Contextual Representation and Reasoning with Description Logics

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Motivation

- Information on the SW is valid w.r.t. some assumed context

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MATCHES

Presented by Emirates

Italy 1:1 Paraguay

1:1 (0:1)

Daniele DE ROSSI (63') Antolin ALCARAZ (39')

Match 11 - Group F - 14 June

Referee Benito ARCHUNDIA (MEX)

Cape Town - Green Point Stadium

Summary

Italy and Paraguay share spoils

Italy opened their FIFA World Cup™ defence with a come-from-behind 1-1 draw in Group F against Paraguay on a rainy Monday night in Cape Town.

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FIFA.com's Focus

- Italy meet their match
- Honda creates history for Japan
- Danes no match for Dutch
- Daniele DE ROSSI

Budweiser Man of the Match

PAR

Antolin ALCARAZ

Defender
has been elected
MAN OF THE MATCH

HYUNDAI Fan Photo

The Fan of the Tournament vote is now closed. Check back soon to find out which fan is the lucky winner of a brand new Hyundai i10!

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Line-up

Italy	Paraguay
1 Gianluigi BUFFON (GK) (-46'HT)	(GK)(C) Justo VILLAR 1
3 Domenico CRISCITO	Claudio MOREL 3
4 Giorgio CHIELLINI	Carlos BONET 6
5 Fabio CANNAVARO (C)	Enrique VERA 13
6 Daniele DE ROSSI ⚽	Paulo DA SILVA 14
7 Simone PEPE	Victor CACERES 15
9 Vincenzo IAQUINTA	Cristian RIVEROS 16
11 Alberto GILARDINO (-72')	(-60') Aureliano TORRES 17

Standings

	Team	MP	GF	GA	Pts
	PAR	3	3	1	5
	SVK	3	4	5	4
	NZL	3	2	2	3
	ITA	3	4	5	2

More »

Photos

Statistics

Italy		Paraguay
10	Shots	8
8	Corner kicks	4
1	Yellow cards	1
0	Second yellow card and red card	0
0	Red Cards	0
52%	Possession (%)	48%

Logic of Context (McCarthy 1993)

- If context of formulae ϕ and ψ is different:
  introduce context identifiers $c_1, c_2, \ldots$
  and special predicate ist/2

  use $\text{ist}(c_1, \phi)$ and $\text{ist}(c_2, \psi)$

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  $\text{ist}(c_1, \mathit{Winner}(\mathit{Spain}))$, $\text{ist}(c_2, \mathit{Winner}(\mathit{Italy}))$

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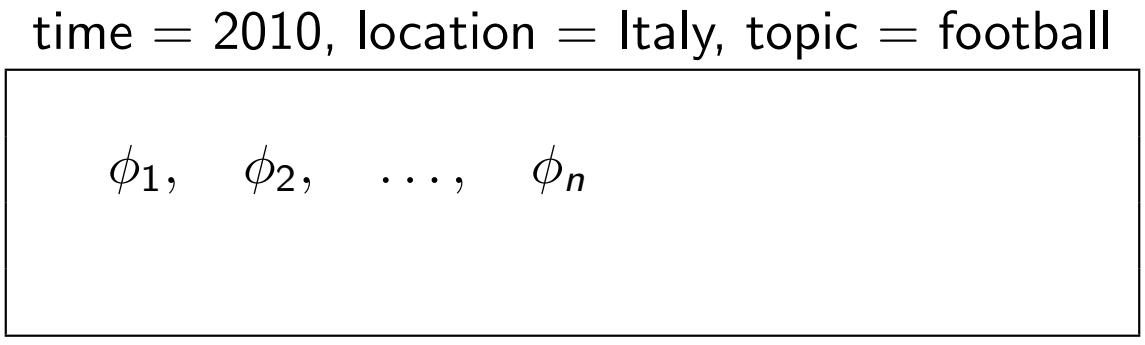
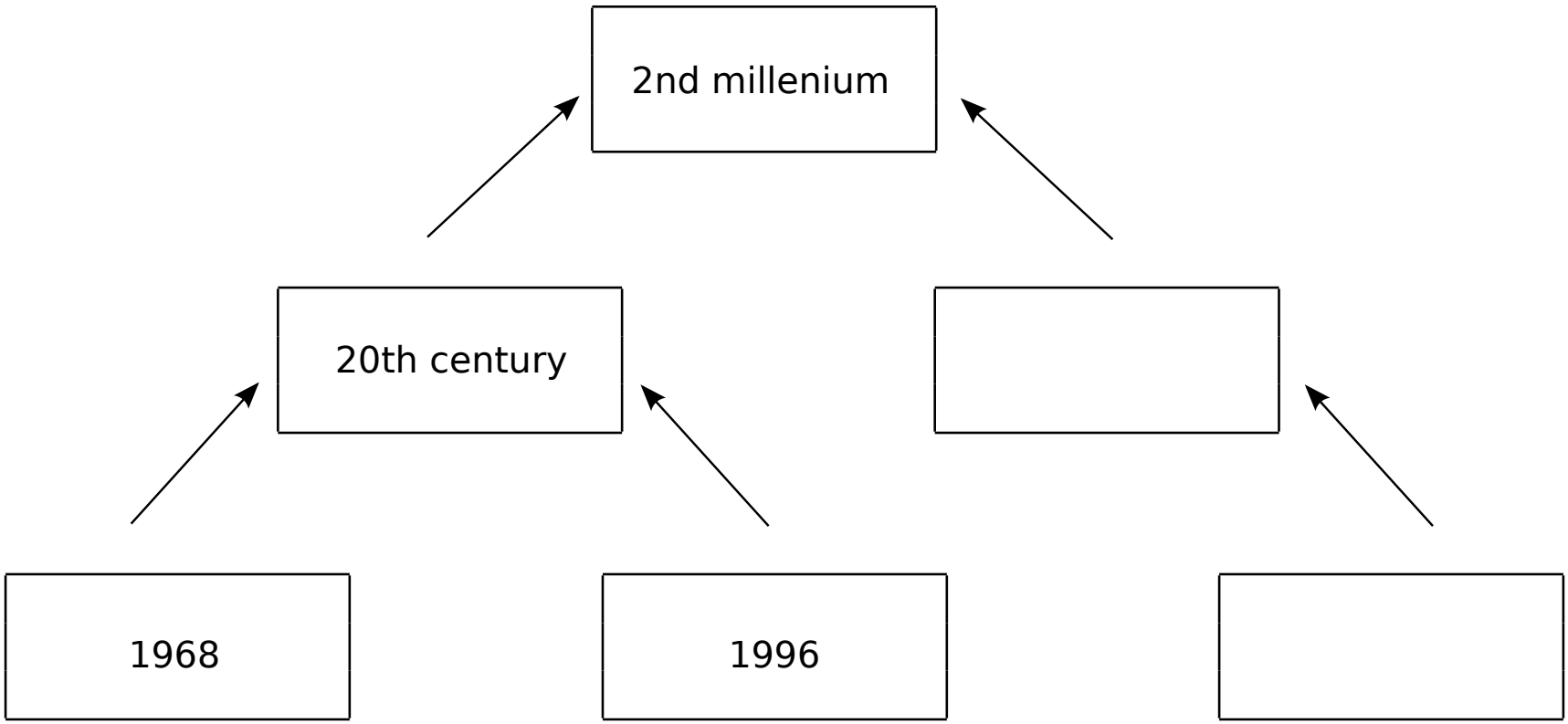
- knowledge lifting:
  $\forall x\ \text{ist}(c_1, \mathit{Winner}(x)) \rightarrow \text{ist}(c_2, \mathit{Team}(x))$

Context as a Box (Benerecetti et al. 2000)



Dimensional Space (CYC, Lenat 1998)



- Context can be organized in dimensional space
- W.r.t. narrower–broader relation

CKR: Objectives

- Tailor the logic of context for SW
- Reasoning tasks: subsumption, entailment, query answering
- Develop a tractable version
- Implement a working prototype
- Evaluate rep. power & performance

Preliminaries: Description Logics

- Language
  - Individuals $a, b, \ldots$
  - Concepts $A, B, C \ldots$
  - Roles $R, S, \ldots$
- Complex concepts
  - $C ::= A | \neg C | C \sqcap D | C \sqcup D | \exists R.C | \forall R.C$
- KB $\mathcal{K} = \langle \mathcal{T}, \mathcal{A} \rangle$ contains axioms:
  - Subsumption $C \sqsubseteq D$
  - Class assertions $C(a)$
  - Role assertions $R(a, b)$

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	RDF
Subsumption $C \sqsubseteq D$	C `rdfs:subClassOf` D
Class assertions $C(a)$	a `rdf:type` C
Role assertions $R(a, b)$	a R b

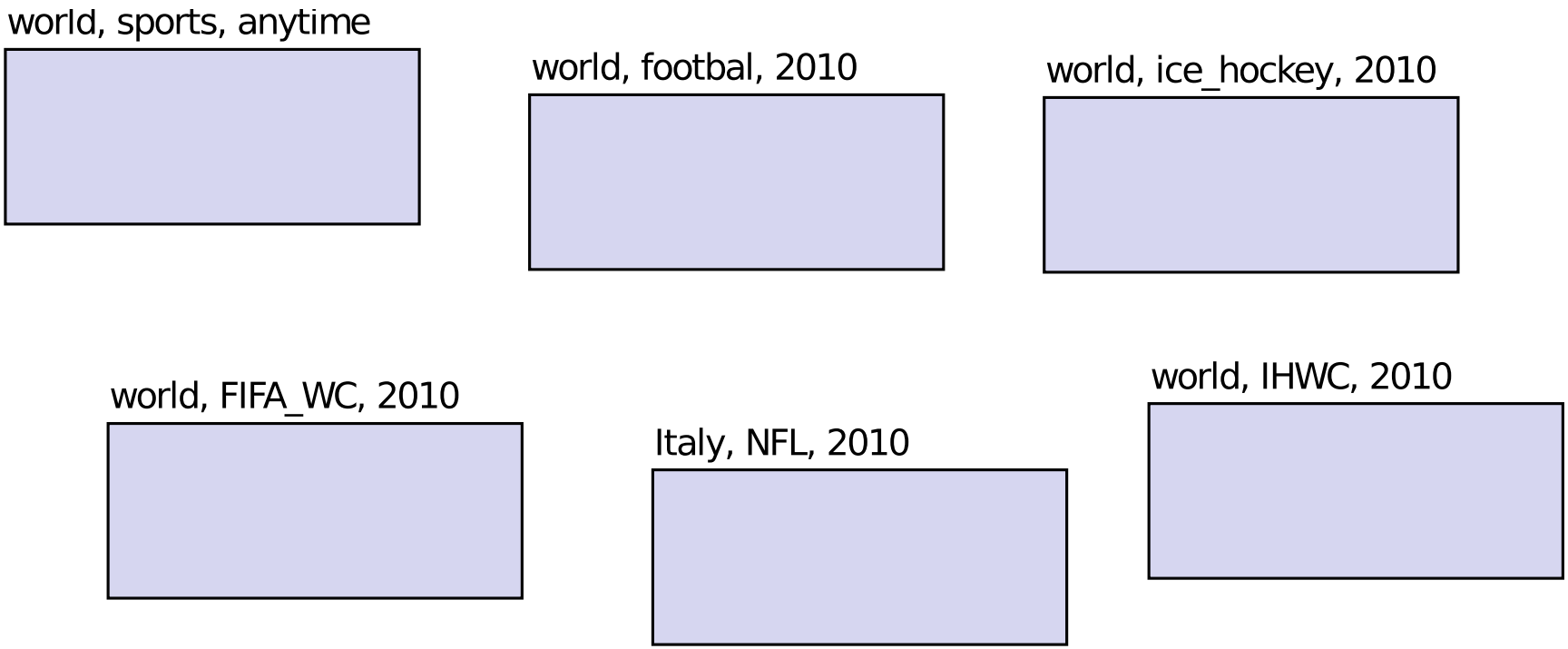
Preliminaries: Semantics

Interpretation $\mathcal{I} = \langle \Delta^{\mathcal{I}}, \cdot^{\mathcal{I}} \rangle$, $\Delta^{\mathcal{I}} \neq \emptyset$

$\neg C$	$\Delta^{\mathcal{I}} \setminus C^{\mathcal{I}}$
$C \sqcap D$	$C^{\mathcal{I}} \cap D^{\mathcal{I}}$
$C \sqcup D$	$C^{\mathcal{I}} \cup D^{\mathcal{I}}$
$\exists R.C$	$\{x \in \Delta^{\mathcal{I}} \mid \exists y \in \Delta^{\mathcal{I}} \ \langle x, y \rangle \in R^{\mathcal{I}} \wedge y \in C^{\mathcal{I}}\}$
$\forall R.C$	$\{x \in \Delta^{\mathcal{I}} \mid \forall y \in \Delta^{\mathcal{I}} \ \langle x, y \rangle \in R^{\mathcal{I}} \implies y \in C^{\mathcal{I}}\}$
$C \sqsubseteq D$	$C^{\mathcal{I}} \subseteq D^{\mathcal{I}}$
$C(a)$	$a^{\mathcal{I}} \in C^{\mathcal{I}}$
$R(a, b)$	$\langle a^{\mathcal{I}}, b^{\mathcal{I}} \rangle \in R^{\mathcal{I}}$

- $\mathcal{I}$ is a model of $\mathcal{K}$ iff $\mathcal{I} \models \phi$ for all $\phi \in \mathcal{T} \cup \mathcal{A}$
- $\mathcal{K} \models C$ iff $C^{\mathcal{I}} \neq \emptyset$ in some model of $\mathcal{K}$
- $\mathcal{K} \models C \sqsubseteq D$ iff $C^{\mathcal{I}} \subseteq D^{\mathcal{I}}$ in all models of $\mathcal{K}$

Syntax: Contexts



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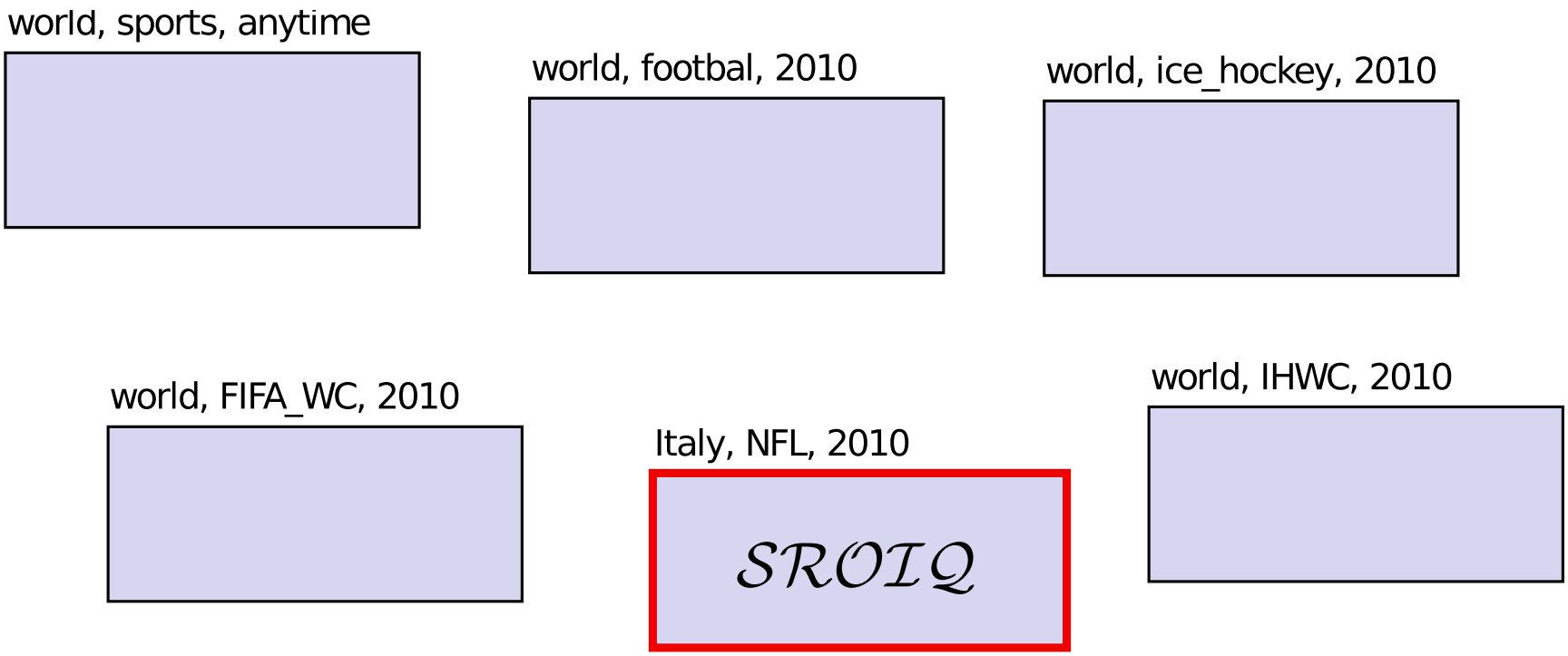

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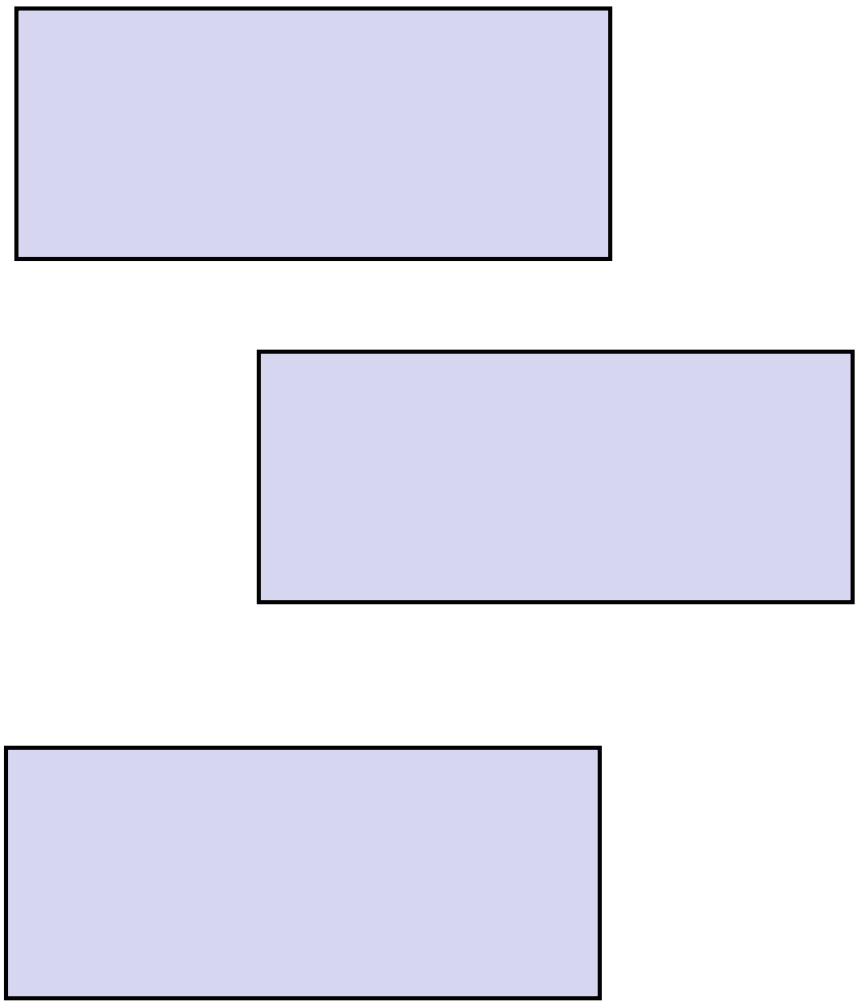
Syntax: Meta-knowledge



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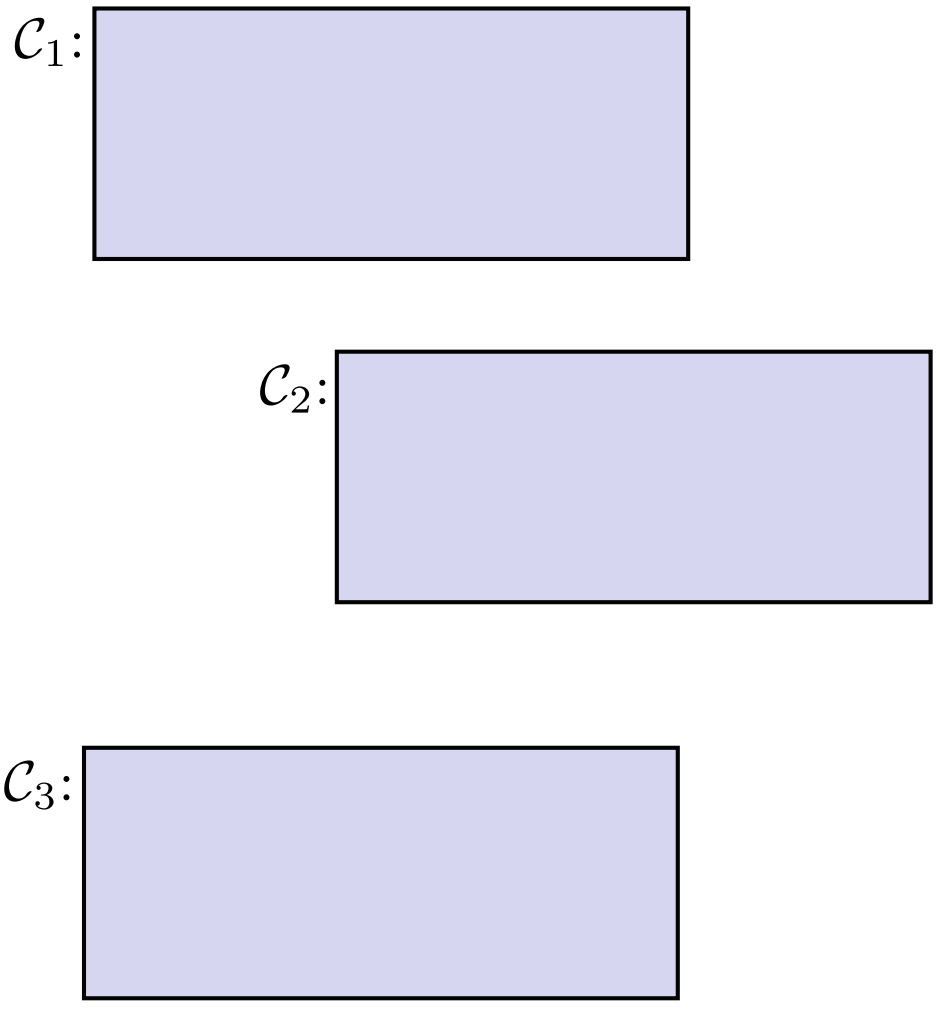

- context IDs

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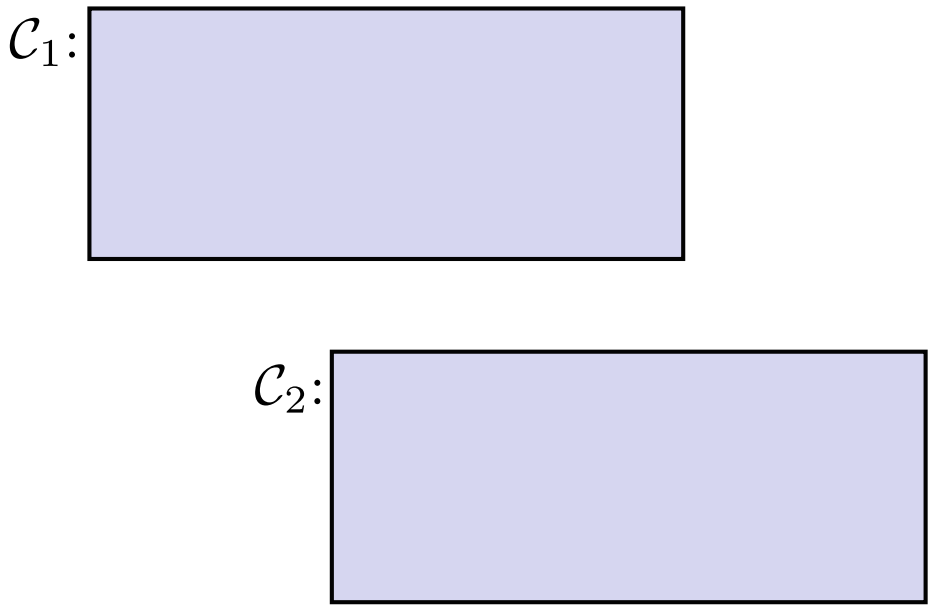

- context IDs
- dimensional values

  location($\mathcal{C}_1$, Italy)

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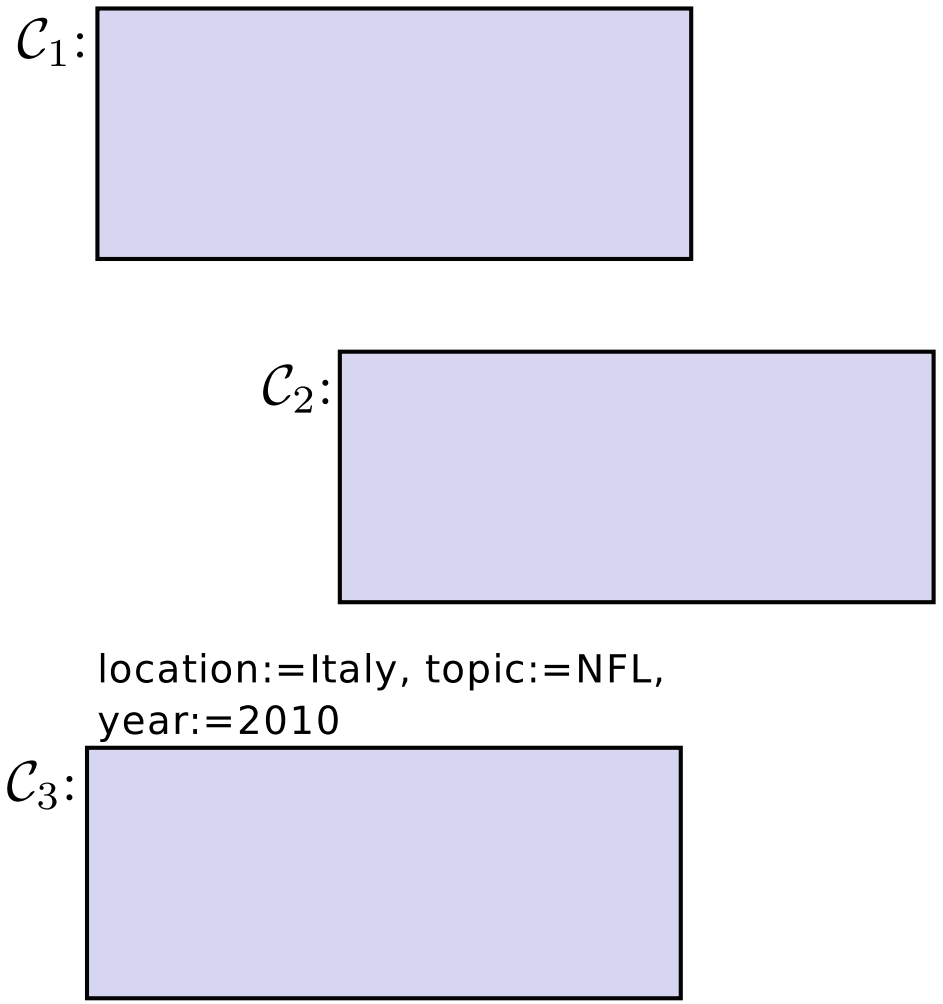

- context IDs
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  location($\mathcal{C}_1$, Italy)
  topic($\mathcal{C}_1$, NFL)
  time($\mathcal{C}_1$, 2010)

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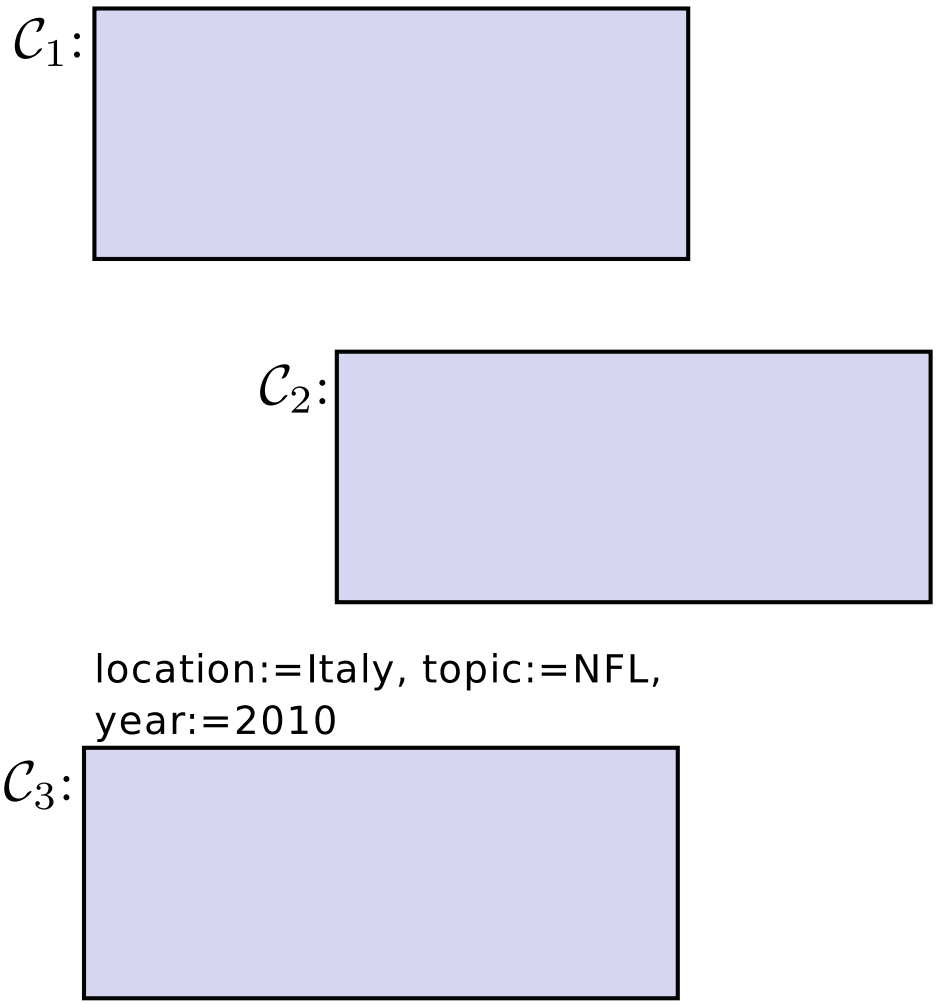

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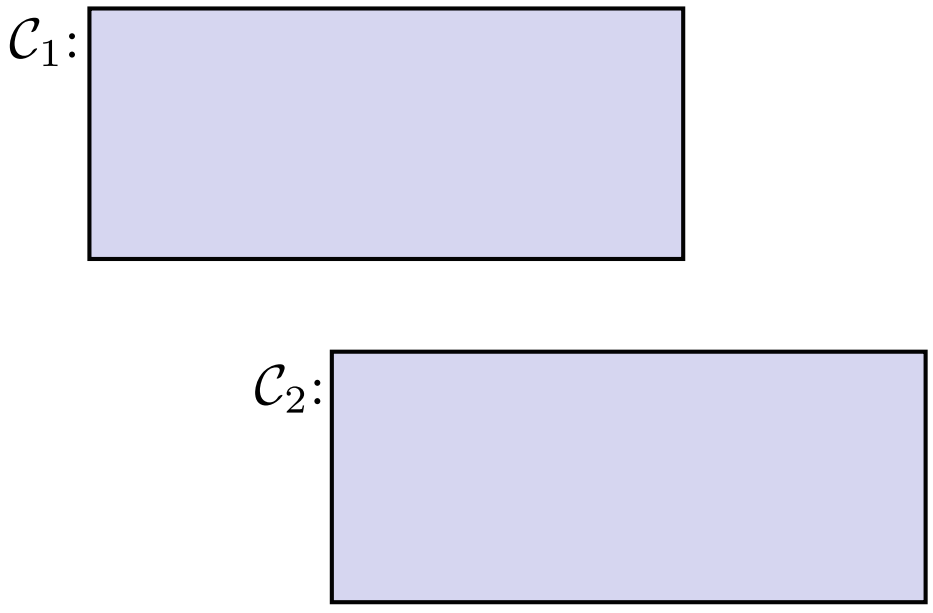

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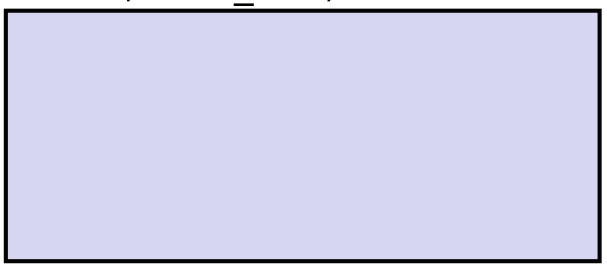
Syntax: Meta-knowledge

world, sports, anytime

$\mathcal{C}_1$:

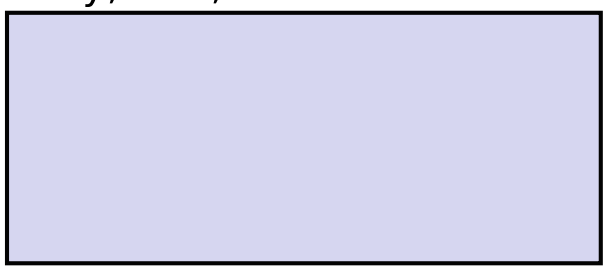
world, FIFA_WC, 2010

$\mathcal{C}_2$:



Italy, NFL, 2010

$\mathcal{C}_3$:



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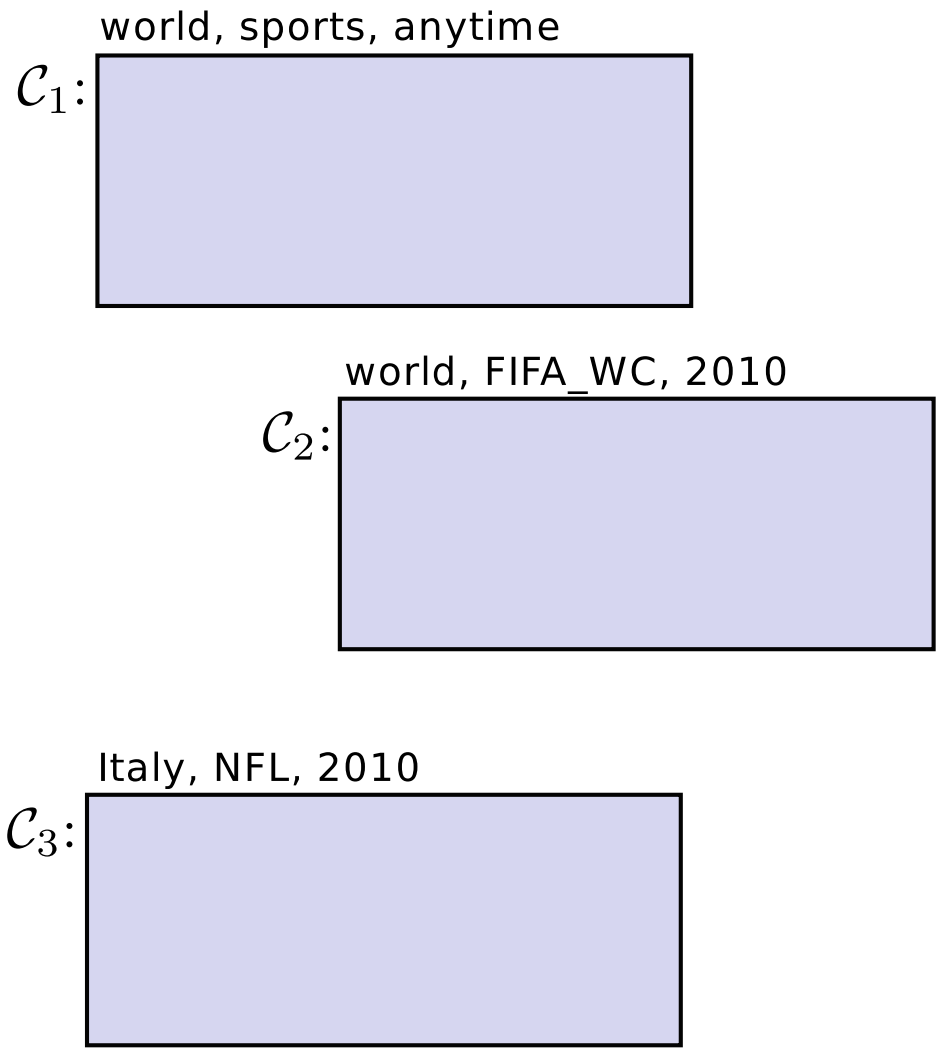

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  location($\mathcal{C}_1$, Italy)
  topic($\mathcal{C}_1$, NFL)
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- dimensional vectors
- dimensional coverage

  Italy $\prec$ World
  FIFA_WC $\prec$ football
  football $\prec$ sports

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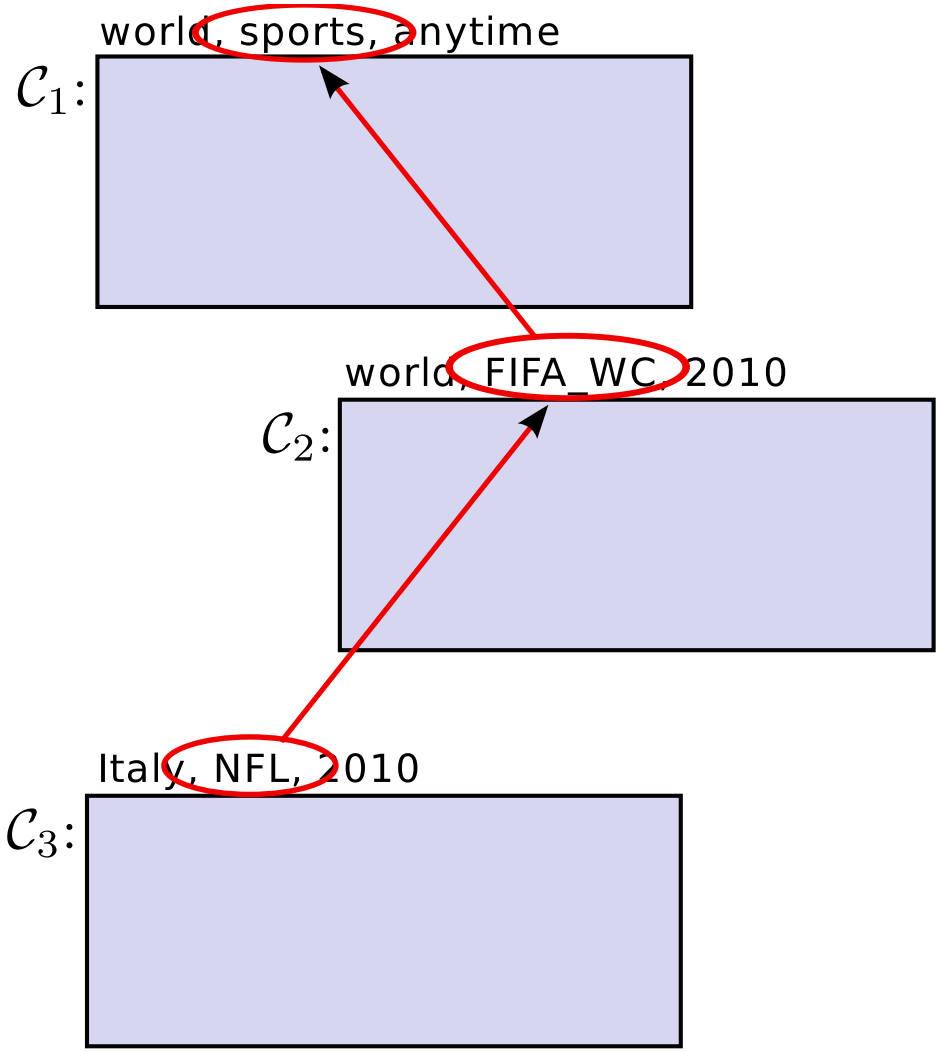

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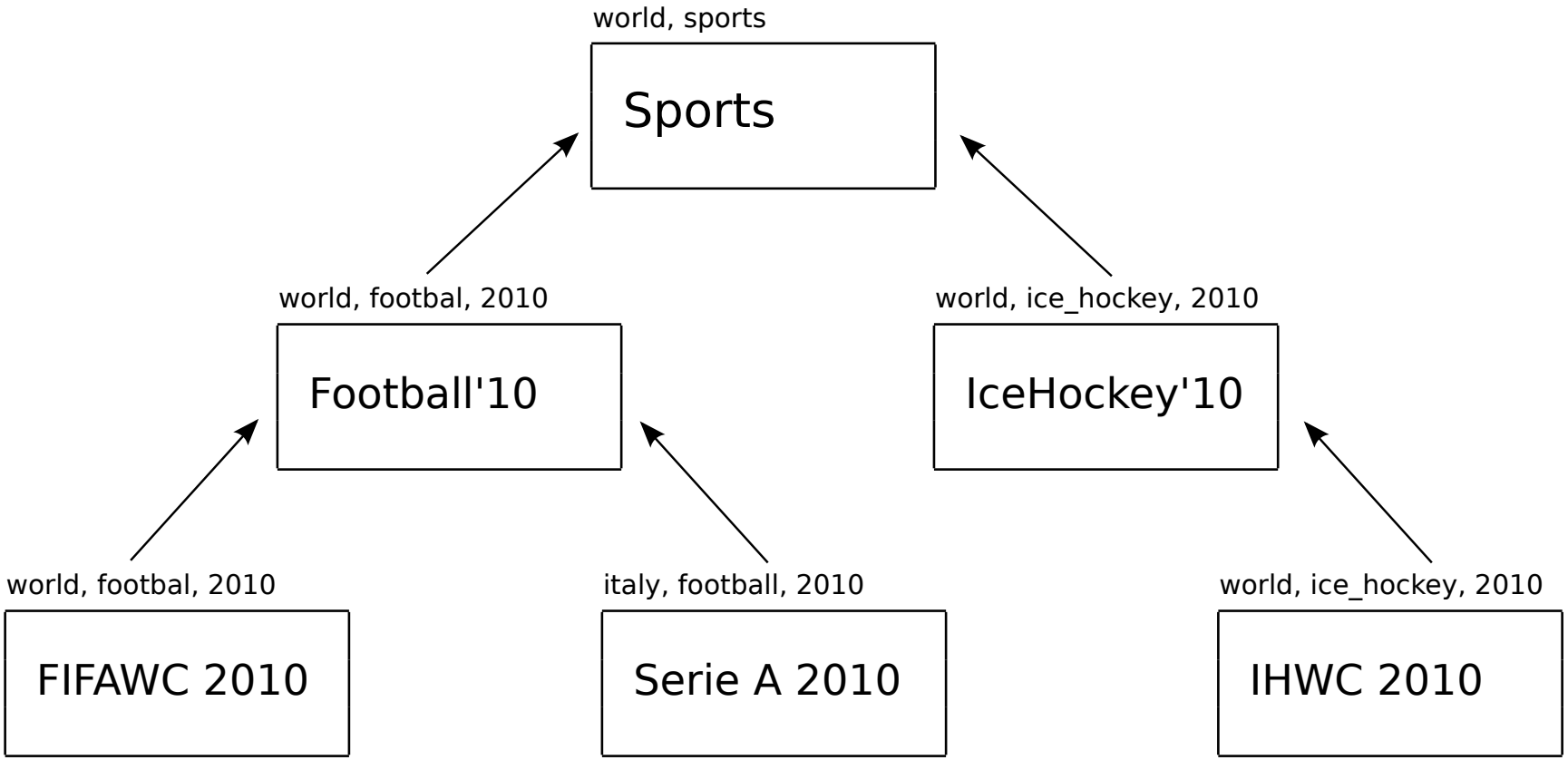
Hierarchy of Contexts



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  - new symbol $X_{A_{i_1}:=d_1,\ldots,A_{i_n}:=d_n}$

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- Locality of knowledge
  - Context/roles X have independent meaning in different contexts
- Qualified symbols: refer to entities from different context
  - new symbol $X_{A_{i_1}:=d_1,\ldots,A_{i_n}:=d_n}$
    - for all concept/role X
    - for all dimensional vectors $A_{i_1}:=d_1, \ldots, A_{i_n}:=d_n$

Syntax: Qualified Symbols

- Example usage:

world, FIFA_WC, 2010

$$\mathsf{Team} \sqsubseteq \mathsf{NationalTeam}_{\mathsf{world,football,2010}} \sqcap \mathsf{MenTeam}_{\mathsf{world,football,2010}}$$

Team(Team_Italy)

Team(Team_Paraguay)

Referee(Benito_Archundia)

has_coach(Team_Italy, Marcello_Lippi)

...

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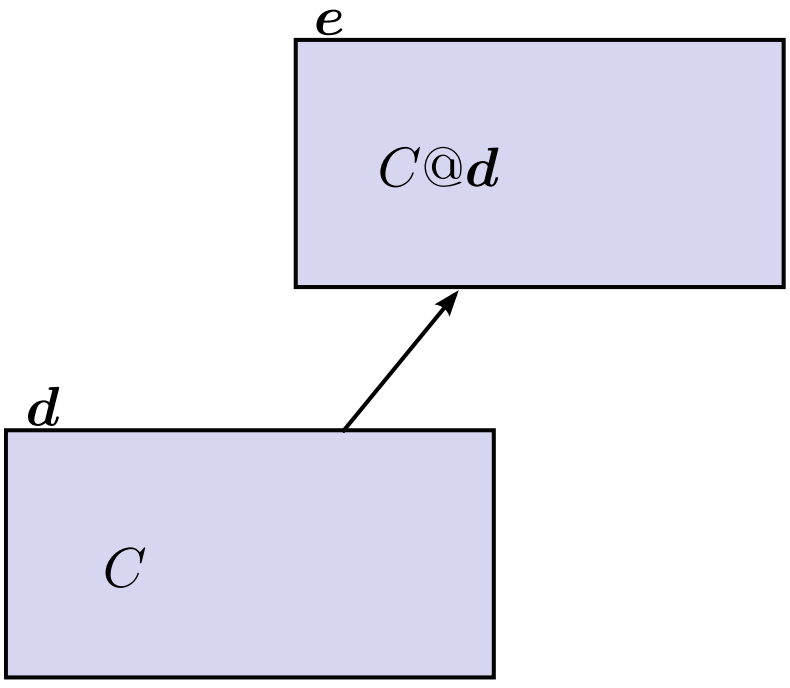
plays_for(Daniele_Derossi, Team_Italy)
$\mathsf{plays\_for}_{\mathsf{Italy,NFL}}$(Daniele_Derossi, AC_Roma)
plays_for(Nelson_Valdez, Team_Paraguay)
$\mathsf{plays\_for}_{\mathsf{Germany,NFL}}$(Nelson_Valdez, Borussia_Dortmund)
...

CKR: Semantics

$$\mathfrak{I} = \{\mathcal{I}_{\mathbf{d}}\}_{\mathcal{C}_{\mathbf{d}} \in \mathfrak{K}} \qquad \Delta_{\mathbf{d}} \subseteq \Delta_{\mathbf{e}} \text{ if } \mathbf{d} \prec \mathbf{e}$$

1. $(\top_{\mathbf{d}})^{\mathcal{I}_{\mathbf{f}}} \subseteq (\top_{\mathbf{e}})^{\mathcal{I}_{\mathbf{f}}}$ if $\mathbf{d} \prec \mathbf{e}$
2. $(A_{\mathbf{f}})^{\mathcal{I}_{\mathbf{d}}} \subseteq (\top_{\mathbf{f}})^{\mathcal{I}_{\mathbf{d}}}$
3. $(R_{\mathbf{f}})^{\mathcal{I}_{\mathbf{d}}} \subseteq (\top_{\mathbf{f}})^{\mathcal{I}_{\mathbf{d}}} \times (\top_{\mathbf{f}})^{\mathcal{I}_{\mathbf{d}}}$
4. $a^{\mathcal{I}_{\mathbf{d}}} = a^{\mathcal{I}_{\mathbf{e}}}$, given $\mathbf{d} \prec \mathbf{e}$,
   either if $a^{\mathcal{I}_{\mathbf{d}}}$ is defined,
   or if $a^{\mathcal{I}_{\mathbf{e}}}$ is defined and $a^{\mathcal{I}_{\mathbf{e}}} \in \Delta_{\mathbf{d}}$
5. $(X_{\mathbf{d}_{\mathbf{B}}})^{\mathcal{I}_{\mathbf{e}}} = (X_{\mathbf{d}_{\mathbf{B}}+\mathbf{e}})^{\mathcal{I}_{\mathbf{e}}}$
6. $(X_{\mathbf{d}})^{\mathcal{I}_{\mathbf{e}}} = (X_{\mathbf{d}})^{\mathcal{I}_{\mathbf{d}}}$ if $\mathbf{d} \prec \mathbf{e}$
7. $(A_{\mathbf{f}})^{\mathcal{I}_{\mathbf{d}}} = (A_{\mathbf{f}})^{\mathcal{I}_{\mathbf{e}}} \cap \Delta_{\mathbf{d}}$ if $\mathbf{d} \prec \mathbf{e}$
8. $(R_{\mathbf{f}})^{\mathcal{I}_{\mathbf{d}}} = (R_{\mathbf{f}})^{\mathcal{I}_{\mathbf{e}}} \cap (\Delta_{\mathbf{d}} \times \Delta_{\mathbf{d}})$ if $\mathbf{d} \prec \mathbf{e}$
9. $\mathcal{I}_{\mathbf{d}} \models \mathrm{K}(\mathcal{C}_{\mathbf{d}})$

Characterization: Embedding @**d**



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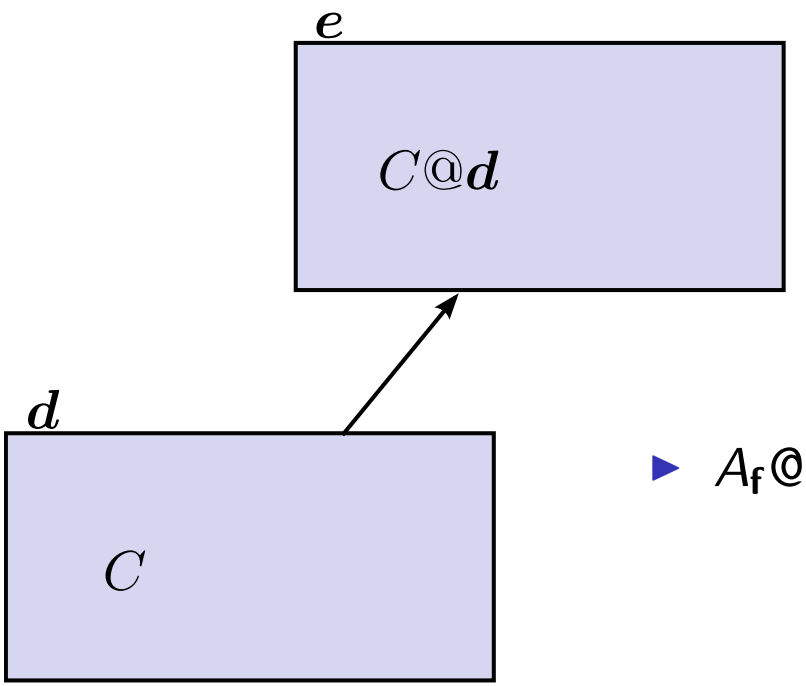

- $A_{\mathbf{f}}@\mathbf{d} = \begin{cases} A_{\mathbf{f}} & \text{if } \mathbf{f} \preceq \mathbf{d} \\ A_{\mathbf{f}} \sqcap \top_{\mathbf{d}} & \text{otherwise} \end{cases}$

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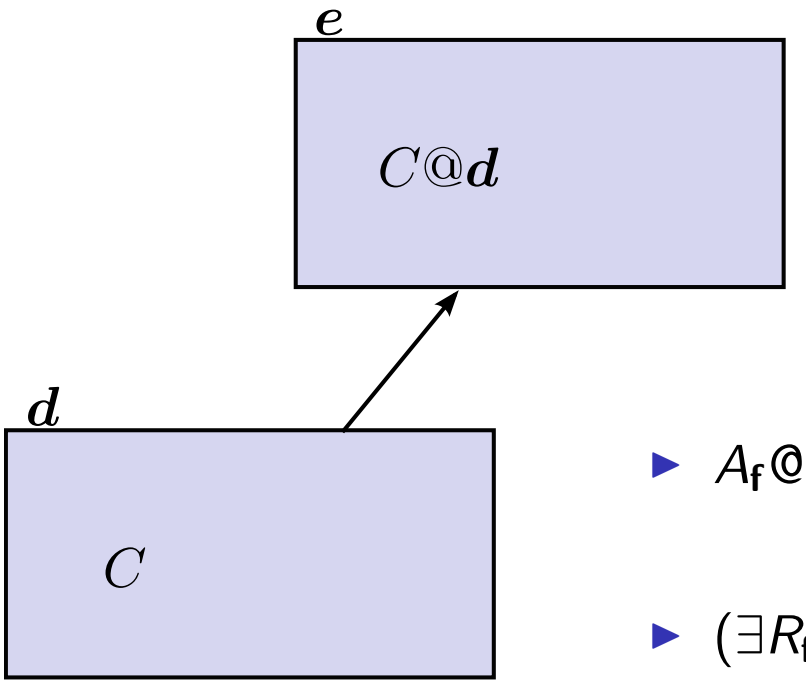

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- $(\exists R_{\mathbf{f}}.C)@\mathbf{d} = \begin{cases} \exists R_{\mathbf{f}}.(C@\mathbf{d}) & \text{if } \mathbf{f} \preceq \mathbf{d} \\ \top_{\mathbf{d}} \sqcap \exists R_{\mathbf{f}}.(C@\mathbf{d}) & \text{otherwise} \end{cases}$

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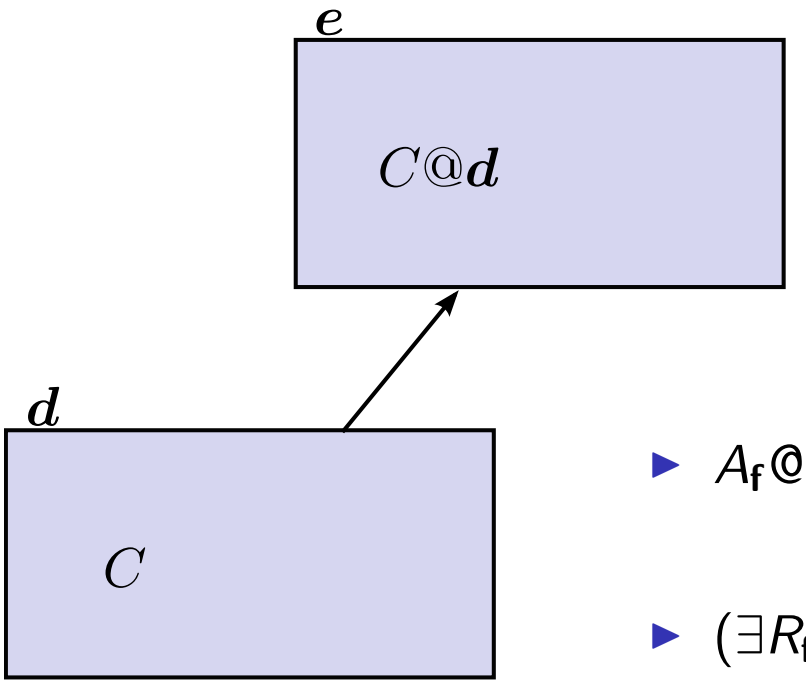

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- $(C \sqsubseteq D)\mathbf{@d} = C\mathbf{@d} \sqsubseteq D\mathbf{@d}$

  ...

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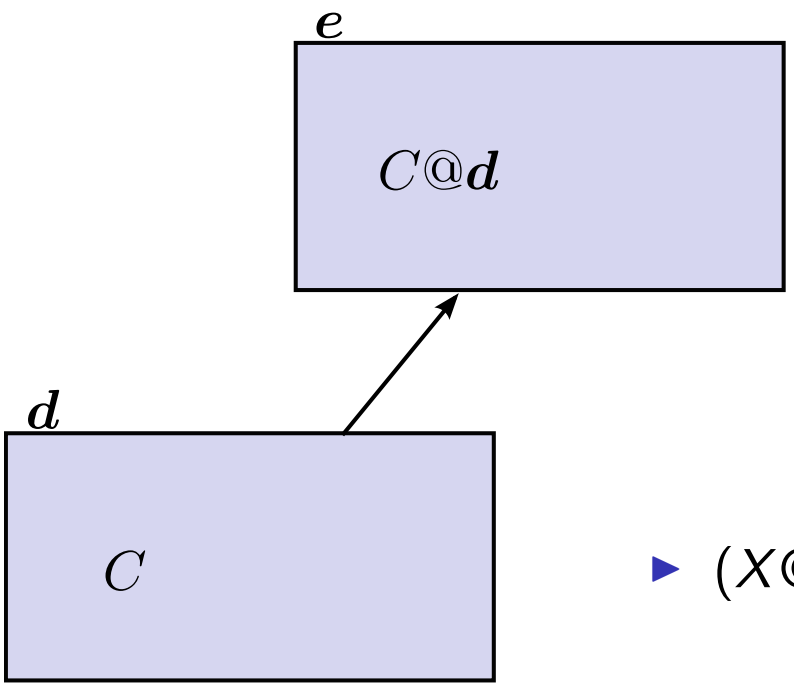
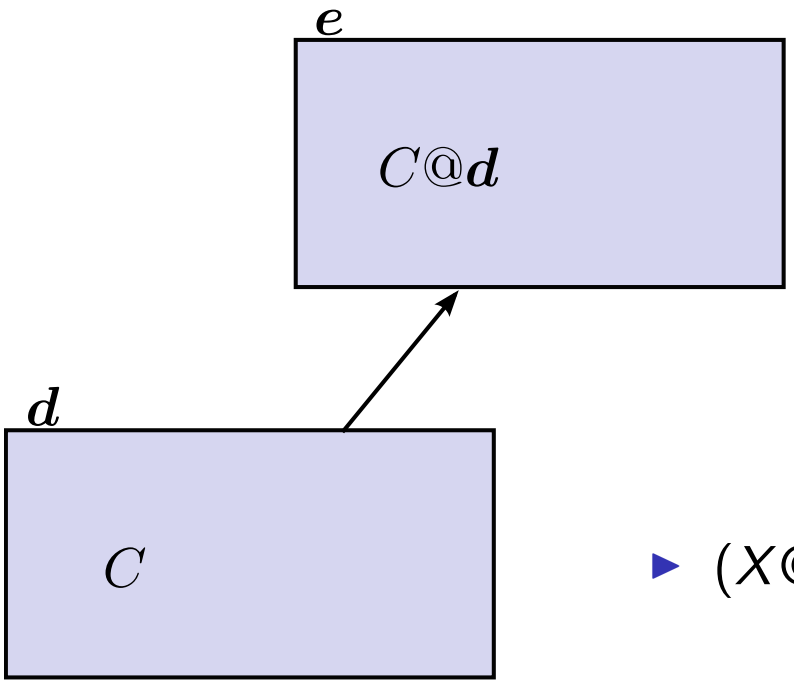


- $(X\mathbf{@d})^{\mathcal{I}_{\mathbf{e}}} = X^{\mathcal{I}_{\mathbf{d}}}$

Characterization: Embedding @d



- $(X\mathbf{@d})^{\mathcal{I}_\mathbf{e}} = X^{\mathcal{I}_\mathbf{d}}$
- $\mathcal{I}_\mathbf{e} \models \phi\mathbf{@d} \iff \mathcal{I}_\mathbf{d} \models \phi$

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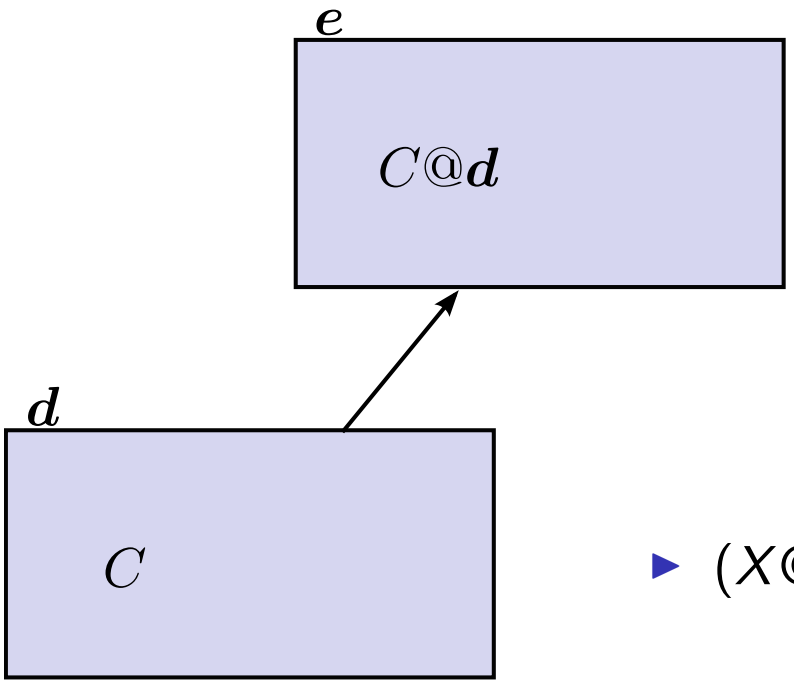

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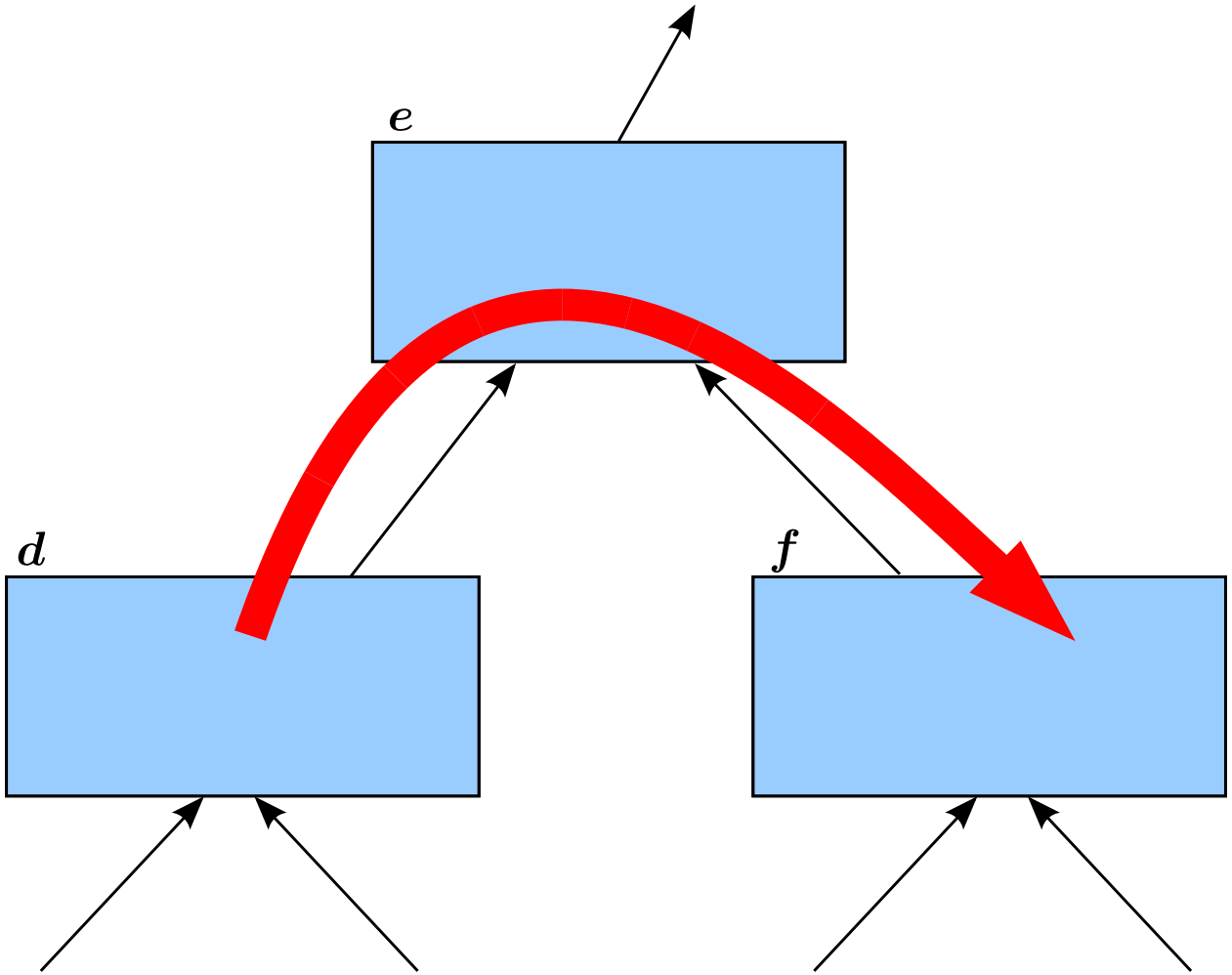
Properties: Knowledge Propagation over Common Super-context



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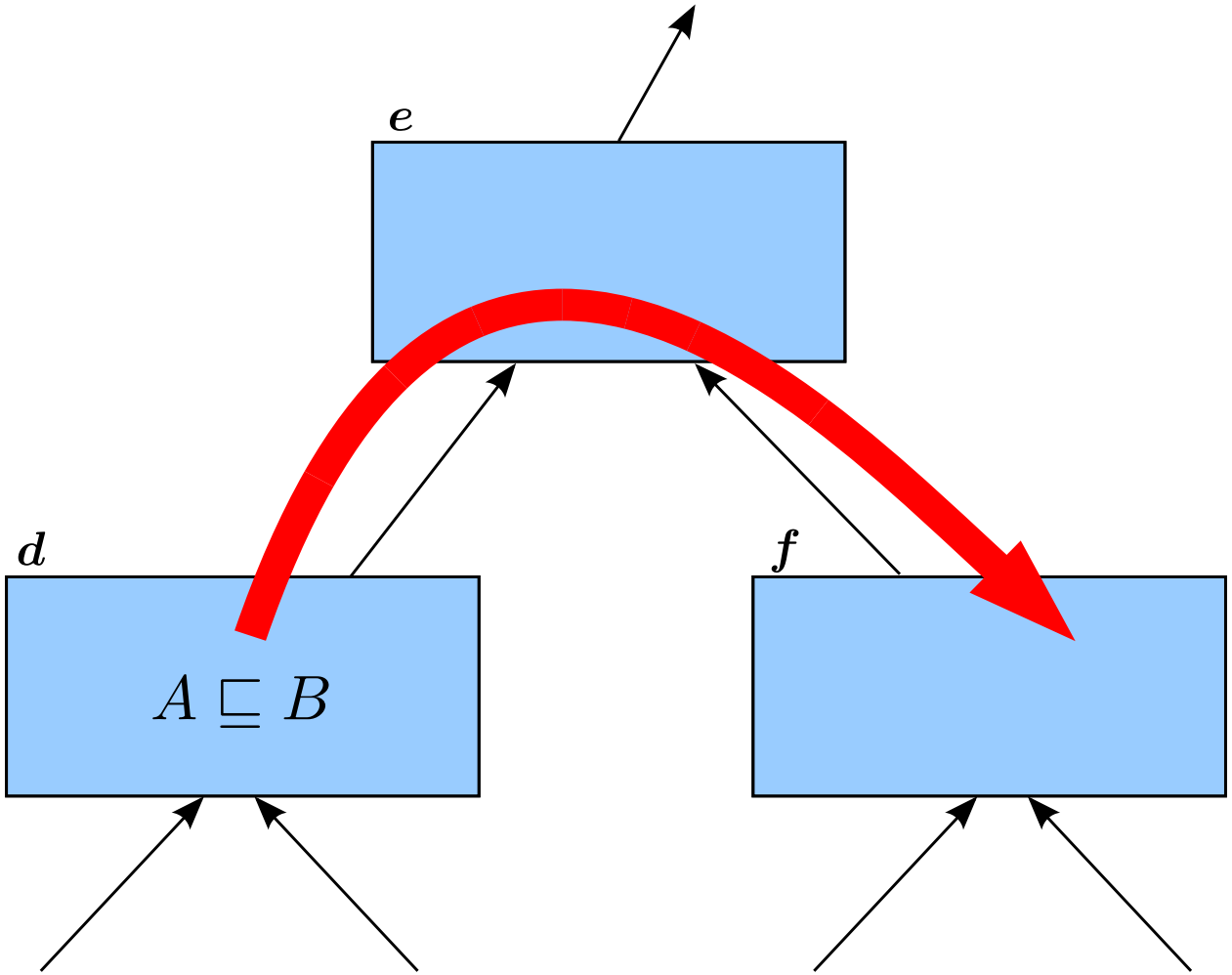

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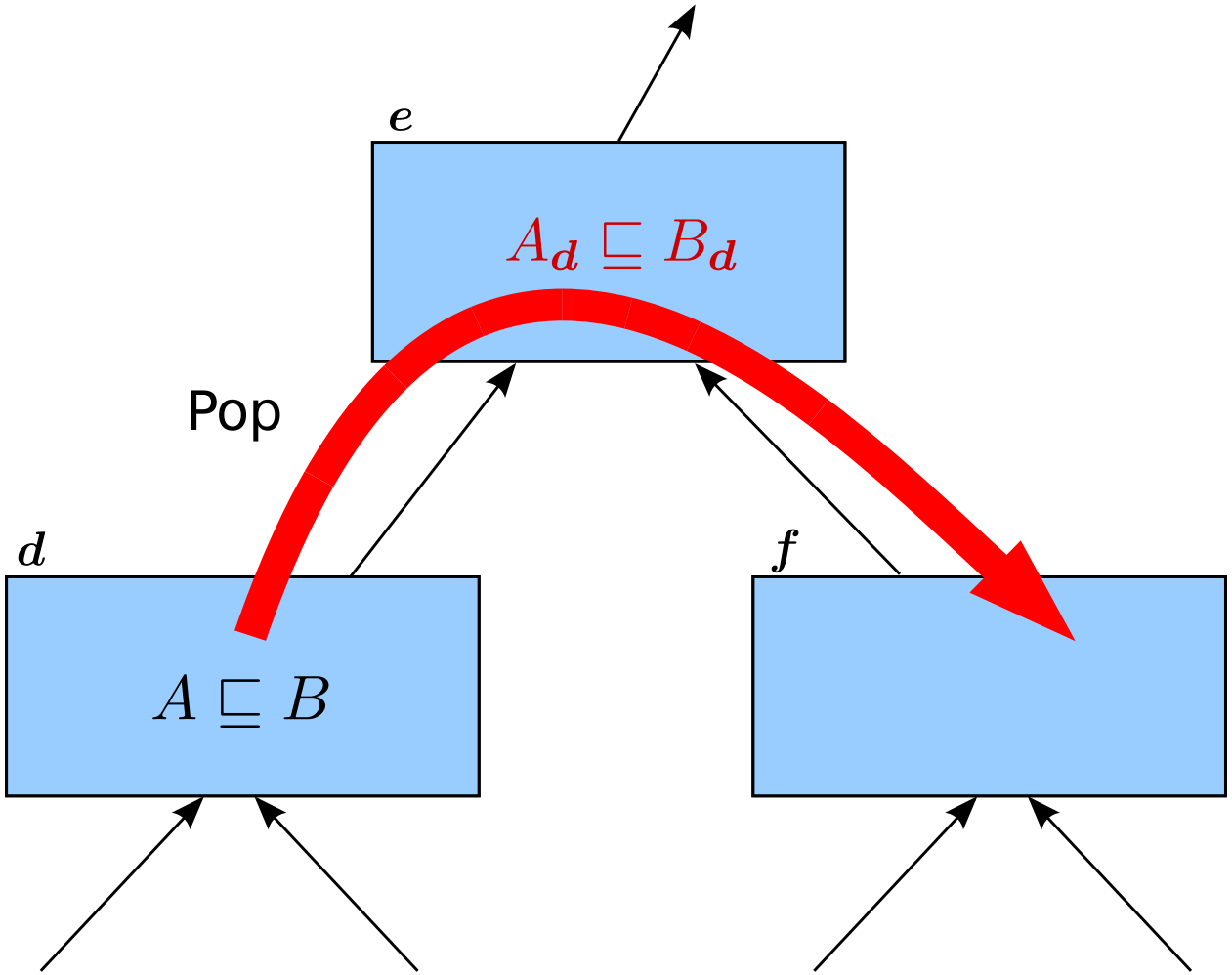

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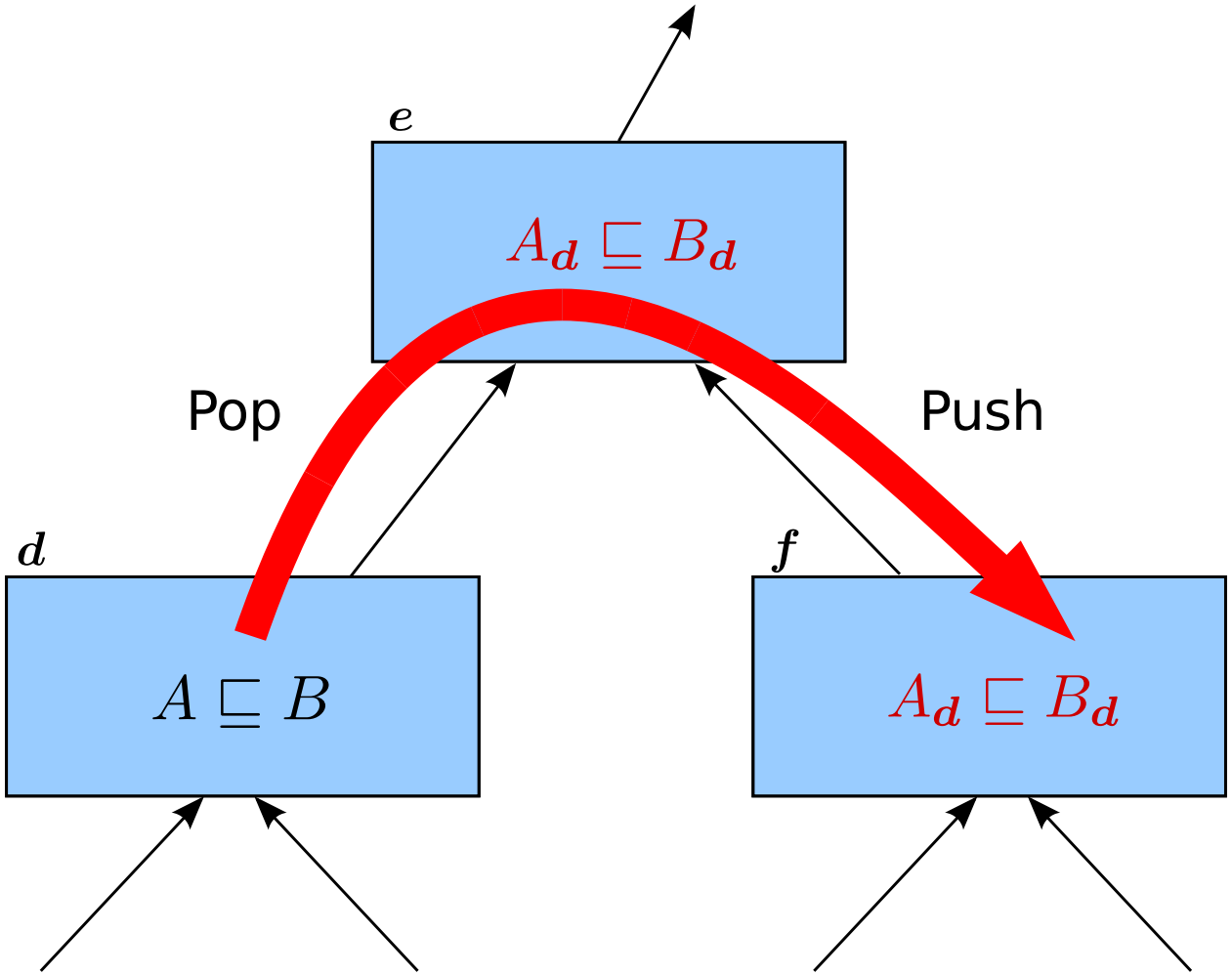
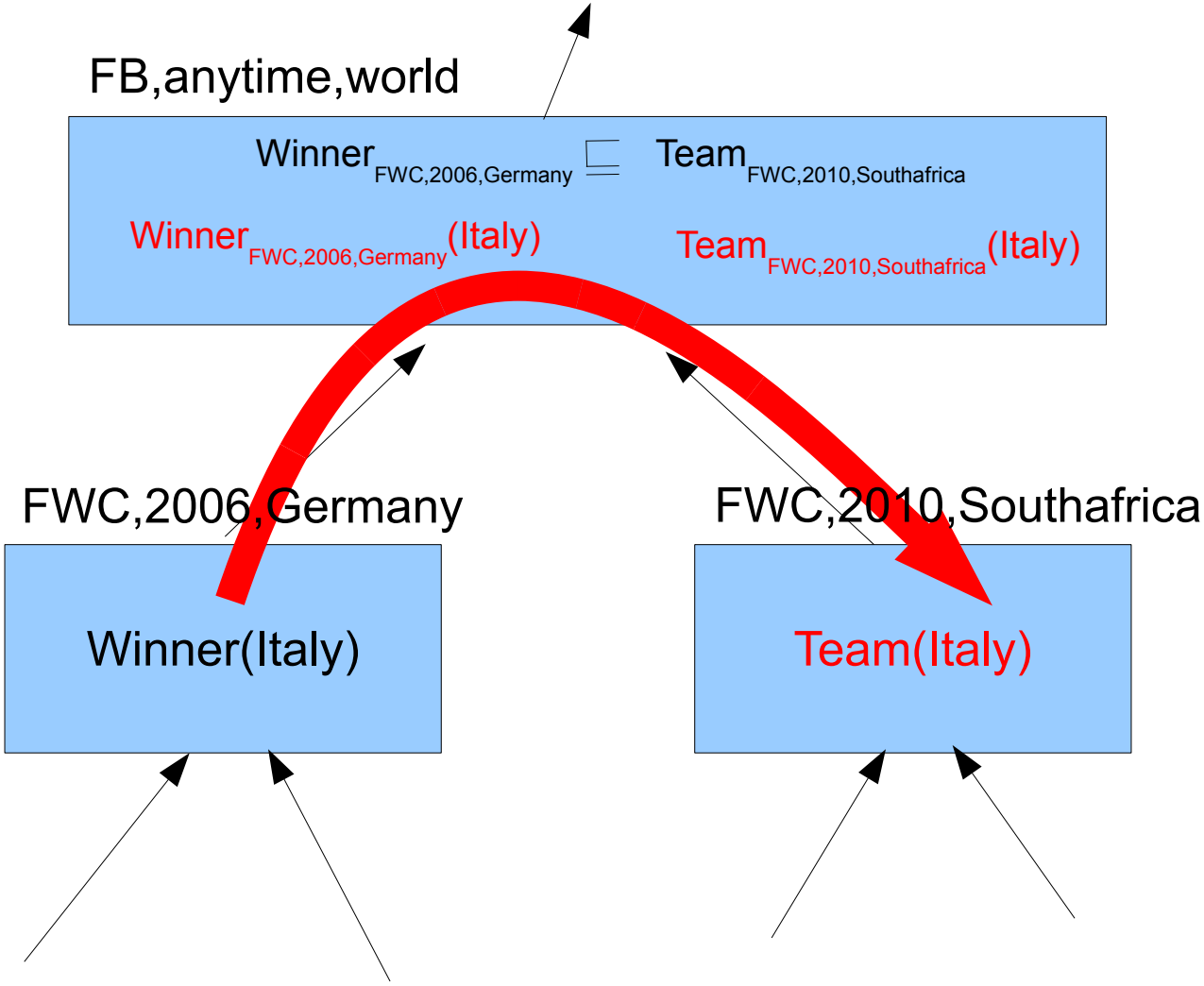
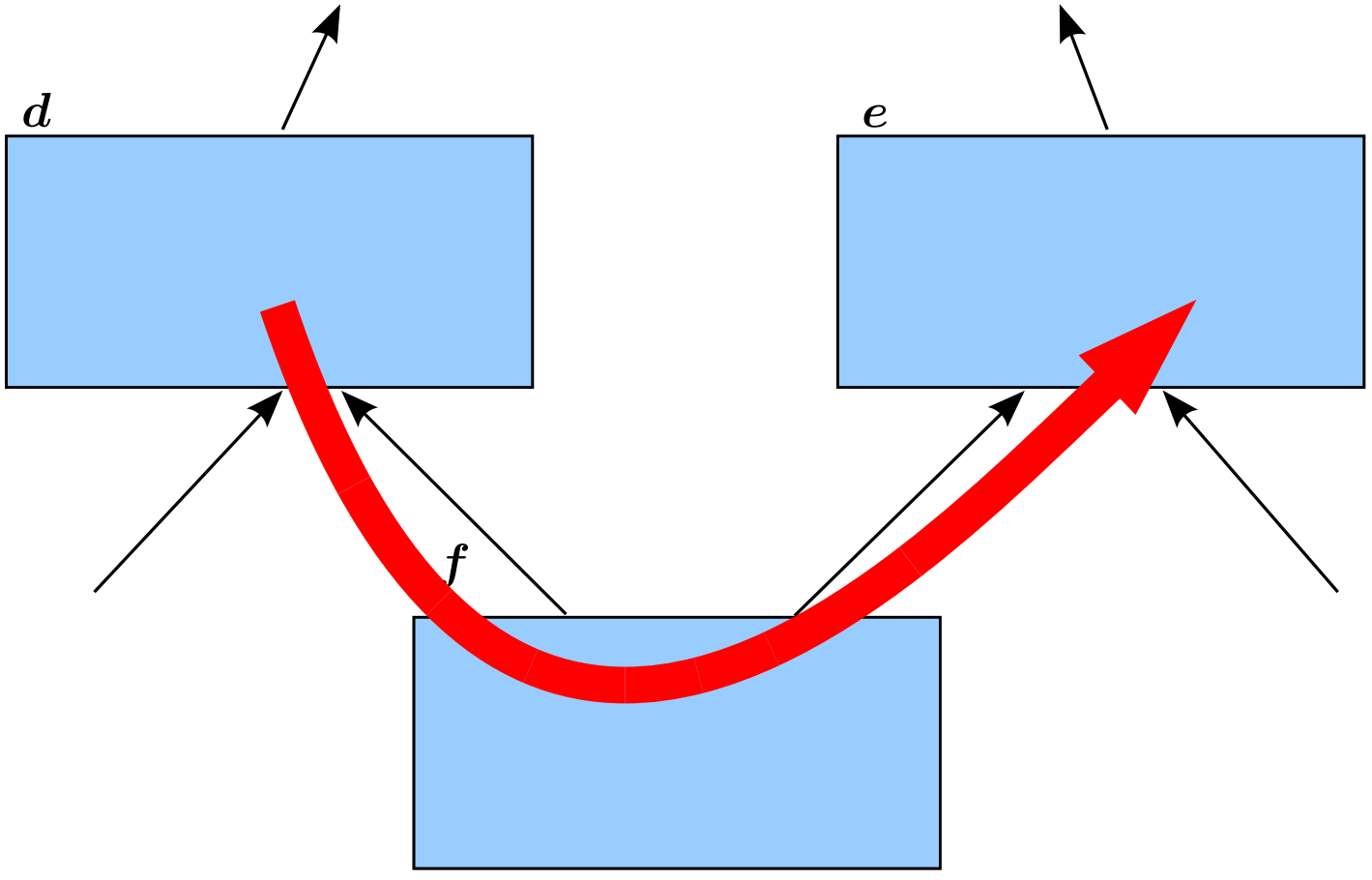


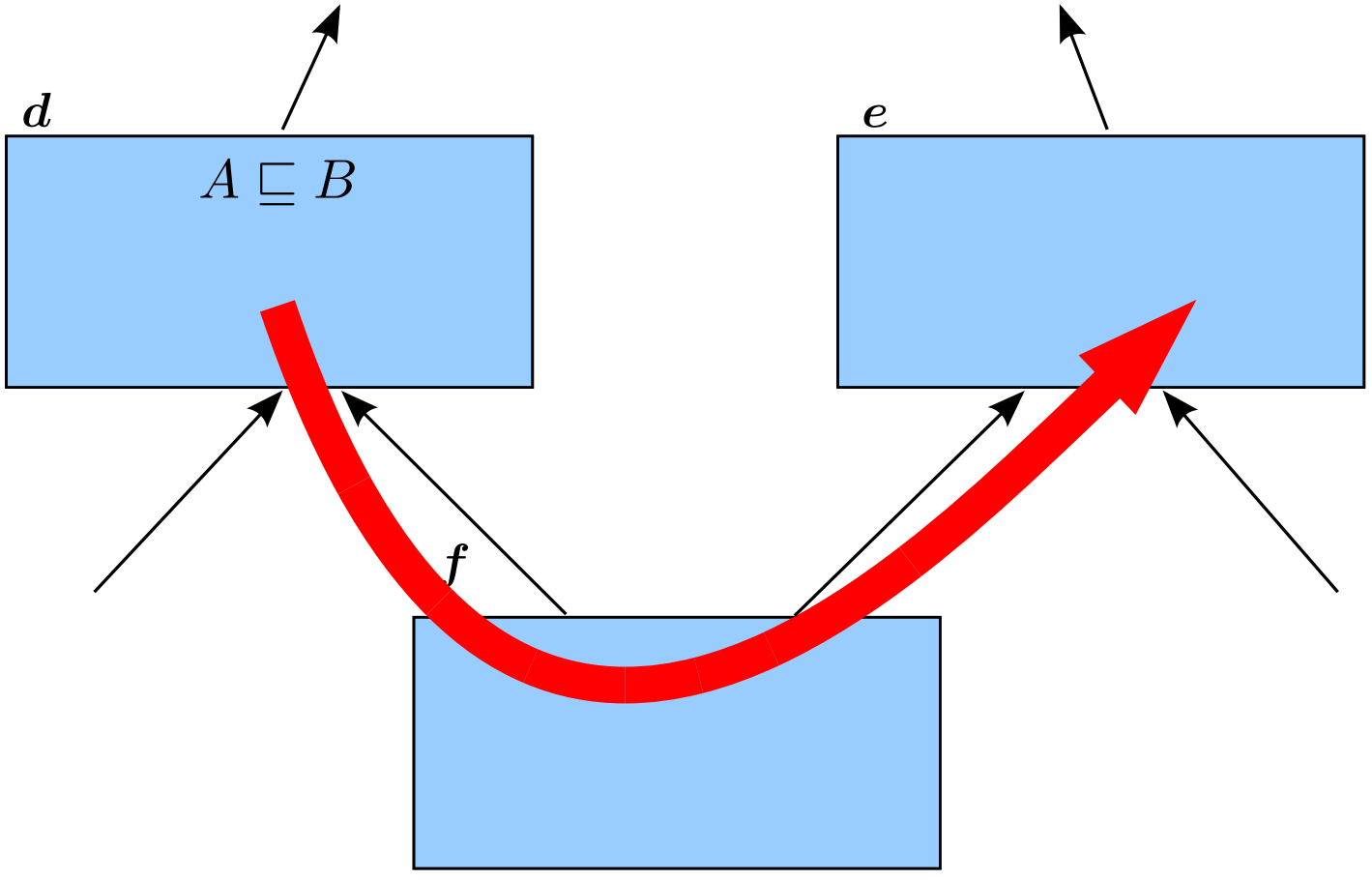
Properties: Knowledge Propagation over Common Super-context



Properties: Knowledge Propagation over Common Sub-context



Properties: Knowledge Propagation over Common Sub-context



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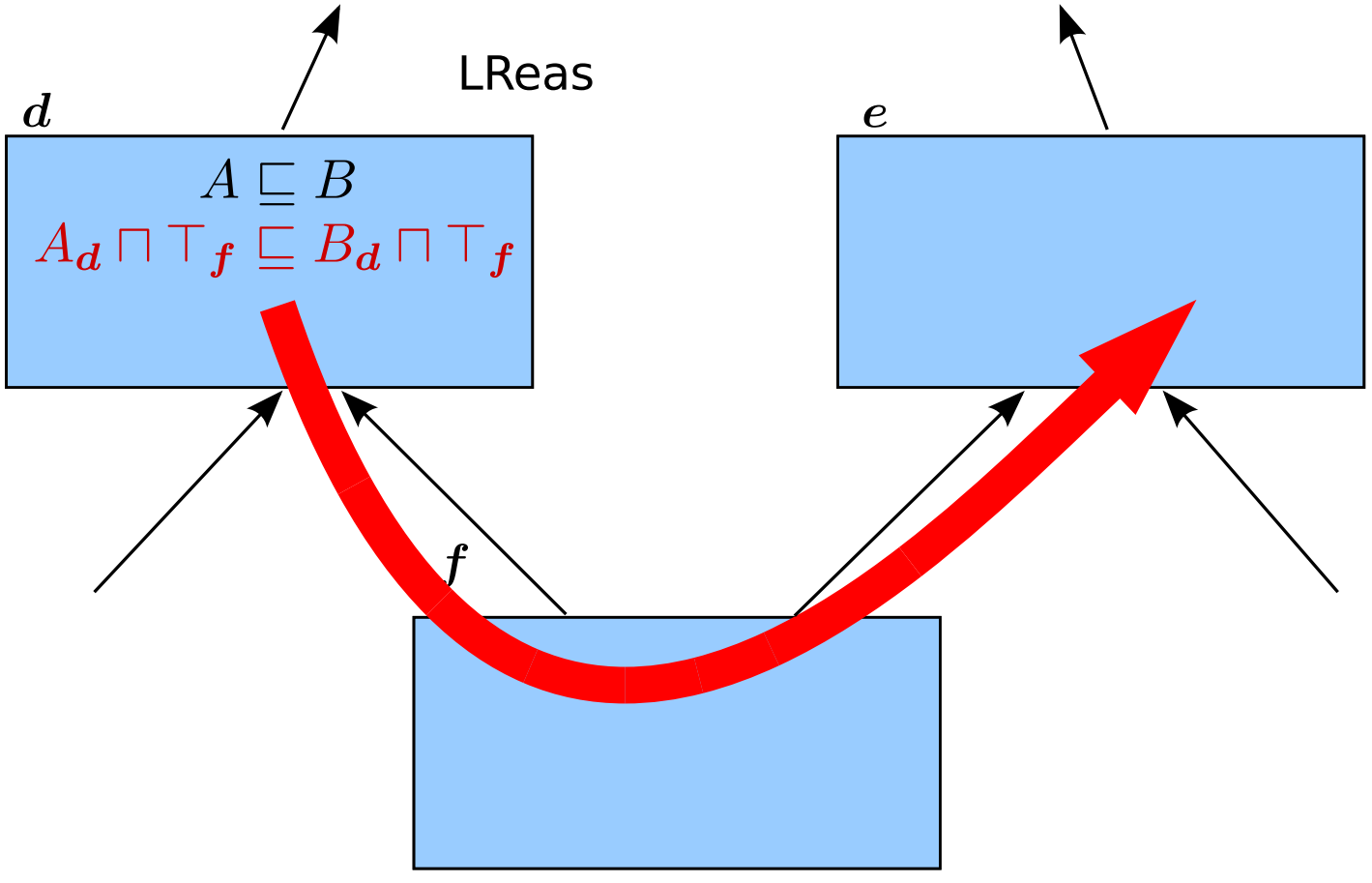

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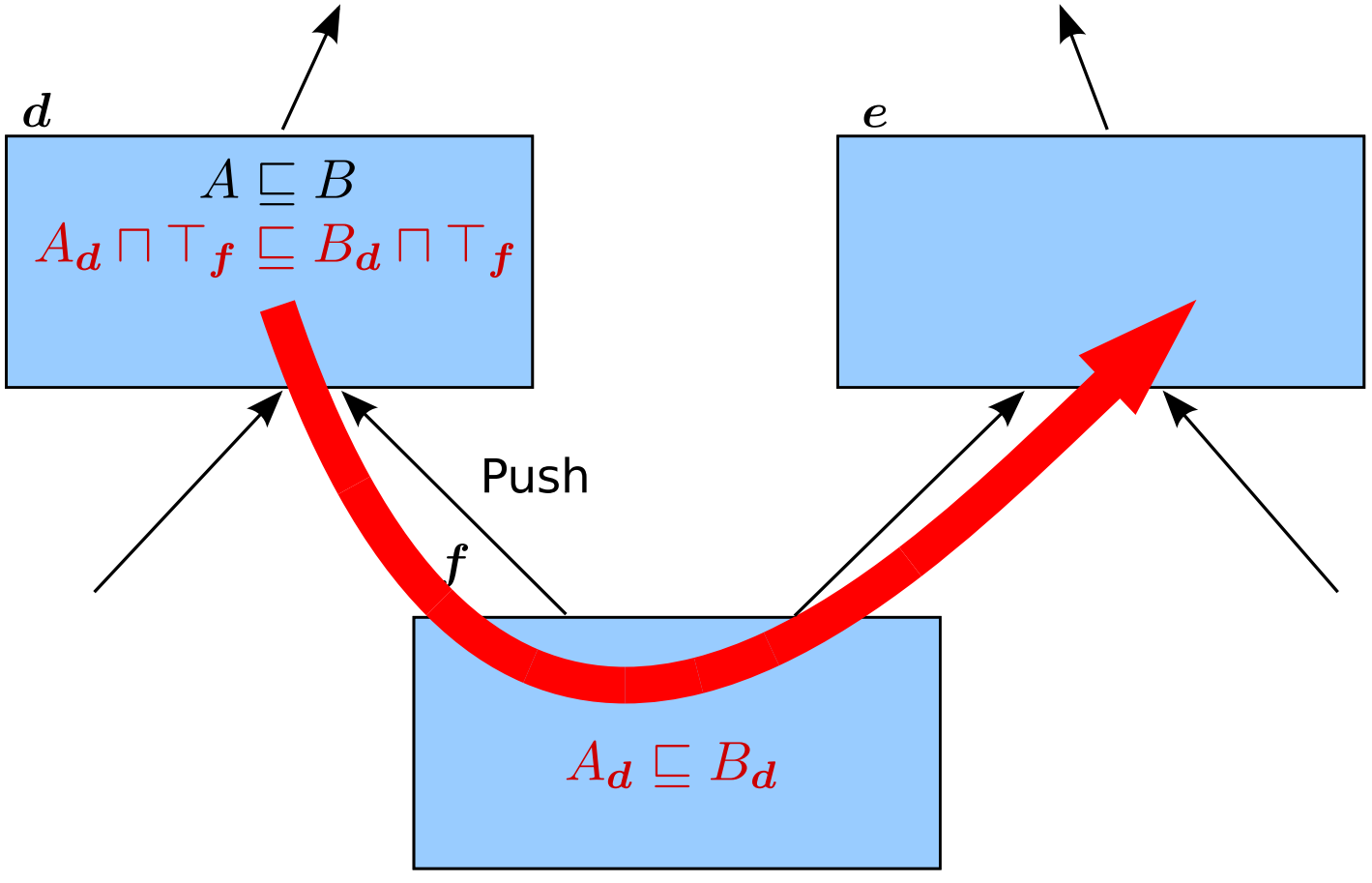

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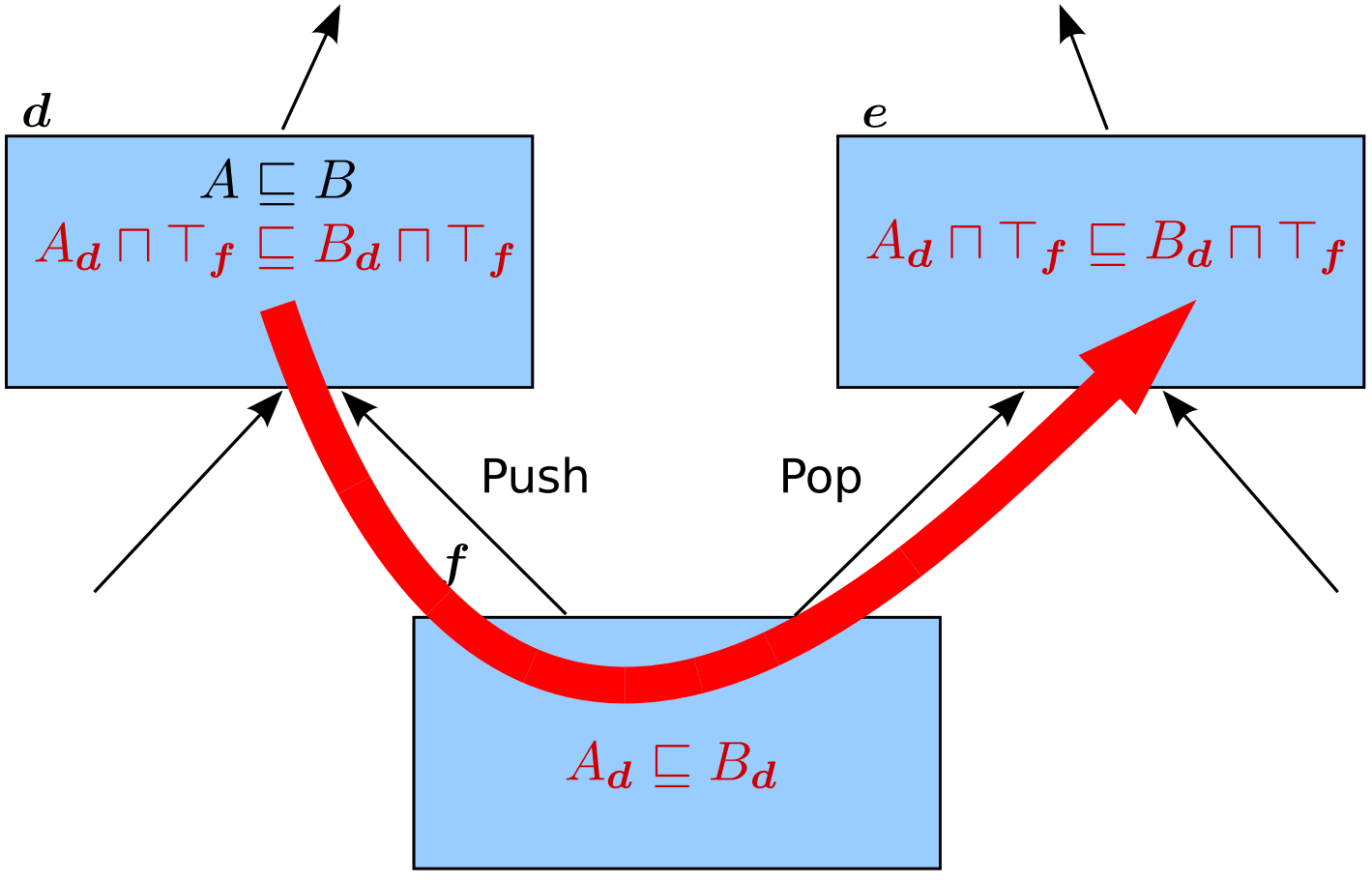

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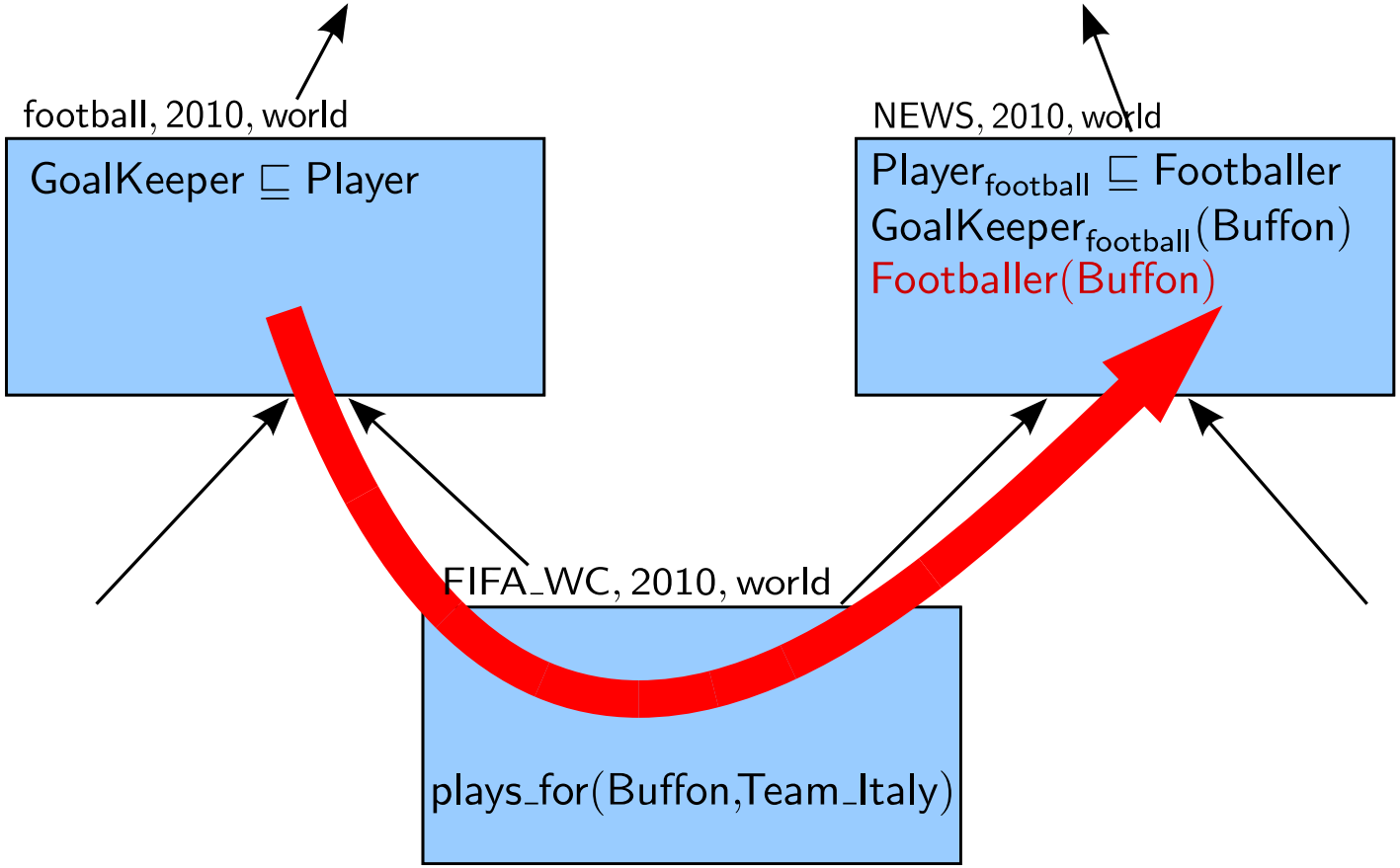

Reasoning in CKR

- DL-based CKR . . . . . tableaux algorithm
- OWL RL-base CKR . . . . . tractable forward chaining

$\mathcal{ALC}$ Tableau Algorithm

$$\forall R.\neg C \sqcap (\exists R.C \sqcup \exists R.D)$$

$\mathcal{ALC}$ Tableau Algorithm

$$\forall R.\neg C \sqcap (\exists R.C \sqcup \exists R.D)$$

-

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$\forall R.\neg C, \exists R.C \sqcup \exists R.D$

•

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$\forall R.\neg C \sqcap (\exists R.C \sqcup \exists R.D)$
$\forall R.\neg C, \exists R.C \sqcup \exists R.D$
$\exists R.C$

- $\bullet$

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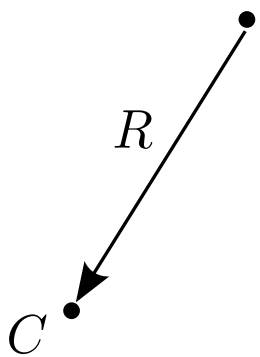

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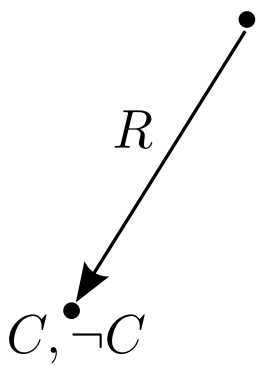

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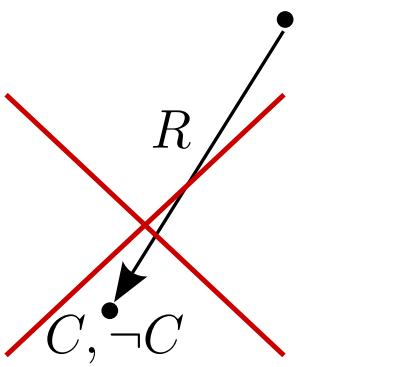

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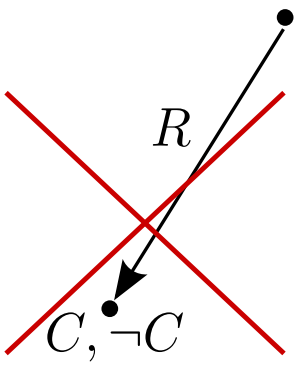

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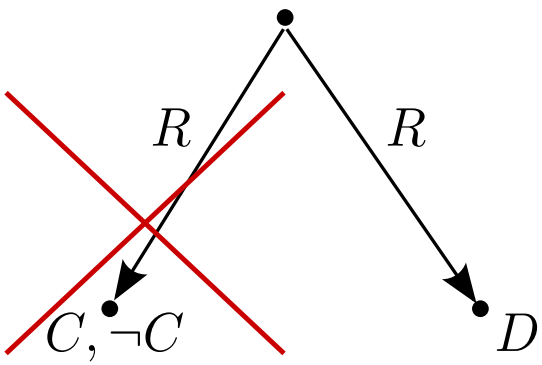

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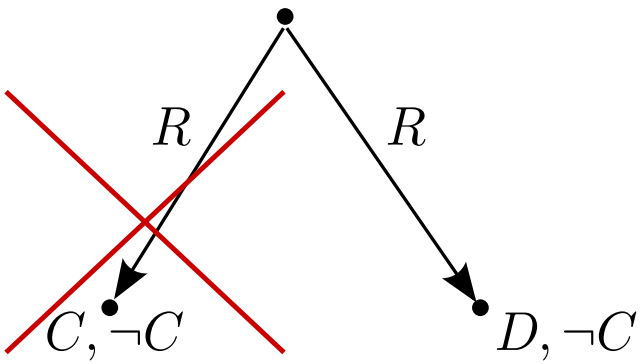
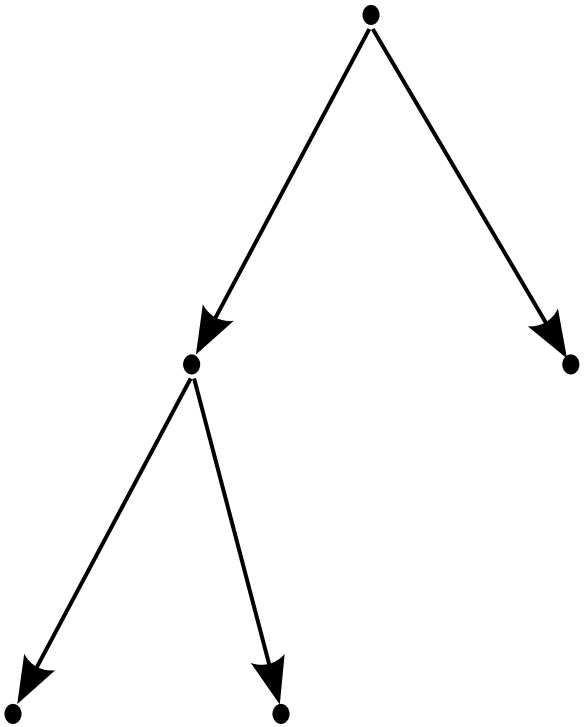


$\mathcal{ALC}$-based CKR Tableau Algorithm



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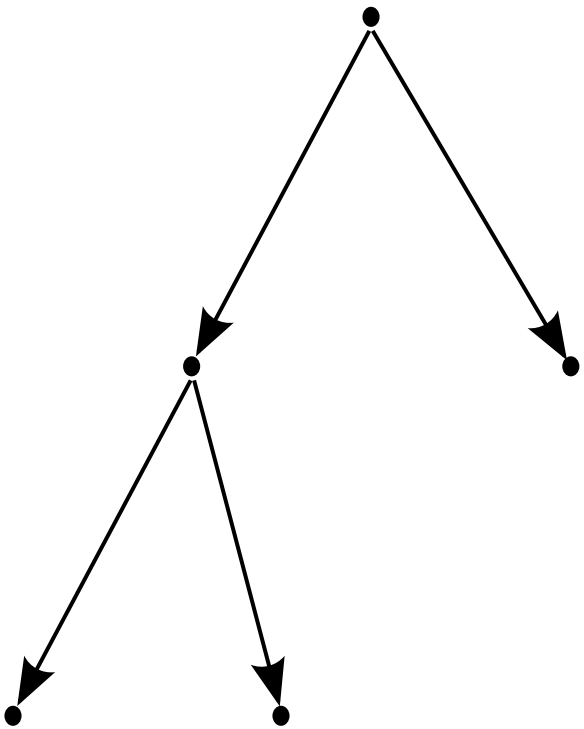

$V_d \mid V_e \qquad d \prec e$

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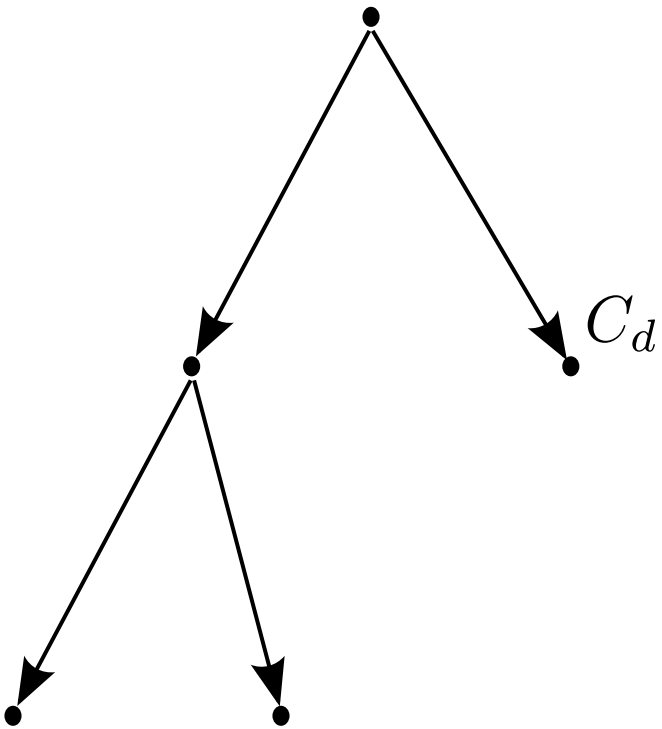

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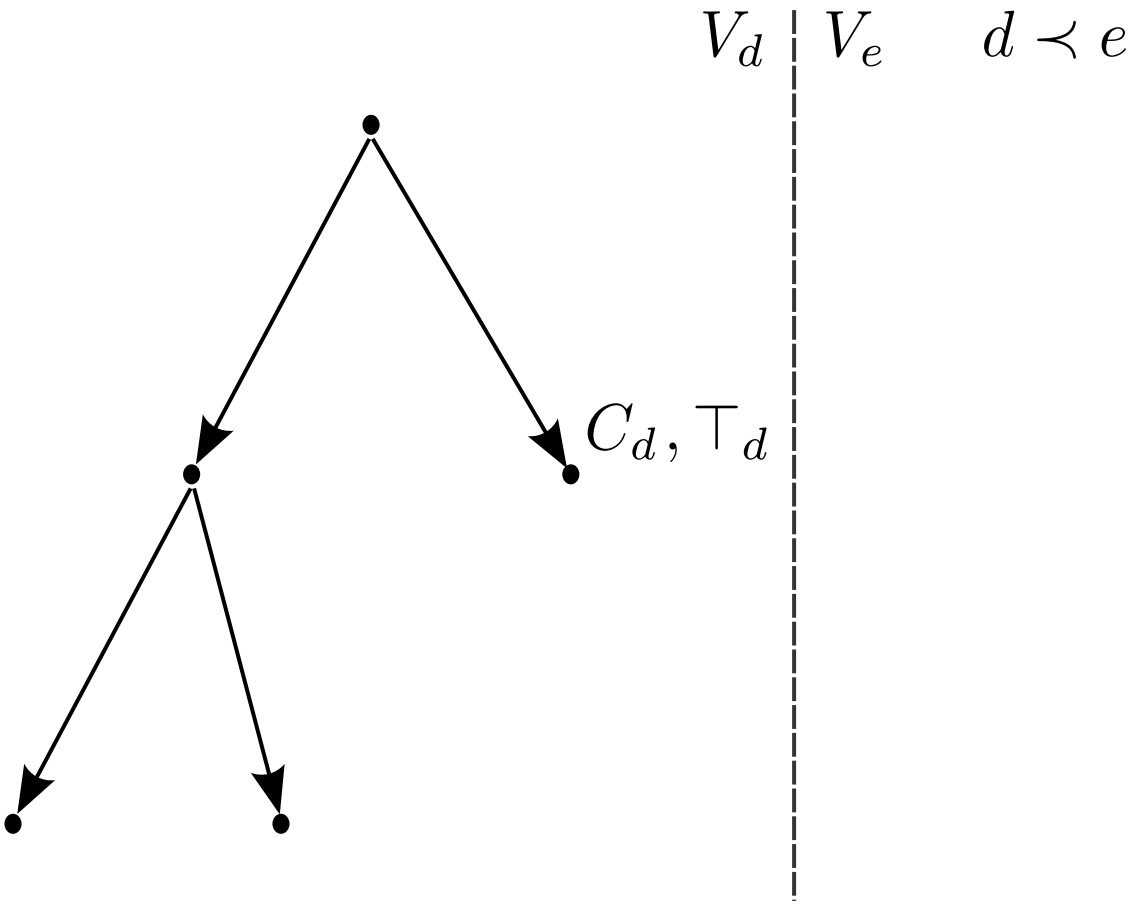

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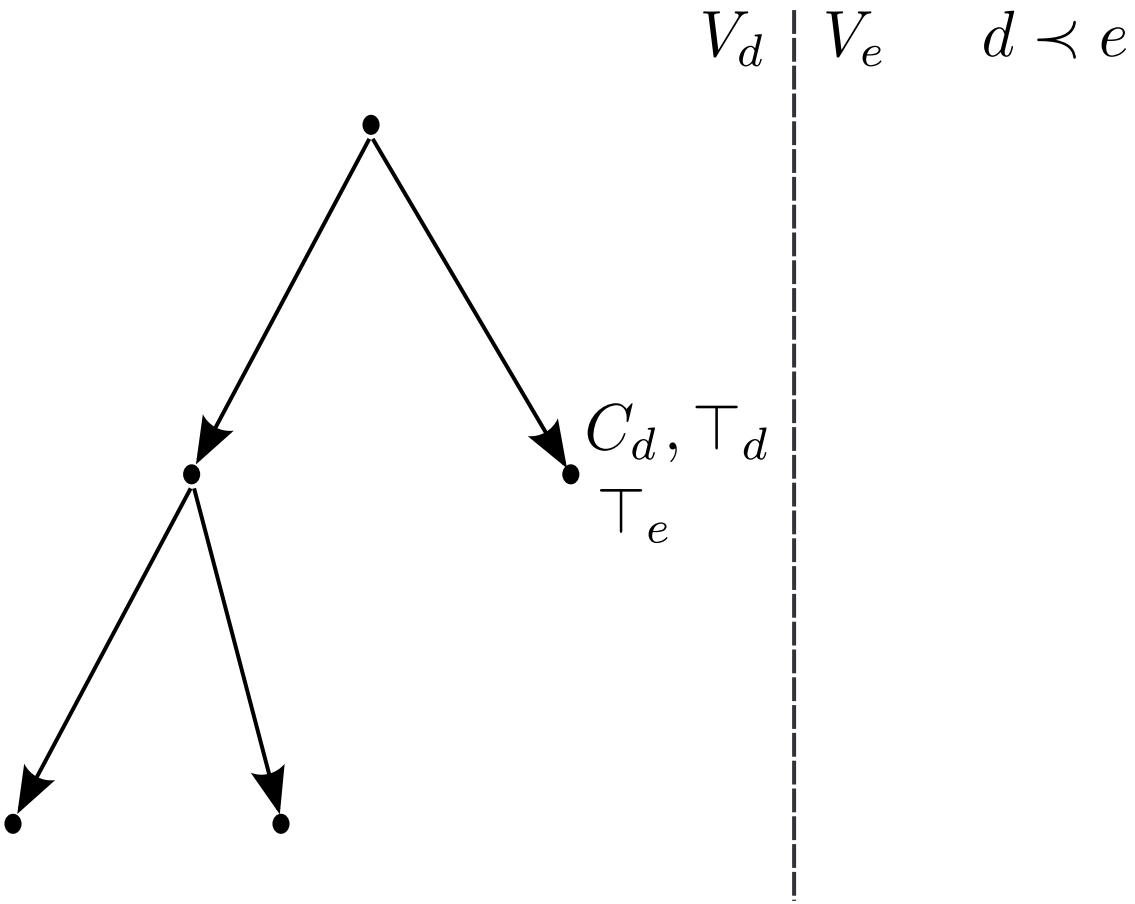

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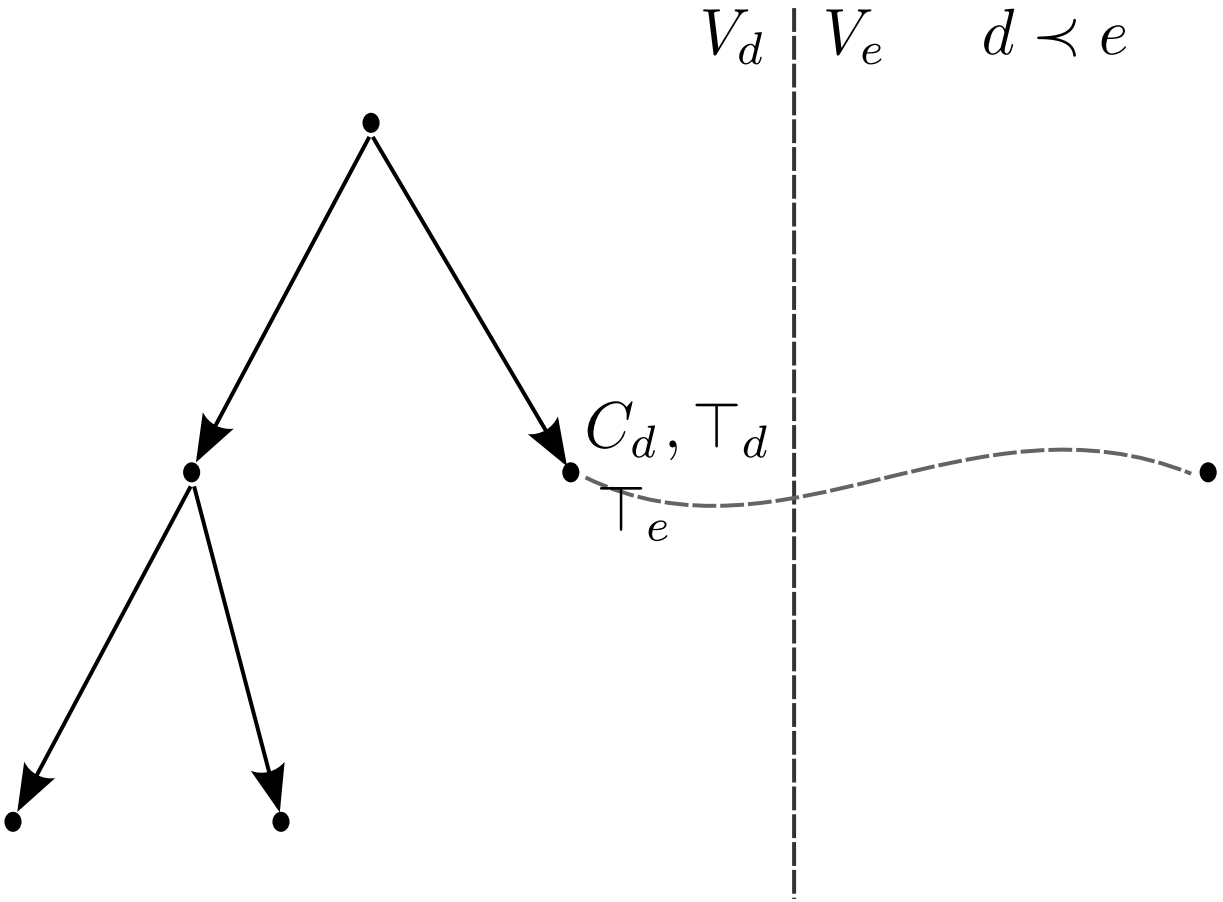

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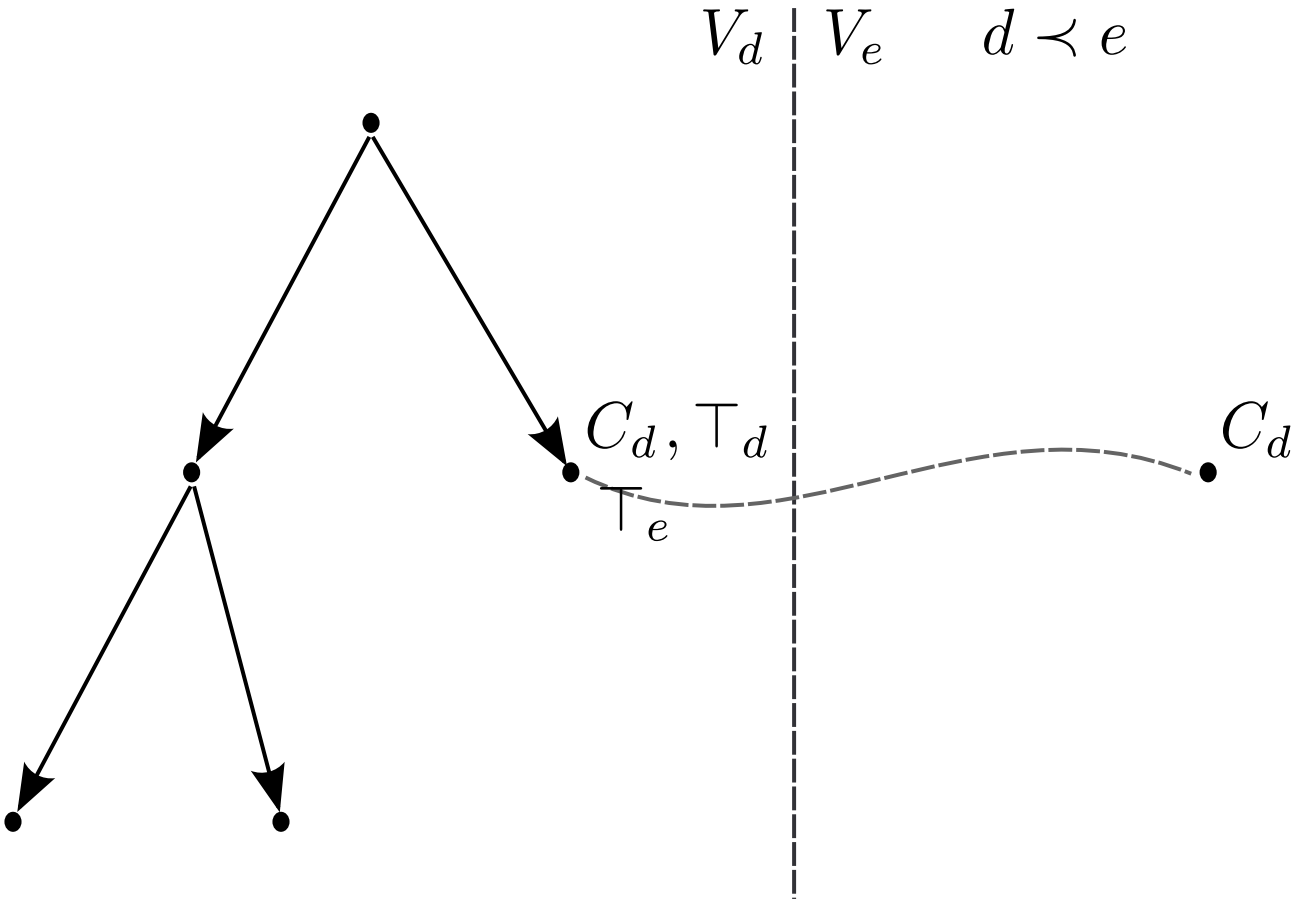

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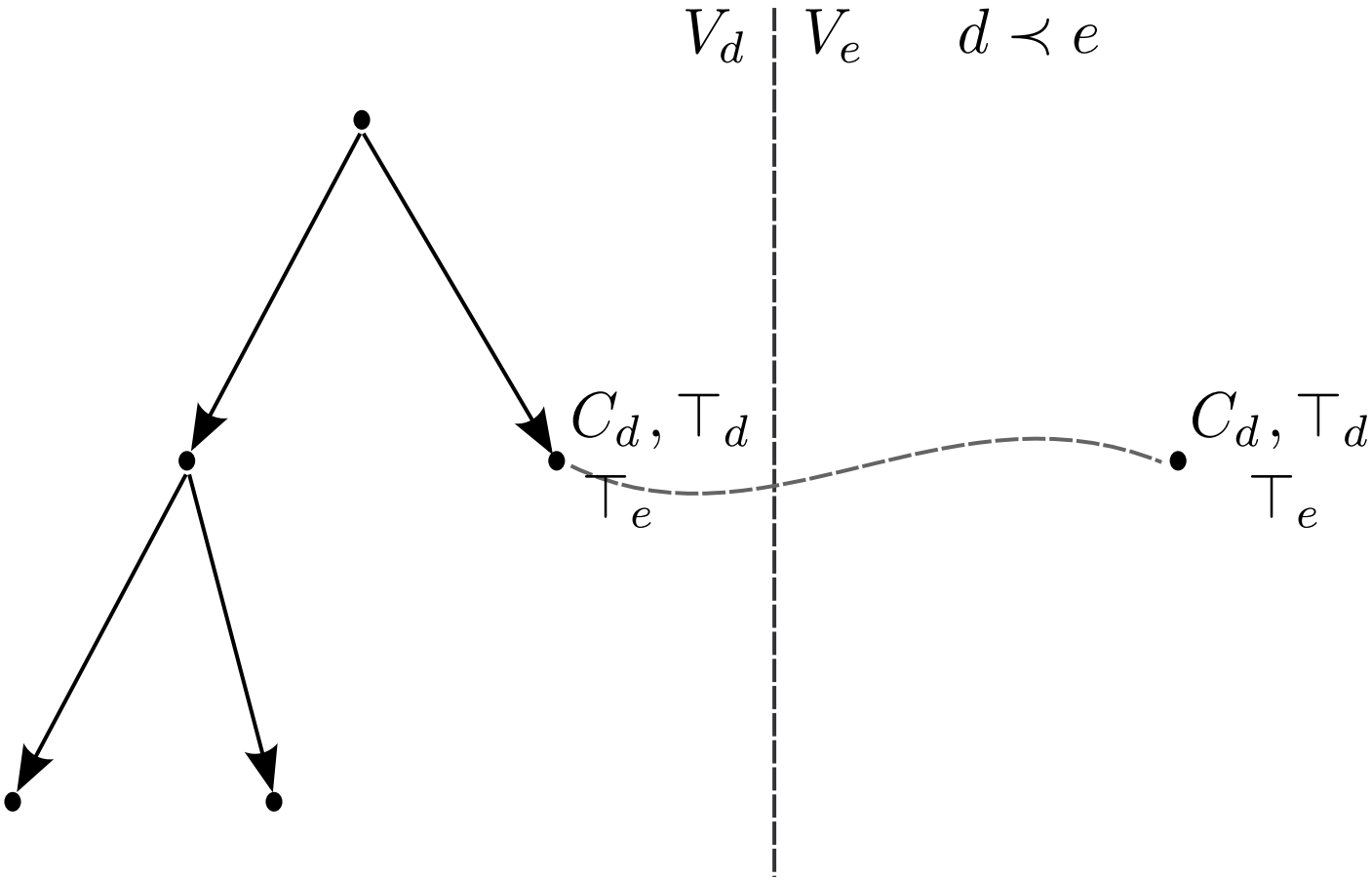

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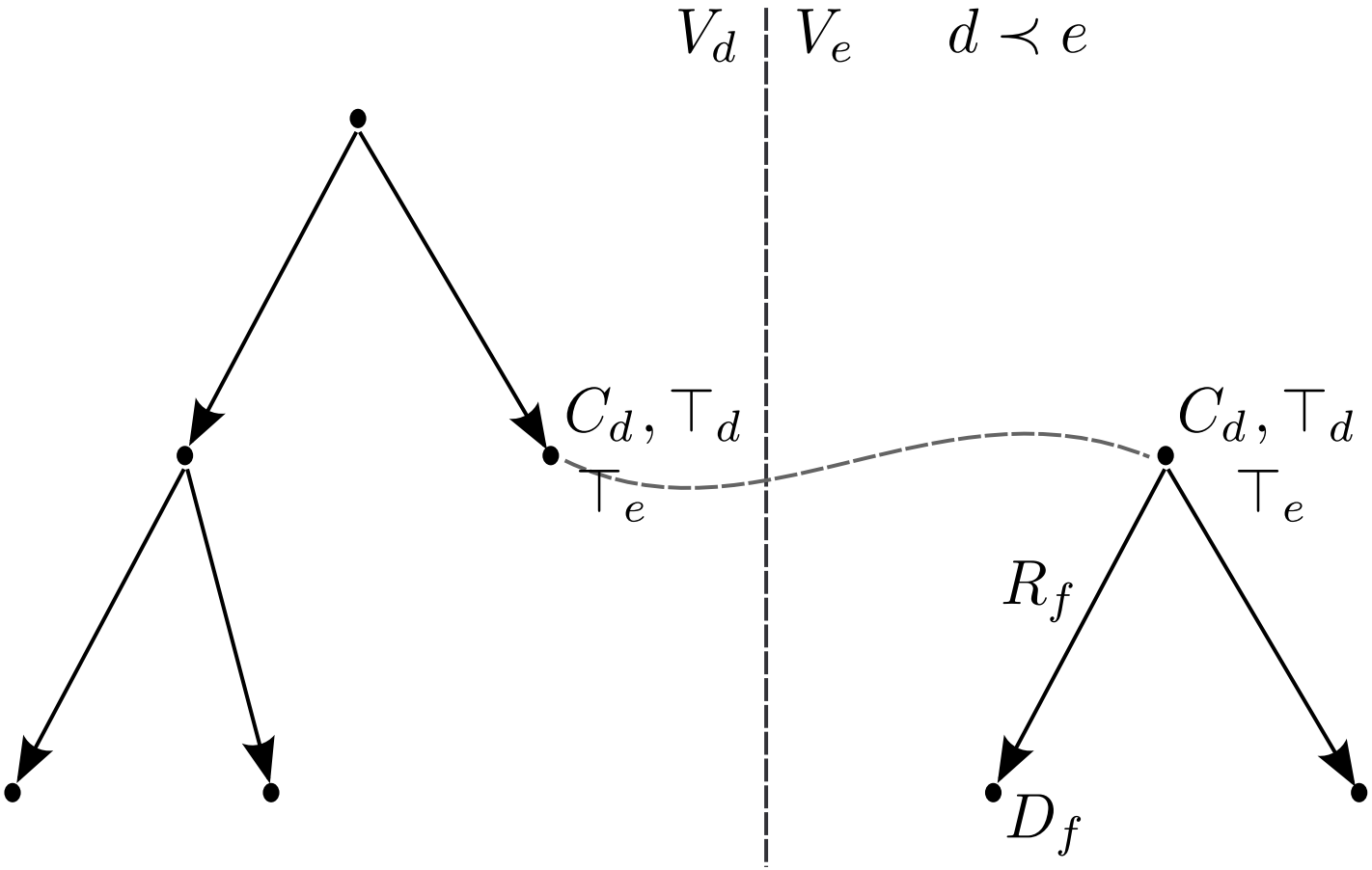

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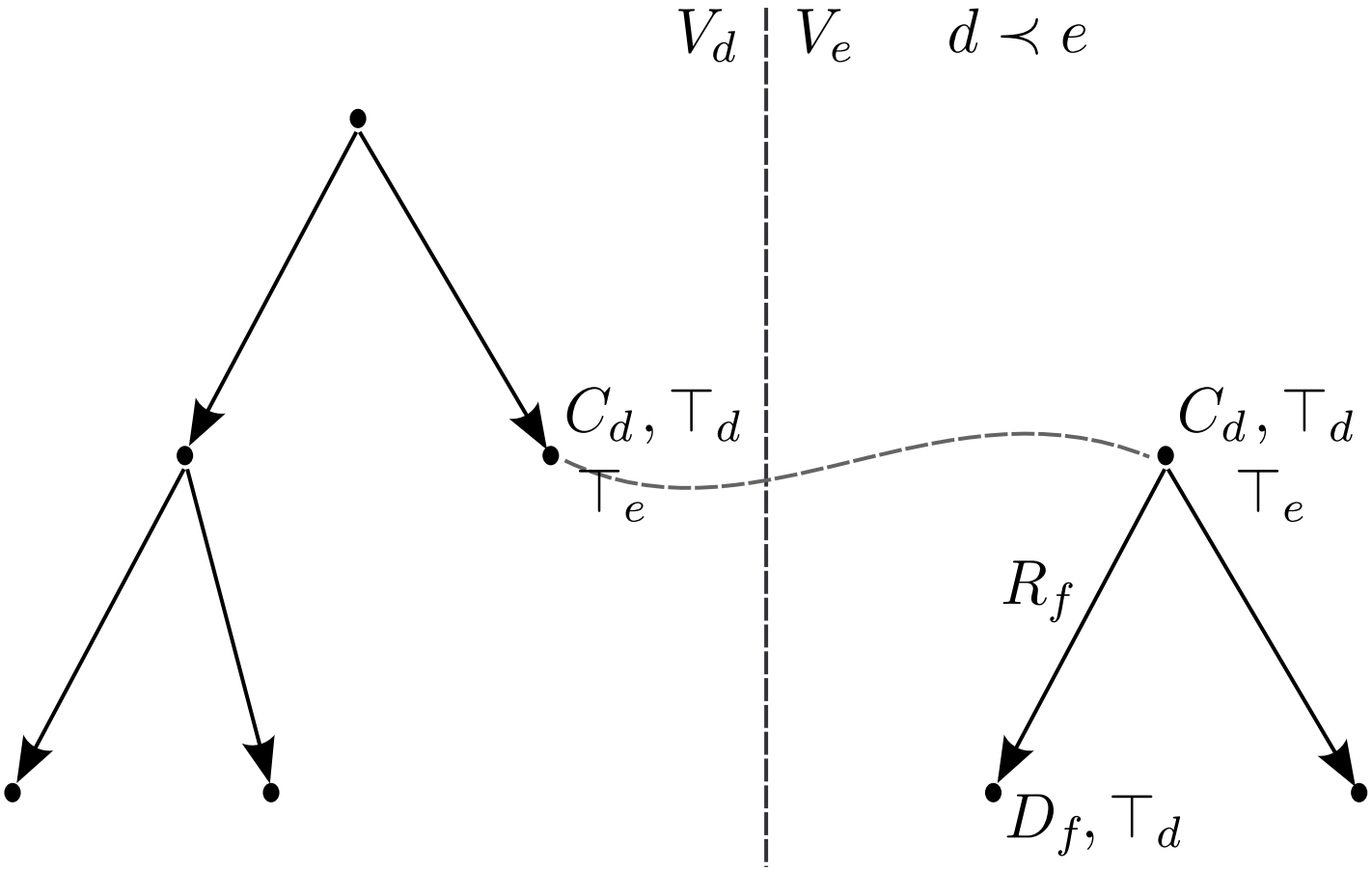

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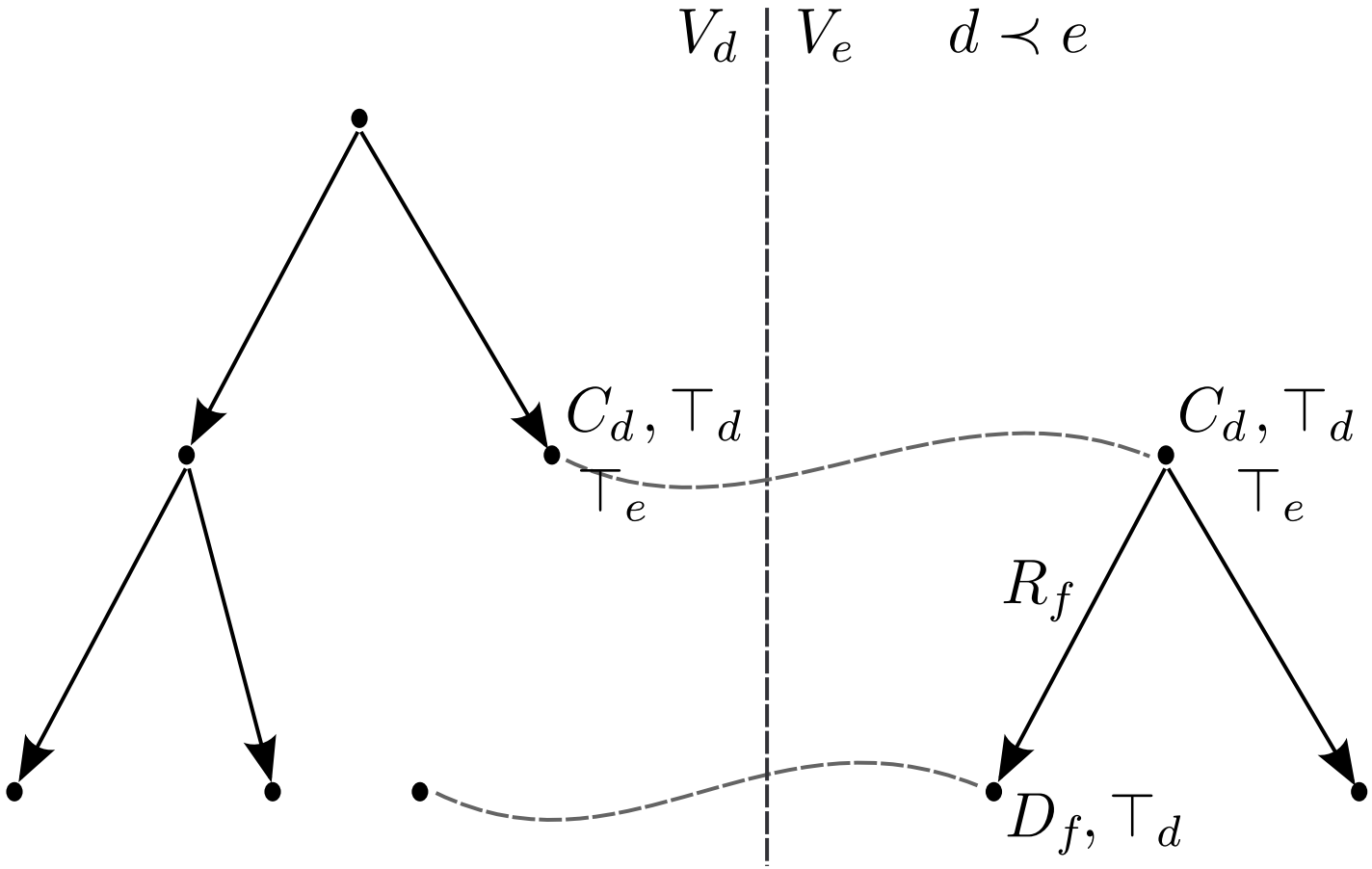

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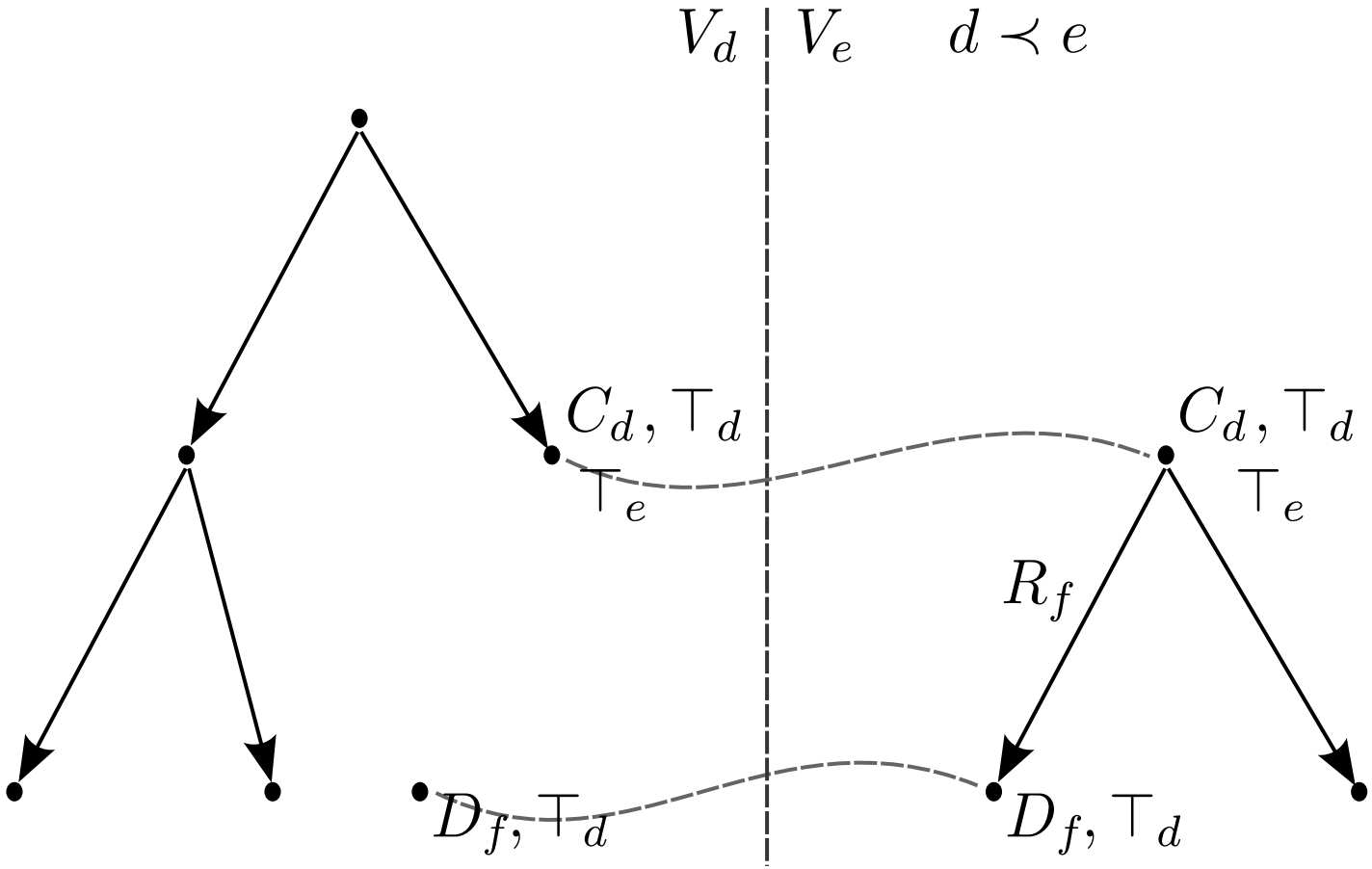

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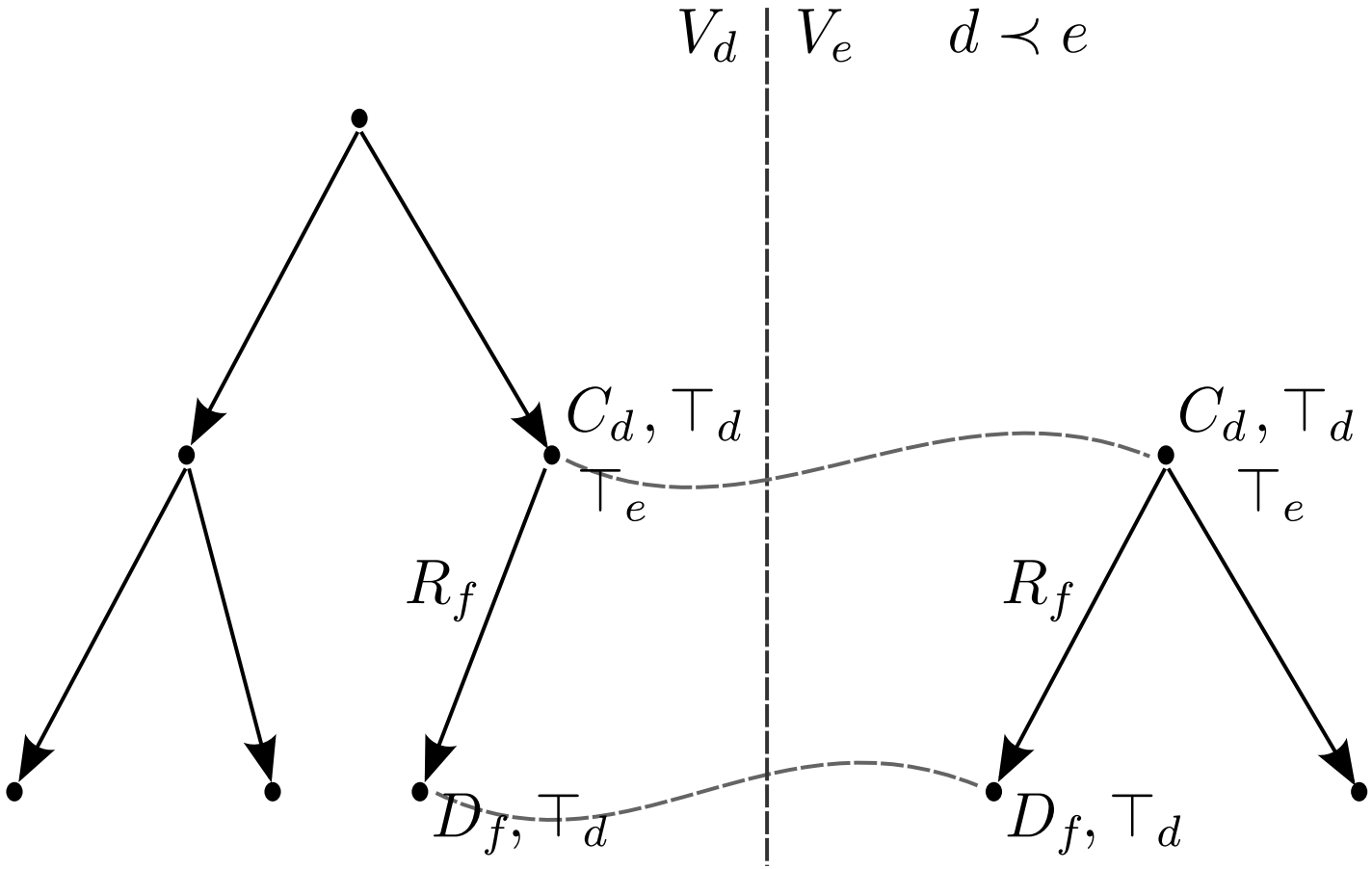

OWL 2 RL-based CKR Tableau Algorithm

- Forward chaining algorithm
- Extends OWL RL algorithm by a number of rules

$$\begin{array}{l} \mathbf{h} : (a\ \texttt{rdf:type}\ C_{\mathbf{d}}) \\ \mathbf{g} \preceq \mathbf{h} \\ \texttt{presentIn}(\mathbf{g}, a) \end{array} \quad \Longrightarrow \quad \mathbf{g} : (a\ \texttt{rdf:type}\ C_{\mathbf{d}})$$

Implementation

- Implementation for OWL 2 RL fragment
  - Implemented over Sesame RDF data store
  - Contexts implemented as named graphs
  - Propagation rules implement CKR semantics
  - Contextualized queries

Use Case

- How can one model with this thing?
- How does it perform?

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- FIFA World Cup domain
- Suitable for contextualization
- One edition $\sim$ 50 contexts

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- How can one model with this thing?
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- FIFA World Cup domain
- Suitable for contextualization
- One edition $\sim$ 50 contexts
- Compare w flat RDF model
- Evaluate query execution times
- See:
  `https://dkm.fbk.eu/images/4/4a/TR-FBK-DKM-2011-3.pdf`

Contextualized Queries

- Contextualized extension of SPARQL
- See:
  `https://dkm.fbk.eu/images/2/2a/TR-FBK-DKM-2011-2.pdf`

Summary: Reasoning & Complexity

	OWL 2 RL	$\mathcal{ALC}$	$\mathcal{SROIQ}$
Reasoning	forward	tableaux	reduction
Complexity	PTIME	EXPTIME	2NEXPTIME
Implementation	Yes	-	-
Querying	Yes	-	-

Conclusion

- Contextualization is a demanding task for SW
- CKR offers a viable solution

- Supports OWL 2 or any of its fragment
- Tableau and tractable reasoning
- Invariant complexity
- Implementation
- Contextualized queries