

Semantic Web Technologies

OWL DL and RDF Rules

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Outline

OWL in RDF
Mapping OWL DL to RDF

Reasoning with OWL
RDF-based Rule Reasoning
DL-based Reasoning

OWL DL and Logic Programming
Description Logic Programs
Beyond DLP

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OWL Lite/DL vs. RDF

- ▶ RDF Graph defined through translation from Abstract Syntax
- ▶ Example:

```
Class(Human partial Animal
      restriction(hasLegs cardinality(2))
      restriction(hasName allValuesFrom(xsd:string)))
```

Human	rdf:type	owl:Class
Human	rdfs:subClassOf	Animal
Human	rdfs:subClassOf	_:X1
_:X1	rdf:type	owl:Restriction
_:X1	owl:onProperty	hasLegs
_:X1	owl:cardinality	"2"8sd:nonNegativeInteger
Human	rdfs:subClassOf	_:X2
_:X2	rdf:type	owl:Restriction
_:X2	owl:onProperty	hasName
_:X2	owl:allValuesFrom	xsd:string

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OWL Lite/DL vs. RDF

- ▶ Not every RDF graph is OWL Lite/DL ontology
- ▶ Example:
 - A** rdf:type **A**
- ▶ How to check whether an RDF graph **G** is OWL DL?
 1. Construct an OWL ontology **O** in Abstract Syntax
 2. Translate to RDF graph **G'**
 3. If **G=G'**, then **G** is OWL DL
 - ▶ Otherwise, go to step (1)

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OWL DL in RDF

- ▶ Mapping from OWL Abstract Syntax to RDF Graphs: given OWL ontology O , return RDF graph $T(O)$
- ▶ OWL DL
- ▶ Reuses RDF(S) vocabulary as much as possible
 - e.g. `rdfs:subClassOf`, `rdf:type`
- ▶ Complete translation online at:
 - <http://www.w3.org/TR/owl-semantics/mapping.html>
- ▶ We skip annotations here

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Translating Ontologies

Abstract Syntax

Ontology(O $axiom_1$... $axiom_n$)

RDF graph

O rdf:type owl:Ontology .
T($axiom_1$) ... T($axiom_n$)

In case O is not present, a blank node is introduced.

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Translating partial Class definition

Abstract Syntax

Class(classID partial *description*₁ ... *description*_{*n*})

RDF graph

```
classID rdf:type owl:Class .
classID rdfs:subClassOf T(description1) . ...
classID rdfs:subClassOf T(descriptionn) .
```

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Translating complete Class definition

Abstract Syntax

Class(classID complete *description*₁ ... *description*_{*n*})

RDF graph

```
classID rdf:type owl:Class .
classID owl:intersectionOf T(SEQ description1 ...
descriptionn) .
```

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Translating complete Class definition

T(SEQ *description*₁ ... *description*_{*n*})

RDF graph

```
_:l1 rdf:type rdf:List . [opt]
_:l1 rdf:first T(item1) . _:l1 rdf:rest _:l2 .
...
_:ln rdf:type rdf:List . [opt]
_:ln rdf:first T(itemn) . _:ln rdf:rest rdf:nil .
```

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Enumerated class

Abstract Syntax

EnumeratedClass(classID iID1 ... iIDn)

RDF graph

```
classID rdf:type owl:Class .
classID owl:oneOf T(SEQ iID1 ... iIDn) .
```

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Disjoint classes

Abstract Syntax

DisjointClasses(*description*₁ ... *description*_{*n*})

RDF graph

```
T(descriptionj) owl:disjointWith T(descriptioni) .
1 ≤ i < j ≤ n
```

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Translating Union

Abstract Syntax

unionOf(*description*₁ ... *description*_{*n*})

RDF graph

```
_:x rdf:type owl:Class .
_:x owl:unionOf T(SEQ description1 ...
descriptionn) .
```

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Translating Intersection

Abstract Syntax

intersectionOf(description1 ... descriptionn)

RDF graph

```
_:x rdf:type owl:Class .
_:x owl:intersectionOf T(SEQ description1 ...
descriptionn) .
```

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Translating Restrictions

Abstract Syntax

restriction(ID component1 ... componentn)
(With at least two components)

RDF graph

```
_:x rdf:type owl:Class .
_:x owl:intersectionOf
T(SEQ(restriction(ID component1) ...
restriction(ID componentn))) .
```

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Translating Restrictions

Abstract Syntax

restriction(ID allValuesFrom(range))

RDF graph

```
_:x rdf:type owl:Restriction .
_:x owl:onProperty T(ID) .
_:x owl:allValuesFrom T(range) .
```

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Translating Restrictions

Abstract Syntax

restriction(ID minCardinality(min))

RDF graph

```
_:x rdf:type owl:Restriction .
_:x owl:onProperty T(ID) .
_:x owl:minCardinality "min"^^xsd:nonNegativeInteger .
```

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Translating Individuals

Abstract Syntax

Individual(iID
type(type1) ... type(typen)
value(pID1 v1) ... value(pIDk vk))

RDF graph

```
iID rdf:type T(type1) . ... iID rdf:type T(typen) .
iID T(pID1) T(v1) . ... iID T(pIDk) T(vk) .
```

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RDF Rules: N3

- ▶ RDF Rules: extension of Turtle to **rules**
- ▶ `rdf:type` may be abbreviated to `a`
- ▶ Syntax:
 $\{ (triple\ pattern\ .)^* \} \Rightarrow \{ (triple\ pattern\ .)^* \} .$
- ▶ Rule safety:
 - ▶ Variables on right-hand side of \Rightarrow (**head**) **must** occur on left-hand side **body**
- ▶ Variables implicitly universally quantified over rule
- ▶ \Rightarrow as standard implication in Logic Programming
- ▶ Rule with empty head is **integrity constraint**
- ▶ Rule with empty body is **fact**

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RDF Rules: examples

```
{?A rdfs:subClassOf ?B. ?B rdfs:subClassOf ?A} =>
  {?A owl:equivalentClass ?B}.

{?D owl:complementOf ?C.
  ?D owl:equivalentClass owl:Nothing} =>
  {?C owl:equivalentClass owl:Thing}.

{?A owl:differentFrom ?A} => {}.
```

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Rule-based OWL reasoning

- ▶ Cannot **exactly** capture OWL DL semantics
- ▶ OWL DL semantics can be approximated to large extent, e.g., equality:
 - ▶ Equality not really in the (rule) language
 - ▶ Can be simulated with `owl:sameAs`
- ▶ Hard to characterize which part of Semantics is captured
- ▶ Can capture part of OWL Full semantics
- ▶ Rule-based RDF reasoning popular on Semantic Web (e.g. Jena, CWM, Euler, ...)

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Basic Ideas of DLs

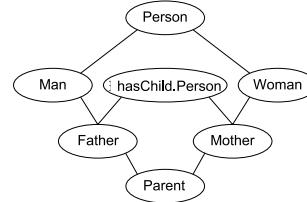
- ▶ Basic syntactic building blocks
 - ▶ Atomic concepts
 - ▶ Atomic roles
 - ▶ Individuals
- ▶ Limited constructs for building complex concepts, roles
- ▶ Implicit knowledge can be inferred automatically
 - ▶ Subsumption

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Inference of implicit knowledge

Consider the TBox:
 $Woman \equiv Person \sqcap Female$
 $Man \equiv Person \sqcap \neg Woman$
 $Mother \equiv Woman \sqcap \exists hasChild.Person$
 $Father \equiv Man \sqcap \exists hasChild.Person$
 $Parent \equiv Mother \sqcup Father$

entails the following subsumption hierarchy:



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Review of DL Basics

- ▶ Set-based term descriptions
- ▶ Intentional knowledge
 - ▶ A DL ontology is not a database!
- ▶ Main inference procedure: subsumption reasoning
 - ▶ If a concept D is more general than a concept C , it **subsumes** that concept:
 $C \sqsubseteq D$
- ▶ Efficient TBox reasoning
- ▶ ABox reasoning (query answering) not well developed

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OWL constructs

OWL Construct	DL	Example
intersectionOf	$C_1 \sqcap \dots \sqcap C_n$	$Human \sqcap Male$
unionOf	$C_1 \sqcup \dots \sqcup C_n$	$Doctor \sqcup Lawyer$
complementOf	$\neg C$	$\neg Male$
oneOf	$\{o_1, \dots, o_n\}$	$\{john, mary\}$
allValuesFrom	$\forall P.C$	$\forall hasChild.Doctor$
someValuesFrom	$\exists P.C$	$\exists hasChild.Lawyer$
value	$\exists P.\{o\}$	$\exists citizenOf.USA$
minCardinality	$\geq nP.C$	$\geq 2hasChild.Lawyer$
maxCardinality	$\leq nP.C$	$\leq 1hasChild.Male$
cardinality	$= nP.C$	$= 1hasParent.Female$

+ XML Schema datatypes: int, string, real, etc...

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OWL axioms

OWL Axiom	DL	Example
SubClassOf	$C_1 \sqsubseteq C_2$	<i>Human</i> \sqsubseteq <i>Animal</i> \sqcap <i>Biped</i>
EquivalentClasses	$C_1 \equiv \dots \equiv C_n$	<i>Man</i> \equiv <i>Human</i> \sqcap <i>Male</i>
SubPropertyOf	$P_1 \sqsubseteq P_2$	<i>hasDaughter</i> \sqsubseteq <i>hasChild</i>
EquivalentProperties	$P_1 \equiv \dots \equiv P_n$	<i>cost</i> \equiv <i>price</i>
SameIndividual	$o_1 = \dots = o_n$	<i>President_Bush</i> = <i>G.W_Bush</i>
DisjointClasses	$C_i \sqsubseteq \neg C_j$	<i>Male</i> $\sqsubseteq \neg$ <i>Female</i>
DifferentIndividuals	$o_i \neq o_j$	<i>john</i> \neq <i>peter</i>
inverseOf	$P_1 \equiv P_2^-$	<i>hasChild</i> \equiv <i>hasParent</i> ⁻
Transitive	$P^+ \sqsubseteq P$	<i>ancestor</i> ⁺ \sqsubseteq <i>ancestor</i>
Symmetric	$P \equiv P^-$	<i>connectedTo</i> \equiv <i>connectedTo</i> ⁻

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More examples

```
Class( firstYearCourse partial restriction (isTaughtBy allValuesFrom
( Professor )))

Class(mathCourse partial restriction (isTaughtBy hasValue (949352)))

Class(academicStaffMember partial restriction (teaches someValuesFrom
( undergraduateCourse)))

Class(course partial restriction (isTaughtBy minCardinality(1)))

Class(department partial restriction (hasMember minCardinality(10))
restriction (hasMember maxCardinality(30)))
```

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More examples

In DL syntax:

```
firstYearCourse  $\sqsubseteq \forall$ isTaughtBy.Professor
mathCourse  $\sqsubseteq \exists$ isTaughtBy.{949352}
academicStaffMember  $\sqsubseteq \exists$ teaches.undergraduateCourse
course  $\sqsubseteq \geq 1$ isTaughtBy
department  $\sqsubseteq \geq 10$ hasMember  $\sqcap \leq 30$ hasMember
```

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More examples

```
Class(course partial complementOf(staffMember))

Class(peopleAtUni complete unionOf(staffMember student))

Class(facultyInCS complete intersectionOf( faculty
restriction (belongsTo hasValue (CSDepartment))))

Class(adminStaff complete intersectionOf( staffMember
complementOf(unionOf(faculty techSupportStaff))))
```

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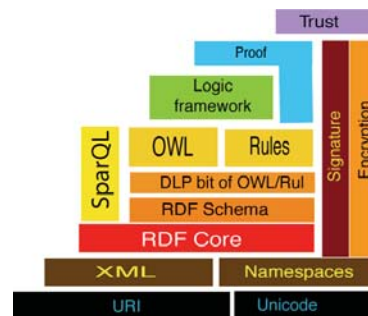
More examples

In DL syntax:

```
course  $\sqsubseteq \neg$ staffMember
peopleAtUni  $\equiv$  staffMember  $\sqcup$  student
facultyInCS  $\equiv$  faculty  $\sqcap \exists$ belongsTo.{CSDepartment}
adminStaff  $\equiv$  staffMember  $\sqcap \neg$ (faculty  $\sqcup$  techSupportStaff)
```

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Semantic Web Languages



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Why relate DL and LP?

Why not use DL or LP for everything?

- ▶ LP: Efficient algorithms and implementations for query answering
- ▶ DL: Efficient algorithms and implementations for subsumption reasoning
- ▶ Thus: it depends on the reasoning task which language to use
- ▶ Many existing implementations of rules systems (e.g., SQL1999 \approx Datalog with linear recursion)
- ▶ Web Ontology Language (OWL) based on DL
- ▶ Thus: in order to leverage existing rule implementations for the Semantic Web, we need to translate!

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Recap: Logic Programming

- ▶ Any FOL term is a term in LP
- ▶ Any FOL atomic formula is an atomic formula in LP
- ▶ Any Horn formula is a rule in LP (quantification usually omitted)
 - ▶ $H \leftarrow B_1 \wedge \dots \wedge B_n$
- ▶ Logic programming is a syntactic subset of FOL
- ▶ **Note!** Negation-as-failure in LP is an **extension** of Horn rules
 - ▶ $\neg \neq \text{not}$

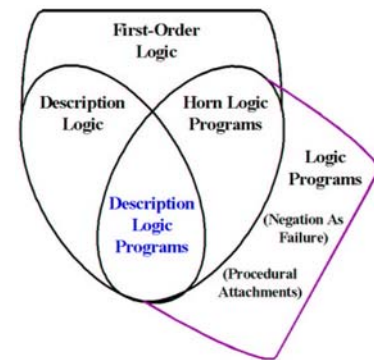
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Entailment

- ▶ General First-Order entailment:
 - ▶ $\phi \models \psi$ iff for every interpretation \mathcal{I} : if $\mathcal{I} \models \phi$ then $\mathcal{I} \models \psi$
 - ▶ Thus, the set of models of ϕ $M(\phi)$ is a subset of $M(\psi)$: $M(\phi) \subseteq M(\psi)$
 - ▶ e.g., $p(x) \wedge q(x) \models p(x)$
- ▶ Ground entailment:
 - ▶ $\phi \models \psi_{ground}$ iff for every interpretation \mathcal{I} : if $\mathcal{I} \models \phi$ then $\mathcal{I} \models \psi_{ground}$ and ψ_{ground} **does not** contain variables
 - ▶ e.g., $(p(x) \rightarrow q(x)) \wedge p(a) \models q(a)$
- ▶ Logic Programming only defines ground entailment
- ▶ Horn Logic (i.e., Horn subset of FOL) is equivalent to Logic Programming wrt. ground entailment
 - ▶ For any set of Horn formulas ϕ and a ground Horn formula ψ_{ground} : $\phi \models_{FOL} \psi_{ground}$ iff $\phi \models_{LP} \psi_{ground}$
 - ▶ \models_{FOL} is classical First-Order entailment; \models_{LP} is LP entailment

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Relation between DL and LP



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Description Logic Programs

- ▶ "Intersection" of Description Logics and Logic Programming
- ▶ That part of Description Logics (OWL in particular) which can be translated to a Logic Program
- ▶ Horn Logic subset of *SHOIN*, **reduced** to a Logic Program: Description Logic Program: DLP
- ▶ General idea:
 1. Translate *SHOIN* axiom to First-Order Logic
 2. Rewrite to Horn Logic
 - ▶ If rewriting not possible: formula not in DLP
 3. Reduce to Logic Program

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Recap: *SHOIN*

Concept descriptions

$C, D \longrightarrow A$		(atomic concept)
\top		(universal concept)
\perp		(bottom concept)
$C \sqcap D$		(intersection)
$C \sqcup D$		(disjunction)
$\neg C$		(negation)
$\forall R.C$		(value restriction)
$\exists R.C$		(existential quantification)
$\{o_1, \dots, o_n\}$		(enumeration)
$\exists R.\{o\}$		(hasValue)
$\geq nR$		(minimal cardinality)
$\leq nR$		(maximal cardinality)

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Recap: SHOIN

Individual assertions

$$a \in C$$

$$\langle a, b \rangle \in R$$

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Recap: SHOIN

Axioms

$$C \sqsubseteq D \quad (\text{class subsumption})$$

$$C \equiv D \quad (\text{equivalence})$$

$$Q \sqsubseteq R \quad (\text{property subsumption})$$

$$R \equiv Q^- \quad (\text{inverse roles})$$

$$R \equiv R^- \quad (\text{symmetric roles})$$

$$R^+ \sqsubseteq R \quad (\text{transitive properties})$$

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Mapping SHOIN to FOL

A (atomic concept)	$A(x)$
\top	\top
\perp	\perp
$C \sqcap D$	$tr(C) \wedge tr(D)$
$C \sqcup D$	$tr(C) \vee tr(D)$
$\neg C$	$\neg tr(C)$
$\forall R.C$	$\forall y : R(x, y) \rightarrow tr(C, y)$
$\exists R.C$	$\exists y : R(x, y) \wedge tr(C, y)$
$\{o_1, \dots, o_n\}$	$x = o_1 \vee \dots \vee x = o_n$
$\exists R.\{o\}$	$R(x, o)$
$\geq nR$	$\exists y_1, \dots, y_n : \bigwedge R(x, y_i) \wedge \bigwedge y_i \neq y_j$
$\leq nR$	$\forall y_1, \dots, y_{n+1} : \bigwedge R(x, y_i) \rightarrow \bigvee y_i = y_j$

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Mapping SHOIN to FOL

$a \in A$	$A(a)$
$\langle a, b \rangle \in R$	$R(a, b)$
$C \sqsubseteq D$	$\forall x : tr(C, x) \rightarrow tr(D, x)$
$C \equiv D$	$\forall x : tr(C, x) \leftrightarrow tr(D, x)$
$Q \sqsubseteq R$	$\forall x, y : Q(r, y) \rightarrow R(x, y)$
$R \equiv Q^-$	$\forall x, y : R(x, y) \leftrightarrow Q(y, x)$
$R^+ \sqsubseteq R$	$\forall x, y, z : R(x, y) \wedge R(y, z) \rightarrow R(x, z)$

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Identifying DLP (1)

- ▶ Next step: identify DLP-fragment of SHOIN
- ▶ Start with the axioms
 - ▶ Easy case: properties

$Q \sqsubseteq R$	$\forall x, y : Q(r, y) \rightarrow R(x, y)$
$R \equiv Q^-$	$\forall x, y : R(x, y) \leftrightarrow Q(y, x)$
$R^+ \sqsubseteq R$	$\forall x, y, z : R(x, y) \wedge R(y, z) \rightarrow R(x, z)$

 All Horn Logic!
 - ▶ Equivalence axioms: $C \equiv D$
 Reduce to: $C \sqsubseteq D, D \sqsubseteq C$
 - ▶ Subsumption axioms: $C \sqsubseteq D \mapsto \forall x : tr(C, x) \rightarrow tr(D, x)$
 $tr(C, x)$ is the **body** of the rule
 $tr(D, x)$ is the **head** of the rule

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Identifying DLP (2)

- ▶ $C \sqsubseteq D$
 - ▶ **Remember:** the **body** is a conjunction of literals; the **head** is a single literal
 - ▶ Thus: C and D look different
 - ▶ C is called the **left-hand side** (lhs)
 - ▶ D is called the **right-hand side** (rhs)
- ▶ We distinguish between:
 - ▶ Descriptions allowed on the left-hand side
 - ▶ Descriptions allowed on the right-hand side

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Identifying DLP (3)

SHOIN	FOL	lhs	rhs
A (atomic concept)	$A(x)$	+	+
\top	\top	+/-	+
\perp	\perp	+	-
$C \sqcap D$	$tr(C) \wedge tr(D)$	+	+
$C \sqcup D$	$tr(C) \vee tr(D)$	+	-
$\neg C$	$\neg tr(C)$	-	-
$\forall R.C$	$\forall y : R(x, y) \rightarrow tr(C, y)$	-	+
$\exists R.C$	$\exists y : R(x, y) \wedge tr(C, y)$	+	-
$\{o_1, \dots, o_n\}$	$x = o_1 \vee \dots \vee x = o_n$	+	-
$\exists R.\{o\}$	$R(x, o)$	+	+
$\geq nR$	$\exists y_1, \dots, y_n : \bigwedge R(x, y_i) \wedge \bigwedge y_i \neq y_j$	+	-
$\leq nR$	$\forall y_1, \dots, y_{n+1} : \bigwedge R(x, y_i) \rightarrow \bigvee y_i = y_j$	-	-

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Identifying DLP (4)

- Individual assertions:

$$a \in A \quad \Bigg| \quad A(a)$$

$$\langle a, b \rangle \in R \quad \Bigg| \quad R(a, b)$$

Trivially in DLP!

- Example: $\top \sqcap \exists P.A \sqcap \{o_1, o_2\} \sqcap B \sqsubseteq \forall P.B$

Step 1: rewrite to FOL:

$$\forall x : \top \wedge (\exists y : P(x, y) \wedge A(y)) \wedge (x = o_1 \vee x = o_2) \wedge B(x) \rightarrow (\forall y : P(x, y) \wedge B(y))$$

Step 2: rewrite to Horn Logic:

$$1: \forall x : \top \wedge (\exists y : P(x, y) \wedge A(y)) \wedge (x = o_1 \vee x = o_2) \wedge B(x) \rightarrow (\forall y : P(x, y) \wedge B(y)) \Leftrightarrow$$

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Example (cont'd)

$$2: \forall x : \neg \top \vee \neg (\exists y : P(x, y) \wedge A(y)) \vee \neg (x = o_1 \vee x = o_2) \vee \neg B(x) \vee (\forall y : P(x, y) \wedge B(y)) \Leftrightarrow$$

$$3: \forall x : \neg (\exists y : P(x, y) \wedge A(y)) \vee \neg (x = o_1 \vee x = o_2) \vee \neg B(x) \vee (\forall y : P(x, y) \wedge B(y)) \Leftrightarrow$$

$$4: \forall x : (\forall y : \neg (P(x, y) \wedge A(y))) \vee \neg (x = o_1 \vee x = o_2) \vee \neg B(x) \vee (\forall y : P(x, y) \wedge B(y)) \Leftrightarrow$$

$$5: \forall x, y : \neg P(x, y) \vee \neg A(y) \vee \neg (x = o_1 \vee x = o_2) \vee \neg B(x) \vee (\forall y : P(x, y) \wedge B(y)) \Leftrightarrow$$

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Example (cont'd)

$$6: \forall x, y : \neg P(x, y) \vee \neg A(y) \vee (\neg x = o_1 \wedge \neg x = o_2) \vee \neg B(x) \vee (\forall y : P(x, y) \wedge B(y)) \Leftrightarrow$$

$$7: \forall x, y, z : \neg P(x, y) \vee \neg A(y) \vee (\neg x = o_1 \wedge \neg x = o_2) \vee \neg B(x) \vee (P(x, z) \wedge B(z)) \Leftrightarrow$$

$$8: \forall x, y, z : \neg P(x, y) \vee \neg A(y) \vee \neg x = o_1 \vee \neg B(x) \vee (P(x, z) \wedge B(z)) \Leftrightarrow$$

$$\forall x, y, z : \neg P(x, y) \vee \neg A(y) \vee \neg x = o_2 \vee \neg B(x) \vee (P(x, z) \wedge B(z)) \Leftrightarrow$$

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Example (cont'd)

$$9: \forall x, y, z : \neg P(x, y) \vee \neg A(y) \vee \neg x = o_1 \vee \neg B(x) \vee P(x, z)$$

$$\forall x, y, z : \neg P(x, y) \vee \neg A(y) \vee \neg x = o_1 \vee \neg B(x) \vee B(z)$$

$$\forall x, y, z : \neg P(x, y) \vee \neg A(y) \vee \neg x = o_2 \vee \neg B(x) \vee P(x, z)$$

$$\forall x, y, z : \neg P(x, y) \vee \neg A(y) \vee \neg x = o_2 \vee \neg B(x) \vee B(z)$$

Step 3: Reduce to Logic Program

$$P(x, z) :- P(x, y), A(y), x=o1, B(x).$$

$$B(z) :- P(x, y), A(y), x=o1, B(x).$$

$$P(x, z) :- P(x, y), A(y), x=o2, B(x).$$

$$B(z) :- P(x, y), A(y), x=o2, B(x).$$

Semantic reduction: only entailment of ground atoms

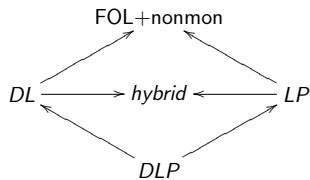
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Integration of DL and LP beyond DLP

- DLP has limited expressiveness
 - No disjunction
 - No existentials
 - No negation
 - No chaining variables over predicates
- DLP allows **extension** to DL or LP, no real **interoperation**

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Outlook: Integration beyond DLP



- ▶ Extension of DLP
 - ▶ Interoperation only for inexpressive ontologies
- ▶ Unified language
 - ▶ Obviously undecidable
 - ▶ Little research has been done
- ▶ Hybrid integration
 - ▶ Full DL and LP
 - ▶ Interaction limited to retain decidability
 - ▶ Several existing approaches (e.g. [Eiter, 2004; Rosati, 2006])

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Summary

OWL in RDF

Mapping OWL DL to RDF

Reasoning with OWL

RDF-based Rule Reasoning
DL-based Reasoning

OWL DL and Logic Programming

Description Logic Programs
Beyond DLP

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Required reading

- ▶ OWL Guide: <http://www.w3.org/TR/owl-guide/>
- ▶ Ian Horrocks, Peter F. Patel-Schneider, and Frank van Harmelen. From SHIQ and RDF to OWL: The making of a web ontology language. *Journal of Web Semantics*, 1(1):7, 2003.

Further reading

- ▶ Grosz et al. Description logic programs: Combining logic programs with description logic. In *WWW-2003*.
- ▶ OWL Reference: <http://www.w3.org/TR/owl-ref/>
- ▶ OWL Abstract syntax and Semantics: <http://www.w3.org/TR/owl-semantics/>
- ▶ T. Eiter, T. Lukasiewicz, R. Schindlauer, H. Tompits: Combining Answer Set Programming with Description Logics for the Semantic Web. In *KR 2004*.

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