# An overview of
# Semantic Web Languages and Technologies

# Semantic Web Technologies

- W3C “recommendations”
  - RDF, RDFS, RDFa, OWL, SPARQL, RIF, R2R, etc…
- Common tools and systems -- commercial, free and open sourced
  - Ontology editors, triple stores, reasoners, etc.
- Common ontologies and data sets
  - Foaf, DBpedia, SKOS, PROV, etc.
- Infrastructure systems
  - Search, ontology metadata, linking services
- Non W3C: Schema.org, Freebase, …

# Common KR languages

- Knowledge representation and reasoning (KR&R) has always been an important part of AI & other disciplines
- Many approaches have been developed, implemented and evolved since the 1960s
- Most were one-offs, used only by their developers
- Starting in the 1990s, there was an interest in developing a common KR language to support knowledge reuse and distributed KB systems
- The Semantic Web languages (e.g., OWL) are a current generation of this idea
  - There are currently no other widely used KR languages

# Questions

- Database (DB) vs. knowledge base (KB)?
  - TL;DR: DBs have facts, KBs have general knowledge and (maybe) facts
  - DBs typically have simple schemas (knowledge) and lots of data (facts)
  - KBs have complex schemas (aka ontologies) and may or may not have a lot of instances (data)
- KBs support inference, e.g.,

  parent(?x,?y) => person(?x), person(?y), child(?y,?x), older(?x,?y), ?x≠?y

  Parent(john,mary) => person(john), child(mary,john), …

# Questions

What's the impact of using different structures to represent data or knowledge?

- Natural language
- Program code
- Relations vs. graphs vs. objects
- Logic vs. rules vs. procedures
- Neural networks
- Tensors

# Questions

What's our "semantic" model for facts and knowledge?

- Classical logic is a common choice
  - man(socrates), $\forall$x man(x) => mortal(x)
  - Classical logic has limitations: facts and relations and "rules" are either (always) True or False for all time
- May need to represent and reason with probabilistic or fuzzy facts and knowledge
- May need to handle dynamic facts or knowledge

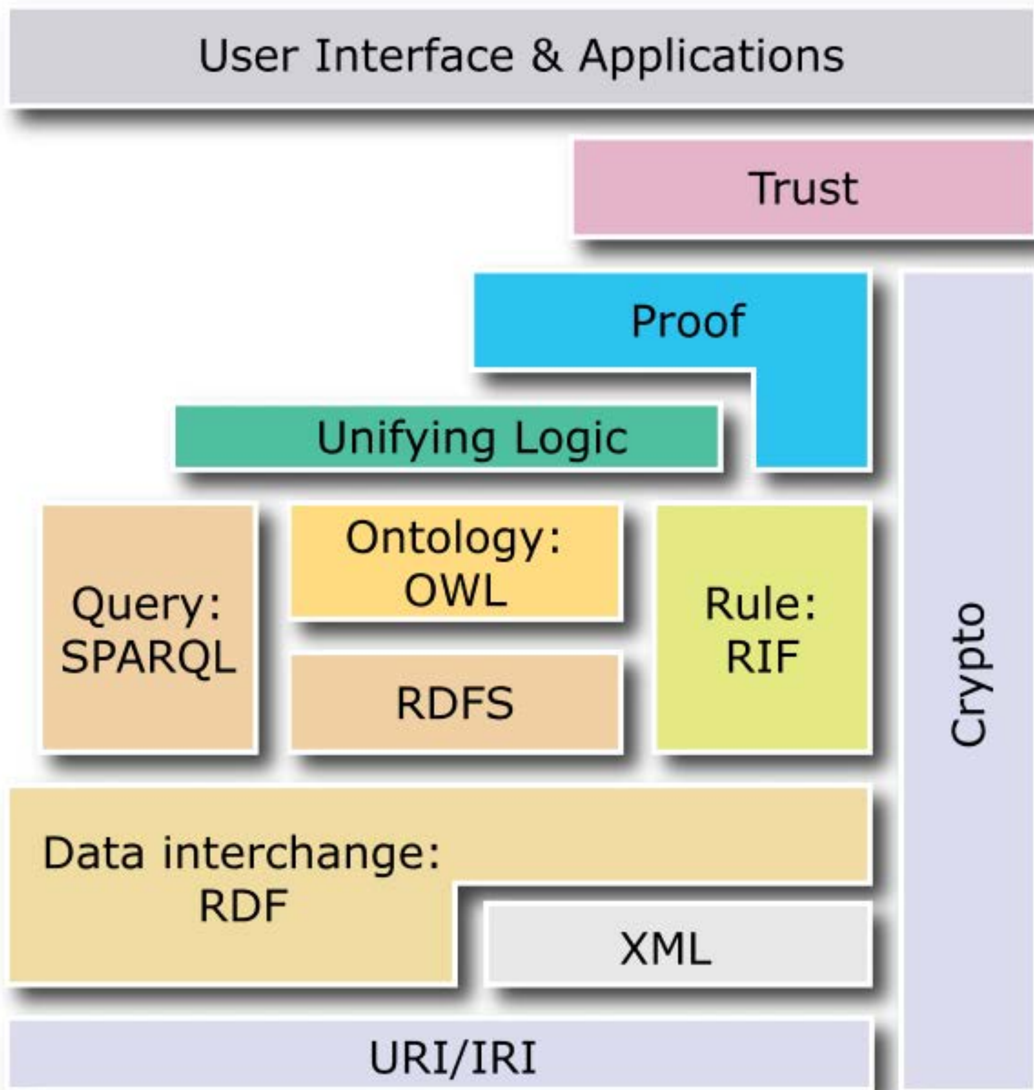
# Semantic Web Technologies

- Basic approach uses classical logic for underlying semantics
  - + Simple, well understood, good reasoning algorithms
  - - No probabilities, adding extensions (e.g., for time) adds complexity
- Knowledge represented as a graph
  - + Simple, good tool support
  - - May be too simple

# Two Semantic Web Notions

- **The semantic web**
  - Idea of a web of machine understandable information
  - Agnostic about the technology used to support it
  - May involve more AI (e.g., NLP, machine learning)
  - Human end users in the center
- **The Semantic Web**
  - Current vision of a semantic web as defined by the W3C community: a Web of data
  - Using W3C supported standards, i.e., RDF, OWL, SPARQL, XML, RIF, etc.
  - By machines for machines with human-oriented applications on top

# W3C Semantic Web Stack



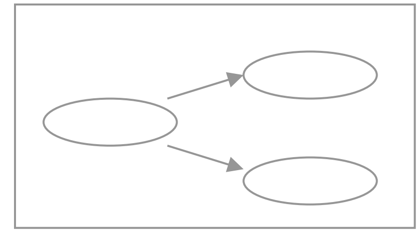
# RDF is the first SW language

**XML Encoding**

```
<rdf:RDF …….. .>
     <…. >
     <…. >
</rdf:RDF>
```

**RDF Data Model**

**Graph**



**Good for people, viz, graph DBMS**

**Good for Machine Processing**

**Triples**

stmt(docInst, rdf_type, Document)
stmt(personInst, rdf_type, Person)
stmt(inroomInst, rdf_type, InRoom)
stmt(personInst, holding, docInst)
stmt(inroomInst, person, personInst)

**Good For Reasoning and Databases**

**JSON Encoding**

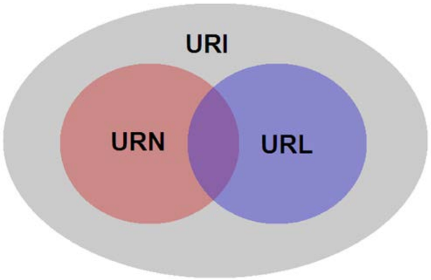
```
{"@context":{
 "name": "http://…/name",
 "Person": "http://…/Person"}
 "@type": "Person",
 "name": "Markus Lanthaler"
}
```

*RDF is a simple language for building graph based representations*

# The RDF Data Model

- An RDF document is an unordered collection of statements, each with a **subject**, **predicate** and **object** (aka **triples**)
- A triple can be thought of as a labelled arc in a graph
- Statements describe properties of web **resources**
- Resource are objects that can be pointed to by a **URI**:
  - a document, a picture, a paragraph on the Web, …
  - E.g., http://umbc.edu/~finin/cv.html
  - a book in the library, a real person (?)
  - isbn://5031-4444-3333
- Properties themselves are also resources (URIs)

# URIs are a foundation




- URI = Uniform Resource Identifier
  - "The generic set of all names/addresses that are short strings that refer to resources"
  - URLs (Uniform Resource Locators) are a subset of URIs, used for resources that can be *accessed* on the web
- URIs look like URLs, often with fragment identifiers pointing to a document part:
  - http://foo.com/bar/mumble.html#pitch

# URIs are a foundation

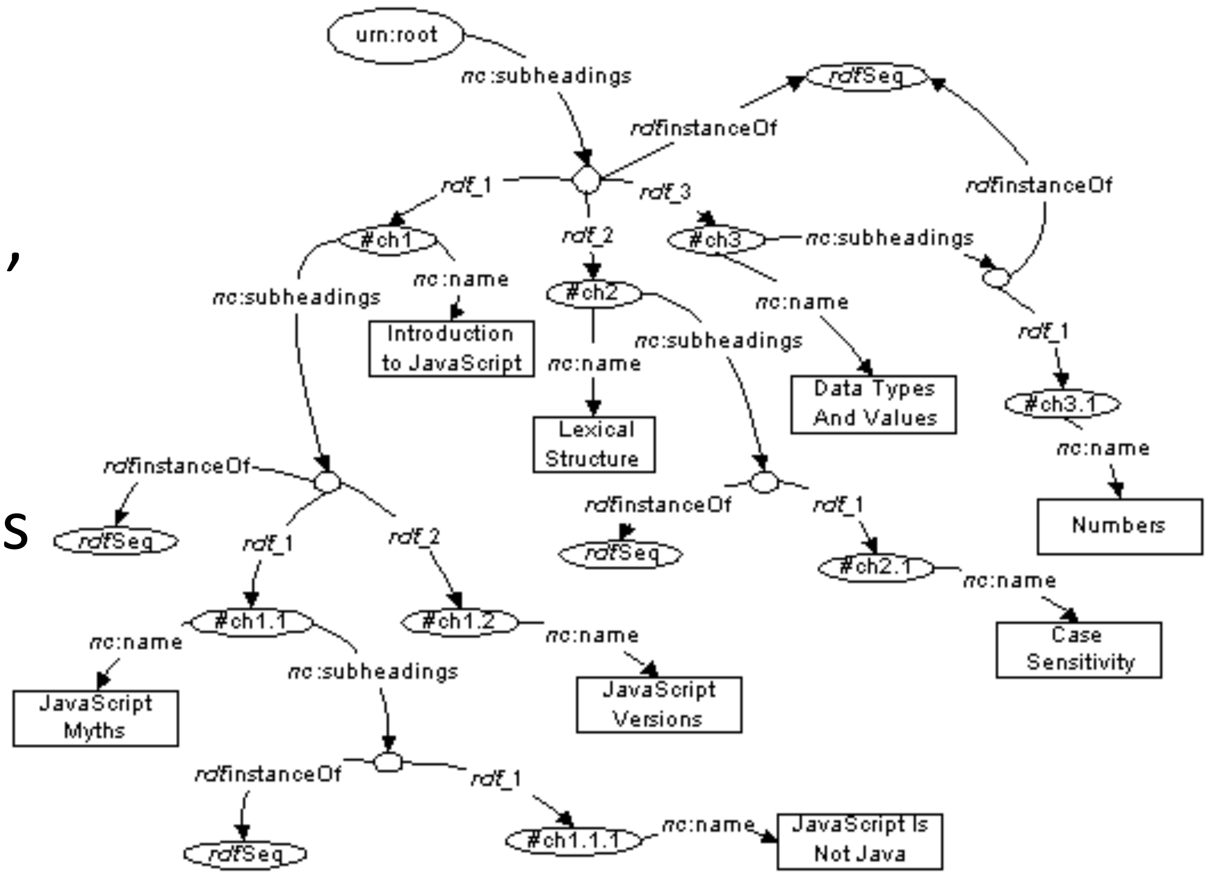
- URIs are unambiguous, unlike natural language terms -- the web provides a global **namespace**
- We can use a URI to **denote** something, e.g., a concept, entity, event or relation
- We usually assume references to the same URI are to the same thing

# What does a URI mean?

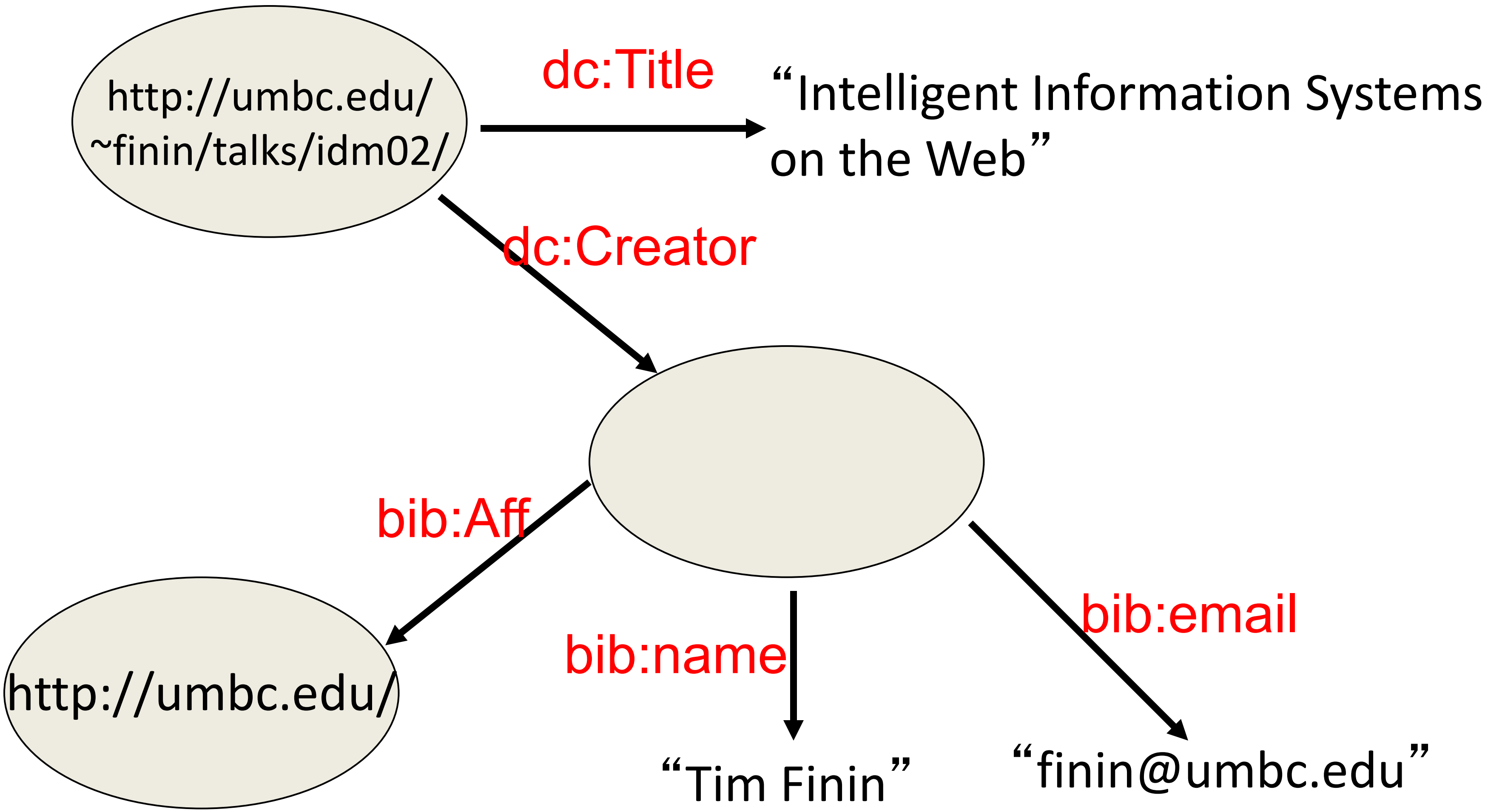
- Sometimes URIs denote a web resource
  - http://umbc.edu/~finin/finin.jpg denotes a file
  - We can use RDF to make assertions about the resource, e.g., it’s an image and depicts a person with name Tim Finin, …
- Sometimes concepts in the external world
  - E.g., http://umbc.edu/ denotes a particular university located in Baltimore
  - This is done by social convention
- Cool URIs don’t change
  - http://www.w3.org/Provider/Style/URI

# The RDF Graph

- An RDF document is an unordered collection of triples
- The subject of one triple can be the object of another
- The result is a directed, labelled graph
- A triple's object can also be a literal, e.g., a string
- Graphs are simpler that relational tables or objects
- This is both a plus and a minus



# Simple RDF Example



# Serialization

- A graph is an abstract model, we'll need to **serialize** it as text for many reasons, e.g., display, editing, exchange, …
- Multiple standard RDF serializations
- Most important: XML, Turtle, ntriples, JSON-LD
- Most Semantic Web tools can read or write in any of these serializations

# XML encoding for RDF

```
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
    xmlns:dc="http://purl.org/dc/elements/1.1/"
    xmlns:bib=http://daml.umbc.edu/ontologies/bib/>
<rdf:Description rdf:about="http://umbc.edu/~finin/talks/idm02/">
  <dc:title>Intelligent Information Systems on the Web</dc:title>
  <dc:creator>
    <rdf:Description>
      <bib:Name>Tim Finin</bib:Name>
      <bib:Email>finin@umbc.edu</bib:Email>
      <bib:Aff rdf:resource="http://umbc.edu/" />
    </rdf:Description>
  </dc:creator>
</rdf:Description>
</rdf:RDF>
```

# Note the prefix declarations

```
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
   xmlns:dc="http://purl.org/dc/elements/1.1/"
   xmlns:bib=http://daml.umbc.edu/ontologies/bib/>
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      <bib:Aff rdf:resource="http://umbc.edu/" />
    </rdf:Description>
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</rdf:Description>
</rdf:RDF>
```
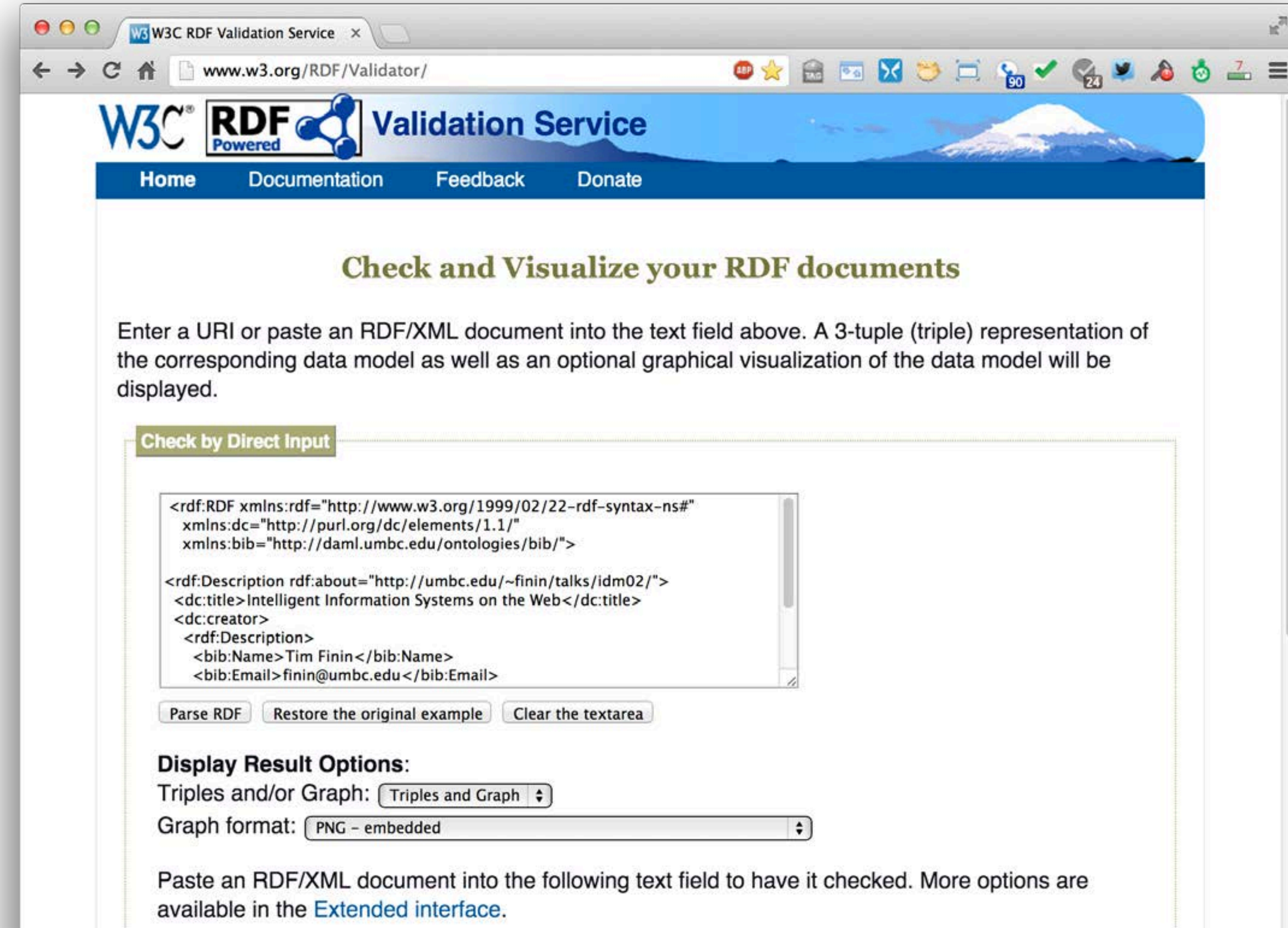

Makes it easy to include terms from three different “vocabularies”:

- **rdf** for terms that are part of its representation language (e.g., rdf:type)
- **dc** for terms from the Dublin Core vocabulary developed by librarians
- **bib** for terms from a bibliography vocabulary developed at UMBC

# An RDF validation service




http://www.w3.org/RDF/Validator/

# Easy to convert between serializations

- Most software tools can read and write different serializations
- rdf2rdf is a simple handy utility for converting from one RDF serialization to another
- Any23 is an open source library, web service and command line tool that extracts structured data in RDF format from a variety of Web documents

# N-triple representation

- N-triples is a  line-oriented serialization for RDF
- URIs are wrapped in angle brackets, ended with a period

*<subject>*  *<predicate>*  *<object>* .

<http://umbc.edu/~finin/talks/idm02/> <http://purl.org/dc/elements/1.1/title> "Intelligent Information Systems on the Web" .

<http://umbc.edu/~finin/talks/idm02/> <http://purl.org/dc/elements/1.1/creator> _:node17i6ht38ux1 .

_:node17i6ht38ux1 <http://daml.umbc.edu/ontologies/bib/Name> "Tim Finin" .

_:node17i6ht38ux1 <http://daml.umbc.edu/ontologies/bib/Email> "finin@umbc.edu" .

_:node17i6ht38ux1 <http://daml.umbc.edu/ontologies/bib/Aff> <http://umbc.edu/> .

# Turtle Serialization

- Turtle: a compact  and readable serialization

```
# prefix declarations
@prefix rdf: http://www.w3.org/1999/02/22-rdf-syntax-ns# .
@prefix dc: http://purl.org/dc/elements/1.1/ .
@prefix bib: http://daml.umbc.edu/ontologies/bib/ .

<http://umbc.edu/~finin/talks/idm02/>
   dc:title "Intelligent Information Systems on the Web" ;
   dc:creator
      [ bib:Name "Tim Finin” ;
        bib:Email finin@umbc.edu ;
        bib:Aff: "http://umbc.edu/" ]  .
```

# Turtle Syntax

```
:subj
    :property1 :value1;
    :property2 :value2, value3;
    :property3 :value4.
```

# More RDF Vocabulary

- RDF has terms for describing lists, bags, sequences, simple datatypes, etc.
- RDF is a “pure” graph representation language
  - Nodes and edges are simple objects
  - Both have identifiers that are URIs
- Suppose we want to associate a probability with an edge, e.g.,

  (:flipper rdf:type :mammal) :probability 0.9

  (:flipper rdf:type :fish) :probability 0.1

# Property graphs?

- RDF is a “pure” graph model with only labeled nodes and edges
- Many popular graph databases implement property graphs (e.g., Neo4j)
- Nodes & edges can have properties, whose values are *literals* or maybe *lists of literals*
- Results in a more compact graph
- But, as we’ll see, introduces some limitations

# More RDF Vocabulary

- RDF also can describe triples through **reification**
- Enabling statements about statements

:flipper rdf:type :mammal .

- All non-literals have to be URIs
- RDF uses prefixes for readability
- We can specify what a null prefix means
- If we don't it means "in this file"
- https://prefix.cc/ is one service for finding standard prefixes

# More RDF Vocabulary

- RDF also can describe triples through **reification**
- Enabling statements about statements

```
:flipper rdf:type :mammal .
_:s1 rdf:type rdf:Statement .
_:s1 rdf:subject :flipper .
_:s1 rdf:predicate :type .
_:s1 rdf:object :mammal .
_:s1 :probability 0.9
```

- The underscore prefix is special
- It introduces *blank nodes*
- We'll talk about this in more detail later
- For now, think of it as introducing "a new, nameless thing"

# More RDF Vocabulary

- RDF also can describe triples through **reification**
- Enabling statements about statements

```
:flipper rdf:type :mammal .
_:s1 a rdf:Statement;
        rdf:subject :flipper;
        rdf:predicate :type;
        rdf:object :mammal;
        :probability 0.9 .
```

- Lookup the rdf namespace via https://prefix.cc/
- Visit it on the web
- You'll see it defines 18 terms that have special meaning in RDF

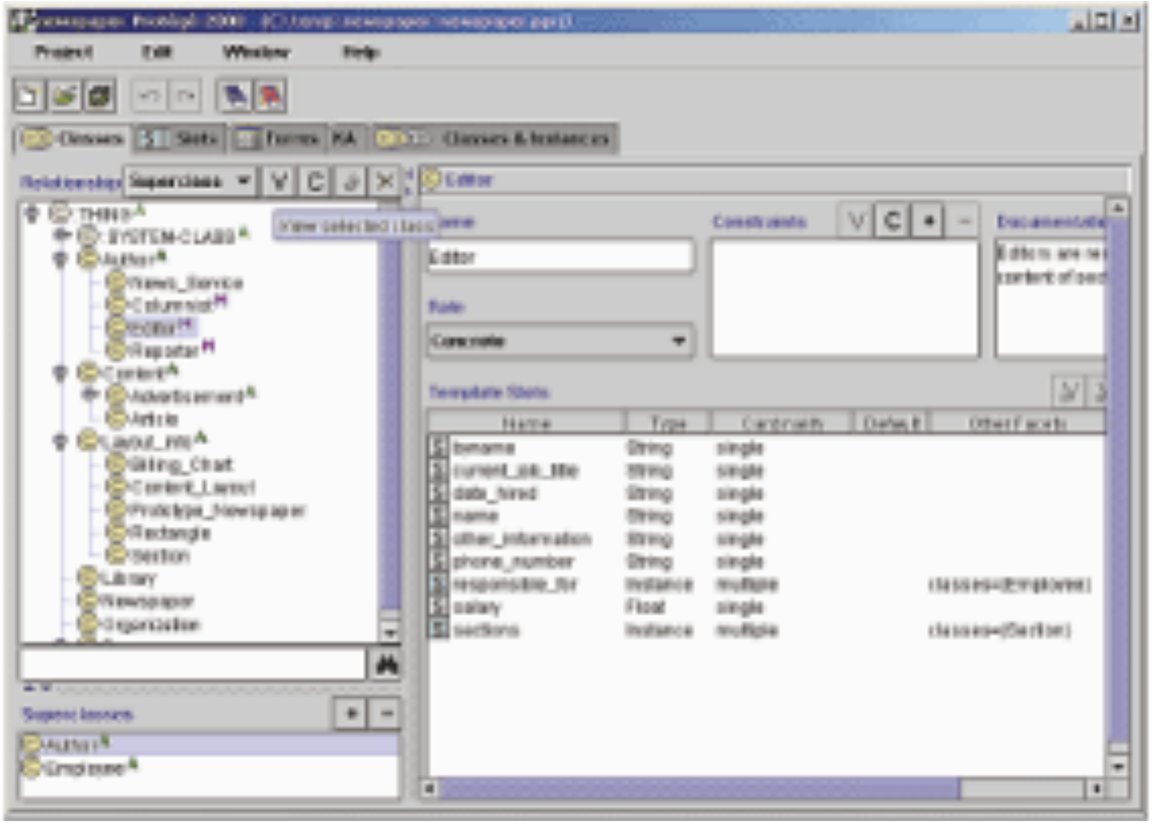
# More RDF Vocabulary

- RDF ABILITY TO describe triples through **reification** enables statements about statements

```
:john bdi:believes _:s.
_:s rdf:type rdf:Statement.
_:s rdf:subject <http://ex.com/catalog/widgetX>.
_:s rdf:predicate cat:salePrice .
_:s rdf:object "19.95" .
```

# RDF Schema (RDFS)

- **RDF Schema adds taxonomies for classes & properties**
  - subClass and subProperty
- **and some metadata.**
  - domain and range constraints on properties
- **Many widely used KG tools can import and export in RDFS**



**Stanford Protégé KB editor**

- Java, open sourced
- extensible, lots of plug-ins
- provides reasoning & server capabilities

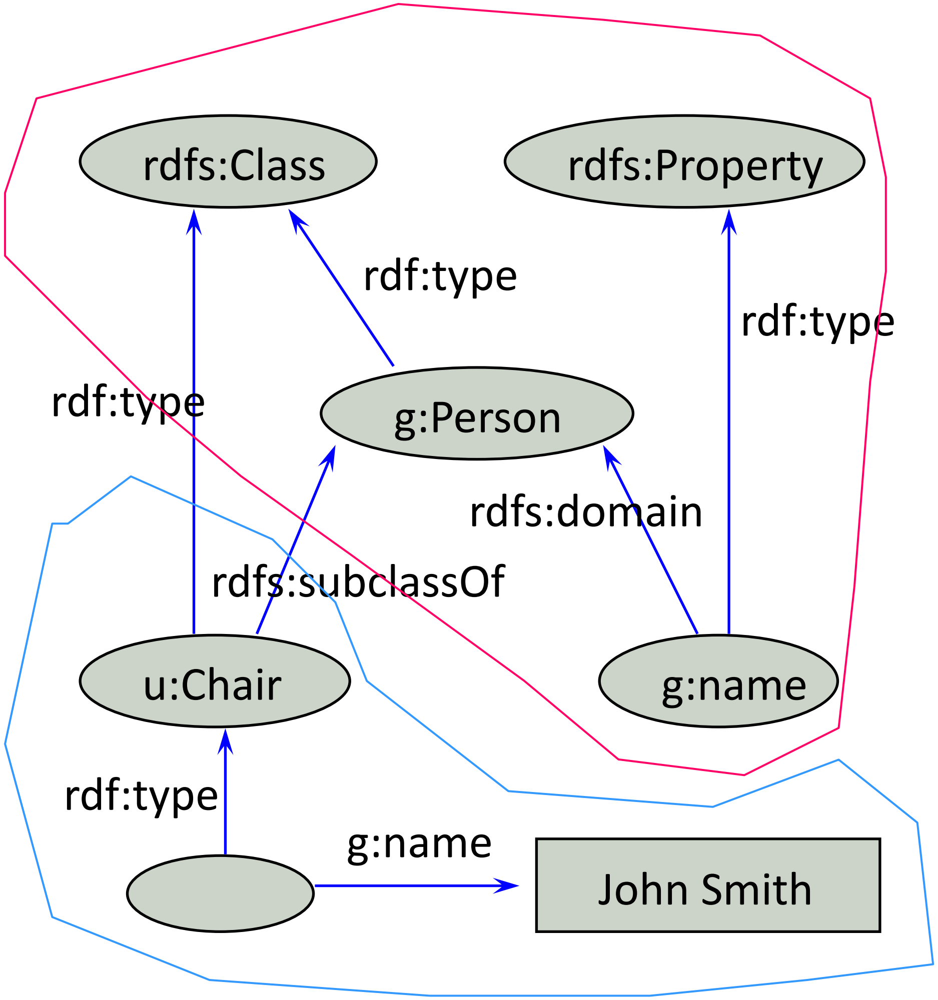
# RDFS Vocabulary

RDFS introduces the following terms and gives each a meaning w.r.t. the rdf data model

- Terms for classes
  - rdfs:Class
  - rdfs:subClassOf
- Terms for properties
  - rdfs:domain
  - rdfs:range
  - rdfs:subPropertyOf
- Special classes
  - rdfs:Resource
  - rdfs:Literal
  - rdfs:Datatype

- Terms for collections
  - rdfs:member
  - rdfs:Container
  - rdfs:ContainerMembershipProperty
- Special properties
  - rdfs:comment
  - rdfs:seeAlso
  - rdfs:isDefinedBy
  - rdfs:label

# RDF and RDF Schema




**Schema-level information**

@prefix rdf: http://www.w3.org/1999/02/22-rdf-syntax-ns# .
@prefix rdfs: http://www.w3.org/2000/01/rdf-schema# .
@prefix g: http://schema.org/gen .
@prefix u: http://schema.org/univ .

g:name rdf:type rdfs:Property;
rdfs:domain g:Person .

u:Chair rdfs:subclassOf g:Person .

**Instance-level information**

_:john rdf:type u:Chair;
g:name "John Smith" .

# RDFS supports simple inferences

New and Improved!
100% Better than XML!!

- An RDF ontology plus some RDF statements may imply additional RDF statements
- Not true of XML data
- Note that this is **part of the data model** and not of the accessing or processing code

```
@prefix rdfs: <http://www...>.
@prefix : <...genesis.n3>.
:parent rdfs:domain :Person;
           rdfs:range :Person.
:mother
   rdfs:subProperty parent;
   rdfs:domain :Woman.
:eve :mother :cain.
```

```
:parent a rdf:Property.
:Person a rdf:Class.
:Woman rdfs:subClassOf Person.
:mother a rdf:Property.
:eve a :Person;
      a :Woman;
      :parent :cain.
:cain a :Person.
```

# RDFS Terms

- Information on the RDFS vocabulary is given by the file its prefix resolves to
- https://www.w3.org/2000/01/rdf-schema
- It provides some insight, e.g., rdfs: domain goes from a rdfs:Property to a rdfs:Resource
- Not a formal definition though; that's given in logic

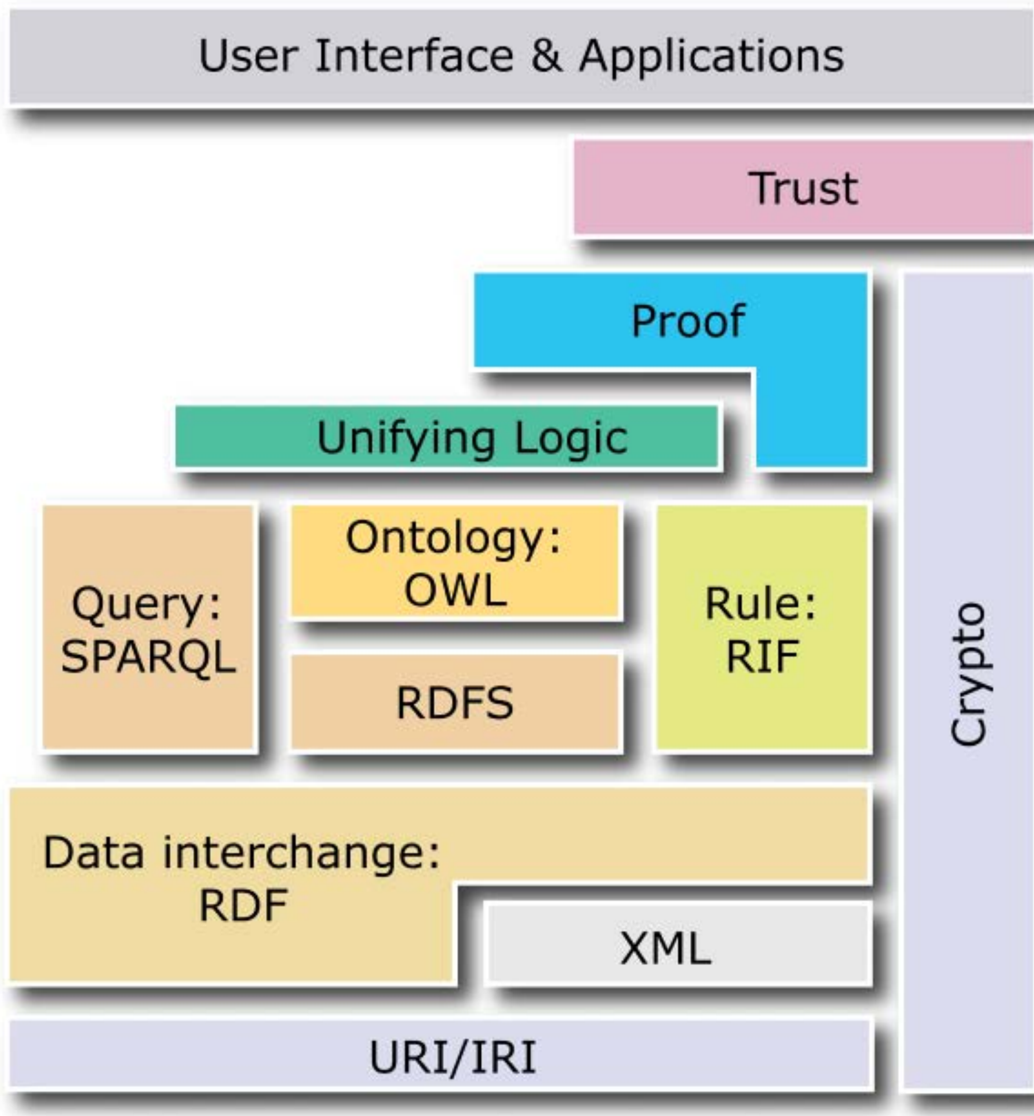
# Is RDF(S) better than XML?

Q: For a specific application, should I use XML or RDF?

A: It depends…

- XML's model is
  - a tree, i.e., a strong hierarchy
  - applications may rely on hierarchy position
  - relatively simple syntax and structure
  - not easy to *combine* trees
- RDF's model is
  - a *loose* collections of relations
  - applications may do database-like search
  - not easy to recover hierarchy
  - easy to combine relations in one big collection
  - great for the integration of heterogeneous information

# W3C Semantic Web Stack



# Problems with RDFS

- RDFS **too weak** to describe resources in detail, e.g.
  - No *localised range and domain* constraints

    Can’t say that the range of hasChild is person when applied to persons and dog when applied to dogs
  - No *existence/cardinality* constraints

    Can’t say that all *instances* of person have a mother that is also a person, or that persons have exactly two parents
  - No *transitive, inverse or symmetrical* properties

    Can’t say isPartOf is a transitive property, hasPart is the inverse of isPartOf or touches is symmetrical
- We need RDF terms providing these and other features.

# W3C's Web Ontology Language (OWL)

- DARPA project, DAML+OIL, begat OWL
- OWL released as W3C recommendation 2/10/04
- See the W3C OWL pages for overview, guide, specification, test cases, etc.
- Three layers of OWL are defined of decreasing levels of complexity and expressiveness
  - **OWL Full** is the whole thing
  - **OWL DL** (Description Logic) introduces restrictions
  - **OWL Lite** is an entry level language intended to be easy to understand and implement
- Owl 2 became a W3C recommendation in 2009, updated in 2012

# OWL ↔ RDF

- An OWL document is a set of RDF statements
  - OWL defines semantics for certain statements
  - Does **NOT** restrict what can be said; documents can include arbitrary RDF
  - But no OWL semantics for non-OWL statements
- Adds capabilities common to description logics, e.g., cardinality constraints, defined classes, equivalence, disjoint classes, etc.
- Supports ontologies as objects (e.g., importing, versioning, …
- A complete OWL reasoning is significantly more complex than a complete RDFS reasoner

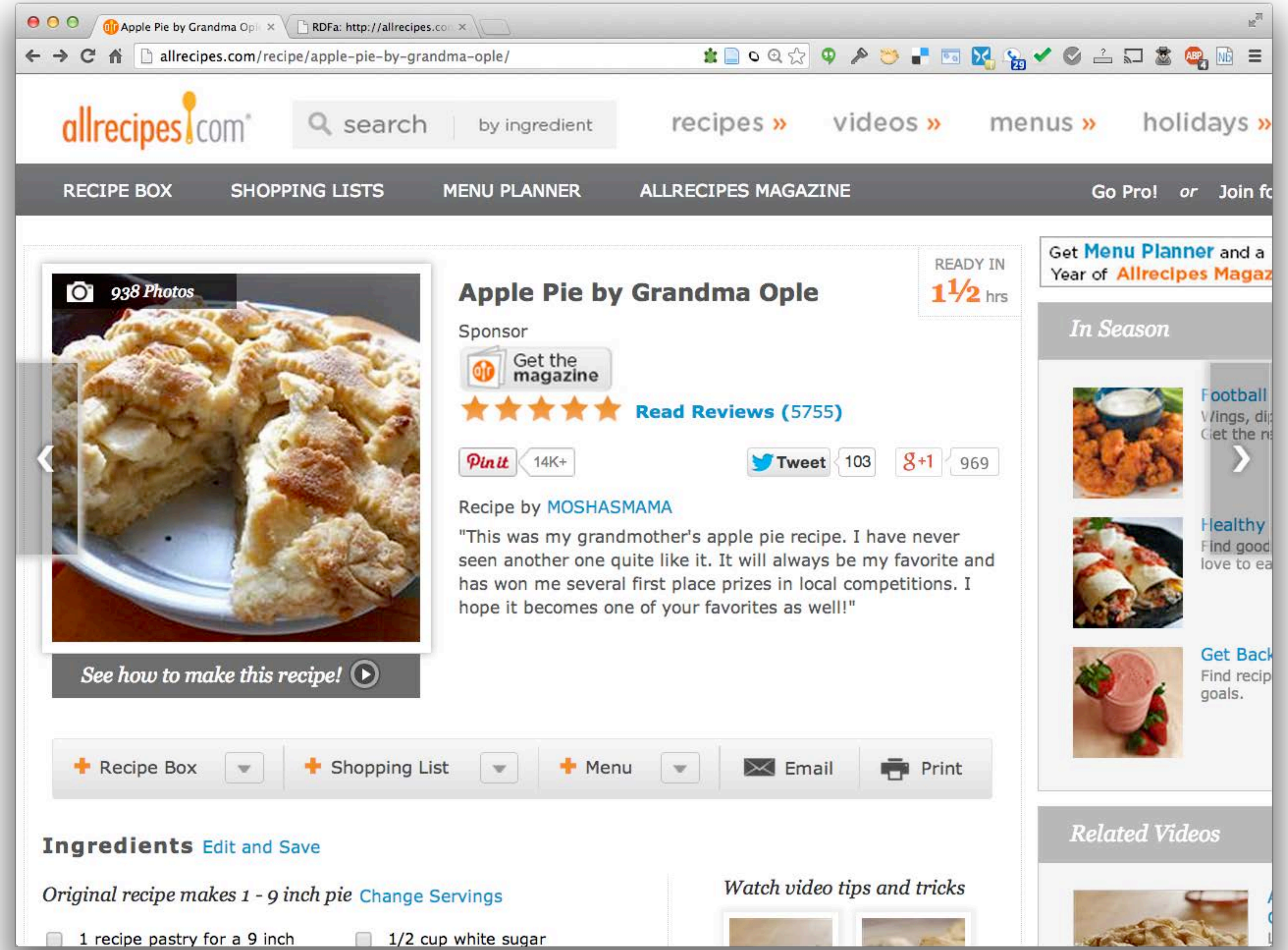
# OWL $\leftrightarrow$ RDF

- RDF allows us to define instance-level data
- RDFS adds the ability to add some schema-level data
- OWL extends this to allow much more schema-level information
- We typically use RDFS and OWL to define domain **ontologies** (i.e., schemas)
- And then use those ontologies to state information about **instances**
- **Aside:** I typically reserve the word *ontology* to refer to schema definitions. These can include individuals, of course, but often do not.

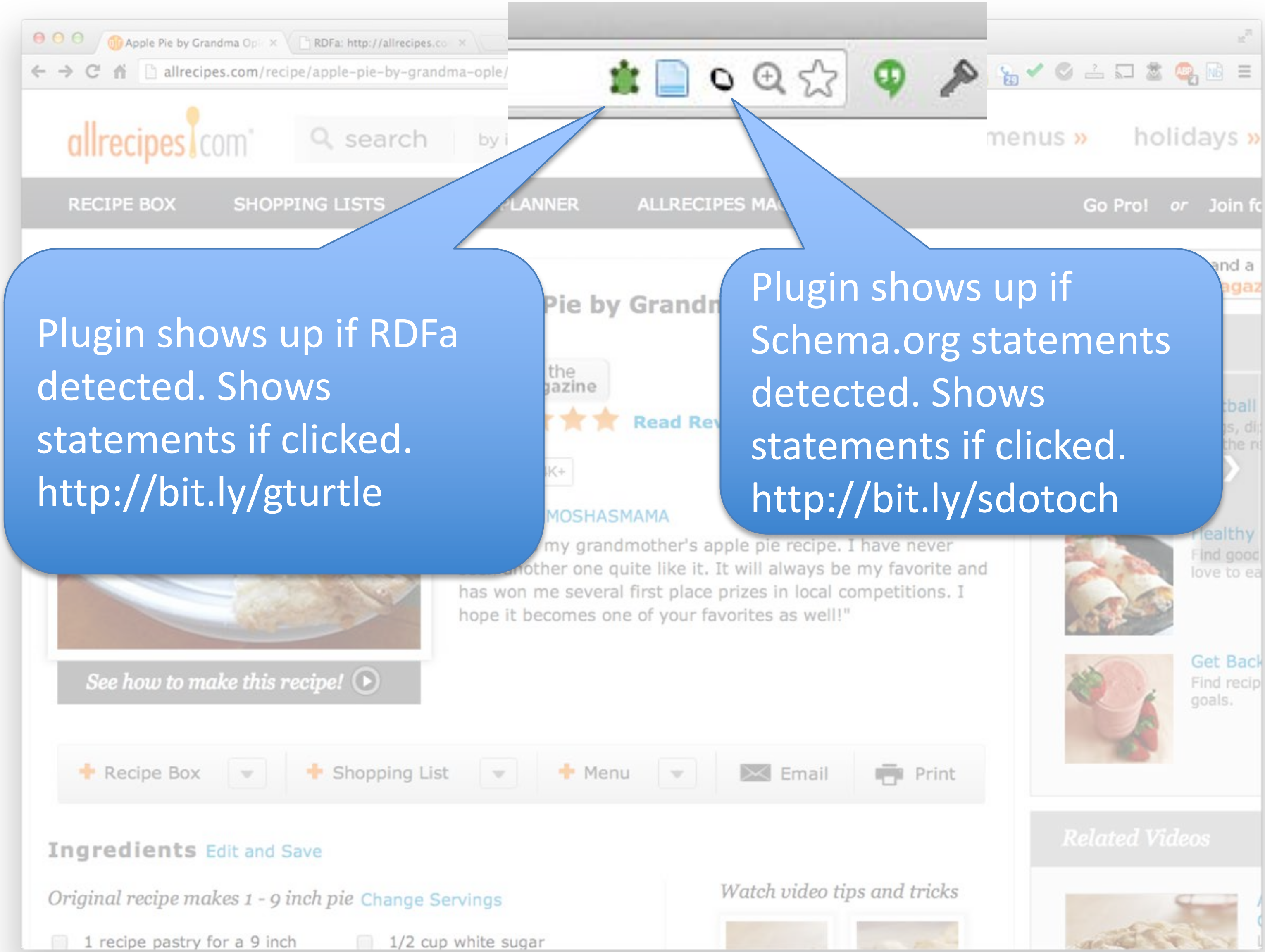
# Embedding Semantic Data in HTML

- Embedding semantic data in HTML allows documents to be understood by people and machines
  - RDFa is a ‘standard’ for embedding RDF in HTML as tag attributes
  - JSON-LD is a ‘standard’ for embedding RDF in a simple json-compatible serialization
- Facebook looks for embedded RDFa statements using its opengraph (og) vocabulary
- Bestbuy embeds produce info in RDFa

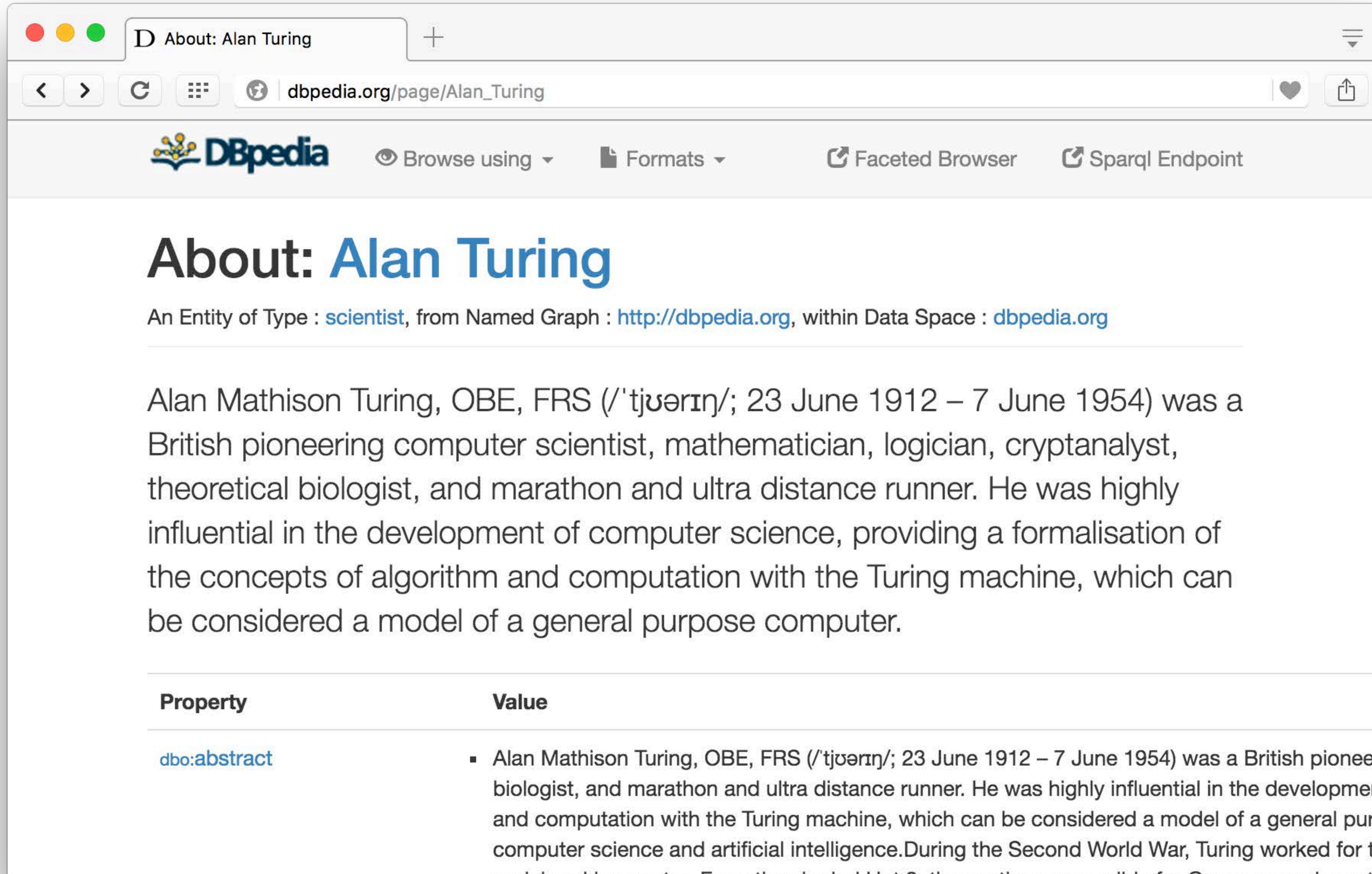
# Detecting semantic data via a browser



# Detecting semantic data via a browser

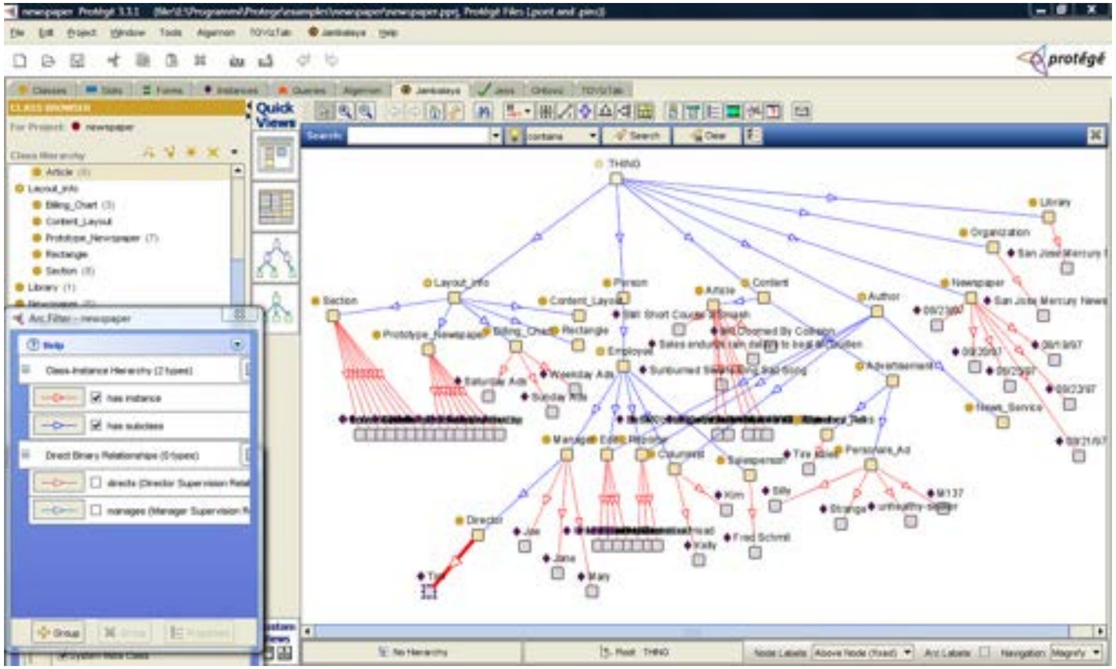


# Semantic Data Browser/Query



# Ontology Editor

- There are a number of editors available for creating and editing ontologies and data
- We recommend using [Protégé](), a java-based free system developed at Stanford
  - Good support for reasoning
  - Lots of plugins



# Triple Stores

- A triple store is a database for RDF triples
- It usually has a native API and often accepts SPARQL queries
- It might do reasoning, either in an *eager* manner (as triples are loaded) or *on demand* (to answer queries), etc.
- Some stores focus on scalability and others on flexibility and features
- We'll look at several, including Sesame, Apache Jena and stardog

# Frameworks and Libraries

- There are frameworks, libraries and packages for most programming languages
- Jena is a very comprehensive Java framework originally developed by HP and now Apache
- Others are available for Python, Ruby, C#, Perl, PHP, Prolog, Lisp, etc.

# Conclusion

- There’s quite a bit of technology needed to support the Semantic Web
- This has been a brief tour
- We’ll cycle back on these and explore them in more detail
- And give you a chance to use and experiment with them