Rewriting with Acyclic Queries: Mind Your Head

Gaetano Geck Jens Keppeler Thomas Schwentick Christopher Spinrath

TU Dortmund University

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Rewritings

R

1	2
2	3

S

2	1
3	1

T

1	4
2	5

relational database

Rewritings

Query $H(x, w) \leftarrow R(x, y),\ S(y, z),\ T(z, w)$

R	
1	2
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S	
2	1
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relational database

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Query $H(x, w) \leftarrow R(x, y),\ S(y, z),\ T(z, w)$

no direct access

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no direct access

View
$V_1(x, z) \leftarrow R(x, y), S(y, z)$

View
$V_2(z, w) \leftarrow S(y, z), T(z, w)$

R

1	2
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Query $H(x, w) \leftarrow R(x, y),\ S(y, z),\ T(z, w)$

no direct access

V_1	
1	1
2	1

View
$V_1(x, z) \leftarrow R(x, y), S(y, z)$

V_2	
1	4

View
$V_2(z, w) \leftarrow S(y, z), T(z, w)$

relational database

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1	2
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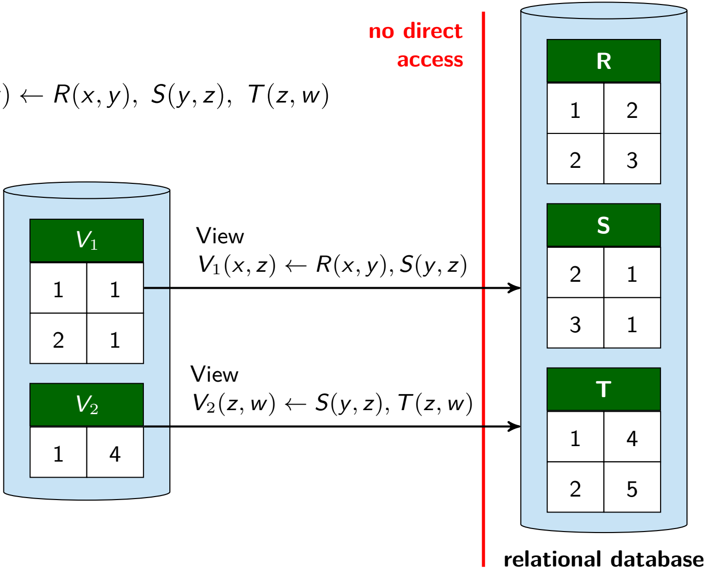

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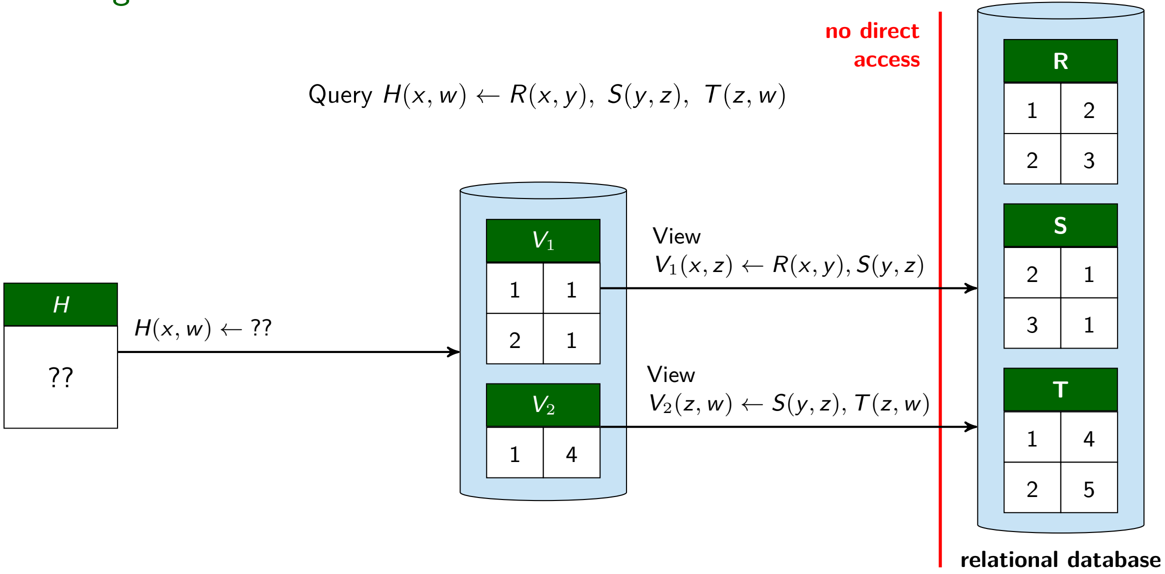
no direct access
Query $H(x,w) \leftarrow R(x,y),\ S(y,z),\ T(z,w)$
R
1 2
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relational database
View
$V_1(x,z) \leftarrow R(x,y), S(y,z)$
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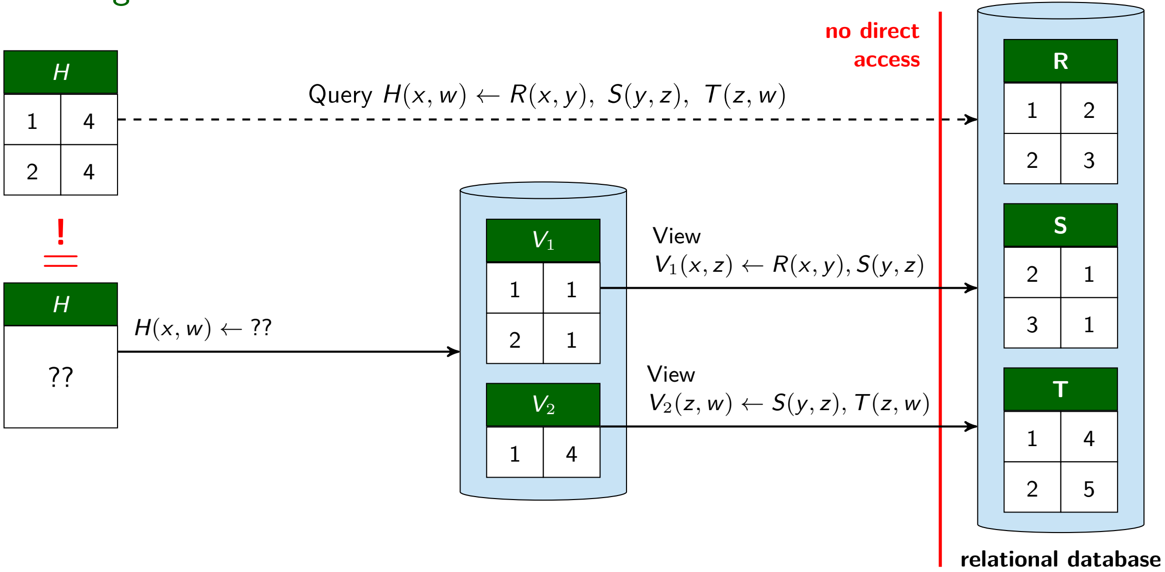
V_1
1 1
2 1
V_2
1 4
H
??
$H(x,w) \leftarrow$??

Rewritings


H
1 4
2 4
!
=
H
??
H(x, w) ← ??
Query H(x, w) ← R(x, y), S(y, z), T(z, w)
no direct access
V1
1 1
2 1
V2
1 4
View
V1(x, z) ← R(x, y), S(y, z)
View
V2(z, w) ← S(y, z), T(z, w)
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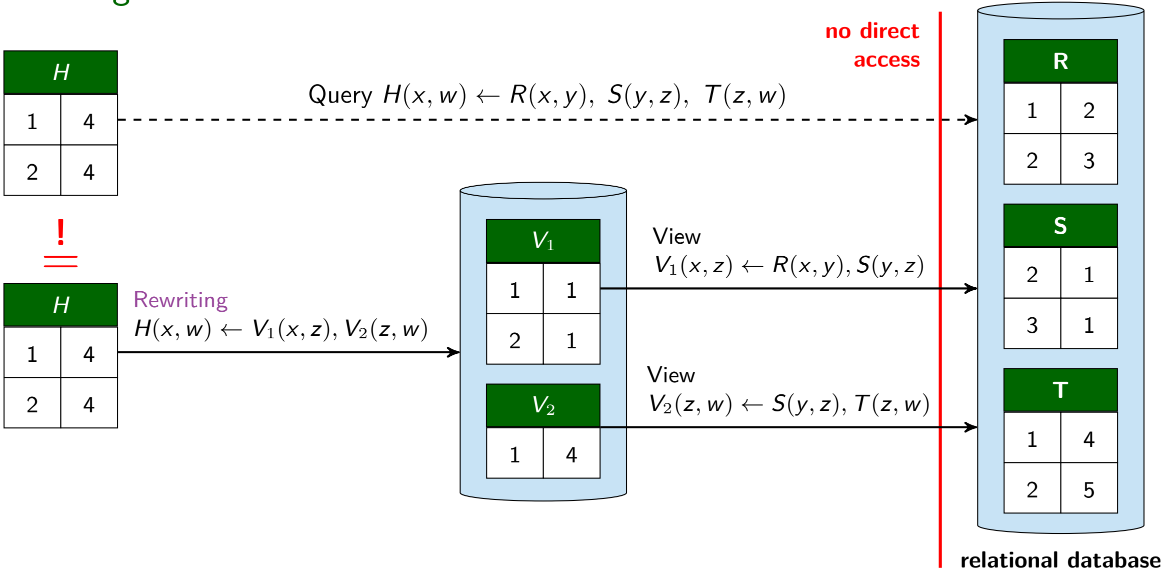
Rewritings


no direct access
H
1 4
2 4
Query $H(x, w) \leftarrow R(x, y),\ S(y, z),\ T(z, w)$
R
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2 3
!
=
H
1 4
2 4
Rewriting
$H(x, w) \leftarrow V_1(x, z), V_2(z, w)$
V_1
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V_2
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View
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relational database

Rewritings for Conjunctive Queries

Conjunctive Queries are of the form

$$\underbrace{H(x,w)}_{\text{head}} \leftarrow \underbrace{R(x,y), \overbrace{S(y,z)}^{\text{atom}}, T(z,w)}_{\text{body}}$$

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Views are just conjunctive queries with a special role

global-as-view,
exact, positive,
materialised or not

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A Rewriting

- for a query Q
- with respect to a set $\mathcal{V}$ of views

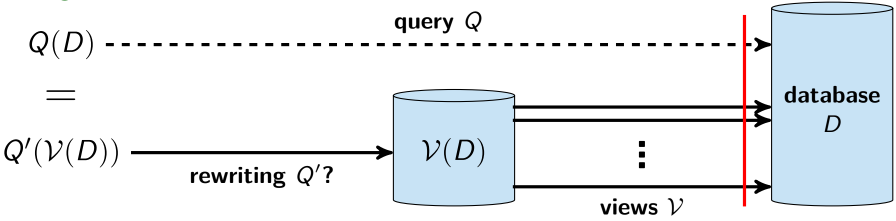
is a query Q' such that

$$Q'(\mathcal{V}(D)) = Q(D)$$

holds for all databases D

exact/equivalent
rewriting

The Rewriting Problem



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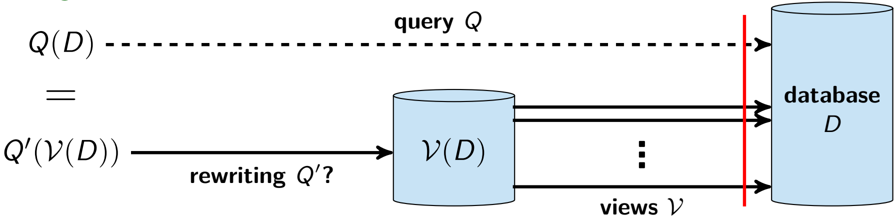


The Rewriting Problem

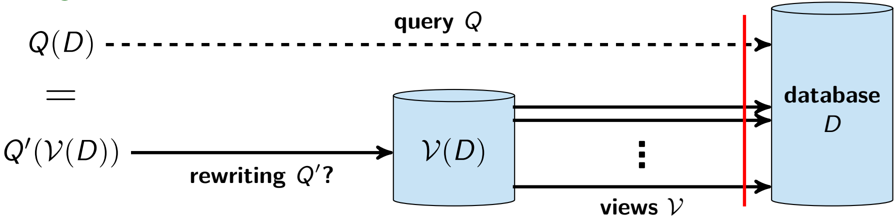
Input:

- conjunctive query Q
- set $\mathcal{V}$ of views

Question:

Is there a rewriting for Q with respect to $\mathcal{V}$?

The Rewriting Problem



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Theorem (Levy, Mendelzon, Sagiv, and Srivastava 1995)

The rewriting problem for

- *conjunctive queries and*
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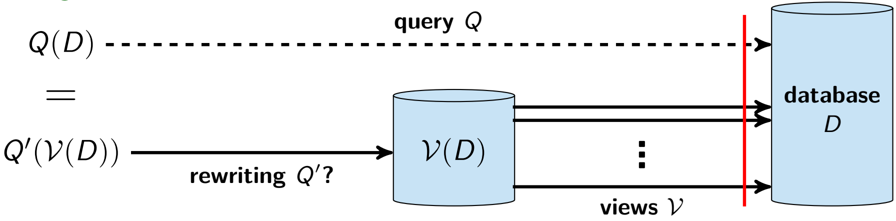
is NP-complete.

The Rewriting Problem



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→ Restrict everything to structurally simple queries

Acyclic Conjunctive Queries

For acyclic queries many problems are in polynomial time: containment, evaluation, ...

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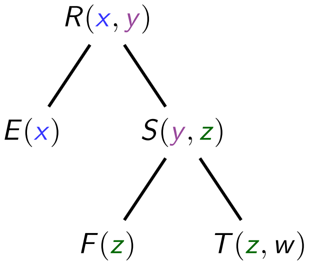
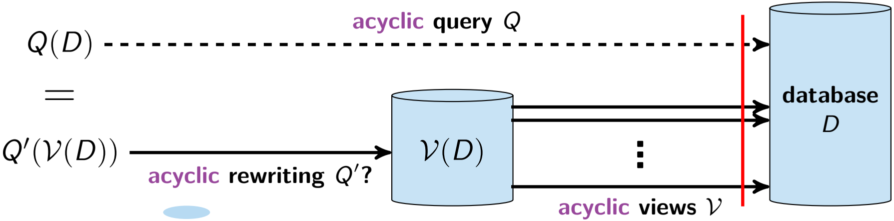
Example

$H(x, y) \leftarrow R(x, y), S(y, z), F(z), E(x), T(z, w)$ is acyclic



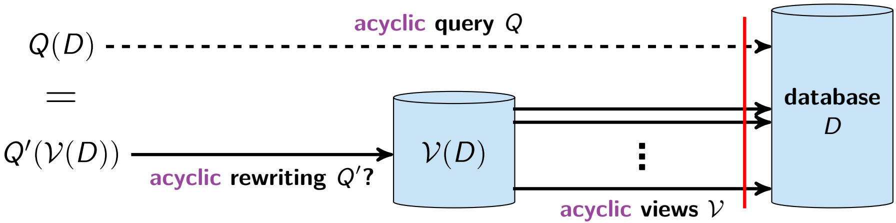
For every variable:
the induced subgraph is connected

Complexity of the Acyclic Rewriting Problem



If the query is acyclic, we would like the rewriting to be acyclic as well

Complexity of the Acyclic Rewriting Problem



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The acyclic rewriting problem for

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- Even if only a single view is given

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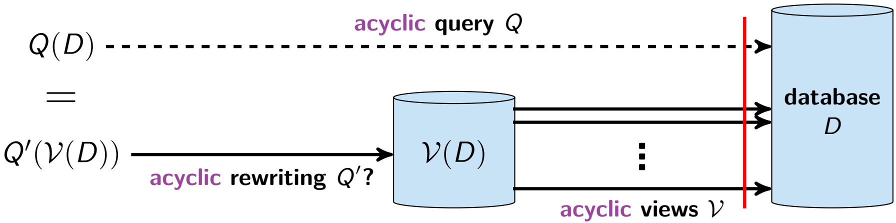

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Proof Approach

- in NP: guess and verify
- NP-hardness: reduction from 3SAT

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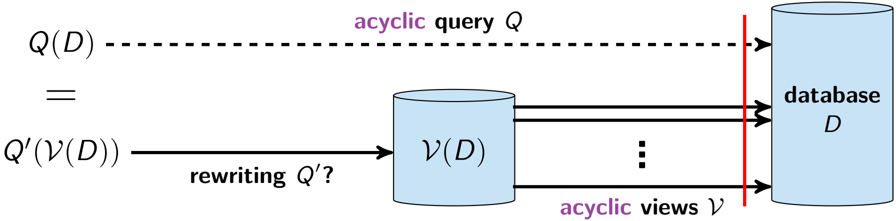

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Acyclic Rewritings

Theorem

For every

- *acyclic query and*
- *views defined by conjunctive queries*

the following holds: If there is a rewriting, then there is an acyclic rewriting.

Acyclic Rewritings – Example

Acyclic Query

$$H(x, y) \leftarrow R(x, y), S(y, z), F(z), E(x), T(z, w)$$

Views

$$V_1(x, y) \leftarrow R(x, y), S(y, z)$$

$$V_2(y, z) \leftarrow S(y, z), F(z)$$

$$V_3(z, x) \leftarrow E(x), T(z, w)$$

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Rewriting

$H(x, y) \leftarrow V_1(x, y), V_2(y, z), V_3(z, x)$

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This rewriting

- is cyclic
- minimal
  (no atom can be removed)

Acyclic Rewritings – Example

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$V_1(x, y) \leftarrow R(x, y), S(y, z)$

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$H(x, y) \leftarrow V_1(x, y), V_2(y, z), V_3(z, x)$

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Acyclic Rewriting

$H(x, y) \leftarrow V_1(x, y), V_2(y, z), V_3(z', x), V_3(z, x')$

Acyclic Rewritings

Theorem

For every

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For every

- *acyclic query and*
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the following holds: If there is a rewriting, then there is an acyclic rewriting.

Proof ingredients

1. Characterisation: There is a rewriting if and only if there is a consistent cover partition (similar to other characterisations in the literature)
2. Refinement of the partition along a join tree

Proof Ingredient: Characterisation

Query

$H(x, y) \leftarrow R(x, y), S(y, z), F(z), E(x), T(z, w)$

Views

$V_1(x, y) \leftarrow R(x, y), S(y, z)$

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Rewriting

$H(x, y) \leftarrow V_1(x, y), \quad V_2(y, z), \qquad V_3(z, x)$

Proof Ingredient: Characterisation

Query

$$H(x,y) \leftarrow \underbrace{R(x,y)}_{A_1}, \underbrace{S(y,z), F(z)}_{A_2}, \underbrace{E(x),\ T(z,w)}_{A_3}$$

partition A_1 A_2 A_3

Views

$$V_1(x,y) \leftarrow R(x,y), S(y,z)$$
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$$H(x,y) \leftarrow \underbrace{R(x,y)}_{A_1}, \underbrace{S(y,z), F(z)}_{A_2}, \underbrace{E(x),\ T(z,w)}_{A_3}$$

partition A_1 A_2 A_3

$A_1 \leftrightarrow V_1(x,y)$, $A_2 \leftrightarrow V_2(y,z)$, $A_3 \leftrightarrow V_3(z,x)$

Rewriting

$$H(x,y) \leftarrow V_1(x,y),\quad V_2(y,z),\quad V_3(z,x)$$

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Proof Ingredient: Refinement

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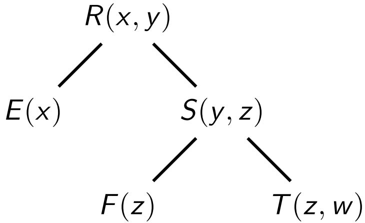
Join tree for the query



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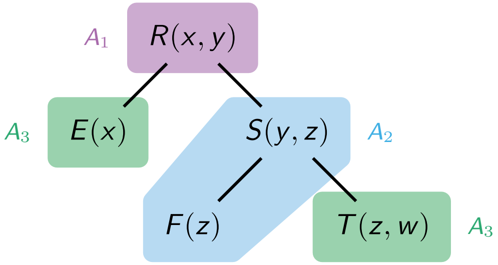

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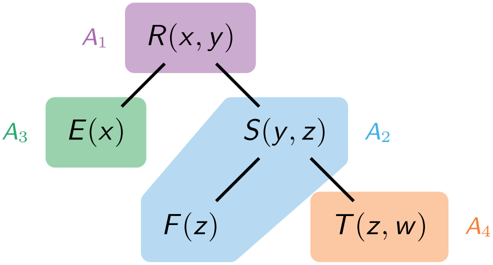

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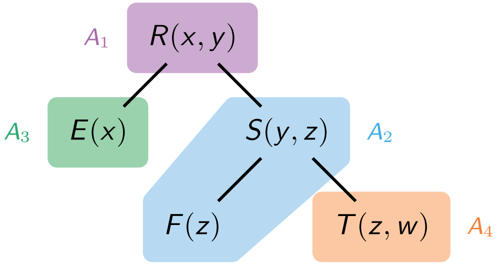

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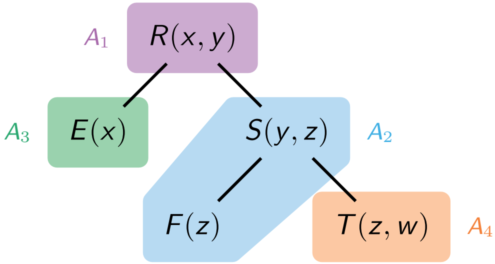

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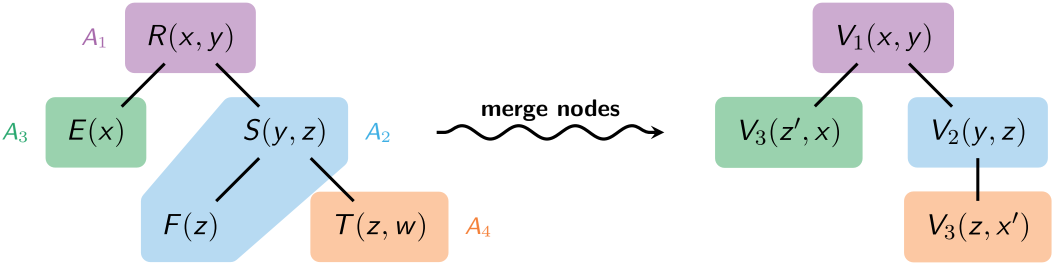

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Acyclic Rewriting

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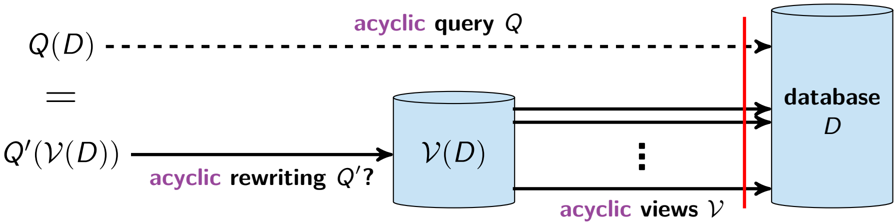
Complexity Results – The Good News



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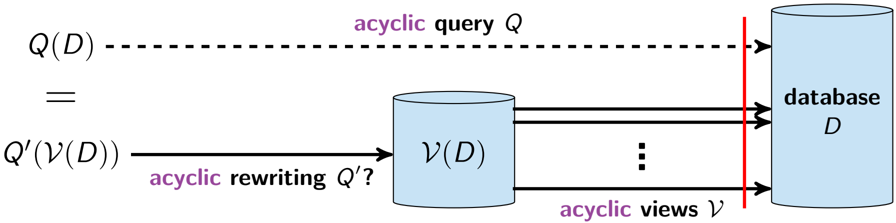

For tractability: Mind your head!

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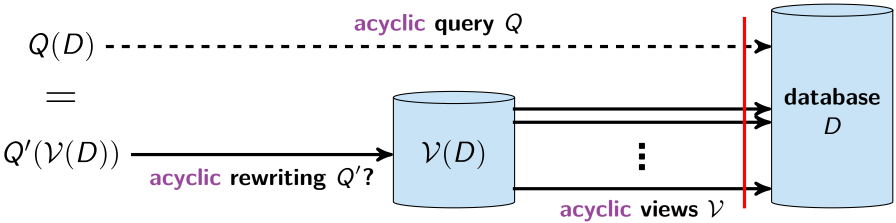

For tractability: Mind the views' heads!

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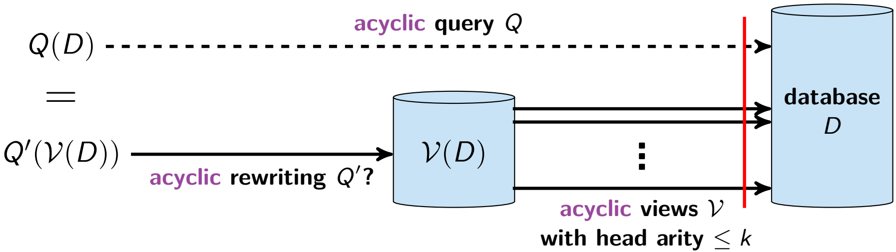

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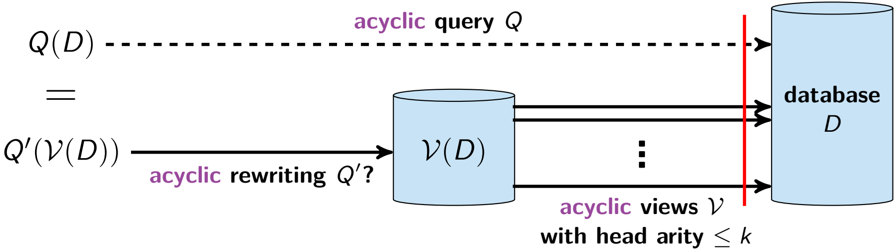

Theorem

For every $k \geq 0$ the acyclic rewriting problem for

- *acyclic queries and*
- *acyclic views with heads of arity at most k*

is in polynomial time.

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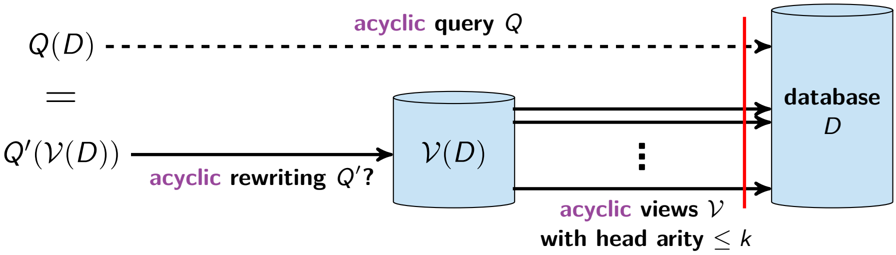

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- If an acyclic rewriting exists, it can be computed in polynomial time

Acyclic Views with Bounded Head Arity

Proposition (Nash, Segoufin, and Vianu 2010)

For every

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- *views defined by conjunctive queries*

there is a rewriting, if and only if the canonical candidate is a rewriting.

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2. Test whether the canonical candidate is a rewriting

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1. Compute the canonical candidate
2. Test whether the canonical candidate is a rewriting
3. Transform the canonical candidate into an acyclic rewriting

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there is a rewriting, if and only if the canonical candidate is a rewriting.

Algorithm

1. Compute the canonical candidate
2. Test whether the canonical candidate is a rewriting
   - in polynomial time for acyclic queries
3. Transform the canonical candidate into an acyclic rewriting

Acyclic Views with Bounded Head Arity

Proposition (Nash, Segoufin, and Vianu 2010)

For every

- *conjunctive query and*
- *views defined by conjunctive queries*

there is a rewriting, if and only if the canonical candidate is a rewriting.

Algorithm

1. Compute the canonical candidate
   - can be of exponential size for acyclic views
   - is of polynomial size for acyclic views with bounded head arity
2. Test whether the canonical candidate is a rewriting
   - in polynomial time for acyclic queries
3. Transform the canonical candidate into an acyclic rewriting

The Canonical Candidate

Query

$H(x, y) \leftarrow R(x, y), S(y, z), F(z), E(x), T(z, w)$

Views

$V_1(x, y) \leftarrow R(x, y), S(y, z)$

$V_2(y, z) \leftarrow S(y, z), F(z)$

$V_3(z, x) \leftarrow E(x), T(z, w)$

The Canonical Candidate

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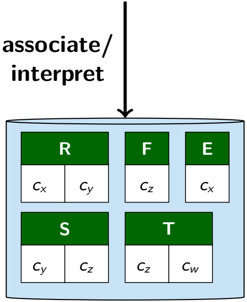

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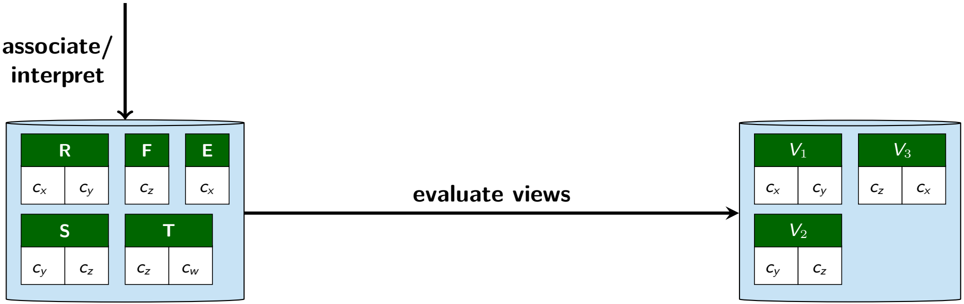

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Canonical Candidate/Rewriting

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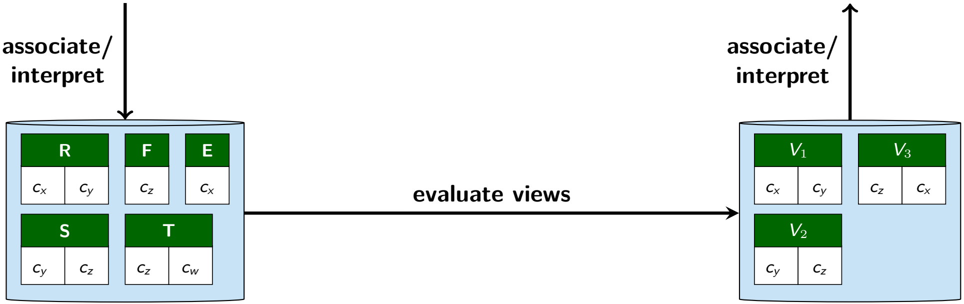

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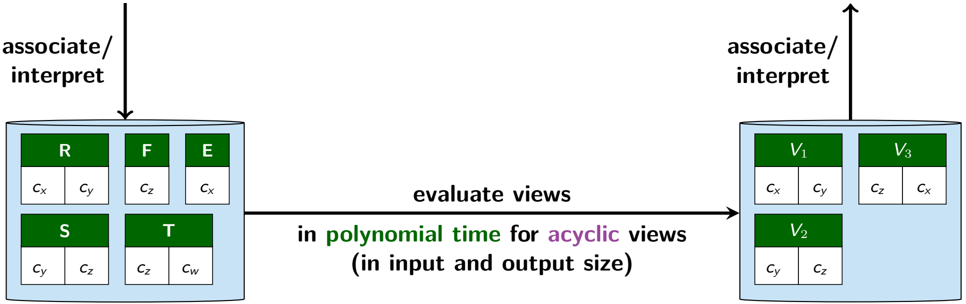

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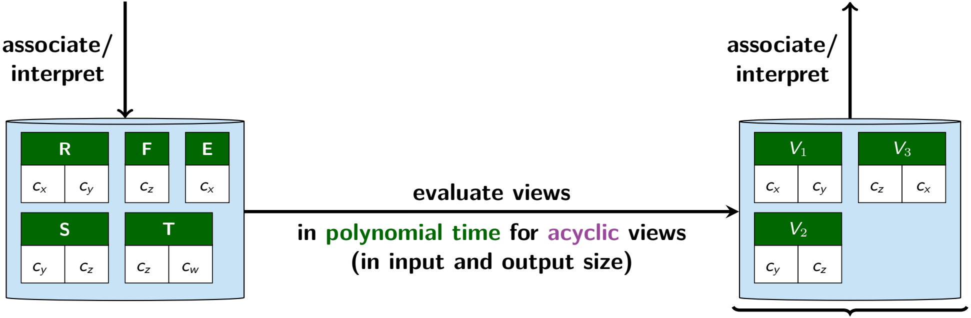

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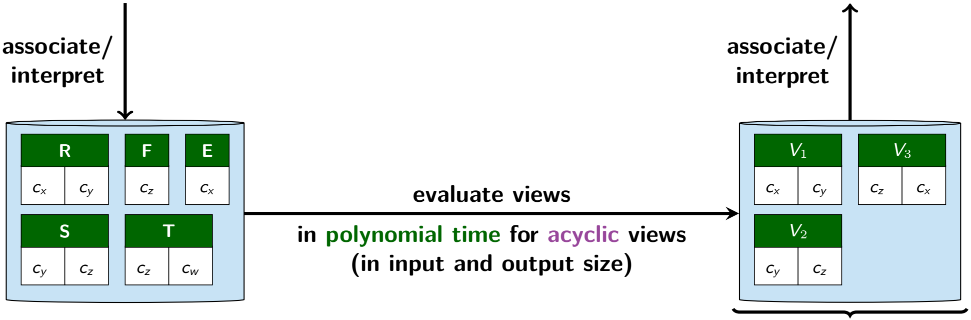

is of **polynomial size** for views with **bounded head arity**

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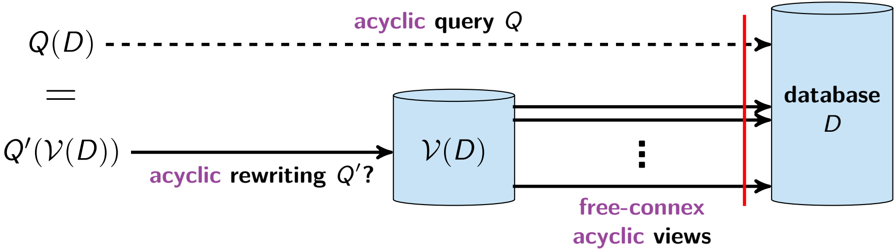
Complexity Results – The Good News



Free-Connex Acyclic Views

A conjunctive query is free-connex acyclic if

- it is acyclic and
- there is a join tree which includes the query's head atom

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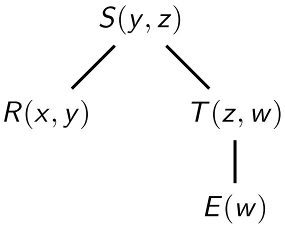

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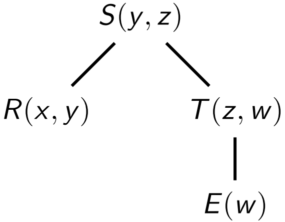
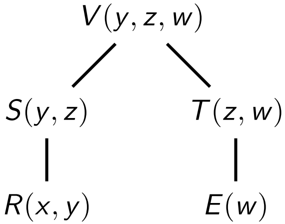


Join tree (with head atom)



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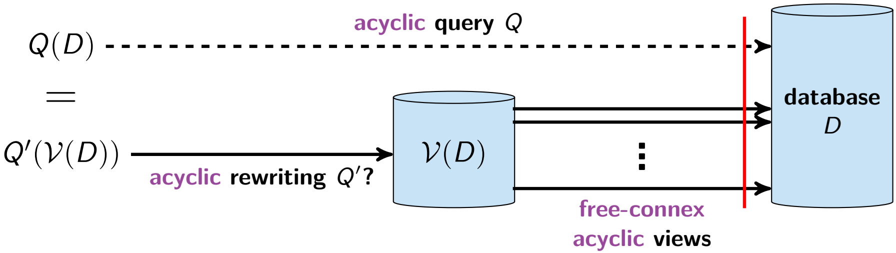

Theorem

For every $k \geq 0$ the acyclic rewriting problem for

- *acyclic queries and*
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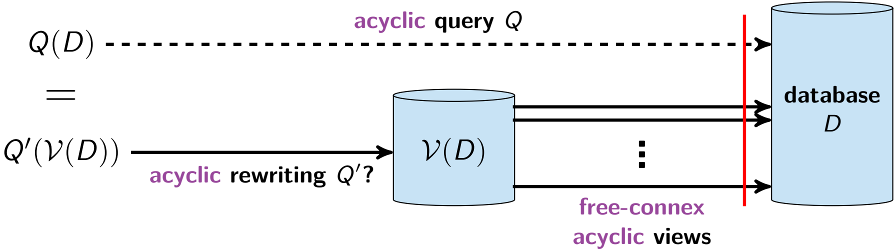
- *over a database schema of arity at most k*

is in polynomial time.

Free-Connex Acyclic Views



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- If an acyclic rewriting exists, it can be computed in polynomial time

Free-Connex Acyclic Views

View

$V(y, z, w) \leftarrow R(x, y), S(y, z), T(z, w), E(w)$

Database relations have arity at most $k = 2$

Free-Connex Acyclic Views

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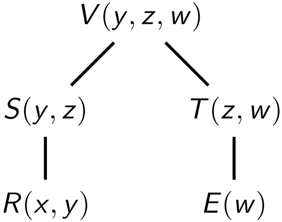

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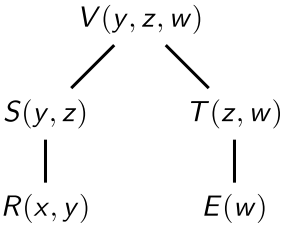

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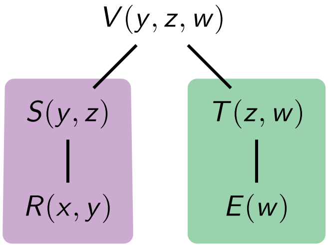

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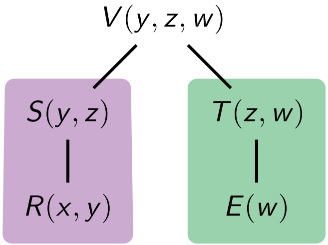

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1. Root the tree at the head atom
2. For each subtree create a view with head arity $\leq k = 2$

$V_1(y, z) \leftarrow R(x, y), S(y, z), T(z, w), E(w)$

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$V(y, z, w)$ is "equivalent" to $V_1(y, z), V_2(z, w)$

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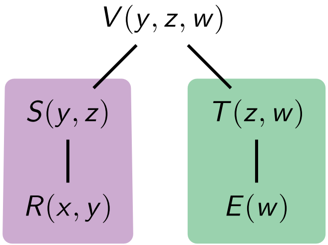

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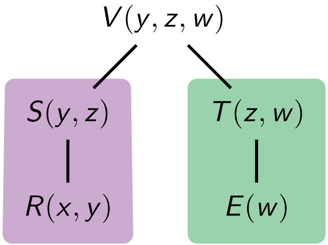

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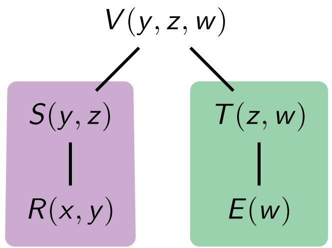

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5. Analogously for atoms $V_2(u,v)$

Conclusion

Summary

- If there is any rewriting for an acyclic query, then there is an acyclic rewriting
- The acyclic rewriting problem is NP-complete for acyclic queries and acyclic views
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- The result for free-connex acyclic views can be generalised to acyclic views with bounded weak head arity
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Mind your head!

References

Levy, Alon Y., Alberto O. Mendelzon, Yehoshua Sagiv, and Divesh Srivastava (1995). "Answering Queries Using Views." In: Proceedings of the Fourteenth ACM SIGACT-SIGMOD-SIGART Symposium on Principles of Database Ed. by Mihalis Yannakakis and Serge Abiteboul. ACM Press, pp. 95–104.

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