Knowledge Graph Design for Data Sharing, Integration, and Reuse

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Data Semantics Lab

- **10 PhD students, 1 Master student, 7 undergrads**
- **Kansas State University, Manhattan, KS. http://daselab.org**
- **Semantic Web Data Management; Neural-Symbolic Integration**

Knowledge Graphs

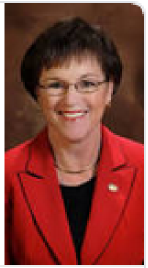
Knowledge Graphs and their schemas are made to enable easier

- **data sharing**
- **data discovery**
- **data integration**
- **data reuse**

Google Knowledge Graph

Laura Kelly

Governor of Kansas



Laura Kelly is an American politician serving as the 48th governor of Kansas since 2019. A member of the Democratic Party, she represented the 18th district in the Kansas Senate from 2005 to 2019. Kelly ran for governor in the 2018 election and defeated the Republican nominee, Kansas Secretary of State Kris Kobach. Wikipedia

Born: January 24, 1950 (age 69 years), New York, NY

Spouse: Ted Daughety

Party: Democratic Party

Office: Governor of Kansas since 2019

Education: Indiana University, Bradley University, Indiana University Bloomington

Children: Kathleen Daughety, Molly Daughety

→ hasEducation →

Indiana University

iu.edu

Indiana University is a multi-campus public university system in the state of Indiana, United States. Indiana University has a combined student body of more than 110,000 students, which includes approximately 46,000 students enrolled at the Indiana University Bloomington campus. Wikipedia

Mascot: Referred to as "The Hoosiers"

Endowment: 1.986 billion USD

Students: 110,436 university-wide

President: Michael McRobbie

Academic staff: 8,733 university-wide

Subsidiaries: Indiana University Bloomington, MORE

→ hasPresident →

Michael McRobbie

President of Indiana University

president.iu.edu

Michael Alexander McRobbie AO is an Australian-American computer scientist, educator and academic administrator. He became the eighteenth president of Indiana University on July 1, 2007. Wikipedia

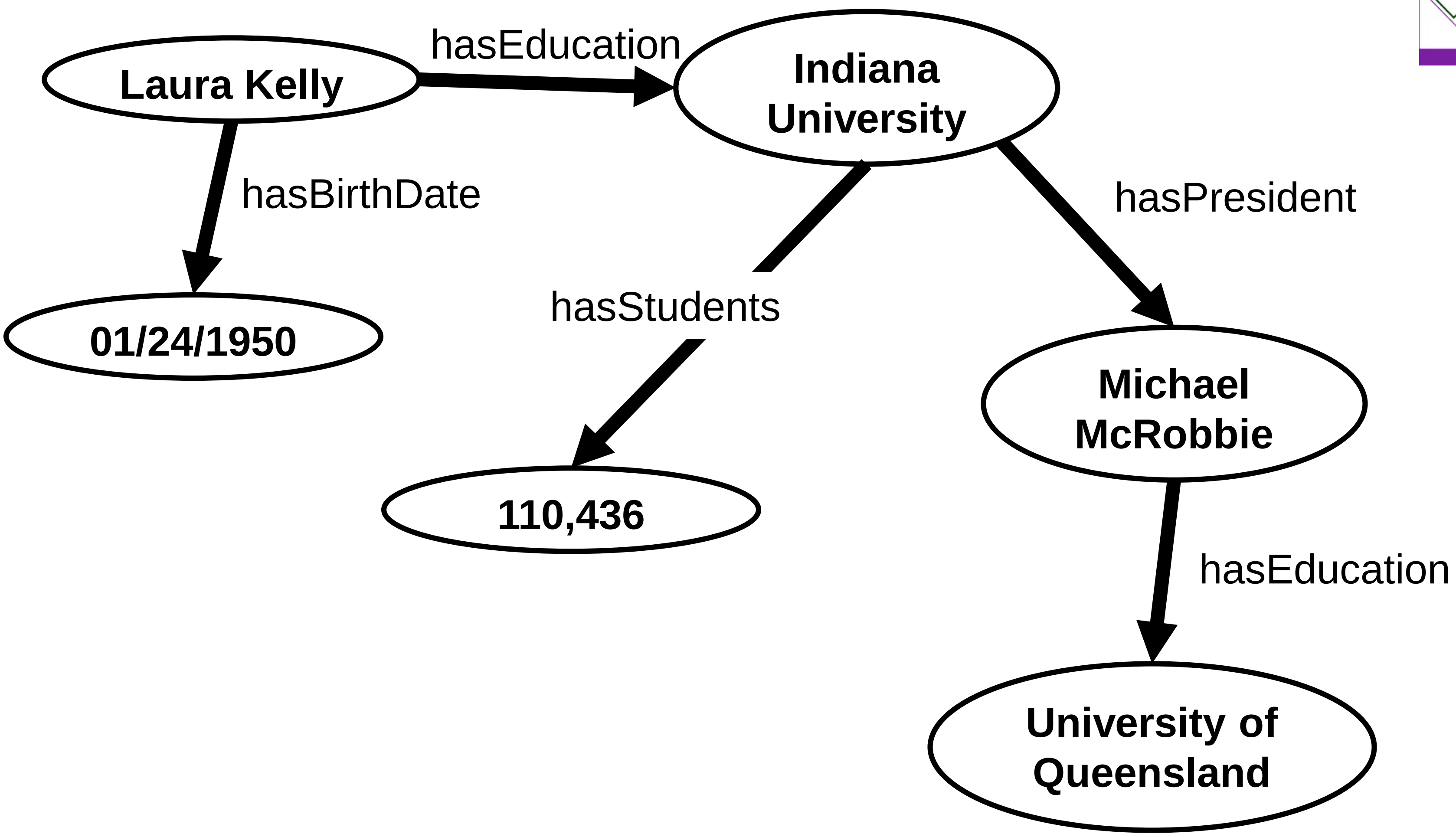
Born: October 11, 1950 (age 69 years), Melbourne, Australia

Spouse: Laurie Burns (m. 2005)

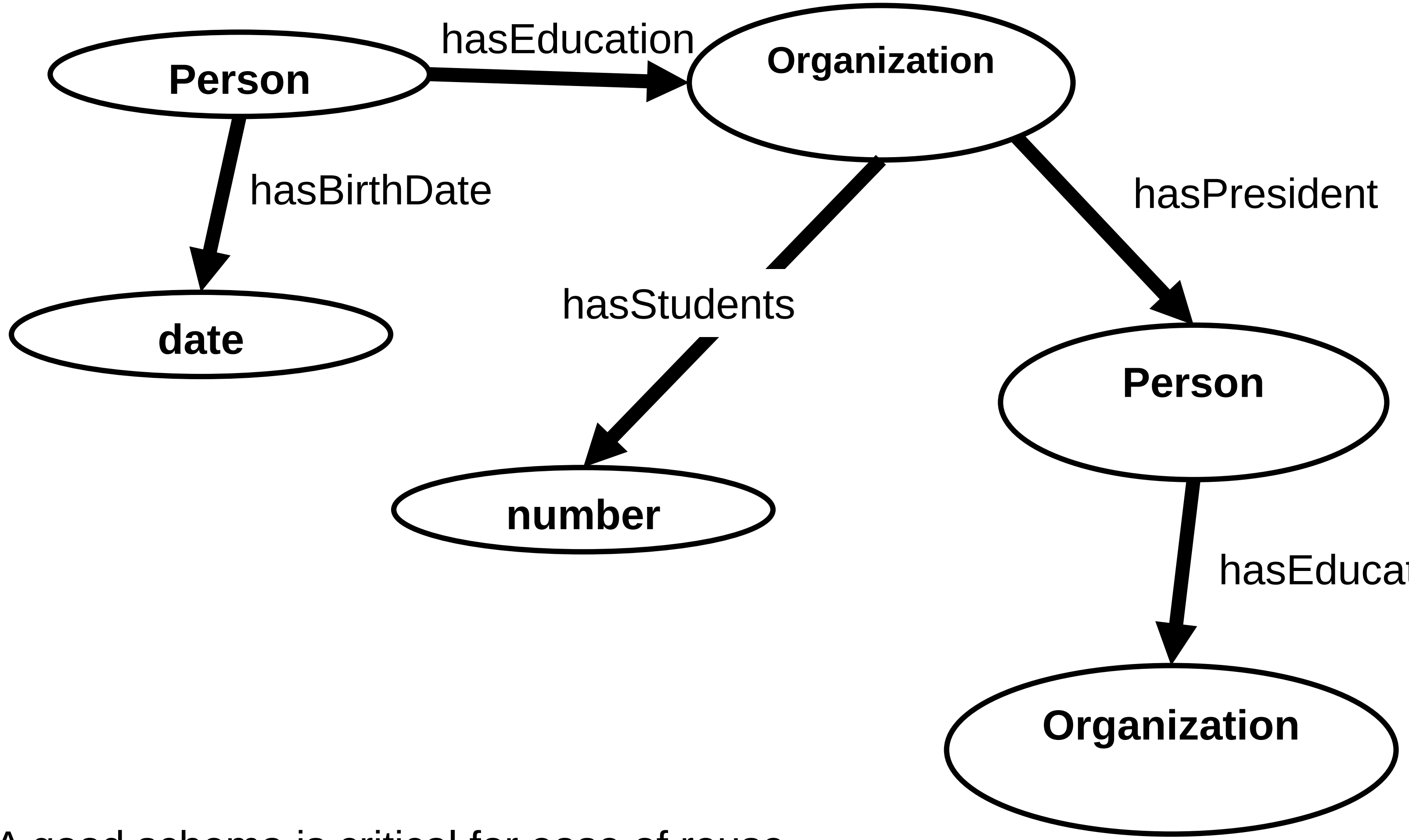
Education: The Australian National University, The University of Queensland

Books: Automated Theorem-proving in Non-classical Logics, Automated Deduction - Cade-13

Knowledge Graphs



Schema (as diagram)



A good schema is critical for ease of reuse

Knowledge Graphs

Knowledge Graphs and their schemas are made to enable easier

- **data sharing**
- **data discovery**
- **data integration**
- **data reuse**

Knowledge Graph Standards

W3C Recommendation

RDF 1.1 Concepts and Abstract Syntax

W3C Recommendation 25 February 2014

This version:
http://www.w3.org/TR/2014/REC-rdf11-concepts-20140225/
Latest published version:
http://www.w3.org/TR/rdf11-concepts/
Previous version:
http://www.w3.org/TR/2014/PR-rdf11-concepts-20140109/
Previous Recommendation:
http://www.w3.org/TR/rdf-concepts
Editors:
Richard Cyganiak, DERI, NUI Galway
David Wood, 3 Round Stones
Markus Lanthaler, Graz University of Technology

W3C Recommendation

OWL 2 Web Ontology Language Primer (Second Edition)

W3C Recommendation 11 December 2012

This version:
http://www.w3.org/TR/2012/REC-owl2-primer-20121211/
Latest version (series 2):
http://www.w3.org/TR/owl2-primer/
Latest Recommendation:
http://www.w3.org/TR/owl-primer
Previous version:
http://www.w3.org/TR/2012/PER-owl2-primer-20121018/
Editors:
Pascal Hitzler, Wright State University
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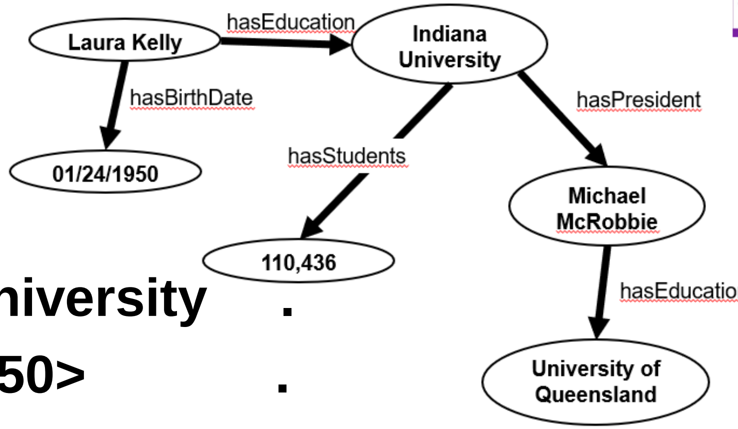
Peter F. Patel-Schneider, Nuance Communications
Sebastian Rudolph, FZI Research Center for Information

RDF in a nutshell



:LauraKelly :hasEducation :IndianaUniversity .
:LauraKelly :hasBirthDate <01/24/1950> .

:IndianaUniversity :hasPresident :MichaelMcRobbie .
:IndianaUniversity :hasStudents <110,436> .

Etc.

Identifiers are URIs.

You call these node-edge-node pieces "(RDF) triples".

A knowledge graph is a set of RDF triples.

This syntax is called RDF Turtle syntax.

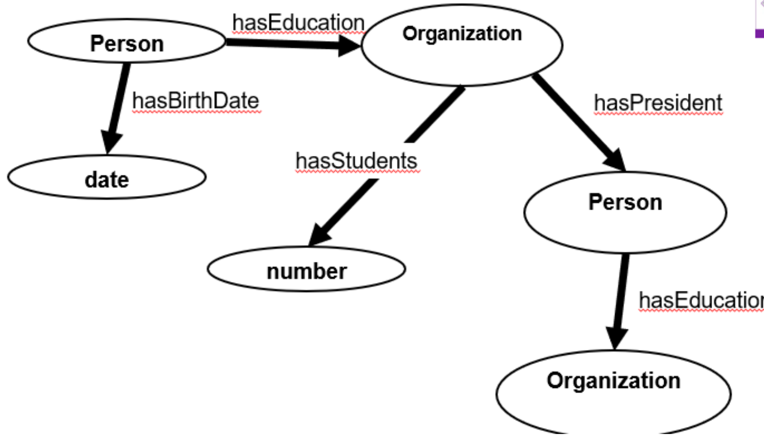
The standard prescribes a serialization in XML.

Linked Data: Volume

Geoindexed Linked Data – courtesy of Krzysztof Janowicz, 2012

http://stko.geog.ucsb.edu/location_linked_data

OWL in a nutshell



Relations between

- **Classes (Types)**
- **Relations (Properties)**
- **Datatypes**

Exact relationships are recorded using a formal logic.

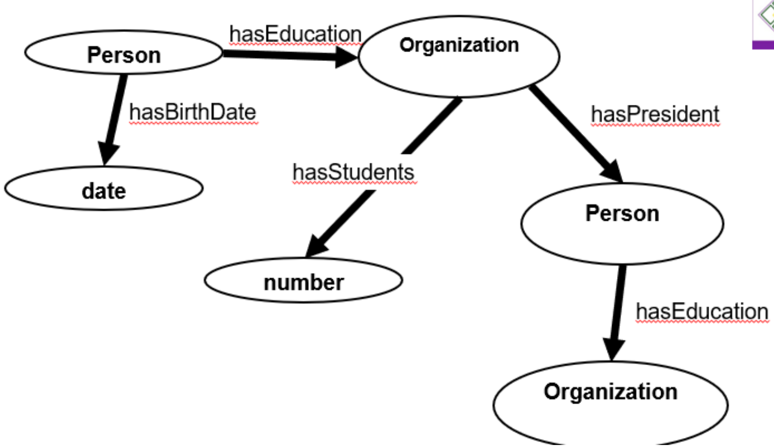
E.g., "Every University has a President"

(forall x)

(University(x) →

(exists y) (hasPresident(x,y) AND President(y)))

OWL in a nutshell



Classes: unary predicates (types)

Relations: binary predicates (properties)

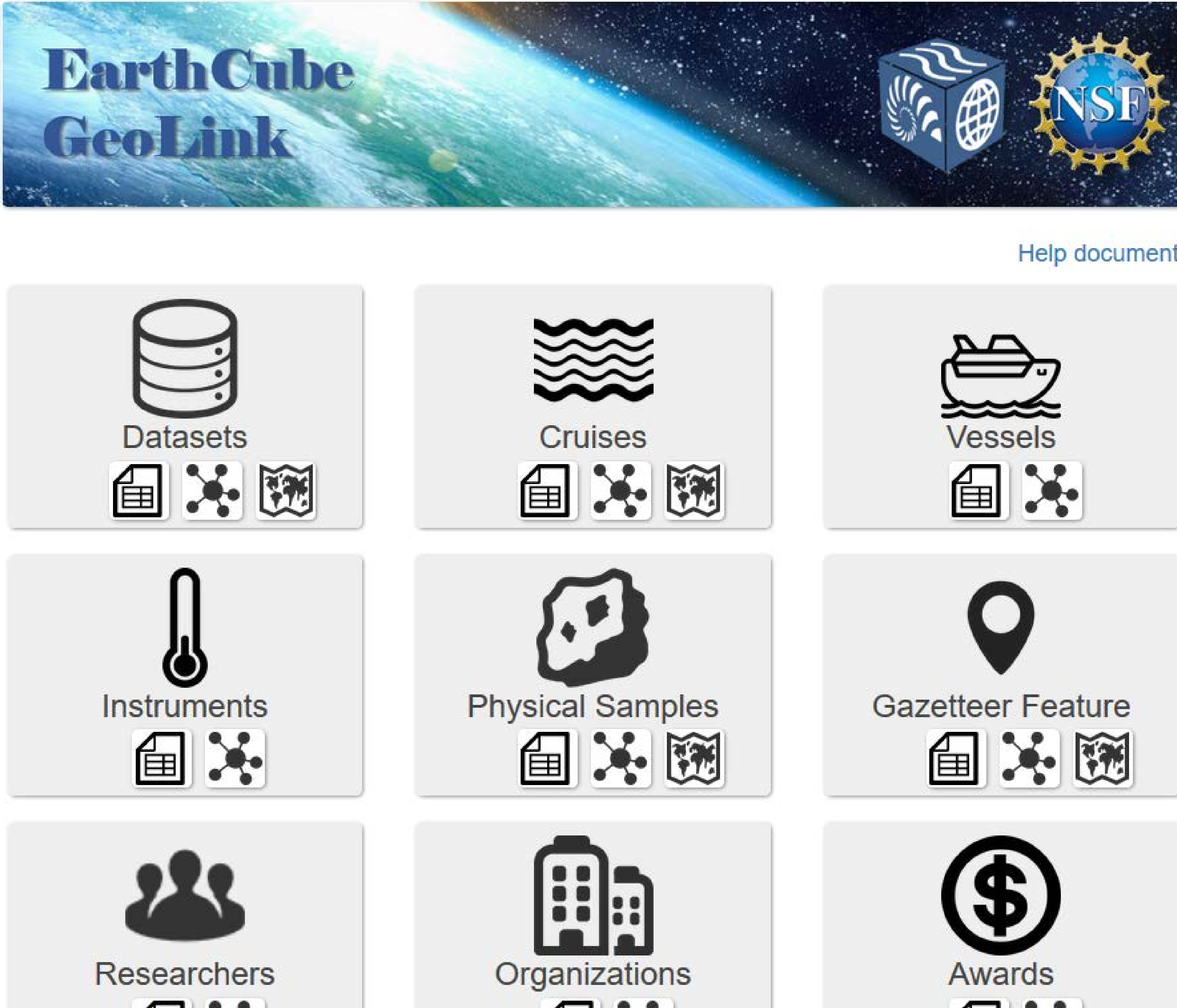
Logical AND, OR, NEGATION, IMPLICATION

Some restricted use of quantifiers

In particular: You can specify

- subClass relationships ("Mammal" is subClass of "Animal")
- subProperty relationships ("hasMother" subProperty of "hasParent")
- Domains and ranges of properties.

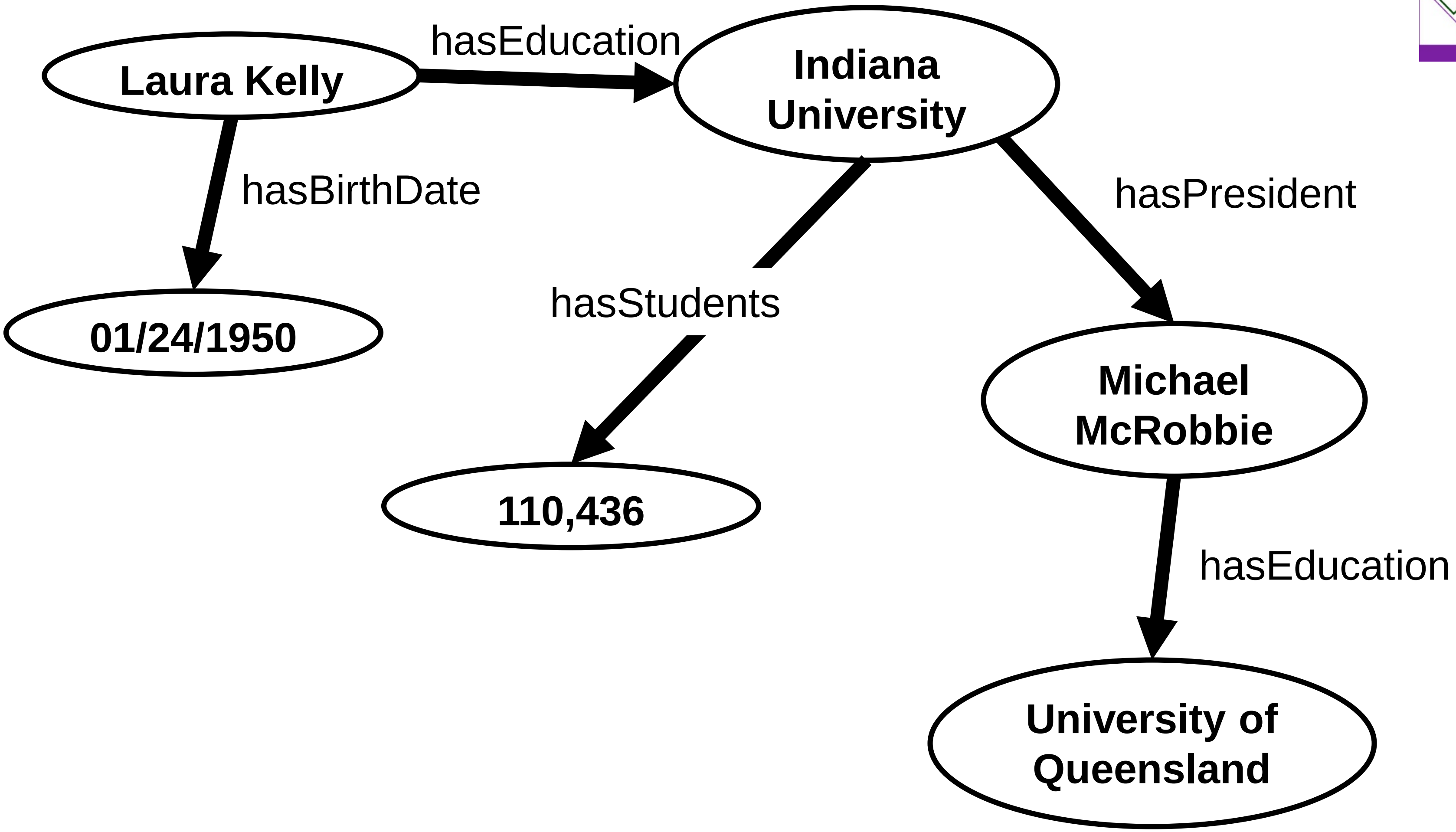
In team modeling, most members don't have to worry about these details. We heavily use schema diagrams to facilitate team modeling.


EarthCube
GeoLink
NSF
Help document
Datasets
Cruises
Vessels
Instruments
Physical Samples
Gazetteer Feature
Researchers
Organizations
Awards

e Lab

enslaved.org

This is not a good Knowledge Graph!



What makes a good data model?

- Structure resonates with both
  - human expert conceptualizations
  - data and use case requirements
- Generally low maintenance cost
  - Sustainable: robust for future use and re-use
  - Extendable without high management costs

- Ease of use with software and tools
- Machine processable (standards)

- Meets technical, legal, societal requirements
- Stakeholder buy-in

Some of our research

Lead Question:

How to lower knowledge graph management cost while meeting requirements.

Principles:

Our design and development process

- **bridges interdisciplinary barriers,**
- **produces artefacts which resonate with human expert understanding,**
- **is fully compatible with leading standards,**
- **is made to save on development and management costs.**

Knowledge Graph Schema Modeling

Note: “Knowledge Graph Schema” is a newer term for “Ontology”

Premise

Many ontologies are hard to understand and to re-use.

Some reasons:

- Poor (ad-hoc) modeling.
- Large, monolithic ontologies.
- Different use-case requirements on granularity (some parts too fine-grained, others too coarse).
- Different requirements on data representation for parts of the ontology (e.g., how spatial information is encoded).

Approach: Two main components

1. Modules
   – Rather than thinking of an ontology primarily as an enhanced taxonomy, we think of it as a set of interrelated (and possibly overlapping) modules.
   – Each module is essentially a part of an ontology representing a complex concept in a way which “makes sense” for a human expert. E.g., “oceanographic cruise”.
2. Use of ontology design patterns (ODPs)
   – An ODP is a solution template for a recurring ontology modeling problem.
   – ODPs are instantiated (and modified) to become modules. E.g., a general “Trajectory” ODP may be used as a template to create an “ocean science cruise trajectory” module.

Modeling Teamwork

The modeling team ideally has:

- **domain experts**
- **data experts**
- **ontology engineers**

Divide and Conquer

- **First decide on the set of modules to be modeled, then draft modules one at a time.**

Joint modeling

- **Work mainly through schema diagrams and natural language with the domain and data experts.**
- **Ontology engineers spell out model details between meetings, and cycle back to the experts for feedback.**

Modeling process – steps

1. Define use case or scope of use cases
2. Make competency questions while looking at possible data sources and scoping the problem, i.e., decide on what should be modeled now, and what should be left for a possible later extension.
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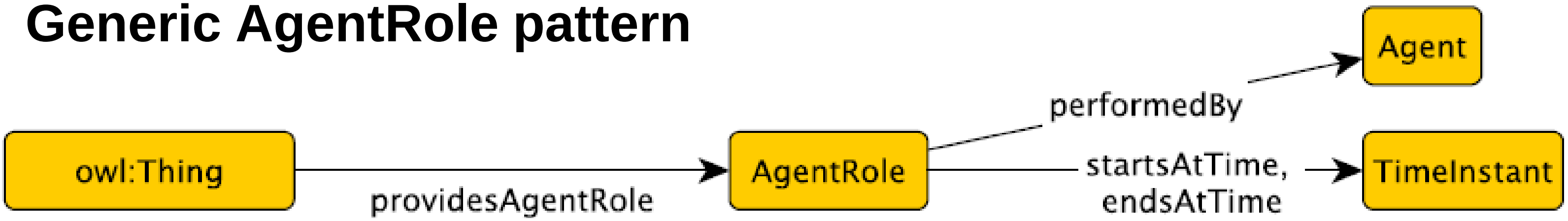
A Few Pattern Examples

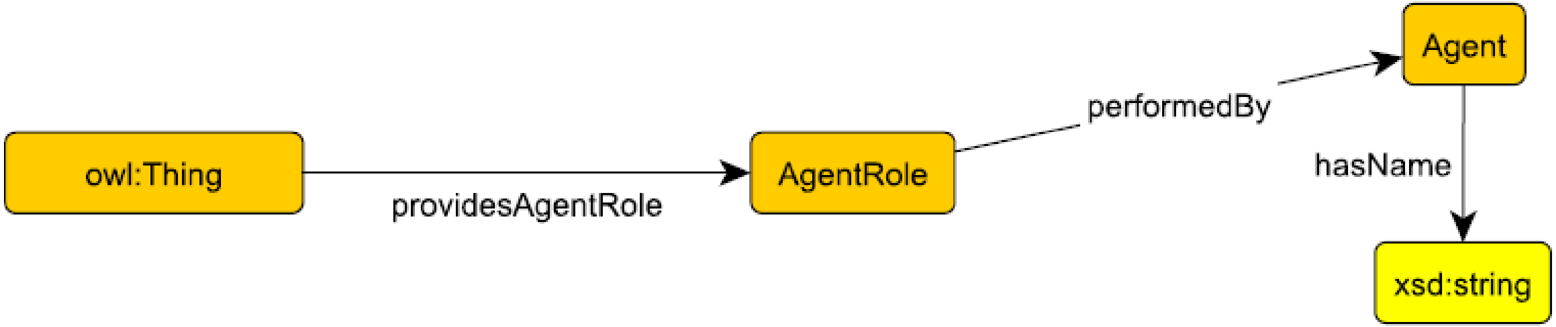
Joining patterns

Generic AgentRole pattern



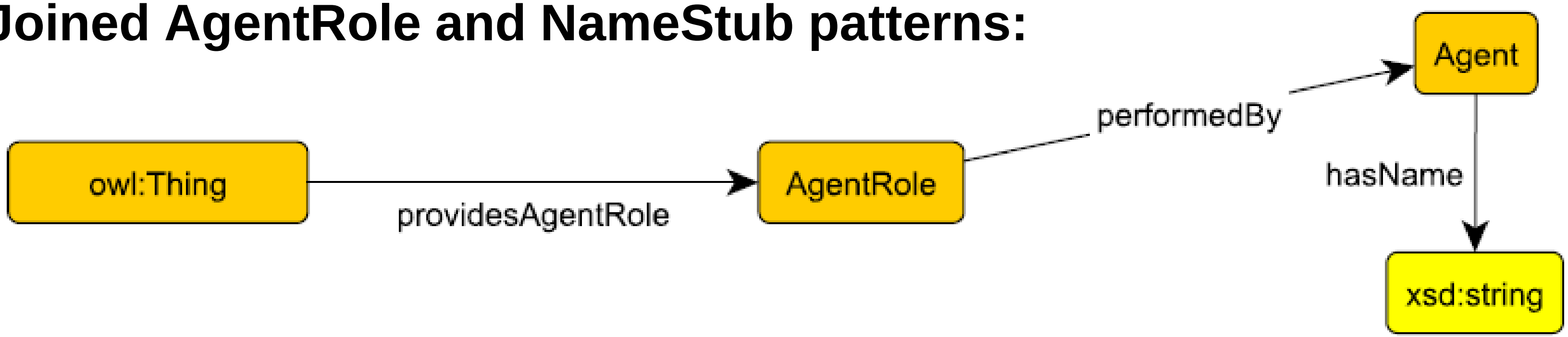
Generic NameStub pattern

Joined:

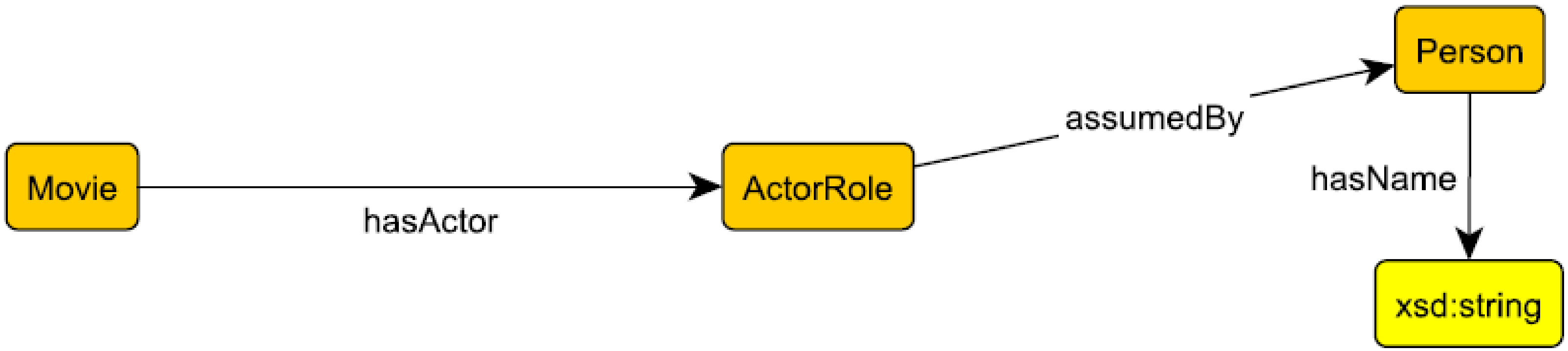


Patterns as templates

Joined AgentRole and NameStub patterns:

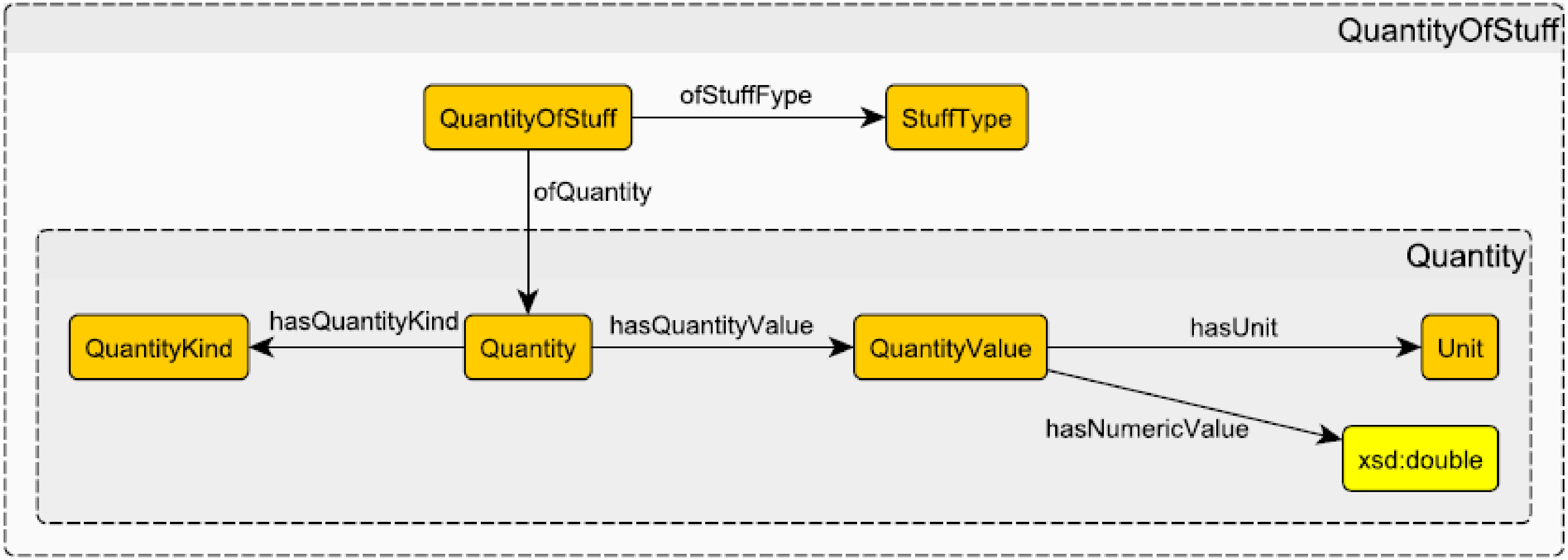


Used as a template for a concrete modeling problem:



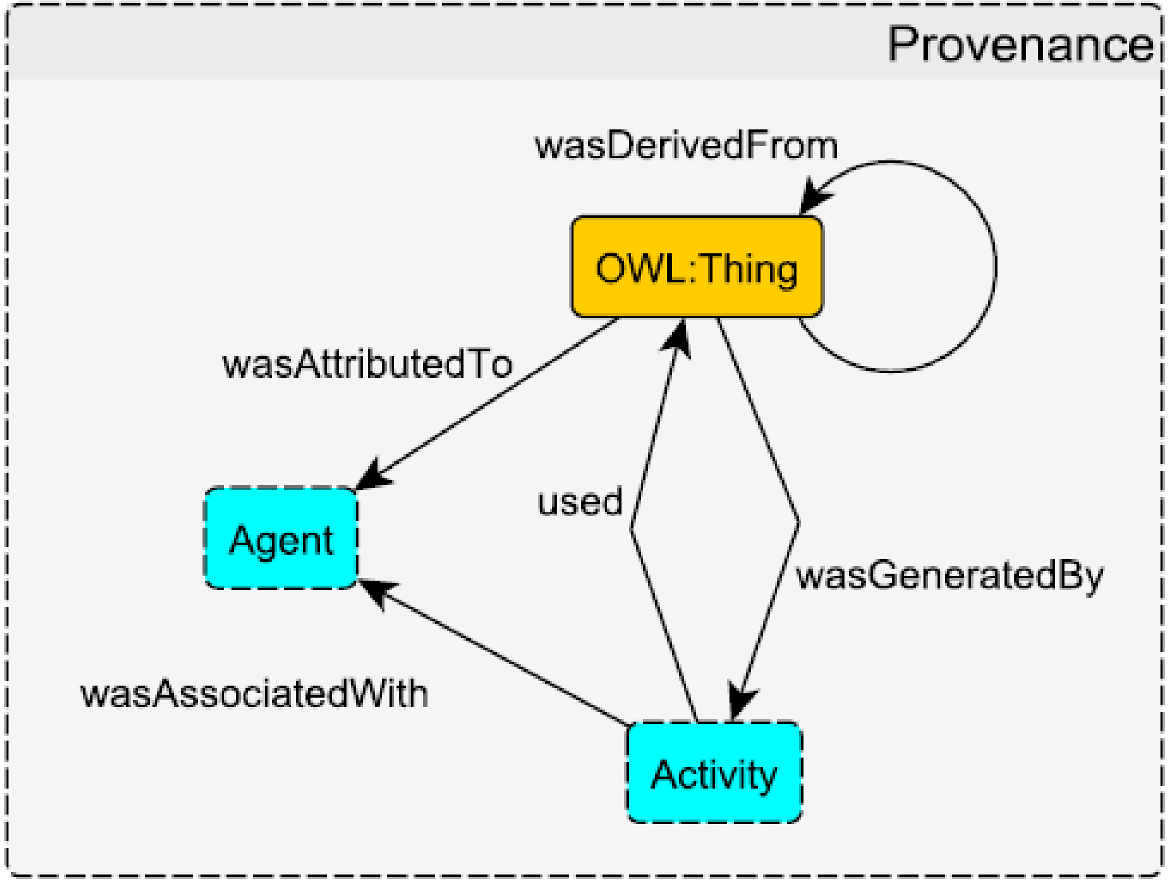
Quantities and Units

Borrowed from the QUDT ontology

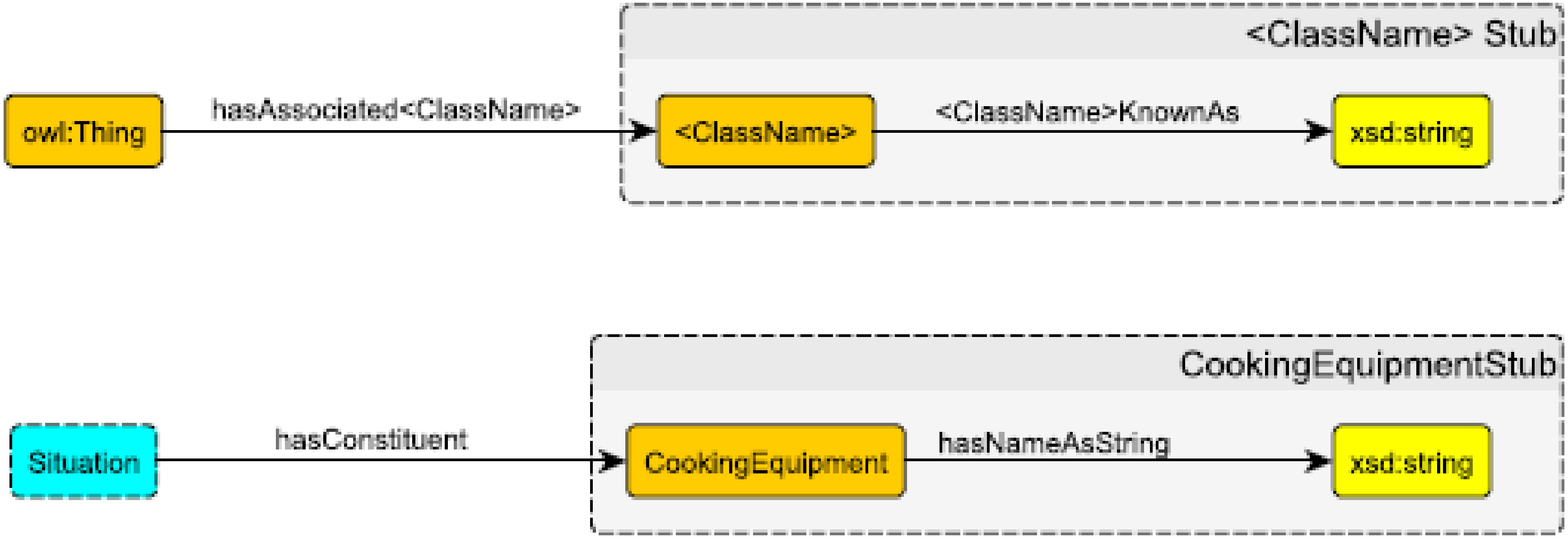


Provenance

Borrowed from PROV-O



The Stub Metapattern



Bottom: The CookingEquipmentStub derived from it.

Recipes Example

Recpies Example

Written version of this part

Pascal Hitzler, Adila Krisnadhi

A Tutorial on Modular Ontology Modeling with Ontology Design Patterns: The Cooking Recipes Ontology.

Technical Report, DaSe Lab, Department of Computer Science and Engineering, Wright State University, Dayton, OH, August 2018.

22 pages

http://daselab.cs.wright.edu/pub2/mom-recipes-example.pdf

Modeling process – steps

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Problem setting

Design an ontology which can be used as part of a "recipe discovery" website. The ontology shall be set up such that content from existing recipe websites can in principle be mapped to it (i.e., the ontology gets populated with data from the recipe websites). On the discovery website, detailed graph-queries (using the ontology) shall produce links to recipes from different recipe websites as results. The ontology should be extendable towards incorporation of additional external data, e.g., nutritional information about ingredients or detailed information about cooking equipment.

Modeling process – steps

1. Define use case or scope of use cases
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Competency Questions

- From available data and from application use cases, devise competency questions, i.e. questions which should be convertible into queries, which in turn should be answerable using the data.

Gluten-free low-calorie desserts.

How do I make a low-carb pot roast?

How do I make a Chili without beans?

Sweet breakfast under 100 calories.

Breakfast dishes which can be prepared quickly with 2 potatoes, an egg, and some our.

How do I prepare Chicken thighs in a slow cooker?

A simple recipe with pork shoulder and spring onions.

A side prepared using Brussels sprouts, bacon, and chestnuts.

Modeling process – steps

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Key notions

- Use the competency questions.
- Possibly also query domain experts as to the main notions for the application domain.
- E.g. for the recipes scenario, these would include
  - Recipe
  - Food
  - Time
  - Equipment
  - Classification of food (e.g., as a side)
  - Difficulty level
  - Nutritional information
  - Provenance

Key notions

- **Then prioritize which notions to model first. In this case, e.g.**

  recipe

  food

  equipment

  classification

  difficulty level

  time

  nutritional information

  provenance

Modeling process – steps

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Identifying suitable patterns

- **Understand the nature of the things you are modeling.**

Recipe: Document? Sequence? Process? Plan? Description?
Food: A concrete piece of food? An abstract quantity of food?
Equipment: Do we want a complex model at this stage? No. Stub

Classification: Do we want a complex model at this stage? No. Stub

Difficulty level: Do we want a complex model at this stage? No. Stub

Time: Probably already incorporated in plan?

Nutritional information: model along some existing standard?

Provenance: just that!

Modeling process – steps

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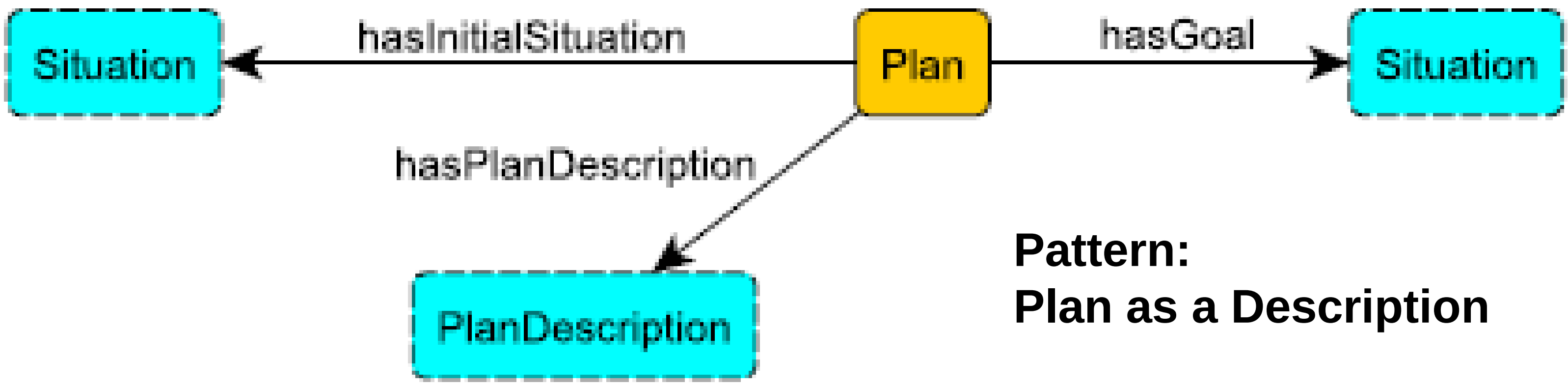
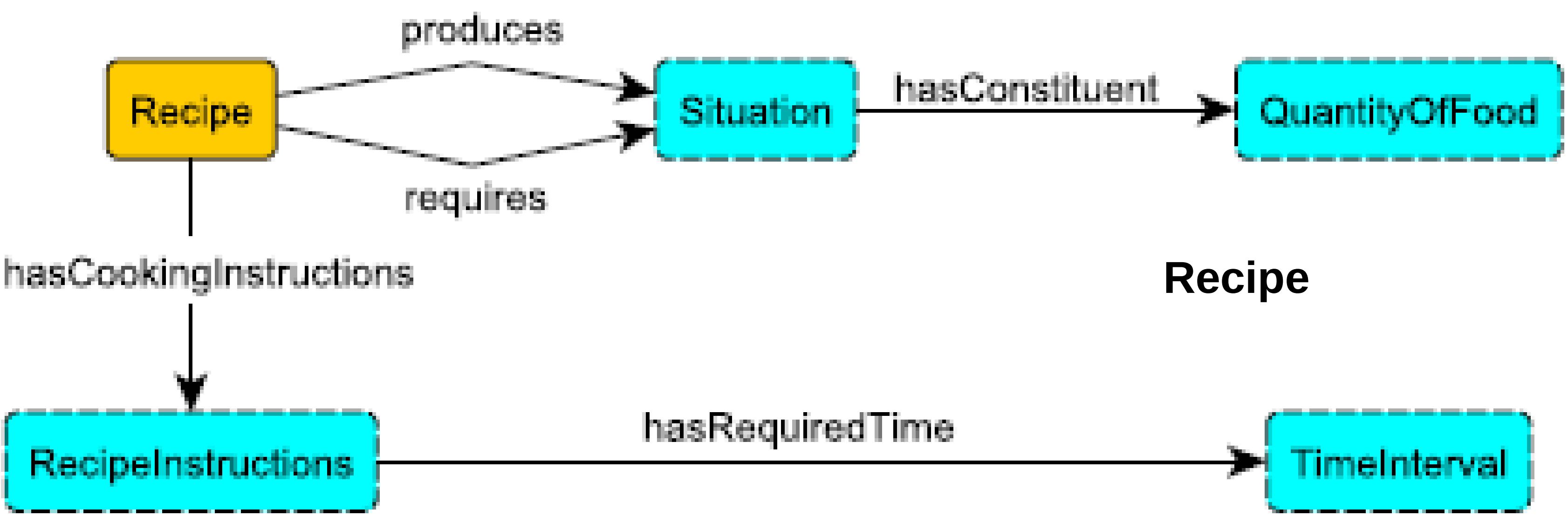
Recipe

A **plan**, a **description**.



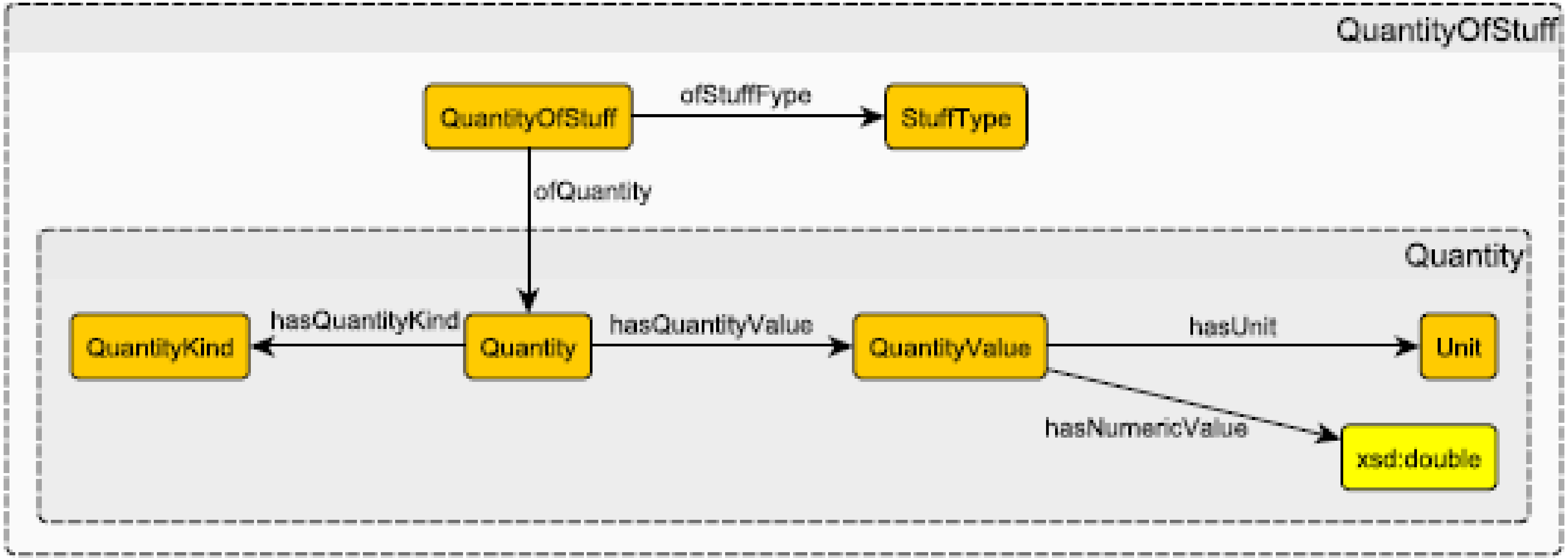
Pattern:
Plan as a Description



Recipe

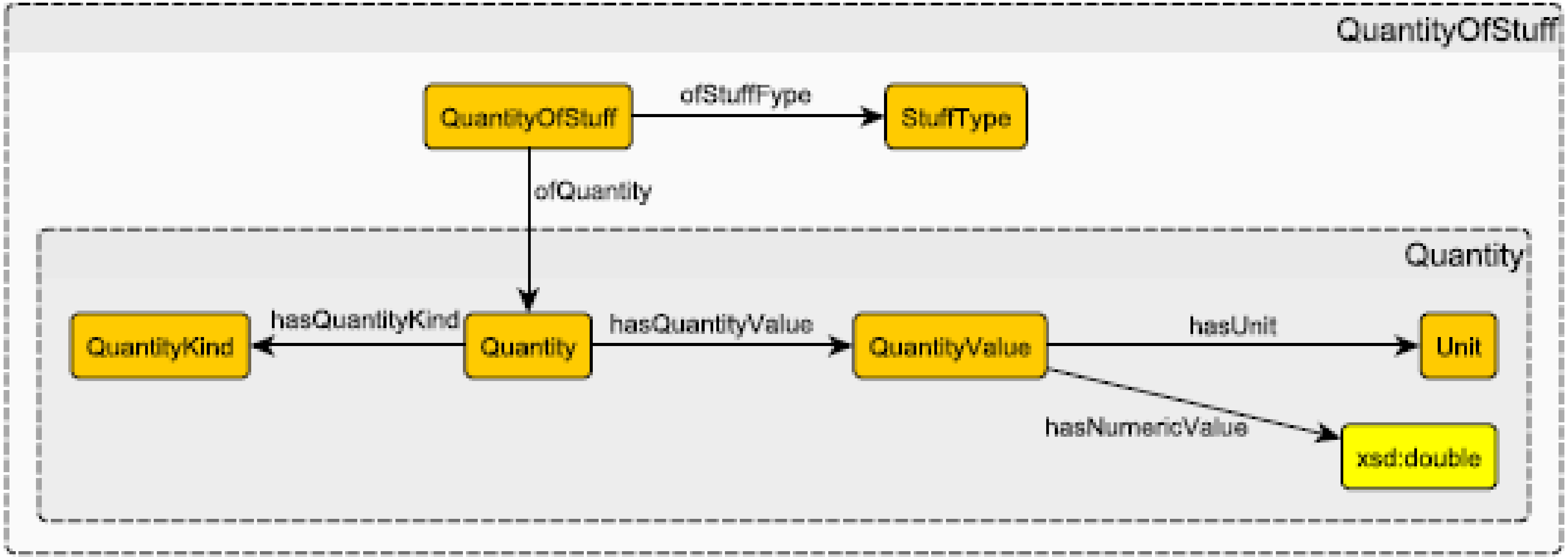
Food

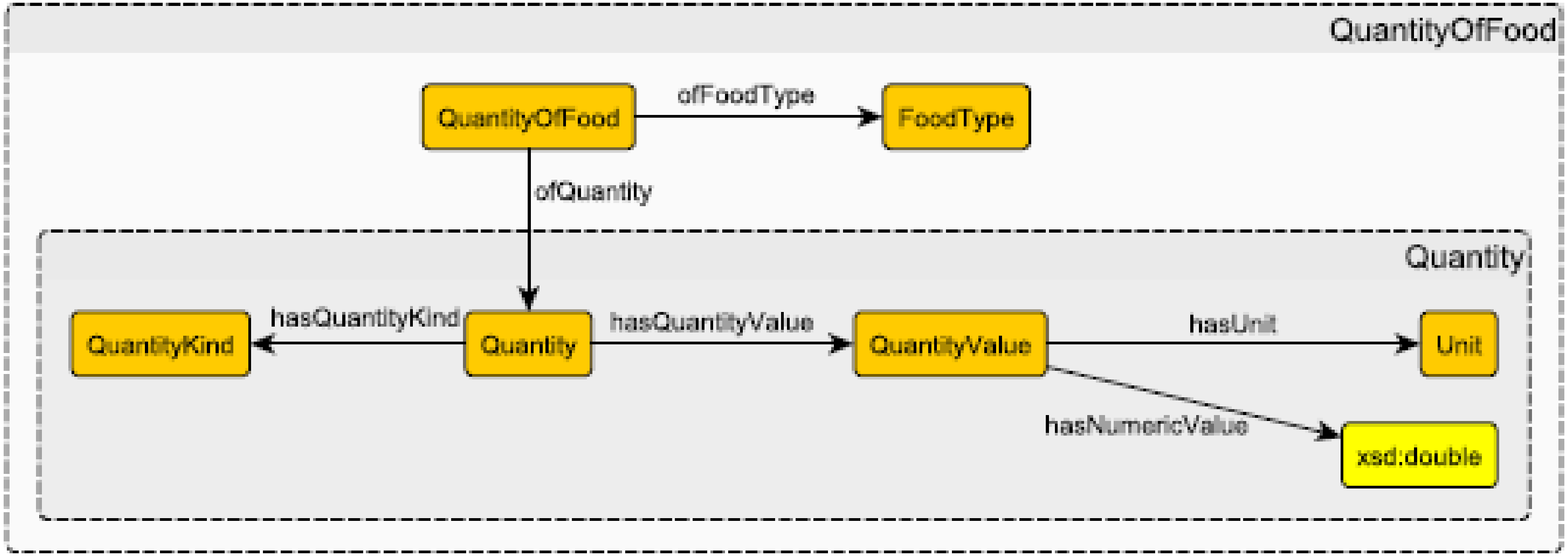
An abstract quantity of food.



Pattern:
QuantityOfStuff (with Quantity sub-pattern)

(derived from QUDT)


QuantityOfStuff
QuantityOfStuff
ofStuffType
StuffType
ofQuantity
Quantity
QuantityKind
hasQuantityKind
Quantity
hasQuantityValue
QuantityValue
hasUnit
Unit
hasNumericValue
xsd:double


QuantityOfFood
QuantityOfFood
ofFoodType
FoodType
ofQuantity
Quantity
QuantityKind
hasQuantityKind
Quantity
hasQuantityValue
QuantityValue
hasUnit
Unit
hasNumericValue
xsd:double

Equipment

No complex model desired at this stage. We just want to use strings, i.e., use our stub meta-pattern.

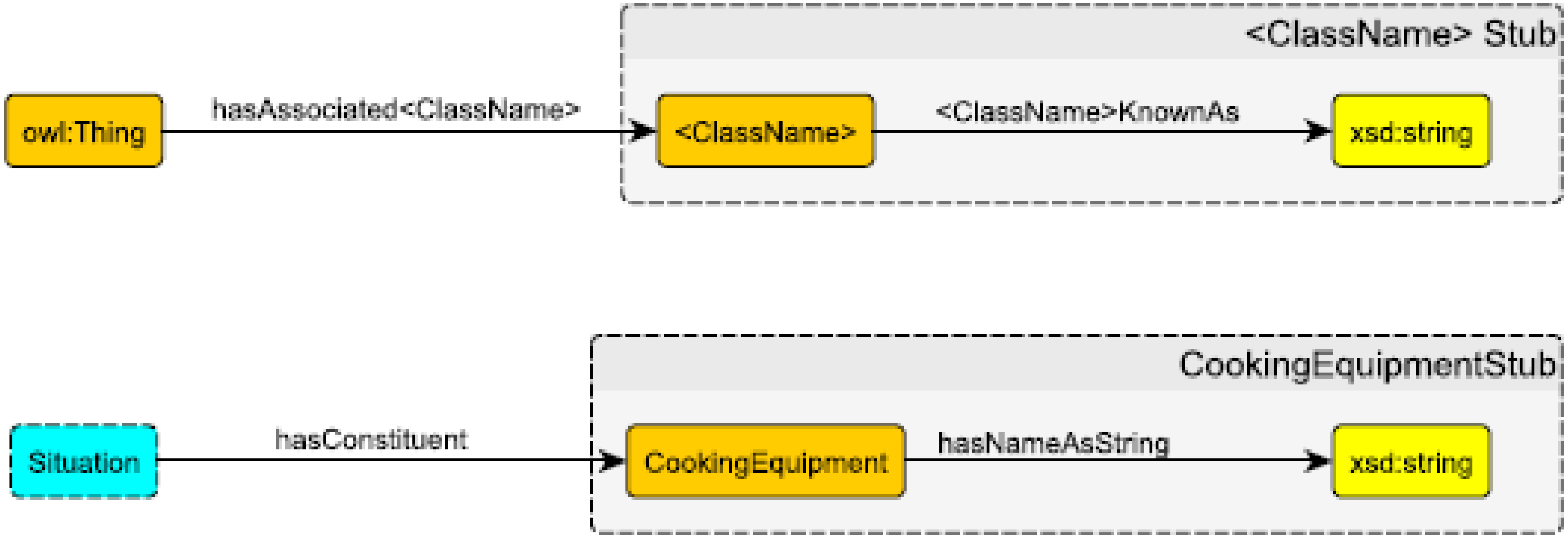
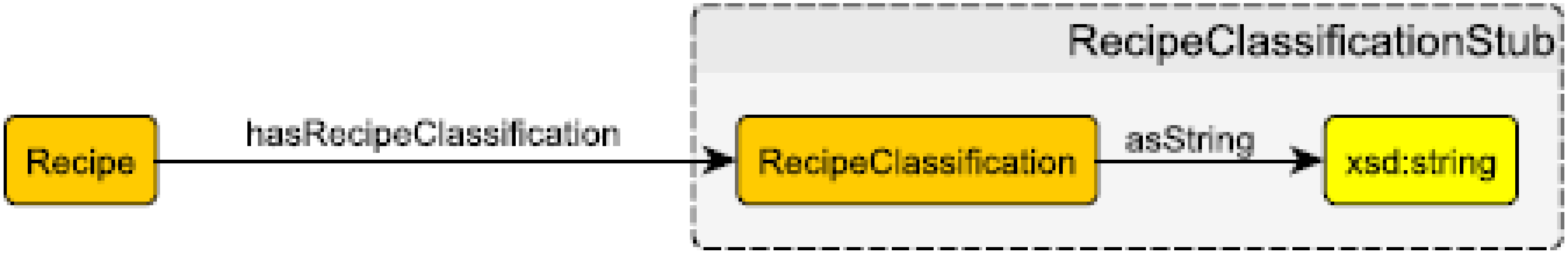


Figure 2.10: Top, the Stub (meta)pattern. Bottom, its instantiation for equipment.

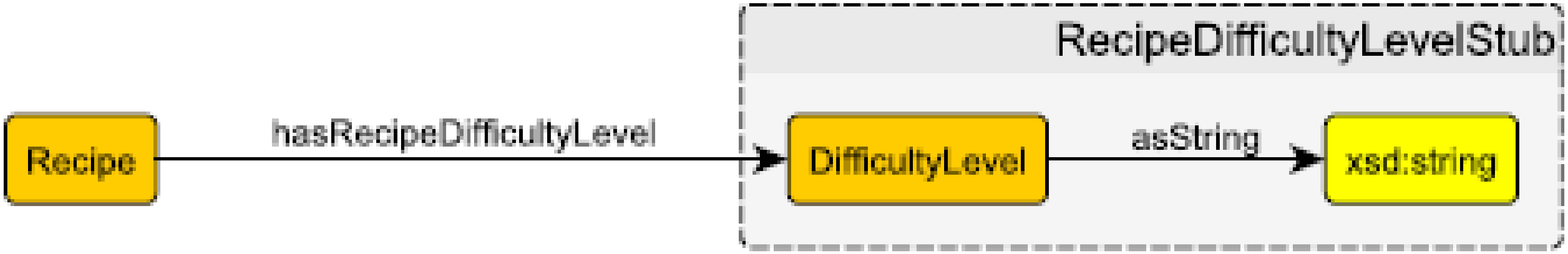
Classification (e.g., entrée)

No complex model desired at this stage. We just want to use strings, i.e., use our stub meta-pattern.



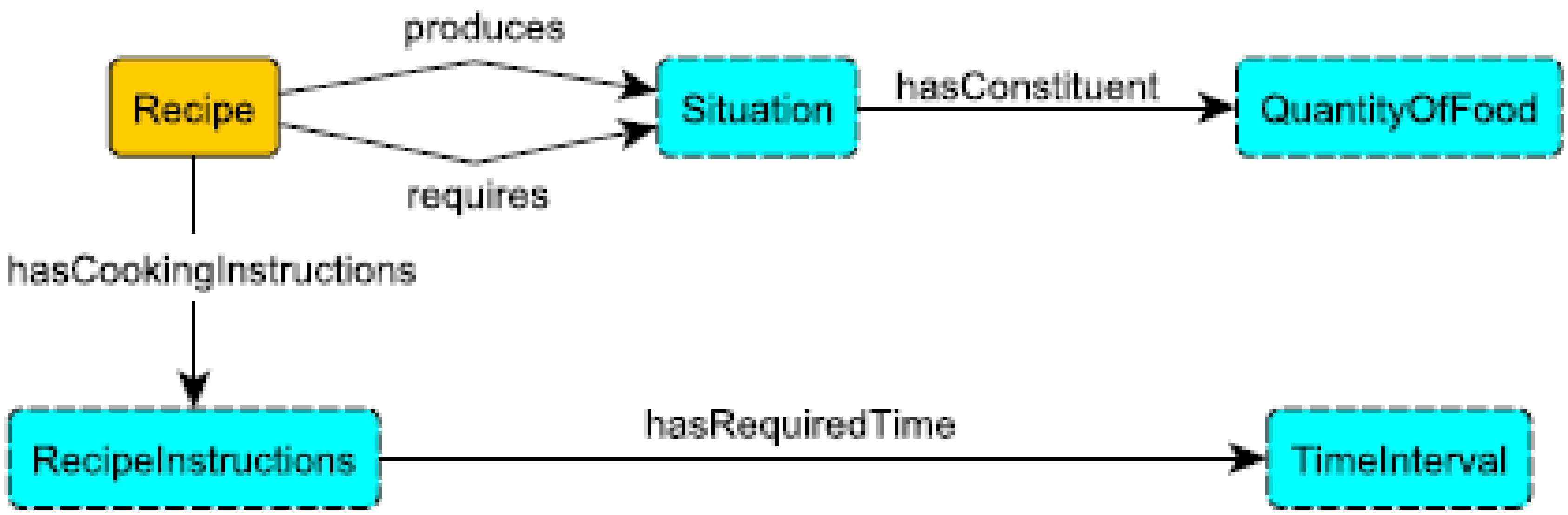
Difficulty level

No complex model desired at this stage. We just want to use strings, i.e., use our stub meta-pattern.



Time

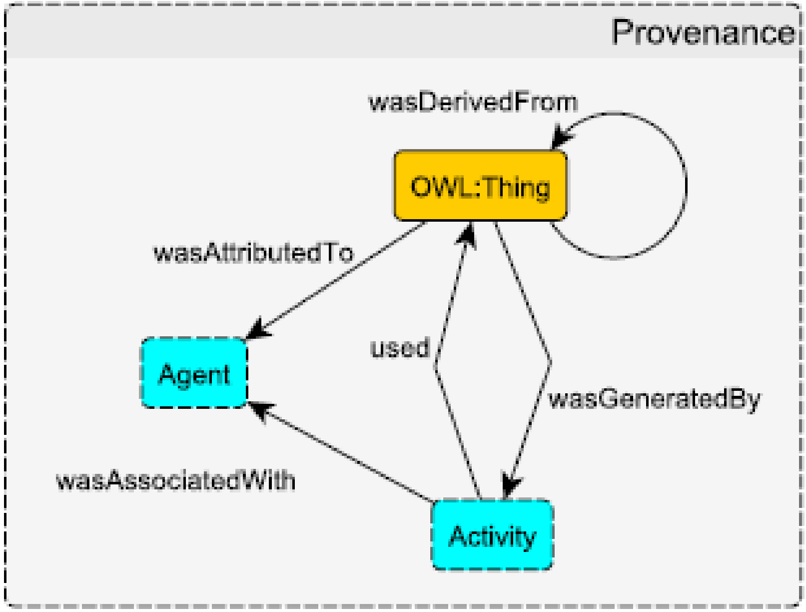
Already incorporated in plan!



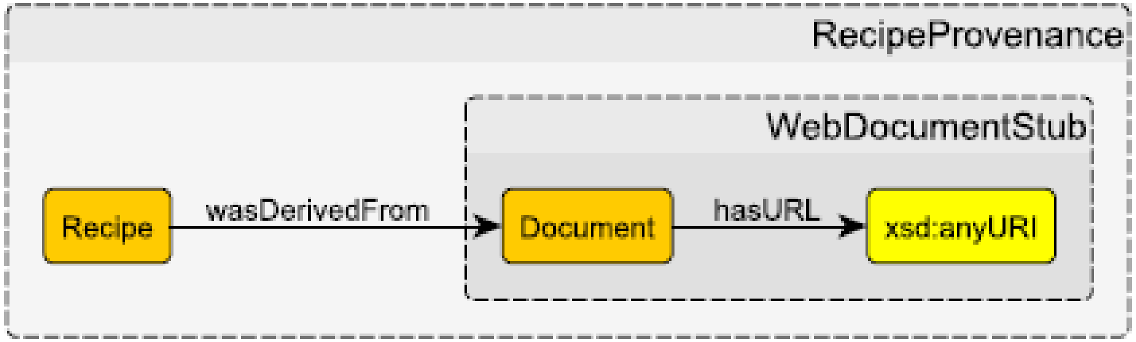
Provenance

Use an ontology design pattern based on PROV-O.

PROV-O derived Provenance pattern:



We'll use only this:



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Nutritional information

DaSe Lab

Model along some existing standard.

Let's use the U.S. FDA Nutritional Facts label standard.

Nutrition Facts

Serving Size 2/3 cup (55g)
Servings Per Container About 8

Amount Per Serving

Calories 230 Calories from Fat 40

	% Daily Value*
Total Fat 8g	**12%**
Saturated Fat 1g	**5%**
Trans Fat 0g	
Cholesterol 0mg	**0%**
Sodium 160mg	**7%**
Total Carbohydrate 37g	**12%**
Dietary Fiber 4g	**16%**
Sugars 1g	
Protein 3g	

Vitamin A	10%
Vitamin C	8%
Calcium	20%
Iron	45%

* Percent Daily Values are based on a 2,000 calorie diet. Your daily value may be higher or lower depending on your calorie needs.

	Calories:	2,000	2,500
Total Fat	Less than	65g	80g
Sat Fat	Less than	20g	25g
Cholesterol	Less than	300mg	300mg
Sodium	Less than	2,400mg	2,400mg
Total Carbohydrate		300g	375g
Dietary Fiber		25g	30g

Nutritional information

Model along some existing standard.

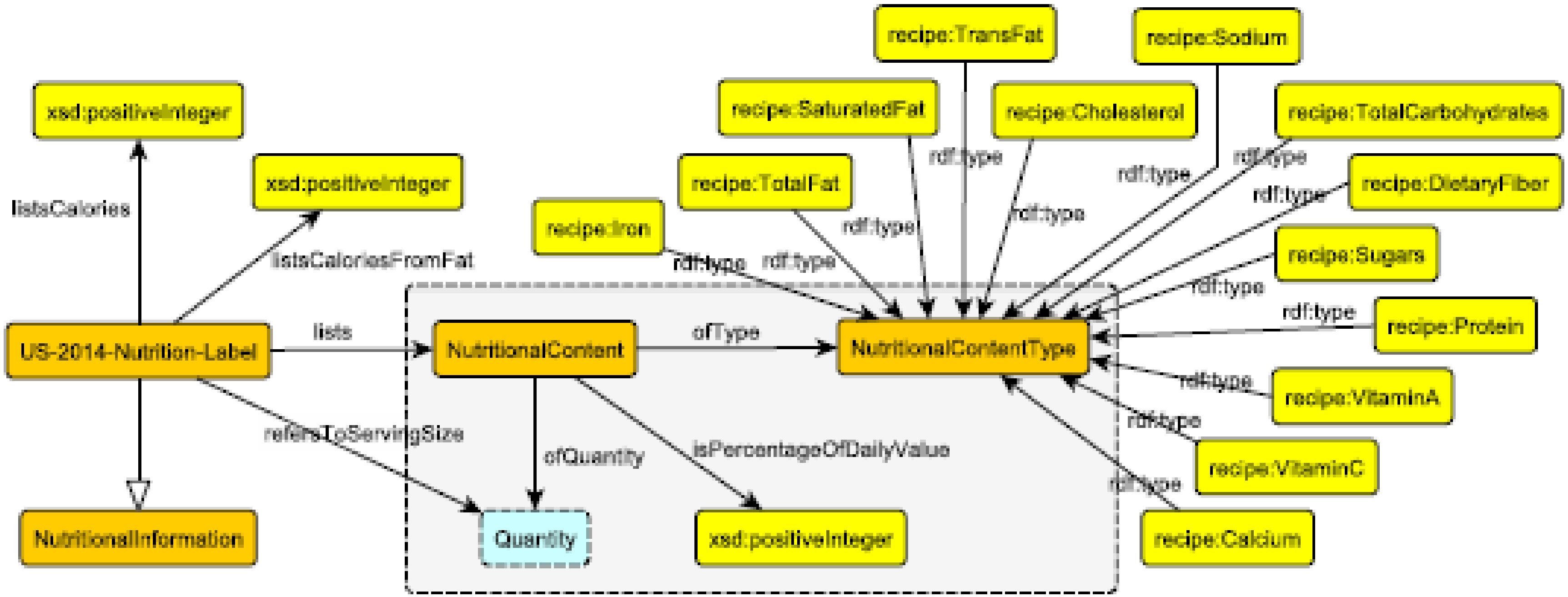

Figure 2.13: Nutritional Information module. The box indicates a modified instance of the QuantityOfStuff pattern.

Adequacy check

- Triplify sample data using the ontology.
  Does it work?

- Check if competency questions can be answered.

- Add axioms as appropriate (the graph is only for intuition, the OWL axioms are the actual ontology).

- (there are more post-hoc details to be taken care of, but let's leave it at that)

Modeling process – steps

1. Define use case or scope of use cases
2. Make competency questions while looking at possible data sources and scoping the problem, i.e., decide on what should be modeled now, and what should be left for a possible later extension.
3. Identify key notions from the data and the use case and identify which pattern should be used for each (if a suitable pattern is available). Many can remain "stubs" if detailed modeling is not yet necessary.
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5. Add axioms for each module, informed by the pattern axioms.
6. Put the modules together and add axioms which involve several modules.
7. Reflect on all class, property and individual names and possibly improve them. Also check module axioms whether they are still appropriate after putting all modules together.
8. Create OWL files.

Axiomatization

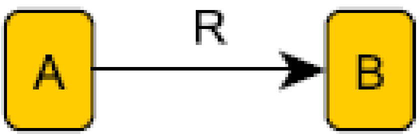
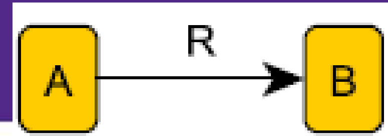


Figure 2.17: Generic node-edge-node schema diagram for explaining systematic axiomatization

1. $A \sqcap B \sqsubseteq \bot$
2. $\exists R.\top \sqsubseteq A$
3. $\exists R.B \sqsubseteq A$
4. $\top \sqsubseteq \forall R.B$
5. $A \sqsubseteq \forall R.B$
6. $A \sqsubseteq R.B$
7. $B \sqsubseteq R^{-}.A$
8. $\top \sqsubseteq \leq 1 R.\top$
9. $\top \sqsubseteq \leq 1 R.B$
10. $A \sqsubseteq \leq 1 R.\top$
11. $A \sqsubseteq \leq 1 R.B$
12. $\top \sqsubseteq \leq 1 R^{-}.\top$
13. $\top \sqsubseteq \leq 1 R^{-}.A$
14. $B \sqsubseteq \leq 1 R^{-}.\top$
15. $B \sqsubseteq \leq 1 R^{-}.A$

Figure 2.18: Most common axioms which could be produced from a single edge R between nodes A and B in a schema diagram: description logic notation.

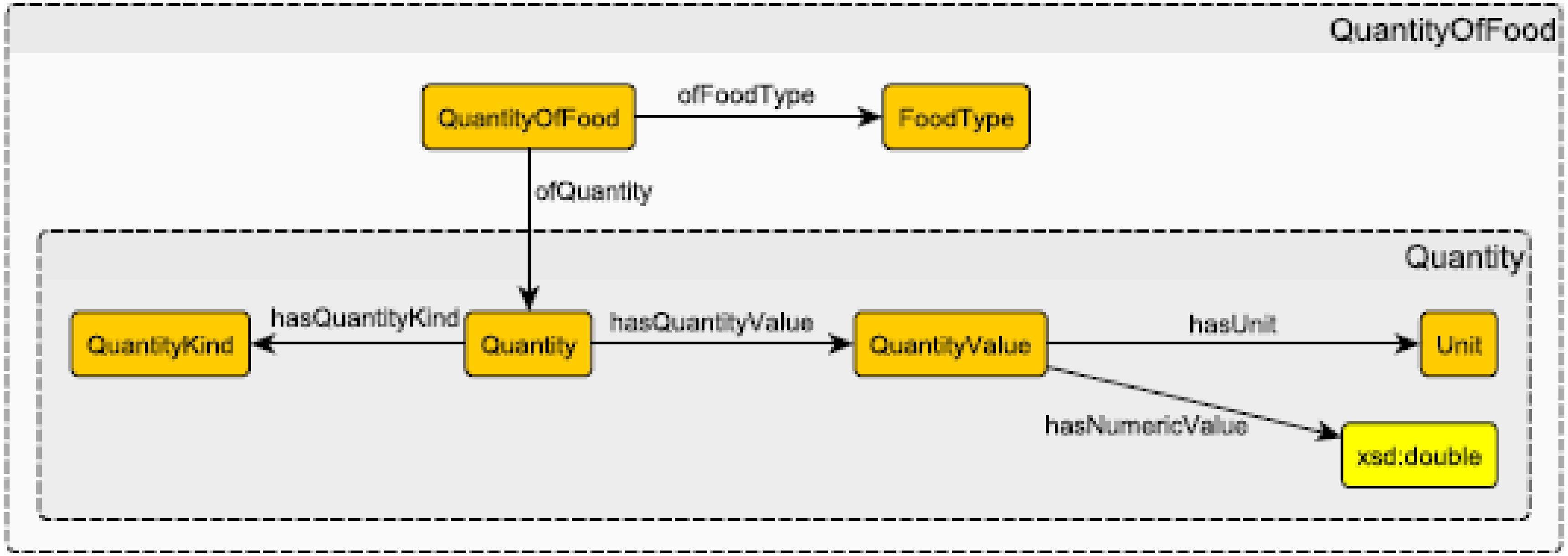
Axiomatization



1. A DisjointWith B (disjointness)
2. R some `owl:Thing` SubClassOf A (domain)
3. R some B SubClassOf A (scoped domain)
4. `owl:Thing` SubClassOf R only B (range)
5. A SubClassOf R only B (scoped range)
6. A SubClassOf R some B (existential)
7. B SubClassOf inverse R some A (inverse existential)
8. `owl:Thing` SubClassOf R max 1 `owl:Thing` (functionality)
9. `owl:Thing` SubClassOf R max 1 B (qualified functionality)
10. A SubClassOf R max 1 `owl:Thing` (scoped functionality)
11. A SubClassOf R max 1 B (qualified scoped functionality)
12. `owl:Thing` SubClassOf inverse R max 1 `owl:Thing` (inverse functionality)
13. `owl:Thing` SubClassOf inverse R max 1 A (inverse qualified functionality)
14. B SubClassOf inverse R max 1 `owl:Thing` (inverse scoped functionality)
15. B SubClassOf inverse R max 1 A (inverse qualified scoped functionality)

Figure 2.19: Most common axioms which could be produced from a single edge R between nodes A and B in a schema diagram: Manchester syntax.

Example Axiomatization



ofFoodType, ofQuantity: scoped range, existential

hasQuantityKind, hasQuantityValue: scoped domain, scoped range, existential, inverse existential, scoped qualified functionality

hasUnit: scoped range, existential, scoped qualified functionality

hasNumericValue: scoped range, existential, functionality

Mutually disjoint: QuantityOfFood, FoodType, QuantityKind, Quantity, QuantityValue, Unit

Modeling process – steps

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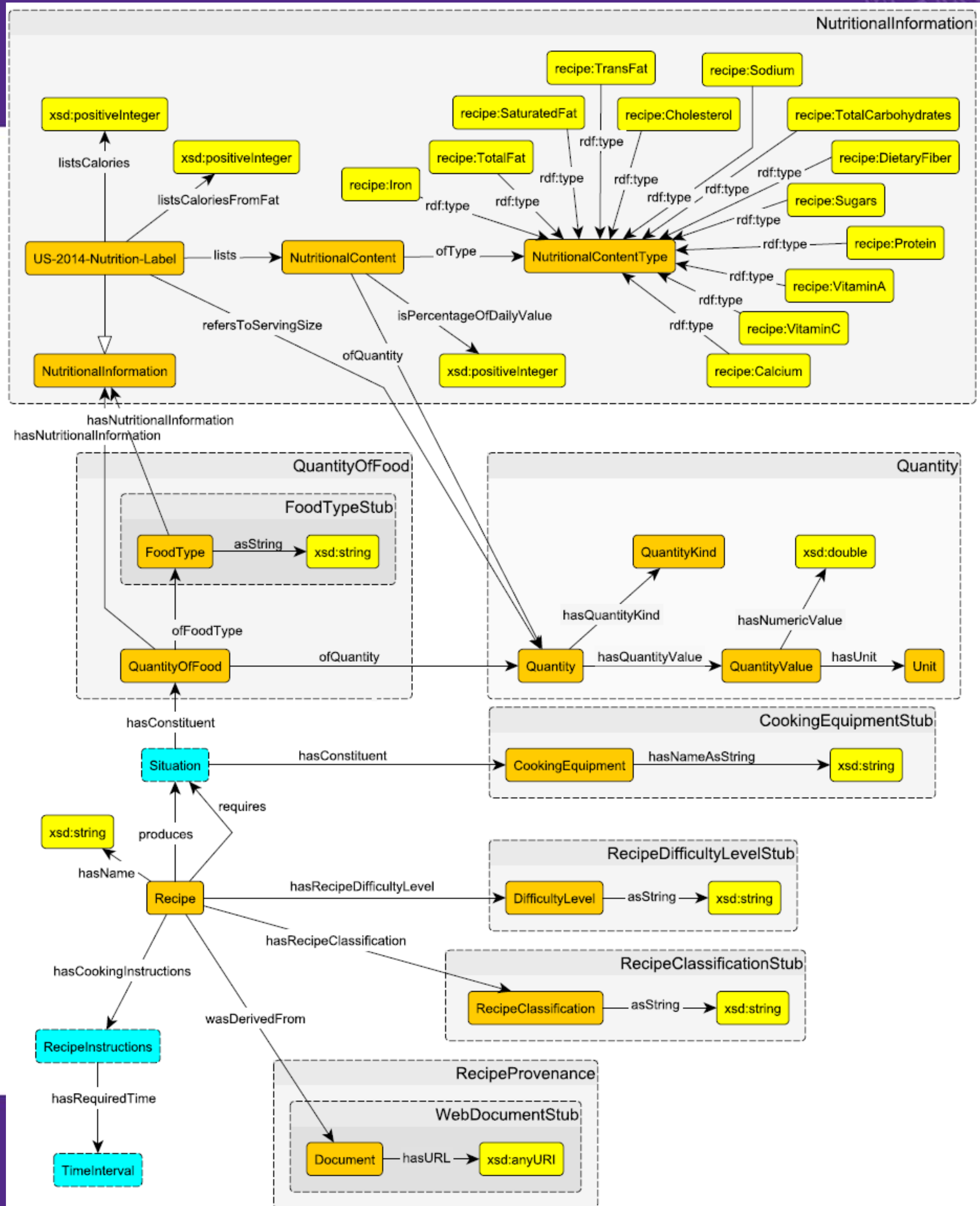
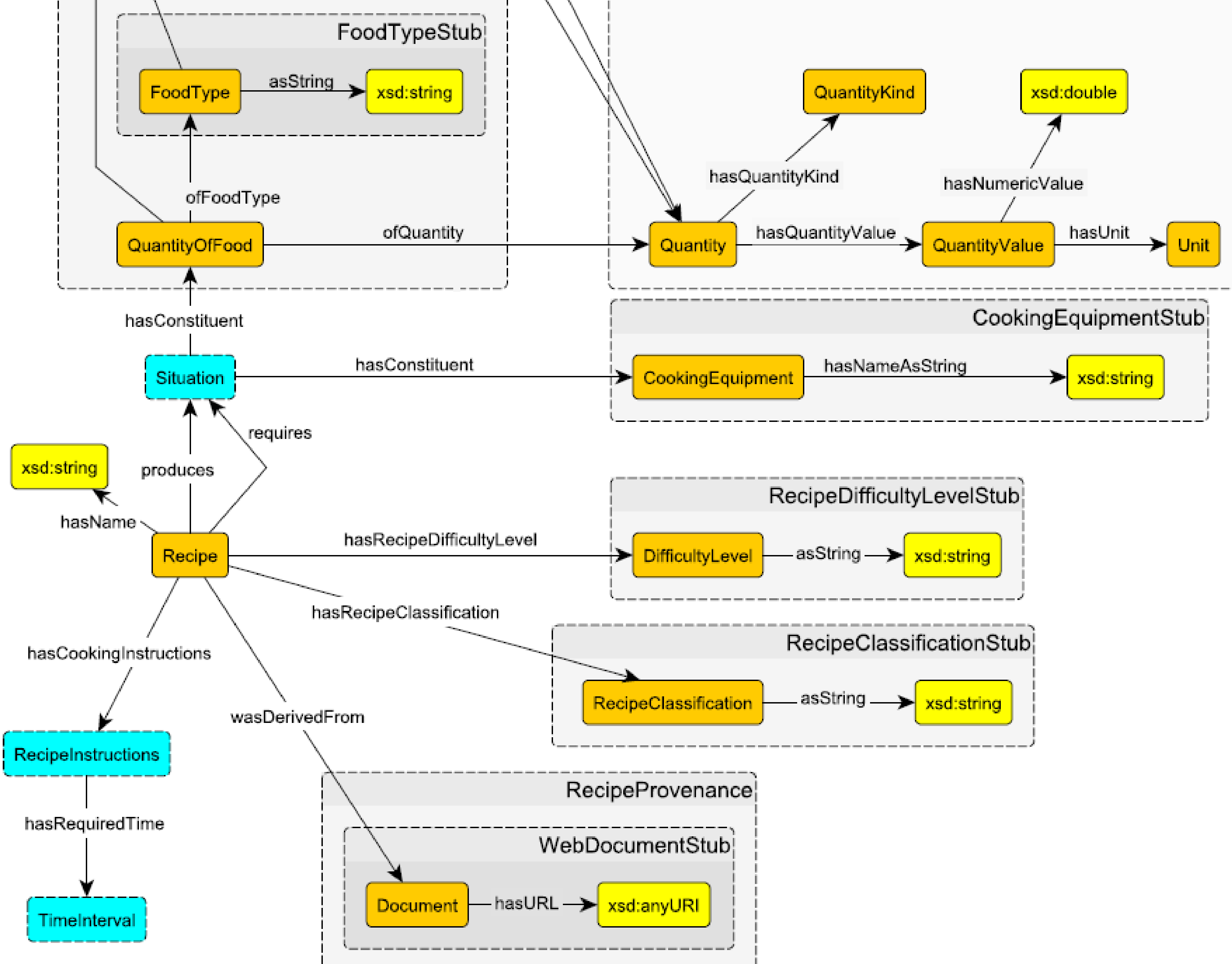
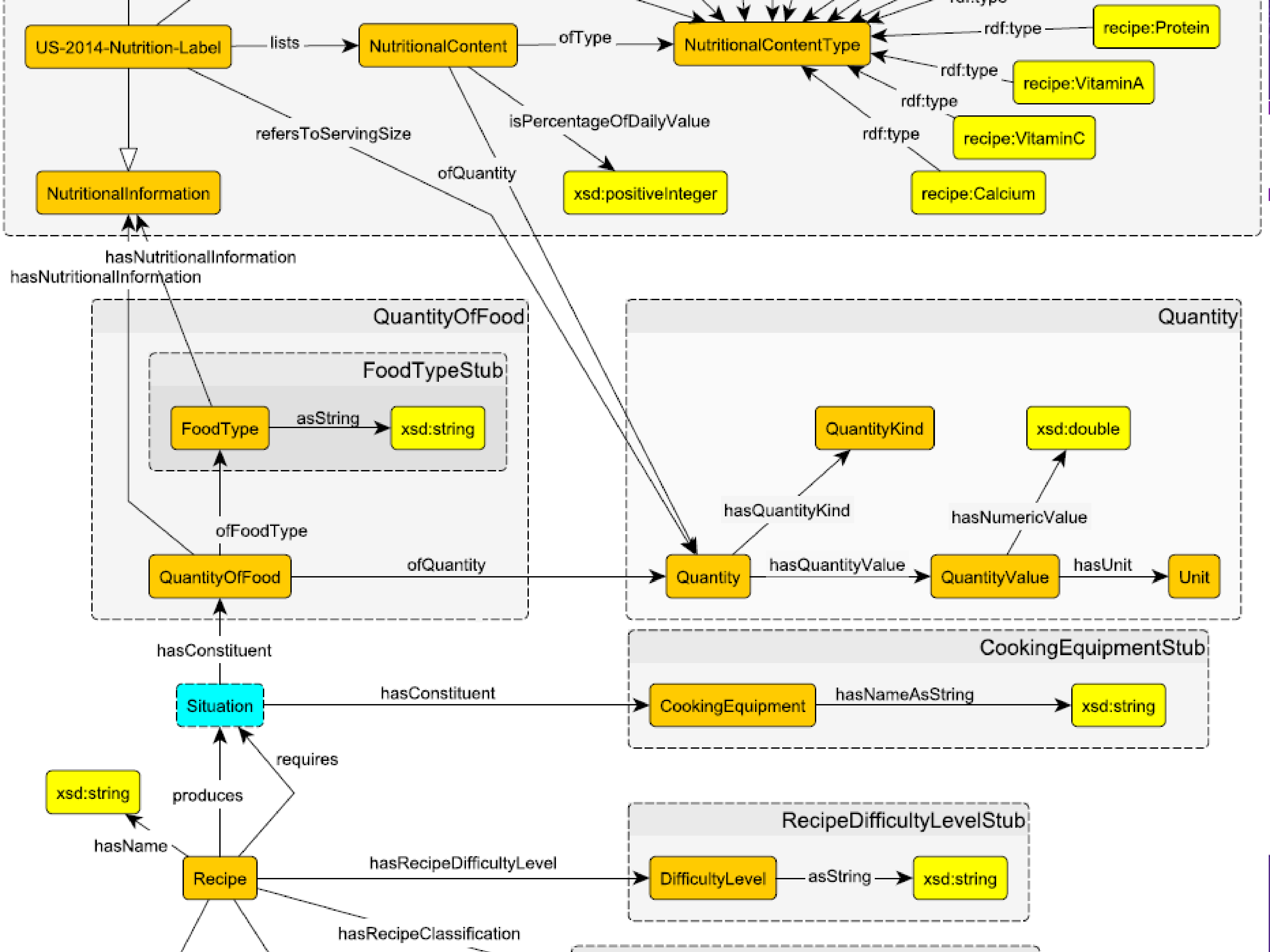
8. Create OWL files.


NutritionalInformation
recipe:TransFat
recipe:Sodium
recipe:SaturatedFat
recipe:Cholesterol
recipe:TotalCarbohydrates
xsd:positiveInteger
xsd:positiveInteger
recipe:TotalFat
recipe:DietaryFiber
recipe:Iron
recipe:Sugars
recipe:Protein
listsCalories
listsCaloriesFromFat
rdf:type
US-2014-Nutrition-Label
lists
NutritionalContent
ofType
NutritionalContentType
recipe:VitaminA
recipe:VitaminC
recipe:Calcium
refersToServingSize
isPercentageOfDailyValue
ofQuantity
xsd:positiveInteger
NutritionalInformation
hasNutritionalInformation
hasNutritionalInformation
QuantityOfFood
FoodTypeStub
FoodType
asString
xsd:string
ofFoodType
QuantityOfFood
ofQuantity
Quantity
QuantityKind
xsd:double
hasQuantityKind
hasNumericValue
Quantity
hasQuantityValue
QuantityValue
hasUnit
Unit
hasConstituent
CookingEquipmentStub
Situation
hasConstituent
CookingEquipment
hasNameAsString
xsd:string
requires
produces
xsd:string
hasName
RecipeDifficultyLevelStub
Recipe
hasRecipeDifficultyLevel
DifficultyLevel
asString
xsd:string
hasRecipeClassification
RecipeClassificationStub
RecipeClassification
asString
xsd:string
hasCookingInstructions
wasDerivedFrom
RecipeInstructions
RecipeProvenance
WebDocumentStub
hasRequiredTime
Document
hasURL
xsd:anyURI
TimeInterval


FoodTypeStub
FoodType
asString
xsd:string
ofFoodType
QuantityOfFood
ofQuantity
QuantityKind
xsd:double
hasQuantityKind
hasNumericValue
Quantity
hasQuantityValue
QuantityValue
hasUnit
Unit
hasConstituent
CookingEquipmentStub
Situation
hasConstituent
CookingEquipment
hasNameAsString
xsd:string
requires
xsd:string
produces
hasName
RecipeDifficultyLevelStub
Recipe
hasRecipeDifficultyLevel
DifficultyLevel
asString
xsd:string
hasRecipeClassification
RecipeClassificationStub
hasCookingInstructions
RecipeClassification
asString
xsd:string
wasDerivedFrom
RecipeInstructions
RecipeProvenance
hasRequiredTime
WebDocumentStub
TimeInterval
Document
hasURL
xsd:anyURI



rdf:type
US-2014-Nutrition-Label
lists
NutritionalContent
ofType
NutritionalContentType
rdf:type
recipe:Protein
rdf:type
recipe:VitaminA
rdf:type
recipe:VitaminC
rdf:type
recipe:Calcium
refersToServingSize
isPercentageOfDailyValue
ofQuantity
xsd:positiveInteger
NutritionalInformation
hasNutritionalInformation
hasNutritionalInformation
QuantityOfFood
FoodTypeStub
FoodType
asString
xsd:string
ofFoodType
QuantityOfFood
ofQuantity
Quantity
QuantityKind
xsd:double
hasQuantityKind
hasNumericValue
Quantity
hasQuantityValue
QuantityValue
hasUnit
Unit
hasConstituent
CookingEquipmentStub
Situation
hasConstituent
CookingEquipment
hasNameAsString
xsd:string
requires
xsd:string
produces
hasName
RecipeDifficultyLevelStub
Recipe
hasRecipeDifficultyLevel
DifficultyLevel
asString
xsd:string
hasRecipeClassification

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Tools

- We are currently developing a set of compatible tools, as Protégé plug-ins.
  - See http://comodide.com/
- We are also developing ODP libraries.
  - See https://daselab.cs.ksu.edu/content/modl-modular-ontology-design-library

Thanks!

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