Semantic Web: Schism of the Languages

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Where is Stony Brook?

Outline

- What is the Semantic Web?
- Ontologies: Conceptual models of the Semantic Web
- Semantic Web languages
  - Description Logic
  - Rule-based languages
  - The nature of the schism
  - Rule Interchange Format (RIF)
- Conclusions
  - Problems
  - Outlook

What is Semantic Web?

- Electricity of the 21st Century:

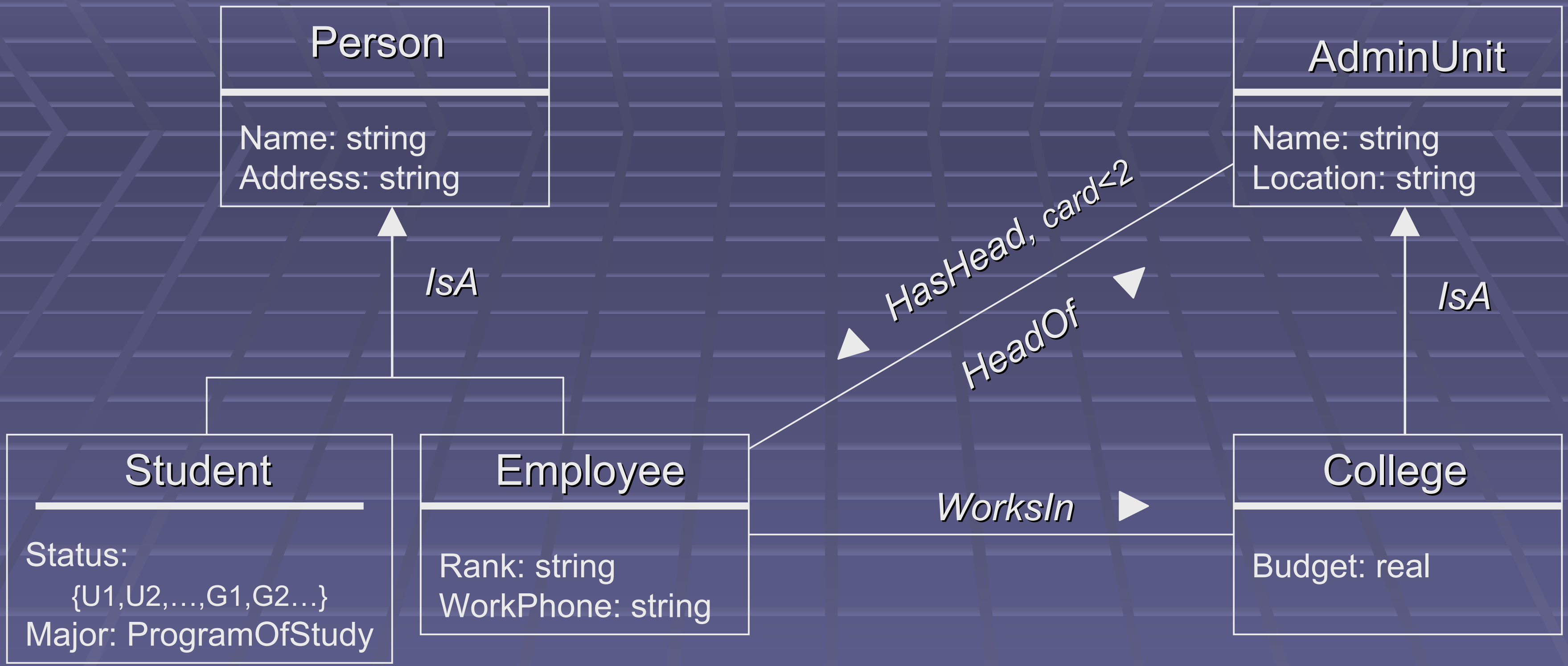
  Machine-*understandable* information everywhere

- Semantically meaningful search
  - Suggest fine restaurants *according to **X** taste* within *walking distance* from *Y*
- Semantic Web services: Software agents doing useful stuff for us autonomously
  - Organize my trip to **X**, **Y**, **Z**, back to **W** for 3 days, and leave one morning for a meeting in **V**. Need to be in **T** by date **D**. Take care of the tickets, hotels, transportation, visas, etc.

The Silver Bullet of the Semantic Web

- Ontologies
  - A database schema (like E-R)
    - Classification hierarchies
    - Typing
    - Constraints
  - … and some more
    - concept human is *same-as* concept person
    - property prerequisite is *transitive*
    - property spouse is *symmetric*

An Ontology



- The definitional part
  - Dean = *HeadOf* of College
  - GradStudent = Student with Status $\in$ {G1,…,G5}
  - *HasHead* = inverse of *HeadOf*
  - … … …

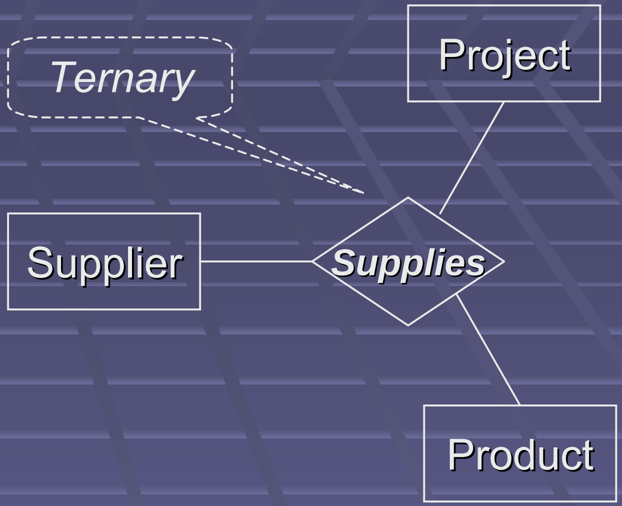
Why Ontologies?

- They give precise meaning to terms (concepts, properties) in an application domain.
- => applications can talk to each other
  - can *unambiguously* interpret the info they exchange
  - even if they use different ontologies

=> *semantic interoperability*

Beyond Ontologies

- Need more than just unary (*classes*) and binary (*properties*) predicates
  - E-R diagrams go further than ontologies in this respect
- Need machinery for defining more complex concepts & properties
- Need more than just concepts and properties
  - Processes (e.g., for Web services)
  - Authorization schemes (can be very complex)
  - Networks of trust



PreferredSupplier(?Supplier, ?Product)
if ?Supplier *Supplies* ?Product to another project within same organization and …

How are Ontologies Represented?

- Description logic (DL)
  - Subset of classical logic (dates back to late 70's: *KL-1*, Brachman et. al.)
  - W3C standard, *OWL-DL* – Web Ontology Language, is based on a description logic called SHOIN(D)
  - Pros:
    - Predictable complexity
    - Sometimes can do surprisingly non-trivial reasoning
  - Cons:
    - Can be awkward to use (strange, highly controlled language)
    - Quite limited

      => Declarative ontologies are processed with Java
    - Little experience with real life problems

How are Ontologies Represented?

- Rule-based languages
  - Pros:
    - Typically much easier to use than DL, more expressive
      (where it counts for a man-on-the-street)
    - Efficient implementations
    - Vast experience with real life problems
    - Complete applications can be built declaratively
  - Cons:
    - No standard, variety of semantics
      - W3C has established a Rule Interchange Format working group
    - Has limitations in expressivity compared to DL in some areas

Overview of Description Logic

- *Primitive Concepts* – unary predicates; define objects that populate concepts
  - E.g., *Student, Employee*
- *Properties of objects* – binary predicates:
  - E.g., *HasName(john, 'John Doe')*
- *Objects* – constants:
  - E.g., *John, Mary*
- *Terminological descriptions*: T-Box
  - Expressions for constructing new concepts:
    - E.g., graduate-students-who-took-2-or-more-courses
  - Assertions about relationships between concepts
    - E.g., spouse is a symmetric relationship

Overview of Description Logic (cont'd)

- *World descriptions*: A-Box
  - Assertions about individuals being members of classes (concepts) or having properties
    - E.g., *Mary* $\in$ *Student, John hasAge 44*
- *Inference*
  - Whether a concept definition is satisfiable
  - Whether some concept is a sub-concept of another
  - Whether two concepts are disjoint
  - *In a sufficiently rich DL, the above three are equivalent*

DL Terminological Descriptions – Constructors

A (Student)	*Name of a concept*
$\top$, $\bot$	*Anything, Nothing*
$\neg$C $\neg$Student	*Not* C (where C is a concept expression) *Non-students*
C $\sqcap$ D, C $\sqcup$ D Student $\sqcap$ Employee	C *intersect* D, C *union* D Students who are employees
$\forall$ *Prop*.Concept $\forall$ *Color*.BrightColor	Concept defined as {x | x.*Prop* $\subseteq$ Concept} Brightly-colored things
$\exists$ *Prop*.Concept	Concept defined as {x | x.*Prop* $\cap$ Concept $\neq$ ø}
$\leq$n Prop.Concept $\leq$3 *Publication*.GoodPaper	{x | numberOf(x.*Prop* $\cap$ Concept) $\leq$ n} People who wrote less than 4 good papers
$\geq$n *Prop*.Concept	{x | numberOf(x.*Prop* $\cap$ Concept) $\geq$ n}
Prop$^-$, *Prop*$_+$	Inverse of *Prop*, transitive closure of *Prop*

DL Terminological Assertions

$C \subseteq D$ Student $\subseteq$ ($\exists$ *Takes*.Class)	All objects of concept C are also in D All student take classes
Prop1 $\subseteq$ *Prop2* *hasSon* $\subseteq$ *hasChild*	*Prop1* is a subproperty (subrelation) of *Prop2* *one who has sons has children as well*
$C = D$	C and D are the same property ($C \subseteq D$ & $D \subseteq C$), where C is a concept name. Usually used in definitions of new concepts
Prop1 = *Prop2*	*Prop1* $\subseteq$ *Prop2* and *Prop2* $\subseteq$ *Prop1*. Usually used for definitions of new properties
Prop in $\textbf{Roles}_{+}$	*Prop* is transitive

World Descriptions (A-Box)

College(engineering)	engineering is a kind of a college in a university
headOf(bob, engineering)	bob manages the engineering college
hasHead(engineering, bob)	engineering college has bob as manager

Ontological Knowledge in DL

- Concept of a Dean:

  Dean = $\exists$ *Manages*.College

- Mother:

  Mother = Woman $\sqcap$ $\exists$ *HasChild*.Person

- Student is a subclass of Person:

  Student $\subseteq$ Person

“Surprises” with DLs

- Can be awkward
  - Concept of “Grandmother”

    Grandmother =

    Person $\sqcap$ Female $\sqcap$ $\exists$ hasChild.($\exists$ hasChild.Person)
- Insufficiently expressive
  - Concept of “Uncle” (cannot be expressed in DL)

    $\forall$X,Y,Z (Uncle(X,Y) <-> Brother(X,Z) & Parent(Z,Y))

DL Reasoning

- Can answer hard questions
  - *Terminological* (*potentially* useful for integration of information, schema checking, query optimization)
    - Whether $\text{ConceptExpr}_1 \subseteq \text{ConceptExpr}_2$
    - Whether ConceptExpr is satisfiable
      - NExpTime for OWL-DL (the most popular DL)
  - *Query answering* (most common use)
    - Whether a concrete individual x belongs to ConceptExpr
    - Find all x such that ConceptExpr(x) is entailed by the ontology
- Query answering not really scalable

OWL (Web Ontology Language)

- *OWL-DL*
  - The most-used dialect of OWL
  - Includes more or less the above mentioned DL constructs with restrictions (e.g., no cardinality constraints on transitive properties)
- *OWL-Full*
  - Attempt to make OWL compatible with RDFS (Resource Description Framework Schema), an earlier *ill-conceived* standard
  - Terminological reasoning undecidable
  - Not used that much
- OWL-Lite
  - A simpler subset of OWL-DL
  - Rarely used

Rule Languages

- Ontologies are represented as facts + rules
  - Terminological descriptions

    subclass(Student, Person)

    $\forall$?M?C Mother(?M,?C) <- Woman(?M) & hasChild(?M,?C) & Person(?C)

    $\forall$?U?P?F Uncle(?U,?P) <- Father(?F,?P) & Brother(?U,?F)

    Types: Mother(Woman,Person)
    Father(Man,Person)

  - World descriptions

    father(John,Bob)
    hasChild(Mary,Bob)

Rule-based Reasoning

- *Terminological*
  - Whether $\text{Concept}_1 \subseteq \text{Concept}_2$
  - Whether Concept is satisfiable
    - Both problems are undecidable in general
    - But $\text{Concept}_1 \subseteq \text{Concept}_2$ or nonempty(Concept)

    <u>*in a particular* world</u> is polynomial time in the size of the data
- *Query answering*
  - Whether $x \in$ Concept, x - individual
  - Find all x such that $x \in$ Concept is entailed by the ontology
    - Both polynomial (in the size of the data), very scalable

Weaknesses of Rule Systems

- Existential information

  Every person has a father

  $\forall$?P$\exists$?F Father(?P,?F) <- Person(?P)

  cannot be expressed directly in a rule-based language

- For most purposes existentials can be *approximated* with Skolem functions

  $\forall$?P Father(?P, _#(?F)) <- Person(?P)

  _# is a unique new function symbol

- Even harder to represent disjunctive information

  Example: Dead(John) or Alive(John)

The Nature of the Schism

- Rule-based and DL languages may appear very close – even syntactically
- But they are very different semantically:
  - DL is a subset of classical logic
  - Rule-based languages have certain capabilities of the second-order logic
    - despite deceptively first-order-looking syntax!

The Schism: A Travel Example

take-a-flight(?From,?To) <- flight(?From,?To)

take-a-train(?From,?To) <- not flight(?From,?To)

flight(London,Edinburgh)

flight(London,Amsterdam)

Query: take-a-train(London,Bristol) ?

In classical logic:

can only derive take-a-train(London,Bristol) or flight(London,Bristol)

- *Cannot* derive take-a-train(London,Bristol)

In rule-based logics:

Cannot derive flight(London,Bristol) ?

-> *conclude* not flight(London,Bristol)

-> *derive* take-a-train(London,Bristol)

The Logic of Rules

- The kind of non-classical reasoning used by rule languages is variously known as
  - Default Negation
  - Negation as failure (NAF)
  - Closed-world assumption (CWA)
  - Common-sense reasoning
  - Nonmonotonic logic
- Precise formalization is not exactly trivial, and there is more than one

The Logic of Rules (cont'd)

- Can CWA be simulated in classical logic?

  take-a-flight(?From,?To) <-> flight(?From,?To)

  take-a-train(?From,?To) <-> not flight(?From,?To)

  flight(London,Edinburgh)

  flight(London,Amsterdam)

  - now can derive

    not flight(London,Bristol)

    take-a-train(London,Bristol)

  … as if using CWA

- This can be done in *some* cases but *not in general*

The Logic of Rules (cont'd)

- Transitive closure

  trip(?From,?To) <- flight(?From, ?To)

  trip(?From,?To) <- trip(?From,?Mid) and trip(?Mid,?To)

- In classical logic: trip is transitive & contains flight
- In rule languages: trip ≡ *transitive closure* of flight
- Transitive closure *cannot* be expressed in classical logic
- The semantics of rule languages is based on minimal models and preference relations among them

Bridging the Schism

- … and a war was ranging
- Proposed ways out
  - MKNF – Autoepistemic logic of Minimal Belief and Negation as Failure (Lifschitz, 1991)
    - Motik&Rosati 2006
  - Oracle-based solutions – treat DL-based ontologies as black boxes
    - Eiter et. al. 2003/4
  - Autoepistemic Logic
    - De Bruijn et al., 2006

But Schism Not Going Away

- Combining rules and ontologies for what?
- What is the role of rules and of DL reasoning in the grand schema of things?
  - Does DL's A-box reasoning make sense?
  - DL's for schema reasoning – rules for querying data?
  - Dual use of DL's T-box (Motik):
    - Classical for schema reasoning
    - Nonclassical (together with rules) for querying
- Danger of over-selling wrong technologies for wrong tasks

Enter the Rule Interchange Format (RIF)

- Rules landscape is fragmented:
  - Too many kinds of rules
  - Too many syntaxes
  - Too many semantics
  - Too many commercial interests
  - Most industrial uses of rules are not based on sound logical theories
- Only hope is to be able to exchange rule sets “of the same kind” through a common well-defined language (RIF)

RIF Highlights

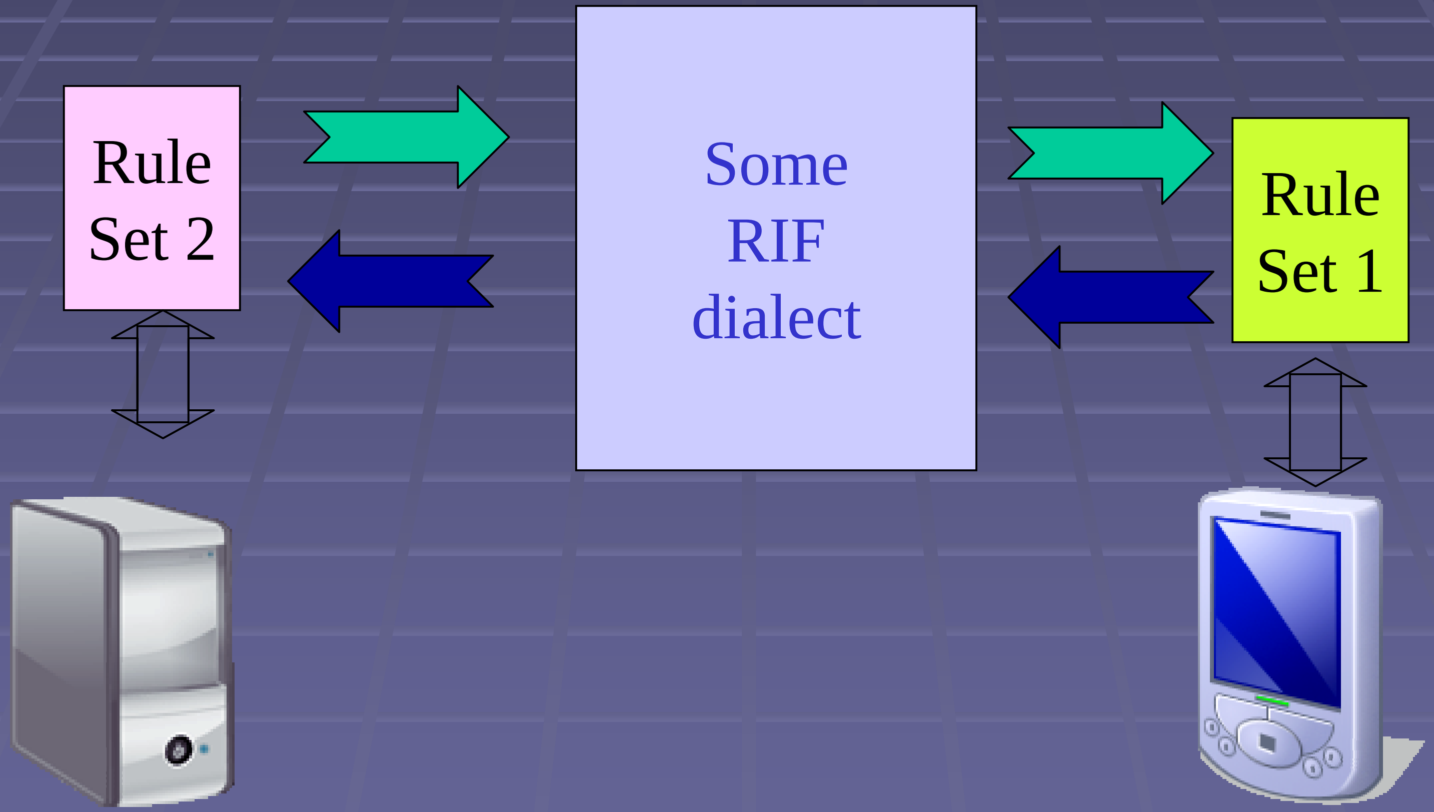
- Well-defined syntax and semantics
- RIF Core
- RIF Dialects extending the core
  - Rule sets to be exchanged through dialects in semantics-preserving ways
- Some may choose to use RIF as an actual language and not just an exchange medium

Schism May Widen

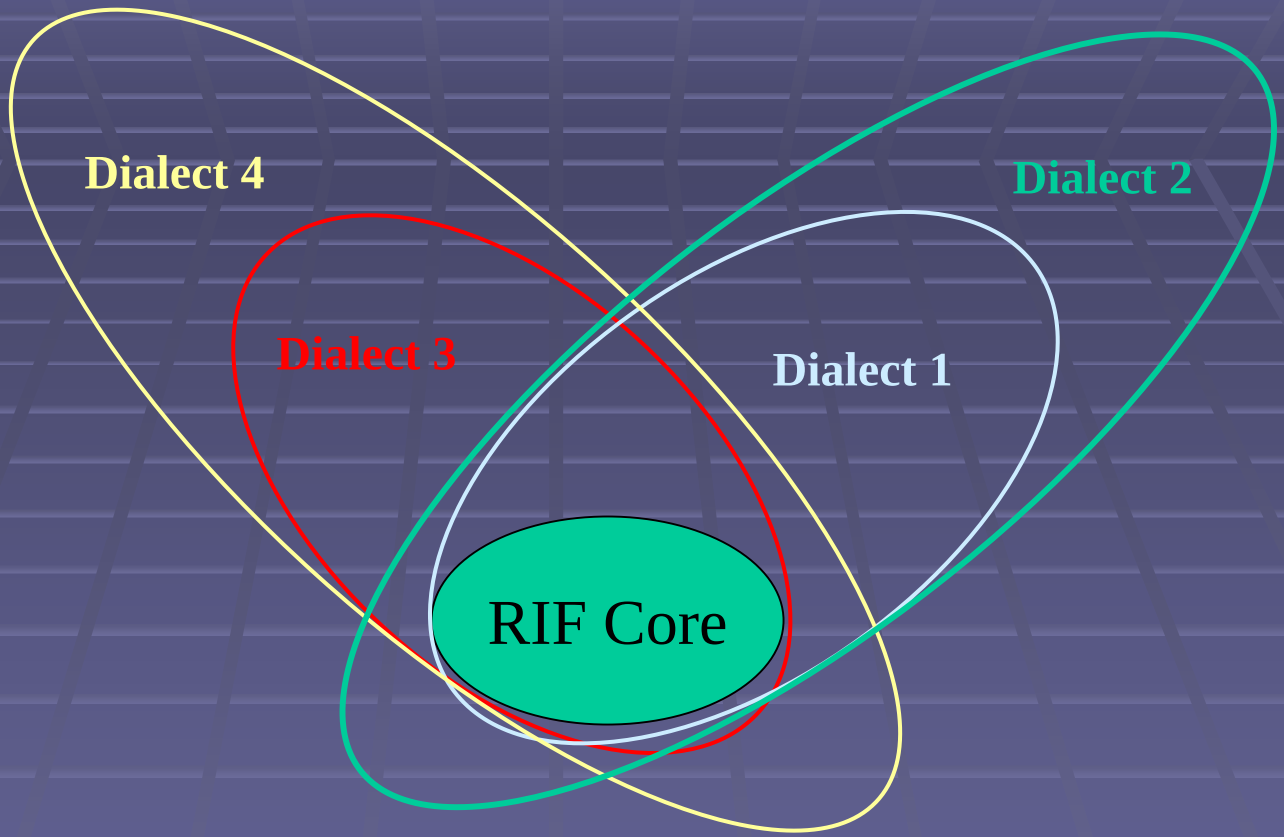
- OWL may add some rules
  - Will solve the “uncle” problem, but loose decidability

- RIF will have loosely coupled interface to OWL
  - Probably Eiter et. al.-like
  - People will figure out how to use both
  - RDF will be integrated more tightly – through F-logic like frames

How Will RIF Work?



RIF Dialects



- Each dialect must have precise syntax & semantics
- Dialects can extend each other
- All must extend the core (both syntactically and semantically)

RIF Core

- Basically Horn clauses with extensions
  - Most notably: frames a la F-logic
- A Web language
  - URIs as constants, concepts, etc.
  - Support for XML data types
- First draft (WD1) – released end of April 2007
  - Boley & Kifer – technical editors
- Other drafts: Use Cases and Requirements – published earlier

Planned RIF Dialects

- Committed to eventually support roughly the following kinds of dialects:
  - PR: production rules (interest from the industry)
  - ECA rules (trigger-like)
  - LP: a logic programming-based dialect
  - FO: first-order logic (some kind of)
  - Constraints
  - HiLog like higher-order extensions

Research Issues

- Practical unification of knowledge representation with DL and Rules – still very much an open problem
- Uncertain and inconsistent information coming from different sources
- Algorithms and approaches for scalable inference on the Web
  - Massive amounts of data and rules
- Making logic accessible to domain experts (who are not logicians)
  - High-level logic languages, like F-logic, etc.
  - Visual editors for creating ontologies and rules
  - Generation of explanations for inference
- Finding a killer application!

Research Issues (cont'd)

- Information integration
  - Query subsumption:
    - whether Ontology $\models$ $Query_1$ -> $Query_2$ for a given Ontology
    - or whether Ontology $\models$ $Query_1$ -> $Query_2$, $\forall$Ontology
  - These problems are undecidable in general; many special cases have high complexity
  - Challenge is to identify useful decidable classes of ontologies/queries
  - Useful classes with low complexity
- Modeling exceedingly complex application domains like Web services (see next)

What is a Semantic Web Service?

- A good candidate for the "killer application" that will make the semantic Web a must-have
- Research issues in Semantic Web Services
  - *Advertising and discovery*
    - Logical service descriptions will enable agents (people, other services) to discover services that can potentially fulfill given needs
  - *Contracting*
    - Logic-based descriptions of the legal obligations of parties. Will potentially require legislation to enforce such contracts
  - *Process modeling & enactment*
    - Will enable automatic composition, invocation, and monitoring of services

Outlook

- OWL - 1st step towards the Semantic Web
- Clear that rules are coming in the form of RIF
- Must understand how these two *should* work together in practice (not just how they *could* work)
- Cause for optimism:

  Strong industrial interest & participation in virtually all aspects of the Semantic Web
  - OWL
  - RIF
  - Semantic Web Services

Questions?