

# On Different Approaches to Syntactic Analysis Into Bi-Lexical Dependencies An Empirical Comparison of Direct, PCFG-Based, and HPSG-Based Parsers

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## Abstract

We compare three different approaches to parsing into syntactic, bi-lexical dependencies for English: a ‘direct’ data-driven dependency parser, a statistical phrase structure parser, and a hybrid, ‘deep’ grammar-driven parser. The analyses from the latter two are post-converted to bi-lexical dependencies. Through this ‘reduction’ of all three approaches to syntactic dependency parsers, we determine empirically what performance can be obtained for a common set of dependency types for English, across a broad variety of domains. In doing so, we observe what trade-offs apply along three dimensions, accuracy, efficiency, and resilience to domain variation. Our results suggest that the hand-built grammar in one of our parsers helps in both accuracy and cross-domain performance.

## 1 Motivation

Bi-lexical dependencies, i.e. binary head–argument relations holding exclusively between lexical units, are widely considered an attractive target representation for syntactic analysis. At the same time, Cer et al. (2010) and Foster et al. (2011), inter alios, have demonstrated that higher dependency accuracies can be obtained by parsing into a phrase structure representation first, and then reducing parse trees into bi-lexical dependencies.<sup>1</sup> Thus, if one is willing to accept pure syntactic dependencies as a viable interface (and evaluation) representation, an experimental setup like the one of Cer et al. (2010) allows the exact experimental comparison of quite different parsing approaches.<sup>2</sup> Existing such studies to date are lim-

<sup>1</sup>This conversion from one representation of syntax to another is lossy, in the sense of discarding constituency information, hence we consider it a reduction in linguistic detail.

<sup>2</sup>In contrast, much earlier work on cross-framework comparison involved post-processing parser outputs in form and content, into a target representation for which gold-standard annotations were available. In § 2 below, we argue that such conversion inevitably introduces blur into the comparison.

ited to purely data-driven (or statistical) parsers, i.e. systems where linguistic knowledge is exclusively acquired through supervised machine learning from annotated training data. For English, the venerable Wall Street Journal (WSJ) portion of the Penn Treebank (PTB; Marcus et al., 1993) has been the predominant source of training data, for phrase structure and dependency parsers alike.

Two recent developments make it possible to broaden the range of parsing approaches that can be assessed empirically on the task of deriving bi-lexical syntactic dependencies. Flickinger et al. (2012) make available another annotation layer over the same WSJ text, ‘deep’ syntacto-semantic analyses in the linguistic framework of Head-Driven Phrase Structure Grammar (HPSG; Pollard & Sag, 1994; Flickinger, 2000). This resource, dubbed DeepBank, is available since late 2012. For the type of HPSG analyses recorded in DeepBank, Zhang and Wang (2009) and Ivanova et al. (2012) define a reduction into bi-lexical syntactic dependencies, which they call Derivation Tree-Derived Dependencies (DT). Through application of the converter of Ivanova et al. (2012) to DeepBank, we can thus obtain a DT-annotated version of the standard WSJ text, to train and test a data-driven dependency and phrase structure parser, respectively, and to compare parsing results to a hybrid, grammar-driven HPSG parser. Furthermore, we can draw on a set of additional corpora annotated in the same HPSG format (and thus amenable to conversion for both phrase structure and dependency parsing), instantiating a comparatively diverse range of domains and genres (Oepen et al., 2004). Adding this data to our setup for additional cross-domain testing, we seek to document not only what trade-offs apply in terms of dependency accuracy vs. parser efficiency, but also how these trade-offs are affected by domain and genre variation, and, more generally, how resilient the different approaches are to variation in parser inputs.

## 2 Related Work

Comparing between parsers from different frameworks has long been an area of active interest, ranging from the original PARSEVAL design (Black et al., 1991), to evaluation against ‘formalism-independent’ dependency banks (King et al., 2003; Briscoe & Carroll, 2006), to dedicated workshops (Bos et al., 2008). Grammatical Relations (GRs; Briscoe & Carroll, 2006) have been the target of a number of benchmarks, but they require a heuristic mapping from ‘native’ parser outputs to the target representations for evaluation, which makes results hard to interpret. Clark and Curran (2007) established an upper bound by running the mapping process on gold-standard data, to put into perspective the mapped results from their CCG parser proper. When Miyao et al. (2007) carried out the same experiment for a number of different parsers, they showed that the loss of accuracy due to the mapping process can swamp any actual parser differences. As long as heuristic conversion is required before evaluation, cross-framework comparison inevitably includes a level of fuzziness. An alternative approach is possible when there is enough data available in a particular representation, and conversion (if any) is deterministic. Cer et al. (2010) used Stanford Dependencies (de Marneffe & Manning, 2008) to evaluate a range of statistical parsers. Pre- or post-converting from PTB phrase structure trees to the Stanford dependency scheme, they were able to evaluate a large number of different parsers.

Fowler and Penn (2010) formally proved that a range of Combinatory Categorical Grammars (CCGs) are context-free. They trained the PCFG Berkeley parser on CCGBank, the CCG annotation of the PTB WSJ text (Hockenmaier & Steedman, 2007), advancing the state of the art in terms of supertagging accuracy, PARSEVAL measures, and CCG dependency accuracy. In other words, a specialized CCG parser is not necessarily more accurate than the general-purpose Berkeley parser; this study, however, fails to also take parser efficiency into account.

In related work for Dutch, Plank and van Noord (2010) suggest that, intuitively, one should expect that a grammar-driven system can be more resilient to domain shifts than a purely data-driven parser. In a contrastive study on parsing into Dutch syntactic dependencies, they substantiated this expectation by

showing that their HPSG-based Alpino system performed better and was more resilient to domain variation than data-driven direct dependency parsers.

## 3 Background: Experimental Setup

In the following, we summarize data and software resources used in our experiments. We also give a brief introduction to the DT syntactic dependency scheme and a comparison to ‘mainstream’ representations.

**DeepBank** HPSG analyses in DeepBank are manually selected from the set of parses licensed by the English Resource Grammar (ERG; Flickinger, 2000). Figure 1 shows an example ERG derivation tree, where labels of internal nodes name HPSG constructions (e.g. subject-head or head-complement: `sb-hd_mc_c` and `hd-cmp_u_c`, respectively; see below for more details on unary rules). Preterminals are labeled with fine-grained lexical categories, dubbed ERG lexical types, that augment common parts of speech with additional information, for example argument structure or the distinction between count, mass, and proper nouns. In total, the ERG distinguishes about 250 construction types and 1000 lexical types.

DeepBank annotations were created by combining the native ERG parser, dubbed PET (Callmeier, 2002), with a discriminant-based tree selection tool (Carter, 1997; Oepen et al., 2004), thus making it possible for annotators to navigate the large space of possible analyses efficiently, identify and validate the intended reading, and record its full HPSG analysis in the treebank. Owing to this setup, DeepBank in its current version 1.0 lacks analyses for some 15 percent of the WSJ sentences, for which either the ERG parser failed to suggest a set of candidates (within certain bounds on time and memory usage), or the annotators found none of the available parses acceptable.<sup>3</sup> Furthermore, DeepBank annotations to date only comprise the first 21 sections of the PTB WSJ corpus. Following the splits suggested by the DeepBank developers, we train on Sections 0–19, use Section 20 for tuning, and test against Section 21 (abbreviated as WSJ below).<sup>4</sup>

<sup>3</sup>Thus, limitations in the current ERG and PET effectively lead to the exclusion of a tangible percentage of sentences from our training and testing corpora. We discuss methodological ramifications of this setup to our study in § 9 below.

<sup>4</sup>To ‘protect’ Section 21 as unseen test data, also for the ERG parser, this final section in Version 1.0 of DeepBank was not ex-

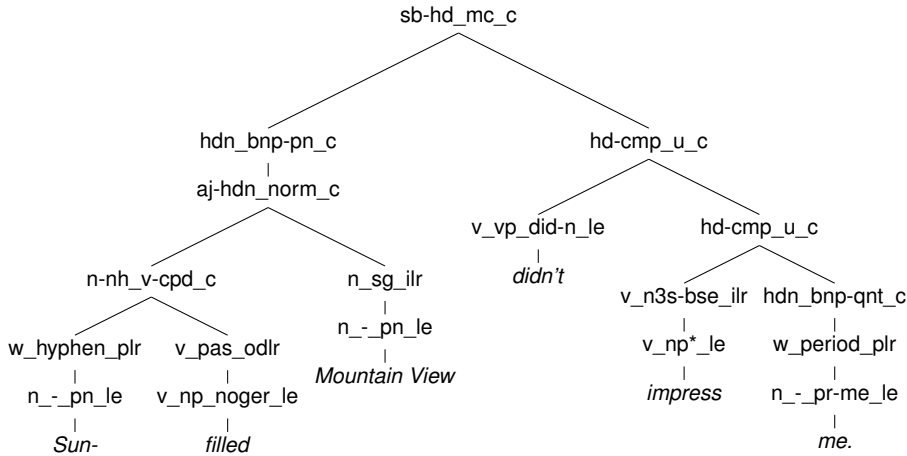


Figure 1: Sample HPSG derivation: construction identifiers label internal nodes, lexical types the preterminals.

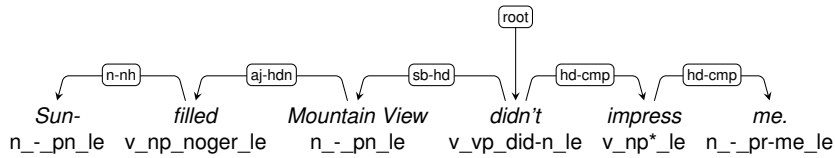


Figure 2: Sample DT bi-lexical dependencies: construction identifiers are generalized at the first underscore.

**DT Dependencies** As ERG derivations are grounded in a formal theory of grammar that explicitly marks heads, mapping these trees onto bi-lexical dependencies is straightforward (Zhang & Wang, 2009). Ivanova et al. (2012) coin the term DT for ERG Derivation Tree-Derived Dependencies, where they reduce the inventory of some 250 ERG syntactic rules to 48 broad HPSG constructions. The DT syntactic dependency tree for our running example is shown in Figure 2.

To better understand the nature of the DT scheme, Ivanova et al. (2012) offer a quantitative, structural comparison against two pre-existing dependency standards for English, viz. those from the CoNLL dependency parsing competitions (Nivre et al., 2007) and the ‘basic’ variant of Stanford Dependencies. They observe that the three dependency representations are broadly comparable in granularity and that there are substantial structural correspondences between the schemes. Measured as average Jaccard similarity over unlabeled dependencies, they observe the strongest correspondence between DT and CoNLL (at a Jaccard index of 0.49, compared to 0.32 for DT and Stanford, and 0.43 between CoNLL and Stanford).

posed to its developers until the grammar and disambiguation model were finalized and frozen for this release.

Ivanova et al. (2013) complement this comparison of dependency schemes through an empirical assessment in terms of ‘parsability’, i.e. accuracy levels available for the different target representations when training and testing a range of state-of-the-art parsers on the same data sets. In their study, the dependency parser of Bohnet and Nivre (2012), henceforth B&N, consistently performs best for all schemes and output configurations. Furthermore, parsability differences between the representations are generally very small.

Based on these observations, we conjecture that DT is as suitable a target representation for parser comparison as any of the others. Furthermore, two linguistic factors add to the attractiveness of DT for our study: it is defined in terms of a formal (and implemented) theory of grammar; and it makes available more fine-grained lexical categories, ERG lexical types, than is common in PTB-derived dependency banks.

**Cross-Domain Test Data** Another benefit of the DT target representation is the availability of comparatively large and diverse samples of additional test data. The ERG Redwoods Treebank (Oepen et al., 2004) is similar in genealogy and format to DeepBank, comprising corpora from various domains and genres. Although Redwoods counts a total of some 400,000 annotated tokens, we only draw on it for addi-

	Name	Sentences	Tokens	Types
DeepBank	Train	33,783	661,451	56,582
	Tune	1,721	34,063	8,964
	WSJ	1,414	27,515	7,668
Redwoods	CB	608	11,653	3,588
	SC	864	13,696	4,925
	VM	993	7,281	1,007
	WS	520	8,701	2,974

Table 1: Sentence, token, and type counts for data sets.

tional *testing* data. In other words, we do not attempt parser re-training or adaptation against this additional data, but rather test our WSJ-trained parsers on out-of-domain samples from Redwoods. We report on four such test corpora, viz. (a) a software advocacy essay, *The Cathedral and the Bazaar* (CB); (b) a subset of the SemCor portion of the Brown Corpus (SC; Francis & Kucera, 1982); (c) a collection of transcribed, task-oriented spoken dialogues (VM; Wahlster, 2000); and (d) part of the Wikipedia-derived WeScience Corpus (WS; Ytrestøl et al., 2009). Table 1 provides exact sentence, token, and type counts for these data sets.

**Tokenization Conventions** A relevant peculiarity of the DeepBank and Redwoods annotations in this context is the ERG approach to tokenization. Three aspects in Figure 1 deviate from the widely used PTB conventions: (a) hyphens (and slashes) introduce token boundaries; (b) whitespace in multi-word lexical units (like *ad hoc*, *of course*, or *Mountain View*) does not force token boundaries; and (c) punctuation marks are attached as ‘pseudo-affixes’ to adjacent words, reflecting the rules of standard orthography. Adolphs et al. (2008) offer some linguistic arguments for this approach to tokenization, but for our purposes it suffices to note that these differences to PTB tokenization may in part counter-balance each other, but do increase the types-per-tokens ratio somewhat. This property of the DeepBank annotations, arguably, makes English look somewhat similar to languages with moderate inflectional morphology. To take advantage of the fine-grained ERG lexical categories, most of our experiments assume ERG tokenization. In two calibration experiments, however, we also investigate the effects of tokenization differences on our parser comparison.

**PET: Native HPSG Parsing** The parser most commonly used with the ERG is called PET (Callmeier, 2002), a highly engineered chart parser for unification grammars. PET constructs a complete parse forest,

using subsumption-based ambiguity factoring (Oepen & Carroll, 2000), and then extracts from the forest *n*-best lists of complete analyses according to a discriminative parse ranking model (Zhang et al., 2007). For our experiments, we trained the parse ranker on Sections 00–19 of DeepBank and otherwise used the default configuration (which corresponds to the environment used by the DeepBank and Redwoods developers), which is optimized for accuracy. This parser, performing exact inference, we will call  $ERG_a$ .

In recent work, Dridan (2013) augments ERG parsing with lattice-based sequence labeling over lexical types and lexical rules. Pruning the parse chart prior to forest construction yields greatly improved efficiency at a moderate accuracy loss. Her lexical pruning model is trained on DeepBank 00–19 too, hence compatible with our setup. We include the best-performing configuration of Dridan (2013) in our experiments, a variant henceforth referred to as  $ERG_e$ . Unlike the other parsers in our study, PET internally operates over an ambiguous token lattice, and there is no easy interface to feed the parser pre-tokenized inputs. We approximate the effects of gold-standard tokenization by requesting from the parser a 2000-best list, which we filter for the top-ranked analysis whose leaves match the treebank tokenization. This approach is imperfect, as in some cases no token-compatible analysis may be on the *n*-best list, especially so in the  $ERG_e$  setup (where lexical items may have been pruned by the sequence-labeling model). When this happens, we fall back to the top-ranked analysis and adjust our evaluation metrics to robustly deal with tokenization mismatches (see below).

**B&N: Direct Dependency Parsing** The parser of Bohnet and Nivre (2012), henceforth B&N, is a transition-based *dependency parser* with joint tagger that implements global learning and a beam search for non-projective labeled dependency parsing. This parser consistently outperforms pipeline systems (such as the Malt and MST parsers) both in terms of tagging and parsing accuracy for typologically diverse languages such as Chinese, English, and German. We apply B&N mostly ‘out-of-the-box’, training on the DT conversion of DeepBank Sections 00–19, and running the parser with an increased beam size of 80.

**Berkeley: PCFG Parsing** The Berkeley parser (Petrov et al., 2006; henceforth just Berkeley) is a gen-

Labels Cycles	Unary Rules Preserved						Unary Rules Removed			
	Long		Short		Mixed		Long		Short	
	5	6	5	6	5	6	5	6	5	6
<b>Gaps</b>	2	5	0	0	11	19	3	3	0	0
<b>TA</b>	90.96	90.62	91.11	91.62	90.93	90.94	88.46	87.65	89.16	88.46
<b>F<sub>1</sub></b>	76.39	75.66	79.81	80.33	76.70	76.74	74.53	73.72	75.15	73.56
<b>LAS</b>	86.26	85.90	82.50	83.15	86.72	86.16	83.96	83.20	80.49	79.56
<b>UAS</b>	89.34	88.92	89.80	90.34	89.42	88.84	87.12	86.54	87.95	87.15

Table 2: Tagging accuracy, PARSEVAL F<sub>1</sub>, and dependency accuracy for Berkeley on WSJ development data.

erative, unlexicalized *phrase structure* parser that automatically derives a smoothed latent-variable PCFG from the treebank and refines the grammar by a split-merge procedure. The parser achieves state-of-the-art performance on various standard benchmarks. In §4 below, we explain how we adapt ERG derivations for training and testing with Berkeley; for comparison to the other parsers in terms of DT dependency accuracy, we apply the converter of Ivanova et al. (2012) to Berkeley outputs. For technical reasons, however, the optional mapping from ERG to PTB tokenization is not applicable in this setup, and hence our experiments involving Berkeley are limited to ERG tokens and fine-grained lexical categories.

**Evaluation** Standard evaluation metrics in dependency parsing are labeled and unlabeled attachment scores (LAS, UAS; implemented by the CoNLL eval.pl scorer). These measure the percentage of tokens which are correctly attached to their head token and, for LAS, have the right dependency label. As assignment of lexical categories is a core part of syntactic analysis, we complement LAS and UAS with tagging accuracy scores (TA), where appropriate. However, in our work there are two complications to consider when using eval.pl. First, some of our parsers occasionally fail to return any analysis, notably Berkeley and ERG<sub>e</sub>. For these inputs, our evaluation re-inserts the missing tokens in the parser output, padding with dummy ‘placeholder’ heads and dependency labels.

Second, a more difficult issue is caused by occasional tokenization mismatches in ERG parses, as discussed above. Since eval.pl identifies tokens by their position in the sentence, any difference of tokenization will lead to invalid results. One option would be to treat all system outputs with token mismatches as parse failures, but this over-penalizes, as potentially correct dependencies among corresponding tokens are also removed from the parser output. For this reason, we modify the evaluation of dependency accuracy to

use sub-string character ranges, instead of consecutive identifiers, to encode token identities. This way, tokenization mismatches local to some sub-segment of the input will not ‘throw off’ token correspondences in other parts of the string.<sup>5</sup> We will refer to this character-based variant of the standard CoNLL metrics as LAS<sub>c</sub> and UAS<sub>c</sub>.

#### 4 PCFG Parsing of HPSG Derivations

Formally, the HPSG analyses in the DeepBank and Redwoods treebanks transcend the class of context-free grammars, of course. Nevertheless, one can pragmatically look at an ERG derivation as if it were a context-free phrase structure tree. On this view, standard, off-the-shelf PCFG parsing techniques are applicable to the ERG treebanks. Zhang and Krieger (2011) explore this space experimentally, combining the ERG, Redwoods (but not DeepBank), and massive collections of automatically parsed text. Their study, however, does not consider parser efficiency.<sup>6</sup>

In contrast, our goal is to reflect on practical trade-offs along multiple dimensions. We therefore focus on Berkeley, as one of the currently best-performing (and relatively efficient) PCFG engines. Due to its ability to internally rewrite node labels, this parser should be expected to adapt well also to ERG derivations. Compared to the phrase structure annotations in the PTB, there are two structural differences evident in Figure 1. First, the inventories of phrasal and lexical labels are larger, at around 250 and 1000, respectively, compared to only about two dozen phrasal categories and 45 parts of speech in the PTB. Second, ERG derivations contain more unary (non-branching)

<sup>5</sup>Where tokenization is identical for the gold and system outputs, the score given by this generalized metric is exactly the same as that of eval.pl. Unless indicated otherwise, punctuation marks are included in scoring.

<sup>6</sup>Their best PCFG results are only a few points F<sub>1</sub> below the full HPSG parser, using massive PCFGs and exact inference; parsing times in fact exceed those of the native HPSG parser

	Gaps	Time	TA <sub>c</sub>	LAS <sub>c</sub>	UAS <sub>c</sub>
Berkeley	1+0	1.0	92.9	86.65	89.86
B&N	0+0	1.7	92.9	86.76	89.65
ERG <sub>a</sub>	0+0	10	97.8	92.87	93.95
ERG <sub>e</sub>	13+44	1.8	96.4	91.60	92.72

Table 3: Parse failures and token mismatches (‘gaps’), efficiency, and tagging and dependency accuracy on WSJ.

rules, recording for example morphological variation or syntacto-semantic category changes.<sup>7</sup>

Table 2 summarizes a first series of experiments, seeking to tune the Berkeley parser for maximum accuracy on our development set, DeepBank Section 20. We experimented with preserving unary rules in ERG derivations or removing them (as they make no difference to the final DT analysis); we further ran experiments using the native (‘long’) ERG construction identifiers, their generalizations to ‘short’ labels as used in DT, and a variant with long labels for unary and short ones for branching rules (‘mixed’). We report results for training with five or six split–merge cycles, where fewer iterations generally showed inferior accuracy, and larger values led to more parse failures (‘gaps’ in Table 2). There are some noticeable trade-offs across tagging accuracy, dependency accuracy, and coverage, without a single best performer along all three dimensions. As our primary interest across parsers is dependency accuracy, we select the configuration with unary rules and long labels, trained with five split–merge cycles, which seems to afford near-premium LAS at near-perfect coverage.<sup>8</sup>

## 5 In-Domain Results

Our first cross-paradigm comparison of the three parsers is against the WSJ in-domain test data, as summarized in Table 3. There are substantive differences between parsers both in terms of coverage, speed, and accuracy. Berkeley fails to return an analysis for one input, whereas ERG<sub>e</sub> cannot parse 13 sentences (close to one percent of the test set); just as the 44 inputs where parser output deviates in tokenization from the treebank, this is likely an effect of the lexical pruning applied in this setup. At an average of one

<sup>7</sup>Examples of morphological rules in Figure 1 include `v_pas_odlr` and `v_n3s-bse_ilr`, for past-participle and non-third person singular or base inflection, respectively. Also, there are two instances of bare noun phrase formation: `hdn_bnp-pn_c` and `hdn_bnp-qnt_c`.

<sup>8</sup>A welcome side-effect of this choice is that we end up using native ERG derivations without modifications.

second per input, Berkeley is the fastest of our parsers; ERG<sub>a</sub> is exactly one order of magnitude slower. However, the lexical pruning of Dridan (2013) in ERG<sub>e</sub> leads to a speed-up of almost a factor of six, making this variant of PET perform comparable to B&N. Maybe the strongest differences, however, we observe in tagging and dependency accuracies: The two data-driven parsers perform very similarly (at close to 93% TA and around 86.7% LAS); the two ERG parsers are comparable too, but at accuracy levels that are four to six points higher in both TA and LAS. Compared to ERG<sub>a</sub>, the faster ERG<sub>e</sub> variant performs very slightly worse—which likely reflects penalization for missing coverage and token mismatches—but it nevertheless delivers much higher accuracy than the data-driven parsers. In subsequent experiments, we will thus focus only on ERG<sub>e</sub>.

## 6 Error Analysis

The ERG parsers outperform the two data-driven parsers on the WSJ data. Through in-depth error analysis, we seek to identify parser-specific properties that can explain the observed differences. In the following, we look at (a) the accuracy of individual dependency types, (b) dependency accuracy relative to (predicted and gold) dependency length, and (c) the distribution of LAS over different lexical categories.

Among the different dependency types, we observe that the notion of an adjunct is difficult for all three parsers. One of the hardest dependency labels is `hdn-aj` (post-adjunction to a nominal head), the relation employed for relative clauses and prepositional phrases attaching to a nominal head. The most common error for this relation is verbal attachment.

It has been noted that dependency parsers may exhibit systematic performance differences with respect to dependency length (i.e. the distance between a head and its argument; McDonald & Nivre, 2007). In our experiments, we find that the parsers perform comparably on longer dependency arcs (upwards of fifteen words), with ERG<sub>a</sub> constantly showing the highest accuracy, and Berkeley holding a slight edge over B&N as dependency length increases.

In Figure 3, one can eyeball accuracy levels per lexical category, where conjunctions (c) and various types of prepositions (p and pp) are the most difficult for all three parsers. That the DT analysis of coordination is challenging is unsurprising. Schwartz et al.

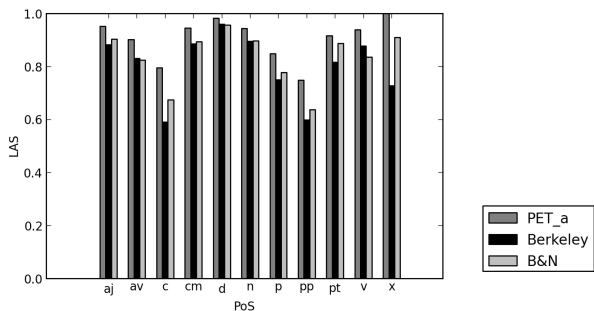


Figure 3: WSJ per-category dependency accuracies on coarse lexical head categories: adjective, adverb, conjunction, complementizer, determiner, noun, preposition, lexical prepositional phrase, punctuation, verb, and others.

(2012) show that choosing conjunctions as heads in coordinate structures is harder to parse for direct dependency parsers (while this analysis also is linguistically more expressive). Our results confirm this effect also for the PCFG and (though to a lesser degree) for  $ERG_a$ . At the same time, conjunctions are among the lexical categories for which  $ERG_a$  most clearly outperforms the other parsers. Berkeley and B&N exhibit LAS error rates of around 35–41% for conjunctions, whereas the  $ERG_a$  error rate is below 20%. For many of the coordinate structures parsed correctly by  $ERG_a$  but not the other two, we found that attachment to root constitutes the most frequent error type—indicating that clausal coordination is particularly difficult for the data-driven parsers.

The attachment of prepositions constitutes a notorious difficulty in syntactic analysis. Unlike ‘standard’ PoS tag sets,  $ERG$  lexical types provide a more fine-grained analysis of prepositions, for example recognizing a lexicalized PP like *in full*, or making explicit the distinction between semantically contentful vs. vacuous prepositions. In our error analysis, we find that parser performance across the various prepositional sub-types varies a lot. For some prepositions, all parsers perform comparatively well; e.g.  $p\_np\_ptcl\_of\_le$ , for semantically vacuous *of*, ranks among the twenty most accurate lexical categories across the board. Other types of prepositions are among the categories exhibiting the highest error rates, e.g.  $p\_np\_i\_le$  for ‘common’ prepositions, taking an NP argument and projecting intersective modifier semantics. Even so, Figure 3 shows that the attachment of prepositions (p and pp) is an area where  $ERG_a$  excels most markedly. Three frequent prepo-

		Gaps	TA <sub>c</sub>	LAS <sub>c</sub>	UAS <sub>c</sub>
CB	Berkeley	1+0	87.1	78.13	83.14
	B&N	0+0	87.7	77.70	82.96
	$ERG_e$	8+8	95.3	90.02	91.58
SC	Berkeley	1+0	87.2	79.81	85.10
	B&N	0+0	85.9	78.08	83.21
	$ERG_e$	11+7	94.9	89.94	91.26
VM	Berkeley	7+0	84.0	74.40	83.38
	B&N	0+0	83.1	75.28	82.86
	$ERG_e$	11+42	94.4	90.18	91.75
WS	Berkeley	7+0	87.7	80.31	85.09
	B&N	0+0	88.4	80.63	85.24
	$ERG_e$	4+12	96.9	90.64	91.76

Table 4: Cross-domain coverage (parse failures and token mismatches) and tagging and dependency accuracies.

sitional lexical types that show the largest  $ERG_a$  advantages are  $p\_np\_ptcl\_of\_le$  (*history of Linux*),  $p\_np\_ptcl\_le$  (*look for peace*), and  $p\_np\_i\_le$  (*talk about friends*). Looking more closely at inputs where the parsers disagree, they largely involve (usages of) prepositions which are lexically selected for by their head. In other words, most prepositions in isolation are ambiguous lexical items. However, it appears that lexical information about the argument structure of heads encoded in the grammar allows  $ERG_a$  to analyse these prepositions (in context) much more accurately.

## 7 Cross-Domain Results

To gauge the resilience of the different systems to domain and genre variation, we applied the same set of parsers—without re-training or other adaptation—to the additional Redwoods test data. Table 4 summarizes coverage and accuracy results across the four diverse samples. Again, Berkeley and B&N pattern alike, with Berkeley maybe slightly ahead in terms of dependency accuracy, but penalized on two of the test sets for parse failures. LAS for the two data-driven parsers ranges between 74% and 81%, up to 12 points below their WSJ performance. Though large, accuracy drops on a similar scale have been observed repeatedly for purely statistical systems when moving out of the WSJ domain without adaptation (Gildea, 2001; Nivre et al., 2007). In contrast,  $ERG_e$  performance is more similar to WSJ results, with a maximum LAS drop of less than two points.<sup>9</sup> For

<sup>9</sup>It must be noted that, unlike the WSJ test data, some of these cross-domain data sets have been used in  $ERG$  development throughout the years, notably VM and CB, and thus the grammar is likely to have particularly good linguistic coverage of this data.

		Gaps	Lexical Types		PTB PoS Tags	
			LAS <sub>c</sub>	UAS <sub>c</sub>	LAS <sub>c</sub>	UAS <sub>c</sub>
WSJ	B&N	0+0	88.78	91.52	91.56	93.63
	ERG <sub>e</sub>	13+9	92.38	93.53	92.38	93.53
CB	B&N	0+0	81.56	86.18	84.54	88.53
	ERG <sub>e</sub>	8+4	90.77	92.21	90.77	92.21
SC	B&N	0+0	81.69	86.11	85.17	88.85
	ERG <sub>e</sub>	11+0	90.13	91.86	90.13	91.86
VM	B&N	0+0	77.00	83.73	82.76	88.11
	ERG <sub>e</sub>	10+0	91.55	93.08	91.55	93.08
WS	B&N	0+0	82.09	86.17	84.59	88.41
	ERG <sub>e</sub>	4+0	91.61	92.62	91.61	92.62

Table 5: Coverage and dependency accuracies with PTB tokenization and either detailed or coarse lexical categories.

Wikipedia text (WS; previously unseen data for the ERG, just as for the other two), for example, both tagging and dependency accuracies are around ten points higher, an error reduction of more than 50%. From these results, it is evident that the general linguistic knowledge available in ERG parsing makes it far more resilient to variation in domain and text type.

## 8 Sanity: PTB Tokenization and PoS Tags

Up to this point, we have applied the two data-driven parsers in a setup that one might consider somewhat ‘off-road’; although our experiments are on English, they involve unusual tokenization and lexical categories. For example, the ERG treatment of punctuation as ‘pseudo-affixes’ increases vocabulary size, which PET may be better equipped to handle due to its integrated treatment of morphological variation. In two concluding experiments, we seek to isolate the effects of tokenization conventions and granularity of lexical categories, taking advantage of optional output flexibility in the DT converter of [Ivanova et al. \(2012\)](#).<sup>10</sup> Table 5 confirms that tokenization does make a difference. In combination with fine-grained lexical categories still, B&N obtains LAS gains of two to three points, compared to smaller gains (around or below one point) for ERG<sub>e</sub>.<sup>11</sup> However, in this setup

Conversely, SC has hardly had a role in grammar engineering so far, and WS is genuinely unseen (for the current ERG and Redwoods release), i.e. treebankers were first exposed to it once the grammar and parser were frozen.

<sup>10</sup>As mapping from ERG derivations into PTB-style tokens and PoS tags is applied when converting to bi-lexical dependencies, we cannot easily include Berkeley in these final experiments.

<sup>11</sup>When converting to PTB-style tokenization, punctuation marks are always attached low in the DT scheme, to the immediately preceding or following token, effectively adding a large group of ‘easy’ dependencies.

our two earlier observations still hold true: ERG<sub>e</sub> is substantially more accurate within the WSJ domain and far more resilient to domain and genre variation. When we simplify the syntactic analysis task and train and test B&N on coarse-grained PTB PoS tags only, in-domain differences between the two parsers are further reduced (to 0.8 points), but ERG<sub>e</sub> still delivers an error reduction of ten percent compared to B&N. The picture in the cross-domain comparison is not qualitatively different, also in this simpler parsing task, with ERG<sub>e</sub> maintaining accuracy levels comparable to WSJ, while B&N accuracies degrade markedly.

## 9 Discussion and Conclusion

Our experiments sought to contrast state-of-the-art representatives from three parsing paradigms on the task of producing bi-lexical syntactic dependencies for English. For the HPSG-derived DT scheme, we find that hybrid, grammar-driven parsing yields superior accuracy, both in- and in particular cross-domain, at processing times comparable to the currently best direct dependency parser. These results corroborate the Dutch findings of [Plank and van Noord \(2010\)](#) for English, where more training data is available and in comparison to more advanced data-driven parsers. In most of this work, we have focussed exclusively on parser inputs represented in the DeepBank and Redwoods treebanks, ignoring 15 percent of the original running text, for which the ERG and PET do not make available a gold-standard analysis. While a parser with partial coverage can be useful in some contexts, obviously the data-driven parsers must be credited for providing a syntactic analysis of (almost) all inputs. However, the ERG coverage gap can be straightforwardly addressed by falling back to another parser when necessary. Such a system combination would undoubtedly yield better tagging and dependency accuracies than the data-driven parsers by themselves, especially so in an open-domain setup. A secondary finding from our experiments is that PCFG parsing with Berkeley and conversion to DT dependencies yields equivalent or mildly more accurate analyses, at much greater efficiency. In future work, it would be interesting to include in this comparison other PCFG parsers and linear-time, transition-based dependency parsers, but a tentative generalization over our findings to date is that linguistically richer representations enable more accurate parsing.



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