Topics in Database Systems: Modern Database Systems

CS848 Spring 2022

David Toman

Wednesday 10:30-1:00 (DC 2568)

`cs.uwaterloo.ca/~david/cs848/`

Proliferation of NEW DB(-like) Implementations

Quick sample:

AEROSPIKE, cassandra, APACHE HBASE, mobject (precision data management), memsql, monetdb

mongoDB, ORACLE NOSQL DATABASE, SQLite, APACHE RIVER, SAP HANA, VOLTDB (SMART DATA FAST.)

... and dozens of others

In contrast to...

... before Y∼2000 it was pretty much divided between

the big four (ORALE, IBM/DB2, Sybase, and MS Server)

and (later, with the advent of the WEB) Postgress, MySQL, etc.

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Why so many? And why Main-Memory?

New Circumstances

1. cheap and abundant hardware (Extra CPUs and Main Memory)
2. changes in applications/workloads (often *fit* in main memory!)
3. cost (we won't focus on this though)

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Topics of Interest

1. What are the main differences between managing memory resident data v.s. data in external storage?
   - impact on query/update processing
     how many *instructions* does it take to answer simple queries?
   - what happens to ACID (and can we afford durability at all)?
2. What is the impact on *programming interface* to MMDBs?
   - declarative (SQL-like) vs. procedural (C++-like)
   - query optimization?
3. What is the impact of multi-core/CPU hardware
   - data partitioning and query compilation/allocation
   - communication/synchronization between parallel operations
     dependency on architecture (Multicore, NUMA, Shared-nothing)?
4. UDTs (user-defined topics)

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Outline&Organization

- Organization:
  - ⇒ Lectures (4-5),
  - ⇒ Presentations of papers (reading list), and
  - ⇒ Projects
- First meeting: **Wed May 4, 2022 at 10:30 in DC 2568**
- Prerequisites:
  - ⇒ *Intro to Databases* (CS348-like), and
  - ⇒ standard programming skills
    (although this is not necessarily an implementation class)
- Class web site: `cs.uwaterloo.ca/~david/cs848/`
  reading list, schedule of classes/presentations, policies, etc.

Organization (ii)

Week 1: Organization,
Issues in *classical* DB implementations, and
What can be done about it?

Week 2: Introduction to DB implementation,
Classical Approaches vs. Query compilation (examples);
Discussion/assignment of presentations/projects.

Weeks 3-5: More on Query Compilation:
Multi-level Store (a.k.a. Disks),
Sorted Data and better algorithms,
How does this really work?
What to do about Updates? (and perhaps more)

Weeks 7-12: In-class Paper/Project Discussion&Consultation

Week 13: Summary and Wrap-up

$\Rightarrow$ see the course website for details

Assessment

1. class participation (20%)
2. in class presentation of a topic/paper from the reading list (optional, up to 30%)
3. project (50-80%)

NB: I'll discuss assignments/presentations/projects later in class...

$\Rightarrow$ but look at the *reading list* on the web site

DATABASE IMPLEMENTATION

(STANDARD APPROACHES AND TECHNIQUES)

Requirements (user point of view)

Goal of a DBMS

Execute user queries/updates (as fast as possible)

(typical) Requirements:

1. Stores all of your Data (scalability)
2. Physical Data Independence (SQL vs. B-trees et al.)
3. Durability (the idea of a *transaction*)
4. Isolation (sharing/concurrency)

$\Rightarrow$ do we need all of the above all the time?

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Standard Architecture: Client-Server "System"

Query/Update Compiler

⇒ compiles a *logical expression* to a *plan*

Query/Update Execution Engine:

⇒ executes a *prepared plan*

1. Query processor (access paths)
2. Transaction Manager
3. Recovery Manager
4. Buffer Pool

Where does the Time go? (a case study)

- SHORE (Scalable Heterogeneous Object Repository, Wisconsin ’90s)
  ⇒ the whole database is preloaded in main memory
- TPC-C (OLTP) benchmark: “new order” and “payment” transactions
  ⇒ 50/50 mix of the transactions in experiments
- Experiments show performance gain by removing/simplifying:
  1. B-Tree keys (no prefix compression)
  2. no logging (no durability)
  3. no locks (no concurrency)
  4. no latches (no transactions: begin/commit/. . .)
  5. no buffer manager (remember DB preloaded!)

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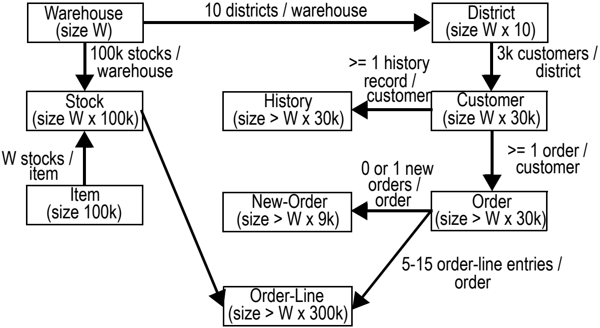

Figure 3. TPC-C Schema.

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Where does the Time go? (setup)

Assumptions:

1. all data preloaded into main memory
2. transactions compiled and linked against SHORE
3. 50-50 mix
4. 40k transaction runs

New Order

```
begin
for loop(10)
.....Btree lookup(I), pin
Btree lookup(D), pin
Btree lookup (W), pin
Btree lookup (C), pin
update rec (D)
for loop (10)
.....Btree lookup(S), pin
.....update rec (S)
.....create rec (O-L)
.....insert Btree (O-L)
create rec (O)
insert Btree (O)
create rec (N-O)
insert Btree (N-O)
insert Btree 2ndary(N-O)
commit
```

Payment

```
begin
Btree lookup(D), pin
Btree lookup (W), pin
Btree lookup (C), pin
update rec (C)
update rec (D)
update rec (W)
create rec (H)
commit
```

Figure 4. Calls to Shore's methods for New Order and Payment transactions.

Where does the Time go?

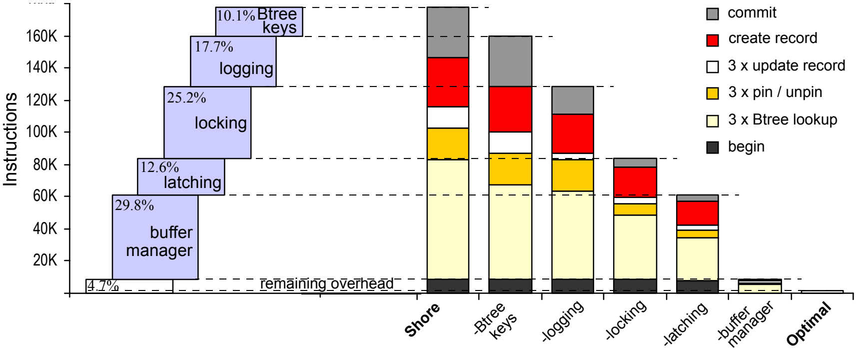

Figure 5. Detailed instruction count breakdown for Payment transaction.

Where does the Time go?

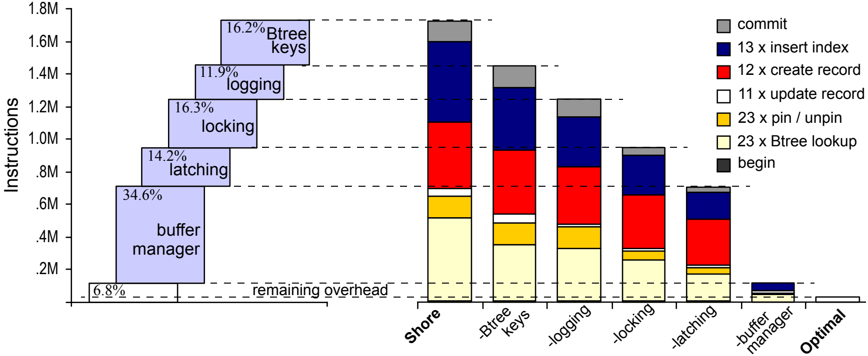

Figure 6. Detailed instruction count breakdown for New Order transaction.

Where does the Time go?

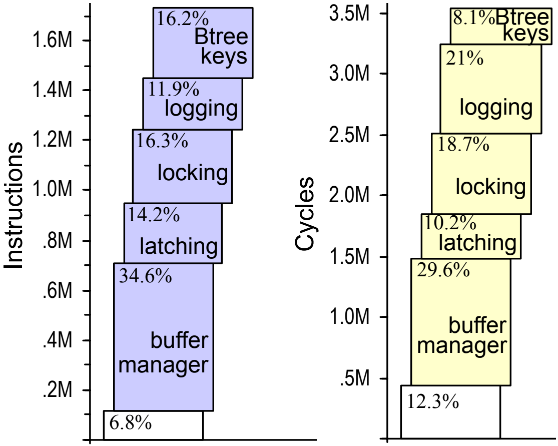

Figure 8. Instructions (left) vs. Cycles (right) for New Order.

Where does the Time go? (conclusions)

Having a giant buffer cache to fit the whole dataset

doesn't seem to solve all problems (90+% OVERHEAD!)

However. . .

. . . the savings in experiments at cost of functionality

⇒ can MMDBs be engineered to mittigate the overhead

without sacrifising functionality?

- Single threading vs. multicore
- Availability (replication) vs. logging
- Variations on isolation
- Cache-conscious data structures

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Compilation-based Approaches

IDEA:

can we use a

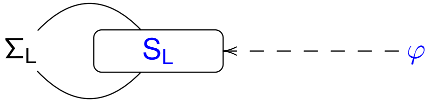
- high level system *description*
- a compiler

to generate *tailored* code for our appilication?

Compilation-based Approaches

Definability and Rewriting

Queries	range-restricted FOL (a.k.a. SQL)
Schema	range-restricted FOL $\Sigma := \Sigma^L \cup \Sigma^{LP} \cup \Sigma^P$
Data	CWA (complete information)

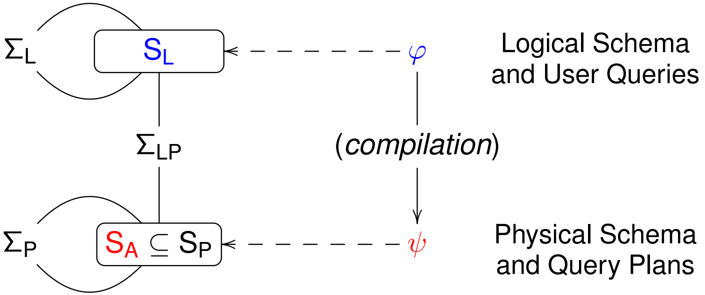


Logical Schema
and User Queries

Compilation-based Approaches

Definability and Rewriting

Queries	range-restricted FOL	over S_L *definable* w.r.t. Σ and S_A
Schema	range-restricted FOL	$\Sigma := \Sigma^L \cup \Sigma^{LP} \cup \Sigma^P$
Data	CWA (complete information	for S_A symbols)



[Borgida, de Bruijn, Franconi, Seylan, Straccia, Toman, Weddell: On Finding Query Rewritings under Expressive Constraints. SEBD 2010: 426-437]

Compilation-based Approaches

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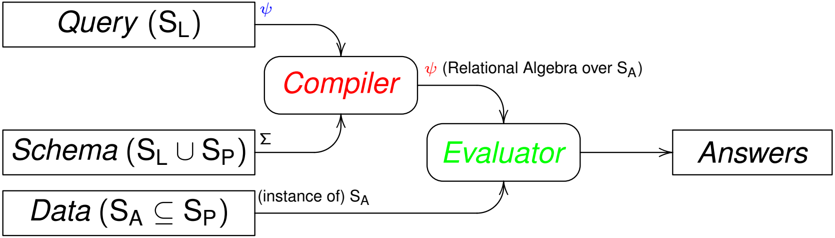
- to users it looks like a *single model* (of the logical schema)
- implementation can pick from many models

  but *definable* queries answer the same in each of them



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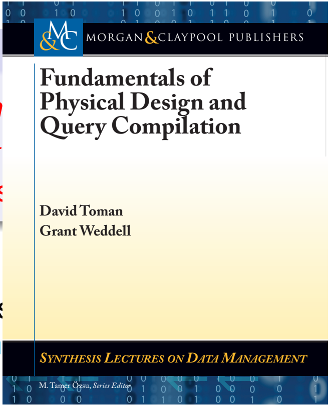

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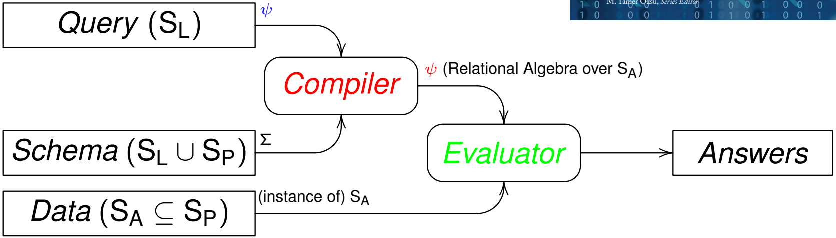

Example

```
% ------- conceptual modelling --------
%  disjoint coverage
student(x,y) <-> (ugrad(x,y) or grad(x,y)),
ugrad(x,y) and grad(x,z) -> bot,
%  student id is a key
student(x,y) and student(x,z) -> y=z,
%
% ------- physical modelling --------
% two access paths:  p0astudent and p1agrad use record ids
student(x,y) <-> ex(r,p0astudent(r,x,y)),
grad(x,y)    <-> ex(r,p0astudent(r,x,y) and p1agrad(r)),
% record ids are keys too
p0astudent(r,x,y) and p0astudent(r,z,w) -> x=z,
p0astudent(r,x,y) and p0astudent(s,x,z) -> r=s,
%
% ------- queries --------
q0gs(x,y) <-> grad(x,y),
q0us(x,y) <-> ugrad(x,y)
```

Example (cont.)

```
david@david$ cat tests/old_format/848ex/students.fol | ...

query(q0gs,2,0,[var(1,int),var(2,int)]) <->
 project([var(3,int)],
  nlj(
   ap(p0astudent,[var(3,int),var(1,int),var(2,int)],fscan)
   ap(p1agrad,[var(3,int)],flookup,1)
  )
 )

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  nlj(
   ap(p0astudent,[var(3,int),var(1,int),var(2,int)],fscan)
   complement(
    ap(p1agrad,[var(3,int)],flookup,1)
   )
  )
 )
```

Example (header file: us.h)

```
#include "runtime.h"
// struct for us
struct us_data {
// public:
     long    var_1;
     long    var_2;
     long    var_3;
// operators:
// AP private:
     struct fscan_data    apvar0;
     struct flookup_data  apvar1;
};
```

Example (C source: us.c)

```
#include <stdio.h>
#include <stdlib.h>
#include "us.h"

static int inline __attribute__((always_inline)) getfirst_simpcomp2(struct us_data *q) {
   if (getfirst_p1agrad(&(q->apvar1), &(q->var_3))) return 0;
   return 1;
};
static int inline __attribute__((always_inline)) getnext_simpcomp2(struct us_data *q) {
   return 0;
};

static int inline __attribute__((always_inline)) getfirst_nlj3(struct us_data *q) {
   if (!getfirst_p0astudent(&(q->apvar0), &(q->var_3), &(q->var_1), &(q->var_2))) return 0;
   while (!getfirst_simpcomp2(q))
      if (!getnext_p0astudent(&(q->apvar0), &(q->var_3), &(q->var_1), &(q->var_2))) return 0;
   return 1;
};
static int inline __attribute__((always_inline)) getnext_nlj3(struct us_data *q) {
   if (getnext_simpcomp2(q)) return 1;
   while (getnext_p0astudent(&(q->apvar0), &(q->var_3), &(q->var_1), &(q->var_2)))
      if (getfirst_simpcomp2(q)) return 1;
   return 0;
};

static int inline __attribute__((always_inline)) getfirst_project4(struct us_data *q) {
   return getfirst_nlj3(q);
};
static int inline __attribute__((always_inline)) getnext_project4(struct us_data *q) {
   return getnext_nlj3(q);
};
```

Take Home

Focus of this class: DB engine vs. Compilation aproaches

Lots of open issues:

1. Main memory data organization
2. Multilevel memory/storage
3. Ordered data
4. Parallelism and partitioning (many levels)
5. . . .

Next time

1. Basics of DB implementation (crash course)
2. Basics of Query Compilation (with examples)
3. Discussion of presentations/projects

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