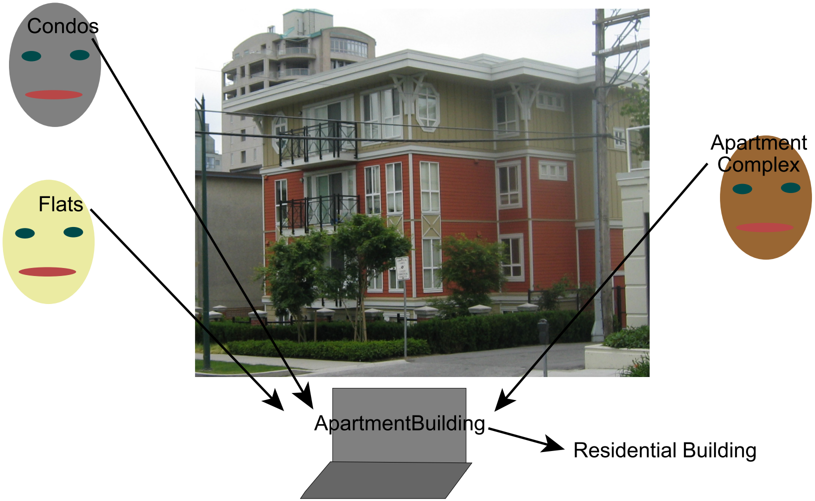
Knowledge Sharing

- A **conceptualization** is a map from the problem domain into the representation. A conceptualization specifies:
  - What sorts of individuals are being modeled
  - The vocabulary for specifying individuals, relations and properties
  - The meaning or intention of the vocabulary
- If more than one person is building a knowledge base, they must be able to share the conceptualization.
- An **ontology** is a specification of a conceptualization. An ontology specifies the meanings of the symbols in an information system.

Mapping from a conceptualization to a symbol



Semantic Web

- Ontologies are published on the web in machine readable form.
- Builders of knowledge bases or web sites adhere to and refer to a published ontology:
  - a symbol defined by an ontology means the same thing across web sites that obey the ontology.
  - if someone wants to refer to something not defined, they publish an ontology defining the terminology.
    Others adopt the terminology by referring to the new ontology.
    In this way, ontologies evolve.
  - Separately developed ontologies can have mappings between them published.

Challenges of building ontologies

- They can be huge: finding the appropriate terminology for a concept may be difficult.

Challenges of building ontologies

- They can be huge: finding the appropriate terminology for a concept may be difficult.
- How one divides the world can depend on the application. Different ontologies describe the world in different ways.
- People can fundamentally disagree about an appropriate structure.

Challenges of building ontologies

- They can be huge: finding the appropriate terminology for a concept may be difficult.
- How one divides the world can depend on the application. Different ontologies describe the world in different ways.
- People can fundamentally disagree about an appropriate structure.
- Different knowledge bases can use different ontologies.
- To allow KBs based on different ontologies to inter-operate, there must be mapping between ontologies.
- It has to be in user's interests to use an ontology.

Challenges of building ontologies

- They can be huge: finding the appropriate terminology for a concept may be difficult.
- How one divides the world can depend on the application. Different ontologies describe the world in different ways.
- People can fundamentally disagree about an appropriate structure.
- Different knowledge bases can use different ontologies.
- To allow KBs based on different ontologies to inter-operate, there must be mapping between ontologies.
- It has to be in user's interests to use an ontology.
- The computer doesn't understand the meaning of the symbols. The formalism can constrain the meaning, but can't define it.

Semantic Web Technologies

- XML the Extensible Markup Language provides generic syntax.
  $\langle tag \ldots / \rangle$ or
  $\langle tag \ldots \rangle \ldots \langle / tag \rangle$.
- URI a Uniform Resource Identifier is a name of an individual (resource). This name can be shared. Often in the form of a URL to ensure uniqueness.
- RDF the Resource Description Framework is a language of triples
- OWL the Web Ontology Language, defines some primitive properties that can be used to define terminology. (Doesn't define a syntax).

Main Components of an Ontology

- **Individuals** the things / objects in the world (not usually specified as part of the ontology)
- **Classes** sets of individuals
- **Properties** between individuals and their values

Individuals

- Individuals are things in the world that can be named. (Concrete, abstract, concepts, reified).
- Unique names assumption (UNA): different names refer to different individuals.
- The UNA is not an assumption we can universally make: "The Queen", "Elizabeth Windsor", etc.
- Without the determining equality, we can't count!
- In OWL we can specify:

$$i_1 \;\; \mathit{SameIndividual} \;\; i_2.$$

$$i_1 \;\; \mathit{DifferentIndividuals} \;\; i_3.$$

Classes

- A class is a set of individuals. E.g., house, building, officeBuilding
- One class can be a subclass of another

  $$house \;\; subClassOf \;\; building.$$

  $$officeBuilding \;\; subClassOf \;\; building.$$

- The most general class is *Thing*.
- Classes can be declared to be the same or to be disjoint:

  $$house \;\; EquivalentClasses \;\; singleFamilyDwelling.$$

  $$house \;\; DisjointClasses \;\; officeBuilding.$$

- Different classes are not necessarily disjoint.
  E.g., a building can be both a commercial building and a residential building.

Properties

- A property is between an individual and a value.
- A property has a domain and a range.

  livesIn domain person.

  livesIn range placeOfResidence.
- An *ObjectProperty* is a property whose range is an individual.
- A *DatatypeProperty* is one whose range isn't an individual, e.g., is a number or string.
- There can also be property hierarchies:

  livesIn subPropertyOf enclosure.

  principalResidence subPropertyOf livesIn.

Properties (Cont.)

- One property can be inverse of another

  livesIn InverseObjectProperties hasResident.

- Properties can be declared to be transitive, symmetric, functional, or inverse-functional. (Which of these are only applicable to object properties?)
- We can also state the minimum and maximal cardinality of a property.

  principalResidence minCardinality 1.

  principalResidence maxCardinality 1.

Property and Class Restrictions

- We can define complex descriptions of classes in terms of restrictions of other classes and properties.
  E.g., A homeowner is a person who owns a house.

Property and Class Restrictions

- We can define complex descriptions of classes in terms of restrictions of other classes and properties.
  E.g., A homeowner is a person who owns a house.

$$homeOwner \subseteq person \cap \{x : \exists h \in house \text{ such that } x \; owns \; h\}$$

Property and Class Restrictions

- We can define complex descriptions of classes in terms of restrictions of other classes and properties.
  E.g., A homeowner is a person who owns a house.

$$homeOwner \subseteq person \cap \{x : \exists h \in house \text{ such that } x \; owns \; h\}$$

$$homeOwner \quad subClassOf \quad person.$$
$$homeOwner \quad subClassOf$$
$$ObjectSomeValuesFrom(owns, house).$$

OWL Class Constructors

owl:Thing $\equiv$ all individuals
owl:Nothing $\equiv$ no individuals
owl:ObjectIntersectionOf$(C_1, \ldots, C_k) \equiv C_1 \cap \cdots \cap C_k$
owl:ObjectUnionOf$(C_1, \ldots, C_k) \equiv C_1 \cup \cdots \cup C_k$
owl:ObjectComplementOf$(C) \equiv Thing \setminus C$
owl:ObjectOneOf$(I_1, \ldots, I_k) \equiv \{I_1, \ldots, I_k\}$
owl:ObjectHasValue$(P, I) \equiv \{x : x\ P\ I\}$
owl:ObjectAllValuesFrom$(P, C) \equiv \{x : x\ P\ y \rightarrow y \in C\}$
owl:ObjectSomeValuesFrom$(P, C) \equiv$
$\{x : \exists y \in C$ such that $x\ P\ y\}$
owl:ObjectMinCardinality$(n, P, C) \equiv$
$\{x : \#\{y | xPy$ and $y \in C\} \geq n\}$
owl:ObjectMaxCardinality$(n, P, C) \equiv$
$\{x : \#\{y | xPy$ and $y \in C\} \leq n\}$

OWL Predicates

rdf:type$(I, C) \equiv I \in C$
rdfs:subClassOf$(C_1, C_2) \equiv C_1 \subseteq C_2$
owl:EquivalentClasses$(C_1, C_2) \equiv C_1 \equiv C_2$
owl:DisjointClasses$(C_1, C_2) \equiv C_1 \cap C_2 = \{\}$
rdfs:domain$(P, C) \equiv$ if xPy then $x \in C$
rdfs:range$(P, C) \equiv$ if xPy then $y \in C$
rdfs:subPropertyOf$(P_1, P_2) \equiv xP_1y$ implies xP_2y
owl:EquivalentObjectProperties$(P_1, P_2) \equiv xP_1y$ if and only if xP_2y
owl:DisjointObjectProperties$(P_1, P_2) \equiv xP_1y$ implies not xP_2y
owl:InverseObjectProperties$(P_1, P_2) \equiv xP_1y$ if and only if yP_2x
owl:SameIndividual$(I_1, \ldots, I_n) \equiv \forall j \forall k\ I_j = I_k$
owl:DifferentIndividuals$(I_1, \ldots, I_n) \equiv \forall j \forall k\ j \neq k$ implies $I_j \neq I_k$
owl:FunctionalObjectProperty$(P) \equiv$ if xPy_1 and xPy_2 then $y_1 = y_2$
owl:InverseFunctionalObjectProperty$(P) \equiv$
if x_1Py and x_2Py then $x_1 = x_2$
owl:TransitiveObjectProperty$(P) \equiv$ if xPy and yPz then xPz
owl:SymmetricObjectProperty $\equiv$ if xPy then yPx

Knowledge Sharing

- One ontology typically imports and builds on other ontologies.
- OWL provides facilities for version control.
- Tools for mapping one ontology to another allow inter-operation of different knowledge bases.
- The semantic web promises to allow two pieces of information to be combined if
  - they both adhere to an ontology
  - these are the same ontology or there is a mapping between them.

Example: Apartment Building

An apartment building is a residential building with more than two units and they are rented.

Example: Apartment Building

An apartment building is a residential building with more than two units and they are rented.

```
:numberOfUnits rdf:type    owl:FunctionalObjectProperty;
           rdfs:domain :ResidentialBuilding;
           rdfs:range  owl:OneOf(:one :two :moreThanTwo).
```

Example: Apartment Building

An apartment building is a residential building with more than two units and they are rented.

```
:numberOfUnits rdf:type    owl:FunctionalObjectProperty;
             rdfs:domain :ResidentialBuilding;
             rdfs:range  owl:OneOf(:one :two :moreThanTwo).

:ApartmentBuilding
    owl:EquivalentClasses
          owl:ObjectIntersectionOf (
                owl:ObjectHasValue(:numberOfUnits
                                   :moreThanTwo)
                owl:ObjectHasValue(:onwership
                                   :rental)
             :ResidentialBuilding).
```

Aristotelian definitions

Aristotle [350 B.C.] suggested the definition if a class C in terms of:

- Genus: the super-class
- Differentia: the attributes that make members of the class C different from other members of the super-class

"If genera are different and co-ordinate, their differentiae are themselves different in kind. Take as an instance the genus 'animal' and the genus 'knowledge'. 'With feet', 'two-footed', 'winged', 'aquatic', are differentiae of 'animal'; the species of knowledge are not distinguished by the same differentiae. One species of knowledge does not differ from another in being 'two-footed'."

Aristotle, *Categories*, 350 B.C.

Example: hotel ontology

Define the following:

- Room
- BathRoom
- StandardRoom - what is rented as a room in a hotel
- Suite
- RoomOnly

Example: hotel ontology

Define the following:

- Room
- BathRoom
- StandardRoom - what is rented as a room in a hotel
- Suite
- RoomOnly
- Hotel
- HasForRent
- AllSuitesHotel
- NoSuitesHotel
- HasSuitesHotel

Basic Formal Ontology (BFO)

- entity
  - continuant
    - independent continuant
      - site
      - object aggregate
      - object
      - fiat part of object
      - boundary of object
    - dependent continuant
      - realizable entity
        - function
        - role
        - disposition
      - quality
    - spatial region
      - volume / surface / line / point

BFO (cont.)

- occurrent
  - temporal region
    - connected temporal region
      - temporal interval
      - temporal instant
    - scattered temporal region
  - spatio-temporal region
    - connected spatio-temporal region
      - spatio-temporal interval / spatio-temporal instant
    - scattered spatio-temporal region
  - processual entity
    - process
    - process aggregate
    - processual context
    - fiat part of process
    - boundary of process

Continuants vs Occurrents

- A continuant exists in an instance of time and maintains its identity through time.
- An occurrent has temporal parts.
- Continuants participate in occurrents.
- a person, a life, a finger, infancy: what is part of what?

Continuants vs Occurrents

- A continuant exists in an instance of time and maintains its identity through time.
- An occurrent has temporal parts.
- Continuants participate in occurrents.
- a person, a life, a finger, infancy: what is part of what?
- a holiday, the end of a lecture, an email, the sending of an email, the equator, earthquake, a smile, a laugh, the smell of a flower

Continuants

- a pen, a person, Newtonian mechanics, the memory of a past event: objects
- a flock of birds, the students in CS422, a card collection: object aggregates
- a city, a room, a mouth, the hole of a doughnut: site
- the dangerous part of a city, part of Grouse Mountain with the best view: fiat part of an object.