Logical Inference for Question Answering

Gabor Angeli

Stanford University

April 14, 2015

Natural Logic Inference for **Common Sense Reasoning**

Kittens play with yarn

Kittens play with computers

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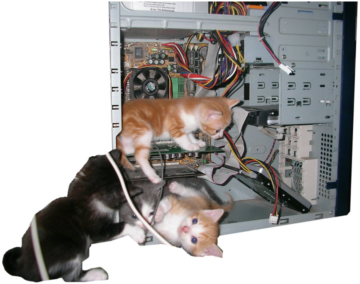

Common Sense Reasoning for NLP

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

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a city fears violence

demonstrators fear 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

Dogs drive cars

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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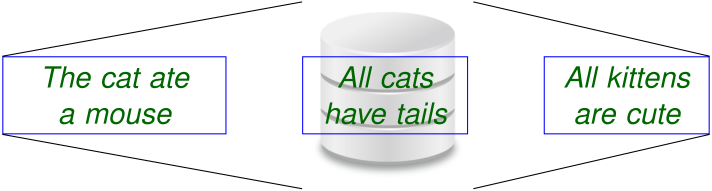
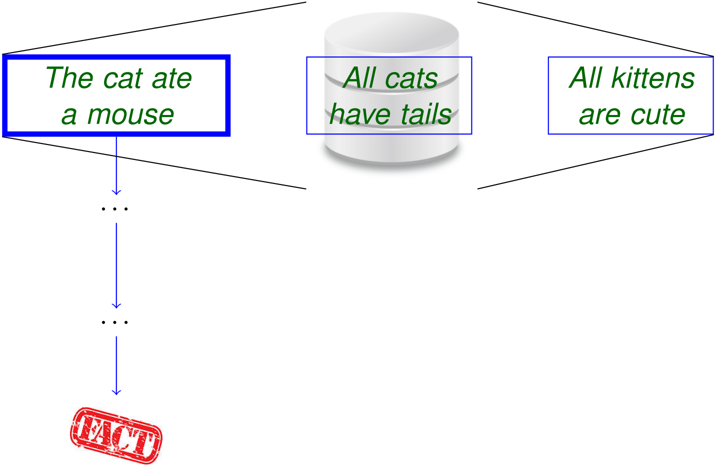


Infer new facts...



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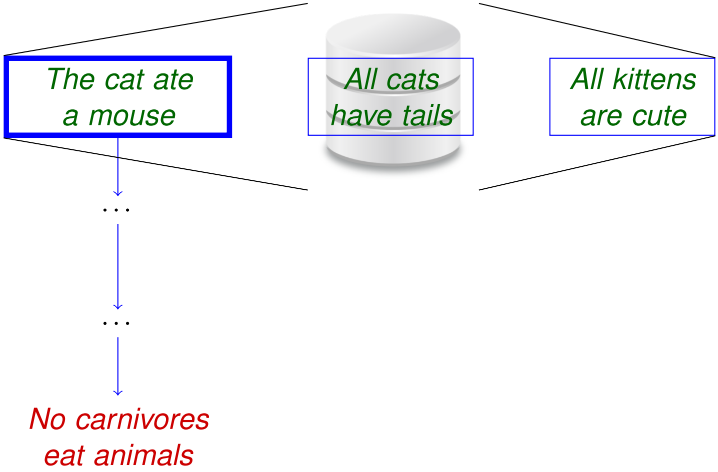


Infer new facts...

The cat ate a mouse

All kittens are cute

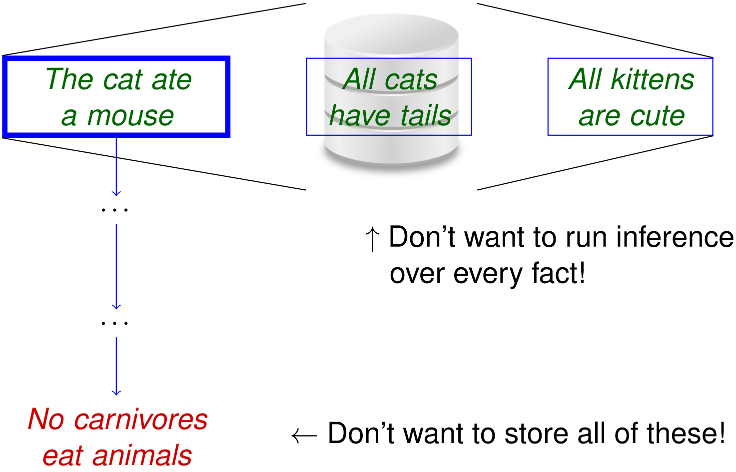
. . .

. . .

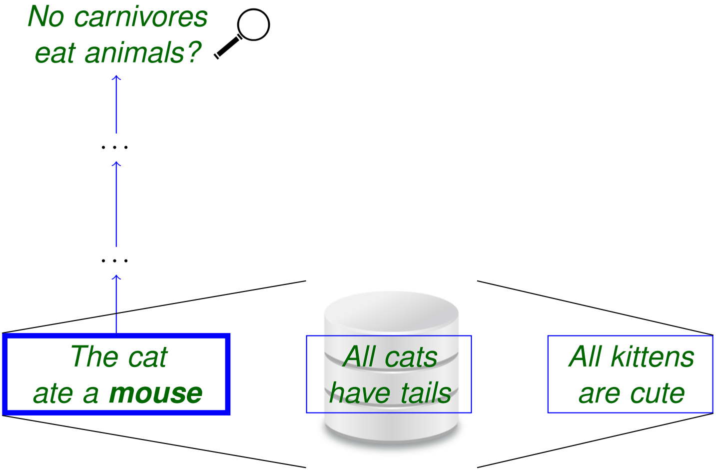
No carnivores eat animals

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

Infer new facts...



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

The cat ate a __mouse__

All cats have tails

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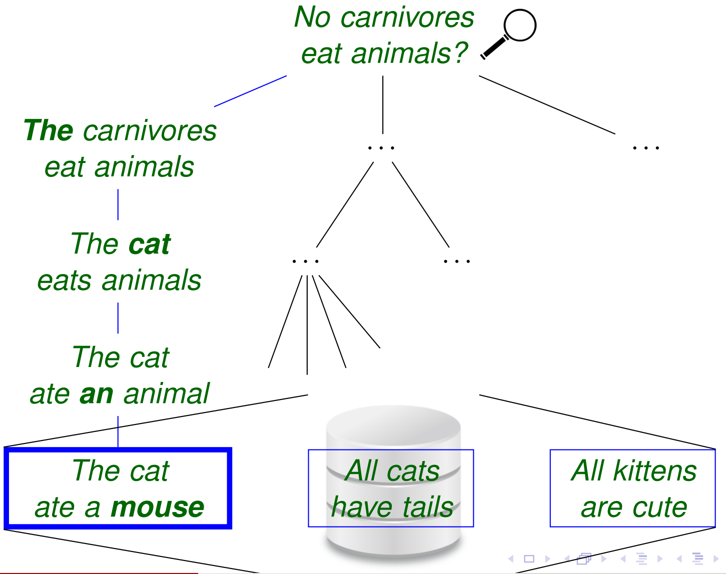
...Without aligning to any particular premise.



A Better Knowledge Base Lookup

Lookup in 270 million entry KB...

...by lemmas	12% recall
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- Fast.
- Minimal pre-processing of query.
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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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- Most cats eat mice
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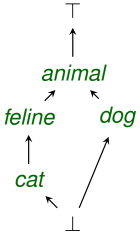
Facts are text; inference is lexical mutation

Natural Logic and Polarity

Treat hypernymy as a *partial order*.



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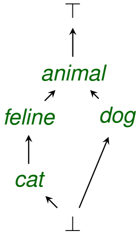

***Polarity* is the direction a lexical item can move in the ordering.**

animal

feline

$\boxed{\text{cat}}$

house cat

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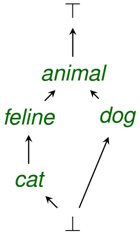

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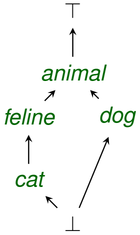

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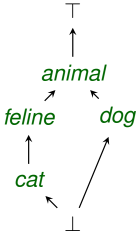

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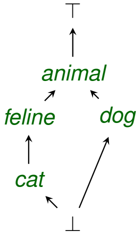

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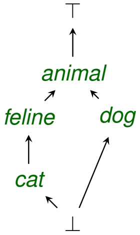

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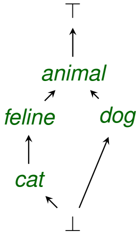

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An Example Inference

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

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

An Example Inference

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

Mutations must respect *polarity*.

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	cats		mice
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	kitties	eat	pine vole

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	felines		mammals
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$\boxed{\uparrow \textbf{All}_{\downarrow\uparrow}}$	$\boxed{\downarrow \text{house cats}}$	$\boxed{\uparrow \text{consume}}$	$\boxed{\uparrow \text{rodents}}$
	kitties	eat	mice

An Example Inference

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Mutations must respect *polarity*.

Inference is reversible.

	felines		mammals
	cats		placentals
↑ **All**$_{\downarrow\uparrow}$	↓ house cats	↑ consume	↑ rodents
	kitties	eat	mice

Properties of Natural Logic

✓ Computationally fast during inference.

- "Semantic" parse of query is just syntactic parse.
- Inference is lexical mutations / insertions / deletions.

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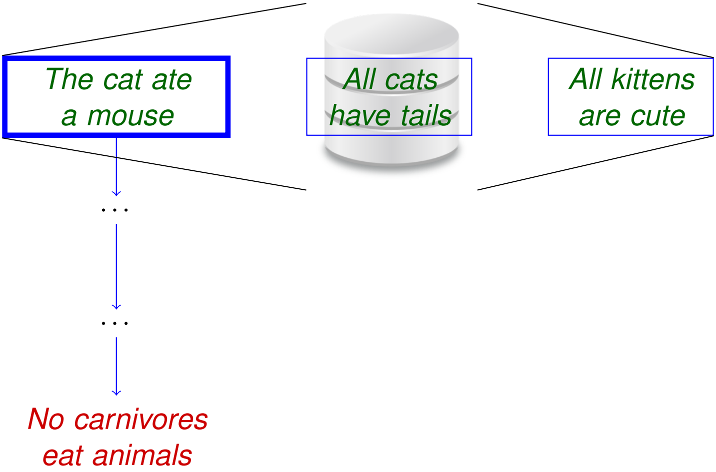
✓ Still captures common inferences.
- We make these types of inferences regularly and instantly.
- We expect *readers* to make these inferences instantly.

Natural Logic Inference is Search



Natural Logic Inference is Search

No carnivores eat animals?

The carnivores eat animals (with *The* in bold)

The cat eats animals (with *cat* in bold)

The cat ate an animal (with *an* in bold)

The cat ate a mouse (with *mouse* in bold)

All cats have tails

All kittens are cute

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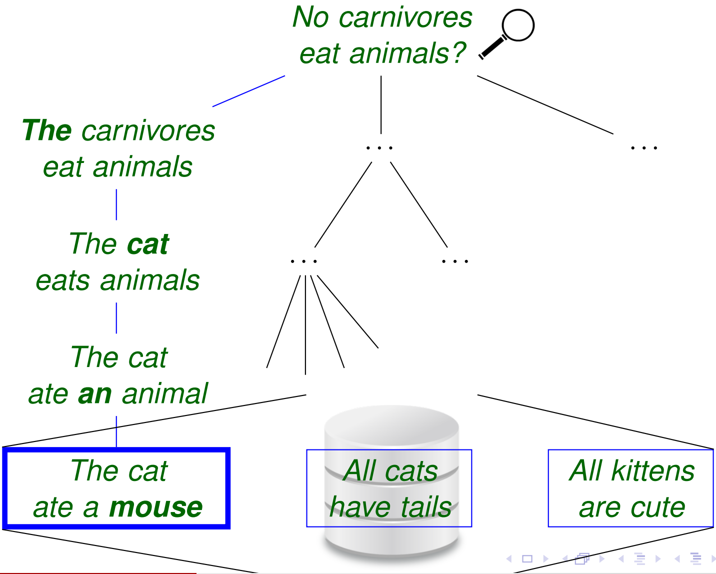

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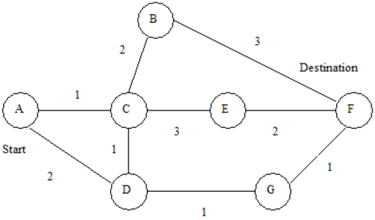

Nodes (*fact*, truth maintained $\in \{\text{true}, \text{false}\}$)

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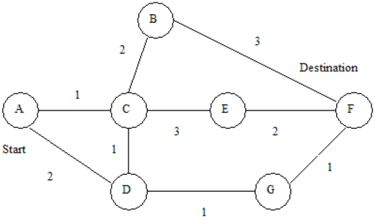

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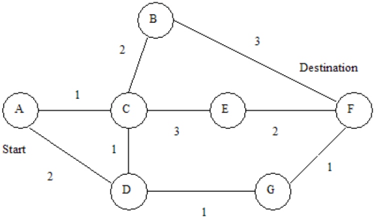

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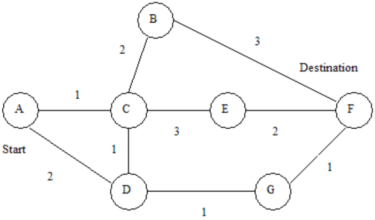

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Edges Mutations of the current fact
Edge Costs How “wrong” an inference step is (learned)

An Example Search (as reverse inference)

Search mutates *opposite* to polarity

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

An Example Search (as reverse inference)

Truth maintained: *true*

Current Node:

	organism		living thing
	animal	consume	organism
↑ **No**$_{\downarrow\downarrow}$	↓ carnivores	↓ eat	↓ 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*

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

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Truth maintained: *false*

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Current Node:	↑ **The**$_{\uparrow\uparrow}$	↑ cats	↑ eat	↑ **chordates**
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Truth maintained: *false*

Current Node:

	carnivores		animals
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All$_{\downarrow\uparrow}$	kitties	slurp	fieldmice

An Example Search (as reverse inference)

Truth maintained: *false*

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
$\uparrow$ **No**$_{\downarrow\downarrow}$	$\uparrow$ carnivores	$\downarrow$ eat	$\uparrow$ animals
	felines	slurp	chordate

$\Downarrow$

No carnivores eat animals?

An Example Search (as graph search)

ROOT

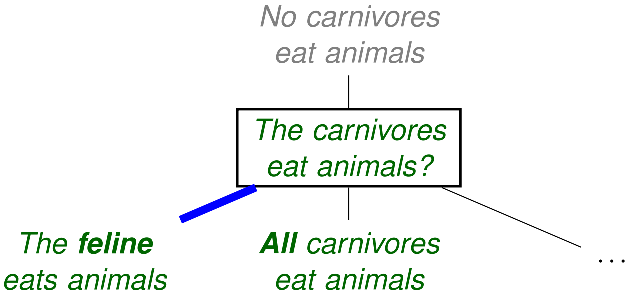
No carnivores eat animals?

***The** carnivores eat animals*

*No **cats** eat animals*

. . .

An Example Search (as graph search)



An Example Search (as graph search)

The carnivores eat animals

The feline eats animals?

*The **cat** eats animals*

*The cat eats **chordate***

...

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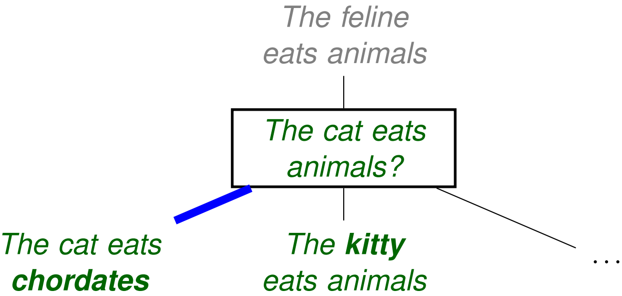

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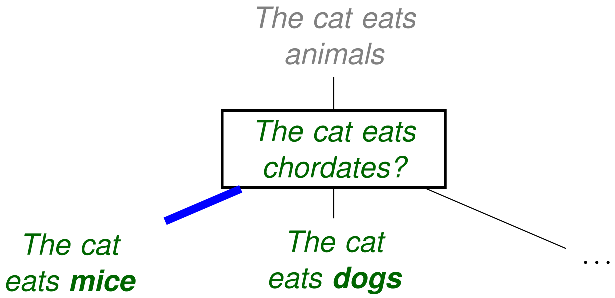

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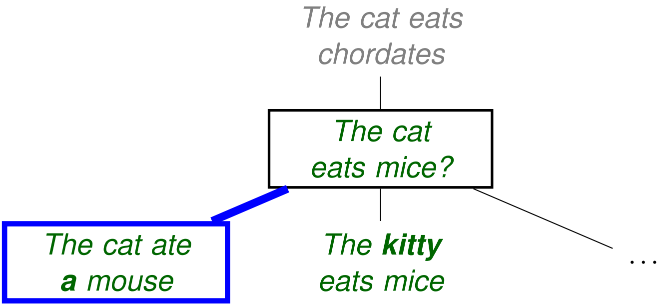

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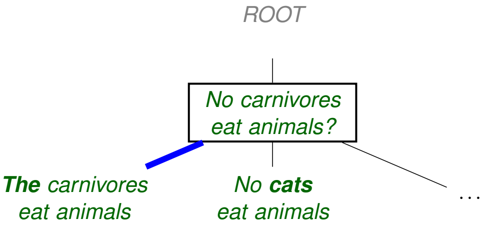

Template	Instance	Edge
Operator Negate		

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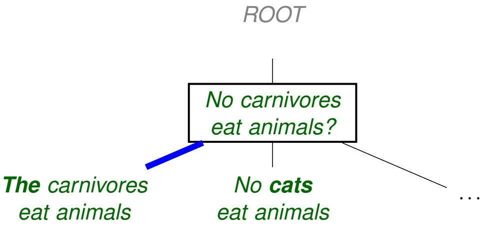

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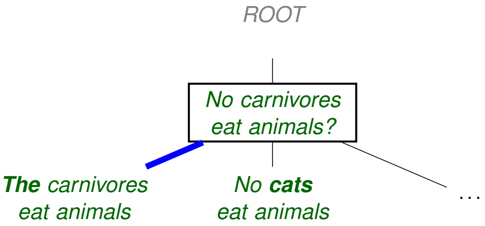

Template	**Instance**	**Edge**
Operator Negate	*No* $\rightarrow$ *The*	*No carnivores eat animals* $\rightarrow$ *The carnivores eat animals*

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

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  $\therefore$ *all bats are nocturnal* $\xrightarrow{?}$ *not all bats are diurnal*

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$\bowtie$	$\equiv$	$\sqsubseteq$	$\sqsupseteq$	$\curlywedge$	$\downharpoonleft\upharpoonright$	$\smile$	$\#$
$\equiv$	$\equiv$	$\sqsubseteq$	$\sqsupseteq$	$\curlywedge$	$\downharpoonleft\upharpoonright$	$\smile$	$\#$
$\sqsubseteq$	$\sqsubseteq$	$\sqsubseteq$	$\#$	$\downharpoonleft\upharpoonright$	$\downharpoonleft\upharpoonright$	$\#$	$\#$
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$\downharpoonleft\upharpoonright$	$\downharpoonleft\upharpoonright$	$\#$	$\downharpoonleft\upharpoonright$	$\sqsubseteq$	$\#$	$\sqsubseteq$	$\#$
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$\upharpoonleft\!\downharpoonright$	$\upharpoonleft\!\downharpoonright$	$\#$	[illegible]	$\sqsubseteq$	$\#$	$\sqsubseteq$	$\#$
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- 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.
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Not a blind test set!

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

FraCaS Results

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M07: MacCartney and Manning (2007)

M08: MacCartney and Manning (2008)

- *Classify* entailment after aligning premise and hypothesis.

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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
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Our Knowledge Base:

- 270 million lemmatized Ollie extractions.

ConceptNet Results

Systems

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- 4x improvement in recall.

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Complexity doesn’t grow with knowledge base size.

Thanks!