Announcements

HW 5 correction

Writing 3 up for real now
An **ontology** is a model of data/information and their interactions

Biology has a well known ontology:
Dewey decimal

Most libraries use the Dewey decimal system:

Textbook number: 006.3 20
Chamber of Secrets: 823.914
In this system, each digit represents a different classification:

500 = Natural science
590 = Zoological sciences
595 = Other invertebrates
595.7 = Insects
595.78 = Lepidoptera
595.789 = Butterflies
Ontology

There have been attempts to create an ontology of the real world inside computers.

A well known (and still continuing) example is the Cyc project (software proprietary):
www.cyc.com

For example, you should be able to ask:
(#$isa #$UofM #$University)
... and it should say “true”
Ontology

Having a general purpose knowledge base is very time consuming for two main reasons:
1. Inputting all information possible
2. Defining relationships between information correctly and succinctly

Perhaps not too surprising, all-encompassing ontologies have not been too successful, though more limited ones work
Ontology

Thankfully, often you do not need to get too specific and still have a useful ontology.

Quite often (but not always), you are interested in a category of something, not a specific one.
To describe an ontology, we will use first order logic (and add a few new general relations).

The major difference is that we will allow “objects” to be sets in addition to single items.

For example, we might make a set Person which both you and I are part of (this is changing it from a relation “Person(x)” to an object “CannotFly(People)”).

The main reason for creating a grouping object is to add a Member() and Subset() relations

Member(x, y): “x” (an item) is in “y” (a set)
Subset(x, y): “x” (a set) where every item in “x” is also in “y” (another set)

We will simplify notation by borrowing math's:

\[ x \in y \quad \text{same meaning} \quad \text{Member}(x, y) \]
\[ x \subseteq y \quad \text{same meaning} \quad \text{Subset}(x, y) \]
Ontology

This is useful as we can declare general properties and inherit/reuse relations

Suppose we wanted to put everyone in this class into the an ontology

We would have to say:
Person(Alice)^Class(Alice)^Name(Alice)...
Person(Bob) ^ Class(Bob) ^ Name(Bob)...
Person(Catherine) ^ Class(Catherine) ^ ... ...
Ontology

We can define transitivity of both Member() and Subset(), namely:

\[ x \in y \land y \subset z \Rightarrow x \in z \]
\[ x \subset y \land y \subset z \Rightarrow x \subset z \]

This allows properties to “transfer” from more general parts of the ontology to specifics

(This is very similar to inheritance in object oriented programming)
A more concise way of saying this is then:

\[ x \in People \Rightarrow Name(x) \land Person(x) \]

\[ InClass \subseteq People \]

\[ Class(x) \Rightarrow x \in InClass \]

Then just:

\[ Class(Alice) \land Class(Bob) \land Class(Catherine) \ldots \]

This simplifies the expression and makes it easier to query the ontology.
Ontology

We will borrow more from set theory:
Disjoint(x) - nothing in x shares members (i.e. no overlap between parts of x)

ExhaustiveDecomposition(x,y) - x contains the list of all things in y (i.e. if something is in y, it must also be something in x)

Partition(x,y) - Combination of above two (i.e. if something is in y, it is also in a single x)
Disjunction

$\text{Disjoint}(x) \iff (\forall c_1, c_2 \; c_1 \in s \land c_2 \in s \land c_1 \neq c_2 \Rightarrow \text{Intersection}(c_1, c_2) = )$

$x = \{A, B\}$
Disjunction

Disjoint(\{Phones, Dogs\}) as there are no objects which are dogs and you can call someone upon (yet...)
Exhaustive decomposition

$ExhaustiveDecomposition(x, y) \iff \forall i \in y \iff \exists c_2 \ c_2 \in x \land i \in c_2$

$y = \text{any point in bounding rectangle}$

$x = \{\text{red triangle, blue ellipse, green square, black trapezoid}\}$
Exhaustive decomposition

ExhaustiveDecomposition({Ink, Graphite, Petroleum, OtherChemical}, WritingUtensil)

While every writing utensil is one of these types, there can be overlap

For example:

\[ x = \text{that} \]
\[ x \in \text{WritingUtensil} \]
\[ x \in \text{Ink} \land x \in \text{OtherChemical} \]
Partition

\[\text{Partition}(x, y) \iff \text{Disjoint}(x) \land \text{Exhaustive Decomposition}(x, y)\]

Every point in \(S\) is either in \(\{A_1, A_2, A_3, A_4\}\) but never in more than one
Partition

Partition(\{A, B, C, D, F\}, Grade)

Every grade is either an A, B, C, D or F and you can only get one grade (you cannot have both a B and F at the same time)
Book's ontology

Diagram:
- **AbstractObjects**
  - Sets
  - Numbers
  - RepresentationalObjects
    - Categories
    - Sentences
    - Measurements
      - Times
      - Weights
- **GeneralizedEvents**
  - Intewul
  - Places
  - PhysicalObjects
  - Processes
  - Things
    - Animals
    - Agents
    - Solid
    - Liquid
    - Gas
  - Stuff
  - Humans
We will look at 3 things: 1, 2 and 3
Measurement

Measurements add another special relation, a relative compare

This makes sense as Mass(50) > Mass(20) (i.e. Op>(Mass(50), Mass(20)) )

This is also important for qualitative measures: Tasty(Pizza) > Tasty(Carrot)
Things vs. Stuff

Thing (count nouns) = a single countable item

1 llama 3 llamas

Stuff (mass nouns) = objects that are only measurable as there is no “whole”

little smoke lots of smoke
Things vs. Stuff

The key difference between things and stuff is whether or not it is divisible and keeps the same properties.

Divide = Different

Divide = Same
Things vs. Stuff

Intrinsic property = Unchanging properties (i.e. core aspects)

Mostly properties of “stuff”... For example: color, smell, chemical makeup, etc.

Extrinsic property = Properties of the collection

Mostly properties of “things”... For example: mass, shape, length, etc.
Events/Time

Time allows us to have a object that changes value over time (but there is a single object)

4511Teacher(James) would simply say that I am a teacher for this class

If you also say “4511Teacher(Amy)” then it would seem to imply that there are two instructors for this class (not a first!)
To overcome this, we add a True relation, which also takes a time whether or not this is true at that time:

True(4511Teacher(James), Spring2018)  
... and also ... 
True(4511Teacher(Amy), Fall2016)

This clears up that Amy was teaching a few semesters ago, and me now
Events/Time

Discrete events have a fixed start and end time, while a process is a fluid transition.

This is similar to the difference between things and stuff:

Discrete events = non-divisible = things  
(for example: final exam time)
Process = divisible = stuff  
(for example: global warming)
Events/Time

Additional time relations... Zzz...

- $x \preceq y$  \hspace{1cm} $x$ precedes $y$
- $y \preceq x$  \hspace{1cm} $y$ is preceded by $x$
- $x \meets y$  \hspace{1cm} $x$ meets $y$
- $y \meets x$  \hspace{1cm} $y$ is met by $x$
- $x \overlaps y$  \hspace{1cm} $x$ overlaps $y$
- $y \overlaps x$  \hspace{1cm} $y$ is overlapped by $x$
- $x \starts y$  \hspace{1cm} $x$ starts $y$
- $y \starts x$  \hspace{1cm} $y$ is started by $x$
- $x \during y$  \hspace{1cm} $x$ during $y$
- $y \contains x$  \hspace{1cm} $y$ contains $x$
- $x \finishes y$  \hspace{1cm} $x$ finishes $y$
- $y \finishes x$  \hspace{1cm} $y$ is finished by $x$
- $x \equals y$  \hspace{1cm} $x$ equals $y$
Ontology: knowledge relations

So far we focused on defining relationships between different pieces of information.

For example, if we know “frogs hop” and “frogs are amphibians”, we can conclude “some amphibians hop”.

Deducing new facts are fundamental to having an expressive knowledge base, as it would be too hard to encode every single fact.
Mental models

However, not all facts are transferable

Consider this information: “I know someone in Italy” and “That friend knows the weather”, but I cannot conclude that “I know the weather in Italy” unless my friend tells me it

Here this is less a physical world fact and more a fact inside my head, which is essentially unknown to anyone else
Mental models

A common way to frame ways of thinking are “Belief, Desire and Intention” (BDI)

https://www.youtube.com/watch?v=96_RS1x2jL0

Each agent has their own local knowledge and goals, which can be communicated
Mental models

Full mental models are an active part of research, so we will focus on just “knows”

\( K_a(P) \) will denote agent “a” knows fact “P”

For example, \( K_{James}(\text{next slide}) \) as I am aware what the next slide is

We will denote this as \( K_J(N) \) for short
Mental models

While I know about myself, I do not know if you know what the next slide is

However, I do know that you either “know the next slide” or “don't know…”

Thus, $K_J(K_{You}(N) \text{ or } K_{You}(\neg N))$

A world is a possible state of the world that I can be in (i.e. possible cases)
Mental models

A world/case is accessible from another world, if the knowledge of a person is consistent

In our example with “N” = you know the next slide, we can make a graph:

\[ w_0 : N \quad \rightarrow \quad w_1 : \neg N \]

\[ \quad \leftrightarrow \quad = \text{my accessibility} \]

\[ \leftrightarrow \quad = \text{your accessibility} \]
Mental models

I have a link between $w_0$ and $w_1$, as in both worlds $[K_{\text{You}}(N) \text{ or } K_{\text{You}}(\neg N)]$ is true.

You however know whether or not you know the next slide (e.g. $K_{\text{You}}(N)$), so you cannot go between these two worlds.

Both possible worlds exist, as in the model I am unsure (despite you knowing).
Let's model another fact: next Tuesday’s topic (denoted "T"), which only I know... graph is:

\[ w_0: N, T \quad \rightarrow \quad w_1: \neg N, T \]
\[ w_2: N, \neg T \quad \rightarrow \quad w_3: \neg N, \neg T \]

\[ \quad \rightarrow \quad = \text{my accessibility (no self arrows)} \]
\[ \quad \rightarrow \quad = \text{your accessibility (no self arrows)} \]
Mental models

You try it! What if I did not know Tuesday’s topic either? How would this change?

\[ w_0 : N, T \]
\[ w_1 : \neg N, T \]
\[ w_2 : N, \neg T \]
\[ w_3 : \neg N, \neg T \]

\[ \leftarrow \rightarrow \] = my accessibility (no self arrows)
\[ \leftarrow \rightarrow \] = your accessibility (no self arrows)
Mental models

You try it! What if I did not know Tuesday’s topic either? How would this change?

\[ w_0 : N, T \quad \leftrightarrow \quad w_1 : \neg N, T \]
\[ w_2 : N, \neg T \quad \leftrightarrow \quad w_3 : \neg N, \neg T \]

\[ \text{↔} = \text{my accessibility (no self arrows)} \]
\[ \text{↔} = \text{your accessibility (no self arrows)} \]
We can actually combine them:

- \( w_0 : N, T \) to \( w_1 : \neg N, T \)
- \( w_4 : N, T \) to \( w_5 : \neg N, T \)
- \( w_6 : N, \neg T \) to \( w_7 : \neg N, \neg T \)
- \( w_2 : N, \neg T \) to \( w_3 : \neg N, \neg T \)

\( w_0 \) to \( w_3 \) = I do know \( T \), \( w_4 \) to \( w_7 \) = I don't
Mental models: logic

Logic rules apply to this “knows” as well.

For example, if Bird(x) => Fly(x)
Then, K_j(Bird(tweety)) => K_j(Fly(tweety))

This can extend to mental implication as well (for facts that only one entity knows):
(K_j(P) ^ K_j(P => Q) => K_j(Q)
Mental models: logic

However, you have to be careful with $K_a$, as the order matters with previous logic ops.

For example:

$\exists x \ K_a(Friend(x)) = \text{in every possible world, one person is always your friend}$

$K_a(\exists x \ Friend(x)) = \text{you have a friend in every world, but could be different people}$
Mental models: logic

You must also put $K_A$ before any knowledge piece that is specific to a person

$$K_A(P \lor \neg P) \equiv K_A(\text{True}), \text{ which is a worthless statement ("A knows true things are true")}$$

$$[K_A(P) \lor K_A(\neg P)] \text{ is a useful statement, which indicates that "A knows the state of P"}$$
Mental models: inference

With the additional rules for $K_a$, you can use ordinary first-order logic to resolve statements.

However, this might not be enough... Consider this picture:

It is just some trees, right? ... Right?!