

CoE-SQL: In-Context Learning for Multi-Turn Text-to-SQL with Chain-of-Editions

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Abstract

Recently, Large Language Models (LLMs) have been demonstrated to possess impressive capabilities in a variety of domains and tasks. We investigate the issue of prompt design in the multi-turn text-to-SQL task and attempt to enhance the LLMs’ reasoning capacity when generating SQL queries. In the conversational context, the current SQL query can be modified from the preceding SQL query with only a few operations due to the context dependency. We introduce our method called CoE-SQL which can prompt LLMs to generate the SQL query based on the previously generated SQL query with an edition chain. We also conduct extensive ablation studies to determine the optimal configuration of our approach. Our approach outperforms different in-context learning baselines stably and achieves state-of-the-art performances on two benchmarks SPaC and CoSQL using LLMs, which is also competitive to the SOTA fine-tuned models.

1 Introduction

Text-to-SQL (Zhong et al., 2017; Xu et al., 2017) is a semantic parsing task that translates the natural language question into the appropriate SQL query according to the given database schema. This technique is critical in building a natural language interface to relational databases (Androulopoulos et al., 1995), which alleviates the burden on programmers to curate valid and correct annotations.

In this work, we focus on the contextual settings (Yu et al., 2019b,a) where users interact with the system in multi-turn scenarios. In each turn, the text-to-SQL parser understands and interprets the current user question into a SQL query based on the entire dialogue history. Considering the requirement of context modeling, EditSQL (Zhang et al., 2019a) introduces copy mechanism during the generation of SQL queries to re-use the SQL spans in history. DELTA (Chen et al., 2021b)

firstly paraphrases the long context into a single question and transforms the original problem into single-turn parsing. IGSQ (Cai and Wan, 2020a) and HIESQL (Zheng et al., 2022a) both utilize the concept of cross-turn schema interaction into the specialized design of graph encoders. STAR (Cai et al., 2022) and CQR-SQL (Xiao et al., 2022) inject the capability of context modeling through self-supervised pre-training tasks. Though remarkable progress has been achieved, these task-specific methods rely on complicated model design which is labor-intensive and training-inefficient.

The advent of LLMs (Ouyang et al., 2022) provides a promising solution in the text-to-SQL field, that is in-context learning with few-shot exemplars (Brown et al., 2020). In this branch, DIN-SQL (Pourreza and Rafiei, 2023) adopts the concept of Chain-of-Thought (CoE, Wei et al., 2023) and establishes a new milestone in single-turn settings. ACT-SQL (Zhang et al., 2023) further eliminates the necessity of manually crafting CoT exemplars and automatically constructs useful demonstrations. However, adapting the ICL method into contextual settings is less investigated. ACT-SQL attempts to reduce the original problem into single-turn problems via sentence rewriting. But poor performances are reported on multi-turn benchmarks due to severe error propagation.

In this work, we propose Chain-of-Edition framework to tackle the multi-turn text-to-SQL task (CoE-SQL). Inspired by recent progress in code edition (Chen et al., 2023), we attempt to model the changes in the output SQL program across different interaction turns explicitly. These changes can be serialized into the reasoning thought, as a specific implementation of CoT, to track the shift in the user focus and intention. The underlying mechanism is that, in a coherent and consistent dialogue, the user’s questions often depend on the previous focus, and the latest request or intent can be obtained by modifying the already

Turn 1
Q: <i>What are the phone names available in Alberta?</i>
SQL: SELECT T1.Name FROM phone AS T1 JOIN phone_market AS T2 JOIN market AS T3 ON T1.Phone_ID = T2.Phone_ID AND T2.Market_ID = T3.Market_ID WHERE T3.District = "Alberta"
Edit: no edition
Turn 2
Q: <i>Show the district as well.</i>
SQL: SELECT T1.Name, T3.District FROM phone AS T1 JOIN phone_market AS T2 JOIN market AS T3 ON T1.Phone_ID = T2.Phone_ID AND T2.Market_ID = T3.Market_ID WHERE T3.District = "Alberta"
Edit: add select column T3.District
Turn 3
Q: <i>Remove the restriction of those in Alberta only, show all instead.</i>
SQL: SELECT T1.Name, T3.District FROM phone AS T1 JOIN phone_market AS T2 JOIN market AS T3 ON T1.Phone_ID = T2.Phone_ID AND T2.Market_ID = T3.Market_ID WHERE T3.District = "Alberta"
Edit: delete where clause T3.District = "Alberta"

Table 1: A multi-turn example from SPaRC (Yu et al., 2019b). Each edition is based on the previous turn.

generated semantic representations (SQL program) through a few simple rules. For example, in Table 1, after attaining the raw SQL query in turn one, the user is too “lazy” to declare the full intention and only convey the difference. This can be easily captured by a simple column insertion on the target SQL query. Similarly, in turn 3, the complete SQL can be obtained via a simple deletion of the WHERE clause based on turn 2, instead of generating the tedious long output. To achieve this, we thoroughly analyze the entire training set and summarize 14 unit edit rules (3.2). Next, we propose an abstract syntax tree (AST) comparison algorithm to automatically extract the chain of edition rules with the minimum length (3.3). After that, we serialize and prepend those editions in the prompt before the output of each turn. Different serialization styles are analyzed (3.4), including self-defined edit rules, python code and natural language description. And we find that the NL description performs the best on two benchmarks, SPaRC (Yu et al., 2019b) and CoSQL (Yu et al., 2019a).

Our contributions can be summarized:

1. We propose CoE-SQL to tackle the complex multi-turn text-to-SQL, which formalizes the SQL editions as a specific reasoning process.

This method is more interpretable towards how LLM deals with context modeling to simulate human thinking.

2. We provide the checklist of unit edit rules, and the corresponding tree comparison algorithm to automatically extract the edition chain by comparing two abstract syntax trees (ASTs).
3. We conduct comprehensive ablation study to analyze different CoE configurations and achieve state-of-the-art results with LLMs on the validation sets of two benchmarks SPaRC and CoSQL. It is also competitive to SOTA fine-tuned models.

2 Related Work

Multi-turn text-to-SQL models Before LLMs are applied in the multi-turn text-to-SQL task, researches mainly focus on building and fine-tuning specialized deep neural networks. (Zhang et al., 2019b) and (Wang et al., 2020) use the previously generated SQL queries to improve the parsing accuracy. IGSQ (Cai and Wan, 2020b) utilizes the graph neural network to model database schema items in the conversational scenario. R²SQL (Hui et al., 2021) and HIE-SQL (Zheng et al., 2022b) present a dynamic schema-linking graph which incorporates the current utterance, the previous preceding utterances, the database schema, and the last most recent SQL query. RASAT (Qi et al., 2022) is a Transformer (Vaswani et al., 2023) architecture augmented with relation-aware self-attention that could leverage a variety of relational structures while effectively inheriting the pre-trained parameters from the T5 model (Raffel et al., 2023). RASAT employs the PICARD method (Scholak et al., 2021) which constrains the auto-regressive decoder by rejecting invalid tokens.

Despite the impressive results of specialized models, there are some unavoidable drawbacks. Creating and labeling a comprehensive text-to-SQL dataset requires a significant amount of resources and time. Additionally, training and refining the model is a laborious process that requires a lot of computing power.

In-context learning for text-to-SQL Recent studies have explored the potential of LLMs for the text-to-SQL task, with Rajkumar et al. (2022) using the zero-shot and few-shot learning setting to empirically evaluate the capabilities of LLMs such as GPT-3 (Brown et al., 2020) and Codex (Chen

et al., 2021a). Nan et al. (2023) focused on the strategy of exemplar selection, requiring an additional predictor to assess the difficulty of the SQL. DIN-SQL (Pourreza and Rafiei, 2023) provides a more complex approach, decomposing the problem into several simpler sub-problems.

The above works merely employ LLMs on the single-turn text-to-SQL task. ACT-SQL (Zhang et al., 2023) generates the chain-of-thoughts automatically and extends its approach onto the multi-turn text-to-SQL task. ACT-SQL converts the multi-turn dataset into the single-turn one by rewriting and completing questions with context dependencies. However, ACT-SQL performs poorly under the multi-turn setup due to the error propagation occurring in the process of question rewriting. In contrast, our proposed CoE-SQL is an edit-based method which can directly utilize the context dependency instead of rewriting the question.

3 Methodology

In the few-shot in-context learning setting, the multi-turn text-to-SQL task can be formulated as

$$R_n = \text{LLM}(I, D, Q_{\leq n}, R_{< n}, \mathcal{E}).$$

R_n represents the response to the current question created by LLMs. I represents the instruction. D represents the database schema. $Q = [Q_1, Q_2, \dots, Q_n]$ represents the entire context consisting of n questions. $R = [R_1, R_2, \dots, R_{n-1}]$ represents LLMs’ responses to the previous questions. $\mathcal{E} = [E_1, E_2, \dots, E_{|\mathcal{E}|}]$ is the list of $|\mathcal{E}|$ exemplars used in few-shot learning.

3.1 Overview of CoE

In the real-world scenario, users are more likely to start the conversation with a relatively simple question because they are unfamiliar with the detailed structure of the system. With the increasing the number of conversation turns, the user question and the corresponding SQL query will become more complex. It is more difficult and redundant for LLMs to generate a complex SQL query from scratch, since the entire thinking and logical reasoning process is generally intricate. On the contrary, generating the current SQL query by updating the previous one through a few editions is a better option.

In Section 3.2, we provide our definition of unit edit rules that can help edit the SQL query. In Section 3.3, we explain how to extract the edition

chain by comparing the two ASTs of two SQL queries. In Section 3.4, we introduce the different styles of edition chains used in our work. And finally in Section 3.5, we provide a simple method to help LLMs better analyze the edition process.

3.2 Definition of Unit Edit Rules

In order to edit a SQL query into another SQL query, we first define the set of unit edit rules. According to the different SQL components, we totally define 14 unit edit rules shown in Table 11. Taking the conversation instance in Table 1 as an example, we can apply the unit edit rule `EditSelectItem(-, market.District)` to edit SQL 1 into SQL 2. We can also apply the `EditWhereCondition(market.District = “Alberta”, -)` unit edit rule to edit SQL 2 into SQL 3.

3.3 Extraction of Edition Chains

We use the few-shot learning method to activate LLMs’ ability of utilizing our pre-defined unit edit rules. Therefore, we need to select exemplars from the training dataset and then extract the edition chains in each conversation. Since this work does not focus on selecting better exemplars, we use a simple exemplars selection strategy. We first randomly choose k_d database schemas and then randomly choose k_e dataset examples for each database schema. Thus, total $k_d \times k_e$ exemplars are put in the prompting text for the few-shot learning. In the following process, we need to extract the edition chains from these exemplars.

Assume that the dataset example consists of n questions $[Q_1, Q_2, \dots, Q_n]$ and n corresponding SQL queries $[S_1, S_2, \dots, S_n]$. Consider the i -th one as the current turn. Notably, the edition chain is determined by the difference between the current SQL query S_i and the previous SQL query $S_j (j < i)$. A reasonable approach to extracting the edition chain is to compare the two ASTs.

Figure 1 shows an example of a comparison between two ASTs. Notice that the FROM clause component is omitted in this figure. We compare each node pair in the two ASTs. Two nodes are considered equal iff they represent the same grammar rule and all of their child nodes are equal. The edition chain can be constructed according to the unequal part. By recognizing the grammar rules of the nodes in the unequal part, we can determine that the edition chain contains exactly one unit edit rule, i.e. `EditWhereCondition(-, Stu.GPA > 3)`. The detailed procedure is outlined in Algorithm 1.

Algorithm 1: Extraction of Edition Chains

Input : Previous tree node t_{old} , current tree node t_{new}
Output : Edition chain C
 $C \leftarrow \{\}$;
for f in $\text{get_fields}(t_{old})$ **do**
 $s_{old} \leftarrow t_{old}.\text{get_son}(f)$;
 $s_{new} \leftarrow t_{new}.\text{get_son}(f)$;
 if s_{old} is tree and s_{new} is tree **then**
 $C_{sub} \leftarrow \text{ExtractCoE}(s_{old}, s_{new})$;
 // recursively call the function
 $C.\text{update}(C_{sub})$;
 end
 else if s_{old} is None and s_{new} is tree **then**
 $e \leftarrow \text{get_add_edition}(s_{new}, f)$;
 $C.\text{add}(e)$;
 end
 else if s_{old} is tree and s_{new} is None **then**
 $e \leftarrow \text{get_delete_edition}(s_{old}, f)$;
 $C.\text{add}(e)$;
 end
 else if $s_{old} \neq s_{new}$ **then**
 $e \leftarrow \text{get_change_edition}(s_{old}, s_{new}, f)$;
 $C.\text{add}(e)$;
 end
end
return C

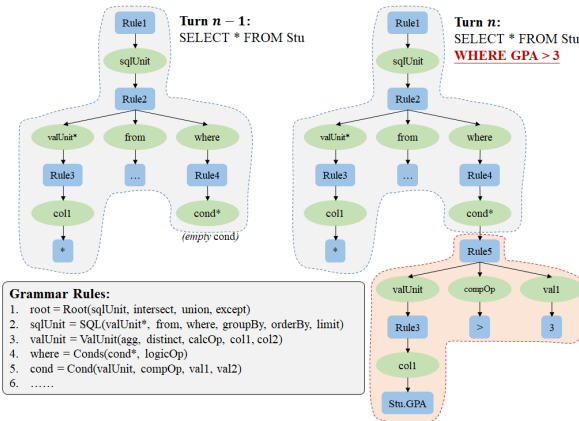


Figure 1: Comparison between two ASTs.

With the method of comparing two ASTs, we can construct the edition chains for every exemplar automatically. LLMs can learn the chain-of-editions method during the few-shot learning process.

In quite a few conversations, the current question Q_i may not inherit from the exactly previous question Q_{i-1} but the more previous one $Q_j (j < i - 1)$. Also, the current question may start a new topic irrelevant to the original one. To tackle the above two problems, we enumerate all the previous $i - 1$ SQL queries and construct an edition chain $\text{CoE}_{i,j}$ for each SQL pair (S_i, S_j) where $j = 1, 2, \dots, i - 1$. We eliminate those edition chains with lengths greater than l_c (edition chains consisting of more than l_c unit edit rules) where l_c is a threshold. If the edition chain contains too many unit edit rules, we believe that the corresponding two questions are irrelevant. In that case, writing the current SQL query directly is more efficient than editing from the previous one. As for the left edition chains, we select the edition chain with the least number of tokens as the final edition chain.

3.4 Style of Edition Chains

We attempt to use three different styles to put the edition chain in the prompting text. Table 2 shows the detailed formats where the example chain-of-edition consists of two unit edit rules, namely `EditSelectItem(*, COUNT(*))` and `EditWhereCondition(-, Stu.GPA > 3)`.

With the edit rule style, we directly write our unit edit rules into the prompting text. With the Python code style, we regard the SQL query as a Python dict and convert unit edit rules into corresponding Python codes to update the Python dict. With the natural language style, unit edit rules are converted into plain texts which are closer to the corpus used in the LLMs' pretraining step.

3.5 Analysis of Differences Between Pre- and Post-Questions

When preprocessing the exemplar, the edition chain can be extracted by comparing the different ASTs. However, when handling the test case, LLMs have to predict the edition chain by comparing the current question and the previous question. Thus we complete the question analysis for the exemplars. Given the current question and the previous question, we instruct LLMs to generate the difference between them. The analysis texts of each exemplar are also added into the prompting text, which can motivate LLMs to analyze the difference be-

Style	Prompting Text
Edit Rule	FROM clause: - no change is needed
	SELECT clause: - EditSelectItem(*, COUNT(*))
	WHERE clause: - EditWhereCondition(-, Stu.GPA > 3)
	GROUP BY clause: - no change is needed
	ORDER BY clause: - no change is needed
	LIMIT clause: - no change is needed
	INTERSECT/UNION/EXCEPT: - no change is needed
Python Code	sql['select'].remove('*')
	sql['select'].append('COUNT(*)')
	sql['where'].append('Stu.GPA > 3')
Natural Language	FROM clause: - no change is needed
	SELECT clause: - change * to COUNT(*)
	WHERE clause: - add WHERE condition Stu.GPA > 3
	GROUP BY clause: - no change is needed
	ORDER BY clause: - no change is needed
	LIMIT clause: - no change is needed
	INTERSECT/UNION/EXCEPT: - no change is needed

Table 2: Three styles of serialization for CoE.

tween pre- and post-questions. Notice that, this thought-before-edition trick is an adaptation of the thought-before-action idea in ReAct (Yao et al., 2022) framework.

4 Experiments

4.1 Experiment Setup

Models We use the GPT-3.5-turbo-16k model to evaluate our proposed CoE-SQL. The CoE-SQL approach is based on self-defined edit operations, indicating that this method would not perform well if insufficient exemplars are provided. Only sufficient exemplars can cover most unit edit rules. Therefore, we expect LLMs to have a long context window. That’s the reason we choose GPT-3.5-turbo-16k with a 16,385 tokens context window instead of GPT-3.5-turbo with a 4,096 tokens context window.

Hyperparameters The temperature in the API of LLMs is set to 0, meaning that the greedy decoding strategy is being used. Text-to-SQL tasks require the model to produce SQL queries that adhere to strict grammar regulations. If the temperature is too high, the LLMs are likely to generate SQL queries that are invalid or not pertinent to the posed questions. Regarding the exemplars used for the

few-shot learning, we set the number of database schemas k_d to 4 and set the number of examples from each database schema k_e to 4.

Datasets We assess our proposed approach on SPaRC (Yu et al., 2019b) and CoSQL (Yu et al., 2019a). SPaRC is composed of 4,298 coherent question sequences, including more than 12k individual questions and the related SQL queries. CoSQL has 10k+ annotated SQL queries. Each dialogue in CoSQL is designed to mimic a real-world situation, where a regular user is exploring the database and an expert is retrieving answers with SQL. They also provide an evaluation script that divides SQL queries into four difficulty levels (easy, medium, hard, and extra).

Evaluation metrics We assess the performance of our approach using three commonly used evaluation metrics for the text-to-SQL task: exact match accuracy (EM), execution accuracy (EX), and test-suite accuracy (TS). EM requires that each component of the predicted SQL is the same as the corresponding component of the gold SQL, disregarding the values in the query. EX evaluates the correctness of the execution result of the predicted SQL, which is usually more precise than EM. TS also evaluates the execution result, but requires the result to be correct across multiple database instances per database schema¹.

Since we are evaluating LLMs’ performances in the multi-turn text-to-SQL task, question match accuracy (QM) and interaction match accuracy (IM) need to be considered respectively. QM is 1 if the predicted SQL query for the single question is correct, and IM is 1 if all the predicted SQL queries in the context are correct.

4.2 Main Results

In our main experiments, we choose the natural language style for the edition chain. We set the maximum length of the edition chain l_c to 4 when testing on SPaRC and 3 when testing on CoSQL. Table 3 and Table 4 show the performance of our proposed CoE-SQL and other previous works on the dev sets of SPaRC and CoSQL respectively.

Notably, when comparing in-context learning approaches with fine-tuned models, the EM evaluation metric is not that worthy to be paid attention to. Fine-tuned models can learn the dataset feature

¹<https://github.com/taoyds/test-suite-sql-eval>

Fine-tuned Model	QM			IM		
	EM ↑	EX ↑	TS ↑	EM ↑	EX ↑	TS ↑
GAZP+BERT (Zhong et al., 2020)	48.9	47.8	-	-	-	-
HIE-SQL+GraPPa (Zheng et al., 2022a)	64.7	-	-	45.0	-	-
RASAT+PICARD (Qi et al., 2022)	67.7	73.3	-	49.1	54.0	-
In-Context Learning Approach						
ACT-SQL (Zhang et al., 2023)	51.0	63.8	56.9	24.4	38.9	29.6
Baseline (Ours)	50.0	67.0	59.5	30.8	46.7	37.9
CoE-SQL (Ours)	56.0	70.3	63.3	36.5	50.5	41.9

Table 3: Performances of CoE-SQL and other previous works on SParC dev set.

Fine-tuned Model	QM			IM		
	EM ↑	EX ↑	TS ↑	EM ↑	EX ↑	TS ↑
GAZP+BERT (Zhong et al., 2020)	42.0	38.8	-	-	-	-
HIE-SQL+GraPPa (Zheng et al., 2022a)	56.4	-	-	28.7	-	-
RASAT+PICARD (Qi et al., 2022)	58.8	67.0	-	27.0	39.6	-
In-Context Learning Approach						
ACT-SQL (Zhang et al., 2023)	46.0	63.7	55.2	13.3	30.7	21.5
Baseline (Ours)	47.8	69.4	58.5	20.1	38.9	27.6
CoE-SQL (Ours)	52.4	69.6	60.6	23.9	39.6	30.4

Table 4: Performances of CoE-SQL and other previous works on CoSQL dev set.

from the training set. These models are more likely to generate the SQL query with the same structure as the gold SQL query and thus can achieve higher EM scores. On the contrary, LLMs tend to write the SQL query based on their original knowledge learning in the pretraining phase. Only a few exemplars from the training dataset cannot provide sufficient information about the dataset feature. Therefore, LLMs are more likely to generate the SQL query with the accurate semantic and logic and the correct execution result. In general, we would like to mainly focus on the EX and TS evaluation metrics in the following discussion. Most fine-tuned models only provide their EM scores. We compare our method with the GAZP and the RASAT methods because these two models provide their EX scores, where RASAT is the SOTA one.

Compared with fine-tuned models, our proposed CoE-SQL approach achieves a 70.3% EX(QM) score and a 50.5% EX(IM) score on SParC dev set, which has surpassed the GAZP + BERT model (Zhong et al., 2020) a lot and has been comparable to the RASAT + PICARD model (Qi et al., 2022). CoE-SQL even achieves the highest EX(QM) score on CoSQL dev set. The experiment result proves that LLMs have possessed the strong ability for handling the complex multi-turn text-to-

SQL task. Using the GPT-3.5-turbo-16k LLM, the CoE-SQL approach can perform almost as well as the previous best fine-tuned model (with EX score). We believe that our CoE-SQL can achieve a better performance if larger LLMs (e.g. GPT-4) are applied.

Furthermore, the CoE-SQL approach achieves the highest EM, EX, and TS scores among the existing in-context learning methods. The ACT-SQL method converts the multi-turn dataset into the single-turn one by rewriting and completing the questions with context dependencies. Comparing our simple baseline method and the ACT-SQL method, we can conclude that paraphrasing the multi-turn dataset with LLMs is not a good choice. It performs even worse than the baseline method. Based on the edit operations, CoE-SQL performs much better than the baseline method which merely takes the original database schema and questions as the LLMs’ input. This indicates that editing SQL queries is an effective method in the multi-turn text-to-SQL task.

Case study Table 5 shows an instance from the SParC dev set. The condition “employees under age 30” is mentioned in the first question. The baseline method successfully keeps this condition in the second query but forgets it in the final query.

However, due to the chain-of-edition mechanism, the CoE-SQL method retains this condition from the beginning to the end. More detailed case studies can be found in Appendix B.

Turn 1

Question: Find all employees who are under age 30.

Baseline: SELECT * FROM employee WHERE age < 30 ✓

CoE-SQL: SELECT * FROM employee WHERE age < 30 ✓

Turn 2

Question: Which cities did they come from?

Baseline: SELECT DISTINCT city FROM employee WHERE age < 30 ✓

CoE-SQL: SELECT City FROM employee WHERE age < 30 ✓

Turn 3

Question: Show the cities from which more than one employee originated.

Baseline: SELECT city FROM employee GROUP BY city HAVING count(*) > 1 ✗

CoE-SQL: SELECT City FROM employee WHERE age < 30 GROUP BY City HAVING COUNT(*) > 1 ✓

Table 5: Case study from the SParC dev set.

4.3 Ablation Study

In this section, we show the experiment results of the ablation study to find out the best setting of CoE-SQL. We only report the TS score since it is most suitable for the in-context learning method.

Style of edition chains Table 6 shows the performance of CoE-SQL on SParC dev set influenced by three styles of prompting text for chain-of-editions mentioned in Section 3.4. The experiment result proves that the natural language style is the most suitable one. This is because LLMs like GPT models are mostly trained with natural language corpora. The chain-of-editions style with the edit rule performs relatively poor, since our unit edit rules are self-designed and very unlikely to appear in the pretraining corpus. Although LLMs must have seen many Python codes during pretraining, the Python-code style still receives bad scores. We believe that this is because the Python codes generated by LLMs are used to update the Python dict that represents the SQL query. The structure of this Python dict is complex and unfamiliar for LLMs,

though we have provided the structure in the instruction and exemplars.

Style	TS(QM) ↑	TS(IM) ↑
Edit Rule	61.2	40.5
Python Code	58.6	37.9
Natural Language	63.3	41.9

Table 6: CoE-SQL performance on SParC dev set influenced by three styles of prompting text for chain-of-editions.

When using the Python-code style, the prompting text mainly consists of three parts, i.e. the Python code that represents the edit rule, the Python dict that represents the SQL components, and the current SQL query. Thus we complete more ablation studies about these LLMs-generated parts. Table 7 shows the result. First, we change the order of the Python dict and the SQL query in the exemplar. Second, we complete the post-processing according to different parts which are marked with “*” symbols in the table. When post-processing with the code, we run the LLM-generated code to update the dict and get the SQL by parsing the updated dict. When post-processing with the dict, we directly get the SQL by parsing the dict generated by LLMs. The experiment shows that appending the dict after the SQL is generally a better choice. The Python codes generated by LLMs are not that reliable. It is better to directly use the Python dict or the SQL itself.

Python-Code Style	TS(QM) ↑	TS(IM) ↑
code*+dict+SQL	51.8	28.7
code+dict*+SQL	57.2	34.8
code+dict+SQL*	58.3	36.3
code*+SQL+dict	52.5	29.1
code+SQL+dict*	58.6	37.9
code+SQL*+dict	56.9	36.0

Table 7: CoE-SQL performance on SParC dev set influenced by different Python-code styles of prompting text for chain-of-editions. Different python-code styles indicate that the three components code, dict, and SQL are put in the prompting text in different orders. The “*” mark means that we use this specific component to complete the post-processing procedure.

When using the natural language style, we add “no change is needed” in the prompt if the clause is not edited as shown in Table 2. The experiment result in Table 8 proves that this prompting text is necessary. Through adding this special sentence,

the CoE prompting text in the exemplars can be regular and normalized, since all the components and clauses can be mentioned in the context. LLMs are generally better at receiving and handling regular and normalized contexts.

Natural Language Style	TS(QM) \uparrow	TS(IM) \uparrow
Natural Language	63.3	41.9
w/o “no change is needed”	62.8	41.0

Table 8: CoE-SQL performance on SPaRC dev set influenced by the “no change is needed” prompting text.

Analysis of differences between pre- and post-Questions Table 9 proves that the question analysis mentioned in Section 3.5 is effective in our approach. The analysis of differences between the current question and the previous one is beneficial for LLMs to think more about the possible edit rules. Without the analysis, the TS(QM) score and the TS(IM) score both drop about 2%.

Method	TS(QM) \uparrow	TS(IM) \uparrow
CoE-SQL	63.3	41.9
w/o analysis	61.3	39.8

Table 9: CoE-SQL performance on SPaRC dev set influenced by the question analysis.

Coverage of edition chain As mentioned in Section 3.3, if a edition chain is too long, LLMs would generate the SQL query directly instead of using the edit-based method. We can control the coverage of the edition chain on the training dataset by changing the maximum length of the edition chain l_c . Figure 2 shows the performances on SPaRC dev set influenced by l_c . According to the experiment result, we set l_c to 4 in our main experiment. If l_c is too small, LLMs would be more likely to directly generate the SQL query without using the edit-based method. If l_c is too large, LLMs would always edit the SQL query although the CoE-SQL approach may not be suitable for the current testing case.

We also try another way to control the chain-of-edition coverage in the training dataset. We remove the relatively complex unit edit rules and only retain the commonly used ones. Therefore, LLMs would not be forced to edit the SQL query if the SQL query contains complex clauses. Table 10 shows the experiment results with the different definitions of unit edit rules. In the first row, we

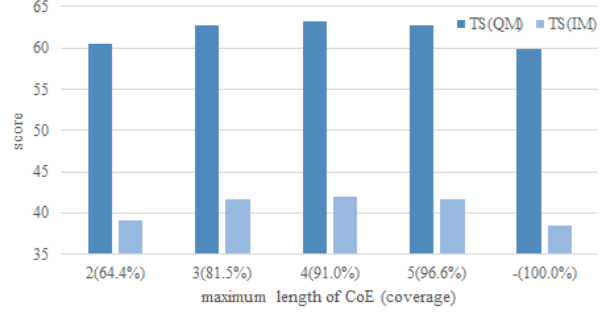


Figure 2: CoE-SQL performance on SPaRC dev set influenced by the maximum length of the edition chain.

only keep the unit edit rules involving the SELECT clause and the WHERE clause. In the second row, we add the unit edit rules that are relative to the FROM clause. In the third row, we do not set any limitations. The experiment result indicates that this method is not that effective. With the change of the unit edit rules, the LLMs’ performance does not change a lot. This explains why we use the maximum length of the edition chain to limit the edit-based approach.

Unit Edit Rules (Coverage)	TS(QM) \uparrow	TS(IM) \uparrow
S + W (48.1%)	60.0	38.9
F + S + W (65.9%)	60.3	38.2
- (100.0%)	59.9	38.4

Table 10: CoE-SQL performance on SPaRC dev set influenced by the definition of unit edit rules. F represents the unit edit rules about the FROM clause. S represents the unit edit rules about the SELECT clause. W represents the unit edit rules about the WHERE clause.

5 Conclusion

We propose our CoE-SQL approach for the multi-turn text-to-SQL task based on editing the previous SQL query to the current SQL query. We explore the definition and the style of our unit edit rules. We also provide the method to extract the edition chain by comparing two ASTs of two different SQL queries. Furthermore, our proposed CoE framework follows the human thinking process. The experiment results demonstrate that our approach achieves the best performances on the SPaRC and CoSQL dev set among existing in-context learning approaches and is also comparable to the SOTA fine-tuned model. We complete some ablation studies and prove the effectiveness of various components in CoE-SQL.

Limitations

There are some limitations in our work. First, we mainly concentrate on investigating the effectiveness of the edition chain. We do not explore anything about the exemplar selection strategy which can influence LLMs’ performances a lot. Second, we cannot ensure that we have thoroughly optimized the CoE-SQL approach. There still may exist some methods for the optimization. Third, our approach does not surpass the previous SOTA fine-tuned model on the SPaC and CoSQL dev sets under some evaluation metrics. These are all difficult tasks that need to be addressed in the future work.

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A Unit Edit Rules

Unit Edit Rule	Explanation
EditSelectItem(oldItem, newItem)	Replace oldItem with newItem in the SELECT clause. Add newItem into the SELECT clause if oldItem is "-". Delete oldItem from the SELECT clause if newItem is "-".
EditFromTable(oldTable, newTable)	Replace oldTable with newTable in the FROM clause. Add newTable into the FROM clause if oldTable is "-". Delete oldTable from the FROM clause if newTable is "-".
EditNestedFromClause(SQL)	Edit the nested FROM clause with SQL. Delete the nested FROM clause if SQL is "-".
EditJoinCondition(oldCondition, newCondition)	Replace oldCondition with newCondition in the ON clause. Add newCondition into the ON clause if oldCondition is "-". Delete oldCondition from the ON clause if newCondition is "-".
EditJoinLogicalOperator(and/or)	Edit the logical operator in the ON clause.
EditWhereCondition(oldCondition, newCondition)	Replace oldCondition with newCondition in the WHERE clause. Add newCondition into the WHERE clause if oldCondition is "-". Delete oldCondition from the WHERE clause if newCondition is "-".
EditWhereLogicalOperator(and/or)	Edit the logical operator in the WHERE clause.
EditGroupByColumn(oldColumn, newColumn)	Replace oldColumn with newColumn in the GROUP BY clause. Add newColumn into the GROUP BY clause if oldColumn is "-". Delete oldColumn from the GROUP BY clause if newColumn is "-".
EditHavingCondition(oldCondition, newCondition)	Replace oldCondition with newCondition in the HAVING clause. Add newCondition into the HAVING clause if oldCondition is "-". Delete oldCondition from the HAVING clause if newCondition is "-".
EditHavingLogicalOperator(and/or)	Edit the logical operator in the HAVING clause.
EditOrderByItem(oldItem, newItem)	Replace oldItem with newItem in the ORDER BY clause. Add newItem into the ORDER BY clause if oldItem is "-". Delete oldItem from the ORDER BY clause if newItem is "-".
EditOrder(asc/desc)	Edit the order in the ORDER BY clause.
EditLimit(oldLimit, newLimit)	Replace oldLimit with newLimit in the LIMIT clause. Add newLimit into the LIMIT clause if oldLimit is "-". Delete oldLimit from the LIMIT clause if newLimit is "-".
EditIUE(intersect/union/except, left/right, SQL)	Append SQL to the left/right side of the previous SQL with intersect/union/except keyword. Delete the left/right side of the previous SQL with intersect/union/except keyword if SQL is "-".

Table 11: All 14 defined unit edit rules.

B Detailed Experiment Results

Table 12 and Table 13 show the detailed performances of ACT-SQL (Zhang et al., 2023), our baseline, and our CoE-SQL on the SPaC and CoSQL dev sets respectively. All the results in these two tables are TS scores. The results prove that the CoE-SQL approach performs better than the previous methods with different difficulty levels and numbers of conversational turns.

Approach	TS(QM)	TS(IM)	Easy	Medium	Hard	Extra	Turn 1	Turn 2	Turn 3	Turn 4	Turn > 4
ACT-SQL (Zhang et al., 2023)	56.9	29.6	77.2	51.9	40.0	17.9	72.5	55.7	41.5	34.1	100.0
Baseline (Ours)	59.5	37.9	77.6	58.5	42.8	15.7	69.2	59.5	49.6	43.2	100.0
CoE-SQL (Ours)	63.3	41.9	81.8	59.9	46.2	26.9	76.1	60.0	53.3	48.9	100.0

Table 12: Detailed performances on the SPaC dev set.

Approach	TS(QM)	TS(IM)	Easy	Medium	Hard	Extra	Turn 1	Turn 2	Turn 3	Turn 4	Turn > 4
ACT-SQL (Zhang et al., 2023)	55.2	21.5	76.5	46.6	42.3	17.8	65.2	54.7	50.8	48.2	42.3
Baseline (Ours)	58.5	27.6	79.9	48.7	46.6	22.4	66.6	58.2	55.3	56.1	40.8
CoE-SQL (Ours)	60.6	30.4	79.1	54.7	50.3	21.5	67.2	61.8	57.0	56.1	47.9

Table 13: Detailed performances on the CoSQL dev set.

Table 14 shows two testing cases from the SPaC dev set. The complete LLMs' responses are shown in the table. In the first case, CoE-SQL successfully retains the WHERE condition while the trivial baseline method forgets this key information during the conversation. The second case demonstrates that the CoE-SQL approach can also assist LLMs to handle complex logical reasoning processes such as the JOIN operation for multi-tables and the GROUP BY operation in this case.

Turn 1

Question: Find all employees who are under age 30.

Baseline: SELECT * FROM employee WHERE age < 30 ✓

CoE-SQL:

Let's think step by step.

SQL 17-1 can be written directly instead of being edited from previous SQL.

So SQL 17-1 is:

SELECT * FROM employee WHERE age < 30 ✓

Turn 2

Question: Which cities did they come from?

Baseline: SELECT DISTINCT city FROM employee WHERE age < 30 ✓

CoE-SQL:

Let's think step by step.

SQL 17-2 can be edited from SQL 17-1.

The previous question asked for all employees who are under the age of 30, while the current question asks for the cities they come from.

Therefore, following edit operations are used:

FROM clause:

- no change is needed

SELECT clause:

- change * to employee.City

WHERE clause:

- no change is needed

GROUP BY clause:

- no change is needed

ORDER BY clause:

- no change is needed

LIMIT clause:

- no change is needed

INTERSECT/UNION/EXCEPT:

- no change is needed

So SQL 17-2 is:

SELECT City FROM employee WHERE age < 30 ✓

Turn 3

Question: Show the cities from which more than one employee originated.

Baseline: SELECT city FROM employee GROUP BY city HAVING count(*) > 1 ✗

CoE-SQL:

Let's think step by step.

SQL 17-3 can be edited from SQL 17-2.

The previous question asked for the cities from which the employees originated, while the current question asks for the cities from which more than one employee originated.

Therefore, following edit operations are used:

FROM clause:

- no change is needed

SELECT clause:

- no change is needed

WHERE clause:

- no change is needed

GROUP BY clause:

- add HAVING condition COUNT(*) > 1

ORDER BY clause:

- no change is needed

LIMIT clause:

- no change is needed

INTERSECT/UNION/EXCEPT:

- no change is needed

So SQL 17-3 is:

SELECT City FROM employee WHERE age < 30 GROUP BY City HAVING COUNT(*) > 1 ✓

Turn 1

Question: What are all the airlines?

Baseline: SELECT Airline FROM airlines ✓

CoE-SQL:

Let's think step by step.

SQL 17-1 can be written directly instead of being edited from previous SQL.

So SQL 17-1 is:

SELECT Airline FROM airlines ✓

Turn 2

Question: Which ones have more than 10 flights?

Baseline: SELECT Airline FROM flights GROUP BY Airline HAVING count(*) > 10 ✗

CoE-SQL:

Let's think step by step.

SQL 17-2 can be edited from SQL 17-1.

The previous question asked for all the airlines, while the current question asks for the airlines that have more than 10 flights.

Therefore, following edit operations are used:

FROM clause:

- add table flights

- add JOIN condition airlines.uid = flights.Airline

SELECT clause:

- no change is needed

WHERE clause:

- add WHERE condition COUNT(*) > 10

GROUP BY clause:

- add column airlines.Airline

ORDER BY clause:

- no change is needed

LIMIT clause:

- no change is needed

INTERSECT/UNION/EXCEPT:

- no change is needed

So SQL 17-2 is:

SELECT airlines.Airline FROM airlines JOIN flights ON airlines.uid = flights.Airline GROUP BY airlines.Airline HAVING COUNT(*) > 10 ✓

Table 14: Detailed case studies from the SParC dev set.

C Prompts

In this section, we show our prompt engineering with an example from the SParC train set.

C.1 Baseline

role: system

content:

Given the database schema, you need to translate the question into the SQL query.

role: user

content:

Database schema:

create table party (

 Party_ID number,

 Party_Theme text,

 Location text,

 First_year text,

 Last_year text,

 Number_of_hosts number,

 primary key (Party_ID)

)

/*

3 example rows from table party:

Party_ID	Party_Theme	Location	First_year	Last_year	Number_of_hosts
1	Spring	Hemkade 48 Zaandam	2000	2001	5
2	Club Q-BASE	Hemkade 48 Zaandam	2002	2002	23
3	Hardcore Resurrection	Various locations	2000	2003	4

*/

create table host (

 Host_ID number,

 Name text,

 Nationality text,

 Age text,

 primary key (Host_ID)

)

/*

3 example rows from table host:

Host_ID	Name	Nationality	Age
1	Austin Daye	United States	43
2	Lloyd Daniels	United States	37
3	Kornel David	Hungary	31

*/

create table party_host (

 Party_ID number,

 Host_ID number,

 Is_Main_in_Charge others,

 primary key (Party_ID),

 foreign key (Party_ID) references party(Party_ID),

 foreign key (Host_ID) references host(Host_ID)

)

/*

3 example rows from table party_host:

Party_ID	Host_ID	Is_Main_in_Charge
1	1	T
8	7	T
6	10	F

*/

Question: What are all the parties?

role: assistant

content:

SELECT * FROM party

role: user

content:

Question: Order them by the number of hosts.

role: assistant

content:

SELECT * FROM party ORDER BY Number_of_hosts ASC

C.2 Self-Defined Edit Rule Style

role: system

content:

Given the database schema, you need to translate the question into the SQL query.

You can use following operations to edit SQL:

1. EditIUE(intersect/union/except, left/right, SQL): Append SQL to the left/right side of the previous SQL with intersect/union/except keyword. Delete the left/right side of the previous SQL with intersect/union/except keyword if SQL is "-".
2. EditFromTable(oldTable, newTable): Replace oldTable with newTable in the FROM clause. Add newTable into the FROM clause if oldTable is "-". Delete oldTable from the FROM clause if newTable is "-".
3. EditJoinCondition(oldCondition, newCondition): Replace oldCondition with newCondition in the ON clause. Add newCondition into the ON clause if oldCondition is "-". Delete oldCondition from the ON clause if newCondition is "-".
4. EditJoinLogicalOperator(and/or): Edit the logical operator in the ON clause.
5. EditNestedFromClause(SQL): Edit the nested FROM clause with SQL. Delete the nested FROM clause if SQL is "-".
6. EditSelectItem(oldItem, newItem): Replace oldItem with newItem in the SELECT clause. Add newItem into the SELECT clause if oldItem is "-". Delete oldItem from the SELECT clause if newItem is "-".
7. EditWhereCondition(oldCondition, newCondition): Replace oldCondition with newCondition in the WHERE clause. Add newCondition into the WHERE clause if oldCondition is "-". Delete oldCondition from the WHERE clause if newCondition is "-".
8. EditWhereLogicalOperator(and/or): Edit the logical operator in the WHERE clause.
9. EditGroupByColumn(oldColumn, newColumn): Replace oldColumn with newColumn in the GROUP BY clause. Add newColumn into the GROUP BY clause if oldColumn is "-". Delete oldColumn from the GROUP BY clause if newColumn is "-".
10. EditHavingCondition(oldCondition, newCondition): Replace oldCondition with newCondition in the HAVING clause. Add newCondition into the HAVING clause if oldCondition is "-". Delete oldCondition from the HAVING clause if newCondition is "-".
11. EditHavingLogicalOperator(and/or): Edit the logical operator in the HAVING clause.
12. EditOrderByItem(oldItem, newItem): Replace oldItem with newItem in the ORDER BY clause. Add newItem into the ORDER BY clause if oldItem is "-". Delete oldItem from the ORDER BY clause if newItem is "-".
13. EditOrder(asc/desc): Edit the order in the ORDER BY clause.
14. EditLimit(oldLimit, newLimit): Replace oldLimit with newLimit in the LIMIT clause. Add newLimit into the LIMIT clause if oldLimit is "-". Delete oldLimit from the LIMIT clause if newLimit is "-".

role: user

content:

Database schema:

```
create table party (  
    Party_ID number,  
    Party_Theme text,  
    Location text,  
    First_year text,  
    Last_year text,  
    Number_of_hosts number,  
    primary key (Party_ID)  
)  
/*
```

3 example rows from table party:

Party_ID	Party_Theme	Location	First_year	Last_year	Number_of_hosts
1	Spring	Hemkade 48 Zaandam	2000	2001	5
2	Club Q-BASE	Hemkade 48 Zaandam	2002	2002	23
3	Hardcore Resurrection	Various locations	2000	2003	4

```
*/
```

```
create table host (  
    Host_ID number,  
    Name text,  
    Nationality text,  
    Age text,  
    primary key (Host_ID)  
)  
/*
```

3 example rows from table host:

Host_ID	Name	Nationality	Age
1	Austin Daye	United States	43
2	Lloyd Daniels	United States	37
3	Kornel David	Hungary	31

```
*/
```

```
create table party_host (  
    Party_ID number,  
    Host_ID number,  
    Is_Main_in_Charge others,  
    primary key (Party_ID),  
    foreign key (Party_ID) references party(Party_ID),  
    foreign key (Host_ID) references host(Host_ID)  
)  
/*
```

3 example rows from table party_host:

Party_ID	Host_ID	Is_Main_in_Charge
1	1	T
8	7	T
6	10	F

```
*/
```

Question 1-1: What are all the parties?

role: assistant:

content:

Let's think step by step.

SQL 1-1 can be written directly instead of being edited from previous SQL.

So SQL 1-1 is:
 SELECT * FROM party

role: user:
 content:
 Question 1-2: Order them by the number of hosts.

role: assistant
 content:
 Let's think step by step.
 SQL 1-2 can be edited from SQL 1-1.
 The previous question asked for a list of all the parties, while the current question asks for the parties to be ordered by the number of hosts they have.
 Therefore, following edit operations are used:
 FROM clause:
 - no change is needed
 SELECT clause:
 - no change is needed
 WHERE clause:
 - no change is needed
 GROUP BY clause:
 - no change is needed
 ORDER BY clause:
 - EditOrderByItem(-, party.Number_of_hosts)
 - EditOrder(asc)
 LIMIT clause:
 - no change is needed
 INTERSECT/UNION/EXCEPT:
 - no change is needed
 So SQL 1-2 is:
 SELECT * FROM party ORDER BY Number_of_hosts ASC

C.3 Python Code Style

role: system
 content:
 Given the database schema, you need to translate the question into the SQL query.

role: user
 content:
 Database schema:
 create table party (
 Party_ID number,
 Party_Theme text,
 Location text,
 First_year text,
 Last_year text,
 Number_of_hosts number,
 primary key (Party_ID)
)

/*

3 example rows from table party:

Party_ID	Party_Theme	Location	First_year	Last_year	Number_of_hosts
----------	-------------	----------	------------	-----------	-----------------

```

1      Spring      Hemkade 48 Zaandam      2000      2001      5      995
2      Club Q-BASE      Hemkade 48 Zaandam      2002      2002      23      996
3      Hardcore Resurrection      Various locations      2000      2003      4      997
*/                                           998
create table host (                                           999
    Host_ID number,                                           1000
    Name text,                                                 1001
    Nationality text,                                          1002
    Age text,                                                  1003
    primary key (Host_ID)                                     1004
)                                                           1005
/*                                                           1006
3 example rows from table host:                               1007
Host_ID      Name      Nationality      Age               1008
1      Austin Daye      United States      43               1009
2      Lloyd Daniels      United States      37               1010
3      Kornel David      Hungary      31               1011
*/                                           1012
create table party_host (                                     1013
    Party_ID number,                                           1014
    Host_ID number,                                           1015
    Is_Main_in_Charge others,                                  1016
    primary key (Party_ID),                                    1017
    foreign key (Party_ID) references party(Party_ID),        1018
    foreign key (Host_ID) references host(Host_ID)            1019
)                                                           1020
/*                                                           1021
3 example rows from table party_host:                         1022
Party_ID      Host_ID      Is_Main_in_Charge      1023
1      1      T               1024
8      7      T               1025
6      10     F               1026
*/                                           1027
Question 1-1: What are all the parties?                       1028
                                                         1029
role: assistant:                                             1030
content:                                                     1031
Let's think step by step.                                    1032
SQL 1-1 can be written directly instead of being edited from previous SQL. 1033
So SQL 1-1 is:                                              1034
SELECT * FROM party                                         1035
So SQL dict 1-1 is:                                         1036
{                                                           1037
    "from": {                                               1038
        "tables": [                                         1039
            "party"                                          1040
        ]                                                    1041
    },                                                       1042
    "select": [                                             1043
        "*"                                                  1044
    ]                                                        1045
}                                                           1046

```

role: user:
content:
Question 1-2: Order them by the number of hosts.

role: assistant
content:
Let's think step by step.
SQL 1-2 can be edited from SQL 1-1.
The previous question asked for a list of all the parties, while the current question asks for the parties to be ordered by the number of hosts they have.
Therefore, following edit operations are used:
sql['order_by']['columns'].append('party.Number_of_hosts')
sql['order_by']['order'] = 'ASC'
So SQL 1-2 is:
SELECT * FROM party ORDER BY Number_of_hosts ASC
So SQL dict 1-2 is:
{
 "from": {
 "tables": [
 "party"
]
 },
 "select": [
 "*"
],
 "order_by": {
 "columns": [
 "party.Number_of_hosts"
],
 "order": "ASC"
 }
}

C.4 Natural Language Style

role: system
content:
Given the database schema, you need to translate the question into the SQL query.

role: user
content:
Database schema:
create table party (
 Party_ID number,
 Party_Theme text,
 Location text,
 First_year text,
 Last_year text,
 Number_of_hosts number,
 primary key (Party_ID)
)
/*

3 example rows from table party:

Party_ID	Party_Theme	Location	First_year	Last_year	Number_of_hosts
1	Spring	Hemkade 48 Zaandam	2000	2001	5
2	Club Q-BASE	Hemkade 48 Zaandam	2002	2002	23
3	Hardcore Resurrection	Various locations	2000	2003	4

*/

```
create table host (  
    Host_ID number,  
    Name text,  
    Nationality text,  
    Age text,  
    primary key (Host_ID)
```

)

/*

3 example rows from table host:

Host_ID	Name	Nationality	Age
1	Austin Daye	United States	43
2	Lloyd Daniels	United States	37
3	Kornel David	Hungary	31

*/

```
create table party_host (  
    Party_ID number,  
    Host_ID number,  
    Is_Main_in_Charge others,  
    primary key (Party_ID),  
    foreign key (Party_ID) references party(Party_ID),  
    foreign key (Host_ID) references host(Host_ID)
```

)

/*

3 example rows from table party_host:

Party_ID	Host_ID	Is_Main_in_Charge
1	1	T
8	7	T
6	10	F

*/

Question 1-1: What are all the parties?

role: assistant:

content:

Let's think step by step.

SQL 1-1 can be written directly instead of being edited from previous SQL.

So SQL 1-1 is:

```
SELECT * FROM party
```

role: user:

content:

Question 1-2: Order them by the number of hosts.

role: assistant

content:

Let's think step by step.

SQL 1-2 can be edited from SQL 1-1.

The previous question asked for a list of all the parties, while the current question asks for the parties to be ordered by the number of hosts they have.

Therefore, following edit operations are used:

FROM clause:

- no change is needed

SELECT clause:

- no change is needed

WHERE clause:

- no change is needed

GROUP BY clause:

- no change is needed

ORDER BY clause:

- add party.Number_of_hosts
- change order to ASC

LIMIT clause:

- no change is needed

INTERSECT/UNION/EXCEPT:

- no change is needed

So SQL 1-2 is:

```
SELECT * FROM party ORDER BY Number_of_hosts ASC
```