Connectionist-Inspired Incremental PCFG Parsing

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Introduction

Goals and Motivation

Create a cognitively-motivated parser

- [Schuler, 2009] outlines a cognitively-motivated parser, which requires book-keeping nodes built in to work with PCFGs (engineering fix).
- We'd like to be able to strip out elements included solely for engineering.

Background

Why PCFGs? [Jurafsky, 1996]

- Simple
- Widespread use, community understanding
- Easily integrated with other technologies
- Latent variable training procedures easily obtained [Petrov et al., 2006]
- Tractable recognition $\mathcal{O}(n^3)$

Problems with CKY

- Not incremental $\mathcal{O}(n^3)$
- In certain applications, word/phrase breaks not certain (ASR, MT, etc)

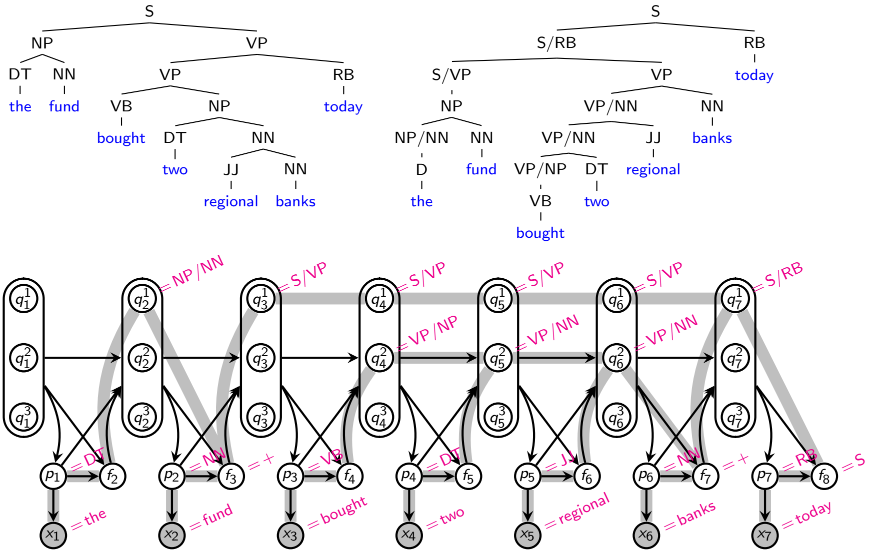
Background

Why Incremental?

- Operates on incomplete information
- Can make use of information about recent content/structure
- $\mathcal{O}(n)$
- Streaming task

Must operate on a beam to efficiently stream

The Setup


S
NP
VP
DT
NN
the
fund
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bought
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regional
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S/RB
RB
today
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the
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=VP/NP
=VP/NN
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=DT
=NN
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=VB
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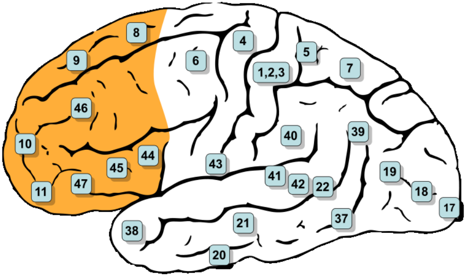
=NN
=+
=RB
=S
=the
=fund
=bought
=two
=regional
=banks
=today

Neural Motivation



- Corresponding structure seen in C-R axis of DL-PFC (proximal to Broca's) [Petrides, 1987, Botvinick, 2007]

Cognitive Motivation

- Can define graph-theory connected components (sub-graphs) of a semantic dependency graph (of 'concepts' [Kintsch, 1988] or discourse referents)
- F-node = create new independent connected component linked via an episodic trace [Sederberg et al., 2008] to previous connected component
- Connected components act as 'chunks' [Miller, 1956]

Design Motivations

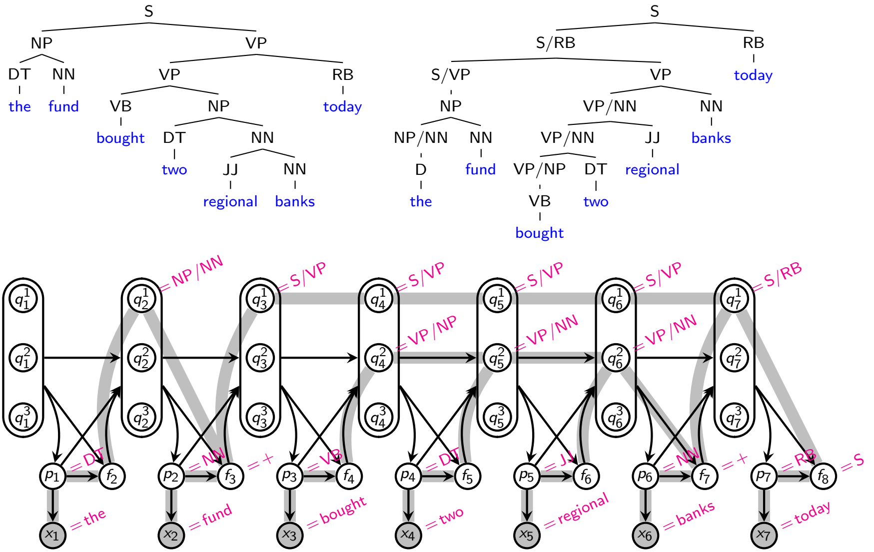
Schuler (2009) based on:

- HHMM [Murphy and Paskin, 2001] but too general (next slide)
- 4 layers [Cowan, 2001]

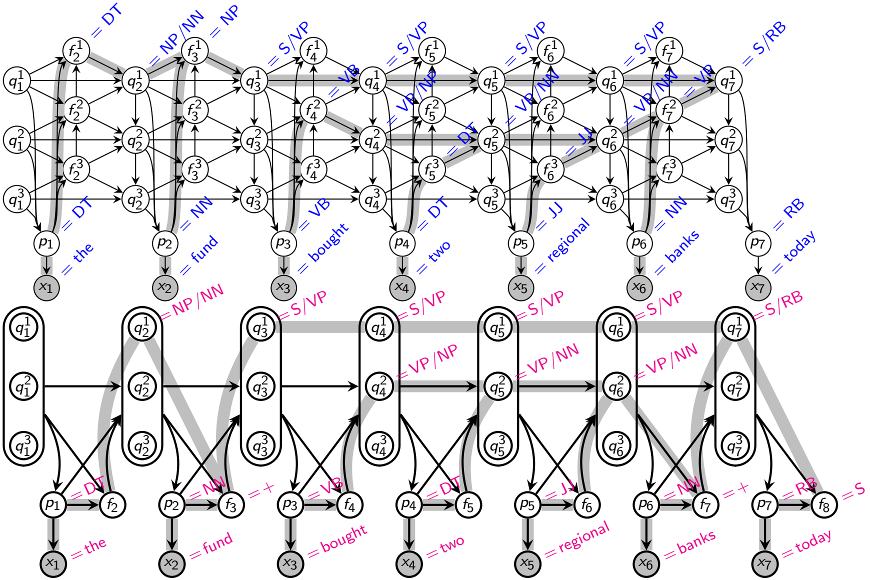
Serial recall chunking [Miller, 1956] seems to be different from language chunking or chunking with distractions [Cowan, 2001].

[Schuler et al., 2010] found 4 layers yielded >99.9% coverage of WSJ.

Single Expansion, Single Reduction



The Model



= DT
= NP/NN
= NP
= S/VP
= S/VP
= S/VP
= S/VP
= S/RB
= VB
= VP/NP
= VP/NN
= VP/NN
= VP
= DT
= JJ
= DT
= NN
= VB
= DT
= JJ
= NN
= RB
= the
= fund
= bought
= two
= regional
= banks
= today
=NP/NN
=S/VP
=S/VP
=S/VP
=S/VP
=S/RB
=VP/NP
=VP/NN
=VP/NN
=DT
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=+
=VB
=DT
=JJ
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=RB
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=fund
=bought
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=regional
=banks
=today

Tree Training

Split-Merge Berkeley Grammar Trainer
[Petrov et al., 2006]

- Input: TB-annotated sentences
  (S (ADVP happily) (NP-SUBJ John). . .)

Tree Training

Split-Merge Berkeley Grammar Trainer
[Petrov et al., 2006]

- Input: TB-annotated sentences
  (S (ADVP happily) (NP-SUBJ John)...)
- EM classification performed over a given number of split-merge cycles
- Output: Subcat-Annotated PCFG
  (S^g_10 -> ADVP^g_21 NP^g_4 1.462527*E*-18)

Profit:

- More specialized and informative PCFG

Cost:

- Training time
- Increased size of grammar

Through the Crucible

Testing Methodology

Internal Testing

- Timing Comparisons [Hidden State Factoring]

External Testing

- Roark (2001) Parser [Incremental]
- Petrov and Klein (2007) Parser [CKY Chart Parser]

Paydirt

Accuracy Results

System	R	P	F
Schuler et al. 2008/2010	83.4	83.7	83.5
Roark 2001	86.6	86.5	86.5
Schuler 2009* (2000)	87.9	87.8	87.8
van Schijndel et al (250)	85.6	87.1	86.3
van Schijndel et al (500)	86.8	87.4	87.1
van Schijndel et al (1000)	87.4	87.6	87.5
van Schijndel et al (2000)	87.9	87.8	87.8
van Schijndel et al (5000)	87.9	87.8	87.8
Petrov Klein (Binary)	88.1	87.8	88.0
Petrov Klein (+Unary)	88.3	88.6	88.5

*Without grammar trainer, Schuler 2009 (2000) F-Score = 75.06.

Paydirt

Timing Results

System	Sec/Sent
Schuler 2009	74
Current Model	12

Table : Speed comparison using a beam-width of 500 elements

Digging Deeper

Future Work

- Incremental Dependency Parsing (including Unbounded)
- Incremental Semantic Role Labelling
- Interactive associative memory access
- Coreference resolution

Questions?

Thanks!

Overtime

More slides!

Paydirt

Full Accuracy Results

System	R	P	F
Schuler et al. 2008/2010	83.4	83.7	83.5
Roark 2001	86.6	86.5	86.5
Schuler 2009 (2000)	87.9	87.8	87.8
van Schijndel et al (50)	75.9	84.6	80.0
van Schijndel et al (100)	81.7	85.6	83.6
van Schijndel et al (250)	85.6	87.1	86.3
van Schijndel et al (500)	86.8	87.4	87.1
van Schijndel et al (1000)	87.4	87.6	87.5
van Schijndel et al (1500)	87.6	87.7	87.7
van Schijndel et al (2000)	87.9	87.8	87.8
van Schijndel et al (5000)	87.9	87.8	87.8
Petrov Klein (Binary)	88.1	87.8	88.0
Petrov Klein (+Unary)	88.3	88.6	88.5

How does it work?

Theory/Equation time

Most likely sequence

$$\hat{q}_{1..T}^{1..D} \stackrel{\text{def}}{=} \underset{q_{1..T}^{1..D}}{\operatorname{argmax}} \prod_{t=1}^{T} \mathsf{P}_{\theta_Q}(q_t^{1..D} \mid q_{t-1}^{1..D}\, p_{t-1}) \cdot \mathsf{P}_{\theta_{P,d'}}(p_t \mid b_t^{d'}) \cdot \mathsf{P}_{\theta_X}(x_t \mid p_t) \quad (1)$$

where d' is the lowest non-empty q_t^d

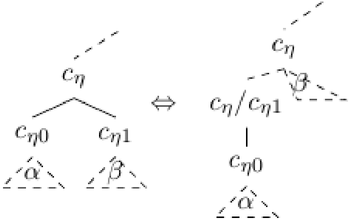
How does it work?

Theory/Equation time
Right-Corner: Single expansion, Single reduction
E-R+, E-R-, E+R+, E+R-

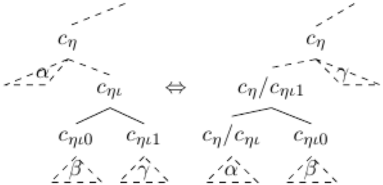
θ_Q

$$
\begin{aligned}
&\mathsf{P}_{\theta_Q}(q_t^{1..D} \mid q_{t-1}^{1..D}\ p_{t-1}) \\
&\overset{\text{def}}{=} \mathsf{P}_{\theta_F}(\text{'0'} \mid b_{t-1}^{d'}\ p_{t-1}) \cdot \mathsf{P}_{\theta_{A,d'}}(\text{'–'} \mid b_{t-1}^{d'-1}\ a_{t-1}^{d'}) \cdot [\![a_t^{d'-1} = a_{t-1}^{d'-1}]\!] \cdot \mathsf{P}_{\theta_{B,d'-1}}(b_t^{d'-1} \mid b_{t-1}^{d'-1}\ a_{t-1}^{d'}) \\
&\qquad \cdot [\![q_t^{1..d'-2} = q_{t-1}^{1..d'-2}]\!] \cdot [\![q_t^{d'..D} = \text{'–'}]\!] \\
&\quad + \mathsf{P}_{\theta_F}(\text{'0'} \mid b_{t-1}^{d'}\ p_{t-1}) \cdot \mathsf{P}_{\theta_{A,d'}}(a_t^{d'} \mid b_{t-1}^{d'-1}\ a_{t-1}^{d'}) \cdot \mathsf{P}_{\theta_{B,d'}}(b_t^{d'} \mid a_t^{d'}\ a_{t-1}^{d'+1}) \\
&\qquad \cdot [\![q_t^{1..d'-1} = q_{t-1}^{1..d'-1}]\!] \cdot [\![q_t^{d'+1..D} = \text{'–'}]\!] \\
&\quad + \mathsf{P}_{\theta_F}(\text{'1'} \mid b_{t-1}^{d'}\ p_{t-1}) \cdot \mathsf{P}_{\theta_{A,d'}}(\text{'–'} \mid b_{t-1}^{d'}\ p_{t-1}) \cdot [\![a_t^{d'} = a_{t-1}^{d'}]\!] \cdot \mathsf{P}_{\theta_{B,d'}}(b_t^{d'} \mid b_{t-1}^{d'}\ p_{t-1}) \\
&\qquad \cdot [\![q_t^{1..d'-1} = q_{t-1}^{1..d'-1}]\!] \cdot [\![q_t^{d'+1..D} = \text{'–'}]\!] \\
&\quad + \mathsf{P}_{\theta_F}(\text{'1'} \mid b_{t-1}^{d'}\ p_{t-1}) \cdot \mathsf{P}_{\theta_{A,d'}}(a_t^{d'+1} \mid b_{t-1}^{d'}\ p_{t-1}) \cdot \mathsf{P}_{\theta_{B,d'}}(b_t^{d'+1} \mid a_t^{d'+1}\ p_{t-1}) \\
&\qquad \cdot [\![q_t^{1..d'} = q_{t-1}^{1..d'}]\!] \cdot [\![q_t^{d'+2..D} = \text{'–'}]\!]
\end{aligned} \tag{2}
$$

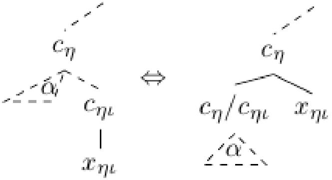
The right-corner transform (tree)



(1)



(2)



(3)

The right-corner transform (grammar)

$$\frac{c_\eta \rightarrow c_{\eta 0}\; c_{\eta 1} \in G}{c_\eta / c_{\eta 1} \rightarrow c_{\eta 0} \in G'} \tag{1}$$

$$\frac{c_{\eta\iota} \rightarrow c_{\eta\iota 0}\; c_{\eta\iota 1} \in G,\quad c_\eta \in C}{c_\eta / c_{\eta\iota 1} \rightarrow c_\eta / c_{\eta\iota}\; c_{\eta\iota 0} \in G'} \tag{2}$$

$$\frac{c_{\eta\iota} \rightarrow x_{\eta\iota} \in G,\quad c_\eta \in C}{c_\eta \rightarrow c_\eta / c_{\eta\iota}\; c_{\eta\iota} \in G'} \tag{3}$$

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