

# NaturalLI: Natural Logic Inference for Common Sense Reasoning

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Stanford University

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*Kittens play with yarn*

*Kittens play with computers*

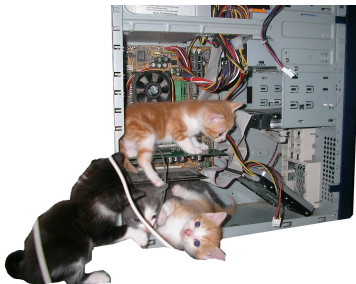


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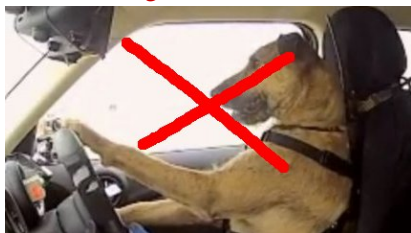
*Put a sarcastic comment in your talk. That's a great idea.*

*Sarcasm in your talk is a great idea*



# Common Sense Reasoning for Vision

*Dogs drive cars*



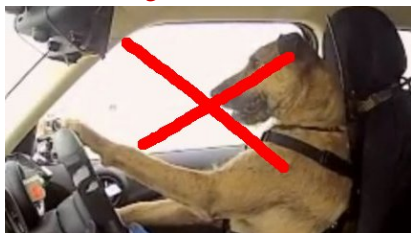
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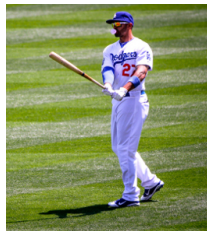
*People drive cars*



*Baseball is played underwater*



*Baseball is played on grass*



# Prior Work on Common Sense Reasoning

**Old School AI:** Nuanced reasoning; tiny coverage.

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**Information Extraction:** Shallow inference, large data.

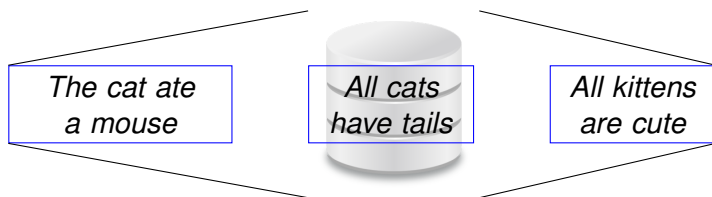
- OpenIE (Yates et al., 2007), NELL (Carlson et al., 2010).
- *Extraction* of facts from a large corpus; fuzzy lookup.



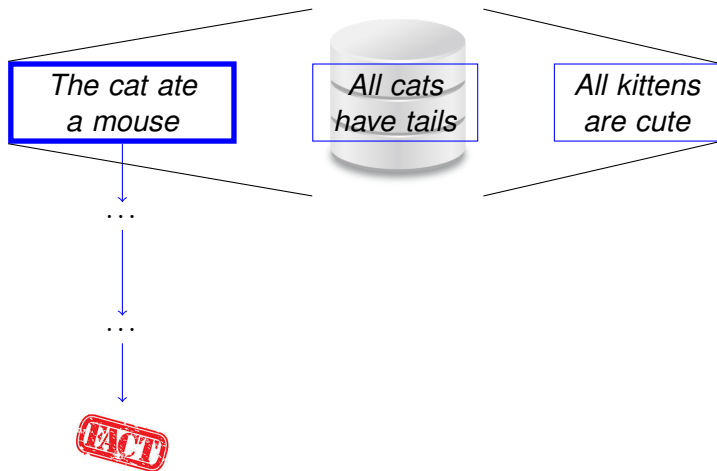
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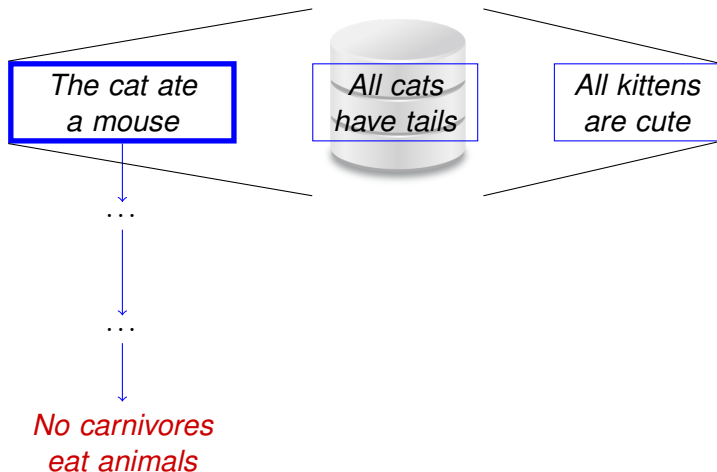
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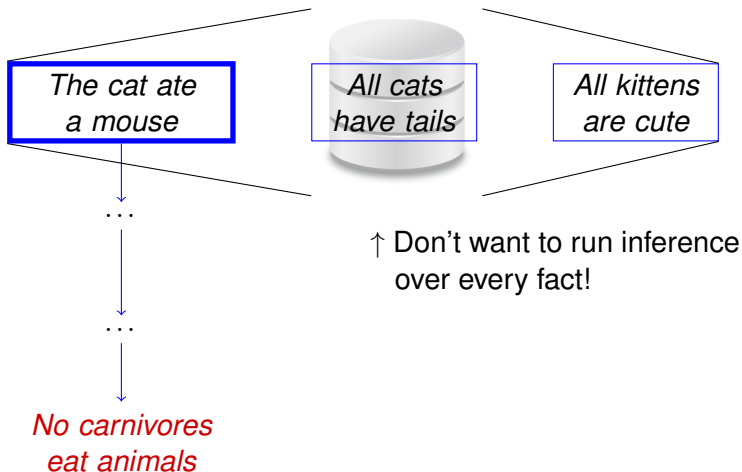


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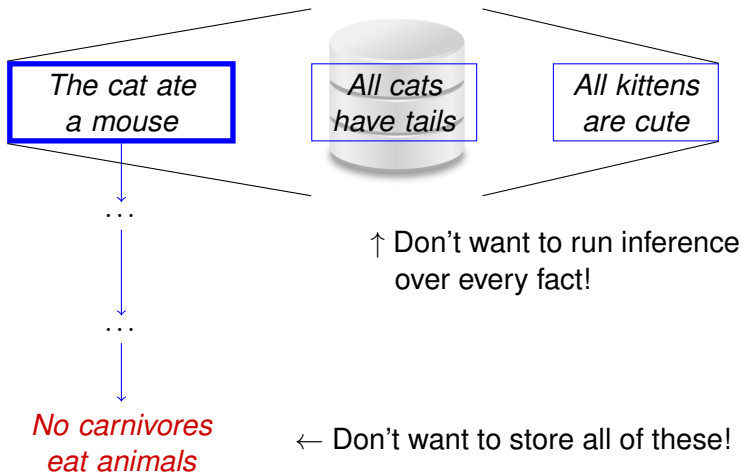




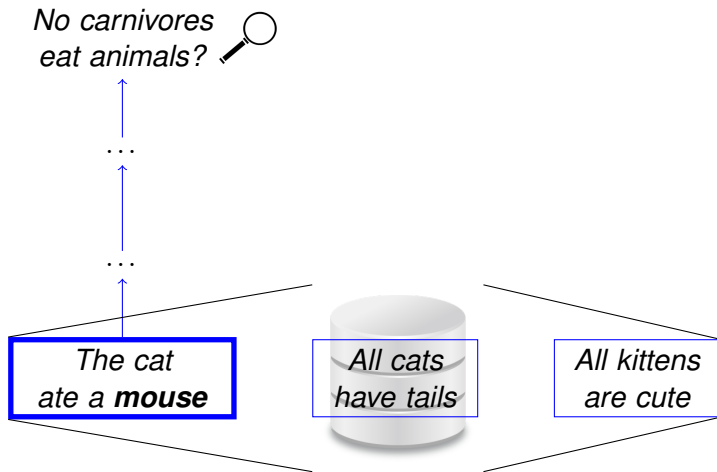
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# Infer new facts...



# Infer new facts...on demand from a query...



# ...Using text as the meaning representation...

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The cat  
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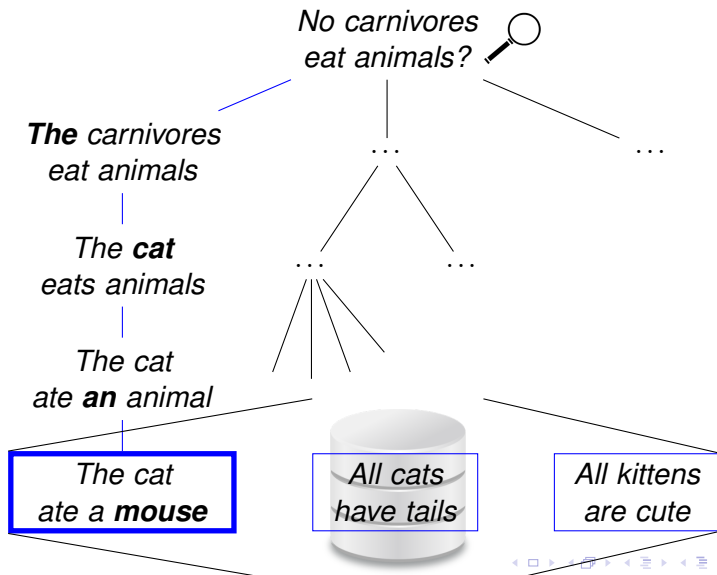
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All kittens  
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...Without aligning to any particular premise.



# A Better Knowledge Base Lookup

## Lookup in 270 million entry KB...

**...by lemmas**      12% recall

**...with NaturalLI**    49% recall (91% precision)



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Natural Logic



# Natural Logic as Syllogisms

## s/Natural Logic/Syllogistic Reasoning/g

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(*all mice are rodents*)

∴ *Some cat ate a **rodent***



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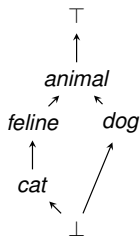
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## Facts are text; inference is lexical mutation



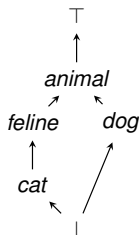
# Natural Logic and Polarity

Treat hypernymy as a *partial order*.

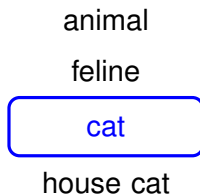


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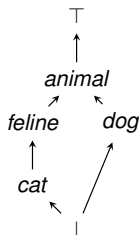
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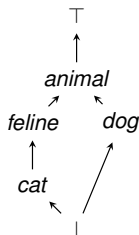


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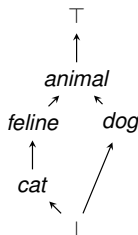


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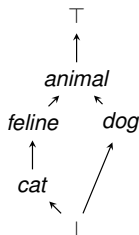


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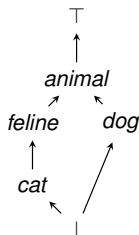


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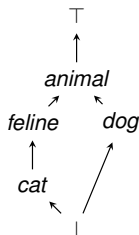


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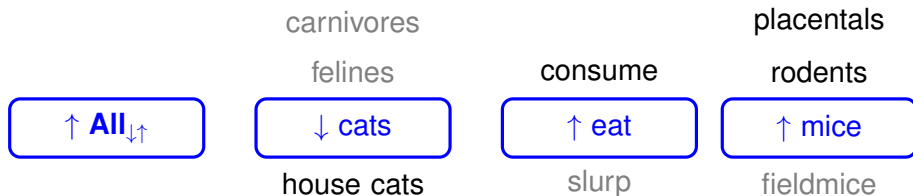
↓ cat

house cat



# An Example Inference

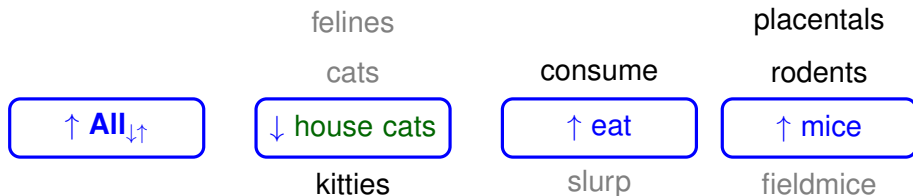
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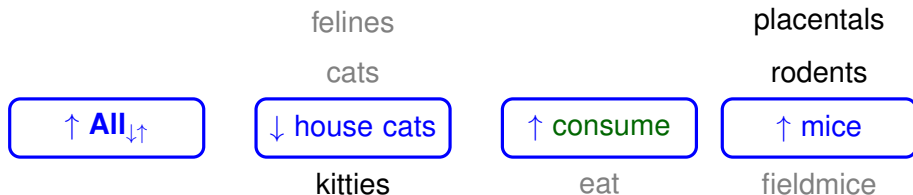




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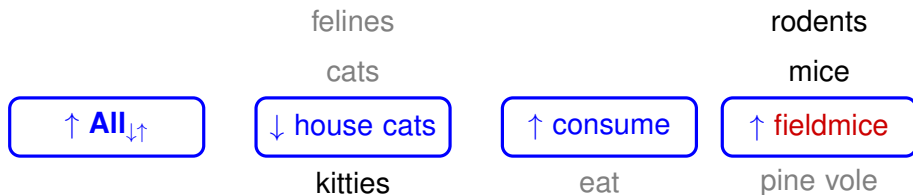
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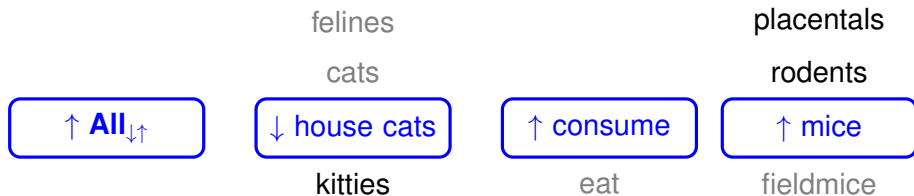
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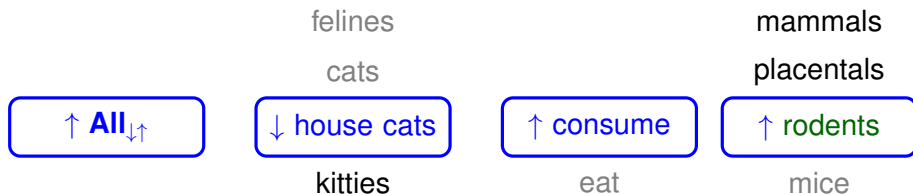
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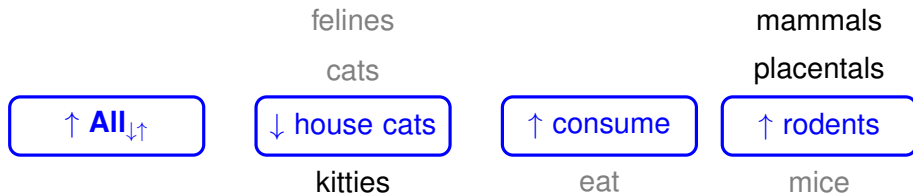


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Inference is reversible.



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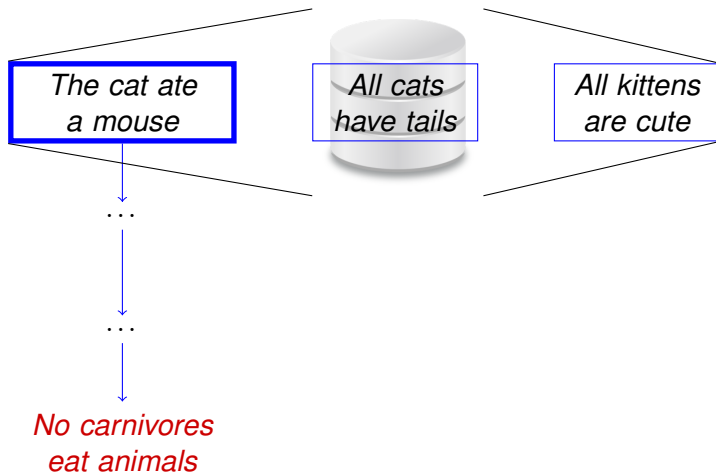


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  - We expect *readers* to make these inferences instantly.



# Natural Logic Inference is Search



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eat animals? 🔍

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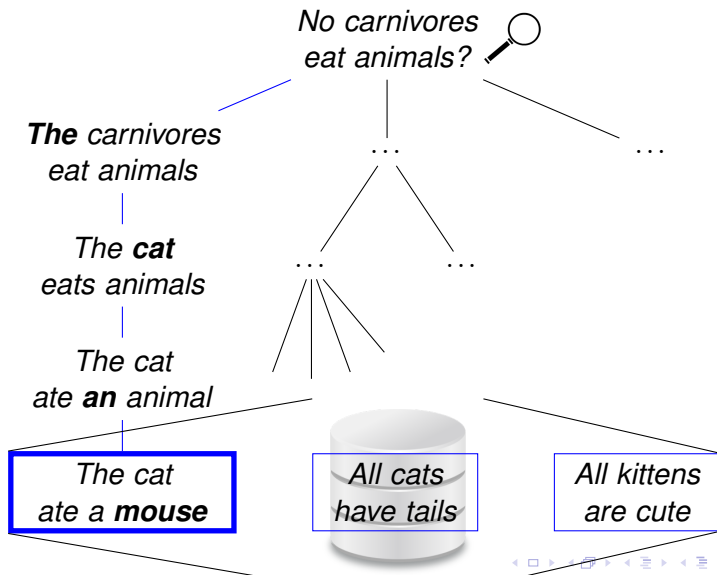
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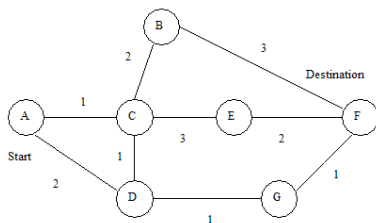
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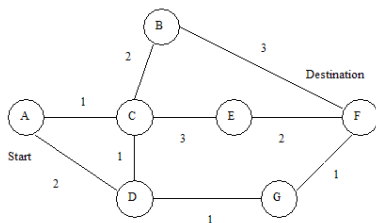
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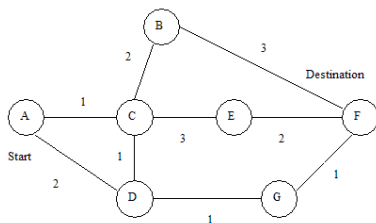
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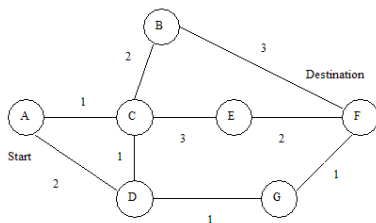
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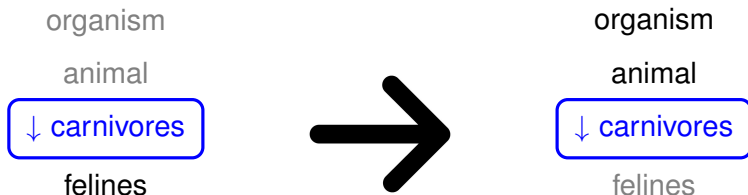
**Edge Costs** How “wrong” an inference step is (learned)





# An Example Search (as reverse inference)

Search mutates *opposite* to polarity



# An Example Search (as reverse inference)

Truth  
maintained:

*true*

Current  
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# An Example Search (as reverse inference)

**Truth  
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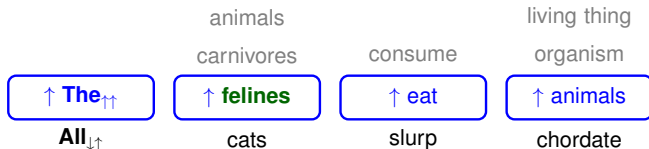


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# An Example Search (as graph search)

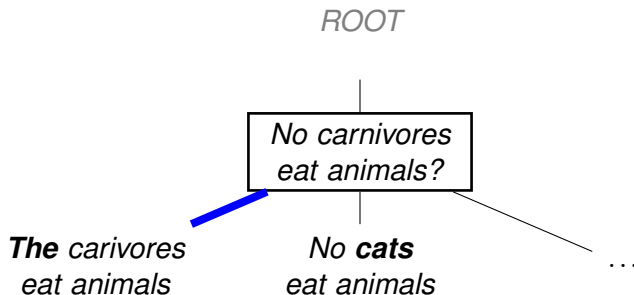
## Shorthand for a node:



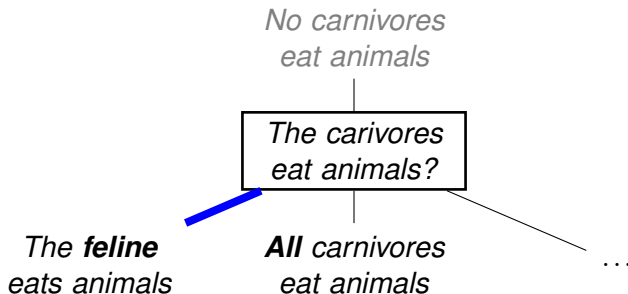
*No carnivores  
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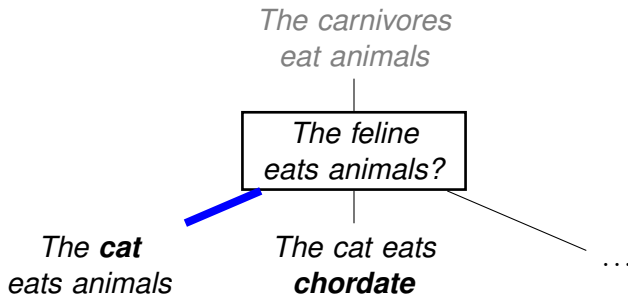
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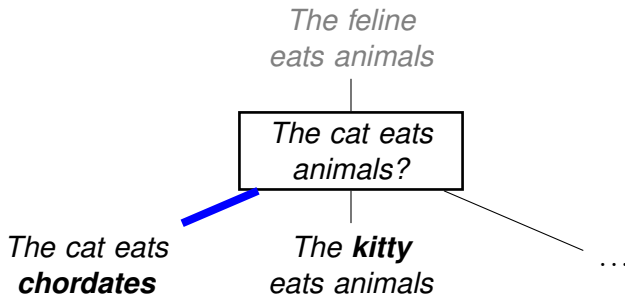
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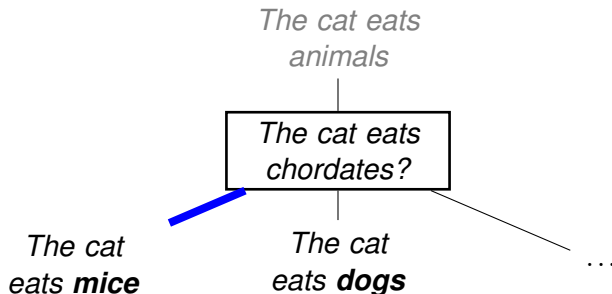
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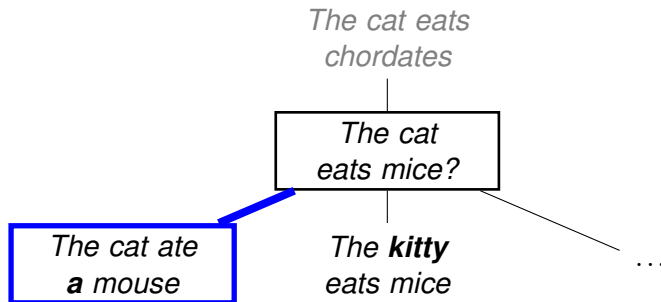
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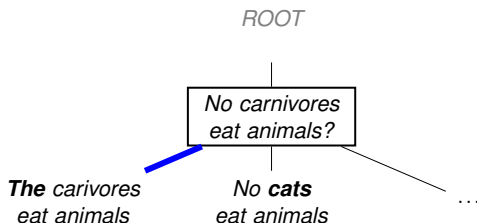
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# An Example Search (with edges)



**Template**

**Instance**

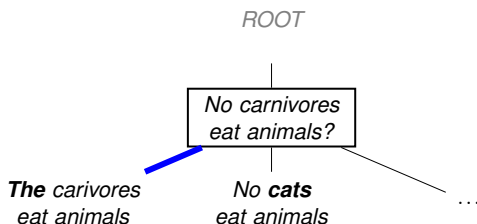
**Edge**

Operator Negate





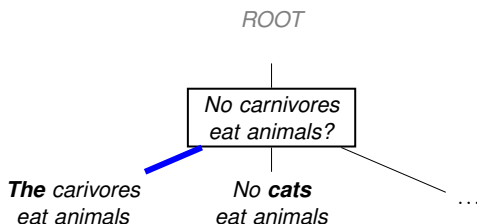
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Template	Instance	Edge
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# An Example Search (with edges)



Template	Instance	Edge
Operator Negate	<i>No</i> → <i>The</i>	<i>No carnivores eat animals</i> → <i>The carnivores eat animals</i>



# Edge Templates

Template	Instance
Hypernym	<i>animal</i> $\rightarrow$ <i>cat</i>
Hyponym	<i>cat</i> $\rightarrow$ <i>animal</i>
Antonym	<i>good</i> $\rightarrow$ <i>bad</i>
Synonym	<i>cat</i> $\rightarrow$ <i>true cat</i>
Add Word	<i>cat</i> $\rightarrow$ .
Delete Word	. $\rightarrow$ <i>cat</i>
Operator Weaken	<i>some</i> $\rightarrow$ <i>all</i>
Operator Strengthen	<i>all</i> $\rightarrow$ <i>some</i>
Operator Negate	<i>all</i> $\rightarrow$ <i>no</i>
Operator Synonym	<i>all</i> $\rightarrow$ <i>every</i>
Nearest Neighbor	<i>cat</i> $\rightarrow$ <i>dog</i>



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**Cost of a path is**  $\theta \cdot \mathbf{f}$ .

**Can learn parameters  $\theta$ .**



# Contribution: Simple Transitivity

**Taken for granted:**  $A \Rightarrow B$  and  $B \Rightarrow C$  then  $A \Rightarrow C$ .



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**More complicated in (prior work on) Natural Logic:**

- *nocturnal*  $\xrightarrow{\downarrow}$  *diurnal*,      *all*  $\xrightarrow{\wedge}$  *not all*  
∴ *all bats are nocturnal*  $\xrightarrow{?}$  *not all bats are diurnal*



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$\bowtie$	$\equiv$	$\sqsubseteq$	$\supseteq$	$\uparrow$	$\Downarrow$	$\smile$	#
$\equiv$	$\equiv$	$\sqsubseteq$	$\supseteq$	$\uparrow$	$\Downarrow$	$\smile$	#
$\sqsubseteq$	$\sqsubseteq$	$\sqsubseteq$	#	$\Downarrow$	$\Downarrow$	#	#
$\supseteq$	$\supseteq$	#	$\supseteq$	$\smile$	#	$\smile$	#
$\uparrow$	$\uparrow$	$\smile$	$\Downarrow$	$\equiv$	$\supseteq$	$\sqsubseteq$	#
$\Downarrow$	$\Downarrow$	#	$\Downarrow$	$\sqsubseteq$	#	$\sqsubseteq$	#
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≡	≡	⊆	⊇	人	↓	∪	#
⊆	⊆	⊆	#	↓	↓	#	#
⊇	⊇	#	⊇	#	#	∪	#
人	人	∪	↓	⊆	⊆	⊆	#
↓	↓	#	⊆	⊆	#	⊆	#
∪	∪	∪	⊆	⊇	⊇	#	#
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## Natural Logic Analog of Transitivity:

**State Fact**

$\Rightarrow$  *all bats are nocturnal,*

**Mutation**



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State	Fact	Mutation
$\Rightarrow$	<i>all bats are nocturnal,</i>	$(nocturnal \xrightarrow{\downarrow} diurnal)$
$\Rightarrow \neg$	<i>all bats are diurnal,</i>	$(all \xrightarrow{\uparrow} not\ all)$
$\Rightarrow$	<i>not all bats are diurnal</i>	

- Complex *join table* can be reduced to tracking a simple binary distinction.



# Experiments

## FraCaS Textual Entailment Suite:

- Used in MacCartney and Manning (2007; 2008).
- RTE-style problems: is the hypothesis entailed from the premise?  
P: At least three commissioners spend a lot of time at home.  
H: *At least three commissioners spend time at home.*  
P: At most ten commissioners spend a lot of time at home.  
H: *At most ten commissioners spend time at home.*
- 9 focused sections; 3 in scope for this work.



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## Not a blind test set!

- “Can we make deep inferences without knowing the premise *a priori*?”



# FraCaS Results

## Systems

**M07:** MacCartney and Manning (2007)

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- *Classify* entailment after aligning premise and hypothesis.

**N:** NaturalLI (this work)

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<b>Applicable (1,5,6)</b>		<b>76</b>	<b>90</b>	<b>89</b>



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## ConceptNet:

- A semi-curated collection of common-sense facts.  
*not all birds can fly*  
*noses are used to smell*  
*nobody wants to die*  
*music is used for pleasure*
- Negatives: ReVerb extractions marked false by Turkers.
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## Our Knowledge Base:

- 270 million lemmatized Ollie extractions.



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- 4x improvement in recall.





# Conclusions

## Takeaways

- *Deep* inferences from a *large* knowledge base.
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- 12% recall  $\rightarrow$  49% recall @ 91% precision.
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## Complexity doesn't grow with knowledge base size.



# Thanks!



<http://plato42.stanford.edu/naturalli>

