# Evaluation of Recursive Queries

*Part 2: Pushing Selections*



## Aggregate Operators

```
SELECT A.Part, SUM(A.Qty)
FROM Assembly A
GROUP BY A.Part
```

```
NumParts(Part, SUM(<Qty>)) :- Assembly(Part, Subpt, Qty).
```

- The < … > notation in the head indicates grouping; the remaining arguments (Part, in this example) are the GROUP BY fields.
- In order to apply such a rule, must have all of Assembly relation available.
- Stratification with respect to use of < … > is the usual restriction to deal with this problem; similar to negation.



## Datalog vs. SQL Notation

- Don't let the rule syntax of Datalog fool you: a collection of Datalog rules can be rewritten in SQL syntax, if recursion is allowed.

```
WITH RECURSIVE Comp(Part, Subpt) AS

(SELECT A1.Part, A1.Subpt FROM Assembly A1)
UNION
(SELECT A2.Part, C1.Subpt
 FROM Assembly A2, Comp C1
 WHERE A2.Subpt=C1.Part)

SELECT * FROM Comp C2
```



## Evaluation of Datalog Programs

- Repeated inferences: When recursive rules are repeatedly applied in the naïve way, we make the same inferences in several iterations.
- Unnecessary inferences: Also, if we just want to find the components of a particular part, say wheel, computing the fixpoint of the Comp program and then selecting tuples with wheel in the first column is wasteful, in that we compute many irrelevant facts.



## Avoiding Repeated Inferences

- Seminaive Fixpoint Evaluation: Avoid repeated inferences by ensuring that when a rule is applied, at least one of the body facts was generated in the most recent iteration. (Which means this inference could not have been carried out in earlier iterations.)
  - For each recursive table P, use a table delta_P to store the P tuples generated in the previous iteration.
  - Rewrite the program to use the delta tables, and update the delta tables between iterations.

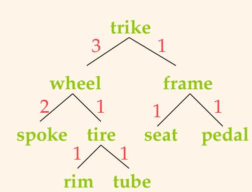
```
Comp(Part, Subpt) :- Assembly(Part, Part2, Qty),
                     delta_Comp(Part2, Subpt).
```



## Avoiding Unnecessary Inferences

```
SameLev(S1,S2) :- Assembly(P1,S1,Q1), Assembly(P1,S2,Q2).
SameLev(S1,S2) :- Assembly(P1,S1,Q1),
                  SameLev(P1,P2), Assembly(P2,S2,Q2).
```

- There is a tuple (S1,S2) in SameLev if there is a path up from S1 to some node and down to S2 with the same number of up and down edges.



## Avoiding Unnecessary Inferences

- Suppose that we want to find all SameLev tuples with spoke in the first column. We should "push" this selection into the fixpoint computation to avoid unnecessary inferences.
- But we can't just compute SameLev tuples with spoke in the first column, because some other SameLev tuples are needed to compute all such tuples:

**SameLev(spoke,seat) :- Assembly(wheel,spoke,2),**
**SameLev(wheel,frame), Assembly(frame,seat,1).**



## "Magic Sets" Idea

- Idea: Define a "filter" table that computes all relevant values, and restrict the computation of SameLev to infer only tuples with a relevant value in the first column.

**Magic_SL(P1) :- Magic_SL(S1), Assembly(P1,S1,Q1).**
**Magic_SL(spoke).**

**SameLev(S1,S2) :- Magic_SL(S1), Assembly(P1,S1,Q1), Assembly(P1,S2,Q2).**
**SameLev(S1,S2) :- Magic_SL(S1), Assembly(P1,S1,Q1), SameLev(P1,P2), Assembly(P2,S2,Q2).**



## The Magic Sets Algorithm

- Generate an "adorned" program
  - Program is rewritten to make the pattern of bound and free arguments in the query explicit; evaluating SameLevel with the first argument bound to a constant is quite different from evaluating it with the second argument bound
  - This step was omitted for simplicity in previous slide
- Add filters of the form "Magic_P" to each rule in the adorned program that defines a predicate P to restrict these rules
- Define new rules to define the filter tables of the form Magic_P



## Generating Adorned Rules

- The adorned program for the query pattern SameLev$^{bf}$, *assuming a left-to-right order of rule evaluation* :

**SameLev$^{bf}$ (S1,S2) :- Assembly(P1,S1,Q1), Assembly(P1,S2,Q2).**

**SameLev$^{bf}$ (S1,S2) :- Assembly(P1,S1,Q1),**
**SameLev$^{bf}$ (P1,P2), Assembly(P2,S2,Q2).**

- An argument of (a given body occurrence of) SameLev is b if it appears to the left in the body, or in a b arg of the head of the rule.
- Assembly is not adorned because it is an explicitly stored table.



## Defining Magic Tables

- After modifying each rule in the adorned program by adding filter "Magic" predicates, a rule for Magic_P is generated from each occurrence O of P in the body of such a rule:
  - Delete everything to the right of O
  - Add the prefix "Magic" and delete the free columns of O
  - Move O, with these changes, into the head of the rule

**SameLev$^{bf}$ (S1,S2) :- Magic_SL$^{bf}$(S1), Assembly(P1,S1,Q1),**
**SameLev$^{bf}$ (P1,P2), Assembly(P2,S2,Q2).**

**Magic_SL$^{bf}$(P1) :- Magic_SL$^{bf}$(S1), Assembly(P1,S1,Q1).**



## Nested Queries in SQL (No Recursion)

```
SELECT    E, Sal, Avg, Ecnt
FROM      emp(E, Sal, D, J),
          dinfo(D, Avg, Ecnt)
WHERE     J = "Sr pgmer"

dinfo(D, A, C) AS
   SELECT      D, AVG(Sal), count(*)
   FROM        emp
   GROUPBY     D
```

"Find senior programmers and their salary, and also average salary and headcount in their depts."

## Example – Datalog and Magic

- Datalog
  - Einfo(E, Sal, Avg, Ecnt) :- J="Sr pgmer", emp(E, Sal, D, J), dinfo(D, Avg, Ecnt).
  - dinfo(D, A, C) :- …
- MAGIC
  - m_emp$^{fffb}$(J) :- J="Sr pgmer".
  - m_dinfo$^{bff}$(D) :- { J = "Sr pgmer" }, m_emp$^{fffb}$(J), emp(E, Sal, D, J).
  - dinfo$^{bff}$(D, A, C) :- m_dinfo$^{bff}$(D), …



## Magic

1. Identifies subqueries

   Idea: Use rules of the form:
   If <…> is a (sub)query and also conditions <…> hold,
   Then <…> are also subqueries.
2. Restricts computation

   Idea: Modify the view definition by joining with the table of queries.
   This join acts as a "Filter".
3. Classify queries

   Idea: Using "Adornments", or "Query forms". All queries of the form p$^{bf}$(c,y)? are "MAGIC" tuples m_p$^{bf}$(c).
4. Magic on subqueries  :- …, p(x, y, z), $q_1$(y, u), $q_2$(z, y) …

   Can use magic for $q_1$ subqueries:
   m_$q_1$(y) :- … p(x, y, z).
   $q_1$(x, y) :- m_$q_1$(x), …
   $q_2$ subqueries handled some other way.

So, suitable for rule-based optimizer.



## Dealing with Subqueries – Other ways

- CORRELATION

  When a subquery is generated, compute all answers , then continue.
  - Not (gasp!) set-oriented.
  - Current DB solution. (DB2 etc.)
- PROLOG

  When a subquery is generated, compute one answer, then continue.
  - May have to "BACKTRACK".



## Example – Recursion, Duplicates

```
SELECT      P, S, count(*)
FROM        contains(P, S)
GROUPBY     [P, S]

Contains(p, s)    AS
   (    SELECT P, S
        FROM          subpart(P, S) ) UNION
   (    SELECT P, S
        FROM          subpart(P, T),
                      contains(T, S) )
```

"Find all subparts of a part along with a count of how often the subpart is used."



## Correlation

```
OUTER  SELECT     Ename
       FROM       emp e1
       WHERE      Job = "Sr pgmer" AND
                  Sal >
INNER             (     SELECT      AVG(e2,Sal)
                        FROM        emp e2
                        WHERE       e2.D = e1.D )
```

For each senior programmer, the average salary of her/his department is computed.

- Not set-oriented.
- Possible redundancy.



## Decorrelation

```
SELECT     Ename
FROM       emp, dep_avgsal
WHERE      Job = "Sr pgmer"       AND
           Sal > Asal             AND
           emp.D = dep_avgsal.D

      dep_avgsal     AS
           SELECT         D, AVG(Sal)
           FROM           emp
           GROUPBY        D
```

- Set-oriented, no redundancy.
- But…, irrelevant computation.

## Voila! Magic!

```
SELECT Ename
FROM   emp, dep_avgsal
WHERE  Job = "Sr pgmer"  AND
       Sal > Asal AND emp.D = dep_avgsal.D
```

```
msg(D)          AS
    SELECT      DISTINCT   D
    FROM        emp
    WHERE       Job = "Sr pgmer"

dep_avgsal(D, ASal)   AS
    SELECT      D, AVG(Sal)
    FROM        msg, emp
    WHERE       msg.D = emp.D
    GROUPY      D
```



## From Datalog to SQL

- Conditions
  - X + Y >10
- Grouping and aggregation

| | | |
|---|---|---|
| John | toy | 20 |
| Joe | toy | 30 |
| Susan | cs | 50 |
| David | cs | * |

avgsal = 25

- Multisets
  - If you don't remove duplicates. That is a feature!



## Example- Conditions

```
SELECT      Ename, Mgr
FROM        emp, dept
WHERE       Job = "Sr pgmer"   AND
            Sal > 50000        AND
            emp.D = dept.D
```

Cast Magic

m_emp$^{fbfb}$(Sal, Job) AS

Job = "Sr Pgmer" AND

Sal > 50000

What really happens?

$$\left(\sigma_{\substack{job=\text{"Sr Pgmer"}\\ Sal>50000}} emp\right) \bowtie_{D=D} dept$$

"Grounding"



## Datalog to SQL: A summary

Conditions
- Magic transformation is followed by some "GROUNDING" steps.

Multisets (Duplicates)

Semantics
- # copies of a tuple = # of derivations

Operationally
- Just skip duplicate checks

Magic
- All "magic" tables are DISTINCT

Groupby, Aggregates
- Must check if restrictions (selections, conditions) can be "pushed down"
- With recursion, may need stratification.



## Comparing Magic and Correlation

We must consider three factors:
1. Binding propagation
2. Repeated work (duplicates)
3. Set-Orientation

| | Correlation* | Magic |
|---|---|---|
| 1. | √ | √ |
| 2. | × (√) | √ |
| 3. | × | √ |



## Experiments

Experiments run on DB V2R2 DBMS.

Benchmark DB

| Table | Tuple Size | #Tuples | #Column | #4k Pages |
|---|---|---|---|---|
| itm | 34 | 170,000 | 4 | 1,850 |
| wkc | 28 | 500 | 10 | 5 |
| Itl | 78 | 2,550,000 | 13 | 57,980 |
| itp | 43 | 339,440 | 14 | 4,250 |

## Results

Experiment 1

Binding propagation, no duplicates, set-orientation not significant.

| Query | Time | I/O |
|---|---|---|
| Original | 100 | 100 |
| Correlated | 0.40 | 0.06 |
| Magic | 0.46 | 0.25 |

Experiment 2

Binding set contains duplicates (~100), set-orientation not significant.

| Query | Time | I/O |
|---|---|---|
| Original | 100 | 100 |
| Correlated | 2.10 | 0.005 |
| Magic | 0.25 | 0.069 |



## Results – Cont.

Experiment 3

Binding set has some duplicates, set-orientation is significant. (Bindings on non-index column)

| | Query | Time | I/O |
|---|---|---|---|
| 10 bindings | Original | 100 | 100 |
| | Correlated | 513 | 453 |
| | Magic | 55 | 46 |
| 100 bindings | Original | 100 | 100 |
| | Correlated | 5136 | 4526 |
| | Magic | 111 | 62 |

Experiment 4

Variant of experiments 3 with more expensive subquery. (10 binding).

| Query | Time | I/O |
|---|---|---|
| Original | 100 | 100 |
| Correlated | 52.5 | 22.7 |
| Magic | 8.6 | 5.2 |



## Conclusions

- Magic is:
  - Applicable to full SQL.
  - Suitable for rule-based optimization.
  - Efficient.
  - Stable.
  - Parallelizable.