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Holographic CCG Parsing

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Motivation

➢ Explicit modeling of phrase structure

- Recent CCG supertagging and parsing models demonstrate high performance yet rely on **non-explicit modeling** of dependencies between words through neural networks.

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☞ **Explicit modeling** of phrase structure with neural networks.

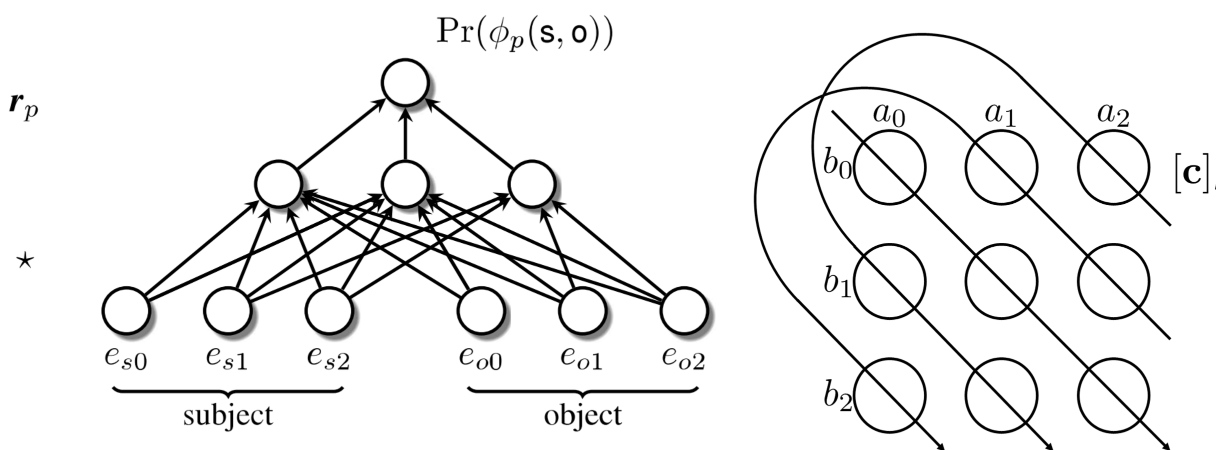
➢ Syntactic phrase-level representation

☞ Compose **syntactically rich phrase-level representations** while maintaining training efficiency.

Holographic CCG

➢ Holographic Embeddings (Nickel et al., 2016)

- Embedding knowledge graphs into vector space for statistical modeling
- Vector composition using **circular correlation** to capture dependencies between entities
- **Similarity of knowledge graphs and phrase structures that need to capture dependencies between components**



$$\mathbf{c} = \mathbf{a} \star \mathbf{b}$$

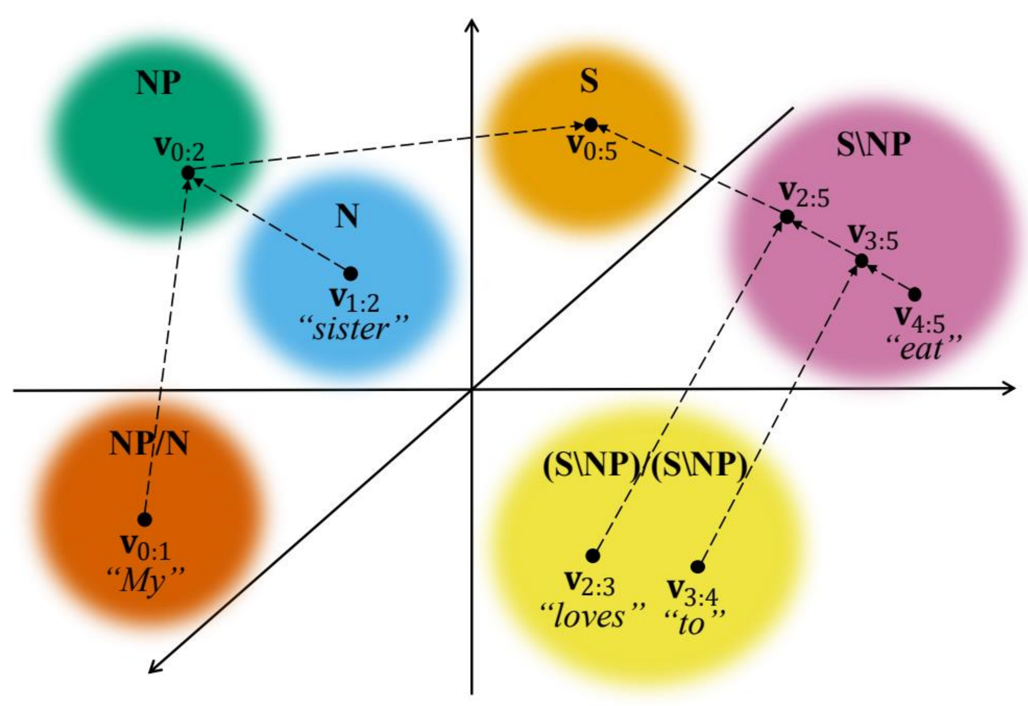
$$[\mathbf{c}]_k = [\mathbf{a} \star \mathbf{b}]_k = \sum_{i=0}^{d-1} a_i b_{(k+i)} \mod d$$

$$c_0 = a_0 b_0 + a_1 b_1 + a_2 b_2$$
$$c_1 = a_0 b_1 + a_1 b_2 + a_2 b_0$$
$$c_2 = a_0 b_2 + a_1 b_0 + a_2 b_1$$

(Nickel et al., 2016)

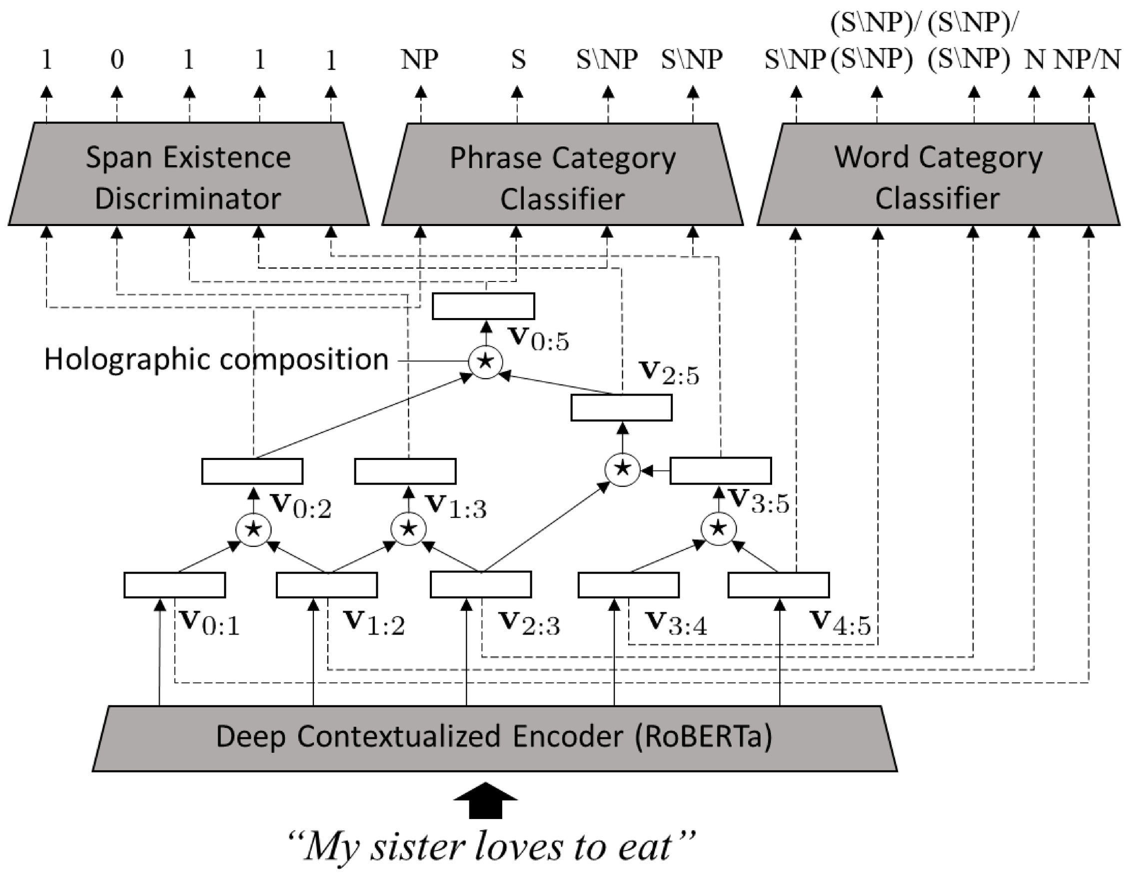
➢ Holographic CCG (Hol-CCG)

- Formulate CCG as a **recursive compositional operation** between distributed representations in a vector space.
- Applicable to **Supertagging** and **Span-based Parsing**.



➢ Model Structure

1. Encode word sequence into distributed representations.
2. Recursively compose phrase-level representations.
3. Predict CCG categories and span existence.



➢ Span-based Parsing

1. Store word-level representations.
2. Recursively compose phrase-level representations.
3. Directly evaluates category assignment to phrases.

Algorithm 1: Span-based CKY parsing

$\mathbf{v}_{0:1}, \mathbf{v}_{1:2}, \cdots, \mathbf{v}_{n-1:n} = Encode(w_1, w_2, \cdots, w_n)$;
for $i = 0, \cdots, n-1$ **do**
  $P_w(i, i+1) = SM(\mathbf{Q}_w \sigma(LN(\mathbf{U}_w \mathbf{v}_{i:i+1} + \mathbf{b}_w)) + \mathbf{c}_w)$; ▷ Equation (11)
  for $C \in \{X | P_w(i, i+1)[X] > t_w = 0.1\}$ **do**
    $prob[i, i+1, C] = \log P_w(i, i+1)[C]$;
    $vector[i, i+1, C] = \mathbf{v}_{i:i+1}$;
for $\ell = 2, \cdots, n$ **do**
  for $i = 0, \cdots, n-\ell$ **do**
    $j = i + \ell$;
    for $k = i+1, \cdots, j-1$ **do**
      for $C_1 \in \{X | prob[i, k, X] > 0\}$ **do**
        $\mathbf{v}_{i:k} = vector[i, k, C_1]$;
        for $C_2 \in \{X | prob[k, j, X] > 0\}$ **do**
          $\mathbf{v}_{k:j} = vector[k, j, C_2]$;
          for $C \in \{X | C_1 C_2 \to X \in R\}$ **do**
            $\mathbf{v}_{i:j} = \mathbf{v}_{i:k} \star \mathbf{v}_{k:j}$; ▷ Equations (4) and (5)
            $P_s(i, j) = SM(\mathbf{Q}_s \sigma(LN(\mathbf{U}_s \mathbf{v}_{i:j} + \mathbf{b}_s)) + \mathbf{c}_s)$; ▷ Equation (13)
            if $P_s(i, j)[e] > t_s = 0.01$ **then**
              $P_p(i, j) = SM(\mathbf{Q}_p \sigma(LN(\mathbf{U}_p \mathbf{v}_{i:j} + \mathbf{b}_p)) + \mathbf{c}_p)$; ▷ Equation (12)
              if $P_p(i, j)[C] > t_p = 0.01$ **then**
                $p = \log P_p(i, j)[C] + \log P_s(i, j)[e] + prob[i, k, C_1] + prob[k, j, C_2]$;
                if $p > prob[i, j, C]$ **then**
                  $prob[i, j, C] = p$;
                  $backpointer[i, j, C] = (k, C_1, C_2)$;
                  $vector[i, j, C] = \mathbf{v}_{i:j}$;

Experiment

- Dataset: CCGbank (Hockenmaier et al., 2007)
- Calculate the model's prediction error by cross entropy
  - ➢ Category assignment to words and phrases: $\mathcal{L}_w, \mathcal{L}_p$
  - ➢ Existence of span: $\mathcal{L}_s$
- Compare models by changing the combination of back-propagating errors ($\mathcal{L}$)
  - ➢ Baseline: $\mathcal{L} = \mathcal{L}_w$
  - ➢ Hol-CCG: $\mathcal{L} = \mathcal{L}_w + \mathcal{L}_p + \mathcal{L}_s$
- Supertagging by Baseline and Hol-CCG
- Parsing using C&C Parser (Clark and Curran, 2007) and Hol-CCG's span-based parsing

Result & Discussion

- Hol-CCG outperforms baseline.
- Span-based Parsing outperforms C&C Parser.
- **Explicit modeling of word/phrase dependencies** through composition of phrase representations is effective for both supertagging and parsing.

Training Objectives	Parser	Acc	LF
$\mathcal{L}_w$(baseline)	C&C	96.41 ± 0.03	91.77 ± 0.03
$\mathcal{L}_w + \mathcal{L}_p + \mathcal{L}_s$(Hol-CCG)	C&C	$\underline{\mathbf{96.59 \pm 0.02}}$	$\underline{\mathbf{92.03 \pm 0.04}}$
	Span	-	$\underline{\mathbf{92.61 \pm 0.03}}$

- Hol-CCG achieved SoTA in supertagging accuracy and LF with C&C Parser.
- Hol-CCG's span-based parsing is competitive with current SoTA performance.

Model	Parser	Acc	LF
Vaswani et al., 2016	C&C	94.5	88.32
Bhargava and Penn, 2020	C&C	96.00	90.9
Prange et al., 2021	C&C	96.22	90.91
Clark, 2021	C&C	-	91.9
	Span	-	<u>**92.9**</u>
Hol-CCG	C&C	<u>**96.60**</u>	<u>**92.12**</u>
	Span	-	92.67

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