**External Sorting**

Chapter 11

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**2-Way Sort: Requires 3 Buffers**

- Pass 1: Read a page, sort it, write it.
  - only one buffer page is used
- Pass 2, 3, ..., etc.:
  - three buffer pages used.

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**Why Sort?**

- A classic problem in computer science!
- Data requested in sorted order
  - e.g., find students in increasing gpa order
- Sorting is first step in bulkloading B+ tree index.
- Sorting useful for eliminating duplicate copies in a collection of records (Why?)
- Sort-merge join algorithm involves sorting.
- Problem: sort 1Gb of data with 1Mb of RAM.
  - why not virtual memory?

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**General External Merge Sort**

* More than 3 buffer pages. How can we utilize them? *
- To sort a file with \( N \) pages using \( B \) buffer pages:
  - Pass 0: use \( B \) buffer pages. Produce \( \lceil N / B \rceil \) sorted runs of \( B \) pages each.
  - Pass 2, ..., etc.: merge \( B \) runs.

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**Cost of External Merge Sort**

- Number of passes: \( 1 + \lceil \log_B \lceil N / B \rceil \) \( \leq \) \( \lceil \log_B N \rceil \)
- Cost = \( 2N \times \) (# of passes)
- E.g., with 5 buffer pages, to sort 108 page file:
  - Pass 0: \( \lceil 108 / 5 \rceil = 22 \) sorted runs of 5 pages each
    - (last run is only 3 pages)
  - Pass 1: \( \lceil 22 / 4 \rceil = 6 \) sorted runs of 20 pages each
    - (last run is only 8 pages)
  - Pass 2: 2 sorted runs, 80 pages and 28 pages
  - Pass 3: Sorted file of 108 pages

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Number of Passes of External Sort

<table>
<thead>
<tr>
<th>N</th>
<th>B=3</th>
<th>B=5</th>
<th>B=9</th>
<th>B=17</th>
<th>B=129</th>
<th>B=255</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>7</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1,000</td>
<td>10</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>10,000</td>
<td>13</td>
<td>7</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>100,000</td>
<td>17</td>
<td>9</td>
<td>6</td>
<td>5</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>1,000,000</td>
<td>20</td>
<td>10</td>
<td>7</td>
<td>5</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>10,000,000</td>
<td>23</td>
<td>12</td>
<td>8</td>
<td>6</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>100,000,000</td>
<td>26</td>
<td>14</td>
<td>9</td>
<td>7</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>1,000,000,000</td>
<td>30</td>
<td>15</td>
<td>10</td>
<td>8</td>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>

Internal Sort Algorithm

- Quicksort is a fast way to sort in memory.
- An alternative is “tournament sort” (a.k.a. “heapsort”)
  - Top: Read in B blocks
  - Output: move smallest record to output buffer
  - Read in a new record r
  - Insert r into “heap”
  - If r not smallest, then GOTO Output
  - Else remove r from “heap”
  - Output “heap” in order: GOTO Top

More on Heapsort

- Fact: average length of a run in heapsort is 2B
  - The “snowplow” analogy
- Worst-Case:
  - What is min length of a run?
  - How does this arise?
- Best-Case:
  - What is max length of a run?
  - How does this arise?
- Quicksort is faster, but...

Number of Passes of Optimized Sort

<table>
<thead>
<tr>
<th>N</th>
<th>B=1,000</th>
<th>B=5,000</th>
<th>B=10,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1,000</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>10,000</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>100,000</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1,000,000</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>10,000,000</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>100,000,000</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>1,000,000,000</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

* Block size = 32, initial pass produces runs of size 2B.

I/O for External Merge Sort

- ... longer runs often means fewer passes!
- Actually, do I/O a page at a time
- In fact, read a block of pages sequentially!
- Suggest we should make each buffer (input/output) be a block of pages.
  - But this will reduce fan-out during merge passes!
  - In practice, most files still sorted in 2-3 passes.

Double Buffering

- To reduce wait time for I/O request to complete, can prefetch into `shadow block`.
  - Potentially, more passes; in practice, most files still sorted in 2-3 passes.
**Sorting Records!**

- Sorting has become a blood sport!
  - Parallel sorting is the name of the game...
- Datamation: Sort 1M records of size 100 bytes
  - Typical DBMS: 15 minutes
  - World record: 3.5 seconds
- New benchmarks proposed:
  - Minute Sort: How many can you sort in 1 minute?
  - Dollar Sort: How many can you sort for $1.00?

**Using B+ Trees for Sorting**

- Scenario: Table to be sorted has B+ tree index on sorting column(s).
- Idea: Can retrieve records in order by traversing leaf pages.
- Is this a good idea?
- Cases to consider:
  - B+ tree is clustered: Good idea!
  - B+ tree is not clustered: Could be a very bad idea!

**Clustered B+ Tree Used for Sorting**

- Cost: most to the left-most leaf, then retrieve all leaf pages (Alternative 1)
- If Alternative 2 is used? Additional cost of retrieving data records:
  - each page fetched just once.

* Always better than external sorting!*

**External Sorting vs. Unclustered Index**

<table>
<thead>
<tr>
<th>N</th>
<th>Sorting</th>
<th>p=1</th>
<th>p=10</th>
<th>p=100</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>210</td>
<td>100</td>
<td>1,000</td>
<td>10,000</td>
</tr>
<tr>
<td>1,000</td>
<td>2,000</td>
<td>1,000</td>
<td>10,000</td>
<td>100,000</td>
</tr>
<tr>
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<td>40,000</td>
<td>10,000</td>
<td>100,000</td>
<td>1,000,000</td>
</tr>
<tr>
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<td>600,000</td>
<td>100,000</td>
<td>1,000,000</td>
<td>10,000,000</td>
</tr>
<tr>
<td>1,000,000</td>
<td>8,000,000</td>
<td>1,000,000</td>
<td>10,000,000</td>
<td>100,000,000</td>
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<td>10,000,000</td>
<td>80,000,000</td>
<td>10,000,000</td>
<td>100,000,000</td>
<td>1,000,000,000</td>
</tr>
</tbody>
</table>

* p: # of records per page
* B=4,000 and block size = 32 for sorting
* B=2,000 is the more realistic value.

**Summary**

- External sorting is important; DBMS may dedicate part of buffer pool for sorting!
- External merge sort minimizes disk I/O cost:
  - Pass 0: Produces sorted runs of size B (if buffer pages).
  - 1st pass: merge runs.
  - # of runs merged at a time depends on B and block size.
  - Larger block size means less I/O cost per page.
  - Larger block size means smaller # of runs merged.
  - In practice, # of runs rarely more than 2 or 3.
Summary, cont.

- Choice of internal sort algorithm may matter:
  - Quicksort: Quick!
  - Heap/tournament sort: slower (2x), longer runs
- The best sorts are wildly fast:
  - Despite 40+ years of research, we’re still improving!
- Clustered B+ tree is good for sorting; unclustered tree is usually very bad.