PA152: Efficient Use of DB

6. Sorting Algorithms

Vlastislav Dohnal

Applications of Sorting

- On result presentation
  - SELECT … ORDER BY
- Doing joins
  - SELECT … r JOIN s
- Filtering duplicates
  - SELECT DISTINCT …

Assumptions

- Main Memory
  - Limited capacity – M blocks
- Data stored on disk
  - Input (relation) is read from a disk
- Output kept in memory
  - Output is usually processed by next operations
- Costs of sorting
  - Number of disk accesses

Sorting in Memory

- Many in-mem algorithms
  - BubbleSort – $O(n^2)$
  - QuickSort – $\Theta(n \log n)$
  - MergeSort – $O(n \log n)$
  - InsertSort – $O(n^2)$
  - HeapSort – $O(n \log n)$
  - RadixSort – $O(kn)$
  - CountingSort – $O(k+n)$
  - …

Examples (in-mem)

- Counting Sort
  - Small cardinality of domain (values)
  - E.g., need to sort 100 grades (A-F)
    - Create an array for all grades
    - Count the number of occurrences of each grade
    - Write the grades into correct (sorted) position
- Radix Sort
  - Recursive sorting by bytes (bits)
  - Apply the CountingSort byte by byte
    - First round – get counts
    - Second round – locate and store the values to correct places

Sorting in Memory: Facts

- Data in main memory
- Sorting in-place
- Use little additional memory (log *n*)

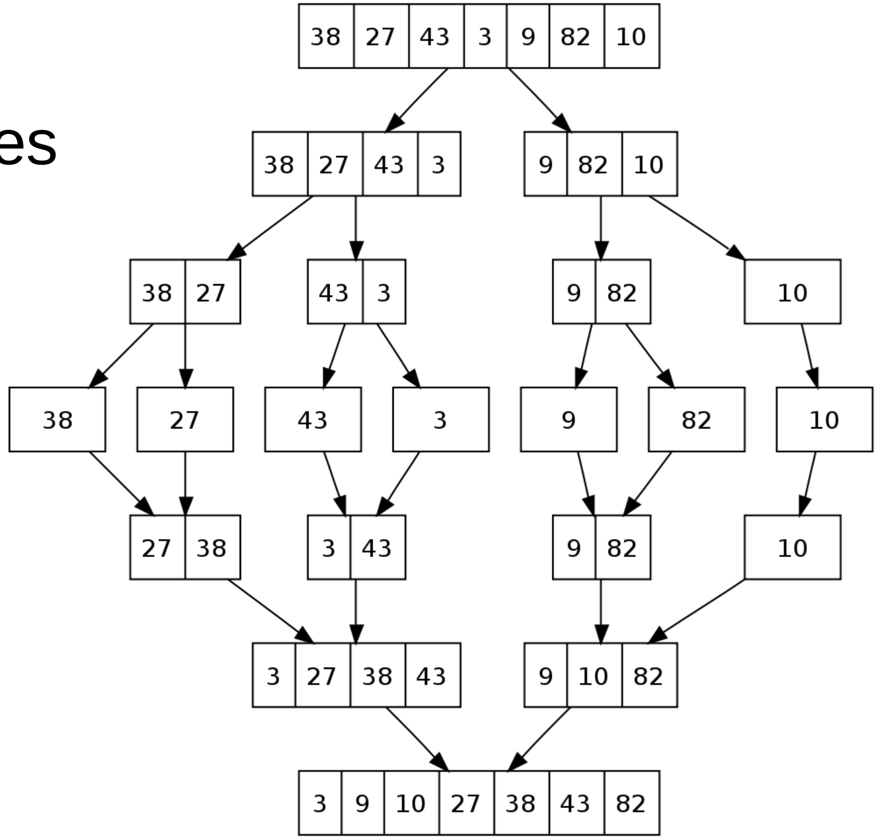
Small Main Memory

- Data compression
  - Process only key values and pointers to records; not whole records
  - OK, but on output whole records must be read $\rightarrow$ random accesses
- Memory virtualization
  - Typically, slow $\rightarrow$ too many I/Os
- Algorithm modification
  - Combine more algorithms (ideas)
  - MergeSort and QuickSort often used

MergeSort – in memory

i.e., for small relations!!!

- “Divide and conquer” principle
  - Split to halves
    - Until individual key values
  - Merge partly-sorted partitions
    - By linear scan of both parts
    - The smallest value sent to output
- O(n log n)



Source: Wikipedia.org, MergeSort Algorithm

MergeSort – disk-based variant

- Two-Phase Multiway MergeSort
- Procedure
  1. Create runs of size of available RAM
  2. Sort each run
     1. Read the run from a disk
     2. Sort in mem
     3. Write out to the disk
  3. Read all sorted runs at once and merge them

Two-phase MergeSort

- Example
  - Relation of 100 mil. records, 100 bytes each
  - Blok of 8 KiB, i.e., about 80 records
    - Relation stored in 1 250 000 blocks (9.5 GiB)
  - Memory buffer for sorting
    - 6 400 blocks (50 MiB)
- Phase 1
  - $\lceil$1 250 000 / 6 400$\rceil$ runs = 196 runs
    - The last run contains 2,000 blocks only
  - Seq I/O: 1 250 000 reads + 1 250 000 writes

Two-phase MergeSort

- Phase 2
  - In-memory merging of two runs is slow!
    - i.e., $\log_2$(# of runs) reading and writing the relation
    - For 196 runs – 8× reading and writing the whole file
  - <u>Multi-way</u> merging
    - Read all runs block by block
    - Do merging into an output block

Two-phase MergeSort

- Phase 2
  - Repeat
    - Find the smallest value out of all runs
    - Write it to output block
      - If full → flush it to disk
    - An empty block of a run → read the next block of it
  - Resulting in 1x reading and 1x writing of relation
    - i.e., 1 250 000 read random IOs
      + 1 250 000 write (random) IOs
- In total 4·B(R) I/Os,
    - where 2·B(R) sequentially, 2·B(R) randomly
  - i.e., O(*n*)

Two-phase MergeSort – Limitations

- Parameters
  - M – size of main memory buffer in blocks
  - B(R) – size of relation R in blocks
- Limitations
  - Max. run length: M
  - Max. number of runs: $M-1$
  - Max. relation size: $M \cdot (M-1)$
- Running example: 100B record, 50MiB buffer, 8KiB block
  - Max. 40 953 600 blocks (312GB)
  - Max. 3 276 288 000 records
    - If not enough, three-phase sort can be applied…