Learning to generate: Concept-to-text generation using machine learning

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Aberdeen, NLG Summer School
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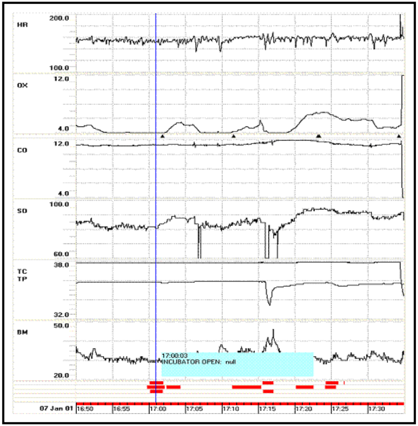
Introduction

Introduction

- ROOT
  - exhibit
    - statue
      - kouros
        - exhibit7
        - exhibit12
      - complex-statue
      - portrait
      - imperial-portrait
    - coin
    - jewel
    - relief
    - ...
  - a-location
    - museum
      - museum1
    - archeological-site
  - ...

Introduction



Sensor Data

Full Descriptor	**Time**
SETTING;VENTIL;FiO2 (36%)	10.30
MEDICATION;Morphine	10.44
ACTION;CARE;TURN/ CHANGE POSITION;SUPINE	10.46-10.47
ACTION;RESP;HAND BABY	10.47-10.51
SETTING;VENTIL;FiO2 (60%)	10.47
ACTION;RESP;INTUBATE	10.51-10.52

Action Records

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Concept-to-text generation refers to the task of automatically producing textual output from nonlinguistic input (Reiter and Dale, 2000)

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Wind Chill

Time	Min	Mean	Max
06-21	0	0	0

Temperature

Time	Min	Mean	Max
06-21	52	61	70

Wind Speed

Time	Min	Mean	Max
06-21	11	22	29

Wind Direction

Time	Mode
06-21	S

Gust

Time	Min	Mean	Max
06-21	0	20	39

Precipitation Potential

Time	Min	Mean	Max
06-21	26	81	100

Sky Cover

Time	Percent (%)
06-21	75-100
06-09	75-100
06-13	50-75
09-21	75-100
13-21	75-100

Rain Chance

Time	Mode
06-21	Def
06-09	Lkly
06-13	Def
09-21	Def
13-21	Def

Snow Chance

Time	Mode
06-21	–
06-09	–
06-13	–
09-21	–
13-21	–

Sleet Chance

Time	Mode
06-21	–
06-09	–
06-13	–
09-21	–
13-21	–

Freezing Rain Chance

Time	Mode
06-21	–
06-09	–
06-13	–
09-21	–
13-21	–

Thunder Chance

Time	Mode
06-21	Def
06-09	Lkly
06-13	Chc
09-21	Def
13-21	Def

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%.

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Concept-to-text generation refers to the task of automatically producing textual output from nonlinguistic input (Reiter and Dale, 2000)

Desktop

Cmd	Name	Type
left-click	start	button

Start

Cmd	Name	Type
left-click	settings	button

Location

Name	Type
start menu	button
control panel	window

Start Target

Cmd	Name	Type
left-click	control panel	button

Navigate Window

Cmd	Name	Type
left-click	accounts and users	window

Context Menu

Cmd	Name	Type
left-click	advanced	tab

Action Context Menu

Cmd	Name	Type
left-click	advanced	button

Window Target

Cmd	Name	Type
double-click	users and passwords	item

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

Double-click users and passwords.

On the advanced tab, click advanced.

Introduction

What has been done so far?

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- Expert knowledge deployed for the creation of hand-crafted rules - single domain

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- Manually annotated corpora - discourse relations, alignments

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- Expert knowledge deployed for the creation of hand-crafted rules - single domain
- Manually annotated corpora - discourse relations, alignments
- Breakdown of process into a pipeline of modules

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- Recast NLG into a generative model
- Learn parameters from (un)-annotated data - multiple domains
- Search for the best parameters that fit the input and decode into text

Outline

- Problem Formulation
- Learning Alignments
- Pipeline Approach
- Joint Approaches

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

Cloud Sky Cover	
Time	**Percent (%)**
06:00-09:00	25-50
09:00-12:00	50-75

mostly cloudy,

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mostly cloudy,

Key Idea

Temperature

Time	Min	Mean	Max
06:00-21:00	9	15	21

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

Wind Speed

Time	Min	Mean	Max
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Wind Direction

Time	Mode
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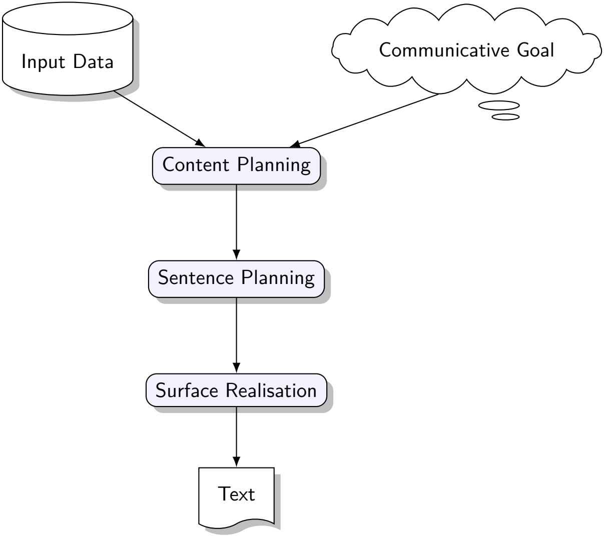
06:00-21:00	S

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.

Traditional NLG Pipeline



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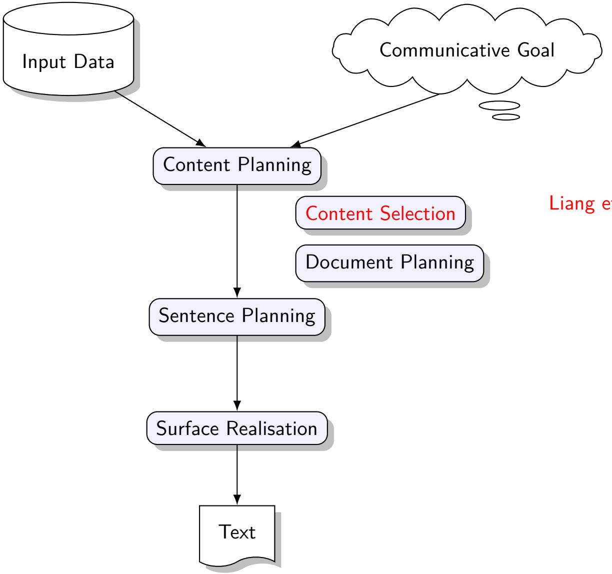

Liang et al. (2009)

Liang et al., ACL 2009

Learning Semantic Correspondences with Less Supervision

Alignment Task

Wind Chill

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Time	Mode
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06-09	–
06-13	–
09-21	–
13-21	–

Sleet Chance

Time	Mode
06-21	–
06-09	–
06-13	–
09-21	–
13-21	–

Generative Story

1. Record choice: choose a sequence of records $\mathbf{r} = \left(r_1, \ldots, r_{|\mathbf{r}|}\right)$

$$p(\mathbf{r} \mid \mathbf{d}) = \prod_{i}^{|\mathbf{r}|} p(r_i.t \mid r_{i-1}.t) \frac{1}{|\mathbf{s}(r_i.t)|}$$

$$p(\mathbf{r}, \mathbf{f}, \mathbf{c}, \mathbf{w} | \mathbf{d}) = p(\mathbf{r}|\mathbf{d}) p(\mathbf{f}|\mathbf{r}) p(\mathbf{c}, \mathbf{w}|\mathbf{r}, \mathbf{f}, \mathbf{d})$$

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2. Field choice: for each chosen record r_i, select a sequence of fields $f_i = \left(f_{i1}, \ldots, f_{i|f_i|}\right)$

$$p(\mathbf{f} \mid r_i.t) = \prod_{k}^{|r_i.\mathbf{f}|} p(r_i.f_k \mid r_i.f_{k-1})$$

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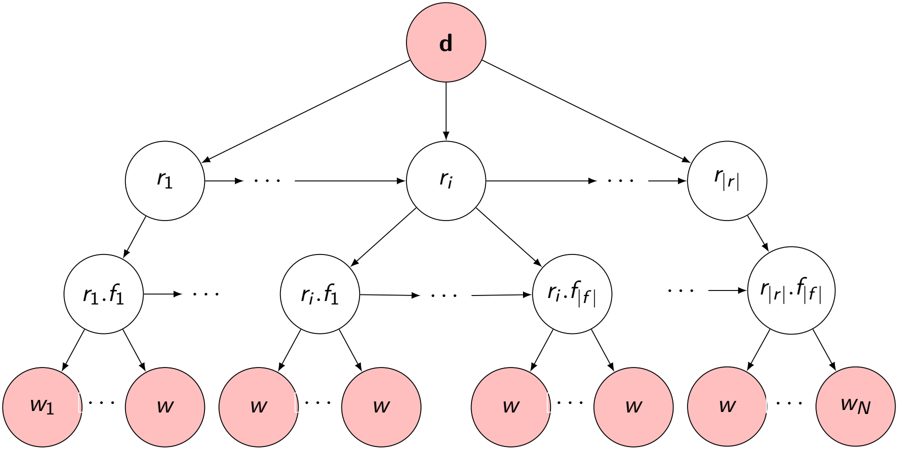
3. Word choice: for each chosen field f_{ik}, choose a number $c_{ik} > 0$ uniformly, and generate a sequence of c_{ik} words.

$$p(\mathbf{w} \mid r_i, r_i.f_k, r_i.f_k.t, c_{ik}) = \prod_{j}^{|\mathbf{w}|} p(w_j \mid r_i.t, r_i.f_k.v)$$

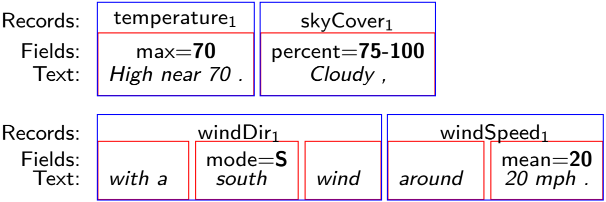
$$p(\mathbf{r}, \mathbf{f}, \mathbf{c}, \mathbf{w} | \mathbf{d}) = p(\mathbf{r}|\mathbf{d}) p(\mathbf{f}|\mathbf{r}) p(\mathbf{c}, \mathbf{w}|\mathbf{r}, \mathbf{f}, \mathbf{d})$$

Hierarchical Semi-Markov Model (HSMM)



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

Aligned Output



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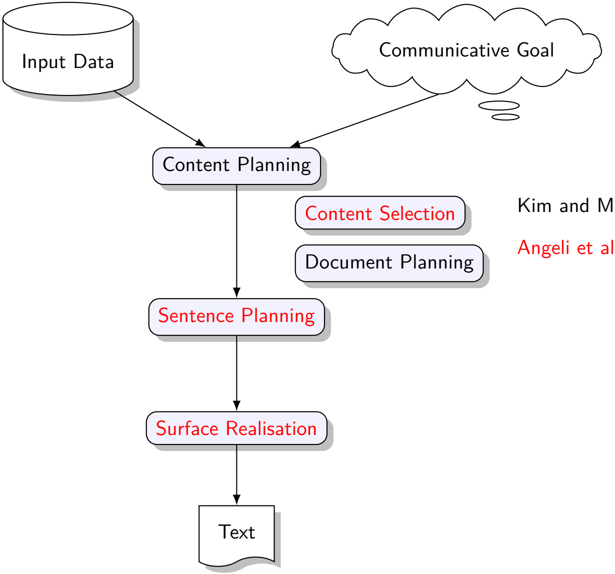
- **Pipeline Approach**
- Joint Approaches

Traditional NLG Pipeline



Kim and Mooney (2010)

Angeli et al. (2010)

Angeli et al., EMNLP 2010

A Simple Domain-Independent Probabilistic Approach to Generation

Generative Story

for $i = 1, 2, \ldots :$

1. **choose** a record $r_i \in \mathbf{d}$

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Generative Story

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4. **choose** a template $T_k \in r_i.t.f_j.\mathbf{T}$

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Each **decision** is governed by a set of feature templates

Feature Templates

Record	R1	list of $k = 1, 2$ record types	$r_2.t$=temp $\wedge$ $(r_1.t,\ r_0.t)$=(skyCover, START)
	R2	set of prev record types	$r_2.t$=temp $\wedge$ $\{r_1.t\}$=$\{$skyCover$\}$
	R3	record type already gen	$r_2.t$=temp $\wedge$ $r_j.t \neq$temp, $\forall j < 2$
	R4	field values	$r_2.t$=temp $\wedge$ r_2.v[min]=10, r_2.v[max]=20
	R5	STOP under LM	r_3.t=STOP $\times$ $p_{LM}($STOP$\mid$`degrees .`$)$

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Field	F1	field set	f_2= $\{$time, min, mean, max$\}$
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Template	W1	base/coarse	B(T_2) = ⟨`with a low around [min]`⟩
			C(T_2) = ⟨`with a [time] around [min]`⟩
	W2	field values	
	W3	1_{st} word of T under LM	p_{LM}(`with`|`cloudy ,`)

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$$p(\mathbf{c}|\mathbf{d};\theta) = \prod_{j=1}^{|\mathbf{c}|} p(c_j|c_{<j};\theta)$$

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L-BFGS learning: Use Liang et al. (2009) alignments to compute features

Decoding

$$\hat{c}_j = \arg\max_{c_j} p\big(c_j | c_{<j}; \theta\big)$$

- Greedy search: choose the best decision $\hat{c}_j$ until the STOP record is drawn

Decoding

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- Alternatively, sample from the distribution $p(c_j | c_{<j}; \theta)$;
- Viterbi search over $\arg\max_{c_j} p(c_j | \mathbf{d}; \theta)$

Conclusions

- Generation recast into a generative story
- Ensemble of local decisions
- Discriminatively trained end-to-end generation system

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- How about we model generation jointly and learn without supervision?

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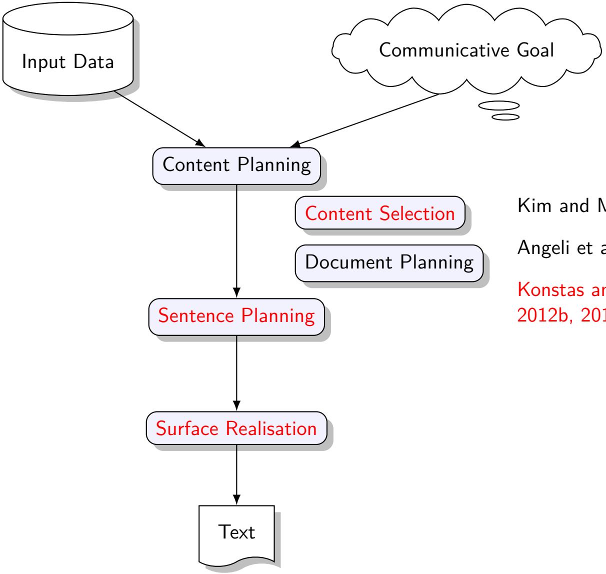
- Pipeline Approach
- **Joint Approaches**

Traditional NLG Pipeline



Kim and Mooney (2010)

Angeli et al. (2010)

Konstas and Lapata (2012a, 2012b, 2013b)

Konstas and Lapata, NAACL 2012

Unsupervised Concept-to-text Generation with Hypergraphs

Konstas and Lapata, JAIR 2013

A Global Model for Concept-to-Text Generation

Grammar

Grammar

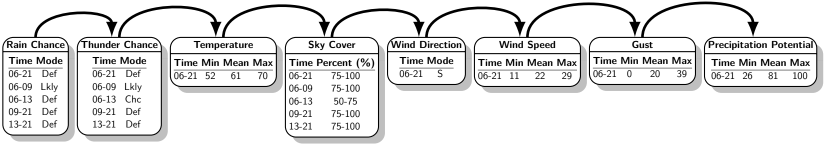
1. $\text{S} \rightarrow \text{R}(\textit{start})$

Grammar

1. $\text{S} \rightarrow \text{R}(start)$
2. $\text{R}(r_i.t) \rightarrow \text{FS}(r_j, start)\text{R}(r_j.t) \mid \text{FS}(r_j, start)$

$\text{R}(skyCover_1.t) \rightarrow \text{FS}(temperature_1, start)\text{R}(temperature_1.t)$

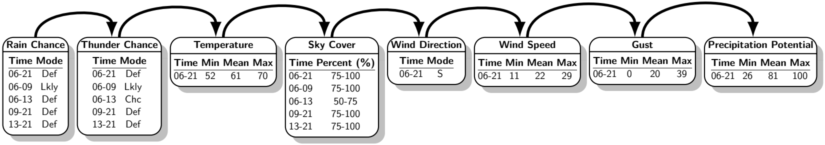
Grammar



1. $\mathrm{S} \rightarrow \mathrm{R}(start)$
2. $\mathrm{R}(r_i.t) \rightarrow \mathrm{FS}(r_j, start)\mathrm{R}(r_j.t) \mid \mathrm{FS}(r_j, start)$

$$\mathrm{R}(skyCover_1.t) \rightarrow \mathrm{FS}(temperature_1, start)\mathrm{R}(temperature_1.t)$$

Grammar



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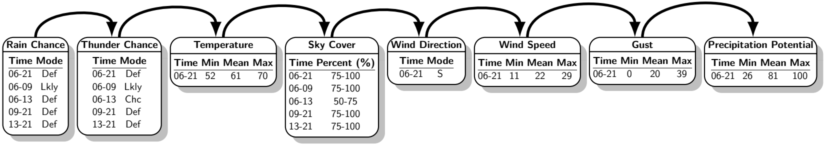
2. $\mathrm{R}(r_i.t) \rightarrow \mathrm{FS}(r_j, start)\mathrm{R}(r_j.t) \mid \mathrm{FS}(r_j, start)$
3. $\mathrm{FS}(r, r.f_i) \rightarrow \mathrm{F}(r, r.f_j)\mathrm{FS}(r, r.f_j) \mid \mathrm{F}(r, r.f_j)$

$$\mathrm{FS}(wSpeed_1, min) \rightarrow \mathrm{F}(wSpeed_1, max)\mathrm{FS}(wSpeed_1, max)$$

Grammar



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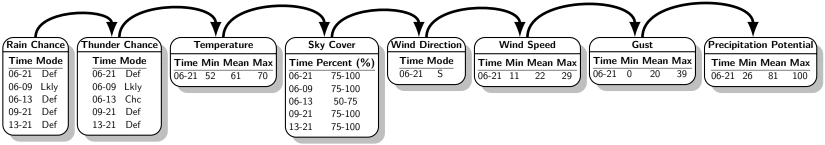
$$\text{F}(gust_1, min) \rightarrow \text{W}(gust_1, mean)\text{F}(gust_1, mean)$$

Grammar



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$\mathrm{W}(skyCover_1, \%) \rightarrow \text{cloudy } [\%.v = \text{'75–100'}]$

Grammar

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

Decoding

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

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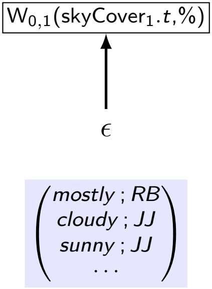
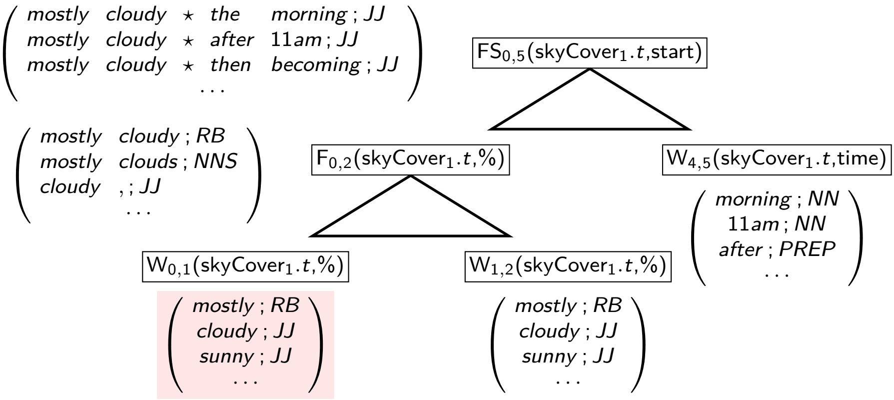
- Bottom-up Viterbi search
- Keep k-best derivations at each node, cube pruning (Chiang, 2007)
- $p(g)$ rescores derivations by linearly interpolating:
  - n-gram language model
  - dependency model (DMV; Klein and Manning, 2004)
- Implement using hypergraphs (Klein and Manning, 2001)

Decoding

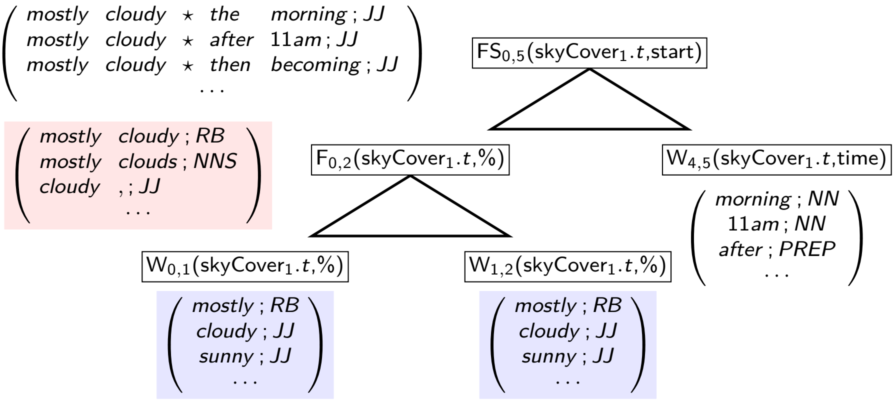
Leaf nodes ϵ emit a k-best list of words



Decoding


mostly cloudy ⋆ the morning ; JJ
mostly cloudy ⋆ after 11am ; JJ
mostly cloudy ⋆ then becoming ; JJ
...
FS0,5(skyCover1.t,start)
mostly cloudy ; RB
mostly clouds ; NNS
cloudy , ; JJ
...
F0,2(skyCover1.t,%)
W4,5(skyCover1.t,time)
morning ; NN
11am ; NN
after ; PREP
...
W0,1(skyCover1.t,%)
W1,2(skyCover1.t,%)
mostly ; RB
cloudy ; JJ
sunny ; JJ
...
mostly ; RB
cloudy ; JJ
sunny ; JJ
...

Decoding



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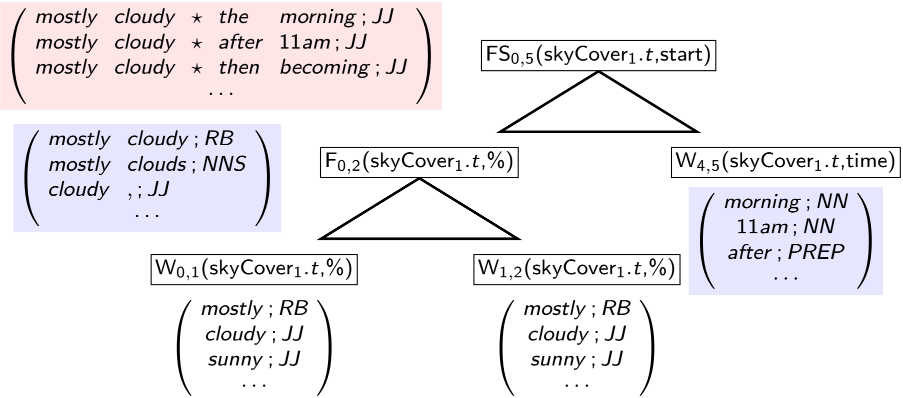
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Experimental Setup

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

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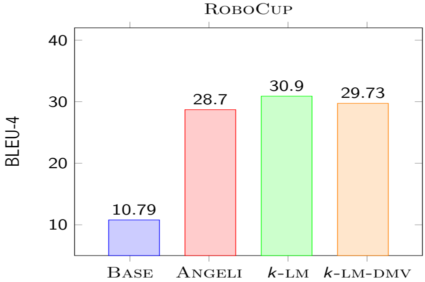
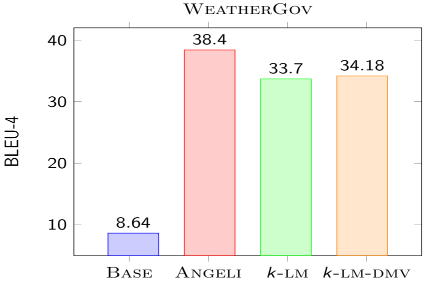
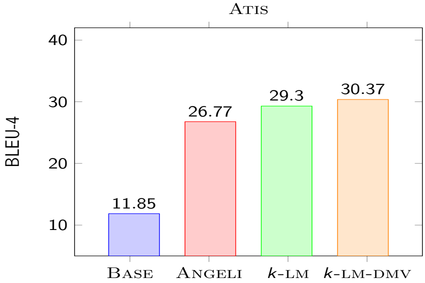
System Comparison

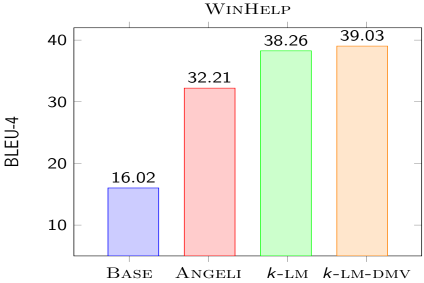
- 1−best, *k*-Best-lm, *k*-Best-lm-dmv
- Angeli et al. (2010)

Results: Automatic Evaluation

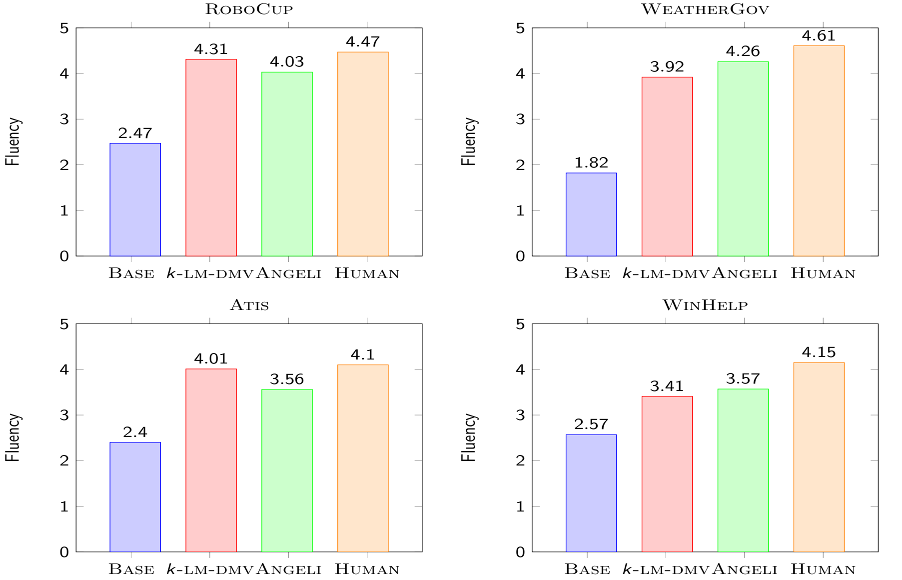








Results: Human Evaluation (Fluency)



Output

WeatherGov

Temperature

Time	Min	Mean	Max
06:00-21:00	30	38	44

Cloud Sky Cover

Time	Percent (%)
06:00-21:00	75-100

Chance of Rain

Time	Mode
06:00-11:00	Slight Chance

Wind Speed

Time	Min	Mean	Max
06:00-21:00	6	6	7

Wind Direction

Time	Mode
06:00-21:00	ENE

Precipitation Potential (%)

Time	Min	Mean	Max
06:00-21:00	9	20	35

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.

Output

ATIS

Input:

Flight	
from	**to**
milwaukee	phoenix

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

Search	
type	**what**
query	flight

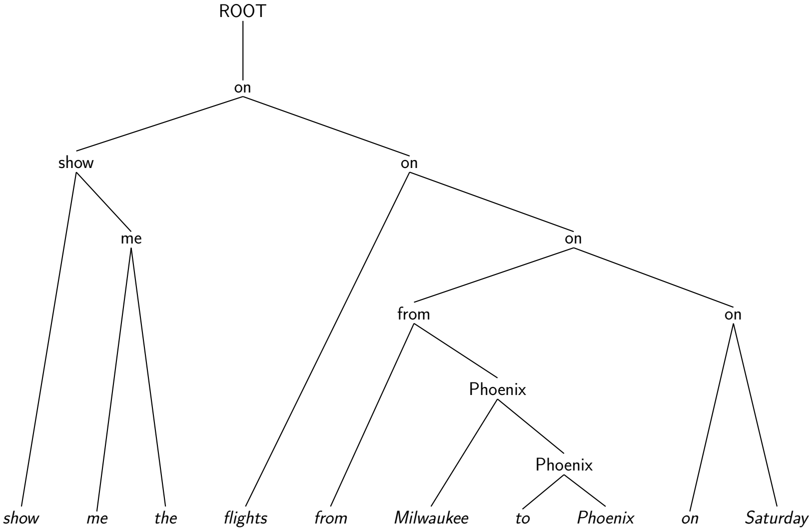
k-BEST: **What are the flights from Milwuakee to Phoenix on Saturday**

ANGELI : Show me the flights between Milwuakee and Phoenix on Saturday

HUMAN: Milwuakee to Phoenix on Saturday

Dependency Output

ATIS



Conclusions

- Generation as parsing problem
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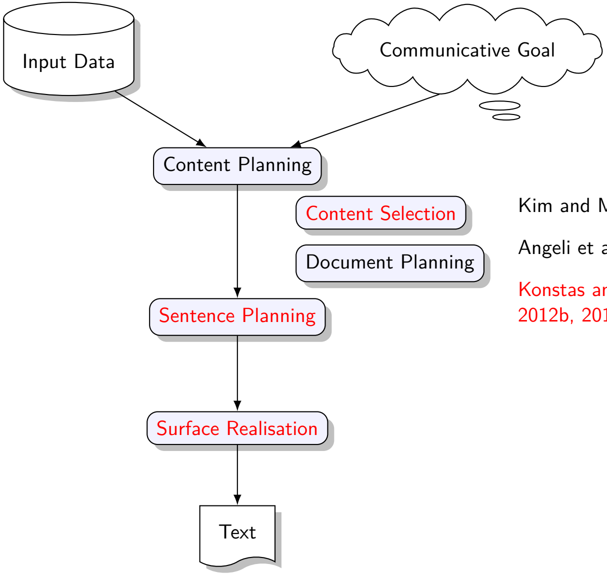
- What about document planning?

Traditional NLG Pipeline



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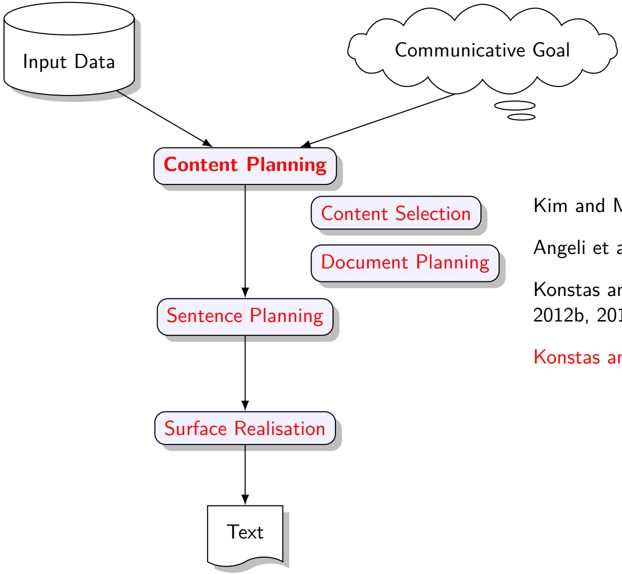

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Konstas and Lapata, EMNLP 2013

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

Key Idea

Desktop

Cmd	Name	Type
left-click	start	button

Start

Cmd	Name	Type
left-click	settings	button

Location

Name	Type
start menu	button
control panel	window

Start Target

Cmd	Name	Type
left-click	control panel	button

Navigate Window

Cmd	Name	Type
left-click	accounts and users	window

Context Menu

Cmd	Name	Type
left-click	advanced	tab

Action Context Menu

Cmd	Name	Type
left-click	advanced	button

Window Target

Cmd	Name	Type
double-click	users and passwords	item

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

Double-click users and passwords.

On the advanced tab, click advanced.

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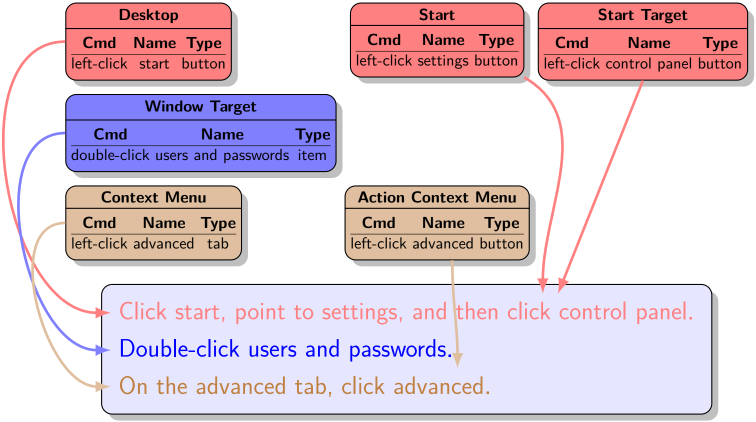
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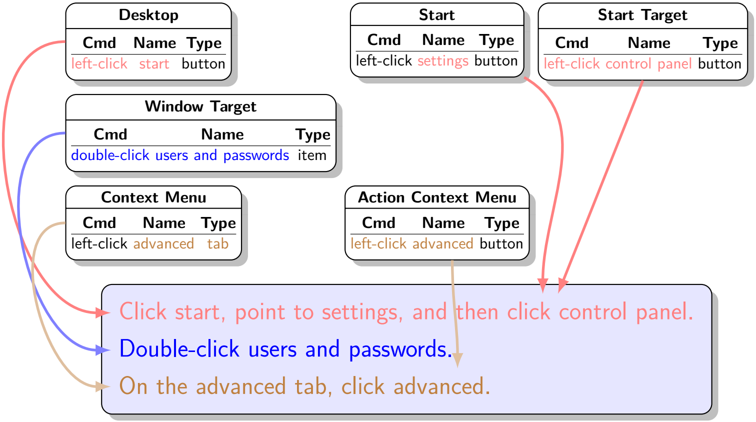
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Patterns of record sequences *within* a sentence and *among* sentences

Rhetorical Structure Theory (Mann and Thompson, 1988) inspired plans

Planning with Record Sequences

Key idea: Grammar on sequences of record types

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

Planning with Record Sequences

Key idea: Grammar on sequences of record types

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

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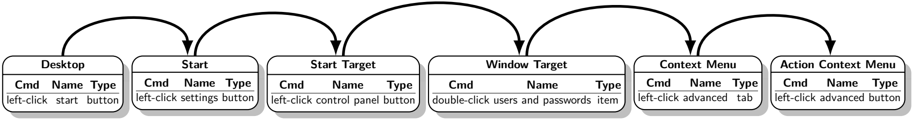
   Then split a sentence further into a sequence of record types.

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

Extended Grammar



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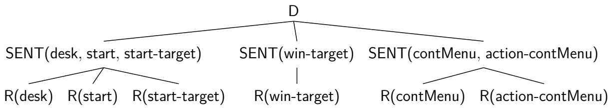

1. $D \rightarrow SENT(t_i, \ldots, t_j) \ldots SENT(t_l, \ldots, t_m)$
2. $SENT(t_i, \ldots, t_j) \rightarrow R(r_a.t_i) \ldots R(r_k.t_j) \cdot$
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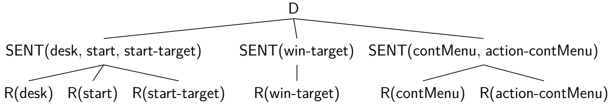

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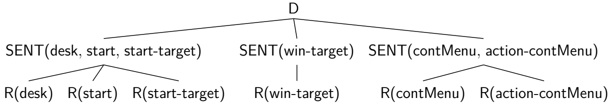

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Plan B: Extract grammar rules from training data

Grammar Extraction

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

contextMenu	action-contextMenu
On the advanced tab ,	click advanced.

Liang et al. (2009)

Grammar Extraction

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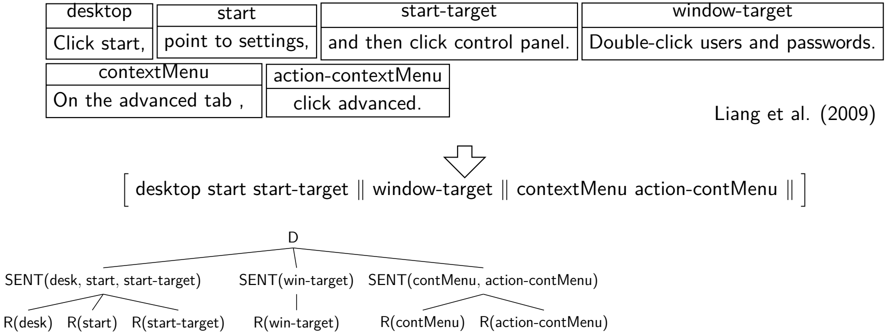
Liang et al. (2009)

⇩

[desktop start start-target ‖ window-target ‖ contextMenu action-contMenu ‖]

Grammar Extraction



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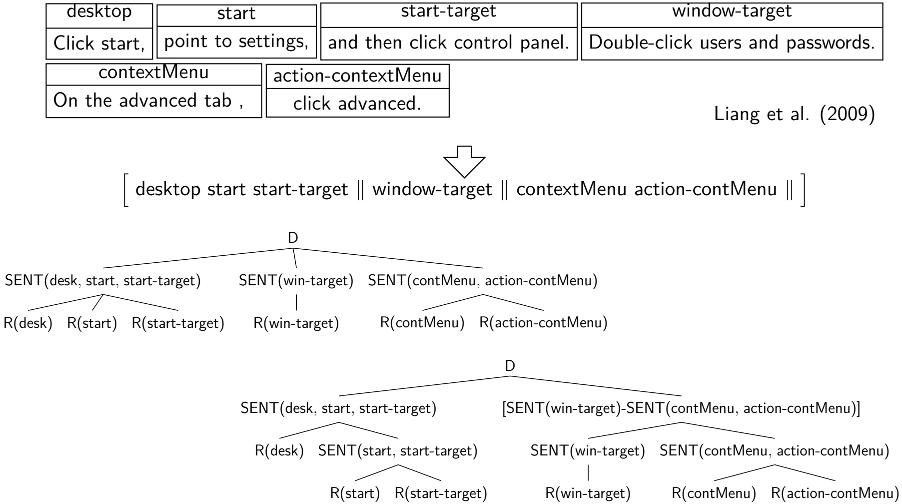
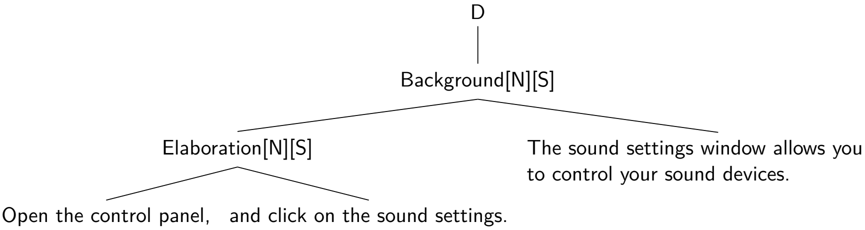


Planning with Rhetorical Structure Theory

RST (Mann and Thompson, 1988)



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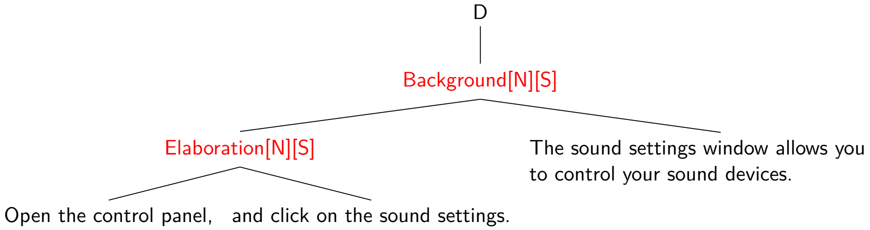

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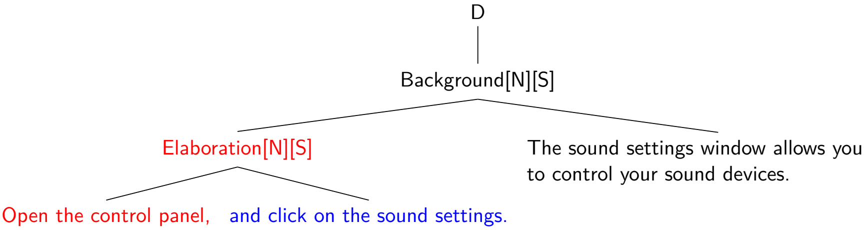

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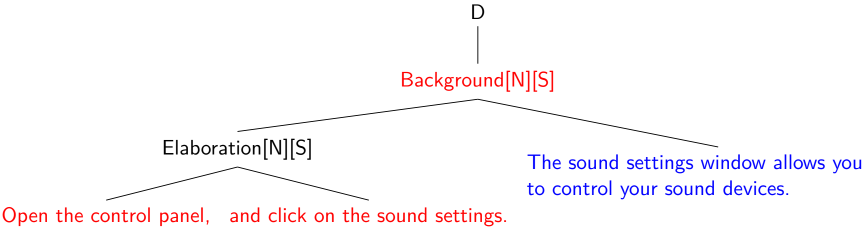

Planning with Rhetorical Structure Theory

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

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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

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

contextMenu	action-contextMenu
On the advanced tab ,	click advanced.

Liang et al. (2009)

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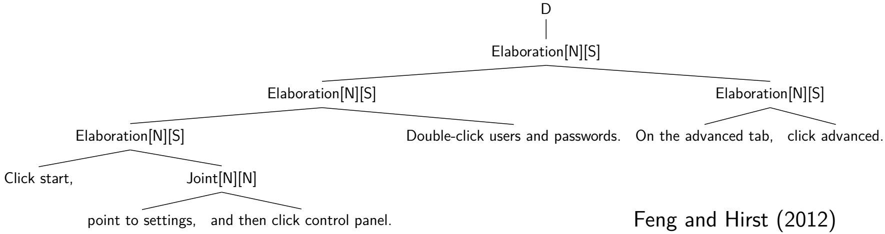
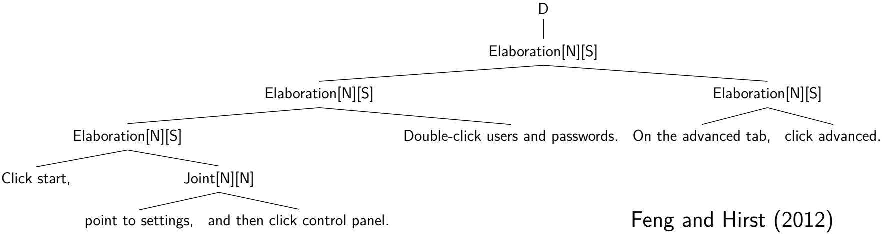


Feng and Hirst (2012)

Grammar Extraction



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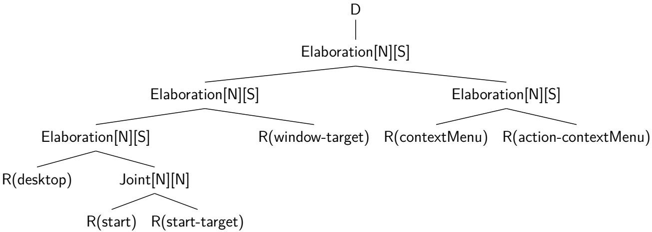

Extended Grammar

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

Experimental Setup

Data

- WeatherGov : weather reports [4 sents, 345 words] (Liang et al., 2009)
- WinHelp : troubleshooting guides [4.3 sents, 629 words] (Branavan et al., 2009)

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- Automatic evaluation: BLEU-4
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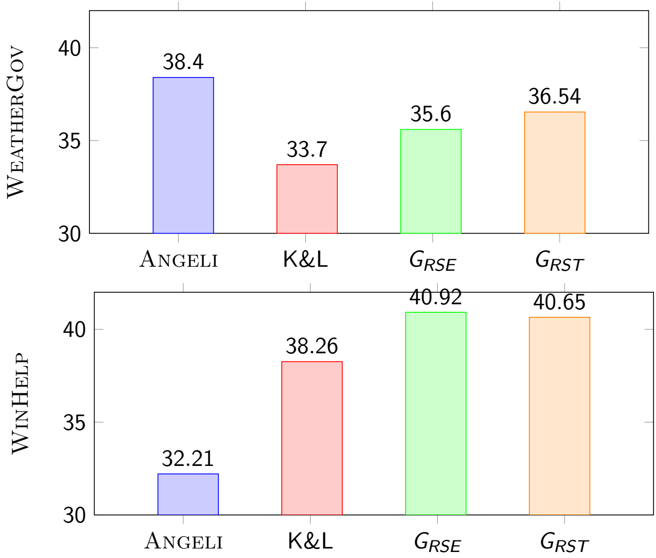
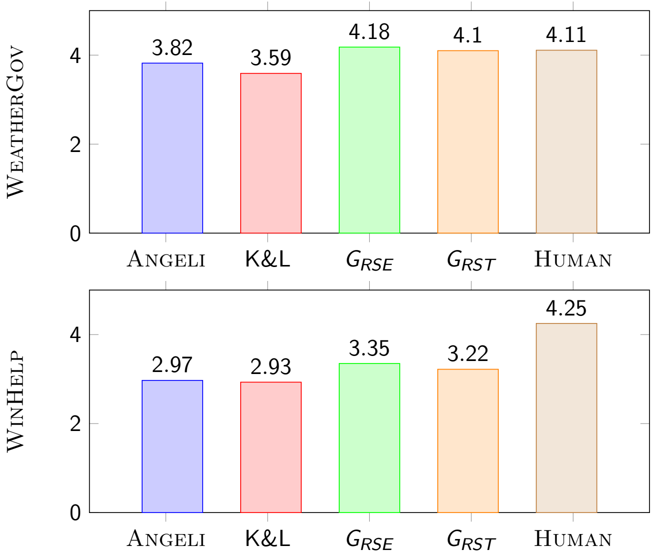
System Comparison

- G_{RSE}, G_{RST}
- Konstas and Lapata (2012a)
- Angeli et al. (2010)

Results: Automatic Evaluation (BLEU-4)



Results: Human Evaluation (Coherence)



Output

G_{RSE}	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. Click install, and then click add. Click network monitor driver, and then click ok.
K&L	Click start, point to settings, and then click control panel. Double-click network and dial-up connections. Double-click network and dial-up connections. Right-click local area connection, and then click ok.
Human	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. Click install, click protocol, and then click add. Click network monitor driver, and then click ok.

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})

Recap

- Recast NLG into a generative model
  - History-based local decisions - Add more features
  - Hierarchical joint model - Add more layers
- Learn parameters from (un)-annotated data - multiple domains
- Decoding: greedy search, *k*-best Viterbi search

Where do we go from here?

- Generate from more open-ended formalisms: AMR
- More challenging factual domains: biographies from Wikipedia
- More sophisticated sentence planning: aggregation, referring expressions
- More engineering: address sparsity, with Deep Learning

- Apply document planning grammars to summarisation

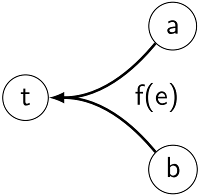
Thank you

Questions ?

Hypergraphs

Definition

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 $\mathbf{R}$.



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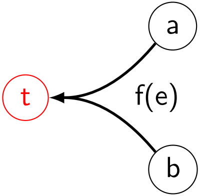

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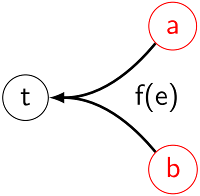

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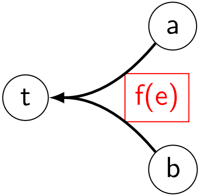
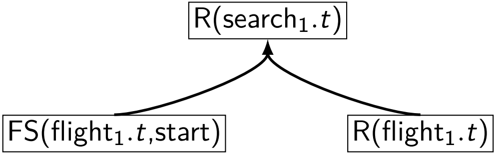


Hypergraph Construction

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



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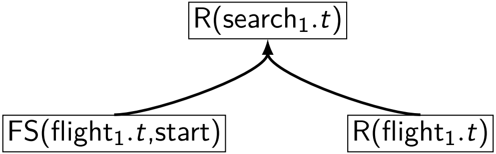

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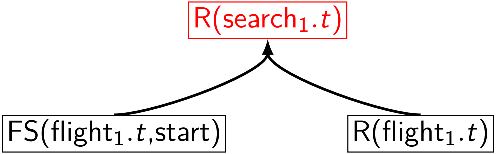

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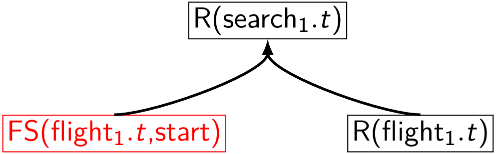

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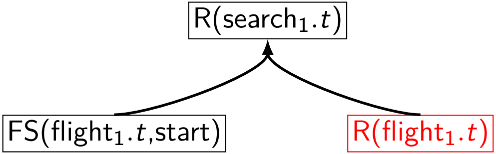

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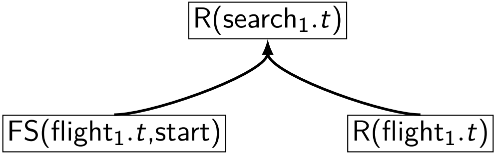

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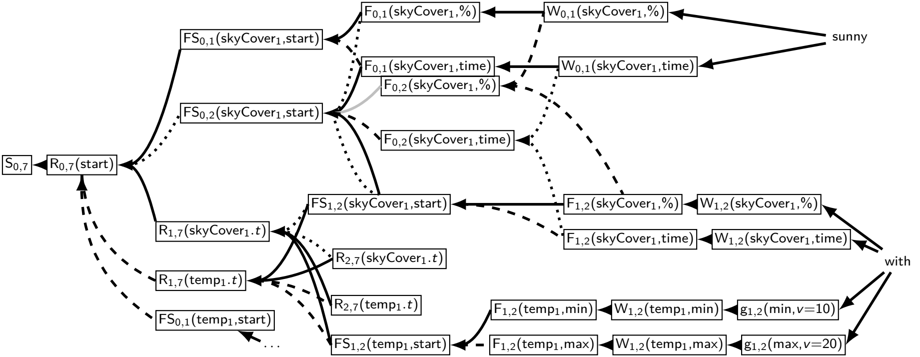
Hypergraph Example



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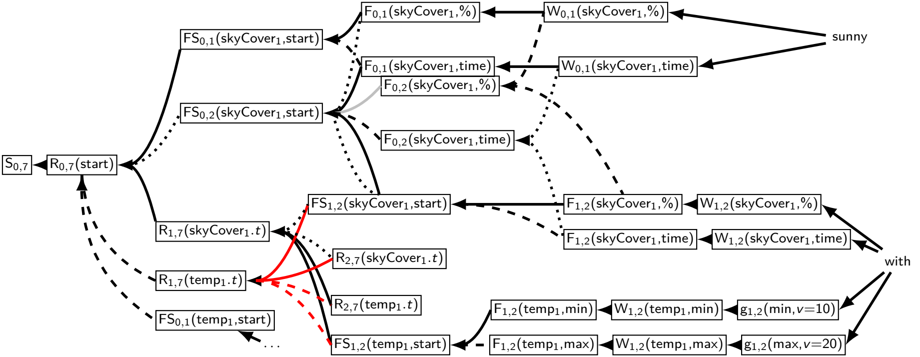

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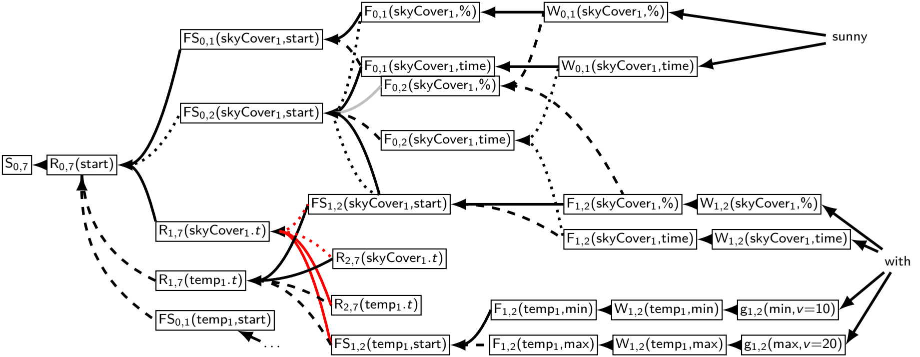

Determining Text Length

- Train a linear regression model
- Idea: The more records and fields that have values in the database → 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