NaturalLI: Natural Logic Inference for Common Sense Reasoning

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Stanford University

October 26, 2014

Natural Logic Inference for **Common Sense Reasoning**

Kittens play with yarn

Kittens play with computers

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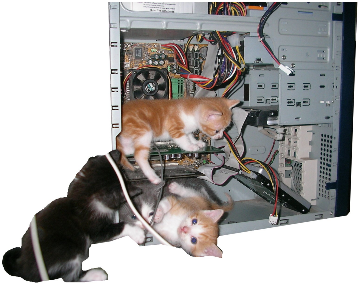

Common Sense Reasoning for NLP

The city refused the demonstrators a permit because they feared violence.

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a city fears violence

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I ate the cake with a cherry vs. *I ate the cake with a fork*

cakes come with cherries

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I ate the cake with a cherry vs. *I ate the cake with a fork*

cakes come with cherries

cakes are eaten using cherries

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

People drive cars

Common Sense Reasoning for Vision

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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.

- Default reasoning (Reiter 1980; McCarthy 1980).
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- Episodic Logic (Schubert, 2002).

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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.

Start with a large knowledge base

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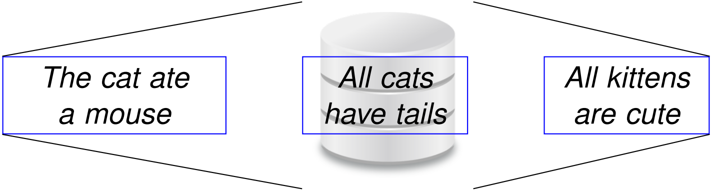

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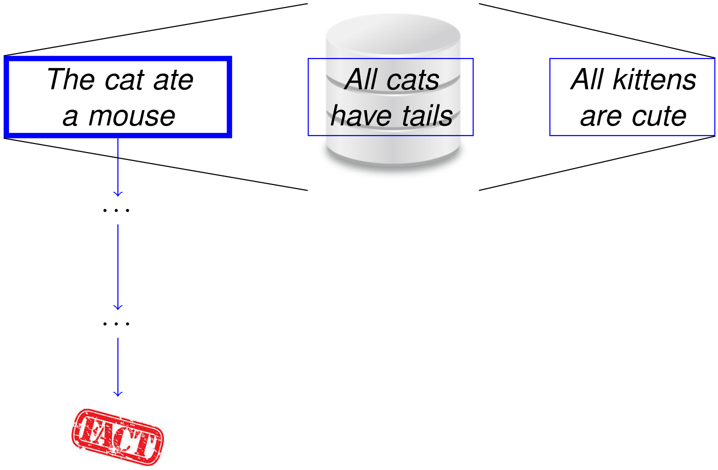

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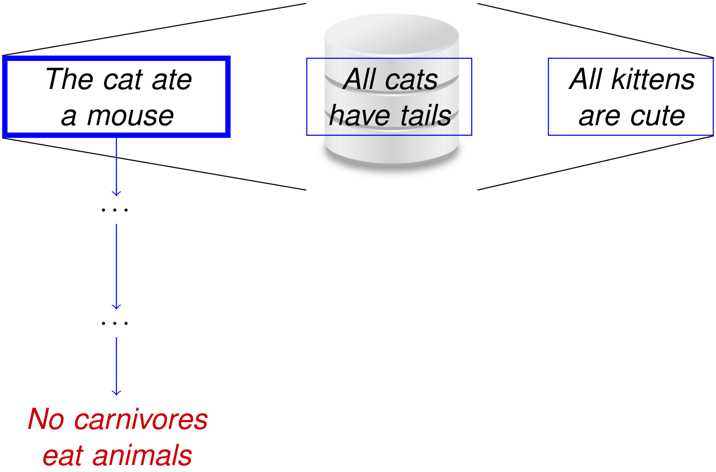

Infer new facts...

The cat ate a mouse

All cats have tails

All kittens are cute

. . .

. . .

No carnivores eat animals

↑ Don't want to run inference over every fact!

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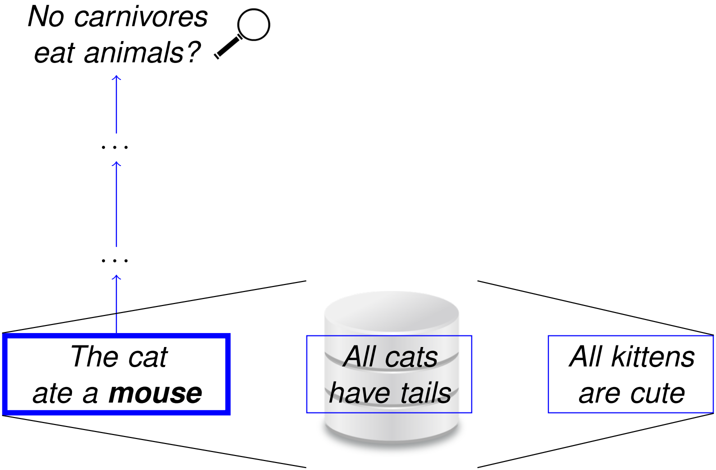
← Don't want to store all of these!

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



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

No carnivores eat animals?

The *carnivores eat animals*

The ***cat*** *eats animals*

The cat ate ***an*** *animal*

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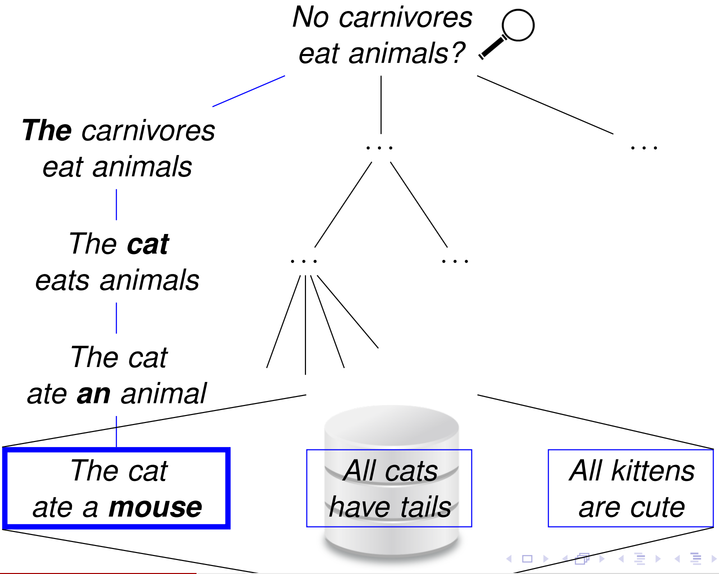
...Without aligning to any particular premise.



A Better Knowledge Base Lookup

Lookup in 270 million entry KB...

...by lemmas	12% recall
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- Minimal pre-processing of query.
- Minimal pre-processing of knowledge base.

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Natural Logic

Natural Logic as Syllogisms

s/Natural Logic/Syllogistic Reasoning/g

Some cat ate a mouse
(all mice are rodents)
$\therefore$ *Some cat ate a* ***rodent***

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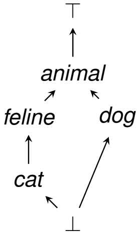
Facts are text; inference is lexical mutation

Natural Logic and Polarity

Treat hypernymy as a *partial order*.



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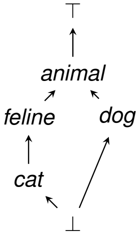

***Polarity* is the direction a lexical item can move in the ordering.**

animal

feline

$\boxed{\text{cat}}$

house cat

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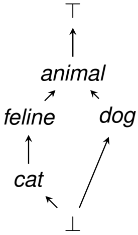

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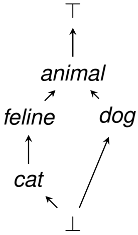

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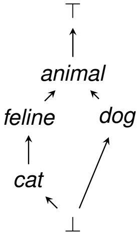

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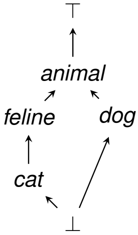

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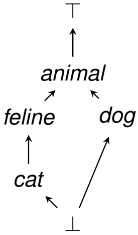

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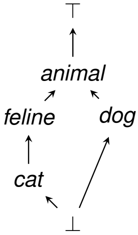

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An Example Inference

Quantifiers determines the *polarity* (↑ or ↓) of words.

	carnivores		placentals
	felines	consume	rodents
↑ **All**$_{\downarrow\uparrow}$	↓ cats	↑ eat	↑ mice
	house cats	slurp	fieldmice

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Mutations must respect *polarity*.

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	kitties	eat	pine vole

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	kitties	eat	mice

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Mutations must respect *polarity*.

Inference is reversible.

felines

cats

mammals

placentals

↑ **All**$_{\downarrow\uparrow}$ | ↓ house cats | ↑ consume | ↑ rodents

kitties

eat

mice

Properties of Natural Logic

✓ Computationally fast during inference.

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- Inference is lexical mutations / insertions / deletions.

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✓ Computationally fast during pre-processing.
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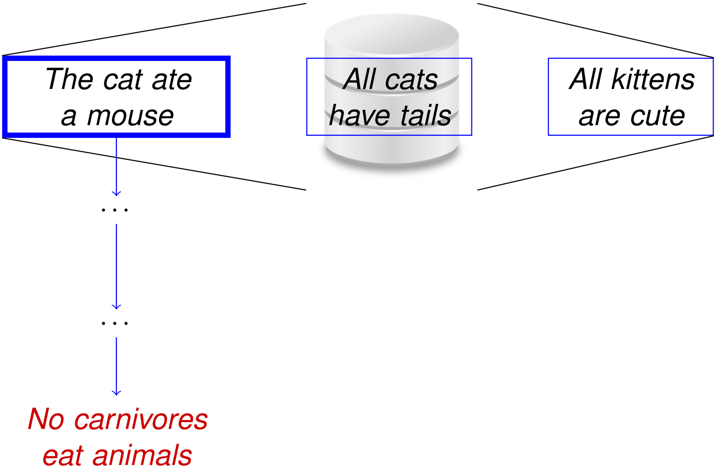
✓ Still captures common inferences.
- We make these types of inferences regularly and instantly.
- We expect *readers* to make these inferences instantly.

Natural Logic Inference is Search



Natural Logic Inference is Search

No carnivores eat animals?

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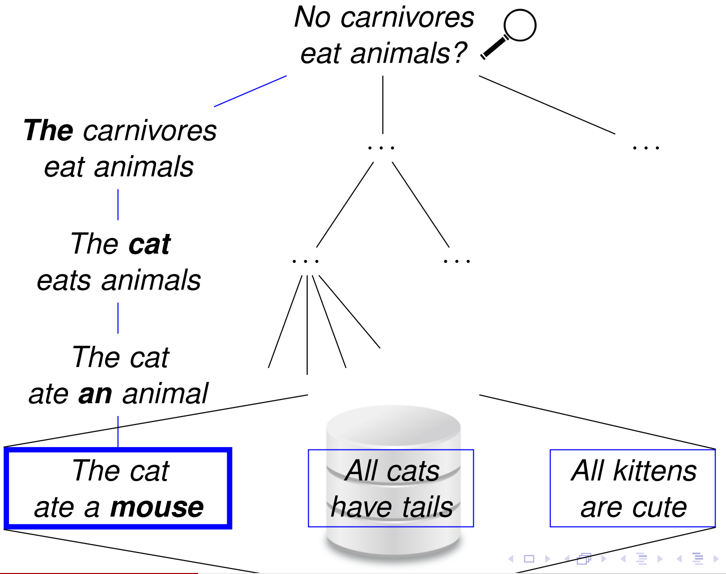

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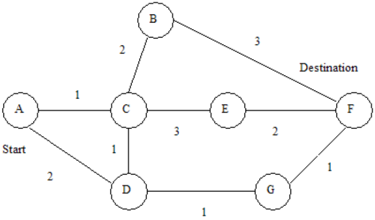

Nodes (*fact*, truth maintained $\in \{\text{true}, \text{false}\}$)

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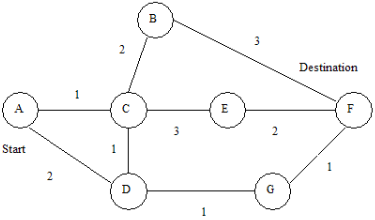

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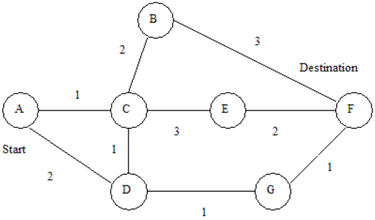

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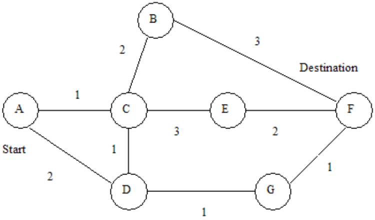

Nodes	(*fact*, truth maintained $\in \{\text{true}, \text{false}\}$)
Start Node	(*query fact*, *true*)
End Nodes	*any known fact*
Edges	Mutations of the current fact
Edge Costs	How "wrong" an inference step is (learned)

An Example Search (as reverse inference)

Search mutates *opposite* to polarity

organism		organism
animal		animal
$\boxed{\downarrow \text{carnivores}}$	$\rightarrow$	$\boxed{\downarrow \text{carnivores}}$
felines		felines

An Example Search (as reverse inference)

Truth maintained: *true*

Current Node:

	organism		living thing
	animal	consume	organism
$\uparrow$ **No**$_{\downarrow\downarrow}$	$\downarrow$ carnivores	$\downarrow$ eat	$\downarrow$ animals
	felines	slurp	chordate

An Example Search (as reverse inference)

Truth maintained: *false*

Current Node:

	organism		living thing
	animal	consume	organism
$\uparrow$ The$_{\uparrow\uparrow}$	**$\uparrow$ carnivores**	**$\uparrow$ eat**	**$\uparrow$ animals**
All$_{\downarrow\uparrow}$	felines	slurp	chordate

An Example Search (as reverse inference)

Truth maintained: *false*

Current Node:

	animals		living thing
	carnivores	consume	organism
$\uparrow$ **The**$_{\uparrow\uparrow}$	$\uparrow$ **felines**	$\uparrow$ eat	$\uparrow$ animals
All$_{\downarrow\uparrow}$	cats	slurp	chordate

An Example Search (as reverse inference)

Truth maintained:

false

Current Node:

	carnivores		living thing
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All$_{\downarrow\uparrow}$	kitties	slurp	chordate

An Example Search (as reverse inference)

Truth maintained: *false*

		carnivores		organisms
		felines	consume	animals
Current Node:	↑ **The**$_{\uparrow\uparrow}$	↑ cats	↑ eat	↑ **chordates**
	All$_{\downarrow\uparrow}$	kitties	slurp	mice

An Example Search (as reverse inference)

Truth maintained: *false*

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Current Node:

	carnivore			animal
	feline	consumed		chordate
$\uparrow$ **The**$_{\uparrow\uparrow}$	$\uparrow$ cat	$\uparrow$ ate	$\uparrow$ **a**$_{\uparrow\uparrow}$	$\uparrow$ mouse
All$_{\downarrow\uparrow}$	kitty	slurped	**All**$_{\downarrow\uparrow}$	fieldmouse

An Example Search (as graph search)

Shorthand for a node:

	organism		living thing
	animal	consume	organism
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No carnivores eat animals?

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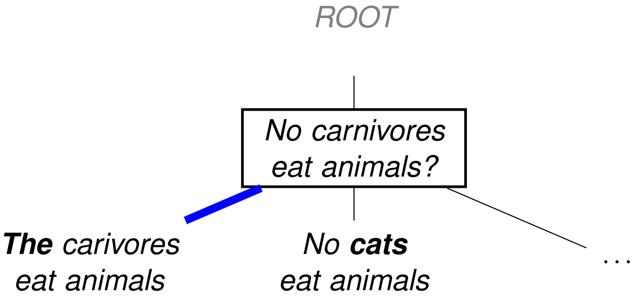

An Example Search (as graph search)

No carnivores eat animals

The carivores eat animals?

*The **feline** eats animals*

***All** carnivores eat animals*

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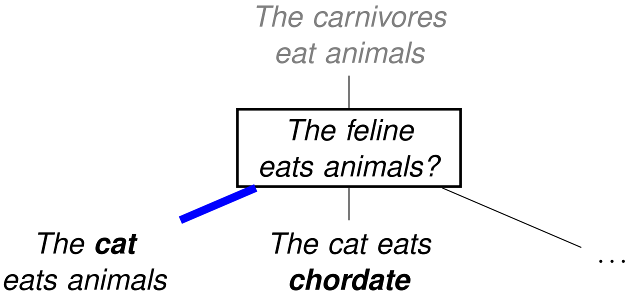

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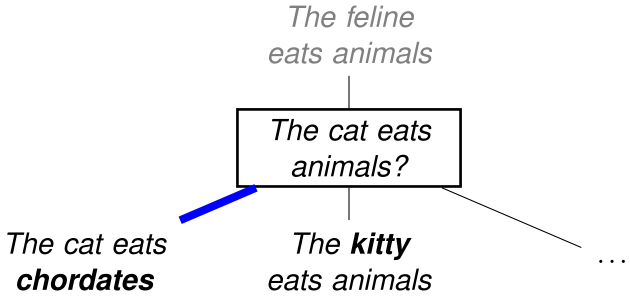

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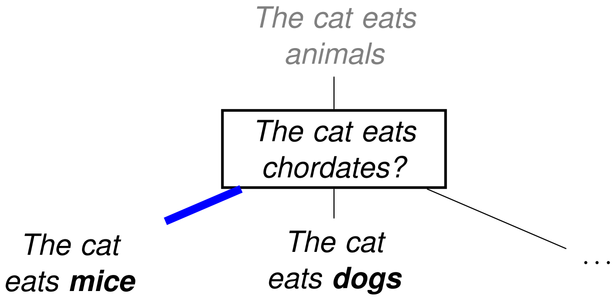

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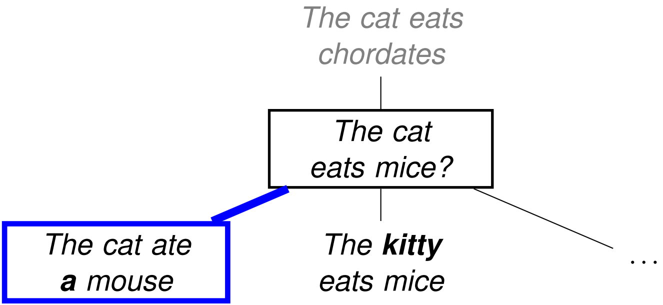

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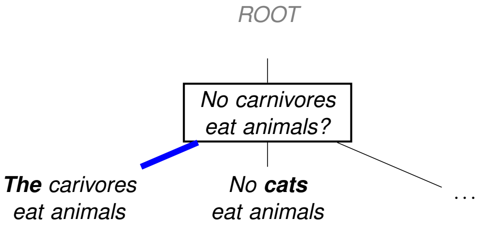

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Operator Negate		

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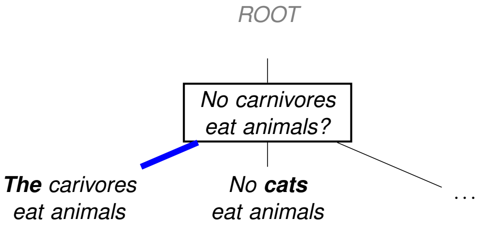

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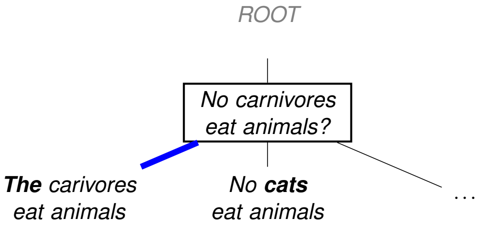

Template	Instance	Edge
Operator Negate	*No* $\rightarrow$ *The*	*No carnivores eat animals* $\rightarrow$ *The carnivores eat animals*

Edge Templates

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

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Want to make likely (but not certain) inferences.

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

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Detail: Variation among *edge instances* of a template.

- WordNet: *cat* $\rightarrow$ *feline* **vs.** *cup* $\rightarrow$ *container*.
- Nearest neighbors distance.
- Each *edge instance* has a distance f.

Cost of an edge is $\theta_i \cdot f_i$.
Cost of a path is $\theta \cdot \mathbf{f}$.
Can learn parameters θ.

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$\equiv$	$\equiv$	$\sqsubseteq$	$\sqsupseteq$	$\curlywedge$	$\downharpoonleft\upharpoonright$	$\smile$	$\#$
$\sqsubseteq$	$\sqsubseteq$	$\sqsubseteq$	$\#$	$\downharpoonleft\upharpoonright$	$\downharpoonleft\upharpoonright$	$\#$	$\#$
$\sqsupseteq$	$\sqsupseteq$	$\#$	$\sqsupseteq$	$\smile$	$\#$	$\smile$	$\#$
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- Complex *join table* can be reduced to tracking a simple binary distinction.

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Not a blind test set!

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

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Our Knowledge Base:

- 270 million lemmatized Ollie extractions.

ConceptNet Results

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Direct Lookup: Lookup by lemmas.

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- 4x improvement in recall.

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Complexity doesn't grow with knowledge base size.

Thanks!

http://plato42.stanford.edu/naturalli