Kittens play with yarn

Kittens play with computers
Kittens play with yarn

Kittens play with computers
The city refused the demonstrators a permit because they feared violence.
The city refused the demonstrators a permit because they feared violence.

- A city fears violence
- Demonstrators fear violence
The city refused the demonstrators a permit because they feared violence.

a city fears violence
demonstrators fear violence

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

cakes come with cherries

cakes are eaten using cherries
The city refused the demonstrators a permit because they feared violence.

a city fears violence
demonstrators fear violence

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).
- Theorem proving (e.g., Datalog).
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**Textual Entailment:** Rich inference; small data.
- RTE Challenges.
- Episodic Logic (Schubert, 2002).
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- RTE Challenges.
- Episodic Logic (Schubert, 2002).

**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
Start with a large knowledge base

- The cat ate a mouse
- All cats have tails
- All kittens are cute
Infer new facts...

- The cat ate a mouse
- All cats have tails
- All kittens are cute
The cat ate a mouse

All cats have tails

All kittens are cute

No carnivores eat animals
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 run inference over every fact!
Infer new facts...

- The cat ate a mouse
- All cats have tails
- All kittens are cute

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

↓ Don’t want to store all of these!

No carnivores eat animals
Infer new facts...on demand from a query...

No carnivores eat animals?

The cat ate a mouse

All cats have tails

All kittens are cute
...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

All kittens are cute
Without aligning to any particular premise.

The carnivores eat animals.

The cat eats animals.

The cat ate an animal.

The cat ate a mouse.

No carnivores eat animals?

All cats have tails.

All kittens are cute.
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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Maintain good properties of fuzzy lookup.

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- Minimal pre-processing of query.
- Minimal pre-processing of knowledge base.
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Natural Logic
s/Natural Logic/Syllogistic Reasoning/g

Some cat ate a mouse
(all mice are rodents)
∴ Some cat ate a rodent
Natural Logic as Syllogisms

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Some cat ate a mouse
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Cognitively easy inferences are easy:

Most cats eat mice

∴ Most cats eat rodents
Natural Logic as Syllogisms

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“All students who know a foreign language learned it at university.”
Natural Logic as Syllogisms

Some cat ate a mouse
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∴ Some cat ate a *rodent*

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“All students who know a foreign language learned it at university.”
∴ “They learned it at school.”

Facts are text; inference is lexical mutation
Treat hypernymy as a **partial order**.

\[
\downarrow
\uparrow
\quad \text{animal} \quad \downarrow
\uparrow
\quad \text{feline} \quad \text{dog}
\quad \uparrow
\text{cat}
\downarrow
\]

Polarity is the direction a lexical item can move in the ordering.
Natural Logic and Polarity

Treat hypernymy as a *partial order*.

\[ \top \]
\[ \text{animal} \]
\[ \text{feline} \]
\[ \text{cat} \]
\[ \text{dog} \]
\[ \bot \]

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

animal

feline

**cat**

house cat
Natural Logic and Polarity

Treat hypernymy as a *partial order*.

\[
\begin{array}{c}
\top \\
\downarrow \\
\text{animal} \\
\downarrow \\
\text{feline} \\
\downarrow \\
\text{cat} \\
\downarrow \\
\bot
\end{array}
\]

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

\[
\begin{array}{c}
\text{animal} \\
\uparrow \\
\text{feline} \\
\uparrow \\
\text{cat} \\
\uparrow \\
\text{house cat}
\end{array}
\]
Natural Logic and Polarity

Treat hypernymy as a *partial order*.

\[
\top \quad \text{animal} \quad \downarrow \quad \text{feline} \quad \downarrow \quad \text{dog} \quad \downarrow \quad \text{cat} \quad \downarrow \quad \bot
\]

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

\[
\text{living thing} \quad \uparrow \quad \text{animal} \quad \uparrow \quad \text{feline} \quad \uparrow \quad \text{cat}
\]
Natural Logic and Polarity

Treat hypernymy as a *partial order*.

\[
\begin{array}{c}
\top \\
\uparrow \\
\text{animal} \\
\uparrow \\
\text{feline} \\
\uparrow \\
\text{cat} \\
\downarrow \\
\bot \\
\end{array}
\]

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

\[
\begin{array}{c}
\text{thing} \\
\downarrow \\
\text{living thing} \\
\uparrow \text{animal} \\
\text{feline} \\
\end{array}
\]
Natural Logic and Polarity

Treat hypernymy as a *partial order*.

\[ \top \quad \downarrow \quad \text{animal} \quad \downarrow \quad \text{feline} \quad \text{dog} \quad \downarrow \quad \text{cat} \quad \downarrow \quad \bot \]

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

\[ \text{thing} \quad \downarrow \quad \text{living thing} \quad \downarrow \quad \text{animal} \quad \downarrow \quad \text{feline} \]
Natural Logic and Polarity

Treat hypernymy as a *partial order*.

\[
\begin{array}{c}
\top \\
\downarrow \\
\text{animal} \\
\downarrow \\
\text{feline} & \text{dog} \\
\downarrow \\
\text{cat} \\
\downarrow \\
\bot
\end{array}
\]

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

\[
\begin{array}{c}
\text{living thing} \\
\downarrow \\
\text{animal} \\
\text{feline} \\
\downarrow \\
\text{cat}
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\[
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\uparrow \\
\downarrow \\
\text{cat} \\
\downarrow \\
\bot
\]

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

animal

feline

↓ cat

house cat
Quantifiers determines the *polarity* (↑ or ↓) of words.
Quantifiers determines the *polarity* (↑ or ↓) of words.
Mutations must respect *polarity*.

↑ All ↓

↑ house cats ↓

↑ eat ↓

↑ mice ↓

gobelines
cats
kitties

consume
slurp

placentals
rodents
fieldmice
An Example Inference

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

- **↑ All**
  - felines
  - cats
  - kitties

- **↓ house cats**

- **↑ consume**
  - placentals
  - rodents
  - mice

- **↑ mice**
  - fieldmice
An Example Inference

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

Mutations must respect *polarity*.

\[ \uparrow \text{All} \downarrow \uparrow \]

felines
cats
down house cats
kitties
↑ consume
eat
↑ rodents
mice
↑ fieldmice
pine vole
An Example Inference

Quantifiers determines the *polarity* (∧ or ∨) of words.
Mutations must respect *polarity*.

↑ All ↓

felines

cats

↓ house cats

kitties

↑ consume

placentals

rodsents

↑ mice

eat

fieldmice
An Example Inference

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

Mutations must respect *polarity*.

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An Example Inference

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

Mutations must respect *polarity*.

Inference is reversible.

↑ All ↓

↑ house cats

↑ consume

↑ rodents

↑ All ↓

↓ house cats

↓ eat

↓ mammals

↓ placentals

↑ felines

↑ cats

↑ house cats

↑ kittens

↑ eat

↑ rodents

↑ mice

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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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✓ 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.
The cat ate a mouse

All cats have tails

All kittens are cute

No carnivores eat animals
Natural Logic Inference is Search

No carnivores eat animals?

The carnivores eat animals

The cat eats animals

The cat ate an animal

The cat ate a mouse

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Nodes

\[(\text{fact}, \text{truth maintained} \in \{\text{true}, \text{false}\})\]
Natural Logic Inference is Search

Nodes

( fact, truth maintained ∈ \{true, false\} )

Start Node

( query fact, true )

End Nodes

any known fact
Natural Logic Inference is Search

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(fact, truth maintained ∈ {true, false})

Start Node
(query fact, true)

End Nodes
any known fact

Edges
Mutations of the current fact
Natural Logic Inference is Search

Nodes
(\textit{fact}, \textit{truth maintained} \in \{\textit{true}, \textit{false}\})

Start Node
(\textit{query fact}, \textit{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

![Diagram showing the relationship between organisms, animals, carnivores, and felines.](image)
An Example Search (as reverse inference)

Truth maintained: true

Current Node:

- organism
- animal
- consume
- living thing
- organism
- carnivores
- felines
- eat
- slurp
- animals
- chordate

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An Example Search (as reverse inference)

Truth maintained: false

Current Node: ↑ The↑↑ All↓↑ organism animal carnivorues consume ↑ eat slurp living thing organism chordate
An Example Search (as reverse inference)

Truth maintained: false

Current Node:

- The
- felines
- eat
- animals
- carnivores
- consume
- living thing
- organism
- chordate

The current node is the `↑ animals` node, indicating a search for animals. The truth maintained is false, suggesting that the search did not find any evidence to confirm the statement.
An Example Search (as reverse inference)

Truth maintained: false

Current Node:

- **The cats**
- All carnivores
- felines
- consume
- eat
- slurp
- living thing
- organism
- chordate

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An Example Search (as reverse inference)

Truth maintained: false

Current Node:
- The
- All
- cats
- eat
- chordates
- carnivores
- felines
- consume
- kittens
- slurp
- animals
- mice

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An Example Search (as reverse inference)

Truth maintained: false

Current Node:

- **The**
- **All**
- **cats**
- **kitties**
- **eat**
- **slurp**
- **mice**
- **fieldmice**

- **carnivores**
- **felines**
- **consume**
- **animals**
- **chordates**
An Example Search (as reverse inference)

Truth maintained: false

Current Node:

↑ The↑↑
All↑

↑ cat
kitty

↑ ate
slurped

↑ a↑↑
All↑↑

↑ mouse
fieldmouse
An Example Search (as graph search)

Shorthand for a node:

- organism
- animal
- consume
- living thing
- organism

↑ No ↓
↑ carnivores ↓
↑ felines ↓
↓ eat
↓ slurp
↑ animals
↑ 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)

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

The feline eats animals?

The cat eats animals

The cat eats chordate

...
An Example Search (as graph search)

- The feline eats animals
- The cat eats animals?
- The cat eats chordates
- The kitty eats animals
- ...
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)

The cat eats chordates

The cat eats mice?

The cat ate a mouse

The kitty eats mice

...
An Example Search (with edges)

ROOT

No carnivores eat animals?

The carnivores eat animals

No cats eat animals

Template: Operator Negate

Instance

Edge

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An Example Search (with edges)

- **Operator**: Negate
- **Template**: No carnivores eat animals?
- **Instance**: No cats eat animals
- **Edge**: No → The
No carnivores eat animals?

Template:
Operator Negate

Instance:
No → The carnivores eat animals

Edge:
No carnivores eat animals → The carnivores eat animals
# Edge Templates

<table>
<thead>
<tr>
<th>Template</th>
<th>Instance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyponym</td>
<td>cat → animal</td>
</tr>
<tr>
<td>Animal</td>
<td>cat → animal</td>
</tr>
<tr>
<td>Antonym</td>
<td>good → bad</td>
</tr>
<tr>
<td>Synonym</td>
<td>cat → true cat</td>
</tr>
<tr>
<td>Add Word</td>
<td>cat → ·</td>
</tr>
<tr>
<td>Delete Word</td>
<td>· → cat</td>
</tr>
<tr>
<td>Operator Weaken</td>
<td>some → all</td>
</tr>
<tr>
<td>Operator Strengthen</td>
<td>all → some</td>
</tr>
<tr>
<td>Operator Negate</td>
<td>all → no</td>
</tr>
<tr>
<td>Operator Synonym</td>
<td>all → every</td>
</tr>
<tr>
<td>Nearest Neighbor</td>
<td>cat → dog</td>
</tr>
</tbody>
</table>
“Soft” Natural Logic

Want to make likely (but not certain) inferences.

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

Detail: Variation among edge instances of a template.

WordNet: cat → feline vs. cup → container.

Nearest neighbors distance.

Each edge instance has a distance $f_i$.

Cost of an edge is $\theta_i \cdot f_i$.

Cost of a path is $\theta \cdot f$.

Can learn parameters $\theta_i$. 
“Soft” Natural Logic

Want to make likely (but not certain) inferences.

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- Each *edge template* has a cost $\theta \geq 0$. 

---

WordNet: cat $\rightarrow$ feline vs. cup $\rightarrow$ container. Nearest neighbors distance.

Each *edge instance* has a distance $f_i$. Cost of an edge is $\theta_i \cdot f_i$. Cost of a path is $\theta \cdot f$. Can learn parameters $\theta$. 

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Contribution: Simple Transitivity

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

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:

- $\textit{nocturnal} \uparrow \rightarrow \textit{diurnal}$, $\textit{all} \uparrow \rightarrow \textit{not all}$
- $\therefore \textit{all bats are nocturnal} \uparrow \rightarrow \textit{not all bats are diurnal}$
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More complicated in (prior work on) Natural Logic:

- nocturnal $\uparrow$ diurnal, all $\leftrightarrow$ not all
- \[
\therefore \text{ all bats are nocturnal} \not\rightarrow \text{ not all bats are diurnal}
\]
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- *nocturnal* $\uparrow \rightarrow$ *diurnal*, *all* $\subseteq \rightarrow$ *not all*

  $\therefore$ *all bats are nocturnal* $\uparrow \rightarrow$ *not all bats are diurnal*
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<thead>
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<th>$\exists$</th>
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Natural Logic Analog of Transitivity:

State  Fact  Mutation
⇒  all bats are nocturnal,
Contribution: Simple Transitivity

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Gabor Angeli, Chris Manning (Stanford) | NaturalLI: Natural Logic Inference for Common Sense Reasoning | October 26, 2014
Contribution: Simple Transitivity

Natural Logic Analog of Transitivity:

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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)
- *Classify* entailment after aligning premise and hypothesis.

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Applicable (1,5,6) | 76  | 90  | 89 |
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- A semi-curated collection of common-sense facts.
  
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  \textit{nobody wants to die}
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- Negatives: ReVerb extractions marked false by Turkers.
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ConceptNet Results

Systems

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4x improvement in recall.

Gabor Angeli, Chris Manning (Stanford)  NaturalLI: Natural Logic Inference for Com
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Complexity doesn’t grow with knowledge base size.
Thanks!