CSE 544 Principles of Database Management Systems

Fall 2016

Lecture 9 – Structural query optimization

Conjunctive Queries

- Definition:
  Q(X) :- R1(X1), R2(X2), ..., Rm(Xm)
- Same as a single datalog rule
- Terminology:
  - Atoms
  - Head variables
  - Existential variables

- CQ = denotes the set of conjunctive queries

Examples

- Example of CQ

$$q(x,y) = \exists z.(R(x,z) \wedge \exists u.(R(z,u) \wedge R(u,y)))$$

$$q(x) = \exists z.\exists u.(R(x,z) \wedge R(z,u) \wedge R(u,y))$$

- Examples of non-CQ:

$$q(x,y) = S(x,y) \wedge \forall z.(R(x,z) \rightarrow R(y,z))$$

$$q(x) = T(x) \vee \exists z.S(x,z)$$

Types of CQ

- **Full** CQ: head variables are all variables
  Q(x,y,z,u) :- R(x,y),S(y,z),T(z,u)

- **Boolean** CQ: no head variables
  Q() :- R(x,y),S(y,z),T(z,u)

- With or without self-joins:
  Q(x,u) :- R(x,y),S(y,z),R(z,u)
  Q(x,u) :- R(x,y),S(y,z),T(z,u)

Extensions

- With inequalities $CQ^{<}$:
  Q(x) :- R(x,y),S(y,z),T(z,u),y<u
- With disequalities $CQ^{\neq}$:
  Q(x) :- R(x,y),S(y,z),T(z,u),y≠u
- With aggregates:
  Q(x,count(*)) :- R(x,y),S(y,z),T(z,u)
  Q(x, sum(u)) :- R(x,y),S(y,z),T(z,u)

Complexity of Query Evaluation

- The query evaluation problem is this:
  given a query Q and a database D, compute Q(D)

- Three complexity measures:
  - **Data complexity**. Fix Q. The complexity is f(|D|)
    Variation: f(|Input|, |Output|)
  - **Query (or expression) complexity**. Fix D. The complexity is f(|Q|)
  - **Combined complexity**. The complexity if f(|D|,|Q|)

- Example: data complexity of R ⋈ S

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- Discuss more about complexity in class...

Question in Class

- Q(x,w) :- R(x,y),S(y,z),T(z,u),K(u,v),L(v,w)
- Assume |R|=|S|=|T|=|K|=|L| = N
- What is the complexity of Q?

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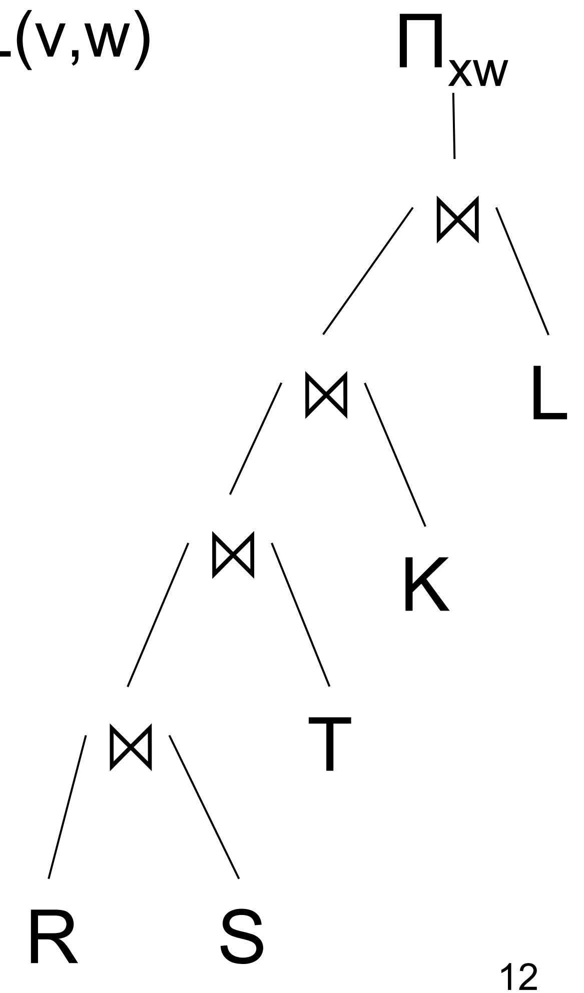
- What is the complexity of this plan?



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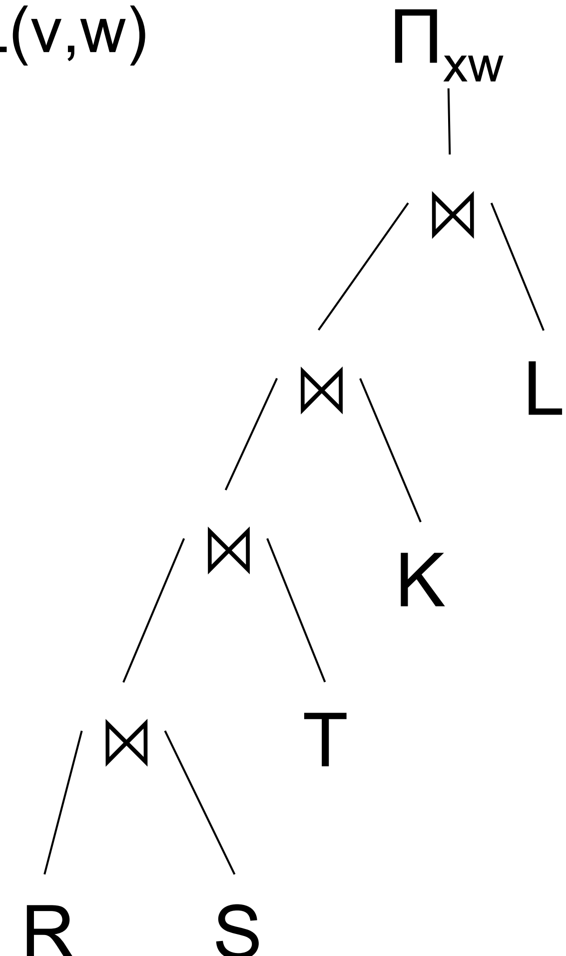
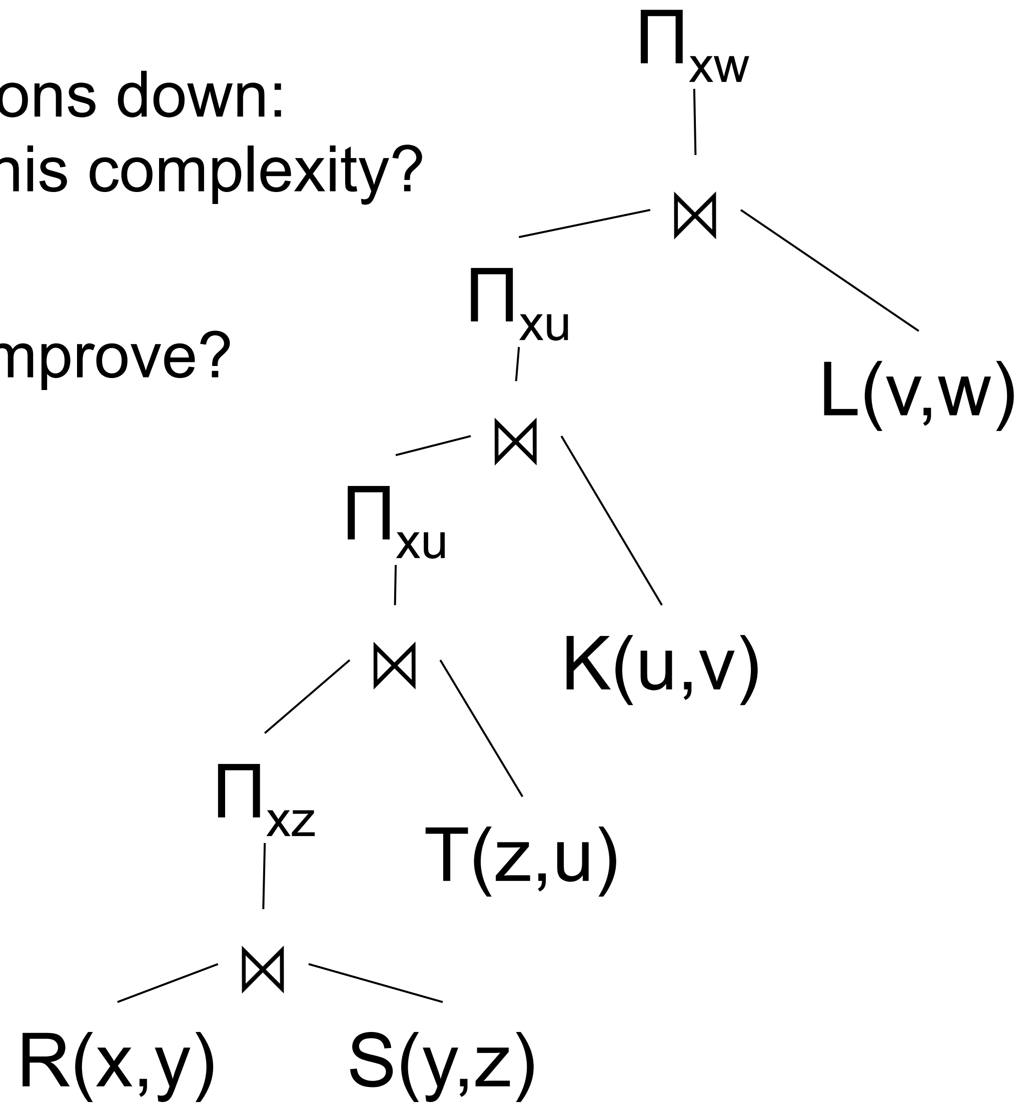
- Assume |R|=|S|=|T|=|K|=|L| = N
- What is the complexity of Q?
- What is the complexity of this plan?
- Can you find a more efficient plan?



Question in Class

- Push projections down:
  What about this complexity?

- Can we still improve?



Law of Semijoins

- Input: R(A1,…An), S(B1,…,Bm)
- Output: T(A1,…,An)

Definition: the semi-join operation is

$$R \ltimes S = \Pi_{A1,\dots,An}(R \bowtie S)$$

- Data complexity: O(|R| + |S|) ignoring log-factors

- The law of semijoins is:

$$R \bowtie S = (R \ltimes S) \bowtie S$$

Laws with Semijoins

- Very important in parallel databases
- Often combined with Bloom Filters (my plan is to discuss them in the next lecture)
- Read pp. 747 in the textbook

- Also used in query optimization, sometimes called “magic sets” (see Chaudhuri’s paper)

- Historical note: magic sets were invented after semi-join reductions, and the connection became clear only later

Semijoin Reducer

- Given a query:

$$Q = R_1 \bowtie R_2 \bowtie \ldots \bowtie R_n$$

- A *semijoin reducer* for Q is

$$R_{i1} = R_{i1} \ltimes R_{j1}$$
$$R_{i2} = R_{i2} \ltimes R_{j2}$$
$$\ldots\ldots$$
$$R_{ip} = R_{ip} \ltimes R_{jp}$$

such that the query is equivalent to:

$$Q = R_{k1} \bowtie R_{k2} \bowtie \ldots \bowtie R_{kn}$$

- A *full reducer* is such that no dangling tuples remain

Example

- Example:

$$Q = R(A,B) \bowtie S(B,C)$$

- A semijoin reducer is:

$$R_1(A,B) = R(A,B) \ltimes S(B,C)$$

- The rewritten query is:

$$Q = R_1(A,B) \bowtie S(B,C)$$

Semijoin Reducer

- More complex example:

$$Q = R(A,B) \bowtie S(B,C) \bowtie T(C,D,E)$$

- What is a full reducer?

Semijoin Reducer

- More complex example:

$$Q = R(A,B) \bowtie S(B,C) \bowtie T(C,D,E)$$

- A full reducer is:

$$S'(B,C) := S(B,C) \ltimes R(A,B)$$
$$T'(C,D,E) := T(C,D,E) \ltimes S'(B,C)$$
$$S''(B,C) := S'(B,C) \ltimes T'(C,D,E)$$
$$R'(A,B) := R(A,B) \ltimes S''(B,C)$$

$$Q = R'(A,B) \bowtie S''(B,C) \bowtie T'(C,D,E)$$

Practice at Home...

- Find semi-join reducer for R(x,y),S(y,z),T(z,u),K(u,v),L(v,w)

Not All Queries Have Full Reducers

- Example:

$$Q = R(A,B) \bowtie S(B,C) \bowtie T(A,C)$$

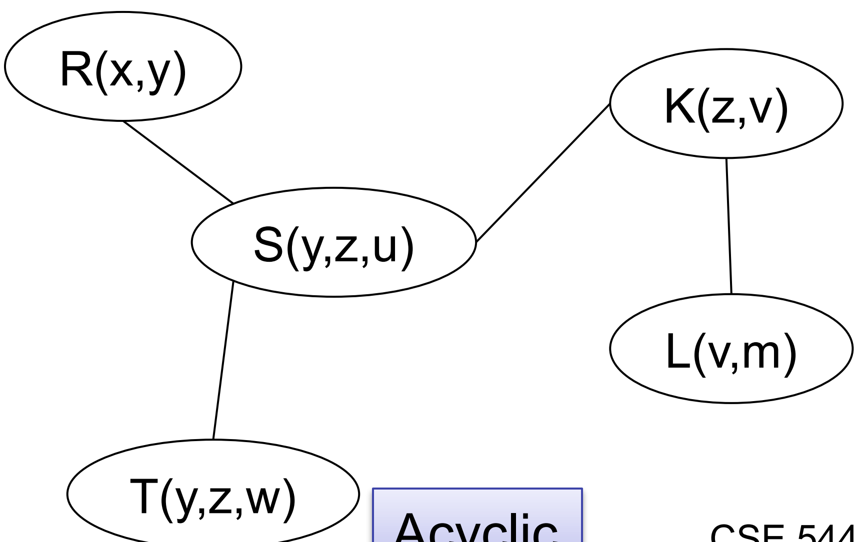
- Can write many different semi-join reducers

- But no full reducer of length O(1) exists

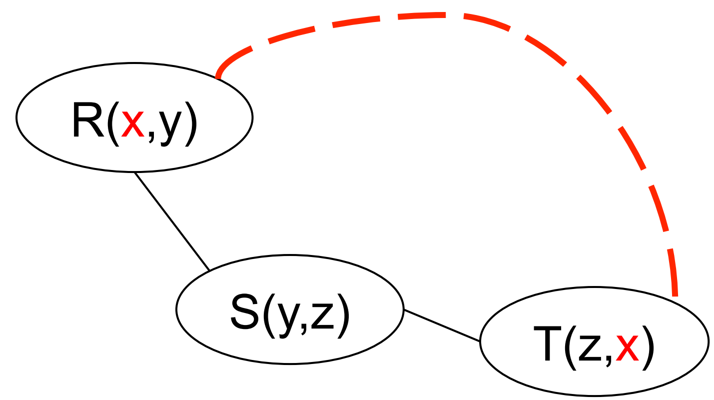
Acyclic Queries

- Fix a Conjunctive Query without self-joins

- Q is <u>*acyclic*</u> if its atoms can be organized in a tree such that for every variable the set of nodes that contain that variable form a connected component



Acyclic



R(x,y),S(y,z),T(z,x) is cyclic

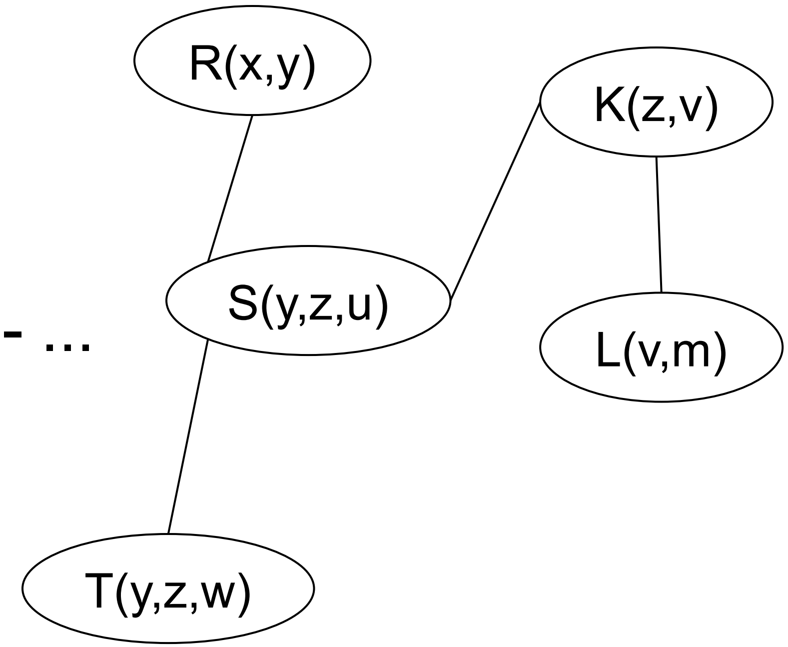
Yannakakis Algorithm

- Given: acyclic query Q
- Compute Q on any database in time O(|Input|+|Output|)

- Step 1: semi-join reduction
  - Pick any root node x in the tree decomposition of Q
  - Do a semi-join reduction sweep from the leaves to x
  - Do a semi-join reduction sweep from x to the leaves
- Step 2: compute the joins bottom up, with early projections

Examples in Class

- Boolean query: Q() :- ...
- Non-boolean: Q(x,m) :- ...
- With aggregate: Q(x,sum(m)) :- ...
- And also: Q(x,count(*)) :- ...



In all cases: runtime = O(|R|+|S|+...+|L| + |Output|)

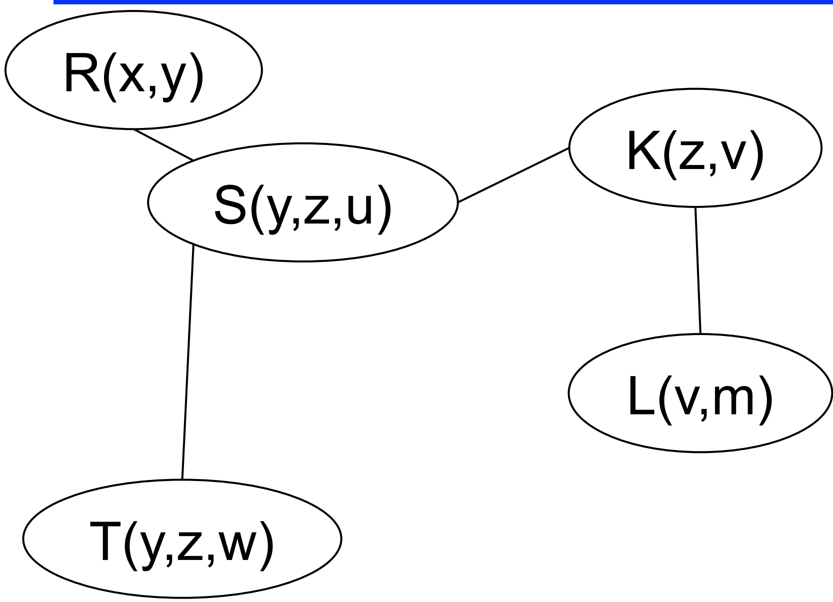
Testing if Q is Acyclic

- An *ear* of Q is an atom R(X) with the following property:
  - Let X' ⊆ X be the set of join variables (meaning: they occur in at least one other atom)
  - There exists some other atom S(Y) such that X' ⊆ Y

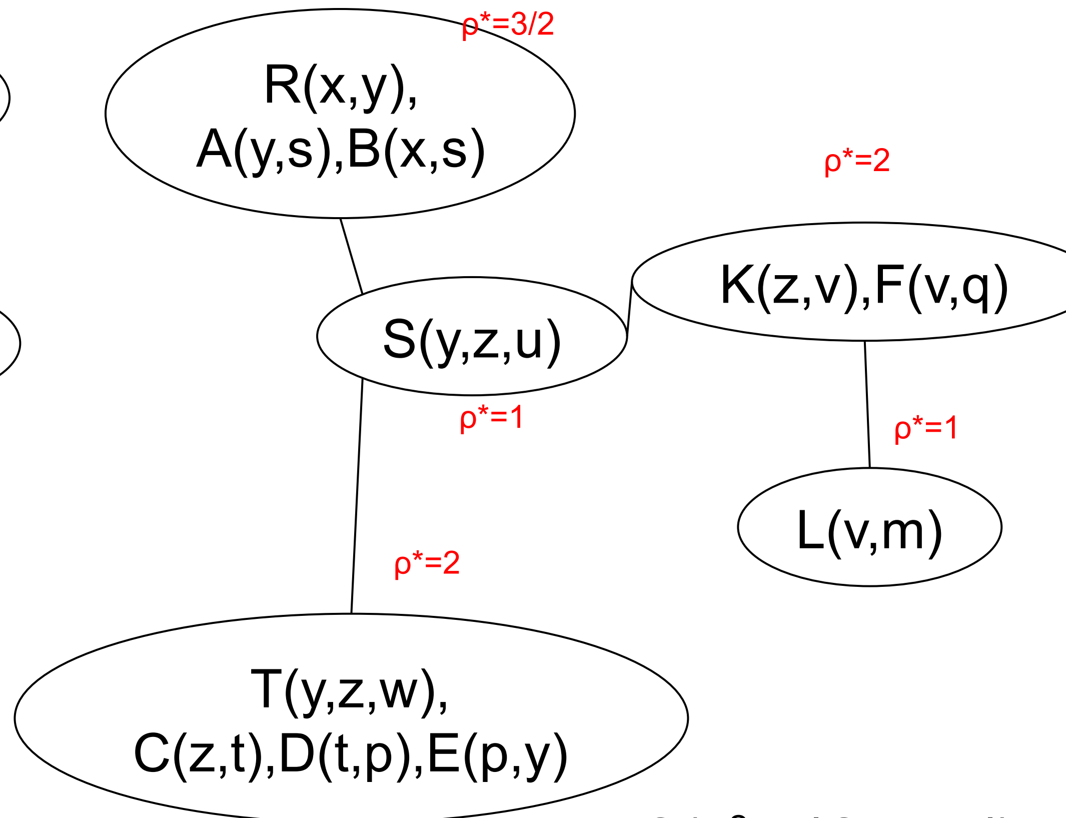
- The GYO algorithm (Graham,Yu,Özsoyoğlu) for testing if Q is acyclic:
  - While Q has an ear R(X), remove the atom R(X) from the query
  - If all atoms were removed, then Q is acyclic
  - If atoms remain but there is no ear, then Q is cyclic

- Show example in class

Computing Cyclic Queries



O(n + |Output|)



$O(n^2 + |Output|)$

ftw = max(ρ*) = 2

Next lecture...