[Full paper available at http://korrekt.org/page/ELP]

ELP
Tractable Rules for OWL 2

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Where do we want to get to?

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Semantic Web language that is ...

- focussed on data,
- rule-oriented,
- able to express schema knowledge,
- easy to implement,
- of polynomial worst-case complexity,
- compatible with OWL.

OWL and Description Logics

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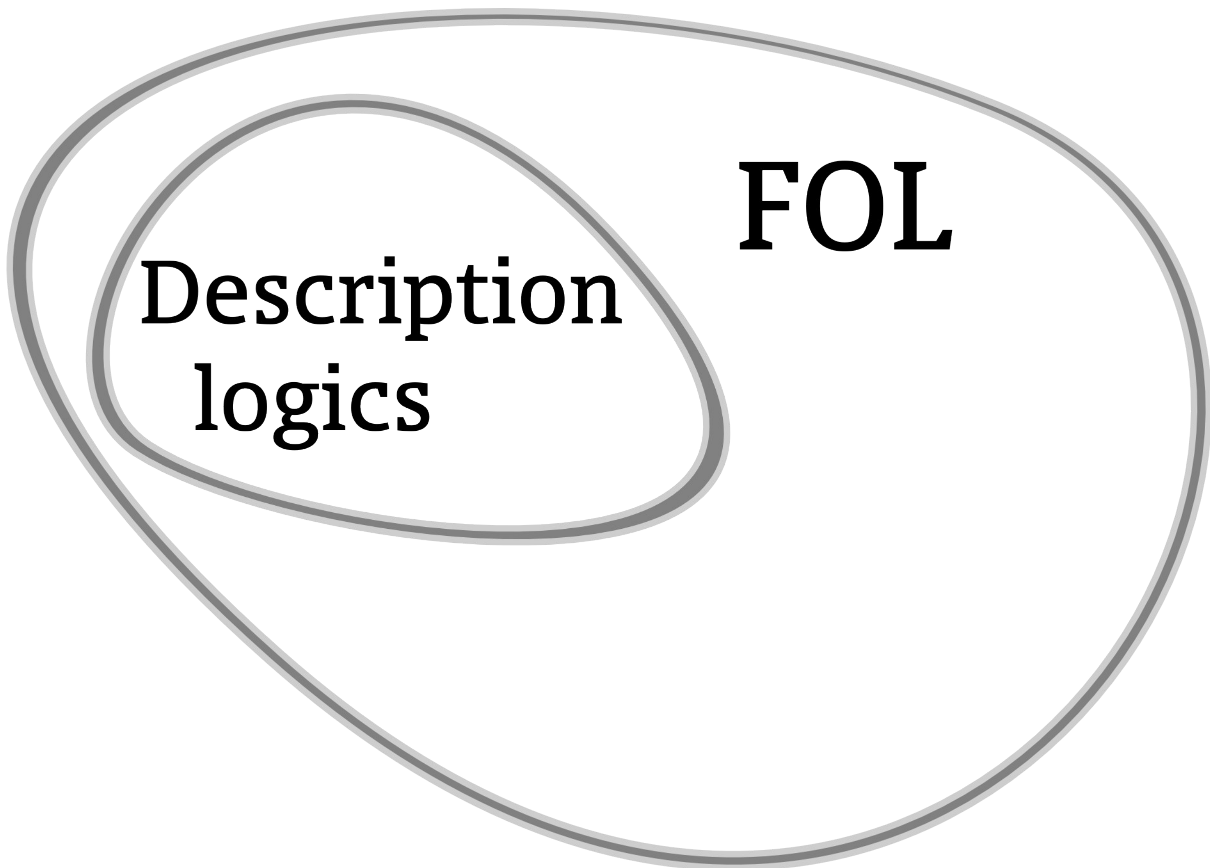


OWL and Description Logics

"Sebastian ordered some Thai curry."

$sebastian : \exists orderedDish.ThaiCurry$

$\exists x.\ orderedDish(sebastian, x) \wedge \mathrm{ThaiCurry}(x)$

OWL and Description Logics

"Everything ordered as a dish is actually a dish."

$$\top \sqsubseteq \forall orderedDish.Dish$$

$$\forall x.\forall y.\ orderedDish(x,y) \rightarrow \mathrm{Dish}(y)$$

OWL and Description Logics

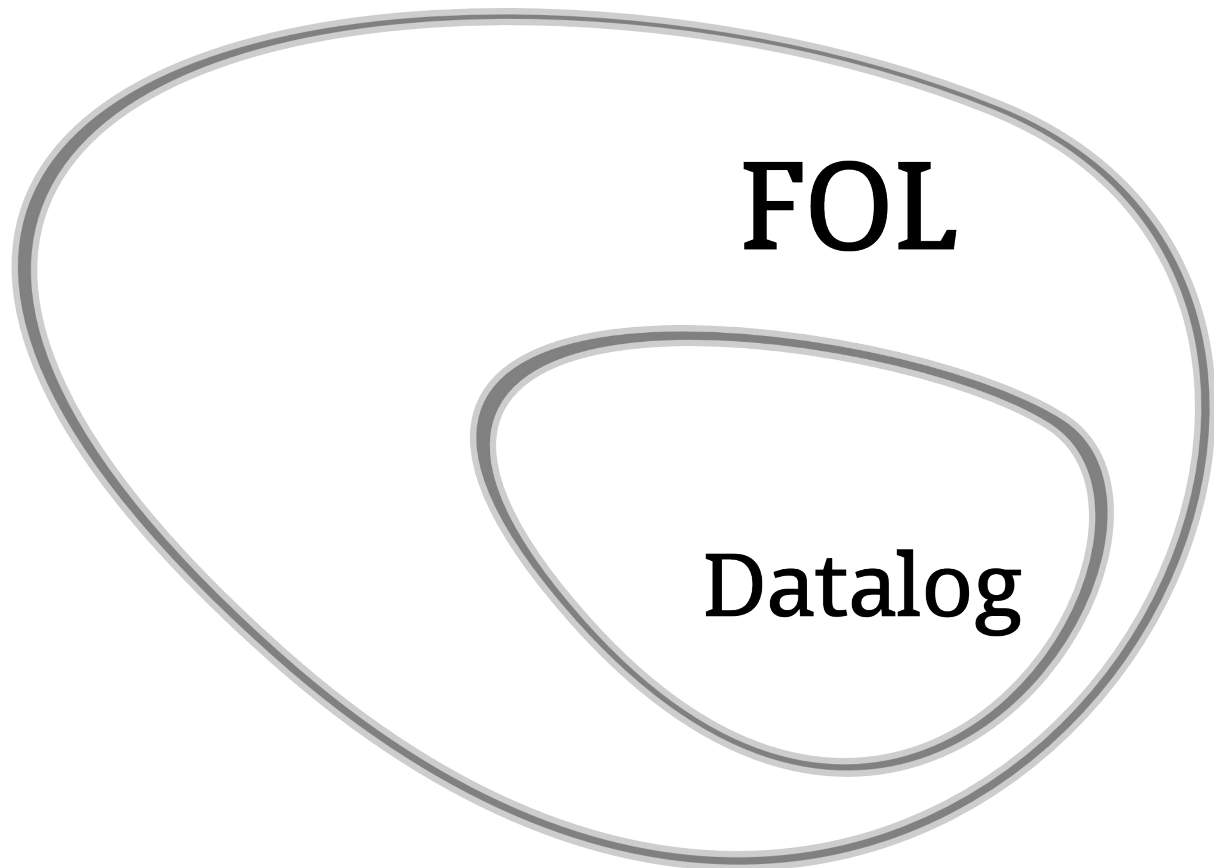
"Every Thai curry dish contains peanut oil."

$$\mathit{ThaiCurry} \sqsubseteq \exists \mathit{contains}.\{\mathit{peanutOil}\}$$

$$\forall x.\ \mathit{ThaiCurry}(x) \rightarrow \mathit{contains}(x, \mathit{peanutOil})$$

Rules in First-Order Logic

Rules in First-Order Logic



Rules in First-Order Logic

"Nut allergics dislike nut products."

$$NutAllergic(x) \land NutProduct(y) \rightarrow dislikes(x,y)$$

Rules in First-Order Logic

"People who order a dish they dislike are unhappy."

$$orderedDish(x,y) \land dislikes(x,y) \rightarrow Unhappy(x)$$

Rules in First-Order Logic

"If someone dislikes an ingredient of a dish, she will also dislike the dish."

$$dislikes(x,z) \land Dish(y) \land contains(y,z) \rightarrow dislikes(x,y)$$

Rules in First-Order Logic

"Sebastian is a nut allergic, and peanut oil is a nut product."

→ *NutAllergic(sebastian)*

→ *NutProduct(peanutOil)*

Can we combine datalog rules and DL axioms?

“

$$ThaiCurry \sqsubseteq \exists contains.\{peanutOil\}$$

$$\top \sqsubseteq \forall orderedDish.Dish$$

$$sebastian{:}\ \exists orderedDish.ThaiCurry$$

$$NutAllergic(x) \wedge NutProduct(y) \rightarrow dislikes(x,y)$$

$$orderedDish(x,y) \wedge dislikes(x,y) \rightarrow Unhappy(x)$$

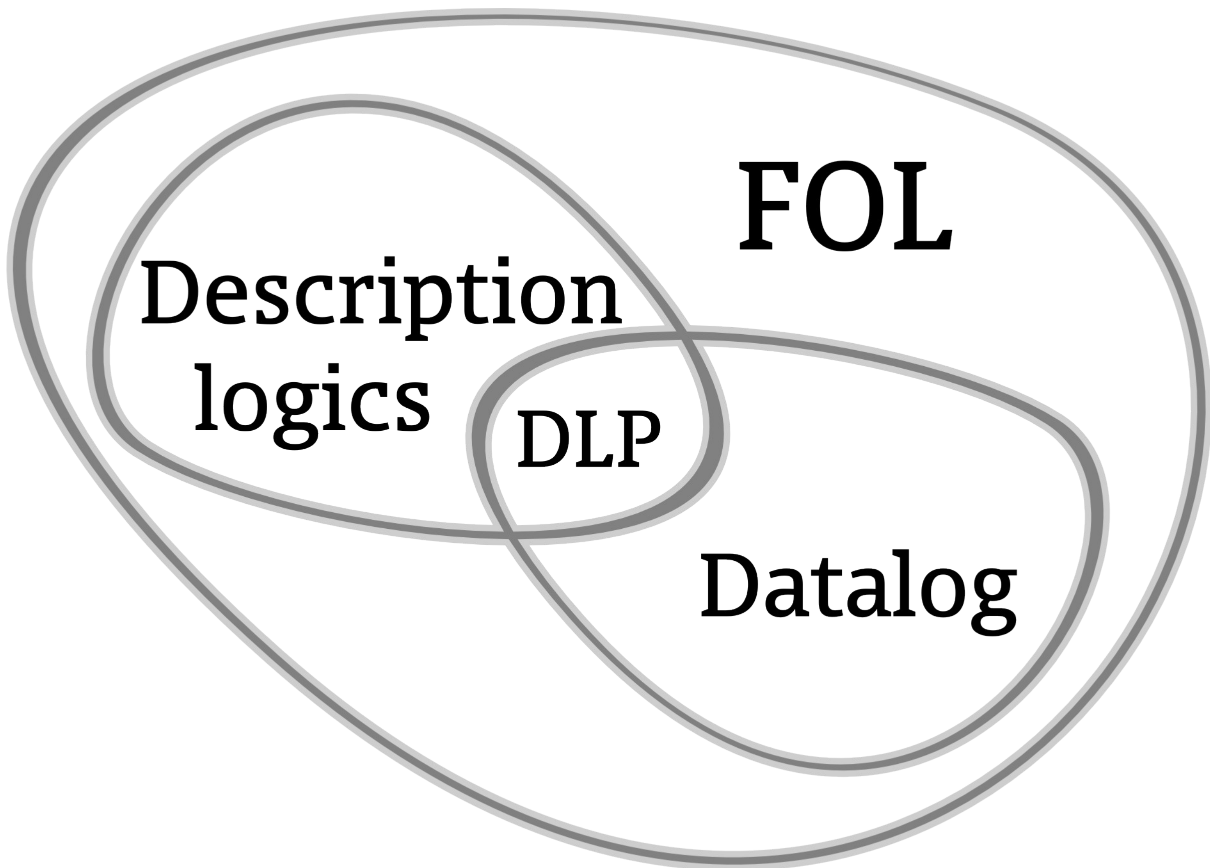
$$dislikes(x,z) \wedge Dish(y) \wedge contains(y,z) \rightarrow dislikes(x,y)$$

$$\rightarrow NutAllergic(sebastian)$$

$$\rightarrow NutProduct(peanutOil)$$

”

Combining OWL and Rules



DLP: “OWL ∩ datalog”

$\mathit{ThaiCurry} \sqsubseteq \exists \mathit{contains}.\{\mathit{peanutOil}\}$

$\top \sqsubseteq \forall \mathit{orderedDish}.\mathit{Dish}$

$\mathit{sebastian}: \exists \mathit{orderedDish}.\mathit{ThaiCurry}$

$\mathit{NutAllergic}(x) \wedge \mathit{NutProduct}(y) \rightarrow \mathit{dislikes}(x,y)$

$\mathit{orderedDish}(x,y) \wedge \mathit{dislikes}(x,y) \rightarrow \mathit{Unhappy}(x)$

$\mathit{dislikes}(x,z) \wedge \mathit{Dish}(y) \wedge \mathit{contains}(y,z) \rightarrow \mathit{dislikes}(x,y)$

$\rightarrow \mathit{NutAllergic}(\mathit{sebastian})$

$\rightarrow \mathit{NutProduct}(\mathit{peanutOil})$

SWRL: "OWL ∪ datalog"

$ThaiCurry \sqsubseteq \exists contains.\{peanutOil\}$

$\top \sqsubseteq \forall orderedDish.Dish$

$sebastian: \exists orderedDish.ThaiCurry$

$NutAllergic(x) \land NutProduct(y) \rightarrow dislikes(x,y)$

$orderedDish(x,y) \land dislikes(x,y) \rightarrow Unhappy(x)$

$dislikes(x,z) \land Dish(y) \land contains(y,z) \rightarrow dislikes(x,y)$

$\rightarrow NutAllergic(sebastian)$

$\rightarrow NutProduct(peanutOil)$

SWRL is undecidable.

DL-safe Rules

DL-safe Rules

Restrict rules to apply only to named individuals.

DL-safe Rules

$$\mathit{ThaiCurry} \sqsubseteq \exists \mathit{contains}.\{\mathit{peanutOil}\}$$

$$\top \sqsubseteq \forall \mathit{orderedDish}.\mathit{Dish}$$

$$\mathit{sebastian}: \exists \mathit{orderedDish}.\mathit{ThaiCurry}$$

$$\mathit{NutAllergic}(x) \wedge \mathit{NutProduct}(y) \rightarrow \mathit{dislikes}(x,y)$$

$$\mathit{orderedDish}(x,y) \wedge \mathit{dislikes}(x,y) \rightarrow \mathit{Unhappy}(x)$$

$$\mathit{dislikes}(x,z) \wedge \mathit{Dish}(y) \wedge \mathit{contains}(y,z) \rightarrow \mathit{dislikes}(x,y)$$

$$\rightarrow \mathit{NutAllergic}(\mathit{sebastian})$$

$$\rightarrow \mathit{NutProduct}(\mathit{peanutOil})$$

DL Rules

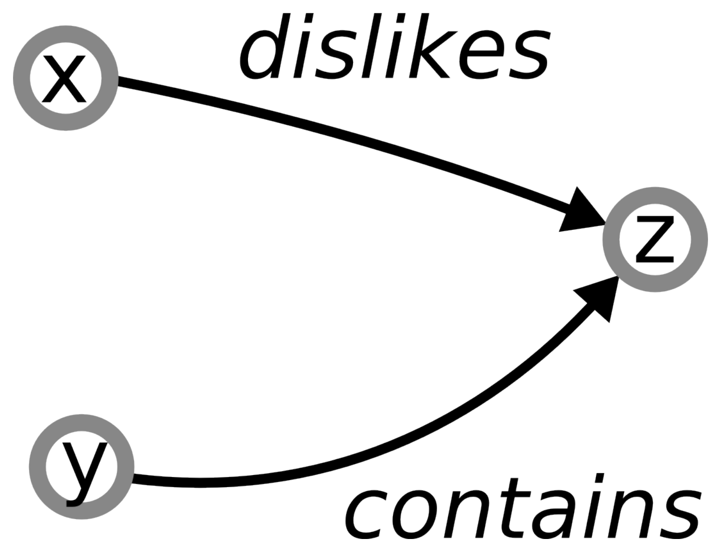
DL Rules

Restrict to rules that could (indirectly) be encoded with DL anyway.*

*) rules with “tree-shaped” bodies

DL Rules*

$$dislikes(x,z) \land Dish(y) \land contains(y,z) \rightarrow dislikes(x,y)$$



*) rules with “tree-shaped” bodies

DL Rules

$ThaiCurry \sqsubseteq \exists contains.\{peanutOil\}$ ✓

$\top \sqsubseteq \forall orderedDish.Dish$ ✓

$sebastian: \exists orderedDish.ThaiCurry$ ✓

$NutAllergic(x) \wedge NutProduct(y) \rightarrow dislikes(x,y)$ ✓

$orderedDish(x,y) \wedge dislikes(x,y) \rightarrow Unhappy(x)$ ✗

$dislikes(x,z) \wedge Dish(y) \wedge contains(y,z) \rightarrow dislikes(x,y)$ ✓

$\rightarrow NutAllergic(sebastian)$ ✓

$\rightarrow NutProduct(peanutOil)$ ✓

DL-safe rules + DL Rules

DL-safe rules + DL Rules

$ThaiCurry \sqsubseteq \exists contains.\{peanutOil\}$ ✔

$\top \sqsubseteq \forall orderedDish.Dish$ ✔

$sebastian: \exists orderedDish.ThaiCurry$ ✔

$NutAllergic(x) \wedge NutProduct(y) \rightarrow dislikes(x,y)$ ✔

$orderedDish(x,y) \wedge dislikes(x,y) \rightarrow Unhappy(x)$ 🔒

$dislikes(x,z) \wedge Dish(y) \wedge contains(y,z) \rightarrow dislikes(x,y)$ ✔

$\rightarrow NutAllergic(sebastian)$ ✔

$\rightarrow NutProduct(peanutOil)$ ✔

DL-safe rules + DL Rules

Desired conclusion does not follow

It is still computationally expensive

DL-safe rules: ExpTime

DL Rules: like DL, i.e. NExpTime for OWL DL

Tractable Profiles in OWL 2

Tractable Profiles in OWL 2

OWL RL: *Horn logic* fragment, similar to DLP, no existentials

OWL EL: includes existentials, based on DL *EL++*

Regaining Tractability: OWL 2 EL

$ThaiCurry \sqsubseteq \exists contains.\{peanutOil\}$ ✔

$\top \sqsubseteq \forall orderedDish.Dish$ ✔

$sebastian: \exists orderedDish.ThaiCurry$ ✔

$NutAllergic(x) \wedge NutProduct(y) \rightarrow dislikes(x,y)$ ✘

$orderedDish(x,y) \wedge dislikes(x,y) \rightarrow Unhappy(x)$ ✘

$dislikes(x,z) \wedge Dish(y) \wedge contains(y,z) \rightarrow dislikes(x,y)$ ✘

$\rightarrow NutAllergic(sebastian)$ ✔

$\rightarrow NutProduct(peanutOil)$ ✔

Regaining Tractability: OWL 2 RL

$ThaiCurry \sqsubseteq \exists contains.\{peanutOil\}$

$\top \sqsubseteq \forall orderedDish.Dish$

$sebastian: \exists orderedDish.ThaiCurry$

$NutAllergic(x) \land NutProduct(y) \rightarrow dislikes(x,y)$

$orderedDish(x,y) \land dislikes(x,y) \rightarrow Unhappy(x)$

$dislikes(x,z) \land Dish(y) \land contains(y,z) \rightarrow dislikes(x,y)$

$\rightarrow NutAllergic(sebastian)$

$\rightarrow NutProduct(peanutOil)$

OWL EL: PTime complete

OWL RL: PTime complete

OWL EL: PTime complete

OWL RL: PTime complete

OWL EL+RL:
N2ExpTime complete

Bringing it all together: ELP

Bringing it all together: ELP

DL Rules for OWL EL

+

Conjunctions of Roles*

+

DL-safe *variables*

*) those roles must be “simple”

Theorem

Inferencing in ELP is PTime complete.

Bringing it all together: ELP

$$ThaiCurry \sqsubseteq \exists contains.\{peanutOil\}$$

$$\top \sqsubseteq \forall orderedDish.Dish$$

$$sebastian: \exists orderedDish.ThaiCurry$$

$$NutAllergic(x) \wedge NutProduct(y) \rightarrow dislikes(x,y)$$

$$orderedDish(x,y) \wedge dislikes(x,y) \rightarrow Unhappy(x)$$

$$dislikes(x,z) \wedge Dish(y) \wedge contains(y,z) \rightarrow dislikes(x,y)$$

$$\rightarrow NutAllergic(sebastian)$$

$$\rightarrow NutProduct(peanutOil)$$

Bringing it all together: ELP

$\rightarrow Unhappy(sebastian)$

Note

ELP supports inferencing in OWL EL and OWL RL.

Understanding DL-safety

$$\mathit{ThaiCurry} \sqsubseteq \exists \mathit{contains}.\boldsymbol{\mathit{FishProduct}}$$

$$\top \sqsubseteq \forall \mathit{orderedDish}.\mathit{Dish}$$

$$\boldsymbol{\mathit{markus}}: \exists \mathit{orderedDish}.\mathit{ThaiCurry}$$

$$\boldsymbol{\mathit{Vegetarian}}(x) \wedge \boldsymbol{\mathit{FishProduct}}(y) \rightarrow \mathit{dislikes}(x,y)$$

$$\mathit{orderedDish}(x,y) \wedge \mathit{dislikes}(x,y) \rightarrow \mathit{Unhappy}(x)$$

$$\mathit{dislikes}(x,z) \wedge \mathit{Dish}(y) \wedge \mathit{contains}(y,z) \rightarrow \mathit{dislikes}(x,y)$$

$$\rightarrow \boldsymbol{\mathit{Vegetarian}(\mathit{markus})}$$

Understanding DL-safety

Unhappy(markus)

cannot be concluded

Towards Implementation

Theorem

Inferencing in ELP can be reduced in linear time to inferencing in 3-variable datalog.

Reasoning through Datalog

- Transformation to datalog is completely syntactic.
- Each axiom/rule can be transformed individually.
- Datalog engines can be used as blackbox.
- Instance and subsumption checking directly in datalog.

Summary

ELP: DL-based tractable rule language

- Almost completely expressible in OWL 2
- Support for OWL EL and OWL RL
- Linear-time conversion to 3-var datalog
  → simple implementation strategy

Happy(markus) *Happy(sebastian)*

Happy(pascal)

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