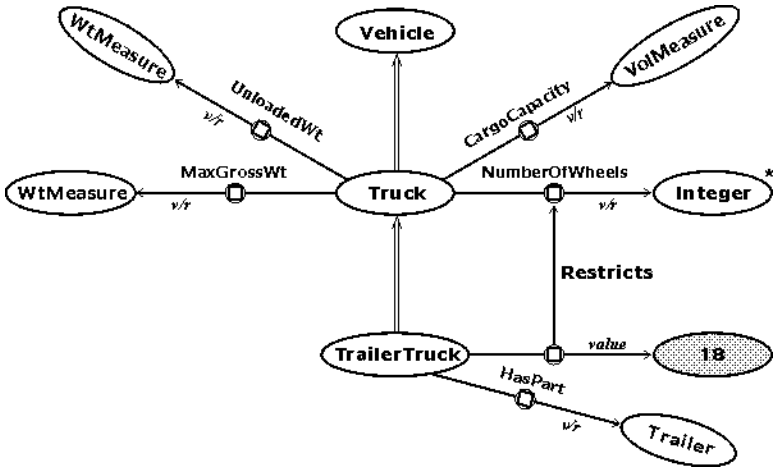
Object-Oriented Representation

What is Object-Oriented?

$$\forall x\, P(x) \vee \forall x\, Q(x) \Rightarrow \forall x\, (P(x) \vee Q(x))$$
$$\exists x\, (P(x) \wedge Q(x)) \Rightarrow \exists x\, P(x) \wedge \exists x\, Q(x)$$
$$\exists x\, P(x) \wedge \forall x\, Q(x) \Rightarrow \exists x\, (P(x) \wedge Q(x))$$
$$\forall x\, P(x) \Rightarrow P(c)$$
$$P(c) \Rightarrow \exists x\, P(x)$$



- Flat representation
- Each sentence is self-contained
- Can be independently understood
- Information about an entity is scattered in multiple sentences

vs

-Sentences are grouped
-Structured and organized
- Usually a correspondence with the user interface
- Translatable to logic

Outline

- Background
  - Frames
  - Semantic Networks
  - Object-orientation
- An example object-oriented KR language
  - Inheritance reasoning
  - Other inference operations
- Applications

Frames

- When one encounters a new situation, one selects from memory a structure called a *Frame.* This is a remembered framework to be adapted to fit reality by changing details as necessary – Marvin Minsky 1974
- Example: Birthday Party

DRESS ——— SUNDAY BEST.
PRESENT —— MUST PLEASE HOST. MUST BE BOUGHT AND GIFT-WRAPPED.
GAMES ——— HIDE AND SEEK. PIN TAIL ON DONKEY.
DECOR ——— BALLOONS. FAVORS. CREPE-PAPER.
PARTY-MEAL–CAKE. ICE-CREAM. SODA. HOT DOGS.
CAKE ——— CANDLES. BLOW-OUT. WISH.
SING BIRTHDAY SONG.
ICE-CREAM — STANDARD THREE-FLAVOR.

Reasoning Operations on Frames

- Expectation: How to select an initial frame to meet some conditions
  - Child's birthday party
- Elaboration: How to select and assign sub-frames to represent additional details
  - North American birthday party vs an Asian Party
- Alteration: How to find a frame to replace one that does not fit well
  - No gifts allowed
- Novelty: What to do if no acceptable frame can be found?
- Learning: What frames should be stored or modified as a result of experience?

Semantic Network

- Directed labeled graphs used to represent concepts and the relationships between them
  - A concept refers to things in the application domain
    - Animal, Vertebra, Cat, etc

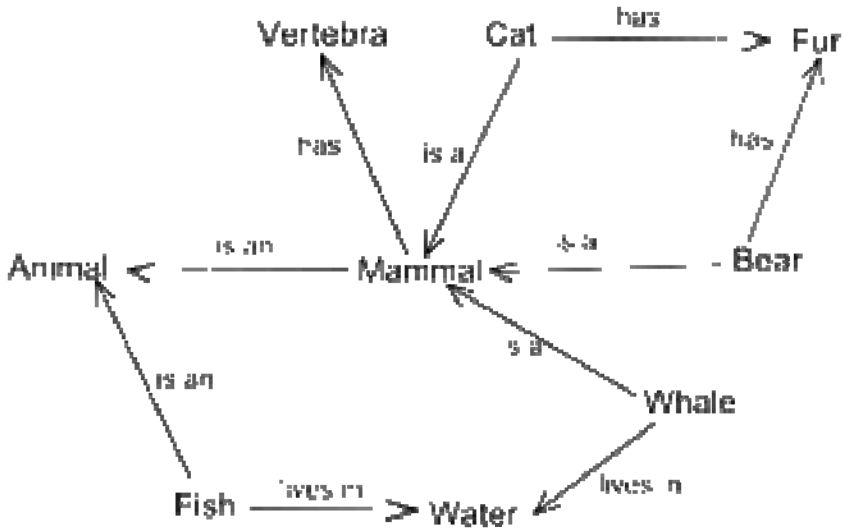
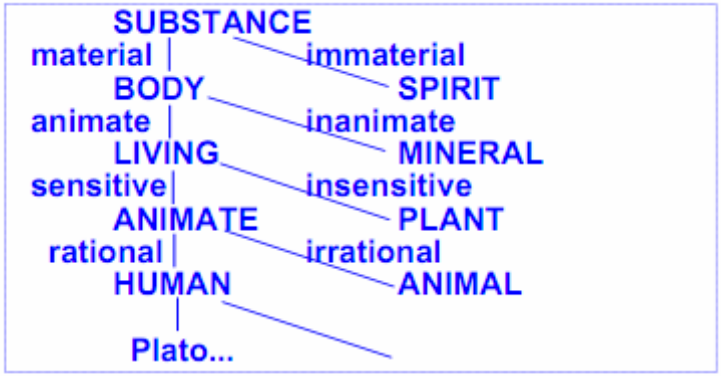


Image adapted from Wikipedia: http://en.wikipedia.org/wiki/Semantic_network

Semantic Network

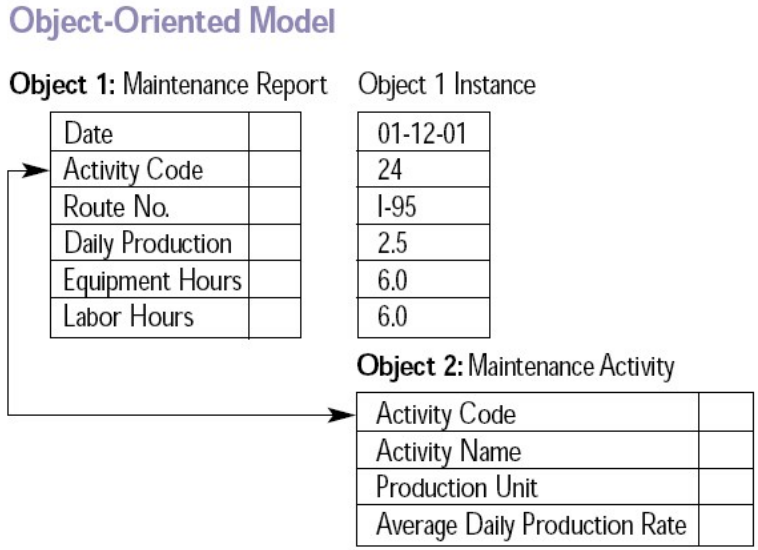
- Such representations have had a long distinguished history in philosophy and science
  - Prophyry's tree (3rd AD)
  - Charles Peirce's existential graphs (1890's) used in philosophy / logic
  - O. Stelz's concept hierarchies (1920's) – psychology
  - Ross Quillian's associative memory model (1966) – Psychology / computer science



Porphyry, 3rd century AD.

Object-Oriented Languages

- Many modern programming languages support features such as data abstraction and inheritance: Java
- Object databases represent information as objects and support object-oriented programming



Observation

- Graphical representations have several features in common
  - A hierarchy of classes
  - Classes have properties that can inherit
  - Facets provide further descriptors of values
- Such representations are pervasive in modern systems and have been formalized in a variety of ways
- In this lecture we will consider one such representation language

An Example Object-Oriented KR Language

- Loosely based on Open Knowledge Base Connectivity
  - Provides a knowledge model
    - The knowledge model was developed based on extensive survey of object-centered representation and reasoning systems under development in mid-nineties [Karp ’92]
    - It incorporates common features found across a broad range of those systems
  - Defines a set of knowledge base operations
    - Define the basic inference operations that a object-oriented KR system must support
- Even though this work is over 10 years old, its simplicity and elegance is still compelling and relevant to modern systems

Knowledge Model

- A universe of discourse consists of all entities about which knowledge is to be expressed
- The universe of discourse always includes all constants of the following basic types:
  - Integers
  - Floating point numbers
  - Strings
  - Symbols
  - Lists
  - Classes
- The universe also includes logical constants: *true* and *false*

Class

- Classes are sets of entities
- All sets of entities are considered to be classes
  - A class is equivalent to a unary relation

Example:
Person is a class and represents set of all people

Individual

- Each of the entities in a class is said to be an instance of that class
- An individual is an entity that is not a set

Examples:

- John is an individual, and is not a set, and is an instance of Person

instance-of

- The class membership relation *instance-of* holds between an instance and a class is a binary relation that maps entities to classes

(<=> (*holds* ?C ?I) (*instance-of* ?I ?C))

- The relation type-of is defined as the inverse of relation *instance-of*

(<=> (*type-of* ?C ?I) (*instance-of* ?I ?C))

subclass-of

- A class CSub is a subclass of class CSuper if and only if all instances of Csub are also instances of CSuper

(<=> (subclass-of ?Csub ?Csuper)
(forall ?I (=> (instance-of ?I ?Csub)
(instance-of ?I ?Csuper))))

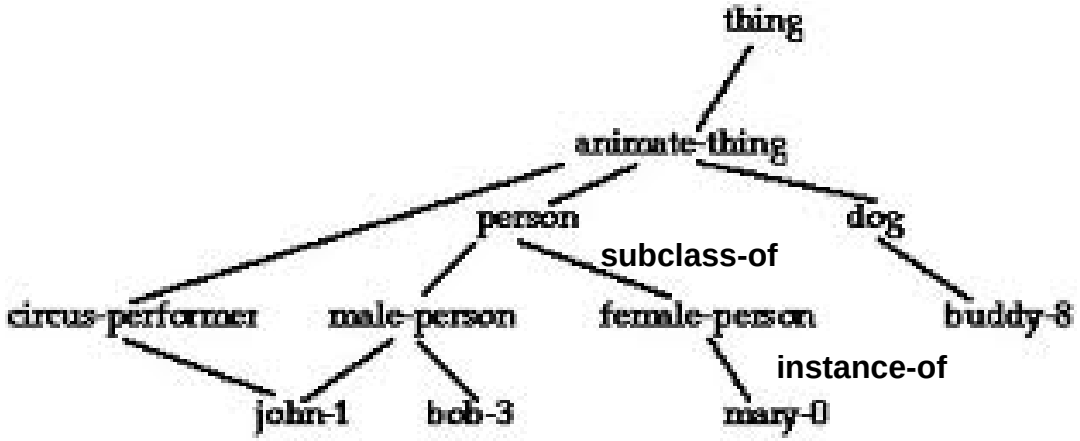


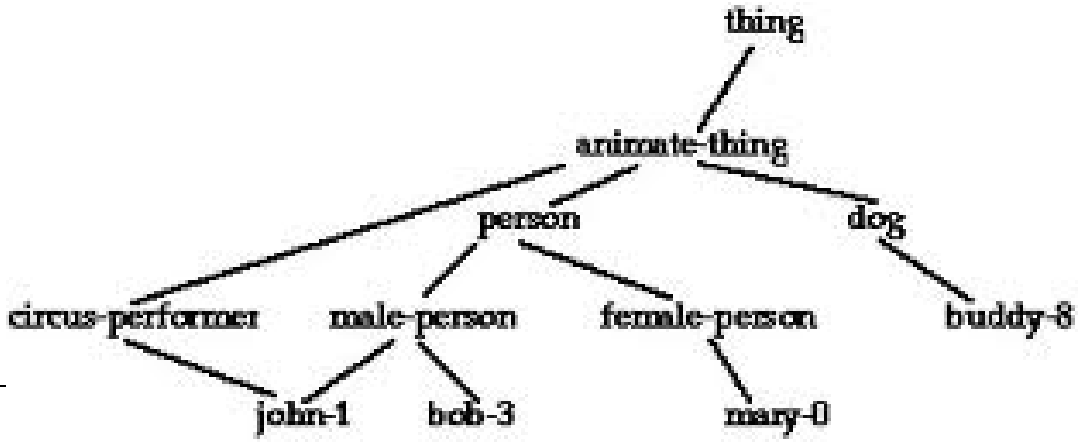
Image adapted from Chris Riesbeck (notes for CS325 at NWU)

subclass-of

- The subclass-of relationship is transitive
  - If A is a subclass of B, and B is a subclass of C, A is a subclass of C

```
(=>
    (and (subclass-of ?a ?b)
         (subclass-of ?b ?c))
              (subclass-of ?a ?c)))
```

Male-person is a
subclass of animate-thing



Meta Class

- A class can be an instance of another class
  - A class that has another class as an instance is referred to as a *meta class*

Example:

Linnaen Taxonomy

Animal, Ecysozoan, Eumetzoa, …

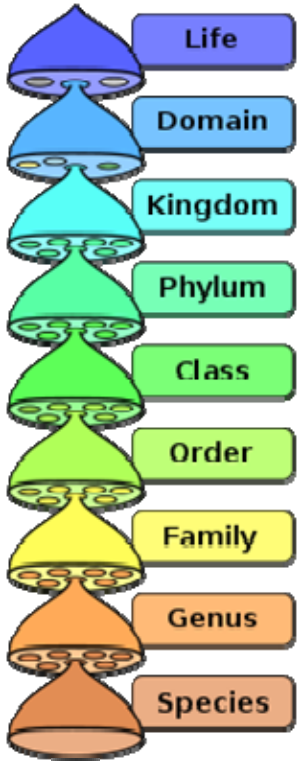
Biological Classification

Kingdom, Phylum, Order, …

The class Animal is an instance of class Kingdom

Animal is an instance of Kingdom

Cow is not an instance of Kingdom



Picture credit: http://en.wikipedia.org/wiki/Kingdom_(biology)

Own Slots

- An entity has associated with it a collection of *own* slots
  - An *own* slot describes the direct properties of an entity
    - If the age of *John* is 42, then the value of the *own* slot *age* of *John* is 42
  - An *own* slot is equivalent to a binary relation
    - (age John 42)
  - Both classes and individuals can have *own* slots
    - A class *Person* has an own slot *average-age*: average of the age of all the instances of the class *Person*

Template Slots

- A class has associated with a collection of *template* slots
  - Template slots describe properties of the instance of a class
  - Own slots of a class describe the properties of the class itself

    Example:

    Class: Blue-Eyed-Person
    template slot: eye-color
    template-slot-value: Blue

    Individual: John
    instance-of: Blue-Eyed-Person
    own slot: eye-color
    own slot value: Blue

  - The values of template slots are ***inherited*** to instances as values of the corresponding own slot

Template Slots

- Formally, each value V of a template slot S of a class C represents the assertion that the relation template-slot-value holds for the relations S, the class represented by C, and the entity represented by V

(template-slot-value S C V)

- The relation in turn holds between each instance I of class C and value V

(S I V)

(=> (template-slot-value ?S ?C ?V)
(=> (instance-of ?I ?C) (holds ?S ?I ?V))

Necessary vs Sufficient Properties

- Necessary properties of a class are necessarily true

Example:

A Person has an age, a parent, a height, …

- Sufficient properties are properties sufficient to conclude the class membership

Example:

A Blue-Eyed-Person is a Person with eye-color Blue

If an instance of unknown type had an age, it does not mean that it is a Blue-Eyed-Person

Primitive vs Defined Classes

- Primitive class is a class that only has necessary properties

Example: Person

- Defined class is a class that can be defined in terms of another class by giving it sufficient properties

Example: Blue-Eyed-Person

a Person with eye-color Red

Domain

- If a slot S has *domain* C, then every entity *I* that has a value for slot *S*, must be an *instance-of* C

Example:

The domain of slot *has-salary* is class *Employee*

```
(=> (DOMAIN ?S ?C)
        (=> (holds ?S ?F ?V) (instance-of ?F ?C))
        (=> (template-slot-value ?S ?F ?V)
                (or (= ?F ?C) (subclass-of ?F ?C))))
```

Range

- If a slot S has *range* C, then every entity *I* that has a value *V* for slot *S*, *V* must be an *instance-of* C

Example:

The range of slot *has-salary* is class *Amount-In-Dollars*

(=> (range ?S ?C)
(=> (holds ?S ?F ?V) (instance-of ?V ?C))
(=> (template-slot-value ?S ?F ?V) (instance-of ?V ?C)))

Facets

- An own slot can have associated with it an own facet that provides more information about that slots

Example:

John has exactly two Friends

John

own slots: has Friends

cardinality: 2

Facets

- An template slot can have associated with it template slots that inherit like the template slot values

Example:

Person has exactly 1 Father

Person

template slot: has-Parent

cardinality: 1

Default Values

- Each slot can have two kinds of values
  - Known true: values that are definitely known to be true
  - Default: values that are generally true but could be overridden

Example:

Class: Stanford Student
template slot: residence-city
default value: Stanford

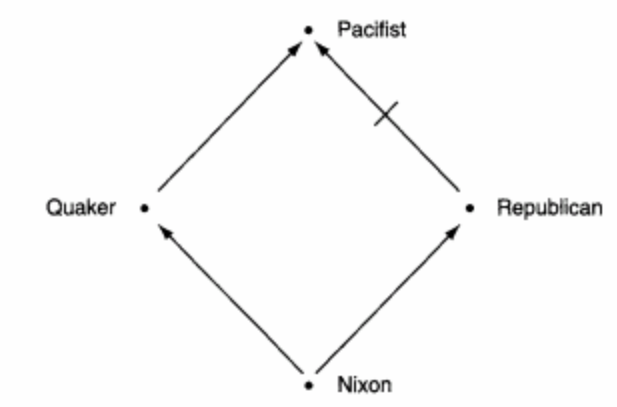
template slot: studies-at
known true: Stanford

Problems with Default Values

- When a class has more than one super class, its instances may inherit values that conflict with each other

Example:

- Nixon/Diamond example:
  - Nixon is a both Republican and Quaker, Republicans have a non-pacifist policy, and Quakers have a pacifist policy. One of the two values must be blocked from inheriting



Problems with Default Values

- When a class has more than one super class, its instances may inherit values that conflict with each other

Example:

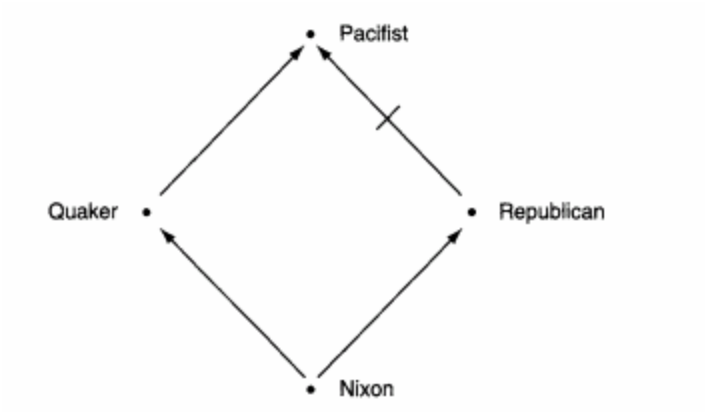
- Burgundy house example:
  - A Red-House has template-slot-value for color as Red
  - Burgundy House is a subclass of Red House
  - We want the value color of the roof to be overridden to burgundy

Methods for Dealing with Conflicting Values

- Skeptical Inheritance
- Override Inheritance

Skeptical Inheritance

- Inherit values only when the inherited values do not lead to contradiction
  - In the Nixon Diamond example, neither pacifist nor non-pacifist value will be inherited
  - The problem of contradiction is avoided
  - Nothing is done to resolve the contradiction



Override Inheritance

- A value specified at a more specific class overrides the value at a more general class
  - In the burgundy house example, the value of color specified for the more specific class overrides the value inherited from the super class
  - The values specified at a super-class are lost

Other Methods for Defaults

- Allow a designer to associate priorities with inherited values
- Provide heuristics to guess the correct value
  - Textbook chapter on inheritance reasoning has examples

Accessing the Knowledge Base

- Two kinds of interfaces
  - A set of function calls
  - An interface based on a logical language

Systematic Design of Functions

- For each kind of knowledge, provide: add, delete, put, replace

add-class-subclass
delete-class-subclass
put-class-subclass
replace-class-subclass

add-instance-type
delete-instance-type
put-instance-type
replace-instance-type

add-slot-value
delete-slot-value
put-slot-value
replace-slot-value

add-facet-value
delete-facet-value
put-slot-value
Replace-slot-value

Mandatory vs Optional

- A reasoning system must support a set of core operations called mandatory operations
- Rest of the operations can be defined in terms of the mandatory operations

Example:

Mandatory operation: get-class-subclasses

Optional operation: subclass-of-p

Question:

What is the core set of operations for a reasoning system?

Logical Interface

- Basic operations: Tell, Untell and Ask
- Assertion language: instance-of, subclass-of, template-slot-value,

Sentence	Effect of Executing (tell ⟨sentence⟩)
(`slot` frame value)	(**add-slot-value** frame slot value :slot-type :own)
(`facet` slot frame value)	(**add-facet-value** frame slot facet value)
(`instance-of` frame class)	(**add-instance-type** frame class)
(`type-of` class frame)	(**add-instance-type** frame class)
(`primitive` class)	Not a **tellable** sentence
(`template-slot-value` slot class value)	(**add-slot-value** class slot value :slot-type :template)
(`template-facet-value` facet slot class value)	(**add-facet-value** class slot facet value :slot-type :template)
(`class` class)	(**create-class** class)
(`individual` individual)	(**create-individual** individual)
(`slot-of` slot frame)	(**attach-slot** frame slot :slot-type :own)
(`facet-of` facet slot frame)	(**attach-facet** frame slot facet :slot-type :own)
(`template-slot-of` slot class)	(**attach-slot** slot class :slot-type :template)
(`template-facet-of` facet slot class)	(**attach-facet** class slot facet :slot-type :template)
(`subclass-of` class superclass)	(**add-class-superclass** class superclass)
(`superclass-of` superclass class)	(**add-class-superclass** class superclass)

Controlling the Inference

- Inference Level
  - Direct: return only the directly asserted values
  - Taxonomic: return only the inherited values
  - All-inferable: return all possible values
- Completeness
  - Return true if all values have been computed with certainty

Reasoning Operations on Frames

- Expectation: How to select an initial frame to meet some conditions
  - Child's birthday party
    - Sufficient properties
- Elaboration: How to select and assign sub-frames to represent additional details
  - North American birthday party vs an Asian Party
    - Inheritance
- Alteration: How to find a frame to replace one that does not fit well
  - No gifts allowed
    - Defaults
- Novelty: What to do if no acceptable frame can be found?
  - Not covered
- Learning: What frames should be stored or modified as a result of experience?
  - Not covered

Limitation of Object-Oriented Representation

- Since such representations rely heavily on binary relations, it is difficult to represent ternary relations
  - A is between B and C
- A standard workaround is to reify the binary relation

A has

own slot is-between: B, C

A has

own slot is-between: Between-Objects-1

Between-Objects-1 has

own slot objects: B, C

Limitations of Object Oriented Representation

- Negation cannot be represented uniformly
  - Jim does not have pneumonia
- Disjunction cannot be represented naturally
  - Jim has either Mumps or Rubella
- Quantification is not a part of the language
  - All of Jim's diseases are infectious
- The semantics of the relations (as in any logic) are not intrinsic to the representation