CS 7810 - Knowledge Representation and Reasoning (for the Semantic Web)

02 – Resource Description Framework (RDF)

Adila Krisnadhi

Data Semantics Lab,
Wright State University, Dayton, OH

Outline

DaSe Lab

1. Motivation: Graph Data Model
2. Syntax and Serialization Format
3. Datatypes
4. Multi-valued/n-ary relationships
5. Blank nodes
6. Dataset

Acknowledgements

- Most of the slides in this presentation are adapted from:
  - Sebastian Rudolph, “Introduction to RDF”, slides for Foundations of Semantic Web Technologies course, Dresden, April 11, 2014.
  - Pascal Hitzler, “Slides 2 – 01/05/2011”, slides for Knowledge Representation for the Semantic Web course, Winter quarter 2012.

Outline

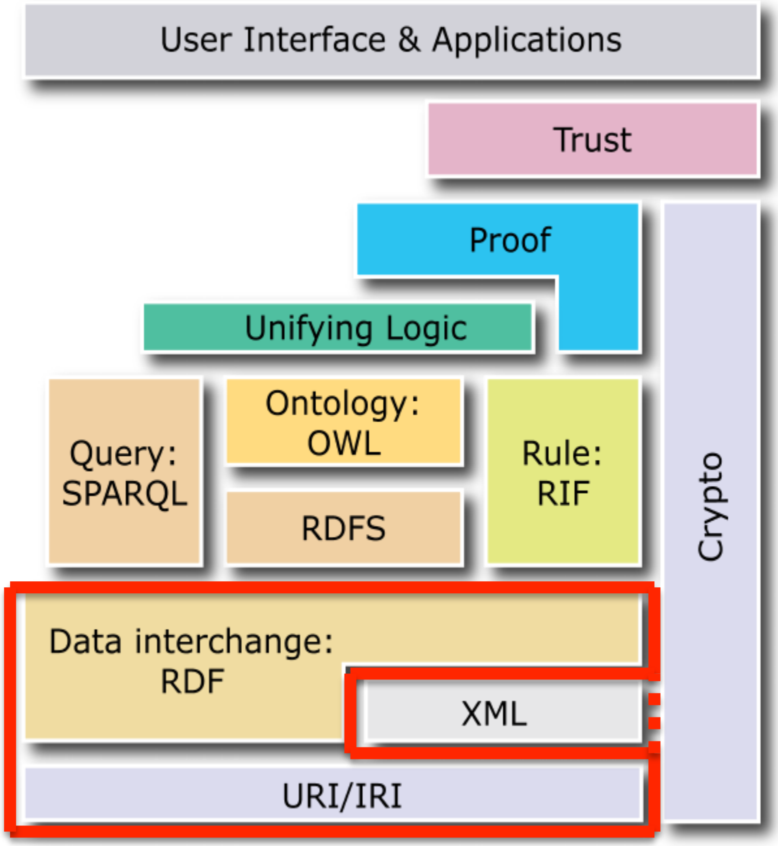
1. **Motivation: Graph Data Model**
2. Syntax and Serialization Format
3. Datatypes
4. Multi-valued/n-ary relationships
5. Blank nodes
6. Dataset

Recap: From Net to Web to Graph

- “It’s not the wires – it’s the computers!”
- “It’s not the computers – it’s the documents!”
- “It’s not the documents – it’s the things!”

[Tim Berners-Lee (2007). https://www.w3.org/DesignIssues/Abstractions.html]

RDF in the SW Stack



https://www.w3.org/2007/03/layerCake.png

A Modeling Problem

Encode the following sentence in XML:

“The book ‘Foundations of Semantic Web Technologies’ was published by CRC Press”

```
<publication>
        <publisher>CRC Press</publisher>
        <book><title>Foundations of Semantic Web Technologies</title></book>
</publication>
```

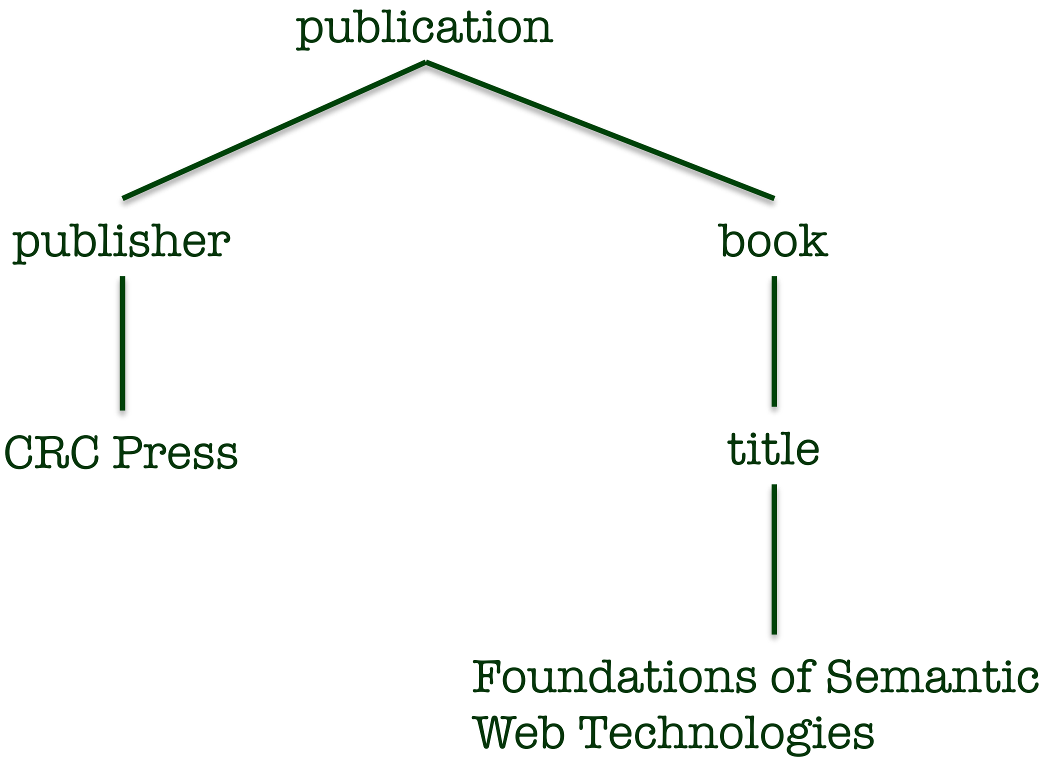
```
<publisher name=“CRC Press”>
        <publication book=“Foundations of Semantic Web Technologies”/>
</publisher>
```

```
<book>
        <title>Foundations of Semantic Web Technologies<\title>
        <publisher>CRC Press</publisher>
</book>
```

And many more alternatives ….

XML is tree-based (1)

```
<publication>
        <publisher>CRC Press</publisher>
        <book><title>Foundations of Semantic Web Technologies</title></book>
</publication>
```



publication

publisher

book

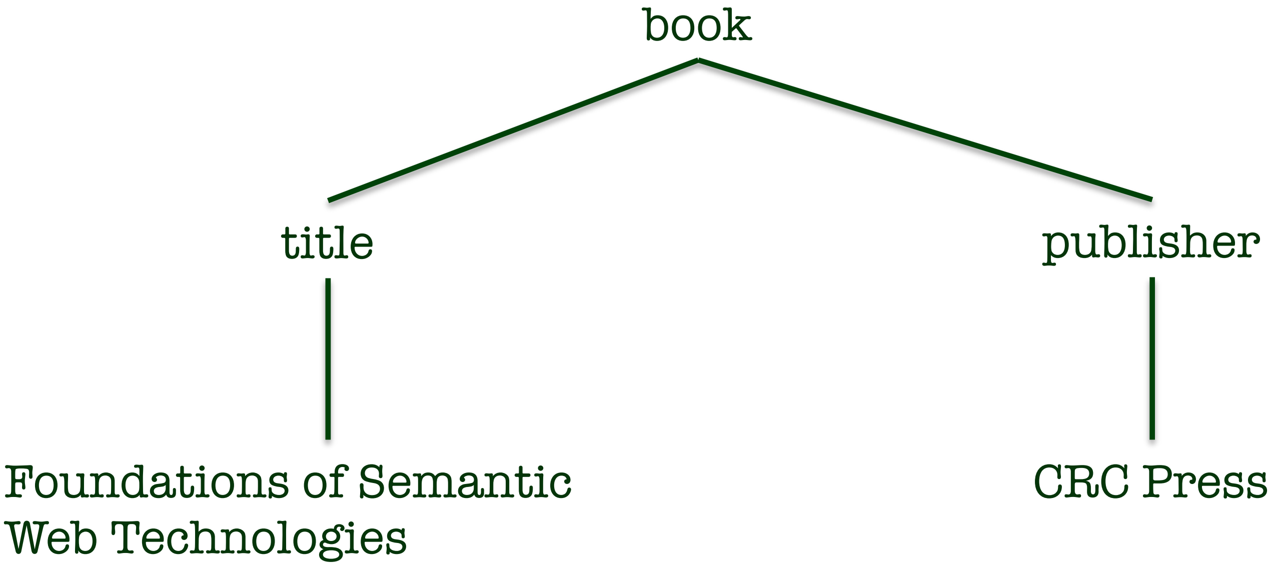
CRC Press

title

Foundations of Semantic Web Technologies

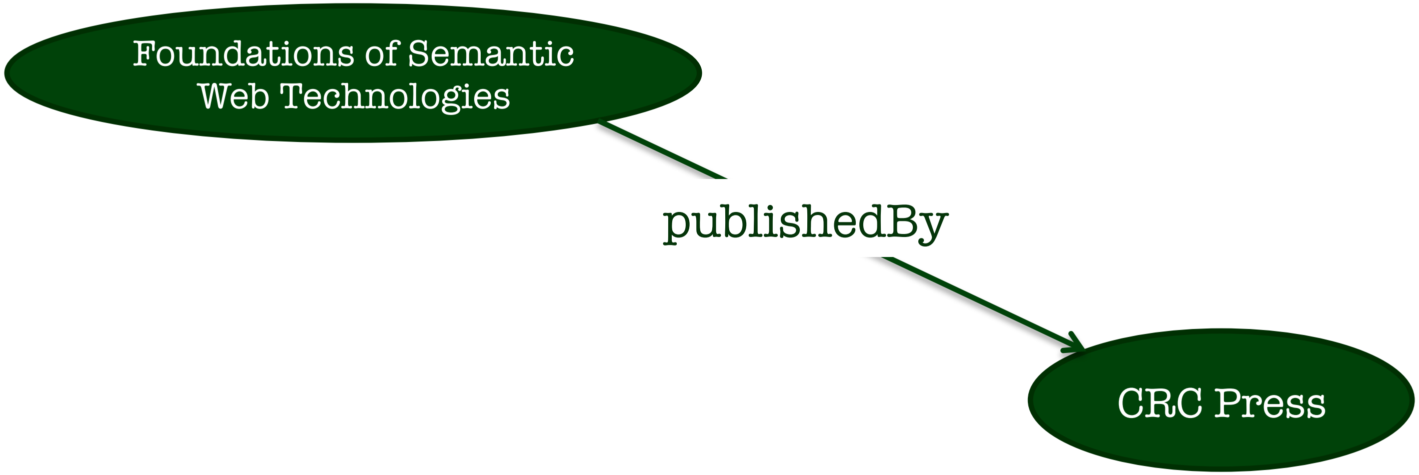
XML is tree-based (2)

```
<book>
	<title>Foundations of Semantic Web Technologies<\title>
	<publisher>CRC Press</publisher>
</book>
```



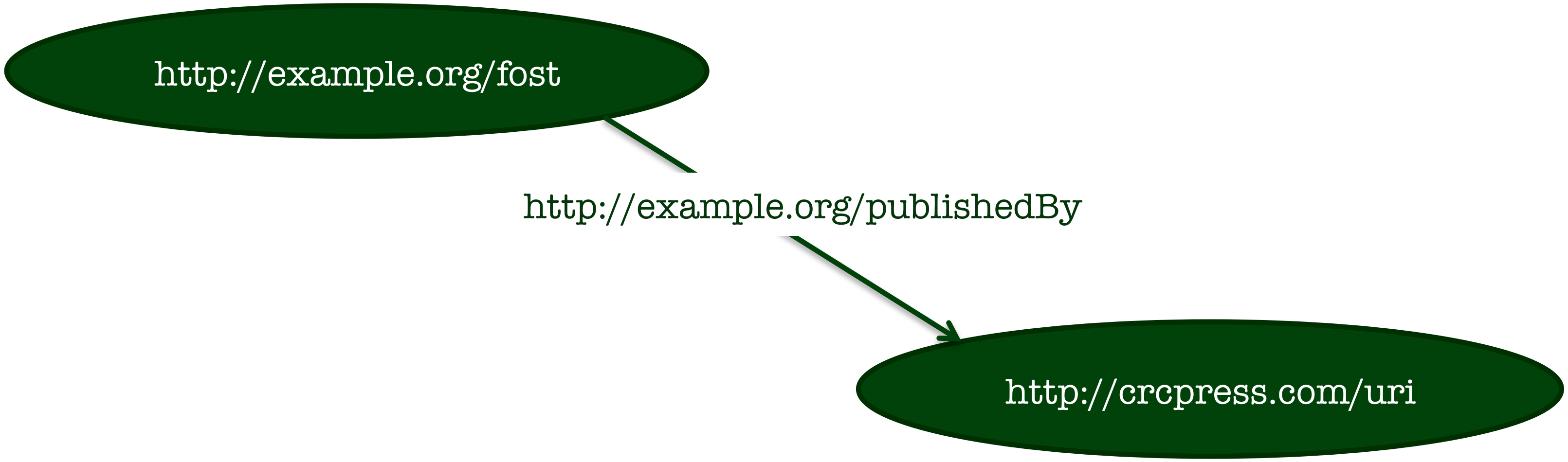
Graphs instead of Trees (1)

- Earlier XML trees essentially represent the same relationship.
- Combining trees are cumbersome
  - and the result isn’t always clear (may not even be a tree!).
- Solution: use (directed) graph model.



Graphs instead of Trees (2)

- And since we're on the Web, we use URI, instead of strings, to represent entities.



About RDF

- RDF = Resource Description Framework
  - W3C Recommendation 2004 (RDF 1.0)
  - W3C Recommendation 2014 (RDF 1.1)
- RDF is a data model:
  - Initially intended for describing metadata of Web resources, but found more general use later.
  - Represents structured information
  - A universal, machine readable data exchange format (with several types of standard serialization).

Outline

1. Motivation: Graph Data Model
2. **Syntax and Serialization Format**
3. Datatypes
4. Multi-valued/n-ary relationships
5. Blank nodes
6. Dataset

RDF Components

- Resource/entity: anything in the world
  - physical things, documents, abstract concepts, numbers, strings, …
- RDF components correspond to resources:
  - *IRI/URI*: identifier of a resource
  - *Literal*: data value
  - *Blank node*: denote a resource without giving it a name (i.e., the resource exists but doesn’t have a name or the name is unknown)

URI / IRI (1)

- Graph model enables simple composition of distributed data
  - True w.r.t. the structure, but not necessarily w.r.t. the content
- Problem 1: the same resource may be labeled with two different identifiers.
  - e.g., no globally agreed identifier for the book “Foundations of Semantic Web Technologies”
- Problem 2: the same identifier may be used for two different resources.
  - e.g., “CRC” may refer to the publishing house, or the Cincinnati Recreation Commission
- Solution: XML and RDF use URI

URI / IRI (2)

- URI = Uniform Resource Identifier
- String of characters for identifying a resource.
- Specified in RFC 3986
- Generalized from Uniform Resource Locator (URL), i.e., Web address.
  - Every URL is a URI.
  - Some URIs are not URL – sometimes called Uniform Resource Name (URN).
- Now generalized to Internationalized Resource Identifier (IRI) – specified in RFC 3987 – by allowing non-ASCII characters.
- A single URI cannot refer to two distinct objects
  - If a URI occurs in two distinct data sources, it always refer to the same resource.

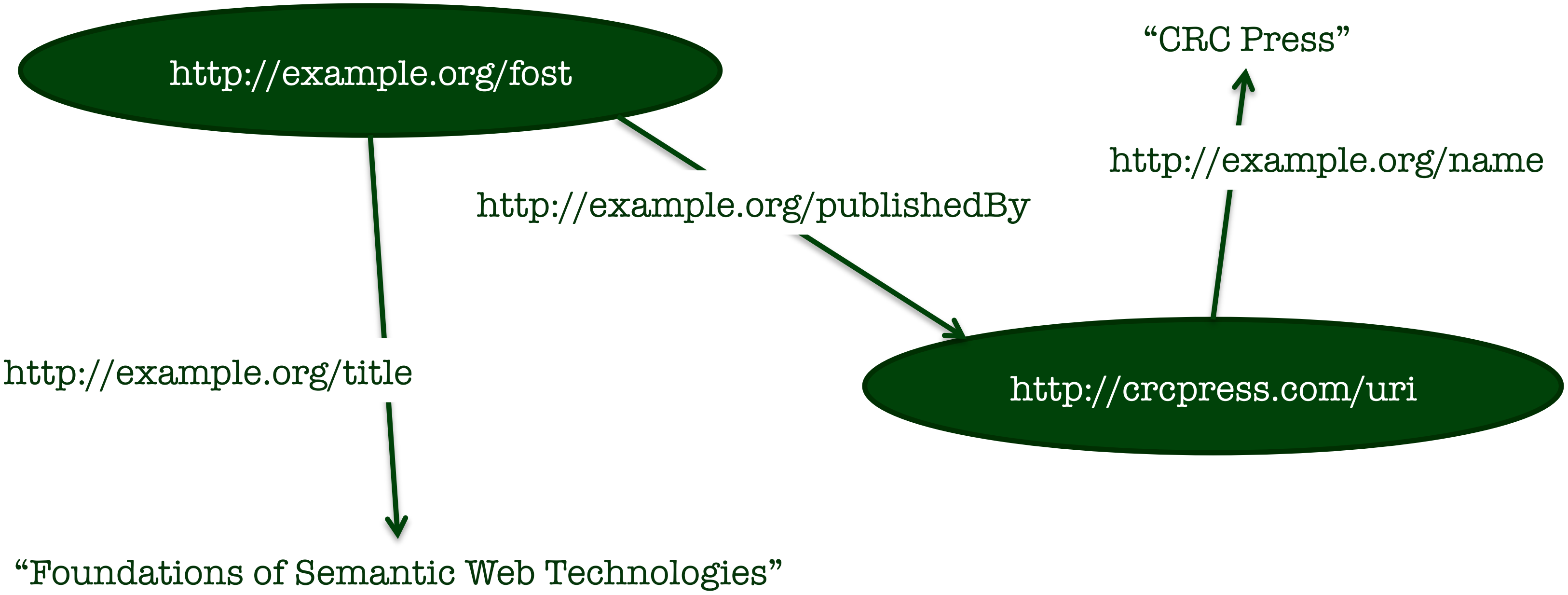
URI / IRI: Syntax

scheme : [//authority] path [?query][#fragment]

- Scheme (mandatory): classifies type of URI
  - http, ftp, mailto, file, irc
- Authority (optional): typically domain name, possibly with user and port details
  - example.org:8080, google.com, john@example.com
- Path (mandatory): main part of URI, possibly empty, e.g., in email addresses. May be organized as hierarchy with slash ('/') separator.
  - /, /etc/passwd/, ~/../krisnadhi
  - paths must have initial /, unless no authority is given
- Query (optional): preceded by ?, provides additional non-hierarchical information.
- Fragment (optional): preceded by #, provides second level of identifying resources.
- All parts of URI, except scheme and authority/host, are case-sensitive, unless specified otherwise by the scheme.
  - There are detailed exceptions (read the RFC!)

Literals

- for representing data value
- denoted as strings
- may optionally be suffixed with either a datatype URI or language tag (but not both)
- interpreted by associated datatype
- literals without an associated datatype or language tag are treated as strings

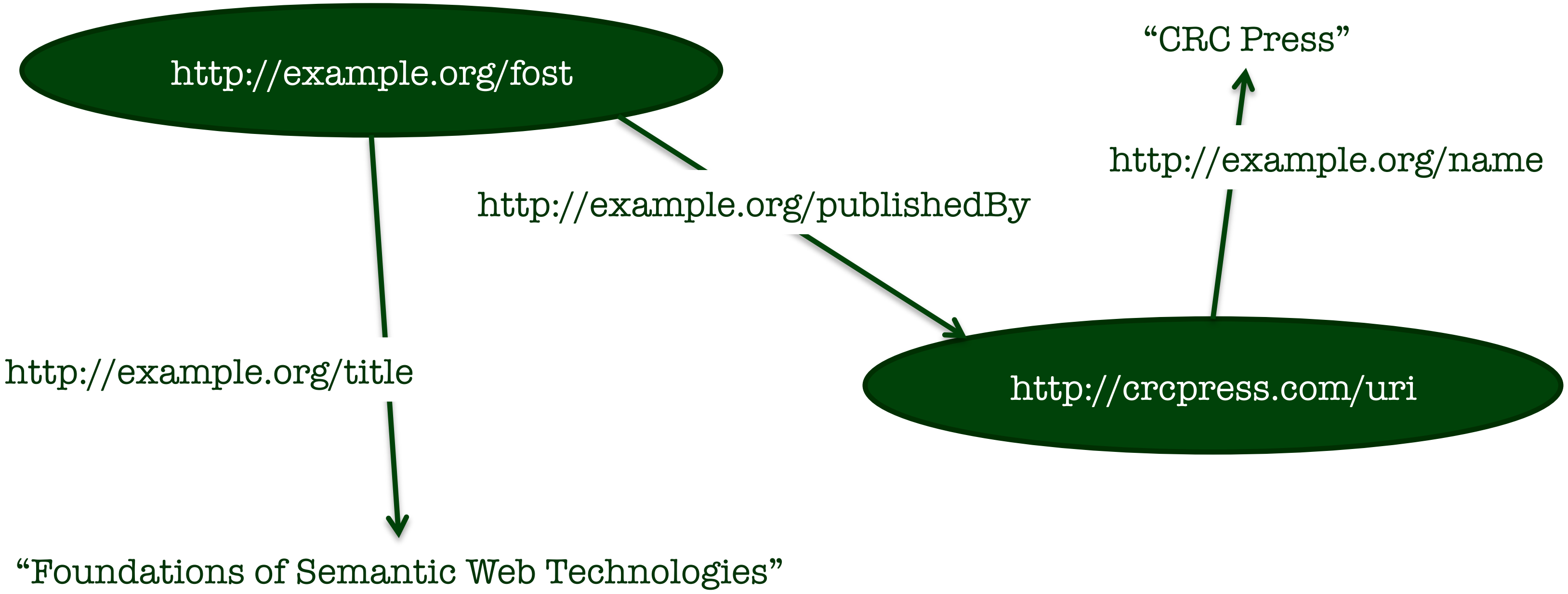


Blank Nodes

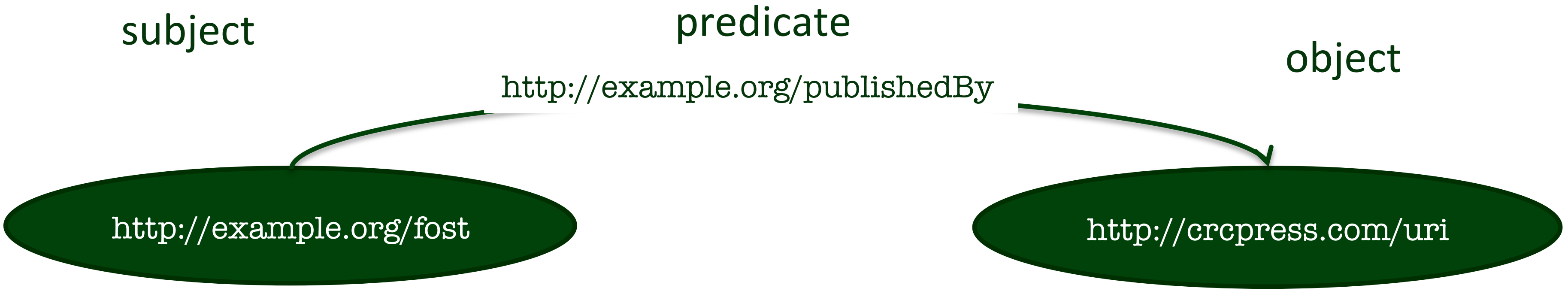
- Discussed later ☺

From Graph to Triple

- Graph can be represented in different ways.
- RDF chooses triples, i.e., an RDF graph is a set of (node-edge-node) triples.
- How many triples are there below?



RDF Triple



- Permitted component:
  - subject: URI or blank node
  - predicate: URI
  - object: URI, blank node, or literal
- Node and edge labels are unique, so the graph can always be reconstructed from the set of triples.

RDF Serialization

- RDF serialization format: concrete syntax for writing RDF files or transferring RDF data over network.
  - N-Triples
  - Turtle
  - RDF/XML [The only serialization format of RDF 1.0]
  - Trig
  - JSON-LD
  - N-Quads
  - RDFa
- RDF Document: a document (e.g., a file) that encodes an RDF graph or RDF dataset in a particular concrete syntax.

N-Triples

- Simple enumeration of triples; suitable for line-based parsing.
- A simplified version of Tim Berners-Lee’s Notation 3 (N3).
- N-Triples document: each line is either a triple or a comment.
- A triple: a sequence of (subject, predicate, object) terms, separated by whitespace and terminated with a full stop (‘.’)
- A comment: parts of a line beginning with a pound sign (‘#’) until the end of line, provided the pound sign occurs outside any URI or literal.
- URIs: enclosed with ‘<‘ and ‘>’
- Blank nodes: prefixed with underscore and colon (‘_:’)
- Literals: enclosed with double quotes; may optionally be suffixed with a datatype indicator (double carets followed by datatype URI) or a language tag (ampersand followed by a language codestring).

```
<http://example.org/fost> <http://example.org/publishedBy> <http://crcpress.com/uri> .
# comment here
<http://example.org/fost> <http://example.org/title> “Foundations of Semantic Web Technologies”@en .
<http://crcpress.com/uri> <http://example.org/name> “CRC Press”^^<http://www.w3.org/2001/XMLSchema#string> .
```

Turtle – Terse RDF Triple Language

- every N-Triples document is a Turtle document
- Triples end with a full stop. Groupings are possible (see example).
- Whitespaces outside URIs and literals are only as token separator. Newlines are not important, unlike N-Triples.
- URIs:
  - Full URIs: enclosed by '<' and '>'
  - Abbreviated URIs: use a previously declared namespace prefix (no enclosing angled brackets).
- Literals:
  - Quoted literals (like N-Triples, but datatype URI may be abbreviated)
  - Numeric (integer, decimal, floating point) literals, e.g., 5 is shorthand for "5"^^xsd:integer
  - Boolean literals: 'true' or 'false' (without quotes, case sensitive).
- Blank nodes:
  - Prefixed with '_:' like N-Triples, i.e., labeled blank nodes; or
  - Use square brackets (see example later).

Turtle

```
<http://example.org/fost>
      <http://example.org/publishedBy> <http://crcpress.com/uri> .
# comment here

<http://example.org/fost> <http://example.org/title>
      “Foundations of Semantic Web Technologies”@en .

<http://crcpress.com/uri> <http://example.org/name>
“CRC Press”^^<http://www.w3.org/2001/XMLSchema#string> .
```

Turtle

Abbreviated URIs using prefix

```
@prefix ex: <http://example.org/> .
@prefix crc: <http://crcpress.com/> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .

ex:fost  ex:publishedBy crc:uri .
ex:fost ex:title   “Foundations of Semantic Web Technologies”@en .
crc:uri ex:name  “CRC Press”^^xsd:string .
```

Turtle

```
@prefix ex: <http://example.org/> .
@prefix crc: <http://crcpress.com/> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .

ex:fost  ex:publishedBy crc:uri .
ex:fost  ex:title    “Foundations of Semantic Web Technologies”@en .
crc:uri  ex:name  “CRC Press”^^xsd:string .
crc:uri  ex:name  “CRC” .
```

- Grouping triples with the same subject
- Grouping triples with the same subject and predicate.

```
@prefix ex: <http://example.org/> .
@prefix crc: <http://crcpress.com/> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .

ex:fost   ex:publishedBy crc:uri ;
          ex:title   “Foundations of Semantic Web Technologies”@en .
crc:uri   ex:name  “CRC Press”^^xsd:string ,  “CRC” .
```

RDF/XML

- Namespaces used to disambiguate tags (like in XML)
- RDF-specific tags have predefined namespace, by convention, abbreviated as ‘rdf’

```
<?xml version="1.0" encoding="utf-8"?>
<rdf:RDF xmlns:crc="http://crcpress.com/" xmlns:ex="http://example.org/"
            xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
            xmlns:xsd="http://www.w3.org/2001/XMLSchema#”>

  <rdf:Description rdf:about=”http://example.org/fost">
    <ex:publishedBy rdf:resource="http://crcpress.com/uri"/>
  </rdf:Description>
  <rdf:Description rdf:about=”http://example.org/fost">
    <ex:title xml:lang="en">Foundations of Semantic Web Technologies</ex:title>
  </rdf:Description>
  <rdf:Description rdf:about="http://crcpress.com/uri">
    <ex:name rdf:datatype="http://www.w3.org/2001/XMLSchema#string">CRC Press</ex:name>
  </rdf:Description>
  <rdf:Description rdf:about="http://crcpress.com/uri">
    <ex:name>CRC</ex:name>
  </rdf:Description>
</rdf:RDF>
```

RDF/XML

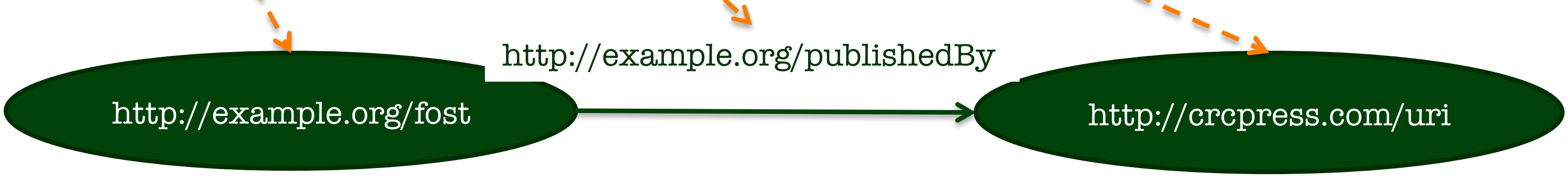
- rdf:Description element encodes the subject
- all direct children of the rdf:Description element encoding a subject are predicates
- predicate elements contain the object either through rdf:resource attribute or another rdf:Description element (see two examples below).

```
....
<rdf:Description rdf:about=”http://example.org/fost">
   <ex:publishedBy rdf:resource="http://crcpress.com/uri"/>
</rdf:Description>
....
```

```
....
<rdf:Description rdf:about=”http://example.org/fost">
   <ex:publishedBy>
        <rdf:Description rdf:about="http://crcpress.com/uri”/>
   <ex:publishedBy>
</rdf:Description>
....
```

RDF/XML

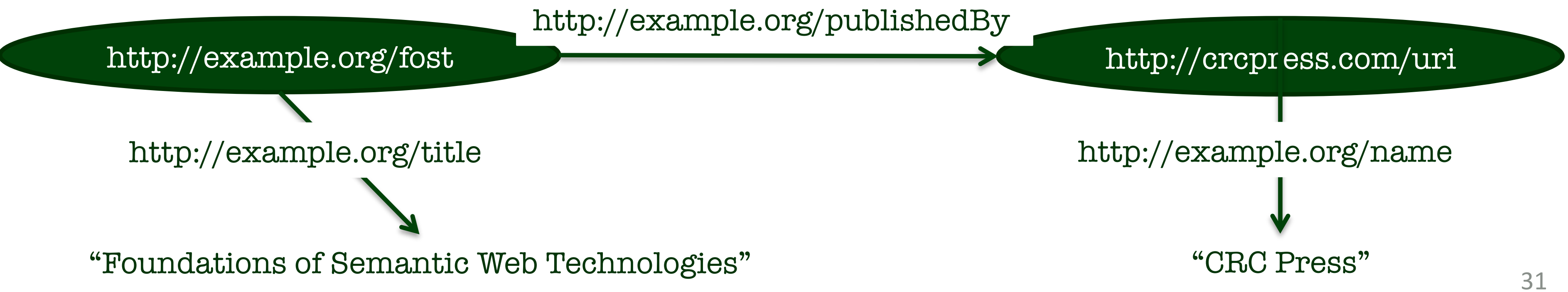
```
<?xml version="1.0" encoding="utf-8"?>
<rdf:RDF xmlns:ex="http://example.org/"
            xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#" >

   <rdf:Description rdf:about=”http://example.org/fost">
      <ex:publishedBy>
          <rdf:Description rdf:about="http://crcpress.com/uri"/>
      </ex:publishedBy>
   </rdf:Description>
</rdf:RDF>
```



RDF/XML

- Untyped literals can be included as a free text into the predicate element.
- Condensed form:
  - One subject with several predicate elements.
  - One object description serves as subject of another triple.

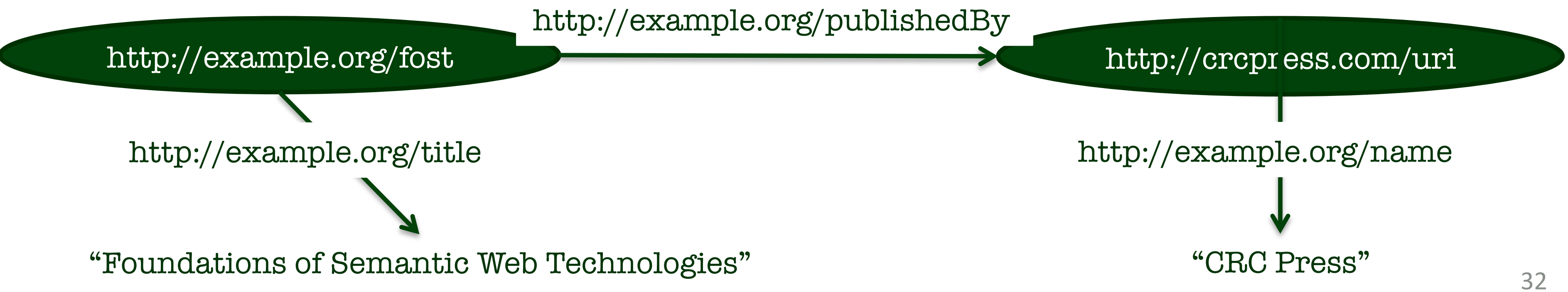
```
<rdf:Description rdf:about="http://example.org/fost">
   <ex:title>Foundations of Semantic Web Technologies</ex:title>
   <ex:publishedBy>
      <rdf:Description rdf:about="http://crcpress.com/uri"/>
         <ex:name>CRC Press</ex>name>
       </rdf:Description>
   </ex:publishedBy>
</rdf:Description>
```



RDF/XML

- Alternative: literal as attribute of the subject with the corresponding predicate as the attribute name.
- Object URI as value of the attribute rdf:resource inside predicate tag.

```
<rdf:Description rdf:about="http://example.org/fost"
                          ex:title=“Foundations of Semantic Web Technologies”>
      <ex:publishedBy rdf:resource=“http://crcpress.com/uri”/>
 </rdf:Description>
 <rdf:Description rdf:about="http://crcpress.com/uri"/>
       <ex:name>CRC Press</ex>name>
 </rdf:Description>
```



http://example.org/fost

http://example.org/publishedBy

http://crcpr ess.com/uri

http://example.org/title

http://example.org/name

“Foundations of Semantic Web Technologies”

“CRC Press”

RDF/XML

- Namespace is essential in XML serialization, since colon (‘:’) in XML attributess is not allowed unless used with a namespace.
- Problem: namespace cannot be used in values of XML attributes, e.g., rdf:about=“ex:fost” is **wrong** since ‘ex’ would be interpreted as URI scheme.
- Solution: use XML ENTITY

```
<?xml version="1.0" encoding="utf-8"?>
<rdf:RDF xmlns:ex="http://example.org/" xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#">
<!DOCTYPE rdf:RDF[ <!ENTITY ex 'http://example.org/'> ]>

    <rdf:Description rdf:about=”&ex;fost">
        <ex:title xml:lang="en">Foundations of Semantic Web Technologies</ex:title>
    </rdf:Description>
</rdf:RDF>
```

RDF/XML

- Use of base namespace

```
<?xml version="1.0" encoding="utf-8"?>
<rdf:RDF xmlns:crc="http://crcpress.com/" xmlns:ex="http://example.org/"
        xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
        xmlns:xsd="http://www.w3.org/2001/XMLSchema#" xmlns:base="http://example.org/">

  <rdf:Description rdf:about="fost">
    <ex:publishedBy rdf:resource="http://crcpress.com/uri"/>
  </rdf:Description>
  <rdf:Description rdf:about="fost">
    <ex:title xml:lang="en">Foundations of Semantic Web Technologies</ex:title>
  </rdf:Description>
  <rdf:Description rdf:about="http://crcpress.com/uri">
    <ex:name rdf:datatype="http://www.w3.org/2001/XMLSchema#string">CRC Press</ex:name>
  </rdf:Description>
  <rdf:Description rdf:about="http://crcpress.com/uri">
    <ex:name>CRC</ex:name>
  </rdf:Description>
</rdf:RDF>
```

Turtle vs RDF/XML

- Turtle is MUCH easier to read and write.
- Tool and programming support for XML are MUCH more widely available.
  - That's why the normative syntax for RDF 1.0 was XML only.
- There are tools to convert different RDF serialization format.

Other serialization formats?

- Trig
- JSON-LD
- N-Quads
- RDFa

See W3C standard documents ☺

Outline

1. Motivation: Graph Data Model
2. Syntax and Serialization Format
3. **Datatypes**
4. Multi-valued/n-ary relationships
5. Blank nodes
6. Dataset

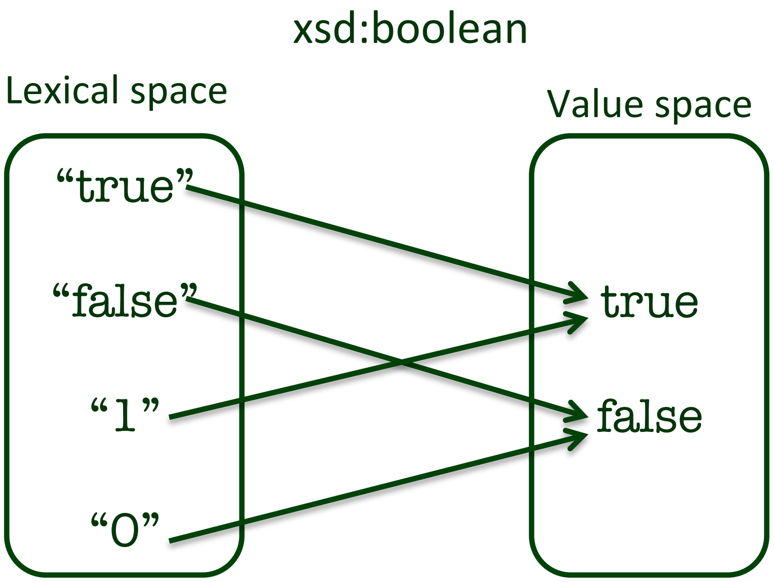
Datatypes

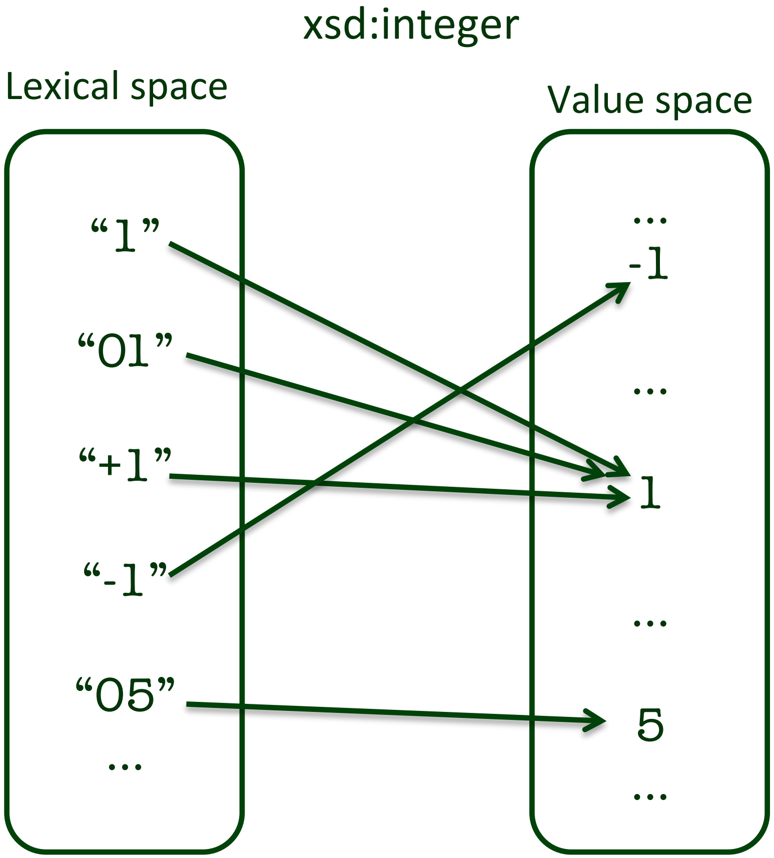
- Each datatype is identified by a URI.
  - http://www.w3.org/2001/XMLSchema#string is for string.
- Serialization: see previous examples where we use typed literal: “CRC Press”^^xsd:string.
- Many XML Schema datatypes are RDF-compatible.
- rdf:HTML datatype for HTML content as literal value
- rdf:XMLLiteral datatype for XML content as literal value

Datatypes

- Each datatype has a lexical space, a value space, and a lexical-to-value mapping, e.g.,
- Simple literals (no explicit type and language tag) belong to xsd:string
- Language-tagged literals belong to rdf:langString

Datatypes





- For xsd:string: "02" < "2"
- For xsd:integer: "02" = "2"

Outline

1. Motivation: Graph Data Model
2. Syntax and Serialization Format
3. Datatypes
4. **Multi-valued/n-ary relationships**
5. Blank nodes
6. Dataset

N-ary relationship

- “For preparation of Chutney, you need 1 lb green mango, a teaspoon Cayenne pepper, …”
- What’s wrong with this modeling attempt? (Try visualizing it).

```
@prefix ex: <http://example.org/> .
ex:Chutney      ex:hasIngredient  "1lb green mango",
                                  "1 tsp. Cayenne pepper",
                                  ...
```

N-ary relationship

- How about this one? (Try visualizing it)

```
@prefix ex: <http://example.org/> .
ex:Chutney      ex:hasIngredient  ex:greenMango ;
                ex:amount         "1 lb” ;
                ex:hasIngredient  ex:CayennePepper ;
                ex:amount         "1 tsp.” ;
                …
```

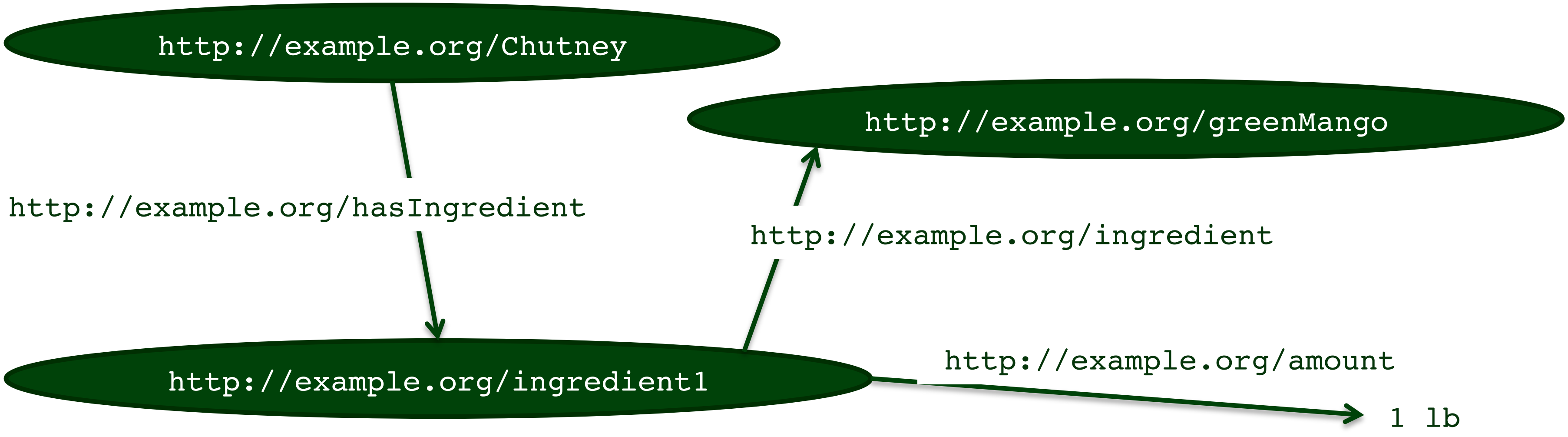
N-ary relationship

- The problem: we have a proper ternary relationship (like in relational databases).

dish	Ingredient	Amount
chutney	green mango	1 lb.
chutney	Cayenne pepper	1 tsp.

- Representation in RDF needs auxiliary nodes.

N-ary relationships


http://example.org/Chutney
http://example.org/greenMango
http://example.org/hasIngredient
http://example.org/ingredient
http://example.org/ingredient1
http://example.org/amount
1 lb

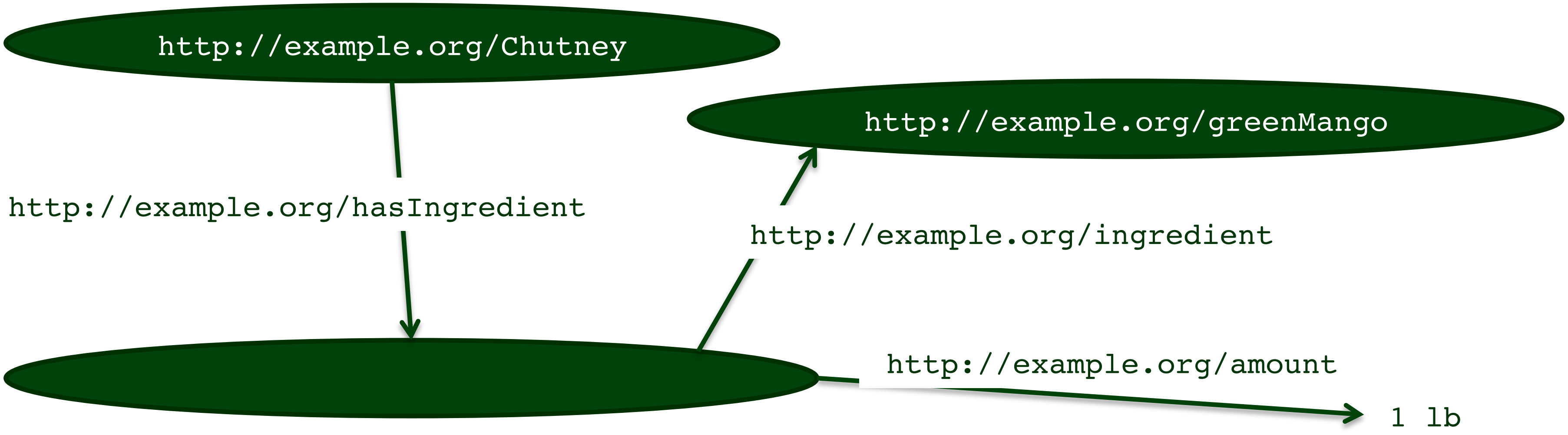
```
@prefix ex: <http://example.org/> .
ex:Chutney        ex:hasIngredient ex:ingredient1 .
ex:ingredient1    ex:ingredient    ex:greenMango ;
                  ex:amount     “1 lb” .
...
```

Outline

1. Motivation: Graph Data Model
2. Syntax and Serialization Format
3. Datatypes
4. Multi-valued/n-ary relationships
5. **Blank nodes**
6. Dataset

Blank nodes

- Blank nodes (bnodes) can be used for nodes that need not be named.
- Can be read as an existential statement.


http://example.org/Chutney
http://example.org/greenMango
http://example.org/hasIngredient
http://example.org/ingredient
http://example.org/amount
1 lb

Blank Nodes

- RDF/XML syntax:

```
<rdf:Description rdf:about="http://example.org/Chutney">
    <ex:hasIngredient rdf:nodeID="id1" />
</rdf:Description>
<rdf:Description rdf:nodeID="id1">
    <ex:ingredient rdf:resource="http://example.org/greenMango"/>
    <ex:amount>1 lb<ex:amount/>
</rdf:Description>
```

- abbreviated:

```
<rdf:Description rdf:about="http://example.org/Chutney">
    <ex:hasIngredient rdf:parseType="Resource">
        <ex:ingredient rdf:resource="http://example.org/greenMango"/>
        <ex:amount>1 lb<ex:amount/>
    </ex:hasIngredient>
</rdf:Description>
```

Blank Nodes

- Turtle syntax:

```
@prefix ex: <http://example.org/> .
ex:Chutney   ex:hasIngredient    _:id1 .
_:id1        ex:ingredient       ex:greenMango ;
             ex:amount           "1 lb" .
```

- abbreviated (using square brackets):

```
@prefix ex: <http://example.org/> .
ex:Chutney   ex:hasIngredient
                 [  ex:ingredient    ex:greenMango ;
                    ex:amount        "1 lb" ] .
```

Blank Node Identifiers

- Blank node identifiers: local identifiers used in some concrete RDF syntax (i.e., serialization format) or RDF store implementations.
  - Thus, entirely dependent on the implementation of the serialization or RDF store.
  - e.g., in Turtle, we use '_:' prefix to indicate such identifiers.
- Always locally scoped to the file or RDF store.
- NOT persistent and NOT portable.
- Need to be careful when dealing with multiple blank nodes, especially from different RDF data sources.
- During processing, we may need to Skolemize blank nodes: replacing them with globally unique URIs (called Skolem URI/IRI) that are not previously used.

Graph Isomorphism

- Often, we want to know if two RDF graphs are structurally “the same”
- We use the notion of isomorphism.
- Graph G1 and G2 are isomorphic (i.e., have identical form) if there is a mapping/function M from G1 to G2 such that:
  - M is a bijection
  - M maps blank nodes in G1 to blank nodes in G2.
  - M(lit) = lit, for each literal lit occurring as a node in G1
  - M(uri) = uri, for each URI/IRI uri occurring as a node in G1
  - The triple (s,p,o) is in G1 <u>if and only if</u> the triple (M(s), p, M(o)) is in G2.
- Note: we use equality definition for literals and URI/IRIs defined in the RDF specs.

Outline

1. Motivation: Graph Data Model
2. Syntax and Serialization Format
3. Datatypes
4. Multi-valued/n-ary relationships
5. Blank nodes
6. **Dataset**

Datasets

- RDF Dataset = A collection of RDF graphs such that:
  - Exactly one graph is the default graph. The default graph does not have a name and may be empty.
  - Zero or more named graphs. The name of each named graph is either a URI or a blank node.
    - Graph names are unique within a dataset.
- Serialization of RDF datasets are supported by TriG, N-Quads, JSON-LD
  - There is no mention of the notion of RDF Dataset in the RDF 1.1 XML syntax specification.

Other RDF Features

- Container: open collection
- Collection: closed collection
- Reification
- Utility properties

We'll discuss this along with RDF Schema.