Query Processing for Non-traditional Applications

CS848 Spring 2013

Cheriton School of CS

Query Plans

Physical Design and Query Compilation: Overview

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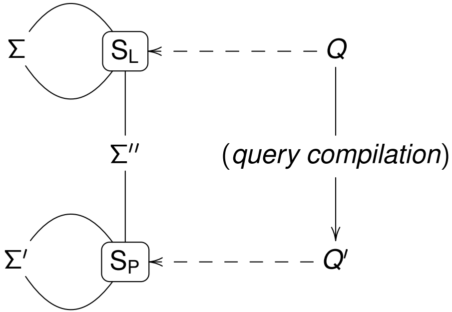

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$$\forall a, y.\texttt{emp-rid-name}(a, y) \rightarrow \exists x.\texttt{emp-rid-eid}(a, x)$$ (same for `-slry`)

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$\forall a, x.\texttt{emp-rid-eid}(a, x) \leftrightarrow \texttt{emp-eid-rid}(x, a)$ (same for $\texttt{-name}$, $\texttt{-slry}$)

Queries over Column Store Physical Design

1. $\texttt{employee}(x, y, z)$

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4. $\exists x.\texttt{employee}(x, y, z)\{y\}$

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Issues to resolve (today)

- Why are the above *plans* implement the *user queries*?
- What "formulas" do qualify as *plans*?

  ⇒ how do we interpret *logical connectives* as programs?
- Are all (desired) *plans* captured by appropriate formulas?

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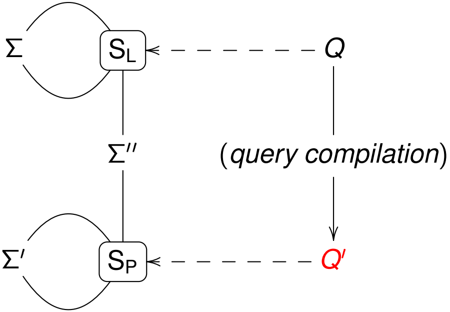

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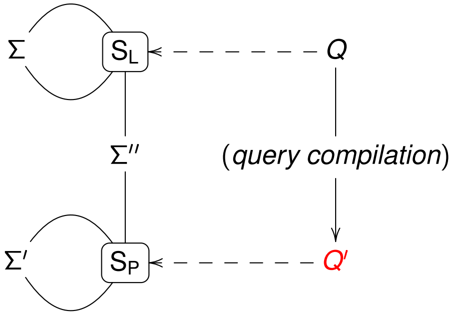

We consider the structure of *Q'*:

- what formulas can be interpreted as *plans*
  - ⇒ how do we deal with *SETS* in programs?
- what additional *non-logical* operations can be used.

Outline

1. Iterator Protocols to communicate Sets (review)
2. Atomic Plan Operations: Access Paths (review)
3. Logical Connectives/Quantifiers as Plan Operators
4. Beyond Logical Operators: Dealing with Duplicates

ACME Case: Access Path Code Templates

Pseudo-code templates realizing a `first/next` protocol for `emp-array0` might be given as follows (variables would be renamed for each occurrence of `emp-array0` in a query plan).

```
function emp-array0-first
  i := 0
  return emp-array0-next
```

```
function emp-array0-next
  i := i + 1
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Assumes a global state recording bindings of (possible copies of) variables.

1. x_1, x_2 and x_3 to communicate the contents of `emp-array`.
2. i and n to record scanning status and size of `emp-array`.

Note: Code templates for access paths must be provided by ACME's DBA department.

Iterator Execution

Hereon, assume **C** denotes the following code that *prints a line* for each result computed by a query plan Q, where $(\text{In}(Q) \cup \text{Out}(Q)) = \{x_1, \ldots, x_m\}$.

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if Q-first
  repeat
    println("x1" = x1, ..., "xm" = xm)
  until not Q-next
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Running **C** for a database (given by interpretation) $\mathcal{I}$ produces the following output.

$$\begin{array}{l} x_1 = e_{1,1},\ x_2 = e_{1,2},\ x_3 = e_{1,3} \\ x_1 = e_{2,1},\ x_2 = e_{2,2},\ x_3 = e_{2,3} \\ \quad\vdots \\ x_1 = e_{n,1},\ x_2 = e_{n,2},\ x_3 = e_{n,3} \end{array}$$

Access Paths

The *access paths* $S_A \subseteq S_P$ are predicate symbols *associated* with a *physical capability* realized by an iterator implementation.

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Requirements (for access path $\mathtt{AP}/k + l/l$:

- given a *fixed values for parameters* there are only finitely many answers (bindings) to the remaining variables, i.e., the set

  $$\{a_1, \ldots, a_k \mid \mathcal{I}, \mathcal{V} \models \exists x_1, \ldots, x_l.\mathtt{AP}(x_1, \ldots, x_l, y_1, \ldots, y_k) \wedge (\bigwedge x_i = p_i)\}$$

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A *plan interpretation* $\mathcal{I}$ satisfies the above for every access path in S_A.

(More Esoteric) Access Paths

1. Built-in "operations":
   - arithmetic (`plus`/3/2, `times`/3/2, etc.)
   - string manipulation (`concat`/3/2, `substr`/4/3, etc.)
   - ...
2. data type tests (`is-integer`/1/1)
3. pointer dereference and field extraction from records
4. (page) reads from external storage
5. ...

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2. If $Q =$ "$\exists x.Q_1$" then $x \notin \mathrm{In}(Q_1)$.

Parameters and User Query Embeddings

Input variables, *output variables* and *user query mapping* are as follows, where $\text{Param}(\text{Uq}(Q)) = \text{In}(Q)$ always holds.

$$\text{In}(Q) = \begin{cases} \text{In}(Q_1) \cup (\text{In}(Q_2) - \text{Out}(Q_1)) & \text{if } Q = \text{“}(Q_1 \wedge Q_2)\text{”}, \\ \text{In}(Q_1) & \text{if } Q = \text{“}\exists x.Q_1\text{”, “}\{Q_1\}\text{”, or “}[Q_1]_i\text{”, and} \\ \emptyset & \text{if } Q = \text{“ }!_i\text{ ”.} \end{cases}$$

$$\text{Out}(Q) = \begin{cases} \text{Out}(Q_1) \cup \text{Out}(Q_2) & \text{if } Q = \text{“}(Q_1 \wedge Q_2)\text{”}, \\ \text{Out}(Q_1) \setminus \{x\} & \text{if } Q = \text{“}\exists x.Q_1\text{”}, \\ \text{Out}(Q_1) & \text{if } Q = \text{“}\{Q_1\}\text{” or “}[Q_1]_i\text{”, and} \\ \emptyset & \text{if } Q = \text{“ }!_i\text{ ”.} \end{cases}$$

$$\text{Uq}(Q) = \begin{cases} (\text{Uq}(Q_1) \wedge \text{Uq}(Q_2)) & \text{if } Q = \text{“}(Q_1 \wedge Q_2)\text{”}, \\ \exists x.\,\text{Uq}(Q_1) & \text{if } Q = \text{“}\exists x.Q_1\text{”}, \\ \text{Uq}(Q_1) & \text{if } Q = \text{“}\{Q_1\}\text{” or “}[Q_1]_i\text{”, and} \\ \text{true} & \text{if } Q = \text{“ }!_i\text{ ”.} \end{cases}$$

Conjunctive Query Plans: Semantics

function $(Q_1 \wedge Q_2)$-first
  if not Q_1-first return false
  while not Q_2-first do
    if not Q_1-next return false
  return true

function $(Q_1 \wedge Q_2)$-next
  if Q_2-next return true
  while Q_1-next do
    if Q_2-first return true
  return false

---

function $(\exists x.Q_1)$-first
  return Q_1-first

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---

function $\{Q_1\}$-first
  if not exists store S
    create S
  if Q_1-first
    empty S
    add $\langle x_1, \ldots, x_n \rangle$ *to S*
    return true
  return false

function $\{Q_1\}$-next
  while Q_1-next do
    if not $\langle x_1, \ldots, x_n \rangle \in S$
      add $\langle x_1, \ldots, x_n \rangle$ *to S*
      return true
  return false

Conjunctive Query Plans: Semantics

```
function ([Q1]i)-first        function ([Q1]i)-next
  cuti := false                 if cuti return false
  return Q1-first               return Q1-next
```

```
function (!i)-first           function (!i)-next
  cuti := true                  return false
  return true
```

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Semantics of compare(x_1, x_2) and assign(x_1, x_2) is given as follows.

```
function compare-first        function compare-next
  if x1 = x2 return true        return false
  return false
```

```
function assign-first         function assign-next
  x2 := x1                      return false
  return true
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Semantics of $\texttt{compare}(x_1, x_2)$ and $\texttt{assign}(x_1, x_2)$ is given as follows.

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function compare-first          function compare-next
  if x1 = x2 return true          return false
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function assign-first           function assign-next
  x2 := x1                        return false
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```

Also assume any theory Σ includes the following.

$$\forall x_1, x_2.\texttt{compare}(x_1, x_2) \equiv \texttt{assign}(x_1, x_2) \equiv (x_1 \approx x_2)$$

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$$\exists u.(\texttt{emp-array0}(u, x, y) \wedge \texttt{compare}(z, u))$$

Input and output variables: $\{z\}$ and $\{x, y\}$, respectively.

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3. If this comparison evaluates to `true` then add the contents of this element to the result.

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2. For each element of `emp-array` returned by this scan, compare the `salary` field with the supplied parameter value z (by using an operator for nested cross product coupled with another atomic query subplan using access path `compare`).
3. If this comparison evaluates to `true` then add the contents of this element to the result.

Note: (a) Duplicate preserving projection has no effect on execution

ACME Case: Scanning and Selection

Consider where the APS department needs a plan that will *report the* `employee-number` *x and* `name` *y of each* `employee` *that has a given* `salary` *z.* A query plan using access path `emp-array0` can now be formulated.

$$\exists u.(\texttt{emp-array0}(u, x, y) \wedge \texttt{compare}(z, u))$$

Input and output variables: $\{z\}$ and $\{x, y\}$, respectively.

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1. Use access path `emp-array0` to scan `emp-array` (an atomic query subplan).
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3. If this comparison evaluates to `true` then add the contents of this element to the result.

Note: (a) Duplicate preserving projection has no effect on execution, and (b) duplicate elimination is not required since employees must have unique employee numbers.

ACME Case: Scanning and Cutting

Consider where the APS department needs a plan that will *report the* `name` *y of any* `employee` *that has a given* `salary` *z and* `employee-number` *x.*

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Consider where the APS department needs a plan that will *report the* `name` y *of any* `employee` *that has a given* `salary` z *and* `employee-number` x*.* A query plan Q using access path `emp-array0` can also be formulated.

$$\exists u, v.(\texttt{emp-array0}(u, v, y) \wedge \texttt{compare}(x, v) \wedge \texttt{compare}(z, u))$$

Input and output variables: $\{y\}$ and $\{x, z\}$, respectively.

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Input and output variables: $\{y\}$ and $\{x, z\}$, respectively. Pseudo-code templates realizing a `first/next` protocol for Q is then defined as follows.

```
function Q-first
  i := 0
  while i < n do
    i := i + 1
    u := emp-array[i].emp-salary
    v := emp-array[i].emp-num
    y := emp-array[i].emp-name
    if x = v
      if z = u return true
  return false
```

```
function Q-next
  while i < n do
    i := i + 1
    u := emp-array[i].emp-salary
    v := emp-array[i].emp-num
    y := emp-array[i].emp-name
    if x = v
      if z = u return true
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Recall that employees have unique employee numbers. Can therefore add cut introduction and named cut operators to Q to improve performance.

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Pseudo-code templates realizing a `first/next` protocol for Q are then modified as follows.

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    if x = v
      if z = u return true
      return false
  return false
```

```
function Q-next
  return false
```

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A query plan using access path `emp-array0` implementing this query is as follows.

$$\{\exists x, y \, . \, \texttt{emp-array0}(z, x, y)\}$$

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The plan uses a top-level duplicate elimination operation that will use temporary store to accumulate new salary values as they occur in a scan of `emp-array` with access path `emp-array0`.

General Query Plans: Syntax

The *query plans* induced by S add two final productions:

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Parameters and User Query Embeddings

Input variables, *output variables* and *user query mapping* are extended as follows, where $\text{Param}(\text{Uq}(Q)) = \text{In}(Q)$ always holds.

$$\text{In}(Q) = \begin{cases} \text{In}(Q_1) \cup \text{In}(Q_2) & \text{if } Q = \text{``}(Q_1 \vee Q_2)\text{''}, \text{ and} \\ \text{In}(Q_1) & \text{if } Q = \text{``}\neg Q_1\text{''}. \end{cases}$$

$$\text{Out}(Q) = \begin{cases} \text{Out}(Q_1) \cap \text{Out}(Q_2) & \text{if } Q = \text{``}(Q_1 \vee Q_2)\text{''}, \text{ and} \\ \emptyset & \text{if } Q = \text{``}\neg Q_1\text{''}. \end{cases}$$

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General Query Plans: Semantics

```
function (Q1 ∨ Q2)-first
  (Q1 ∨ Q2)-flag := true
  if Q1-first return true
  (Q1 ∨ Q2)-flag := false
  return Q2-first
```

```
function (Q1 ∨ Q2)-next
  if (Q1 ∨ Q2)-flag
    if Q1-next return true
  (Q1 ∨ Q2)-flag := false
  return Q2-next
```

```
function (¬Q1)-first
  if Q1-first return false
  return true
```

```
function (¬Q1)-next
  return false
```

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A query plan using access path `emp-array0` implementing this query is as follows.

$$\{(\exists y, z.(\texttt{emp-array0}(z, x, y) \land \texttt{compare}(p_1, z)) \lor \exists u, v.(\texttt{emp-array0}(v, x, u) \land \texttt{compare}(p_2, v)))\}$$

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An execution proceeds as follows.

1. Scan `emp-array` and add the employee number of any employee with a salary given by input parameter p_1 to a temporary store S if not already there.
2. Scan `emp-array` for a second time and add the employee number of any employee with a salary given by input parameter p_2 to S if not already there.

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An alternative plan can be formulated that avoids the need for two scans of `emp-array`.

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The plan illustrates a common plan idiom for determining if a given value occurs in a given small fixed set of values.

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Two possible reasons for requiring top-level duplicate elimination.

1. Individual employee numbers may be related to more than one salary or employee name.
2. Parameters p_1 and p_2 may not be distinct.

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The second reason can be ruled out by modifying the plan to ensure the second subplan for the concatenation operator will only return additional results when p_1 and p_2 are distinct.

$$\begin{aligned}&\exists y, z.(\texttt{emp-array0}(z, x, y)\\ &\quad \wedge (\texttt{compare}(p_1, z) \vee (\neg\, \texttt{compare}(p_1, p_2) \wedge \texttt{compare}(p_2, z))))\end{aligned}$$

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Note that the query mapping for this plan is no longer a positive query.

An alternative plan avoids simple complement by using a cut.

$$\exists y, z.(\texttt{emp-array0}(z, x, y) \wedge [(\texttt{compare}(p_1, z) \vee \texttt{compare}(p_2, z))]_1 \wedge\, !_1))$$

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Two plans using access path `emp-array0` and a simple complement operator are as follows.

$$
\begin{aligned}
&\exists y, z.(\texttt{emp-array0}(z, x, y) \\
&\quad \land \neg \exists u, v, w.(\texttt{emp-array0}(u, v, w) \\
&\qquad \land \texttt{compare}(y, w) \\
&\qquad \land \neg \texttt{compare}(x, v)))
\end{aligned}
$$

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&\exists y, z.(\texttt{emp-array0}(z, x, y) \\
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\end{aligned}$$

Question: Which is more efficient?

When do Plans Implement User Queries?

Requirements

Given a *plan interpretation* $\mathcal{I}$, the plan Q' (driven by **C**) outputs exactly the valuations that make the *user query* Q true in $\mathcal{I}$.

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- we show how to *model* many (if not most) features of standard SQL implementations using the operators introduced today with the help of creative physical design and selection of access paths (next time).

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How do we *actually* find plans?

1. we search for Q' that (as a formula) *is logically equivalent* to Q under the logical and physical schama constraints Σ, and
2. we *improve* Q' by eliminating *duplicate elimination operations* and by inserting *cuts*.

Queries over Column Store Physical Design Revisited

1. $\texttt{employee}(x, y, z)$

   $\exists a.\texttt{emp-eid-rid}(x, a) \wedge \texttt{emp-rid-name}(a, y) \wedge \texttt{emp-rid-slry}(a, z)$
2. $\exists y, z.\texttt{employee}(x, y, z)$

   $\exists a.\texttt{emp-eid-rid}(x, a)$
3. $\exists z.\texttt{employee}(x, y, z)$

   $\exists a.\texttt{emp-eid-rid}(x, a) \wedge \texttt{emp-rid-name}(a, y)$
4. $\exists x.\texttt{employee}(x, y, z)\{y\}$

   $\{\exists a.\texttt{emp-name-rid}(y, a) \wedge \texttt{emp-rid-slry}(a, z)\}$

Results:

- Plans for queries 1-4 are logically equivalent to the given user queries.
- Plans 1-3 can avoid duplicate eimination operator.

Related Issues

- Relational Algebra
- Domain Independence and Range restricted Queries
- Temporary storage
- Ordered properties of iterated semantics (merge joins?)
- Streaming queries