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An Efficient Fine-tuning Method for Hierarchical Semantic Parsing in Task-Oriented Dialog System by Structure-aware Boosting and Grammar Constraints

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Task-oriented dialogue (TOD) systems have become increasingly crucial in various domains, providing efficient and appropriate interactions with users to perform specific tasks. These systems, such as voice assistants and chatbots, rely on semantic parsing models to convert user queries into machine-understandable representations, enabling accurate interpretation and appropriate responses. While traditional semantic parsing methods have shown effectiveness in handling flat intent-slot structures, they struggle to cope with the complexities introduced by hierarchical semantic parsing (HSP). Hierarchical representations offer increased expressiveness, allowing for more nuanced interpretations of user queries, but they also pose challenges in accurately labeling and capturing nested structures. In recent years, the field of natural language processing (NLP) has witnessed significant advancements, largely driven by the remarkable success of pre-trained language models like BERT. These models have demonstrated exceptional performance across a wide range of tasks, including hierarchical semantic parsing. Among these models, the RINE model has emerged as a leader by providing state-of-the-art (SOTA) results. The distinctive strength of the RINE model lies in its innovative utilization of a recursive insertion-based mechanism. This mechanism allows the model to leverage the decoded tree from previous steps as direct input for the current step, enabling more effective and context-aware parsing. Despite the impressive achievements observed in the realm of hierarchical semantic parsing, there is still significant room for enhancing the overall performance of these systems. Previous works do not explicitly consider structured information within utterances. However, this information about sentence structures is crucial in the semantic parsing task, specifically when parsing complex utterances of hierarchical semantic parsing.

Taking these points into consideration, this thesis focuses on two key enhancements: strengthening the hierarchical structure awareness of pre-trained language models and employing dynamic pruning of unpromising decoding directions using inductive grammar. By incorporating sentence structure information, we aim to improve the performance of hierarchical semantic parsing systems. To achieve this objective, we propose the StructSP framework, which leverages hierarchical representations for their deep fine-grained structure and consists of two distinct phases: structure-aware boosting and grammar-based RINE. In the structure-aware boosting phase, our aim is to enhance the representation of structured information within pre-trained language models. We extend the vanilla mask language modeling (MLM) task by giving higher priority to logical tokens present in the linearized hierarchical representation. By doing so, we encourage the model to focus on the essential elements of the logical structure and improve its understanding of the semantic relationships. Furthermore, we introduce a novel subtask called relative tree agreement, which allows the model to develop closer vector representations for relative trees in the same parsing process. By learning the hidden relationships between these intermediate parsing steps, our framework gains a more comprehensive understanding of the logical structure and improves its ability to capture intricate dependencies. In the second phase, grammar-based RINE, we incorporate grammar extracted from annotated data to help in the prediction of node labels. By utilizing this grammar during the parsing process, we aim to guide the model toward more accurate predictions by preventing branches in the decoding process that won't yield a solution, thus mitigating errors and improving the overall performance of the system.

To evaluate the proposed StructSP framework, comprehensive experiments were conducted on the widely used TOP and TOPv2 datasets. The performance comparison with several previous approaches on the TOP dataset demonstrates the effectiveness of the proposed approach. Our method achieves an impressive exact match (EM) score of 88.18, outperforming existing SOTA models by notable margins. Specifically, it surpasses the current SOTA model, RINE, by 0.61 EM points. The experiments on the TOPv2 dataset, which includes low-resource scenarios, further highlight the superiority of our approach. In these settings, our models outperform the RINE model by up to 1.02 EM points. The results indicate that our StructSP framework effectively leverages hierarchical semantic structured information, demonstrating its potential to enhance the accuracy and reliability of semantic parsing systems. The incorporation of grammar proves to be beneficial in most cases, guiding the decoding process and improving label predictions. However, in extremely limited training data scenarios, the performance gains from grammar utilization may not be substantial due to insufficient coverage of grammar patterns in the data. Addressing this issue requires further investigation and potential improvements in grammar aggregation techniques.

In the analysis section, we conducted a systematic ablation study to evaluate the impact of different factors on the performance of our proposed model. By comparing the performance of the full-setting model, which includes both the Structure-aware boosting and Grammar-based RINE phases, with variations where specific components were selectively disabled, we identified the key elements that significantly influenced the model's performance. The results highlighted the importance of structure-focused MLM and relative tree agreement in the structure-aware boosting phase, as well as the incorporation of grammar in the grammar-based RINE phase, as these factors contributed to enhanced performance on the TOP dataset. Furthermore, we investigated the impact of the masking probability on the model's performance by varying the value of masking probabilities during training. Finally, to gain insights into the model's performance on specific input queries, we conducted a case study comparing the outputs of the baseline RINE model with our StructSP model on the validation set of the TOP dataset. We presented some examples, showcasing instances where our model outperformed the baseline in accurately capturing the underlying semantics of the input query. While our model demonstrated improved performance in most cases, there were also examples where both models produced incorrect outputs, highlighting areas for potential improvement in handling intricate queries.

In summary, this thesis contributes to the field of hierarchical semantic parsing by proposing an innovative approach to integrate hierarchical semantic structured information into pre-trained language models. By leveraging grammar during the parsing process, our method achieves superior performance compared to existing SOTA models in task-oriented semantic parsing. This work demonstrates the potential of our StructSP framework to advance the accuracy and reliability of semantic parsing systems in various applications. Future work could focus on refining the grammar aggregation process, exploring other mechanisms for deep structure awareness, and investigating techniques to improve performance in low-resource scenarios.