NaturalLI: Natural Logic Inference for Common Sense Reasoning

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Stanford University

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Natural Logic Inference for **Common Sense Reasoning**

Kittens play with yarn

Kittens play with computers

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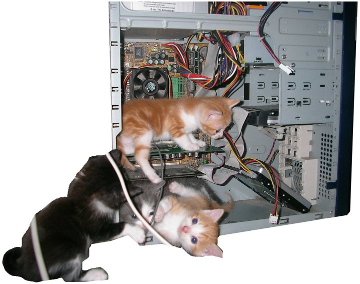

Common Sense Reasoning for NLP

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

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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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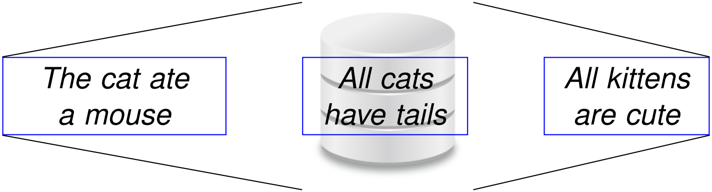

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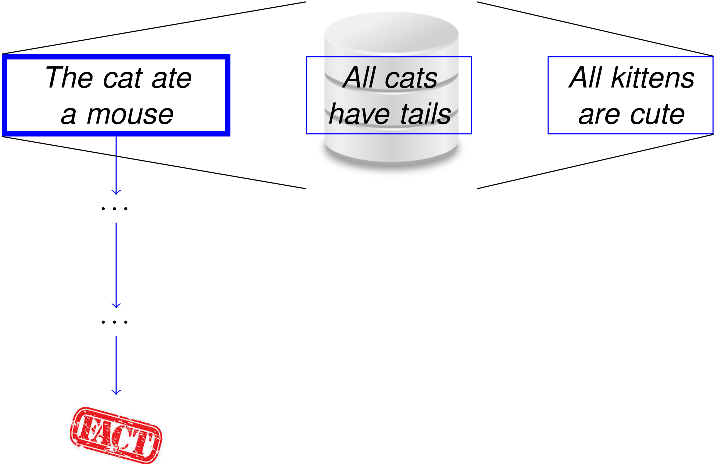

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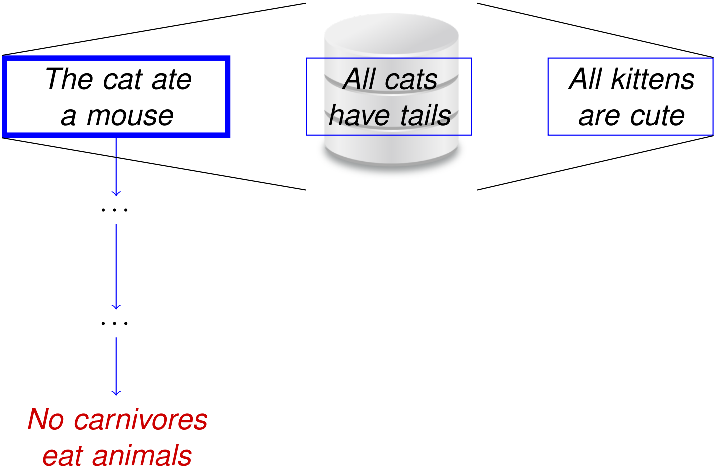

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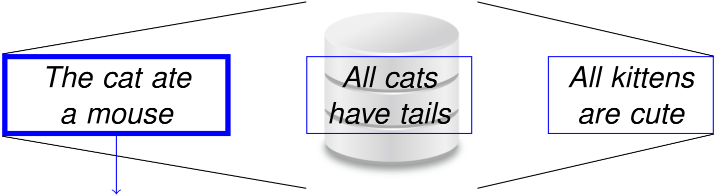


. . .

. . .

No carnivores eat animals

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

Infer new facts...

The cat ate a mouse

All cats have tails

All kittens are cute

…

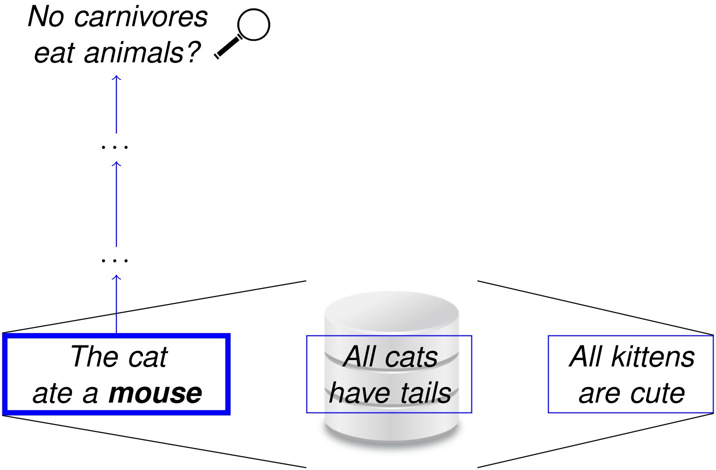
…

No carnivores eat animals

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

← Don't want to store all of these!

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



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

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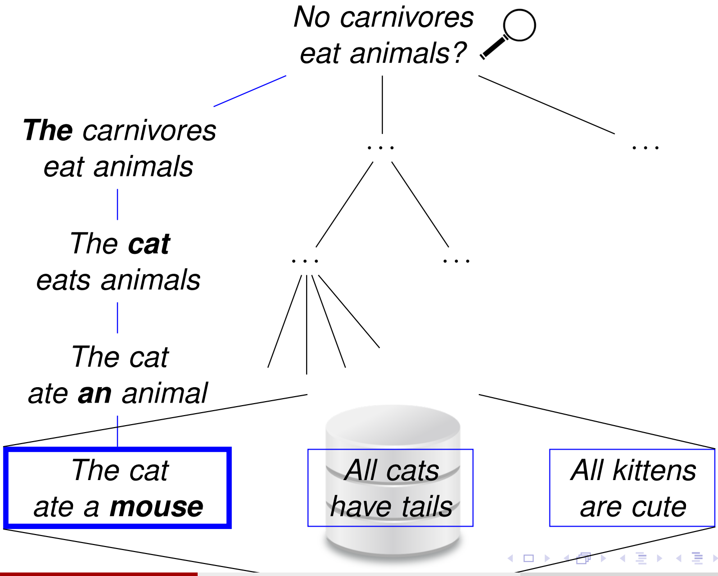
...Without aligning to any particular premise.



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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- 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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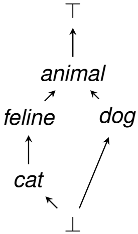
Facts are text; inference is lexical mutation

Natural Logic and Polarity

Treat hypernymy as a *partial order*.



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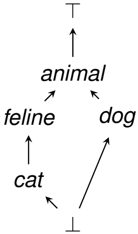

***Polarity* is the direction a lexical item can move in the ordering.**

animal

feline

$\boxed{\text{cat}}$

house cat

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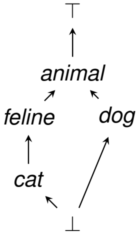

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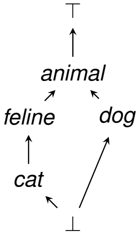

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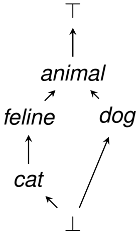

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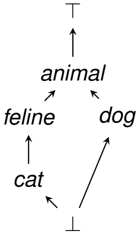

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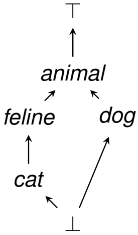

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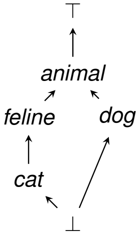

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An Example Inference

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

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Mutations must respect *polarity*.

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Inference is reversible.

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

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✓ Computationally fast during inference.

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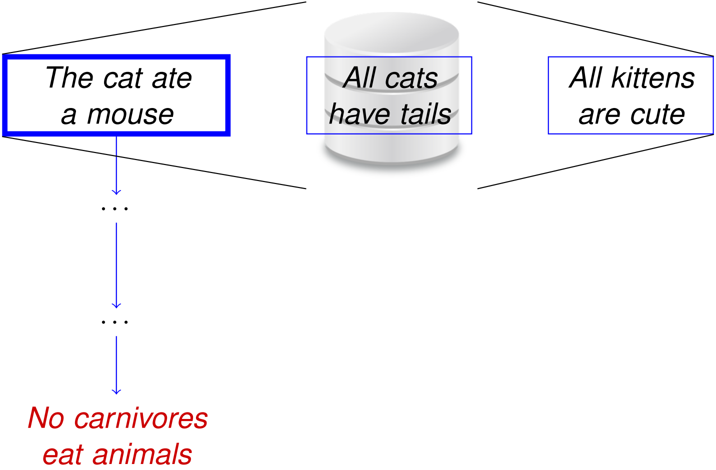
- ✓ Still captures common inferences.
  - We make these types of inferences regularly and instantly.
  - We expect *readers* to make these inferences instantly.

Natural Logic Inference is Search



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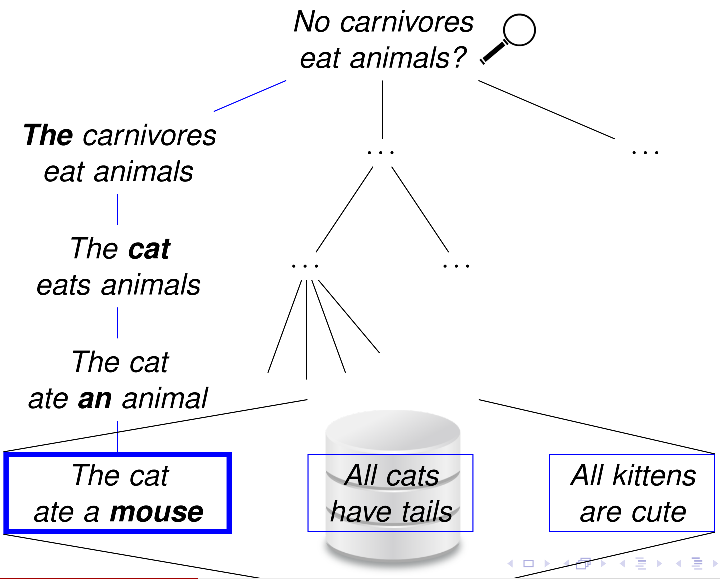

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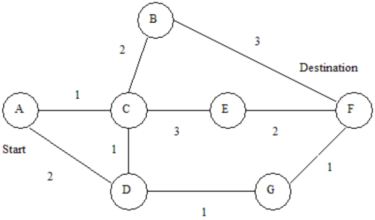

Nodes (*fact*, truth maintained $\in \{\text{true}, \text{false}\}$)

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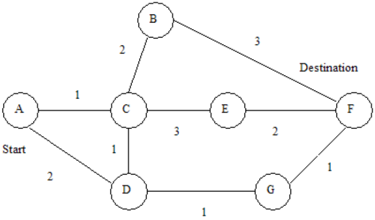

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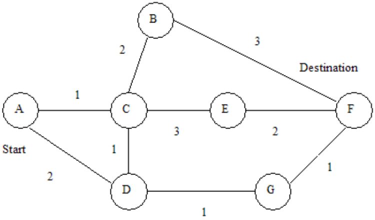

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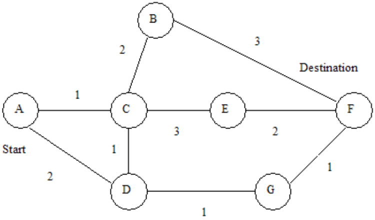

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Edges Mutations of the current fact
Edge Costs How "wrong" an inference step is (learned)

An Example Search (as reverse inference)

Search mutates *opposite* to polarity

organism		organism
animal		animal
↓ carnivores	→	↓ 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*

		organism		living thing
		animal	consume	organism
Current Node:	$\uparrow$ **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

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Current Node:

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All$_{\downarrow\uparrow}$	kitties	slurp	chordate

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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
$\uparrow$ **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)

No carnivores eat animals

The carnivores eat animals?

*The **feline** eats animals*

***All** carnivores eat animals*

…

An Example Search (as graph search)

The carnivores eat animals

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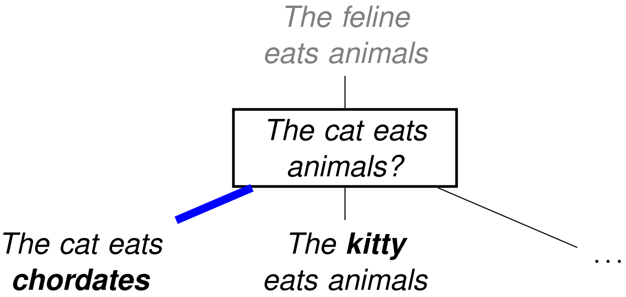
*The cat eats **chordate***

...

An Example Search (as graph search)



An Example Search (as graph search)

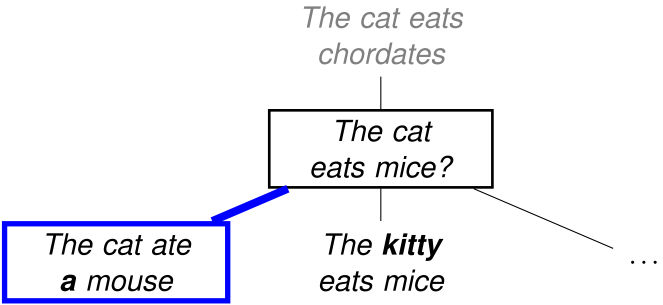
The cat eats animals

|

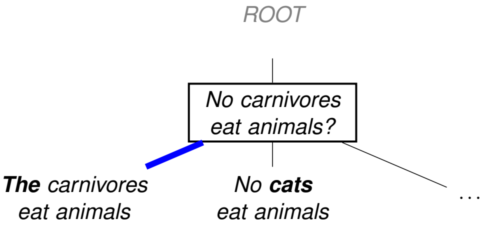
The cat eats chordates?

*The cat eats **mice*** — *The cat eats **dogs*** — …

An Example Search (as graph search)



An Example Search (with edges)



Template	Instance	Edge
Operator Negate		

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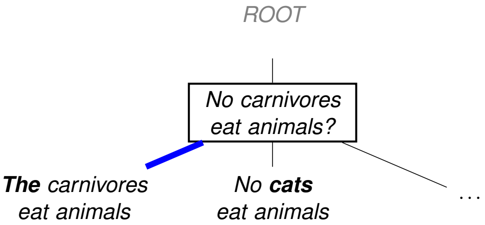

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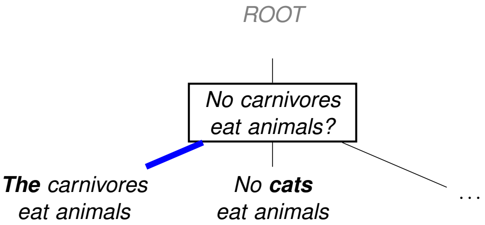

Template	**Instance**	**Edge**
Operator Negate	*No* $\rightarrow$ *The*	*No carnivores eat animals* $\rightarrow$ *The carnivores eat animals*

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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Want to make likely (but not certain) inferences.

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

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* $\xrightarrow{|}$ *diurnal*, *all* $\xrightarrow{\curlywedge}$ *not all*

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

Contribution: Simple Transitivity

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

More complicated in (prior work on) Natural Logic:

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$\sqsubseteq$	$\sqsubseteq$	$\sqsubseteq$	$\#$	$\mid$	$\mid$	$\#$	$\#$
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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.
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- 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)

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

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- 4x improvement in recall.

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Complexity doesn't grow with knowledge base size.

Thanks!