Evaluation of Pointer Swizzling Techniques for DBMS Buffer Management

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Pointer Swizzling as in “In-Memory Performance for Big Data”

Subsection 1

Locate Pages in the Buffer Pool without Pointer Swizzling

Overview of Search Strategies ([HR01])

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Search Strategy

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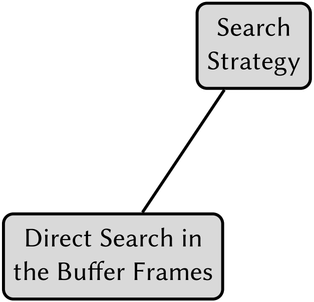

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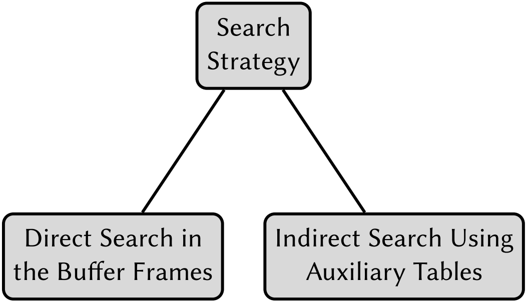
Search Strategy
Direct Search in the Buffer Frames
Indirect Search Using Auxiliary Tables

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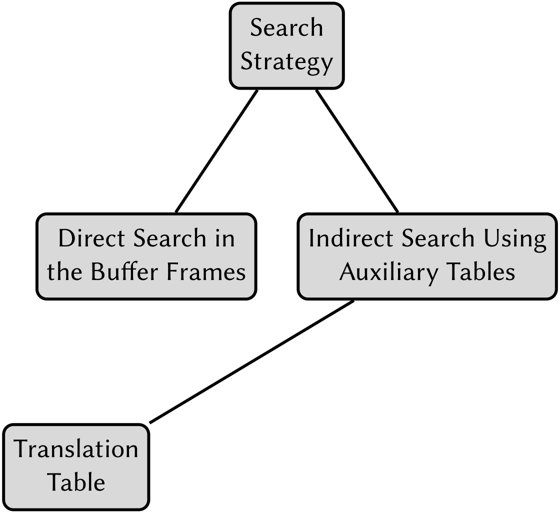
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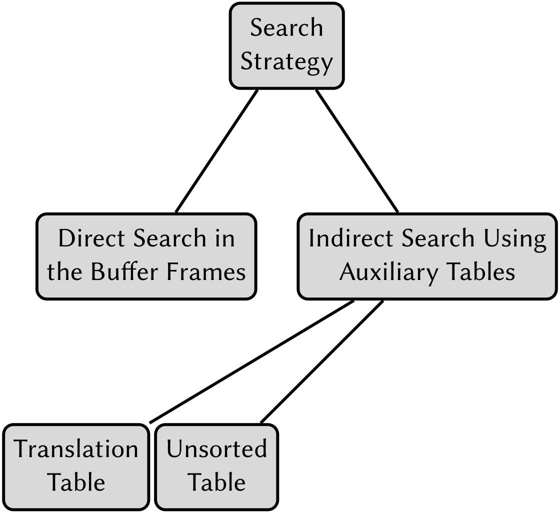
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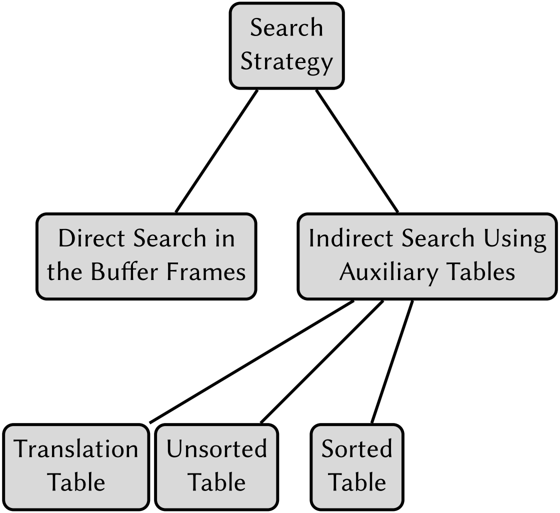
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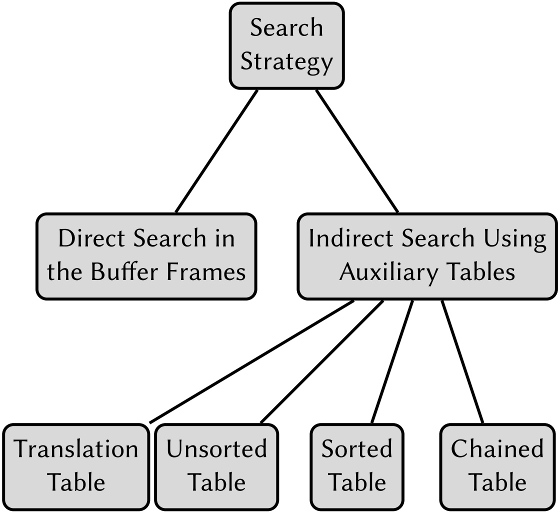
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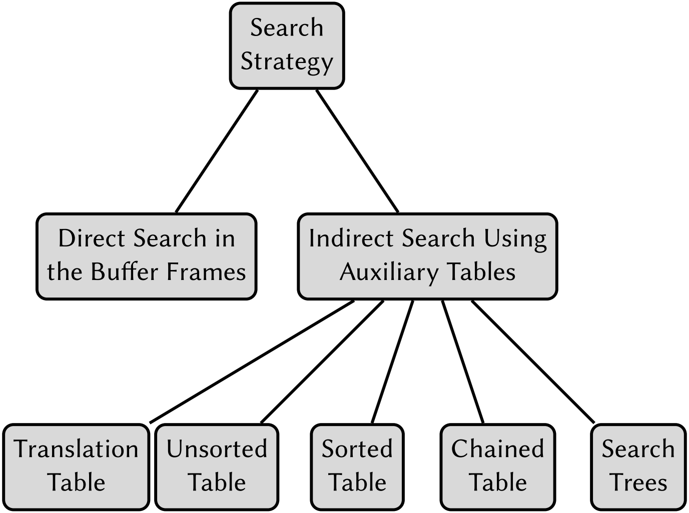

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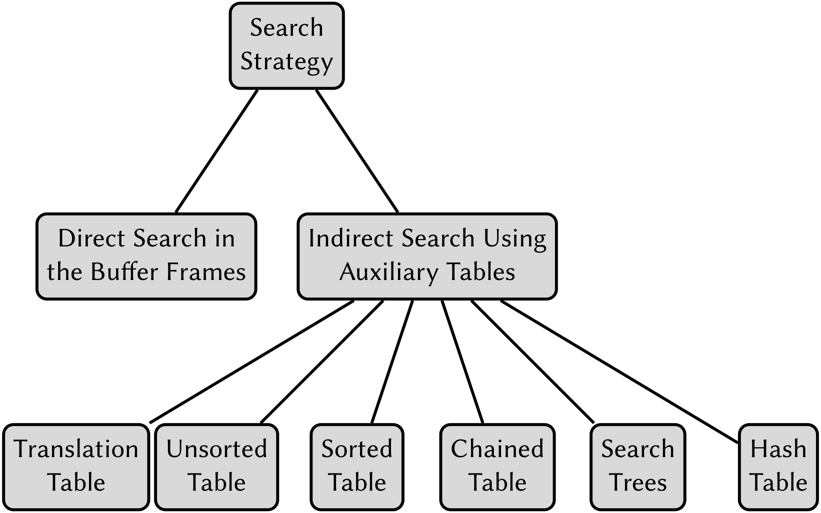

Direct Search in the Buffer Frames & Unsorted Table

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Unsorted Table

- Auxiliary data structure of size $S_{\text{pace}} \in \mathcal{O}\left(n\right)$

0	1	2	3	4	5	6	7	8
7785	**6977**	**4347**	**3380**	**5610**	**6376**	**4877**	**3332**	**3354**

Figure: An unsorted table used to map buffer frames to page IDs.

Direct Search in the Buffer Frames & Unsorted Table

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Translation Table

Translation Table

- Auxiliary data structure with one entry per page in the database
  $\Longrightarrow \; S_{\text{pace}} \in \mathcal{O}\left(p\right)$

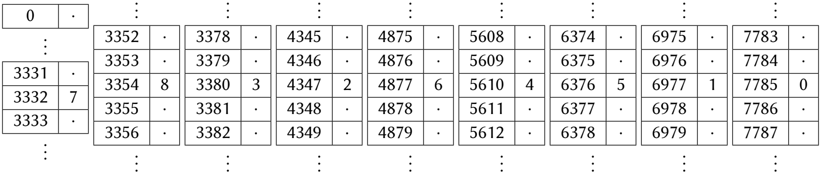
0	·
⋮	
3331	·
3332	7
3333	·
⋮	

⋮		⋮		⋮		⋮		⋮		⋮		⋮		⋮	
3352	·	3378	·	4345	·	4875	·	5608	·	6374	·	6975	·	7783	·
3353	·	3379	·	4346	·	4876	·	5609	·	6375	·	6976	·	7784	·
3354	8	3380	3	4347	2	4877	6	5610	4	6376	5	6977	1	7785	0
3355	·	3381	·	4348	·	4878	·	5611	·	6377	·	6978	·	7786	·
3356	·	3382	·	4349	·	4879	·	5612	·	6378	·	6979	·	7787	·
⋮		⋮		⋮		⋮		⋮		⋮		⋮		⋮	

Figure: A translation table used to map page IDs to buffer frames.

Translation Table

- Auxiliary data structure with one entry per page in the database $\Longrightarrow\ S_{\text{pace}} \in \mathcal{O}(p)$
- $T^{\text{search}} \in \mathcal{O}(1)$, $T^{\text{insert}} \in \mathcal{O}(1)$



0	·
⋮	
3331	·
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⋮		⋮		⋮		⋮		⋮		⋮		⋮		⋮	
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Sorted & Chained Table

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- Auxiliary data structure using a table sorted by page ID only containing cached pages

3332	**3354**	**3380**	**4347**	**4877**	**5610**	**6376**	**6977**	**7785**
→ **7**	→ **8**	→ **3**	→ **2**	→ **6**	→ **4**	→ **5**	→ **1**	→ **0**

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3332	**3354**	**3380**	**4347**	**4877**	**5610**	**6376**	**6977**	**7785**
$\rightarrow$ **7**	$\rightarrow$ **8**	$\rightarrow$ **3**	$\rightarrow$ **2**	$\rightarrow$ **6**	$\rightarrow$ **4**	$\rightarrow$ **5**	$\rightarrow$ **1**	$\rightarrow$ **0**

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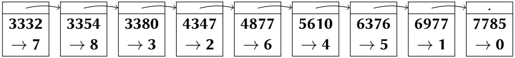
- Auxiliary data structure using a linked list sorted by page ID only containing cached pages



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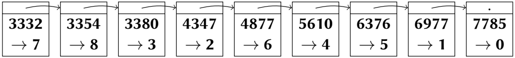

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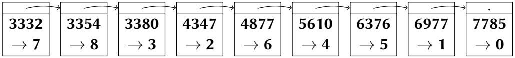
- $T_{\text{avg}}^{\text{search}} \in \mathcal{O}\left(\log_2 n\right)$, $T_{\text{avg}}^{\text{insert}} \in \mathcal{O}\left(\log_2 n\right)$
- Binary search requires more links!



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Search Trees

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- Auxiliary data structure is similar to the one of the chained table

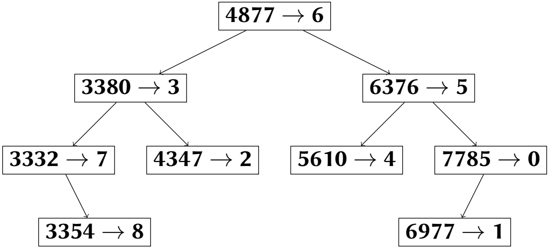
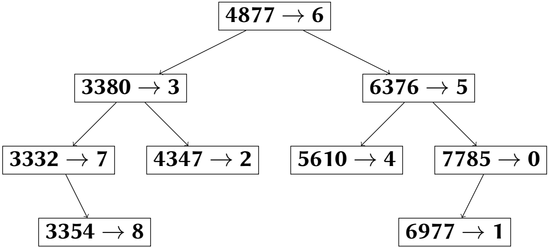


Figure: A balanced search tree used to map page IDs to buffer frames.

Search Trees

- Auxiliary data structure is similar to the one of the chained table
- Many different data structures like AVL-trees, red–black trees or splay trees can be used



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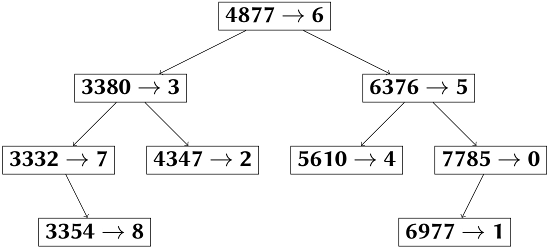

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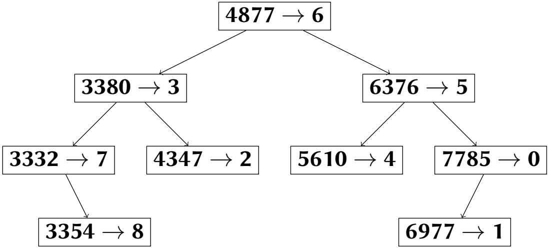
- $T_{\text{avg}}^{\text{search}} \in \mathcal{O}(\log n)$, $T_{\text{avg}}^{\text{insert}} \in \mathcal{O}(\log n)$
- The worst case costs and the worst cases vary between the different search tree data structures



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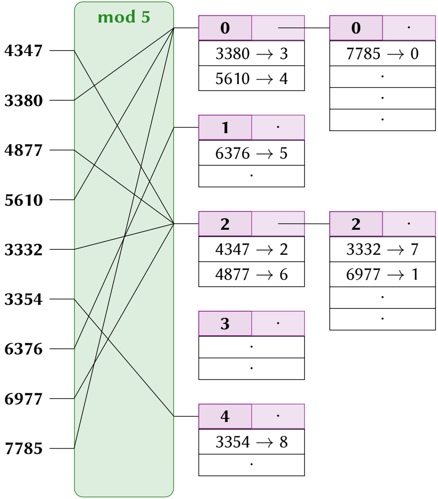
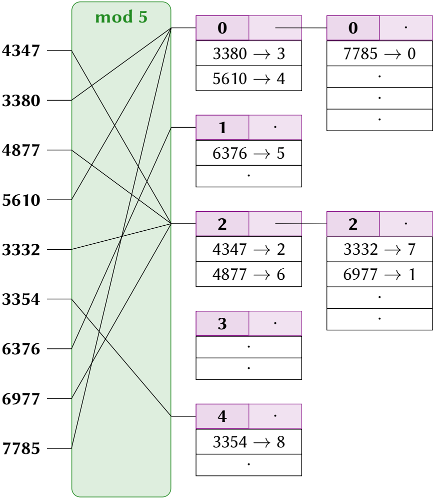
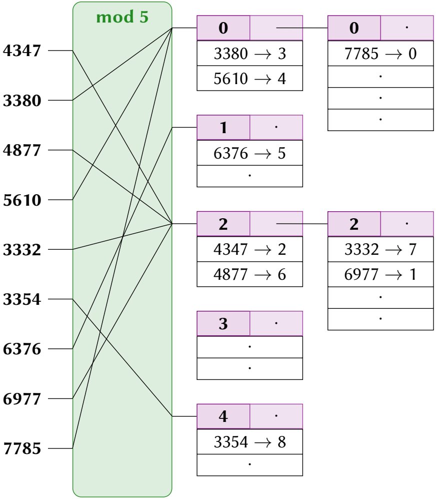

mod 5
4347
3380
4877
5610
3332
3354
6376
6977
7785
0
3380 → 3
5610 → 4
0
7785 → 0
1
6376 → 5
2
4347 → 2
4877 → 6
2
3332 → 7
6977 → 1
3
4
3354 → 8

Hash Table



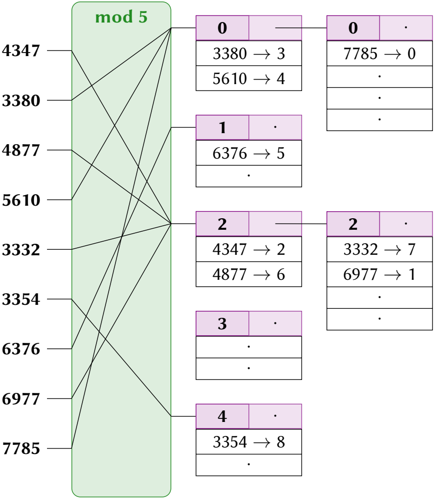
- Each page ID is mapped to a hash bucket using a hash function

Hash Table



- Each page ID is mapped to a hash bucket using a hash function
- Only the page IDs of buffered pages are in the hash table

Hash Table



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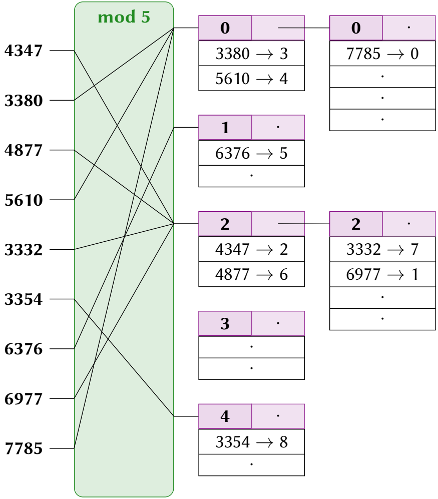

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- $T_{\text{avg}}^{\text{search}} \in \mathcal{O}(1)$, $T_{\text{avg}}^{\text{insert}} \in \mathcal{O}(1)$, $T_{\text{worst}}^{\text{search}} \in \mathcal{O}(n)$

Locate Pages in Buffer Pool with Hash Table ([Gra+14])

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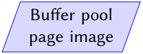
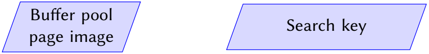


Buffer pool page image

Locate Pages in Buffer Pool with Hash Table ([Gra+14])


Buffer pool page image

Search key

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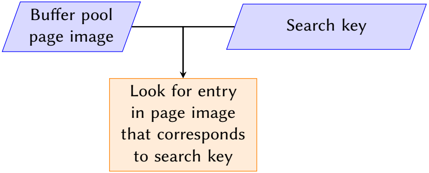

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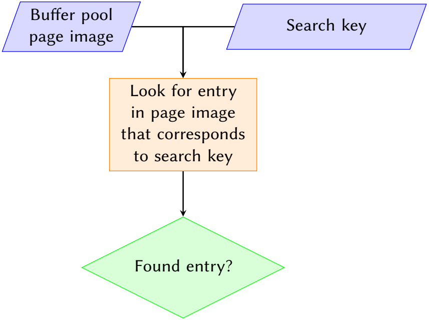

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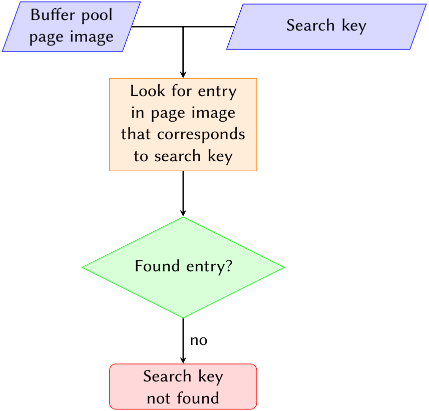

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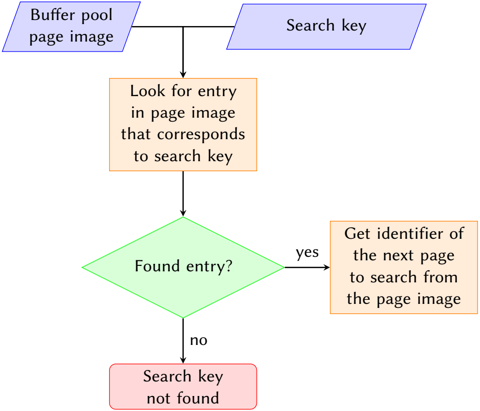
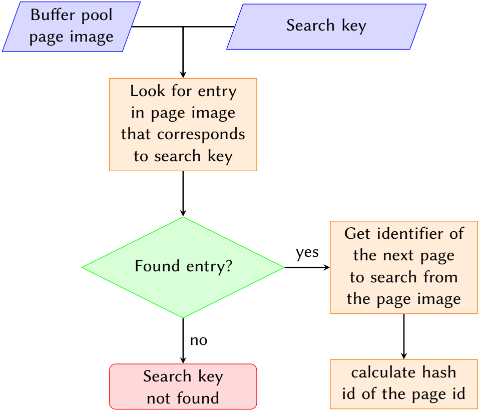

Buffer pool page image
Search key
Look for entry in page image that corresponds to search key
Found entry?
yes
Get identifier of the next page to search from the page image
no
Search key not found

Locate Pages in Buffer Pool with Hash Table ([Gra+14])


Buffer pool page image

Search key

Look for entry in page image that corresponds to search key

Found entry?

yes

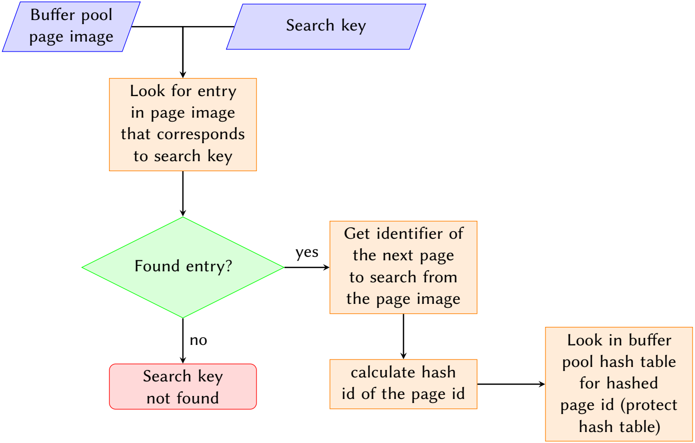
Get identifier of the next page to search from the page image

calculate hash id of the page id

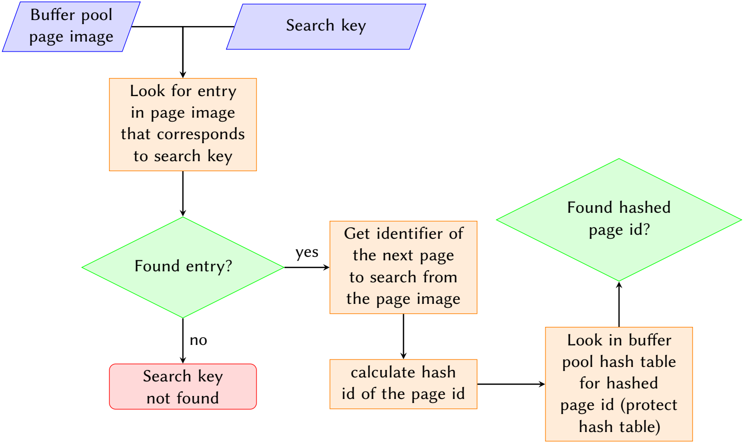
no

Search key not found

Locate Pages in Buffer Pool with Hash Table ([Gra+14])


Buffer pool page image
Search key
Look for entry in page image that corresponds to search key
Found entry?
yes
Get identifier of the next page to search from the page image
no
Search key not found
calculate hash id of the page id
Look in buffer pool hash table for hashed page id (protect hash table)

Locate Pages in Buffer Pool with Hash Table ([Gra+14])


Buffer pool page image
Search key
Look for entry in page image that corresponds to search key
Found entry?
yes
no
Search key not found
Get identifier of the next page to search from the page image
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Found hashed page id?

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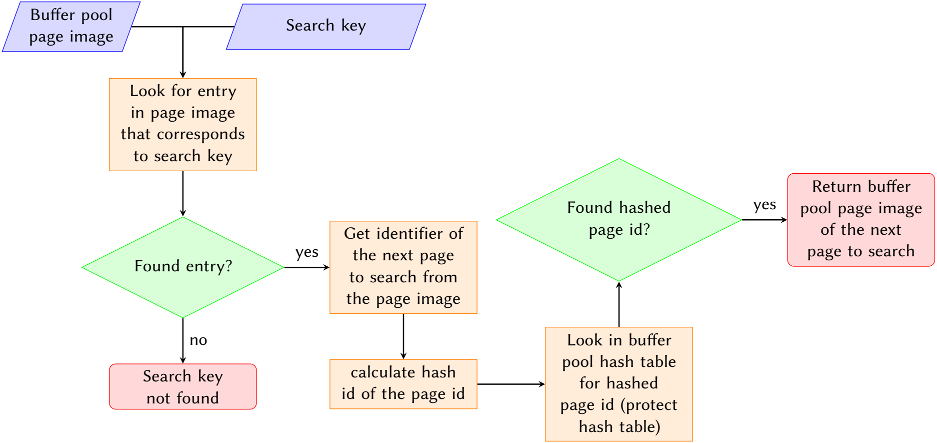
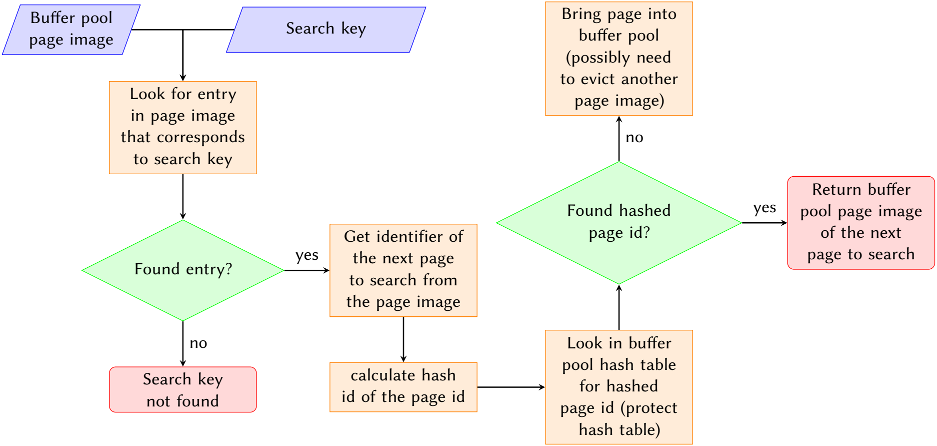
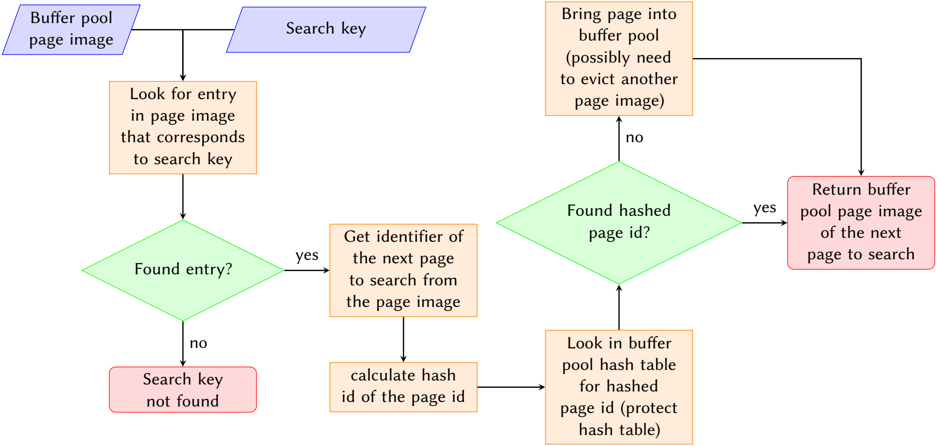

Buffer pool page image
Search key
Look for entry in page image that corresponds to search key
Found entry?
no
Search key not found
yes
Get identifier of the next page to search from the page image
calculate hash id of the page id
Look in buffer pool hash table for hashed page id (protect hash table)
Found hashed page id?
yes
Return buffer pool page image of the next page to search

Locate Pages in Buffer Pool with Hash Table ([Gra+14])


Buffer pool page image
Search key
Look for entry in page image that corresponds to search key
Found entry?
yes
no
Search key not found
Get identifier of the next page to search from the page image
calculate hash id of the page id
Look in buffer pool hash table for hashed page id (protect hash table)
Found hashed page id?
no
Bring page into buffer pool (possibly need to evict another page image)
yes
Return buffer pool page image of the next page to search

Locate Pages in Buffer Pool with Hash Table ([Gra+14])


Buffer pool page image
Search key
Look for entry in page image that corresponds to search key
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no
Search key not found
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Get identifier of the next page to search from the page image
calculate hash id of the page id
Look in buffer pool hash table for hashed page id (protect hash table)
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no
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Return buffer pool page image of the next page to search

Subsection 2

Locate Pages in the Buffer Pool with Pointer Swizzling

Pointer Swizzling

Definition

To swizzle a pointer means to transform the address of the persistent object referenced there to a more direct address of the transient object in a way that this transformation could be used during multiple indirections of this pointer ([Mos92]).

Classification of the Pointer Swizzling Approach following [WD95]

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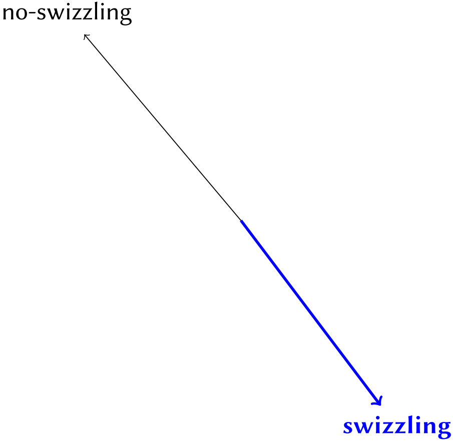
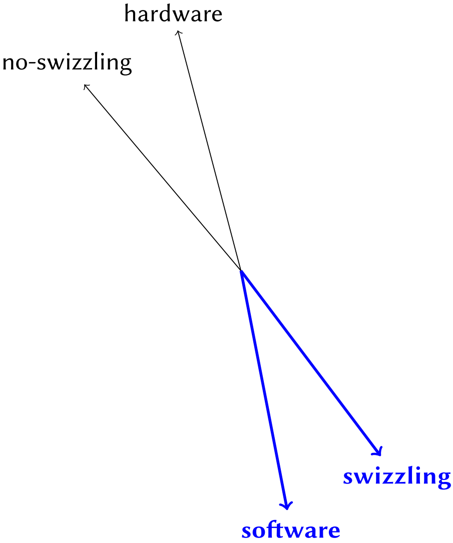
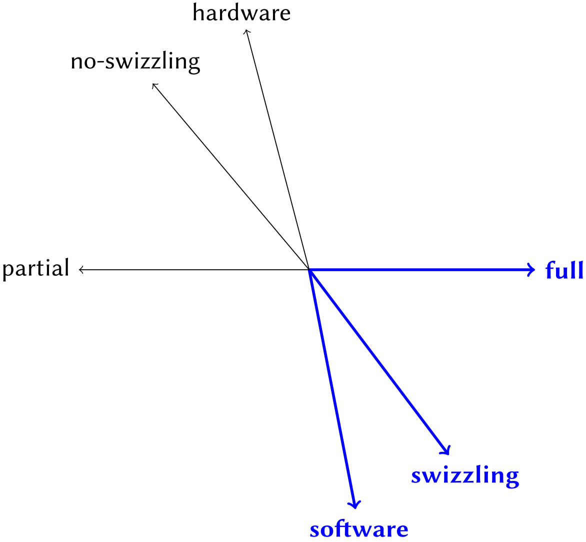


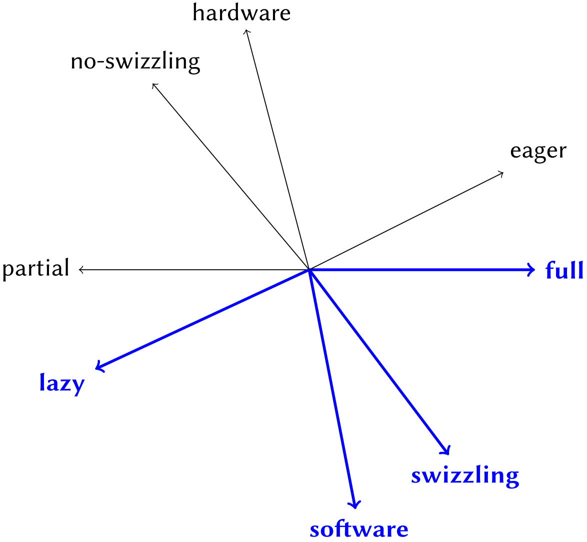
Classification of the Pointer Swizzling Approach following [WD95]



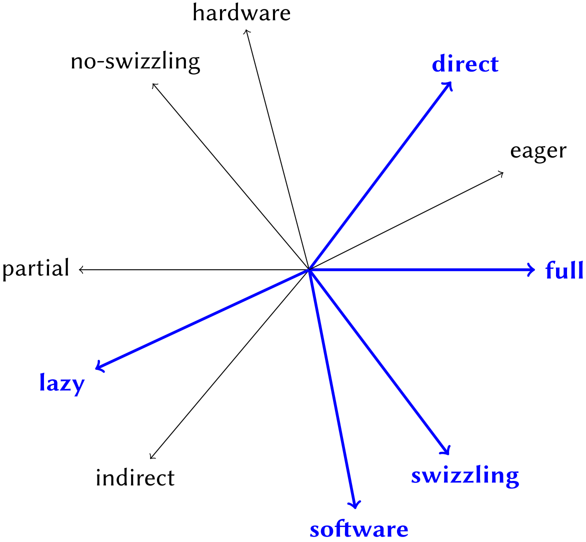
Classification of the Pointer Swizzling Approach following [WD95]



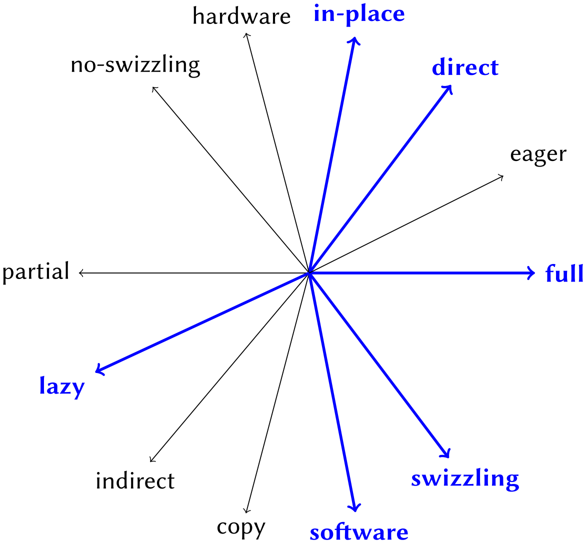
Classification of the Pointer Swizzling Approach following [WD95]



Classification of the Pointer Swizzling Approach following [WD95]



Classification of the Pointer Swizzling Approach following [WD95]



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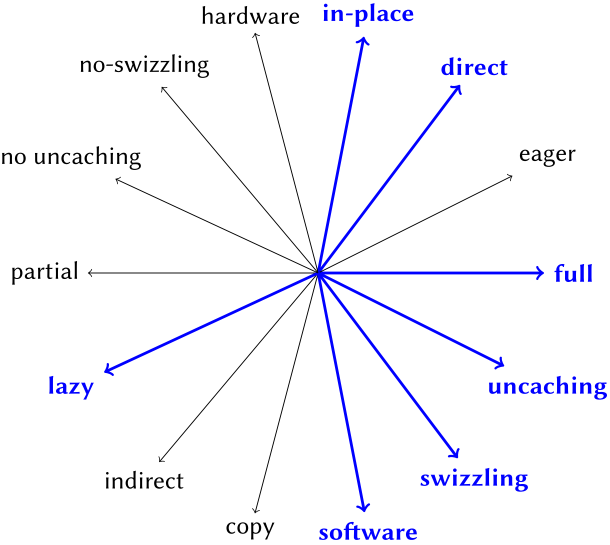
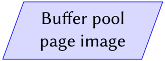


Locate Pages in Buffer Pool w/ Pointer Swizzling ([Gra+14])

Locate Pages in Buffer Pool w/ Pointer Swizzling ([Gra+14])



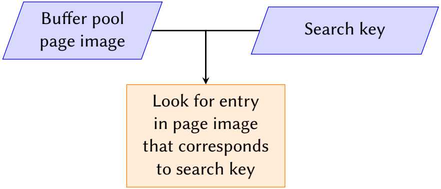
Buffer pool page image

Locate Pages in Buffer Pool w/ Pointer Swizzling ([Gra+14])

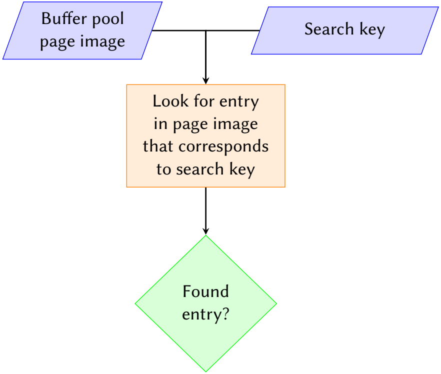
Buffer pool page image

Search key

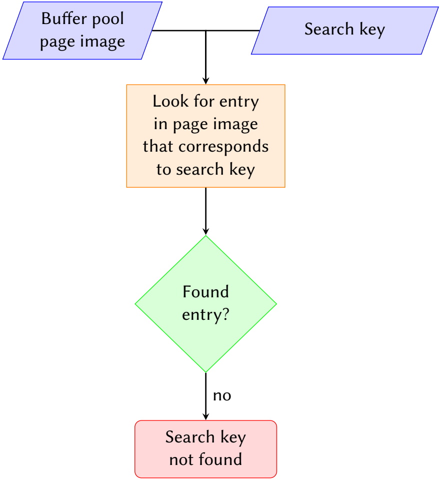
Locate Pages in Buffer Pool w/ Pointer Swizzling ([Gra+14])



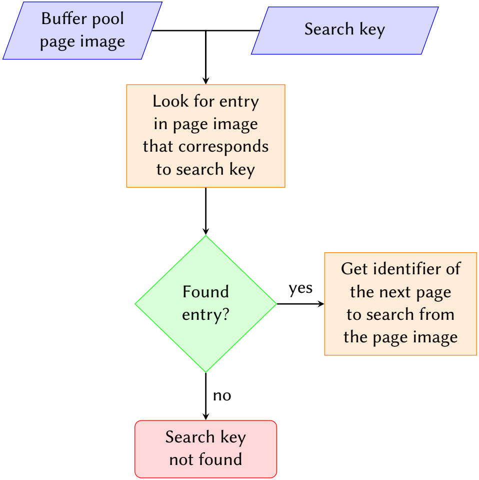
Locate Pages in Buffer Pool w/ Pointer Swizzling ([Gra+14])



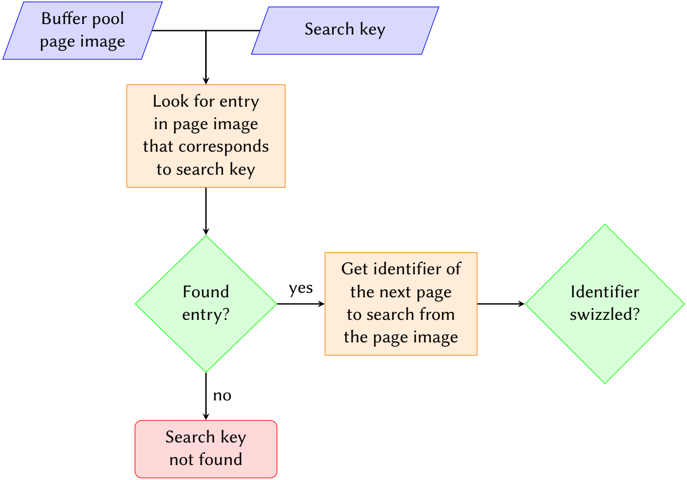
Locate Pages in Buffer Pool w/ Pointer Swizzling ([Gra+14])



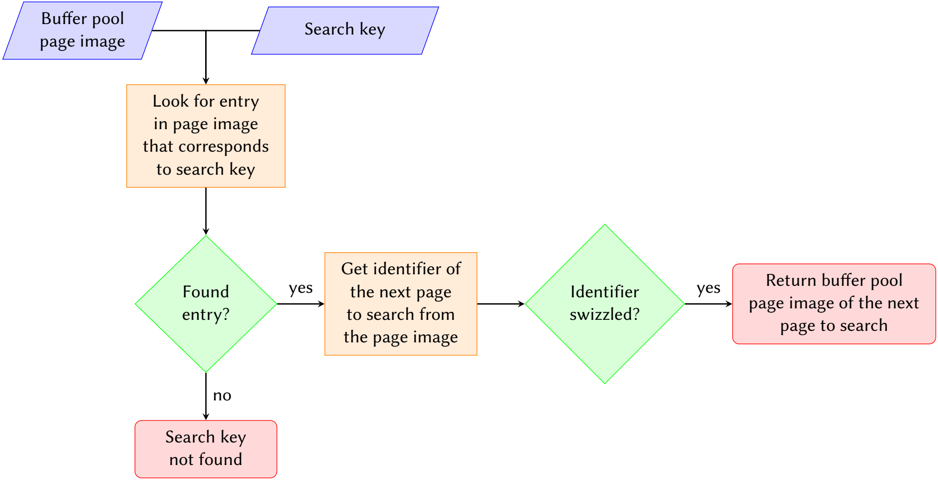
Locate Pages in Buffer Pool w/ Pointer Swizzling ([Gra+14])


Buffer pool page image
Search key
Look for entry in page image that corresponds to search key
Found entry?
yes
Get identifier of the next page to search from the page image
no
Search key not found

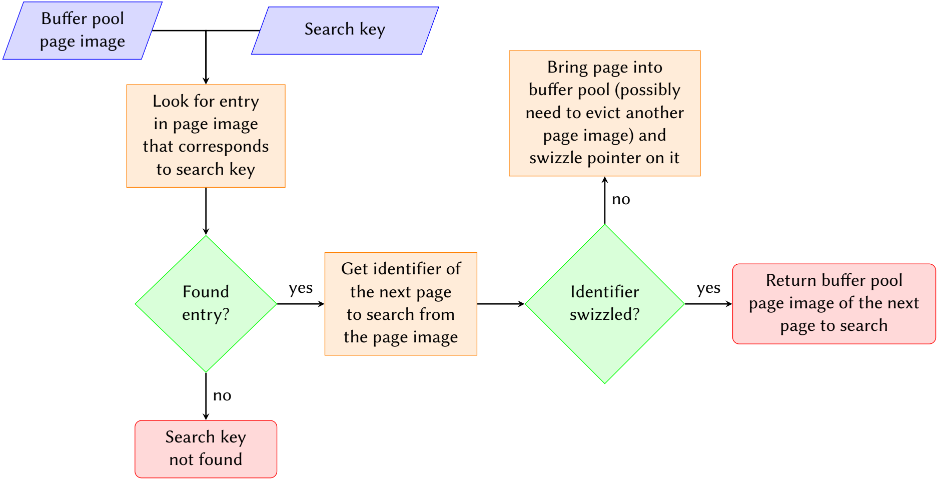
Locate Pages in Buffer Pool w/ Pointer Swizzling ([Gra+14])


Buffer pool page image
Search key
Look for entry in page image that corresponds to search key
Found entry?
yes
Get identifier of the next page to search from the page image
Identifier swizzled?
no
Search key not found

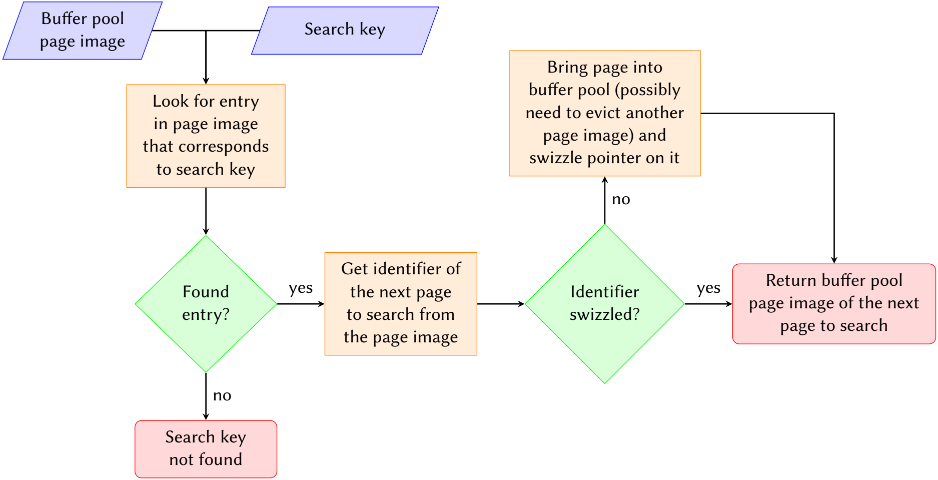
Locate Pages in Buffer Pool w/ Pointer Swizzling ([Gra+14])


Buffer pool page image
Search key
Look for entry in page image that corresponds to search key
Found entry?
yes
no
Search key not found
Get identifier of the next page to search from the page image
Identifier swizzled?
yes
Return buffer pool page image of the next page to search

Locate Pages in Buffer Pool w/ Pointer Swizzling ([Gra+14])


Buffer pool page image
Search key
Look for entry in page image that corresponds to search key
Found entry?
yes
no
Search key not found
Get identifier of the next page to search from the page image
Identifier swizzled?
no
Bring page into buffer pool (possibly need to evict another page image) and swizzle pointer on it
yes
Return buffer pool page image of the next page to search

Locate Pages in Buffer Pool w/ Pointer Swizzling ([Gra+14])


Buffer pool page image
Search key
Look for entry in page image that corresponds to search key
Found entry?
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no
Search key not found
Get identifier of the next page to search from the page image
Identifier swizzled?
no
Bring page into buffer pool (possibly need to evict another page image) and swizzle pointer on it
yes
Return buffer pool page image of the next page to search

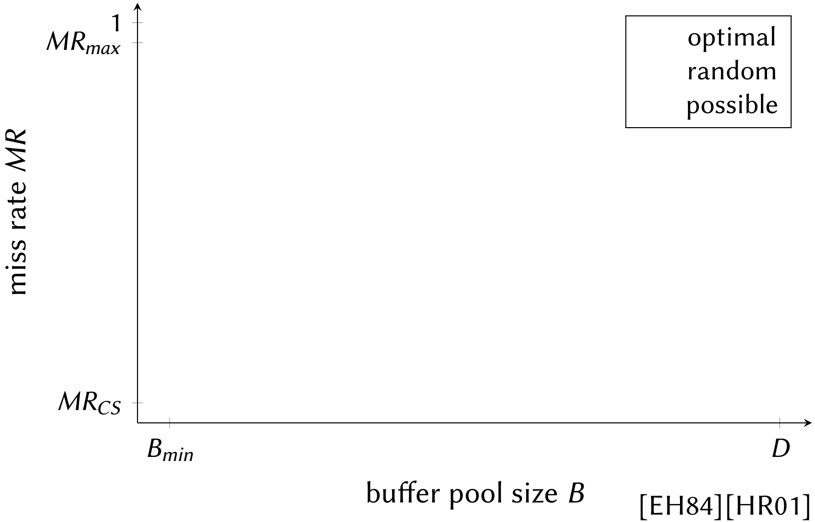
Section 2

Performance Evaluation of the Buffer Management Utilizing Pointer Swizzling

Subsection 1

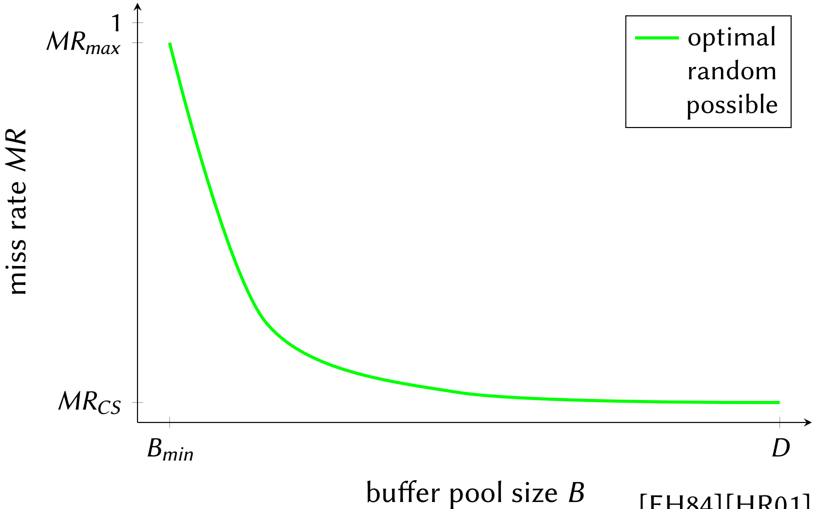
Expected Performance

Performance of Different Buffer Pool Sizes



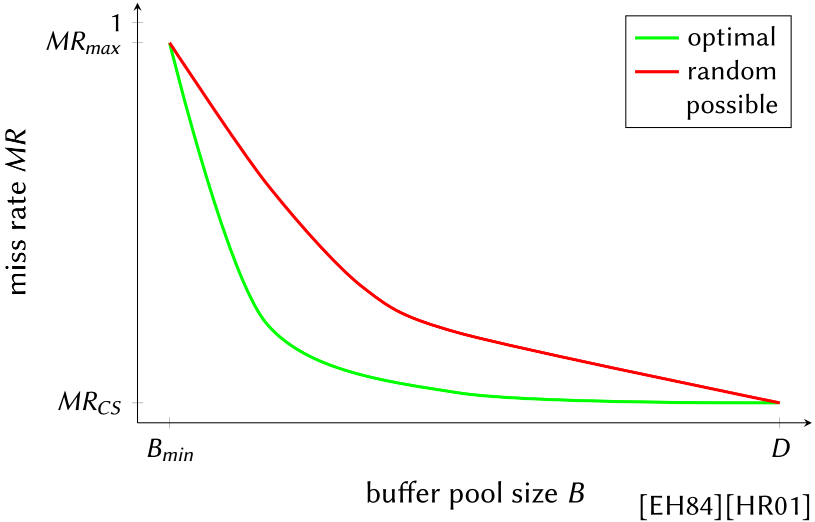
[EH84][HR01]

Performance of Different Buffer Pool Sizes



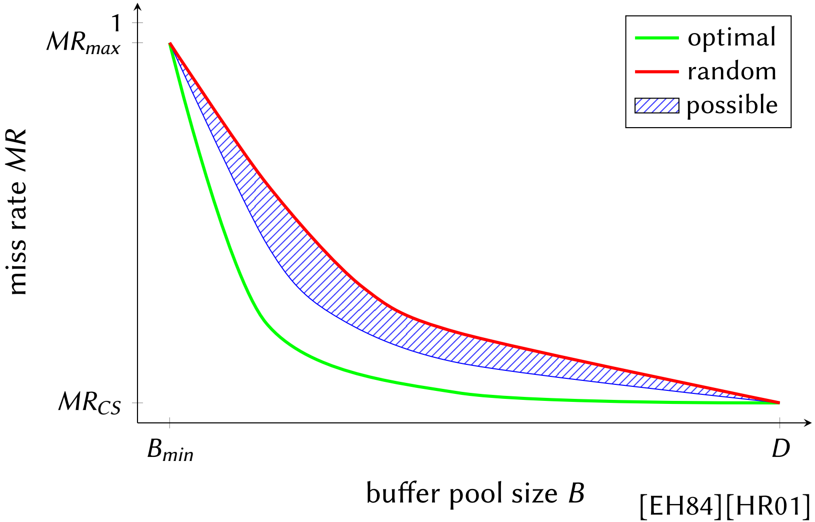
[EH84][HR01]

Performance of Different Buffer Pool Sizes



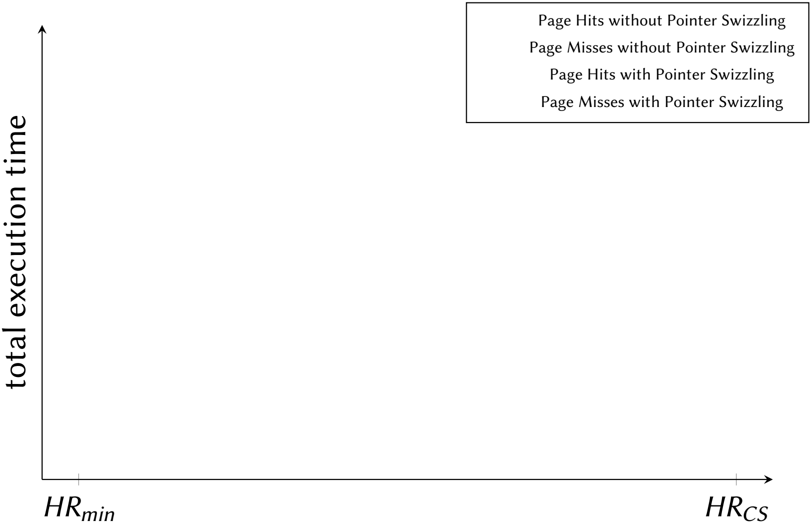
[EH84][HR01]

Performance of Different Buffer Pool Sizes

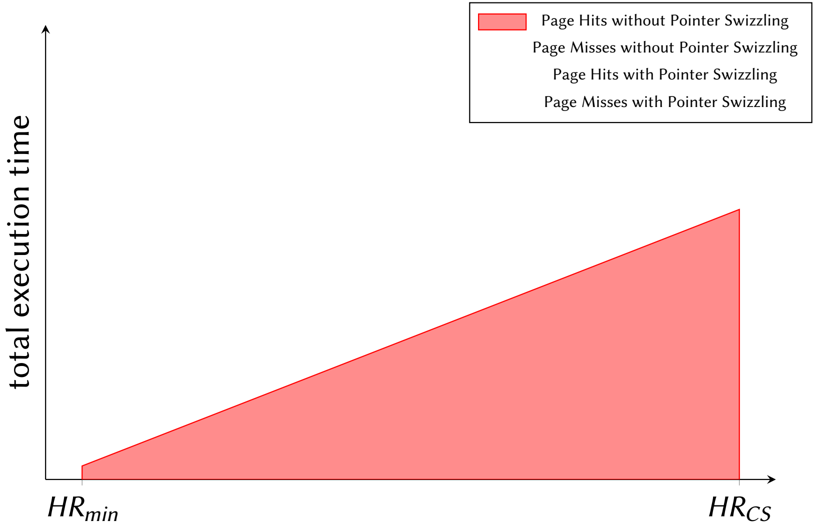


[EH84][HR01]

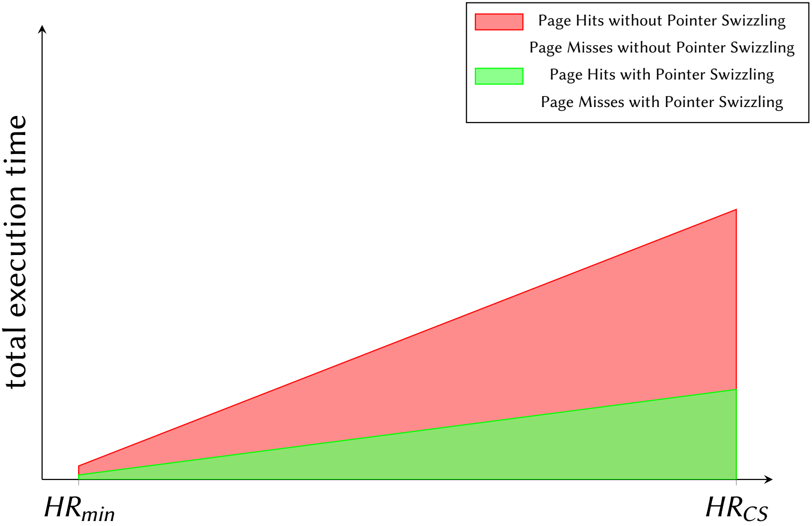
Buffer Management with and without Pointer Swizzling



Buffer Management with and without Pointer Swizzling



Buffer Management with and without Pointer Swizzling



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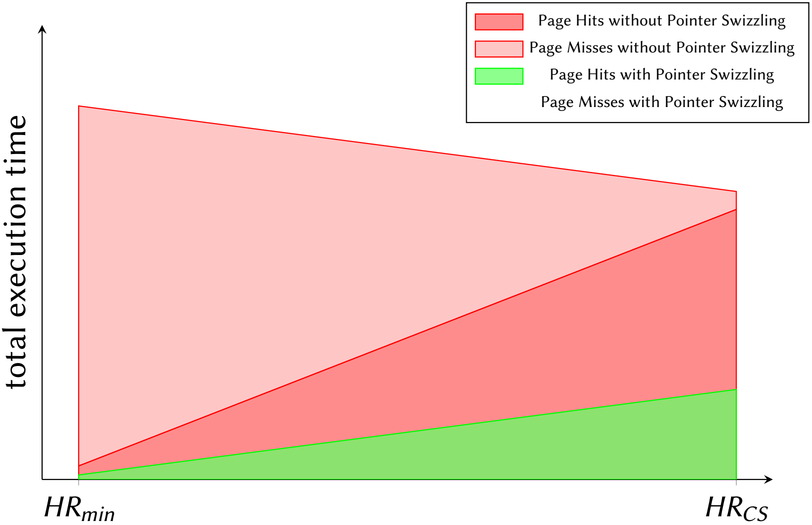
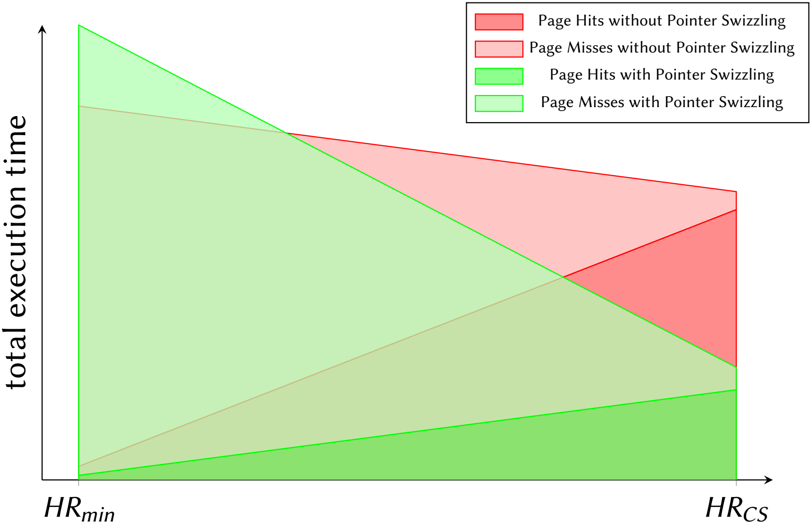
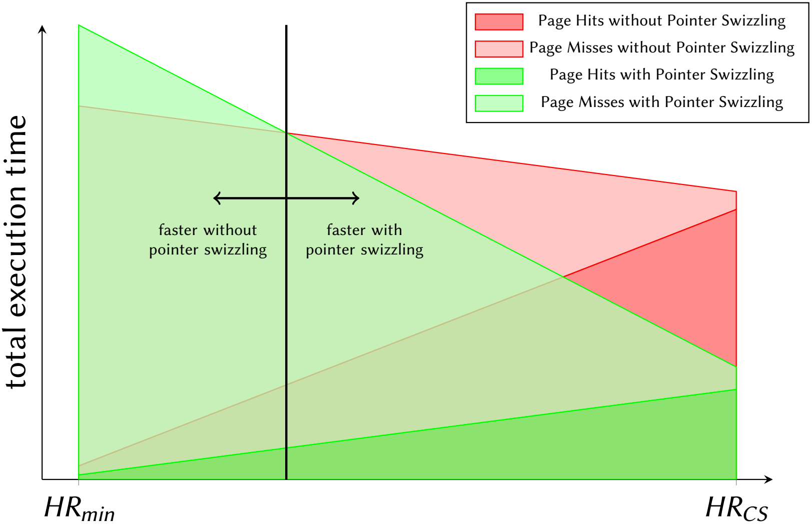


Buffer Management with and without Pointer Swizzling



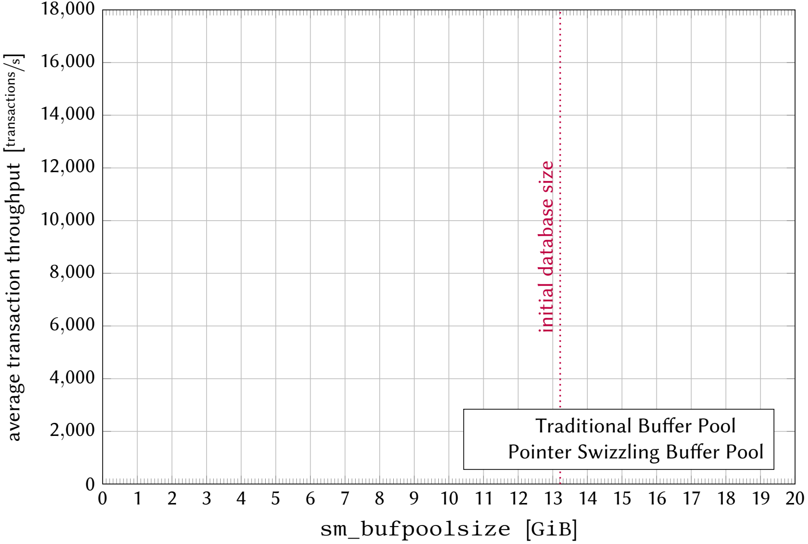
Buffer Management with and without Pointer Swizzling



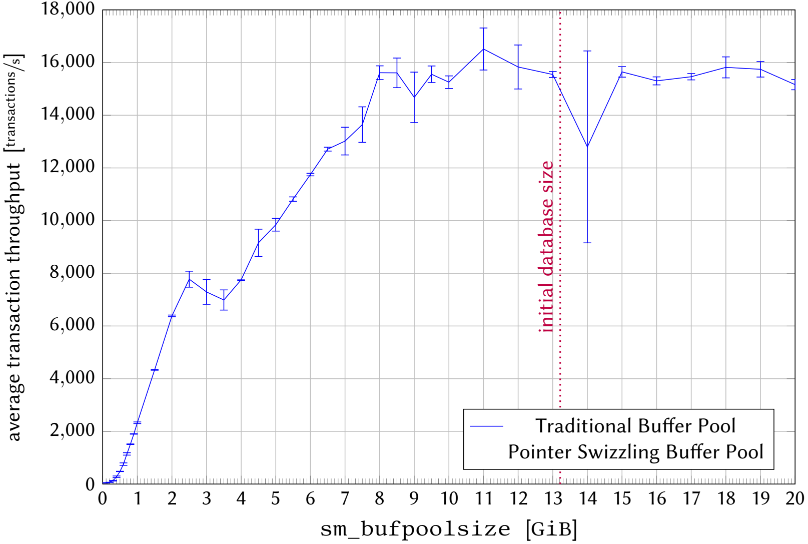
Subsection 2

Measured Performance

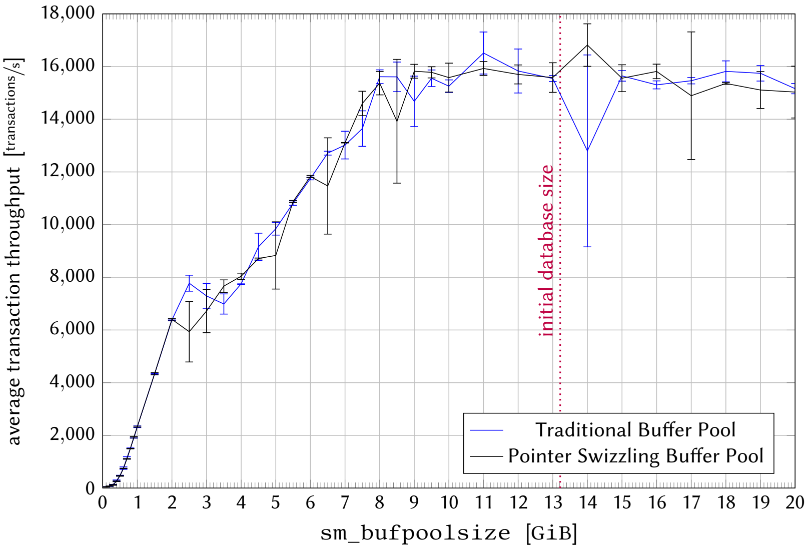
Transaction Throughput (TPC-C)



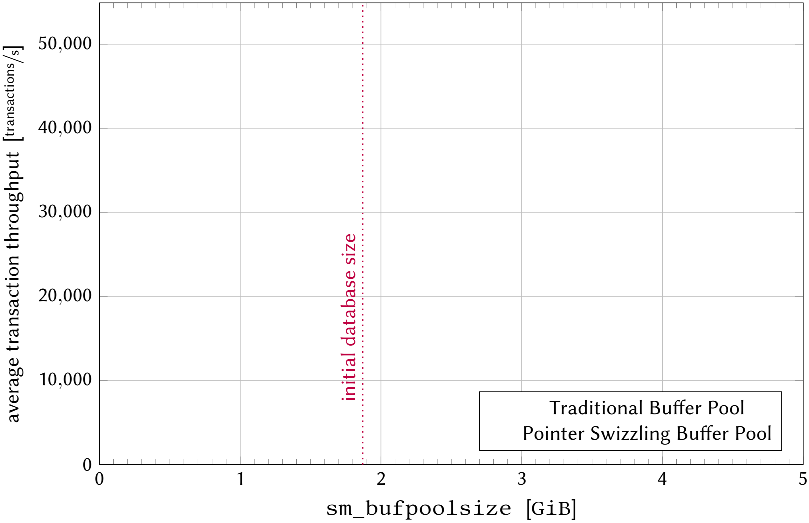
Transaction Throughput (TPC-C)



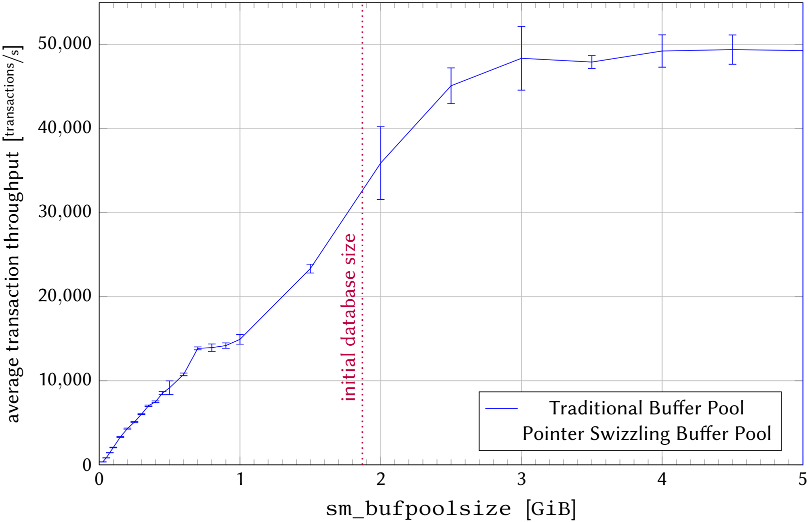
Transaction Throughput (TPC-C)



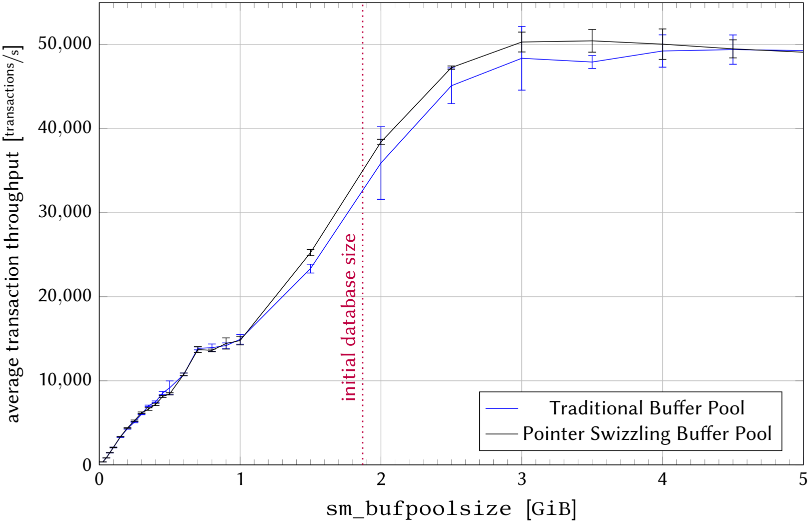
Transaction Throughput (TPC-B)



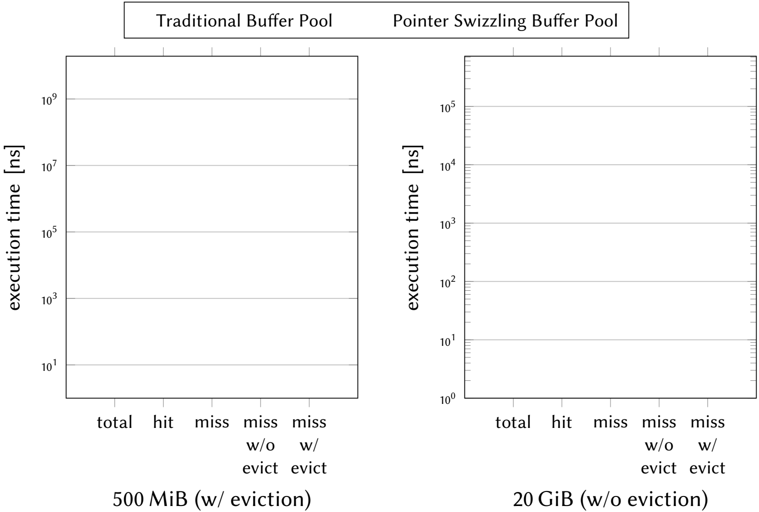
Transaction Throughput (TPC-B)



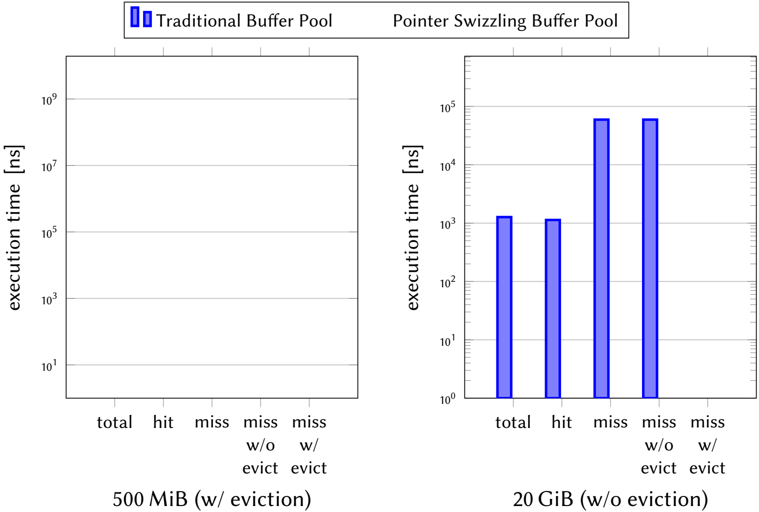
Transaction Throughput (TPC-B)



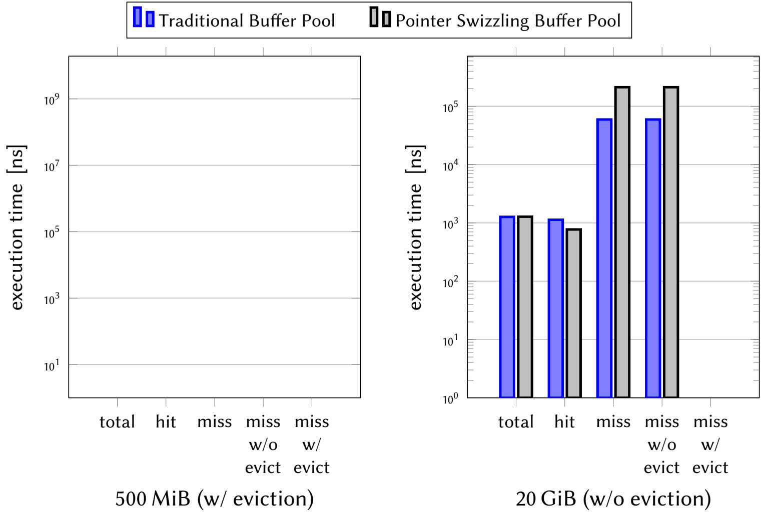
Buffer Pool Performance Acquiring Shared Latches



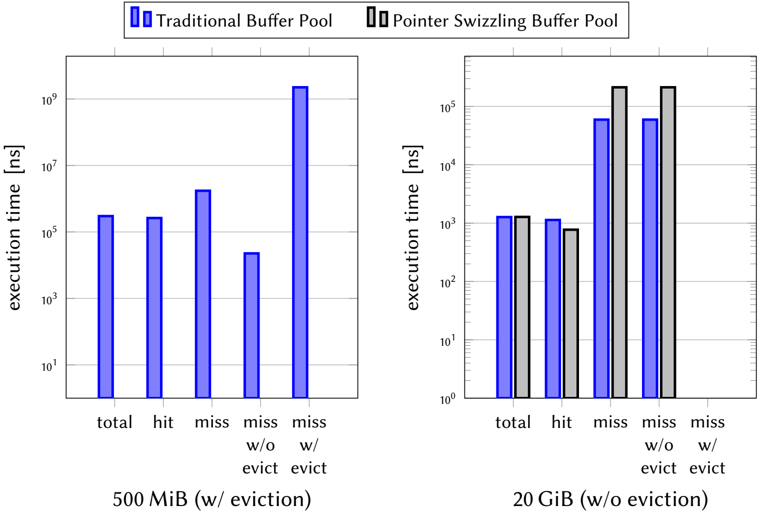
Buffer Pool Performance Acquiring Shared Latches



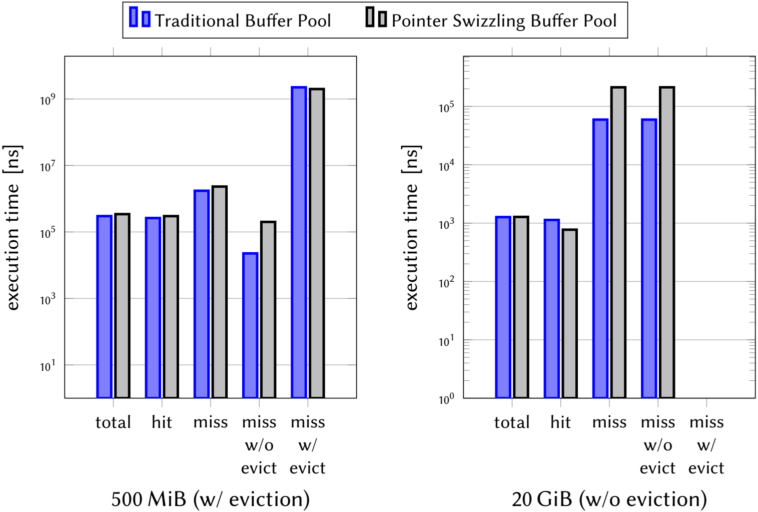
Buffer Pool Performance Acquiring Shared Latches



Buffer Pool Performance Acquiring Shared Latches



Buffer Pool Performance Acquiring Shared Latches



Subsection 3

Conclusion

Conclusion

Conclusion

Overall Performance

Conclusion

Overall Performance

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Conclusion

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Buffer Pool Performance

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Buffer Pool Performance

- A page hit is faster when pointer swizzling is activated.

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- A page hit is faster when pointer swizzling is activated.
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Buffer Pool Performance

- A page hit is faster when pointer swizzling is activated.
- A page miss is slower when pointer swizzling is activated.
- After the cold start phase, activated pointer swizzling will improve the buffer pool performance for large buffer pools.

Section 3

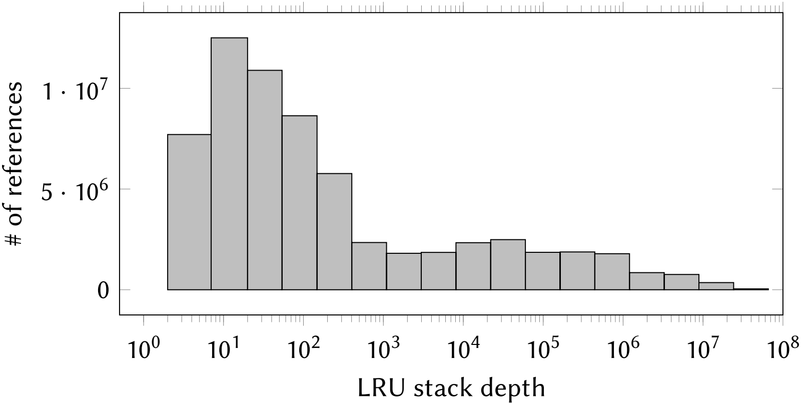
Page Eviction Strategies in the Context of Pointer Swizzling

Motivation not to Analyze Different Page Eviction Strategies

Motivation not to Analyze Different Page Eviction Strategies

- Even LRU results in decent hit rates

TPC-C with Warehouses: 100, Threads: 25



But …

But ...

- Page reference pattern containing a loop slightly to long to fit in the buffer pool:

But ...

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    - **OPT:** Hit rate close to 1

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  - **LRU:** Hit rate of 0

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  - **LRU:** Hit rate of 0
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  - **LFU:** Pages waste buffer frames probably during the whole running time of the DB

But ...

- Page reference pattern containing a loop slightly to long to fit in the buffer pool:
  - **OPT:** Hit rate close to 1
  - **LRU:** Hit rate of 0
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- Huge access time gap $\implies$ Every saved page miss significantly improves the performance

But ...

- Page reference pattern containing a loop slightly to long to fit in the buffer pool:
  - **OPT**: Hit rate close to 1
  - **LRU**: Hit rate of 0
- Some pages gets referenced very frequent for a limited time:
  - **OPT**: Pages would be evicted after their last reference
  - **LFU**: Pages waste buffer frames probably during the whole running time of the DB
- Huge access time gap $\implies$ Every saved page miss significantly improves the performance
- Pointer swizzling even amplifies that effect

Subsection 1

Probable pitfalls when Implementing a Page Eviction Strategy for a DBMS Buffer Manager

General Problems Concerning DBMS Buffer Managers

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- Fixed pages cannot be evicted but a long timespan between a fix and an unfix of a page could make it a candidate for eviction.

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General Problems Concerning DBMS Buffer Managers

- Fixed pages cannot be evicted but a long timespan between a fix and an unfix of a page could make it a candidate for eviction.
- A page pinned for refix cannot be evicted but a long timespan in which a page is pinned could make it a candidate for eviction.
- Dirty pages cannot be evicted but a page being dirty for a long timespan due to the update propagation using write-back policy could make it a candidate for eviction.

Additional Problem When Using Pointer Swizzling

Additional Problem When Using Pointer Swizzling

- A page containing swizzled pointer cannot be evicted but a page unfixed before the last unfix of one of its child pages could make it a candidate for eviction before its child pages got evicted.

Solutions

Solutions

- Check each of the restrictions before the eviction of a page.

Solutions

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- Update the statistics of the eviction strategy during an unfix, too.

Solutions

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- Update the statistics of the eviction strategy during an unfix, too.
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- Use write-thru for update propagation or a page cleaner decoupled from the buffer pool as proposed in [SHG16].

Solutions

- Check each of the restrictions before the eviction of a page.
- Update the statistics of the eviction strategy during an unfix, too.
- Update the statistics of the eviction strategy during an pin and unpin, too.
- Use write-thru for update propagation or a page cleaner decoupled from the buffer pool as proposed in [SHG16].
- Use a page eviction strategy that takes into account the content of pages (like the structure of an B tree).

Subsection 2

Evaluated Page Replacement Strategies

RANDOM

Overview

RANDOM

Overview

- Simplest page eviction strategy

RANDOM

Overview

- Simplest page eviction strategy
- Evicts a random page that can be evicted

RANDOM

Overview

- Simplest page eviction strategy
- Evicts a random page that can be evicted
- Won't evict frequently used pages as they're latched all the time

GCLOCK

Overview

GCLOCK

Overview

- Slight enhancement of the CLOCK algorithm: *generalized CLOCK*

GCLOCK

Overview

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- Uses finer-grained statistics about the recency of page references

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Overview

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GCLOCK

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- Slight enhancement of the CLOCK algorithm: *generalized CLOCK*
- Uses finer-grained statistics about the recency of page references
- Parameter k defines granulation of statistics
  - $\boldsymbol{k = 1}$: CLOCK

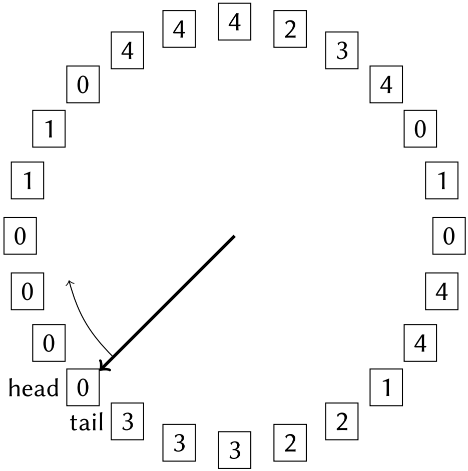
GCLOCK

Overview

- Slight enhancement of the CLOCK algorithm: *generalized CLOCK*
- Uses finer-grained statistics about the recency of page references
- Parameter k defines granulation of statistics
    - $\boldsymbol{k = 1}$**:** CLOCK
    - $\boldsymbol{k = \#}$**frames:** Similar to LRU

GCLOCK

Example



GCLOCK

Advantage of Higher *k*-Values

GCLOCK

Advantage of Higher *k*-Values

Advantages of Lower *k*-Values

GCLOCK

Advantage of Higher *k*-Values

- More detailed statistics about page references
  $\implies$ Higher hit rate
  $\implies$ Higher performance

Advantages of Lower *k*-Values

GCLOCK

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Advantages of Lower *k*-Values

- Lower processing time required to find an eviction victim
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GCLOCK

Advantage of Higher *k*-Values

- More detailed statistics about page references
  $\Longrightarrow$ Higher hit rate
  $\Longrightarrow$ Higher performance

Advantages of Lower *k*-Values

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- Lower memory overhead due to shorter `referenced`-numbers

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  $\Longrightarrow$ Higher performance
- Lower memory overhead due to shorter referenced-numbers

$\Longrightarrow$ Trade-off between CPU- and I/O-optimization

CAR

Overview

CAR

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- Extensive enhancement of the CLOCK algorithm: *Clock with Adaptive Replacement* [BM04]

CAR

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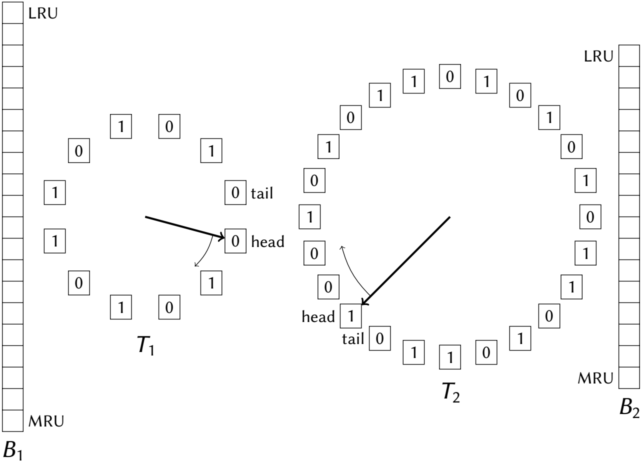
    - Scan-resistence

CAR

Example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MRU
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1
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tail
0
head
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1
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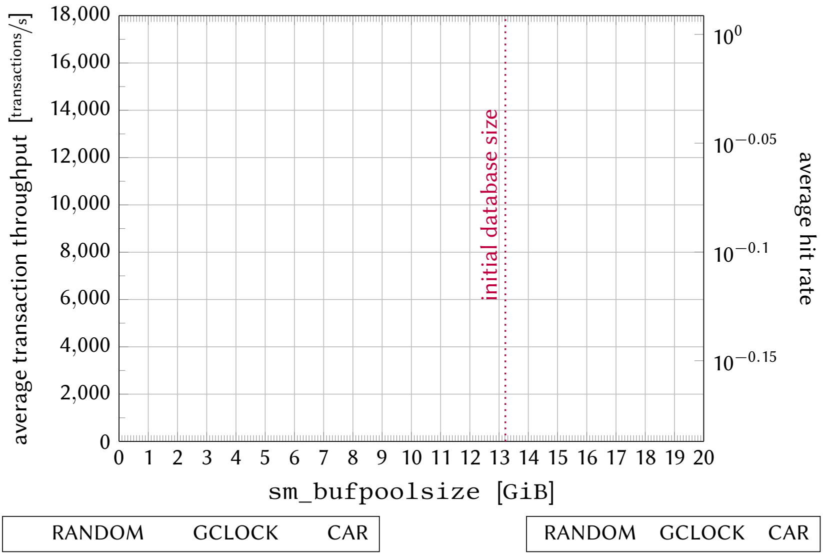
0
1
0
1
0
1
0
1
1
0
1
0
1
1
0
tail
1
head
0
0
1
0
1
0
1
1
T_2
LRU
MRU
B_2

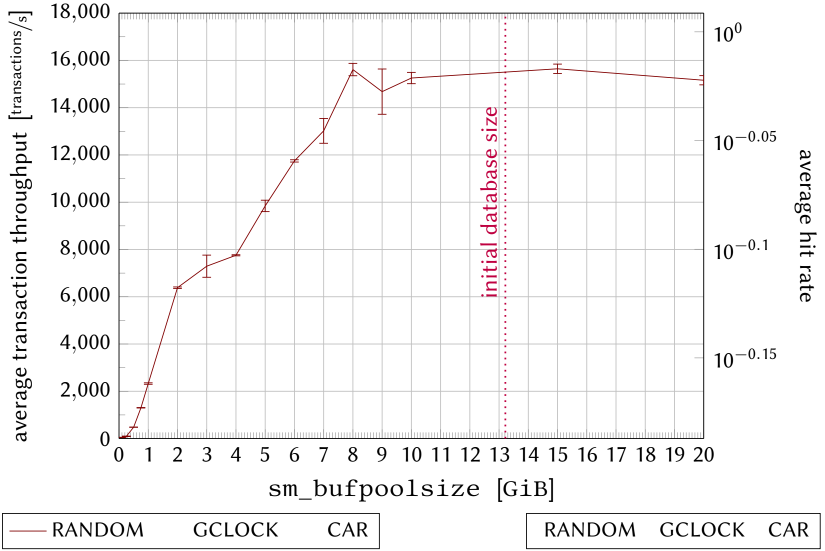
Subsection 3

Performance Evaluation

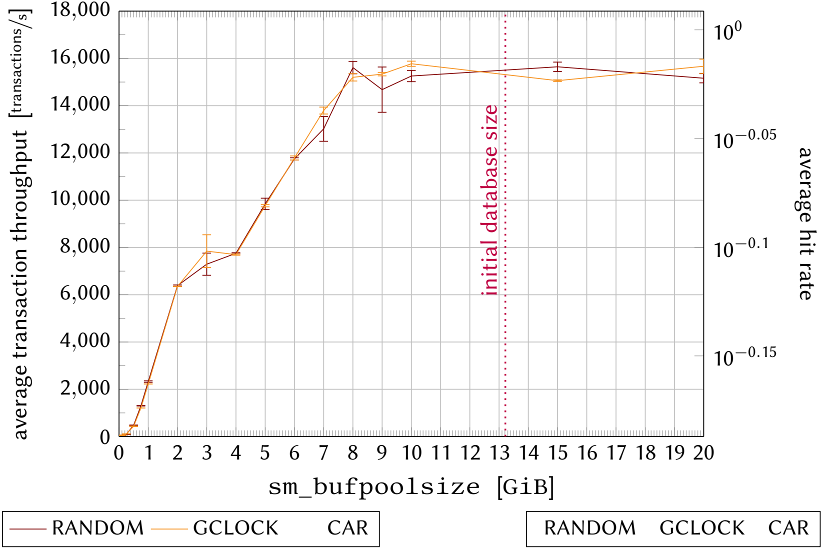
Buffer Pool Without Pointer Swizzling (TPC-C)



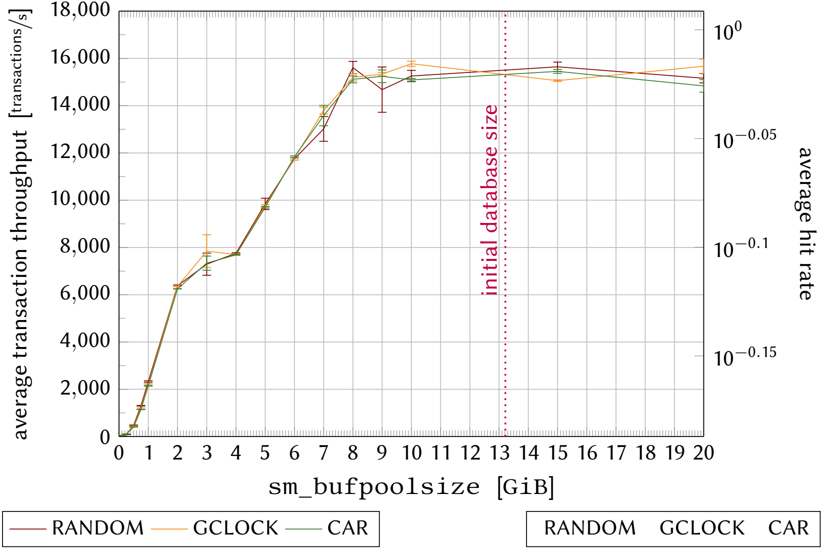
Buffer Pool Without Pointer Swizzling (TPC-C)



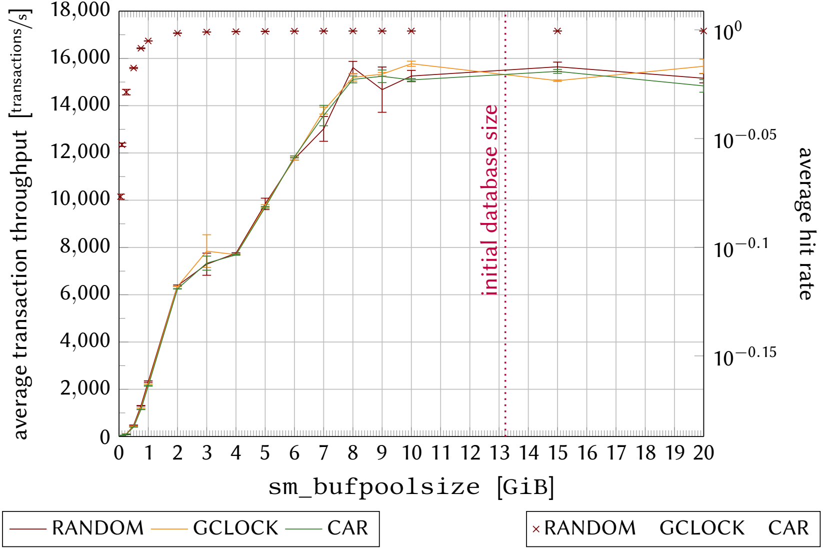
Buffer Pool Without Pointer Swizzling (TPC-C)



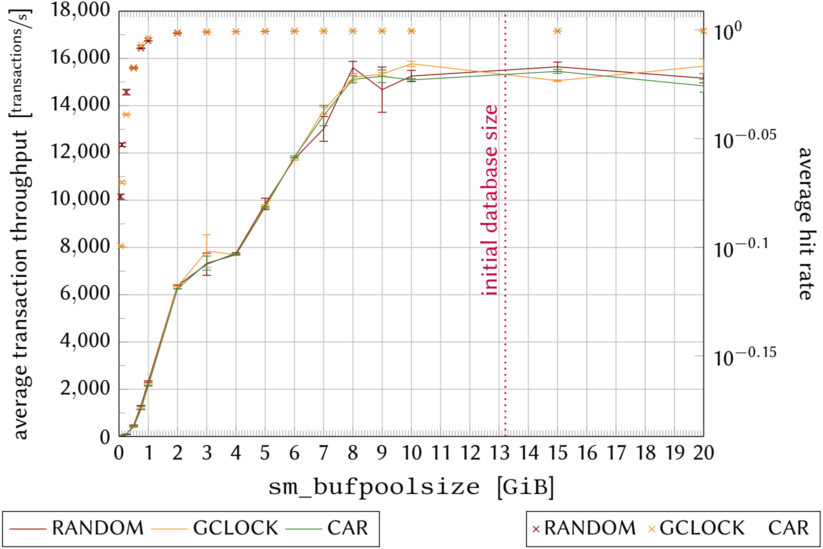
Buffer Pool Without Pointer Swizzling (TPC-C)



Buffer Pool Without Pointer Swizzling (TPC-C)



Buffer Pool Without Pointer Swizzling (TPC-C)



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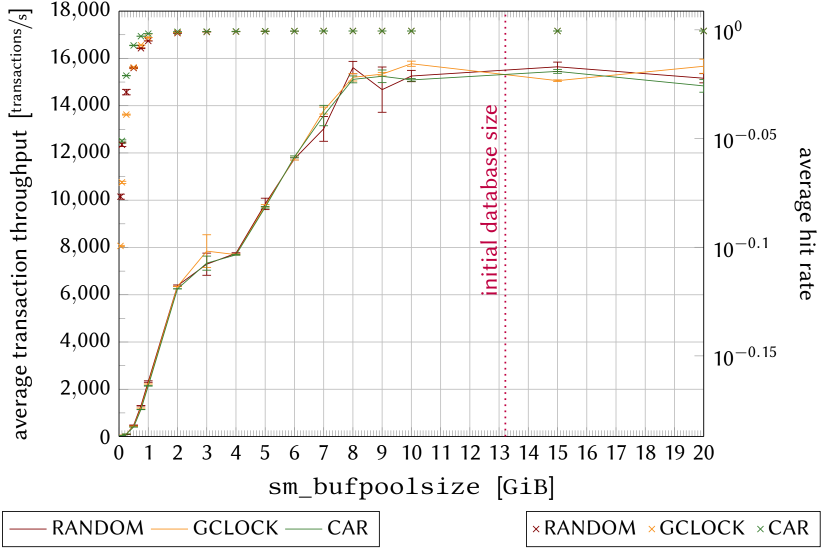
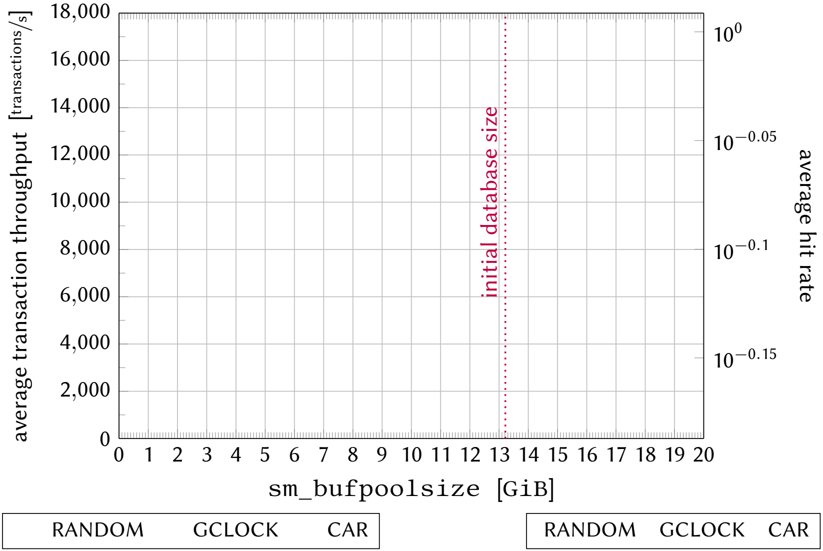


Buffer Pool With Pointer Swizzling (TPC-C)



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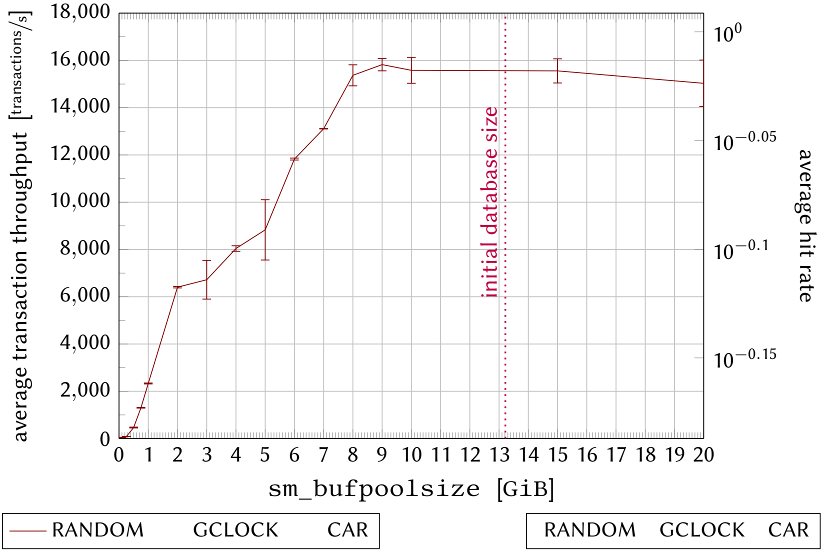

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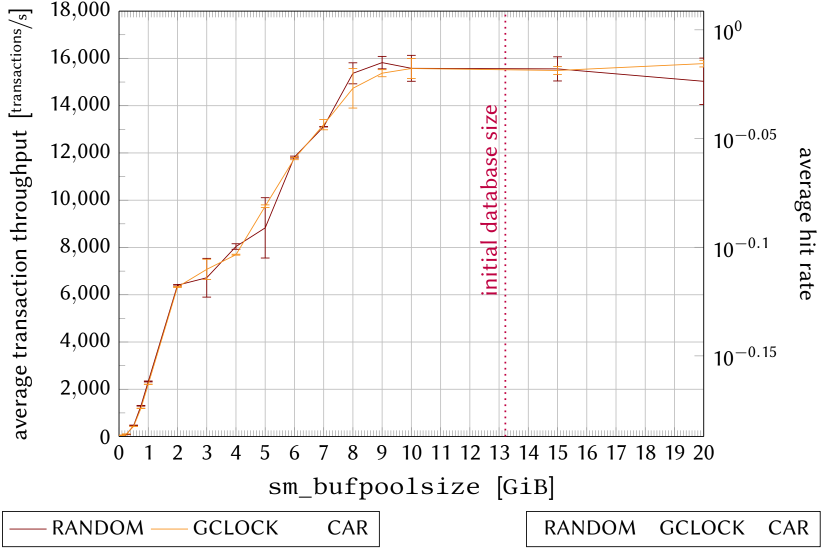

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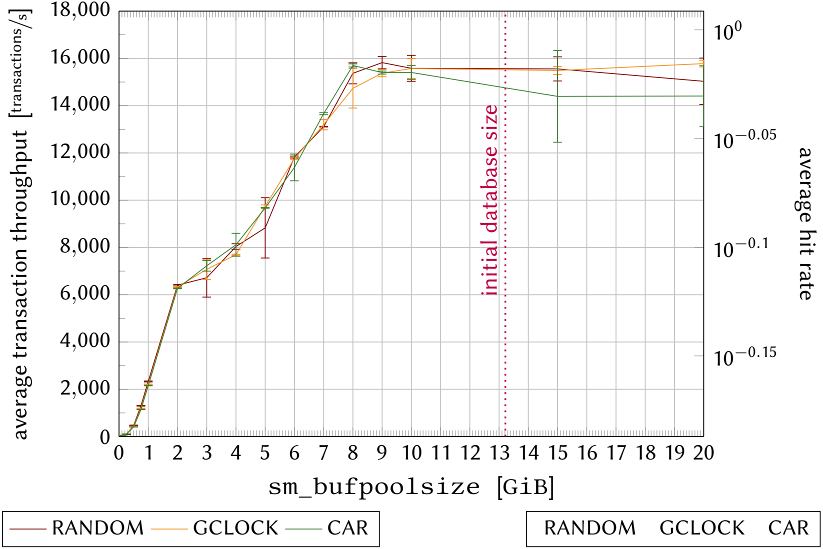

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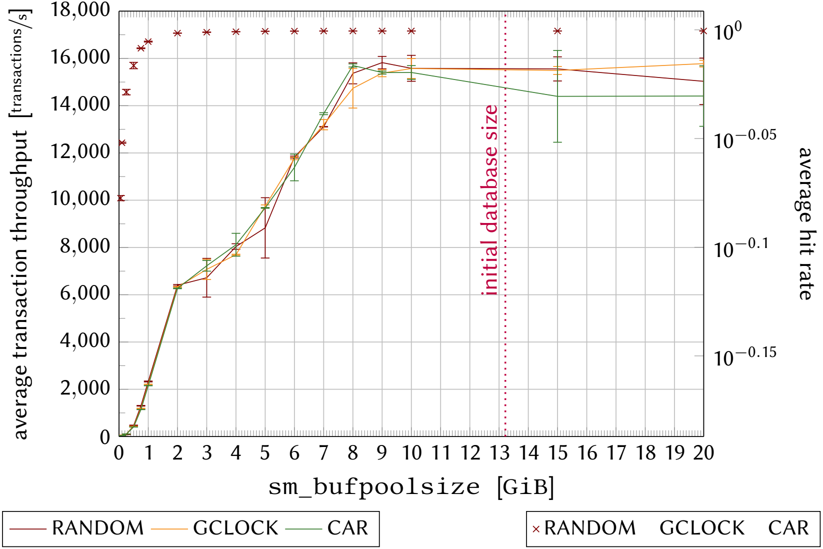

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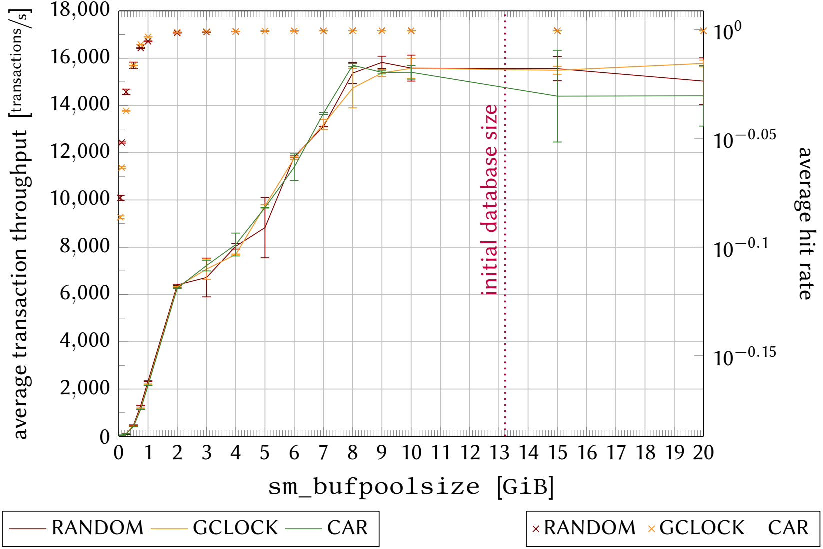

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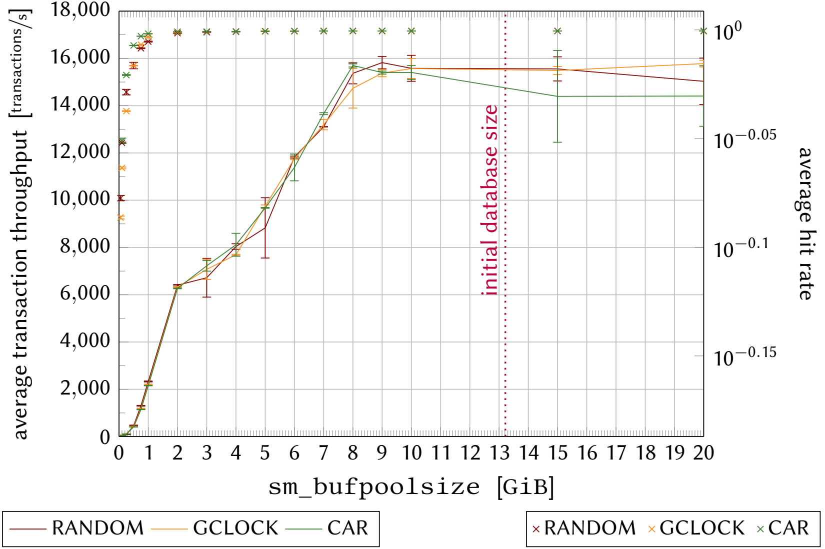
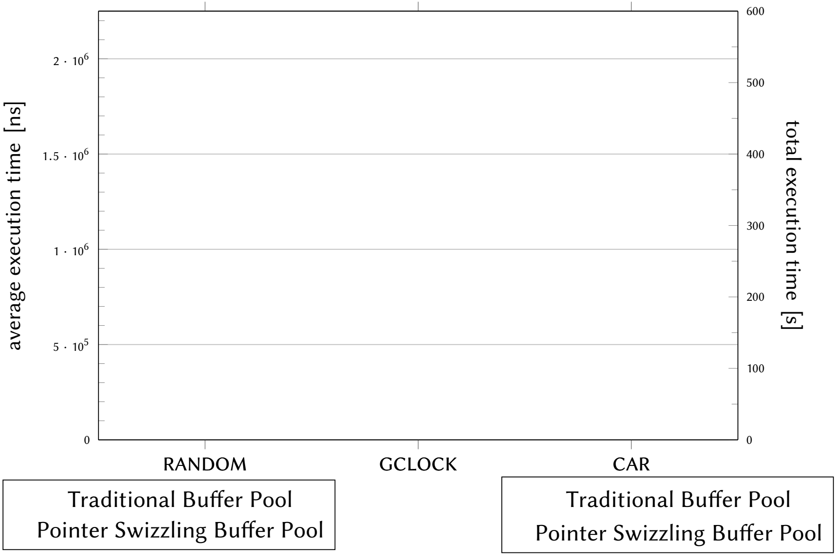


Operation Performance



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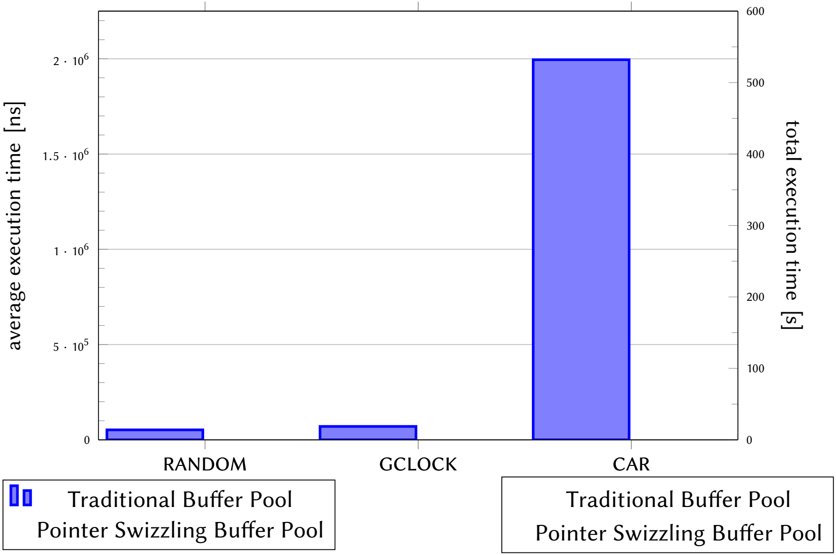

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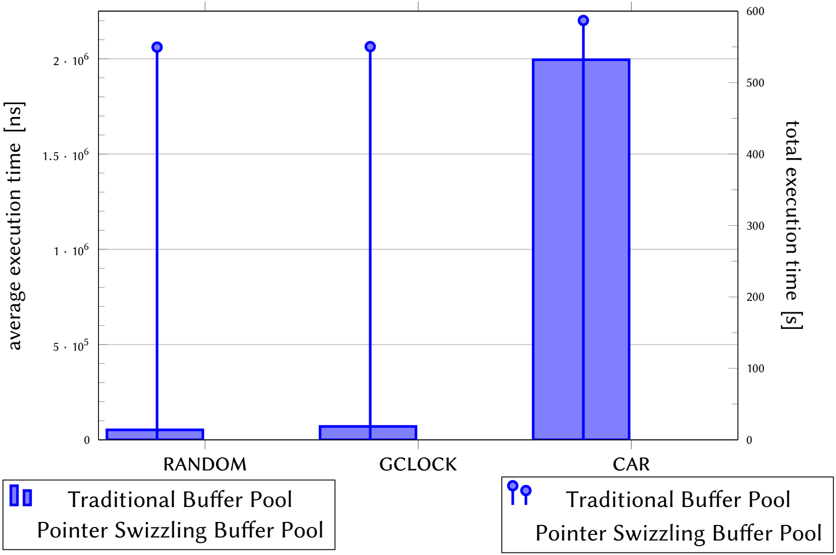

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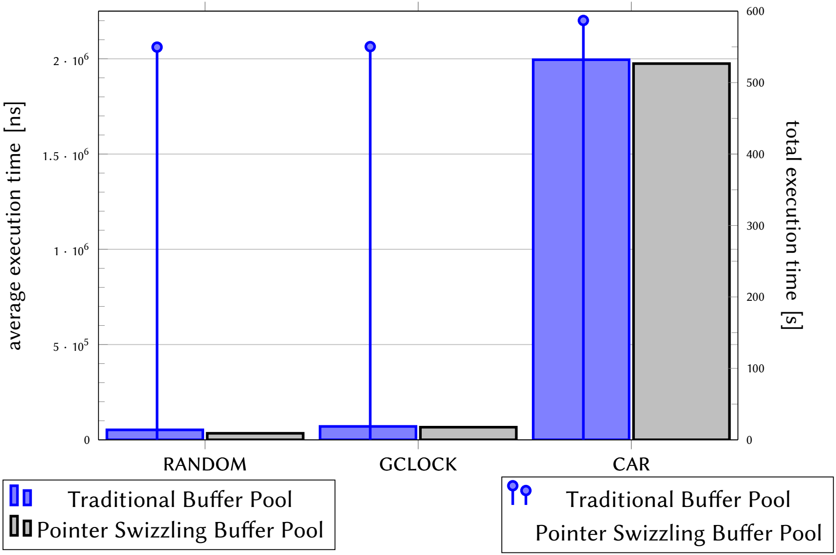

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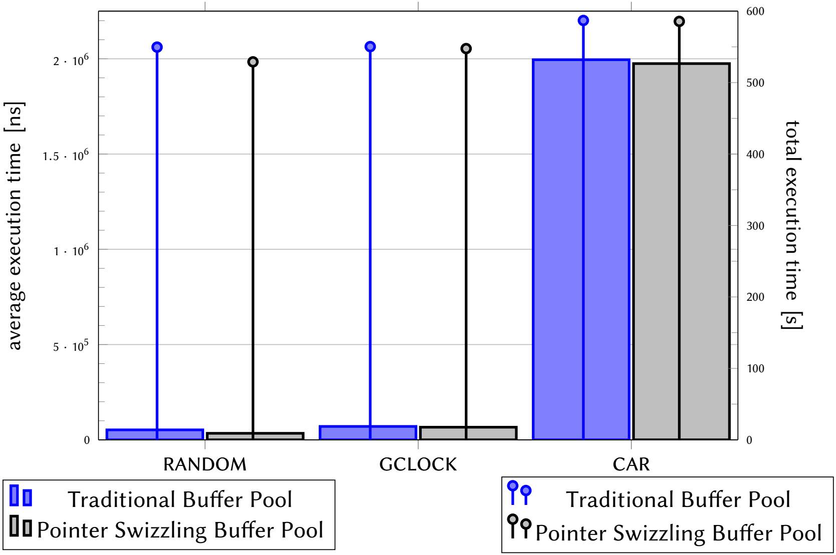

Subsection 4

Conclusion

Conclusion

Performance

Conclusion

Performance

- CAR has a significantly higher hit rate than RANDOM or GCLOCK

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- The computational effort spent to do CAR eviction is 27–58 times higher

Conclusion

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- Major differences in hit rate are only for buffer pool sizes of $\leq \frac{1}{10}$ of the database size
- The computational effort spent to do CAR eviction is 27–58 times higher
- The overall performance of CAR isn't better than the one of RANDOM or GCLOCK

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