Ontology Engineering for the Semantic Web and Beyond

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A large part of this tutorial is based on
"Ontology Development 101: A Guide to Creating Your First Ontology"
by Natalya F. Noy and Deborah L. McGuinness
http://protege.stanford.edu/publications/ontology_development/ontology101.html

Outline

- What is an ontology?
- Why develop an ontology?
- Step-By-Step: Developing an ontology
- Going deeper: Common problems and solutions
- Ontologies in the Semantic Web languages
- Current research issues in ontology engineering

What Is An Ontology

- An ontology is an explicit description of a domain:
  - concepts
  - properties and attributes of concepts
  - constraints on properties and attributes
  - Individuals *(often, but not always)*
- An ontology defines
  - a common vocabulary
  - a shared understanding

Ontology Examples

- Taxonomies on the Web
  - Yahoo! categories
- Catalogs for on-line shopping
  - Amazon.com product catalog
- Domain-specific standard terminology
  - Unified Medical Language System (UMLS)
  - UNSPSC - terminology for products and services

What Is "Ontology Engineering"?

Ontology Engineering: Defining terms in the domain and relations among them

- Defining concepts in the domain (classes)
- Arranging the concepts in a hierarchy (subclass-superclass hierarchy)
- Defining which attributes and properties (slots) classes can have and constraints on their values
- Defining individuals and filling in slot values

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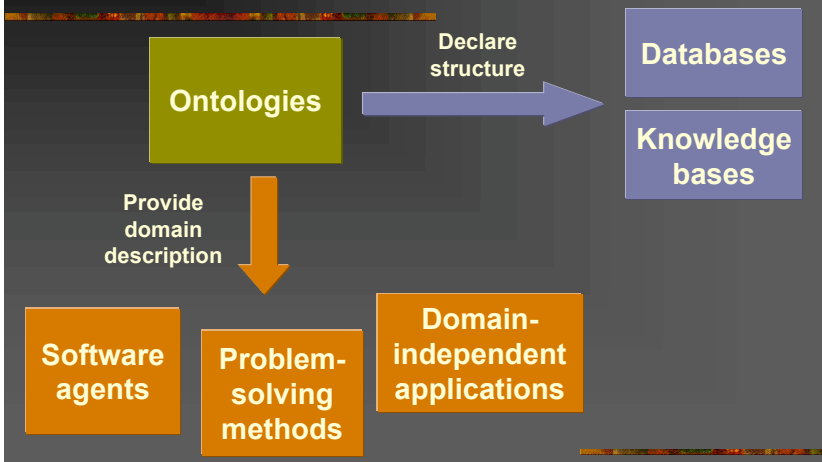
Why Develop an Ontology?

- To share common understanding of the structure of information
  - among people
  - among software agents
- To enable reuse of domain knowledge
  - to avoid "re-inventing the wheel"
  - to introduce standards to allow interoperability

More Reasons

- To make domain assumptions explicit
  - easier to change domain assumptions (consider a genetics knowledge base)
  - easier to understand and update legacy data
- To separate domain knowledge from the operational knowledge
  - re-use domain and operational knowledge separately (e.g., configuration based on constraints)

An Ontology Is Often Just the Beginning



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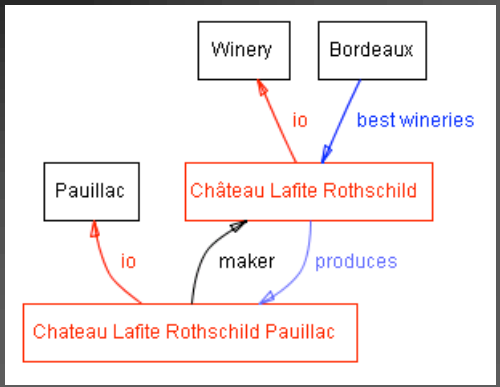
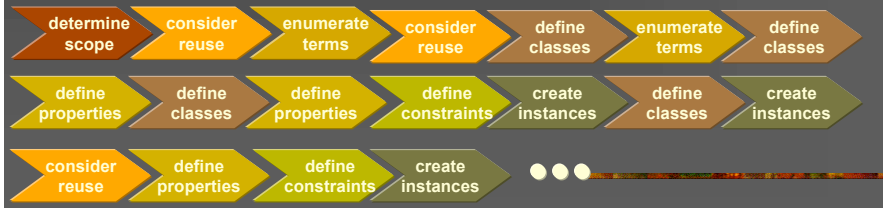
Wines and Wineries



Ontology-Development Process

In this tutorial:

In reality - an iterative process:



Ontology Engineering versus Object-Oriented Modeling

An ontology

- reflects the structure of the world
- is often about structure of concepts
- actual physical representation is not an issue

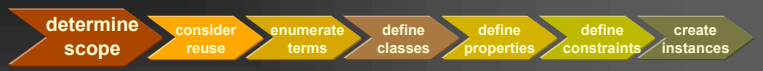
An OO class structure

- reflects the structure of the data and code
- is usually about behavior (methods)
- describes the physical representation of data (long int, char, etc.)

Preliminaries - Tools

- All screenshots in this tutorial are from Protégé-2000, which:
  - is a graphical ontology-development tool
  - supports a rich knowledge model
  - is open-source and freely available (http://protege.stanford.edu)
- Some other available tools:
  - Ontolingua and Chimaera
  - OntoEdit
  - OilEd

Determine Domain and Scope



- What is the domain that the ontology will cover?
- For what we are going to use the ontology?
- For what types of questions the information in the ontology should provide answers (competency questions)?

Answers to these questions may change during the lifecycle

Competency Questions

- Which wine characteristics should I consider when choosing a wine?
- Is Bordeaux a red or white wine?
- Does Cabernet Sauvignon go well with seafood?
- What is the best choice of wine for grilled meat?
- Which characteristics of a wine affect its appropriateness for a dish?
- Does a flavor or body of a specific wine change with vintage year?
- What were good vintages for Napa Zinfandel?

Consider Reuse

- Why reuse other ontologies?
  - to save the effort
  - to interact with the tools that use other ontologies
  - to use ontologies that have been validated through use in applications

What to Reuse?

- Ontology libraries
  - DAML ontology library (www.daml.org/ontologies)
  - Ontolingua ontology library (www.ksl.stanford.edu/software/ontolingua/)
  - Protégé ontology library (protege.stanford.edu/plugins.html)
- Upper ontologies
  - IEEE Standard Upper Ontology (suo.ieee.org)
  - Cyc (www.cyc.com)

What to Reuse? (II)

- General ontologies
  - DMOZ (www.dmoz.org)
  - WordNet (www.cogsci.princeton.edu/~wn/)
- Domain-specific ontologies
  - UMLS Semantic Net
  - GO (Gene Ontology) (www.geneontology.org)

Enumerate Important Terms

- What are the terms we need to talk about?
- What are the properties of these terms?
- What do we want to say about the terms?

Enumerating Terms - The Wine Ontology

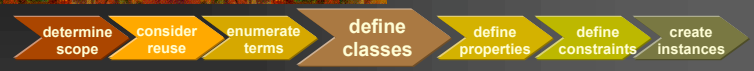
wine, grape, winery, location,

wine color, wine body, wine flavor, sugar content

white wine, red wine, Bordeaux wine

food, seafood, fish, meat, vegetables, cheese

Define Classes and the Class Hierarchy



- A class is a concept in the domain
  - a class of wines
  - a class of wineries
  - a class of red wines
- A class is a collection of elements with similar properties
- Instances of classes
  - a glass of California wine you'll have for lunch

Class Inheritance

- Classes usually constitute a taxonomic hierarchy (a subclass-superclass hierarchy)
- A class hierarchy is usually an IS-A hierarchy:

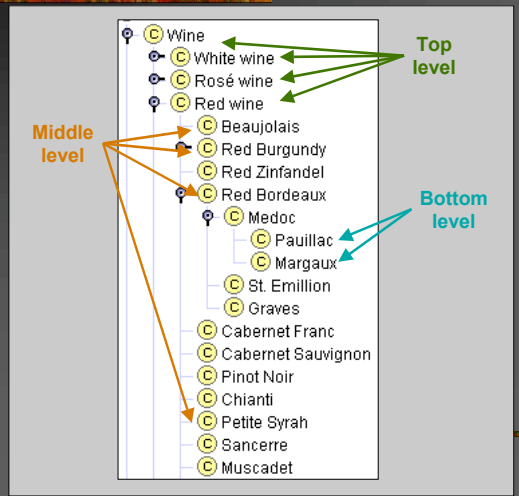
  an instance of a subclass is an instance of a superclass

- If you think of a class as a set of elements, a subclass is a subset

Class Inheritance - Example

- Apple is a subclass of Fruit
  Every apple is a fruit
- Red wines is a subclass of Wine
  Every red wine is a wine
- Chianti wine is a subclass of Red wine
  Every Chianti wine is a red wine

Levels in the Hierarchy



Modes of Development

- top-down – define the most general concepts first and then specialize them
- bottom-up – define the most specific concepts and then organize them in more general classes
- combination – define the more salient concepts first and then generalize and specialize them

Documentation

- Classes (and slots) usually have documentation
  - Describing the class in natural language
  - Listing domain assumptions relevant to the class definition
  - Listing synonyms
- Documenting classes and slots is as important as documenting computer code!

Define Properties of Classes – Slots

- Slots in a class definition describe attributes of instances of the class and relations to other instances

  Each wine will have color, sugar content, producer, etc.

Properties (Slots)

- Types of properties
  - "intrinsic" properties: flavor and color of wine
  - "extrinsic" properties: name and price of wine
  - parts: ingredients in a dish
  - relations to other objects: producer of wine (winery)
- Simple and complex properties
  - simple properties (attributes): contain primitive values (strings, numbers)
  - complex properties: contain (or point to) other objects (e.g., a winery instance)

Slots for the Class Wine

Template Slots

Name	Type	Cardinality	Other Facets
body	Symbol	single	allowed-values={FULL,MEDIUM,LIGHT}
color	Symbol	single	allowed-values={RED,ROSÉ,WHITE}
flavor	Symbol	single	allowed-values={DELICATE,MODERATE,STRONG}
grape	Instance	multiple	classes={Wine grape}
maker	Instance	single	classes={Winery}
name	String	single	
sugar	Symbol	single	allowed-values={DRY,SWEET,OFF-DRY}

(in Protégé-2000)

Slot and Class Inheritance

- A subclass inherits all the slots from the superclass

  If a wine has a name and flavor, a red wine also has a name and flavor
- If a class has multiple superclasses, it inherits slots from all of them

  Port is both a dessert wine and a red wine. It inherits "sugar content: high" from the former and "color:red" from the latter

Property Constraints

- Property constraints (facets) describe or limit the set of possible values for a slot
  - *The name of a wine is a string*
  - *The wine producer is an instance of Winery*
  - *A winery has exactly one location*

Facets for Slots at the Wine Class

Template Slots

Name	Type	Cardinality	Other Facets
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maker	Instance	single	classes={Winery}
name	String	single	
sugar	Symbol	single	allowed-values={DRY,SWEET,OFF-DRY}

Common Facets

- Slot cardinality – the number of values a slot has
- Slot value type – the type of values a slot has
- Minimum and maximum value – a range of values for a numeric slot
- Default value – the value a slot has unless explicitly specified otherwise

Common Facets: Slot Cardinality

- Cardinality
  - Cardinality N means that the slot must have N values
- Minimum cardinality
  - Minimum cardinality 1 means that the slot must have a value (required)
  - Minimum cardinality 0 means that the slot value is optional
- Maximum cardinality
  - Maximum cardinality 1 means that the slot can have at most one value (single-valued slot)
  - Maximum cardinality greater than 1 means that the slot can have only one value (multiple-valued slot)

Common Facets: Value Type

- String: a string of characters (“Château Lafite”)
- Number: an integer or a float (15, 4.5)
- Boolean: a true/false flag
- Enumerated type: a list of allowed values (high, medium, low)
- Complex type: an instance of another class
  - Specify the class to which the instances belong

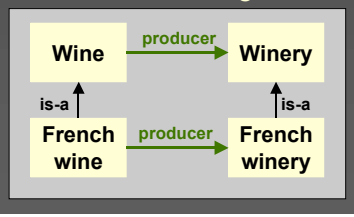
The Wine class is the value type for the slot “produces” at the Winery class

Domain and Range of Slot

- Domain of a slot – the class (or classes) that have the slot
  - More precisely: class (or classes) instances of which can have the slot
- Range of a slot – the class (or classes) to which slot values belong

Facets and Class Inheritance

- A subclass inherits all the slots from the superclass
- A subclass can override the facets to “narrow” the list of allowed values
  - Make the cardinality range smaller
  - Replace a class in the range with a subclass



Create Instances

- Create an instance of a class
  - The class becomes a direct type of the instance
  - Any superclass of the direct type is a type of the instance
- Assign slot values for the instance frame
  - Slot values should conform to the facet constraints
  - Knowledge-acquisition tools often check that

Creating an Instance: Example

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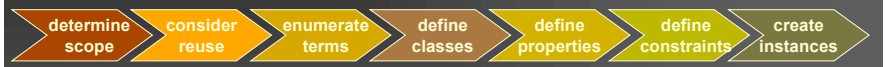
Going Deeper

- Breadth-first coverage



- Depth-first coverage

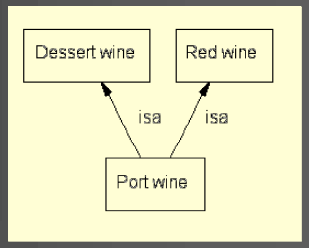
Defining Classes and a Class Hierarchy

- The things to remember:
  - There is no single correct class hierarchy
  - But there are some guidelines
- The question to ask:

  "Is each instance of the subclass an instance of its superclass?"

Multiple Inheritance

- A class can have more than one superclass
- A subclass inherits slots and facet restrictions from all the parents
- Different systems resolve conflicts differently

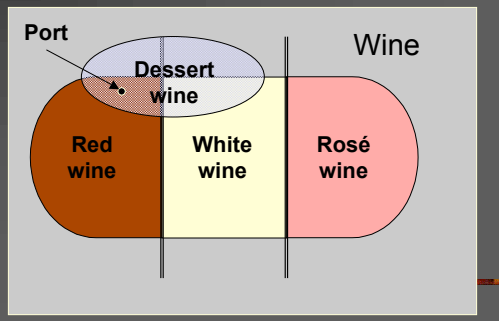


Disjoint Classes

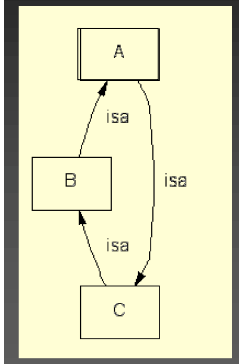
- Classes are disjoint if they cannot have common instances
- Disjoint classes cannot have any common subclasses either

Red wine, White wine, Rosé wine are disjoint

Dessert wine and Red wine are not disjoint

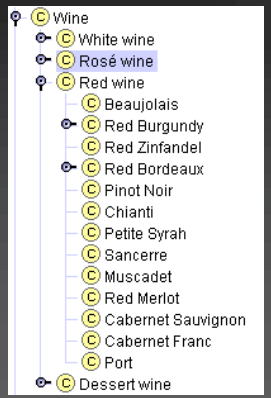


Avoiding Class Cycles



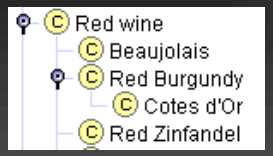
- Danger of multiple inheritance: cycles in the class hierarchy
- Classes A, B, and C have equivalent sets of instances
  - By many definitions, A, B, and C are thus equivalent

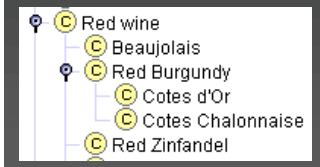
Siblings in a Class Hierarchy



- All the siblings in the class hierarchy must be at the same level of generality
- Compare to section and subsections in a book

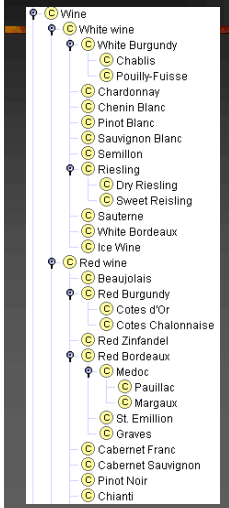
The Perfect Family Size





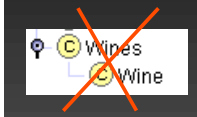
- If a class has only one child, there may be a modeling problem
- If the only Red Burgundy we have is Côtes d'Or, why introduce the subhierarchy?
- Compare to bullets in a bulleted list

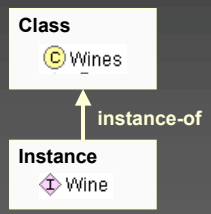
The Perfect Family Size (II)



- If a class has more than a dozen children, additional subcategories may be necessary
- However, if no natural classification exists, the long list may be more natural

Single and Plural Class Names



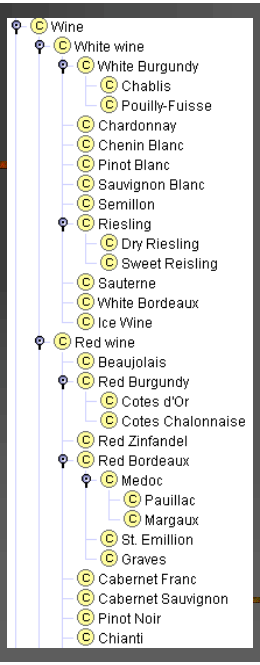


- A "wine" is not a kind-of "wines"
- A wine is an instance of the class Wines
- Class names should be either
  - all singular
  - all plural

Classes and Their Names

- Classes represent concepts in the domain, not their names
- The class name can change, but it will still refer to the same concept
- Synonym names for the same concept are not different classes
  - Many systems allow listing synonyms as part of the class definition

A Completed Hierarchy of Wines



Back to the Slots: Domain and Range

- When defining a domain or range for a slot, find the most general class or classes
- Consider the flavor slot
  - Domain: Red wine, White wine, Rosé wine
  - Domain: Wine
- Consider the produces slot for a Winery:
  - Range: Red wine, White wine, Rosé wine
  - Range: Wine

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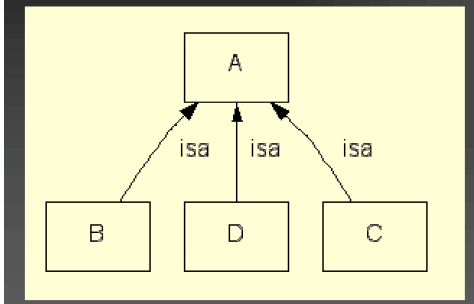
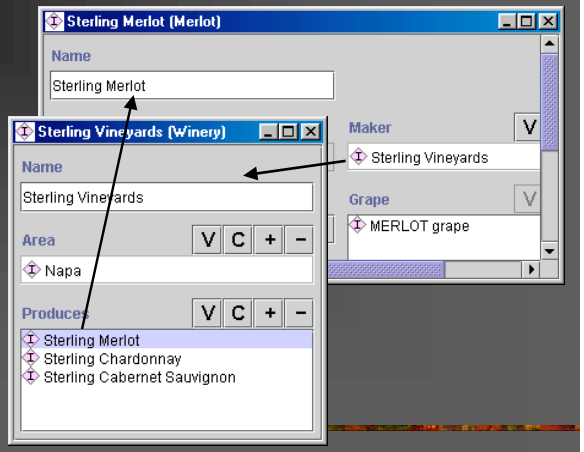
Defining Domain and Range



- A class and a superclass – replace with the superclass
- All subclasses of a class – replace with the superclass
- Most subclasses of a class – consider replacing with the superclass

Inverse Slots

Maker and Producer are inverse slots



Inverse Slots (II)

- Inverse slots contain redundant information, but
  - Allow acquisition of the information in either direction
  - Enable additional verification
  - Allow presentation of information in both directions
- The actual implementation differs from system to system
  - Are both values stored?
  - When are the inverse values filled in?
  - What happens if we change the link to an inverse slot?

Default Values

- Default value – a value the slot gets when an instance is created
- A default value can be changed
- The default value is a common value for the slot, but is not a required value
- For example, the default value for wine body can be FULL

Limiting the Scope

- An ontology should not contain all the possible information about the domain
  - No need to specialize or generalize more than the application requires
  - No need to include all possible properties of a class
    - Only the most salient properties
    - Only the properties that the applications require

Limiting the Scope (II)

- Ontology of wine, food, and their pairings probably will not include
  - Bottle size
  - Label color
  - My favorite food and wine
- An ontology of biological experiments will contain
  - Biological organism
  - Experimenter
- Is the class Experimenter a subclass of Biological organism?

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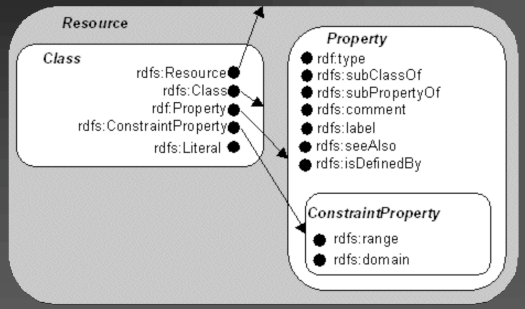
Ontologies and the SW Languages

- Most Semantic Web languages are designed explicitly for representing ontologies
  - RDF Schema
  - DAML+OIL
  - SHOE
  - XOL
  - XML Schema

SW Languages

- The languages differ in their
  - syntax
    - We are not concerned with it here – An ontology is a conceptual representation
  - terminology
    - Class-concept
    - Instance-object
    - Slot-property
  - expressivity
    - What we can express in some languages, we cannot express in others
  - semantics
    - The same statements may mean different things in different languages

RDF and RDF Schema Classes



RDF Schema Specification 1.0 (http://www.w3.org/TR/2000/CR-rdf-schema-20000327/)

RDF(S) Terminology and Semantics

- Classes and a class hierarchy
  - All classes are instances of rdfs:Class
  - A class hierarchy is defined by rdfs:subClassOf
- Instances of a class
  - Defined by rdf:type
- Properties
  - Properties are global:
    A property name in one place is the same as the property name in another (assuming the same namespace)
  - Properties form a hierarchy, too (rdfs:subPropertyOf)

Property Constraints in RDF(S)

- Cardinality constraints
  - No explicit cardinality constraints
  - Any property can have multiple values
- Range of a property
  - a property can have only one range
- Domain of a property
  - a property can have more than one domain (can be attached to more than one class)
- No default values

DAML+OIL: Classes And a Class Hierarchy

- Classes
  - Each class is an instance of daml:Class
- Class hierarchy
  - Defined by rdfs:subClassOf
- More ways to specify organization of classes
  - Disjointness (daml:disjointWith)
  - Equivalence (daml:sameClassAs)
- The class hierarchy can be computed from the properties of classes

More Ways To Define a Class in DAML+OIL

- Union of classes
  - *A class Person is a union of classes Male and Female*
- Restriction on properties
  - *A class Red Thing is a collection of things with color: Red*
- Intersection of classes
  - *A class Red Wine is an intersection of Wine and Red Thing*
- Complement of a class
  - *Carnivores are all the animals that are not herbivores*
- Enumeration of elements
  - *A class Wine Color contains the following instances: red, white, rosé*

Property Constraints in DAML+OIL

- Cardinality
  - Minimum, maximum, exact cardinality
- Range of a property
  - A property range can include multiple classes: the value of a property must be an instance of each of the classes
  - Can specify explicit union of classes if need different semantics
- Domain of a property – same as range
- No default values

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Research Issues in Ontology Engineering

- Content generation
- Analysis and evaluation
- Maintenance
- Ontology languages
- Tool development

Content: Top-Level Ontologies

- What does "top-level" mean?
  - Objects: tangible, intangible
  - Processes, events, actors, roles
  - Agents, organizations
  - Spaces, boundaries, location
  - Time
- IEEE Standard Upper Ontology effort
  - Goal: Design a single upper-level ontology
  - Process: Merge upper-level of existing ontologies

Content: Knowledge Acquisition

- Knowledge acquisition is a bottleneck
- Sharing and reuse alleviate the problem
- But we need automated knowledge acquisition techniques
  - Linguistic techniques: ontology acquisition from text
  - Machine-learning: generate ontologies from structured documents (e.g., XML documents)
  - Exploiting the Web structure: generate ontologies by crawling structured Web sites
  - Knowledge-acquisition templates: experts specify only part of the knowledge required

Analysis

- Analysis: semantic consistency
  - Violation of property constraints
  - Cycles in the class hierarchy
  - Terms which are used but not defined
  - Interval restrictions that produce empty intervals (min > max)
- Analysis: style
  - Classes with a single subclass
  - Classes and slots with no definitions
  - Slots with no constraints (value type, cardinality)
- Tools for automated analysis
  - Chimaera (Stanford KSL)
  - DAML validator

Evaluation

- One of the hardest problems in ontology design
- Ontology design is subjective
- What does it mean for an ontology to be correct (objectively)?
- The best test is the application for which the ontology was designed

Ontology Maintenance

- Ontology merging
  - Having two or more overlapping ontology, create a new one
- Ontology mapping
  - Create a mapping between ontologies
- Versioning and evolution
  - Compatibility between different versions of the same ontology
  - Compatibility between versions of an ontology and instance data

Ontology Languages

- What is the “right” level of expressiveness?
- What is the “right” semantics?
- When does the language make “too many” assumptions?

Ontology-Development Tools

- Support for various ontology language (knowledge interchange)
- Expressivity
- Usability
  - More and more domain experts are involved in ontology development
  - Multiple parentheses and variables will no longer do

Where to Go From Here?

- Tutorials
  - Natalya F. Noy and Deborah L. McGuinness (2001) “Ontology Development 101: A Guide to Creating Your First Ontology” http://protege.stanford.edu/publications/ontology_development/ontology101.html
  - Farquhar, A. (1997). Ontolingua tutorial. http://ksl-web.stanford.edu/people/axf/tutorial.pdf
    - We borrowed some ideas from this tutorial
- Methodology
  - Gómez-Pérez, A. (1998). Knowledge sharing and reuse. Handbook of Applied Expert Systems. Liebowitz, editor, CRC Press.
  - Uschold, M. and Gruninger, M. (1996). Ontologies: Principles, Methods and Applications. Knowledge Engineering Review 11(2)

Transitivity of the Class Hierarchy

- The is-a relationship is transitive:

  B is a subclass of A

  C is a subclass of B

  C is a subclass of A

- A direct superclass of a class is its “closest” superclass