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Concept-to-text Generation via Discriminative Reranking

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Abstract

This paper proposes a data-driven method for concept-to-text generation, the task of automatically producing textual output from non-linguistic input. A key insight in our approach is to reduce the tasks of content selection (“what to say”) and surface realization (“how to say”) into a common parsing problem. We define a probabilistic context-free grammar that describes the structure of the input (a corpus of database records and text describing some of them) and represent it compactly as a weighted hypergraph. The hypergraph structure encodes exponentially many derivations, which we rerank discriminatively using local and global features. We propose a novel decoding algorithm for finding the best scoring derivation and generating in this setting. Experimental evaluation on the ATIS domain shows that our model outperforms a competitive discriminative system both using BLEU and in a judgment elicitation study.

1 Introduction

Concept-to-text generation broadly refers to the task of automatically producing textual output from non-linguistic input such as databases of records, logical form, and expert system knowledge bases (Reiter and Dale, 2000). A variety of concept-to-text generation systems have been engineered over the years, with considerable success (e.g., Dale et al. (2003), Reiter et al. (2005), Green (2006), Turner et al. (2009)). Unfortunately, it is often difficult to adapt them across different domains as they rely mostly on handcrafted components.

In this paper we present a data-driven approach to concept-to-text generation that is domain-independent, conceptually simple, and flexible. Our generator learns from a set of database records and textual descriptions (for some of them). An example from the air travel domain is shown in Figure 1. Here, the records provide a structured representation of the flight details (e.g., departure and arrival time, location), and the text renders some of this information in natural language. Given such input, our model determines which records to talk about (content selection) and which words to use for describing them (surface realization). Rather than breaking up the generation process into a sequence of local decisions, we perform both tasks jointly. A key insight in our approach is to reduce content selection and surface realization into a common parsing problem. Specifically, we define a probabilistic context-free grammar (PCFG) that captures the structure of the database and its correspondence to natural language. This grammar represents multiple derivations which we encode compactly using a weighted hypergraph (or packed forest), a data structure that defines a weight for each tree.

Following a generative approach, we could first learn the weights of the PCFG by maximising the joint likelihood of the model and then perform generation by finding the best derivation tree in the hypergraph. The performance of this baseline system could be potentially further improved using discriminative reranking (Collins, 2000). Typically, this method first creates a list of $n$-best candidates from a generative model, and then reranks them with arbitrary features (both local and global) that are either not computable or intractable to compute within the
Database:

<table>
<thead>
<tr>
<th>Flight</th>
<th>Day Number</th>
<th>Month</th>
<th>Condition</th>
<th>Search</th>
</tr>
</thead>
<tbody>
<tr>
<td>from to</td>
<td>number dep/ar</td>
<td>month dep/ar</td>
<td>arg1 arg2 type</td>
<td>type what query flight</td>
</tr>
<tr>
<td>denver boston</td>
<td>9 departure</td>
<td>august departure</td>
<td>arrival_time 1600 &lt;</td>
<td></td>
</tr>
</tbody>
</table>

λ-expression: $\lambda x. (\text{flight}(x) \land \text{from}(x, \text{denver}) \land \text{to}(x, \text{boston}) \land \text{day\_number}(x, 9) \land \text{month}(x, \text{august}) \land \text{less\_than}(\text{arrival\_time}(x), 1600))$

Text: Give me the flights leaving Denver August ninth coming back to Boston before 4pm.

Figure 1: Example of non-linguistic input as a structured database and logical form and its corresponding text. We omit record fields that have no value, for the sake of brevity.

An appealing alternative is to rerank the hypergraph directly (Huang, 2008). As it compactly encodes exponentially many derivations, we can explore a much larger hypothesis space than would have been possible with an $n$-best list. Importantly, in this framework non-local features are computed at all internal hypergraph nodes, allowing the decoder to take advantage of them continuously at all stages of the generation process. We incorporate features that are local with respect to a span of a sub-derivation in the packed forest; we also (approximately) include features that arbitrarily exceed span boundaries, thus capturing more global knowledge. Experimental results on the ATIS domain (Dahl et al., 1994) demonstrate that our model outperforms a baseline based on the best derivation and a state-of-the-art discriminative system (Angeli et al., 2010) by a wide margin.

Our contributions in this paper are threefold: we recast concept-to-text generation in a probabilistic parsing framework that allows to jointly optimize content selection and surface realization; we represent parse derivations compactly using hypergraphs and illustrate the use of an algorithm for generating (rather than parsing) in this framework; finally, the application of discriminative reranking to concept-to-text generation is novel to our knowledge and as our experiments show beneficial.

2 Related Work

Early discriminative approaches to text generation were introduced in spoken dialogue systems, and usually tackled content selection and surface realization separately. Ratnaparkhi (2002) conceptualized surface realization (from a fixed meaning representation) as a classification task. Local and non-local information (e.g., word $n$-grams, long-range dependencies) was taken into account with the use of features in a maximum entropy probability model. More recently, Wong and Mooney (2007) describe an approach to surface realization based on synchronous context-free grammars. The latter are learned using a log-linear model with minimum error rate training (Och, 2003).

Angeli et al. (2010) were the first to propose a unified approach to content selection and surface realization. Their model operates over automatically induced alignments of words to database records (Liang et al., 2009) and decomposes into a sequence of discriminative local decisions. They first determine which records in the database to talk about, then which fields of those records to mention, and finally which words to use to describe the chosen fields. Each of these decisions is implemented as a log-linear model with features learned from training data. Their surface realization component performs decisions based on templates that are automatically extracted and smoothed with domain-specific knowledge in order to guarantee fluent output.

Discriminative reranking has been employed in many NLP tasks such as syntactic parsing (Charniak and Johnson, 2005; Huang, 2008), machine translation (Shen et al., 2004; Li and Khudanpur, 2009) and semantic parsing (Ge and Mooney, 2006). Our model is closest to Huang (2008) who also performs forest reranking on a hypergraph, using both local and non-local features, whose weights are tuned with the averaged perceptron algorithm (Collins, 2002). We adapt forest reranking to generation and introduce several task-specific features that boost performance. Although conceptually related to Angeli et al. (2010), our model optimizes content selection and surface realization simultaneously, rather than as a sequence. The discriminative aspect of two models is also fundamentally different. We have a single reranking component that applies
throughout, whereas they train different discriminative models for each local decision.

3 Problem Formulation

We assume our generator takes as input a set of database records \( d \) and produces text \( w \) that verbalizes some of these records. Each record \( r \in d \) has a type \( r.t \) and a set of fields \( f \) associated with it. Fields have different values \( f.v \) and types \( f.t \) (i.e., integer or categorical). For example, in Figure 1, \( \text{flight} \) is a record type with fields \( \text{denver} \) and \( \text{boston} \). The values of these fields are \( \text{denver} \) and \( \text{boston} \) and their type is categorical.

During training, our algorithm is given a corpus consisting of several scenarios, i.e., database records paired with texts like those shown in Figure 1. The database (and accompanying texts) are next converted into a PCFG whose weights are learned from training data. PCFG derivations are represented as a weighted directed hypergraph (Gallo et al., 1993). The weights on the hyperarcs are defined by a variety of feature functions, which we learn via a discriminative online update algorithm. During testing, we are given a set of database records without the corresponding text. Using the learned feature weights, we compile a hypergraph specific to this test input and decode it approximately (Huang, 2008). The hypergraph representation allows us to decompose the feature functions and compute them piecemeal at each hyperarc (or sub-derivation), rather than at the root node as in conventional \( n \)-best list reranking. Note that the algorithm does not separate content selection from surface realization, both subtasks are optimized jointly through the probabilistic parsing formulation.

3.1 Grammar Definition

We capture the structure of the database with a number of CFG rewrite rules, in a similar way to how Liang et al. (2009) define Markov chains in their hierarchical model. These rules are purely syntactic (describing the intuitive relationship between records, records and fields, fields and corresponding words), and could apply to any database with similar structure irrespectively of the semantics of the domain.

Our grammar is defined in Table 1 (rules (1)–(9)). Rule weights are governed by an underlying multinomial distribution and are shown in square brackets.

<table>
<thead>
<tr>
<th>Rule</th>
<th>Description</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. S ( \rightarrow ) R((\text{start}))</td>
<td>([P_r = 1])</td>
<td></td>
</tr>
<tr>
<td>2. R((r_i,t)) ( \rightarrow ) FS((r_j,\text{start})) R((r_j,t))</td>
<td>([P(r_j.t \mid r_i.t) \cdot \lambda])</td>
<td></td>
</tr>
<tr>
<td>3. R((r_i,t)) ( \rightarrow ) FS((r_j,\text{start}))</td>
<td>([P(r_j.t \mid r_i.t) \cdot \lambda])</td>
<td></td>
</tr>
<tr>
<td>4. FS((r,r_f)) ( \rightarrow ) F((r,r,f_j)) FS((r,r_f))</td>
<td>([P(f_j \mid f)])</td>
<td></td>
</tr>
<tr>
<td>5. FS((r,r_f)) ( \rightarrow ) F((r,r,f_j))</td>
<td>([P(f_j \mid f)])</td>
<td></td>
</tr>
<tr>
<td>6. F((r,r,f)) ( \rightarrow ) W((r,r_f)) F((r,r,f))</td>
<td>([P(w \mid w_{-1},r,r_f)])</td>
<td></td>
</tr>
<tr>
<td>7. F((r,r,f)) ( \rightarrow ) W((r,r_f))</td>
<td>([P(w \mid w_{-1},r,r_f)])</td>
<td></td>
</tr>
<tr>
<td>8. W((r,r_f)) ( \rightarrow ) (\alpha)</td>
<td>([P(\alpha \mid r,r,f,f.t,f.v)])</td>
<td></td>
</tr>
<tr>
<td>9. W((r,r_f)) ( \rightarrow ) g((f,v))</td>
<td>([P(g(f,v).\text{mode} \mid r,r,f,f.t,f.v = \text{int}]))</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Grammar rules and their weights shown in square brackets.

Rule (1) denotes the expansion from the start symbol \( S \) to record \( R \), which has the special \( \text{start} \) type (hence the notation \( R(\text{start}) \)). Rule (2) defines a chain between two consecutive records \( r_i \) and \( r_j \). Here, \( \text{FS}(r_j,\text{start}) \) represents the set of fields of the target \( r_j \), following the source record \( R(r_i) \). For example, the rule \( R(\text{search}_1,t) \rightarrow \text{FS}(\text{flight}_1,\text{start})R(\text{flight}_1,t) \) can be interpreted as follows. Given that we have talked about \( \text{search}_1 \), we will next talk about \( \text{flight}_1 \) and thus emit its corresponding fields. \( R(\text{flight}_1,t) \) is a non-terminal place-holder for the continuation of the chain of records, and \( \text{start} \) in \( \text{FS} \) is a special boundary field between consecutive records. The weight of this rule is the bigram probability of two records conditioned on their type, multiplied with a normalization factor \( \lambda \). We have also defined a \( \text{null} \) record type i.e., a record that has no fields and acts as a smoother for words that may not correspond to a particular record. Rule (3) is simply an escape rule, so that the parsing process (on the record level) can finish.

Rule (4) is the equivalent of rule (2) at the field etas. Non-terminal symbols are in capitals and denote intermediate states; the terminal symbol \( \alpha \) corresponds to all words seen in the training set, and \( g(f,v) \) is a function for generating integer numbers given the value of a field \( f \). All non-terminals, save the start symbol \( S \), have one or more constraints (shown in parentheses), similar to number and gender agreement constraints in augmented syntactic rules.
level, i.e., it describes the chaining of two consecutive fields $f_i$ and $f_j$. Non-terminal $F(r,r.f)$ refers to field $f$ of record $r$. For example, the rule $FS(\text{flight}_1, \text{from}) \rightarrow F(\text{flight}_1, to)FS(\text{flight}_1, to)$, specifies that we should talk about the field $to$ of record $\text{flight}_1$, after talking about the field $from$. Analogously to the record level, we have also included a special $null$ field type for the emission of words that do not correspond to a specific record field. Rule (6) defines the expansion of field $F$ to a sequence of (binarized) words $W$, with a weight equal to the bigram probability of the current word given the previous word, the current record, and field.

Rules (8) and (9) define the emission of words and integer numbers from $W$, given a field type and its value. Rule (8) emits a single word from the vocabulary of the training set. Its weight defines a multinomial distribution over all seen words, for every value of field $f$, given that the field type is categorical or the special $null$ field. Rule (9) is identical but for fields whose type is integer. Function $g(f,v)$ generates an integer number given the field value, using either of the following six ways (Liang et al., 2009): identical to the field value, rounding up or rounding down to a multiple of 5, rounding off to the closest multiple of 5 and finally adding or subtracting some unexplained noise. The weight is a multinomial over the six generation function $modes$, given the record field $f$.

The CFG in Table 1 will produce many derivations for a given input (i.e., a set of database records) which we represent compactly using a hypergraph or a packed forest (Klein and Manning, 2001; Huang, 2008). Simplified examples of this representation are shown in Figure 2.

3.2 Hypergraph Reranking

For our generation task, we are given a set of database records $d$, and our goal is to find the best corresponding text $w$. This corresponds to the best grammar derivation among a set of candidate derivations represented implicitly in the hypergraph structure. As shown in Table 1, the mapping from $d$ to $w$ is unknown. Therefore, all the intermediate multinomial distributions, described in the previous section, define a hidden correspondence structure $h$, between records, fields, and their values. We find the best scoring derivation $(\hat{w}, \hat{h})$ by maximizing over configurations of $h$:

$$\arg \max_{w,h} \alpha \cdot \Phi(d, w, h)$$

We define the score of $(\hat{w}, \hat{h})$ as the dot product between a high dimensional feature representation $\Phi = (\Phi_1, \ldots, \Phi_m)$ and a weight vector $\alpha$.

We estimate the weights $\alpha$ using the averaged structured perceptron algorithm (Collins, 2002), which is well known for its speed and good performance in similar large-parameter NLP tasks (Liang et al., 2006; Huang, 2008). As shown in Algorithm 1, the perceptron makes several passes over the training scenarios, and in each iteration it computes the best scoring $(\hat{w}, \hat{h})$ among the candidate derivations, given the current weights $\alpha$. In line 6, the algorithm updates $\alpha$ with the difference (if any) between the feature representations of the best scoring derivation $(\hat{w}, \hat{h})$ and the oracle derivation $(w^*, h^*)$. Here, $\hat{w}$ is the estimated text, $w^*$ the gold-standard text, $\hat{h}$ is the estimated latent configuration of the model and $h^*$ the oracle latent configuration. The final weight vector $\alpha$ is the average of weight vectors over $T$ iterations and $N$ scenarios. This averaging procedure avoids overfitting and produces more stable results (Collins, 2002).

3.3 Hypergraph Decoding

Following Huang (2008), we also distinguish features into local, i.e., those that can be computed within the confines of a single hyperedge, and non-local, i.e., those that require the prior visit of nodes other than their antecedents. For example, the
Alignment feature in Figure 2(a) is local, and thus can be computed a priori, but the Word Trigrams is not; in Figure 2(b) words in parentheses are subgenerations created so far at each word node; their combination gives rise to the trigrams serving as input to the feature. However, this combination may not take place at their immediate ancestors, since these may not be adjacent nodes in the hypergraph. According to the grammar in Table 1, there is no direct hyperedge between nodes representing words (W) and nodes representing the set of fields these correspond to (FS); rather, W and FS are connected implicitly via individual fields (F). Note, that in order to estimate the trigram feature at the FS node, we need to carry word information in the derivations of its antecedents, as we go bottom-up.²

Given these two types of features, we can then adapt Huang’s (2008) approximate decoding algorithm to find \((\hat{w}, \hat{h})\). Essentially, we perform bottom-up Viterbi search, visiting the nodes in reverse topological order, and keeping the \(k\)-best derivations for each. The score of each derivation is a linear combination of local and non-local features weights. In machine translation, a decoder that implements forest rescoring (Huang and Chiang, 2007) uses the language model as an external criterion of the goodness of sub-translations on account of their grammaticality. Analogously here, non-local features influence the selection of the best combinations, by introducing knowledge that exceeds the confines of the node under consideration and thus depend on the sub-derivations generated so far. (e.g., word trigrams spanning a field node rely on evidence from antecedent nodes that may be arbitrarily deeper than the field’s immediate children).

Our treatment of leaf nodes (see rules (8) and (9)) differs from the way these are usually handled in parsing. Since in generation we must emit rather than observe the words, for each leaf node we therefore output the \(k\)-best words according to the learned weights \(\alpha\) of the Alignment feature (see Section 4.2), and continue building our sub-generations bottom-up. This generation task is far from trivial: the search space on the word level is the size of the vocabulary and each field of a record can potentially generate all words. Also, note that in decoding it is useful to have a way to score different output lengths \(|w|\). Rather than setting \(w\) to a fixed length, we rely on a linear regression predictor that uses the counts of each record type per scenario as features and is able to produce variable length texts.

3.4 Oracle Derivation

So far we have remained agnostic with respect to the oracle derivation \((w^*, h^+)\). In other NLP tasks such as syntactic parsing, there is a gold-standard parse, that can be used as the oracle. In our generation setting, such information is not available. We do not have the gold-standard alignment between the database records and the text that verbalizes them. Instead, we approximate it using the existing decoder to find the best latent configuration \(h^+\) given the observed words in the training text \(w^*\). This is similar in spirit to the generative alignment model of Liang et al. (2009).

4 Experimental Design

In this section we present our experimental setup for assessing the performance of our model. We give details on our dataset, model parameters and features, the approaches used for comparison, and explain how system output was evaluated.

4.1 Dataset

We conducted our experiments on the Air Travel Information System (ATIS) dataset (Dahl et al., 1994) which consists of transcriptions of spontaneous utterances of users interacting with a hypothetical online flight booking system. The dataset was originally created for the development of spoken language systems and is partitioned in individual user turns (e.g., \(flights\ from\ orlando\ to\ milwaukee,\ show\ flights\ from\ orlando\ to\ milwaukee\ leaving\ after\ six\ o’clock\)) each accompanied with an SQL query to a booking system and the results of this query. These utterances are typically short expressing a specific communicative goal (e.g., a question about the origin of a flight or its time of arrival). This inevitably results in small scenarios with a few words that often unambiguously correspond to a single record. To avoid training our model on a somewhat trivial corpus, we used the dataset introduced in Zettlemoyer

²We also store field information to compute structural features, described in Section 4.2.

³In machine translation, Huang (2008) provides a soft algorithm that finds the forest oracle, i.e., the parse among the reranked candidates with the highest Parseval F-score. However, it still relies on the gold-standard reference translation.
and Collins (2007) instead, which combines the utterances of a single user in one scenario and contains 5,426 scenarios in total; each scenario corresponds to a (manually annotated) formal meaning representation (λ-expression) and its translation in natural language.

Lambda expressions were automatically converted into records, fields and values following the conventions adopted in Liang et al. (2009). Given a lambda expression like the one shown in Figure 1, we first create a record for each variable and constant (e.g., x, 9, august). We then assign record types according to the corresponding class types (e.g., variable x has class type flight). Next, fields and values are added from predicates with two arguments with the class type of the first argument matching that of the record type. The name of the predicate denotes the field, and the second argument denotes the value. We also defined special record types, such as condition and search. The latter is introduced for every lambda operator and assigned the categorical field what with the value flight which refers to the record type of variable x.

Contrary to datasets used in previous generation studies (e.g., ROBOCUP (Chen and Mooney, 2008) and WEATHERGOV (Liang et al., 2009)), ATIS has a much richer vocabulary (927 words); each scenario corresponds to a single sentence (average length is 11.2 words) with 2.65 out of 19 record types mentioned on average. Following Zettlemoyer and Collins (2007), we trained on 4,962 scenarios and tested on ATIS NOV93 which contains 448 examples.

4.2 Features

Broadly speaking, we defined two types of features, namely lexical and structural ones. In addition, we used a generatively trained PCFG as a baseline feature and an alignment feature based on the co-occurrence of records (or fields) with words.

Baseline Feature This is the log score of a generative decoder trained on the PCFG from Table 1. We converted the grammar into a hypergraph, and learned its probability distributions using a dynamic program similar to the inside-outside algorithm (Li and Eisner, 2009).

Alignment Features Instances of this feature family refer to the count of each PCFG rule from Table 1. For example, the number of times rule \( R(\text{search}_1.t) \rightarrow \text{FS}(\text{flight}_1, \text{start})R(\text{flight}_1.t) \) is included in a derivation (see Figure 2(a)).

Lexical Features These features encourage grammatical coherence and inform lexical selection over and above the limited horizon of the language model captured by Rules (6)–(9). They also tackle anomalies in the generated output, due to the ergodicity of the CFG rules at the record and field level:

Word Bigrams/Trigrams This is a group of non-local feature functions that count word n-grams at every level in the hypergraph (see Figure 2(b)). The integration of words in the sub-derivations is adapted from Chiang (2007).

Number of Words per Field This feature function counts the number of words for every field, aiming to capture compound proper nouns and multi-word expressions, e.g., fields from and to frequently correspond to two or three words such as ‘new york’ and ‘salt lake city’ (see Figure 2(d)).

Consecutive Word/Bigram/Trigram This feature family targets adjacent repetitions of the same word, bigram or trigram, e.g., ‘show me the show me the flights’.

Structural Features Features in this category target primarily content selection and influence appropriate choice at the field level:

Field bigrams/trigrams Analogously to the lexical features mentioned above, we introduce a series of non-local features that capture field n-grams, given a specific record. For example the record flight in the air travel domain typically has the values <from to> (see Figure 2(c)). The integration of fields in sub-derivations is implemented in fashion similar to the integration of words.

Number of Fields per Record This feature family is a coarser version of the Field bigrams/trigrams.
feature, which is deemed to be sparse for rarely-seen records.

**Field with No Value** Although records in the ATIS database schema have many fields, only a few are assigned a value in any given scenario. For example, the flight record has 13 fields, of which only 1.7 (on average) have a value. Practically, in a generative model this kind of sparsity would result in very low field recall. We thus include an identity feature function that explicitly counts whether a particular field has a value.

### 4.3 Evaluation

We evaluated three configurations of our model. A system that only uses the top scoring derivation in each sub-generation and incorporates only the baseline and alignment features (1-BEST+BASE+ALIGN). Our second system considers the k-best derivations and additionally includes lexical features (k-BEST+BASE+ALIGN+LEX). The number of k-best derivations was set to 40 and estimated experimentally on held-out data. And finally, our third system includes the full feature set (k-BEST+BASE+ALIGN+LEX+STR). Note, that the second and third system incorporate non-local features, hence the use of k-best derivation lists.5 We compared our model to Angeli et al. (2010) whose approach is closest to ours.6

We evaluated system output automatically, using the BLEU-4 modified precision score (Papineni et al., 2002) with the human-written text as reference. We also report results with the METEOR score (Banerjee and Lavie, 2005), which takes into account word re-ordering and has been shown to correlate better with human judgments at the sentence level. In addition, we evaluated the generated text by eliciting human judgments. Participants were presented with a scenario and its corresponding verbalization (see Figure 3) and were asked to rate the latter along two dimensions: fluency (is the text grammatical and overall understandable?) and semantic correctness (does the meaning conveyed by the text correspond to the database input?). The subjects used a five point rating scale where a high number indicates better performance. We randomly selected 12 documents from the test set and generated output with two of our models (1-BEST+BASE+ALIGN and k-BEST+BASE+ALIGN+LEX+STR) and Angeli et al.’s (2010) model. We also included the original text (HUMAN) as a gold standard. We thus obtained ratings for 48 (12 × 4) scenario-text pairs. The study was conducted over the Internet, using Amazon Mechanical Turk, and was completed by 51 volunteers, all self reported native English speakers.

### 5 Results

Table 2 summarizes our results. As can be seen, inclusion of lexical features gives our decoder an absolute increase of 6.73% in BLEU over the 1-BEST system. It also outperforms the discriminative system of Angeli et al. (2010). Our lexical features seem more robust compared to their templates. This is especially the case with infrequent records, where their system struggles to learn any meaningful information. Addition of the structural features further boosts performance. Our model increases by 8.69%
over the 1-BEST system and 3.85% over ANGELI in terms of BLEU. We observe a similar trend when evaluating system output with METEOR. Differences in magnitude are larger with the latter metric.

The results of our human evaluation study are shown in Table 5. We carried out an Analysis of Variance (ANOVA) to examine the effect of system type (1-BEST, k-BEST, ANGELI, and HUMAN) on the fluency and semantic correctness ratings. Means differences were compared using a post-hoc Tukey test. The k-BEST system is significantly better than the 1-BEST and ANGELI ($a < 0.01$) both in terms of fluency and semantic correctness. ANGELI is significantly better than 1-BEST with regard to fluency ($a < 0.05$) but not semantic correctness. There is no statistically significant difference between the k-BEST output and the original sentences (HUMAN).

Examples of system output are shown in Table 3. They broadly convey similar meaning with the gold-standard; ANGELI exhibits some long-range repetition, probably due to re-iteration of the same record patterns. We tackle this issue with the inclusion of non-local structural features. The 1-BEST system has some grammaticality issues, which we avoid by defining features over lexical n-grams and repeated words. It is worth noting that both our system and ANGELI produce output that is semantically compatible with but lexically different from the gold-standard (compare *please list the flights* and *show me the flights* against *give me the flights*). This is expected given the size of the vocabulary, but raises concerns regarding the use of automatic metrics for the evaluation of generation output.

### Table 2: BLEU-4 and METEOR results on ATIS.

<table>
<thead>
<tr>
<th>System</th>
<th>BLEU</th>
<th>METEOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-BEST+BASE+ALIGN</td>
<td>21.93</td>
<td>34.01</td>
</tr>
<tr>
<td>k-BEST+BASE+ALIGN+LEX</td>
<td>28.66</td>
<td>45.18</td>
</tr>
<tr>
<td>k-BEST+BASE+ALIGN+LEX+STR</td>
<td>30.62</td>
<td>46.07</td>
</tr>
<tr>
<td>ANGELI</td>
<td>26.77</td>
<td>42.41</td>
</tr>
</tbody>
</table>

### Table 3: Mean ratings for fluency and semantic correctness (SemCor) on system output elicited by humans.

<table>
<thead>
<tr>
<th>System</th>
<th>Fluency</th>
<th>SemCor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-BEST+BASE+ALIGN</td>
<td>2.70</td>
<td>3.05</td>
</tr>
<tr>
<td>k-BEST+BASE+ALIGN+LEX+STR</td>
<td>4.02</td>
<td>4.04</td>
</tr>
<tr>
<td>ANGELI</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>

### Figure 3: Example of scenario input and system output.

In the future, we would also like to tackle more challenging domains (e.g., product descriptions) and to enrich our generator with some notion of discourse planning. An interesting question is how to extend the PCFG-based approach advocated here so as to capture discourse-level document structure.
References


Zhiwei Li and Sanjeev Khudanpur. 2009. Forest reranking for machine translation with the perceptron algorithm. In GALE Book. GALE.


