Chapter 13:

Ontologies

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- Is there a flexible way to represent relations?
- How can knowledge bases be made to inter-operate semantically?

Choosing Individuals and Relations

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$prop(Individual, Property, Value)$ is the only relation needed:
called individual-property-value representation
or triple representation

Universality of *prop*

To represent "a is a parcel"

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- $prop(a, type, parcel)$, where *type* is a special property
- $prop(a, parcel, true)$, where *parcel* is a Boolean property

Reification

- To represent $scheduled(cs422, 2, 1030, cc208)$. "section 2 of course $cs422$ is scheduled at 10:30 in room $cc208$."

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- Let $b123$ name the booking:

$$prop(b123, course, cs422).$$
$$prop(b123, section, 2).$$
$$prop(b123, time, 1030).$$
$$prop(b123, room, cc208).$$

- We have reified the booking.
- Reify means: to make into an individual.
- What if we want to add the year?

Semantics Networks

When you only have one relation, *prop*, it can be omitted without loss of information.

Logic:

$$prop(Individual, Property, Value)$$

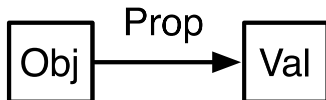
triple:

$$\langle Individual, Property, Value \rangle$$

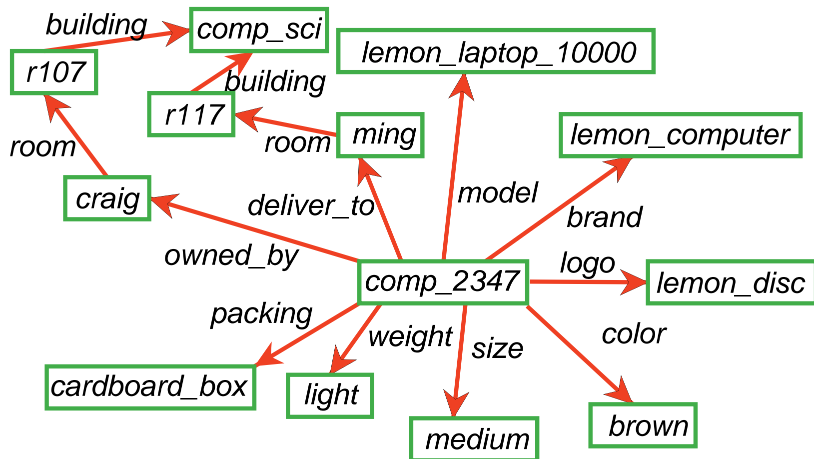
simple sentence:

$$Individual\ Property\ Value.$$

graphically:



An Example Semantic Network



Equivalent Logic Program

$prop(comp_2347, owned_by, craig).$
$prop(comp_2347, deliver_to, ming).$
$prop(comp_2347, model, lemon_laptop_10000).$
$prop(comp_2347, brand, lemon_computer).$
$prop(comp_2347, logo, lemon_disc).$
$prop(comp_2347, color, brown).$
$prop(craig, room, r107).$
$prop(r107, building, comp_sci).$

$\vdots$

Turtle: a simple language of triples

A triple is written as

$$Subject\ Verb\ Object.$$

A comma can group objects with the same subject and verb.

$S\ V\ O_1, O_2.$ is an abbreviation for $\begin{array}{l} S\ V\ O_1. \\ S\ V\ O_2. \end{array}$

A semi-colon can group verb-object pairs for the same subject.

$S\ V_1\ O_1; V_2\ O_2.$ is an abbreviation for $\begin{array}{l} S\ V_1\ O_1. \\ S\ V_2\ O_2. \end{array}$

Square brackets can be used to define an individual that is not given an identifier. It can then be used as the object of a triple.

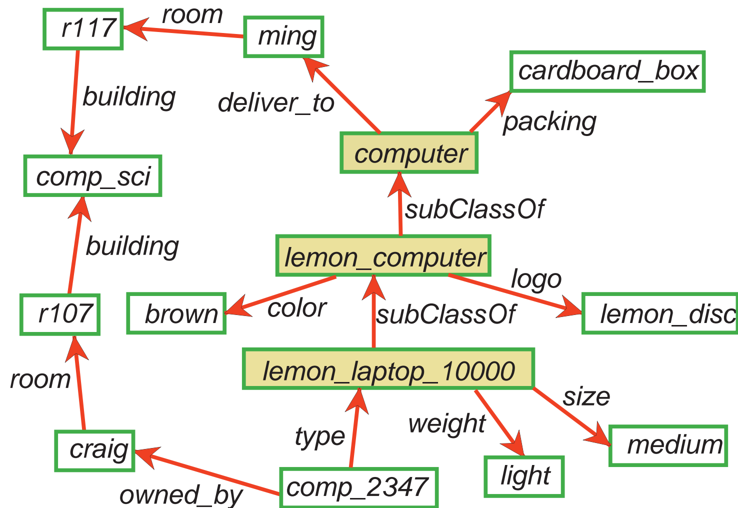
Turtle Example

$$
\begin{array}{l}
\langle \text{comp_3645} \rangle \quad \langle \#\text{owned_by} \rangle \quad \langle \#\text{fran} \rangle \,; \\
\qquad \langle \#\text{color} \rangle \quad \langle \#\text{green} \rangle \,, \langle \#\text{yellow} \rangle \,; \\
\qquad \langle \#\text{managed_by} \rangle \;\; [\; \langle \#\text{occupation} \rangle \quad \langle \#\text{sys_admin} \rangle \,; \\
\qquad\qquad \langle \#\text{serves_building} \rangle \quad \langle \#\text{comp_sci} \rangle].
\end{array}
$$

Primitive versus Derived Properties

- Primitive knowledge is that which is defined explicitly by facts.
- Derived knowledge is knowledge defined by rules.
- a class is a set of individuals that are grouped together as they have similar properties.
- Example: All lemon computers may have $color = brown$. Associate this property with the class, not the individual.
- Allow a special property *type* between an individual and a class.
- Use a special property *subClassOf* between two classes that allows for property inheritance.

A Structured Semantic Network



Logic of Property

An arc $c \xrightarrow{p} v$ from a class c with a property p to value v means every individual in the class has value v on property p:

$$prop(Obj, p, v) \leftarrow$$
$$prop(Obj, type, c).$$

Example:

$$prop(X, weight, light) \leftarrow$$
$$prop(X, type, lemon_laptop_10000).$$
$$prop(X, packing, cardboard_box) \leftarrow$$
$$prop(X, type, computer).$$

Logic of Property Inheritance

You can do inheritance through the subclass relationship:

$$\begin{aligned}&prop(X, type, T) \leftarrow \\ &\quad prop(S, subClassOf, T) \wedge \\ &\quad prop(X, type, S).\end{aligned}$$

Multiple Inheritance

- An individual is usually a member of more than one class. For example, the same person may be a wine expert, a teacher, a football coach,. . . .
- The individual can inherit the properties of all of the classes it is a member of: multiple inheritance.
- With default values,what if an individual inherits conflicting defaults from the different classes?
  multiple inheritance problem.

Choosing Primitive and Derived Properties

- Associate a property value with the most general class with that property value.
- Don't associate contingent properties of a class with the class. For example, if all of current computers just happen to be brown.

Relationship to OO-programming

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- The representation of an object in a knowledge base is only an approximation at one (or a few) levels of abstraction. An OOP system knows everything about an object, but nothing about individuals in the world.
- The class structure of OOP is intended to represent objects designed by a systems analyst or a programmer. A knowledge base is used to represent aspects of the world, which is usually not so well behaved.

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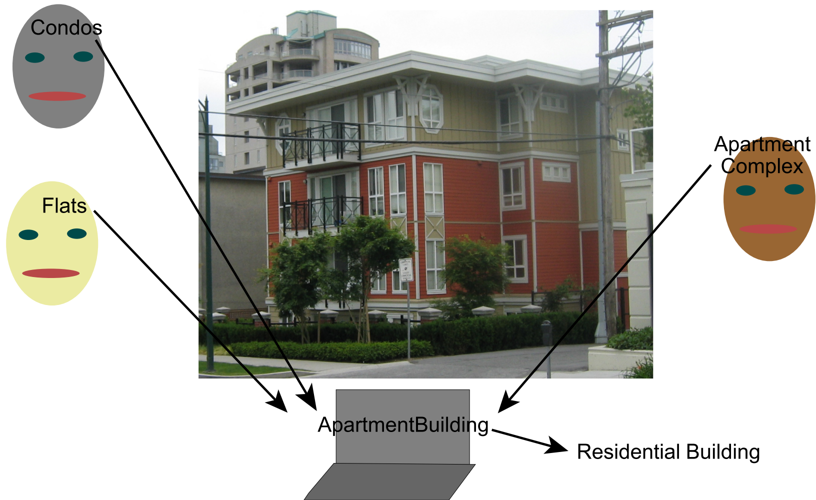
- OOP objects are intended to carry out some kind of computation. A knowledge representation does not actually do anything, it simply refers to objects in the world
- OO modeling tools have facilities to help building good designs. Imposing a good design on the unstructured world might not be helpful.

Knowledge Sharing

- A **conceptualization** is a mapping 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.

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- 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** relationships 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 determining equality, we can't count!
- In OWL we can specify:

$$i_1 \quad SameIndividual \quad i_2.$$

$$i_1 \quad DifferentIndividuals \quad i_3.$$

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 a relationship between an individual and a value.
- A property has a domain (for the individual) and a range (for the value).

  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.
- We can also state the minimum and maximal cardinality of a property.

  principalResidence minCardinality 1.

  principalResidence maxCardinality 1.

Property and Class Restrictions

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$$homeOwner \quad subClassOf \quad person.$$

$$homeOwner \quad subClassOf$$

$$ObjectSomeValuesFrom(owns, house).$$

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$(P, C) \equiv$
$\{x : \exists y \in C \text{ such that } x\ P\ y\}$
owl:ObjectMinCardinality$(n, P, C) \equiv$
$\{x : \#\{y | xPy \text{ and } y \in C\} \geq n\}$
owl:ObjectMaxCardinality$(n, P, C) \equiv$
$\{x : \#\{y | xPy \text{ and } y \in C\} \leq n\}$

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$(I_1, \dots, I_n) \equiv \forall j \forall k \; I_j = I_k$
owl:DifferentIndividuals$(I_1, \dots, I_n) \equiv \forall j \forall k \; j \neq k$ 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.

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```
:ownership
    rdf:type        owl:FunctionalObjectProperty;
    rdfs:domain     :ResidentialBuilding;
    rdfs:range      owl:OneOf(:rental :ownerOccupied :coop).
```

Example: Apartment Building

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

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

```
: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.

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.
  a pen, Europe, a goal, an email, ...
- An occurrent has temporal parts.
  a day, sending of an email, smiling, ...
- Continuants participate in occurrents.
- a person, a life, a finger, infancy: what is part of what?

Continuants

- independent continuants: exists by itself or as part of another continuant
  a person, a leg, an idea, a plan, ...
- dependent continuants: exists only by virtue of other continuants
  an earthquake, a smile, a laugh, the smell of a flower, ...
- spatial region

Continuants

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