Aggregate Queries over Ontologies

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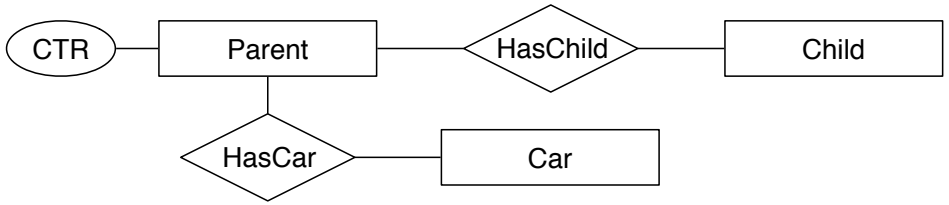

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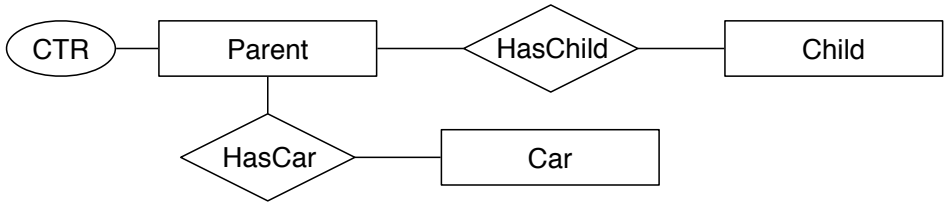

`Family` models (partly) how families receive in Italy subsidies for their children, whose data can come from arbitrary sources

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Less is known, however, about DL or OWL ontologies

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DEF. By deleting aggregation functions and disregarding nestings we can transform an CAQ into its **core**

$$\tilde{q}(\vec{x}, \vec{y}) \leftarrow \phi, \psi.$$

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$$\begin{aligned} Sat_{\mathcal{D}}(\phi, \psi) &:= \{\gamma \mid \gamma \text{ satisfies } \phi \text{ and } \psi \text{ w.r.t. } \mathcal{D}\} \\ Sat_{\mathcal{D}}^{\vec{w}^{\phi}}(\phi, \psi) &:= \{\gamma \restriction \vec{w}^{\phi} \mid \gamma \in Sat_{\mathcal{D}}(\phi, \psi)\} \end{aligned}$$

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DEF. The set of **answers** of q is defined as

$$q^{\mathcal{D}} := \{\langle \vec{d}, \alpha(G_{\vec{d}}) \rangle \mid \vec{d} = \gamma(\vec{x}) \text{ for some } \gamma \in Sat_{\mathcal{D}}^{\vec{w}^{\phi}}(\phi)\}$$

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Anna	VwGolf
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Parent

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Then: *(i)* $G_{\vec{\epsilon}} = \{\!|\langle \texttt{Anna} \rangle|\!\}$, *(ii)* $q_b^{\mathcal{D}_{\text{fam}}} = \{\langle 1 \rangle\}$ and *(iii)* $\tilde{q}_b^{\mathcal{D}_{\text{fam}}} = \{\langle \texttt{Anna} \rangle\}$

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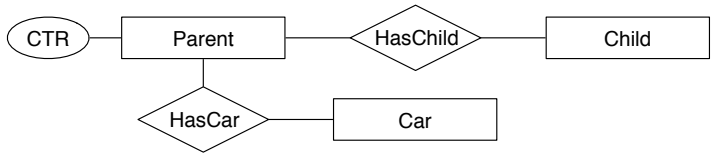

$$\begin{array}{ll} Parent \sqsubseteq \exists CTR & \exists CTR \sqsubseteq Parent \\ & \exists hasChild \sqsubseteq Parent \\ Parent \sqsubseteq \exists hasCar & \exists hasCar \sqsubseteq Parent \\ \exists hasCar^- \sqsubseteq Car & \exists hasChild^- \sqsubseteq Child \end{array}$$

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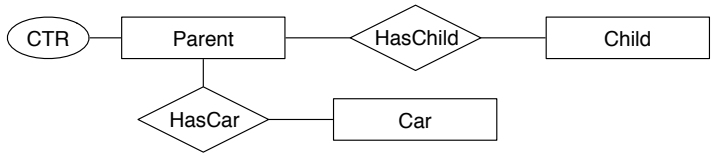

$$\begin{array}{ll} \mathit{Parent} \sqsubseteq \exists \mathit{CTR} & \exists \mathit{CTR} \sqsubseteq \mathit{Parent} \\ & \exists \mathit{hasChild} \sqsubseteq \mathit{Parent} \\ \mathit{Parent} \sqsubseteq \exists \mathit{hasCar} & \exists \mathit{hasCar} \sqsubseteq \mathit{Parent} \\ \exists \mathit{hasCar}^- \sqsubseteq \mathit{Car} & \exists \mathit{hasChild}^- \sqsubseteq \mathit{Child} \end{array}$$

Whereas $\mathcal{D}_{\text{fam}}$ now stores data consistent with the $\mathcal{T}_{\text{fam}}$ ontology:

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PName
Anna

CTR

PName	Amount
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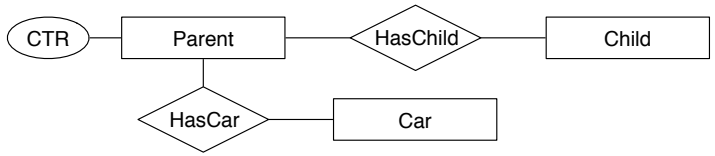

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By combining them we get an OBDAS $\langle \mathcal{T}_{\text{fam}}, \mathcal{D}_{\text{fam}} \rangle$ over the family domain

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$$\tilde{q}_b(x) \leftarrow Parent(x), hasCar(x, y).$$

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This does not carry on to AQs

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(ii) $\mathcal{D}''$ is obtained from $\mathcal{D}_{\mathsf{fam}}$ by putting

$$\mathit{hasCar}^{\mathcal{D}''} := \mathit{hasCar}^{\mathcal{D}_{\mathsf{fam}}} \cup \{\langle \mathtt{Luisa}, \mathtt{Smart} \rangle\}$$

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In different DBs, multiplicities can differ: consider the following two DBs $\mathcal{D}'$ and $\mathcal{D}''$ satisfying $\langle \mathcal{T}_{\mathsf{fam}}, \mathcal{D}_{\mathsf{fam}} \rangle$ where

(i) $\mathcal{D}' := \mathcal{D}_{\mathsf{fam}}$ and

(ii) $\mathcal{D}''$ is obtained from $\mathcal{D}_{\mathsf{fam}}$ by putting

$$\mathit{hasCar}^{\mathcal{D}''} := \mathit{hasCar}^{\mathcal{D}_{\mathsf{fam}}} \cup \{\langle \mathtt{Luisa}, \mathtt{Smart} \rangle\}$$

Then, ${q'_b}^{\mathcal{D}''} = \{\langle 2 \rangle\}$, $q_b^{\mathcal{D}'} = \{\langle 1 \rangle\}$ and

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THEO. The certain answers of CAQs over OBDASs are, in general, empty

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Therefore:

$$\mathit{cert}(q_b, \mathcal{T}_{\mathsf{fam}}, \mathcal{D}_{\mathsf{fam}}) = \emptyset$$

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EAQs extend the syntax and semantics of AQs

Epistemic Aggregate Queries (EAQs)

Consider an ODBAS $\mathcal{K} := \langle \mathcal{O}, \mathcal{D} \rangle$, $\mathcal{D}'$ a DB s.t. $\mathcal{D}' \models \mathcal{K}$ and an EAQ $q(\vec{x}, \alpha(\vec{y})) \leftarrow \mathbf{K}\vec{x}, \vec{y}, \vec{z}.\phi, [\psi]$ with auxiliary query $q_{aux}(\vec{x}, \vec{y}, \vec{z}) \leftarrow \phi, \psi$

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DEF. The **K satisfying assignments** and the **K restricted satisfying assignments** are defined as

$$\begin{aligned} KSat_{\mathcal{D}',\mathcal{K}}(\vec{w}; \phi, \psi) &:= \{\gamma \in Sat_{\mathcal{D}'}(\phi, \psi) \mid \gamma(\vec{w}) \in cert(q_{aux}, \mathcal{K})\} \\ KSat^{\vec{x} \cup \vec{y} \cup \vec{z}^{\phi}}_{\mathcal{D}',\mathcal{K}}(\vec{w}; \phi, \psi) &:= \{\gamma \upharpoonright \vec{x} \cup \vec{y} \cup \vec{z}^{\phi} \mid \gamma \in KSat_{\mathcal{D}',\mathcal{K}}(\vec{w}; \phi, \psi)\} \end{aligned}$$

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$$H_{\vec{d}} := \{\!|\gamma(\vec{y}) \mid \gamma(\vec{x}) = \vec{d} \text{ and } \gamma \in KSat^{\vec{x}\cup\vec{y}\cup\vec{z}^{\phi}}_{\mathcal{D}',\mathcal{K}}(\vec{w}; \phi, \psi)|\!\}$$

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Epistemic Aggregate Queries (EAQs)

EXAMPLE. Consider the EAQ q_b^k for **(b)**

$$q_b^k(\mathbf{countd}(x)) \leftarrow \mathbf{K}x, y.Parent(x), hasCar(x, y)$$

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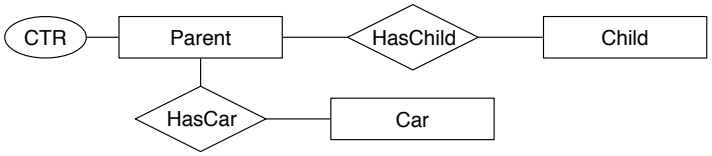
EXAMPLE. Consider the EAQ q_b^k for **(b)**

$$q_b^k(\textbf{countd}(x)) \leftarrow \mathbf{K}x, y.Parent(x), hasCar(x, y)$$

That asks how many parents are known to own a car by the OBDAS $\langle \mathcal{T}_{fam}, \mathcal{D}_{fam} \rangle$:



Parent

PName
Anna

CTR

PName	Amount
Luisa	100
Anna	150

hasCar

PName	CType
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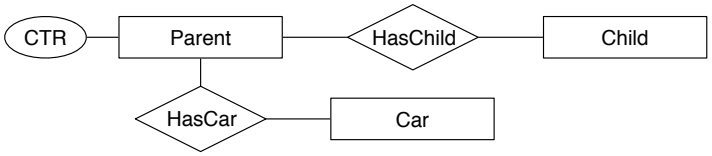

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Since we now restrict ourselves to information explicitly stated in the ODBAS, we get

$$H_{\vec{\epsilon}} = \{\!|\langle \texttt{Anna} \rangle, \langle \texttt{Anna} \rangle|\!\}$$

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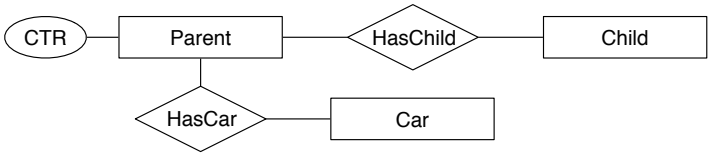

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Therefore, $\textbf{countd}(\{\!|\texttt{Anna}, \texttt{Anna}|\!\}) = 1$ and the epistemic certain answers are

$$ECert(q_b^k, \mathcal{T}_{fam}, \mathcal{D}_{fam}) = \{\langle 1 \rangle\}$$

The Generic Algorithm GA

Input:	EAQ	$q(\vec{x}, \alpha(\vec{y})) \leftarrow \mathbf{K}\vec{x}, \vec{y}, \vec{z}.\ \phi, [\psi]$
	DL-Lite ODBAS	$\mathcal{K}$
Output:	set of tuples	O

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Do: build q_{aux}: $q_{aux}(\vec{x}, \vec{y}, \vec{z}) \leftarrow \phi, \psi$

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build q_1: $q_1(\vec{x}, \alpha(y)) \leftarrow v_0(\vec{x}, \vec{y}, \vec{z}^{\phi})$

compute certain answers: $D_1 := cert(aux_q, \langle \mathcal{D}, \mathcal{T} \rangle)$

project on **K**-variables: $D_2 := v_0^{D_1}$

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GA is sound and complete w.r.t. $Ecert(q, \mathcal{K})$ under certain conditions

Properties

Let $\mathcal{K} := \langle \mathcal{T}, \mathcal{D} \rangle$ be an ODBA, let $q(\vec{x}, \alpha(\vec{y})) \leftarrow \mathbf{K}\vec{x}, \vec{y}, \vec{z}.\ \phi, [\psi]$ be an EAQ and $x, y \in \mathit{Var}(\phi, \psi)$

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DEF. The relation of **functional dependence** is the reflexive and transitive closure of variable dependence

Properties

Let $\mathcal{K} := \langle \mathcal{T}, \mathcal{D} \rangle$ be an ODBA, let $q(\vec{x}, \alpha(\vec{y})) \leftarrow \mathbf{K}\vec{x}, \vec{y}, \vec{z}.\ \phi, [\psi]$ be an EAQ and $x, y \in \mathit{Var}(\phi, \psi)$

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Restrictedness ensures non-triviality, soundness and completeness

Properties

EXAMPLE. Consider EAQ q_c^k for question **(c)**

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$Parent \sqsubseteq \exists CTR$ $\quad \exists CTR \sqsubseteq Parent$

$\exists hasChild \sqsubseteq Parent$

$Parent \sqsubseteq \exists hasCar$ $\quad \exists hasCar \sqsubseteq Parent$

$\exists hasCar^- \sqsubseteq Car$ $\quad \exists hasChild^- \sqsubseteq Child$

Parent
PName
Anna

CTR	
PName	Amount
Luisa	100
Anna	150

hasCar	
PName	CType
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(i) If we add to $\mathcal{T}_{fam}$ the assertions (funct *hasChild*) and $Parent \sqsubseteq \exists hasChild$, restricting z, then

$$Ecert(q_c^k, \mathcal{T}_{fam}, \mathcal{D}_{fam}) = \{\langle \mathtt{Luisa}, 100\rangle\langle \mathtt{Anne}, 150\rangle\}$$

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Restrictedness guarantees non-emptyness with "intensional" aggregates

Properties

THEO. (**count**)

THEO. (**countd**,**min**,**max**)

Properties

THEO. (**sum**)

THEO. (**avg**)

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We would also like to study the problems of containment and equivalence of EAQs (i.e. optimization)