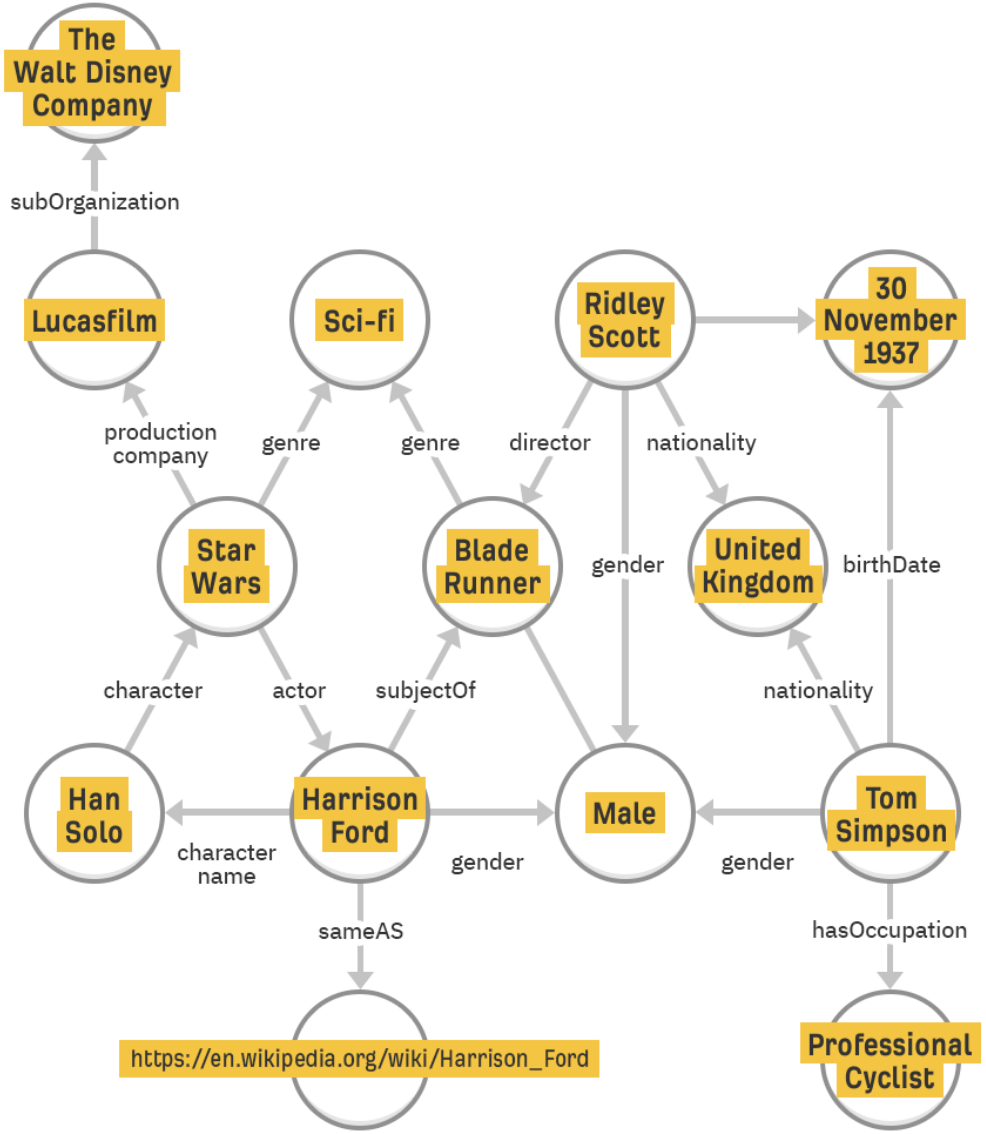
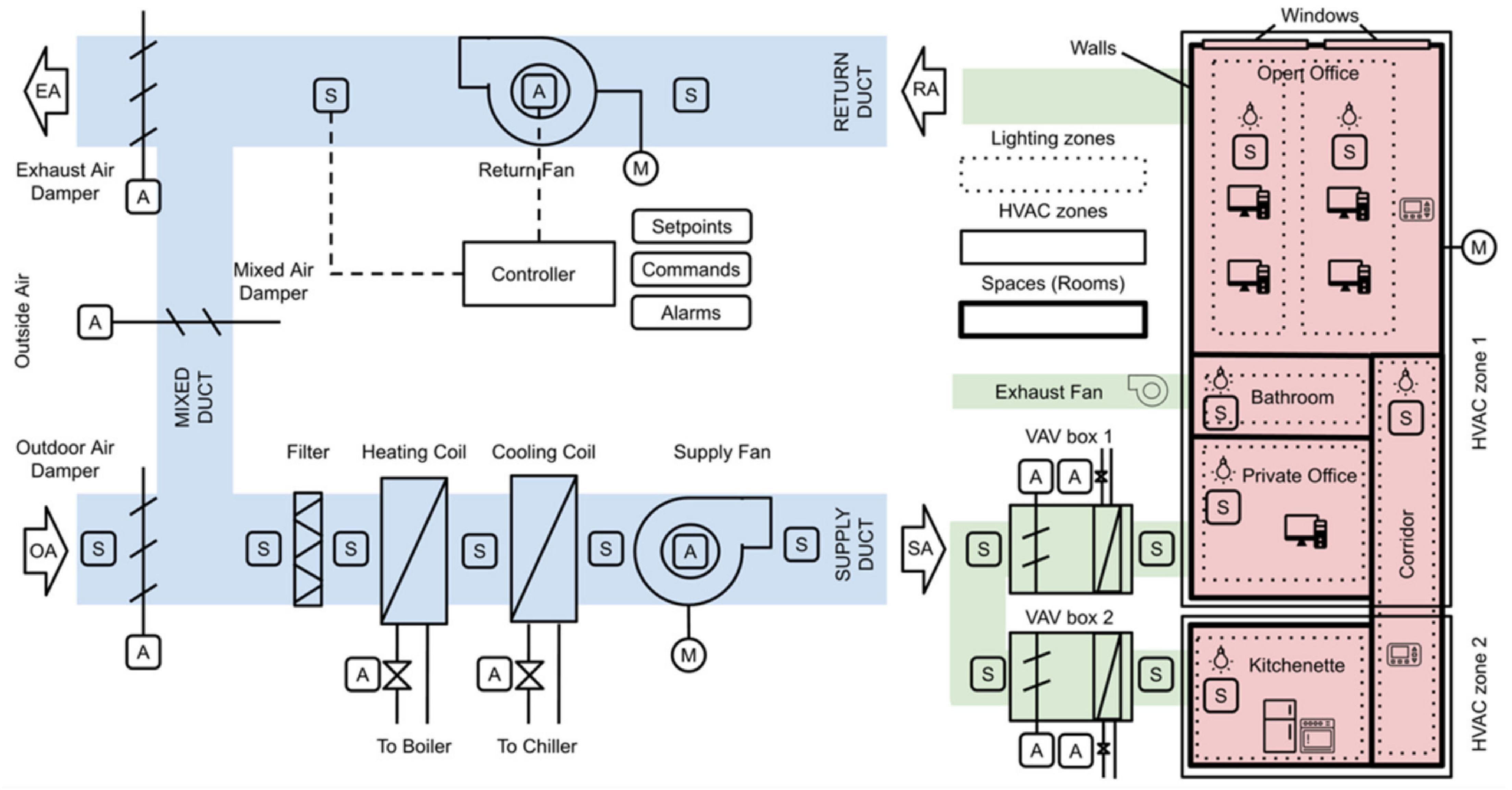
Lecture 10.1 - Knowledge Representation

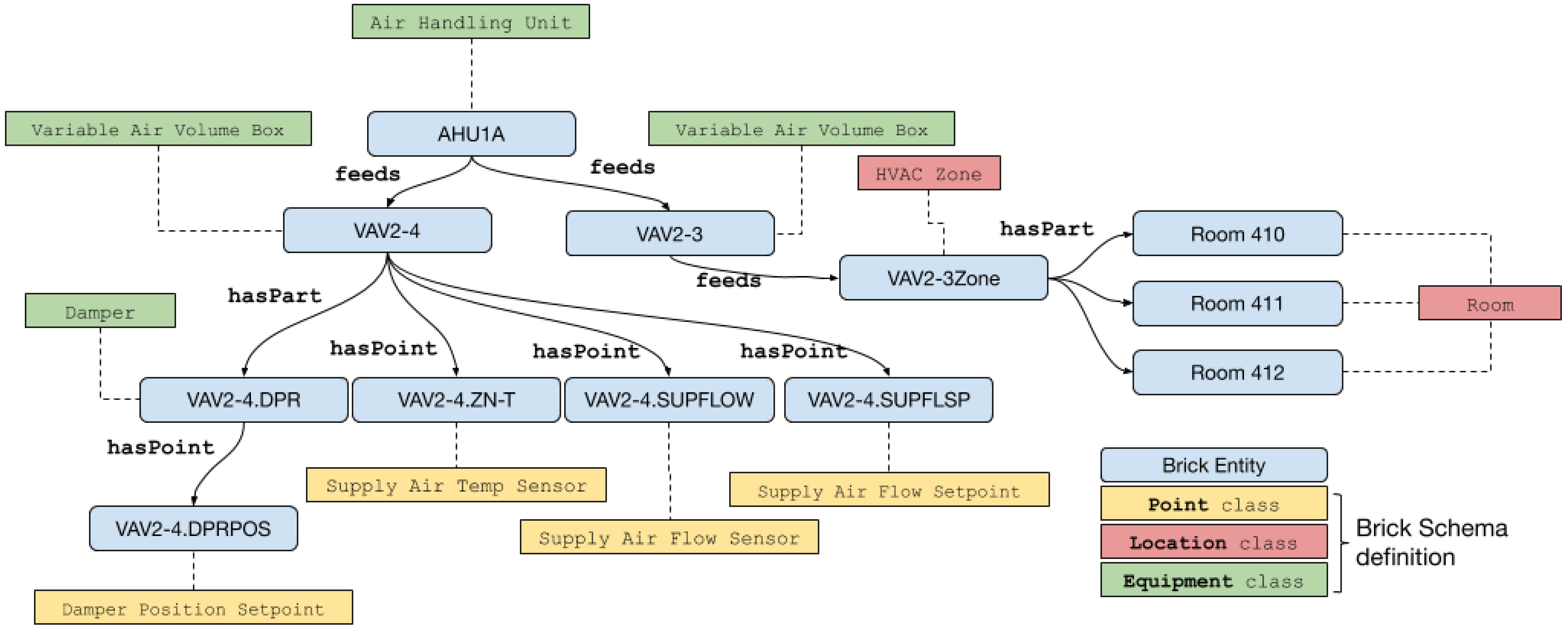
> How to represent diverse facts about the real world in a form that can be used to reason and solve problems?

Gleb Sizov
Norwegian University of Science and Technology





EA
Exhaust Air Damper
Return Fan
RETURN DUCT
RA
Walls
Windows
Open Office
Lighting zones
HVAC zones
Spaces (Rooms)
Setpoints
Commands
Alarms
Controller
Mixed Air Damper
Outside Air
MIXED DUCT
Exhaust Fan
Bathroom
Private Office
Corridor
HVAC zone 1
Kitchenette
HVAC zone 2
VAV box 1
VAV box 2
Outdoor Air Damper
OA
Filter
Heating Coil
Cooling Coil
Supply Fan
SUPPLY DUCT
SA
To Boiler
To Chiller

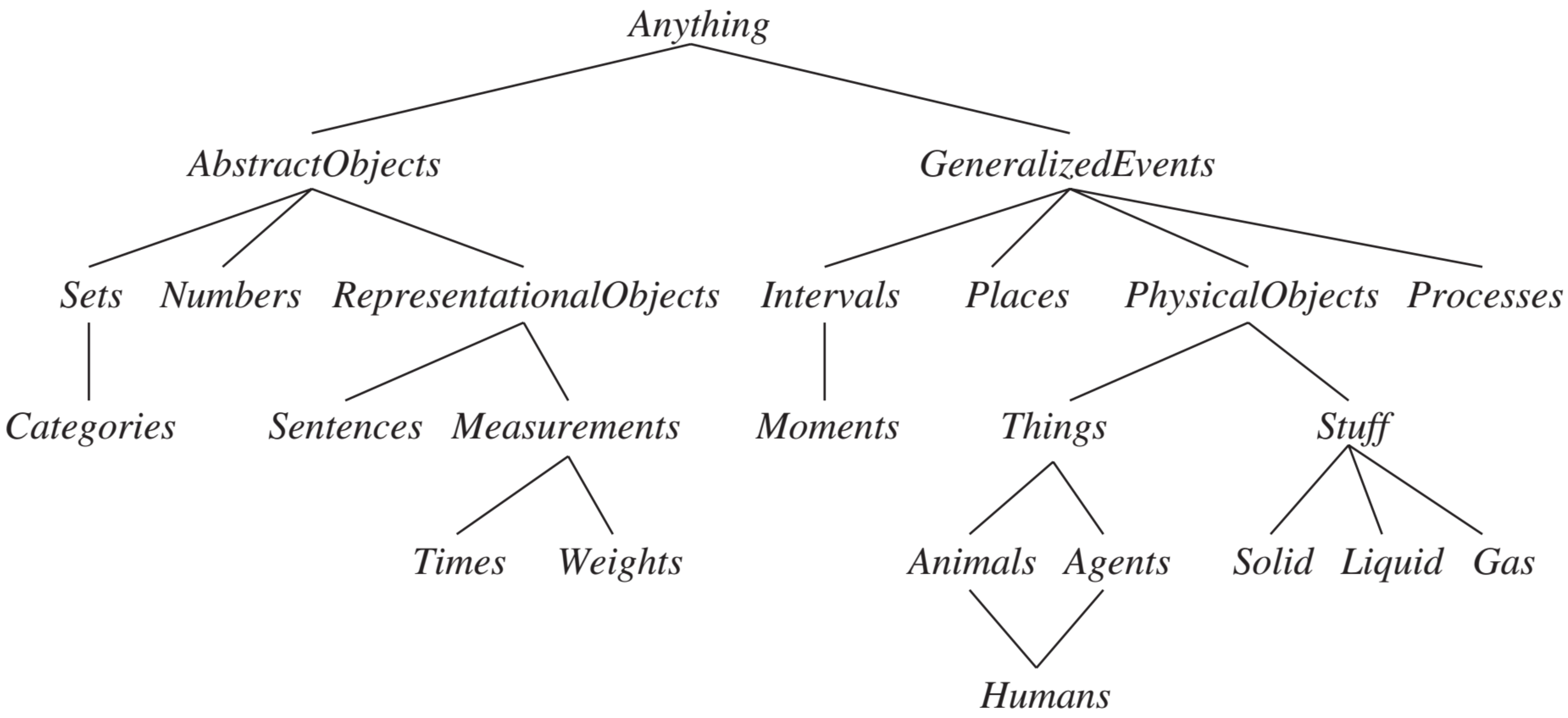

Air Handling Unit
AHU1A
Variable Air Volume Box
Variable Air Volume Box
feeds
feeds
HVAC Zone
VAV2-4
VAV2-3
hasPart
Room 410
feeds
VAV2-3Zone
Room 411
Room
hasPart
Damper
hasPoint
hasPoint
hasPoint
Room 412
VAV2-4.DPR
VAV2-4.ZN-T
VAV2-4.SUPFLOW
VAV2-4.SUPFLSP
hasPoint
Brick Entity
Supply Air Temp Sensor
Supply Air Flow Setpoint
Point class
VAV2-4.DPRPOS
Supply Air Flow Sensor
Location class
Brick Schema definition
Equipment class
Damper Position Setpoint

Ontological engineering

> How to create general and flexible representations?

- Physhical objects
- Actions
- Time
- Beliefs

Upper ontology - general framework fo concepts



General-purpose vs special-purpose ontology

1. Should be applicable in more or less any special domain
    - Add domain-sepcific axioms.
    - Address all representational issues
2. Different areas of knowledge need to be unified.
    - Reasoning and problems solving could involve several areas simultaneously

Example: Robot circuit-repair system - electrical components, physical layout, time, labor cost

Creating general-purpose ontology

How general-purpose ontologies are created:

1. By a team of trained ontologists or logicians, e.g. CYC
2. By importing categories, attributes and vales from existing databases, e.g DBpedia from Wikipedia
3. By parsing and extracting information from text, e.g. TextRunner from Web
4. By crowdsourcing, e.g. OpenMind

> None of the top AI applications use general-purpose ontology.
> They use special-purpose ontologies and machine learning.

It is hard to agree on an ontology when many parties are involved.

Categories and objects

Importance of categories:

1. Much of the reasoning takes place at the level of categories, e.g. buying a basketball, not BB_{34}
2. Categories help to make predictions about objects. e.g. $Watermalon(w)$ - good for frit salad

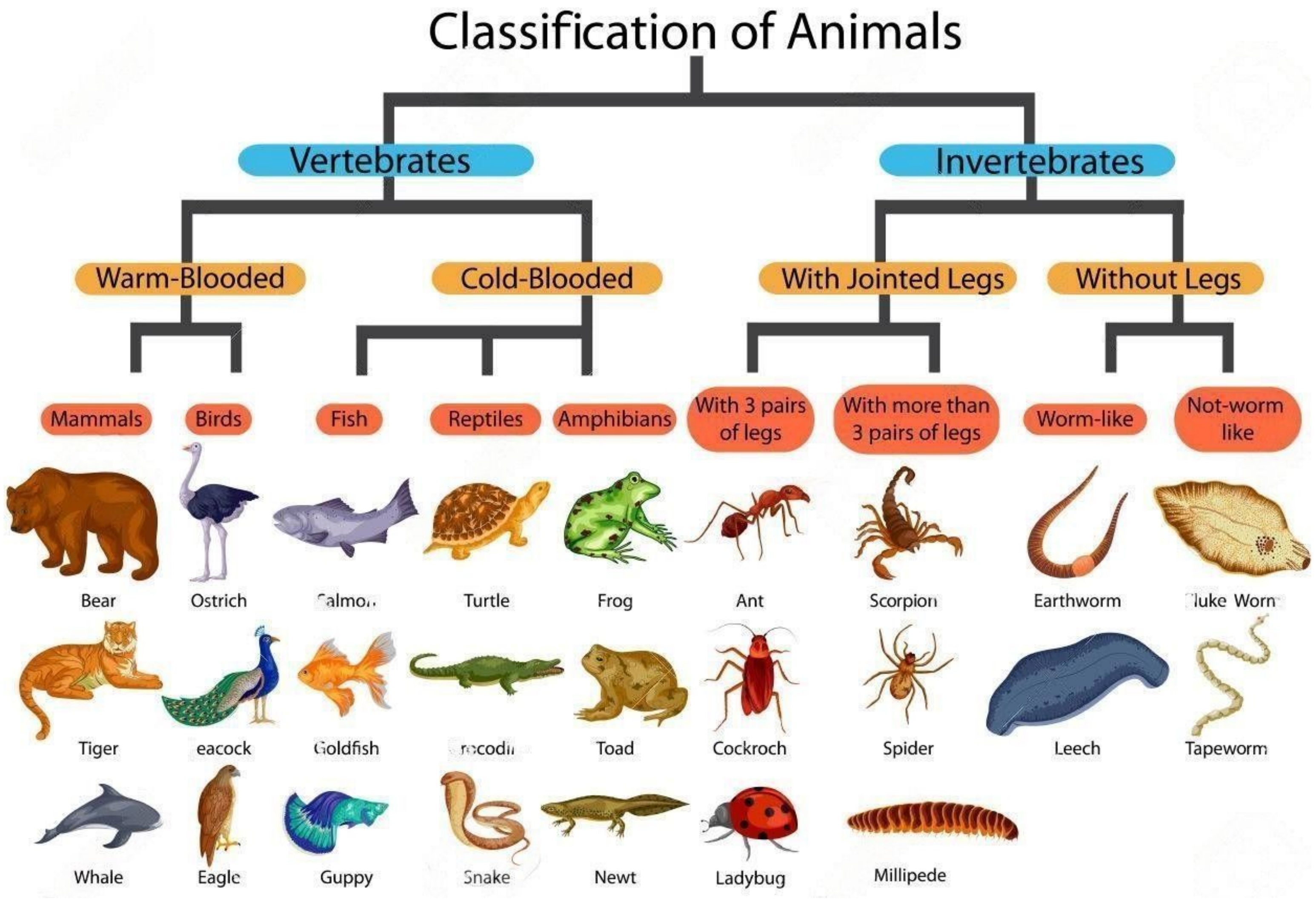
Representation of categories and inheritance

1. Predicate e.g. $Apple(a)$
2. **Reify** the category as an object, e.g.

$$Apples$$
$$a \in Apples$$
$$Applies \subset Fruits$$
$$Fruits \subset Foods$$

Inheritance. e.g. a **inherits** edibility of $Foods$.

Taxonomy - taxonomic hierarchy



First order logic and categories

An object is a member of a category:

$BB_{12} \in Basketballs$

$Member(BB12, Basketballs)$

A category is a subclass of another category:

$Basketballs \subset Balls$

$Subcategory(Basketballs, Balls)$

All members of a category have some properties:

$(x \in Basketballs) \Rightarrow Spherical(x)$

All members of a category can be recognized by some properties:

$Orange(x) \wedge Round(x) \wedge Diameter(x) = 9.5\text{''} \wedge x \in Balls \Rightarrow x \in Basketballs$

Natural kinds

Some categories can be defined exactly:

$x \in Bachelors \Leftrightarrow Unmarried(x) \wedge x \in Adults \wedge x \in Males$

Natural kind categories have no exact defintion.

$x \in Typical(Tomatoes) \Rightarrow Red(x) \wedge Spherical(x)$

Relations between categories

Disjoint: No members in common

$Disjoint(\{Animals, Vegetables\})$

Exhaustive Decomposition: All members are covered by categories

$ExhaustiveDecomposition($
$\{Americans, Canadians, Mexicans\}, NorthAmericans)$

Partition: An exhaustive decomposition of disjoing sets.

$Partition(\{Animals, Plants, Fungi\}, LivingThings)$

Composition

$PartOf(Bucharest, Romania)$

$PartOf(Romania, Europe)$

$PartOf(Europe, Earth)$

Transitive:

$PartOf(x, y) \land PartOf(y, z) \Rightarrow PartOf(x, z)$

Reflexive:

$PartOf(x, x)$

> **Composite objects** are often characterized by structural relations among parts, e.g. biped is an object with exactly two legs attached to a body.

Measurements

1. $Length(L1) = Inches(1.5) = Centimeters(3.81)$
2. $Diameter(Basketball_{12}) = Inches(9.5)$
3. $ListPrice(Basketball_{12}) = \$(19)$
4. $Weight(BunchOf(Apple1, Apple2, Apple3)) = Pounds(2)$
5. $d \in Days \Rightarrow Duration(d) = Hours(24)$

Event calculus

Fluents:

$At(Shankar, Berkeley)$

Events:

$E_1 \in Flyings \land Flyer(E_1, Shankar) \land Origin(E_1, SF) \land Destination(E_1, DC)$

Time points:

$T(At(Shankar, Berkeley), t_1, t_2)$

Example - effect of flying:

$E = Flyings(a, here, there) \land Happens(E, t_1, t_2) \Rightarrow Terminates(E, At(a, here), t_1) \land Initiates(E, At(a, there), t_2)$

Time

$$
\begin{aligned}
&Interval\,(i) \;\Rightarrow Duration\,(i) = (Time\,(End\,(i)) - Time\,(Begin\,(i)))\,,\\
&Time\,(Begin\,(AD1900)) = Seconds\,(0)\,.\\
&Time\,(Begin\,(AD2001)) = Seconds\,(3187324800)\,.\\
&Time\,(End\,(AD2001)) = Seconds\,(3218860800)\,.\\
&Duration\,(AD2001) = Seconds\,(31536000)\,.
\end{aligned}
$$

Time relations

$$
\begin{aligned}
Meet\,(i, j) \quad &\Leftrightarrow \quad End\,(i) = Begin\,(j) \\
Before\,(i, j) \quad &\Leftrightarrow \quad End\,(i) < Begin\,(j) \\
After\,(j, i) \quad &\Leftrightarrow \quad Before\,(i, j) \\
During\,(i, j) \quad &\Leftrightarrow \quad Begin\,(j) < Begin\,(i) < End\,(i) < End\,(j) \\
Overlap\,(i, j) \quad &\Leftrightarrow \quad Begin\,(i) < Begin\,(j) < End\,(i) < End\,(j) \\
Starts\,(i, j) \quad &\Leftrightarrow \quad Begin\,(i) = Begin\,(j) \\
Finishes\,(i, j) \quad &\Leftrightarrow \quad End\,(i) = End\,(j) \\
Equals\,(i, j) \quad &\Leftrightarrow \quad Begin\,(i) = Begin\,(j) \wedge End\,(i) = End\,(j)
\end{aligned}
$$

Mental Objects

Knowledge *about* beliefs and deduction.

Useful for controlling inference.

Q: Is the prime minister sitting down right now?

Propositional attitudes:

$Knows(Lois, CanFly(Superman))$

Referential transparency - terms used don't matter:

$(Superman = Clark) \land Knows(Lois, CanFly(Superman)) \models Knows(Lois, CanFly(Clark))$

We need **referential opacity** - terms used do matter.

Modal logic

Modal operators:

$\boldsymbol{K}_A P$, means A knows P

$\boldsymbol{B}_A P$, means A has a belief P

Lois knows that Clark knows whether Superman's secret identity is Clark:

$\boldsymbol{K}_{Lois}[\boldsymbol{K}_{Clark} Identity(Superman, Clark) \lor \boldsymbol{K}_{Clark} \neg Identity(Superman, Clark)]$

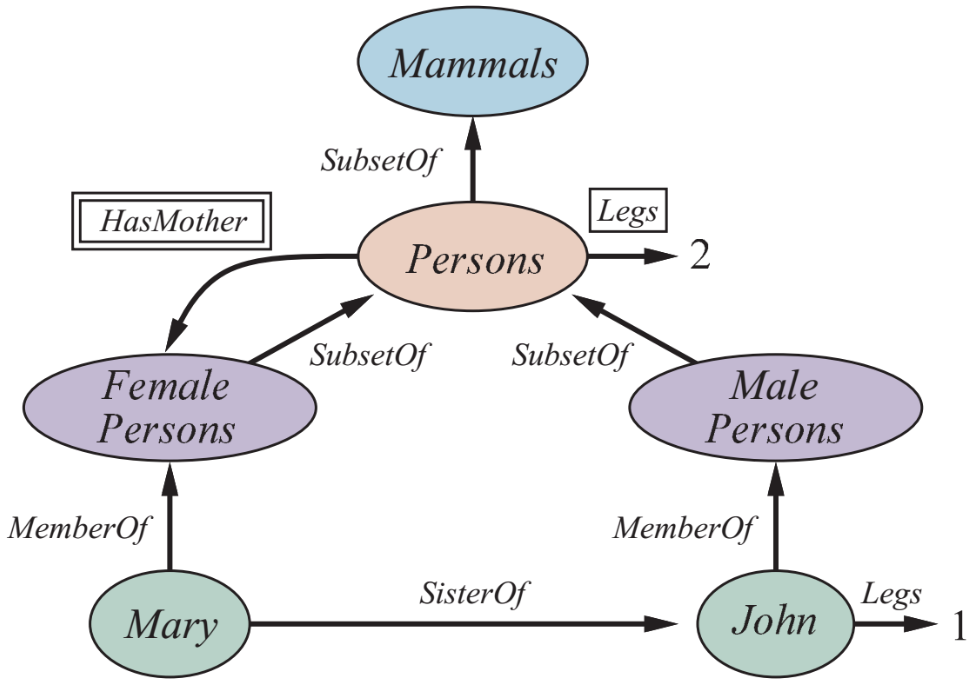
Some axioms:

1. $(\boldsymbol{K}_a P \land \boldsymbol{K}_a (P \Rightarrow Q)) \ \Rightarrow \boldsymbol{K}_a Q$
2. $\boldsymbol{K}_a P \Rightarrow P$
3. $\boldsymbol{K}_a P \Rightarrow \boldsymbol{K}_a (\boldsymbol{K}_a P)$

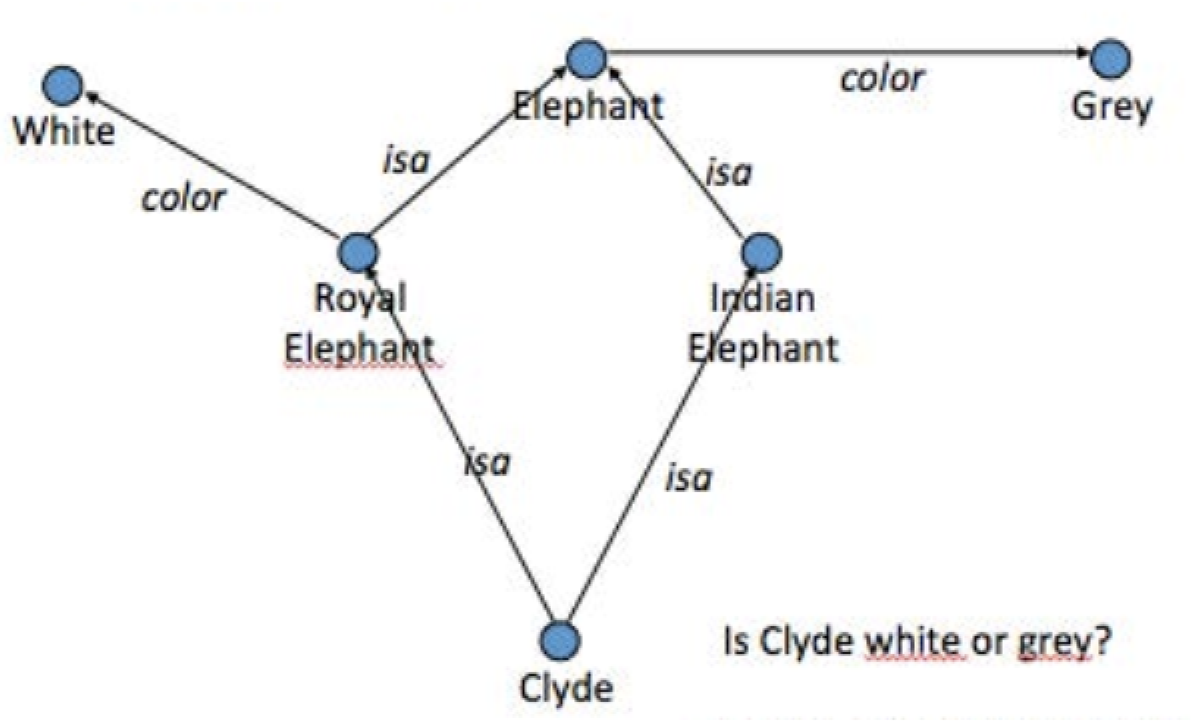
Issue: **Logical omniscience** - knowing all consequences.

Semantic networks

1. Semantic network is a type of logic.
2. Focus on connections between pieces of knowledge.
3. Efficient inference algorithm through inheritance.
4. Ability to represent **default values** for categories and allow **overrides**

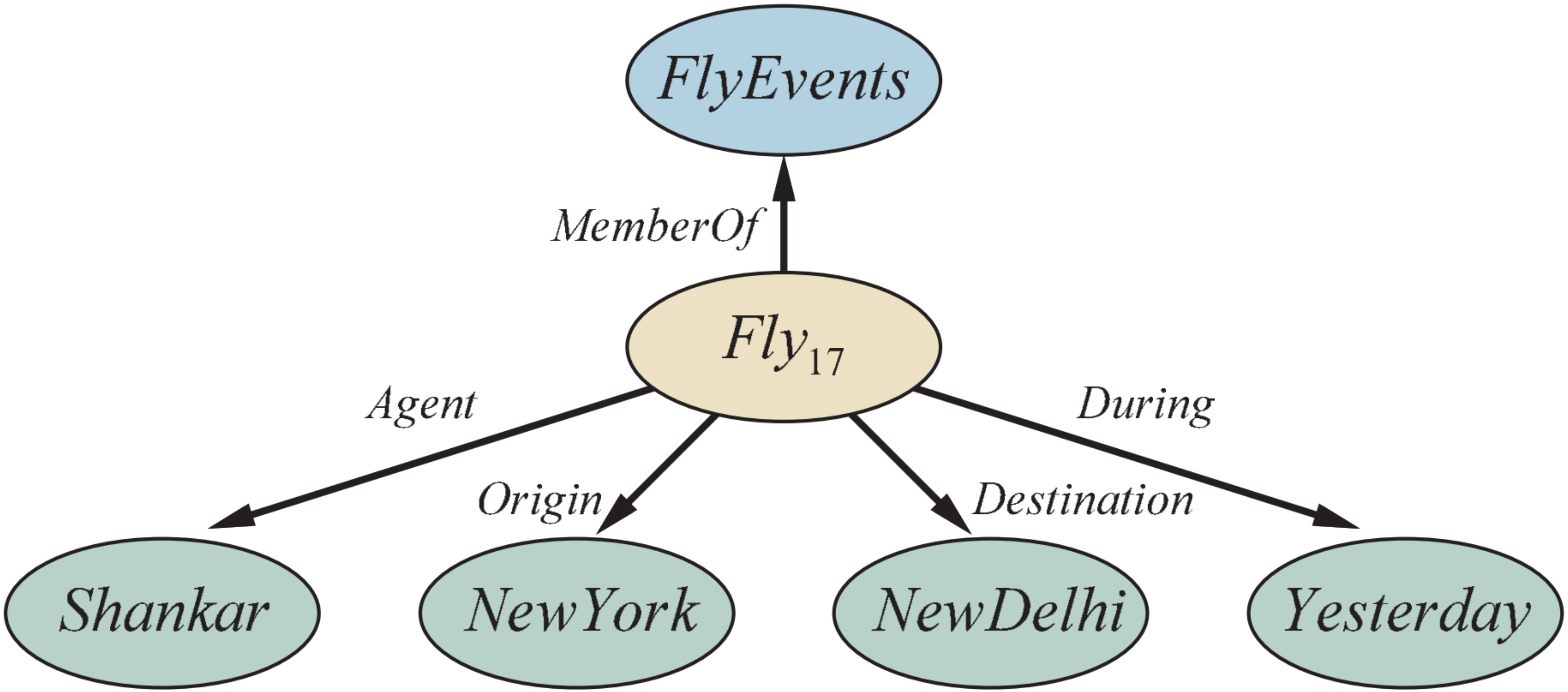


Semantic networks - Multiple inheritance



Semantic networks - N-ary assertions

$Fly(Shankar, NewYork, NewDelhi, Yesterday)$



Frames

> Semantic networks where nodes have structure.

- Contains slot with values
- Support inheritance and overrides
- Value can be another frame or procedure

employee
isa : person — necessary slot
personal-id-no: 800911-5841
gender : (get-gender)
age : (calculate-age) — demon slot (lisp procedure)
employed-since : Jan 1 2000
length-of-employment : (get-employ-length)
*employment-type : full-time — default slot

room
isa : section-of-building
has-part : floor
has-part : wall
has-part : floor
*has-part : window
has-part : door
*no-of-doors : 1
no-of-walls : 4

storage-room
isa : room
has-part : no-window
no-of-doors : 2

Description logics (DL)

Main aspects:

1. Make it easier to describe definitions and properties of categories
2. Add formal (logic-based) semantics to frames and semantic networks.
3. Tractability of inference.

Example:
Men with at least three sons who are all unemployed and married to doctors, and at most two daughters who are all professors in physics or math departments.

$$
\begin{aligned}
&And(Man, AtLeast(3, Son), AtMost(2, Daughter),\\
&All(Son, And(Unemployed, Married, All(Spouse, Doctor))),\\
&All(Daughter, And(Professor, Fills(Department, Physics, Math)))).
\end{aligned}
$$

Description logics - inference

Inference mechanisms:

1. **Subsumption** - check if one category subset of another
2. **Classification** - check if an object belong to a category
3. **Consistency** - check if membership cirteria are satisfieable

Problem solving steps:

1. Describe a problem.
2. Check if it subsumed by solution categories.

Issues: Lack of negation and disjunction.

Reasoning with default information

FOL is **monotonic**:
If $KB \models \alpha$ then $KB \wedge \beta \models \alpha$

Commonsense reasoning is **nonmonotonic**, e.g.

1. Inheritance in semantic networks with default values
2. Closed-world assumption: if α not in KB then $KB \models \neg\alpha$, but $KB \wedge \alpha \models \alpha$

Circumscription

> More powerful and precise version of the closed-world assumption.

$$Bird(x) \land \neg Abnormal_1(x) \Rightarrow Flies(x)$$

$Abnormal_1$ is to be **circumscribed**

Assume $\neg Abnormal_1(x)$ unless $Abnormal_1(x)$

Example:

$Tweety$ flies until we asser $Abnormal_1(Tweety)$.

Default logic

Use **default rules** for nonmonotonic conclusions.

Example:

$Bird(x) : Flies(x)/Flies(x)$

Meaning: if $Bird(x)$ is true and $Flies(x)$ is consistent with KB then $Flies(x)$.

Default rule components: prerequisite (P), justification (J), conclusion (C)

$P : J_1 \ldots.., J_n/C$

If P and $J_1 \ldots.., J_n$ cannot be proven false, then the conclusion can be drawn.

Truth maintainance systems (TMS)

1. KB contains P
2. $Tell(KB, \neg P)$
3. To avoid contradiction we must $Retract(KB, P)$

What about Q inferred from P, e.g. $P \Rightarrow Q$?
Q might also have other justifications, e.g. $R \Rightarrow Q$

TMS revises beliefs to avoid contradictions.