From Horn-$\mathcal{SRIQ}$ to Datalog: A Data-Independent Transformation that Preserves Assertion Entailment

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Introduction

The DL Horn-$\mathcal{SRIQ}$: Syntax

$$C_1 \sqcap \ldots \sqcap C_n \sqsubseteq D$$

$$\exists R . C \sqsubseteq D$$

$$C \sqsubseteq \exists R . D$$

$$C \sqsubseteq \leq 1 R . D$$

$$R_1 \circ \ldots \circ R_n \sqsubseteq S$$

$$R^- \sqsubseteq S$$

$$C(a)$$

$$R(a, b)$$

The DL Horn-$\mathcal{SRIQ}$: Syntax

$C_1 \sqcap \ldots \sqcap C_n \sqsubseteq D \quad \rightarrow \quad \mathsf{EnglishSpeaker} \sqcap \mathsf{FrenchSpeaker} \sqsubseteq \mathsf{Bilingual},$
$\mathsf{Vehicle} \sqsubseteq \mathsf{Car}, \mathsf{Vertebrate} \sqcap \mathsf{Invertebrate} \sqsubseteq \bot$

$\exists R.C \sqsubseteq D \quad \rightarrow \quad \exists \mathsf{Attends}.\mathsf{Course} \sqsubseteq \mathsf{Student}$

$C \sqsubseteq \exists R.D \quad \rightarrow \quad \mathsf{Director} \sqsubseteq \exists \mathsf{Directs}.\mathsf{Movie}$

$C \sqsubseteq \leq 1 R.D \quad \rightarrow \quad \mathsf{PhDStudent} \sqsubseteq \leq 1 \mathsf{HasThesisSupervisor}.\mathsf{Faculty}$

$R_1 \circ \ldots \circ R_n \sqsubseteq S \quad \rightarrow \quad \mathsf{HasAncestor} \circ \mathsf{HasAncestor} \sqsubseteq \mathsf{HasAncestor}, \mathsf{HasMother} \sqsubseteq \mathsf{HasParent},$
$\mathsf{HasParent} \circ \mathsf{HasSister} \sqsubseteq \mathsf{HasAunt}$

$R^- \sqsubseteq S \quad \rightarrow \quad \mathsf{HasChild}^- \sqsubseteq \mathsf{HasParent}$

$C(a) \quad \rightarrow \quad \mathsf{Person}(\mathsf{david})$

$R(a, b) \quad \rightarrow \quad \mathsf{HasFriend}(\mathsf{stan}, \mathsf{kyle})$

The DL Horn-$\mathcal{SRIQ}$: Semantics

$$
\begin{array}{rcl}
C_1 \sqcap \ldots \sqcap C_n \sqsubseteq D & \mapsto & \forall x \,.\, C_1(x) \wedge \ldots \wedge C_n(x) \rightarrow D(x) \\
\exists R \,.\, C \sqsubseteq D & \mapsto & \forall x, y \,.\, R(x, y) \wedge C(y) \rightarrow D(x) \\
C \sqsubseteq \exists R \,.\, D & \mapsto & \forall x \,.\, C(x) \rightarrow \exists y \,.\, R(x, y) \wedge D(y) \\
C \sqsubseteq\, \leq 1 R \,.\, D & \mapsto & \forall x, y, z \,.\, C(x) \wedge R(x, y) \wedge D(y) \wedge R(x, z) \wedge D(z) \rightarrow y \approx z \\
R_1 \circ \ldots \circ R_n \sqsubseteq S & \mapsto & \forall x_0, \ldots, x_n \,.\, R_1(x_0, x_1) \wedge \ldots \wedge R_n(x_{n-1}, x_n) \rightarrow R(x_0, x_n) \\
R^- \sqsubseteq S & \mapsto & \forall x, y \,.\, R(x, y) \rightarrow S(y, x) \\
A(a) & \mapsto & A(a) \\
R(a, b) & \mapsto & R(a, b)
\end{array}
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R_1 \circ \ldots \circ R_n \sqsubseteq S &\quad\mapsto\quad R_1(x_0,x_1) \wedge \ldots \wedge R_n(x_{n-1},x_n) \rightarrow R(x_0,x_n) \\
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\end{aligned}
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The DL Horn-$\mathcal{SRIQ}$: Semantics

Terminological axioms

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\begin{aligned}
C_1 \sqcap \ldots \sqcap C_n \sqsubseteq D \quad &\mapsto \quad C_1(x) \land \ldots \land C_n(x) \to D(x) \\
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The DL Horn-$\mathcal{SRIQ}$: Semantics

Terminological axioms

$C_1 \sqcap \ldots \sqcap C_n \sqsubseteq D$	$\mapsto$	$C_1(x) \wedge \ldots \wedge C_n(x) \rightarrow D(x)$
$\exists R . C \sqsubseteq D$	$\mapsto$	$R(x, y) \wedge C(y) \rightarrow D(x)$
$C \sqsubseteq \exists R . D$	$\mapsto$	$C(x) \rightarrow \exists y . R(x, y) \wedge D(y)$
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Assertions / Facts

The DL Horn-$\mathcal{SRIQ}$: Semantics

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Assertions / Facts

Ontology

Set of terminological axioms / TBox

$$\mathcal{O} = \langle \mathcal{T}, \mathcal{F} \rangle$$

Set of facts / ABox

Datalog

$$\mathsf{Features}(x, y) \rightarrow \mathsf{Actor}(y)$$

$$\mathsf{ActsIn}(x, y) \rightarrow \mathsf{Features}(y, x)$$

$$\mathsf{HasID}(x, y) \wedge \mathsf{HasID}(x, z) \rightarrow y \approx z$$

$$\mathsf{Directs}(x, y) \wedge \mathsf{Features}(y, z) \rightarrow \mathsf{DirectsActor}(x, z)$$

$$\mathsf{Reviews}(x, y) \wedge \mathsf{IsAuthorOf}(z, y) \wedge \mathsf{CollaboratesWith}(x, y) \rightarrow \mathsf{IllegalReviewer}(x, y)$$

$$\mathsf{P}(x, y, z) \wedge \mathsf{S}(y, w, v) \wedge \mathsf{V}(y, v) \rightarrow \mathsf{D}(x)$$

Datalog

$$\mathsf{Features}(x, y) \to \mathsf{Actor}(y)$$

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$$\mathsf{Person}(\mathsf{david})$$

$$\mathsf{HasFriend}(\mathsf{stan}, \mathsf{kyle})$$

$$\mathsf{R}(\mathsf{a}, \mathsf{b}, \mathsf{c})$$

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Rules

$$\text{Reviews}(x, y) \wedge \text{IsAuthorOf}(z, y) \wedge \text{CollaboratesWith}(x, y) \rightarrow \text{IllegalReviewer}(x, y)$$
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Program

$$\mathscr{P} = \langle \mathscr{R}, \mathscr{F} \rangle$$

Set of rules ($\mathscr{R}$)

Set of facts ($\mathscr{F}$)

Datalog

$$\mathsf{Features}(x,y) \rightarrow \mathsf{Actor}(y)$$
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Assertions / Facts

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Program

$$\mathscr{P} = \langle \mathscr{R}, \mathscr{F} \rangle$$

$\mathscr{R}$: **Set of rules**

$\mathscr{F}$: **Set of facts**

Remark: Existential quantification is not allowed in Datalog.

Datalog

Assertions / Facts

$$\mathsf{Person}(\mathsf{david})$$
$$\mathsf{HasFriend}(\mathsf{stan}, \mathsf{kyle})$$
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$$\mathsf{Features}(x, y) \to \mathsf{Actor}(y)$$
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Set of rules ($\mathscr{R}$)

Set of facts ($\mathscr{F}$)

Remark: Existential quantification is not allowed in Datalog.

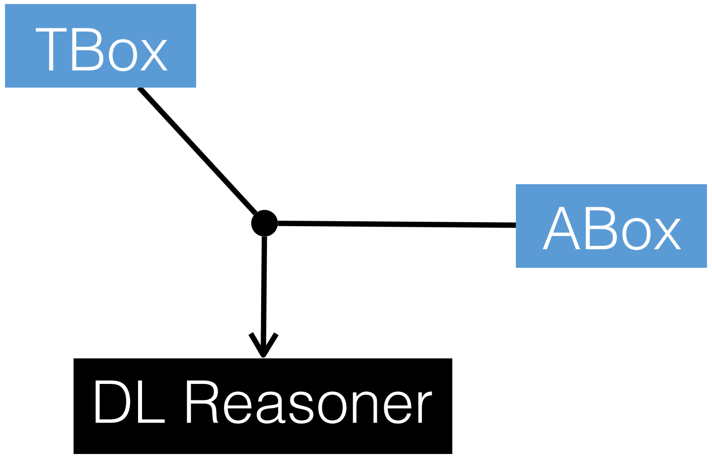
$$\mathsf{Director} \sqsubseteq \exists \mathsf{Directs} . \mathsf{Movie}$$
$$\mathsf{Director}(x) \to \exists y . \mathsf{Directs}(x, y) \wedge \mathsf{Movie}(y)$$

Solving Assertion Retrieval with Datalog Rewritings

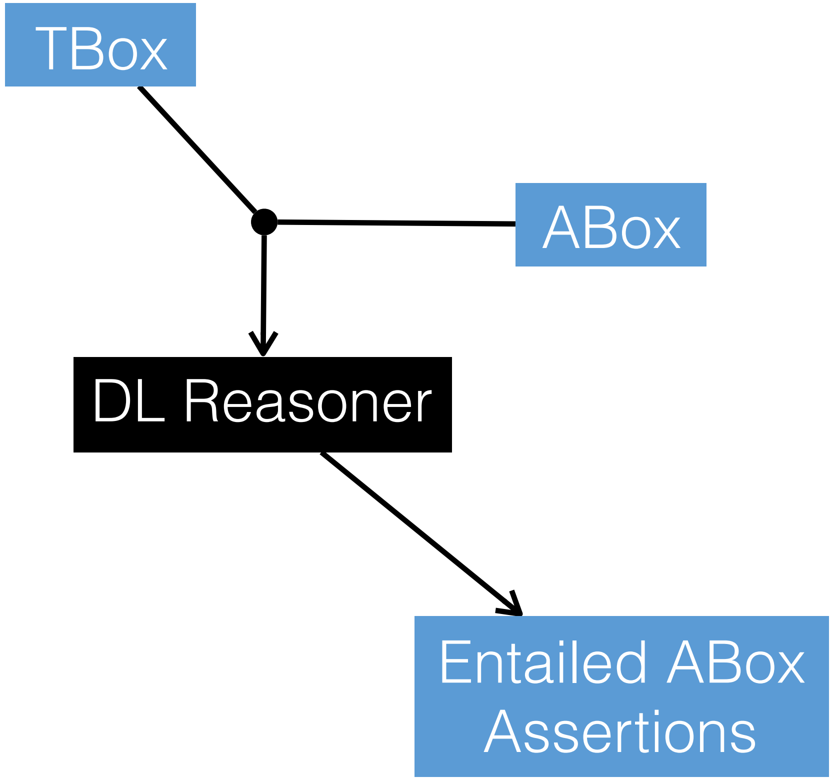
TBox

ABox

Solving Assertion Retrieval with Datalog Rewritings

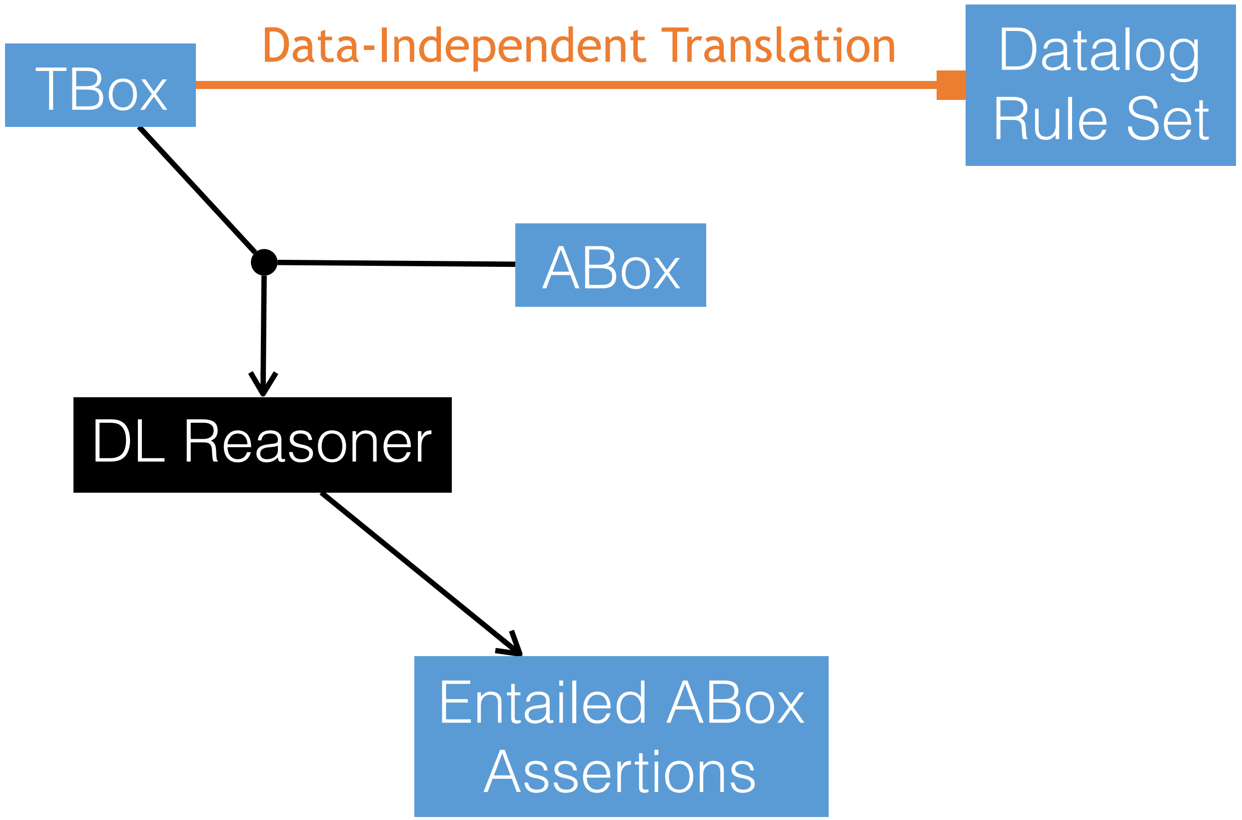


Solving Assertion Retrieval with Datalog Rewritings



(i.e., facts over named individuals)

Solving Assertion Retrieval with Datalog Rewritings



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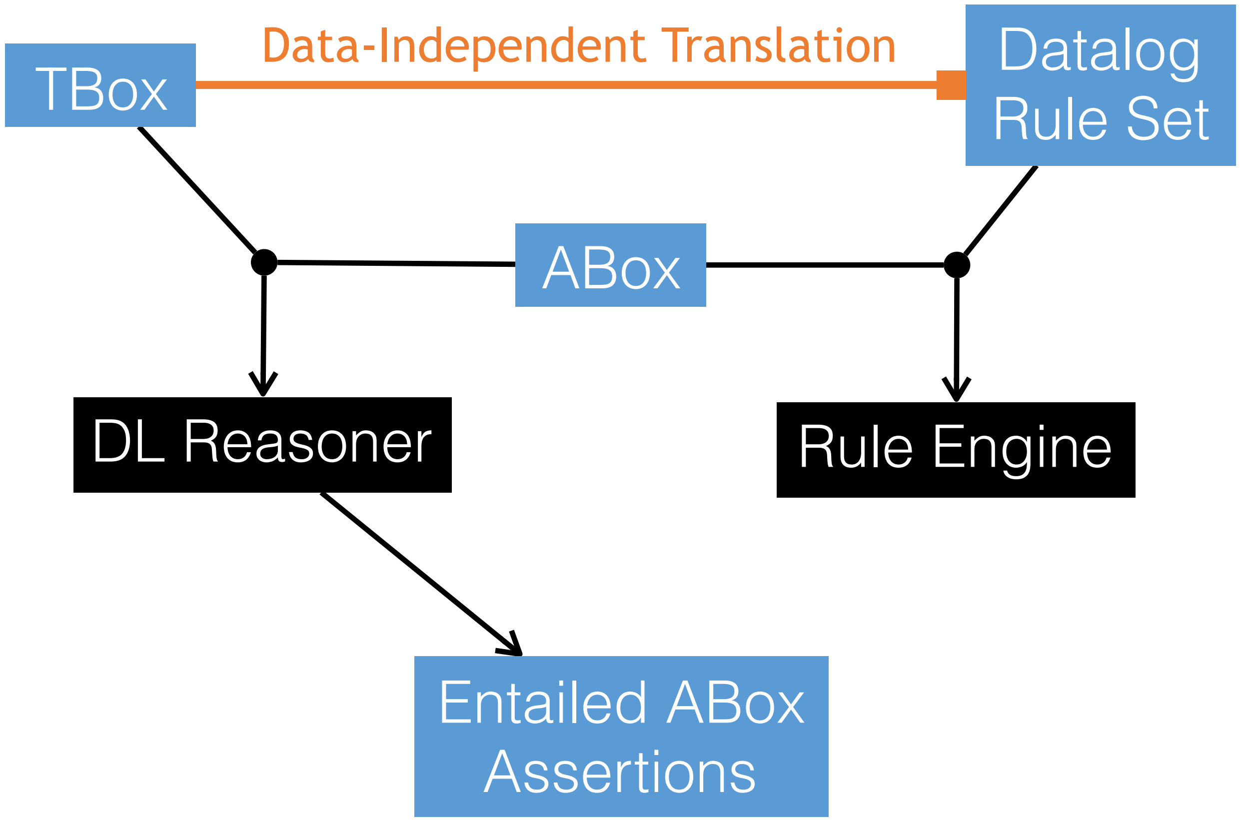
Solving Assertion Retrieval with Datalog Rewritings



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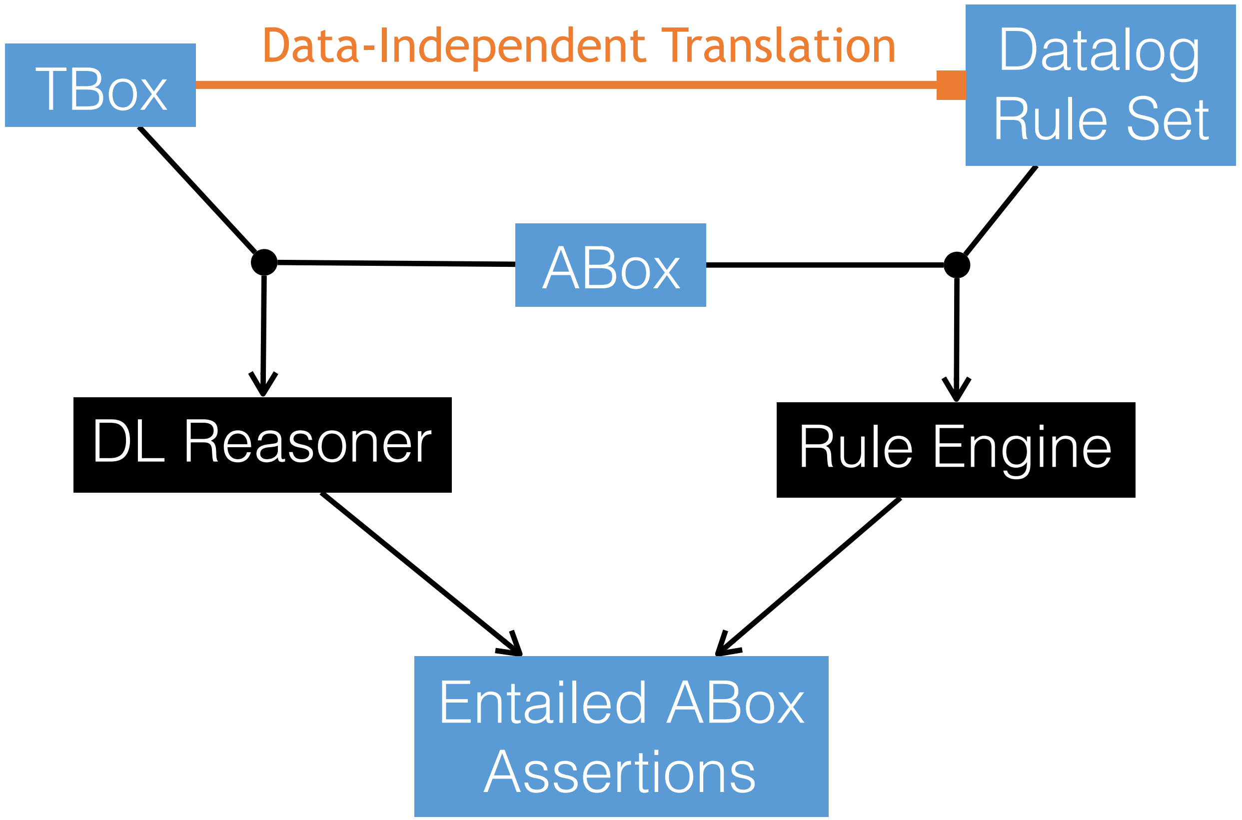
Solving Assertion Retrieval with Datalog Rewritings



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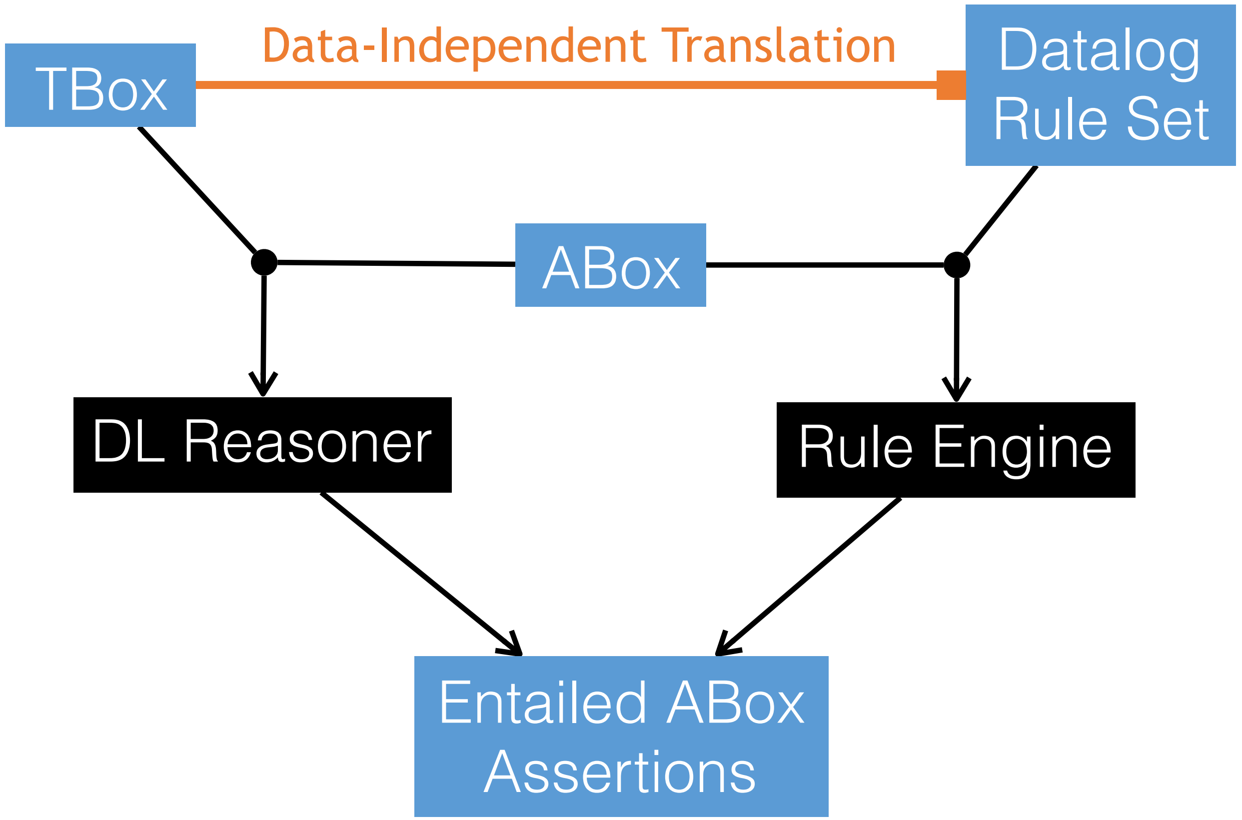
Solving Assertion Retrieval with Datalog Rewritings

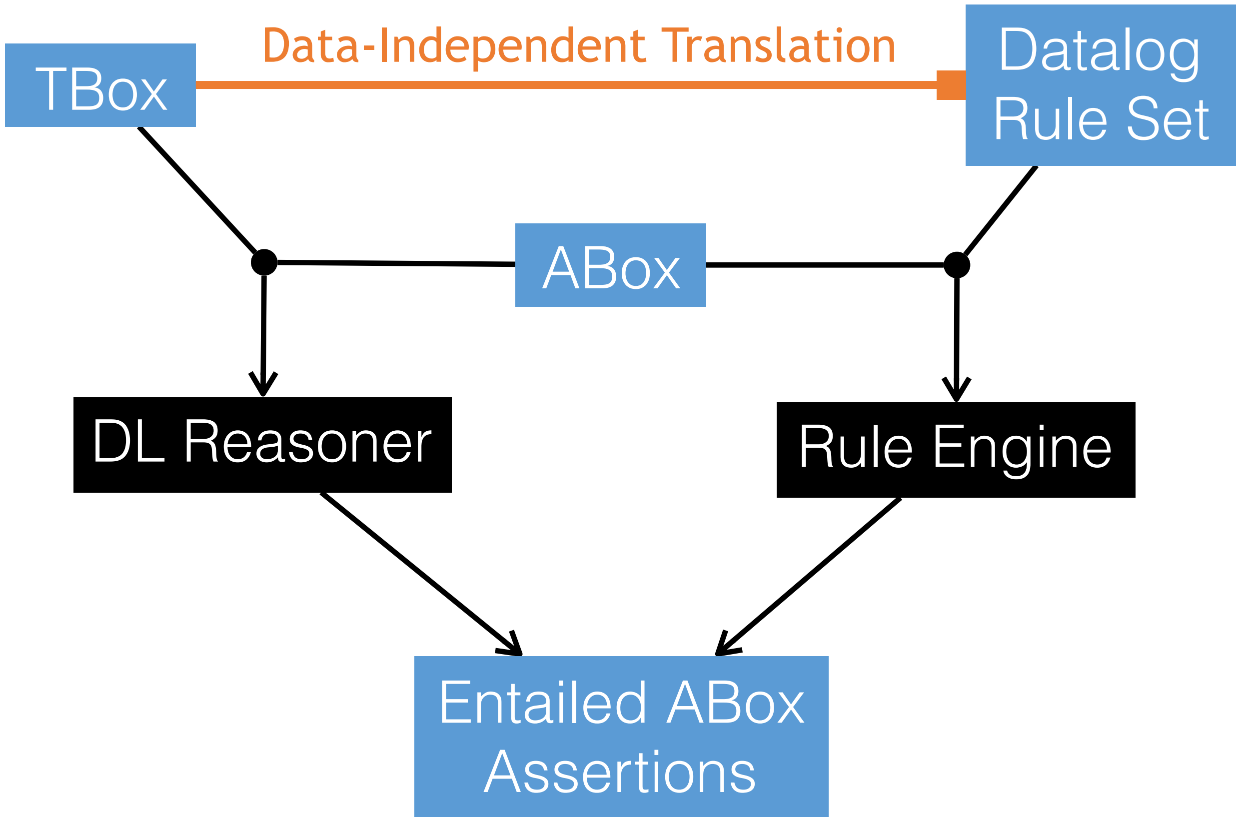


(i.e., facts over named individuals)

Motivation

* Research expressivity
* Performance improvements

Solving Assertion Retrieval with Datalog Rewritings



(i.e., facts over named individuals)

Motivation

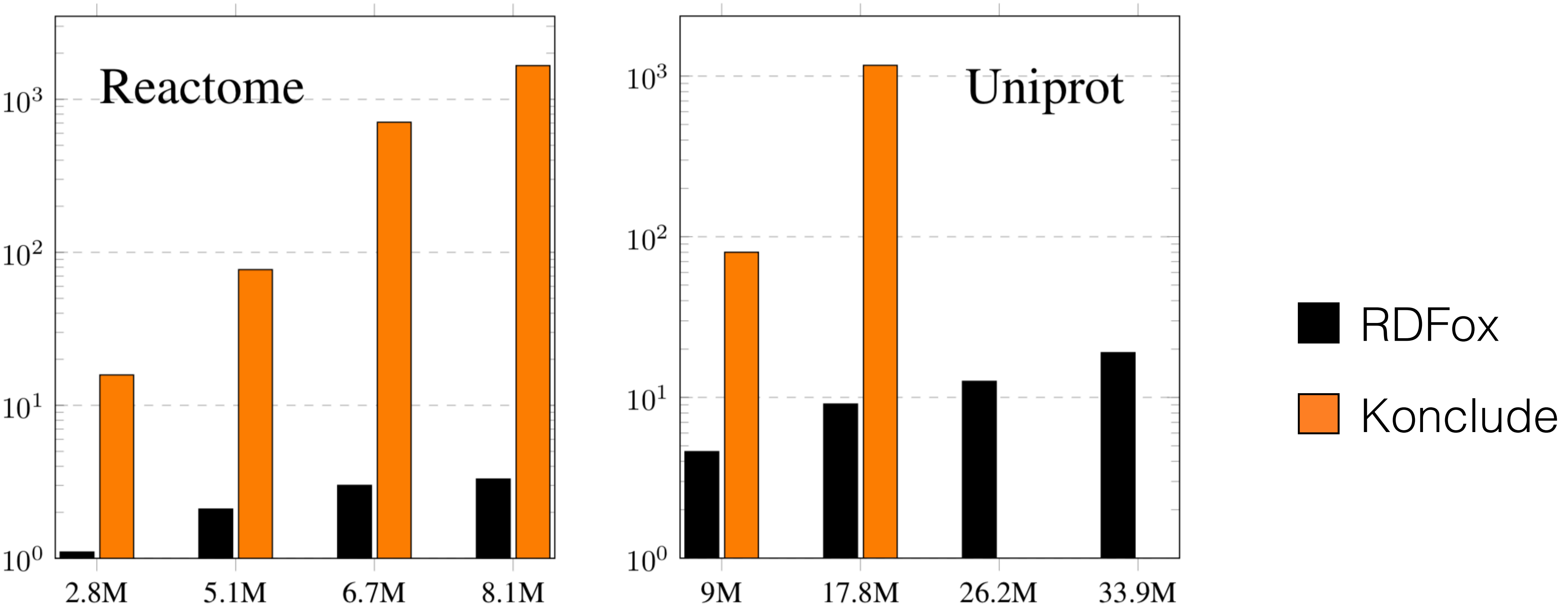
* Research expressivity
* Performance improvements

Challenges

* Correctness and complexity
* Implement translation and evaluate performance

Evaluation

Reasoning with Rewritings



TBox size: 485
Rewriting size: 549

TBox size: 304
Rewriting size: 367

Size of Rewritings

- MOWLCorpus: TBoxes with less 1000 axioms and containing role chain axioms
- 187 TBoxes
- 121 computed rewritings w/o OOM errors

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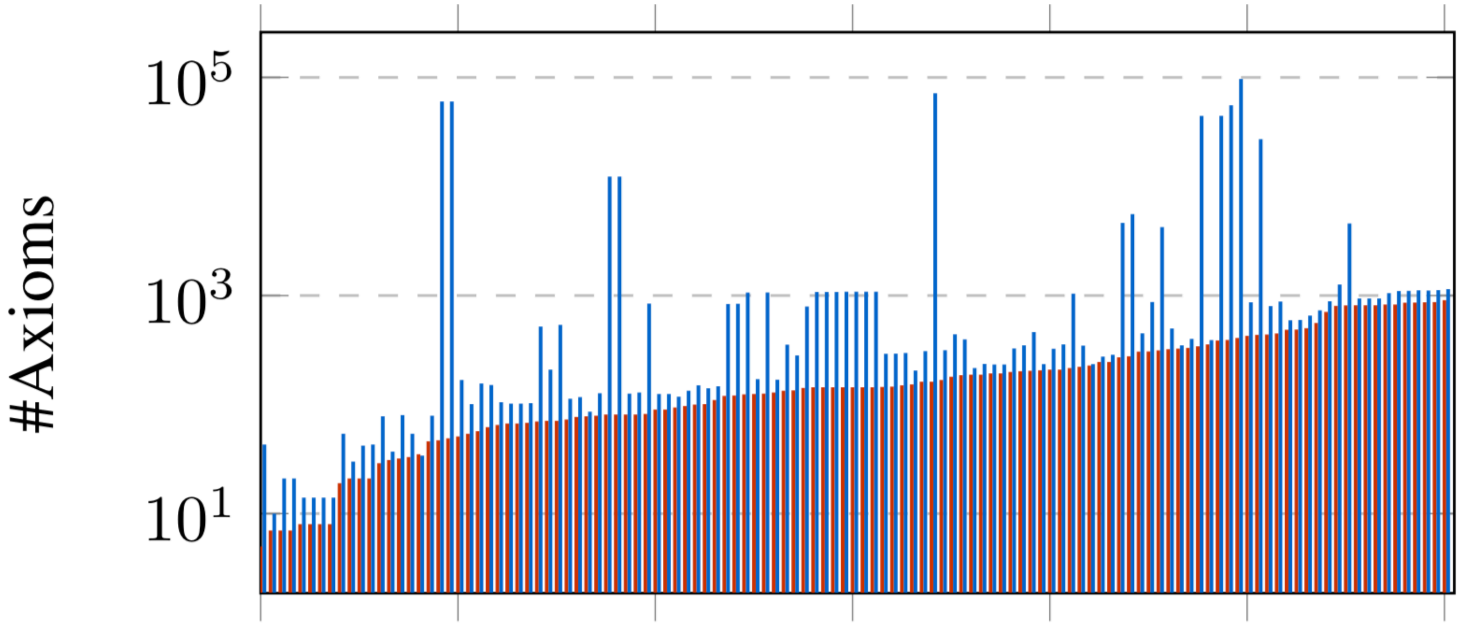
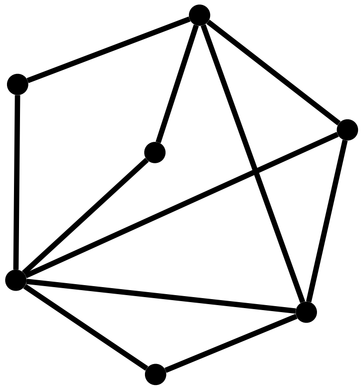


From Horn-$\mathcal{ALCHIQ}$ to Datalog

From Horn-$\mathcal{ALCHIQ}$ to Datalog

$$R_1 \circ \ldots \circ R_n \sqsubseteq S \quad \rightarrow \quad R \sqsubseteq S$$

Forest Model Property



$C_1 \sqcap \ldots \sqcap C_n \sqsubseteq D$

$C \sqsubseteq \exists R . D$

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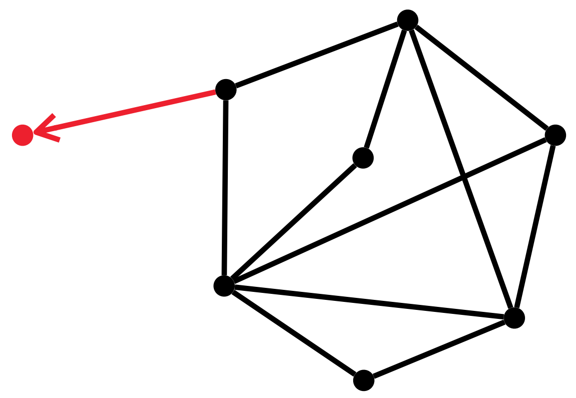
$R \sqsubseteq S$

Forest Model Property



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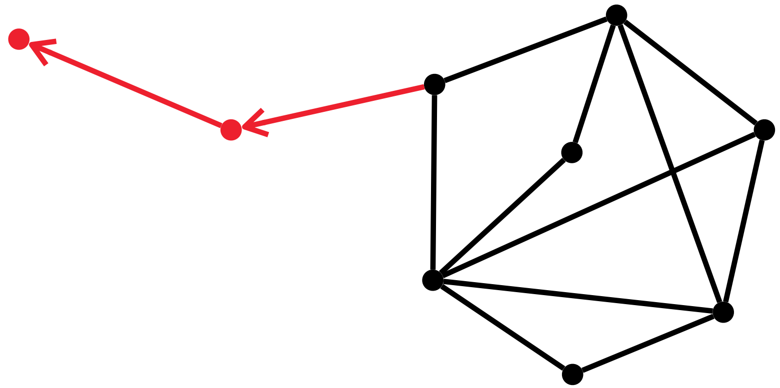

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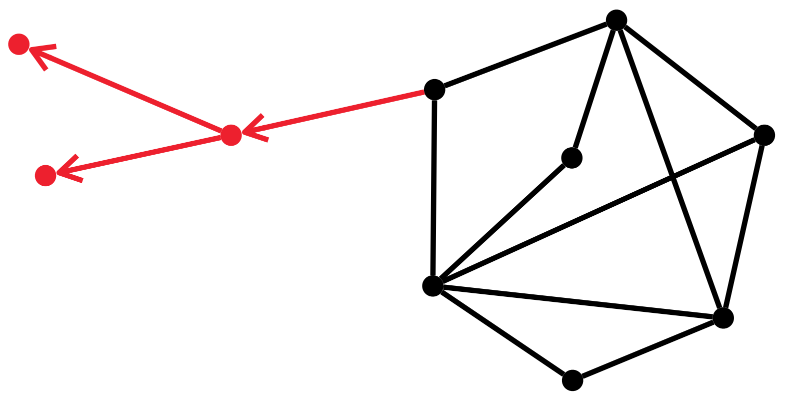

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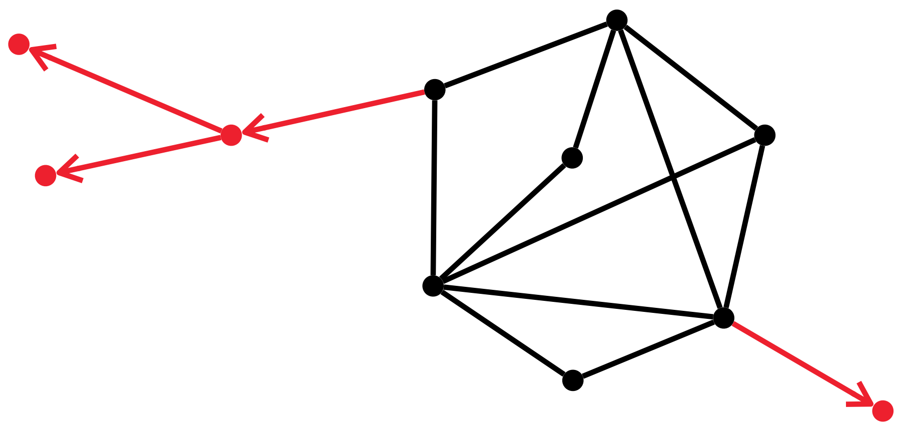

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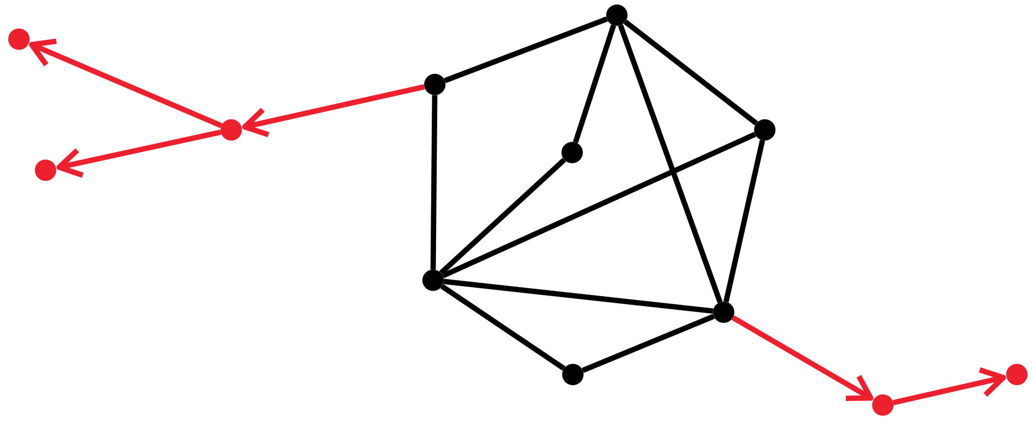

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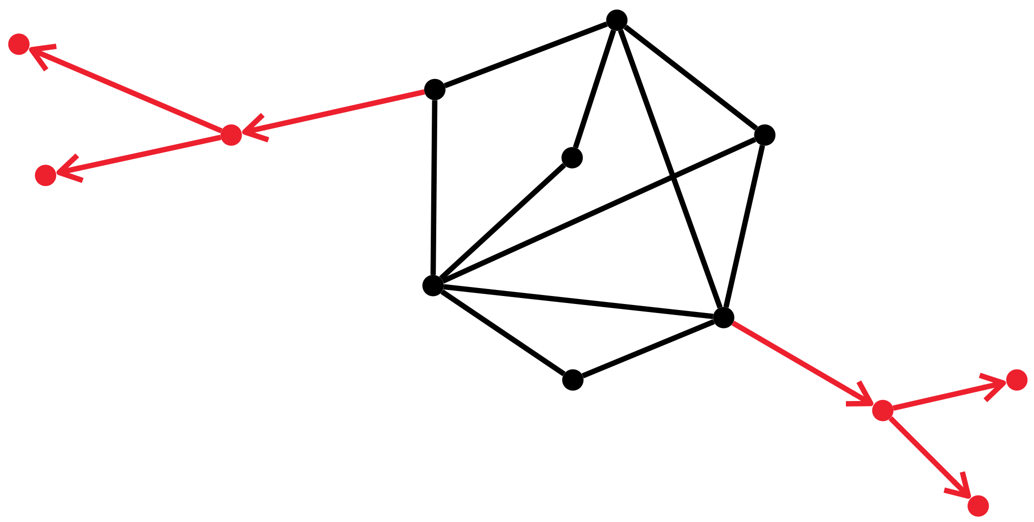

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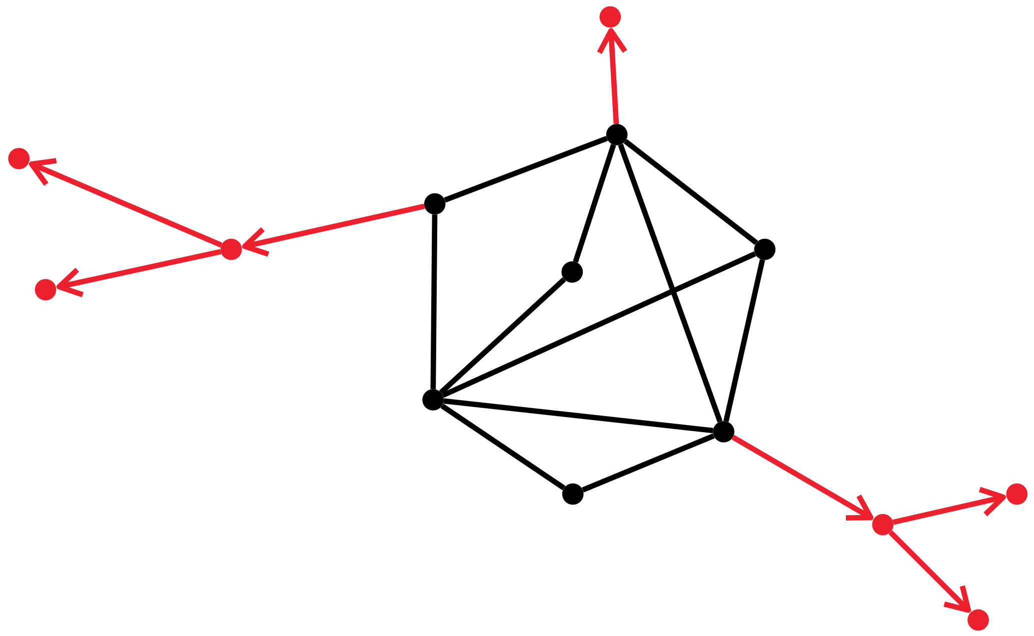

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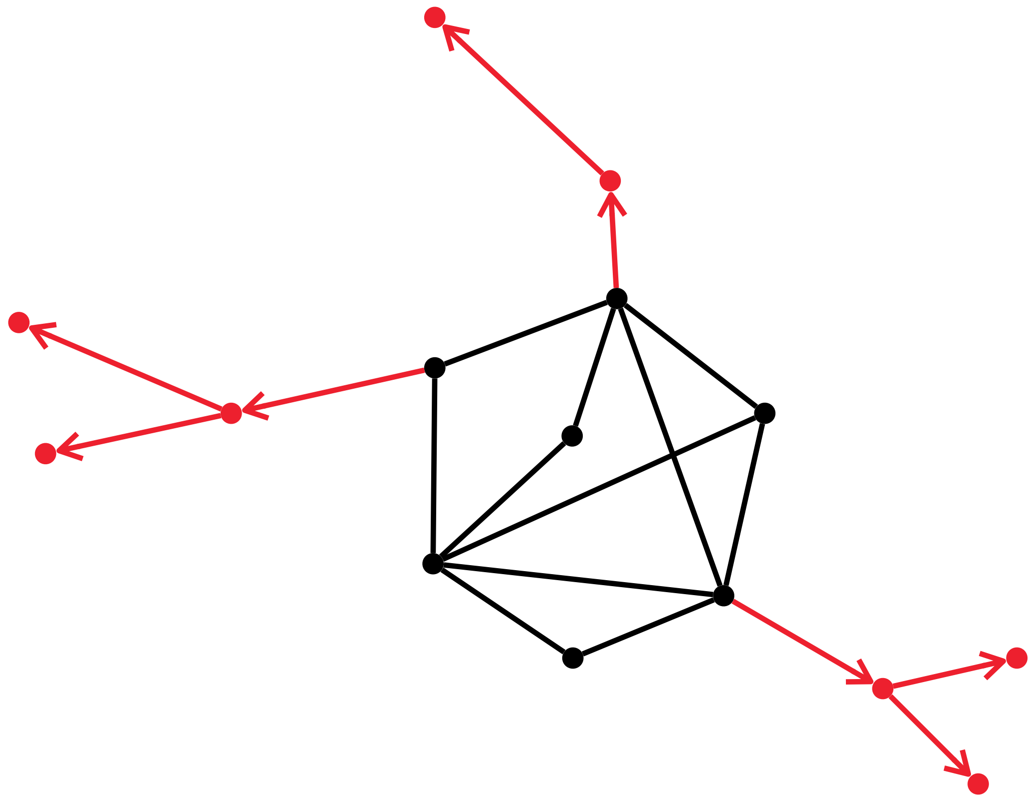

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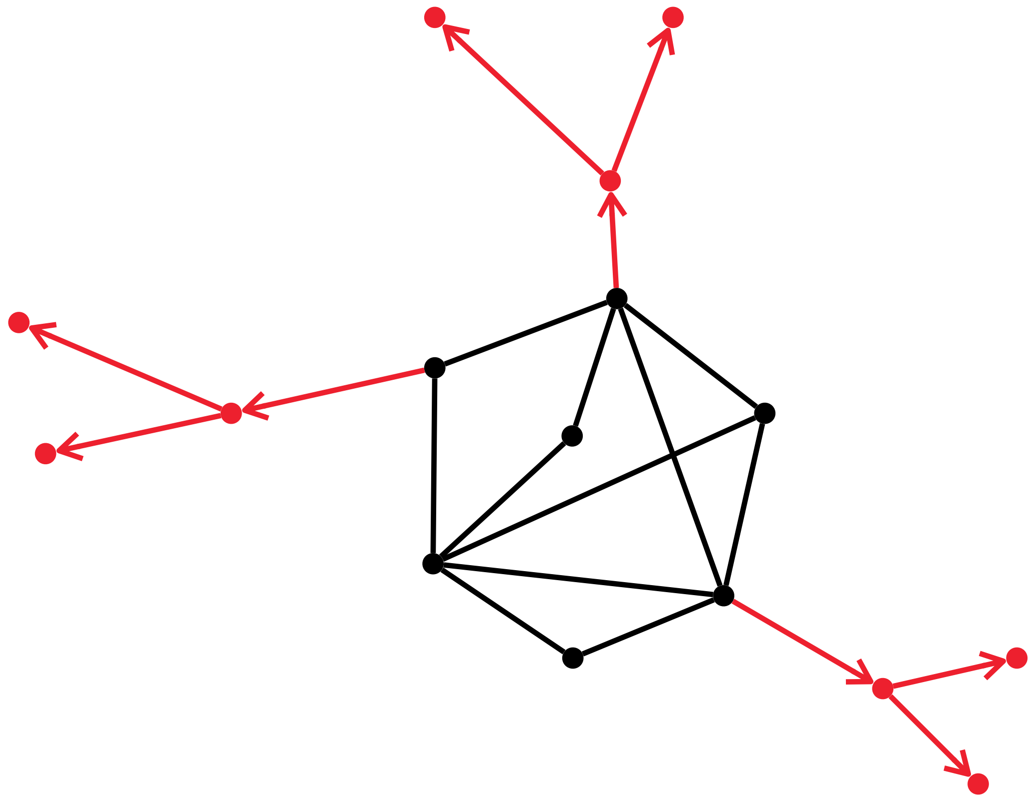

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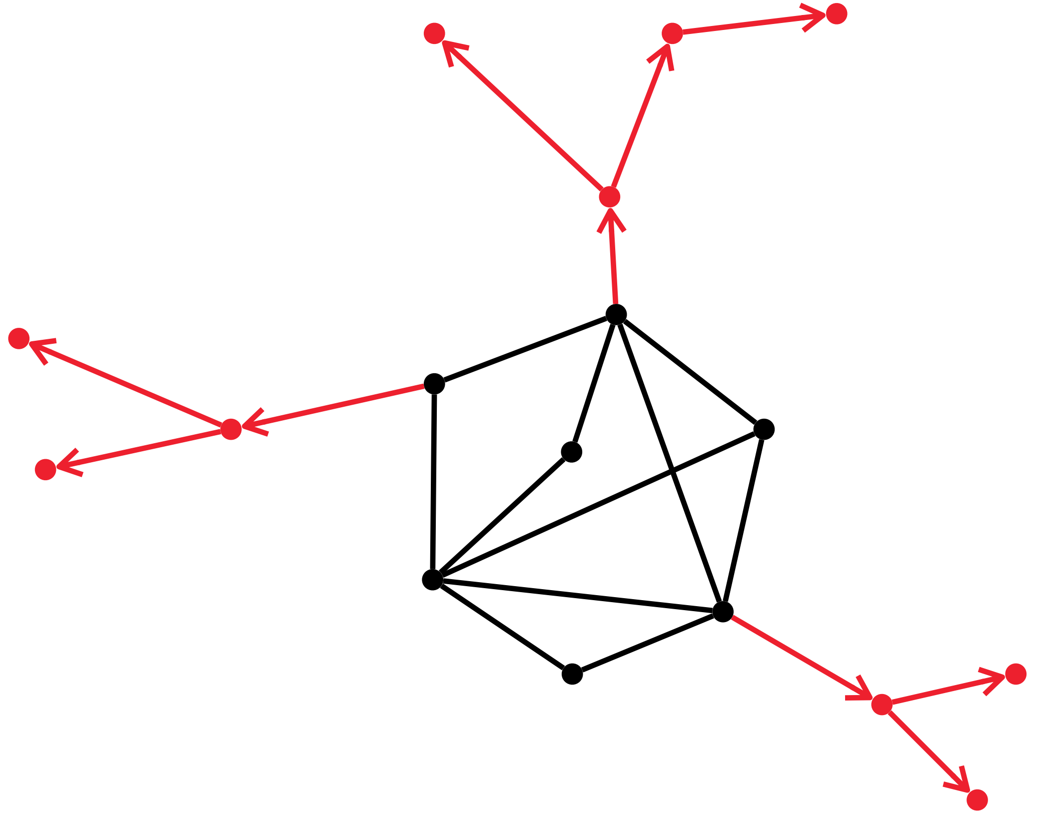

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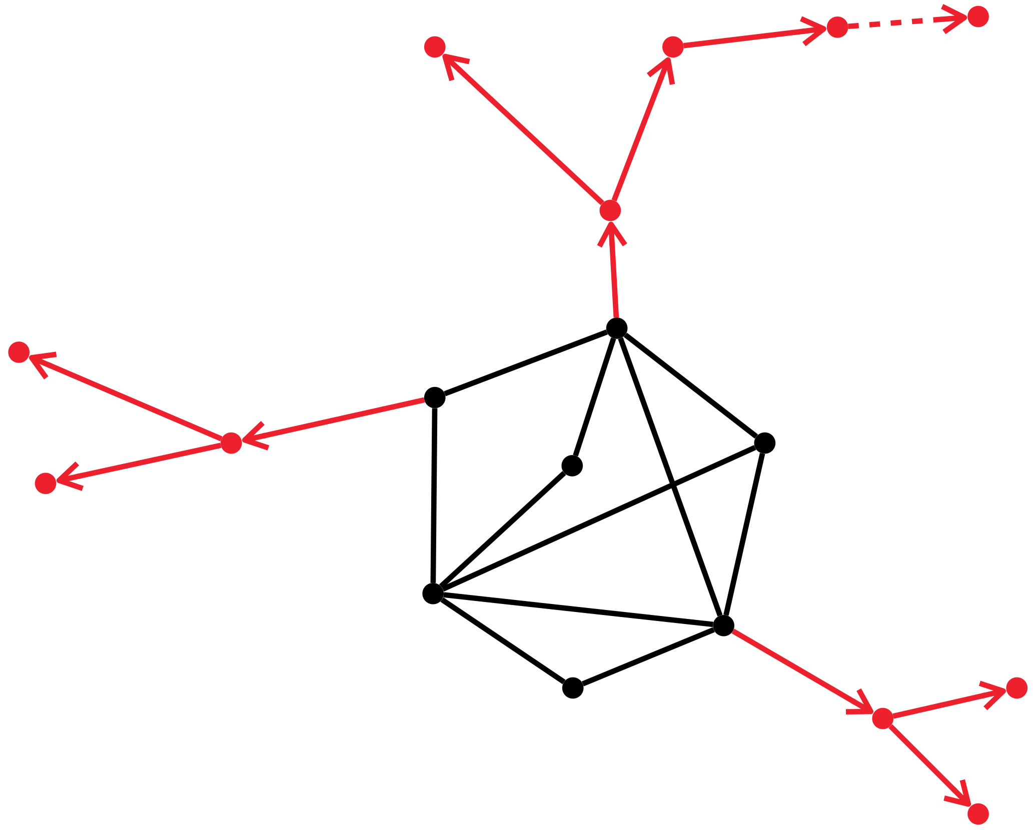

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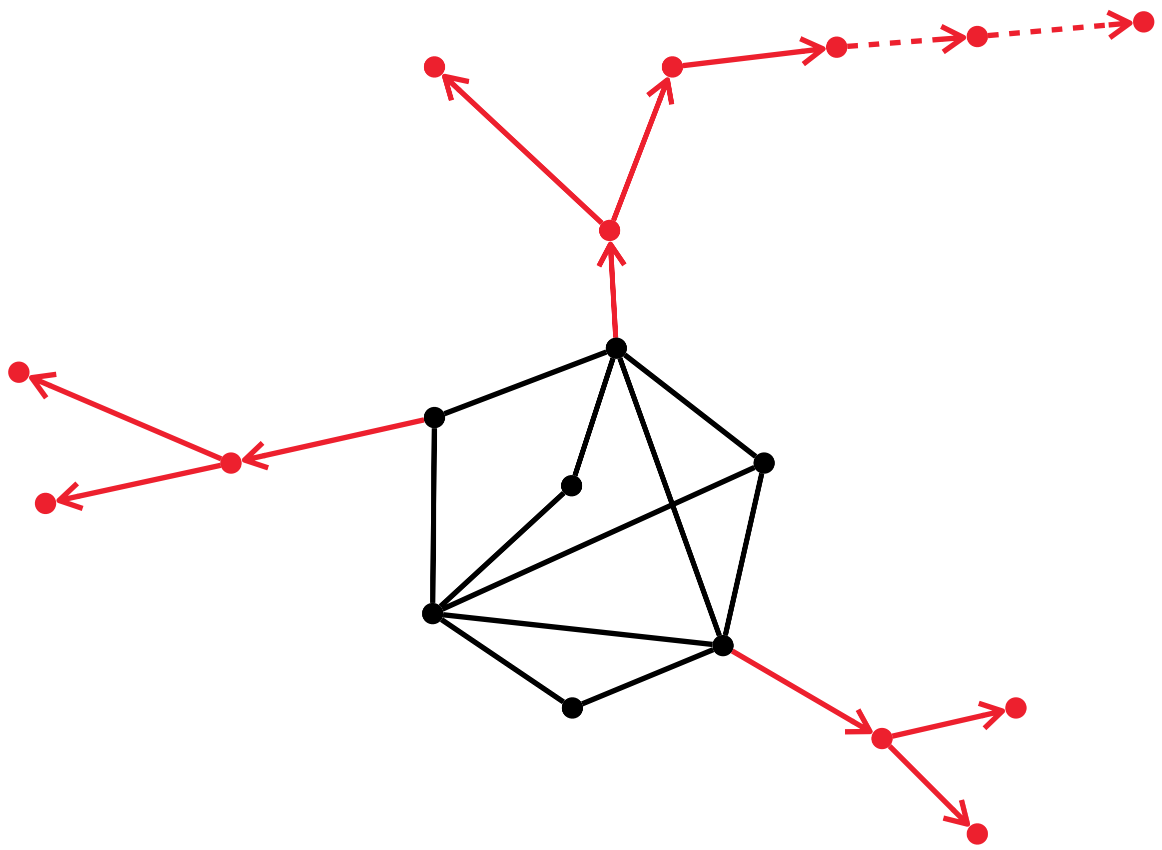
Forest Model Property



$C_1 \sqcap \ldots \sqcap C_n \sqsubseteq D$

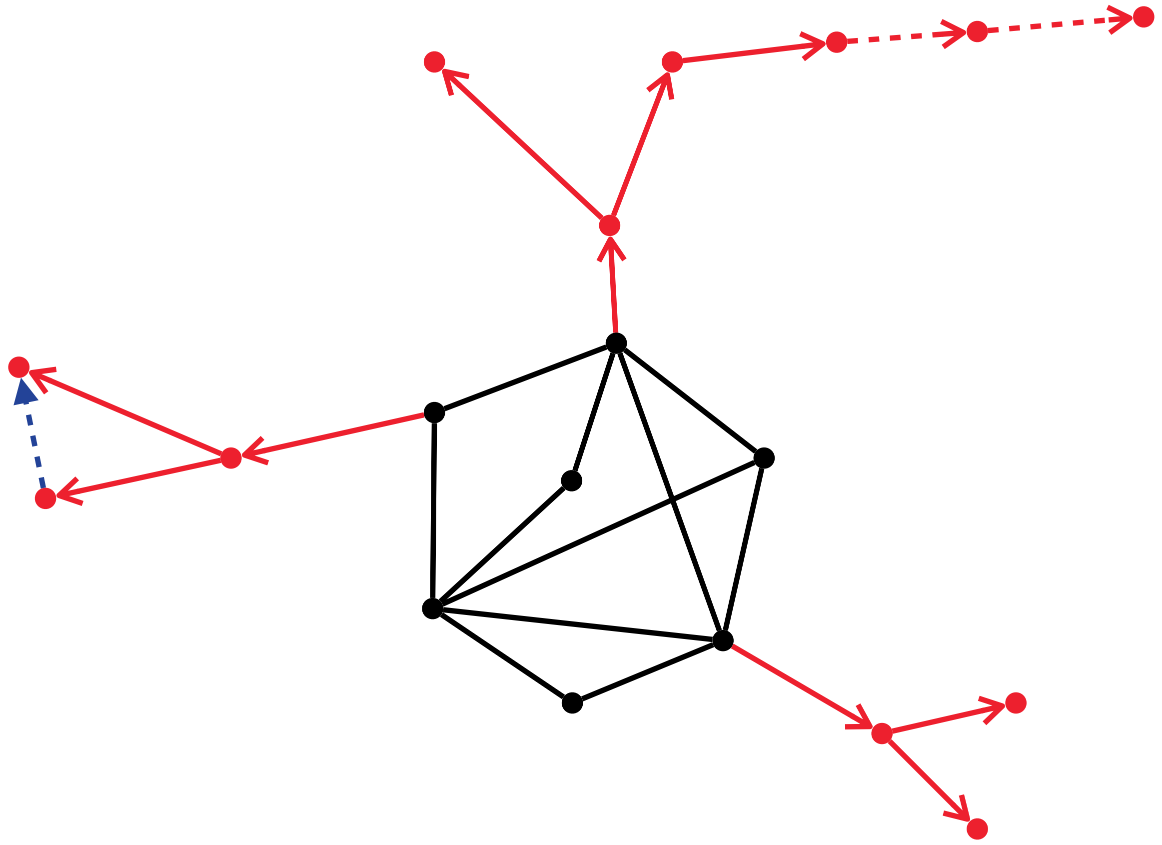
$C \sqsubseteq \exists R . D$

$\exists R . C \sqsubseteq D$

$C \sqsubseteq \leq 1 R . D$

$R \sqsubseteq S$

Forest Model Property



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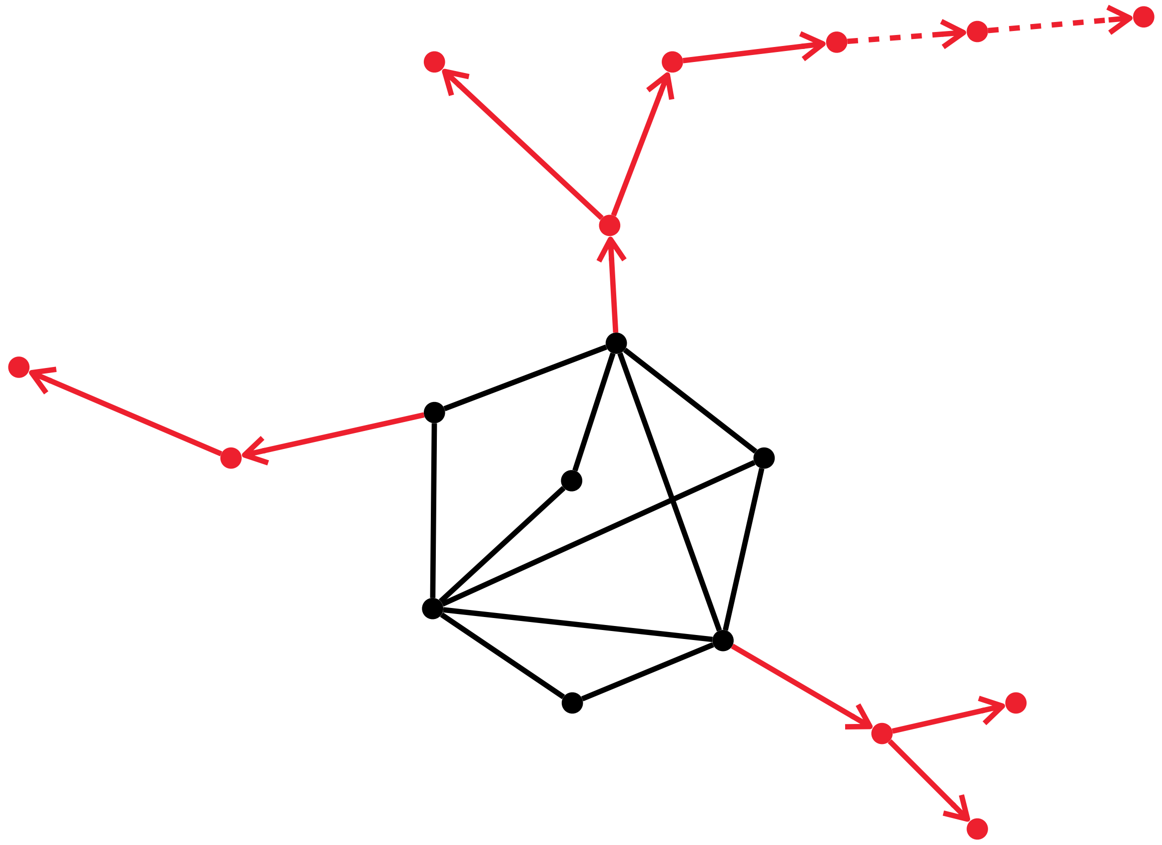

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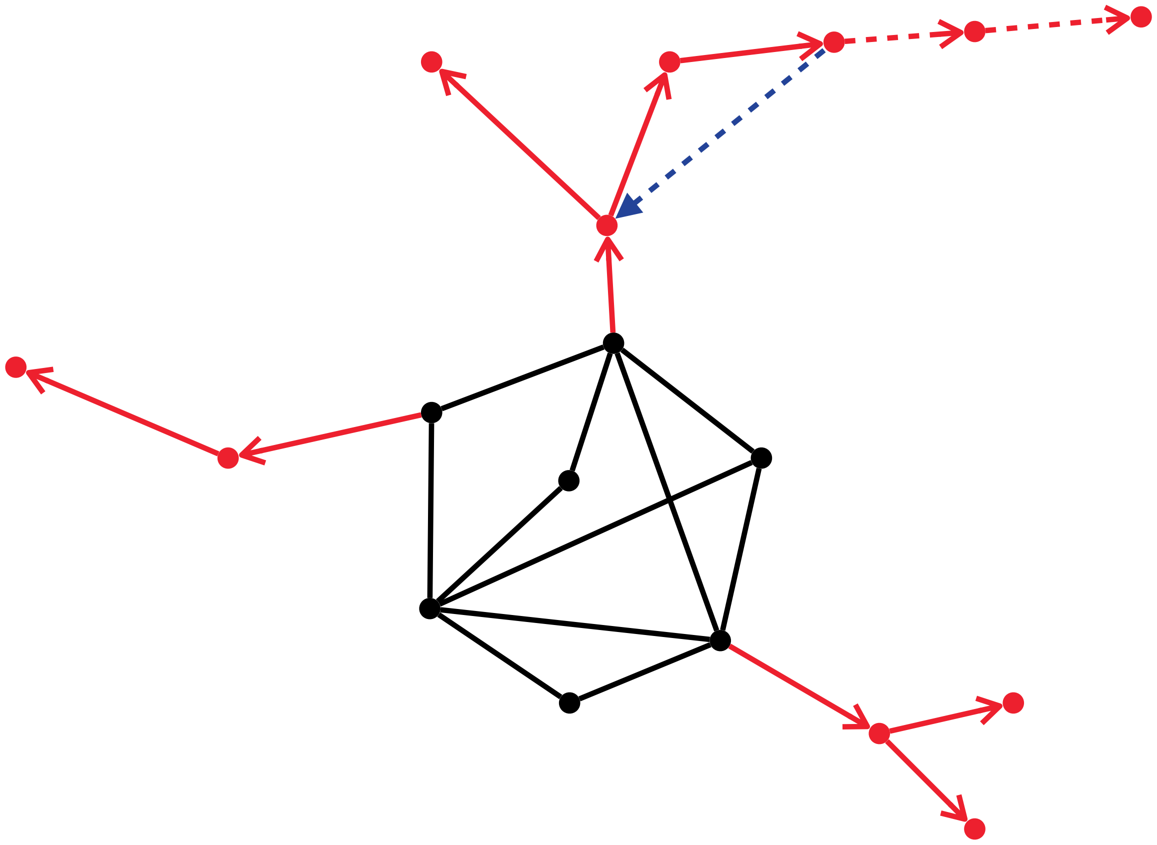

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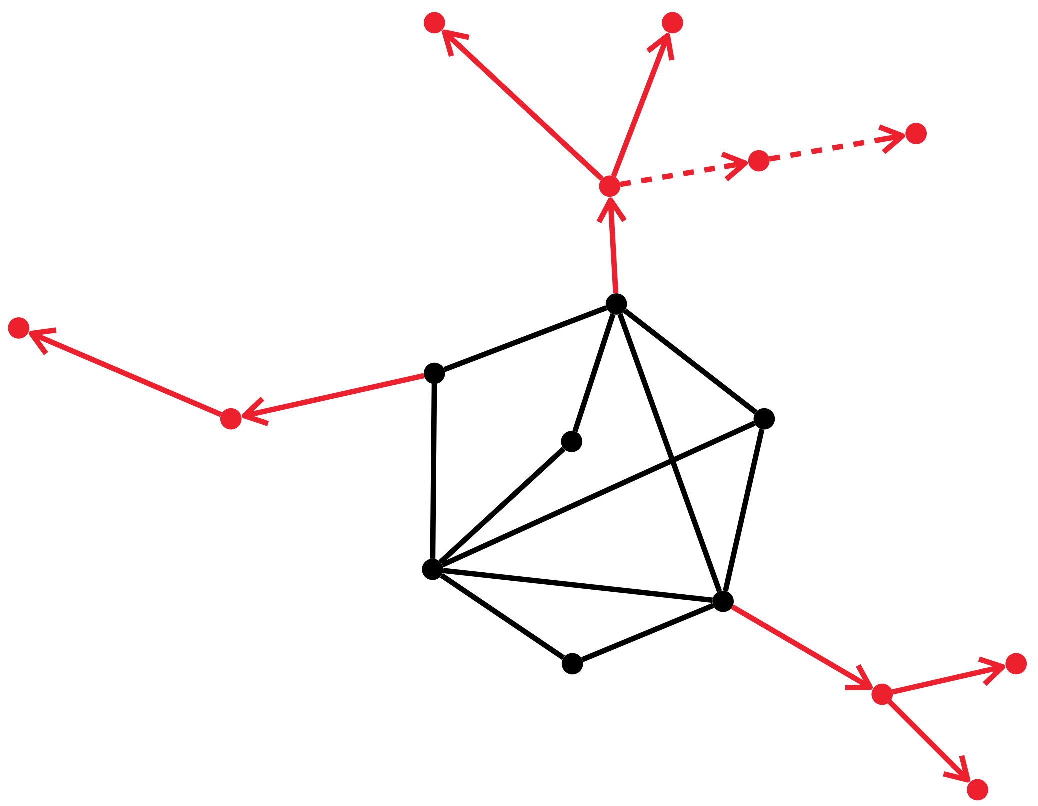

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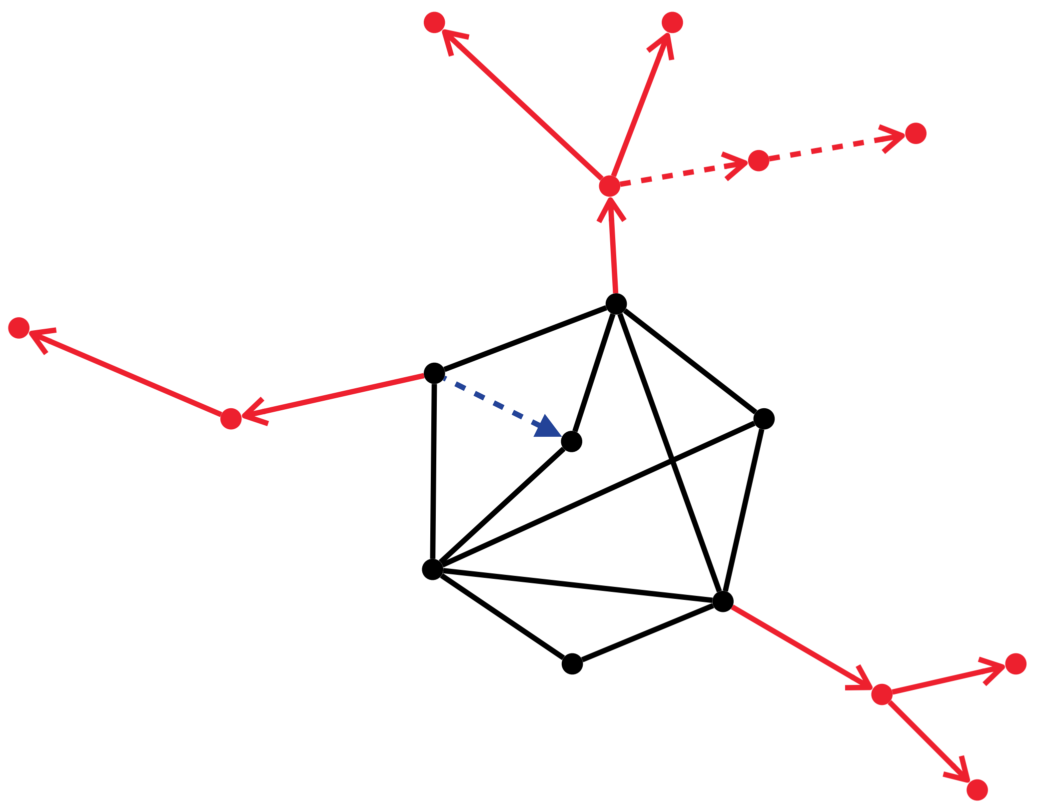

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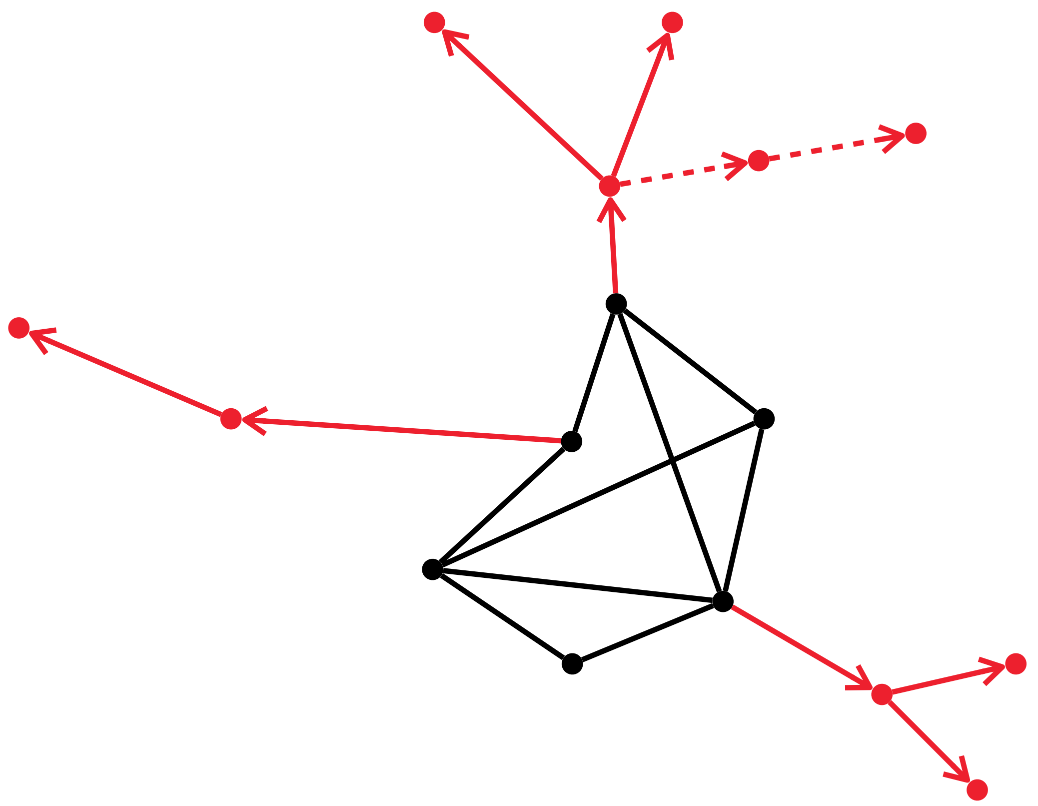

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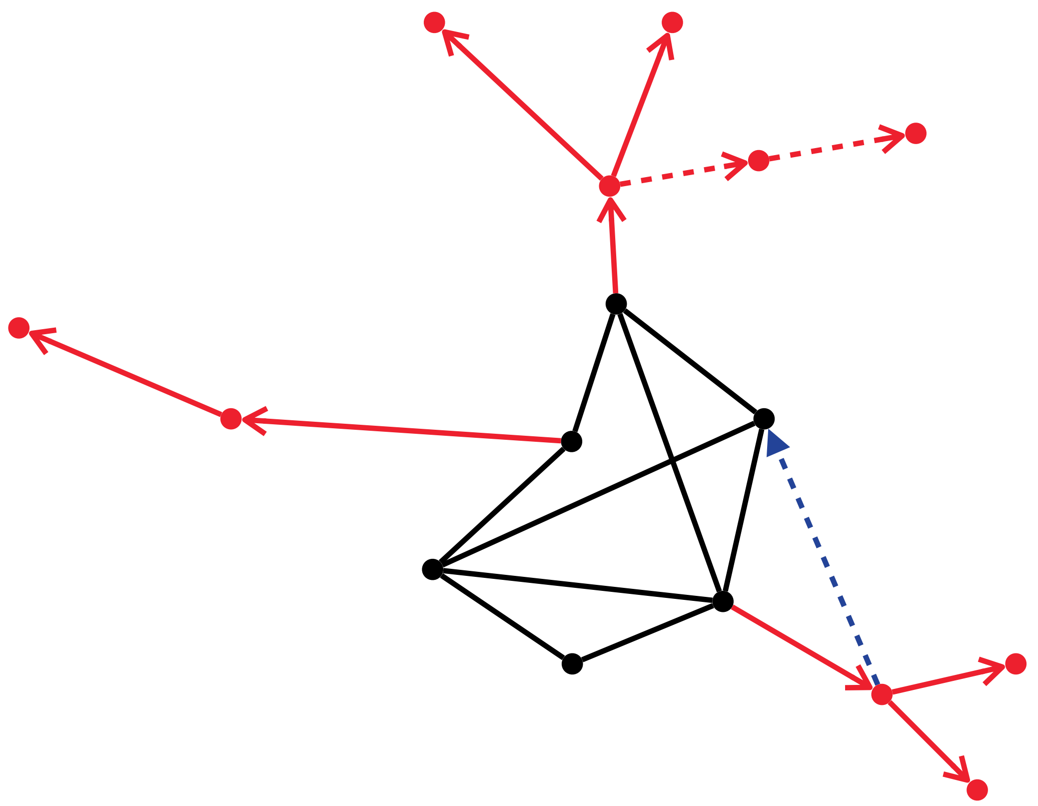

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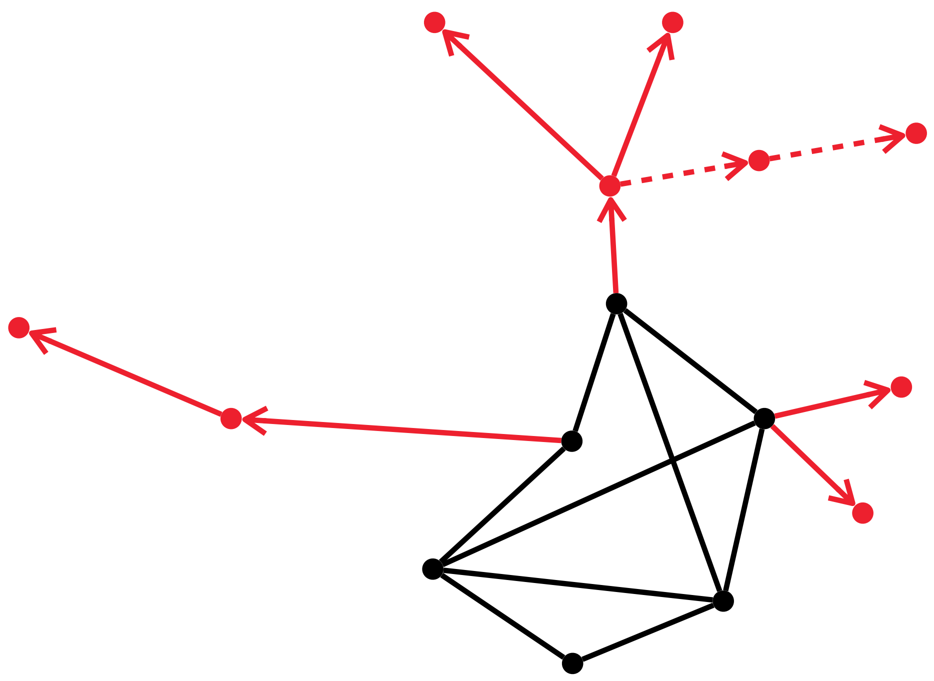

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“Unnamed-to-Named” Consequences

“Unnamed-to-Named” Consequences

Successor-to-predecessor

“Unnamed-to-Named” Consequences

Successor-to-predecessor

$C \sqsubseteq \exists R.D$

$D \sqsubseteq \exists S.E$

$\exists S.E \sqsubseteq F$

$\exists R.F \sqsubseteq G$

• $a : C$

"Unnamed-to-Named" Consequences

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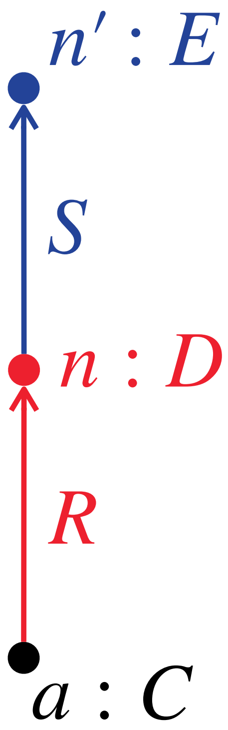

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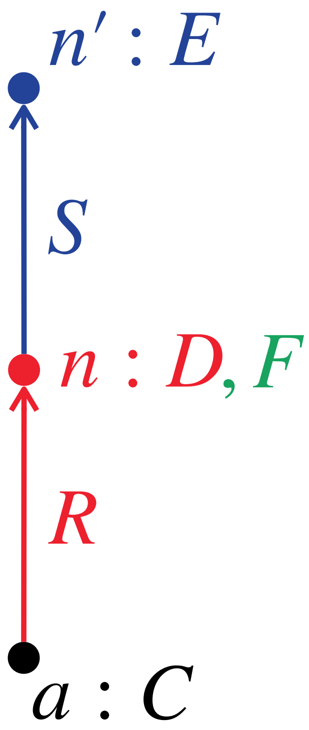

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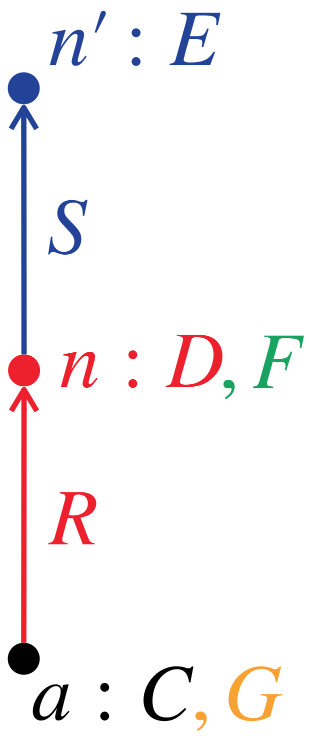

"Unnamed-to-Named" Consequences

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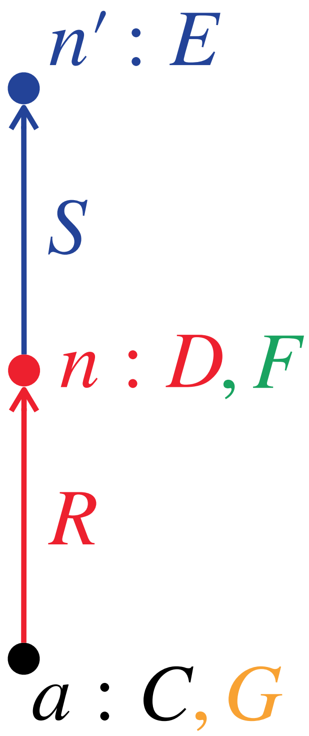
$C(x) \rightarrow G(x)$



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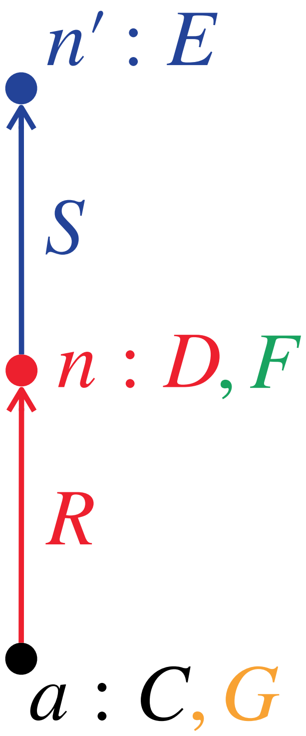

Folding

“Unnamed-to-Named” Consequences

Successor-to-predecessor

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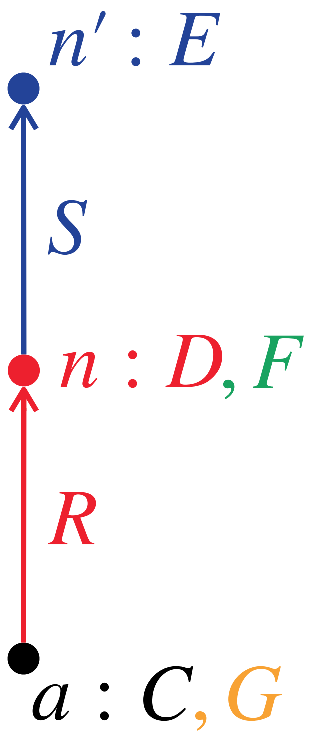


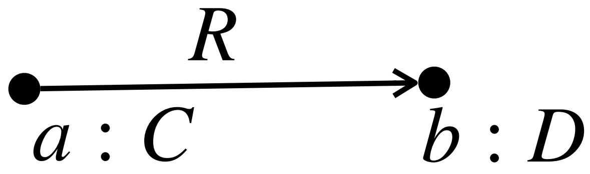
Folding

$C \sqsubseteq \exists S.E$

$S \sqsubseteq R$

$E \sqsubseteq D$

$C \sqsubseteq \leq 1R.D$



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$D \sqsubseteq \exists S\,.\,E$

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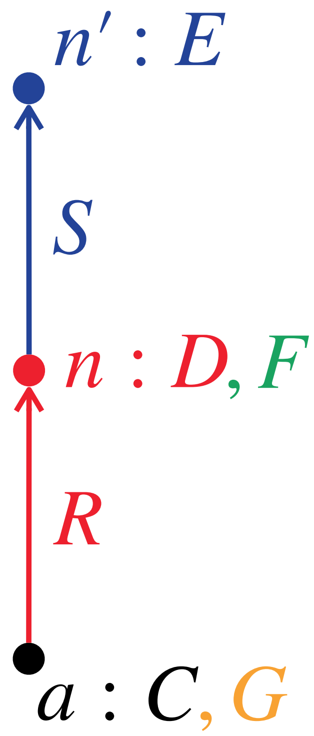

Folding

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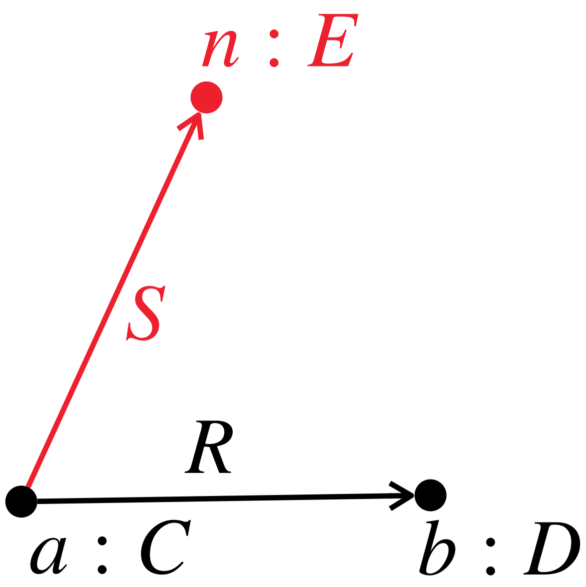
$C \sqsubseteq\, \leq 1 R\,.\,D$



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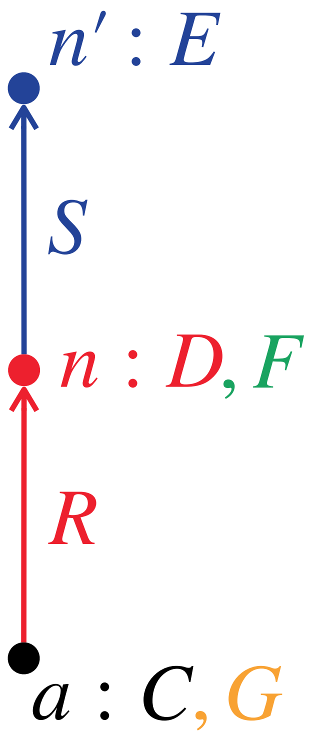

Folding

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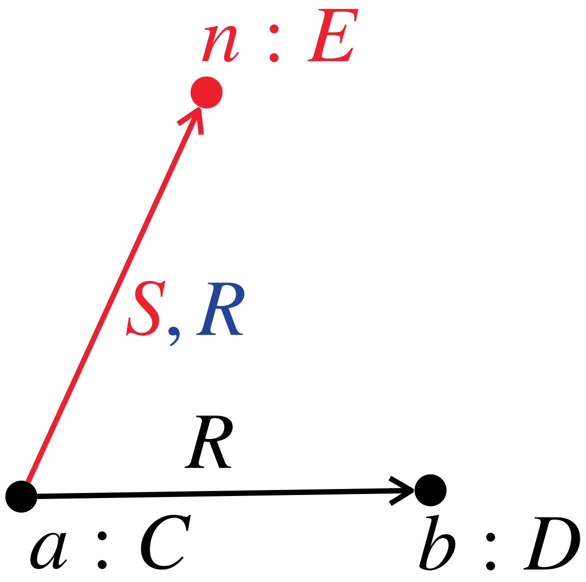
$C \sqsubseteq\ \leq 1R\,.\,D$



"Unnamed-to-Named" Consequences

Successor-to-predecessor

$C \sqsubseteq \exists R . D$

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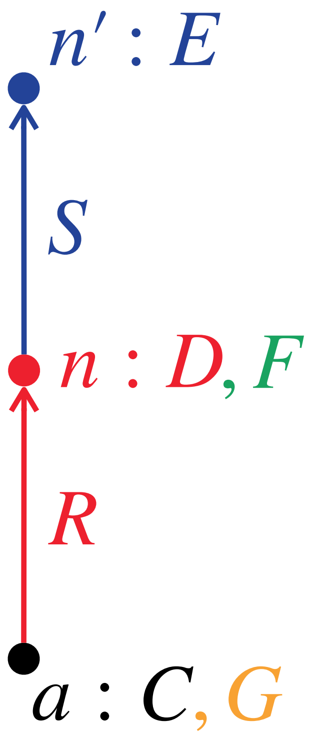
$C(x) \rightarrow G(x)$



Folding

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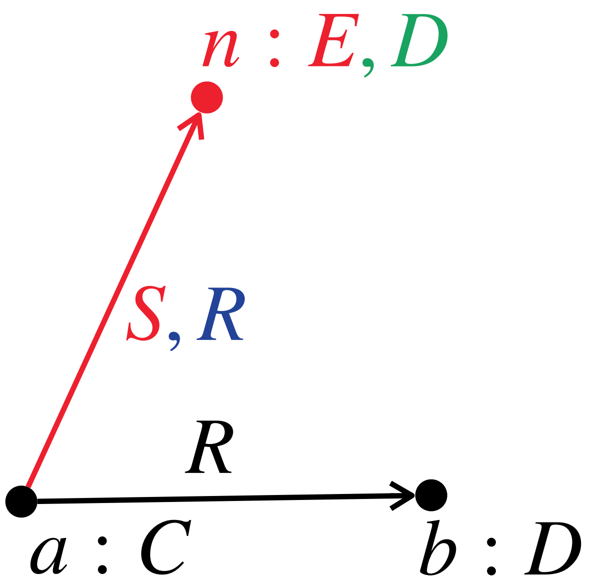

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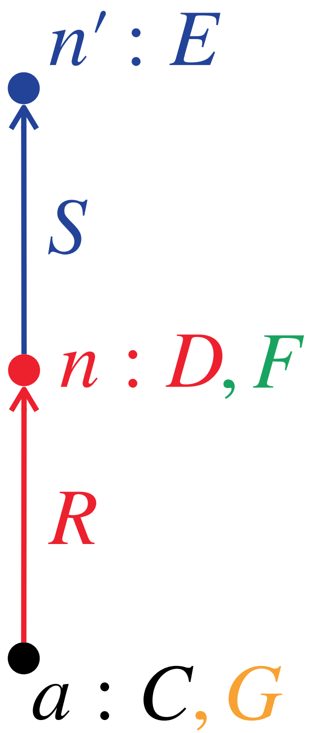

Folding

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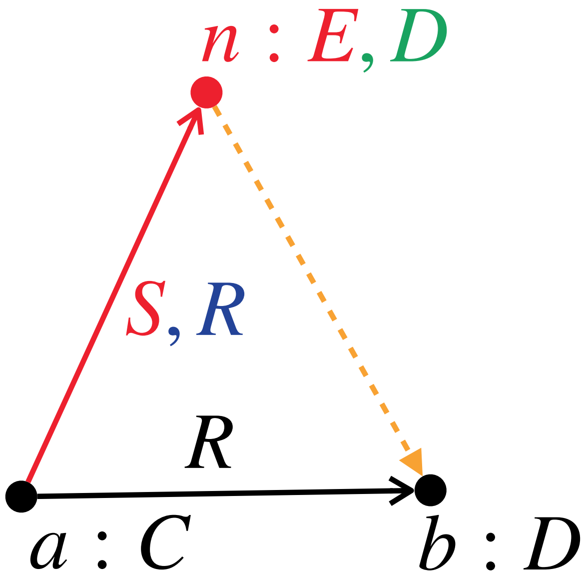

“Unnamed-to-Named” Consequences

Successor-to-predecessor

$C \sqsubseteq \exists R . D$

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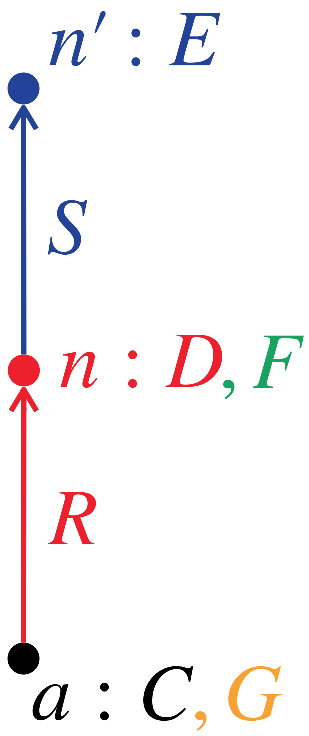

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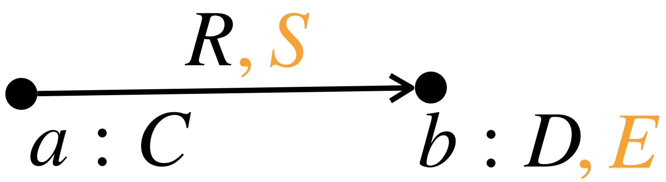

"Unnamed-to-Named" Consequences

Successor-to-predecessor

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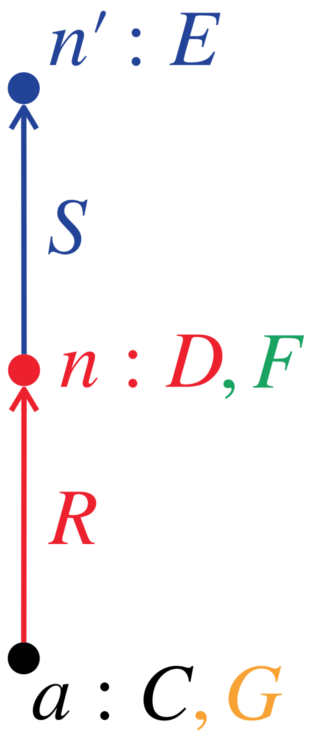

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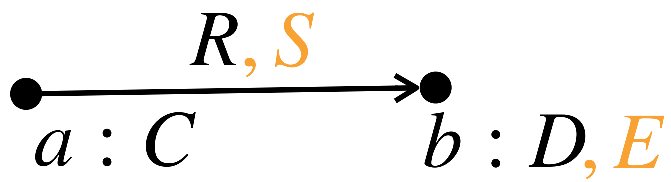

$C(x) \wedge R(x, y) \wedge D(y) \rightarrow S(x, y)$

$C(x) \wedge R(x, y) \wedge D(y) \rightarrow E(y)$

Computing IQ Rewritings for Horn-$\mathcal{ALCHIQ}$

Consider some Horn-ALCHIQ TBox $\mathcal{T}$.

Then, the rule set $\mathcal{R}_{\mathcal{T}}$ defined as follows is an IQ-preserving rewriting for $\mathcal{T}$.

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For all $C_1 \sqcap \ldots \sqcap C_n \sqsubseteq D \in \Omega(\mathcal{T})$

$C_1(x) \wedge \ldots \wedge C_n(x) \rightarrow D(x) \in \mathcal{R}_\mathcal{T}$

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For all $C_1 \sqcap \ldots \sqcap C_n \sqsubseteq D \in \Omega(\mathcal{T})$

$C_1(x) \land \ldots \land C_n(x) \to D(x) \in \mathcal{R}_{\mathcal{T}}$

$\Omega(\mathcal{T})$ is the set of all axioms of one of the following forms entailed by $\mathcal{T}$.

$C_1 \sqcap \ldots \sqcap C_n \sqsubseteq D$

$C_1 \sqcap \ldots \sqcap C_n \sqsubseteq \exists(R_1 \sqcap \ldots \sqcap R_m) . (D_1 \sqcap \ldots \sqcap D_k)$

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Consequence-based Reasoning Calculi
[IJCAI 2017] Yevgeny
[AAAI 2012] Eiter et al.

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For all $C_1 \sqcap \ldots \sqcap C_n \sqsubseteq D \in \Omega(\mathcal{T})$
$C_1(x) \wedge \ldots \wedge C_n(x) \rightarrow D(x) \in \mathcal{R}_{\mathcal{T}}$

For all $C \sqsubseteq \leq 1 R . D \in \mathcal{T}$,
$C(x) \wedge R(x, y) \wedge D(y) \wedge R(x, z) \wedge D(z) \rightarrow y \approx z \in \mathcal{R}_{\mathcal{T}}$,
$C(x) \wedge C_1(x) \wedge \ldots \wedge C_n(x) \wedge R(x, y) \wedge D(y) \rightarrow E(y) \in \mathcal{R}_{\mathcal{T}}$ if $C_1 \sqcap \ldots \sqcap C_n \sqsubseteq \exists R . (D \sqcap E) \in \Omega(\mathcal{T})$, and
$C(x) \wedge C_1(x) \wedge \ldots \wedge C_n(x) \wedge R(x, y) \wedge D(y) \rightarrow S(x, y) \in \mathcal{R}_{\mathcal{T}}$ if $C_1 \sqcap \ldots \sqcap C_n \sqsubseteq \exists (R \sqcap S) . D \in \Omega(\mathcal{T})$

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From Horn-$\mathcal{SRIQ}$ to Datalog

From Horn-$\mathcal{SRIQ}$ to Datalog

Check out our poster!

From Horn-$\mathcal{SRIQ}$ to Datalog: A Data-Independent Transformation that Preserves Assertion Entailment

David Carral, Larry González, and Patrick Koopmann

TECHNISCHE UNIVERSITÄT DRESDEN

Poster: KRR5901