CKR: a general framework for context in Semantic Web

(Theory, prototype and extension to ASP)

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Outline

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Introduction and motivation

Need for context in Semantic Web

- Most of Semantic Web data holds in specific contextual space
  (time, location, topic...)
- No explicit support for modelling and reasoning with context sensitive knowledge in SW
  (Often handcrafted in implementation)

➔ Need for well-defined theory of contexts

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➔ Need for well-defined theory of contexts

Contextualized Knowledge Repository (CKR)

- DL based framework for representation and reasoning with contextual knowledge in the Semantic Web
- Contextual theory: based on formal AI theories of context
  [McCarthy, 1993, Lenat, 1998, Ghidini and Giunchiglia, 2001]

Other DL contextual frameworks:
[Bao et al., 2010, Klarman and Gutiérrez-Basulto, 2011, Straccia et al., 2010].

Contextual modelling needs

A study on typical use of context in SW lead us to the definition of a set of representation requirements:

Requirements

- Statement contextualization: associate context to facts
- Symbols locality: local meaning for symbols
- Cross-context TBox statements: knowledge relations across contexts
- Complex contextualization: more than one contextual values to facts
- Modularity: separation of knowledge in independent modules
- Unified reasoning and query: inference and query use context structure
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➔ Definition of “contextual primitives” of CKR

(e.g. cross-context statements ➔ *eval* operator,
complex contextualization ➔ c.classes and modules . . .)

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CKR introduction

The structure of a CKR is composed by 2 layers:

Global context

- Metaknowledge: structure of contexts, context classes, relations, modules and attributes
- (Global) object knowledge:
  object knowledge shared by all contexts

(Local) contexts

- Object knowledge with references:
  local object knowledge with references to value of predicates in other contexts
- Knowledge distributed across different modules

$\mathcal{SROIQ}$-RL

Restriction of $\mathcal{SROIQ}$ to the syntax of OWL-RL axioms:

- Left-side concept C:

$$C := A \mid \{a\} \mid C_1 \sqcap C_2 \mid C_1 \sqcup C_2 \mid \exists R.C_1 \mid \exists R.\{a\} \mid \exists R.\top$$

- Right-side concept D:

$$D := A \mid D_1 \sqcap D_2 \mid \neg C_1 \mid \forall R.D_1 \mid \exists R.\{a\} \mid \leqslant nR.C_1 \mid \leqslant nR.\top$$

  with $n \in \{0, 1\}$

- Both-side concept E:

$$E := A \mid E_1 \sqcap E_2 \mid \exists R.\{a\}$$

- TBox axioms: $C \sqsubseteq D, \quad E \equiv E$
- ABox axioms: $D(a), \quad R(a, b)$

Metalanguage $\mathcal{L}_\Gamma$

Metavocabulary: $\Gamma = \mathrm{NC}_\Gamma \uplus \mathrm{NR}_\Gamma \uplus \mathrm{NI}_\Gamma$

- **N** $\subseteq \mathrm{NI}_\Gamma$: context names
- **M** $\subseteq \mathrm{NI}_\Gamma$: module names
- **C** $\subseteq \mathrm{NC}_\Gamma$: context classes, including class Ctx
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- For A $\in$ **A**, a set $\mathsf{D}_\mathsf{A} \subseteq \mathrm{NI}_\Gamma$ of attribute values of A

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Metalanguage $\mathcal{L}_\Gamma$: $\mathcal{SROIQ}$-RL axioms over context expressions:

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Individual variable this: $c \in \mathbf{N} \cup \{\mathrm{this}\}$

Object language $\mathcal{L}_\Sigma$

Object vocabulary: any DL vocabulary $\Sigma = \mathrm{NC}_\Sigma \uplus \mathrm{NR}_\Sigma \uplus \mathrm{NI}_\Sigma$

Eval expression

Given X an object expression in Σ and C a context expression in Γ

$$eval(X, \mathsf{C})$$

"The interpretation of X in all the contexts of type C"

Left-side only: "imports" meaning of X from all of the contexts in C

Object language $\mathcal{L}_\Sigma$: $\mathcal{SROIQ}$-RL axioms over object expressions

Object language with references $\mathcal{L}^e_\Sigma$: extension with eval expressions

Contextualized Knowledge Repository

Contextualized Knowledge Repository:

$$\mathfrak{K} = \langle \mathfrak{G}, \{\mathrm{K}_\mathsf{m}\}_{\mathsf{m} \in \mathbf{M}} \rangle$$

- $\mathfrak{G}$ is a KB over $\Gamma \cup \Sigma$, containing metalanguage axioms in $\mathcal{L}_\Gamma$ or global object axioms in $\mathcal{L}_\Sigma$
- for every module name $\mathsf{m} \in \mathbf{M}$,
  K_m is a KB over Σ, containing object axioms with references in $\mathcal{L}^e_\Sigma$

Tourism example: introduction

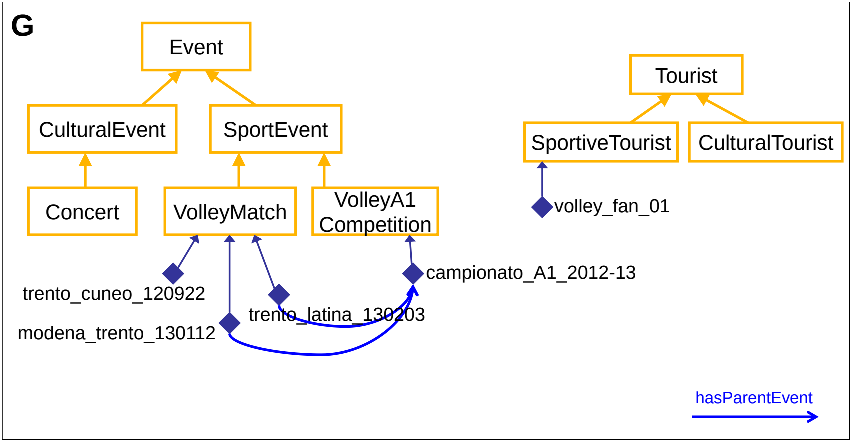
Tourism example:

- Idea: Tourism recommendation for events in Trentino
- Structure of contexts represent events and tourists information

➔ Task: find interesting events on the base of tourists' preferences

We model this domain in a CKR $\mathfrak{K}_{tour} = \langle \mathfrak{G}, \{\mathrm{K}_{\mathsf{m}}\}_{\mathsf{m} \in \mathbf{M}} \rangle$

Tourism example: CKR structure



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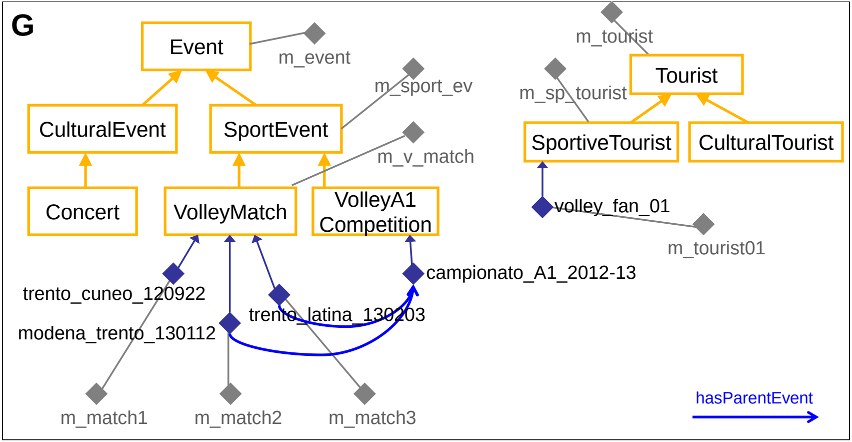

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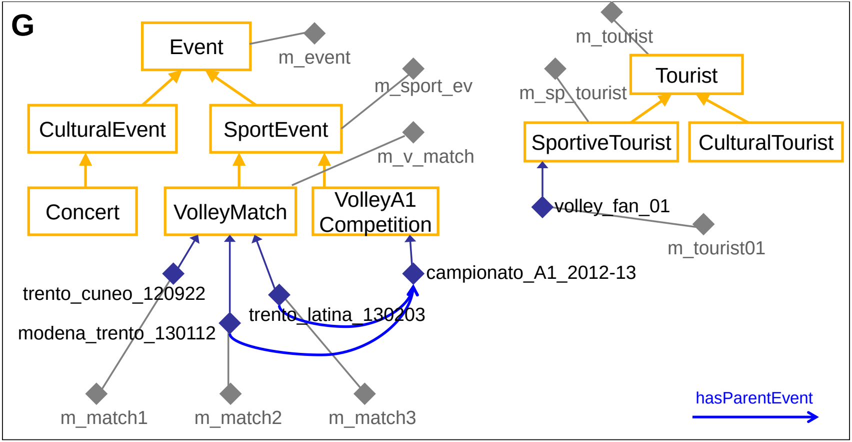

Kevent	Ksport_ev	Kv_match	Kmatch1	...	Ktourist01

Tourism example: some modules contents

In $K_{\text{v\_match}}$: $HomeTeam \sqsubseteq Team$ $HostTeam \sqsubseteq Team$
$Winner \sqsubseteq Team$ $Loser \sqsubseteq Team$

In K_{match2}: $HomeTeam(casa\_modena\_volley)$ $HostTeam(itas\_trentino\_volley)$
$Winner(casa\_modena\_volley)$ $Loser(itas\_trentino\_volley)$

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...

In $K_{\text{sport\_ev}}$: "Winners of major volley matches are top teams"

$$\mathit{eval}(\mathit{Winner}, \text{VolleyMatch} \sqcap \exists \text{hasParentEvent.VolleyA1Competition}) \sqsubseteq \mathit{TopTeam}$$

In $K_{\text{sp\_tourist}}$: "Top teams are preferred teams"

$$\mathit{eval}(\mathit{TopTeam}, \text{SportEvent}) \sqsubseteq \mathit{PreferredTeam}$$

CKR semantics

CKR Model: given $\mathfrak{K} = \langle \mathfrak{G}, \{\mathrm{K_m}\}_{\mathsf{m} \in \mathbf{M}} \rangle$, a CKR model is a structure:

$$\mathfrak{I} = \langle \mathcal{M}, \mathcal{I} \rangle$$

1. Global interpretation: $\mathcal{M} = \langle \Delta_{\mathcal{M}}, \cdot^{\mathcal{M}} \rangle$ a DL interpretation over $\Gamma \cup \Sigma$

- $\mathcal{M}$ respects interpretation of metalanguage elements (e.g. $\mathbf{N}^{\mathcal{M}} \subseteq \mathsf{Ctx}^{\mathcal{M}}$ and $\mathsf{C}^{\mathcal{M}} \subseteq \mathsf{Ctx}^{\mathcal{M}}$)
- For every $\alpha \in \mathfrak{G}$, $\mathcal{M} \models \alpha$

Given $c \in \mathsf{Ctx}^{\mathcal{M}}$, let:

$$\mathrm{K}(c) = \bigcup \{ \mathrm{K_m} \mid (c, \mathsf{m}^{\mathcal{M}}) \in \mathsf{mod}^{\mathcal{M}} \}$$

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2. Local interpretations: $\mathcal{I}(\mathsf{c}) = \langle \Delta_{\mathsf{c}}, \cdot^{\mathcal{I}(\mathsf{c})} \rangle$, for $\mathsf{c} \in \mathsf{Ctx}^{\mathcal{M}}$, is a DL interpretation over Σ

- $\mathcal{I}(\mathsf{c}), [\mathsf{this}/\mathsf{c}] \models \alpha$, for every α axiom of $\mathrm{K}(\mathsf{c})$.

3. Propagation of global knowledge:

- $\Delta_{\mathsf{c}} \subseteq \Delta_{\mathcal{M}}$;
- for every $a \in \mathrm{NI}_{\Sigma}$, $a^{\mathcal{I}(\mathsf{c})} = a^{\mathcal{M}}$.
- for $\alpha \in \mathfrak{G}$ with $\alpha \in \mathcal{L}_{\Sigma}$, $\mathcal{I}(\mathsf{c}) \models \alpha$.

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4. Interpretation of *eval* expressions: given $\mathsf{c} \in \mathsf{Ctx}^{\mathcal{M}}$ and

- X a concept or role expression
- C a context expression

$$eval(X, \mathsf{C})^{\mathcal{I}(\mathsf{c}),[\mathsf{this}/\mathsf{c}]} = \bigcup_{\mathsf{e} \in \mathsf{C}^{\mathcal{M},[\mathsf{this}/\mathsf{c}]}} X^{\mathcal{I}(\mathsf{e})}$$

"The union of elements of X in the contexts in C"

c-entailment

Definition (c-entailment)

Given $\mathfrak{K}$ over $\langle \Gamma, \Sigma \rangle$ with c $\in$ **N** and an axiom $\alpha \in \mathcal{L}^{e}_{\Sigma}$,
α is c-entailed by $\mathfrak{K}$ ($\mathfrak{K} \models \mathrm{c} : \alpha$)
if for every model $\mathfrak{I} = \langle \mathcal{M}, \mathcal{I} \rangle$ of $\mathfrak{K}$, we have $\mathcal{I}(\mathrm{c}^{\mathcal{M}}), [\mathrm{this}/\mathrm{c}^{\mathcal{M}}] \models \alpha$.

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Definition (global entailment)

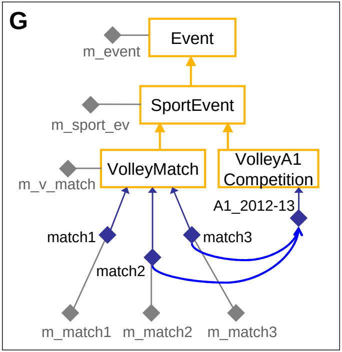
Given $\mathfrak{K}$ over $\langle \Gamma, \Sigma \rangle$ and an axiom α,
α is (globally) entailed by $\mathfrak{K}$ ($\mathfrak{K} \models \alpha$) if:

- $\alpha \in \mathcal{L}^e_\Sigma$ and for every $c \in \mathbf{N}$ and model $\mathfrak{I} = \langle \mathcal{M}, \mathcal{I} \rangle$ of $\mathfrak{K}$, $\mathcal{I}(c^\mathcal{M}), [\text{this}/c^\mathcal{M}] \models \alpha$.
- $\alpha \in \mathcal{L}_\Gamma$ and for every model $\mathfrak{I} = \langle \mathcal{M}, \mathcal{I} \rangle$ of $\mathfrak{K}$, $\mathcal{M} \models \alpha$.

Tourism example: semantics

Suppose we have $\mathfrak{I} = \langle \mathcal{M}, \mathcal{I} \rangle$ s.t. $\mathfrak{I} \models \mathfrak{K}_{tour}$.

For each match matchN, its KB is:
$K(\text{matchN}^{\mathcal{M}}) = K_{\text{event}} \cup K_{\text{sport\_ev}} \cup K_{\text{v\_match}} \cup K_{\text{matchN}}$



K_{match1}	Winner(bre_banca_cuneo_volley) ...
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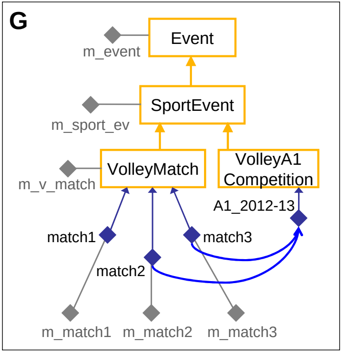
$\mathrm{VolleyMatch} \sqcap \exists \mathrm{hasParentEvent.VolleyA1Competition} = \mathrm{TopMatch}$

$eval(Winner, \mathrm{TopMatch}) \sqsubseteq TopTeam \in \mathrm{K}_{\mathrm{sport\_ev}}$



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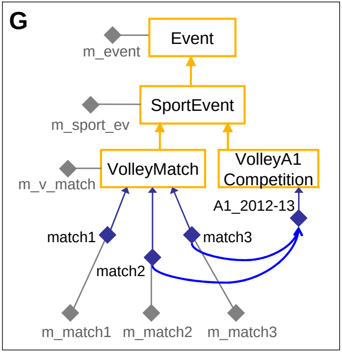

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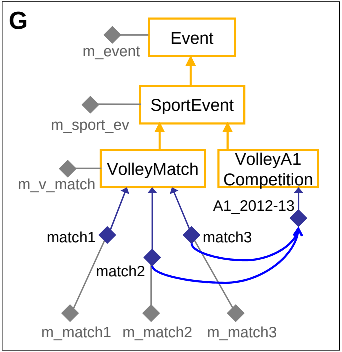

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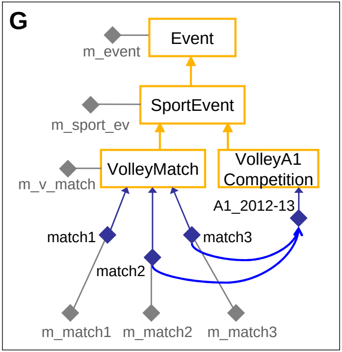

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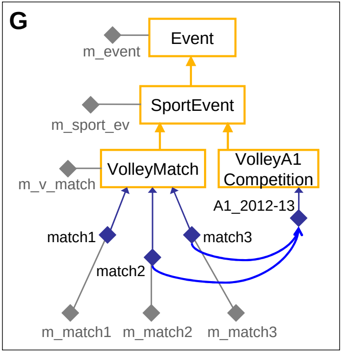

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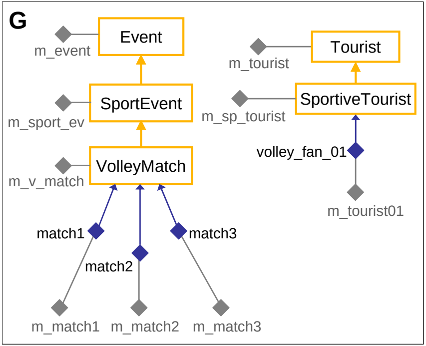

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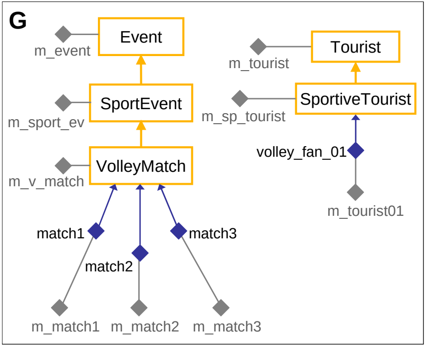

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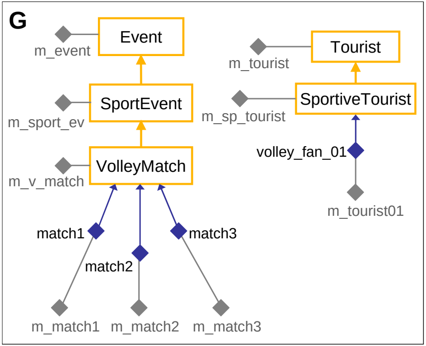

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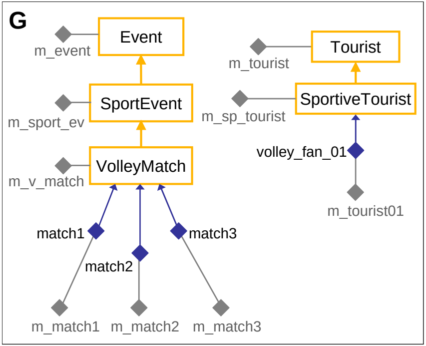


$\mathbf{K}_{\mathbf{match1}}$	Winner(bre_banca_cuneo_volley) ...
$\mathbf{K}_{\mathbf{match2}}$	Winner(casa_modena_volley) ...
$\mathbf{K}_{\mathbf{match3}}$	Winner(itas_trentino_volley) ...

...

Tourism example: semantics

Suppose we have $\mathfrak{I} = \langle \mathcal{M}, \mathcal{I} \rangle$ s.t. $\mathfrak{I} \models \mathfrak{K}_{tour}$.

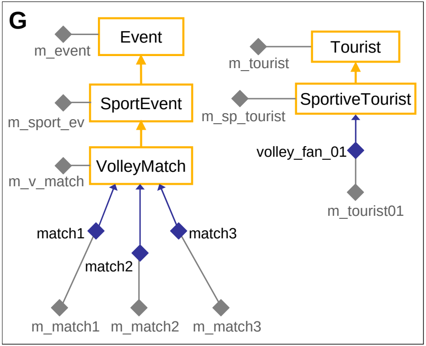
For the context of volley_fan:

$\mathrm{K}(\text{volley\_fan}^{\mathcal{M}}) = \mathrm{K}_{\text{tourist}} \cup \mathrm{K}_{\text{sp\_tourist}} \cup \mathrm{K}_{\text{tourist01}}$

$eval(TopTeam, \text{SportEvent}) \sqsubseteq PreferredTeam \in \mathrm{K}_{\text{sp\_tourist}}$

$$\bigcup_{e \in \{\text{match\_1}, \text{match\_2}, \text{match\_3}\}} TopTeam^{\mathcal{I}(e)}$$

$$\subseteq PreferredTeam^{\mathcal{I}(\text{volley\_fan})}$$



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$$\{itas\_trentino, casa\_modena\}$$

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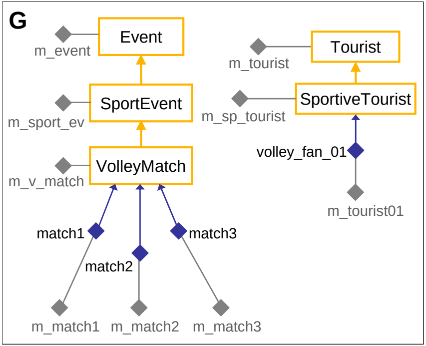

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Outline

Materialization calculus K_{ic}

Materialization calculus K_{ic}:

- Calculus for instance checking in $\mathcal{SROIQ}$-RL CKR
- Extension to the CKR structure of materialization calculus for $\mathcal{SROEL}$ of [Krötzsch, 2010]
- Formalizes the operation of forward closure in implementation

Idea

Composed by 3 sets of rules:

- Input rules I: translation of DL axioms to Datalog atoms
- Deduction rules P: forward inference rules
- Output rules O: translation for DL proved axiom

Normal form

Current version of K_{ic} works on:

- restriction of $\mathcal{SROIQ}$-RL to $\mathcal{SROEL}$ constructs
- closed CKRs (no this)

Normal form for axioms

$$\mathcal{L}_\Gamma, \mathcal{L}_\Sigma : \quad A(a) \quad R(a,b) \quad A \sqsubseteq B \quad \{a\} \sqsubseteq B$$

$$A \sqcap B \sqsubseteq C \quad \exists R.A \sqsubseteq B \quad R \sqsubseteq T \quad R \circ S \sqsubseteq T$$

$$\mathcal{L}_\Gamma : \quad \mathsf{C} \sqsubseteq \exists \mathsf{mod}.\{\mathsf{m}\} \quad \mathsf{C} \sqsubseteq \exists \mathsf{A}.\{\mathsf{d_A}\}$$

$$\{\mathsf{a}\} \sqsubseteq \exists \mathsf{mod}.\{\mathsf{m}\} \quad \{\mathsf{a}\} \sqsubseteq \exists \mathsf{A}.\{\mathsf{d_A}\}$$

$$\mathcal{L}^e_\Sigma : \quad eval(A, \mathsf{C}) \sqsubseteq B \quad eval(R, \mathsf{C}) \sqsubseteq T$$

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$\mathcal{L}_\Gamma$: $\mathsf{C} \sqsubseteq \exists \mathsf{mod}.\{\mathsf{m}\}$ $\mathsf{C} \sqsubseteq \exists \mathsf{A}.\{\mathsf{d_A}\}$

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$\mathcal{L}^e_\Sigma$: $eval(A, \mathsf{C}) \sqsubseteq B$ $eval(R, \mathsf{C}) \sqsubseteq T$

Normal form property

For every closed $\mathfrak{K}$, a $\mathfrak{K}'$ can be computed such that $\mathfrak{K}'$ is in normal form and, for all α using symbols from $\mathfrak{K}$, it holds $\mathfrak{K} \models \alpha$ iff $\mathfrak{K}' \models \alpha$.

Calculus definition

Basic definitions

Given the set of constants $\mathbf{C}$, variables $\mathbf{V}$ and predicates $\mathbf{P}$

Term:	$t \in \mathbf{C} \cup \mathbf{V}$	
Ground substitution:	$\sigma : \mathbf{V} \to \mathbf{C}$	
Datalog atom:	$p(t_1, \ldots, t_n)$	$p \in \mathbf{P}$, t_i terms
Datalog rule:	$B_1, \ldots, B_m \to H$	B_i, H atoms
Fact:	$\to H$	H ground atom
Program:	P	P finite set of rules

Calculus definition

Proof tree

A proof tree for P is a structure $\langle N, E, \lambda \rangle$:

- $\langle N, E \rangle$ is a finite directed tree
- λ is a labelling function
- for each node $v \in N$,
  there exists a rule $B_1, \ldots, B_m \rightarrow H \in P$
  and a ground substitution σ s.t.
  - $\lambda(v) = \sigma(H)$;
  - $\lambda(w_i) = \sigma(B_i)$, with w_i child of v.

Consequence: $P \models H$ if there is a proof tree with root r and $\lambda(r) = H$

Closure: $Clos(P) = \{H \mid H \text{ ground and } P \models H\}$

Calculus definition

Materialization calculus K_{ic} is composed by:

- input translations: $I_{glob}, I_{loc}, I_{el}$,
- deduction rules: $P_{glob}, P_{loc}, P_{el}$,
- output translation: O

- I and O are partial functions
- P are sets of datalog rules
- given α axiom or symbol, c $\in$ **N**, $I(\alpha, \mathrm{c})$ is undefined or a set of datalog facts
- given α axiom, c $\in$ **N**, $O(\alpha, \mathrm{c})$ is undefined or a single datalog fact
- all constant symbols in $I(\alpha, \mathrm{c})$ or $O(\alpha, \mathrm{c})$ are signature symbols appearing in or equal to α

Translation and deduction rules

EL translation rules $I_{el}(S, c)$

$$C(a) \mapsto \{\texttt{inst}(a, C, c)\} \qquad R(a, b) \mapsto \{\texttt{triple}(a, R, b, c)\}$$
$$\{a\} \sqsubseteq C \mapsto \{\texttt{inst}(a, C, c)\} \qquad A \sqsubseteq C \mapsto \{\texttt{subClass}(A, C, c)\}$$
$$A \sqcap B \sqsubseteq C \mapsto \{\texttt{subConj}(A, B, C, c)\} \qquad \exists R.A \sqsubseteq C \mapsto \{\texttt{subEx}(R, A, C, c)\}$$
$$R \sqsubseteq T \mapsto \{\texttt{subRole}(R, T, c)\} \qquad R \circ S \sqsubseteq T \mapsto \{\texttt{subRChain}(R, S, T, c)\}$$

EL deduction rules P_{el}

$$\texttt{subClass}(y, z, c), \texttt{inst}(x, y, c) \rightarrow \texttt{inst}(x, z, c)$$
$$\texttt{subConj}(y_1, y_2, z, c), \texttt{inst}(x, y_1, c), \texttt{inst}(x, y_2, c) \rightarrow \texttt{inst}(x, z, c)$$
$$\texttt{subEx}(v, y, z, c), \texttt{triple}(x, v, x', c), \texttt{inst}(x', y, c) \rightarrow \texttt{inst}(x, z, c)$$
$$\texttt{subRole}(v, w, c), \texttt{triple}(x, v, x', c) \rightarrow \texttt{triple}(x, w, x', c)$$
$$\texttt{subRChain}(u, v, w, c), \texttt{triple}(x, u, y, c), \texttt{triple}(y, v, z, c) \rightarrow \texttt{triple}(x, w, z, c)$$

Output translation $O(\alpha, \mathsf{c})$

$$C(a) \mapsto \{\texttt{inst}(a, C, \mathsf{c})\} \qquad R(a, b) \mapsto \{\texttt{triple}(a, R, b, \mathsf{c})\}$$

Translation and deduction rules

Global rules $I_{glob}(\mathfrak{G})$ and P_{glob}

$$\mathsf{C} \sqsubseteq \exists \mathsf{mod}.\{\mathsf{m}\} \mapsto \{\mathtt{hasMod}(\mathsf{C},\mathsf{m},\mathsf{gm})\} \qquad \mathsf{C} \in \mathbf{C} \mapsto \{\mathtt{subClass}(\mathsf{C},\mathsf{Ctx},\mathsf{gm})\}$$

$$\mathsf{C} \sqsubseteq \exists \mathsf{A}.\{\mathsf{d}\} \mapsto \{\mathtt{hasAtt}(\mathsf{C},\mathsf{A},\mathsf{d},\mathsf{gm})\} \qquad \mathsf{c} \in \mathbf{N} \mapsto \{\mathtt{inst}(\mathsf{c},\mathsf{Ctx},\mathsf{gm})\}$$

$$\{\mathsf{c}\} \sqsubseteq \exists \mathsf{mod}.\{\mathsf{m}\} \mapsto \{\mathtt{triple}(\mathsf{c},\mathsf{mod},\mathsf{m},\mathsf{gm})\}$$

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$$\mathtt{hasMod}(c,m,\mathsf{gm}),\mathtt{inst}(x,c,\mathsf{gm}) \rightarrow \mathtt{triple}(x,\mathsf{mod},m,\mathsf{gm})$$

$$\mathtt{hasAtt}(c,a,d,\mathsf{gm}),\mathtt{inst}(x,c,\mathsf{gm}) \rightarrow \mathtt{triple}(x,a,d,\mathsf{gm})$$

Local rules $I_{loc}(S,\mathsf{c})$ and P_{loc}

$$\mathit{eval}(A,\mathsf{C}) \sqsubseteq B \mapsto \{\mathtt{subEval}(A,\mathsf{C},B,\mathsf{c})\}$$

$$\mathit{eval}(R,\mathsf{C}) \sqsubseteq T \mapsto \{\mathtt{subEvalR}(R,\mathsf{C},T,\mathsf{c})\}$$

$$\mathtt{subEval}(a,c_1,b,c),\mathtt{inst}(c',c_1,\mathsf{gm}),\mathtt{inst}(x,a,c') \rightarrow \mathtt{inst}(x,b,c)$$

$$\mathtt{subEvalR}(r,c_1,t,c),\mathtt{inst}(c',c_1,\mathsf{gm}),\mathtt{triple}(x,r,y,c') \rightarrow \mathtt{triple}(x,t,y,c)$$

Deduction algorithm

Global program PG: $PG(\mathfrak{G}) = I_{glob}(\mathfrak{G}) \cup P_{glob}$

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$$\mathbf{N}_{\mathfrak{G}} = \{\mathsf{c} \in \mathbf{C} \mid \mathtt{inst}(\mathsf{c}, \mathsf{Ctx}, \mathsf{gm}) \in Clos(PG(\mathfrak{G}))\}$$
$$\mathrm{K}_{\mathsf{c}} = \bigcup\{\mathrm{K}_{\mathsf{m}} \mid \mathtt{triple}(\mathsf{c}, \mathsf{mod}, \mathsf{m}, \mathsf{gm}) \in Clos(PG(\mathfrak{G}))\}$$

Local program PC: $PC(\mathsf{c}) = P_{loc} \cup I_{loc}(\mathrm{K}_{\mathsf{c}}, \mathsf{c}) \cup I_{el}(\mathfrak{G}_{\Sigma}, \mathsf{c})$

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CKR program PK: $PK(\mathfrak{K}) = PG(\mathfrak{G}) \cup \bigcup_{\mathsf{c} \in \mathbf{N}_{\mathfrak{G}}} PC(\mathsf{c})$

Given $\alpha \in \mathcal{L}^{e}_{\Sigma}$ and a context $\mathsf{c} \in \mathbf{N}$,
$\mathfrak{K} \vdash \mathsf{c} : \alpha$ when $PK(\mathfrak{K})$ and $O(\alpha, \mathsf{c})$ defined and $PK(\mathfrak{K}) \models O(\alpha, \mathsf{c})$

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$\mathfrak{K} \vdash \mathsf{c} : \alpha$ when $PK(\mathfrak{K})$ and $O(\alpha, \mathsf{c})$ defined and $PK(\mathfrak{K}) \models O(\alpha, \mathsf{c})$

Basic algorithm

- Compute closure of $\mathfrak{G}$
- For every $\mathsf{c} \in \mathbf{N}_{\mathfrak{G}}$, compute its associated K_{c}
- Compute closure of the set of K_{c}

Soundness and completeness

Theorem (Soundness)

Given $\mathfrak{K} = \langle \mathfrak{G}, \{\mathrm{K_m}\}_{\mathrm{m} \in \mathbf{M}} \rangle$ *a closed CKR in normal form, and an atomic assertion* $\alpha \in \mathcal{L}_\Sigma$, $\mathrm{c} \in \mathbf{N}$, $\mathfrak{K} \vdash \mathrm{c} : \alpha$ *implies* $\mathfrak{K} \models \mathrm{c} : \alpha$.

Theorem (Completeness)

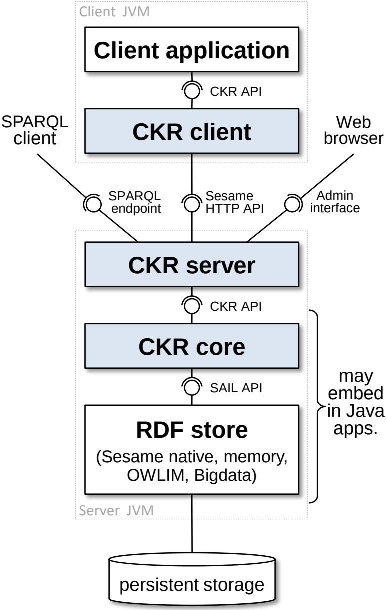
Given $\mathfrak{K} = \langle \mathfrak{G}, \{\mathrm{K_m}\}_{\mathrm{m} \in \mathbf{M}} \rangle$ *a closed CKR in normal form, and an atomic assertion* $\alpha \in \mathcal{L}_\Sigma$, $\mathrm{c} \in \mathbf{N}$, $\mathfrak{K} \models \mathrm{c} : \alpha$ *implies* $\mathfrak{K} \vdash \mathrm{c} : \alpha$.

Outline

CKR Prototype: introduction

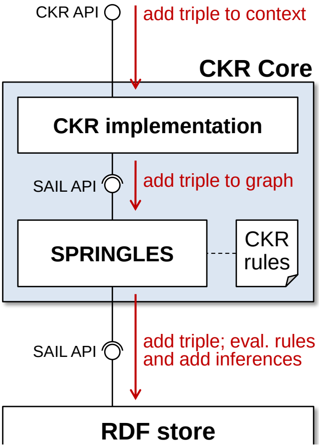
The prototype extends the Sesame Java framework with three modules:

- CKR core – CKR implementation on top of a Sesame RDF store
  - knowledge addition/removal
  - closure materialization
  - SPARQL 1.1 queries
  - transactions
- CKR server – extension of Sesame Server & Workbench
  - exposes CKR primitives
  - includes a SPARQL endpoint
  - includes an admin UI
- CKR client – library to access a CKR from a remote Java application



SPRINGLES

CKR Core is implemented on top of SPRINGLES: SParql-based Rule Inference over Named Graphs Layer Extending Sesame



SPRINGLES features:

- transparent/on-demand closure materialization based on rules
- rules encoded as SPARQL queries addressing Named Graphs (NG)
- customizable rule evaluation strategy

Why SPRINGLES:

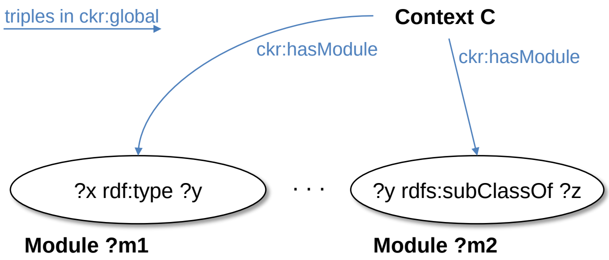
- no inference over NGs in RDF stores

Why SPARQL:

- exploits optimized query engines
- can scale to large KBs (cf. RETE)

CKR calculus in SPRINGLES: rule example

```
:pel-c-subc a spr:Rule ;
  spr:head """ GRAPH ?mx { ?x rdf:type ?z } """ ;
  spr:body """ GRAPH ?m1 { ?y rdfs:subClassOf ?z }
               GRAPH ?m2 { ?x rdf:type ?y }
               GRAPH sys:dep { ?mx sys:derivedFrom ?m1,?m2 }
               FILTER NOT EXISTS {
                 GRAPH ?m0 { ?x rdf:type ?z }
                 GRAPH sys:dep { ?mx sys:derivedFrom ?m0 }
               } """ .
```



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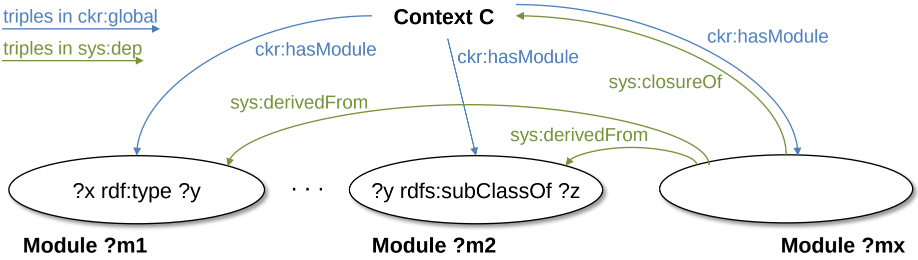

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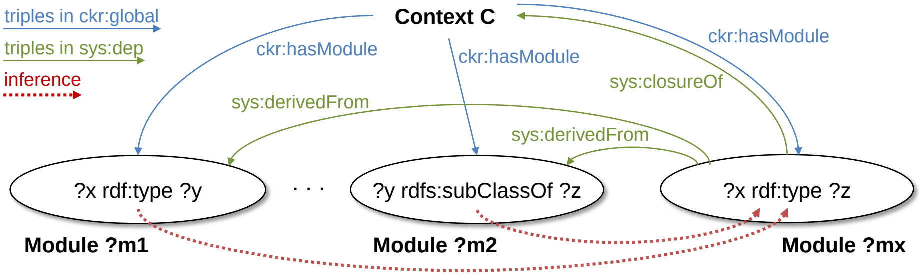


CKR calculus in SPRINGLES: evaluation strategy

Composition of SPRINGLES primitives: parallel rule evaluation, sequence, fixpoint, repeat (not used by CKR)

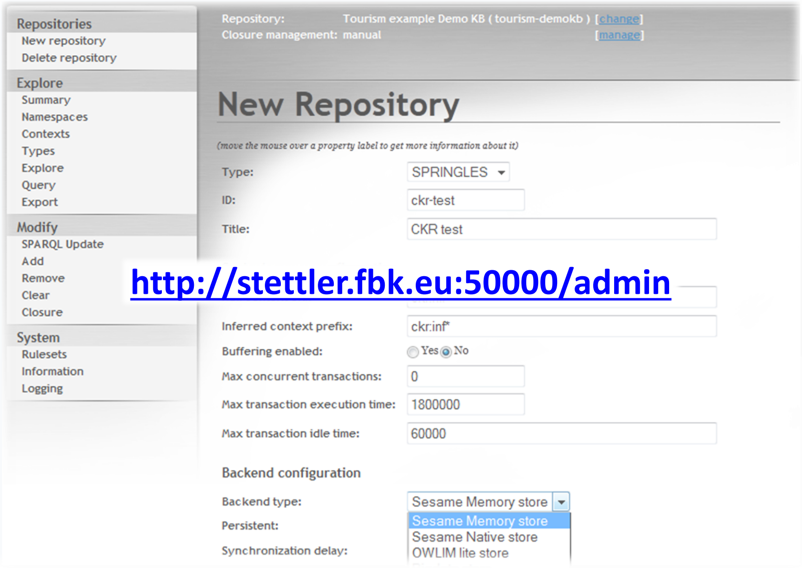
```
:closure-strategy
  spr:sequenceOf ( :task_add_axioms :task_global_closure
                   :task_link_modules :task_ctx_closure ) .
:task_add_axioms
  spr:evalOf (
    :dep-glob :prp-ap :cls-thing :cls-nothing :dt-type ) .

:task_global_closure
  spr:bind "?g_inf = ckr:global-inf" ;
  spr:fixPointOf [ spr:evalOf (
    :pel-c-subc ... :pel-r-subrc :pgl-c-addmod
    :pgl-i-addmod :pgl-c-submodc :pgl-c-subattc ) ] .

:task_link_modules
  spr:evalOf ( :dep-local-i :dep-local-c ) .

:task_ctx_closure
  spr:fixPointOf [ spr:evalOf (
    :pel-c-subc ... :pel-r-subrc
    :plc-c-subevalat :plc-c-subexeval ) ] .
```

Tourism example: inference and query demo



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Outline

Current directions and future works

Directions for formalization and calculus:

- Extension of calculus to full $\mathcal{SROIQ}$-RL
  (add equality assertions and introduction of inconsistency)
- Local evaluation of metaknowledge and this
- Features of context relations e.g. $\mathit{Mono}(\mathsf{R})$
  (represent coverage, previous/successor states in time etc.)
- Extended algorithm:
  Compute closure for modules associated to context classes,
  without replications in contexts

Directions for CKR implementation:

- CKR layer: accessing by contextual primitives
- Definition of SPARQL extension with context primitives
- Evaluation: definition of test knowledge base
- Extensions to SPRINGLES:
  plan language, combination of backward/forward reasoning

Thank you for listening

CKR: a general framework for context in Semantic Web
(Theory, prototype and extension to ASP)

Loris Bozzato, Francesco Corcoglioniti, Luciano Serafini

https://dkm.fbk.eu/

DKM - Data and Knowledge Management Research Unit,
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