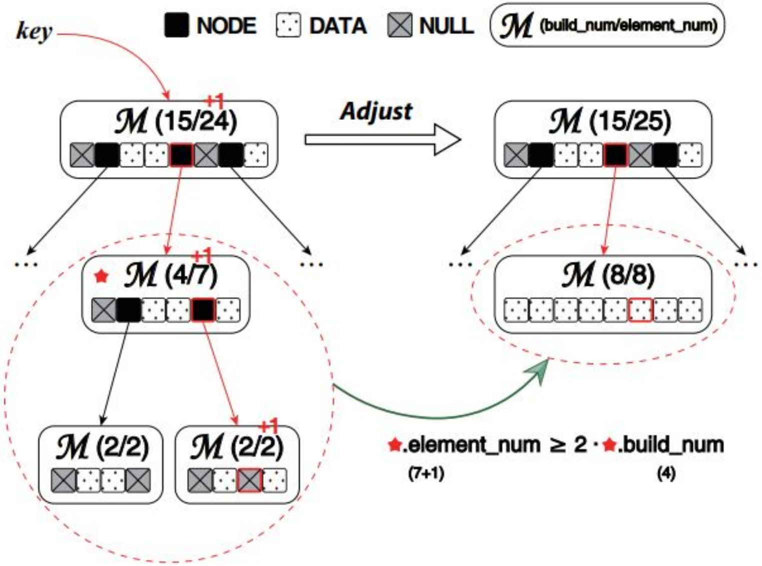


Figure 4: Node Adjustment

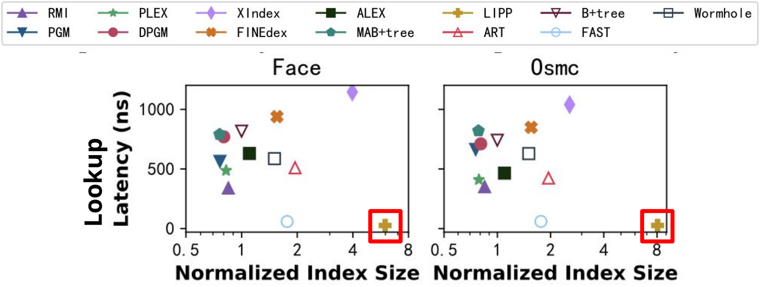
1. Summary

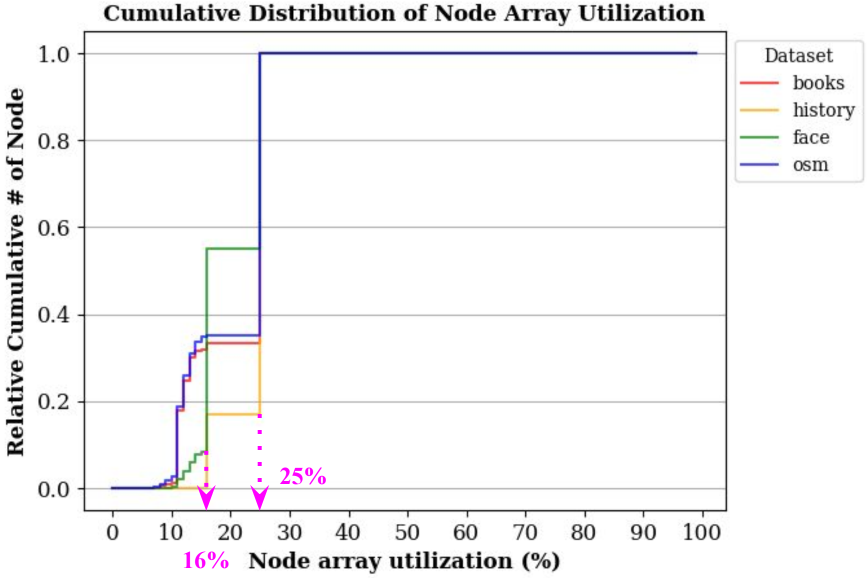
Parameter of Index

Most of raw data is “8,2”, which means “total,node” entries.

There are things the paper doesn't show.

- Array size of child node when first created is hard-coded by 8. (0.25 utilization)
- Array size of new node when need rebuilding(or bulk loading) can be 2x, 3x, and 6x, respectively.





1. Summary

Purpose

Lookup/Insert performance comparison according to size

- Tuning parameter: ALEX(fill factor), LIPP(gap count)

LIPP vs ALEX

- Model
- Array Management Policy
- Shift/Chaining
- SMO

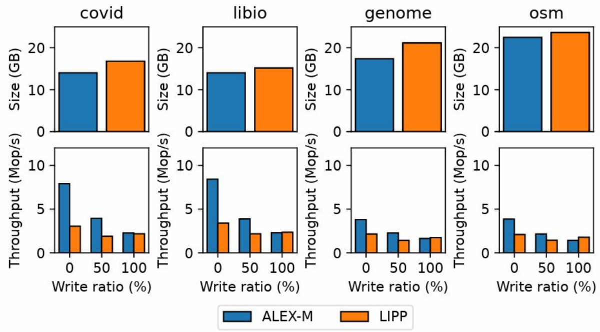
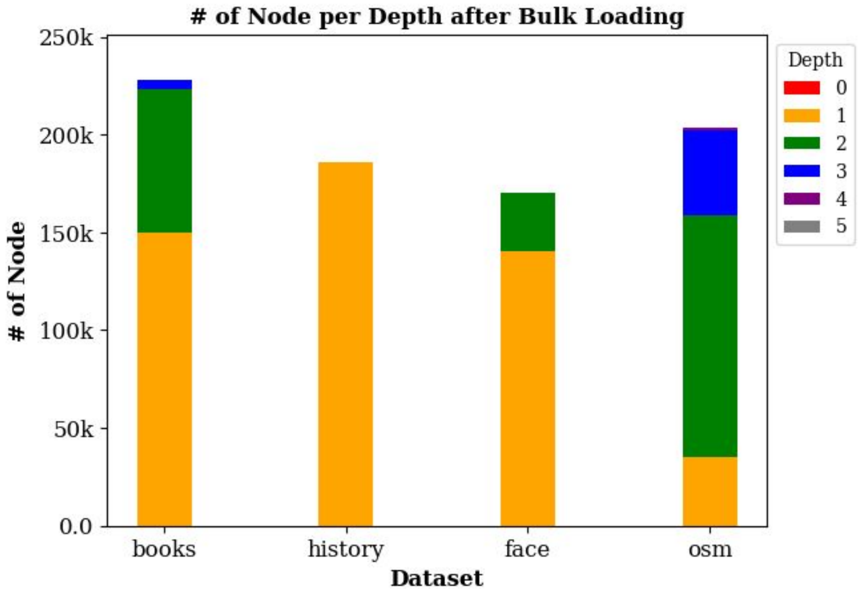
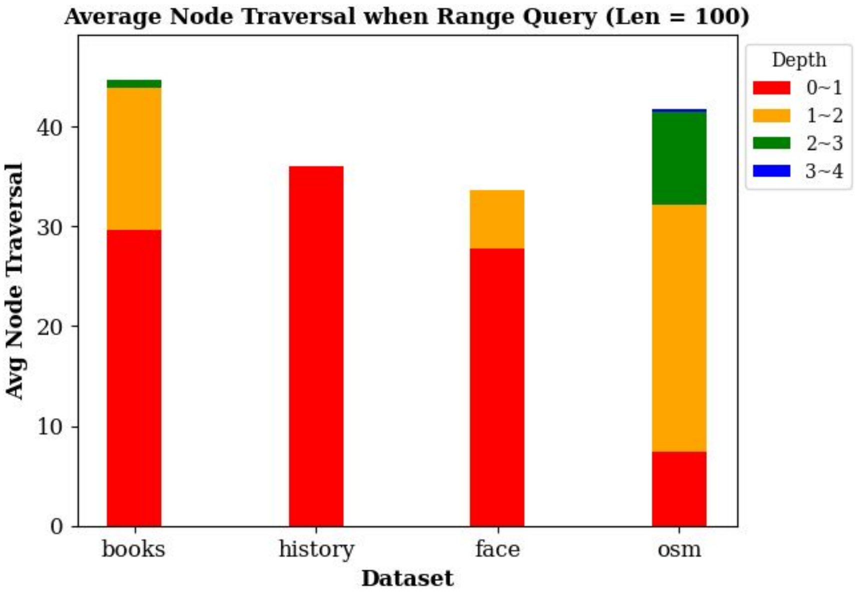


Figure 9: ALEX-M vs. LIPP (when ALEX is tuned to use roughly the same amount of memory as LIPP).

2.1. Experiment

Tendency by Dataset

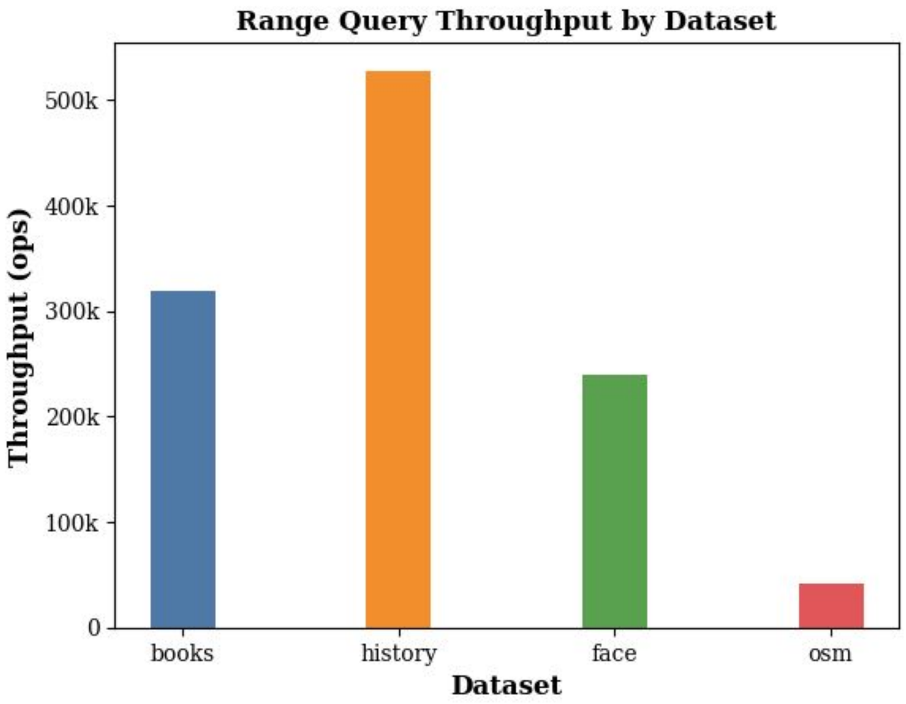




2.2.1. Experiment

scan_num: 100
iteration: 1M
table_size: 100M (key_range: 200M)
operations: range query only

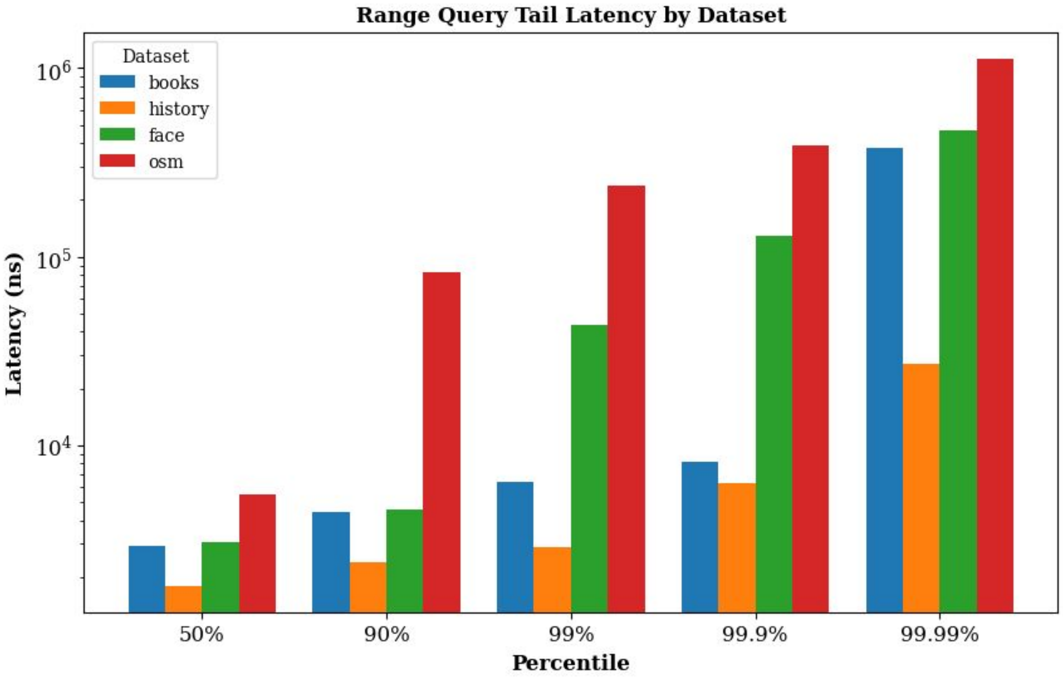
Range Query Throughput by Dataset



2.2.2. Experiment

scan_num: 100
iteration: 1M
table_size: 100M (key_range: 200M)
operations: range query only

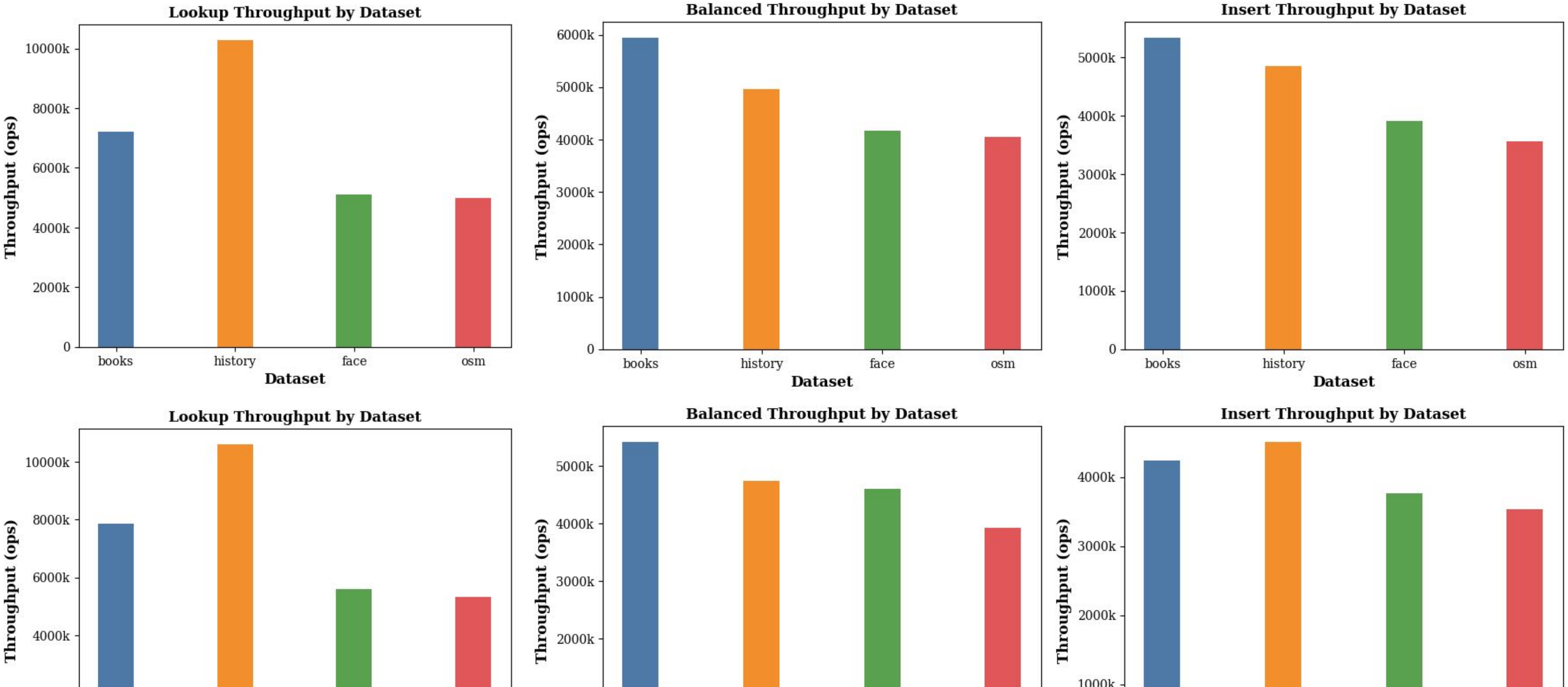
Range Query Latency by Dataset



2.2.2. Experiment

scan_num: 100
iteration: 1M
table_size: 100M (key_range: 200M)
operations: range query only

Lookup Throughput by Dataset



2.2.2. Experiment

scan_num: 100
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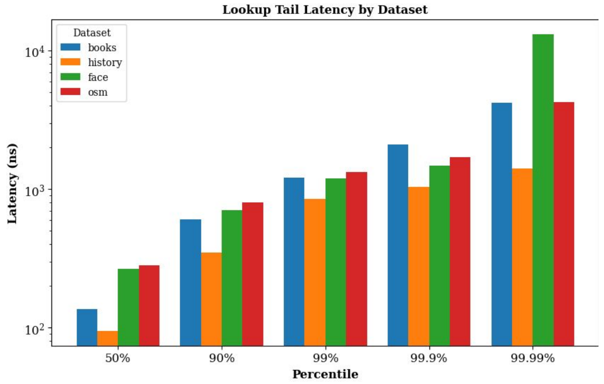
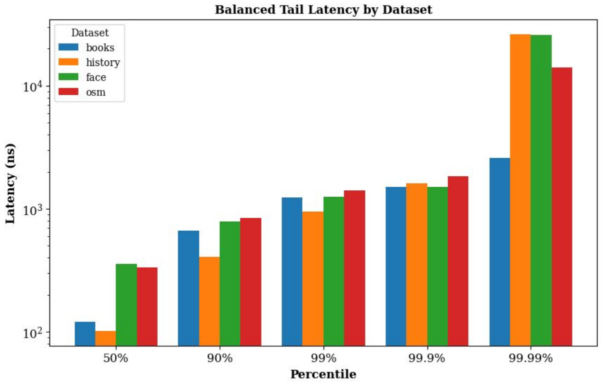
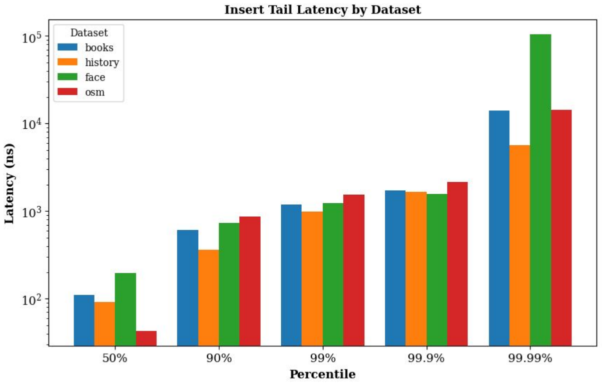
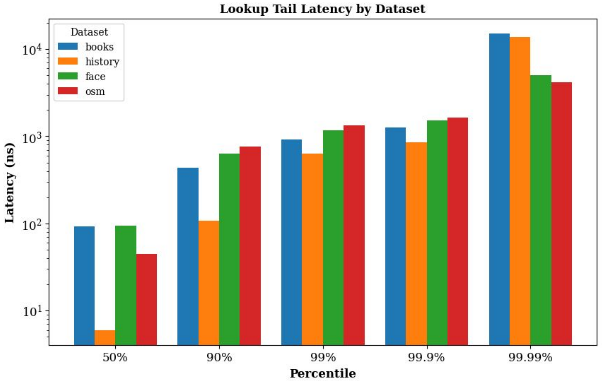
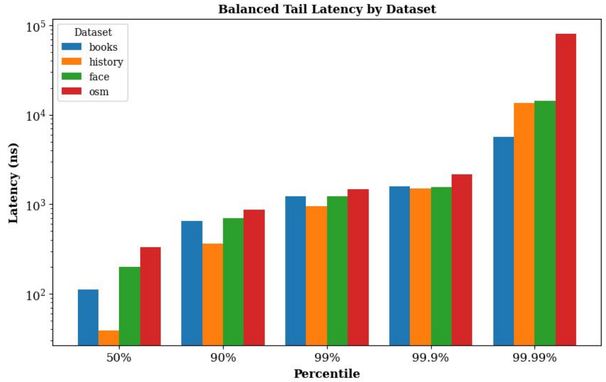
Lookup Latency by Dataset

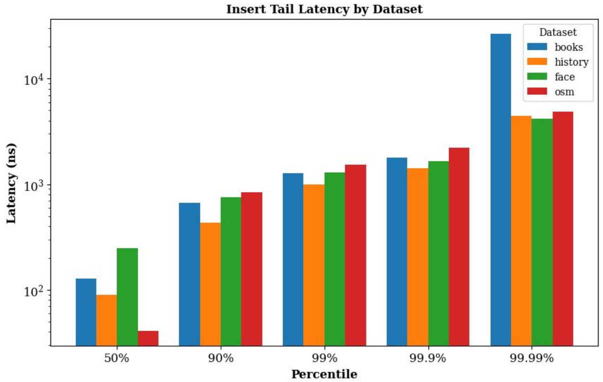












2.3. Dataset Hardness

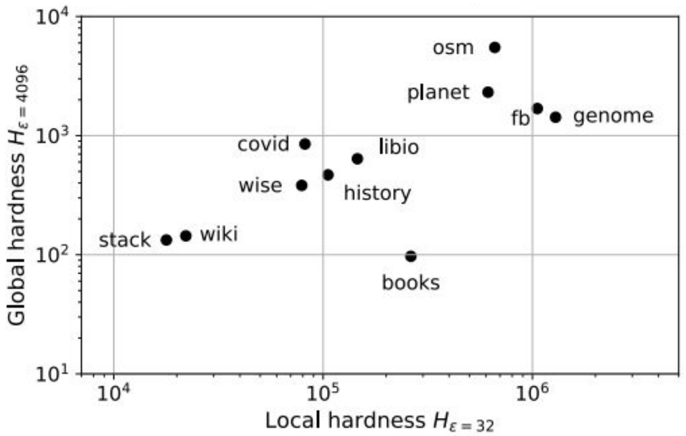
New Criteria

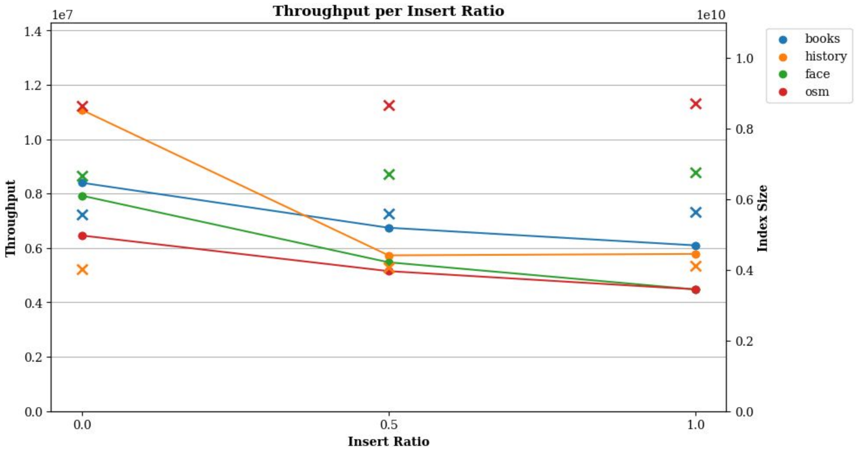
- Previous experiments defined data hardness as the number of segments (optimal PLA model)

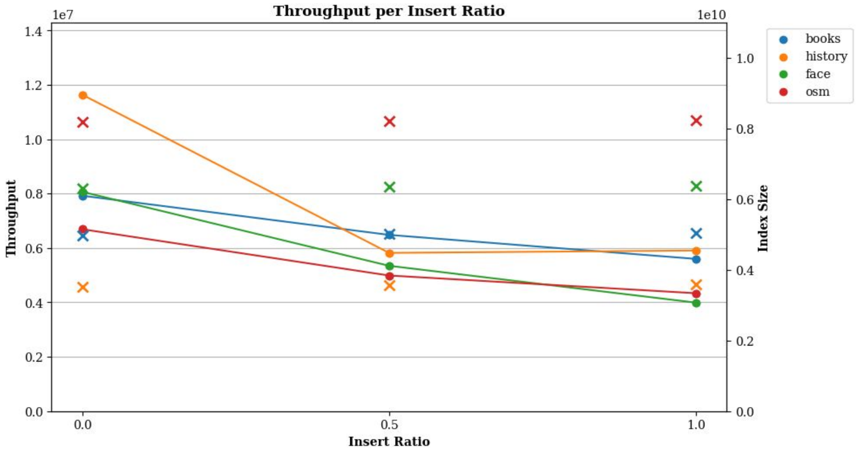
- But our approach is based on **conflict count**, so it is not compatible

- Need to quantify to other criteria

- Plan to use definition of conflict degree of node




Throughput per Insert Ratio
1e7
1e10
books
history
face
osm
Throughput
Index Size
Insert Ratio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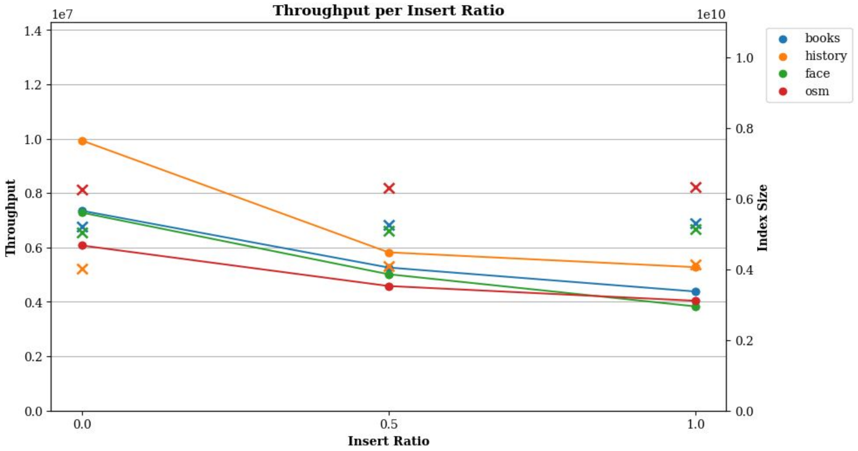
Throughput per Insert Ratio
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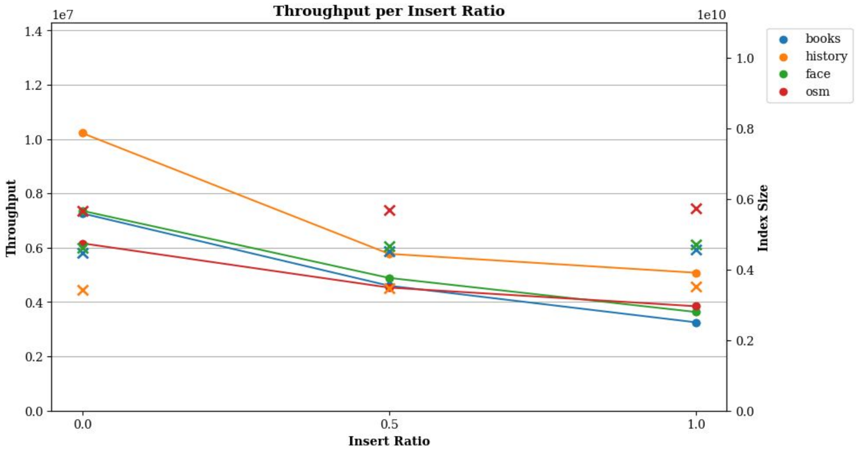
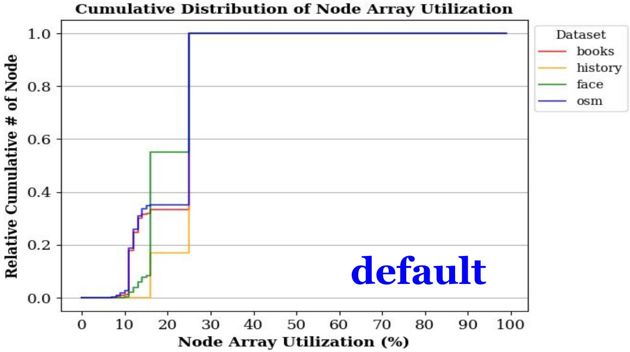

Throughput per Insert Ratio
1e7
1e10
books
history
face
osm
Throughput
Index Size
Insert Ratio

num_items: 8, 6, 4

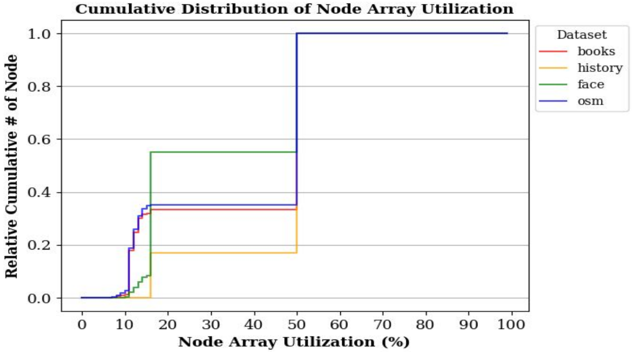
GAP_CNT: 1/2/5

GAP_CNT: $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{6}$

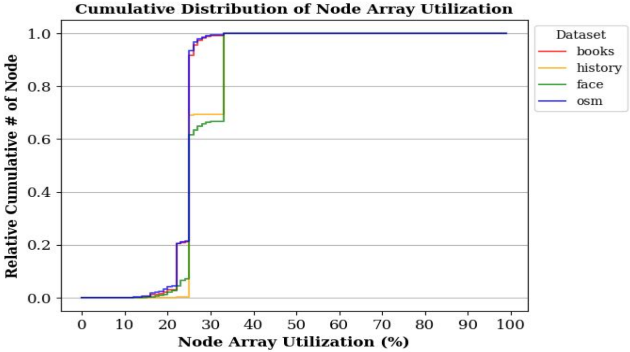
num_items: 8

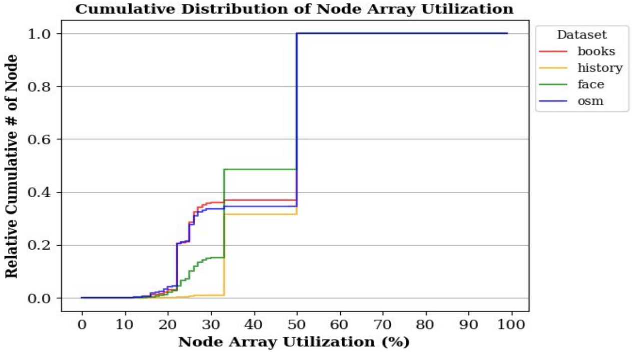


num_items: 4



GAP_CNT: 0/1/2

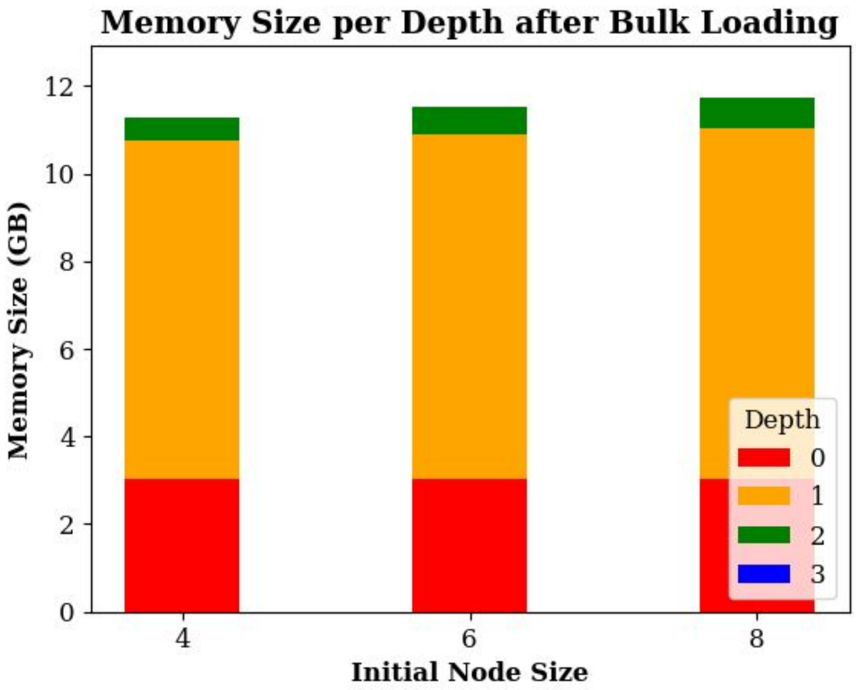


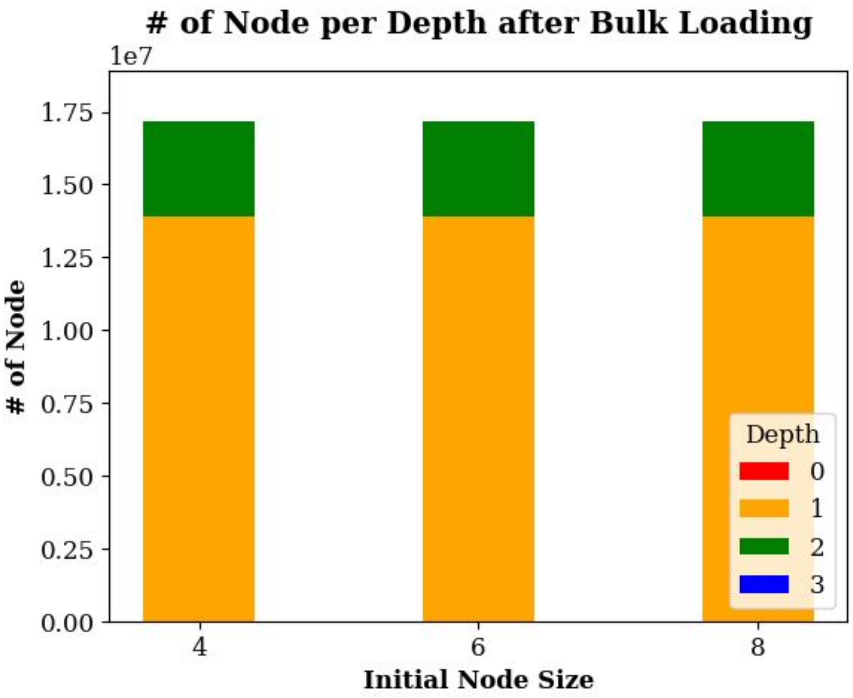


2. Observations

Observed after bulk load **100M** keys
Dataset: **Face**

3) Root Node Size (Initial Node Size)

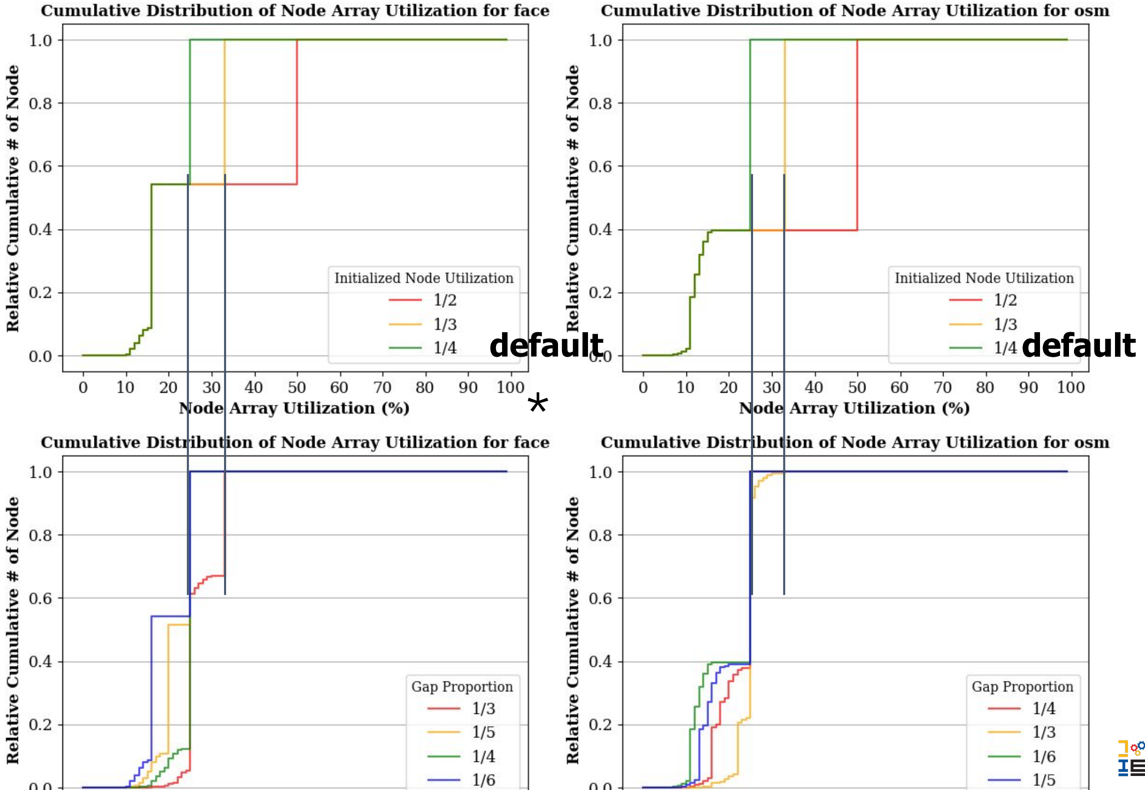




3. Experiment

Observed after bulk load **100M** keys

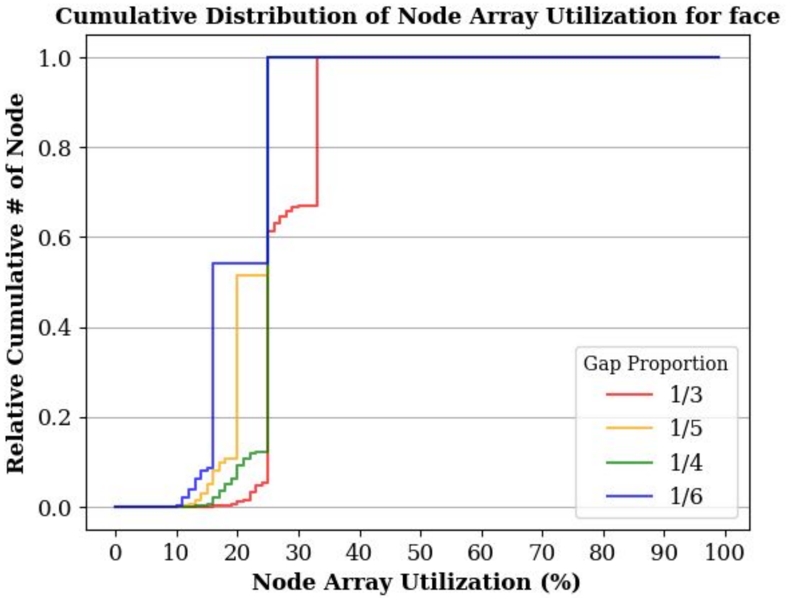
Array Utilization CDF (Initialized Node Size)

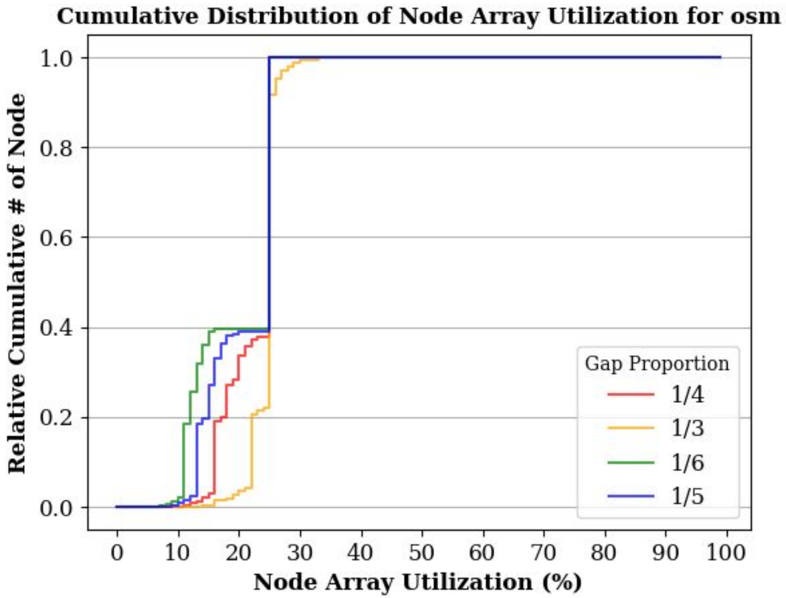


3. Experiment

Observed after bulk load **100M** keys

Array Utilization CDF (Gap Proportion)

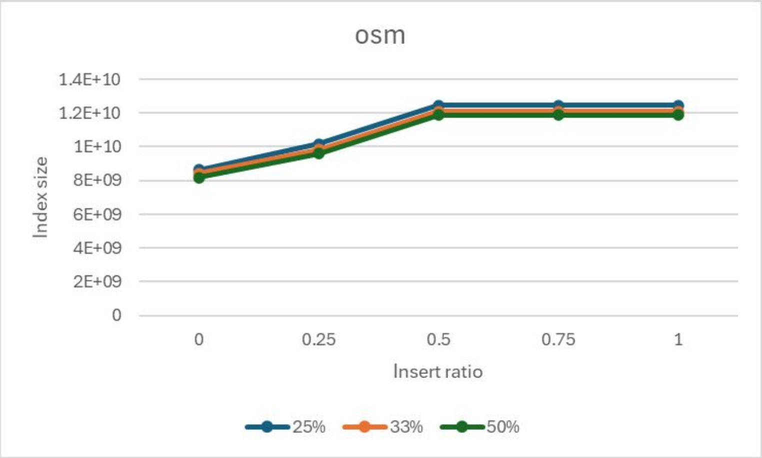


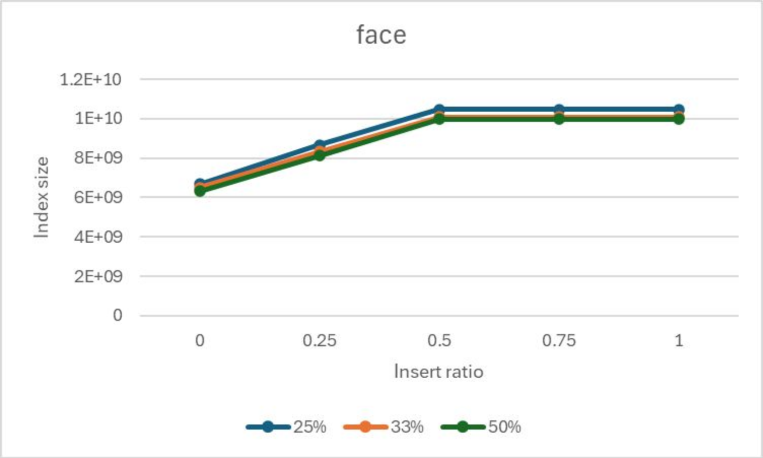


3. Experiment

Goal : lipp의 array utilization policy의 영향 (Size)

Observation . 우리는 개 삽질을 한것이다. 알파 베타가 답이었다.



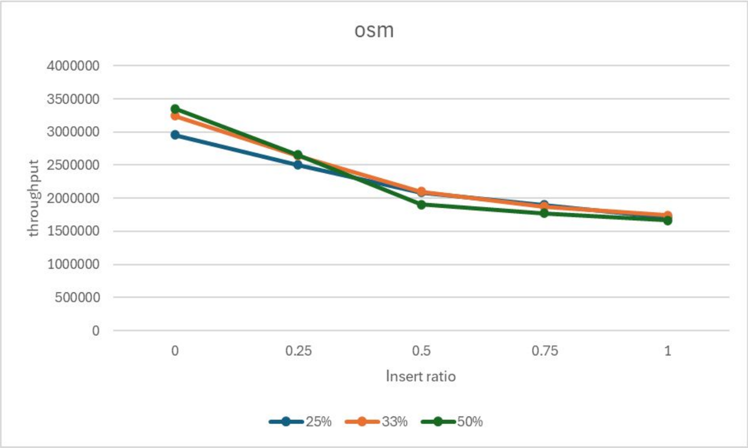


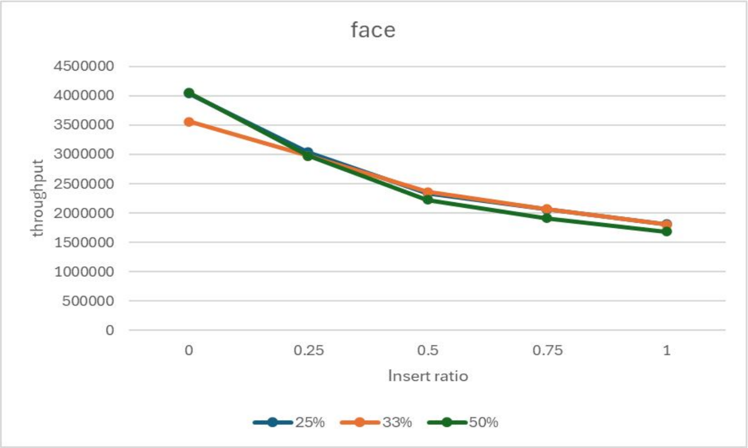
3. Experiment

Goal : lipp의 array utilization policy의 영향 (Performance)

read-write mixed workload

Observation . 모름

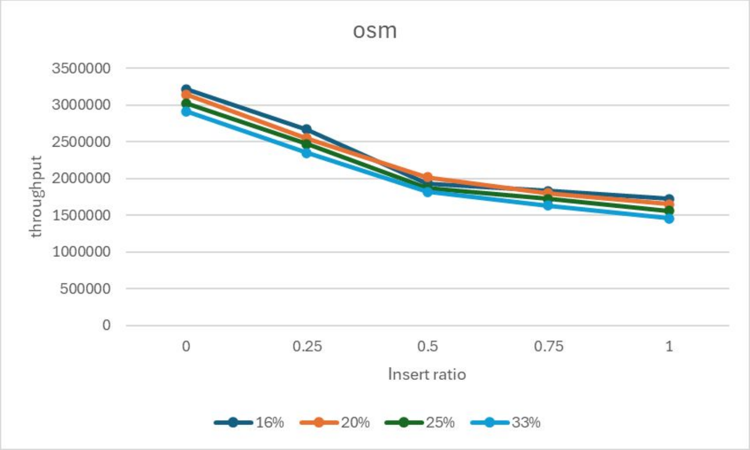


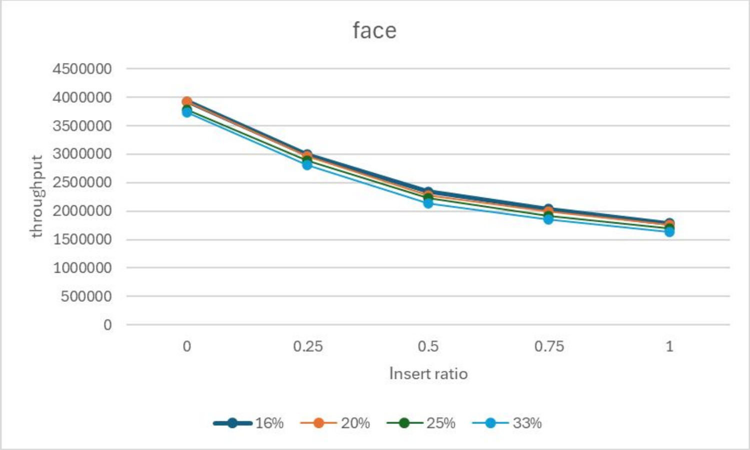


3. Experiment

Goal : lipp의 array utilization policy의 영향 (Performance)

Observation . 모름

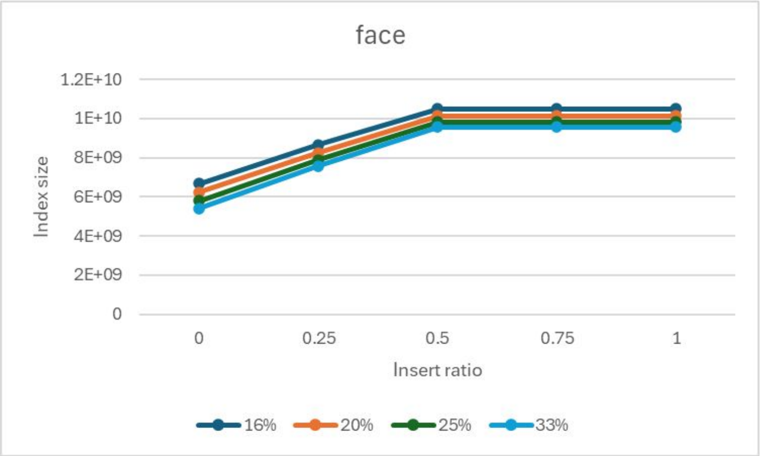




3. Experiment

Goal : lipp의 array utilization policy의 영향 (Size)

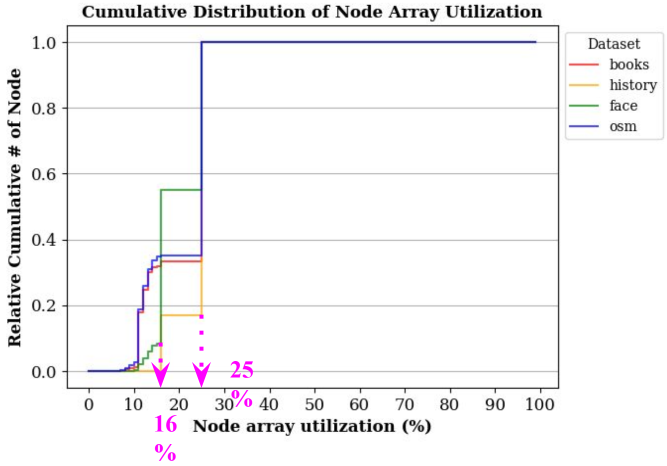
Observation . 모름



Hypothesis

Adjustment trigger

1) fill factor
2) conflict num



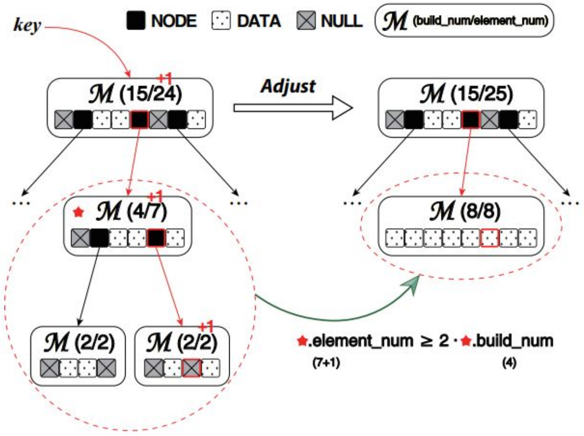


Figure 4: Node Adjustment

해당 노드가 아니라, sub-tree의 utilization을 고려하는 것이므로

beta가 2인 경우의 실제 utilization은 50% 보다 훨씬 작을 수 있음

좀 더 생각해보는 걸루

fill factor 가 문제면, 3/8도 존재해야함...

하지만 ⅜ 왜 없누? 누가 범인이누? 몰루?

아마도 FMCD, Conflict 문제인듯

좀 바꿔야 되긴 할듯요. 정리나 음 새로운 발견?
뭐든. 근데 제가 future work에 쓴거 보시면
가설을 2개로 나눠서 썼는데 보셨어요?

$$\frac{n.element\_num}{n.build\_num} \geq \beta \quad \beta \text{ is set to 2 by default}$$

$$\frac{n.conflict\_num}{n.element\_num - n.build\_num} \geq \alpha \quad \text{we set the threshold } \alpha = 0.1$$

4. Future work

1. A sensitivity analysis into updatable learned index structure
- **Array management policy : fill factor, initial node size (이 산이 아니다!)**
  - 사실 fill factor는 alpha, beta였던 거임 크크 (아님 말고 ㅋ)
- Model : simple linear regression vs kernelized linear regression (**FMCD**)
- Conflict resolving : shifting vs chaining
- SMO (Structural modification operation) : cost-benefit(fanout tree) vs rebuilding

2. Performance comparison between ALEX and LIPP through size
- Need understanding of fill factor parameter each indexes

3. Which techniques are appropriate when considering performance versus space?
- Create a new index based on that analysis
+ Conflict resolving : error-controlled approach (shift-chain hybrid)
+ Concurrency-friendly : semi-ordered