15-721 DB Sys. Design & Impl.

Buffering - LRU-K

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Roadmap

Detailed Roadmap

Reference

E. O'Neil, P. O'Neil, G. Weikum: *The LRU-K Page Replacement Algorithm for Database Disk Buffering,* SIGMOD 1993, pp. 297-306

Outline of LRU-K

- Motivation
- Limitations of previous approaches
- Basic concepts
- Addressing realistic problems
- Algorithm

Motivation

GUESS when the page will be referenced again.
Problems with LRU:?

Motivation

GUESS when the page will be referenced again.

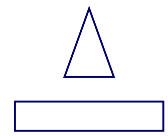
Problems with LRU:

- Makes decision based on too little info
- Cannot tell between frequent/infrequent refs on time
- System spends resources to keep useless stuff around

Example Scenario 1

- Relation CUSTOMER with 20,000 tuples
- Clustered B-tree on CUST_ID, 20b/key
- 4K pages, 4000 bytes useful space
- 100 leaf pages
- Many users
- References L1, R1, L2, R2, L3, R3, …
- Probability to ref Li is .005, to ref Ri is .00005

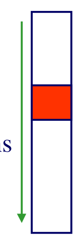
- LRU?



Example Scenario 2

- Relation R with 1,000,000 tuples
- A bunch of processes ref 5000 (0.5%) tuples
- A few batch processes do sequential scans

- LRU?



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Related Work

- Page pool tuning (I.e., domain separation)
  - Needs constant recalibration
  - Cannot handle locality (hot spot patterns)changes
  - Hard to program
- Query execution plan analysis (hot set, DBMIN, hint-passing approaches)
  - Info from the query optimizer
  - Works well when same plan rereferences
- DBMIN is best of the above
  - But multiuser breaks it (optimizer can't detect overlaps)

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Basic concepts

Idea: Take into account history: last K references

(Classic LRU: K=1 (LRU-1))

(keep track of history, and try to predict)

SKIP

Basic concepts (cont'd)

Parameters:

- Pages N={1,2,…,n}
- Reference string r_1, r_2, …, r_t, …
- r_t=p for page p at time t
- b_p = probability that r_t+1=p
- Time between references of p: $I_p = 1/b_p$

Algorithm

- Backward K-distance $b_t(p,K)$:
  #refs from t back to the Kth most recent reference to p
- $b_t(p,K) = \infty$ if Kth ref doesn't exist
- Algorithm:
  Drop page p w/ *max* Backward K-distance $b_t(p,K)$
- **Ambiguous** when infinite (use subsidiary policy, e.g., LRU)
- LRU-2 Is better that LRU-1 – Why? (I_p)

But:

- There are subtle problems:

Realistic problems

- P1: Early page replacement
  - Page $b_t(p,K)$ is infinite, so drop
  - But what if it is a rare but "bursty" case?
- P2: Page reference retained information
  - For K>1- page may be gone / its information still around

P1: Early page replacement

- Should we worry about it?

P1: Early page replacement

- Should we worry about it?
- A: yes - correlated references! Examples?

Correlated References

- (1) Intra-transaction
  – E.g., read tuple/update tuple)
- (2) Transaction/Retry
  – Rolled back and restarted
- (3) Intra-process
  – A process references page via 2 transactions
  – E.g., update RIDs 1-10, commit, update RIDs 11-20
- (4) Inter-process
  – Two processes reference the same page independently

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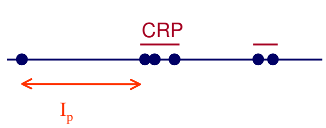
Addressing Correlation

- Problem: For example, assume (1) – read/update
  – Algorithm sees p (read)
  – Drops it (infinite $b_t(p,K)$) (wrong)
  – Sees it again (update)
  – Keeps it around (wrong again)
- Should take into account only non-correlated refs
- But how do we know?

Addressing Correlation (cont.)

- Solution: “Correlated Reference Period” by process
  – No penalty or credit for refs within CRP
  – I_p: interval from end of one CRP to begin of the next



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P2: Reference Retained Information

- Algorithm needs to keep info for pages that may not be resident anymore, e.g.,
  - p is referenced and comes in for the first time
  - $b_t(p.2)$ = infinity, p is dropped
  - p is referenced again
  - if no info on p is retained, p may be dropped again

Reference Retained Information (cont’d)

- “Retained Information Period”
  - Period after which we drop information about page p
  - “Five minute rule” suggests RIP
- Page history information HIST(p) with <=2 refs to p

Data Structures for LRU-K

HIST(p) – history control block of page p

=Times of K more recent references to p) – (correlated)

LAST(p) – time of most recent ref to page p

correlated references OK

- Maintained for all pages p: $B_t(p,K) < RIP$
- Purged asynchronously

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- ➡ Algorithm

LRU-K Algorithm

```
If p is in the buffer { // update history of p
   if (t-LAST(p)) > CRP  { // uncorrelated reference
        // close correlated period and start new
        for i=K-1 to 1
           move HIST(p,i) into slot HIST(p,i+1)
        HIST(p,1)=t
   }
   LAST(p)=t
}
```


LRU-K Algorithm (cont.)

```
else { // select replacement victim
   min=t
   for all pages q in buffer  {
        if t-LAST(q)>CRP // eligible for replacement
                and HIST(q,K)<min) { // max Backward-K
           victim=q
           min=HIST(q,K)
        }
   if victim dirty write back before dropping
```

LRU-K Algorithm (cont.)

```
fetch p into the victim's buffer
   if no HIST(p) exists {
        allocate HIST(p)
        for i=2 to K HIST(p,i)=0
   } else {
        for i=2 to K HIST(p,i)= HIST(p,i-1)
   }
   HIST(p,1)=t // last non-correlated reference
   LAST(p)=t // last reference
}
```


Two-pool Experiment

- Two disk page pools, N1=100 / N2=10,000 pages
- Models alternating index/record references
- Results
  - LRU-1 needs 2-3 times bigger BP to reach LRU-2 hit rate
  - LRU-2 really close to LRU-3 and optimal

Single-pool / Random Access

- One disk page pool, N=1000 pages
- Zipf(*a*,*b*) distribution of reference frequences
  (fraction ***a*** of references accesses fraction ***b*** of pages)
- Results
  - LRU-2 still wins, although not by as much (milder skew)

Real OLTP Workload

- Traces from bank OLTP Xtion references
- 470,000 page references, 20GB database
- Compared to LFU as well
- Results
  - LRU-2 beats LRU-1
  - LRU-2 also beats LFU (why?)

Conclusions

- LRU not good enough
- LFU has limitations
- Other algorithms
  - too complex
  - can't cope with change/multiple users
- LRU-K works well
- Really, LRU-2 is most beneficial
- Today: use simple algorithms, e.g., Oracle

http://www.dbatoolbox.com/WP2001/tuning/multiple_buffer_pools.pdf

Addendum: 2Q

[Theodore Johnson, Dennis Shasha : 2Q: A Low Overhead High Performance Buffer Management Replacement Algorithm. VLDB 1994 : 439-450]

(It has an excellent description of LRU-K!)

2Q - Idea

- Simpler record-keeping/tuning (CPR, RIP)
- Heart of the idea?

2Q - Idea

- Simpler record-keeping/tuning (CPR, RIP)
- Heart of the idea: Instead of keeping statistics for LRU-2, use two queues
  - Am: one LRU for ‘hot’ pages
  - A1: one FIFO for ‘not-yet-proven-hot’ pages
  - if a page from A1 is re-referenced, move to Am
- Like LRU-2: ‘scan resistant’

2Q - subtleties

- Scan: each page is referenced once; goes in and out of the A1 queue, FIFO style
- But: there is still an issue - which one?

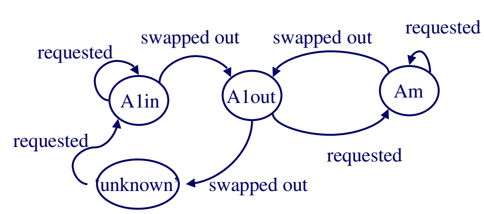
2Q - subtleties

- How to choose the relative sizes of A1 and Am queues
- (fixed division works fine for synthetic data, but NOT for real workloads, where the hot-set size changes dynamically)
- How to resolve the issue?

2Q - final method

- Idea#1: 3 queues:
  - Am: for ‘hot’ pages
  - A1in: for pages of potentially correlated accesses
  - A1out: for pages that have been accessed once
- Idea#2:
  - A1out consists of page-ids only - not pages-slots!

2Q - final method



2Q - drill

- is 2Q 'scan resistant'?
- r1, r2, r3, r4, …, r1000 - how do its queues behave?

2Q - drill

- is 2Q 'scan resistant'?
- r1, r2, r3, r4, …, r1000 - how do its queues behave?
- A:
  - Am will be **empty** (-> available to others)
  - A1in will have the latest pages (ri, r(i-1), …)
  - A1out will have pointers for (most of) the rest

Conclusion: it works as well as LRU-2

- with less record keeping
- faster list processing and
- fewer parameters to tune:
  - 25% of buffers to Ain;
  - A1out should have enough pointers for 50% of buffers