



Artificial Intelligence

3rd year, 1st semester

Knowledge representation and inference systems

“We are drowning in information but starved for knowledge.”—
John Naisbitt



FACULTY OF
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How did you learn that a cat has whiskers?

The screenshot shows the header of the LiveScience website with categories like News, Space & Physics, Health, Animals, History, Forums, and Tech. Below the header, a sub-header for 'Life's Little Mysteries' is visible. The main article title is 'Why Do Cats Have Whiskers?' by Kristen Fisher - Staff Writer - March 15, 2014. It features a large image of a fluffy cat's face. To the right of the article is a sign-up form for an email newsletter with fields for email address, checkboxes for contact info and newsletters from other brands, and a 'SIGN ME UP' button.



Does it matter?

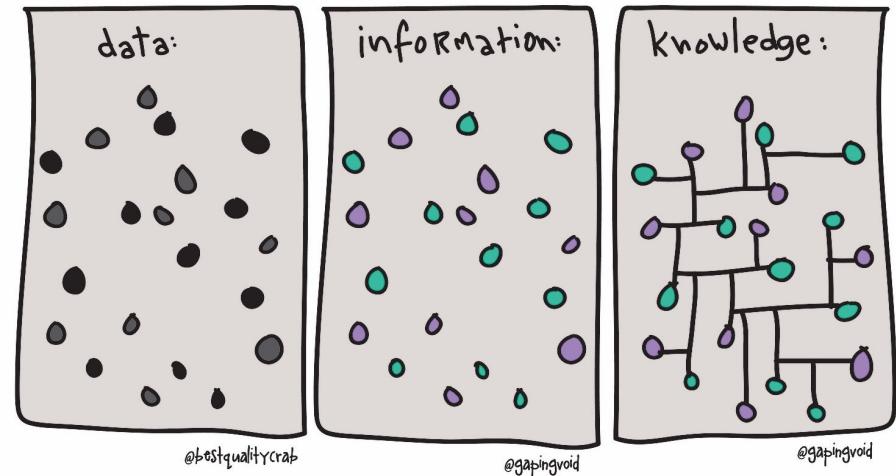


What is knowledge?

Intelligence applied to information produces knowledge.

Knowledge supplements intelligence.

Intelligence is asking the right question, knowledge is having the right answer.





Is knowledge useful to a computer?

Knowledge can supplement a slow or insufficient intelligence.
Example: chatbot templates and the Turing test.

Knowledge is a product, not a process (like intelligence), so it can be provided ready-made to the computer.

Knowledge is built on facts, heuristics and intuition and **can change**.

Let's look at unambiguous and easily parseable representations.



Linnaeus, C. (1753). *Species Plantarum*. Stockholm:
Laurentii Salvii.

REGNUM VEGETABILE.		837
<i>CLAVIS SYSTEMATIS SEXUALIS.</i>		
NUPTIÆ PLANTARUM.		
Actus generationis incolarum Regni vegetabilis.		
<i>Florentia.</i>		
<i>PUBLICÆ.</i>		
Nuptie, omnibus manifeste, aperte celebrantur.		
<i>Flori uniusque visibiles.</i>		
<i>MONOCLINIA.</i>		
Mariti & uxores uno eodemque thalamo gaudent.		
Flori omnes hermaphroditi sunt, & flaminæ cum pistillis in eadem flore.		
<i>DIFFINITAS.</i>		
Mariti inter se non cognati.		
Stamina nulla sua parte connata inter se sunt.		
<i>INDIFFERENTISMUS.</i>		
Mariti nullam subordinationem inter se invicem servant.		
Stamina nullam determinatam proportionem longitudinis inter se invicem habent.		
1. MONANDRIA.	7. HEPTANDRIA.	
2. DIANDRIA.	8. OCTANDRIA.	
3. TRIANDRIA.	9. ENNEANDRIA.	
4. TETRANDRIA.	10. DECANDRIA.	
5. PENTANDRIA.	11. DODECANDRIA.	
6. HEXANDRIA.	12. ICOSANDRIA.	
	13. POLYANDRIA.	
<i>SUBORDINATIO.</i>		
Mariti certi reliquis preferuntur.		
Stamina das semper reliquis breviora sunt.		
14. DIDYNAMIA.	15. TETRADYNAMIA.	
<i>APERTITAS.</i>		
Mariti propinquū & cognati sunt.		
Stamina coherent inter se invicem aliqua sua parte vel cum pistillis.		
16. MONADELPHIA.	19. SYNGENESIA.	
17. DIADELPHIA.	20. GYNANDRIA.	
18. POLYADELPHIA.		
<i>DECLINIA (a δις. τε & ράδιον thalamas f. duplex thalamus.)</i>		
Mariti & Feminae distinctis thalamis gaudent.		
Flori masculi & feminæ in eadem specie.		
21. MONOECIA.	23. POLYGAMIA.	
22. DIOECIA.		
<i>CLANDESTINA.</i>		
Nuptie etiam inlitteratur.		
Flori oculis nubris undis vix conficiuntur.		
24. CRYPTOGAMIA.		C.L.D.



Taxonomy

Greek: taxis (arrangement) nomia (method)

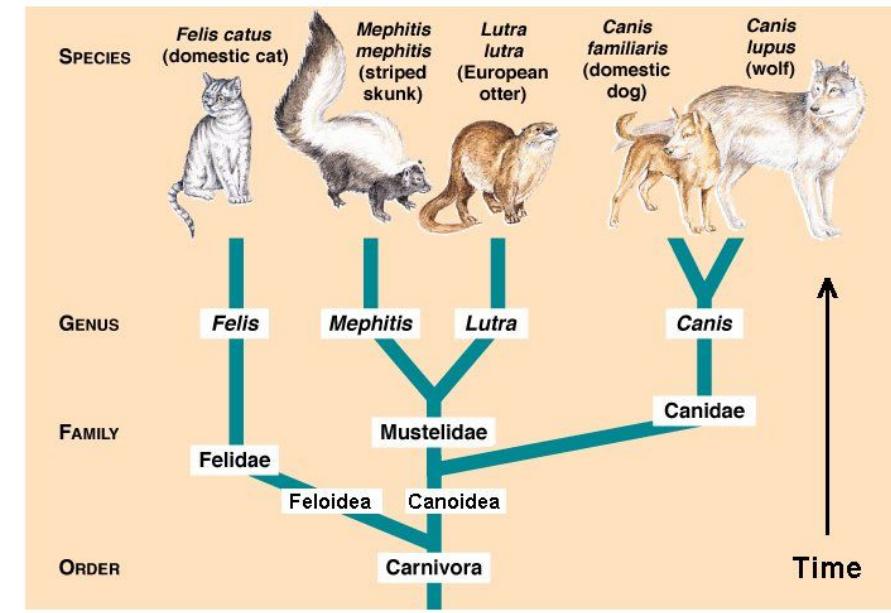
A taxonomy is language independent (as is all knowledge).

Nodes are concepts.

No ambiguity due to careful lexicalisations and domain focus.

Relations are semantic.

Only one type of relation: “is-a”





X IS-A Y: X is a specific type of Y, with additional properties

- Symmetry: if a bear IS-A mammal, a mammal IS-A bear?
- Reflexivity: bear IS-A bear?
- Transitivity: if a black bear IS-A bear and a bear IS-A mammal, a black bear IS-A mammal?
- Connectivity: cat IS-A bear or bear IS-A cat?

“is-a” is asymmetric, irreflexive, transitive and not connected, thus is a strict order relation over the set of concepts (no cycles in a taxonomy).



Are taxonomies enough?

Can you represent all your computer science knowledge in a taxonomy?

Is IS-A enough?

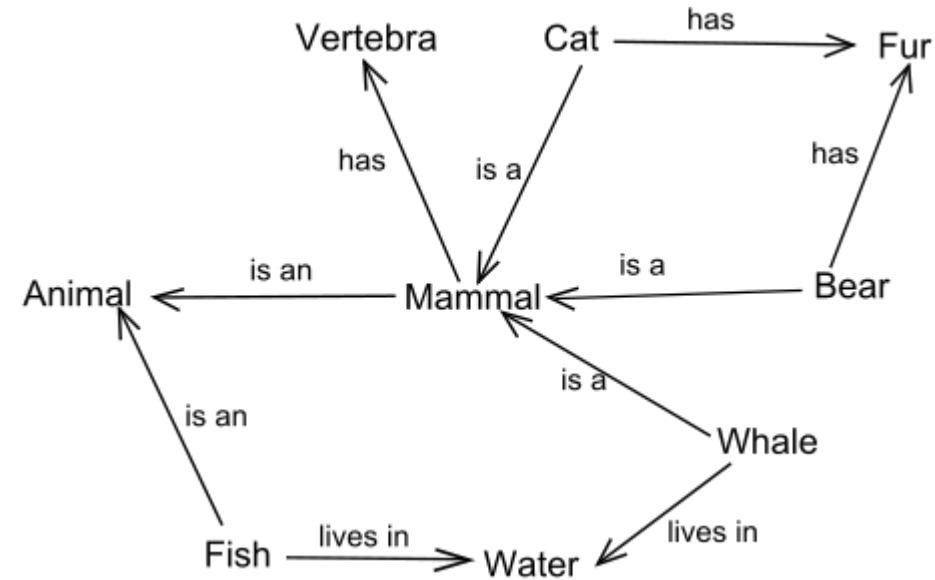
How adaptable is a taxonomy to new knowledge?



Semantic networks

Directed graphs with concepts as nodes and semantic relations labeling edges.

Can also be represented as a list of predicates: has (Cat, Fur), lives in (Fish, Water)





Semantic frames

John drives a car.

Identified by an action (event) OR
a type reference: *Fluffy the cat*

“Cat” frame	
Name	Fluffy
Age	?
Weight	?

“to drive” frame	
Agent	John
Object	a car
Starting point	?
Ending point	?
Reason	?
Beneficiary	?
Modal	?



Events and referential networks

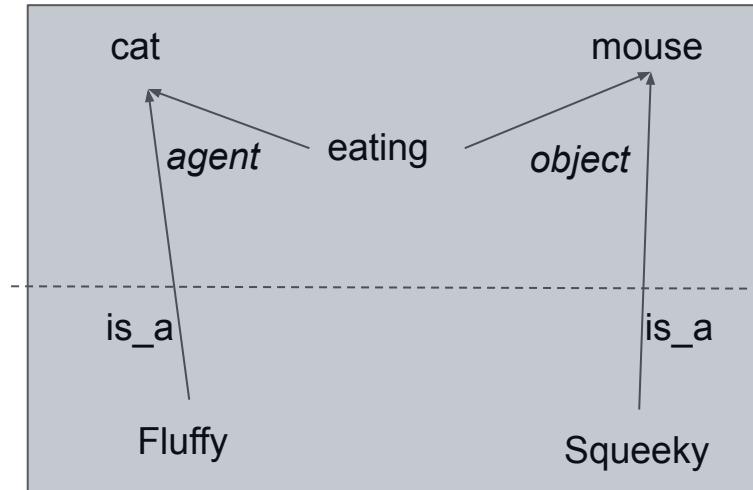
Referential network: part of a semantic network in which nodes identify actual objects, not concepts.

Event: defined as a set of relations with referential network connections. Frames can be references and marked in a semantic network.

Eating:

```
agent(is_a(Fluffy, cat)) ∧  
object(is_a(Squeeky, mouse))
```

Conceptual network



Referential network



Reasoning on semantic networks(I)

Relations are inherited.

$$\begin{aligned} & \text{IS-A(cat, mammal) AND IS-A(mammal, animal)} \\ \Rightarrow & \text{IS-A(cat, animal)} \end{aligned}$$

Answering queries.

Eating: agent (Fluffy) \wedge object (?x)

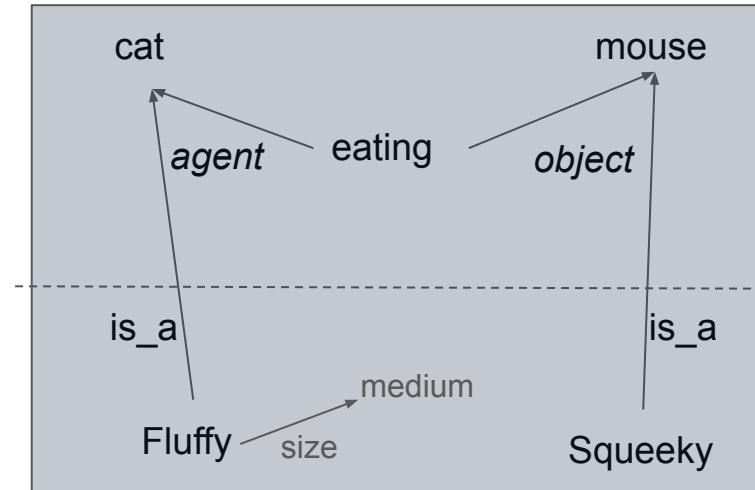


Reasoning on semantic networks(II)

Daemons: procedures used to automatically maintain and enhance a semantic network.

```
If (IS-A(Fluffy,  
animal)) ∧  
(length(Fluffy, ?x)) ∧ ?x  
∈ [50,100] =>  
size(Fluffy, medium)
```

Conceptual network



Referential network



WordNet

Nodes? Synsets = lists of synonymous senses of different words (over 120.000)

S: (n) **student**, pupil, educatee (a learner who is enrolled in an educational institution)

Relations? 6 types of semantic relations:

- Antonymy: opposite meaning of good - bad
- Hyponymy: IS-A (is a specific kind of...) student - person
- Meronymy: part of (is structurally included in...) head - student
- Troponymy: identifies a manner of... whisper - speak
- Entailment: identifies requirements divorce - marriage
- Derivation: related to, produced by product - factory

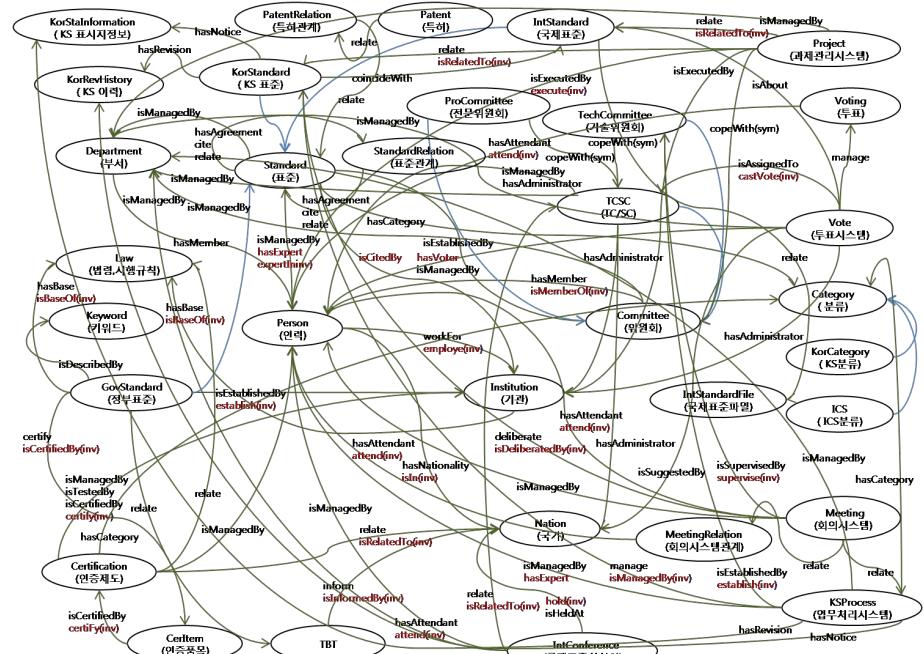


Ontology

Definitions (courtesy of Merriam-Webster):

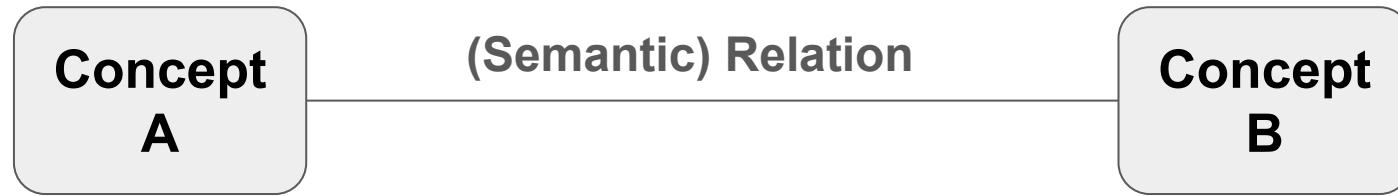
- 1: a branch of metaphysics concerned with the nature and relations of being
 - 2: a particular theory about the nature of being or the kinds of things that have existence

Unambiguous representation of knowledge, more expressive than a taxonomy.





Semantic triplet



Relation(Concept A, Concept B)

We can represent any knowledge using semantic triplets.

Try with any knowledge you possess.

We can build complex structures (ontologies) using these triplets.

The complexity is given by the size, local complexity is reduced. You rarely need to explore the entire ontology.

We can extract complex knowledge from triplets/ontologies.

What is the Relation between A and B? With whom is A/B in Relation? Between who does Relation exists?



Ontology: attempt of a formal definition

A hypergraph $O(C, R)$ and a set I where:

- C is a set of concepts c , where c is defined as a tuple (i, d, l, r, p, r) , where:
 - i is an unique identifier;
 - d is a list of definitions;
 - l is a list of lexicalisations;
 - r is a list of references to other related sources;
 - p is a list of property identifiers (relations with one member);
 - r is a list of relation identifiers with c as a member.



Ontology: attempt of a formal definition

- R is a set of semantic relations r , each defined as a triple (i, m, b) , where:
 - i is an unique identifier;
 - m is the number of members of that relation;
 - b indicates whether the relation is bidirectional.
- I is a set of inferences (rules) over the ontology performing changes to it.

Instance: concept to which no other concept can be linked by IS-A.



Ontology viewers and editors

Most common format: [RDF](#)

- [PuffinSemantics](#)
- [GraphDB](#)
- [WebVOWL](#)

- [Protégé](#)
- [Fluent Editor](#)

Knowledge Graphs are [instanced ontologies](#) and are [very common](#).



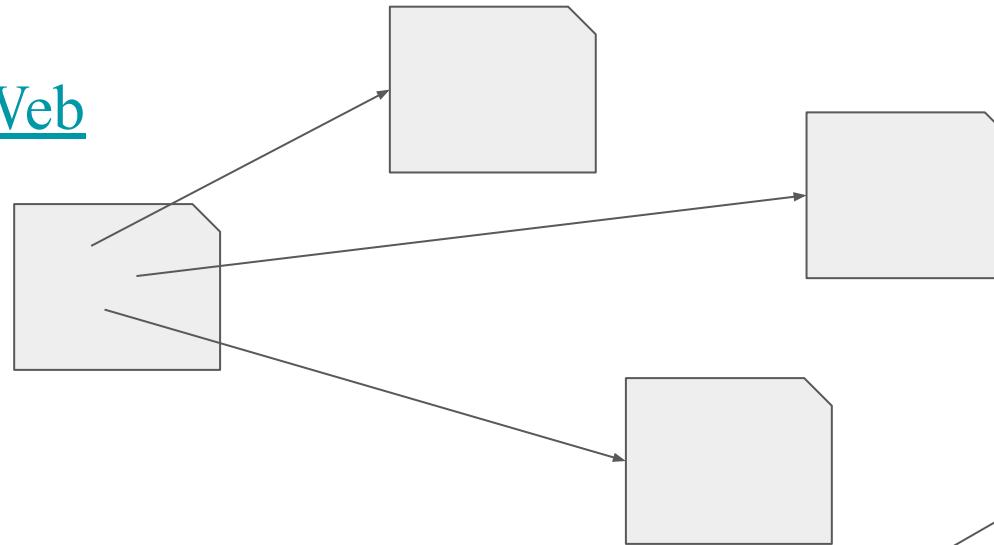
Ontologies: unlimited expressiveness

- Anything can be included as a concept/instance
- Concepts/instances can have any properties
- Any semantic relation can be included
- Consistent relations/properties are not mandatory (but highly recommended)
- Built for continuous maintenance and development - use inferences!

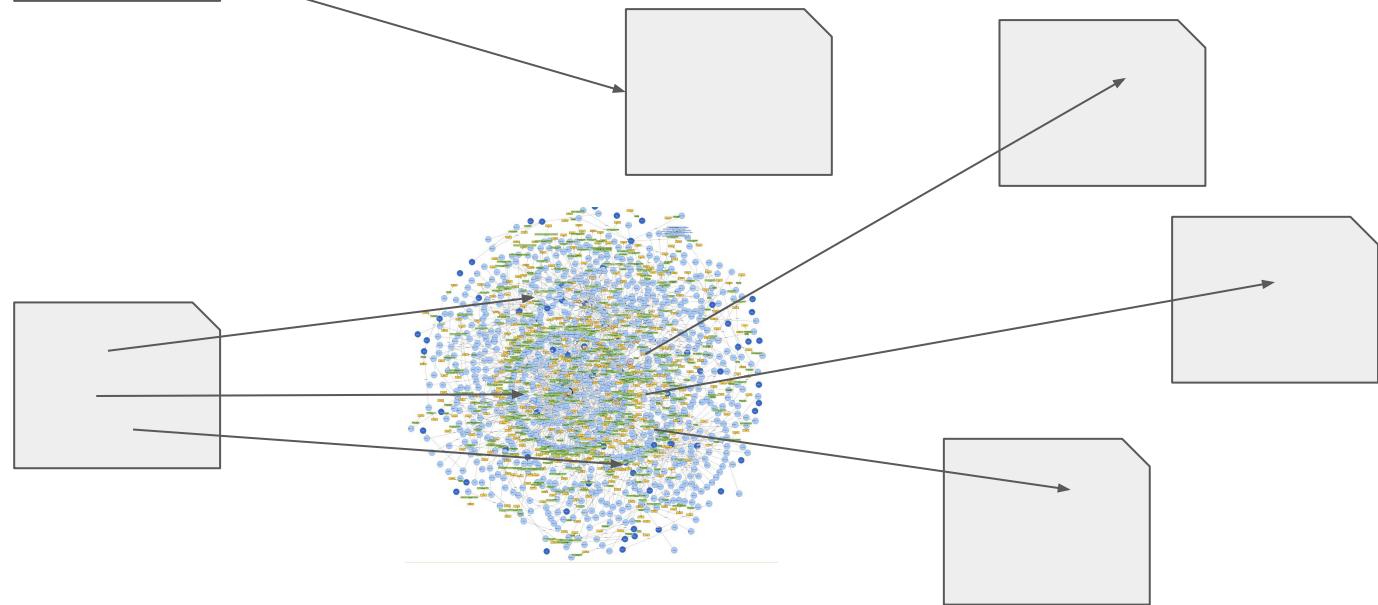


The Semantic Web

Classic web



Semantic web





Semantic web: [current state](#)

Describe linked data?

[JSON-LD](#) [Open Graph](#)

Detailed domain ontologies?

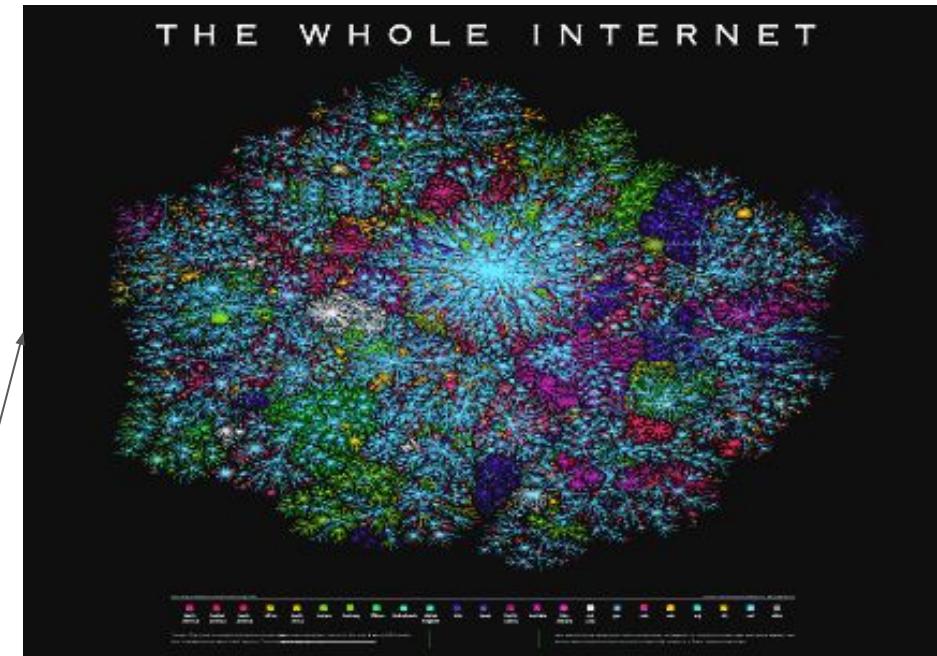
[Dbpedia.org](#) [Schema.org](#)

Semantic web browser?

[LodView](#) [Magpie](#)

OK, so what's the problem? THIS

but also this



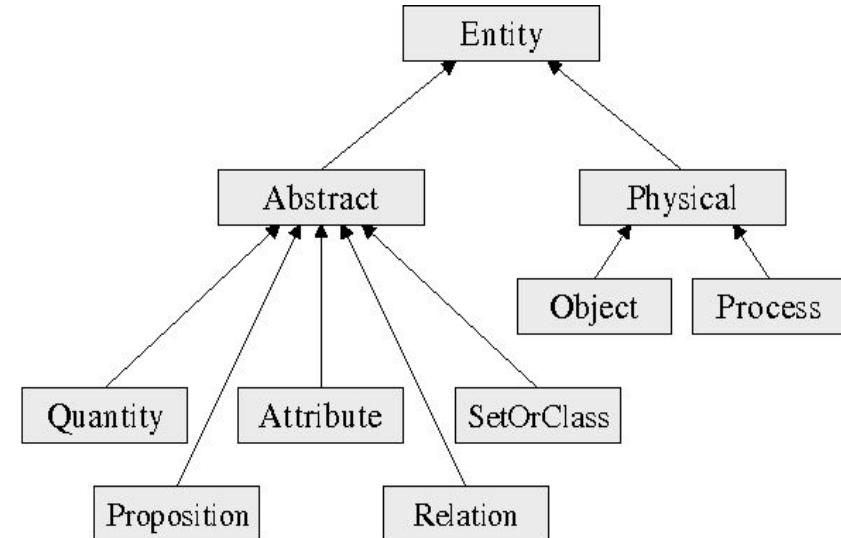


Upper Merged Ontologies

SUMO (approximately 25000 terms linked)

Dolce

Yago



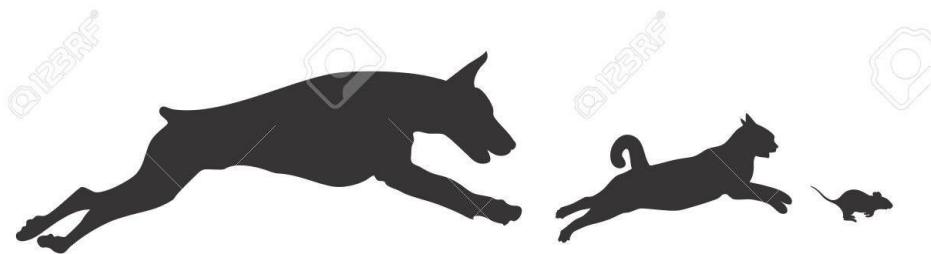


Potential difficulties in knowledge representation

- Semantic parasitism: externally inferred semantics

Metaphors: is “semantic parasitism” something positive or negative in an ontology?

- Semantic subjectivity: different semantics for different contexts





Watson's first experiment

Considering the following series of numbers which was built observing a rule, propose a similar series observing the same rule and one disobeying the same rule.

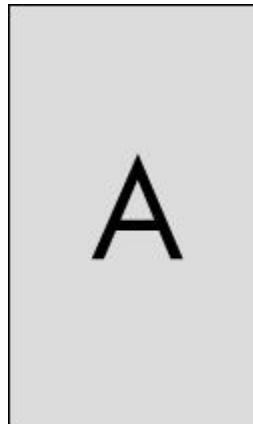
2 - 4 - 6

[More info](#)



Watson's selection task

The four cards have a letter on one side and a number on the other side. Which cards do you need to turn in order to check if the cards obey the rule: All odd numbers have vowels on the other side?



[More info](#)



Alternative to logical cognitive systems

Lewis–Stalnaker possible-worlds semantics:

1. Possible worlds exist (not *actually* in the real world).
2. Other worlds are the same as the real world (same complexity and capabilities). We know of the *actual* world we inhabit.
3. *Actual* is an index for the world it is uttered.
4. Possible worlds cannot be reduced to something more basic.



Alternative: Probabilistic reasoning



Open book

vs

Closed book exam

Tests intelligence in applying knowledge

Test analytical ability (looking for knowledge, recognizing relevant knowledge)

Tests memory

The goal should never be the accumulation of knowledge. The right answer means nothing without the right question (42).

