The Complexity of Resilience and Responsibility for Conjunctive Queries

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Treat exogenous part as fixed, beyond our control; only consider possible changes to the endogenous part.

Resilience as a decision problem

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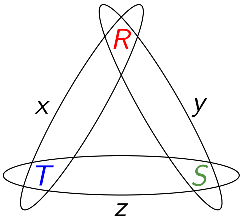
Goal: Characterize the **complexity** of **resilience** for **sj-free conjunctive queries**.

Triangle Query



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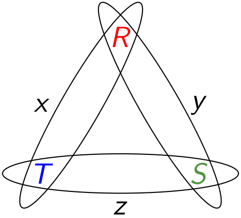

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Query **hypergraph**: relations are vertices;
variables are hyperedges

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Proof: Reduce 3SAT to $\texttt{RES}(q_\triangle)$. Let $\psi = C_1 \wedge \cdots \wedge C_m$ be a 3-CNF formula, $\text{var}(\psi) = \{v_1, \ldots, v_n\}$

Map $\psi \mapsto (D_\psi, k_\psi)$ s.t. $\psi \in \mathrm{3SAT} \Leftrightarrow (D_\psi, k_\psi) \in \texttt{RES}(q_\triangle)$

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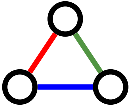

$$(D_\psi, k_\psi) \in \mathtt{RES}(q_\triangle) \ \Leftrightarrow \ \exists \Gamma \ |\Gamma| = k_\psi \wedge D_\psi - \Gamma \text{ has no}$$

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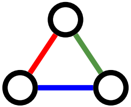

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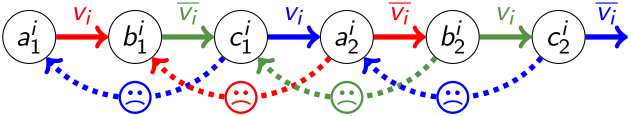
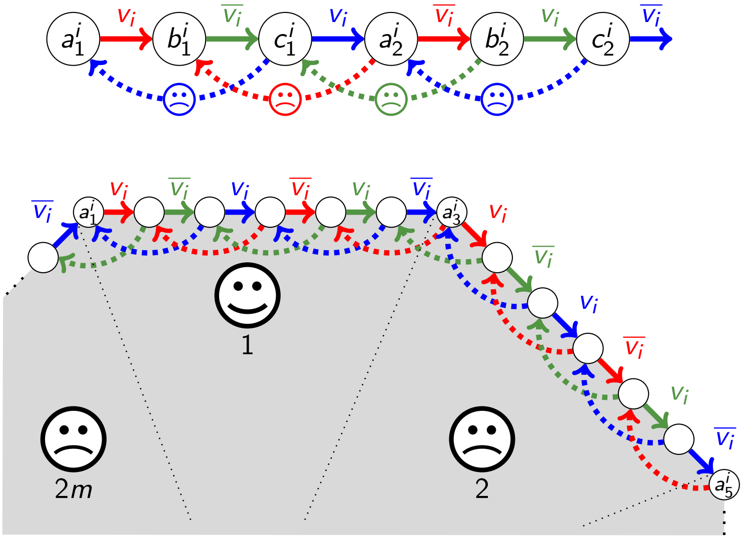
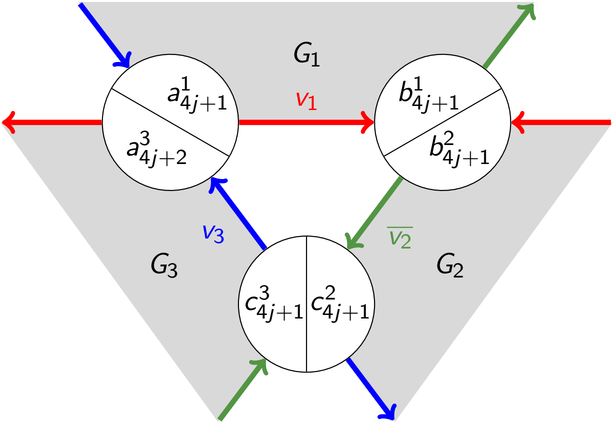
D_ψ has one circular gadget G_i for each variable v_i.



In G_i must choose all v_i's or all $\overline{v_i}$'s

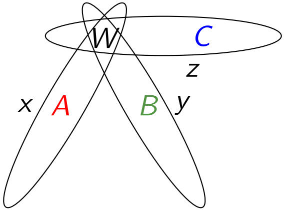


For each clause, e.g., $C_j = (v_1 \vee \overline{v_2} \vee v_3)$, pick the jth occurrences of $v_1 \in G_1$, $\overline{v_2} \in G_2$ and $v_3 \in G_3$. Identify head of v_1 with tail of $\overline{v_2}$, head of $\overline{v_2}$ with tail of v_3, head of v_3 with tail of v_1



This new RGB triangle is automatically removed iff one of the literals in C_j is chosen true. □

Tripod Query



$$q_{\mathrm{T}} \ :- \ A(x), B(y), C(z), W(x,y,z)$$

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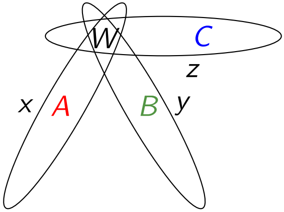

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$\mathrm{var}(A) \;\subseteq\; \mathrm{var}(W)$.

A **dominates** W.

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$$q_{\mathrm{T}} \; :- \; A(x), B(y), C(z), W^{\mathsf{x}}(x,y,z)$$

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$$q_{\triangle} \quad :- \quad R(x,y), S(y,z), T(z,x)$$
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Proof: Show $\mathtt{RES}(q_{\triangle}) \leq \mathtt{RES}(q_{\mathrm{T}})$

$\mathtt{RES}(q_{\mathrm{T}})$ is NP complete.

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Let (D,k) be an instance of $\mathtt{RES}(q_{\triangle})$.

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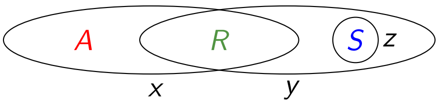
Claim $(D,k) \in \mathrm{RES}(q_{\triangle}) \quad \Leftrightarrow \quad (D',k) \in \mathrm{RES}(q_{\mathrm{T}})$. $\square$

Def. A query is **linear** if all of the vertices of its hypergraph can be drawn along a straight line with all of its hyperedges convex.

For example, the following query is linear:

$$q :- A(x), R(x,y), S(y,z)$$



Linear Queries are Easy

Prop. For any linear sj-free conjuctive query q, $\texttt{RES}(q) \in \mathrm{P}$.

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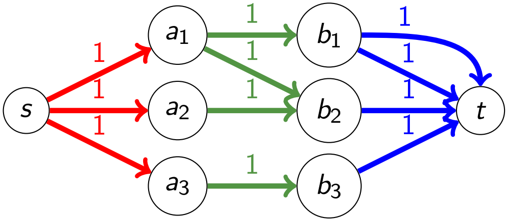
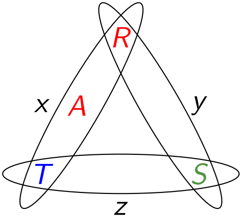
Proof: Use Network Flow.

$\mathtt{RES}(D, q)$ is the min cut of corresponding network.

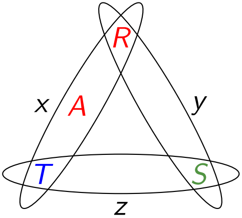


q :– $A(x)$ $R(x, y)$ $S(y, z)$

□



$$q_{\text{rats}} \quad :- \quad A(x), R(x,y), S(y,z), T(z,x)$$



Is Rats **hard** or **easy** ?

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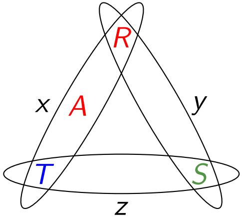

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\end{aligned}
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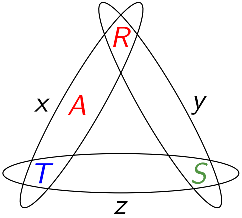

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q_2 &\equiv A(x), R^{\mathsf{x}}(x,y,z), S(y,z), T^{\mathsf{x}}(z,x) && \text{Dissociation} \\
\mathrm{RES}(q_1) &\leq \mathrm{RES}(q_2)
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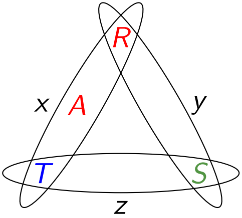

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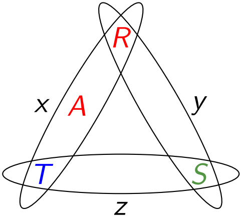

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q_4 & \equiv & A(x), R^x(x,y,z), S(y,z) & \text{Repetition} \\
\mathrm{RES}(q_3) & \equiv & \mathrm{RES}(q_4) &
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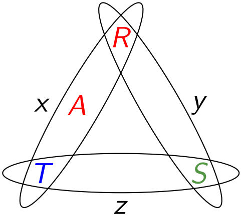

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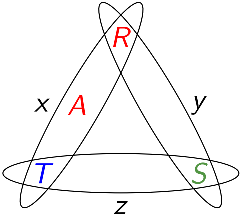
q_4 is **linear** and therefore **easy**!



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q_4 & \equiv & A(x), R^{\times}(x,y,z), S(y,z) & \text{Repetition} \\
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\text{RES}(q_{\text{rats}}) & \leq & \text{RES}(q_5) & q_{\text{rats}} \text{ is easy!}
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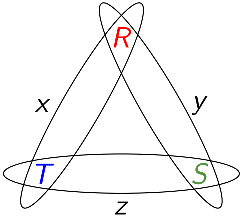
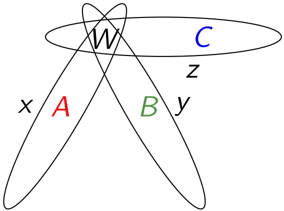
What do the triangle and the tripod have in common?





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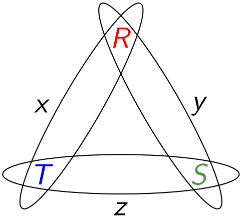

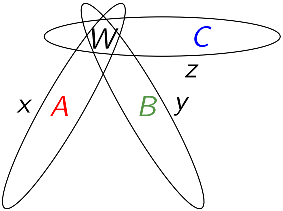

$q_{\triangle}$:− $R(x, y), S(y, z), T(z, x)$ q_{T} :− $A(x), B(y), C(z), W^x(x, y, z)$

Def. A **triad** is a set of three endogenous atoms, $\mathcal{T} = \{S_0, S_1, S_2\}$ such that for every pair i, j, there is a path from S_i to S_j that uses no variable occurring in the other atom of $\mathcal{T}$.

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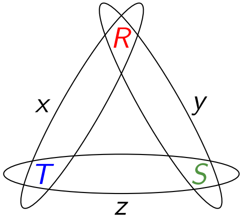

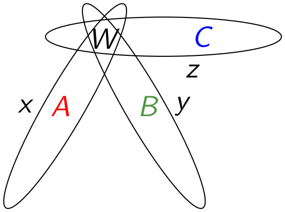

$q_{\triangle} :- R(x,y), S(y,z), T(z,x)$ $\quad$ $q_{\mathrm{T}} :- A(x), B(y), C(z), W^{x}(x,y,z)$

Def. A **triad** is a set of three endogenous atoms, $\mathcal{T} = \{S_0, S_1, S_2\}$ such that for every pair i, j, there is a path from S_i to S_j that uses no variable occurring in the other atom of $\mathcal{T}$.

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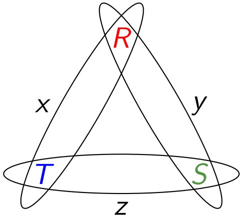

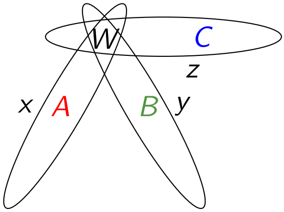

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Proof: Show $\texttt{RES}(q_{\triangle}) \leq \texttt{RES}(q)$

$\square$

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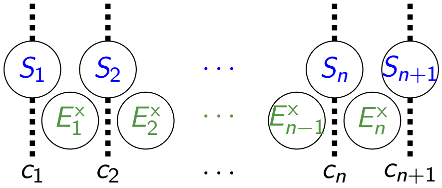
Since there is no triad, we can linearize the endogenous atoms:



□

Dichotomy Theorem for Resilience: Let q be a sj-free conjunctive query all of whose dominated atoms are exogenous. If q has a triad then $\texttt{RES}(q)$ is NP complete. Otherwise, $\texttt{RES}(q) \in \mathrm{P}$.

Extend to Databases with Functional Dependencies

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Extend to Databases with Functional Dependencies

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Dichotomy Theorem for Resilience with FD's Let q^* be an sj-free conjunctive query with FD's, all possible induced rewrites applied and all dominated atoms are exogenous. If q^* has a triad then $\mathrm{RES}(q)$ is NP complete. Otherwise, $\mathrm{RES}(q) \in \mathrm{P}$.

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Corollary Induced rewrites characterized the effect of FD's:

$$\mathtt{RES}(q;\Phi) \quad\equiv\quad \mathtt{RES}(q^*;\Phi) \quad\equiv\quad \mathtt{RES}(q^*)$$

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- **Understand & explain Dichotomy Phenomenon**