Knowledge-Based Systems and Deductive Databases

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11.1 Reasoning with Ontologies
11.2 Semantics in RDF
11.3 SPARQL
RDF (Resource Description Framework) is a markup language to encode knowledge

- Knowledge is represented by triples
  - Triples are simple propositions consisting of subject, predicate, and object
  - Each triple part is either a literal or a resource
  - Each resources is given by an URI references
  - Each URI represents a given entity or concept

- e.g.:
  - mdb:BruceWillis mdb:played_in mdb:DieHard
• RDF documents thus represent graphs of labeled nodes and edges

• RDF itself does not pose any restriction on the used labels
  – Each syntactically correct URI or literal can be used
  – RDF/S is needed for defining valid resources
• **RDF/S** is used to define the **vocabulary** used in RDF graphs
  
  – Can define **classes** and **properties**, etc
  
  – Typically, an RDF graph only states propositions on instances of classes defined by the RDF/S it uses
  
  – RDF/S introduces already some predefined **relationships** (predicates) on classes and thus instances
    
    • Sub-classes, sub-properties, ranges, domains, etc…
11.1 Ontologies

• RDF statements represent formal knowledge in a certain domain and thus the abstracted reality
  – New information can be gathered by combining RDF statements in a suitable way
  – Example:

    \[ \text{St. Bernard} \overset{\text{is_a}}{\longrightarrow} \text{dog} \overset{\text{makes_sound}}{\longrightarrow} \text{‘wuff’} \]
    
    \[ \rightarrow \text{St. Bernard dogs bark!} \]

• The network of relationships created by those statements is called an ontology
11.1 Ontologies

• An ontology is a **formal representation of**…
  – A set of concepts within a domain
  – And the relationships between those concepts

• It can be used…
  – To **define** a domain
  – And to **reason about** the properties of that domain

• Lies on top of the basic RDF representation layer of the Semantic Web stack
Science and philosophy always strived to explain the world and the nature of being

First formal school of studies: Aristotle’s metaphysics (‘beyond the physical’, ca. 360 BC)

Traditional branches of metaphysics

- Ontology (λόγος: word, science and ὄντος: of being)
  - Study of being and existence
- Natural theology
  - Study of God, nature and creation
- Universal science
  - “First Principles”, logics
• **Ontology** tries to describe everything which *is* (exists), and it’s relation and categorization with respect to other things in existence

  – What is *existence*? Which *things* exist? Which are *entities*?
  – Which *entities* are fundamental?
  – What is a *physical object*?
  – How do the *properties* of an object relate to the object itself? What features are the *essence*?
  – What does it means when a physical object exists?
  – What constitutes the *identity* of an object?
  – When does an object *go out of existence*, as opposed to merely *change*?
• Parts of metaphysics evolved into natural philosophy
  – Study of nature and the physical universe
  – In the late 18\textsuperscript{th} century, it became just ‘science’
  – Ontology is still a dominant concept in science
    • Representation of all knowledge about things
11.1 Early Ontologies

• **Ars Generalis Ultima**
  – Created in 1305 by Ramon Llull
  – Ultimate solution for the **Ars Magna** (Great Art)
    • Mechanical combination of terms to create knowledge
    • Basic hope: all facts and truths can be created in this way
  – Heavy use of the **Tree of Knowledge**
    • Tree structure showing an hierarchy of philosophical concepts
    • Together with various “machines” (paper circles, charts, etc.) reasoning was possible
11.1 Early Ontologies

- **Taxonomies** (τάξις: arrangement, νόμος: law) are part of ontology
  - Groups things with similar properties into **taxa**
  - Taxa are put into an **hierarchical structure**
    - Hierarchy represents **supertype-subtype** relationships
    - Represents a **specialization** of taxa, starting with the most general one
11.1 Early Ontologies

- Example: **Linnaean Taxonomy**
  - Classification of all living things by Carl von Linné in 1738
  - Classification into multiple hierarchy layers
    - Domain, Kingdom, Phylum, Subphylum, Class, Cohort, Order, Suborder, Infraorder, Superfamily, Family, Genus, Species
  - Each layer adds additional properties and restrictions
11.1 Early Ontologies

- **Domain: Eukaryotes**
  - Organisms having cell membranes

![Diagram of Eukaryote classification]

- **Kingdom**
  - Protists
  - Fungi
  - Animals
  - Plants

- **Sub-Domains**
  - Chromalveolata
  - Opisthokonta
  - Archaeplastida (Plantae)

- **Relevant Domains**
  - Eubacteria
  - Archaea

- **Notes**
  - Identified as organisms having cell membranes and eukaryotic structure.
11.1 Early Ontologies

- **Example: Red Squirrel**  
  (*Binomial Name: Tamiasciurus hudsonicus*)
  
  - **Kingdom:** Animals
  - **Phylum:** Chordata (with **backbone**)
  - **Class:** Mammalia (with backbone, **nursing its young**)
  - **Order:** Rodentia (backbone, nursing its young, **sharp front teeth**)
  - **Suborder:** Sciuromorpha (backbone, nursing its young, sharp front teeth, **like squirrel**)
  - **Family:** Sciuridae (backbone, nursing its young, sharp front teeth, like squirrel, **bushy tail & lives on trees (i.e. real squirrel)**)
  - **Genus:** Tamiasciurus (backbone, nursing its young, sharp front teeth, like squirrel, bushy tail & trees, **from N-America**)
  - **Species:** Hudsonicus (backbone, nursing its young, sharp front teeth, like squirrel, bushy tail & trees, from N-America, **brown fur with white belly**)

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11.1 Early Ontologies

• Example: Edible Dormouse
  *(Binomial Name: *Glis Glis*)
  – Kingdom: Animals
  – Phylum: Chordata *(with backbone)*
  – Class: Mammalia *(with backbone, nursing its young)*
  – Order: Rodentia *(backbone, nursing its young, sharp front teeth)*
  – Suborder: Sciuromorpha *(backbone, nursing its young, sharp front teeth, like squirrel)*
  – Family: Gliridae *(backbone, nursing its young, sharp front teeth, like squirrel, sleeps long)*
  – Genus: Glis *(backbone, nursing its young, sharp front teeth, bushy tail, like squirrel, eaten by Romans)*
  – Species: Glis *(backbone, nursing its young, sharp front teeth, bushy tail, climbs trees, nothing more to classify)*
11.1 Early Ontologies

- Rodentia (Rodents)
  - Myomorpha (Mouse-like)
  - Castorimorpha (Beaver-like)
  - Sciurromorpha (Squirrel-like)
  - Hystricomorpha (Hedgehog-like)
  - Anomaluromorpha (Springhare-like)

- Sciuridae (Squirrel)
  - Sciurinae (Real Squirrel)
    - Sciurini (Tree Squirrel)
      - Tamiasciurus (Pine Squirrel)
        - Hudsonicus (Red Squirrel)
      - Pteromyini (Flying Squirrel)
    - Ratufinae (Giant Squirrel)
      - Graphiurinae (African Dormouse)
    - Sciurillinae (Pygmy Squirrel)
      - Glirinae (Real Dormouse)

- Aplodontiidae (Mountain Beaver)
- Gliridae (Dormouse)
  - Glirinae (Real Dormouse)
    - Glirulus (Japanese DM)
  - Glirinae (Other Dormice)
- Gliridae (Dormouse)
  - Graphiurinae (African Dormouse)
  - Glirinae (Real Dormouse)
  - Leithiinae (Other Dormice)
- Gliridae (Dormouse)
  - Glirinae (Real Dormouse)
  - Glirulus (Japanese DM)
  - Glis (Edible Dormouse)
  - Glis (Yummy)
11.1 Ontologies

• In **computer science** ontologies are formal, explicit specifications of a **shared conceptualization**
  – Basically an ontology provides a **shared vocabulary**
    • It can be used to define the type of objects and/or concepts that exist, and their **properties** and **relations**
  – Ontologies are often equated with **taxonomic hierarchies** of classes, class definitions, and the subsumption relation
    • But this definition is far too narrow
  – **Domain ontologies** model the real world with respect to a specific domain
    • This also **disambiguates** most terms
    • But domain ontologies are not **compatible** with each other…
11.1 Upper Ontologies

• An **upper ontology** is a model of the common objects that are generally applicable across a wide range of domain ontologies
  – It contains a **core glossary** in whose terms objects in a set of domains can be described
  – There are several **standardized** upper ontologies available for use, including Dublin Core, GFO, OpenCyc, SUMO, and DOLCE
11.1 Upper Ontologies

• **Example: Dublin Core (DC)**
  – The Dublin Core **metadata element set** is a standard for cross-domain information resource description
    • It is widely used to **describe** digital materials such as video, sound, image, text, and composite media like Web pages
    • Defines basic **core** elements, but is expandable
  – The Dublin Core standard includes **two levels:**
    • **Simple Dublin Core** comprises fifteen elements
    • **Qualified Dublin Core** includes three additional elements, as well as a group of element refinements (qualifiers) that refine the semantics of the elements for resource discovery
11.1 Upper Ontologies

• Simple Dublin Core Metadata Element Set (DCMES) defines 15 elements

1. Title  
2. Creator  
3. Subject  
4. Description  
5. Publisher  
6. Contributor  
7. Date  
8. Type  
9. Format  
10. Identifier  
11. Source  
12. Language  
13. Relation  
14. Coverage  
15. Rights

http://www.dublincore.org/
• **Qualified Dublin Core** defines three additional elements
  1. Audience
  2. Provenance
  3. RightsHolder

  – **Elements refinements** make the meaning of an element narrower or more specific

  – **Dumb-Down Principle**
    • If an application does not understand a specific element refinement term, it should be able to **ignore** the qualifier and treat the metadata value as if it were unqualified.
11.1 Upper Ontologies
There are several ways to capture ontologies

- **RDF-S** is able to model formal vocabularies
  - Defines available constants and predicate symbols
- Using those vocabularies, **RDF** allows to express statements
  - **Triples**: Subject, Predicate, Object

Basically the syntax of RDF with RDF-S vocabularies can be seen as a language for expressing propositions (or assertions)
For capturing the semantics of RDF, two approaches can be chosen

- **Model theoretic approach**: Directly define a model semantic for RDF
- **Translation approach**: Translate RDF into logics
- We will showcase and mix both approaches briefly
11.2 RDF-Semantics

• Nomenclature of RDF syntax
  – RDF **Graph**
    • Set of RDF triples
  – RDF **Subgraph**
    • Subset of the graph *triples*
    • A *proper* subgraph is a graph of a proper subset of the triples
A graph may have **blank nodes or blank edges**
- A graph without any blanks is called **ground graph**
- To identify blank nodes, we give them domain-free names
  - e.g.: ?:x or ?:y (… so they look like variables)

**All literals or URIs are summarized as names**
- Names can be considered as constant values in logics
- Thus, names don’t have any inherited semantics
- Also, URIs don’t have semantics
  - Although the URL might be interpretable— but still, this is no formal semantics, e.g. http://www.moviedb.com/movie/dieHard
• All names of a graph are called its **vocabulary**
• Given a graph $G$, and a **mapping** $M$ of blank nodes to some names or nodes:
  – Any graph obtained by replacing some blank nodes $N$ with $M(N)$ is called an **instance of $G$**
• A **proper instance** is a graph where a blank node is mapped to either a name, or two nodes mapped into the same node.
11.2 RDF-Semantics

• A graph is **equivalent**, if a blank node is mapped to a new blank node which was originally not in the graph
  – An equivalent graph has just its “variables” renamed

• A graph is **lean**, if it does not show internal redundancies, e.g. has no instance which is a proper subgraph of the graph
• Furthermore, graphs may be **merged**
  – If two graphs have no common blank nodes, the merge is just the graph of the unioned triples
  – If they do have common blank nodes, the blank nodes of one are mapped to new blank nodes such that both graph have no blanks in common
Based on this, we can **classify, merge and map** graphs with respect to each other

- Those operations are needed when mapping RDF to a logical representation

- RDF graphs express logical facts which, of course, can be mapped to **logic**
  
  - Thus, we may use known methods for interpretation and reasoning
11.2 RDF-Semantics

- Triples can be translated into an **logic formula**

Intuition:

\[
\text{rdf:type}(\text{mdb:dieHard}, \text{mdb:movie}) \land \text{mdb:released_in}(\text{mdb:dieHard}, 1988)
\]
11.2 RDF-Semantics

• How does this translation work? We will need:
  – A translation scheme for mapping RDF to logic
  – The vocabulary induced by a RDF graph as well as the intended model
    • A set of axioms capturing the semantics of the terms
Thus, we can build a formal language $\mathcal{L} = (\Gamma, \Omega, \Pi, \Xi)$ for a given RDF graph

- **Predicate** symbols $\Pi$ are given by all names used as predicates in the graph

- Additionally, $\Pi$ contains RDF’s **special names**:
  - `rdf:Type`: Indicates that a given name is of a given type
  - `rdfs:Resource`: Indicates that a certain name is an resource
  - `rdfs:Class`: Defines a class membership
  - `rdfs:SubClassOf`: Defines a subclass relation
  - `rdfs:Property`: Defines a property
  - `rdfs:range`: Defines the value range of a property
  - `rdfs:domain`: Defines the value domain of a property
  - etc.
11.2 RDF-Semantics

- **Function** symbols $\Omega$ are given by any used RDF functions.
- **Variable** symbols $\Gamma$ are given by the names of the blank nodes.
- **Constant** symbols $\Gamma$ are given by all other names used in the graph.

  - Constants can be separated into:
    - Literals (Strings, Numerals, etc)
    - URI’s
11.2 RDF-Semantics

• Overview

- Names
  - Literals
    - untyped
    - typed
  - URIs

Vocabulary $V$

Constant symbols

Constant symbols & Predicate Symbols
Besides the syntax, we will need a formal interpretation $I = (U, I_C, I_P, I_P)$

- Unfortunately, this will be a little bit dirty…

- The universe of discourse $U$ consisting of
  - $U_R$ all resources
    - Resources especially contain all alpha-numeric string literals
  - $U_P$ all properties
    - Yep…predicates are part of the universe! (in contrast to “classic” logics)

- The mapping $I_P$ of property URIs to properties
- The mapping $I_C$ consisting of $I_{CL}, I_{CR}$
  - $I_{CR}$ mapping typed literals to resources
  - $I_{CL}$ mapping untyped literals to literal values
  - $I_{CU}$ mapping URIs to resources
11.2 RDF-Semantics

• All those mappings use **Herbrand style interpretations**
  – i.e. constants are just mapped to their syntactical representation, but special treatment for classes and propositions on memberships

• Additionally, we need a **extension interpretation** \( I_{\text{EXT}} \) for the properties in \( U_P \)
  – The extension will provide the actual semantics of the property, e.g., in which cases the property evaluated to true and false
    • \( I_{\text{EXT}} : U_P \rightarrow 2^{U_R \times U_R} \)
    • Compares to **Herbrand interpretation**
      – Remember: Different Herbrand interpretations correspond to different subsets of the Herbrand base
11.2 RDF-Semantics

Names

<table>
<thead>
<tr>
<th>Literals</th>
<th>URIs</th>
</tr>
</thead>
<tbody>
<tr>
<td>untyped</td>
<td>typed</td>
</tr>
</tbody>
</table>

Vocabulary

\[ I_{CL} \]
\[ I_{CR} \]
\[ I_{CU} \]
\[ I_P \]

Interpretation

\[ I_{UL} \]
\[ I_{UR} \]
\[ I_{UP} \]
\[ I_{EXT} \]
11.2 RDF-Semantics

• **Model theoretic observation:** When is an interpretation $I$ a **model** of a RDF graph $G$?
  – $I$ is model of $G$, if it is a model of each triple in $G$

• When is an interpretation $I$ a model of a **triple** $t$?
  – $I$ is model of $t$, if it evaluates the triple to true
  – Each triple consists of a **subject** $s_t$, **predicate** $p_t$ and **object** $o_t$
    • Subject, predicate and object need to be element of the vocabulary
    • Furthermore, the predicate must hold i.e. $(I(s_t), I(o_t)) \in I_{\text{EXT}}(p_t)$
• **Blank nodes** in $G$ need to be mapped to literal or URI nodes until $G$ is a ground graph
  - This step accords to a **variable substitution** in logical models

• **Example:**
  - $U_R = \{a, b, p, q, r, 1998\}$
  - $U_P = \{p, q, r\}$
  - $U_L = \{1998\}$
  - $I_L = \{1998 \mapsto 1998\}$
  - $I_U = \{\text{mdb:bruceWillis} \mapsto a, \text{mdb:action} \mapsto b\}$
  - $I_P = \{\text{mdb:released_in} \mapsto p, \text{mdb:genre} \mapsto q, \text{mdb:played_in} \mapsto r\}$
  - $I_{\text{EXT}} = \{p \mapsto \{(c, 1998)\}, q \mapsto \{(c, b)\}, r \mapsto \{(c, a)\}\}$
  - Is the graph a model?
• Provide a node substitution \( ?:x \mapsto c \)

• Check for each triple if the interpretation is a model

- \( (I(?:x), I(mdb:bruceWillis)) = (c,a) \in I_{\text{EXT}}(r) \)
- \( (I(?:x), I(mdb:action)) = (c,b) \in I_{\text{EXT}}(q) \)
- \( (I(?:x), I(1988)) = (c,1988) \in I_{\text{EXT}}(p) \)

- Yes… \( I \) is a model for \( G \)
11.2 RDF-Semantics

• **Orthogonal approach:** *Translate RDF to logic*
  – Logic representation has to retain special RDF features like properties and classes
    • Modeled by special predicate names, e.g. rdf:Property or rdf:Class
  – **Note:** We need to be able to express properties of predicates,
    • e.g. the predicate mdb:Movie describes a **class** (from mdb:Movie rdf:type rdfs:Class)
    • This functionality is usually provided by **higher order logics**!!!
    • However, we only use features of second order logics for easy and well defined tasks (class membership, sub class relations, etc), thus not the full power of second order logic is necessary
      – Remember: General second order logics are **undecidable**…
  – Furthermore, this approach will also work for all other kinds of knowledge representation
    • e.g. DAML, OWL, OWL2, etc…
Following rules of thumb TR[E] can be used to transform RDF expression E into logic

- Any **URI reference** in subject or object
  → **Constant Symbols** or **Predicate Symbol**

- **Blank nodes**
  → **Variable Symbols**

- Any **triple** of the form **a rdf:type b**
  → TR[b](TR[a]) ∧ rdfs:Class(TR(b))
11.2 RDF-Semantics

– Any other triple of the form \( a b c \)
  \[ \rightarrow \text{TR}[b](\text{TR}[a], \text{TR}[c]) \land \text{rdfs:Property}(	ext{TR}(b)) \]

– An RDF graph
  \[ \rightarrow \text{The existential closure of the conjunction of all translations of all triples in the graph} \]

– A set of RDF graphs
  \[ \rightarrow \text{The conjunction of the translation of all graphs} \]
11.2 RDF-Semantics

• Example

\[
\exists x \ (\text{Movie}(x) \land \text{rdfs:Class}(\text{Movie}) \land \\
\text{mdb:genre}(x, \text{mdb:action}) \land \text{rdf:Property}(	ext{mdb:genre}) \land \\
\text{mdb:released_in}(x, 1998) \land \text{rdf:Property}(	ext{mdb:released_in})
\]

Tricky here — statement on properties of properties
However, we are not done by just translating RDF to logics

- We still have to provide means to interpret and evaluate the RDF and RDFS special constructs
  - e.g. rdfs:subclassOf, rdf:type, rdfs:Class

- Thus, we need additional **axioms** and **rules** which will help to evaluate and interpret the translated tuples
11.2 RDF-Semantics

• Following axioms can be used to evaluate base RDF
  – Note: The direct model theoretic approach to RDF semantics will need similar axioms
  – Axioms are used to construct proof trees for evaluating a RDF graphs

\[
\begin{align*}
\text{rdf:} \text{type}(x, y) & \rightarrow y(x) \\
\text{rdf:} \text{Property}(\text{rdf:} \text{type}) & \\
\text{rdf:} \text{Property}(\text{rdf:} \text{subject}) & \\
\ldots & \text{ (for all other rdf special names which are properties & data types)}
\end{align*}
\]
11.2 RDF-Semantics

• RDF/s needs some more axioms

```
rdfs:Resource(x)
rdfs:Class(y) → (y(x) ↔ rdf:type(x, y))
rdfs:range(x, y) → (x(u, v) → y(v))
rdfs:domain(x, y) → (x(u, v) → y(u))
rdfs:subClassOf(x, y) → rdfs:Class(x) ∧ rdfs:Class(y) ∧
    ∀ u (x(u) → y(u))
rdfs:Class(x) → rdfs:subClassOf(x, x)
    ∧ rdfs:subClass(x, rdfs:Resource)
rdfs:subClassOf(x, y) ∧ rdfs:subClassOf(y, z) → rdfs:subClassOf(x, z)
rdfs:Class(rdfs:Resource)
...
```

... (similar axioms for all other resources)

... (similar axioms for properties)
11.2 RDF-Semantics

• Summary of semantics
  – The semantics of RDF can be established by an direct model-theoretic approach
  – or by mapping RDF to logics
    • This approach can also be used for other frame-based knowledge languages and thus allow a direct comparison of expressiveness
    • Will result in higher order logics if not further restricted
    • Different restrictions will reduce the evaluation complexity
      – Next lecture
11.2 RDF-Semantics

• RDF semantics references
  – http://www.w3.org/TR/rdf-mt/
  – http://www.w3.org/TR/2003/NOTE-lbase-20031010/
11.3 SPARQL

• After we have defined the semantics of RDF graphs, we now need a way to retrieve the information
  
  – **SPARQL Protocol And RDF Query Language**
    
    • SPARQL is a *query language* and a protocol for accessing RDF designed by the W3C RDF Data Access Working Group

• **SPARQL Query language** is used to
  
  – *extract information* in the form of URIs, blank nodes, plain and typed literals
  
  – extract RDF subgraphs
  
  – construct **new RDF graphs** based on information in the queried graphs
• Basic idea is to define a set of **Triple Patterns**
  
  – Similar to an RDF Triple (subject, predicate, object), but any component can be a **query variable**, also literal subjects are allowed

```xml
<rdf:type rdf:type rdf:Property/>
```

– **Matching** a triple pattern to a graph introduces bindings between variables and RDF Terms

```xml
```
11.3 SPARQL

• SPARQL uses a **SQL-style syntax**
  – Example with PREFIX dc:
    `<http://purl.org/dc/elements/1.1/>`
    - SELECT ?title
      FROM http://example.org/library
  – **SELECT** identifies the variables to be returned
  – **FROM** gives the name of the graph to be queried
  – **WHERE** query pattern as a list of triple patterns
  – Plus additional functions like **LIMIT, OFFSET**, or **ORDER BY**
11.3 SPARQL Example

Find the URL of the blog by the person named Jon Foobar

```
PREFIX foaf: <http://xmlns.com/foaf/0.1/>

SELECT ?url
FROM <bloggers.rdf>
WHERE {
    ?contributor foaf:name "Jon Foobar" .
}
```

Result
“http://foobar.xx/blog”
11.3 SPARQL – Query Forms

• **SELECT**
  – Returns all, or a subset of the variables bound in a query pattern match

• **CONSTRUCT**
  – Returns an RDF graph constructed by substituting variables in a set of triple templates

• **DESCRIBE**
  – Returns an RDF graph that describes the resources found

• **ASK**
  – Returns whether a query pattern matches or not
11.3 SPARQL – Graph Patterns

• Basic graph pattern
  – Set of triple patterns
• Group pattern
  – A set of graph patterns that must all match
• Value constraints
  – Restrict RDF terms in a solution
• Optional graph patterns
  – Additional patterns may extend the solution
• Alternative graph pattern
  – Two or more possible patterns are tried
• Patterns on named graphs
  – Patterns are matched against named graphs
Assume a graph describing people: return the full names of all people in the graph!

- SELECT ?fullName
  WHERE {?x vCard:FN ?fullName}

- fullName
- =================
- ‘John Smith’
- ‘Mary Smith’
• Return all people over 30 in the KB
  
  – SELECT ?x
    WHERE {?x hasAge ?age .
    FILTER(?age > 30)}
  
  – x

  @prefix ex: <http://example.org/#> .
  @prefix vcard: <http://www.w3.org/vcard-rdf/3.0#> .
  ex:john
    vcard:FN "John Smith" ;
    vcard:N [ 
      vcard:Given "John" ;
      vcard:Family "Smith" ] ;
  ex:hasAge 32 ;
  ex:marriedTo :mary .
  ex:mary
    vcard:FN "Mary Smith" ;
    vcard:N [ 
      vcard:Given "Mary" ;
      vcard:Family "Smith" ] ;
  ex:hasAge 29 .
11.3 SPARQL - Example

• Are there any married people in the graph?
  – ASK { ?person ex:marriedTo ?spouse }

  – yes

@prefix ex: <http://example.org/#> .
@prefix vcard: <http://www.w3.org/vcard-rdf/3.0#> .
ex:john
  vcard:FN "John Smith" ;
  vcard:N [ vcard:Given "John" ; vcard:Family "Smith" ] ;
  ex:hasAge 32 ;
  ex:marriedTo :mary .
ex:mary
  vcard:FN "Mary Smith" ;
  vcard:N [ vcard:Given "Mary" ; vcard:Family "Smith" ] ;
  ex:hasAge 29 .
11.3 SPARQL

• For the full SPARQL standard see
  – http://www.w3.org/TR/rdf-sparql-query/
Ontologies, pt. 2

- Description Logics
- DAML+OIL
- OWL