ACM SIGMOD Programming Contest 2018

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Task

- Output results of SQL queries with joins as fast as possible
- At the start of the program, relations are loaded from binary files
- There is 1 second at the beginning available for preprocessing
- The program then receives SQL queries in batches

Input

```
SELECT SUM(R1.a), SUM(R2.b)
FROM R1
JOIN R2 ON R1.c = R2.d
WHERE R2.a > 5 AND R1.b = 8
```

Output

```
1805, 1337
```

Query processing overview

1. Rewrite the query
   - Quickly filter out empty queries and redundant joins
2. Create indices for all joined columns
   - Clustered indices: full copies of relations sorted by the joined column
   - The workload is read only: indices are fully cached in-memory
3. Build an operator tree from the query
   - Create a left-deep join tree
   - Use merge-sort join and nested loop join with index accesses
   - Operators are fully pipelined (tuple-at-a-time)
4. Split the operator tree into hundreds of disjoint tasks
5. Execute the tasks in parallel and output the results

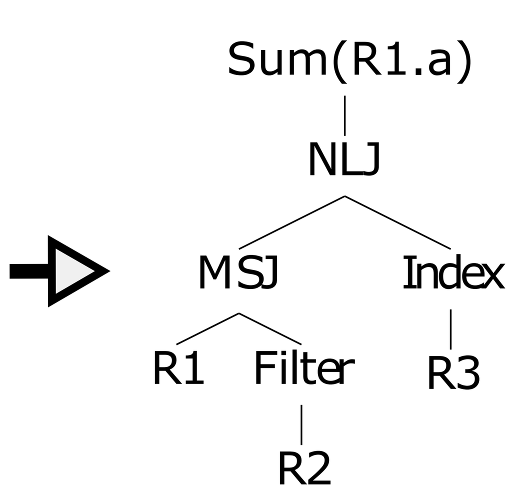
Workload statistics

- Read-only: everything can be cached
- Average column count: 3
- Large variation of row count: from 8k to 20 million
- Most columns are uniformly distributed
- ~40 % of queries can be skipped after rewriting

Operator tree

- Merge-sort is used if possible (both columns sorted)
- Nested loop with index access is used otherwise
- Many virtual calls: mark leaves with **final**, inline hot methods
- Standard rules applied: projection and selection pushdown
- The plan is split into many tasks and executed in parallel

```
SELECT SUM(R1.a)
FROM R1
JOIN R2 ON R1.c = R2.d
JOIN R3 ON R1.d = R3.a
WHERE R2.a > 5
```



Query rewriting

- Remove redundant projections and selections
- Remove joins of foreign-primary key column pairs
- Find bounds of join components and add them as new selections
- Use indices to lookup join ranges: if empty, the query can be skipped
- 40 % of joins eliminated, 40 % of queries skipped

```
SELECT SUM(R1.a), SUM(R2.b)
FROM R1
JOIN R2 ON R1.a = R2.b
JOIN R3 ON R2.c = R3.a
WHERE R3.a > 5
    AND R1.a > 3
```

→

```
SELECT SUM(R1.a)
FROM R1
JOIN R2 ON R1.a = R2.b
WHERE R2.c > 5
    AND R1.a > 8
    AND R1.a < 14
    AND R2.b > 8
    AND R2.b < 14
```

R1.a range: [7, 13]
R2.b range: [9, 18]
R3.a/R2.c is a PK/FK pair

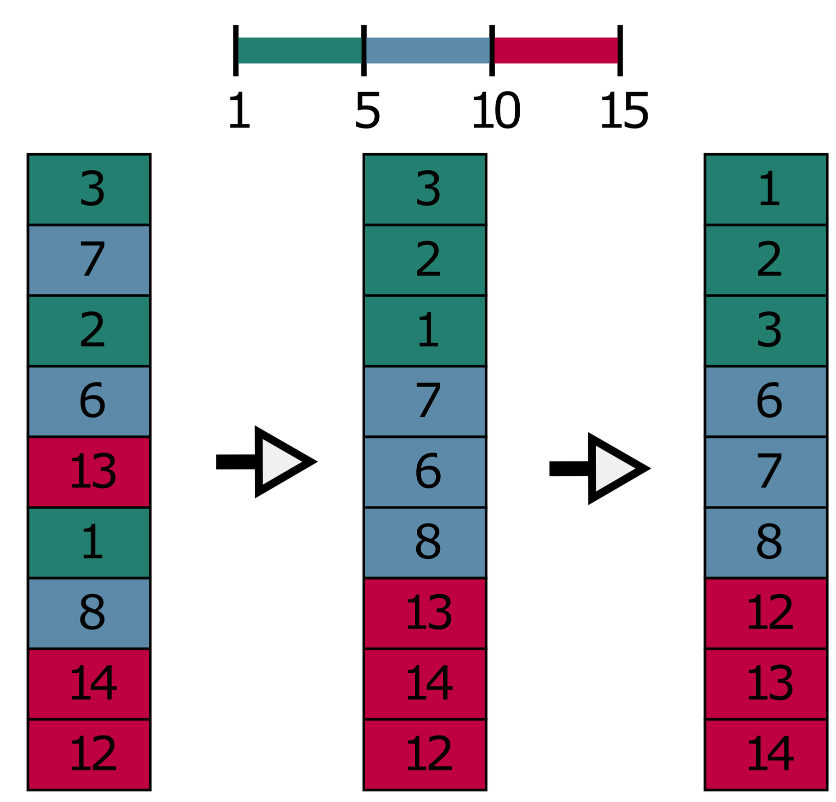
Indices

- Clustered indices: full copies of relations sorted by a specific column
- Lookup: binary search, O(log n)
- Index build initially very slow because of slow sorting

Index build strategy

1. Find min/max of the sorted column
2. Divide column values into 512 KiB groups (parallel)*
3. Sort groups with MSB radix sort (parallel)

* division into groups assumes uniform distribution



Inner aggregation

- Summing with tuple-by-tuple access has high overhead
- Leverage repeating values in sorted columns
- Directly aggregate columns and return (sum, row count)
- Final value: left sum * right count, right sum * left count
- ~2x faster query processing

```
SELECT SUM(R1.b), SUM(R2.b)
FROM R1
JOIN R2 ON R1.a = R2.a
```

SUM(R1.b) = 14 * 4
SUM(R2.b) = 30 * 2

R1.a	R1.b
1	6
1	8

R2.a	R2.b
1	3
1	7
1	9
1	11

General optimizations

NUMA
- Spread memory amongst nodes with first-touch policy
- Spread OpenMP threads amongst sockets (OMP_PLACES=sockets)
- Near NUMA memory accesses ~2x faster than far accesses

JIT compile filters (selections)
1. **mmap** a block of executable memory
2. Compile filter predicates to x64 instructions
3. Run filters directly as functions without interpretation

- Can be done with ~50 lines of C++
- Use godbolt.org for instruction opcodes

Force vectorization
- Move vectorizable loops to separate functions
- Mark pointers with **__restrict__** and **const** if possible
- Keep the function simple to make it easy for the compiler

Fun facts

- ~7200 lines of C++ 14
- 1625 submits
- Index build takes 60 % of execution time

Third-party libraries
- OpenMP
- radix sort (https://github.com/voutcn/kxsort)