An Adaptive Index for Hierarchical Database Systems

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BSc Thesis

February 9, 2018

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The Workload-Aware Property Index (WAPI):

- Detects frequently updated nodes
- Stops pruning such volatile nodes
- Significantly improves update throughput

Unproductive Nodes are an unwanted byproduct:

- When the workload changes, volatile nodes cease to be volatile
- They waste space and slow down queries
- They do not contribute to a query match and contain no data

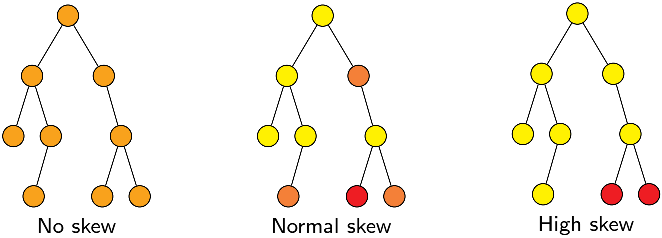
In this thesis we:

- Design and implement two solutions in order to mitigate unproductive nodes
- Analyze the factors impacting the production of unproductive nodes
- Empirically evaluate and compare our two solutions

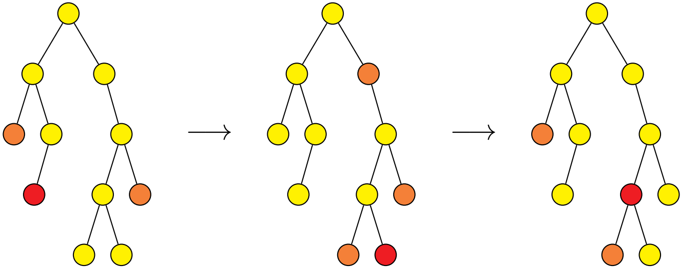
A Content Management System's (CMS) workload is:

- skewed
- update-heavy
- changing

Skewed workload: small subset of nodes gets frequently updated



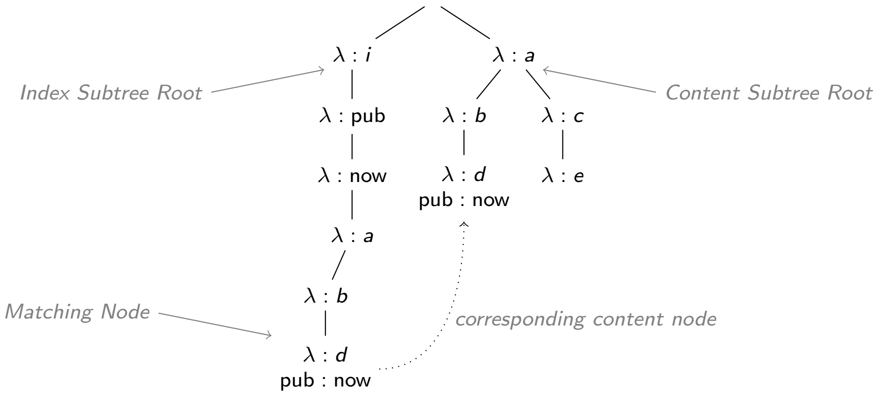
Changing workload: as time passes, hotspots change



CMSs usually use a job-queuing system that has the noted characteristics

Workload-Aware Property Index

Hierarchical Database with WAPI



We mostly executes content-and-structure (CAS) queries. We denote node n's property k as $n[k]$ and node n's descendants as $desc(n)$.

Definition (CAS Query)

Given node m, property k and value v, a CAS query $Q(k, v, m)$ returns all descendants of m which have k set to v, i.e.,

$$Q(k, v, m) = \{n | n \in desc(m) \wedge n[k] = v\}$$

Volatility is the measure which is used by the WAPI in order to distinguish whether to remove a node or not from the index. Wellenzohn et al. [1] propose to look at the recent transactional workload to check whether a node n is volatile.

Definition (Volatility Count)

The volatility count $vol(n)$ of index node n on database instance O_i, is the number of times node n was added or removed from snapshots contained in a Sliding Window of Length L over history H_i, i.e.,

$$vol(n) = |\{G^b | G^b \in H_i \wedge t(G^b) \in [t_n - L + 1, t_n] \wedge \exists G^a[\\ G^a = pre(G^b) \wedge ([n^a \notin N(G^a) \wedge n^b \in N(G^b)] \vee \\ [n^a \in N(G^a) \wedge n^b \notin N(G^b)])]\}|$$

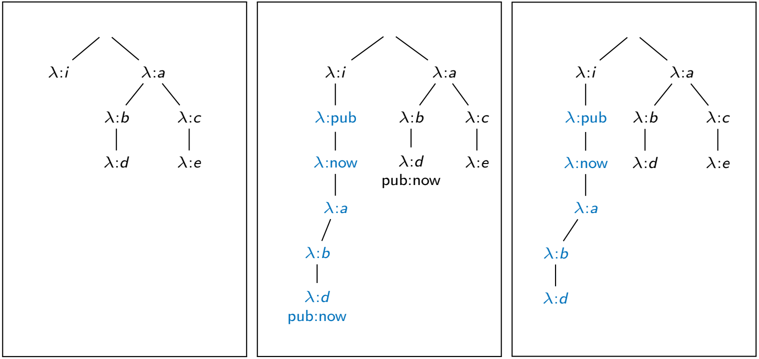
Definition (Volatile Node)

Index node n is volatile iff n's volatility count is greater or equal than the volatility threshold τ, i.e.,

$$volatile(n) \iff vol(n) \geq \tau$$

Index nodes becoming volatile

$$G^0 \xrightarrow{T_1} G^1 \xrightarrow{T_2} G^2$$



Snapshot G^0
$t(G^0) = t$

Snapshot G^1
$t(G^1) = t + 1$

Snapshot G^2
$t(G^2) = t + 2$

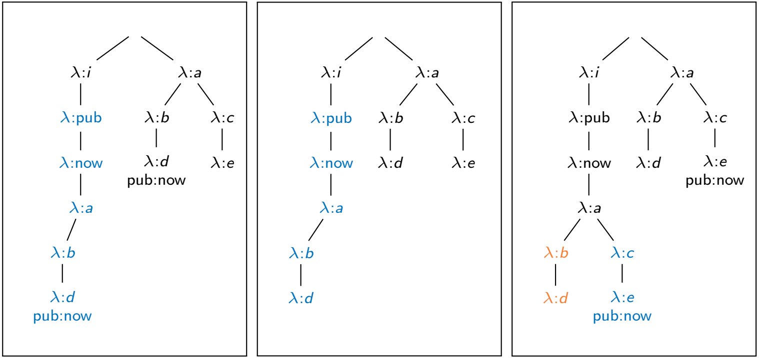
$\tau = 1, L = 2$

Unproductive Nodes

- When nodes are volatile, their volatility count has to be at least τ
- Time passes and the database workload changes
- Insertions and deletions that increased the volatility count drop out of the sliding window
- If the volatility count drops below threshold τ, the node ceases to be volatile
- If the same holds for the node's descendants, we call the node and its descendants unproductive

Index nodes becoming unproductive

$$G^1 \xrightarrow{T_2} G^2 \xrightarrow{T_3} G^3$$



Snapshot G^1
$t(G^1) = t + 1$

Snapshot G^2
$t(G^2) = t + 2$

Snapshot G^3
$t(G^3) = t + 3$

$\tau = 1, L = 2$

Variables impacting unproductive node production rate:

- Volatility threshold τ
- Sliding window length L
- Workload skew s
- Update tx per second

Unproductive index node cleaning, we propose:

- Periodic Garbage Collection (GC)
- Query-Time Pruning (QTP)

Periodic Garbage Collection (GC)

Periodic GC

Main idea:

- Background process
- Periodically traverse index subtree
- Prune any visited unproductive node

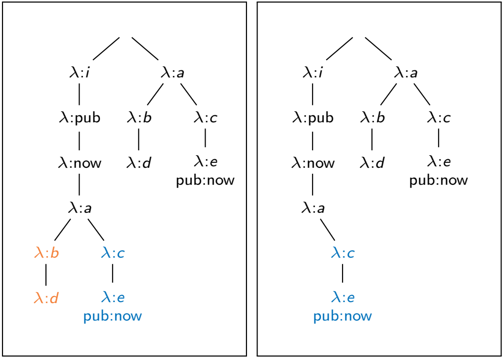
Periodic GC

Algorithm: GarbageCollect

for *node* $n \in$ *desc*$(/i)$ *in postorder tree walk* **do**
  if $chd(n) = \emptyset \wedge \neg matching(n) \wedge \neg volatile(n)$ **then**
    delete node n

Periodic GC

$$G^3 \xrightarrow{T_4} G^4$$



Snapshot G^3
$t(G^3) = t + 3$

Snapshot G^4
$t(G^4) = t + 4$

$\tau = 1, L = 2$

Query-Time Pruning (QTP)

Query-Time Pruning

Main idea:

- Prune unproductive nodes during query execution
- Piggypacking on query execution
- Adds overhead on query runtime

Query-Time Pruning

Algorithm: QueryQTP

Data: Query $Q(k, v, m)$, where k is a property, v a value and m $(= /\lambda_1/\ldots/\lambda_d)$ a content node's path.

Result: A set of nodes satisfying $Q(k, v, m)$

$r \longleftarrow \emptyset$

for *node* $n \in desc(/\imath/\kappa/\upsilon/\lambda_1/\ldots/\lambda_d)$ *in postorder tree walk* **do**

  if $matching(n)$ **then**

    $r \longleftarrow r \cup \{*n\}$

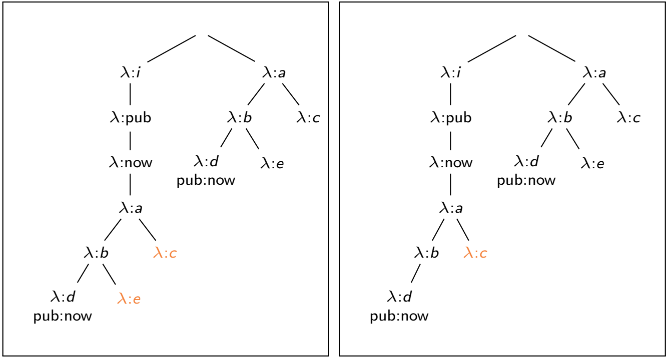
  else if $chd(n) = \emptyset \wedge \neg volatile(n)$ **then**

    delete node n

return r

Query-Time Pruning

$$G^5 \xrightarrow{T_6} G^6$$



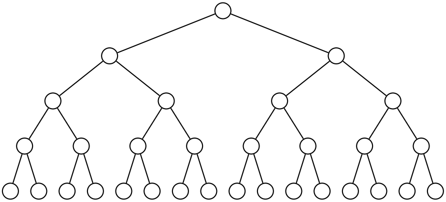
Snapshot G^5 Snapshot G^6

$\tau = 1$, $L = 2$, $Q(\texttt{pub}, \texttt{now}, \texttt{/a/b})$

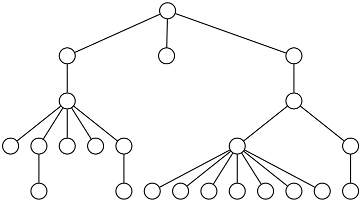
Experimental Evaluation

Datasets

(a) Synthetic



(b) Dell

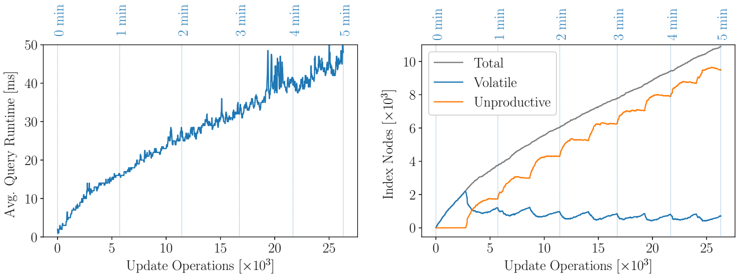


Workload simulation

- Zipf distribution
- Changes every 30 seconds
- 10 update operations per query operation
- Update operation: add and remove an index node

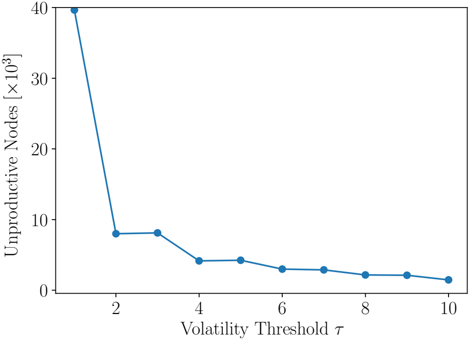
Impact of Unproductive Nodes on Query Runtime

Impact of Unproductive Nodes on Query Runtime

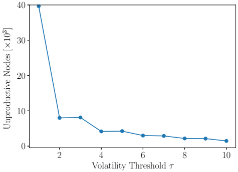


Volatility threshold τ

Volatility threshold τ



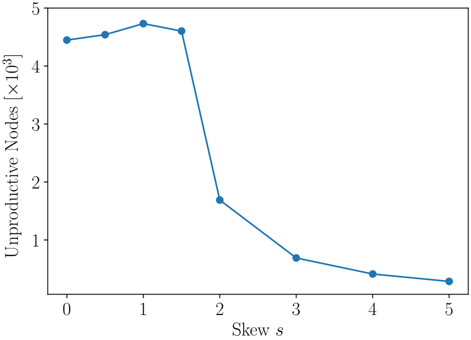
Volatility threshold τ



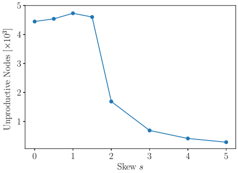
- τ increases $\implies$ nodes are less likely to become volatile
- Fewer volatile nodes $\implies$ fewer unproductive nodes
- Power law relationship between #unproductive nodes and τ

Workload skew s

Workload skew s



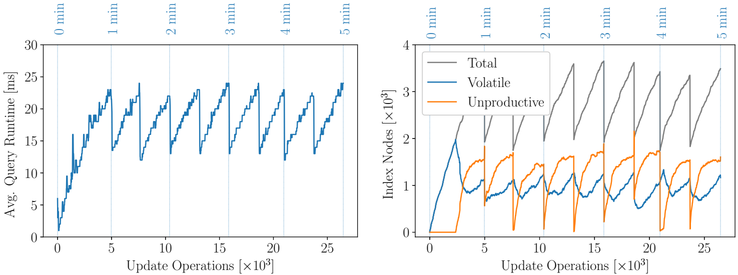
Workload skew s



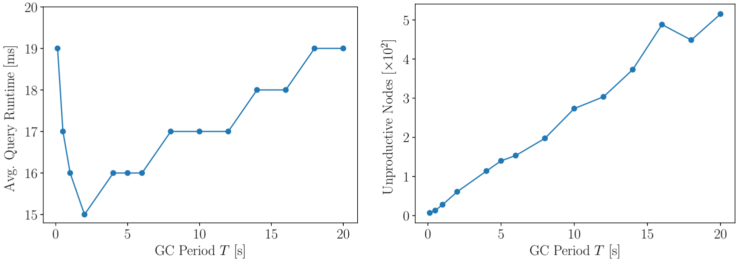
- very high $s \implies$ very small hotspot
- very small s (uniform) $\implies$ no hotspot
- very small/no hotspot $\implies$ nodes are less likely to become volatile and later on unproductive

Periodic Garbage Collection

Periodic GC


0 min
1 min
2 min
3 min
4 min
5 min
Avg. Query Runtime [ms]
Update Operations [×10^3]
Total
Volatile
Unproductive
Index Nodes [×10^3]

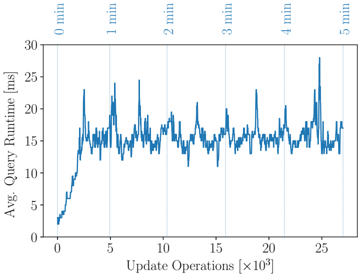
GC period T

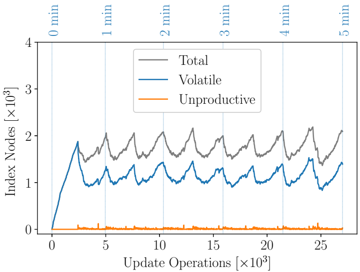


Optimal GC period T^*_{GC}: period with the smallest query runtime

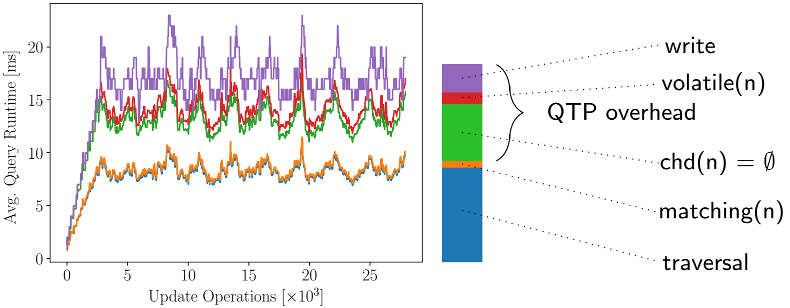
Query-Time Pruning

QTP


0 min
1 min
2 min
3 min
4 min
5 min
Avg. Query Runtime [ms]
Update Operations [×10³]


0 min
1 min
2 min
3 min
4 min
5 min
Total
Volatile
Unproductive
Index Nodes [×10³]
Update Operations [×10³]

QTP


Avg. Query Runtime [ms]
Update Operations [×10³]
0
5
10
15
20
25
write
volatile(n)
QTP overhead
chd(n) = ∅
matching(n)
traversal

QTP

Algorithm: QueryQTP

Data: Query $Q(k, v, m)$, where k is a property, v a value and m $(= /\lambda_1/\dots/\lambda_d)$ a content node's path.

Result: A set of nodes satisfying $Q(k, v, m)$

$r \longleftarrow \emptyset$

for *node* $n \in desc(/\imath/\Bbbk/\upsilon/\lambda_1/\dots/\lambda_d)$ *in postorder tree walk* **do**

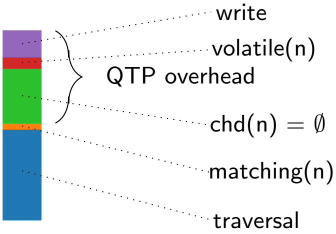
  if $matching(n)$ **then**

    $r \longleftarrow r \cup \{*n\}$

  else if $chd(n) = \emptyset \wedge \neg volatile(n)$ **then**

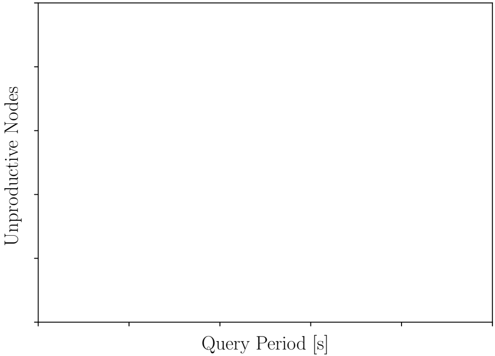
    delete node n

return r

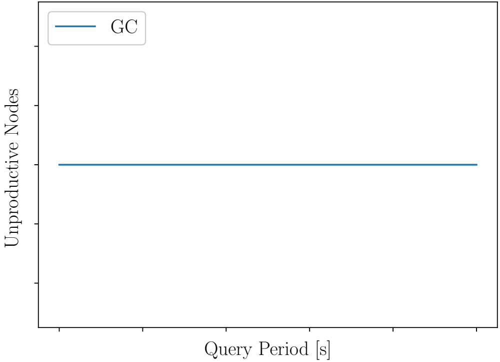


Periodic GC vs. QTP

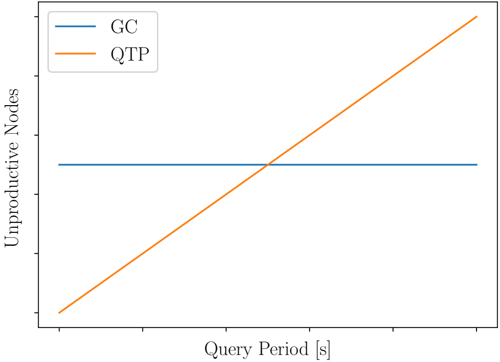
GC vs. QTP, simple model



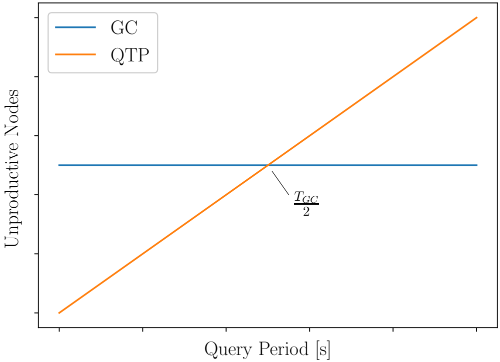
GC vs. QTP, simple model



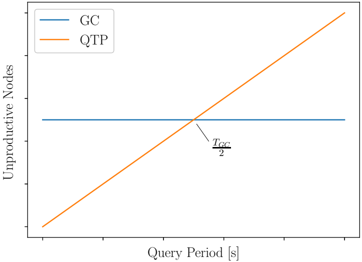
GC vs. QTP, simple model

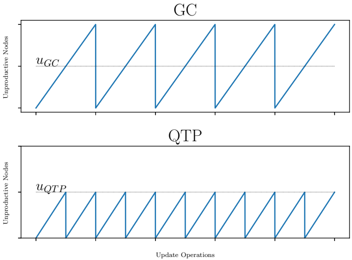


GC vs. QTP, simple model



GC vs. QTP, simple model

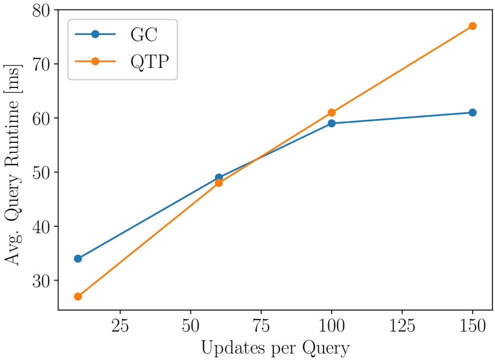




Queries traverse on average the same number of unproductive nodes when using GC or QTP iff the query period T_Q is half the GC period T_{GC}, i.e.,

$$u_{GC} = u_{QTP} \iff T_Q = \frac{T_{GC}}{2}$$

GC vs. QTP


GC
QTP
Avg. Query Runtime [ms]
Updates per Query
80
70
60
50
40
30
25
50
75
100
125
150

Conclusion

Unproductive Nodes

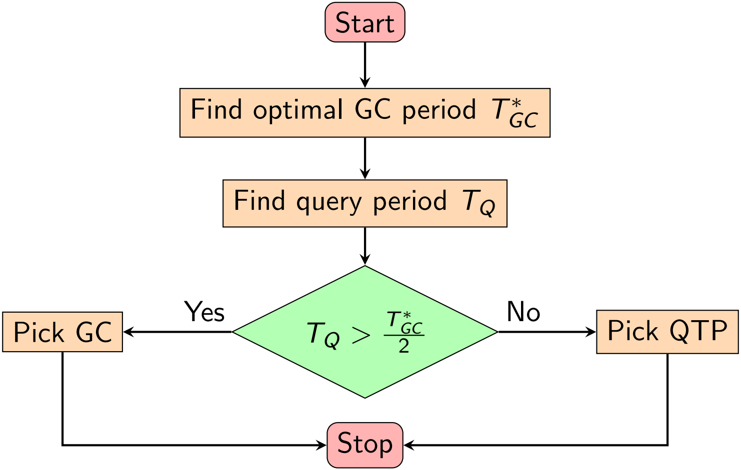
- greater volatility threshold $\tau \implies$ fewer unproductive nodes
- greater sliding window length $L \implies$ more unproductive nodes
- (very) high/low workload skew $s \implies$ fewer unproductive nodes
- more updates per second $\implies$ more unproductive nodes

GC

- Fewer unproductive nodes $\implies$ faster queries
- Sawtooth pattern
- Slows down system if run too often

QTP

- Faster and more stable than GC when queries are frequent
- Adds overhead to queries
- Overhead negligible in the long-term


Start
Find optimal GC period T^*_{GC}
Find query period T_Q
$T_Q > \frac{T^*_{GC}}{2}$
Yes
No
Pick GC
Pick QTP
Stop

Future Work

Future Work

- Concurrency control
- Frequently changing query filter
- Unproductive node production rate

References

WELLENZOHN, K., BÖHLEN, M., HELMER, S., REUTEGGER, M., AND SAKR, S.
A Workload-Aware Index for Tree-Structured Data.
To be published.