

Guiding the PLMs with Semantic Anchors as Intermediate Supervision: Towards Interpretable Semantic Parsing

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Abstract

The recent prevalence of pretrained language models (PLMs) has dramatically shifted the paradigm of semantic parsing, where the mapping from natural language utterances to structured logical forms is now formulated as a Seq2Seq task. Despite the promising performance, previous PLM-based approaches often suffer from hallucination problems due to their negligence of the structural information contained in the sentence, which essentially constitutes the key semantics of the logical forms. Furthermore, most works treat PLM as a black box in which the generation process of the target logical form is hidden beneath the decoder modules, which greatly hinders the model’s intrinsic interpretability. To address these two issues, we propose to incorporate the current PLMs with a hierarchical decoder network. By taking the first-principle structures as the semantic anchors, we propose two novel intermediate supervision tasks, namely *Semantic Anchor Extraction* and *Semantic Anchor Alignment*, for training the hierarchical decoders and probing the model intermediate representations in a self-adaptive manner alongside the fine-tuning process. We conduct intensive experiments on several semantic parsing benchmarks and demonstrate that our approach can consistently outperform the baselines. More importantly, by analyzing the intermediate representations of the hierarchical decoders, our approach also makes a huge step toward the intrinsic interpretability of PLMs in the domain of semantic parsing.

1 Introduction

Semantic parsing refers to the task of converting natural language utterances into machine-executable logical forms (Kamath and Das 2019). With the rise of pretrained language models (PLMs) in natural language processing, most recent works in the field formulate semantic parsing as a Seq2Seq task and develop neural semantic parsers on top of the latest PLMs like T5 (Raffel et al. 2020), Bart (Lewis

et al. 2020), and GPT-3 (Brown et al. 2020), which significantly reduces the manual effort needed in designing compositional grammars (Liang, Jordan, and Klein 2013; Zettlemoyer and Collins 2005). By leveraging the extensive knowledge learned from the pretrain corpus, these PLM-based models exhibit strong performance in comprehending the semantics underlying the source natural language utterance and generating the target logical form that adheres to specific syntactic structures (Shin and Durme 2021; Yin et al. 2022).

Despite the promising performance, current PLM-based approaches most regard both input and output as plain text sequences and neglect the structural information contained in the sentences (Yin et al. 2020; Shi et al. 2021), such as the database (DB) or knowledge base (KB) schema that essentially constitutes the key semantics of the target SQL or SPARQL logical forms. As a result, these PLM-based models often suffer from the hallucination issue (Ji et al. 2022) and may generate incorrect logical form structures that are unfaithful to the input utterance (Nicosia, Qu, and Altun 2021; Gupta et al. 2022). For example, as shown in Figure 1, the PLM mistakenly generates a relationship “product” in the SPARQL query, which is contradictory to the “company produced” mentioned in the natural language.

To prevent the PLMs from generating hallucinated structures, many works propose execution-guided decoding strategies (Wang et al. 2018; Wang, Lapata, and Titov 2021; Ren et al. 2021) and grammar-constrained decoding algorithms (Shin et al. 2021; Scholak, Schucher, and Bahdanau 2021). However, manipulating the decoding process with conditional branches can significantly slow down the model inference (Post and Vilar 2018; Hui et al. 2021). More importantly, in these methods, the DB/KB schema is employed extrinsically as a posteriori correction afterward the model fine-tuning, whereas the inherent ignorance of logical form structures still remains unsolved in the PLMs.

Therefore, another concurrent line of work further pretrains the PLMs with structure-augmented objectives (Herzig et al. 2020; Deng et al. 2021). Specifically, these works usually design unsupervised or weakly-supervised objectives for implicitly modeling the database structures with external or synthetic data corpus (Yu et al. 2020; Shi

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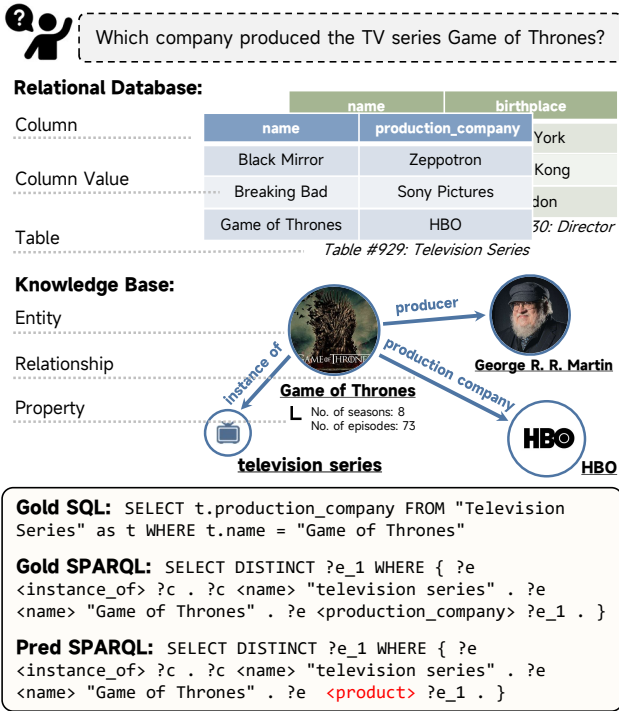


Figure 1: Example of a natural language utterance and the corresponded SQL & SPARQL logical form. Specifically, the logical form sequences are composed of schema items that can be aligned to the structure of a database or knowledge base. Due to the negligence of these structures, PLM may suffer from hallucination issues and generate unfaithful information, as highlighted in the “Pred SPARQL”.

et al. 2022). Although effective, further pertaining a large PLM can incur substantial costs and extra overheads (Yu et al. 2021). Besides, these methods also lack transferability since the structural knowledge is latently coupled inside the models and cannot be easily adapted to a novel task domain with a completely distinct knowledge base or database schema (Wu et al. 2021). Thus, how to explicitly address the structural information during the PLM fine-tuning process is still an open question yet to be addressed.

Aside from the aforementioned issue, existing neural semantic parsers typically treat PLMs as a black box that lacks interpretability. Although some works attempt to probe and explain the latent knowledge within the PLMs using the external modules in a post hoc manner (Liu et al. 2021; Chen et al. 2021b; Stevens and Su 2021), none of the existing works explicitly address the intrinsic interpretability for the task of semantic parsing. The intermediate process of logical form generation is completely hidden inside the PLM decoders, where the latent knowledge is hard to probe.

To address the above challenges, we propose a novel model architecture with intermediate supervision over the hierarchical decoder network. Inspired by the first principle thinking and its successful application in AMR parsing (Cai and Lam 2019), we define “*semantic anchors*” as the building blocks of a logical form that cannot be further de-

composed into more basic structures. Specifically, in a SQL query, the semantic anchors include the tables (relations) and columns (attributes) that constitute the fundamental structure of a relational database (Aho, Beeri, and Ullman 1979; Li and Jagadish 2014); in a SPARQL query, semantic anchors include the entities, relationships, and their respective properties that similarly constitute a knowledge base (Angles and Gutierrez 2008; Baeza 2013).

Thereby, the semantic parsing process can now be broken down into the subtasks of extracting the semantic anchors from input utterances and subsequently recombining the identified semantic anchors into the target logical form based on some specific grammar. We accordingly design two intermediate supervision tasks, namely *Semantic Anchor Extraction* and *Semantic Anchor Alignment*, for explicitly guiding the PLMs to address the structural information alongside the model fine-tuning process. Unlike the previous multi-task learning works that regard PLM as a whole (Radford et al.; Aghajanyan et al. 2021; Xie et al. 2022), we propose a hierarchical decoder architecture that self-adaptively attends to the PLM inner decoder layers for learning the intermediate supervision objectives. Eventually, this framework can equip the PLMs with intrinsic interpretability where the hidden representations of intermediate decoders originally concealed inside the PLMs are now readable for further analysis and investigation.

Experimental results show that our proposed framework can consistently improve PLMs’ performance on semantic parsing datasets OVERNIGHT, KQA PRO and WIKISQL. By investigating the inner representations of the hierarchical decoders, our method also provides a novel testbed for interpreting the intermediate process of logical form generation. In summary, our work contributes to the following aspects:

- In this work, we summarize two major issues that hinder the current PLM-based semantic parsing methods: a) negligence of logical form structures, and b) lack of intrinsic interpretability.
- To alleviate the problems, we propose a novel framework with hierarchical decoder and intermediate supervision tasks *Semantic Anchor Extraction* and *Semantic Anchor Alignment* that explicitly highlight the structural information alongside the PLM fine-tuning process.
- By investigating the intermediate decoder representations, this is also the first work in the field addressing the intrinsic interpretability of PLM-based semantic parsers.

2 Methodology

2.1 Preliminaries

In recent years, pretrained language models (PLMs) like BART (Lewis et al. 2020) and T5 (Raffel et al. 2020) demonstrate strong generalization ability across various Seq2Seq tasks. Within these PLMs, the encoder module first projects the input sequence \mathbf{x} of length m into a sequence of hidden states $\mathbf{H}_E = \{\mathbf{h}_0, \mathbf{h}_1, \dots, \mathbf{h}_m\}$ where each hidden state vector \mathbf{h}_i can be regarded as the contextual embedding of token x_i in the high-dimensional space.

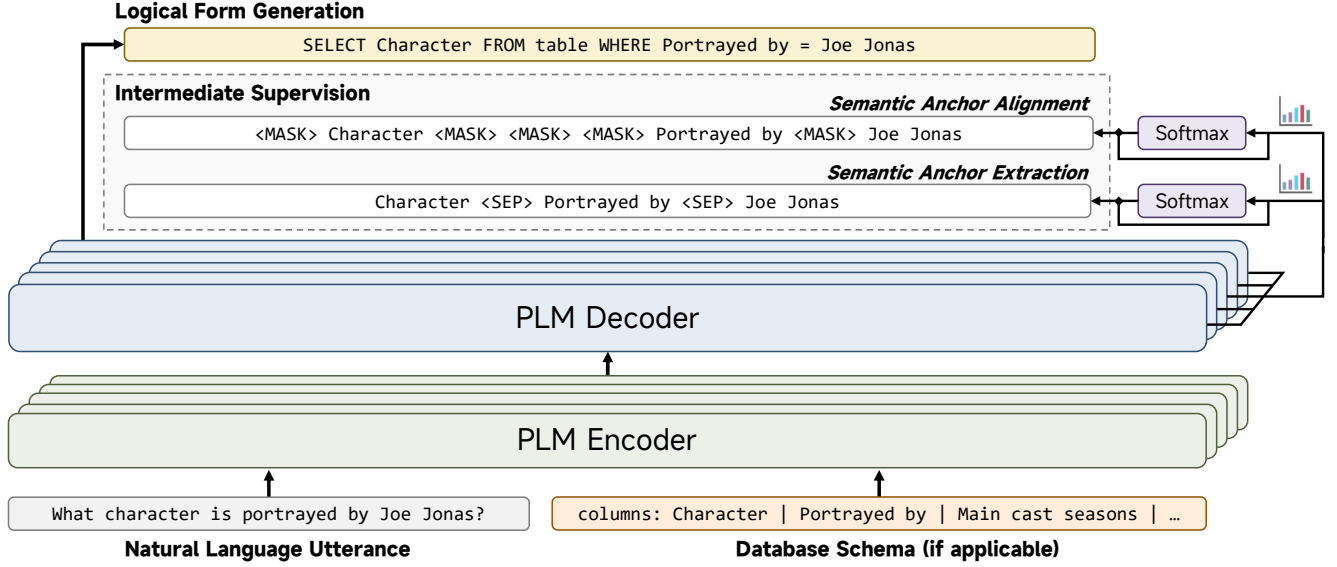


Figure 2: Overall methodology of our proposed approach that incorporates two intermediate supervision tasks *Semantic Anchor Extraction* and *Semantic Anchor Alignment* into the intermediate PLM decoder layers for guiding & probing the simultaneous main task fine-tuning of mapping the natural language utterance into a structured logical form. The middle part of the encoder and decoder modules can be flexibly replaced by any other PLMs.

Subsequently, the last encoder hidden states $\mathbf{H}'_{\mathbb{E}}$ is passed to the PLM decoder module consisting of N layer of decoders. Each decoder layer simultaneously takes the previous decoder hidden states for self-attention computation and the last encoder hidden states for cross-attention computation (Vaswani et al. 2017), so as to produce the new hidden states:

$$\mathbf{H}_{\mathbb{D}}^i = \text{Decoder}_i(\mathbf{H}_{\mathbb{D}}^{i-1}, \mathbf{H}'_{\mathbb{E}} | \theta_{\mathbb{D}}^i) \quad (1)$$

where $\theta_{\mathbb{D}}^i$ refers to the i -th decoder layer parameters and $\mathbf{H}_{\mathbb{D}}^i$ is the corresponding output hidden states. Eventually, the last decoder hidden states $\mathbf{H}_{\mathbb{D}}^N$ are projected into vocabulary-size V -dimensional logits by a language model head and consequently generates the output tokens once at a time with greedy or beam search decoding.

Therefore, the task of semantic parsing can be formally defined as the mapping from a natural language sentence $\mathbf{x} = \{x_1, x_2, \dots, x_m\}$ into a logical form sequence $\mathbf{y} = \{y_1, y_2, \dots, y_k\}$ by maximizing the conditional probability over PLM parameters θ :

$$p(\mathbf{y}) = \prod_{i=1}^k p(y_i | \mathbf{x}, y_1, y_2, \dots, y_{i-1}; \theta). \quad (2)$$

2.2 Semantic Anchor

According to the above formulation, all tokens of a logical form sequence are treated equally by the PLMs, whereas the structural information inside the logical forms is neglected. To analyze the core structures contained in a logical form sequence, we start by giving the formal definitions of knowledge base and relational database.

Knowledge base A knowledge base (KB), often structured as an RDF graph or property graph, can be defined as a directed graph $G = (N, E)$ where N is a set of nodes (or entities), E is a set of edges (or relationships), $\lambda(N \cup E) \rightarrow L$ is a total function that defines the labels of all the nodes and edges, and $\sigma(N \cup E) \rightarrow (P, V)$ is a partial function that defines the (property, value) pairs of certain nodes or edges (Angles et al. 2017).

Thereby, for any logical form y querying a knowledge base, we formally define its *semantic anchors* as the set of tokens corresponding to the knowledge base schema:

$$\mathcal{S}_{y|KB} = \{y_i \in \mathbf{y} | y_i \in (N \cup E \cup L \cup P \cup V)\}, \quad (3)$$

including the KB entities, relationships, their respective labels, and applicable (property, value) pairs.

Relational database A relational database (DB) is defined over a database schema D including a set of relational schemas (or tables) $D = \{R_i | 1 \leq i \leq n\}$, where each relational schema further consists a set of attributes schemas (or columns) $R_i = \{A_j^i | 1 \leq j \leq k\}$ (Li and Jagadish 2014)

Thereby, for any logical form y querying a relational database, we formally define its *semantic anchors* as the set of tokens aligned to the database schema:

$$\mathcal{S}_{y|DB} = \{y_i \in \mathbf{y} | y_i \in (R \cup A)\}, \quad (4)$$

including the DB table names and column names.

2.3 Intermediate Supervision Tasks

Based on the definition of *semantic anchor*, we subsequently design two intermediate supervision tasks by decomposing the semantic parsing process into the subtasks

of 1) extracting the *semantic anchors* from the input natural language utterance, then 2) putting the extracted *semantic anchors* into the right positions of a target sequence according to the grammatical rules of the specified formal language.

Semantic Anchor Extraction For the first intermediate supervision task, we enforce the PLMs to extract the *semantic anchors* to explicitly address the logical form structures during the fine-tuning process. For each logical form sequence y , we concatenate its *semantic anchors* into a new sequence:

$$\mathbf{y}_{\text{SAE}} = \{\mathcal{S}_y^1, \langle \text{SEP} \rangle, \mathcal{S}_y^2, \langle \text{SEP} \rangle, \dots, \mathcal{S}_y^s\}, \quad (5)$$

where $\langle \text{SEP} \rangle$ is a special token for separating two distinct *semantic anchors*. A cross-entropy loss is calculated on this extraction supervision and the corresponding tokens at the intermediate decoder layers.

Semantic Anchor Alignment Thereafter as the second intermediate supervision task, we guide the model to generate the *semantic anchors* with correct relative positions that can be precisely aligned to the final sequence of the target logical form. For each logical form sequence y , we only keep the *semantic anchors* and mask the rest tokens:

$$\mathbf{y}_{\text{SAA}} = \{\langle \text{MASK} \rangle, \langle \text{MASK} \rangle, \mathcal{S}_y^1, \langle \text{MASK} \rangle, \dots, \mathcal{S}_y^s, \dots\} \quad (6)$$

where each *semantic anchor* token $\mathcal{S}_y^i \in \mathcal{S}_y$ occurs in the exact relative position as aligned to the target logical form, and the remaining tokens masked by $\langle \text{MASK} \rangle$ are ignored during the loss computation:

2.4 Hierarchical Decoders

To equip the PLMs with ability of explicit addressing to the structural information and meanwhile improve the intrinsic interpretability of the logical form generation process, we want to find a most natural way to incorporate the semantic anchors during the fine-tuning stage of the model. For a N -layers decoder module, the intermediate hidden states is given as $\{\mathbf{H}_{\mathbb{D}}^i | 1 \leq i \leq N-1\}$.

For each intermediate task \mathcal{T}_s , we train an independent language model head $f_s(\cdot)$ and a set of weighting parameters $\{w_s^i | 1 \leq i \leq N-1\}$. Thereby, we can calculate the aggregation of the intermediate decoder hidden states with a softmax distribution w.r.t. the weighting parameters and a residual connection:

$$\mathbf{H}_{\mathbb{D}}^s = \underbrace{\sum_{i=1}^{N-1} \frac{e^{w_s^i}}{\sum_{j=1}^{N-1} e^{w_s^j}} \mathbf{H}_{\mathbb{D}}^i}_{\text{learnable weights}} + \underbrace{\sum_{i=1}^{N-1} \frac{1}{N-1} \mathbf{H}_{\mathbb{D}}^i}_{\text{residual connection}} \quad (7)$$

This setup enables model to seek for the optimal proportion for the intermediate hidden states. The overall representation $\mathbf{H}_{\mathbb{D}}^s$ is then mapped into logits in the vocabulary space $\mathbb{R}^{|v|}$ with its language model head:

$$\mathbf{v}_s = f_s(\mathbf{H}_{\mathbb{D}}^s), \quad (8)$$

where the probability distribution of the token can be given by the softmax function whereby the cross-entropy loss \mathcal{L}_s of the task can be calculated accordingly:

$$\begin{aligned} \mathcal{L}_s &= \sum_{i=1}^{|v|} p(y_{s,i}) \log p(\hat{y}_i) \\ &= - \sum_{i=1}^{|v|} y_{s,i} \log \frac{\exp(\mathbf{v}_{s,i})}{\sum_{j=1}^{|v|} \exp(\mathbf{v}_{s,j})}. \end{aligned} \quad (9)$$

2.5 Self-adaptive Weighting

Eventually, the overall training of a PLM can now be defined as the aggregation of the main task (*i.e.*, logical form generation) and two intermediate supervision tasks:

$$\mathcal{L} = \mathcal{L}_{\text{main}} + w_1 \mathcal{L}_{\text{SAE}} + w_2 \mathcal{L}_{\text{SAA}}, \quad (10)$$

where w_1 and w_2 denote the weighting factors for the two intermediate supervision tasks. To minimize the undesired interference between multiple learning objectives, we adopt a loss-balanced task weighting strategy to dynamically adjust the weighting factors throughout the PLM fine-tuning process (Liu, Liang, and Gitter 2019).

Specifically, for each intermediate supervision task t , we compute and store the first batch loss with respect to this task at each epoch, denoted as $\mathcal{L}_{(b_0,t)}$. The loss weighting factor w_t is then dynamically adjusted at each iteration as:

$$w_t = \sqrt{\frac{\mathcal{L}_{(b_j,t)}}{\mathcal{L}_{(b_0,t)}}}, \quad (11)$$

where $\mathcal{L}_{(b_j,t)}$ refers to the real-time loss of task t at batch j .

3 Experiments

3.1 Dataset

Overnight OVERNIGHT (Wang, Berant, and Liang 2015) is a popular semantic parsing dataset containing 13,682 examples of natural language question paired with lambda-DCS logical forms across eight data domains over Freebase (Bollacker et al. 2008) so as to explore diverse types of language phenomena. We follow the previous practice (Cao et al. 2019) and randomly sample 20% of the provided training data as a validation set for performance evaluation during the PLM fine-tuning.

KQA Pro KQA PRO (Cao et al. 2022) is a KBQA dataset consisting of 117,790 natural language utterances and corresponded SPARQL queries over the Wikidata knowledge base (Vrandeć and Krötzsch 2014). It widely covers diverse natural language questions with explicitly enhanced linguistic variety and complex query patterns that involve multi-hop reasoning, value comparison, set operations, etc.

WikiSQL WIKISQL (Zhong, Xiong, and Socher 2017) is a classic NL-to-SQL semantic parsing dataset with 80,654 (question, SQL) data pairs grounded on in total 24,241 Wikipedia tables. Due to the simple query structures covering only single tables and limited aggregators, previous

	Exec. Acc.
Non-PLM Methods	
SPO (Wang, Berant, and Liang 2015)	58.8
CrossDomain (Su and Yan 2017)	80.6
Seq2Action (Chen, Sun, and Han 2018)	79.0
2-stage DUAL (Cao et al. 2020)	80.1
PLM-based Methods	
T5-base	74.7
Ours (T5-base)	75.5
BART-base	80.7
GraphQ IR (BART-base) (Nie et al. 2022)	82.1
Ours (BART-base)	82.4
- Semantic Anchor Extraction	81.0
- Semantic Anchor Alignment	81.5
- Hierarchical Decoder	81.2

Table 1: Test accuracies on OVERNIGHT dataset.

	Exec. Acc.
Non-PLM Methods	
EmbedKGQA (Cao et al. 2022)	28.36
RGCN (Cao et al. 2022)	35.07
RNN (Cao et al. 2022)	41.98
PLM-based Methods	
T5-base	83.64
Ours (T5-base)	84.66
BART-base (Cao et al. 2022)	89.68
GraphQ IR (BART-base) (Nie et al. 2022)	91.70
Ours (BART-base)	91.72
- Semantic Anchor Extraction	91.09
- Semantic Anchor Alignment	91.12
- Hierarchical Decoder	90.94

Table 2: Test accuracies on KQA PRO dataset.

PLM-based methods have almost achieved upper-bound performance on WikiSQL with the help of further pretraining and execution-guided decoding. Thus in this paper, for a fair comparison, we only consider single models without using any additional resources or decoding-based techniques.

3.2 Metric

We use *execution accuracy* as our evaluation metric. It examines whether the generated logical form can be executed by the respective KB or DB engines and return the exact set of results as identical to the ground truth logical forms.

3.3 Experimental Settings

We conduct our experiments with $8 \times$ NVIDIA Tesla V100 32GB GPUs and the CUDA environment of 10.2. All PLM models used in this work are acquired from the latest released checkpoints on Huggingface¹. For BART-base, we trained the model with a learning rate of $3e - 5$ and a warm-up proportion of 0.1. For T5-Base, the learning rate is set to

¹<https://huggingface.co/models>

	Exec. Acc.
Non-PLM Methods	
Seq2SQL (Zhong, Xiong, and Socher 2017)	59.4
Coarse-to-Fine (Dong and Lapata 2018)	78.5
Auxiliary Mapping (Chang et al. 2020)	81.7
PLM-based Methods	
T5-base	84.5
Ours (T5-base)	85.0
BART-base	83.6
Ours (BART-base)	84.8
- Semantic Anchor Extraction	84.3
- Semantic Anchor Alignment	84.7
- Hierarchical Decoder	84.2
PLM Methods with Additional Resources	
SQLova + EG (Hwang et al. 2019)	86.2
GRAPPA (Yu et al. 2021)	90.8
SeaD + EG (Xuan et al. 2021)	93.0

Table 3: Test execution accuracies on WIKISQL dataset. For fairness, we compare our methods with the plain-PLMs without using any additional resources (*e.g.*, further pretraining, data augmentation, execution-guided decoding, etc.). The SOTAs are also listed here for readers’ information.

$3e - 4$ without warm-up. The batch size is consistently set to 128, and AdamW is used as the optimizer.

3.4 Results

Experiment results show that our proposed framework can consistently outperform the baselines on the OVERNIGHT, KQA PRO, and WIKISQL datasets, as presented respectively in Table 1, 2, and 3.

Specifically, on both OVERNIGHT and KQA PRO datasets, our framework achieves the new state-of-the-art performance and demonstrates significant accuracy improvement over the PLM baselines. Remarkably, with the help of the intermediate supervision as well as the hierarchical decoder designs, our work even outperforms GraphQ IR (Nie et al. 2022) which requires labor-intensive implementation of an intermediate representation transpiler.

On WIKISQL, our proposed approach also demonstrates superior execution accuracy over the T5-base and BART-base PLM baselines. In spite of the performance gap compared to the state-of-the-art works on WIKISQL, their works all rely heavily on the further pertaining and execution-guided decoding, whereas our approach does not rely on any external resources other than the datasets themselves.

3.5 Ablation Studies

For model ablation, we implement three different settings by removing the respective module:

- **Without Semantic Anchor Extraction** The proposed hierarchical decoder architecture with only the *Semantic Anchor Alignment* task as the intermediate supervision.
- **Without Semantic Anchor Alignment** The proposed hierarchical decoder architecture with only the *Semantic Anchor Extraction* task as the intermediate supervision.

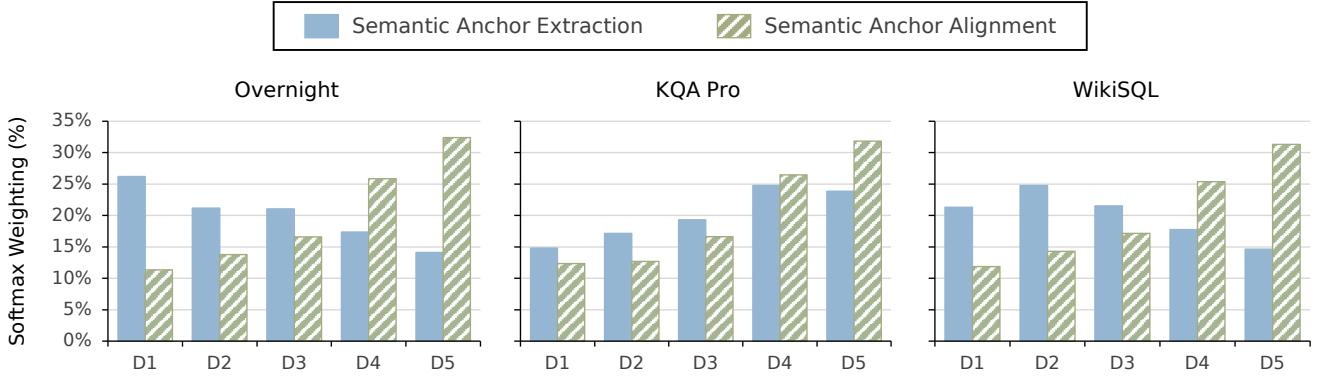


Figure 3: Softmax distribution of the hierarchical decoders over the intermediate supervision tasks of *Semantic Anchor Extraction* and *Semantic Anchor Alignment*. D_i refers to the weighting over the i -th intermediate decoder layer for the specified task.

Dataset	Baseline	Ours	Difference
OVERNIGHT	294	278	-5.76%
KQA PRO	949	855	-10.99%
WIKISQL	372	334	-11.38%

Table 4: Number of hallucination errors made by the BART-base baseline and our model.

- **Without Hierarchical Decoder** Both *Semantic Anchor Extraction* and *Semantic Anchor Alignment* tasks are performed at the final layer of the PLMs in a multi-task learning setting.

The ablated experiments demonstrate consistent trends across all of the benchmarks. Models without *Semantic Anchor Extraction* demonstrate a larger drop in performance compared to those without *Semantic Anchor Alignment*. This can be naturally explained similarly to the human cognition process where the extraction of *semantic anchors* is a more fundamental task as the premise of the latter constitution of a whole sequence. On the other hand, models without the hierarchical decoder also degrade significantly, which affirms our hypothesis that guiding the PLMs with supervision over the intermediate decoder layers can equip the models with improved robustness and intrinsic interpretability.

3.6 Hallucination Analysis

To call back the motivation and evaluate whether our proposed framework can really help alleviate the hallucination issues in PLM-based semantic parsers, we further compare and analyze the generated logical forms from our method as well as from the BART-base baseline. Analysis results are shown in Table 4. By explicitly addressing the *semantic anchors* with intermediate supervision, our method can enforce the PLM to generate faithful structures and significantly reduce hallucination. Apart from the quantitative results, we also conduct case analysis and present two examples from the KQA PRO dataset in Figure 4, where the PLM baseline mistakenly generates unfaithful content and our method can precisely output the correct SPARQL query.

Case #1:
NL Question: Tell me the TV series that has the hash tag of history.
Baseline generated SPARQL: <code>SELECT DISTINCT ?e WHERE { ?e <pred:instance_of> ?c . ?c <pred:name> "television station" . ?e <hashtag> ?pv . ?pv <pred:value> "history" }</code>
Ours generated SPARQL: <code>SELECT DISTINCT ?e WHERE { ?e <pred:instance_of> ?c . ?c <pred:name> "television series" . ?e <hashtag> ?pv . ?pv <pred:value> "history" }</code>
Case #2:
NL Question: Which film has musician Jimi Hendrix as its subject?
Baseline generated SPARQL: <code>SELECT DISTINCT ?e WHERE { ?e <pred:instance_of> ?c . ?c <pred:name> "film" . ?e <narrative_location> ?e_1 . ?e_1 <pred:name> "Jimi Hendrix" . ?e_1 <occupation> ?e_2 . ?e_2 <pred:name> "musician" . }</code>
Ours generated SPARQL: <code>SELECT DISTINCT ?e WHERE { ?e <pred:instance_of> ?c . ?c <pred:name> "film" . ?e <depicts> ?e_1 . ?e_1 <pred:name> "Jimi Hendrix" . ?e_1 <occupation> ?e_2 . ?e_2 <pred:name> "musician" . }</code>

Figure 4: Case analysis of the PLM hallucination issues.

3.7 Interpretability Analysis

By performing intermediate supervision over the inner decoder layers together with the main task fine-tuning, this work also provides a novel testbed for probing the latent knowledge hidden inside a large PLM. Specifically, our framework can equip the PLMs with intrinsic interpretability in the following aspects.

Hierarchical Decoder Distribution As aforementioned in Section 2.4, during the intermediate supervision, the model can self-adaptively attend to the optimal inner decoder layers with weightings adjusted by loss backpropagation. Therefore, by analyzing the weighting distribution over the hierarchical decoders, we can thereby examine the sublayer functionalities of the PLM decoders. As can be observed in Figure 3, PLMs tend to perform *Extraction* at the lower decoder layers and *Alignment* at the upper layers, which can be amazingly aligned to the order of how humans

NL Question: what player had the same amount of blocks this season as kobe bryant ?
Target lambda-DCS Logical Form: <code>(call SW.listValue (call SW.getProperty ((lambda s (call SW.filter (var s) (string num_blocks) (string =) (call SW.getProperty (call SW.getProperty en.player.kobe_bryant (call SW.reverse (string player))) (string num_blocks)))) (call SW.domain (string player))) (string player)))</code>
Semantic Anchors: player, num blocks, kobe bryant
Intermediate Decoder Layer Outputs for <i>Semantic Anchor Extraction</i> : Decoder #1: player had same amount blocks this season as kobe Bryant Decoder #2: player same amount time blocks season kobe Bryant Decoder #3: player player num points points blocks kobe bryant 1 Decoder #4: player num num points points blocks blocks season k bryant Decoder #5: player blocks blocks points blocks blocks blocks season k k bryant
Intermediate Decoder Layer Outputs for <i>Semantic Anchor Alignment</i> : Decoder #1: in1 same season in which he had 3 rebounds namethe number of blocks performed by kobe bryant Decoder #2: _ player_ same_ season 2_bantant_____ Decoder #3: time_ player_ team 3_ - 2obe_ryant_____ Decoder #4: .__ team 3_ game_ -_obe_ryant_____ Decoder #5: call player__ team team of block__ - 3obe_ryant_ry (((((((____ ((((_ (((_____

Figure 5: BART-base inner decoder layer outputs respectively for the two intermediate supervision tasks.

may process the semantic parsing tasks.

Intermediate Layer Output Analysis More importantly, with our proposed hierarchical decoder, the PLM users are now able to probe the hidden representations of the intermediate decoder layers. Specifically, by converting the layer-wise intermediate logits into human-readable outputs, our work can be extended to understand the inner mechanisms behind the PLM processing. We present an example from OVERNIGHT dataset with the BART-base inner 5 decoder layer outputs in Figure 5. We conclude that the lower layers of the PLM are more likely to contain information from the input sequence (e.g., the Decoder #1 outputs for both tasks are quite similar to the input natural language question). As the model hidden representations are further processed, the upper decoder layer outputs have moved closer to the target sequence (e.g., the Decoder #5 output for *Semantic Anchor Alignment* already contain some syntax-related tokens like “call” and “(” in lambda-DCS logical forms).

4 Related Work

4.1 Semantic Parsing

Non-PLM-based methods in this field tend to tackle semantic parsing with representation learning or graph neural networks. (Saxena, Tripathi, and Talukdar 2020) infuses knowledge representation to facilitate reasoning over the knowledge base. (Schlichtkrull et al. 2018) models the knowledge base as a graph by using GCN. Concurrent studies obtain state-of-the-art results on semantic parsing datasets with the capability of existing PLMs. Code-based PLMs like Codex (Chen et al. 2021a) could be applied to the task of semantic parsing and achieve remarkable results (Shin and Durme 2021).

Additionally, many studies pre-train their own models, leveraging the abundance of tabular data. Among them, TaBERT (Yin et al. 2020) and TAPAS (Herzig et al. 2020)

design structure-related unsupervised objectives for further pretraining the BERT model over millions of web tables and the surrounding text. GRAPPA (Yu et al. 2021) and GAP (Shi et al. 2021) utilize data augmentation techniques to synthesize high-quality pretraining corpus and respectively pre-train a RoBERTa and a BART model.

4.2 Multi-task Learning

Multi-task learning plays a significant role in deep learning. (Ruder 2017) states some very crucial definitions for parameter sharing and auxiliary tasks as a type of multitasking. Furthermore, (Kongyoung, Macdonald, and Ounis 2020) provides several dynamic weighting strategies for auxiliary supervision based on the main task loss. Other research uses the gradients of different tasks to compute the approximate effect of the auxiliary tasks to the main task (Lin et al. 2019; Chen et al. 2018). (Du et al. 2018) uses cosine similarity of the gradient of the shared parameters across different tasks to adjust the weighting for auxiliary losses.

4.3 PLM Interpretability

Most of the studies attempt to reveal the latent connection in the PLM with post-hoc interpretation methods such as attention analysis (Clark et al. 2019) and counterfactual manipulation (Stevens and Su 2020). (Yang et al. 2020) study the different functionalities of decoder sub-layers in transformer by analyzing the attention of each sub-layer while performing machine translation tasks. (Shi et al. 2020) take a more proactive approach to supervise the attention with prior knowledge during the training process and get a good result. (Liu et al. 2021) explore the grounding capacity of PLMs by erasing the input tokens in sequential order to observe the change of confidence of each concept to be predicted.

5 Conclusion

In this paper, we address the two major issues inside the PLM-based semantic parsers. We design two intermediate supervision tasks, *Semantic Anchor Extraction* and *Semantic Anchor Alignment*, to guide the PLM training through a novel self-adaptive hierarchical decoder architecture. Extensive experiments show our model can consistently outperform the PLM baselines and achieve new SOTA on OVERNIGHT and KQA PRO datasets. Further analysis indicates that the framework can significantly reduce hallucination errors and demonstrate improved interpretability.

References

- Aghajanyan, A.; Gupta, A.; Shrivastava, A.; Chen, X.; Zettlemoyer, L.; and Gupta, S. 2021. Muppet: Massive Multi-task Representations with Pre-Finetuning. In *Proceedings of the 2021 Conference on Empirical Methods in Natural Language Processing*, 5799–5811.
- Aho, A. V.; Beeri, C.; and Ullman, J. D. 1979. The theory of joins in relational databases. *ACM Transactions on Database Systems (TODS)*, 4(3): 297–314.
- Angles, R.; Arenas, M.; Barceló, P.; Hogan, A.; Reutter, J. L.; and Vrgoc, D. 2017. Foundations of Modern Query Languages for Graph Databases. *ACM Comput. Surv.*, 50(5): 68:1–68:40.
- Angles, R.; and Gutierrez, C. 2008. Survey of graph database models. *ACM Computing Surveys (CSUR)*, 40(1): 1–39.
- Baeza, P. B. 2013. Querying graph databases. In Hull, R.; and Fan, W., eds., *Proceedings of the 32nd ACM SIGMOD-SIGACT-SIGART Symposium on Principles of Database Systems, PODS 2013, New York, NY, USA - June 22 - 27, 2013*, 175–188. ACM.
- Bollacker, K. D.; Evans, C.; Paritosh, P. K.; Sturge, T.; and Taylor, J. 2008. Freebase: a collaboratively created graph database for structuring human knowledge. In Wang, J. T., ed., *Proceedings of the ACM SIGMOD International Conference on Management of Data, SIGMOD 2008, Vancouver, BC, Canada, June 10-12, 2008*, 1247–1250. ACM.
- Brown, T.; Mann, B.; Ryder, N.; Subbiah, M.; Kaplan, J. D.; Dhariwal, P.; Neelakantan, A.; Shyam, P.; Sastry, G.; Askell, A.; et al. 2020. Language models are few-shot learners. *Advances in neural information processing systems*, 33: 1877–1901.
- Cai, D.; and Lam, W. 2019. Core Semantic First: A Top-down Approach for AMR Parsing. In *Proceedings of the 2019 Conference on Empirical Methods in Natural Language Processing and the 9th International Joint Conference on Natural Language Processing (EMNLP-IJCNLP)*, 3799–3809.
- Cao, R.; Zhu, S.; Liu, C.; Li, J.; and Yu, K. 2019. Semantic Parsing with Dual Learning. In Korhonen, A.; Traum, D. R.; and Màrquez, L., eds., *Proceedings of the 57th Conference of the Association for Computational Linguistics, ACL 2019, Florence, Italy, July 28- August 2, 2019, Volume 1: Long Papers*, 51–64. Association for Computational Linguistics.
- Cao, R.; Zhu, S.; Yang, C.; Liu, C.; Ma, R.; Zhao, Y.; Chen, L.; and Yu, K. 2020. Unsupervised Dual Paraphrasing for Two-stage Semantic Parsing. In Jurafsky, D.; Chai, J.; Schluter, N.; and Tetreault, J. R., eds., *Proceedings of the 58th Annual Meeting of the Association for Computational Linguistics, ACL 2020, Online, July 5-10, 2020*, 6806–6817. Association for Computational Linguistics.
- Cao, S.; Shi, J.; Pan, L.; Nie, L.; Xiang, Y.; Hou, L.; Li, J.; He, B.; and Zhang, H. 2022. KQA Pro: A Dataset with Explicit Compositional Programs for Complex Question Answering over Knowledge Base. In Muresan, S.; Nakov,

- P.; and Villavicencio, A., eds., *Proceedings of the 60th Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers)*, ACL 2022, Dublin, Ireland, May 22-27, 2022, 6101–6119. Association for Computational Linguistics.
- Chang, S.; Liu, P.; Tang, Y.; Huang, J.; He, X.; and Zhou, B. 2020. Zero-shot text-to-SQL learning with auxiliary task. In *Proceedings of the AAAI Conference on Artificial Intelligence*, volume 34, 7488–7495.
- Chen, B.; Sun, L.; and Han, X. 2018. Sequence-to-Action: End-to-End Semantic Graph Generation for Semantic Parsing. In Gurevych, I.; and Miyao, Y., eds., *Proceedings of the 56th Annual Meeting of the Association for Computational Linguistics, ACL 2018, Melbourne, Australia, July 15-20, 2018, Volume 1: Long Papers*, 766–777. Association for Computational Linguistics.
- Chen, M.; Tworek, J.; Jun, H.; Yuan, Q.; Pinto, H. P. d. O.; Kaplan, J.; Edwards, H.; Burda, Y.; Joseph, N.; Brockman, G.; et al. 2021a. Evaluating large language models trained on code. *arXiv preprint arXiv:2107.03374*.
- Chen, Z.; Badrinarayanan, V.; Lee, C.-Y.; and Rabinovich, A. 2018. GradNorm: Gradient normalization for adaptive loss balancing in deep multitask networks. In *International conference on machine learning*, 794–803. PMLR.
- Chen, Z.; Chen, L.; Li, H.; Cao, R.; Ma, D.; Wu, M.; and Yu, K. 2021b. Decoupled Dialogue Modeling and Semantic Parsing for Multi-Turn Text-to-SQL. In *Findings of the Association for Computational Linguistics: ACL-IJCNLP 2021*, 3063–3074.
- Clark, K.; Khandelwal, U.; Levy, O.; and Manning, C. D. 2019. What does bert look at? an analysis of bert’s attention. *arXiv preprint arXiv:1906.04341*.
- Deng, X.; Hassan, A.; Meek, C.; Polozov, O.; Sun, H.; and Richardson, M. 2021. Structure-Grounded Pretraining for Text-to-SQL. In *Proceedings of the 2021 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies*, 1337–1350.
- Dong, L.; and Lapata, M. 2018. Coarse-to-Fine Decoding for Neural Semantic Parsing. In *Proceedings of the 56th Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers)*, 731–742.
- Du, Y.; Czarnecki, W. M.; Jayakumar, S. M.; Farajtabar, M.; Pascanu, R.; and Lakshminarayanan, B. 2018. Adapting auxiliary losses using gradient similarity. *arXiv preprint arXiv:1812.02224*.
- Gupta, V.; Shrivastava, A.; Sagar, A.; Aghajanyan, A.; and Savenkov, D. 2022. RetroNLU: Retrieval Augmented Task-Oriented Semantic Parsing. In *Proceedings of the 4th Workshop on NLP for Conversational AI*, 184–196.
- Herzig, J.; Nowak, P. K.; Mueller, T.; Piccinno, F.; and Eisenschlos, J. 2020. TaPas: Weakly Supervised Table Parsing via Pre-training. In *Proceedings of the 58th Annual Meeting of the Association for Computational Linguistics*, 4320–4333.
- Hui, B.; Shi, X.; Geng, R.; Li, B.; Li, Y.; Sun, J.; and Zhu, X. 2021. Improving text-to-sql with schema dependency learning. *arXiv preprint arXiv:2103.04399*.
- Hwang, W.; Yim, J.; Park, S.; and Seo, M. 2019. A Comprehensive Exploration on WikiSQL with Table-Aware Word Contextualization. *CoRR*, abs/1902.01069.
- Ji, Z.; Lee, N.; Frieske, R.; Yu, T.; Su, D.; Xu, Y.; Ishii, E.; Bang, Y.; Madotto, A.; and Fung, P. 2022. Survey of hallucination in natural language generation. *arXiv preprint arXiv:2202.03629*.
- Kamath, A.; and Das, R. 2019. A Survey on Semantic Parsing. In *1st Conference on Automated Knowledge Base Construction, AKBC 2019, Amherst, MA, USA, May 20-22, 2019*.
- Kongyoung, S.; Macdonald, C.; and Ounis, I. 2020. Multi-task learning using dynamic task weighting for conversational question answering.
- Lewis, M.; Liu, Y.; Goyal, N.; Ghazvininejad, M.; Mohamed, A.; Levy, O.; Stoyanov, V.; and Zettlemoyer, L. 2020. BART: Denoising Sequence-to-Sequence Pre-training for Natural Language Generation, Translation, and Comprehension. In Jurafsky, D.; Chai, J.; Schluter, N.; and Tetreault, J. R., eds., *Proceedings of the 58th Annual Meeting of the Association for Computational Linguistics, ACL 2020, Online, July 5-10, 2020*, 7871–7880. Association for Computational Linguistics.
- Li, F.; and Jagadish, H. V. 2014. Constructing an interactive natural language interface for relational databases. *Proceedings of the VLDB Endowment*, 8(1): 73–84.
- Liang, P.; Jordan, M. I.; and Klein, D. 2013. Learning Dependency-Based Compositional Semantics. *Comput. Linguistics*, 39(2): 389–446.
- Lin, X.; Baweja, H.; Kantor, G.; and Held, D. 2019. Adaptive auxiliary task weighting for reinforcement learning. *Advances in neural information processing systems*, 32.
- Liu, Q.; Yang, D.; Zhang, J.; Guo, J.; Zhou, B.; and Lou, J.-G. 2021. Awakening Latent Grounding from Pretrained Language Models for Semantic Parsing. In *Findings of the Association for Computational Linguistics: ACL-IJCNLP 2021*, 1174–1189.
- Liu, S.; Liang, Y.; and Gitter, A. 2019. Loss-balanced task weighting to reduce negative transfer in multi-task learning. In *Proceedings of the Thirty-Third AAAI Conference on Artificial Intelligence and Thirty-First Innovative Applications of Artificial Intelligence Conference and Ninth AAAI Symposium on Educational Advances in Artificial Intelligence*, 9977–9978.
- Nicosia, M.; Qu, Z.; and Altun, Y. 2021. Translate & Fill: Improving Zero-Shot Multilingual Semantic Parsing with Synthetic Data. In *Findings of the Association for Computational Linguistics: EMNLP 2021*, 3272–3284.
- Nie, L.; Cao, S.; Shi, J.; Tian, Q.; Hou, L.; Li, J.; and Zhai, J. 2022. GraphQ IR: Unifying Semantic Parsing of Graph Query Language with Intermediate Representation. *arXiv preprint arXiv:2205.12078*.

- Post, M.; and Vilar, D. 2018. Fast Lexically Constrained Decoding with Dynamic Beam Allocation for Neural Machine Translation. In *Proceedings of the 2018 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies, Volume 1 (Long Papers)*, 1314–1324.
- Radford, A.; Wu, J.; Child, R.; Luan, D.; Amodei, D.; Sutskever, I.; et al. 2019. Language models are unsupervised multitask learners.
- Raffel, C.; Shazeer, N.; Roberts, A.; Lee, K.; Narang, S.; Matena, M.; Zhou, Y.; Li, W.; and Liu, P. J. 2020. Exploring the Limits of Transfer Learning with a Unified Text-to-Text Transformer. *J. Mach. Learn. Res.*, 21: 140:1–140:67.
- Ren, H.; Dai, H.; Dai, B.; Chen, X.; Yasunaga, M.; Sun, H.; Schuurmans, D.; Leskovec, J.; and Zhou, D. 2021. Lego: Latent execution-guided reasoning for multi-hop question answering on knowledge graphs. In *International Conference on Machine Learning*, 8959–8970. PMLR.
- Ruder, S. 2017. An overview of multi-task learning in deep neural networks. *arXiv preprint arXiv:1706.05098*.
- Saxena, A.; Tripathi, A.; and Talukdar, P. P. 2020. Improving Multi-hop Question Answering over Knowledge Graphs using Knowledge Base Embeddings. In Jurafsky, D.; Chai, J.; Schluter, N.; and Tetreault, J. R., eds., *Proceedings of the 58th Annual Meeting of the Association for Computational Linguistics, ACL 2020, Online, July 5-10, 2020*, 4498–4507. Association for Computational Linguistics.
- Schlichtkrull, M. S.; Kipf, T. N.; Bloem, P.; van den Berg, R.; Titov, I.; and Welling, M. 2018. Modeling Relational Data with Graph Convolutional Networks. In Gangemi, A.; Navigli, R.; Vidal, M.; Hitzler, P.; Troncy, R.; Hollink, L.; Tordai, A.; and Alam, M., eds., *The Semantic Web - 15th International Conference, ESWC 2018, Heraklion, Crete, Greece, June 3-7, 2018, Proceedings*, volume 10843 of *Lecture Notes in Computer Science*, 593–607. Springer.
- Scholak, T.; Schucher, N.; and Bahdanau, D. 2021. PICARD: Parsing Incrementally for Constrained Auto-Regressive Decoding from Language Models. In *Proceedings of the 2021 Conference on Empirical Methods in Natural Language Processing*, 9895–9901.
- Shi, P.; Ng, P.; Nan, F.; Zhu, H.; Wang, J.; Jiang, J.; Li, A. H.; Chakravarti, R.; Weidner, D.; Xiang, B.; et al. 2022. Generation-focused Table-based Intermediate Pre-training for Free-form Question Answering.
- Shi, P.; Ng, P.; Wang, Z.; Zhu, H.; Li, A. H.; Wang, J.; dos Santos, C. N.; and Xiang, B. 2021. Learning contextual representations for semantic parsing with generation-augmented pre-training. In *Proceedings of the AAAI Conference on Artificial Intelligence*, volume 35, 13806–13814.
- Shi, T.; Zhao, C.; Boyd-Graber, J.; Daumé III, H.; and Lee, L. 2020. On the potential of lexico-logical alignments for semantic parsing to SQL queries. *arXiv preprint arXiv:2010.11246*.
- Shin, R.; and Durme, B. V. 2021. Few-Shot Semantic Parsing with Language Models Trained On Code. *CoRR*, abs/2112.08696.
- Shin, R.; Lin, C. H.; Thomson, S.; Chen, C.; Roy, S.; Platanios, E. A.; Pauls, A.; Klein, D.; Eisner, J.; and Durme, B. V. 2021. Constrained Language Models Yield Few-Shot Semantic Parsers. In Moens, M.; Huang, X.; Specia, L.; and Yih, S. W., eds., *Proceedings of the 2021 Conference on Empirical Methods in Natural Language Processing, EMNLP 2021, Virtual Event / Punta Cana, Dominican Republic, 7-11 November, 2021*, 7699–7715. Association for Computational Linguistics.
- Stevens, S.; and Su, Y. 2020. An Investigation of Language Model Interpretability via Sentence Editing. *arXiv preprint arXiv:2011.14039*.
- Stevens, S.; and Su, Y. 2021. An Investigation of Language Model Interpretability via Sentence Editing. In *Proceedings of the Fourth BlackboxNLP Workshop on Analyzing and Interpreting Neural Networks for NLP*, 435–446.
- Su, Y.; and Yan, X. 2017. Cross-domain Semantic Parsing via Paraphrasing. In Palmer, M.; Hwa, R.; and Riedel, S., eds., *Proceedings of the 2017 Conference on Empirical Methods in Natural Language Processing, EMNLP 2017, Copenhagen, Denmark, September 9-11, 2017*, 1235–1246. Association for Computational Linguistics.
- Vaswani, A.; Shazeer, N.; Parmar, N.; Uszkoreit, J.; Jones, L.; Gomez, A. N.; Kaiser, Ł.; and Polosukhin, I. 2017. Attention is all you need. *Advances in neural information processing systems*, 30.
- Vrandečić, D.; and Krötzsch, M. 2014. Wikidata: a free collaborative knowledgebase. *Commun. ACM*, 57(10): 78–85.
- Wang, B.; Lapata, M.; and Titov, I. 2021. Learning from Executions for Semantic Parsing. In Toutanova, K.; Rumshisky, A.; Zettlemoyer, L.; Hakkani-Tür, D.; Beltagy, I.; Bethard, S.; Cotterell, R.; Chakraborty, T.; and Zhou, Y., eds., *Proceedings of the 2021 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies, NAACL-HLT 2021, Online, June 6-11, 2021*, 2747–2759. Association for Computational Linguistics.
- Wang, C.; Tatwawadi, K.; Brockschmidt, M.; Huang, P.-S.; Mao, Y.; Polozov, O.; and Singh, R. 2018. Robust text-to-sql generation with execution-guided decoding. *arXiv preprint arXiv:1807.03100*.
- Wang, Y.; Berant, J.; and Liang, P. 2015. Building a Semantic Parser Overnight. In *Proceedings of the 53rd Annual Meeting of the Association for Computational Linguistics and the 7th International Joint Conference on Natural Language Processing of the Asian Federation of Natural Language Processing, ACL 2015, July 26-31, 2015, Beijing, China, Volume 1: Long Papers*, 1332–1342. The Association for Computer Linguistics.
- Wu, Z.; Yang, P.; Yu, P.; Zhu, R.; Han, Y.; Li, Y.; Lian, D.; Zeng, K.; and Zhou, J. 2021. A unified transferable model for ml-enhanced dbms. *arXiv preprint arXiv:2105.02418*.
- Xie, T.; Wu, C. H.; Shi, P.; Zhong, R.; Scholak, T.; Yasunaga, M.; Wu, C.-S.; Zhong, M.; Yin, P.; Wang, S. I.; et al. 2022. Unifedskg: Unifying and multi-tasking structured knowledge grounding with text-to-text language models. *arXiv preprint arXiv:2201.05966*.

- Xuan, K.; Wang, Y.; Wang, Y.; Wen, Z.; and Dong, Y. 2021. Sead: End-to-end text-to-sql generation with schema-aware denoising. *arXiv preprint arXiv:2105.07911*.
- Yang, Y.; Wang, L.; Shi, S.; Tadepalli, P.; Lee, S.; and Tu, Z. 2020. On the sub-layer functionalities of transformer decoder. *arXiv preprint arXiv:2010.02648*.
- Yin, P.; Neubig, G.; Yih, W.-t.; and Riedel, S. 2020. TaBERT: Pretraining for Joint Understanding of Textual and Tabular Data. In *Proceedings of the 58th Annual Meeting of the Association for Computational Linguistics*, 8413–8426.
- Yin, P.; Wieting, J.; Sil, A.; and Neubig, G. 2022. On The Ingredients of an Effective Zero-shot Semantic Parser. 1455–1474.
- Yu, T.; Wu, C.; Lin, X. V.; Wang, B.; Tan, Y. C.; Yang, X.; Radev, D. R.; Socher, R.; and Xiong, C. 2021. GraPPa: Grammar-Augmented Pre-Training for Table Semantic Parsing. In *9th International Conference on Learning Representations, ICLR 2021, Virtual Event, Austria, May 3-7, 2021*. OpenReview.net.
- Yu, T.; Zhang, R.; Polozov, A.; Meek, C.; and Awadallah, A. H. 2020. Score: Pre-training for context representation in conversational semantic parsing. In *International Conference on Learning Representations*.
- Zettlemoyer, L. S.; and Collins, M. 2005. Learning to Map Sentences to Logical Form: Structured Classification with Probabilistic Categorical Grammars. In *UAI '05, Proceedings of the 21st Conference in Uncertainty in Artificial Intelligence, Edinburgh, Scotland, July 26-29, 2005*, 658–666. AUAI Press.
- Zhong, V.; Xiong, C.; and Socher, R. 2017. Seq2SQL: Generating Structured Queries from Natural Language using Reinforcement Learning. *CoRR*, abs/1709.00103.