Advanced Topics in Databases

Introduction

Gunter Saake, Sebastian Breß, David Broneske, Sebastian Dorok, Andreas Meister, Veit Köppen
Otto-von-Guericke University Magdeburg
Summer Term 2014
Motivation for the Lecture

• Familiarize students with current developments in database research

• Topics chosen:
  • First solutions currently make their way into database management systems and applications → practical relevance
  • Solutions not yet fully developed and open problems exist → research relevance

• Possible starting points for scientific work, e.g. master thesis, position in academia, Ph.D. thesis, etc.
Yesterday’s DBMS Hardware

Small main memory

Picture taken from [1]

Disk-based systems

Picture taken from [2]
Assumptions of yesterday’s DBMSs

- Capacity of main memory < 1% of the stored data
- Fixed block size based on the transfer unit between disks and main memory
- Central scheduler to schedule transactions
- No redundant data storage in main memory
- Pipelining is always beneficial (no storage of intermediate results)
- Compiling of SQL for one processor architecture → Reuse of compiled plan
Today’s DBMS Hardware

- Large main memory
- Multi-core CPUs
- Solid state disks
- Co-processors
Future DBMSs

• Capacity of main memory $<$1% of the stored data
  • *DB in main memory*
• Fixed block size based on the transfer unit
  • *direct access of data on all devices*
• Central scheduler to schedule transactions
  • *which processor should do the job?*
• No redundant data storage in main memory
  • *redundant data at co-processors*
• Pipelining is always beneficial
  • *co-processors like GPU support massive parallelism*
• Reuse of compiled plan
  • *load-balancing between co-processors requires different plans*
The Goals of a "Databaser"

- Performance

Picture taken from [6]
The Goals of a "Databaser"

- Performance
- Performance

Picture taken from [6]
The Goals of a "Databaser"

- Performance
- Performance
- Performance

Picture taken from [6]
The Goals of a "Databaser"

- Performance
- Performance
- Performance

Picture taken from [6]
The Goals of a "Databaser"

• Performance
• Performance
• Performance

How can we achieve more performance?

Picture taken from [6]
Trends for DBMS’s

- Use main memory as primary storage → Speed up data access

- Exploit all hardware capabilities such as co-processors → Speed up database operators
Are DBMSs written for yesterdays hardware efficient on todays hardware as well?
Are DBMSs written for yesterdays hardware efficient on todays hardware as well?

”30 years of Moore’s law has antiquated the disk-oriented relational architecture for OLTP applications”  [Stonebraker et al., 2007]
Data Access – Yesterday’s Bottleneck

Bottleneck

Bottleneck
Data Access – Today’s Bottleneck

Bottleneck

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10/21
The World of Co-Processors

PCI Express Bus

Picture taken from [7]
What do we have to change in DBMSs’ architecture to **exploit new hardware capabilities** and to **meet tomorrow’s challenges**?
Overview of Topics

1. GPU-accelerated Data Management (Breß, 2 lectures)

2. Main-Memory DBMSs (Dorok, 2 lectures)

3. Hardware-sensitive DB Algorithms (Broneske, 2 lectures)

4. Advanced Query Optimization (Meister, 2 lectures)

5. High Dimensional Index Structures (Köppen, 2 lectures)
GPU-accelerated Data Management

- Specialized GPU operators
- Predicting the benefit of GPU acceleration
- Data placement strategies
- Increased complexity of query optimization

Logical query plan

CPU only plan (cost: 100)  hybrid plan (cost: 60)  GPU only plan (cost: 80)
Main-Memory DBMSs

Address main-memory access bottleneck using cache-conscious

• data layouts (e.g., column-stores [Abadi et al., 2008]) and
• data processing [Manegold et al., 2000]

Query processing in row-stores

\[
\begin{array}{ccc}
\ldots & \text{Location} & \ldots \\
\hline
\text{MD} & 1 \\
\text{EF} & 5 \\
\text{MD} & 7 \\
\text{EF} & 4 \\
\end{array}
\]

\[
\sigma_{\text{Location} = 'MD'}
\]

\[
\begin{array}{ccc}
\text{Location} \\
\hline
\text{MD} \\
\text{EF} \\
\text{MD} \\
\text{EF} \\
\end{array}
\]

\[
\pi_{\text{Sales}}
\]

\[
\begin{array}{c}
\text{Sales} \\
\hline
1 \\
7 \\
\end{array}
\]

\[
\text{SUM}(\text{Sales})
\]

\[
8
\]

Adapted from [Köppen et al., 2012]

Query processing in column-stores

\[
\begin{array}{ccc}
\text{Location} & \text{Sales} & \text{Year} \\
\hline
\text{MD} & 1 & 2010 \\
\text{EF} & 5 & 2009 \\
\text{MD} & 7 & 2011 \\
\text{EF} & 4 & 2010 \\
\end{array}
\]

\[
\sigma_{\text{Location} = 'MD'}
\]

\[
\text{SUM}(\text{Sales})
\]

\[
8
\]

Adapted from [Köppen et al., 2012]
Hardware-sensitive DB Algorithms

CPU "smaller than"-selection

```c
int pos = 0;
for (int i=0; i < array_size; ++i){
    if (array[i] < comp_val)
        result[pos++] = i;
}
```

GPU "smaller than"-selection

```c
int tid = threadIdx.x + blockIdx.x * blockDim.x;
while (tid < array_size){
    bitmask[tid] = (array[tid] < comparison_value);
    tid += blockDim.x * gridDim.x;
}
```

Optimized Code differs between processing devices w.r.t.

- Access pattern
- Code optimizations (e.g., branch-free code)
- Parallelization capabilities
Advanced Query Optimization

\[ r(\text{ORDER}) \bowtie r(\text{PRODUCT}) \bowtie r(\text{CUSTOMER}) \bowtie r(\text{SUPPLIER}) \]

Equivalent plans for one query \( \implies \) Large search space

Search space increases in modern systems \( \implies \) Advanced optimization algorithms needed:

- Parallelization
- Usage of co-processors

Taken from [Saake et al., 2012]
High-Dimensional Index Structures

- Efficient retrieval of complex data, e.g., multimedia or Data Warehouse
- Multi-dimensional index structures required
- Challenge: Curse of Dimensionality
- Example: Increasing overlapping of MBRs for R-Tree

Adapted from [Köppen et al., 2012]
Organization

- **Lecture**
  - Every week Monday at 11:15 in room G22A-209
  - Two to four weeks for each topic read by Gunter Saake, Sebastian Breß, Sebastian Dorok, David Broneske, Andreas Meister, Veit Köppen
  - Lecture slides will be made available on lecture homepage http://wwwiti.cs.uni-magdeburg.de/iti_db/lehre/advdb/

- **Exercise**
  - Theoretical exercises based on Exercise sheets available on the lecture homepage, held by Andreas Meister
  - Every week Thursday at 11:15 in room G05-208
  - Starting on April 17

- **Exam**
  - Oral exam of 20-30 minutes after end of lecture period
  - Credits (Schein): examination passed with grade \( \leq 4.0 \) or special assignment
References

Column-Stores vs. Row-Stores: How different are they really?
In *SIGMOD*, pages 967–980.

*Data Warehouse Technologien.*
mitp-Verlag.


*Datenbanken: Implementierungstechniken.*
mitp-Verlag, 3rd edition.

The end of an architectural era: (it’s time for a complete rewrite).
Web Resources