# CSC421 Intro to Artificial Intelligence

## UNIT 15:
## Inference in First-Order Logic + Knowledge Engineering

# Outline

- Logic Programming
- Resolution
- Ontological Engineering
- Categories & Objects
- Physical Composition
- Measurements
- Substances & Objects

# Prolog systems

- Basis: backward chaining with Horn clauses + bells and whistles
- Widely used in Europe, Japan ($5^{th}$ gen.)
- Program = set of clauses
  - head :- literal1,....,literaln
  - criminal(X) :- american(X), weapon(Y), sells (X,Y<Z), hostile(Z)
- Efficient unification, retrieval
- Depth-first, left-to-right BC
- Predicates for arithmetic X is Y * Z + 3
- Closed world assumption (negation as failure)

# Prolog examples

- DFS
  - dfs(X) :- goal(X).
  - dfs(X) :- succesor(X, S), dfs(S).
- Loops expressed as recursions
- Appending two lists to produce a third:
  - append([], Y, Y).
  - append([X|L], Y, [X|Z]) :- append(L, Y, Z).
  - Query: append(A,B, [1,2]) ?
  - A = [], B=[1,2]
  - A = [1], B = [2]
  - A = [1,2], B = []

# Resolution

Full first-order version

$$\frac{l_1 \vee l_2 \vee \ldots \vee l_k \qquad m_1 \vee m_2 \vee \ldots \vee m_n}{(l_1 \vee l_2 \vee l_{i-1} \vee l_{i+1} \ldots \vee l_k \vee m_1 \vee m_2 \vee m_{j-1} \vee m_{j+1} \ldots \vee m_n)\theta}$$

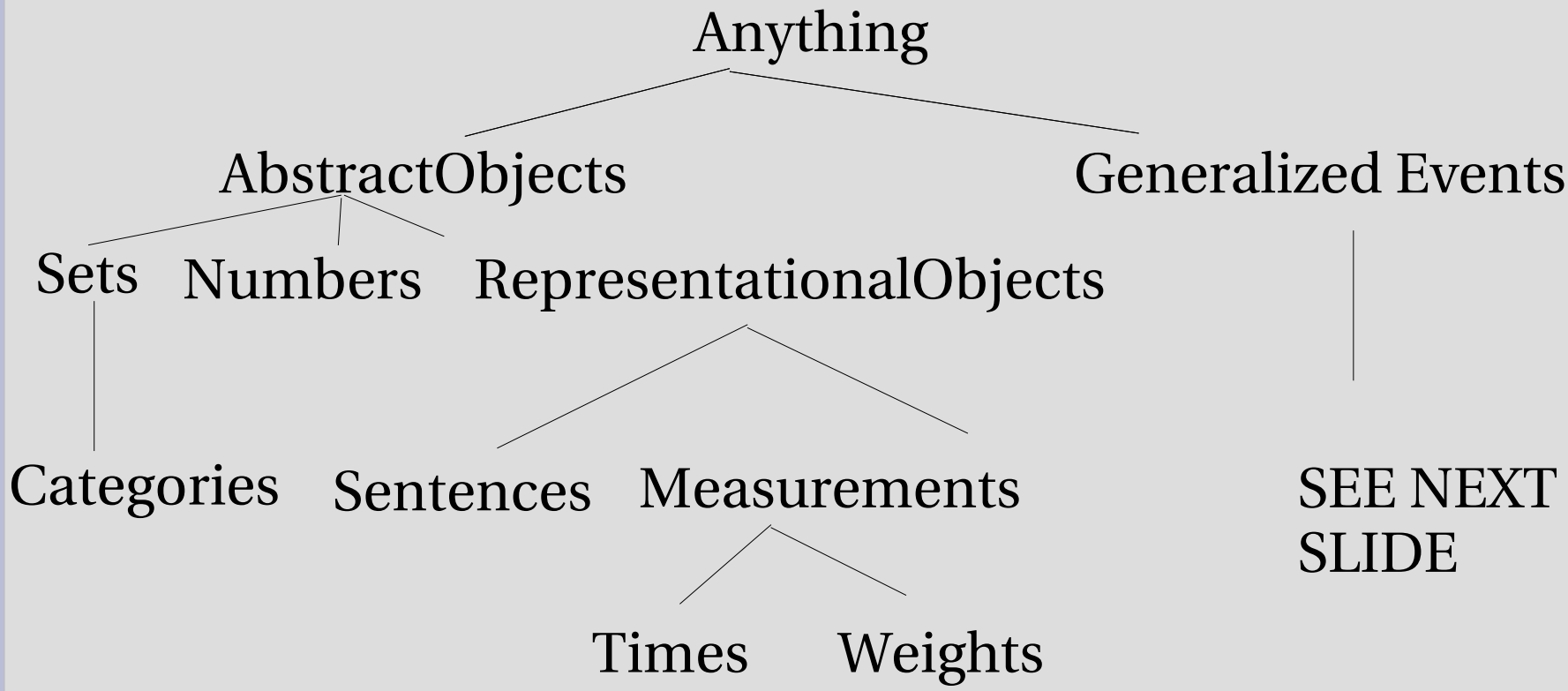
Where $\text{UNIFY}(l_i, \neg m_j) = \theta$

Apply resolution steps to $\text{CNF}(\text{KB} \wedge \neg \alpha)$; complete for FOL

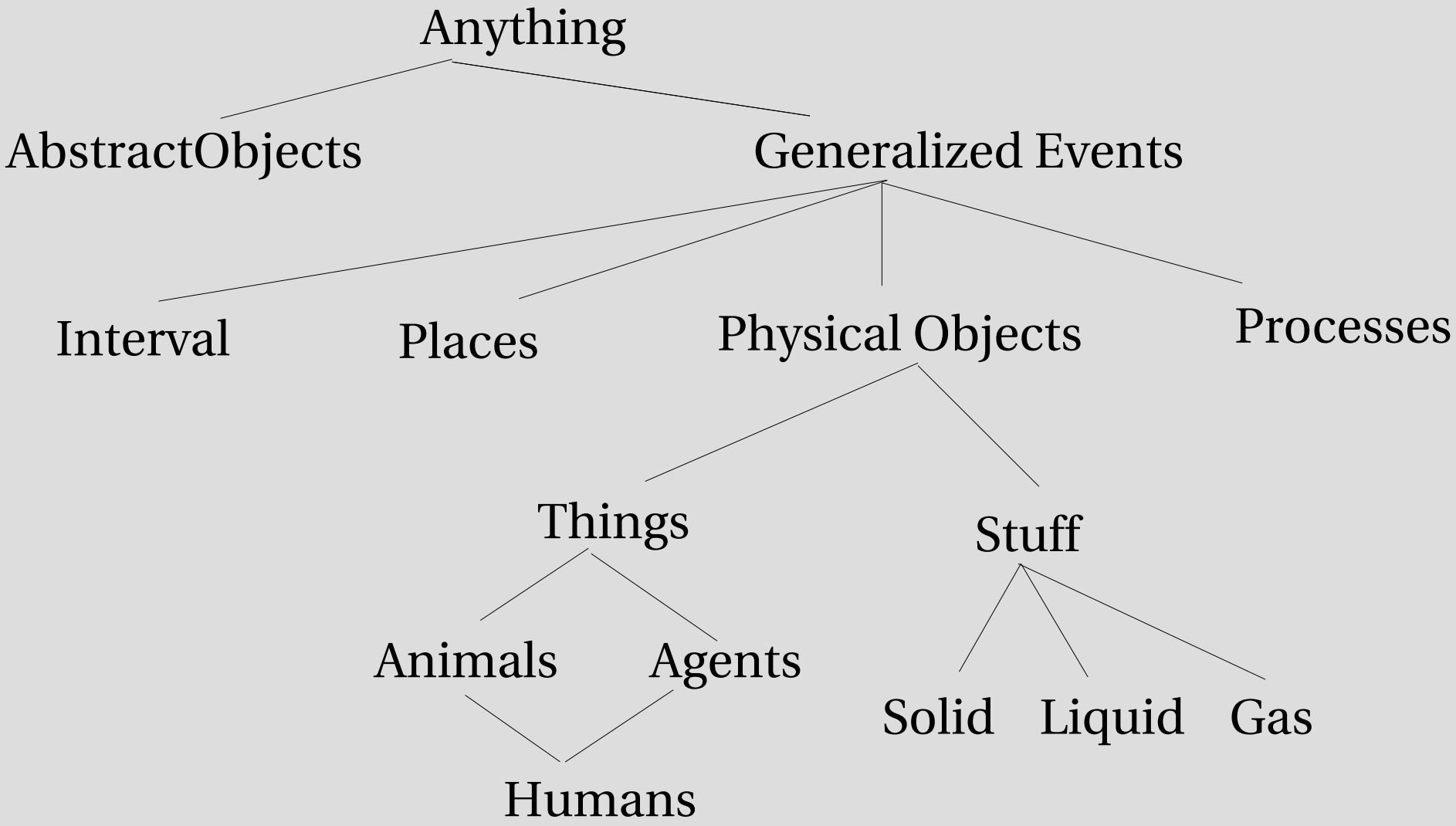
# Resolution Example

- $\neg$ Rich(x) $\vee$ Unhappy(x)  Rich(Ken)
- Unhappy(Ken) with $\theta$ = {x/Ken}
- Conversion to CNF
  - Eliminate biconditionals and implications
  - Move negations inwards
  - Standarize variables
  - Skolemize
  - Drop universal quantifiers
  - Distribute $\wedge$ over $\vee$

# Representing everything - the big picture



# The big picture



# Ontologies

- Upper ontology
- FOL challenges
  - exceptions
  - uncertainty
- Do all ontologies converge on a general purpose ontology
- After centuries of discussion possibly
- General ontology
  - Applicable to any specific domain with addition of domain specific axioms
  - Different areas of ontologies must be “unified”

# Categories & Objects

- Much reasoning in terms of categories
- Predictions about objects once classified
- Green, mottled skin, large size, ovoid shape
  - Infer it is a watermellon (category)
  - Useful for fruit salad (predictions about specific object based on category characteristics)
- Two choices
  - Predicate: Basketball(b)
  - Object (reify): Basketballs
- The two main ideas:
  - Subset(Basketballs, Balls)
  - Member(b, Basketballs)

# More about categories & objects

- Inheritance
  - All foods are edible
  - Fruit is a subclass of Food and Apples is a subclass of Fruit then we know all apples are edible
- Taxonomy
  - Used for centuries – examples
    - Biology
    - Dewey Decimal System
    - Musical genres

# FOL and categories/objects

- An object is a member of a category
  - This ball is a baskball
- A category is a subclass of another category
  - Basketballs are a type of ball.
- All members of of a category have some property
  - All basketballs are round
- Members of a category can be recognized by some properties
  - Orange and round balls are basketballs
- A category as a whole has some properties

# FOL and categories/objects

- An object is a member of a category
  - Bbg $\in$ Basketballs
- A category is a subclass of another category
  - Basketballs $\subset$ Balls
- All balls are round
  - x $\in$ Basketballs => Round(x)
- Orange and round balls are basketballs
  - Orange(x) $\wedge$ Round(x) $\wedge$ x $\in$ Balls => x $\in$ BBalls

# Relations between categories

- Disjoint = no members in common
  - Disjoint(animals, vegetables)
- Exhaustive decomposition
  - Exhaustive Decomposition({American, Canadians, Mexicans}, NorthAmericans)
- Disjoint exhaustive decomposition or partition
  - Partition({Males, Females}, Animals)
- Exercise (without reading book)
  - Try to define in FOL

# Physical Composition

- PartOf relation
- Composite objects – structural relations
- Composite objects without structure
  - The apples in this bag weigh two pounds
- A set of apples is a math concept doesn't have weight
- Bunch of apples (apples as parts not elements)

# Measurement

- Height, mass, cost etc
  - Values for properies = measures
- “Same” length has different “names”
  - 1.5 inches 3.81 cm
- Length(L1) = Inches(1.5) = Centimeters (3.81)
- Centimeters(2.54 x d) = Inches(d)
- Qualitative physics
- Nominal, ordinal, categorical

# Natural Kinds

- Tomatoes tend to be red
- Only true for “typical” instances
- member(x, Typical(Tomatoes)) => Red(x) ^ Round(x)

# Substances and Objects

- "Stuff"
  - Water, butter
  - Count nouns
    - Horses, theorems, basketballs
  - Mass nouns
    - Energy, butter, water
- Intrinsic properties (only => mass noun)
  - Salted, yellow, tasty
- Extrinsic properties (any => count noun)
  - Weight, length, shape
- Stuff vs Thing
- All physical objects belong to both categories