Joint Models for Concept-to-Text Generation

Ioannis Konstas

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University of Edinburgh

University of Washington, Seattle
22 October 2013
Grammar-based Generation
- Unsupervised Concept-to-text Generation w/ Hypergraphs, NAACL 2012

Inducing Document Plans
- Inducing Document Plans for Concept-to-text Generation, ACL 2013

Discriminative Reranking: An exploratory study
- Concept-to-text Generation via Discriminative Reranking, ACL 2012
Concept-to-text generation refers to the task of automatically producing textual output from nonlinguistic input (Reiter and Dale, 2000).
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<table>
<thead>
<tr>
<th>Wind Chill</th>
<th>Temperature</th>
<th>Wind Speed</th>
<th>Wind Direction</th>
<th>Gust</th>
<th>Precipitation Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Min</td>
<td>Time Min</td>
<td>Time Min</td>
<td>Time Mode</td>
<td>Time Min</td>
<td>Time Min</td>
</tr>
<tr>
<td>Mean Max</td>
<td>Mean Max</td>
<td>Mean Max</td>
<td></td>
<td>Mean Max</td>
<td>Mean Max</td>
</tr>
<tr>
<td>06-21 0</td>
<td>06-21 52</td>
<td>06-21 11</td>
<td>06-21 S</td>
<td>06-21 0</td>
<td>06-21 26</td>
</tr>
<tr>
<td>0</td>
<td>61</td>
<td>22</td>
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<td>20</td>
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<td>70</td>
<td>29</td>
<td></td>
<td>39</td>
<td>39</td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sky Cover</th>
<th>Rain Chance</th>
<th>Snow Chance</th>
<th>Sleet Chance</th>
<th>Freezing Rain Chance</th>
<th>Thunder Chance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Percent (%)</td>
<td>Time Mode</td>
<td>Time Mode</td>
<td>Time Mode</td>
<td>Time Mode</td>
<td>Time Mode</td>
</tr>
<tr>
<td>06-21 75-100</td>
<td>06-21 Def</td>
<td>06-21 –</td>
<td>06-21 –</td>
<td>06-21 Def</td>
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</tr>
<tr>
<td>06-09 75-100</td>
<td>06-09 Lkly</td>
<td>06-09 –</td>
<td>06-09 –</td>
<td>06-09 Lkly</td>
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</tr>
<tr>
<td>06-13 50-75</td>
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Showers and thunderstorms. High near 70. Cloudy, with a south wind around 20mph, with gusts as high as 40 mph. Chance of precipitation is 100%.
Concept-to-text generation refers to the task of automatically producing textual output from nonlinguistic input (Reiter and Dale, 2000).

Click start, point to settings, and then click control panel. Double-click users and passwords. On the advanced tab, click advanced.
Traditional NLG Pipeline

Input Data

Content Planning

Sentence Planning

Surface Realisation

Text

Communicative Goal
Traditional NLG Pipeline

- Input Data
- Communicative Goal
- Content Planning
  - Content Selection
  - Document Planning
- Sentence Planning
- Surface Realisation
- Text
Traditional NLG Pipeline

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Communicative Goal

Barzilay and Lapata (2005)
Liang et al. (2009)
Traditional NLG Pipeline

Input Data

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Hovy (1993)
Scott and de Souza (1990)
Duboue and Mckeown (2002)
Traditional NLG Pipeline

- Input Data
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Stent et al. (2004)
Barzilay and Lapata (2006)
Traditional NLG Pipeline

- Input Data
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Wong and Mooney (2007)
Lu and Ng (2011)
Related Work

Traditional NLG Pipeline

Input Data

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Communicative Goal

Kim and Mooney (2010) Pipeline approach

Concept-to-Text Generation

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Traditional NLG Pipeline

Input Data → Content Planning

- Content Selection
- Document Planning

Sentence Planning

Surface Realisation

Text

Communicative Goal

Related Work

Kim and Mooney (2010)
Pipeline approach

Angeli et al. (2010)
Unified approach

Konstas (ILCC)
**Traditional NLG Pipeline**

- **Input Data**
  - Content Planning
    - Content Selection
    - Document Planning
  - Sentence Planning
  - Surface Realisation
  - Text

**Related Work**

- Kim and Mooney (2010)
  - Pipeline approach
- Angeli et al. (2010)
  - Unified approach
- Konstas and Lapata (2012a, 2012b, 2013b)
  - Joint approach
Input

- Input: database records $d$
- Output: words $w$ corresponding to some records of $d$
- Each record $r \in d$ has a type $r.t$ and fields $f$
- Fields have values $f.v$ and types $f.t$ (integer, categorical, string)

Cloud Sky Cover

<table>
<thead>
<tr>
<th>Time</th>
<th>Percent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>06:00-09:00</td>
<td>25-50</td>
</tr>
<tr>
<td>09:00-12:00</td>
<td>50-75</td>
</tr>
</tbody>
</table>

mostly cloudy,
Input

- **Input**: database records \( d \)
- **Output**: words \( w \) corresponding to some records of \( d \)
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Konstas and Lapata, NAACL 2012
Unsupervised Concept-to-text Generation with Hypergraphs

Konstas and Lapata, JAIR 2013. In press
### Key Idea

**Temperature**

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**Wind Speed**

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<tr>
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Cloudy, with a low around 10. South wind between 15 and 30 mph.

Partly cloudy, with a low around 9.

Breezy, with a south wind between 15 and 30 mph.
**Key Idea**

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Grammar

1. $S \rightarrow R(\text{start})$
Grammar

1. \( S \rightarrow R(start) \)
2. \( R(r_i.t) \rightarrow FS(r_j, start)R(r_j.t) | FS(r_j, start) \)

\( R(skyCover_1.t) \rightarrow FS(temperature_1, start)R(temperature_1.t) \)
### Grammar

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Time</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Rain Chance</td>
<td>06-21</td>
<td>Def</td>
</tr>
<tr>
<td></td>
<td>06-09</td>
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</tr>
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<tr>
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1. \( S \rightarrow R(\text{start}) \)
2. \( R(r_i.t) \rightarrow FS(r_j, \text{start})R(r_j.t) \mid FS(r_j, \text{start}) \)

\[ R(\text{skyCover}_1.t) \rightarrow FS(\text{temperature}_1, \text{start})R(\text{temperature}_1.t) \]
Grammar

1. $S \rightarrow R(start)$
2. $R(r_i.t) \rightarrow FS(r_j, start)R(r_j.t) \mid FS(r_j, start)$
3. $FS(r, r.f_i) \rightarrow F(r, r.f_j)FS(r, r.f_j) \mid F(r, r.f_j)$

$FS(wSpeed_1, min) \rightarrow F(wSpeed_1, max)FS(wSpeed_1, max)$
Grammar

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3. $FS(r, r.f_i) \rightarrow F(r, r.f_j)FS(r, r.f_j) \mid F(r, r.f_j)$
4. $F(r, r.f) \rightarrow W(r, r.f)F(r, r.f) \mid W(r, r.f)$

$F(\text{gust}_1, \text{min}) \rightarrow W(\text{gust}_1, \text{mean})F(\text{gust}_1, \text{mean})$
1. \( S \rightarrow R(\text{start}) \)
2. \( R(r_i.t) \rightarrow FS(r_j, \text{start})R(r_j.t) \mid FS(r_j, \text{start}) \)
3. \( FS(r, r.f_i) \rightarrow F(r, r.f_j)FS(r, r.f_j) \mid F(r, r.f_j) \)
4. \( F(r, r.f) \rightarrow W(r, r.f)F(r, r.f) \mid W(r, r.f) \)
5. \( W(r, r.f) \rightarrow \alpha \mid g(f.v) \)

\( W(\text{skyCover}_1, \%) \rightarrow \text{cloudy} [\% . v = '75-100'] \)
Grammar

1. \( S \rightarrow R(start) \)
2. \( R(r_j.t) \rightarrow FS(r_j, start)R(r_j.t) \mid FS(r_j, start) \)
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4. \( F(r, r.f) \rightarrow W(r, r.f)F(r, r.f) \mid W(r, r.f) \)
5. \( W(r, r.f) \rightarrow \alpha \mid g(f.v) \)

**EM Training:** dynamic program similar to the inside-outside algorithm
Decoding

\[ \hat{g} = f \left( \arg \max_{g,h} p(g) \cdot p(g, h \mid d) \right) \]
**Decoding**

\[ \hat{g} = f \left( \arg \max_{g,h} p(g) \cdot p(g, h | d) \right) \]

- Bottom-up Viterbi search
- Keep k-best derivations at each node, cube pruning (Chiang, 2007)
- \( p(g) \) rescores derivations by linearly interpolating:
  - n-gram language model
  - dependency model (DMV; Klein and Manning, 2004)
- Implement using hypergraphs (Klein and Manning, 2001)
Decoding

Leaf nodes $\epsilon$ emit a k-best list of words

$$W_{0,1}(\text{skyCover}_1.t,\%)$$

- mostly (RB)
- cloudy (JJ)
- sunny (JJ)
- ...

Konstas (ILCC)
Decoding

\[
\begin{align*}
\text{mostly cloudy} & \; \star \; \text{the morning} ; \text{JJ} \\
\text{mostly cloudy} & \; \star \; \text{after 11am} ; \text{JJ} \\
\text{mostly cloudy} & \; \star \; \text{then becoming} ; \text{JJ} \\
\text{mostly cloudy} & \; \star \; \text{after} \\
\text{cloudy} & ; \text{JJ} \\
\end{align*}
\]
Decoding

Grammar-based Generation

Key Idea

FS_{0,5}(skyCover_1.t,start)

W_{4,5}(skyCover_1.t,time)

W_{0,1}(skyCover_1.t,\%)

W_{1,2}(skyCover_1.t,\%)

mostly cloudy \* the morning ; JJ
mostly cloudy \* after 11am ; JJ
mostly cloudy \* then becoming ; JJ

mostly cloudy ; RB
mostly clouds ; NNS
cloudy ; ; JJ

mostly ; RB
cloudy ; JJ
sunny ; JJ

Konstas (ILCC)

Concept-to-Text Generation

22 October 2013
Decoding

Grammar-based Generation

Key Idea

FS

\( F_{0,5}(\text{skyCover}_1.t, \text{start}) \)

\( W_{4,5}(\text{skyCover}_1.t, \text{time}) \)

\( W_{0,1}(\text{skyCover}_1.t, \%) \)

\( W_{1,2}(\text{skyCover}_1.t, \%) \)

\( \left( \text{mostly cloudy} \star \text{the} \text{ morning; JJ} \right) \)

\( \left( \text{mostly cloudy} \star \text{after} \text{ 11am; JJ} \right) \)

\( \left( \text{mostly cloudy} \star \text{then becoming; JJ} \right) \)

\( \left( \text{mostly cloudy} ; \text{RB} \right) \)

\( \left( \text{mostly clouds} ; \text{NNS} \right) \)

\( \left( \text{cloudy} ; ; \text{JJ} \right) \)

\( W_0,1(\text{skyCover}_1.t, \%) \)

\( W_1,2(\text{skyCover}_1.t, \%) \)

\( \left( \text{mostly} ; \text{RB} \right) \)

\( \left( \text{cloudy} ; \text{JJ} \right) \)

\( \left( \text{sunny} ; \text{JJ} \right) \)

\( \left( \text{morning} ; \text{NN} \right) \)

\( \left( \text{11am} ; \text{NN} \right) \)

\( \left( \text{after} ; \text{PREP} \right) \)

Konstas (ILCC) Concept-to-Text Generation 22 October 2013 12 / 51
Experimental Setup

Data

- **RoboCup**: simulated sportscasting [214 words] (Chen and Mooney, 2008)
- **WeatherGov**: weather reports [4 sents, 345 words] (Liang et al., 2009)
- **Atis**: flight booking [1 sent, 927 words] (Zettlemoyer and Collins, 2007)
- **WinHelp**: troubleshooting guides [4.3 sents, 629 words] (Branavan et al., 2009)
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Evaluation

- Automatic evaluation: BLEU-4
- Human evaluation: Fluency, Semantic Correctness
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Evaluation

- Automatic evaluation: BLEU-4
- Human evaluation: Fluency, Semantic Correctness

System Comparison

- 1-best, $k$-BEST-LM, $k$-BEST-LM-DMV
- Angeli et al. (2010)
Results: Automatic Evaluation

RoboCup

BLEU-4

1-Best  |  Angeli  |  k-Best-lm  |  k-Best-lm-dmv
10.79   |  28.7    |  30.9       |  29.73
Results: Automatic Evaluation

**WeatherGov**

![Graph showing BLEU-4 scores for different methods: 1-Best, Angeli, k-Best-lm, and k-Best-lm-dmv.](image)

- **1-Best**: 8.64
- **Angeli**: 38.4
- **k-Best-lm**: 33.7
- **k-Best-lm-dmv**: 34.18
Results: Automatic Evaluation

**ATIS**

<table>
<thead>
<tr>
<th>Method</th>
<th>BLEU-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-Best</td>
<td>11.85</td>
</tr>
<tr>
<td>Angeli</td>
<td>26.77</td>
</tr>
<tr>
<td>k-Best-LM</td>
<td>29.3</td>
</tr>
<tr>
<td>k-Best-LM-DMV</td>
<td>30.37</td>
</tr>
</tbody>
</table>
Results: Automatic Evaluation

![WinHELP BLEU-4 Scores]

- **1-Best**: 16.02
- **Angeli**: 32.21
- **k-Best-LM**: 38.26
- **k-Best-LM-DMV**: 39.03
**WeatherGov**

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Cloud Sky Cover</th>
<th>Chance of Rain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Min</td>
<td>Mean</td>
</tr>
<tr>
<td>06:00-21:00</td>
<td>30</td>
<td>38</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wind Speed</th>
<th>Wind Direction</th>
<th>Precipitation Potential (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Min</td>
<td>Mean</td>
</tr>
<tr>
<td>06:00-21:00</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

**k-Best:** A chance of rain showers before 11am. Mostly cloudy, with a high near 44. East wind between 6 and 7 mph.

**Angeli:** A chance of showers. Patchy fog before noon. Mostly cloudy, with a high near 44. East wind between 6 and 7 mph. Chance of precipitation is 35%

**Human:** A 40 percent chance of showers before 10am. Mostly cloudy, with a high near 44. East northeast wind around 7 mph.
### ATIS

- **Flight**
  - **from**: milwaukee
  - **to**: phoenix

- **Day**
  - **day**: saturday
  - **dep/ar/ret**: departure

- **Search**
  - **type what**: query flight

### k-Best:
- **What are the flights from Milwaukee to Phoenix on Saturday**

### Angeli:
- **Show me the flights between Milwaukee and Phoenix on Saturday**

### Human:
- **Milwaukee to Phoenix on Saturday**
ATIS

ROOT

on

show

on

me

from

flights

on

the

Milwaukee

on

from

Phoenix

on

Phoenix

on

Saturday
Conclusions

- Generation as parsing problem
- Unsupervised end-to-end generation system
- Performance comparable to state-of-the-art
Conclusions

- Generation as parsing problem
- Unsupervised end-to-end generation system
- Performance comparable to state-of-the-art

- What about document planning?
Konstas and Lapata, ACL 2013

Inducing Document Plans for Concept-to-text Generation, ACL 2013
Traditional NLG Pipeline

Input Data → Content Planning → Content Selection → Document Planning → Sentence Planning → Surface Realisation → Text

- Kim and Mooney (2010) Pipeline approach
- Angeli et al. (2010) Unified approach
- Konstas and Lapata (2012a, 2012b, 2013a) Joint approach
Inducing Document Planning

Introduction

Traditional NLG Pipeline

Input Data → Content Planning

Content Planning → Content Selection

Content Planning → Document Planning

Document Planning → Sentence Planning

Sentence Planning → Surface Realisation

Surface Realisation → Text

Communicative Goal

- Kim and Mooney (2010)
  Pipeline approach

- Angeli et al. (2010)
  Unified approach

- Konstas and Lapata (2012a, 2012b, 2013a)
  Joint approach

- Konstas and Lapata (2013a)
  Joint approach
Click start, point to settings, and then click control panel. Double-click users and passwords. On the advanced tab, click advanced.
Click start, point to settings, and then click control panel. Double-click users and passwords. On the advanced tab, click advanced.
### Key Idea

<table>
<thead>
<tr>
<th>Desktop</th>
<th>Start</th>
<th>Start Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cmd</td>
<td>Name</td>
<td>Type</td>
</tr>
<tr>
<td>left-click</td>
<td>start button</td>
<td></td>
</tr>
<tr>
<td>left-click</td>
<td>settings button</td>
<td></td>
</tr>
<tr>
<td>left-click</td>
<td>control panel button</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Window Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cmd</td>
</tr>
<tr>
<td>double-click</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Context Menu</th>
<th>Action Context Menu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cmd</td>
<td>Name</td>
</tr>
<tr>
<td>left-click</td>
<td>advanced tab</td>
</tr>
<tr>
<td>left-click</td>
<td>advanced button</td>
</tr>
</tbody>
</table>

Click start, point to settings, and then click control panel. Double-click users and passwords. On the advanced tab, click advanced.
Click start, point to settings, and then click control panel.

Double-click users and passwords.

On the advanced tab, click advanced.
Click start, point to settings, and then click control panel.

Double-click users and passwords.

On the advanced tab, click advanced.
Key Idea: Grammar-based document plans
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- Re-use the generation model based on a PCFG grammar of input
Key Idea: Grammar-based document plans

- Re-use the generation model based on a PCFG grammar of input
- Replace existing locally coherent **Content Selection** model and incorporate global **Document Planning** (explore two solutions):
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- Re-use the generation model based on a PCFG grammar of input
- Replace existing locally coherent **Content Selection** model and incorporate global **Document Planning** (explore two solutions):

  Patterns of record sequences *within* a sentence and *among* sentences

Rhetorical Structure Theory (Mann and Thompson, 1988) inspired plans
Planning with Record Sequences

Key idea: Grammar on sequences of record types ($G_{RSE}$)
Planning with Record Sequences

Key idea: Grammar on sequences of record types ($G_{RSE}$)

1. Click start, point to settings, and then click control panel. || Double-click users and passwords. || On the advanced tab, click advanced. ||

Split a document into sentences, each terminated by a full-stop.
Key idea: Grammar on sequences of record types ($G_{RSE}$)

1. Click start, point to settings, and then click control panel. || Double-click users and passwords. || On the advanced tab, click advanced. ||

Split a document into sentences, each terminated by a full-stop.

2. \[
\text{desktop} \mid \text{start} \mid \text{start-target} \\
\text{Click start, point to settings, and then click control panel.} \\
\text{window-target} \\
\text{Double-click users and passwords.} || \text{contextMenu} \mid \text{action-contextMenu} \\
\text{On the advanced tab, click advanced.} ||
\]

Then split a sentence further into a sequence of record types.
Key idea: Grammar on sequences of record types ($G_{RSE}$)

1. Click start, point to settings, and then click control panel. || Double-click users and passwords. || On the advanced tab, click advanced. || 

Split a document into sentences, each terminated by a full-stop.

2. desktop | start | start-target
Click start, point to settings, and then click control panel. ||
window-target
Double-click users and passwords. ||
contextMenu | action-contextMenu
On the advanced tab, click advanced. ||

Then split a sentence further into a sequence of record types.

3. Goal: Learn patterns of record type sequences within and among sentences
Extended Grammar

1. \[ S \rightarrow R(start) \]
2. \[ R(r_j.t) \rightarrow FS(r_j, start)R(r_j.t) \mid FS(r_j, start) \]
3. \[ FS(r, r.f_i) \rightarrow F(r, r.f_j)FS(r, r.f_j) \mid F(r, r.f_j) \]
4. \[ F(r, r.f) \rightarrow W(r, r.f)F(r, r.f) \mid W(r, r.f) \]
5. \[ W(r, r.f) \rightarrow \alpha \mid g(f.v) \]
Extended Grammar

1. $D \rightarrow SENT(t_i, \ldots, t_j) \ldots SENT(t_l, \ldots, t_m)$
2. $SENT(t_i, \ldots, t_j) \rightarrow R(r_a.t_i) \ldots R(r_k.t_j)$
3. $R(r_i.t) \rightarrow FS(r_j, \text{start})$
4. $FS(r, r.f_i) \rightarrow F(r, r.f_j)FS(r, r.f_j) \mid F(r, r.f_j)$
5. $F(r, r.f) \rightarrow W(r, r.f)F(r, r.f) \mid W(r, r.f)$
6. $W(r, r.f) \rightarrow \alpha \mid g(f.v) \mid \text{gen\_str}(f.v, i)$
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3. $R(r_i \cdot t) \rightarrow FS(r_j, start)$
4. $FS(r, r.f_i) \rightarrow F(r, r.f_j)FS(r, r.f_j) \mid F(r, r.f_j)$
5. $F(r, r.f) \rightarrow W(r, r.f)F(r, r.f) \mid W(r, r.f)$
6. $W(r, r.f) \rightarrow \alpha \mid g(f.v) \mid gen\_str(f.v, i)$

Straightforward solution: Embed the parameters with the original grammar and train using EM
Extended Grammar

1. \( D \rightarrow SENT(t_i, \ldots, t_j) \ldots SENT(t_l, \ldots, t_m) \)

2. \( SENT(t_i, \ldots, t_j) \rightarrow R(r_a.t_i) \ldots R(r_k.t_j) \cdot \)

3. \( R(r_i.t) \rightarrow FS(r_j, start) \)

4. \( FS(r, r.f_i) \rightarrow F(r, r.f_j)FS(r, r.f_j) | F(r, r.f_j) \)

5. \( F(r, r.f) \rightarrow W(r, r.f)F(r, r.f) | W(r, r.f) \)

6. \( W(r, r.f) \rightarrow \alpha | g(f.v) | gen_str(f.v, i) \)

Straightforward solution: Embed the parameters with the original grammar and train using EM

Plan B: Extract grammar rules from training data
## Grammar Extraction

<table>
<thead>
<tr>
<th>desktop</th>
<th>start</th>
<th>start-target</th>
<th>window-target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Click start, point to settings, and then click control panel.</td>
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<td></td>
<td></td>
</tr>
</tbody>
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<tr>
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<th>action-contextMenu</th>
</tr>
</thead>
<tbody>
<tr>
<td>On the advanced tab, click advanced.</td>
<td></td>
</tr>
</tbody>
</table>

Liang et al. (2009)
## Grammar Extraction

<table>
<thead>
<tr>
<th>desktop</th>
<th>start</th>
<th>start-target</th>
<th>window-target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Click start, point to settings, and then click control panel.</td>
<td></td>
<td></td>
<td>Double-click users and passwords.</td>
</tr>
</tbody>
</table>

On the advanced tab, click advanced.

Liang et al. (2009)

\[
\text{desktop start start-target || window-target || contextMenu action-contextMenu ||}
\]
# Grammar Extraction

<table>
<thead>
<tr>
<th>desktop</th>
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<th>start-target</th>
<th>window-target</th>
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<tr>
<th>contextMenu</th>
<th>action-contextMenu</th>
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</thead>
<tbody>
<tr>
<td>On the advanced tab, click advanced.</td>
<td></td>
</tr>
</tbody>
</table>

Liang et al. (2009)

\[
\begin{array}{c}
\text{desktop start start-target} \parallel \text{window-target} \parallel \text{contextMenu action-contMenu} \parallel
\end{array}
\]

- \(D\)
  - \(\text{SENT(desk, start, start-target)}\)
  - \(\text{SENT(win-target)}\)
  - \(\text{SENT(contMenu, action-contMenu)}\)
  - \(\text{R(desk)}\)
  - \(\text{R(start)}\)
  - \(\text{R(start-target)}\)
  - \(\text{R(win-target)}\)
  - \(\text{R(contMenu)}\)
  - \(\text{R(action-contMenu)}\)
**Grammar Extraction**

<table>
<thead>
<tr>
<th>desktop</th>
<th>start</th>
<th>start-target</th>
<th>window-target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Click start, point to settings, and then click control panel. Double-click users and passwords.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>contextMenu</th>
<th>action-contextMenu</th>
</tr>
</thead>
<tbody>
<tr>
<td>On the advanced tab, click advanced.</td>
<td></td>
</tr>
</tbody>
</table>

Liang et al. (2009)

```
[ desktop start start-target || window-target || contextMenu action-contMenu || ]
```

```
D

SENT(desk, start, start-target)  SENT(win-target)  SENT(contMenu, action-contMenu)  

D

SENT(desk, start, start-target)  [SENT(win-target)-SENT(contMenu, action-contMenu)]  
```
RST (Mann and Thompson, 1988)

The sound settings window allows you to control your sound devices.

Open the control panel, and click on the sound settings.
RST (Mann and Thompson, 1988)

- The sound settings window allows you to control your sound devices.
  - Open the control panel, and click on the sound settings.

```
D
  Background[N][S]
      Elaboration[N][S]

      The sound settings window allows you to control your sound devices.
```

D: Delimiting

N: Nucleus

S: Support

**Concepts**
- Background (information that provides context)
- Elaboration (additional information to expand on the main point)
- The sound settings window (the main point)
- Control panel (additional information that supports the main point)
- Sound settings (additional information that supports the main point)
RST (Mann and Thompson, 1988)

The sound settings window allows you to control your sound devices.

Open the control panel, and click on the sound settings.
RST (Mann and Thompson, 1988)

The sound settings window allows you to control your sound devices.

Open the control panel, and click on the sound settings.
Key idea: Grammar using RST relations ($G_{RST}$)
Planning with Rhetorical Structure Theory

Key idea: Grammar using RST relations ($G_{RST}$)

Assumption
Each record in the database input corresponds to a unique non-overlapping span in the collocated text, and can be therefore mapped to an EDU.
## Grammar Extraction

<table>
<thead>
<tr>
<th>desktop</th>
<th>start</th>
<th>start-target</th>
<th>window-target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Click start,</td>
<td>point to settings,</td>
<td>and then click control panel.</td>
<td>Double-click users and passwords.</td>
</tr>
<tr>
<td>contextMenu</td>
<td>action-contextMenu</td>
<td>click advanced.</td>
<td>Liang et al. (2009)</td>
</tr>
</tbody>
</table>
Grammar Extraction

Liang et al. (2009)

Click start, point to settings, and then click control panel. Double-click users and passwords.

On the advanced tab, click advanced.

[Liang et al. (2009)]

[Click start.]_{desktop} [point to settings,]_{start} [and then click control panel.]_{start-target} [Double-click users and passwords.]_{window-target} [On the advanced tab,]_{contextMenu} [click advanced.]_{action-contextMenu}
Double-click users and passwords. On the advanced tab, click advanced.

Click start, point to settings, and then click control panel.

Feng and Hirst (2012)
Grammar Extraction

Click start, point to settings, and then click control panel. Double-click users and passwords. On the advanced tab, click advanced.

Feng and Hirst (2012)
Extended Grammar

1. \( G_{RST} \)
2. \( R(r_i.t) \rightarrow FS(r_j, \text{start}) \)
3. \( FS(r, r.f_i) \rightarrow F(r, r.f_j)FS(r, r.f_j) \mid F(r, r.f_j) \)
4. \( F(r, r.f) \rightarrow W(r, r.f)F(r, r.f) \mid W(r, r.f) \)
5. \( W(r, r.f) \rightarrow \alpha \mid g(f.v) \mid \text{gen\_str}(f.v, i) \)
Experimental Setup

Data

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- **WinHelp**: troubleshooting guides [4.3 sents, 629 words] (Branavan et al., 2009)
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- Automatic evaluation: BLEU-4
- Human evaluation: Fluency, Semantic Correctness, Coherence
Experimental Setup

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System Comparison

- $G_{RSE}$, $G_{RST}$
- Konstas and Lapata (2012a)
- Angeli et al. (2010)
Results: Automatic Evaluation

WeatherGov

<table>
<thead>
<tr>
<th>Model</th>
<th>BLEU-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANGELI</td>
<td>38.4</td>
</tr>
<tr>
<td>K&amp;L</td>
<td>33.7</td>
</tr>
<tr>
<td>G_{RSE}</td>
<td>35.6</td>
</tr>
<tr>
<td>G_{RST}</td>
<td>36.54</td>
</tr>
</tbody>
</table>
Results: Automatic Evaluation

![Bar chart showing BLEU-4 scores for different methods.]

- **WinHELP**: 40.92 for $G_{RSE}$, 40.65 for $G_{RST}$
- **Angeli**: 32.21
- **K&L**: 38.26

*Concept-to-Text Generation*
Results: Human Evaluation (Coherence)
**Output**

<table>
<thead>
<tr>
<th>GRSE</th>
<th>Click start, point to settings, and then click control panel. Double-click network and dial-up connections. Right-click local area connection, and then click properties. <strong>Click install, and then click add.</strong> Click network monitor driver, and then click ok.</th>
</tr>
</thead>
<tbody>
<tr>
<td>K&amp;L</td>
<td>Click start, point to settings, and then click control panel. Double-click network and dial-up connections. <strong>Double-click network and dial-up connections.</strong> Right-click local area connection, and then click ok.</td>
</tr>
<tr>
<td>HUMAN</td>
<td>Click start, point to settings, click control panel, and then double-click network and dial-up connections. Right-click local area connection, and then click properties. <strong>Click install, click protocol, and then click add.</strong> Click network monitor driver, and then click ok.</td>
</tr>
</tbody>
</table>
Conclusions

- End-to-end generation system that incorporates document planning
- **Grammar-based** approach allows for **document planning** naturally: all we need is a discourse grammar
- Provide two solutions for document plans:
  - Linguistically naive record sequence grammar ($G_{RSE}$)
  - RST-inspired grammar ($G_{RST}$)
- How about a more sophisticated content selection model on the field level?
Konstas and Lapata, ACL 2012

Concept-to-text Generation via Discriminative Reranking
Discriminative Reranking Model

Original Model

- Joint model allows for more global decisions
- **Forest resoring** allows for rescoring k-best trees at all internal nodes via LM+DMV integration
Discriminative Reranking Model

Original Model

- Joint model allows for more global decisions
- **Forest rescoring** allows for rescoring k-best trees at all internal nodes via LM+DMV integration

Discriminative Reranking Model
Discriminative Reranking Model

Original Model
- Joint model allows for more global decisions
- **Forest rescoring** allows for rescoring k-best trees at all internal nodes via LM+DMV integration

Discriminative Reranking Model
- Use decoder of the original model as a baseline
- Introduce lexical and structural features up to the field level
- **Discriminative reranking** reranks k-best trees at all internal nodes
- Train using an online learning algorithm
Hidden correspondence $h$ between database $d$ and words $w$
Hypergraph Reranking

<table>
<thead>
<tr>
<th>Flight</th>
<th>Day Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>from Seattle</td>
<td>to New York</td>
</tr>
<tr>
<td>number</td>
<td>dep/ar 23</td>
</tr>
<tr>
<td>Month</td>
<td>dep/ar October</td>
</tr>
<tr>
<td>Search</td>
<td>type query</td>
</tr>
</tbody>
</table>

Hidden correspondence \( h \) between database \( d \) and words \( w \)

\[
(\hat{g}, \hat{h}) = \arg\max_{g,h} \alpha \cdot \Phi(d, \hat{g}, h)
\]

- \( \Phi = (\Phi_1, \ldots, \Phi_m) \): high dimensional feature representation
- \( \alpha \): weight vector
- Learn \( \alpha \) with averaged structured perceptron (Collins, 2002)
Hypergraph Reranking

Given the flights leaving Seattle on October 22nd coming back to New York,

Hidden correspondence $h$ between database $d$ and words $w$

$$(\hat{g}, \hat{h}) = \operatorname{arg\ max}_{g,h} \alpha \cdot \Phi(d, \hat{g}, \hat{h})$$

- $\Phi = (\Phi_1, \ldots, \Phi_m)$: high dimensional feature representation
- $\alpha$: weight vector
- Learn $\alpha$ with averaged structured perceptron (Collins, 2002)
## Hypergraph Reranking

### Table:

<table>
<thead>
<tr>
<th>Flight</th>
<th>Day Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>from to</td>
<td>number dep/ar</td>
</tr>
<tr>
<td>seattle new york</td>
<td>23 departure</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Month</th>
<th>Search</th>
</tr>
</thead>
<tbody>
<tr>
<td>month dep/ar</td>
<td>type what</td>
</tr>
<tr>
<td>october departure</td>
<td>query flight</td>
</tr>
</tbody>
</table>

### Diagram:

Hidden correspondence \( h \) between database \( d \) and words \( w \)

\[
(\hat{g}, \hat{h}) = \arg \max_{g,h} \alpha \cdot \Phi(d, \hat{g}, h)
\]

- \( \Phi = (\Phi_1, \ldots, \Phi_m) \): high dimensional feature representation
- \( \alpha \): weight vector
- Learn \( \alpha \) with averaged structured perceptron (Collins, 2002)
Oracle Derivation

Oracle derivation \((w^*, h^+)\)

1. Use the decoder of the original model but observe the training text.
2. \(w^*\): gold standard text
3. \(h^+\): best latent configuration
Baseline Features

- Baseline Model Feature (local) : Log score of decoder of the original model
Baseline Features

- **Baseline Model Feature (local)**: Log score of decoder of the original model
- **Alignment Features (local)**: Count of each PCFG rule

\[
R(\text{search}_1.t) \\
\text{FS(\text{flight}_1.t, start)} \quad R(\text{flight}_1.t) \\
R(r_i.t) \rightarrow \text{FS}(r_j, \text{start}) R(r_j.t)
\]
Lexical Features

- Word Bigrams/Trigrams (non-local)
- Number of Words per Field (local)
- Consecutive Word/Bigram/Trigram (non-local)
Lexical Features

- **Word Bigrams/Trigrams (non-local)**
- **Number of Words per Field (local)**
- **Consecutive Word/Bigram/Trigram (non-local)**

```
FS_{0,3}(search_{1.t,start})
```

```
W_{0,1}(search_{1.t,type})
```

```
show me what ...
```

```
W_{1,3}(search_{1.t,what})
```

```
me the me flights the flights ...
```

```
<show me the>, <show me flights>, etc.
```
Lexical Features

- Word Bigrams/Trigrams (non-local)
- **Number of Words per Field** (local)
- Consecutive Word/Bigram/Trigram (non-local)

\[ \begin{align*}
&\text{FS}_{0,3}(\text{search}_1.t, \text{start}) \\
&\text{W}_{0,1}(\text{search}_1.t, \text{type}) \quad \ldots \\
&\text{W}_{1,3}(\text{search}_1.t, \text{what}) \\
&\begin{pmatrix}
\text{show} \\
\text{me} \\
\text{what} \\
\ldots
\end{pmatrix}
\quad \ldots \\
&\begin{pmatrix}
\text{me} \\
\text{the} \\
\text{flights} \\
\text{the} \\
\text{flights} \\
\ldots
\end{pmatrix}
\end{align*} \]

\[ \begin{align*}
&\text{F}_{2,4}(\text{flight}_1.t, \text{from}) \\
&\text{FS}_{0,3}(\text{search}_1.t, \text{start}) \\
&\text{W}_{0,1}(\text{search}_1.t, \text{type}) \quad \ldots \\
&\text{W}_{1,3}(\text{search}_1.t, \text{what}) \\
&\begin{pmatrix}
\text{show} \\
\text{me} \\
\text{the} \\
\text{flights}
\end{pmatrix}
\quad \begin{pmatrix}
\text{from}
\end{pmatrix}
\end{align*} \]

\[ <\text{show me the}>, <\text{show me flights}>, \text{etc.} \]
Content Selection at the Field Level Features

- Field Bigrams/Trigrams (non-local)
- Number of Fields per Record (local)
- Fields with no Value (local)
Content Selection at the Field Level Features

- Field Bigrams/Trigrams (non-local)
- Number of Fields per Record (local)
- Fields with no Value (local)
k-best Decoding

- Bottom-up Viterbi search
- Keep k-best derivations at each node, cube pruning (Chiang, 2007)
- Score of j-th derivation: $\alpha \cdot \Phi_L(e) + \alpha \cdot \Phi_N(<e,j>)$
k-best Decoding

\[
\begin{align*}
&\left( \text{show me * the flights [type what]} \right) \\
&\left( \text{show me * what flights [type what]} \right) \\
&\left( \text{show me * all flights [type what]} \right)
\end{align*}
\]

\[
\begin{align*}
&\left( \text{show me [type]} \right) \\
&\left( \text{show the [type]} \right) \\
&\left( \text{what are [type]} \right)
\end{align*}
\]

\[
\begin{align*}
&F_{0,2}(\text{search}_1.t,\text{type}) \\
&F_{0,5}(\text{search}_1.t,\text{start}) \\
&W_{0,1}(\text{search}_1.t,\text{type}) \\
&W_{1,2}(\text{search}_1.t,\text{type}) \\
&W_{4,5}(\text{search}_1.t,\text{what})
\end{align*}
\]
k-best Decoding

\[
\begin{align*}
&\left(\text{show me } \star \text{ the flights} \ [\text{type what}]\right) \\
&\left(\text{show me } \star \text{ what flights} \ [\text{type what}]\right) \\
&\left(\text{show me } \star \text{ all flights} \ [\text{type what}]\right) \\
&\cdots
\end{align*}
\]

\[
\begin{align*}
&\left(\text{show me} \ [\text{type}]\right) \\
&\left(\text{show the} \ [\text{type}]\right) \\
&\left(\text{what are} \ [\text{type}]\right) \\
&\cdots
\end{align*}
\]

\[
\begin{align*}
&W_{0,1}(\text{search}_1.t,\text{type}) \\
&W_{1,2}(\text{search}_1.t,\text{type}) \\
&W_{0,5}(\text{search}_1.t,\text{start}) \\
&W_{4,5}(\text{search}_1.t,\text{what})
\end{align*}
\]
k-best Decoding

(show me * the flights [type what])
(show me * what flights [type what])
(show me * all flights [type what])
...

(show me [type])
(show the [type])
(what are [type])
...

FS0,5(search1.t,start)

F0,2(search1.t,type)

W0,1(search1.t,type)

W1,2(search1.t,type)

W4,5(search1.t,what)

(show [∅])
(me [∅])
(what [∅])
...

(show [∅])
(me [∅])
(what [∅])
...

(show me * the flights [type what])
(show me * what flights [type what])
(show me * all flights [type what])
...

(show me [type])
(show the [type])
(what are [type])
...

FS0,5(search1.t,start)

F0,2(search1.t,type)

W0,1(search1.t,type)

W1,2(search1.t,type)

W4,5(search1.t,what)

(show [∅])
(me [∅])
(what [∅])
...

(show me * the flights [type what])
(show me * what flights [type what])
(show me * all flights [type what])
...

(show me [type])
(show the [type])
(what are [type])
...

FS0,5(search1.t,start)

F0,2(search1.t,type)

W0,1(search1.t,type)

W1,2(search1.t,type)

W4,5(search1.t,what)

(show [∅])
(me [∅])
(what [∅])
...
Experimental Setup

Data

- **ATIS**: flight booking [1 sent, 927 words] (Zettlemoyer and Collins, 2007)
Experimental Setup

Data

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Evaluation

- Automatic evaluation: BLEU-4
- Human evaluation: Fluency, Semantic correctness
Experimental Setup

Data
- **ATIS**: flight booking [1 sent, 927 words] (Zettlemoyer and Collins, 2007)

Evaluation
- Automatic evaluation: BLEU-4
- Human evaluation: Fluency, Semantic correctness

System Comparison
- Baseline: 1-BEST+BASE+ALIGN
- k-best (+Lexical): k-BEST+BASE+ALIGN+LEX
- k-best (+Structural): k-BEST+BASE+ALIGN+LEX+STR
- Angeli et al. (2010)
Results: Automatic Evaluation

WinHELP

<table>
<thead>
<tr>
<th>BLEU-4 Value</th>
<th>Baseline</th>
<th>Angeli</th>
<th>+Lexical</th>
<th>+Structural</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.93</td>
<td></td>
<td>26.77</td>
<td>28.66</td>
<td>31.62</td>
</tr>
</tbody>
</table>

The chart shows the BLEU-4 scores for different models and configurations.
Conclusions

- Discriminative reranking using the structured perceptron
- Introduced local and non-local features
- More sophisticated content selection on the field level
Where do we go from here?

- More challenging factual domains: biographies from Wikipedia
- More sophisticated sentence planning: aggregation, coreference resolution
- Real induction for document planning grammar $G_{RSE}$: ID/LP grammars
- Discriminative reranking: use of parallelisable online learning algorithms
- More engineering: scaling can be an issue for large documents
- Apply document planning grammars to summarisation
Thank you

Questions?
<table>
<thead>
<tr>
<th>System</th>
<th>Fluency</th>
<th>SemCor</th>
</tr>
</thead>
<tbody>
<tr>
<td>RoboCup</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-BEST</td>
<td>2.47</td>
<td>2.33</td>
</tr>
<tr>
<td>k-BEST</td>
<td>4.31</td>
<td>3.96</td>
</tr>
<tr>
<td>ANGELI</td>
<td>4.03</td>
<td>3.70</td>
</tr>
<tr>
<td>HUMAN</td>
<td>4.47</td>
<td>4.37</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>System</th>
<th>Fluency</th>
<th>SemCor</th>
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<tr>
<td>WEATHERGOV</td>
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<td></td>
</tr>
<tr>
<td>1-BEST</td>
<td>1.82</td>
<td>2.05</td>
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<tr>
<td>k-BEST</td>
<td>3.92</td>
<td>3.30</td>
</tr>
<tr>
<td>ANGELI</td>
<td>4.26</td>
<td>3.60</td>
</tr>
<tr>
<td>HUMAN</td>
<td>4.61</td>
<td>4.03</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>System</th>
<th>Fluency</th>
<th>SemCor</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATIS</td>
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<td></td>
</tr>
<tr>
<td>1-BEST</td>
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<td>k-BEST</td>
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<td>3.87</td>
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<tr>
<td>ANGELI</td>
<td>3.56</td>
<td>3.33</td>
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<tr>
<td>HUMAN</td>
<td>4.10</td>
<td>4.01</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>System</th>
<th>Fluency</th>
<th>SemCor</th>
</tr>
</thead>
<tbody>
<tr>
<td>WINHELP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-BEST</td>
<td>2.57</td>
<td>2.10</td>
</tr>
<tr>
<td>k-BEST</td>
<td>3.41</td>
<td>3.05</td>
</tr>
<tr>
<td>ANGELI</td>
<td>3.57</td>
<td>2.80</td>
</tr>
<tr>
<td>HUMAN</td>
<td>4.15</td>
<td>4.04</td>
</tr>
</tbody>
</table>
Discriminative Reranking Results: Human Evaluation

<table>
<thead>
<tr>
<th>System</th>
<th>Fluency</th>
<th>SemCor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-BEST</td>
<td>2.70</td>
<td>3.05</td>
</tr>
<tr>
<td>( k )-BEST</td>
<td>4.02</td>
<td>4.04</td>
</tr>
<tr>
<td>ANGEKI</td>
<td>3.74</td>
<td>3.17</td>
</tr>
<tr>
<td>HUMAN</td>
<td>4.18</td>
<td>4.02</td>
</tr>
</tbody>
</table>

- \( k \)-BEST significantly better than 1-BEST and ANGEKI \((\alpha < 0.01)\)
- \( k \)-BEST and HUMAN are not significantly different
Hypergraphs

Definition

An ordered hypergraph $H$ is a tuple $\langle N, E, t, R \rangle$, where $N$ is a finite set of nodes, $E$ is a finite set of hyperarcs, $t \in N$ is a target node and $R$ is the set of weights. Each hyperarc $e \in E$ is a triple $e = \langle T(e), h(e), f(e) \rangle$, where $h(e) \in N$ is its head node, $T(e) \subseteq N^*$ is a set of tail nodes and $f(e)$ is a monotonic weight function $R_{|T(e)|}$ to $R$. 

\[ \text{Konstas (ILCC)} \]

Concept-to-Text Generation

22 October 2013
An ordered hypergraph $H$ is a tuple $\langle N, E, t, R \rangle$, where $N$ is a finite set of nodes, $E$ is a finite set of hyperarcs, $t \in N$ is a target node and $R$ is the set of weights. Each hyperarc $e \in E$ is a triple $e = \langle T(e), h(e), f(e) \rangle$, where $h(e) \in N$ is its head node, $T(e) \in N^*$ is a set of tail nodes and $f(e)$ is a monotonic weight function $R|_{T(e)}$ to $R$. 
An ordered hypergraph $H$ is a tuple $\langle N, E, t, \mathbf{R} \rangle$, where $N$ is a finite set of nodes, $E$ is a finite set of hyperarcs, $t \in N$ is a target node and $\mathbf{R}$ is the set of weights. Each hyperarc $e \in E$ is a triple $e = \langle T(e), h(e), f(e) \rangle$, where $h(e) \in N$ is its head node, $T(e) \in N^*$ is a set of tail nodes and $f(e)$ is a monotonic weight function $\mathbf{R}|_{T(e)}$ to $\mathbf{R}$. 
Hypergraphs

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![Diagram showing a hyperarc with nodes t, a, and b, and weight function f(e) connecting t to a and b.](image-url)
Hypergraph Construction

Map standard weighted CYK algorithm to hypergraph $H : \langle N, E, t, R \rangle$

$$f(e) = f(FS_{5,7}(flight_1.t, start)) \otimes f(R_{7,9}(flight_1.t)) \otimes w(R(search_1.t) \rightarrow FS(flight_1, start) \ R(flight_1.t))$$

$$R(r_{i}.t) \rightarrow FS(r_{j}, start) R(r_{j}.t)$$
Map standard weighted CYK algorithm to hypergraph $H : \langle N, E, t, R \rangle$

$$f(e) = f(FS_{5,7}(flight_1.t, start)) \otimes f(R_{7,9}(flight_1.t)) \otimes w(R(search_1.t) \rightarrow FS(flight_1, start) \ R(flight_1.t))$$

$R(r_i.t) \rightarrow FS(r_j, start) R(r_j.t)$
Map standard weighted CYK algorithm to hypergraph $H : \langle N, E, t, R \rangle$

$$f(e) = f(\text{FS}_{5,7}(\text{flight}_1.t, \text{start})) \otimes f(\text{R}_{7,9}(\text{flight}_1.t)) \otimes$$

$$w(\text{R}(\text{search}_1.t) \rightarrow \text{FS}(\text{flight}_1, \text{start}) \text{R}(\text{flight}_1.t))$$

$$\text{R}(r_i.t) \rightarrow \text{FS}(r_j, \text{start}) \text{R}(r_j.t)$$
Hypergraph Construction

Map standard weighted CYK algorithm to hypergraph $H : \langle N, E, t, R \rangle$

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Map standard weighted CYK algorithm to hypergraph $H : \langle N, E, t, R \rangle$

$$f(e) = f(FS_{5,7}(flight_{1}.t, start)) \otimes f(R_{7,9}(flight_{1}.t)) \otimes w(R(search_{1}.t) \rightarrow FS(flight_{1}, start) \ R(flight_{1}.t))$$

$$R(r_{i}.t) \rightarrow FS(r_{j}, start) \ R(r_{j}.t)$$
Hypergraph Example
Determining Text Length

- Train a linear regression model
- Idea: The more records and fields that have values in the database $\rightarrow$ the more facts need to be uttered
- Input to the model: Flattened version of the database input, i.e. each feature is a record-field pair
- Feature values: Values vs Counts of Fields