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# Logic and Inference Rules

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# Learning Objectives



- Understand the role of logic on the Semantic Web
- Learn a variety of approaches to use logic rules

# Contents



- Role of Logic Rules in the Semantic Web Stack
- Logic Rule Approaches in Use
- Interplay of Ontologies and Logical Rules
- Non-monotonic Rules

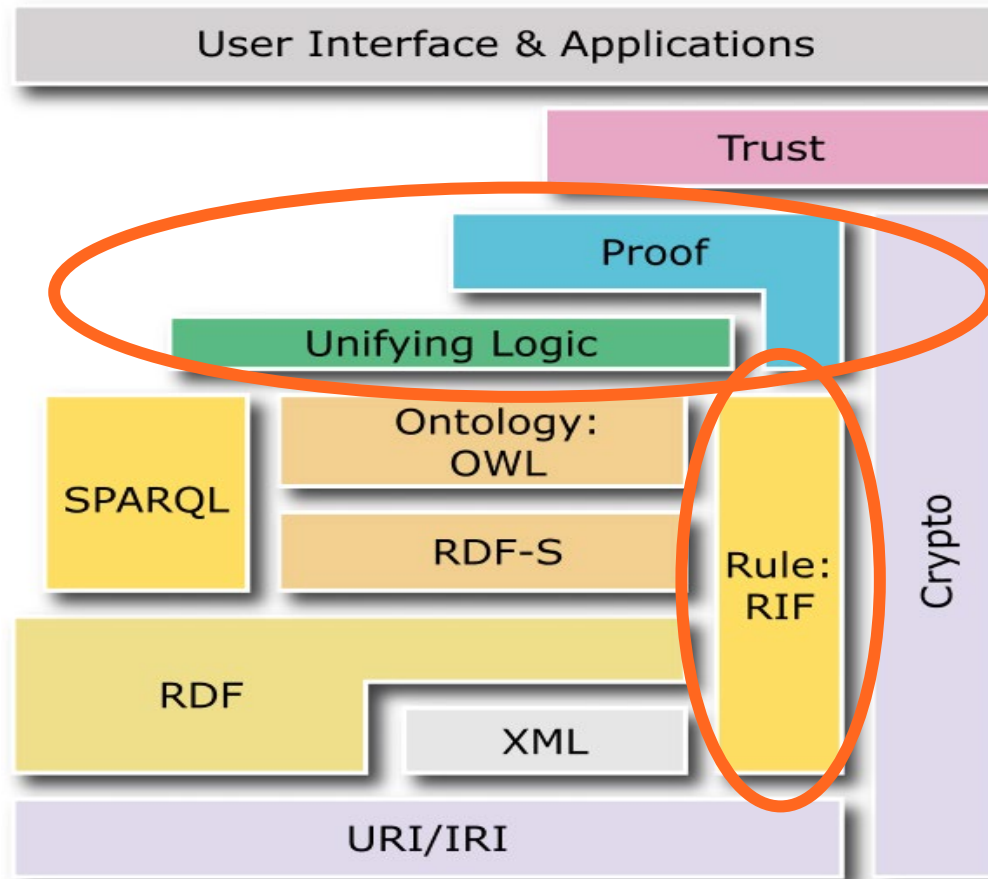


# Logic Rules in the Semantic Web Stack

# Semantic Web Technology Stack



"Layer Cake Model"



# The Importance of Logic



- High-level language for expressing knowledge
- High expressive power
- Well-understood formal semantics
- Proof systems can automatically derive statements syntactically from a set of premises
- Sound & complete proof systems exist
  - *Subsets of First Order Predicate Logic*
  - *Not necessarily available for more expressive logics*
- Logic can provide **explanations** for answers
  - *Trace the proof that leads to a logical consequence*

# Logic Rules: Many Approaches in Use

**SPARQL-based rules**

**Logic programming using RDF data**

- Using Horn Logic

**Rule Interchange Format (RIF)**

**Semantic Web Rule Language SWRL**

**Ontologies and rules**

**Non-monotonic logics**



# SPARQL-based Rules





## Use SPARQL CONSTRUCT for generating new triples

```
CONSTRUCT {  
    ?this ex:grandParent ?grandParent .  
}  
WHERE {  
    ?parent ex:child ?this .  
    ?grandParent ex:child ?parent .  
}
```



## SPIN SPARQL Inferencing Notation



### Overview

SPIN is a [W3C Member Submission](#) that has become the de-facto industry standard to represent SPARQL rules and constraints on Semantic Web models. SPIN also provides meta-modeling capabilities that allow users to define their own SPARQL functions and query templates. Finally, SPIN includes a ready to use library of common functions.

#### [SPIN in Five Slides](#)

For more information see [SPIN Architecture](#) and the [SPIN Overview W3C Page](#).

**Update (July 2017):** Before you explore SPIN further, you may want to read [From SPIN to SHACL](#).

### What You Can Do with SPIN

SPIN is a way to represent a wide range of business rules.

You will not need to learn another proprietary rules language to do so. With SPIN, rules are expressed in [SPARQL](#). In fact, SPIN is also referred to as *SPARQL Rules*. SPARQL is a well-established W3C standard implemented by many industrial-strength RDF APIs and all databases. This means that rules can run directly on RDF data without a need for materialization. SPIN provides a framework that helps users to leverage the fast performance and rich expressivity of SPARQL for various application purposes.

SPIN can be used to:

- **Calculate the value of a property based on other properties** - for example, area of a geometric figure as a product of its height and width, age of a person as a difference between today's date and person's birthday, a display name as a concatenation of the first and last names
- **Isolate a set of rules to be executed under certain conditions** - for example, to support incremental reasoning, to initialize certain values when a resource is first created, or to drive interactive applications

These rules are implemented USING SPARQL CONSTRUCT or SPARQL UPDATE requests (INSERT and DELETE). SPIN Templates also make it possible to define such rules in higher-level domain specific languages so that rule designers do not need to work with SPARQL directly.

Another common need in applications is to check validity of the data. For example, you may want to require that a field is entered and/or that the string entered follows your format requirements.

SPIN offers a way to do constraint checking with closed world semantics and automatically raise inconsistency flags when currently available information does not fit the specified integrity constraints. Constraints are specified using SPARQL ASK or CONSTRUCT queries, or corresponding SPIN Templates.

SPIN combines concepts from object oriented languages, query languages, and rule-based systems to describe object behavior on the web of data. One of the key ideas of SPIN is to link class definitions with SPARQL queries to capture rules and constraints that formalize the expected behavior of those classes. To do so, SPIN defines a light-weight collection of RDF properties.

Finally, SPIN also supports the definition of new SPARQL functions with a transparent and web-friendly framework.

### Core Specifications

- [The SPIN SPARQL Syntax](#)
- [The SPIN Modeling Vocabulary](#)
- [The SPIN Standard Modules Library](#)

# Example of a Rule Using CONSTRUCT

**New triples visible for the next rule (not inserted into data, but added into a special “inferences” graph)**

```
ex:Person
  a      rdfs:Class ;
  rdfs:label "Person"^^xsd:string ;
  rdfs:subClassOf owl:Thing ;
  spin:rule
    [ a      sp:Construct ;
      sp:templates ([ sp:object sp:_grandParent ;
                      sp:predicate ex:grandParent ;
                      sp:subject spin:_this
                    ]) ;
      sp:where ([ sp:object spin:_this ;
                  sp:predicate ex:child ;
                  sp:subject sp:_parent
                ] [ sp:object sp:_parent ;
                    sp:predicate ex:child ;
                    sp:subject sp:_grandParent
                  ])
    ] .
```

In textual SPARQL syntax, the above query would read as:

```
CONSTRUCT {
  ?this ex:grandParent ?grandParent .
}
WHERE {
  ?parent ex:child ?this .
  ?grandParent ex:child ?parent .
}
```

# SPIN – SPARQL Inferencing Notation



For example, the SPARQL query

```
# must be at least 18 years old
ASK WHERE {
  ?this my:age ?age .
  FILTER (?age < 18) .
}
```

can be represented by a blank node in the SPIN RDF Syntax in Turtle as

```
[ a      sp:Ask ;
  rdfs:comment "must be at least 18 years old"^^xsd:string ;
  sp:where ([ sp:object sp:_age ;
             sp:predicate my:age ;
             sp:subject spin:_this
           ] [ a      sp:Filter ;
             sp:expression
               [ sp:arg1 sp:_age ;
                 sp:arg2 18 ;
                 a sp:lt
               ]
           ]
        ])
]
```



# Logic Programming Using RDF Data



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# Making Predicate Logic a Practical Tool in Programming



**Logic programming = programming paradigm based on formal logic and theorem proving**

**→ Prolog language used in Artificial Intelligence**

**Problem: predicate logic is not decidable and not efficient**

- There is no effective method to answer whether an arbitrary formula is logically valid

**Solution: restriction to a reasonable subset of predicate logic**

- Balancing between expressiveness and computational complexity (remember OWL Full vs. OWL DL)

**→ Horn logic**

# Horn Logic & Logic Programming



**A rule (clause) has the form:  $A_1, \dots, A_n \rightarrow B$**

- $A_1, \dots, A_n$  (body) is a conjunction of atomic formulas
- $B$  (head) is an atomic formula

**There are 2 ways of reading a rule:**

- **Deductive rules:** If  $A_1, \dots, A_n$  are known to be true, then  $B$  is also true
- **Reactive (procedural) rules:** If the conditions  $A_1, \dots, A_n$  are true, then carry out the action  $B$

**Examples of Rules**

- $\text{male}(X), \text{parent}(P,X), \text{parent}(P,Y), \text{notSame}(X,Y) \rightarrow \text{brother}(X,Y)$
- $\text{female}(X), \text{parent}(P,X), \text{parent}(P,Y), \text{notSame}(X,Y) \rightarrow \text{sister}(X,Y)$
- $\text{brother}(X,P), \text{parent}(P,Y) \rightarrow \text{uncle}(X,Y)$
- $\text{mother}(X,P), \text{parent}(P,Y) \rightarrow \text{grandmother}(X,Y)$
- $\text{parent}(X,Y) \rightarrow \text{ancestor}(X,Y)$
- $\text{ancestor}(X,P), \text{parent}(P,Y) \rightarrow \text{ancestor}(X,Y)$



## **Facts (rules without a body)**

- **→ male(John)**
- **→ male(Bill)**
- **→ female(Mary)**
- **→ female(Jane)**
- **→ parent(John,Mary)**
- **→ parent(John, Bill)**
- **...**

## **Queries / Goals (as rule bodies)**

- **parent(John, X), female(X) →**
- **grandmother(X,Y) →**





**A query is proved (by Prolog) by deriving a conflict from it (proof by contradiction)**

- Solutions: value substitutions for variables

### **Query**

- *parent(John, X), female(X) ?*
- *grandmother(X, Y) ?*

### **Solution/Answer**

- > *X=Mary;*
- > *X=Alice, Y=Jill;*  
*X=George, Y=Susan;*

**RDF properties and graphs are based on binary predicates**

**-> RDF graph = logic program!**

**Reasoning can be added easily on top of RDF graphs**



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# Application example: recommendation of similar items in MuseumFinland



(←) Pullonsuojus, 2 kpl:istuva koira (> Ripustin:henkari, 'Finn Lassie')

Pullonsuojus, 2 kpl:istuva koira



**Materiaali:** viinapullo: lasi, pulonsuojus: lanka  
**Valmistaja:** Karhulan lasitehdas, Tapio Wirkkala  
**Valmistusaika:** 1962, 1970-1. n.  
**Valmistustekniikka:** viinapullo: tehdasvalmisteinen, pulonsuojus: käsityötä  
**Käyttäjä:** Eero Kallio  
**Käyttöpaikka:** Etelä-Suomen lääni, Suomi  
**Asiasana:** ALKOHOLIJUOMAT, ELÄINHAHMOT, KORISTE-ESINEET  
**Mitat:** pullon pohjan halkaisija 6,5cm, korkeus 22,5cm, pullonsuojuksen korkeus 29,0cm

**Museokokoelma:** LAHDEN HISTORIALLINEN MUSEO

**Vastuumuseo:** LAHDEN KAUPUNGINMUSEO

**Asiasanasto:** Lahden kaupunginmuseon sanasto

**Esineen numero:** LKMLHM:LHM:ES:95073:154

**ID:** 95073154

Viinapullo: Alkon Koskenkorvapullo. Lieriömäinen, loivat hartiat. Korkki ja etuketti puuttuvat. Pulonsuojus: istuvan koiran muotoinen pullonsuojus. Muodostuu kahdesta osasta: koiran vartalosta ja päästä. Koiran vartaloon on ommeltu viisi lankatupsua (jalat ja häntä), ylhäällä lankakristys. Koiran pää on virkattu talouspaperirullasta leikatun kerion ympärille. Kasvoissa mustat napit silminä, erillinen pieni kuono ja kolme lankatupsua (posket ja pääläella oleva otsatukka).

**Esineyppi:**

## Sama käyttäjä

Eero Kallio:

- [Keräilykortti, 14 kpl:tuotemainoskortti, erilaisia](#)
- [Kulho, 4 kpl:jalkiruokakulho](#)
- [Päähine, miehen:turkislakki, 'suikka'](#)
- [Taskuliina, miehen:taskuliinan korvike](#)
- [Jalkineet, miehen:koripallokengät](#)

## Samaan aiheeseen liittyviä esineitä

alkoholijuoma:

- [kanisteri:taskumatti](#)
- [kanisteri:taskumatti](#)
- [kanisteri:taskumatti](#)
- [viinipullo:lasipullo](#)
- [pullo:lasipullo](#)

eläimet:

- [kuvakirja:kuvakirja, kangasta](#)
- [helistin:purulelu](#)
- [muovikarhu:vinkuva karhulelu](#)
- [säätölipas:vanerilipas](#)
- [malja:puuvati](#)



# Rule Interchange Format RIF



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# Rule Interchange Format RIF

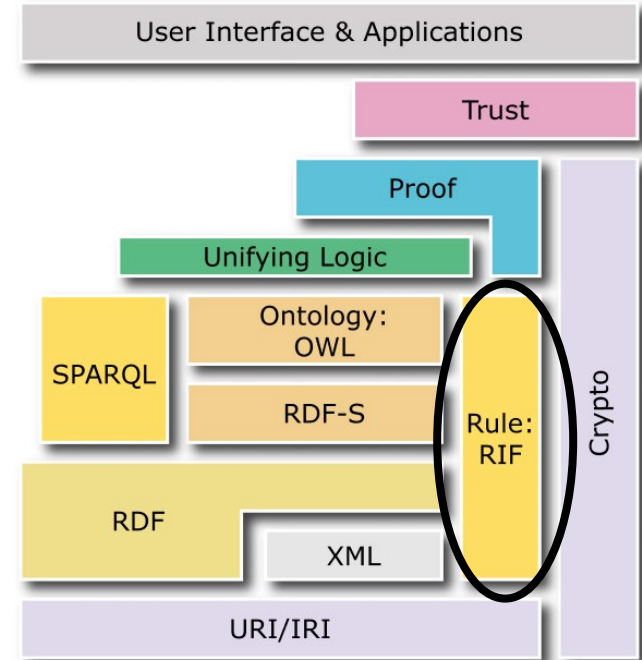


## Goals

- Rule exchange format between different rule systems
- It defines:
  - *First, a shared Core for rule systems*
  - *Then, application-specific extensions (dialects)*
- This way systems can understand each other's operation logic

**Based on earlier RuleML**

**W3C recommendation on 5.2.2013**



# RIF dialects



## RIF Core

- Common core of all RIF dialects
- Essentially function-free Horn logic (Datalog)
- Syntactic extensions
  - *frames (syntactic sugar), IRIs, XML datatypes, built-ins (e.g., for numeric comparison)*

## RIF Basic Logic Dialect (BLD)

- Essentially Horn logic with equality, based on RIF Core
- Compatibility with RDF and OWL (RL)

## RIF Production Rule Dialect (PRD)

- Reactive rules with procedural attachment
- Then part (head) of the rule contains actions

# RIF example



```
Document(  
  Prefix(rdf <http://www.w3.org/1999/02/22-rdf-syntax-ns#>)  
  Prefix(rdfs <http://www.w3.org/2000/01/rdf-schema#>)  
  Prefix(imdbrel <http://example.com/imdbrelations#>)  
  Prefix(dbpedia <http://dbpedia.org/ontology>)  
  
  Group(  
    Forall ?Actor ?Film ?Role (  
      If And(rdf:type(?Actor imdbrel:Actor)  
            rdf:type(?Film imdbrel:Film)  
            rdf:type(?Role imdbrel:Character)  
            imdbrel:playsRole(?Actor ?Role)  
            imdbrel:roleInilm(?Role ?Film))  
      Then dbpedia:starring(?Film ?Actor)  
    )  
  )  
)
```



## RIF Overview (Second Edition)

W3C Working Group Note 5 February 2013

**This version:**

<http://www.w3.org/TR/2013/NOTE-rif-overview-20130205/>

**Latest version:**

<http://www.w3.org/TR/rif-overview/>

**Previous version:**

<http://www.w3.org/TR/2012/NOTE-rif-overview-20121211/>

**Editors:**

Michael Kifer, State University of New York at Stony Brook  
Harold Boley, National Research Council Canada

A [color-coded version of this document showing changes made since the previous version](#) is also available.

This document is also available in these non-normative formats: [PDF version](#).

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### Abstract

This document is an overview of the Rule Interchange Format (RIF). It provides a high-level explanation of RIF concepts and architecture as well as a general survey of RIF documents.

### Status of this Document

#### May Be Superseded

*This section describes the status of this document at the time of its publication. Other documents may supersede this document. A list of current W3C publications and the latest revision of this technical report can be found in the [W3C technical reports index](#) at <http://www.w3.org/TR/>.*

#### Set of Documents

This document is being published as one of a set of 13 documents:

1. [RIF Overview \(Second Edition\)](#) (this document)
2. [RIF Use Cases and Requirements \(Second Edition\)](#)
3. [RIF Core Dialect \(Second Edition\)](#)
4. [RIF Basic Logic Dialect \(Second Edition\)](#)
5. [RIF Production Rule Dialect \(Second Edition\)](#)
6. [RIF Framework for Logic Dialects \(Second Edition\)](#)
7. [RIF Datatypes and Built-Ins 1.0 \(Second Edition\)](#)
8. [RIF RDF and OWL Compatibility \(Second Edition\)](#)
9. [OWL 2 RL in RIF \(Second Edition\)](#)
10. [RIF Combination with XML data \(Second Edition\)](#)
11. [RIF in R2F \(Second Edition\)](#)



# RIF Summary



- **RIF is an exchange language of rules between systems**
- **Not a single one-fits-all language**
  - There are too many approaches around
- **Core + extensions (dialects)**



# Semantic Web Rule Language SWRL



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# Semantic Web Rule Language SWRL



- Goal: build a bridge between OWL and Horn logic
  - SWRL = combination of function-free Horn logic and OWL DL
- Rule form:  $A_1, \dots, A_n \rightarrow B_1, \dots, B_m$ 
  - *Atom forms:  $C(x), P(x,y), \text{sameAs}(x,y), \text{differentFrom}(x,y)$* 
    - $C(x)$ : OWL description
    - $P$ : OWL property
    - $x$  and  $y$ : individuals, variables, or data values
- Main difficulty: restrictions for  $A_i$  and  $B_j$  are needed for decidability
  - *A prominent solution: DL-safe rules*
    - Every variable must appear in a non-description logic atom in the rule body ( $P(x,y)$  in  $A_i$ )
- OWL RL = low-end solution, SWRL high-end solution in integrating rules and DLs

# SWRL Example



**OWL cannot express the axiom “a person whose parents are married, is a child of married parents”**

- SWRL rule expressed in OWL Functional-style syntax (can also be expressed in other OWL/RDF syntaxes and RuleML):

```
Prefix(var:=<urn:swrl#>)

Declaration( Class( :ChildOfMarriedParents ) )
SubClassOf( :ChildOfMarriedParents :Person )

DLSafeRule(
  Body(
    ClassAtom( :Person Variable(var:x) )
    ObjectPropertyAtom( :hasParent Variable(var:x) Variable(var:y) )
    ObjectPropertyAtom( :hasParent Variable(var:x) Variable(var:z) )
    ObjectPropertyAtom( :hasSpouse Variable(var:y) Variable(var:z) )
  )
  Head(
    ClassAtom( :ChildOfMarriedParents Variable(var:x) )
  )
)
```

(Kuba, 2012)



# Ontologies vs. Logical Rules



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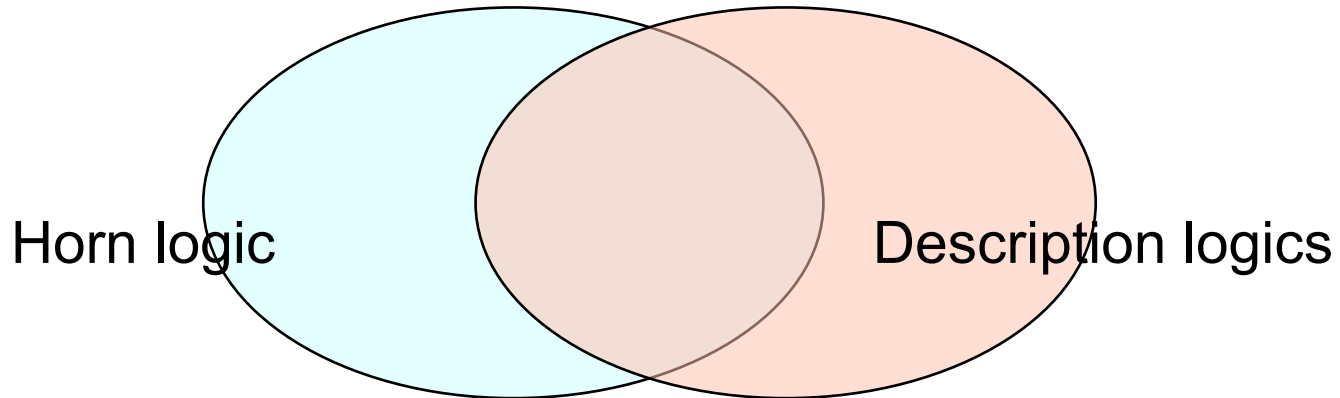
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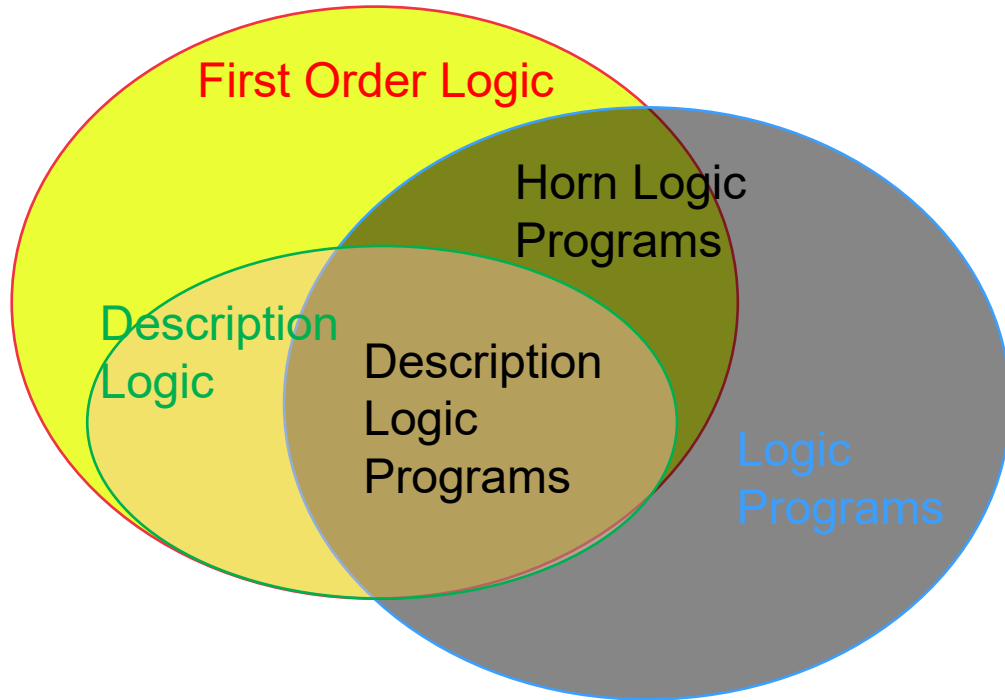
# Horn logic vs. description logics



- E.g., how to represent rules in description logics?
- E.g., how to represent cardinality constraints in Horn logic?



# Logics of the Semantic Web



HLP = FOL & LP  
DLP = DL & HLP

(Antoniou, van Harmelen, 2007)

# Description Logic Programs



- Description Logic Programs (DLP) are the intersection of Horn logic and description logic
- DLP allows to combine advantages of both approaches, e.g.:
  - *A modeler may take a DL view, but*
  - *The implementation may be based on rule technology*
- -> OWL RL



# Keys Challenge in Combining Logic Programming and OWL



## Unique Names Assumption UNA

- Resources are different/same if they have different/same identifiers
- UNA is made in logic programming & databases but not in OWL
- UNA makes sense (only) if we know the unique identifiers

## Closed World Assumption CWA

- If a fact cannot be deduced true it is assumed to be false
  - -> non-monotonic logics!
- CWA made in logic programming & databases but not in logic
- CWA makes sense (only) if our knowledge is complete

# An Interoperability Problem



**Logic programming & databases usually assume**

- UNA + CWA

**Description logics & theorem proving do not assume**

- UNA + CWA

**Result: different conclusions are drawn from same premises**

- Interoperability is lost



# Nonmonotonic Logic and Rules

# Non-monotonic Reasoning



- Our available knowledge is often *incomplete*
- In spite of this, we need to make *plausible conclusions*
- With new knowledge later, conclusions may become false
  - The amount of true facts is not increasing *monotonically*
- **Problem: predicate logic is monotonic**
  - Facts can only be added not removed from the knowledge base!

# Closed World Assumption Leads to Non-monotonic Reasoning



- *CWA leads to nonmonotonic behavior:*
  - *What is not known is assumed to be false*
  - *Addition of true facts may lead to removing assumptions*
- *Logic programming using Prolog is based on CWA and is using non-monotonic reasoning*

# Example: Default Reasoning



- It makes sense to assume that birds can fly:
  - $Bird(X) \Rightarrow Flies(X)$
- If we learn that  $Bird(Tweety)$ :
  - $\Rightarrow Flies(Tweety)$
- However, there are exceptions to this rule
  - $Benguin(X) \Rightarrow -Flies(X)$
- If we later learn  $Benguin(Tweety)$ :
  - $\Rightarrow -Flies(Tweety)$

**Contradiction: Does Tweety fly or not?**

# Challenge and a Solution Approach



**Predicate logic systems, such as description logics (OWL) cannot deal with non-monotonic reasoning**

**A possible solution: select facts by prioritizing rules**

- **Based on higher authority**
  - – E.g. in law, federal law preempts state law
  - – E.g., higher management has more authority than lower
- **Based on rule recency or specificity**
  - – E.g. exceptions override more general rules

**New kind of non-monotonic logic systems are needed for this**

# Summary: Ontology and Rule Languages



**The semantics of the Semantic Web is based on different subsets of the first order predicate logic**

- Ontologies and OWL are based formal description logics
- Rules are based on Horn logic

**Challenges of interoperability and standardization work**

- Variety of logic rule systems
- UNA and CWA assumptions

**Practical application of rules is possible in many ways**

- SPARQL based rules
- Simple rules in OWL
- Logic programming using RDF data