Logical Approach to Physical Data Independence and Query Compilation

Advanced Physical Designs

David Toman

D.R. Cheriton School of Computer Science
University of Waterloo

The Story So Far...

1. Physical Data Independence (OBDA, Data Exchange, ...)
2. Logic-based formalization (Relational model, constraints)
3. Queries and Answers

$$\text{cert}_{\Sigma,D}(\varphi) = \{\vec{a} \mid \Sigma \cup D \models \varphi(\vec{a})\} = \bigcap_{I \models \Sigma \cup D} \{\vec{a} \mid I \models \varphi(\vec{a})\}$$

4. Only queries *logically equivalent* to range-restricted queries over $\mathsf{S_A}$.
   - what does this kind of arrangement allow?
   - why is this *efficient*?
   - how to find such equivalent queries

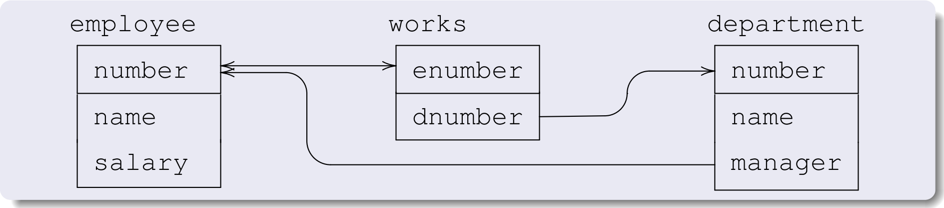
ADVANCED PHYSICAL DESIGNS

Case Studies

- Main-memory pointers
- Hash tables, linked lists, et al.
- Built-in operations
- Two-level store

Main Memory and Pointers

Logical Schema:



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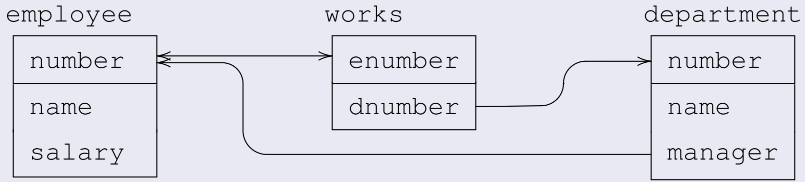

Physical Schema:

```
record emp of                      record dept of
     integer    num                     integer    num
     string     name                    string     name
     integer    salary                  reference  manager
     reference  dept
```

... and an array holding `emp` records (called `empfile`).

Main Memory and Pointers: Formalization

Logical Schema&Constraints:

- $\Rightarrow S_L = \{\texttt{employee}/3, \texttt{department}/3, \texttt{works}/2\};$
- $\Rightarrow \Sigma_L = \{\forall x_1, x_2, y_1, y_2.\exists z.(\texttt{employee}(z, x_1, x_2) \land \texttt{employee}(z, y_1, y_2)) \rightarrow ((x_1 = y_1) \land (x_2 = y_2)),$
  $\forall x, y, z.(\texttt{works}(z, x) \land \texttt{works}(z, y)) \rightarrow (x = y),$
  $\forall x, y, z.\texttt{department}(y, z, x) \rightarrow \exists u, v.\texttt{employee}(x, u, v), \ldots \}$

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Physical Schema&Constraints:

- $\Rightarrow S_A = \{\texttt{empfile}/1/0, \texttt{emp-num}/2/1,$
  $\texttt{emp-name}/2/1, \texttt{emp-salary}/2/1, \texttt{emp-dept}/2/1,$
  $\texttt{dept-num}/2/1, \texttt{dept-name}/2/1, \texttt{dept-manager}/2/1\},$
- $\Rightarrow \Sigma_{LP} = \{\forall x.(\texttt{empfile}(x) \to \exists y.\texttt{emp-num}(x, y)), \ldots,$
  $\forall x, y.(\texttt{emp-dept}(x, y) \to \texttt{deptfile}(y)),$
  $\forall x.(\texttt{deptfile}(x) \to \exists y.\texttt{dept-num}(x, y)), \ldots,$
  $\forall x, y.(\texttt{dept-manager}(x, y) \to \texttt{empfile}(y)),$
  $\forall x.y, z.(\texttt{employee}(x, y, z) \to \exists w.(\texttt{empfile}(w) \land \texttt{emp-num}(w, x))),$
  $\forall x, y, z, w.((\texttt{empfile}(w) \land \texttt{emp-num}(w, x) \land \texttt{emp-name}(w, y) \land \texttt{emp-salary}(w, z)) \to \texttt{employee}(x, y, z)), \ldots\}$

Main Memory and Pointers: Queries and Plans

1. $\exists z.\mathtt{employee}(x, y, z)$:

```
E?z.Employee(x,y,?z)
Plan: 26 (15n,5n)
E?x1.(Empfile(?x1)^Emp-num(?x1,x)^Emp-name(?x1,y))
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2. $\texttt{Department}(x, y, z)$:

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   Department(x,y,z)
   Plan: 241 (35n,5n)
   E?x2.(Empfile(?x2)^Emp-num(?x2,z)^E?x1.(Emp-dept(?x2,?x1)
                      ^Dept-name(?x1,y)^Dept-num(?x1,x)
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$\Rightarrow$ is it better? NO (duplicate elimination)

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```
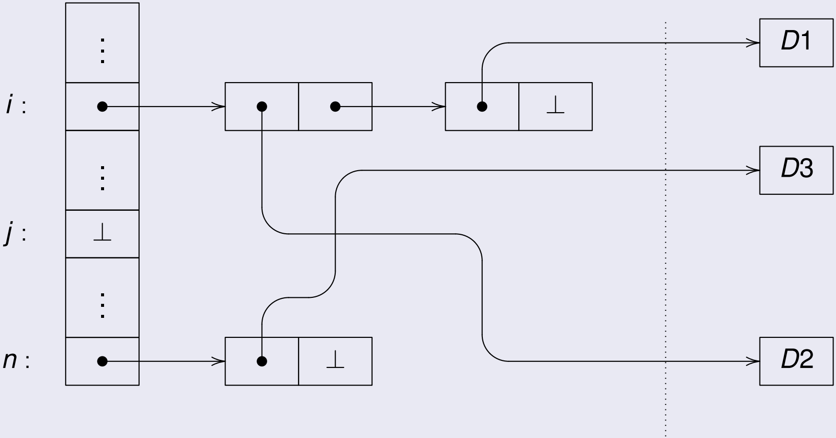
3. $\exists y, v, w.\mathtt{employee}(x1, x2, y) \wedge \mathtt{works}(x1, v) \wedge \mathtt{department}(v, x3, w)$:
```
E?y,?v,?w.Employee(x1,x2,?y)^Works(x1,?v)^Department(?v,x3,?w)
Plan: 50 (40n,5n)
E?x5.(Empfile(?x5)^Emp-num(?x5,x1)^Emp-name(?x5,x2)
                  ^E?x4.(Emp-dept(?x5,?x4)^Dept-name(?x4,x3)))
```

Hashing, Lists, et al.

Hashing with (list-based) Separate Chaining



Hash Array   Separate Chaining Linked Lists   DeptFile

Hashing, Lists, et al.

Access paths:

$\Rightarrow$ $S_A \supseteq \{\texttt{hash}/2/1, \texttt{hasharraylookup}/2/1, \texttt{listscan}/2/1\}$.

Physical Constraints:

$$\Rightarrow \Sigma_{LP} \supseteq \{\forall x, y.((\texttt{deptfile}(x) \wedge \texttt{dept-name}(x, y)) \rightarrow \exists z, w.(\texttt{hash}(y, z) \wedge \texttt{hasharraylookup}(z, w) \wedge \texttt{listscan}(w, x))), \forall x, y.(\texttt{hash}(x, y) \rightarrow \exists z.\texttt{hasharraylookup}(y, z)), \forall x, y.(\texttt{listscan}(x, y) \rightarrow \texttt{deptfile}(y))\}$$

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Queries:

$\Rightarrow \exists y, z.(\texttt{department}(x_1, p, y) \wedge \texttt{employee}(y, x_2, z))\{p\}$.

```
E?y,?z.Department(x1,p,?y)^Employee(?y,x2,?z)  [p]
Plan: 497 (10,1)
E?x6.(Hash(p,?x6)^E?x5.(Hasharraylookup(?x6,?x5)
                  ^E?x4.(Listscan(?x5,?x4)
                  ^E?s0.(Dept-name(?x4,?s0)^Cmp(p,?s0))
                  ^Dept-num(?x4,x1)
                  ^E?x3.(Dept-manager(?x4,?x3)^Emp-name(?x3,x2))))
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How do we introduce *built-in* functions/operations
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Logical Schema: $< /2, \leq /2 \subseteq S_L$ (written conventionally in infix)

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Logical Schema: $< /2, \leq /2 \subseteq \mathsf{S_L}$ (written conventionally in infix)

Physical Schema: $\texttt{less}/2/2 \in \mathsf{S_A}$

$$\Rightarrow \Sigma_{LP} \supseteq \{\forall x, y.(x < y) \leftrightarrow \texttt{less}(x, y)$$
$$\forall x, y.(x \leq y) \leftrightarrow \neg\texttt{less}(y, x)\}$$

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Code:

```
function less-first
  return (x1 < x2)
```

```
function less-next
  return false
```

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```

$\Rightarrow$ we already have $\texttt{cmp}/2/2$ for equality!

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Two-level Store

Problem with Disks

Data is accessed in *blocks* (for efficiency)

$\Rightarrow$ NLJ accesses the *inner relation* number of tuples in the *outer relation*-times

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Standard Solution: Block-based Operators

Block-NLJ operator:

1. read *as big block* of outer tuples in a memory buffer as possible
2. read a block from inner into a memory buffer
3. join the two buffers (producing output)
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... is this extra code really necessary?

Two-level Store

IDEA:

Split the access paths to a *page reader* and
a *record reader* (that expects to be given a page already in memory).

Physical Schema:

$\Rightarrow$ $S_A \supseteq \{\texttt{emp-pgscan}/1/0, \texttt{emp-recscan}/2/1\}$

$$\Rightarrow \Sigma_{LP} \supseteq \{\forall x, y.(\texttt{emp-recscan}(y, x) \rightarrow \texttt{emp-pgscan}(y)),\\ \forall x, y_1, y_2.((\texttt{emp-recscan}(y_1, x) \wedge \texttt{emp-recscan}(y_2, x)) \rightarrow (y_1 \approx y_2)),\\ \forall x.(\texttt{empfile}(x) \equiv \exists y.\texttt{emp-recscan}(y, x)) \}$$

Two-level Store Example

Query:

$$\exists y, z, w.(\texttt{employee}(x_1, y, z) \wedge \texttt{employee}(x_2, y, w))$$

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$$\exists y, z, w.(\texttt{employee}(x_1, y, z) \wedge \texttt{employee}(x_2, y, w))$$

Plan

```
E?y,?z,?w.(Employee(x1,?y,?z)^Employee(x2,?y,?w))
Plan: 803 (2n^2 + 50201,10000)
E?x6.(Emp-pgscan(?x6)^E?x4.(Emp-pgscan(?x4)^
E?x5.(Emp-recscan(?x6,?x5)^Emp-num(?x5,x1)^
E?x3.(Emp-recscan(?x4,?x3)^Emp-num(?x3,x2)^
E?x2.(Emp-name(?x3,?x2)^E?s0.(Emp-name(?x5,?s0)^Cmp(?x2,?s0))))))
```

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1. Flexible modeling framework
   $\Rightarrow$ new features = new access paths + constraints
2. Efficient query plans (comparable to hand-written code)

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Next time: HOW TO FIND REWRITINGS