# NaturalLI: Natural Logic Inference for Common Sense Reasoning

Gabor Angeli, Chris Manning

Stanford University

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*Kittens play with computers*

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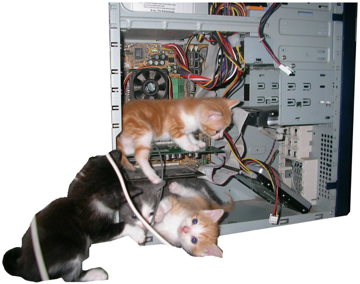

# Common Sense Reasoning for NLP

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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*

*People drive cars*

# Common Sense Reasoning for Vision

*Dogs drive cars*

*People drive cars*

*Baseball is played underwater*

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# Prior Work on Common Sense Reasoning

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

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- RTE Challenges.
- 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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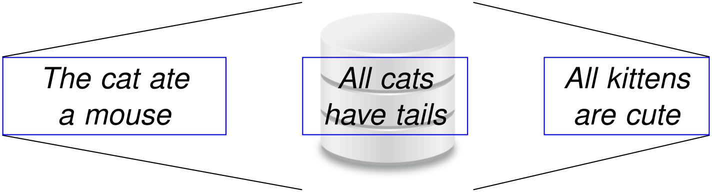

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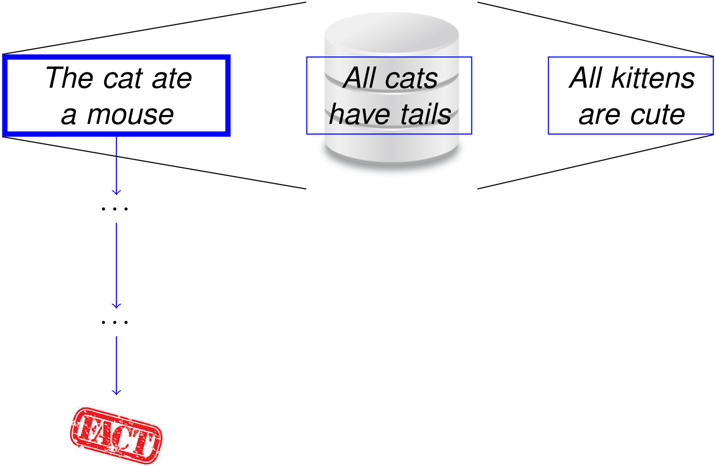

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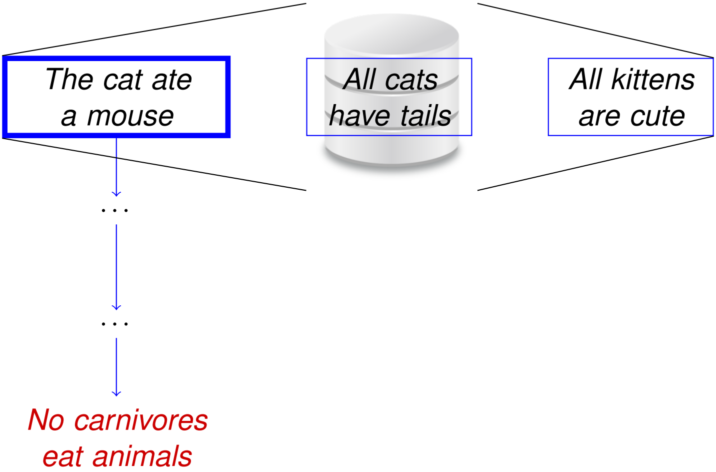

# Infer new facts...

*The cat ate a mouse*


*All kittens are cute*

...

...

*No carnivores eat animals*

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

# Infer new facts...

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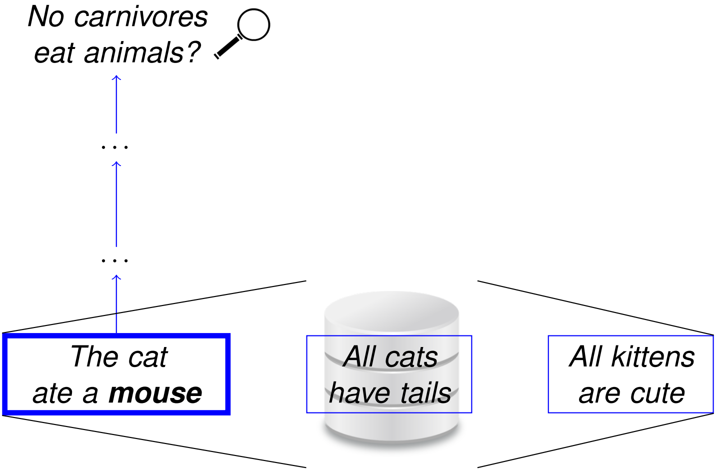
← Don't want to store all of these!

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



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

*No carnivores eat animals?*

***The** carnivores eat animals*

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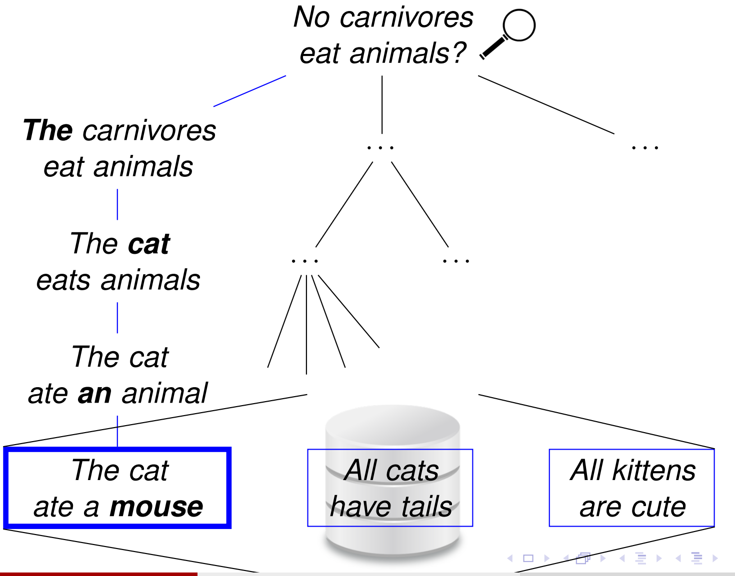
# ...Without aligning to any particular premise.



# 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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**Cognitively easy inferences are easy:**

- Most cats eat mice
  ∴ *Most cats eat **rodents***

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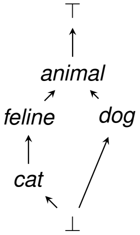
**Facts are text; inference is lexical mutation**

# Natural Logic and Polarity

**Treat hypernymy as a *partial order*.**



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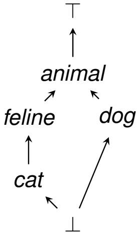


***Polarity*** **is the direction a lexical item can move in the ordering.**

animal

feline

$\boxed{\text{cat}}$

house cat

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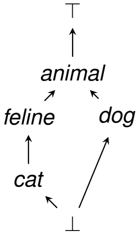


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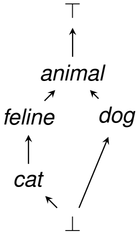


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living thing

animal

↑ feline

cat

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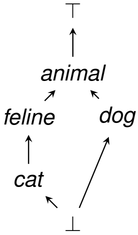


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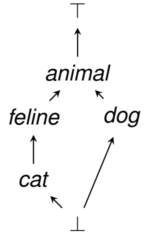


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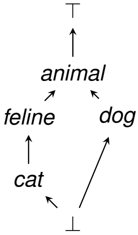


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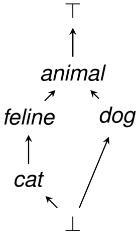


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# An Example Inference

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

**Mutations must respect *polarity*.**

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**Inference is reversible.**

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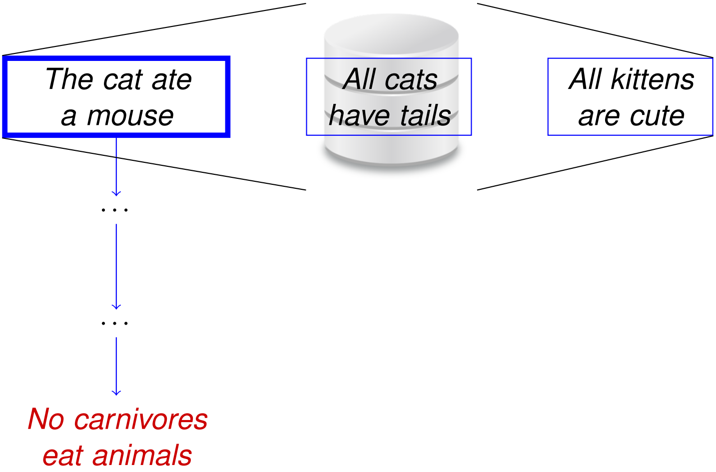
✓ Still captures common inferences.
- We make these types of inferences regularly and instantly.
- We expect *readers* to make these inferences instantly.

# Natural Logic Inference is Search



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*No carnivores eat animals?*

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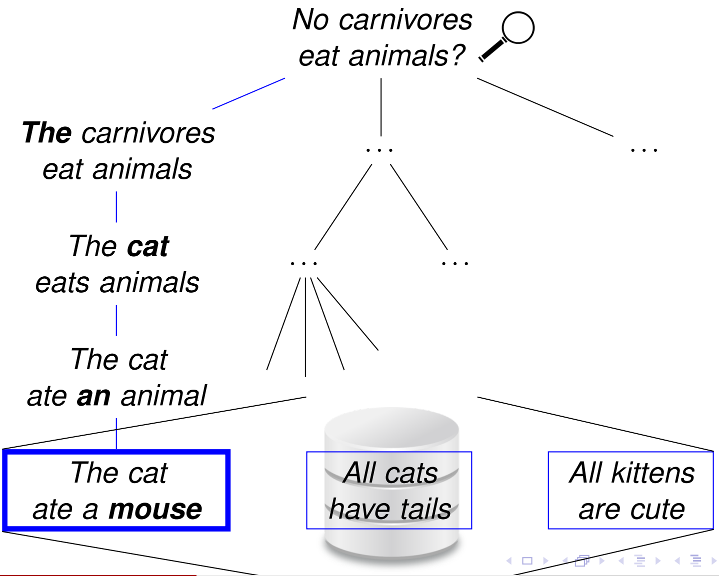

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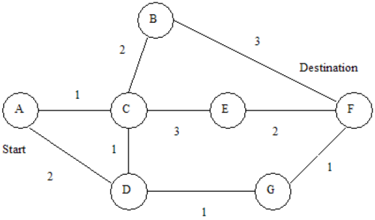


**Nodes** ( *fact*, truth maintained $\in \{\text{true}, \text{false}\}$)

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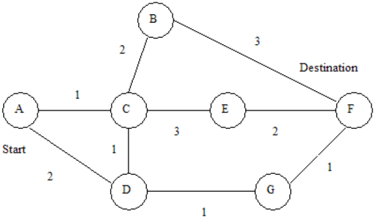


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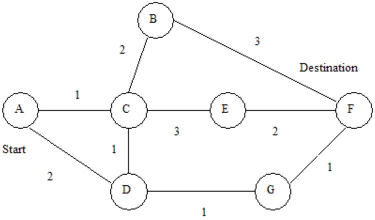


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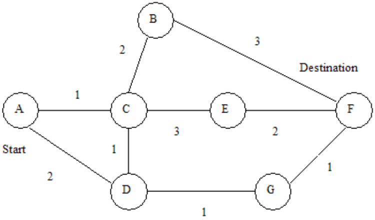


| | |
|---|---|
| **Nodes** | ( *fact*, truth maintained $\in \{\text{true}, \text{false}\}$) |
| **Start Node** | ( *query fact*, *true* ) |
| **End Nodes** | *any known fact* |
| **Edges** | Mutations of the current fact |
| **Edge Costs** | How "wrong" an inference step is (learned) |

# An Example Search (as reverse inference)

**Search mutates *opposite* to polarity**

| organism | | organism |
|---|---|---|
| animal | | animal |
| $\downarrow$ carnivores | → | $\downarrow$ carnivores |
| felines | | felines |

# An Example Search (as reverse inference)

**Truth maintained:** *true*

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

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

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| | | | |
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**Truth maintained:** *false*

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

# An Example Search (as reverse inference)

**Truth maintained:** *false*

carnivores | | animals
felines | consume | chordates

**Current Node:** $\uparrow$ **The**$_{\uparrow\uparrow}$ | $\uparrow$ cats | $\uparrow$ eat | $\uparrow$ **mice**

**All**$_{\downarrow\uparrow}$ | kitties | slurp | fieldmice

# An Example Search (as reverse inference)

**Truth maintained:** *false*

**Current Node:**

| | carnivore | | | animal |
|---|---|---|---|---|
| | feline | consumed | | chordate |
| ↑ **The**$_{\uparrow\uparrow}$ | ↑ cat | ↑ ate | ↑ **a**$_{\uparrow\uparrow}$ | ↑ 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 |

*No carnivores eat animals?*

# An Example Search (as graph search)

*ROOT*

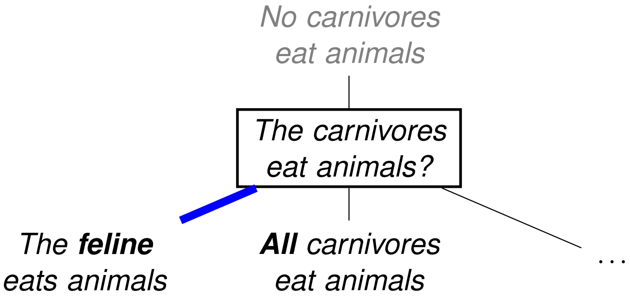
*No carnivores eat animals?*

***The** carnivores eat animals*

*No **cats** eat animals*

. . .

# An Example Search (as graph search)



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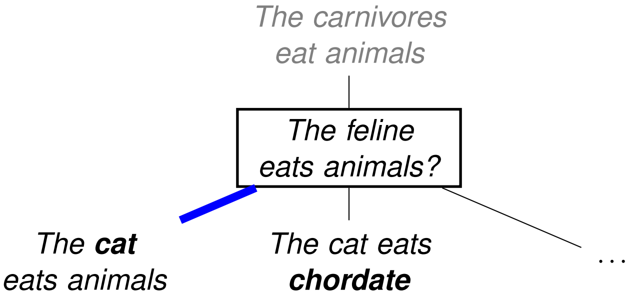

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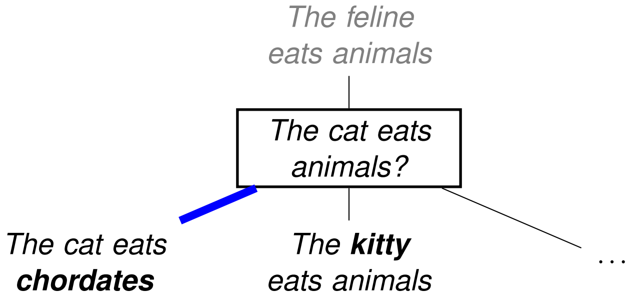


# An Example Search (as graph search)

*The cat eats animals*

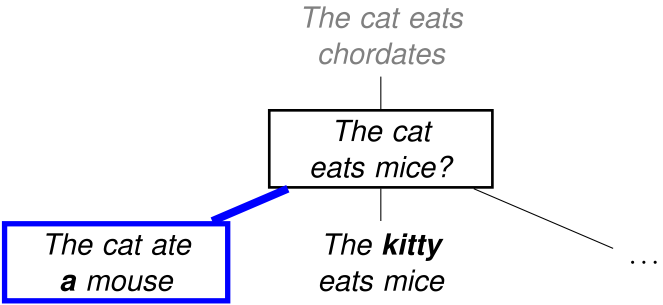
*The cat eats chordates?*

*The cat eats **mice***

*The cat eats **dogs***

...

# An Example Search (as graph search)



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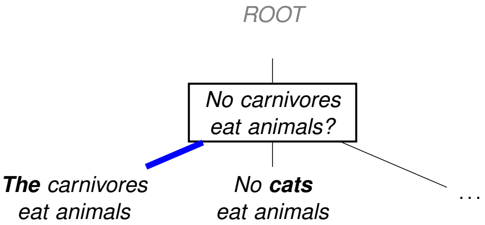


| Template | Instance | Edge |
| --- | --- | --- |
| Operator Negate | | |

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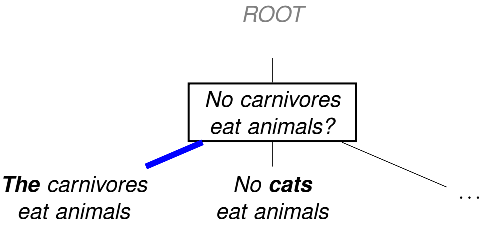


| **Template** | **Instance** | **Edge** |
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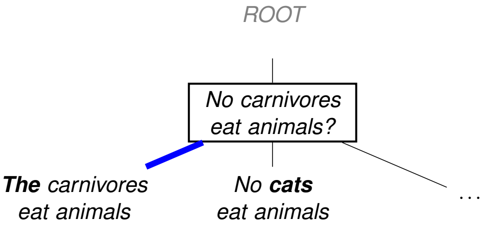


| **Template** | **Instance** | **Edge** |
| --- | --- | --- |
| Operator Negate | *No* $\rightarrow$ *The* | *No carnivores eat animals* $\rightarrow$ *The carnivores eat animals* |

# 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* |

# "Soft" Natural Logic

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- Same motivation as Markov Logic, Probabilistic Soft Logic, etc.

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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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**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)

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- A semi-curated collection of common-sense facts.

  *not all birds can fly*
  *noses are used to smell*
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- 4x improvement in recall.

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**Complexity doesn't grow with knowledge base size.**

# Thanks!