Logical Approach to Physical Data Independence and Query Compilation

Advanced Physical Designs

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The Story So Far...

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

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

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

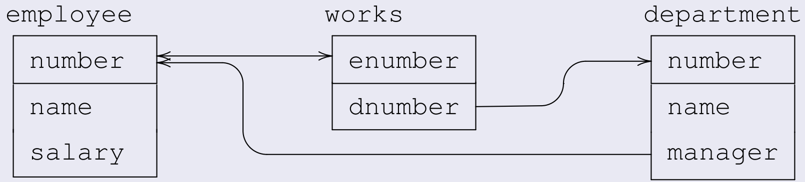
ADVANCED PHYSICAL DESIGNS

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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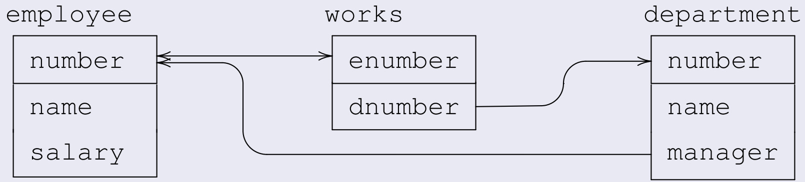

Physical Schema:

```
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:

$$\Rightarrow S_L = \{\texttt{employee}/3, \texttt{department}/3, \texttt{works}/2\};$$

$$\begin{aligned}\Rightarrow \Sigma_L = \{&\forall x_1, x_2, y_1, y_2.\exists z.(\texttt{employee}(z, x_1, x_2) \wedge \texttt{employee}(z, y_1, y_2)) \\ &\qquad \to ((x_1 = y_1) \wedge (x_2 = y_2)), \\ &\forall x, y, z.(\texttt{works}(z, x) \wedge \texttt{works}(z, y)) \to (x = y), \\ &\forall x, y, z.\texttt{department}(y, z, x) \to \exists u, v.\texttt{employee}(x, u, v), \ldots \}\end{aligned}$$

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$\forall x, y, z.\texttt{department}(y, z, x) \rightarrow \exists u, v.\texttt{employee}(x, u, v), \ldots\}$

Physical Schema&Constraints:

$\Rightarrow$ $S_A = \{\texttt{empfile}/1/0, \texttt{emp-num}/2/1,$
$\texttt{emp-name}/2/1, \texttt{emp-salary}/2/1, \texttt{emp-dept}/2/1,$
$\texttt{dept-num}/2/1, \texttt{dept-name}/2/1, \texttt{dept-manager}/2/1\},$

$\Rightarrow$ $\Sigma_{LP} = \{\forall x.(\texttt{empfile}(x) \rightarrow \exists y.\texttt{emp-num}(x, y)), \ldots,$
$\forall x, y.(\texttt{emp-dept}(x, y) \rightarrow \texttt{deptfile}(y)),$
$\forall x.(\texttt{deptfile}(x) \rightarrow \exists y.\texttt{dept-num}(x, y)), \ldots,$
$\forall x, y.(\texttt{dept-manager}(x, y) \rightarrow \texttt{empfile}(y)),$
$\forall x.y, z.(\texttt{employee}(x, y, z) \rightarrow \exists w.(\texttt{empfile}(w) \wedge \texttt{emp-num}(w, x))),$
$\forall x, y, z, w.((\texttt{empfile}(w) \wedge \texttt{emp-num}(w, x) \wedge \texttt{emp-name}(w, y) \wedge \texttt{emp-salary}(w, z)) \rightarrow \texttt{employee}(x, y, z)), \ldots\}$

Main Memory and Pointers: Queries and Plans

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

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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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   Department(x,y,z)
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Is there a *shorter* plan?

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$\Rightarrow$ is it better? NO (duplicate elimination)

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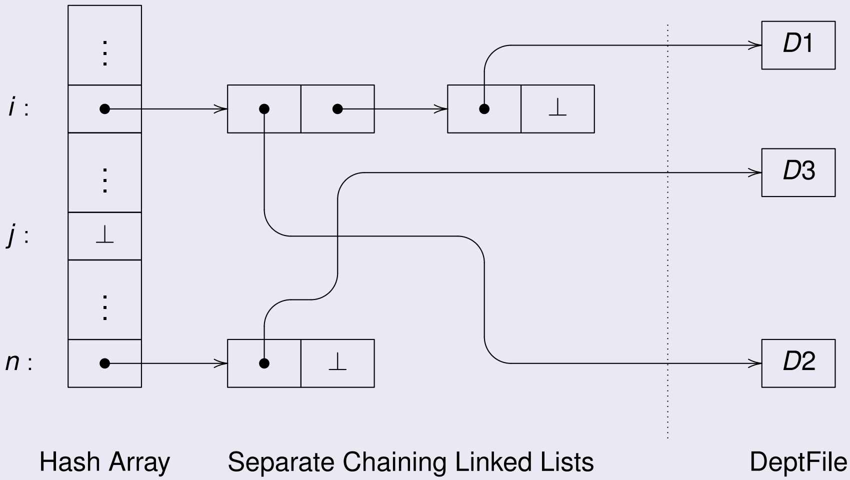
3. $\exists y, v, w.\texttt{employee}(x1, x2, y) \wedge \texttt{works}(x1, v) \wedge \texttt{department}(v, x3, w)$:

```
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



Hashing, Lists, et al.

Access paths:

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

Physical Constraints:

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

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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!

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:

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

$$\begin{aligned}\Rightarrow \Sigma_{LP} \supseteq \{ & \forall x, y.(\texttt{emp-recscan}(y, x) \to \texttt{emp-pgscan}(y)),\\ & \forall x, y_1, y_2.((\texttt{emp-recscan}(y_1, x) \wedge \texttt{emp-recscan}(y_2, x)) \\ & \qquad \to (y_1 \approx y_2)),\\ & \forall x.(\texttt{empfile}(x) \equiv \exists y.\texttt{emp-recscan}(y, x)) \quad \}\end{aligned}$$

Two-level Store Example

Query:

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

Two-level Store Example

Query:

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

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))))))
```

Summary

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