View-based query processing

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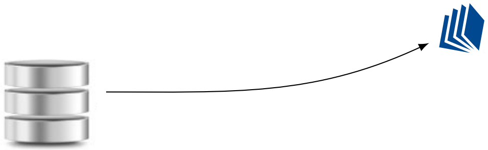
EPIT 2019
Thursday, April, 11th

Introduction

View-based query processing

General setting



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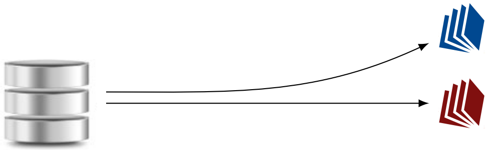

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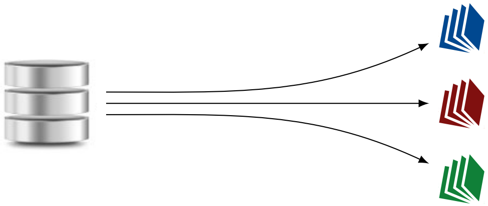

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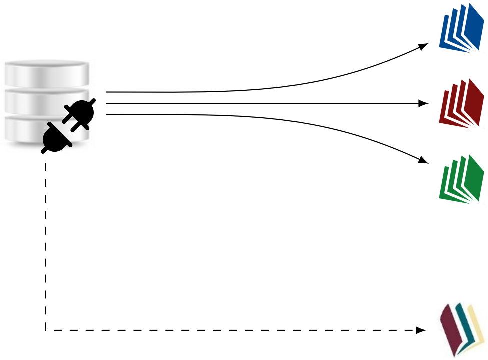

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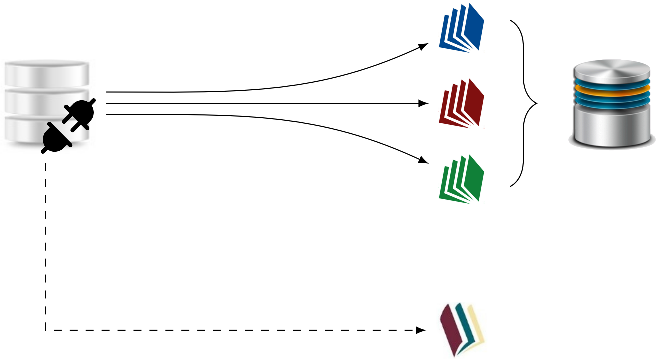

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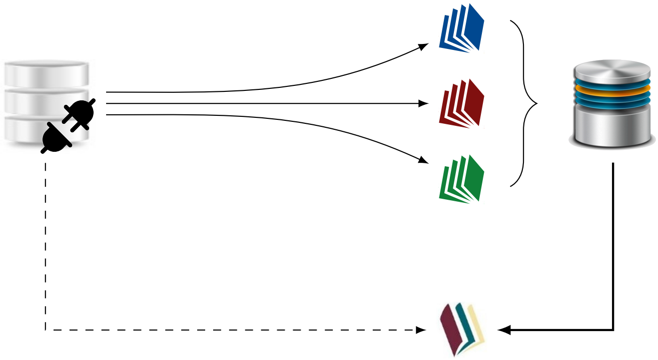
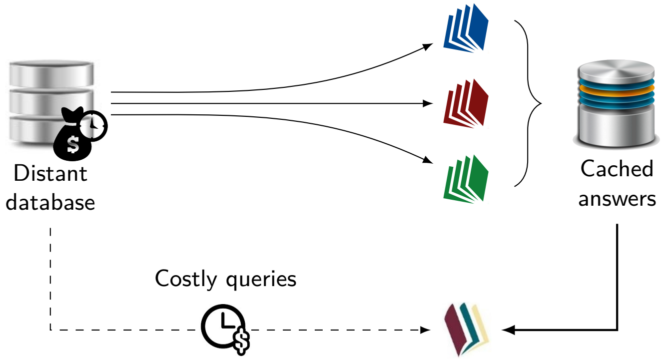


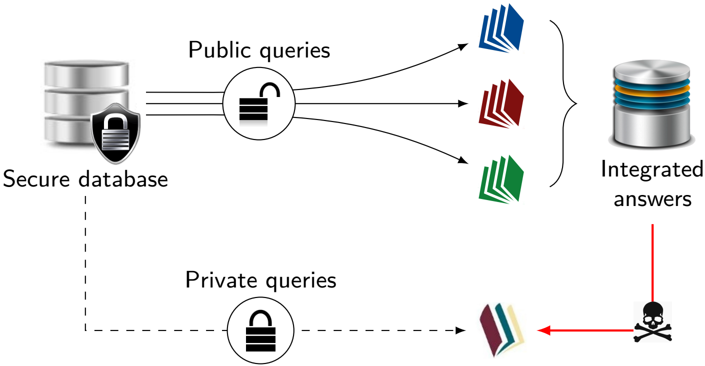
View-based query processing

Scenario : query optimization and caching



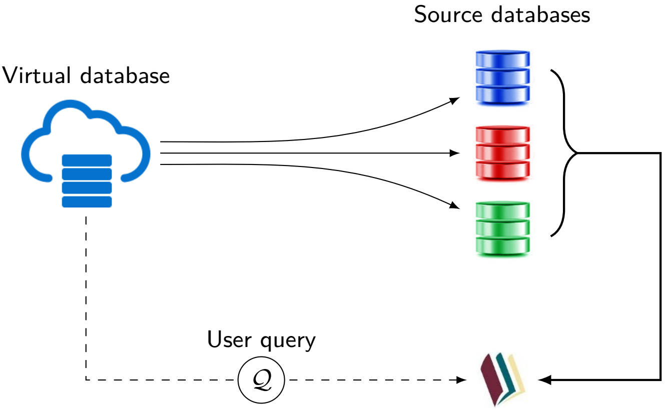
View-based query processing

Scenario : data leak prevention



View-based query procesing

Scenario : virtual data integration



Views

View definition, view image, view instance

Let σ and τ be two database schemas.

- View definition (or simply view): A view definition $\mathbf{V}$ from σ to τ is a set of queries over σ indexed by τ:

$$\mathbf{V} = \{Q_b \mid b \in \tau\}$$

  such that:

$$\forall b \in \tau,\ \text{arity}(b) = \text{arity}(Q_b)$$

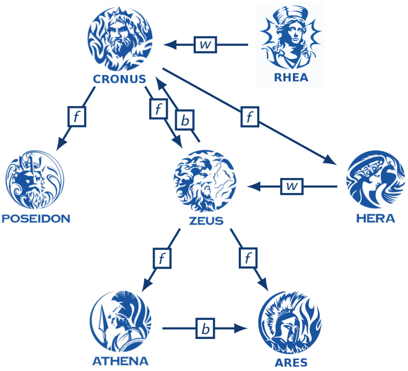
- View instance: A view instance E is a database over τ.

- View image: Given a database D over σ and a view $\mathbf{V}$ from σ to τ, the view image of D, $\mathbf{V}(D)$, is a view instance such that:

$$\forall b \in \tau, \bar{x} \in D, \quad \bar{x} \in b(\mathbf{V}(D)) \ \Leftrightarrow\ \bar{x} \in Q_b(D)$$

Example: view definition, view image, view instance

$\sigma = \{b, f, w\}$



Database D over σ

Example: view definition, view image, view instance

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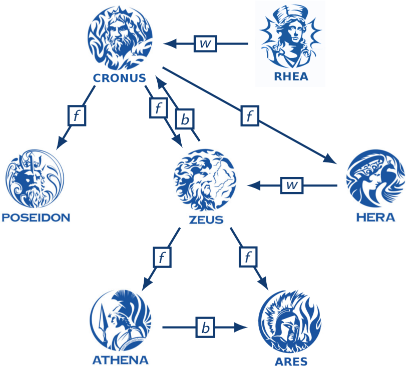
$\tau = \{g, s\}$



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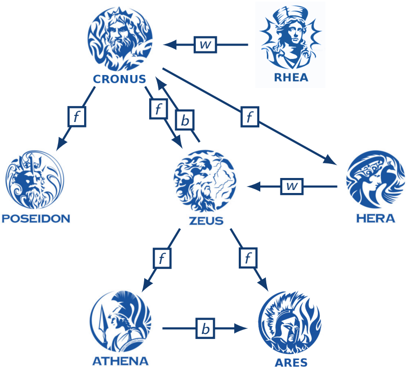
$$\sigma = \{b, f, w\} \qquad \mathbf{V} = \left\{ \begin{array}{c} Q_g(x,y) = x \xrightarrow{w} z \xrightarrow{f} z' \xrightarrow{f} y \\ Q_s(x,y) = x \xleftarrow{f} z \xrightarrow{f} y \wedge x \neq y \end{array} \right\} \qquad \tau = \{g, s\}$$



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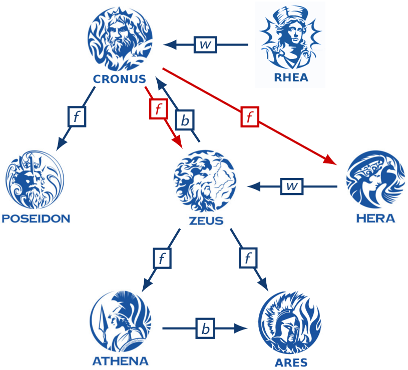

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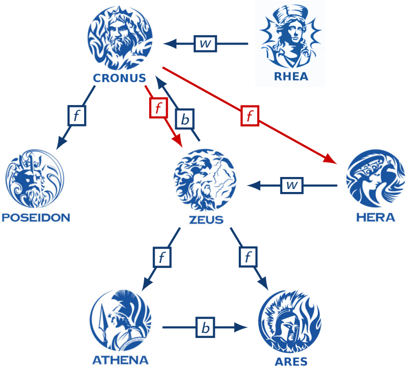

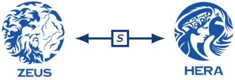

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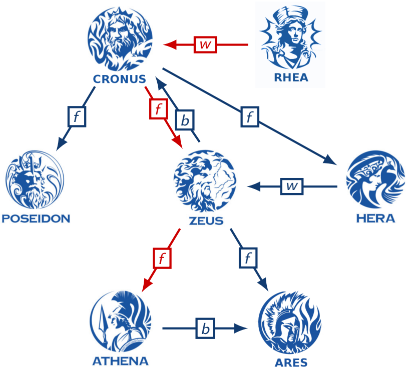

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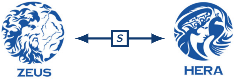

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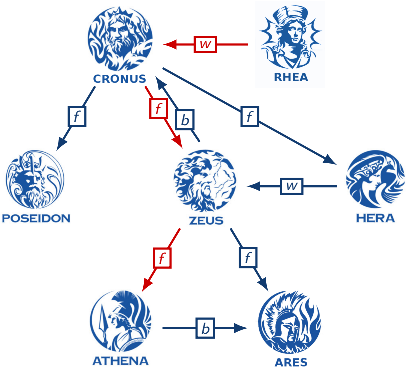

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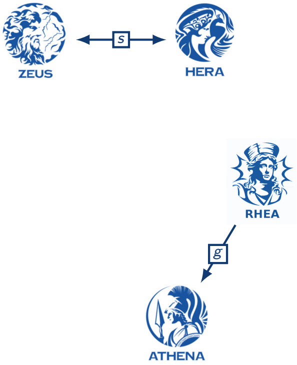

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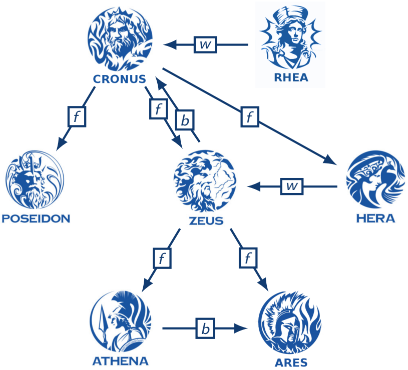

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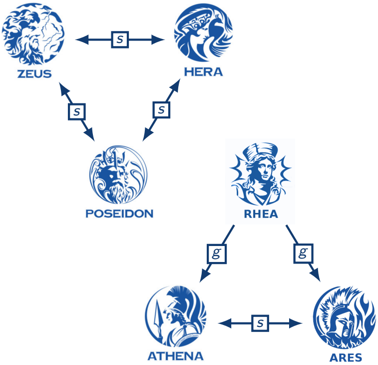

View image $\mathbf{V}(D)$ over τ

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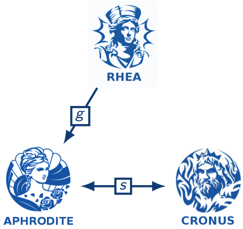

View instance E over τ

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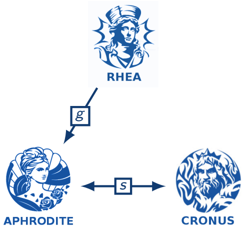
Is E the image of some database D through $\mathbf{V}$?



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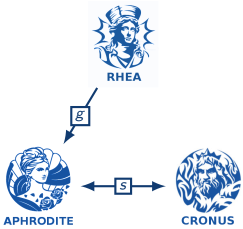

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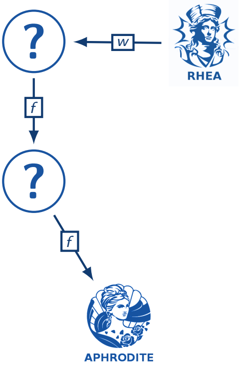

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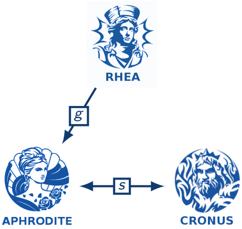

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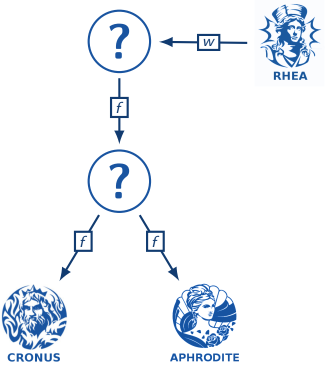

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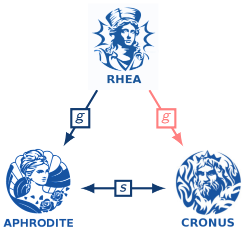

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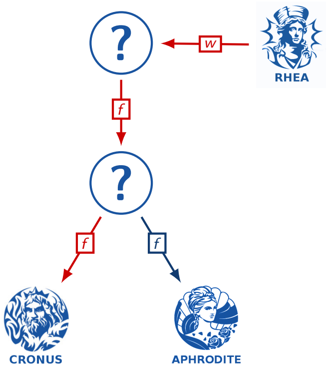

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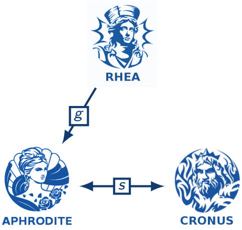

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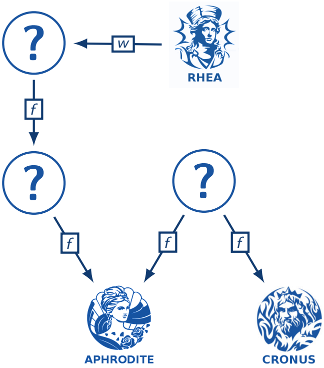

What happened there?

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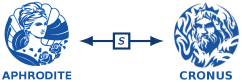

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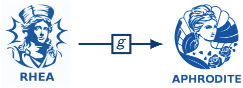

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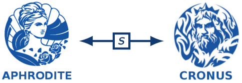

(*because Aphrodite is the daughter of Uranus*
And so is Cronus)

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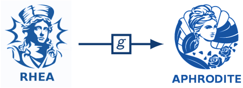

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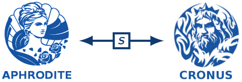

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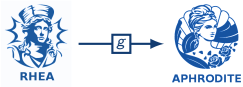

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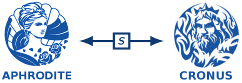

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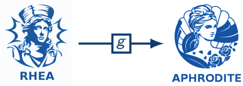

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We failed virtual data integration → the two myths are incompatible

Testing view consistency

PROBLEM	:	VIEW CONSISTENCY
INPUT	:	A view **V** from σ to τ, a view instance E
QUESTION	:	Is there some D over σ such that $\mathbf{V}(D) = E$?

Testing view consistency

PROBLEM	:	VIEW CONSISTENCY FOR LANGUAGE $\mathcal{L}$
INPUT	:	An $\mathcal{L}$-view **V** from σ to τ, a view instance E
QUESTION	:	Is there some D over σ such that $\mathbf{V}(D) = E$?

Testing view consistency

- Combined complexity:

PROBLEM	:	VIEW CONSISTENCY FOR LANGUAGE $\mathcal{L}$
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- Data complexity:

  Let $\mathbf{V}$ be a fixed view from σ to τ in some language $\mathcal{L}$:

PROBLEM	:	VIEW CONSISTENCY($\mathbf{V}$)
INPUT	:	A view instance E
QUESTION	:	Is there some D over σ such that $\mathbf{V}(D) = E$?

Example: how hard is testing consistency?

$\sigma = \{c, e, p\}$ $\mathbf{V} = \left\{ \qquad \right\}$

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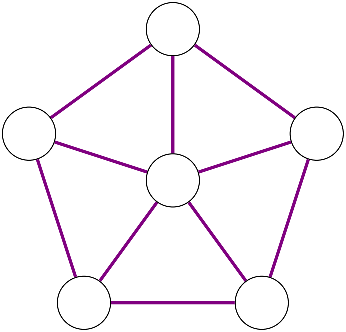
$$\mathbf{V} = \left\{ Q_{\text{edge}}(x, y) = e(x, y) \right\}$$



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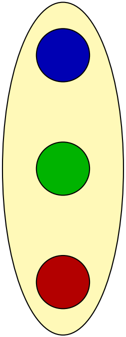

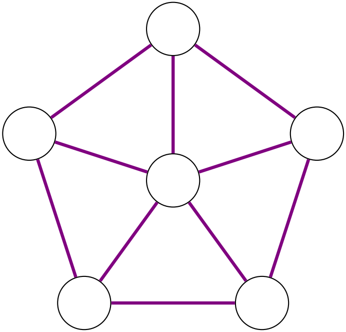

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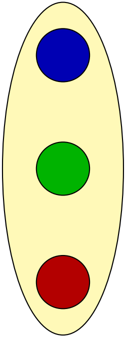

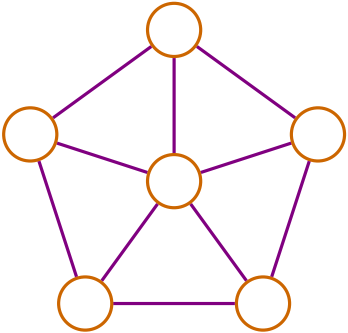

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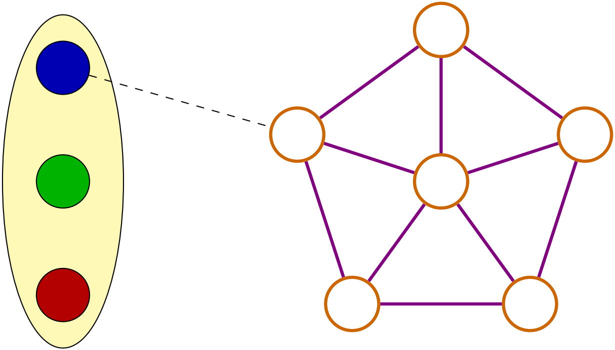

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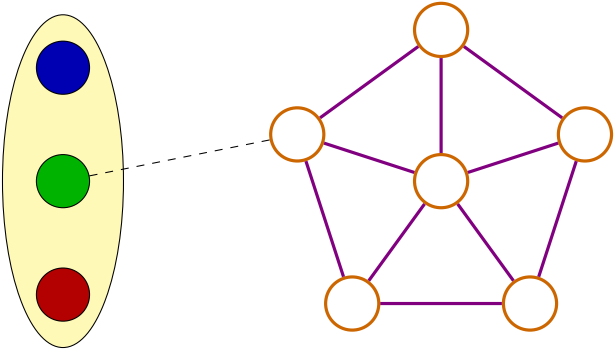

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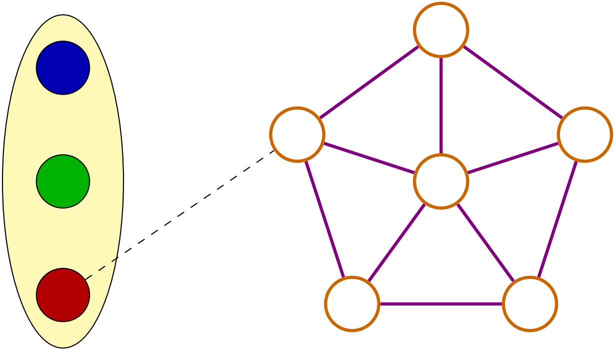

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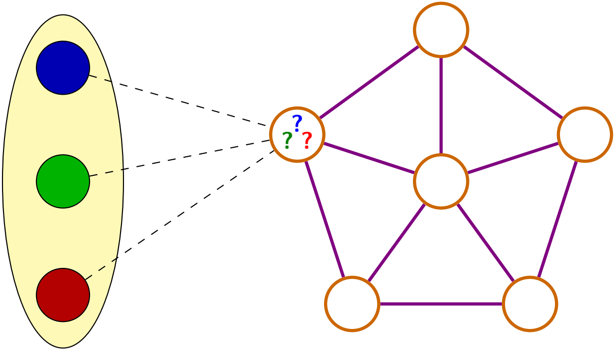

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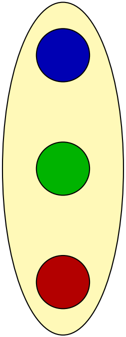

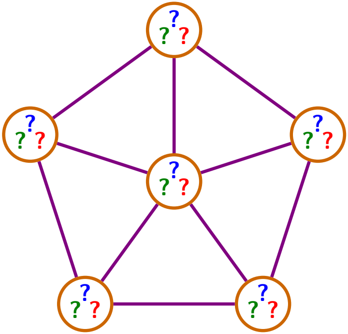

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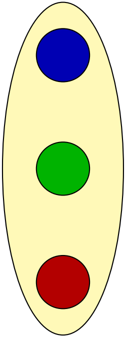

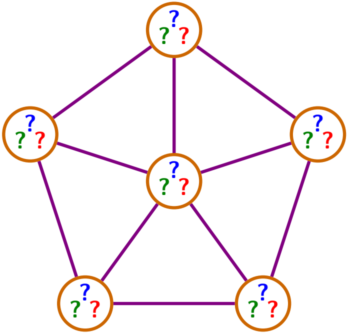

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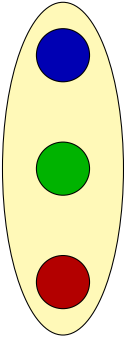

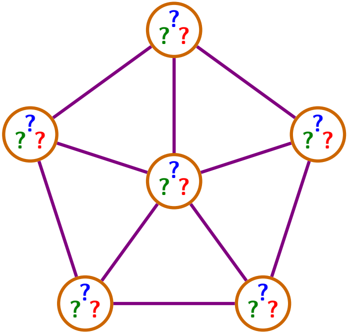

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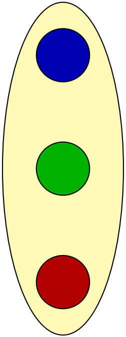

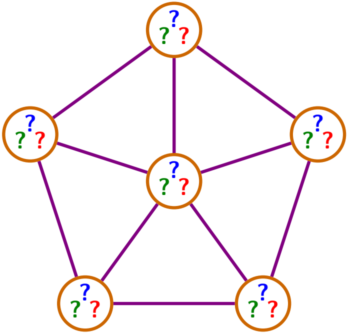

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The view instance is consistent iff the graph is 3-colorable!

How hard is testing consistency?

Short answer: it's hard, even for simple languages and in data complexity.

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Theorem [Abiteboul, Duschka]

There exists a fixed view **V** defined using conjunctive queries such that VIEW CONSISTENCY(**V**) is NP-complete.

Our proof sketch easily extends to UCQ, RPQ, CRPQ...

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Our proof sketch easily extends to UCQ, RPQ, CRPQ...

The problem quickly becomes undecidable for more expressive languages.

Theorem [Abiteboul, Duschka]

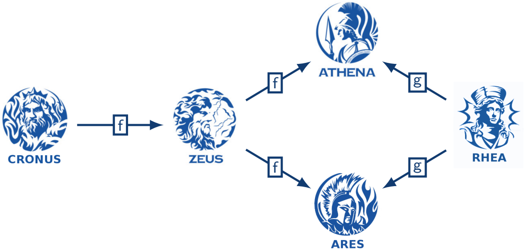
There exists a fixed view **V** defined using Datalog queries such that View Consistency(**V**) is undecidable.

This also holds for context-free path queries, first-order queries...

Certain answers

Example: answering queries using views

$$\sigma = \{b, f, w\} \qquad \mathbf{V} = \left\{ \begin{array}{c} Q_g(x,y) = x \xrightarrow{w} z \xrightarrow{f} z' \xrightarrow{f} y \\ Q_f(x,y) = x \xrightarrow{f} y \end{array} \right\} \qquad \tau = \{f, g\}$$



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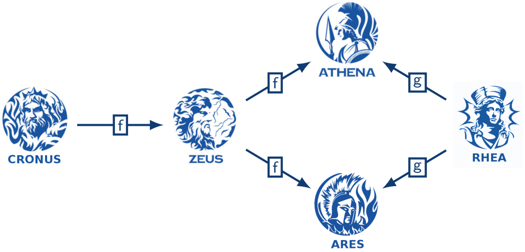

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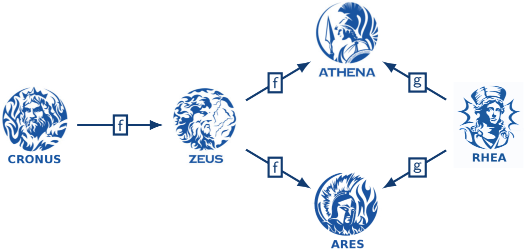

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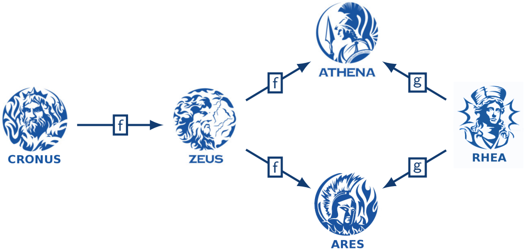

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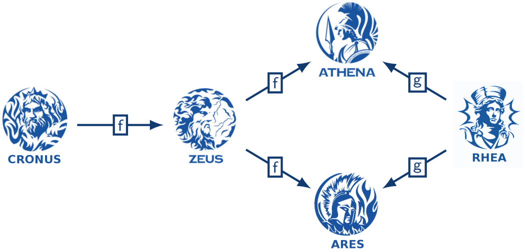

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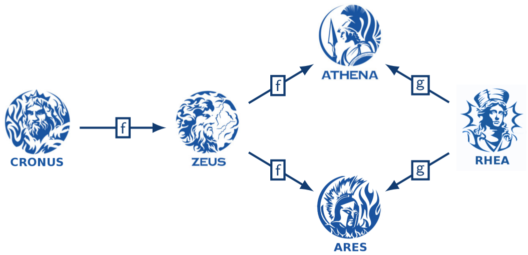

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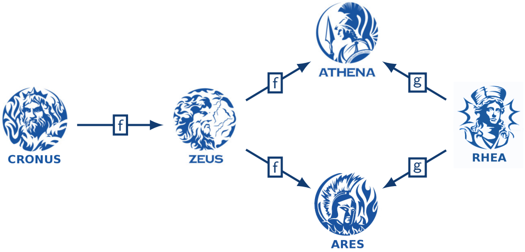

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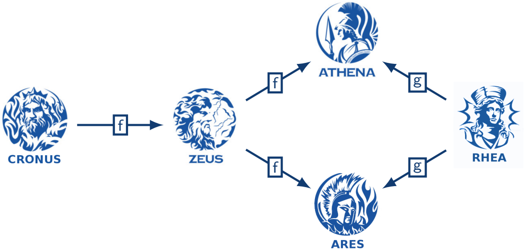

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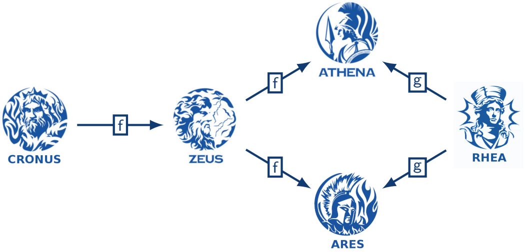

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  $\rightarrow$ Cronus is a candidate; could there be another?

Answering queries using views

Given: $\begin{cases} \mathbf{V} : \text{view from } \sigma \text{ to } \tau \\ E : \text{view instance over } \tau \\ Q : \text{query over } \sigma \end{cases}$

- Certain answers:

$$\boxed{\operatorname{cert}_{Q,\mathbf{V}}(E) = \bigcap_{D \;\mid\; \mathbf{V}(D)=E} Q(D)}$$

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- Certain answers under the exact view assumption:

$$\text{cert}^{\text{exact}}_{Q,\mathbf{V}}(E) = \bigcap_{D \,\mid\, \mathbf{V}(D)=E} Q(D)$$

- Certain answers under the sound view assumption:

$$\text{cert}^{\text{sound}}_{Q,\mathbf{V}}(E) = \bigcap_{D \,\mid\, \mathbf{V}(D)\supseteq E} Q(D)$$

The problem(s) of computing certain answers

PROBLEM	:	CERTAIN ANSWERS
INPUT	:	A view $\mathbf{V}$ from σ to τ, A query Q over σ, A view instance E and $\bar{u} \in E$
QUESTION	:	$\bar{u} \in \mathrm{cert}_{Q,\mathbf{V}}(E)$?

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PROBLEM	:	CERTAIN ANSWERS FOR $\mathcal{L}$ AND $\mathcal{L}'$
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The problem(s) of computing certain answers

- Combined complexity:

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- Data complexity:

  Let $\mathbf{V}$ be a fixed view from σ to τ and Q be a fixed query over σ:

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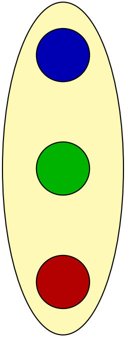

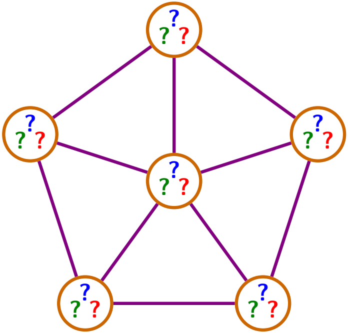

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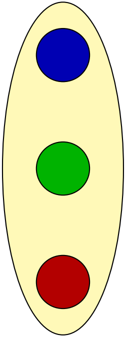

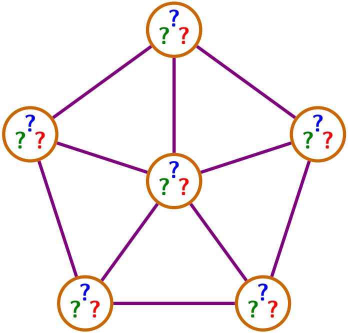

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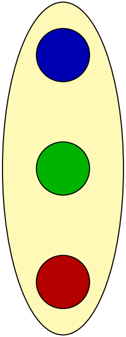

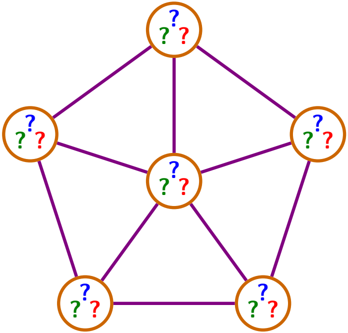

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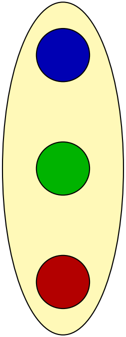

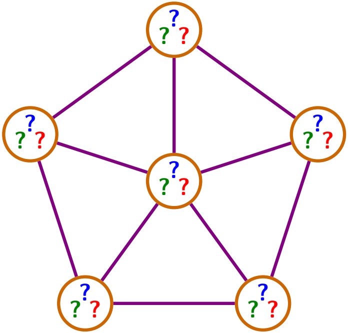

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- Sound view: we can always invent more colors!

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Some results from [Abiteboul, Duschka'98]:

view \ query	CQ	$CQ^{\neq}$	Datalog	FO
CQ	PTIME/coNP	coNP	PTIME/coNP	Undec.
$CQ^{\neq}$	PTIME/coNP	coNP	PTIME/coNP	Undec.
Datalog	coNP/Undec.	Undec.	Undec.	Undec.
FO	Undec.	Undec.	Undec.	Undec.

Complexity of answering queries using sound or exact views.

Determinacy and rewriting

Example: determinacy and rewriting

$$\sigma = \{b, f, w\} \qquad \mathbf{V} = \left\{ \begin{array}{c} Q_{s1}(x) = \exists z \cdot x \xrightarrow{w} z \\ Q_{s2}(x) = \exists z \cdot z \xrightarrow{w} x \\ Q_{gf}(x,y) = x \xrightarrow{f} z \xrightarrow{f} y \end{array} \right\} \qquad \tau = \{gf, s1, s2\}$$

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Yes! Rhea is the grandmother of Athena.
And nothing else: possible and certain answers coincide.

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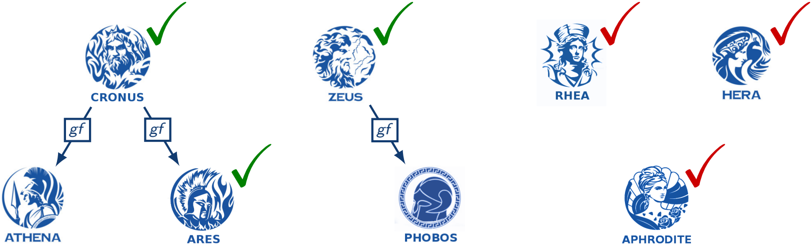

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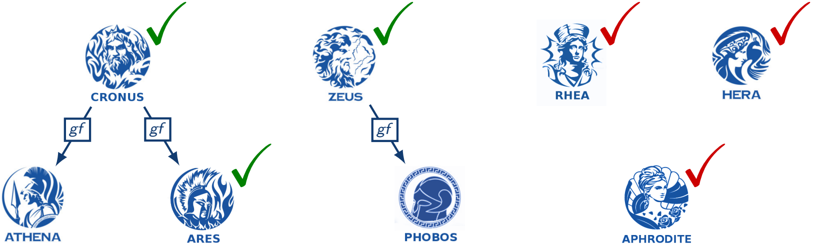
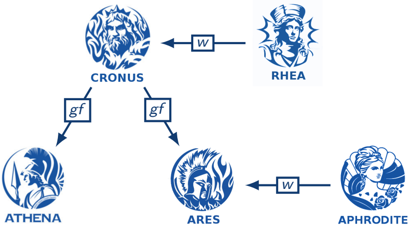


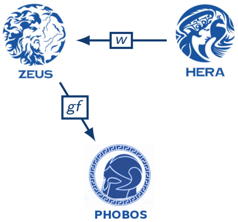
Can we answer $Q(x,y) = x \xrightarrow{w} z \xrightarrow{f} z' \xrightarrow{f} y$ based on the view instance?

There is no way to match husbands and wives...
Nothing is certain and every match is possible.

Example: determinacy and rewriting (2)

$$\sigma = \{b, f, w\} \qquad \mathbf{V} = \left\{ \begin{array}{c} Q_w(x,y) = x \xrightarrow{w} y \\ Q_{gf}(x,y) = x \xrightarrow{f} z \xrightarrow{f} y \end{array} \right\} \qquad \tau = \{gf, w\}$$





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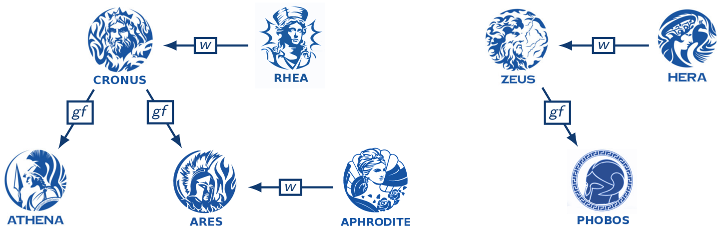

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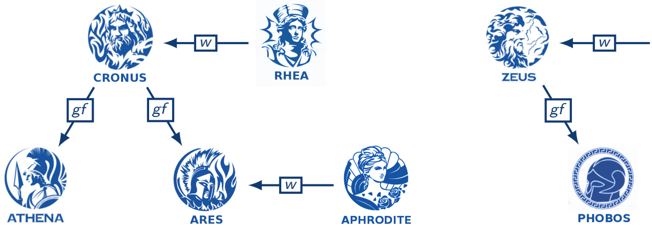

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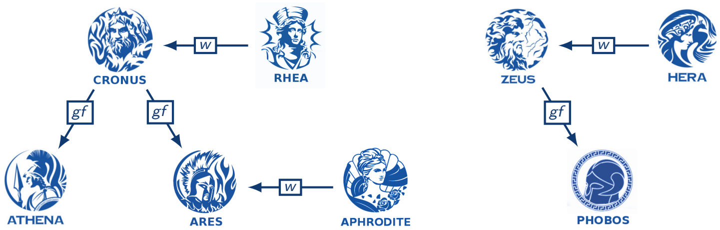

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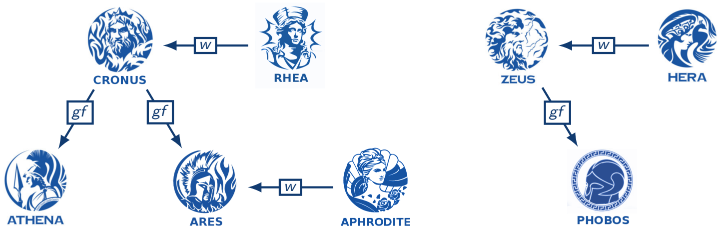

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- Q can be rewritten as $R(x,y) = x \xrightarrow{w} z \xrightarrow{gf} y$ over τ.

Determinacy and rewriting

Let **V** be a view from σ to τ and Q be a query over σ.

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Thus possible and certain answers coincide both with $Q(D)$.

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  The existence of a rewriting immediately implies that $\mathbf{V} \twoheadrightarrow Q$.

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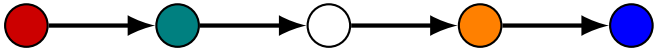

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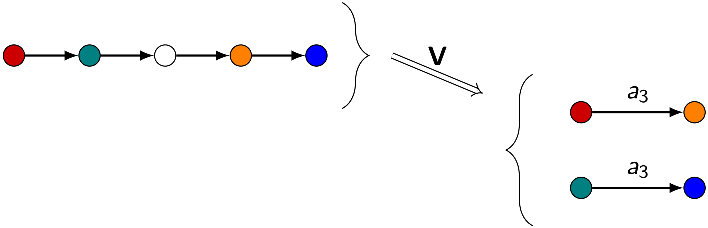

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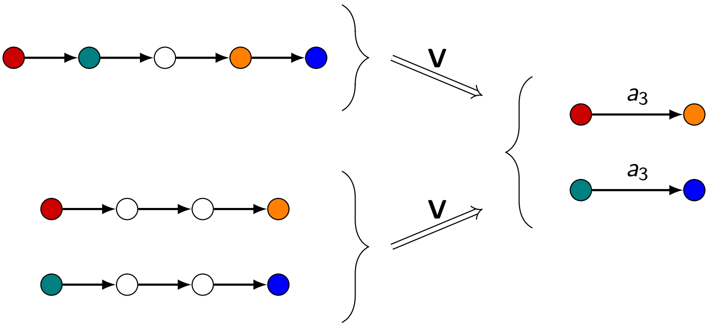

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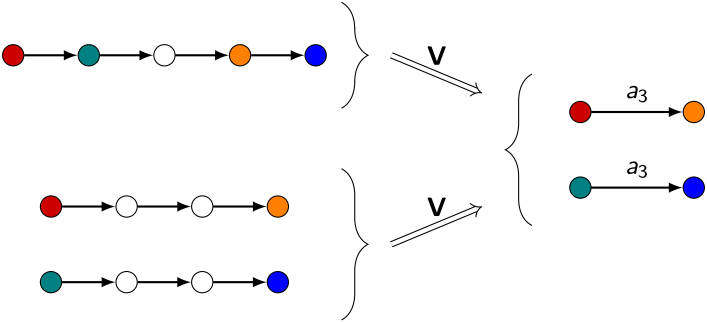

$\mathbf{V}(D) = \mathbf{V}(D')$ but $Q(D) = \{(\bullet, \bullet)\}$ and $Q(D') = \emptyset$

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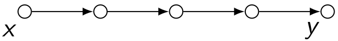

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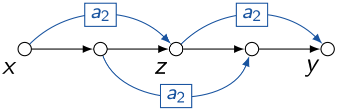

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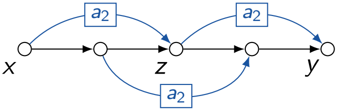

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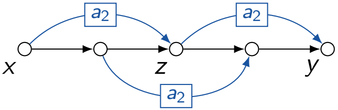

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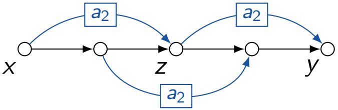

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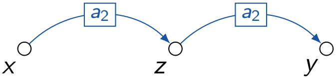

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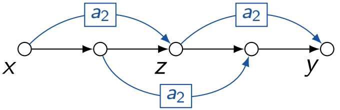

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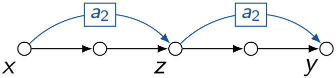

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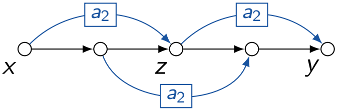

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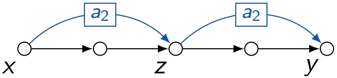

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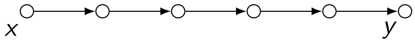

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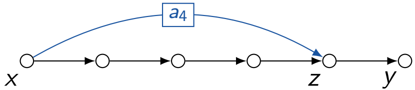

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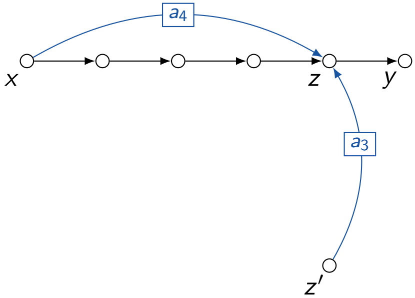

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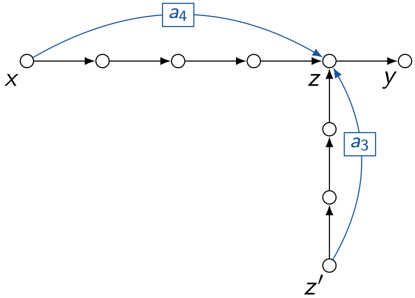

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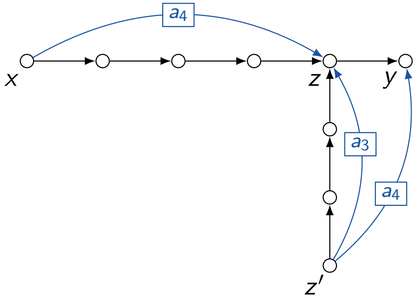

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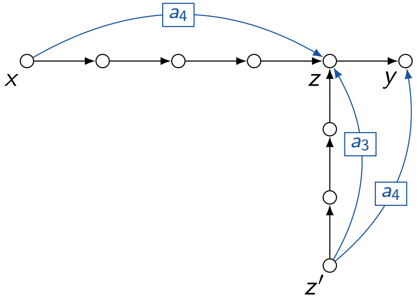

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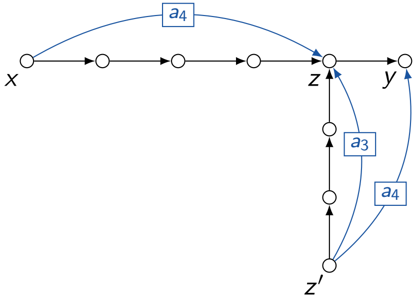

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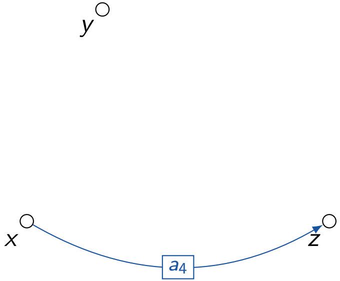

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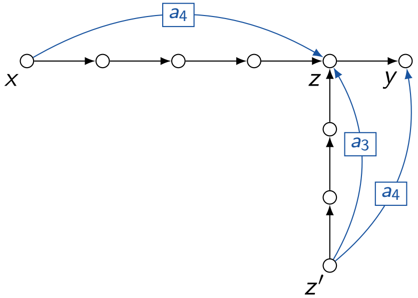

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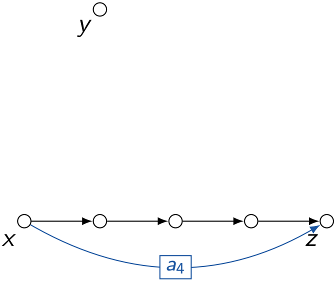

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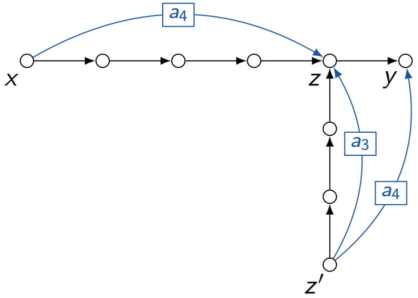

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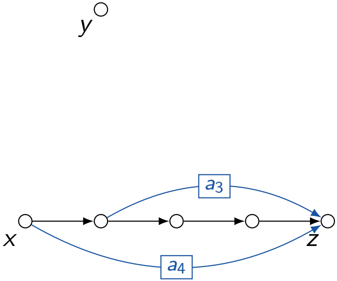

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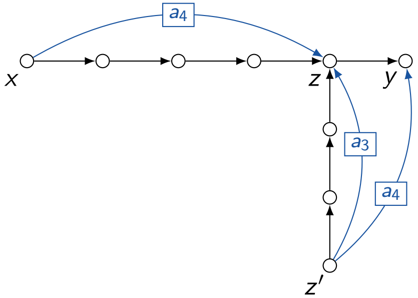

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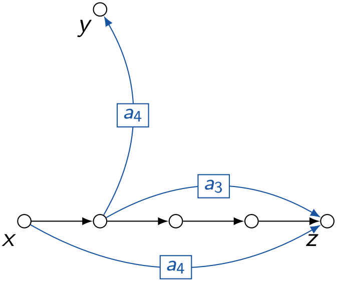

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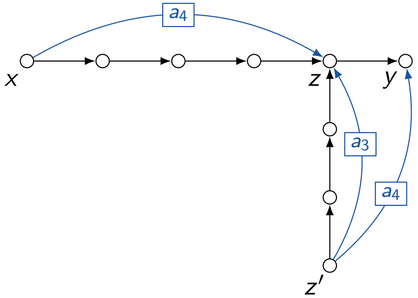

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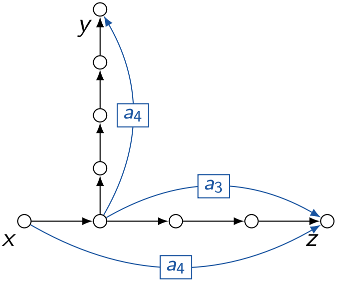

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Let $\mathbf{V}$ be a view from σ to τ and Q be a query over σ.

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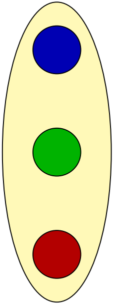
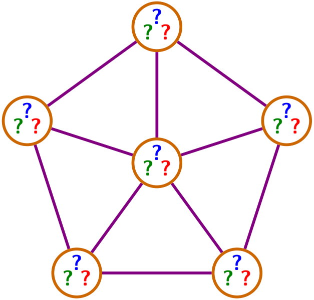
Rewritings can differ in behavior and complexity outside of view images.

Example: different rewritings of varying complexity

$\sigma = \{c, e, p\}$

$$\mathbf{V} = \left\{ \begin{array}{c} Q_{\text{edge}}(x, y) = e(x, y) \\ Q_{\text{palette}}(x) = p(x) \\ Q_{\text{color}}(x) = \exists z \cdot p(z) \wedge c(x, z) \\ Q_{\text{error}}(x, y) = \exists z \cdot c(x, z) \wedge c(y, z) \wedge e(x, y) \end{array} \right\}$$





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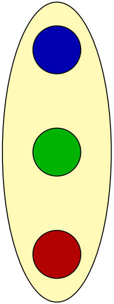

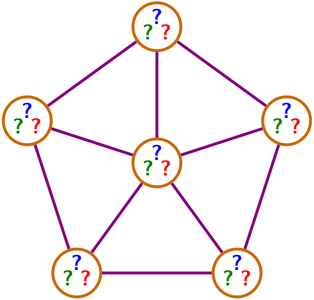

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Example: different rewritings of varying complexity

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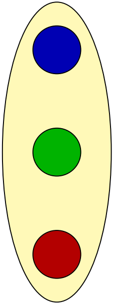

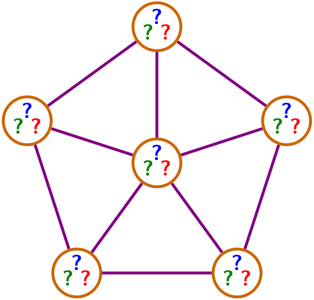

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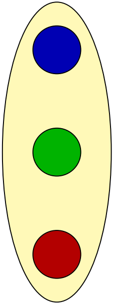

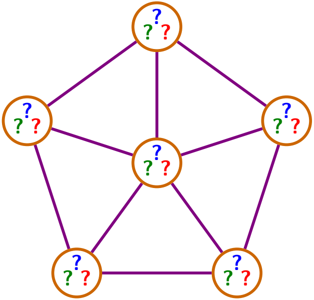

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$R_1(x) = x \in \text{cert}_{Q,\mathbf{V}}(E)$

(check if the graph is 3-colorable)

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(trust the view instance)

Some problems around determinacy and rewritings

PROBLEM	:	DETERMINACY FOR LANGUAGES $\mathcal{L}$ AND $\mathcal{L}'$
INPUT	:	An $\mathcal{L}$-view $\mathbf{V}$ and an $\mathcal{L}'$-query Q
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Example:

- Is there a rewriting that can be expressed in first-order logic?
- Is there a rewriting with PTIME evaluation complexity?
- Is there a rewriting that is monotone?

How hard is the determinacy problem?

Short answer: it's hard, even for simple query and view languages.

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- [Gluch et al'19]: Determinacy is undecidable for finite RPQs.
- [F., Segoufin, Sirangelo'15]: Monotone rewritings of RPQ queries using RPQ views can be expressed in Datalog.

  (Existence is EXPSPACE*-complete, using [Calvanese et al'02])*

Some open problems

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In which language can we rewrite CQ queries using CQ views?

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Question 3
Is determinacy decidable for chain queries and disjunctive chain views?

One last example

Example: disjunctive chain queries – the Chase

$$\sigma = \{a\}$$

$$\tau = \{(2), (1,2)\}$$

$$\mathbf{V} = \left\{ \begin{array}{c} Q_2(x,y) = x \xrightarrow{a^2} y \\ Q_{1,2}(x,y) = (x \xrightarrow{a} y) \vee (x \xrightarrow{a^2} y) \end{array} \right\}$$

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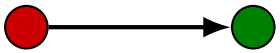

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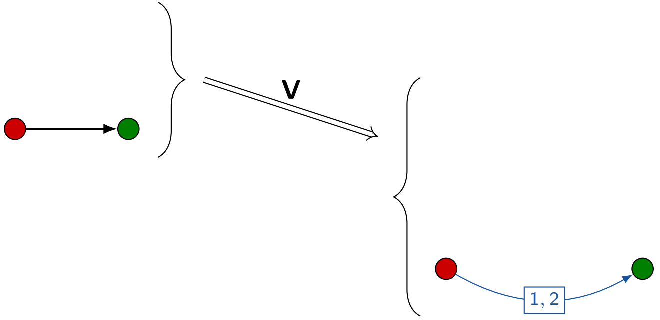

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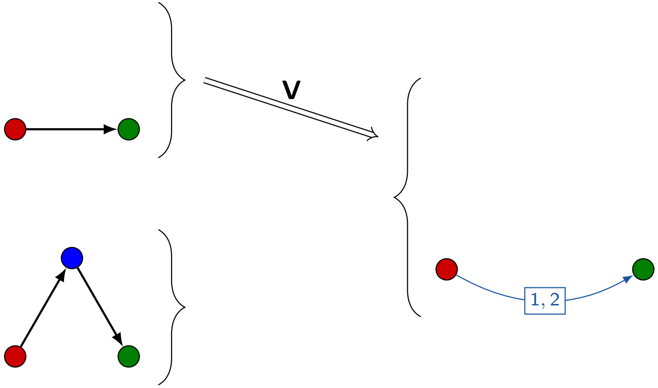

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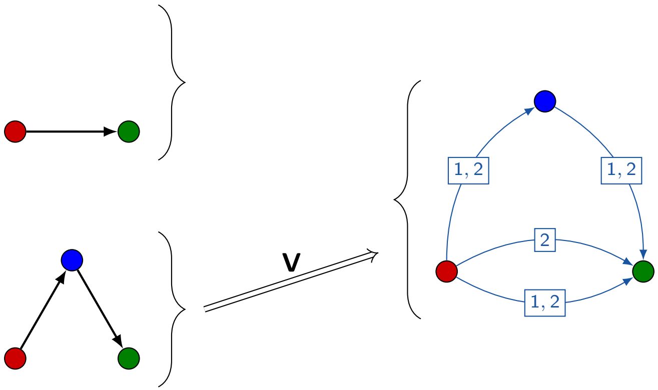

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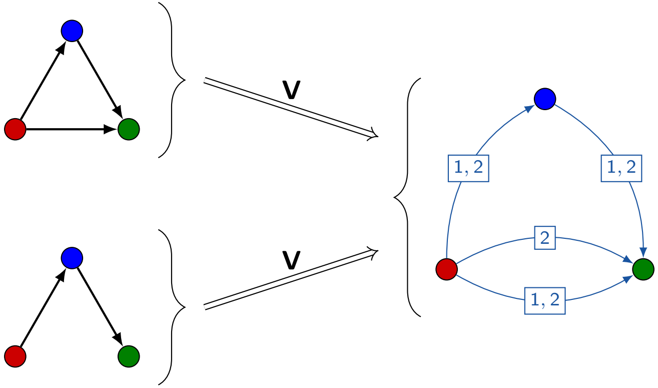

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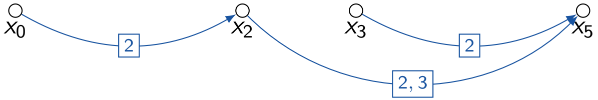

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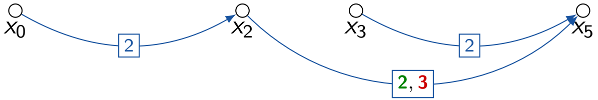

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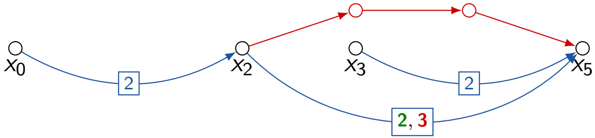

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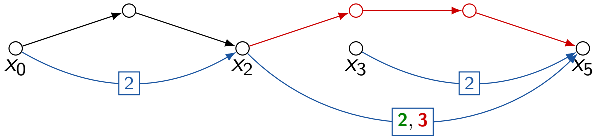

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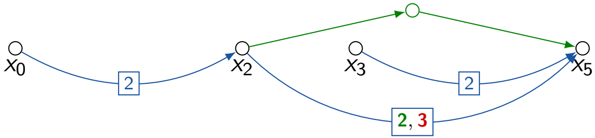

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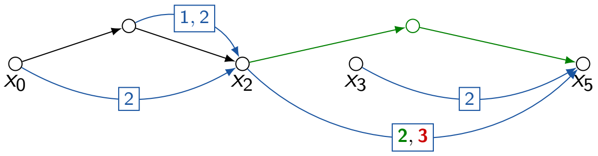

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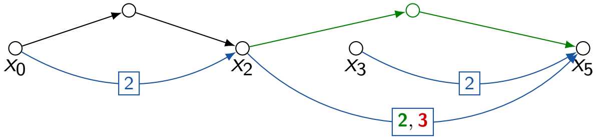

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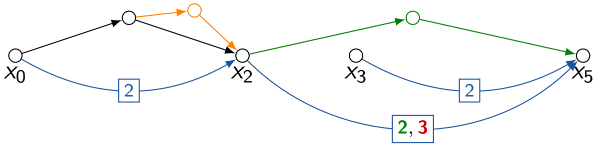
$$\begin{aligned} R(x_0,x_5) = \exists x_2, x_3 \quad & \cdot \quad a_2(x_0,x_2) \wedge a_2(x_3,x_5) \\ & \cdot \quad a_{2,3}(x_2,x_5) \\ & \cdot \quad \forall z \cdot a_{1,2}(z,x_2) \Rightarrow \big(a_2(z,x_2) \vee a_2(z,x_3)\big) \end{aligned}$$



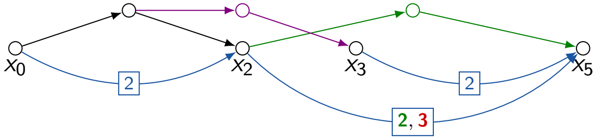
Example: disjunctive chain queries – a rewriting

$$\sigma = \{a\}$$
$$\tau = \{a_2, a_{1,2}, a_{2,3}\}$$

$$\mathbf{V} = \left\{ \begin{array}{c} Q_2(x,y) = x \xrightarrow{a^2} y \\ Q_{1,2}(x,y) = (x \xrightarrow{a} y) \vee (x \xrightarrow{a^2} y) \\ Q_{2,3}(x,y) = (x \xrightarrow{a^2} y) \vee (x \xrightarrow{a^3} y) \end{array} \right\}$$

Does $\mathbf{V}$ determine $Q(x,y) = x \xrightarrow{a^5} y$?

$$\begin{aligned} R(x_0, x_5) = \exists x_2, x_3 \quad & \cdot \quad a_2(x_0, x_2) \wedge a_2(x_3, x_5) \\ & \cdot \quad a_{2,3}(x_2, x_5) \\ & \cdot \quad \forall z \cdot a_{1,2}(z, x_2) \Rightarrow \big(a_2(z, x_2) \vee a_2(z, x_3)\big) \end{aligned}$$



Example: disjunctive chain queries – homework

$$\sigma = \{a\}$$
$$\tau = \{a_2, a_{1,2}, a_{2,5}\}$$

$$\mathbf{V} = \left\{ \begin{array}{c} Q_2(x,y) = x \xrightarrow{a^2} y \\ Q_{1,2}(x,y) = (x \xrightarrow{a} y) \vee (x \xrightarrow{a^2} y) \\ Q_{2,5}(x,y) = (x \xrightarrow{a^2} y) \vee (x \xrightarrow{a^5} y) \end{array} \right\}$$

Can you prove that $\mathbf{V}$ does not determine $Q(x,y) = x \xrightarrow{a^9} y$?

Example: disjunctive chain queries – homework

$$\sigma = \{a\}$$

$$\tau = \left\{a_2, a_{1,2}, a_{2,5}\right\}$$

$$\mathbf{V} = \left\{ \begin{array}{c} Q_2(x,y) = x \xrightarrow{a^2} y \\ Q_{1,2}(x,y) = (x \xrightarrow{a} y) \vee (x \xrightarrow{a^2} y) \\ Q_{2,5}(x,y) = (x \xrightarrow{a^2} y) \vee (x \xrightarrow{a^5} y) \end{array} \right\}$$

Can you prove that **V** does not determine $Q(x,y) = x \xrightarrow{a^9} y$?

I know a proof...

Example: disjunctive chain queries – homework

$$\sigma = \{a\}$$
$$\tau = \{a_2, a_{1,2}, a_{2,5}\}$$

$$\mathbf{V} = \left\{ \begin{array}{c} Q_2(x,y) = x \xrightarrow{a^2} y \\ Q_{1,2}(x,y) = (x \xrightarrow{a} y) \vee (x \xrightarrow{a^2} y) \\ Q_{2,5}(x,y) = (x \xrightarrow{a^2} y) \vee (x \xrightarrow{a^5} y) \end{array} \right\}$$

Can you prove that **V** does not determine $Q(x,y) = x \xrightarrow{a^9} y$?

I know a proof...

...and it's ugly...

Example: disjunctive chain queries – homework

$$\sigma = \{a\}$$
$$\tau = \left\{a_2, a_{1,2}, a_{2,5}\right\}$$

$$\mathbf{V} = \left\{ \begin{array}{c} Q_2(x,y) = x \xrightarrow{a^2} y \\ Q_{1,2}(x,y) = (x \xrightarrow{a} y) \vee (x \xrightarrow{a^2} y) \\ Q_{2,5}(x,y) = (x \xrightarrow{a^2} y) \vee (x \xrightarrow{a^5} y) \end{array} \right\}$$

Can you prove that **V** does not determine $Q(x,y) = x \xrightarrow{a^9} y$?

I know a proof...

...and it's ugly...

If you think you have an elegant proof, come talk to me!

Announcement

If you want to know more...

Announcement

If you want to know more... come work with us!

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1-year postdoc funding at Marne-la-Vallée

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THANK YOU!