Query Processing for Non-traditional Applications

CS848 Spring 2013

Cheriton School of CS

Advanced Physical Designs

Outline

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- References, pointers and linked structures.
- Nulls, partitions and run-time typing.
- Built-in functions and hashing.
- Two-level store.
- Examples relating to ACME's PAYROLL system.

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- References, pointers and linked structures.
- Nulls, partitions and run-time typing.
- Built-in functions and hashing.
- Two-level store.
- Examples relating to ACME's PAYROLL system.[1]

---

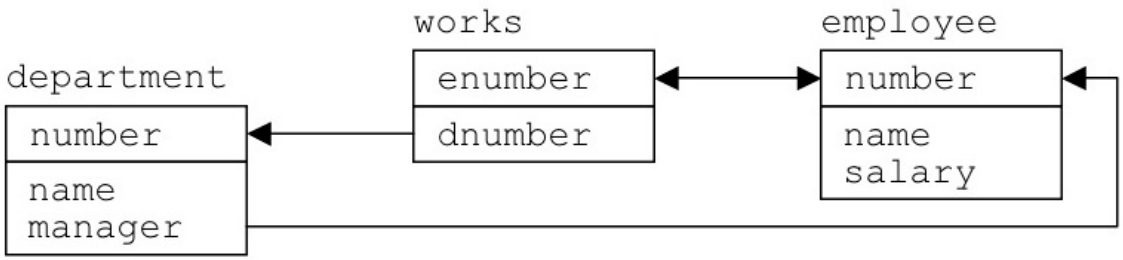
[1] In particular, an extension of the OPTION 1 logical design.

ACME Case: Extending OPTION 1

Assume the APS department extends the logical signature S_L for PAYROLL given by OPTION 1 with two additional predicate symbols to record information about how employees relate to departments.

- $S_L^P = \{\texttt{employee}/3, \texttt{department}/3, \texttt{works}/2\}$, and
- $S_L^F = \emptyset$.

ACME Case: Extending OPTION 1



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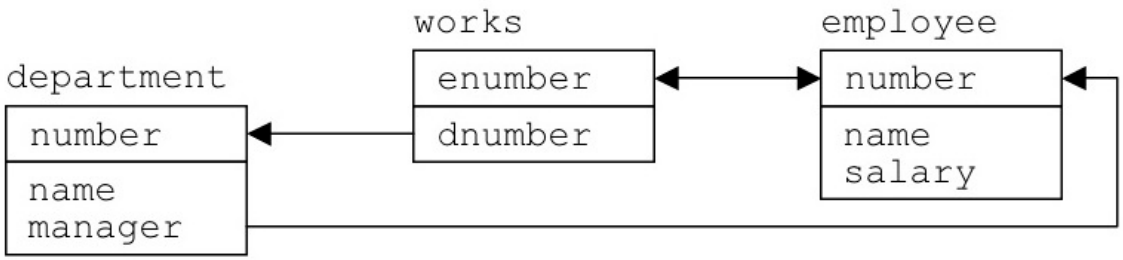

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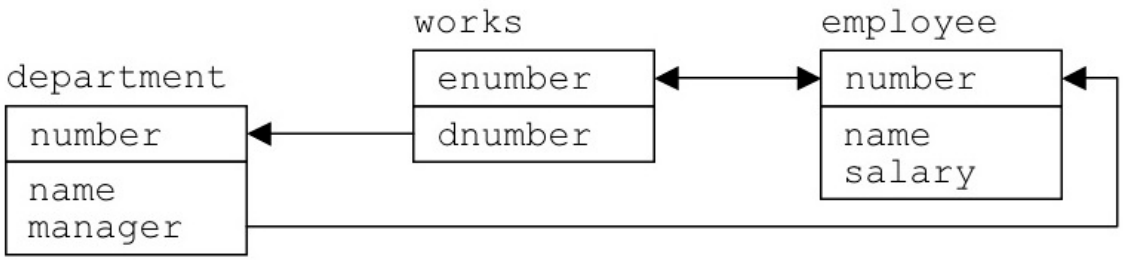

Logical Constraints Σ

1. *Employees can be identified by their number.*

$$\forall x_1, x_2, y_1, y_2.(\exists z.(\texttt{employee}(z, x_1, x_2) \wedge \texttt{employee}(z, y_1, y_2)) \\ \rightarrow ((x_1 \approx y_1) \wedge (x_2 \approx y_2)))$$

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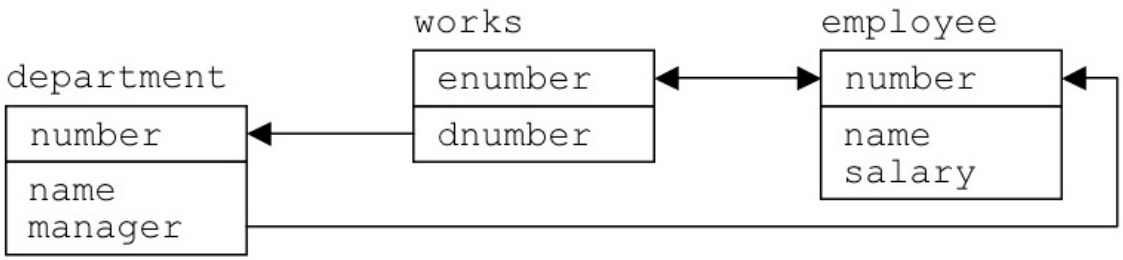

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2. *Departments can also be identified by their number.*

$$\forall x_1, x_2, y_1, y_2.(\exists z.(\texttt{department}(z, x_1, x_2) \wedge \texttt{department}(z, y_1, y_2)) \rightarrow ((x_1 \approx y_1) \wedge (x_2 \approx y_2)))$$

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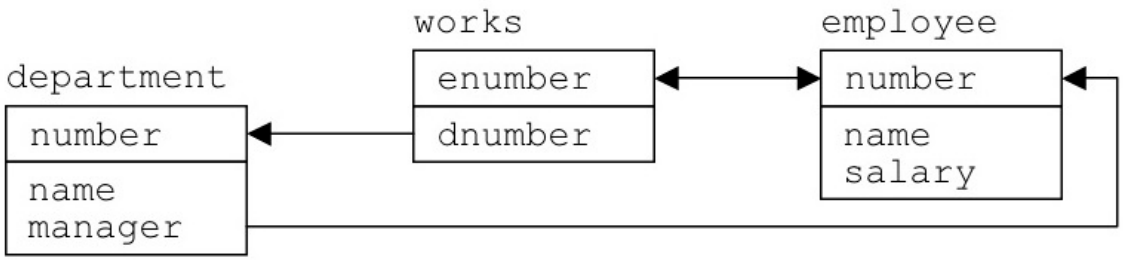

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3. *At most one working relationship to a department can exist for a given employee.*

$$\forall x, y.(\exists z.(\texttt{works}(z, x) \wedge \texttt{works}(z, y)) \rightarrow (x \approx y))$$

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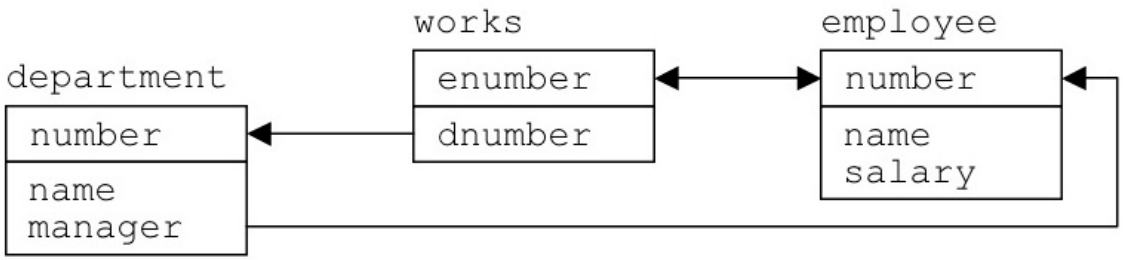

4. *Only employees can be the manager of a department.*

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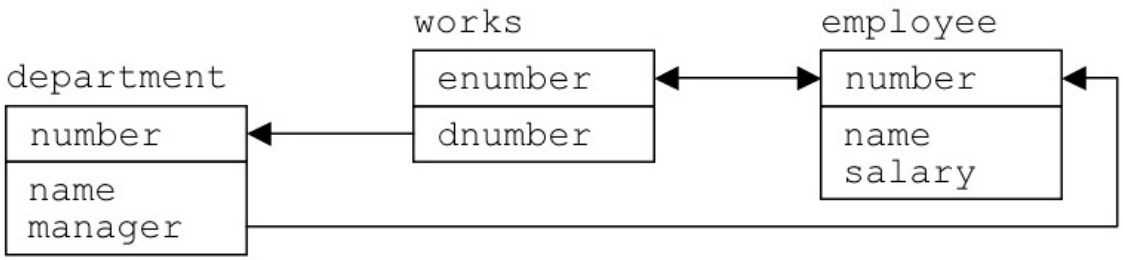

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5. *Working relationships can only exists between employees and departments.*

$$\forall x, y.(\texttt{works}(x, y) \rightarrow \exists u_1, u_2, v_1, v_2.(\texttt{employee}(x, u_1, v_1) \wedge \texttt{department}(y, u_2, v_2)))$$

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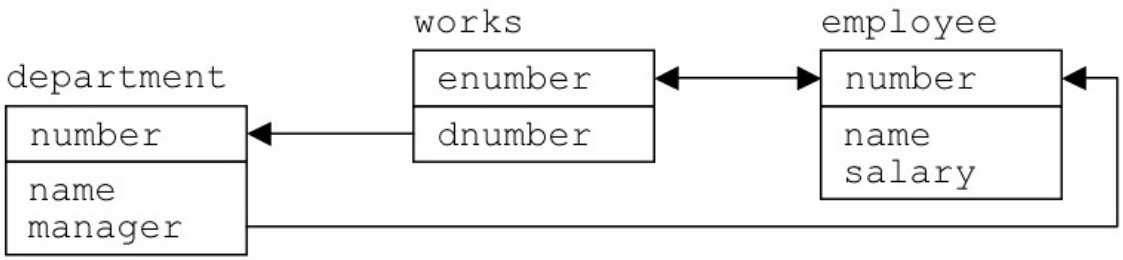

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6. *Every employee must work.*

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

References, Pointers and Linked Structures

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Access to records located in RAM requires *constant time* when search keys correspond to pointer values that *address* or *reference* the store.

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Idiom applies in several circumstances.

- Main memory data.

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- Main memory data.
- Data stored on external devices that provide close to random access: magnetic discs, flash memory, etc.

---

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References, Pointers and Linked Structures

Model this idiom as follows: assume data is organized in *records* of the following form that are located at a particular *address* in the RAM storage.

```
record r of
  field-type_1 f_1
    ⋮
  field-type_k f_k
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Field types can the following.

1. Atomic values, e.g., integers and strings.
2. *Reference* or *pointer* values, called *addresses*, that encode locations of records in RAM store.

Records are captured by a collection of access paths.

$$\{\texttt{r-f}_1/2/1, \ldots, \texttt{r-f}_k/2/1\}$$

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Intended meaning of the following atomic query plan is to interpret the binding for variable x_1 as an address of an "r" record.

$$\mathtt{r}\text{-}\mathtt{f}_i(x_1, x_2)$$

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With respect to our `first/next` protocol, pseudocode that reflects this intended meaning is given as follows.

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function r-fi-first
   x2 := x1 -> fi
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Also assume each access path is associated with a constraint ensuring the operation of extracting a field from a record is a function.

$$\forall x, y_1, y_2.((\texttt{r-f}_i(x, y_1) \wedge \texttt{r-f}_i(x, y_2)) \rightarrow (y_1 \approx y_2))$$

ACME Case: Extended Option 1 Physical Design

Represent individual `employee` and `department` entities as records conforming to the following `emp` and `dept` declarations.

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

```
record dept of
     integer    num
     string     name
     reference  manager
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[1] These data structures allow us to scan the addresses of all `emp` records that represent `employee` entities.

ACME Case: Extended Option 1 Physical Design

A physical design for this data encoding is given as follows.

Physical Signature

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

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Physical Constraints Σ' (a selection)

1. *Every* `emp` *record has all its fields*.

$$\begin{array}{ll} (a) & \forall x.(\texttt{empfile}(x) \rightarrow \exists y.\texttt{emp-num}(x, y)) \\ (b) & \forall x.(\texttt{empfile}(x) \rightarrow \exists y.\texttt{emp-name}(x, y)) \\ (c) & \forall x.(\texttt{empfile}(x) \rightarrow \exists y.\texttt{emp-salary}(x, y)) \\ (d) & \forall x.(\texttt{empfile}(x) \rightarrow \exists y.\texttt{emp-dept}(x, y)) \end{array}$$

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2. *The range of* `emp-dept` *is a* `dept` *record in* `deptfile`.

$$\forall x, y.(\texttt{emp-dept}(x,y) \rightarrow \texttt{deptfile}(y))$$

ACME Case: Extended Option 1 Physical Design

3. *Every* `dept` *record has all its fields.*

$$
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(b) & \forall x.(\texttt{deptfile}(x) \rightarrow \exists y.\texttt{dept-name}(x, y)) \\
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4. *The range of* `dept-manager` *is an* `emp` *record in* `empfile`.

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Mapping Constraints Σ'' (a selection)

1. *For every* `employee` *there is an* `emp` *record.*

$$\forall x.y, z.(\texttt{employee}(x, y, z) \rightarrow \exists w.(\texttt{empfile}(w) \wedge \texttt{emp-num}(w, x)))$$

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2. *The contents of the* `name` *field of an* `emp` *record corresponding to a particular* `employee` *contains this employee's name.*

$$\forall x, y, z, w.((\texttt{employee}(x, y, z) \wedge \texttt{emp-num}(w, x)) \rightarrow \texttt{emp-name}(w, y))$$

ACME Case: Extended Option 1 Physical Design

3. *Same for the* `salary` *field.*

$$\forall x, y, z, w.((\texttt{employee}(x, y, z) \wedge \texttt{emp-num}(w, x)) \rightarrow \texttt{emp-salary}(w, z))$$

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4. *The contents of the* `dept` *field of an* `emp` *record is a reference to the* `dept` *record that represents the* `department` *for which this employee* `works`.

$$\forall x, y, z, w, u, v.((\texttt{employee}(x, y, z) \wedge \texttt{emp-num}(w, x) \wedge \texttt{works}(x, u) \wedge \texttt{dept-num}(v, u)) \rightarrow \texttt{emp-dept}(w, v))$$

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5. *Every* `emp` *record in* `empfile` *represents an* `employee`.

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6. *Every* `emp` *record and the associated* `dept` *record referenced by the* `dept` *field represents a* `works` *relationship.*

$$\forall x, y, v, w.((\texttt{empfile}(w) \wedge \texttt{emp-num}(w, x) \wedge \texttt{emp-dept}(w, v) \wedge \texttt{dept-num}(v, y)) \rightarrow \texttt{works}(x, y))$$

ACME Case: Extended Option 1 Physical Design

7. *For every* `department` *there is a* `dept` *record.*

$$\forall x, y, z.(\texttt{department}(x, y, z) \rightarrow \exists w.(\texttt{deptfile}(w) \wedge \texttt{dept-num}(w, x)))$$

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7. *For every* `department` *there is a* `dept` *record.*

$$\forall x, y, z.(\texttt{department}(x, y, z) \rightarrow \exists w.(\texttt{deptfile}(w) \wedge \texttt{dept-num}(w, x)))$$

8. *Every* `dept` *record has the proper contents for its* `name` *field.*

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9. *Same for its* `manager` *field.*

$$\begin{aligned}\forall x, y, z, w.((&\texttt{department}(x, y, z) \wedge \texttt{dept-num}(w, x)) \\ &\rightarrow \exists v.(\texttt{dept-manager}(w, v) \wedge \texttt{emp-num}(v, z)))\end{aligned}$$

ACME Case: Extended Option 1 Physical Design

7. *For every* `department` *there is a* `dept` *record.*

$$\forall x, y, z.(\texttt{department}(x, y, z) \rightarrow \exists w.(\texttt{deptfile}(w) \wedge \texttt{dept-num}(w, x)))$$

8. *Every* `dept` *record has the proper contents for its* `name` *field.*

$$\forall x, y, z, w.((\texttt{department}(x, y, z) \wedge \texttt{dept-num}(w, x)) \rightarrow \texttt{dept-name}(w, y))$$

9. *Same for its* `manager` *field.*

$$\begin{aligned}\forall x, y, z, w.((&\texttt{department}(x, y, z) \wedge \texttt{dept-num}(w, x)) \\ &\rightarrow \exists v.(\texttt{dept-manager}(w, v) \wedge \texttt{emp-num}(v, z)))\end{aligned}$$

10. *Every* `dept` *record in the* `deptfile` *represents a* `department`.

$$\begin{aligned}\forall x, y, z, w, v.((&\texttt{dept-num}(w, x) \wedge \texttt{dept-name}(w, y) \wedge \texttt{dept-manager}(w, v) \wedge \texttt{emp-num}(v, z)) \\ &\rightarrow \texttt{department}(x, y, z))\end{aligned}$$

ACME Case: Extended Option 1 Queries and Plans

ACME's APS department specifies a user query Q to *list employee numbers, names and department names for all employees*.

$$\exists y, v, w.(\texttt{employee}(x_1, x_2, y) \wedge \texttt{works}(x_1, v) \wedge \texttt{department}(v, x_3, w))$$

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1. $\Sigma \models Q \lhd Q'$, where Σ consists of the above physical design.

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Observations

1. $\Sigma \models Q \lhd Q'$, where Σ consists of the above physical design.
2. Nested loops joins combined with the pseudocode for the field extraction access paths yield the desired plan.
3. Once a reference to an employee record is obtained, all emaining operations are dereferencing operations that run in $O(1)$ in the RAM model.

ACME Case: Extended Option 1 Queries and Plans

Consider the following.

- A functional constraint in the physical design stating that the `emp` records correspond *one-to-one* to `employee` entities.

$$\forall x, y_1, y_2.(\texttt{emp-num}(y_1, x) \wedge \texttt{emp-num}(y_2, x)) \rightarrow (y_1 \approx y_2)$$

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Observations

1. The final duplicate elimination operation has been omitted.
2. The plan runs in $O(n)$ time, where n is the number of employee entities (recall that the underlying data structure with `emp` records is an array or linked list.)

Exercise: Listing Departments

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ACME Case: Nested Loops and Secondary Indices

Assume ACME's APP department specifies a user query that *list pairs of employee numbers of employees with the same name*.

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

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[1] An additional *access path* that allows us to efficiently find references to employee records given an employee *name* would enable plans for the query that avoid this.

ACME Case: Nested Loops and Secondary Indices

Consider adding the following access path and constraint.

$$\texttt{empidx-name}/2/1$$

$$\forall x, y.(\texttt{eidx-name}(x, y) \equiv (\texttt{empfile}(y) \wedge \texttt{emp-name}(y, x)))$$

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This difference is the basis for classifying indexes as *primary* or *secondary*.

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Observations

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2. Could also have embedded `emp` records in the search structure.

This difference is the basis for classifying indexes as *primary* or *secondary*. Allowing references to be first-class citizens in the physical design removes any need for the latter notion.

ACME Case: Optional Department Assignments

Consider removing the following constraint from the extended OPTION 1 design of PAYROLL.

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

The change means that employees may not be associated with any department, a relaxed design in which each employee now works for *at most one* department.

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Goal: To accommodate this change in requirements *without* the need for a major modification of the physical design.

1. Employees and departments continue to be represented by the `emp` and `dept` records.
2. *Signal* that an employee is *not* associated with a department by filling the `dept` field of the associated `emp` record with some `null` value.

ACME Case: Optional Department Assignments

To model this situation, we alter the physical design with constraints relating to this `null` value.

Modified Physical Constraints

1. *The* `dept` *field of an* `emp` *record either contains a* `null` *value or a non-*`null` *reference to a* `dept` *record representing a department.*

$$\forall x, y.(\texttt{emp-dept}(x, y) \rightarrow (\texttt{null}(y) \vee \exists z.\texttt{notnull}(y, z)))$$

$$\forall x, y, z.((\texttt{emp-dept}(x, y) \wedge \texttt{notnull}(y, z)) \rightarrow \texttt{deptfile}(z))$$

Nulls Indicating Value Inapplicable

It is a common idiom in a *physical design* to model missing *optional information* using a default `null` value.

The following access path implements a generic test for a `null` reference.

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Assumes following pseudocode.

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function null-first
  if (x1 == NULL) return true
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Also assume any physical design includes the following constraint ensuring there is at most one `NULL` value.

$$\forall x, y.((\texttt{null}(x) \wedge \texttt{null}(y)) \rightarrow (x \approx y))$$

ACME Case: Checking for Nulls

Assume ACME's APP department specifies a user query that *lists numbers and names of all employees that do not work for any department*.

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

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The following is a query plan implementing the query with respect to the modified physical design.

$$\exists y, z.(\texttt{empfile}(y) \wedge \texttt{emp-num}(y, x_1) \wedge \texttt{emp-name}(y, x_2) \\ \wedge \texttt{emp-dept}(y, z) \wedge \texttt{null}(z))$$

Non-Null Type Casting

The following access path implements a generic type casting for non-null values.

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Also assume any physical design includes the following constraints.

$$\forall x, y, z.((\texttt{notnull}(x, y) \wedge \texttt{notnull}(x, z)) \rightarrow (y \approx z))$$

$$\forall x.((\exists y.\texttt{notnull}(x, y)) \equiv \neg\, \texttt{null}(x))$$

ACME Case: Ensuring Non-Nulls

Assume ACME's APP department specifies a user query that *lists employee numbers, names and department names for all employees (who must now work for a department)*.

$$\exists y, z, w.(\texttt{employee}(x_1, x_2, y) \wedge \texttt{works}(x_1, z) \wedge \texttt{department}(z, x_3, w))$$

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ACME Case: Partitioning Employee Records

Consider the following three constraints.

$$\forall x.(\texttt{empfile-low}(x) \equiv \exists y.(\texttt{empfile}(x) \wedge \texttt{emp-sal}(x, y) \wedge (y \leq 30k)))$$

$$\forall x.(\texttt{empfile-mid}(x) \equiv \exists y.(\texttt{empfile}(x) \wedge \texttt{emp-sal}(x, y) \wedge (30k < y) \wedge (y \leq 130k)))$$

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Assumes constants and that integer values come with predicates denoting a linear order "$\leq$" and a strict linear order "$<$" interpreted in the standard way.[1]

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[1] This is a violation of our assumption that signatures are free of constant and function symbols that is easily rectified.

ACME Case: Partitioning Employee Records

Assume the APS department wishes to *list employee numbers for employees making at most* $130k$.

$$\exists y, z.(\texttt{employee}(x_1, y, z) \wedge (z \leq 130k))$$

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Assume the APS department wishes to *list employee numbers for employees making at most* $130k$.

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Also assume the physical signature for PAYROLL is revised as follows.

- $\{\texttt{empfile}/1\} \subseteq (S_P - S_A)$.
- $\{\texttt{empfile-low}/1/0, \texttt{empfile-mid}/1/0, \texttt{empfile-high}/1/0\} \subseteq S_A$.

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$$\exists y, z.(\texttt{employee}(x_1, y, z) \wedge (z \leq 130k))$$

Also assume the physical signature for PAYROLL is revised as follows.

- $\{\texttt{empfile}/1\} \subseteq (S_P - S_A)$.
- $\{\texttt{empfile-low}/1/0, \texttt{empfile-mid}/1/0, \texttt{empfile-high}/1/0\} \subseteq S_A$.

The following plan using concatenation then implements this query.

$$\exists y.((\texttt{empfile-low}(y) \vee \texttt{empfile-mid}(y)) \wedge \texttt{emp-num}(y, x_1))$$

ACME Case: Partitioning Employee Records

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This plan assumes that the partition covers all employee records and that constraints such as

$$\forall x.((x \leq 130k) \rightarrow (x \leq 30k))$$

can also be deduced.

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Assume the signature of PAYROLL is revised as follows.

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The revision modifies the logical design of PAYROLL.

1. Adds a "subclass" of `employee` called `high-employee`.
2. Introduces the access path `emp-high` to enable checking at run-time for membership in `high-employee`.

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2. *A reference to an* `emp` *record for an employee is also a reference to* `emp` *record for a highly paid employee whenever the reference also qualifies as* `emp-high`.

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A query plan that implements this query is given as follows.

$$\exists y.(\texttt{empfile}(y) \wedge \texttt{emp-high}(y) \wedge \texttt{emp-num}(y, x))$$

Pages and Records: Two-level Store

Physical Signature: $\{\texttt{emp-pgscan}/1/0, \texttt{emp-recscan}/2/1\} \subseteq S_A$
($\texttt{empfile}/1/0$ is no longer an access path).

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Constraints:

1. *Every reference to an* `emp` *record can be obtained by scanning some page of the two-level employee store*:

$$\forall x.(\texttt{empfile}(x) \equiv \exists y.\texttt{emp-recscan}(y, x)).$$

2. *Every record belongs to some page of the two level store*:

$$\forall x, y.(\texttt{emp-recscan}(y, x) \rightarrow \texttt{emp-pgscan}(y)).$$

3. *Every record belongs to a single page in two level store*:

$$\forall x, y_1, y_2.((\texttt{emp-recscan}(y_1, x) \wedge \texttt{emp-recscan}(y_2, x)) \rightarrow (y_1 \approx y_2)).$$

Two-level Store:Queriesand Plans

Query:

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

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Plan:

$$\begin{aligned}\exists y, z, w, v, p, q.\ (&\texttt{emppgscan}(p) \wedge \texttt{emppgscan}(q)\\ &\wedge \texttt{emprecscan}(p, y) \wedge \texttt{emp-num}(y, x_1) \wedge \texttt{emp-name}(y, w)\\ &\wedge \texttt{emprecscan}(q, z) \wedge \texttt{emp-num}(z, x_2) \wedge \texttt{emp-name}(z, v)\\ &\wedge \texttt{compare}(w, v)).\end{aligned}$$

Further Topics in Physical Design

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