Knowledge representation is representation of information with support for inference.

Expert (intelligent) behavior requires knowledge + inference. Are there differences among "data," "information," and "knowledge?"

Knowledge
Information
Data

Knowledge Representation

The First Semantic Network Diagram: Tree of Porphyry

3rd century AD, by the Greek philosopher Porphyry, illustrating Aristotle's categories. (Taken from an article by John Sowa – this version based on a drawing by Peter of Spain in 1329.)

Example of Declarative Representation: An "Isa" Hierarchy

Inference with Isa Hierarchies

“A great-blue-heron is an aquatic-bird.”
isa(great-blue-heron, aquatic-bird).

“An aquatic-bird is a bird.”
isa(aquatic-bird, bird).

“Is a great-blue-heron a bird?”
isa(great-blue-heron, bird)?

“Isa” represents a relation which has certain properties that support types of inference.
Binary Relations

A binary relation $R$ over a domain $D$ is a set of ordered pairs $(x, y)$ where $x$ and $y$ are in $D$.

For example, we could have,

$D = \{a, b, c, d\}$

$R = \{(a, b), (c, a), (d, a)\}$

If $(x, y)$ is in $R$, then we write $R(x, y)$ or $x R y$.

Partial Orders

If for each $x$ in $D$ we have $x R x$, then $R$ is reflexive.

If for each $x$ in $D$ and $y$ in $D$ we have $x R y$ and $y R x$ imply $x = y$, then $R$ is antisymmetric.

If for each $x$ in $D$, $y$ in $D$, and $z$ in $D$ we have $x R y$ and $y R z$ imply $x R z$, then $R$ is transitive.

If $R$ has all 3 properties, $R$ is a partial order.

Example of a Partial Order

Let $D =$ the real numbers

Let $R_0 = \{(x, y) \mid x \leq y\}$

Actually, $R_0$ is $\leq$.

$R_0$ is reflexive, because for all $x$, $x \leq x$.

$R_0$ is antisymmetric, because for all $x, y$: if $(x \leq y)$ and $(y \leq x)$ then $x = y$.

$R_0$ is transitive, because for all $x, y, z$: if $(x \leq y)$ and $(y \leq z)$ then $(x \leq z)$.

Examples of the Partial Order Properties

ISA is reflexive:

A bear is a bear.

$\rightarrow$ ISA(bear, bear)

ISA is antisymmetric:

A bear is an ursid, and an ursid is a bear.

Therefore, bear and ursid represent the same things.

ISA(bear, ursid) $\wedge$ ISA(ursid, bear) $\rightarrow$ bear = ursid

ISA is transitive:

A grizzly is a bear, and a bear is a mammal.

Therefore, a grizzly is a mammal.

ISA(grizzly, bear) $\wedge$ ISA(bear, mammal) $\rightarrow$ ISA(grizzly, mammal)

Redundant Facts

Any fact implied by others via the reflexive, antisymmetric, or transitive properties of a partial order can be considered redundant.

Suppose $a \leq b$

$b \leq c$

$c \leq b$

Then

$a \leq c$ is redundant.

$a \leq a$ is redundant.

$b = c$ is redundant.

$b$ and $c$ could be represented by one name.

Inheritance of Properties via Isa

A fox is a mammal.

A mammal bears live young

Therefore a fox bears live young.
Non-inheritance of Certain Properties

A neutron is an atomic particle.

There are three types of atomic particles.

Therefore there are three types of neutrons (??)

Hasse Diagrams

A Hasse Diagram is a drawing of a graph that represents the transitive reduction of a partial order.

Transitive reduction:
Let $R_0$ be the original relation and $R_1$ be its transitive reduction.

That means all shortcuts have been removed; i.e., if $x R_0 y, y R_0 z$, and $x R_0 z$, then $x R_1 y$ and $y R_1 z$, but NOT $x R_1 z$.

In addition, all reflexive pairs are removed: $x R_0 x$, but NOT $x R_1 x$.

ISA Hierarchy with Redundancy

The full partial order is explicit.

ISA Hierarchy as a Hasse Diagram

Only the transitive reduction is explicit.

Hasse Diagram Example 2

Example for the set \{1,2,3,4,5,6,10,12,15,20,30,60\} and the relation divides.

The “HAS” Relation

“A car has a wheel.”
$x \text{ HAS } y = \text{ An } x \text{ has } y \text{ as a part.}$

“A person has a head.”
“A head has a face.”
“Therefore a person has a face.”

“An organism has some tissue.”
“Some tissue has a cell.”
“Therefore an organism has a cell.”
What are the properties of HAS?

Is it transitive?  Yes
Is it reflexive?  No
Is it symmetric?  No
Is it antisymmetric?  Yes, vacuously
Is it a partial order?  No
Is it an equivalence relation?  No

Interoperation of HAS and ISA

An x is a y.
A y has a z.
Therefore an x has a z.

An x has a y.
A y is a z.
Therefore an x has a z.

Chains of HAS and ISA links

A chain is a sequence of the form
\[ x_1 \ Rel_1 \ x_2, x_2 \ Rel_2 \ x_3, \ldots, x_k \ Rel_k \ x_{k+1} \]
\[ x_1 \ has \ an \ x_{k+1} \ provided... \]

???

Chains of HAS and ISA links

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x_1 has an x_{k+1} provided...

???

Preparation for Inference: Python represent. of ISA facts

```python
ISA = {}
INCLUDES = {}
ARTICLES = {}

def store_isa_fact(category1, category2):
    # Stores one fact of the form A BIRD IS AN ANIMAL
    # That is, a member of CATEGORY1 is a member of CATEGORY2
    try:
        c1list = ISA[category1]
        c1list.append(category2)
    except KeyError:
        ISA[category1] = [category2]
    try:
        c2list = INCLUDES[category2]
        c2list.append(category1)
    except KeyError:
        INCLUDES[category2] = [category1]
```
Linneus.py

- Demonstrates representation of ISA facts.
- Permits inference via transitivity.
- Illustrates a variety of methods for answering queries.
- Extensible (as in Assignment 2).

Other Kinds of Semantic Networks

According to John Sowa, there are 6 general kinds of semantic networks:

1. **Definitional** – including ISA hierarchies.
2. **Assertional** – to represent situations, claims that are not necessarily true, etc. (e.g., logic).
3. **Implicational** – links represent causality or logical implication.
4. **Executable** – processing mechanisms are associated with them; e.g., Petri nets.
5. **Learning** – e.g., neural nets.
6. **Hybrid** – combinations of the above