OWL, DL and Rules

Based on slides from Grigoris Antoniou, Frank van Harmele and **Vassilis Papataxiarhis**

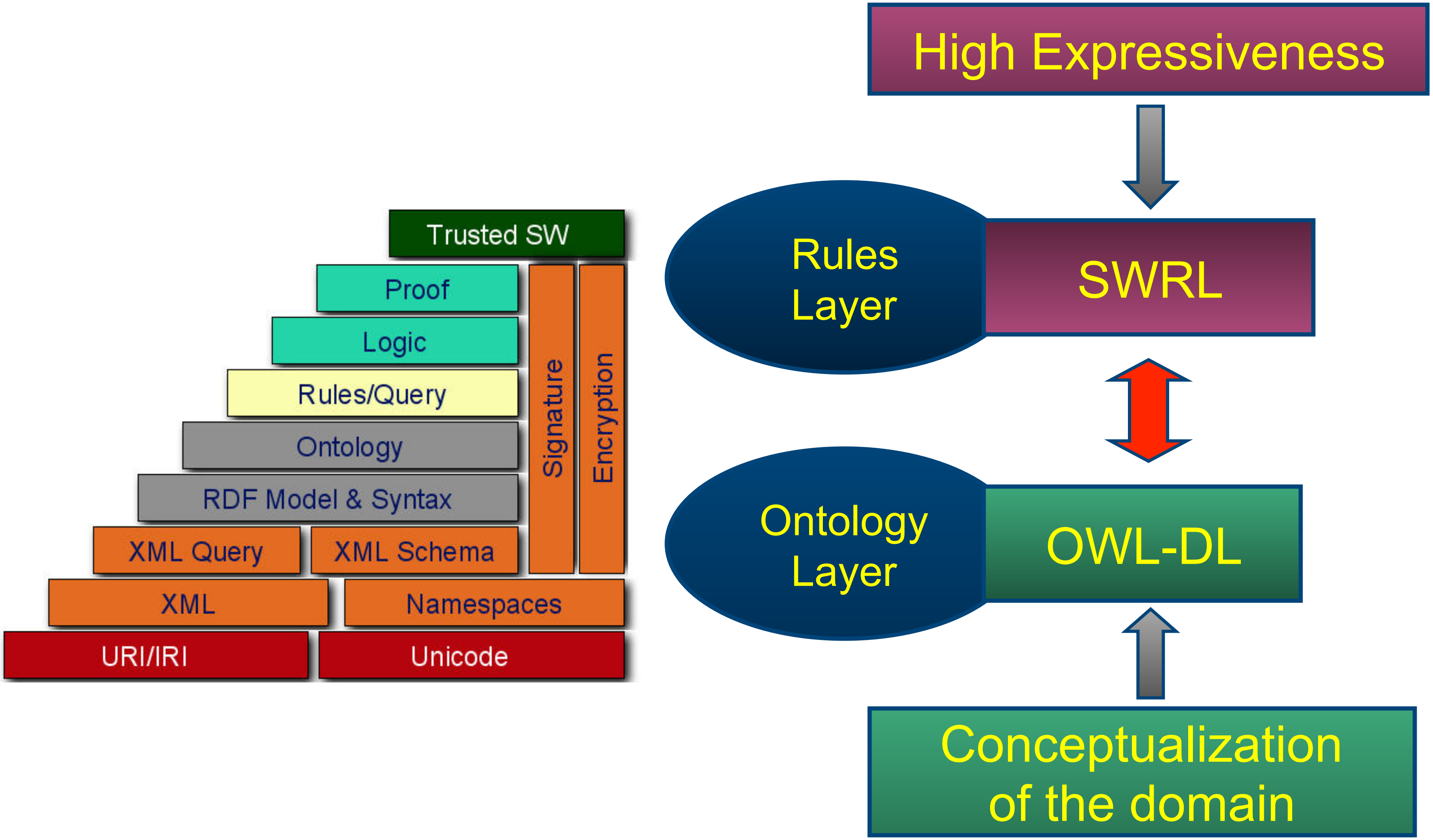
Semantic Web and Logic

- The Semantic Web is grounded in logic
- But what logic?
  - OWL Full = Classical first order logic (FOL)
  - OWL-DL = Description logic
  - N3 rules ~= logic programming (LP) rules
  - SWRL ~= DL + LP
  - Other choices are possible, e.g., default logic, Markov logic, …
- How do these fit together?
- What are the consequences

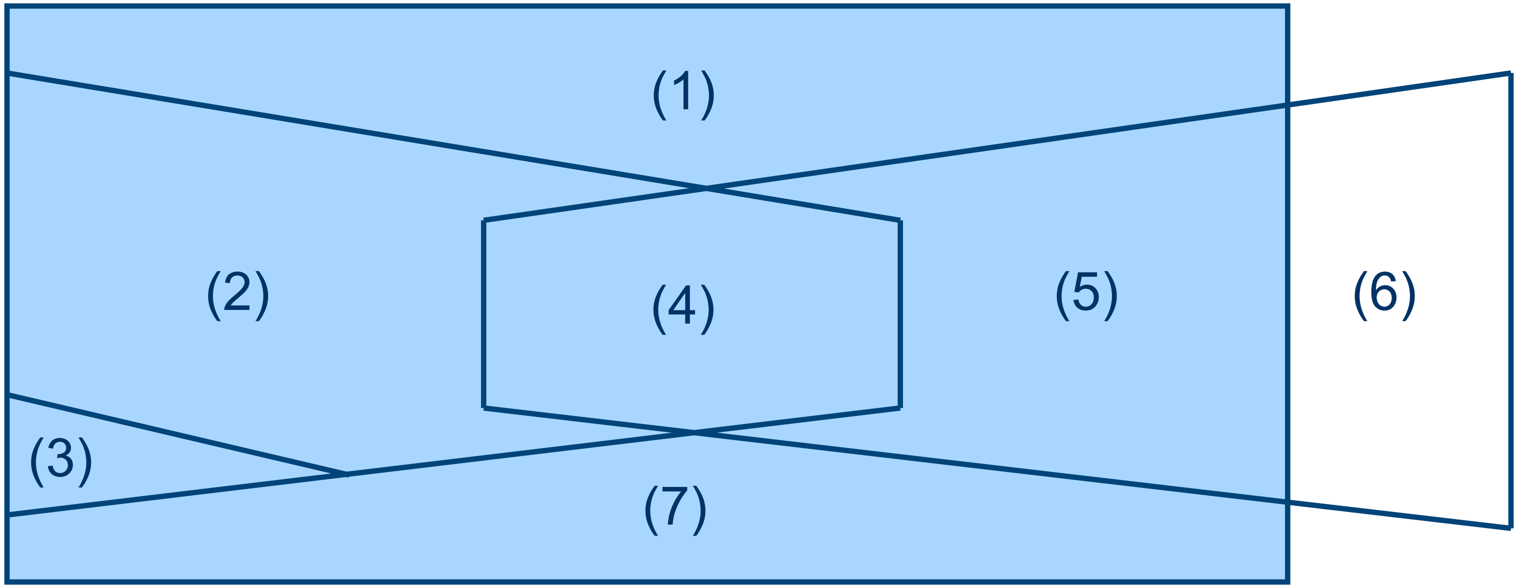
We need both structure and rules

- **OWL's ontologies** are based on Description Logics (and thus in FOL)
  - The Web is an open environment
  - Reusability / interoperability
  - An ontology is a model easy to understand
- Many **rule systems** based on logic programming
  - To achieve decidability, ontology languages don't offer the expressiveness we want. Rules do it well
  - Efficient reasoning support already exists
  - Rules are well-known in practice and often more intuitive

A common approach



LP and classical logic overlap



FOL: (All except (6)),	(2)+(3)+(4): DLs
(4): Description Logic Programs (DLP),	(3): Classical Negation
(4)+(5): Horn Logic Programs,	(4)+(5)+(6): LP
(6): Non-monotonic features (like NAF, etc.)	(7): $\wedge$head and, $\vee$body

Description Logics vs. Horn Logic

- Neither of them is a subset of the other
- It is impossible to assert that persons who study and live in the same city are “local students” in OWL
  - This can be done easily using rules:

    studies(X,Y), lives(X,Z), loc(Y,U), loc(Z,U) → localStudent(X)
- Rules cannot assert the information that a person is either a man or a woman
  - This information is easily expressed in OWL using disjoint union

Basic Difficulties

Classical Logic vs. Logic Programming

- Monotonic vs. Non-monotonic Features
  - Open-world vs. Closed-world assumption
  - Negation-as-failure vs. classical negation
- Non-ground entailment
- Strong negation vs. classical negation
- Equality
- Decidability

What's Horn clause logic

- Prolog and most 'logic'-oriented rule languages use horn clauselogic
  - Defined by UCLA mathematician Alfred Horn
- Horn clauses are a subset of FOL where every sentence is a disjunction of literals (atoms) where at most one is positive

  ~P V ~Q V ~R V S

  ~P V ~Q V ~R
- Atoms are propositional variables (isRaining) or predicates (married(alice, ?x))

An alternate formulation

- Horn clauses can be re-written using the implication operator

  $\sim P \lor Q = P \rightarrow Q$

  $\sim P \lor \sim Q \lor R = P \land Q \rightarrow R$

  $\sim P \lor \sim Q = P \land Q \rightarrow$

- What we end up with is ~ "pure prolog"
  - Single positive atom as the rule conclusion
  - Conjunction of positive atoms as the rule antecedents (conditions)
  - No **not** operator
  - Atoms can be predicates (e.g., mother(X,Y))

Where are the quantifiers?

- Quantifiers (forall, exists) are implicit
  - Variables in *rule head* (i.e., conclusion or consequent) are universally quantified
  - Variables only *in rule body* (i.e., condition or antecedent) are existentially quantified
- Example:
  - isParent(X) ← hasChild(X,Y)
  - forAll X: isParent(X) if Exisits Y: hasChild(X,Y)

We can relax this a bit

- Head can contain a conjunction of atoms
  - $P \wedge Q \leftarrow R$ is equivalent to $P \leftarrow R$ and $Q \leftarrow R$
- Body can have disjunctions
  - $P \leftarrow R \vee Q$ is equivalent to $P \leftarrow R$ and $P \leftarrow Q$
- But something are just not allowed:
  - No disjunction in head
  - No negation operator, i.e. NOT

Facts & rule conclusions are definite

- Definite means *not a disjunction*
- Facts are rule with the trivial true condition
- Consider these true facts:

  $P \lor Q$

  $P \rightarrow R$

  $Q \rightarrow R$

- What can you conclude?
- Can this be expressed in horn logic?

Facts & rule conclusions are definite

- Consider these true facts where **not** is Prolog's "negation as failure" operator

  not(P) ➔ Q, not(Q) ➔P

  P ➔ R

  Q ➔ R

- A horn clause reasoner is unable to prove that either P or Q is necessarily true or false
- And can not show that R must be true

Open- vs. closed-world assumption

- Logic Programming – CWA
  - If KB $\not\models$ *a*, then KB = KB ∪ ¬*a*
- Classical Logic – OWA
  - It keeps the world open.
  - KB:

    Man ⊑ Person, Woman ⊑ Person

    Bob ∈ Man, Mary ∈ Woman

  Query: “find all individuals that are not women”

Non-ground entailment

- The LP-semantics is defined in terms of minimal Herbrand model, i.e. sets of ground facts
- Because of this, Horn clause reasoners can not derive rules, so that can not do general subsumption reasoning

Decidability

- The largest obstacle!
  - Tradeoff between expressiveness and decidability.
- Facing decidability issues from 2 different angles
  - In LP: Finiteness of the domain
  - In classical logic (and thus in DL): Combination of constructs
- Problem:

  Combination of “simple” DLs and Horn Logic are undecidable. (Levy & Rousset, 1998)

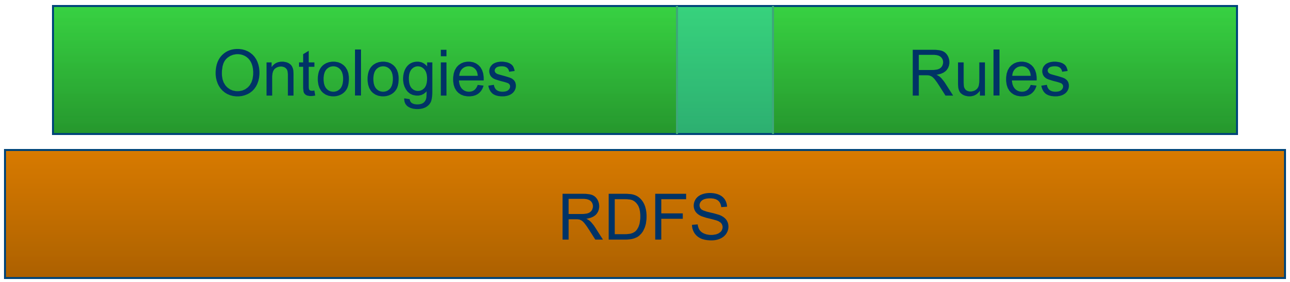
Rules + Ontologies

- Still a challenging task!
- A number of different approaches exists:

  SWRL, DLP (Grosof), dl-programs (Eiter), DL-safe rules, Conceptual Logic Programs (CLP), AL-Log, DL+log
- Two main strategies:
  - Tight Semantic Integration (Homogeneous Approaches)
  - Strict Semantic Separation (Hybrid Approaches)

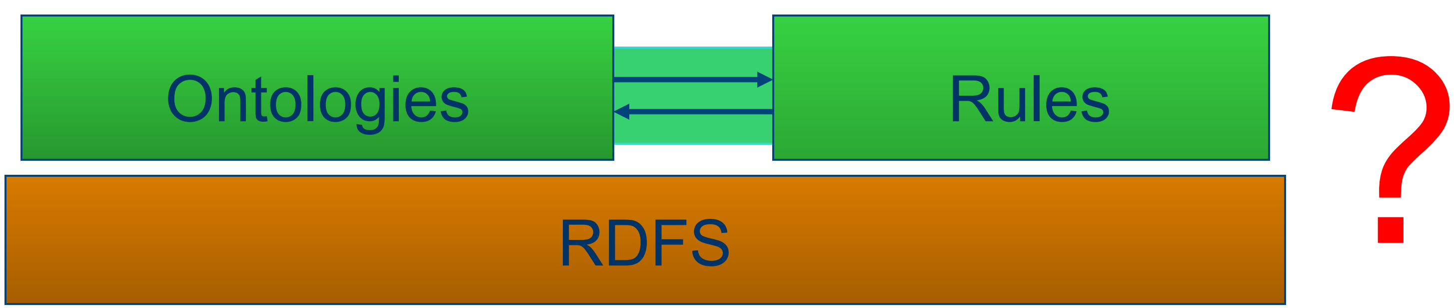
Homogeneous Approach

- Interaction with tight semantic integration
- Both ontologies and rules are embedding in a common logical language
- No distinction between rule predicates and ontology predicates
- Rules may be used for defining classes and properties of the ontology
- Example: SWRL, DLP



Hybrid Approach

- Integration with strict semantic separation between the two layers
- Ontology used to conceptualize the domain
- Rules can't define ontology classes and properties, but some application-specific relations
- Communication via a "safe interface"
- Example: answer set programming (ASP)



The Essence of DLP

- Simplest approach for combining DLs with Horn logic: their **intersection**
  - the Horn-definable part of OWL, or equivalently
  - the OWL-definable part of Horn logic
- The OWL 2 RL profile is the DLP part of OWL

Advantages of DLP

- **Modeling**: Freedom to use either OWL or rules
  - and their associated tools and methodologies
- **Implementation**: use either description logic reasoners or deductive rule systems
  - extra flexibility, interoperability with a variety of tools
- **Expressivity**: existing OWL ontologies frequently use few constructs outside DLP

RDFS and Horn Logic

Statement(a,P,b)	P(a,b)
type(a,C)	C(a)
C subClassOf D	$C(X) \rightarrow D(X)$
P subPropertyOf Q	$P(X,Y) \rightarrow Q(X,Y)$
domain(P,C)	$P(X,Y) \rightarrow C(X)$
range(P,C)	$P(X,Y) \rightarrow C(Y)$

OWL in Horn Logic

C sameClassAs D	$C(X) \rightarrow D(X)$
	$D(X) \rightarrow C(X)$
P samePropertyAs Q	$P(X,Y) \rightarrow Q(X,Y)$
	$Q(X,Y) \rightarrow P(X,Y)$

OWL in Horn Logic (2)

transitiveProperty(P)	P(X,Y), P(Y,Z) → P(X,Z)
inverseProperty(P,Q)	Q(X,Y) → P(Y,X)
	P(X,Y) → Q(Y,X)
functionalProperty(P)	P(X,Y), P(X,Z) → Y=Z

OWL in Horn Logic (3)

(C1 $\cap$ C2) subClassOf D

- C1(X), C2(X) $\rightarrow$ D(X)

C subClassOf (D1 $\cap$ D2)

- C(X) $\rightarrow$ D1(X)
- C(X) $\rightarrow$ D2(X)

OWL in Horn Logic (4)

(C1∪ C2) subClassOf D

- $C1(X) \rightarrow D(X)$
- $C2(X) \rightarrow D(X)$

C subClassOf (D1 ∪ D2)

- Translation not possible!
- C → D1 or D2

OWL in Horn Logic (5)

C subClassOf AllValuesFrom(P,D)

- C(X), P(X,Y) → D(Y)

AllValuesFrom(P,D) subClassOf C

- Translation not possible!

OWL in Horn Logic (6)

C subClassOf SomeValuesFrom(P,D)

- Translation not possible!
- $C(X) \rightarrow P(X,Y), D(Y)$

SomeValuesFrom(P,D) subClassOf C

- $D(X), P(X,Y) \rightarrow C(Y)$

OWL in Horn Logic (7)

- MinCardinality cannot be translated due to existential quantification
- MaxCardinality 1 may be translated if equality is allowed
- Complement cannot be translated, in general

SWRL

- Semantic Web Rule Language
- SWRL is the **union** of DL and horn logic + many built-in functions (e.g., math)
- Submitted to the W3C in 2004, but failed to become a recommendation
  - W3C pursued a more general solution: RIF
- Problem: full SWRL specification leads to undecidability in reasoning
- SWRL is well specified and subsets are widely supported (e.g., in Pellet, HermiT)

SWRL

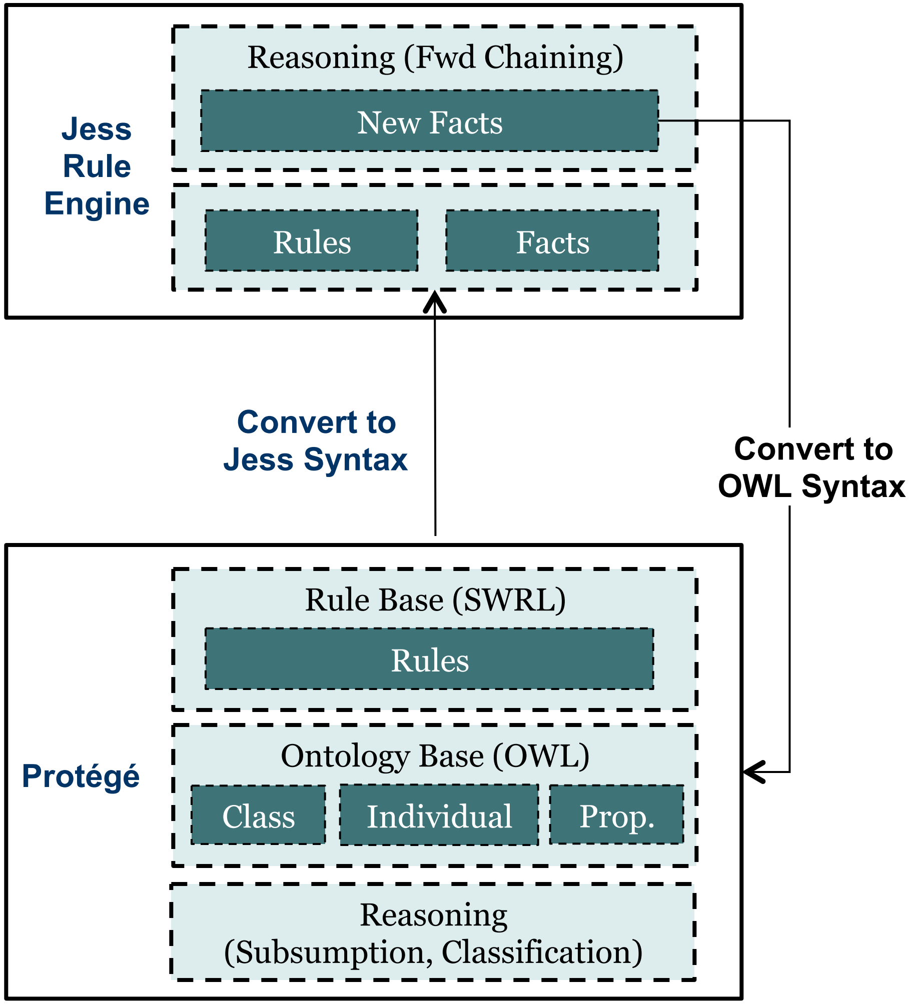
- OWL classes are unary predicates, properties are binary ones

  Person(?p) ^ sibling(?p,?s) ^ Man(?s) → brother(?p,?s)

- Bulit-ins can be booleans or do a computation and unify the result to a variable
  - swrlb:greaterThan(?age2, ?age1)
  - swrlb:subtract(?n1,?n2,?diff)
- There are also OWL axioms and data tests
  - differentFrom(?x, ?y), sameAs(?x, ?y), xsd:int(?x), [3, 4, 5](?x), …

SWRL in Protege

- Protégé 4.x has minimal support for SWL
  - You add/edit rules, some reasoners (Pellet, HermiT) use them
- Protégé 3.x has Jess, an internal rules engine
  - Jess is a production rule system with a long ancestry
- And good tools for editing, managing and using rules
- See the SWRL tab



SWRL architecture for Protégé 3.x

The Essence of SWRL

- Combines OWL DL (and thus OWL Lite) with function-free Horn logic
- Thus it allows Horn-like rules to be combined with OWL DL ontologies

Rules in SWRL

B1, . . . , Bn → A1, . . . , Am

A1, . . . , Am, B1, . . . , Bn have one of the forms:

- C(x)
- P(x,y)
- sameAs(x,y) differentFrom(x,y)

where C is an OWL description, P is an OWL property, and x,y are variables, OWL individuals or OWL data values.

Drawbacks of SWRL

- Main *source of complexity*:

  arbitrary OWL expressions, such as restrictions, can appear in the head or body of a rule

- Adds significant expressive power to OWL, but causes *undecidability*

  there is no inference engine that draws exactly the same conclusions as the SWRL semantics

SWRL Sublanguages

- SWRL adds the expressivity of DLs and function-free rules
- One challenge: identify sublanguages of SWRL with right balance between expressivity and computational viability
- A candidate OWL DL + *DL-safe rules*
  - every variable must appear in a non-description logic atom in the rule body

DL-safe rules

- (all?) reasoners support only DL-safe rules
  - Rule variables bind only to known individuals
- Example (mixing syntaxes):

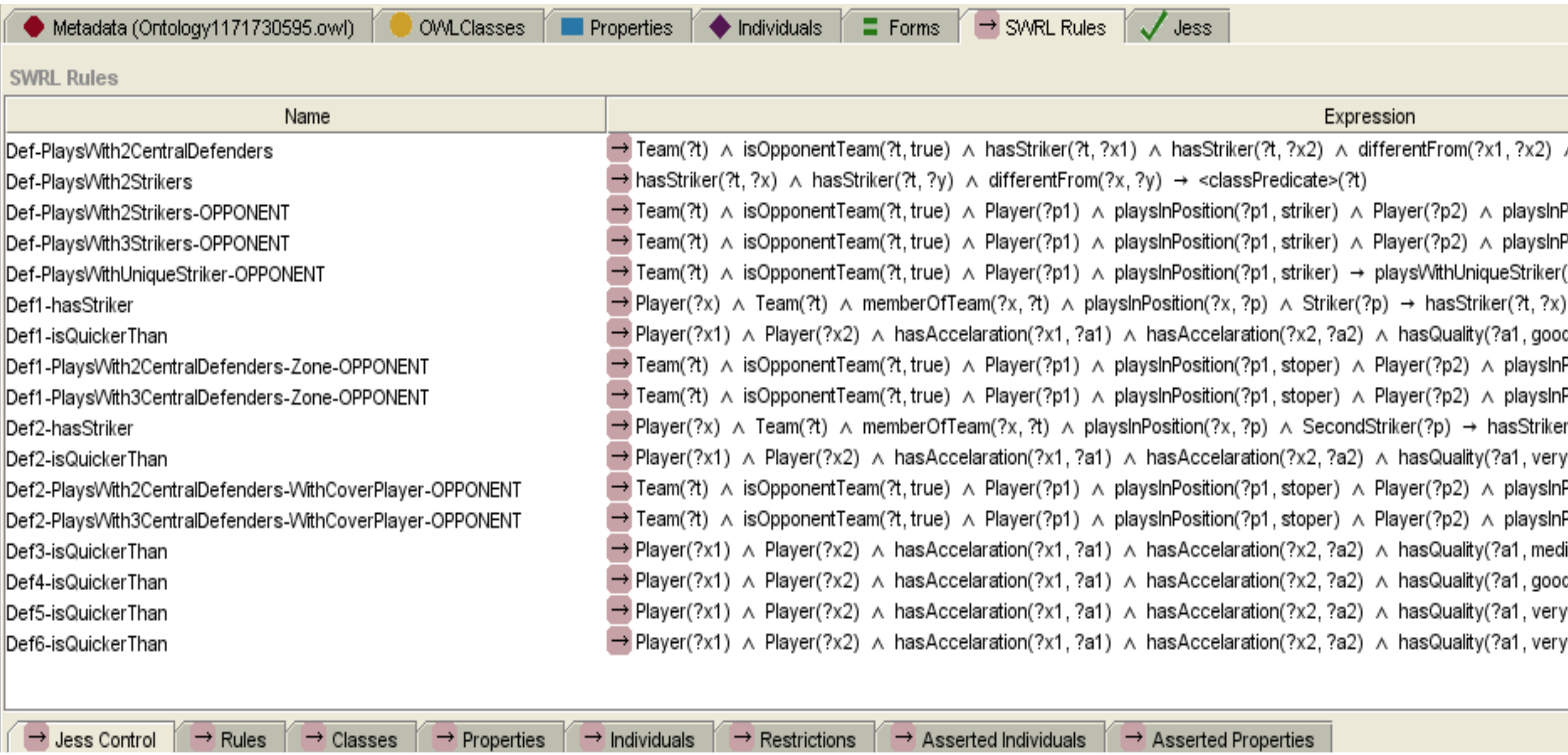
:Vehicle(?v) ^ :Motor(?m) ^ :hasMotor(?v,?m) -> :MotorVehicle(?v)

:Car = :Vehicle and some hasMotor Motor

:x a :Car

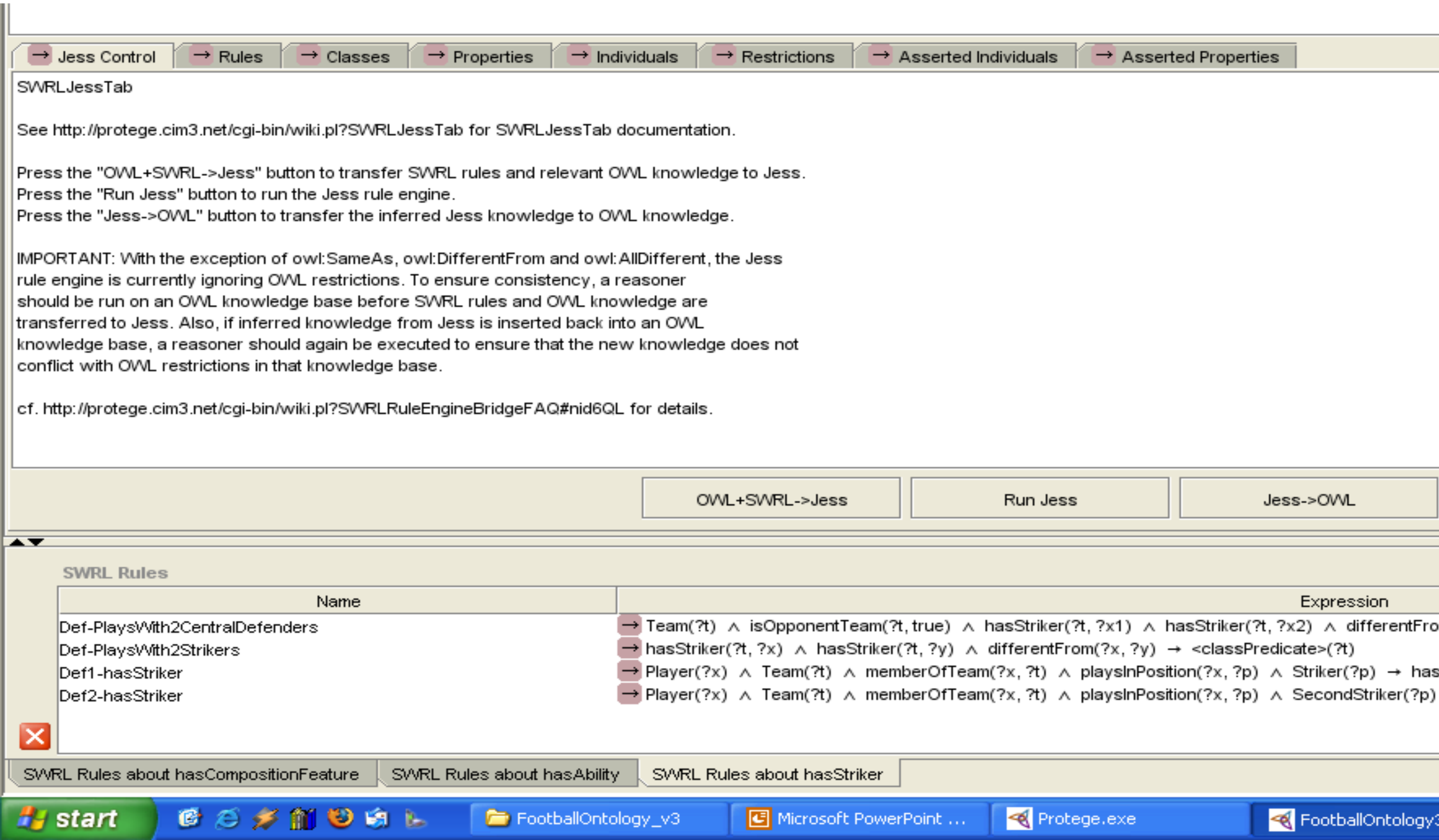
- The reasoner will not bind ?m to a motor since it is not a known individual

Protégé SWRL-Tab

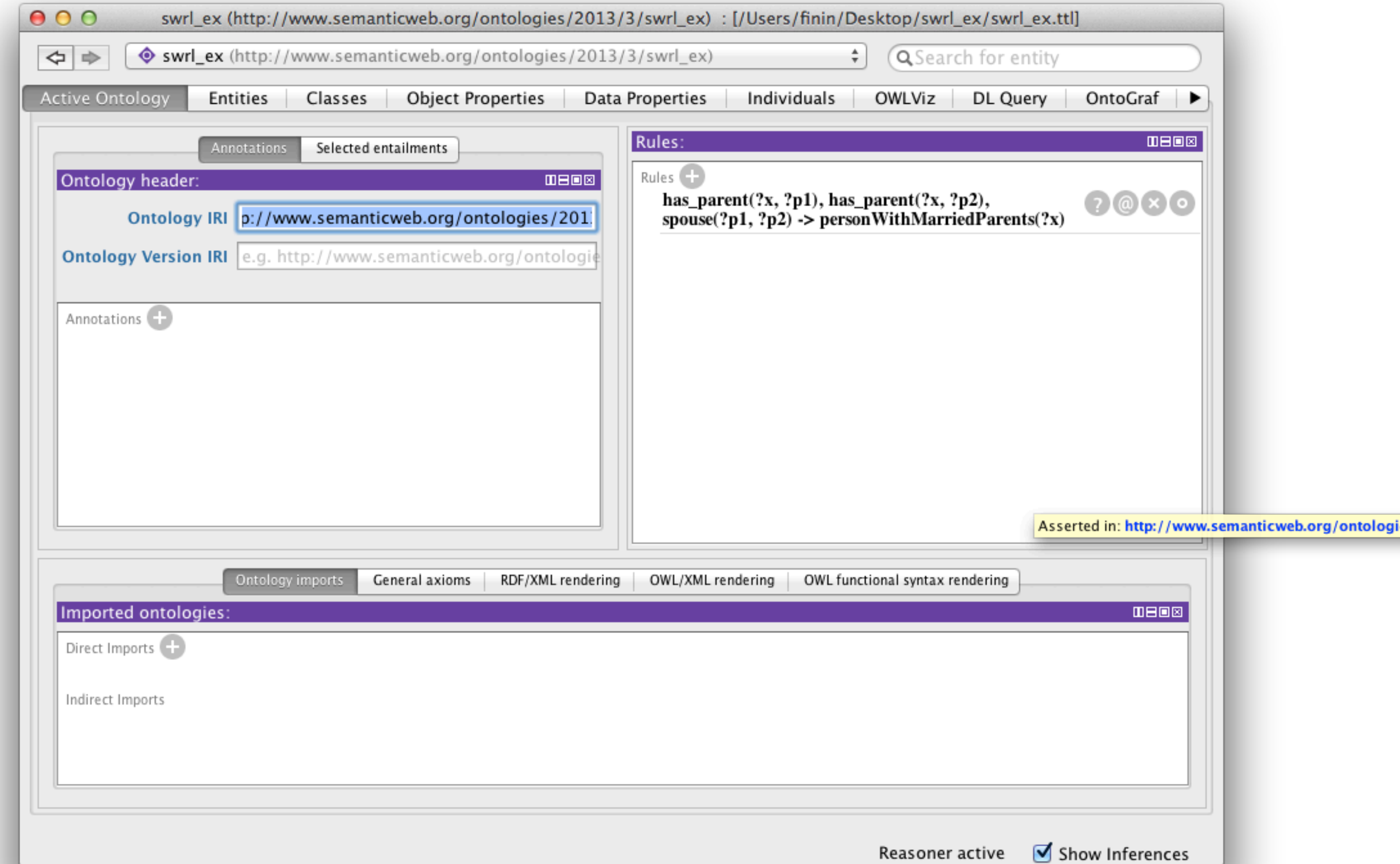


Name	Expression
Def-PlaysWith2CentralDefenders	Team(?t) ∧ isOpponentTeam(?t, true) ∧ hasStriker(?t, ?x1) ∧ hasStriker(?t, ?x2) ∧ differentFrom(?x1, ?x2) ∧
Def-PlaysWith2Strikers	hasStriker(?t, ?x) ∧ hasStriker(?t, ?y) ∧ differentFrom(?x, ?y) → <classPredicate>(?t)
Def-PlaysWith2Strikers-OPPONENT	Team(?t) ∧ isOpponentTeam(?t, true) ∧ Player(?p1) ∧ playsInPosition(?p1, striker) ∧ Player(?p2) ∧ playsInPo
Def-PlaysWith3Strikers-OPPONENT	Team(?t) ∧ isOpponentTeam(?t, true) ∧ Player(?p1) ∧ playsInPosition(?p1, striker) ∧ Player(?p2) ∧ playsInPo
Def-PlaysWithUniqueStriker-OPPONENT	Team(?t) ∧ isOpponentTeam(?t, true) ∧ Player(?p1) ∧ playsInPosition(?p1, striker) → playsWithUniqueStriker(?t
Def1-hasStriker	Player(?x) ∧ Team(?t) ∧ memberOfTeam(?x, ?t) ∧ playsInPosition(?x, ?p) ∧ Striker(?p) → hasStriker(?t, ?x)
Def1-isQuickerThan	Player(?x1) ∧ Player(?x2) ∧ hasAccelaration(?x1, ?a1) ∧ hasAccelaration(?x2, ?a2) ∧ hasQuality(?a1, good)
Def1-PlaysWith2CentralDefenders-Zone-OPPONENT	Team(?t) ∧ isOpponentTeam(?t, true) ∧ Player(?p1) ∧ playsInPosition(?p1, stoper) ∧ Player(?p2) ∧ playsInPo
Def1-PlaysWith3CentralDefenders-Zone-OPPONENT	Team(?t) ∧ isOpponentTeam(?t, true) ∧ Player(?p1) ∧ playsInPosition(?p1, stoper) ∧ Player(?p2) ∧ playsInPo
Def2-hasStriker	Player(?x) ∧ Team(?t) ∧ memberOfTeam(?x, ?t) ∧ playsInPosition(?x, ?p) ∧ SecondStriker(?p) → hasStriker(
Def2-isQuickerThan	Player(?x1) ∧ Player(?x2) ∧ hasAccelaration(?x1, ?a1) ∧ hasAccelaration(?x2, ?a2) ∧ hasQuality(?a1, veryG
Def2-PlaysWith2CentralDefenders-WithCoverPlayer-OPPONENT	Team(?t) ∧ isOpponentTeam(?t, true) ∧ Player(?p1) ∧ playsInPosition(?p1, stoper) ∧ Player(?p2) ∧ playsInPo
Def2-PlaysWith3CentralDefenders-WithCoverPlayer-OPPONENT	Team(?t) ∧ isOpponentTeam(?t, true) ∧ Player(?p1) ∧ playsInPosition(?p1, stoper) ∧ Player(?p2) ∧ playsInPo
Def3-isQuickerThan	Player(?x1) ∧ Player(?x2) ∧ hasAccelaration(?x1, ?a1) ∧ hasAccelaration(?x2, ?a2) ∧ hasQuality(?a1, mediu
Def4-isQuickerThan	Player(?x1) ∧ Player(?x2) ∧ hasAccelaration(?x1, ?a1) ∧ hasAccelaration(?x2, ?a2) ∧ hasQuality(?a1, good)
Def5-isQuickerThan	Player(?x1) ∧ Player(?x2) ∧ hasAccelaration(?x1, ?a1) ∧ hasAccelaration(?x2, ?a2) ∧ hasQuality(?a1, veryG
Def6-isQuickerThan	Player(?x1) ∧ Player(?x2) ∧ hasAccelaration(?x1, ?a1) ∧ hasAccelaration(?x2, ?a2) ∧ hasQuality(?a1, veryG

Protégé SWRL-Tab



SWRL in Protégé 4.2



Non-monotonic rules

- Non-monotonic rules use an “unprovable” operator
- This can be used to implement default reasoning, e.g.,
  - assume P(X) is true for some X unless you can prove hat it is not
  - Assume that a bird can fly unless you know it can not

monotonic

```
canFly(X) :- bird (X)
bird(X) :- eagle(X)
bird(X) :- penguin(X)
eagle(sam)
penguin(tux)
```

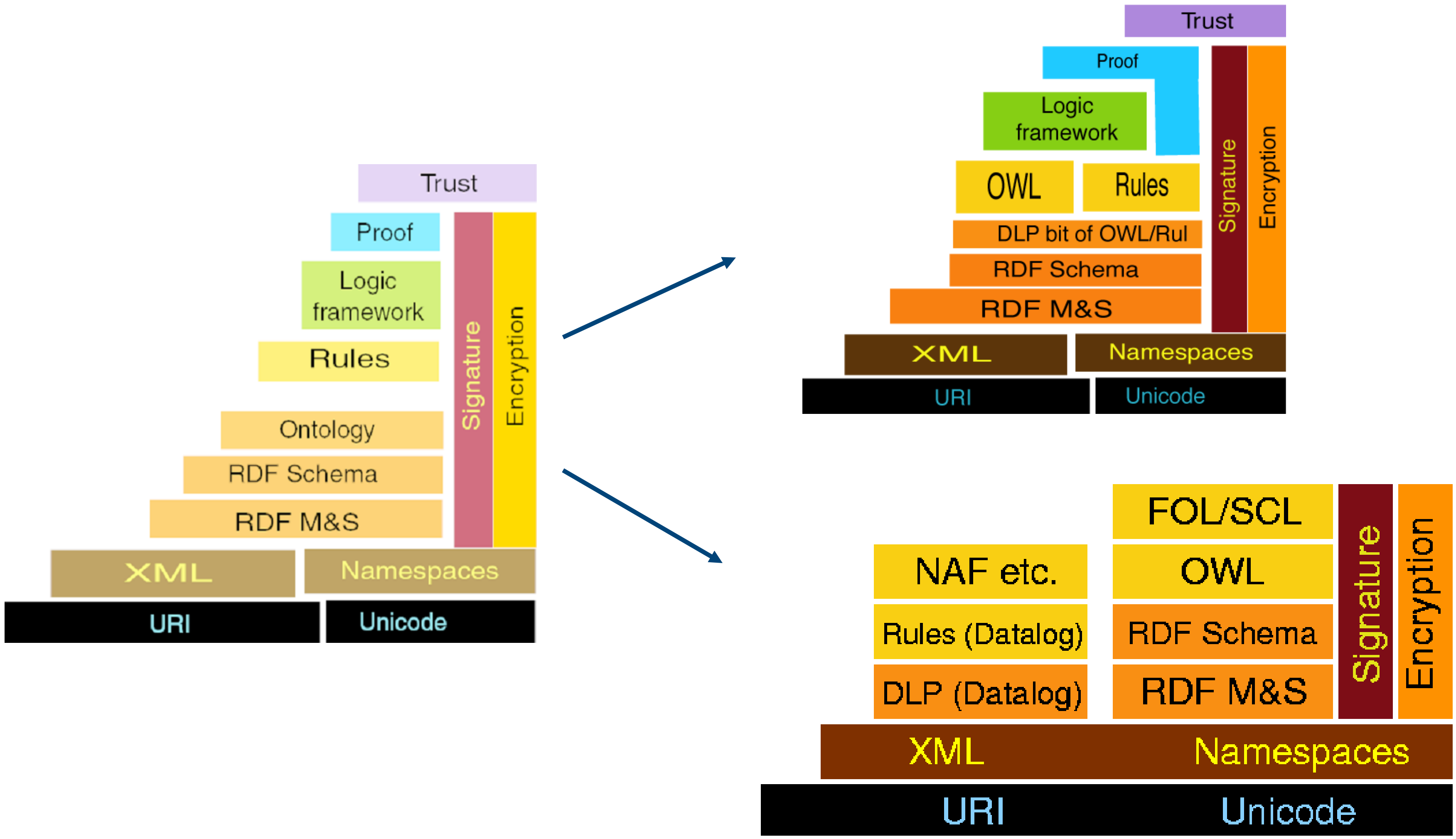
Non-monotonic

```
canFly(X) :- bird (X), \+ not(canFly(X))
bird(X) :- eagle(X)
bird(X) :- penguin(X)
not(canFly(X)) :- penguin(X)
eagle(sam)
penguin(tux)
```

Rule priorities

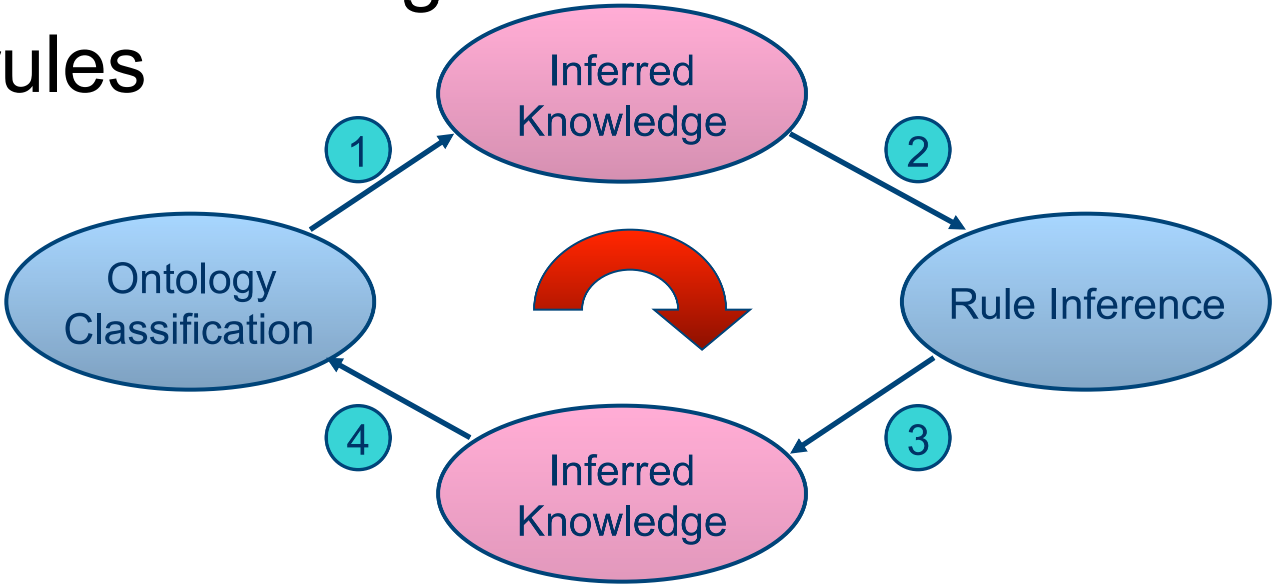
- This approach can be extended to implement systems where rules have priorities
- This seems to be intuitive to people – used in many human systems
  - E.g., University policy overrules Department policy
  - The “Ten Commandments” can not be contravened

Two Semantic Webs?



Limitations

- The rule inference support not integrated with OWL classifier
  - New assertions by rules may violate existing restrictions in ontology
  - New inferred knowledge from classification may produce knowledge useful for rules



Limitations

- Existing solution: solve possible conflicts manually
- Ideal solution: a single module for both ontology classification and rule inference
- What if we want to combine non-monotonic features with classical logic?
- Partial Solutions:
  - Answer set programming
  - Externally via appropriate rule engines

Summary

- Horn logic is a subset of predicate logic that allows efficient reasoning, orthogonal to description logics
- Horn logic is the basis of monotonic rules
- DLP and SWRL are two important ways of combining OWL with Horn rules.
  - DLP is essentially the intersection of OWL and Horn logic
  - SWRL is a much richer language

Summary (2)

- Nonmonotonic rules are useful in situations where the available information is incomplete
- They are rules that may be overridden by contrary evidence
- Priorities are sometimes used to resolve some conflicts between rules
- Representation XML-like languages is straightforward