

H-STAR: LLM-driven Hybrid SQL-Text Adaptive Reasoning on Tables

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Abstract

Tabular reasoning involves interpreting natural language queries about tabular data, which presents a unique challenge of combining language understanding with structured data analysis. Existing methods employ either textual reasoning, which excels in semantic interpretation but struggles with mathematical operations, or symbolic reasoning, which handles computations well but lacks semantic understanding. This paper introduces a novel algorithm H-STAR that integrates both symbolic and semantic (textual) approaches in a two-stage process to address these limitations. H-STAR employs: (1) step-wise table extraction using ‘multi-view’ column retrieval followed by row extraction, and (2) adaptive reasoning that adapts reasoning strategies based on question types, utilizing semantic reasoning for direct lookup and complex lexical queries while augmenting textual reasoning with symbolic reasoning support for quantitative and logical tasks. Our extensive experiments demonstrate that H-STAR significantly outperforms state-of-the-art methods across three tabular question-answering (QA) and fact-verification datasets, underscoring its effectiveness and efficiency.¹

1 Introduction

Tabular data is one of the most widely used formats for storing structured information in real-world applications. Table-based reasoning presents an inherently challenging problem, requiring logical, mathematical, and textual reasoning over unstructured queries and structured tables (Ye et al., 2023). Thus, understanding and inferring tabular data has become a significant area of research in natural language processing. Tabular reasoning tasks (illustrated in Figure 1), such as table-based question answering (Pasupat and Liang, 2015; Nan et al., 2022) and table-based fact verification (Chen et al., 2019), have been extensively explored in the past.

¹The codes and data are available at: <https://github.com/nikhilsab/H-STAR>

row_id	Year	Division	Playoffs	National Cup
0	1935/36	1	Champion	?
1	1936/37	1	DNQ	Champion
...
18	1953/54	1	Champion	Champion
19	1954/55	1	No playoff	?

Fact Verification

Q: NY Americans did not qualify for playoffs in 1936/37
Evidence: Columns: [year, national cup]; Rows: [1]
A: False

Short-form QA

Q: When did NY Americans win the cup after 1936?
Evidence: Columns: [year, playoffs]; Rows: [1,18]
A: 1953/54

Long-form QA

Q: How was the cup performance in 1936/37 and 1953/54?
Evidence: Columns: [year, national cup]; Rows: [1, 18]
A: NY Americans won the national cup in 1936/37 and 1953/54

Figure 1: An illustration of different tabular reasoning tasks (a) Fact-verification, (b) Short-form QA, and (c) Long-form QA. For each task, a question Q is paired with its answer A, which varies by task. Evidence shows the relevant columns and rows needed to answer the question.

Advancements in Large Language Models (LLMs) have led to better performance across various tasks through carefully crafted prompts. In the domain of table reasoning, symbolic approaches such as Program of Thought (Chen et al., 2023) and textual methods like Chain of Thought (CoT) (Wei et al., 2022; Brown et al., 2020) have been explored. However, when applied individually (see Figure 2) these methods often struggle due to the complexities imposed by the intricate mix of numerical, temporal, and textual data, coupled with complex table structures (Shi et al., 2023; Liu et al., 2023; Sui et al., 2024). Textual reasoning excels in natural language understanding but often misinterprets table structures and struggles with quantitative reasoning. Conversely, SQL-based approaches are strong in quantitative problem-solving but perform poorly on noisy or unstructured inputs (Liu et al., 2023). As a result, recent techniques (Cheng et al., 2022; Ye et al., 2023; Wang et al., 2023; Nahid and Rafiei, 2024) that rely solely on textual or symbolic reasoning suffer from similar limitations. There-

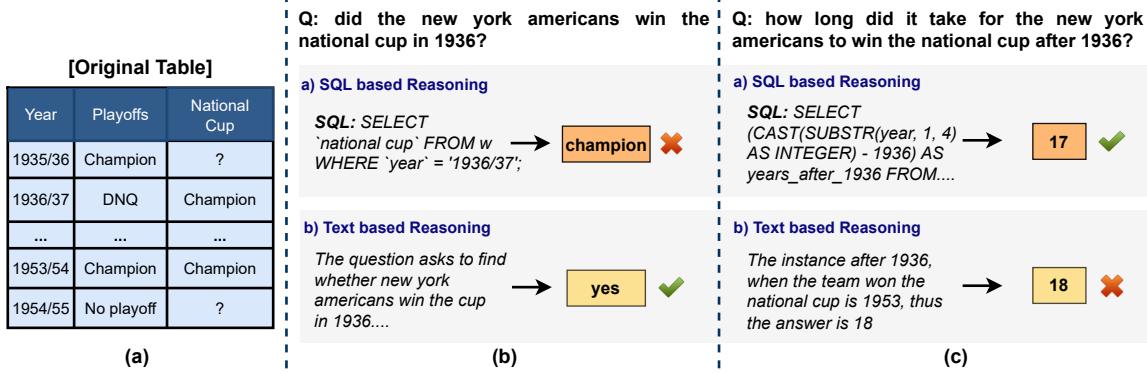


Figure 2: An illustration highlighting the complexity of table reasoning and the need for an integrated approach: (a) Original table, (b) Symbolic reasoning misinterprets the question and returns a value instead of a yes/no response, and (c) Text-based approach fails to solve a math question correctly, leading to an incorrect answer.

fore, it is crucial to explore the question: *How can symbolic and textual approaches be integrated into a hybrid method for tabular reasoning that leverages their complementary strengths while mitigating their individual limitations?*

In this paper, we introduce H-STAR which combines symbolic and textual reasoning abilities of LLMs, achieving the *best of both worlds*. H-STAR decomposes the table reasoning task into two sub-tasks: **(a) Table Extraction** and **(b) Adaptive Reasoning**. In the table extraction phase, we employ a step-by-step ‘multi-view’ chain, first identifying relevant columns using the original table and its transposed form. The filtered table is then used for row extraction, contrary to other approaches, which use the original table for both row and column selection (Ye et al., 2023; Nahid and Rafiei, 2024). Focusing on relevant table cells helps LLMs by providing the right context, thereby reducing hallucinations in reasoning. We employ a combination of SQL-based and text-based techniques in H-STAR’s table extraction phase. In the adaptive reasoning phase, we use the language comprehension capabilities of LLMs to guide them with few-shot examples to decide when to support semantic methods with symbolic (SQL) approaches. H-STAR employs semantic reasoning universally, using it exclusively for direct lookup, common-sense, and complex lexical queries while using an additional SQL step for quantitative, mathematical, and logical tasks. This strategy optimizes performance on diverse question types, supporting text comprehension with computation when required.

We demonstrate the efficacy of H-STAR across three tabular benchmarks involving table QA and table fact verification. Our experiments show that using the combined approach of H-STAR, aligned with multi-view extraction and adaptive reasoning

outperforms all prior state-of-the-art approaches. Our analysis demonstrates that H-STAR is robust and generalizable across LLMs, showcasing its superior reasoning capabilities across various tasks. Our main contributions are:

- (a) We introduce H-STAR, a two-step method unifying table extraction with adaptive reasoning to enhance performance on tabular reasoning. It is a hybrid approach that effectively integrates symbolic (SQL logic) and semantic (textual) methods.
- (b) Through extensive experiments, we demonstrate that H-STAR’s hybrid approach outperforms individually implemented symbolic and semantic methods, particularly excelling on longer tables.
- (c) Our experiments showcase H-STAR’s efficient table extraction and enhanced reasoning capabilities across different models and datasets, emphasizing the importance of every stage in achieving improved performance.

2 H-STAR Approach

H-STAR decomposes the table reasoning task into extraction and reasoning stages, combining LLM’s textual comprehension with symbolic reasoning. It converts the original table (T) into a query-specific table (T_{CR}) (refer Algorithm 1). Figure 3 illustrates our H-STAR approach. Unlike, DATER (Ye et al., 2023) and TabQSLify (Nahid and Rafiei, 2024), which use textual reasoning and text-to-SQL respectively, H-STAR integrates both reasoning types in a complementary manner for table extraction. Our reasoning step dynamically uses symbolic techniques alongside semantic methods for quantitative questions, overcoming the limits of pure textual reasoning. H-STAR operates in two main stages: 1) *Table Extraction* and 2) *Adaptive Reasoning*.

2.1 Table Extraction

Two-dimensional tables consist of columns and rows. Table extraction involves a two-step reasoning chain: **(1)** column extraction and **(2)** row extraction (see Figure 3). As illustrated in Algorithm 1, for a given table T , table extraction returns a table T_{CR} (lines 1-8) based on the input query Q .

Column Extraction. As shown in Algorithm 1, H-STAR uses a ‘multi-view’ technique, first using the original table T (line 1) followed by its transposed form T^T (line 2) for column extraction. Changing the ‘view’ acts as a verifier accounting for any information missed due to the table structure, thus improving the overall performance (see Appendix A.4). In Figure 3, given an input table T and the question Q (*‘How long did it take the New York Americans to win the National Cup after 1936?’*), the LLM employs col_{sql} to generate an SQL query to extract columns ‘year’ (C_1). This is followed by the text-based step col_{text} which processes table T^T to return columns C_2 (‘year’, ‘national cup’). This step captures the ‘national cup’ information relevant to answer the query, which is missed by col_{sql} . Table T is then filtered for columns ‘year’, ‘national cup’ (C') derived from C_1 and C_2 to obtain table T_C (lines 3,4).

Algorithm 1 H-STAR

Input: $(T, Q) \rightarrow \text{Table - Question pair}$

Output: $\hat{A} \rightarrow \text{Predicted Answer}$

Stage A: Table Extraction

Column Extraction

- 1: $C_1 \leftarrow \text{col}_{\text{sql}}(T, Q)$ $\triangleright \text{SQL approach}$
- 2: $C_2 \leftarrow \text{col}_{\text{text}}(T^T, Q)$ $\triangleright \text{Text approach}$
- 3: T^T refers to the transposed table
- 4: $C' \leftarrow C_1 \cup C_2$
- 5: $T_C \leftarrow T.\text{filter}(C')$ $\triangleright \text{Filter table } T \text{ with columns } C' \text{ to get } T_C$
- 6: **Row Extraction**
- 7: $R_1 \leftarrow \text{row}_{\text{sql}}(T_C, Q)$ $\triangleright \text{SQL approach}$
- 8: $R_2 \leftarrow \text{row}_{\text{text}}(T_C, Q, R_1)$ $\triangleright \text{Text approach}$
- 9: $R' \leftarrow R_1 \cup R_2$
- 10: $T_{CR} \leftarrow T_C.\text{filter}(R')$ $\triangleright \text{Filter table } T_C \text{ with rows } R' \text{ to get } T_{CR}$

Stage B: Adaptive Reasoning

- 11: $E_v \leftarrow f_{\text{sql}}(T_{CR}, Q)$
 - 12: $\hat{A} \leftarrow f_{\text{text}}(T_{CR}, Q, E_v)$ $\triangleright \text{Use SQL generated } E_v \text{ with } T_{CR} \text{ to generate } \hat{A}$
 - 13: $\hat{A} \leftarrow f_{\text{text}}(T_{CR}, Q)$ $\triangleright \text{Use only the table } T_{CR} \text{ to generate } \hat{A}$
 - 14: **end if**
 - 15: **return** \hat{A}
-

Row Extraction. After obtaining the filtered table T_C with relevant columns (Algorithm 1, line 4), H-STAR proceeds to the row extraction phase

culminating in the query-specific table T_{CR} (lines 5-8). The filtered table T_C has fewer tokens than T , fitting within the token limit and enabling more efficient row extraction. As shown in Figure 3, the SQL query generated by row_{sql} on the column-filtered table T_C extracts the relevant rows R_1 (‘row 18’). While it returns the appropriate row, it is not sufficient to answer the question. To overcome these limitations, we use text-based row verification row_{text} to obtain the missing rows, ultimately retrieving ‘row 1’ and ‘row 18’ (R_2). Combining R_1 and R_2 gives the relevant rows R' (‘row 1’, ‘row 18’), resulting in the final table T_{CR} .

2.2 Adaptive Reasoning

We propose an adaptive reasoning framework that harnesses the strengths of textual reasoning while mitigating its quantitative limitations through symbolic reasoning. First, we prompt LLMs to leverage their language understanding capabilities to evaluate the query requirements. We apply symbolic reasoning for queries necessitating quantitative analysis and use the generated output (E_v) along with the table (T_{CR}) as the input to the final textual reasoning step. For instance, in Figure 3, when faced with a question like *“How long did it take the New York Americans to win the National Cup after 1936?”*, LLM needs to calculate the answer, and our pipeline prioritizes symbolic reasoning (f_{sql}) through SQL-generated code. This code is executed on a SQL engine, enabling precise answers from the table T_{CR} . The output from this SQL-based evaluation E_v serves as additional evidence, supporting the final reasoning step (f_{text}). By explicitly integrating this quantitative approach, *our algorithm effectively addresses LLMs’ limitations in handling quantitative reasoning*, thereby improving the accuracy and robustness when tackling questions that demand numerical reasoning.

3 Experiments

Benchmark Datasets. We evaluate our method on three datasets covering fact verification, short-form, and long-form question-answering tasks using in-context examples. (a) TabFact (Chen et al., 2019): A fact verification benchmark utilizing Wikipedia tables. We evaluate the test-small set, containing 2,024 statements and 298 tables, with each statement labeled as Entailed (“True”) or Refuted (“False”). (b) WikiTQ (Pasupat and Liang, 2015): The WikiTableQuestions (Wik-

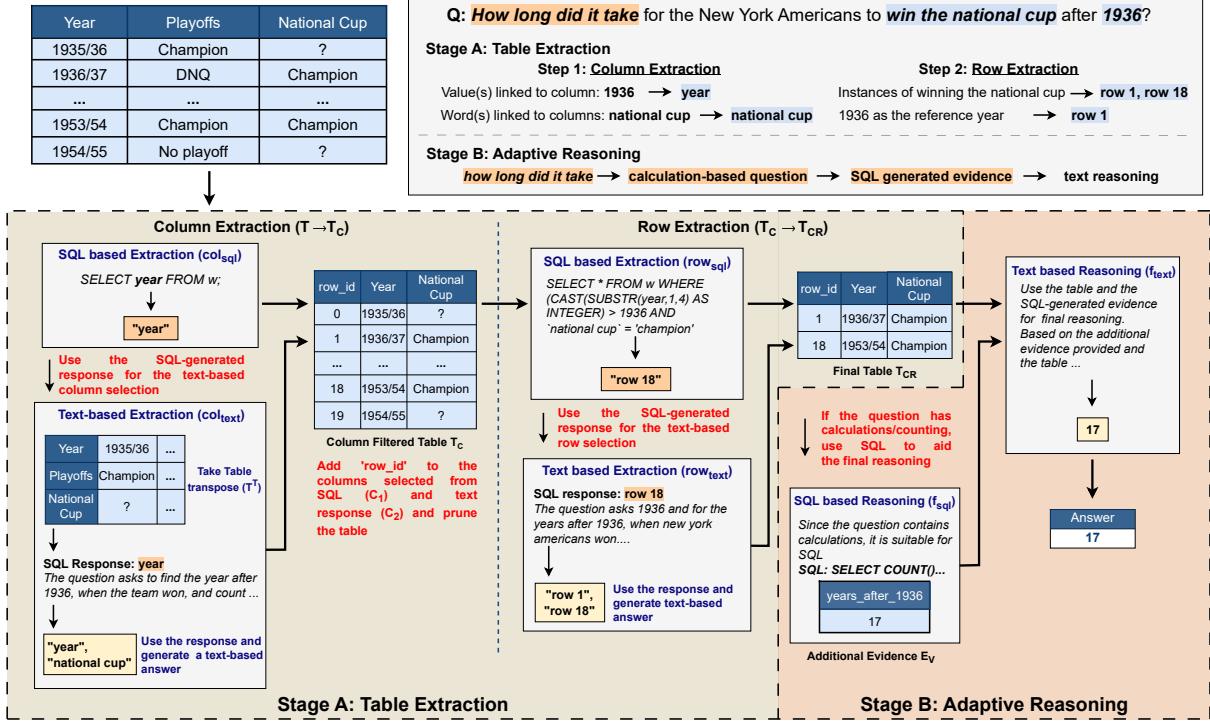


Figure 3: An overview of our proposed method, **H-STAR**, consisting of a combination of code generation and text-based verification. Given a complex table and its question, H-STAR answers using (a) **Table Extraction**: extracts the question-specific table from the original by first selecting the columns followed by rows. (b) **Adaptive Reasoning**: when the question has any mathematical component, it generates an additional table using SQL used in the textual reasoning step.

iTQ) dataset involves question-answering tasks over semi-structured Wikipedia tables. It includes a standard test set with 4,344 table-question pairs. (c) FeTaQA (Nan et al., 2022): FeTaQA (Free-Form Table Question Answering) comprises free-form questions requiring synthesis from multiple table sections for responses. It demands advanced reasoning and profound tabular data understanding, evaluated on a test set of 2003 samples.

Evaluation Metrics. We tailor our evaluation metrics based on the task and dataset characteristics. For fact-verification datasets like TabFact, we evaluate performance using binary classification *accuracy*. For short-form question-answering datasets such as WikiTQ, we assess accuracy by measuring the *exact match* between predicted outputs and the gold-standard answers. For more complex tasks in FeTaQA, which involve long-form question answering, we evaluate performance using *ROUGE-1*, *ROUGE-2*, and *ROUGE-L* metrics (Lin, 2004), comparing predicted outputs against the long-form answers.

LLM Models. In our research, we use state-of-the-art large language models (LLM) such as Gemini-1.5-Flash (Reid et al., 2024), PaLM-2 (Anil et al., 2023), GPT-3.5-Turbo, GPT-4o-mini (OpenAI, 2023), and the open-source Llama-3-70B

(Dubey et al., 2024) for table reasoning tasks. Our model inputs include in-context examples, the table, and the question for each step of the pipeline. All baselines with PALM-2 are from the propriety PALM-2 model, which is different from the public PALM-2 API (used in H-STAR and TabSQLify).

Baseline Methods. We compare our method with (a) generic reasoning based on language models, and (b) table-manipulation reasoning based on language models.

(a) Generic Reasoning. These methods direct the LLM to carry out the required downstream task based on the information from the table and the input question. They include End-to-End QA, which offers only the table and the question, and Few-Shot QA, which involves a few examples with the table-question-answer triplet alongside the table and the question. Chain-of-Thought prompts the LLMs to provide a supporting reasoning chain that leads to the answer.

(b) Table Manipulation. These techniques involve several steps, with the initial stage dedicated to automatically pre-processing the table for the reasoning task. BINDER utilizes in-context examples to produce SQL or Python code containing LLM API calls to generate answers. DATER directs the language model to break down tables and ques-

tions, applying reasoning to the decomposed tables based on sub-questions. Chain-of-Table employs the table as an intermediate output in its reasoning process, iterating through tasks until the final answer is obtained. TabSQLify uses SQL to trim the table and then reasons based on the reduced table.

3.1 Main Results

Table 1 compares the performance of different methods on the TabFact, and WikiTQ datasets, across GPT-3.5-Turbo and PaLM-2. This comparison involves evaluating against generic reasoning, table manipulation techniques, and H-STAR. Appendix A includes analyses on the FeTaQA dataset.

	GPT-3.5-Turbo		PaLM-2	
	TabFact	WikiTQ	TabFact	WikiTQ
<i>Generic Reasoning</i>				
End-to-End QA	70.45	51.84	77.92	60.59
Few-shot QA	71.54	52.56	78.06	60.33
CoT	65.37	53.48	79.05	60.43
<i>Table Manipulation</i>				
BINDER	79.17	56.74	76.98	54.88
DATER	78.01	52.90	84.63	61.48
Chain-of-Table*	80.20	59.94	86.61	67.31
TabSQLify	79.50	64.70	79.78	55.78
H-STAR	85.03	69.56	86.51	68.62

Table 1: Comparison of various methods across datasets. The results are reported from the Chain-of-Table paper for fair comparison. * Chain-of-Table uses a proprietary PaLM-2 model that is better than the publicly available version.

Analysis. (a) On WikiTQ dataset, H-STAR surpasses all baselines with both GPT-3.5-Turbo and PaLM-2 models. H-STAR achieves an accuracy of 69.56% on WikiTQ with GPT-3.5-Turbo, marking an improvement of 17.72% over the vanilla GPT-3.5-Turbo model. (b) On the TabFact dataset, H-STAR outperforms all methods with GPT-3.5-Turbo, attaining an accuracy of 85.03%, which is a 14.58% improvement over the vanilla model. With PaLM-2, H-STAR achieves comparable performance with Chain-of-Table on TabFact while improving over it by 1.3% on WikiTQ.

Comparison Across Methods Table 2 compares H-STAR with ReAcTable (Zhang et al., 2023) and SYNTQA (Zhang et al., 2024b), which use both textual and symbolic approaches for table reasoning. SYNTQA (GPT) uses the GPT model to decide between semantic and symbolic approaches, applying the chosen method for reasoning based on its selection. Additionally, it is compared with ALTER (Zhang et al., 2024a), which augments both queries and table data to facilitate reasoning.

	TabFact	WikiTQ
ReAcTable	73.1	52.5
ALTER	84.3	67.4
SYNTQA (GPT)	-	65.2
H-STAR	85.0	69.6

Table 2: Comparison of various methods across datasets on GPT-3.5-Turbo.

Analysis. H-STAR outperforms methods that use symbolic and textual approaches, such as ReAcTable, SYNTQA(GPT), and ALTER, showing the effectiveness of its complementary reasoning in a two-stage process. Appendix A.1 presents a comparison with more methods.

Performance Across LLMs Table 3 compares the performance of more advanced models like Gemini-1.5-Flash, GPT-4o-mini, and the open-source Llama-3-70B on TabFact and WikiTQ datasets. The results emphasize H-STAR’s generalizability across different models and consistent improvements across datasets. Even advanced models show significant benefits by using H-STAR.

	GPT-4o-mini		Gemini-1.5		Llama-3	
	TF	WTQ	TF	WTQ	TF	WTQ
<i>Generic Reasoning</i>						
End-to-End QA	73.22	59.43	81.12	58.47	78.41	57.89
CoT	75.99	64.31	79.99	64.11	75.34	65.49
<i>Table Manipulation</i>						
TabSQLify	78.30	68.74	79.50	63.92	60.70	66.85
Chain-of-Table	85.09	68.53	86.95	70.05	85.86	70.76
H-STAR	89.42	74.93	89.08	73.14	89.23	75.76

Table 3: Comparison of various models across datasets. TF: TabFact; WTQ: WikiTQ

Analysis. (a) H-STAR shows much higher accuracy for GPT-4o-mini, scoring 89.42% on TabFact and 74.93% on WikiTQ, compared to the End-to-End QA and Chain of Thought methods, which achieve 73.22% and 75.99% on TabFact and 59.43% and 64.31% on WikiTQ. This marks a 16.2% improvement on TabFact and 15.5% on WikiTQ. (b) For Gemini-1.5-Flash, accuracy rises from 81.12% and 58.47% respectively to 89.08% on TabFact and 73.14% on WikiTQ. (c) Similarly, for Llama-3-70B, H-STAR improves the performance across both the datasets by a margin of 11% on TabFact and 18% on WikiTQ, showing consistent gains across models and datasets.

3.2 Efficiency Analysis

Efficiency of Table Extraction. Stage-1 in H-STAR involves the extraction of the table most relevant to the question. Our table extraction

method uses a two-step chain to select the relevant columns followed by the rows. Figure 4 compares the number of average table cells for the extracted table for H-STAR, H-STAR without row extraction, and H-STAR without column extraction with other baselines.

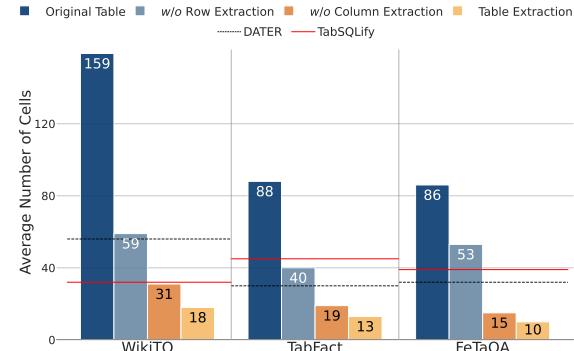


Figure 4: Comparison of average table cells in the final table.

Analysis. In particular, H-STAR significantly reduces the average number of processed table cells - from 159 to 18 for the WikiTQ dataset, from 88 to 13 for the TabFact dataset, and from 86 to 10 for the FeTaQA dataset. In contrast, other table manipulation methods, like TabSQLify and DATER yield higher values. Our approach showcases superior effectiveness, notably reducing cell counts across all datasets. This emphasizes how H-STAR effectively reduces irrelevant information, thus focusing LLMs on the *right evidence for right reasoning*.

Efficiency on Longer Tables. Table-CoT (Chen, 2023) highlights that longer table size, with tables exceeding 30 rows, is a significant cause of erroneous generations. This observation is supported by a decline in LLM performance as the number of tokens in the table increases. In Table 4, we classify LLM performance based on total tokens into three groups - small (< 2000 tokens), medium (2000 to 4000 tokens), and large (> 4000 tokens) and compare H-STAR with table manipulation like methods BINDER, DATER, Chain-of-Table, and TabSQLify.

Method	Small	Medium	Large
BINDER	56.54	25.13	6.41
DATER	62.50	42.34	34.62
Chain-of-Table	68.13	52.25	44.87
TabSQLify	68.15	57.91	52.34
H-STAR	71.64	65.20	64.84

Table 4: Performance of various methods on different table sizes on WikiTQ.

Analysis. The results shown in Table 4 emphasize the challenges LLMs face when reasoning over

longer tables. Our findings align with previous research, revealing a significant decrease in LLM performance as table sizes increase. While other table manipulation methods experience a drop in performance with larger tables, H-STAR maintains consistent performance across all table sizes.

3.3 Error Analysis

H-STAR The disjoint, step-wise nature of H-STAR enables identifying and analyzing failures. Figure 5 shows 100 randomly selected instances from the Tabfact and WikiTQ datasets where H-STAR returns incorrect answers. In this study, ‘Missing Columns’ and ‘Missing Rows’ refer to missing necessary columns and rows, respectively. ‘Incorrect Reasoning’ occurs when H-STAR extracts the correct table, but LLM fails to produce the correct answer. ‘Incorrect Annotations’ include semantically identical answers in different formats, ambiguous questions, and incorrect gold answers. Figure 5 shows that for 100 TabFact failures, 2% are missing columns, 9% missing rows, 79% incorrect LLM reasoning, and 10% incorrect annotations. For WikiTQ, 6% are missing columns, 17% missing rows, 54% incorrect reasoning, and 23% incorrect annotations.

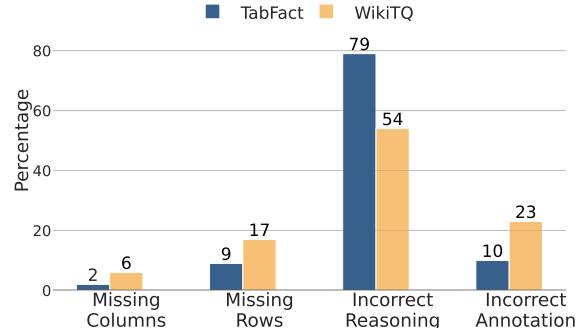


Figure 5: Error distribution on 100 error samples across datasets for H-STAR (GPT-3.5-Turbo).

Analysis. Fewer errors in column and row extraction indicate that H-STAR effectively retrieves the necessary table data. This improvement allows us to “shift left” by addressing issues earlier in the pipeline, enhancing overall performance. The higher percentage of errors in reasoning does not reflect poorly on the LLM; instead, it underscores the effectiveness of our table extraction process.

H-STAR vs Others Figure 6 compares errors in H-STAR, with TabSQLify, and BINDER on 100 WikiTQ samples where TabSQLify fails. TabSQLify extracts wrong tables for 62 out of 100 (6 missing columns, 56 missing rows). Out of the 38

samples that remain, it incorrectly reasons on 29 of the samples (76%). BINDER does not handle table extraction and instead relies on generating multiple neural SQL queries for final reasoning. However, it fails to reason correctly in 70 out of 100 instances.

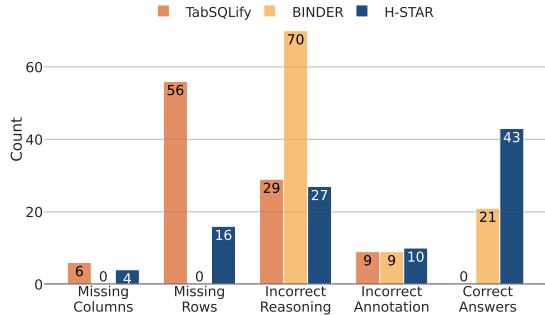


Figure 6: Analysis of error types in 100 samples from WikiTQ where TabSQLify fails. **Note:** As we move from left to right, the total samples decrease for each stage in the pipeline.

In contrast, H-STAR proves more effective in both table extraction and reasoning, generating correct answers on 43 samples. Additionally, it demonstrates fewer errors in table extraction (4 missed columns; 16 missed rows) and reasoning (27 of the remaining 80 samples, i.e. 34%).

4 Ablation Study

To evaluate the significance of the two primary stages in H-STAR: a) **Table extraction** and b) **Adaptive reasoning**, we conducted an ablation study, removing one stage at a time. For the first condition, the final adaptive reasoning stage was substituted with a basic chain-of-thought reasoning process, while maintaining the table extraction stage. Conversely, the second condition retained the adaptive reasoning stage but omitted the table extraction stage, specifically by removing the row extraction and column extraction steps individually and then collectively. A detailed assessment of the contribution of each stage to the overall performance of the method is shown in Table 5. It highlights the importance of each step in the pipeline. Removing any step can result in a performance loss especially adaptive reasoning which causes a 7% drop for both TabFact and WikiTQ datasets. For a detailed error case study and further analysis, refer to the Appendix E.

Method	TabFact	WikiTQ
H-STAR	86.51	68.62
w/o row extraction	86.17	66.30
w/o column extraction	84.04	67.03
w/o table extraction	83.79	63.58
w/o adaptive reasoning	79.35	61.47

Table 5: Performance on TabFact and WikiTQ datasets.

4.1 Impact of the Hybrid Approach

We perform a quantitative study of the impact of the hybrid approach in H-STAR. Figures 16, 17 (Appendix E) depict how using only one of the approaches results in insufficient outputs for column and row extraction tasks respectively. Furthermore, Table 6 shows that not employing a hybrid approach results in a significant performance loss.

Method	TabFact	WikiTQ
CoT	79.05	60.43
H-STAR _{text}	79.43	61.47
Text-to-SQL	52.05	42.03
H-STAR _{sql}	58.50	46.09
H-STAR	86.51	68.62

Table 6: Performance using only text-based/SQL-based reasoning; H-STAR_{text}: H-STAR with textual reasoning only; H-STAR_{sql}: H-STAR with symbolic reasoning only.

Analysis. SQL methods though efficient with numerical reasoning, are highly sensitive to data variations like irregular formatting and mixed data types, leading to a performance drop. In contrast, textual reasoning is more resilient, offering fuzzy matching and better interpretation of data. By combining textual and symbolic reasoning, H-STAR uses their complementary strengths, achieving superior performance.

4.2 Symbolic vs Semantic Approaches

As shown in Table 7 removing SQL extraction drops the accuracy to 85.22% on TabFact and 64.39% on WikiTQ, removing text extraction causes a drop to 83.74% and 60.31%, respectively. SQL reasoning removal results in 84.48% and 64.76%, but omitting text reasoning causes the largest drop, to 58.70% and 54.35%.

Method	TabFact	WikiTQ
H-STAR	86.51	68.62
w/o SQL extraction	85.22	64.39
w/o text extraction	83.74	60.31
w/o SQL reasoning	84.48	64.76
w/o text reasoning	58.70	54.35

Table 7: Performance of H-STAR after systematically removing symbolic part and semantic parts from: 1) table extraction (both row and column extraction); 2) adaptive reasoning.

Analysis. Table 7 shows that text-based approaches excel in both table extraction and reasoning. The evaluation datasets often contain noisy data that SQL-based approaches struggle with due to their reliance on structured schemas. Since text-based reasoning methods are more effective at han-

dling such irregularities, they achieve reasonably high scores, albeit lower than our hybrid approach.

5 Key Findings

Firstly, our evaluation demonstrates that our hybrid approach achieves substantial improvements, surpassing the performance of previous state-of-the-art methods across various table reasoning tasks. Secondly, the quantitative analysis demonstrates that our ‘multi-view’ approach extracts tables specific to the query. Furthermore, the qualitative analysis highlights fewer errors in our table extraction method compared to prior approaches, confirming a decrease in irrelevant information.

Thirdly, our analysis indicates consistent performance even with longer tables, emphasizing our method’s effectiveness in accurately extracting relevant information by filtering out noise. Lastly, the ablation study shows that decomposing the task into sub-tasks significantly enhances the overall performance, with each sub-task playing a crucial role in achieving superior results. Moreover, it also highlights the constraints of relying solely on either text or SQL approaches, which are effectively addressed by our H-STAR approach. Together, these findings emphasize the substantial advantages of our hybrid and multi-view approach in addressing complex table reasoning tasks.

6 Related Work

Table reasoning tasks require the ability to reason over unstructured queries and structured or semi-structured tables. Traditional approaches like TAPAS (Herzig et al., 2020), TAPEX (Liu et al., 2021), TABERT (Yin et al., 2020), TURL (Deng et al., 2022), PASTA (Gu et al., 2022) work on pre-training language models jointly on large-scale tabular and text data to reason in an end-to-end manner. Advancements in LLMs allow them to learn from in-context examples, reducing inference costs. Text-to-SQL (Rajkumar et al., 2022) and Program-of-Thought (Chen et al., 2023) use symbolic methods to solve table-based tasks via Python/SQL programs. Textual-based reasoning techniques like Table-CoT (Chen, 2023) and Tab-CoT (Ziqi and Lu, 2023) extend prompting methods such as zero and few-shot CoT for tabular reasoning.

Decomposing problems into smaller, manageable tasks has proven effective in solving complex reasoning challenges (Zhou et al., 2022; Khot et al., 2022). Recent techniques in table reasoning follow

this approach, either by breaking tasks into fixed sub-tasks (Cheng et al., 2022; Ye et al., 2023; Nahid and Rafiei, 2024) or by employing iterative methods (Jiang et al., 2023; Zhang et al., 2023; Wang et al., 2023). BINDER (Cheng et al., 2022) is an SQL-based approach that modifies SQL statements to include LLM API calls within SQL statements. ALTER (Zhang et al., 2024a) augments both the queries along with the table data. DATER (Ye et al., 2023) and TabSQLify (Nahid and Rafiei, 2024) are table decomposition methods that use semantic and symbolic reasoning respectively. Chain-of-Table (Wang et al., 2023) uses a textual reasoning approach to update tables iteratively before the final reasoning step. ReAcTable (Zhang et al., 2023) extends the ReAct (Yao et al., 2023) framework to table reasoning by employing step-by-step reasoning, iteratively generating sub-tables using external tools like SQL and Python. A detailed explanation has been provided in Appendix C. SYNTQA (Zhang et al., 2024b) is an ensemble approach employing an answer selection mechanism selecting between text-to-SQL and text-based models. In contrast, H-STAR follows a fixed two-stage table extraction and reasoning pipeline, applying both symbolic and semantic approaches complementarily at each stage, which leads to improved performance.

7 Conclusion

In this study, we present H-STAR, a novel method that effectively integrates semantic and symbolic approaches, demonstrating superior performance compared to existing methods in tasks involving table reasoning. Our approach involves a two-step LLM-driven process: firstly, employing ‘multi-view’ table extraction to retrieve tables relevant to a query, and then, implementing adaptive reasoning to select the optimal reasoning strategy based on the input query. We address prior bottlenecks with efficient extraction and reasoning, leading to improved overall performance, particularly on longer tables. Our results highlight the need to move beyond relying solely on either technique and demonstrate the effectiveness of an integrated approach that combines the advantages of both methods. Future directions involve testing the adaptability of our methods to semi-structured, complex hierarchical, and relational tables. Enhancing the reasoning process through techniques such as self-consistency and self-verification shows promising potential.

Limitations

Our current work has focused primarily on a subset of table reasoning tasks using datasets sourced from Wikipedia. While this has laid a solid foundation, it limits exploration into diverse reasoning tasks such as table manipulation, text-to-table generation, and table augmentation, which could provide valuable insights and enhance our approach’s capabilities. Additionally, our method’s generalizability is confined to Wikipedia-based datasets, restricting its application to other domains that require specific domain knowledge, which our current approach lacks. Extending our approach to different domains may necessitate integrating domain-specific knowledge to ensure effective reasoning.

Furthermore, our evaluation has been limited to relatively straightforward table structures. Handling more complex data representations such as semi-structured tables, hierarchical tables, and relational databases remains unexplored territory. These structures present unique challenges that our current approach may not effectively address. Finally, our study has focused solely on the English language, potentially limiting applicability to languages with different linguistic complexities that we have not accounted for.

Ethics Statement

We, the authors, affirm that our work adheres to the highest ethical standards in research and publication. We have carefully considered and addressed various ethical issues to ensure the responsible and fair use of computational linguistics methodologies. To facilitate reproducibility, we provide detailed information, including code, datasets (all publicly available and in compliance with their respective ethical standards), and other relevant resources. Our claims align with the experimental results, though some stochasticity is expected with black-box large language models, which we minimize by maintaining a fixed temperature. We provide comprehensive details on annotations, dataset splits, models used, and prompting methods, ensuring our work can be reliably reproduced.

Acknowledgments

We thank the authors of Tabsqlify and BINDER for sharing their code, and Varun Yerram for his help in setting up the implementation process. This research was supported by the Army Research Office under Grant Number W911NF-20-1-0080 and

partially funded by ONR Contract N00014-19-1-2620. Lastly, we appreciate the reviewing team’s insightful comments.

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A Supplementary Analysis

A.1 Comparison With Diverse Methods

Tables 8 and 9 show results of other baseline methods on WikiTQ and TabFact datasets respectively. Our method, H-STAR, outperformed all other models by substantial margins.

Model	Method	Accuracy
Pre-trained/fine-tuned	TaPas	48.8
	GraPPa	52.7
	LEVER	62.9
	ITR	63.4
	SYNTQA(GPT)*	70.4
Codex ²	GPT-3 CoT	45.7
	TableCoT	48.8
	DATER	65.9
	BINDER	61.9
	ReAcTable	65.8
GPT-3.5-Turbo	ReAcTable	52.5
	TableCoT	52.4
	StructGPT	52.2
	ALTER	67.4
	SYNTQA(GPT)*	65.2
GPT-3.5-Turbo	H-STAR	69.6

Table 8: Comparison of H-STAR with additional methods on WikiTQ dataset. * SYNTQA (GPT) uses GPT-3.5-Turbo to choose between SQL/text reasoning and uses: 1) fine-tuned models for reasoning; 2) GPT-3.5-Turbo for reasoning.

Model	Method	Accuracy
Pre-trained/fine-tuned	Table-BERT	68.1
	LogicFactChecker	74.3
	SAT	75.5
	TaPas	83.9
	TAPEX	85.9
Codex	SaMoE	86.7
	PASTA	90.8
	TableCoT	72.6
	DATER	85.6
	BINDER	85.1
GPT-3.5-Turbo	ReAcTable	83.1
	ReAcTable	73.1
	TableCoT	73.1
GPT-3.5-Turbo	ALTER	84.3
	H-STAR	85.0

Table 9: Comparison of H-STAR with additional methods on TabFact dataset.

²OpenAI Codex model is not available publically anymore.

A.2 FeTaQA

Represented in Table 10 are the results for the Fe-TaQA dataset using the ROUGE scores (Lin, 2004). We observe an incremental improvement in the scores when compared to other methods on the GPT-3.5-Turbo. *The ROUGE scores focus on lexical similarities while ignoring the semantic similarity between predicted and gold outputs.* These metrics are known to be insensitive to capturing improvements when using in-context learning since the model does not learn the expected style of the long-form text just from an instruction or a few examples.

Prompting	ROUGE-1	ROUGE-2	ROUGE-L
PaLM-2*			
DATER	0.63	0.41	0.53
Chain-of-Table	0.66	0.44	0.56
GPT-3.5-Turbo			
Table-CoT	0.62	0.39	0.51
TabSQLify	0.58	0.35	0.48
H-STAR	0.62	0.39	0.52

Table 10: Performance on FeTaQA dataset. PaLM-2* refers to the Google proprietary PaLM-2 model.

Figure 7 illustrates an example where the generated output, despite being correct in answering the question, is penalized by the ROUGE metric. This highlights the limitations of the metric in evaluating the correctness of the generated responses.

Question: When did Art Howe coach the Yale Bulldogs, and what was his overall record with the team?		
Gold Answer: Howe led the Yale football team as head coach for one year (1912) and compiled a 7-1-1 record.		
Prediction: Art Howe coached the Yale Bulldogs in 1912, and his overall record with the team was 7-1-1.		
ROUGE 1: 0.51	ROUGE 2: 0.21	ROUGE L: 0.41

Figure 7: An example of FeTaQA representing low ROUGE scores for correct answers.

Human Evaluation We further evaluate the quality of our generations using human evaluation. We refer to (Nan et al., 2022) and evaluate our generations on four factors: **1) Fluency** based on the nature and grammar of the output; **2) Correctness** measuring the degree of correctness of the prediction; **3) Adequacy** to measure if all the necessary information is contained in the output; **4) Faihtfulness** to check whether the generation is grounded to the final extracted table used for reasoning. We

ask five internal human annotators to assign a score of 1-5 for each criterion and report the percentage of samples having values of 4 or 5. Table 11 shows the results by five annotators for our method and compares it with other prior methods. The performance pattern of H-STAR is similar to human performance with comparable fluency and faithfulness while matching the trend of having higher adequacy over correctness. While we marginally outperform other methods, there is still scope for improvement.

Method	Fluent	Correct	Adequate	Faithful
T5-large	94.6	54.8	50.4	50.4
Human	95	92.4	95.6	95.6
TableCoT	96	82	75	87
TabSQLify	97	88	84	93
H-STAR	96.6	87.6	89.6	94

Table 11: Human evaluation results on FeTaQA dataset.

Qualitative Analysis In this section, we perform a qualitative analysis on 100 samples of FeTaQA with TabSQLify (Nahid and Rafiei, 2024). The study aims to compare the generations of H-STAR with TabSQLify by evaluating the answer quality. The answers are evaluated based on their fluency and adequacy when compared with the gold answers. Table 12 shows that H-STAR has better quality generations in 26% samples, as opposed to only 18% for TabSQLify. ‘Both’ indicates samples where both the algorithms perform on par. This can be attributed to the use of the same LLM. Many failures for TabSQLify are derived from an insufficient table, which further highlights the limitations of using a single-view approach for table extraction.

Method	% of samples
Both	56%
TabSQLify	18%
H-STAR	26%

Table 12: Comparison of H-STAR with TabSQLify on 100 samples.

Figure 8 showcases such an example where TabSQLify returns ‘*information not provided*’ because of incorrect of an extracted table. It can be noted that H-STAR generates an answer comparable with the ground truth for the same. Figure 9 visually depicts the outputs from both methods. It illustrates the evaluation process undertaken to compare the quality of the outputs.

Question: Who won the 1888 Belgian general election?	
H-STAR: The Catholic Party won the 1888 Belgian general election. ✓	TabSQLify: the answer is not provided in the given information. ✗
Answer: The result was a victory for the Catholic Party, which won 98 of the 138 seats in the Chamber of Representatives.	

Figure 8: An example of FeTaQA dataset where TabSQLify fails as a result of insufficient table evidence.

Question: Where and when did the 1963 Giro d’Italia start and finish?	
H-STAR: The 1963 Giro d’Italia started on 19th May in Naples and finished on 9th June in Milan. ✓	TabSQLify: the 1963 giro d’italia started in naples and finished in potenza on may 19th. ✗
Answer: The Giro started in Naples, on 19 May, with a 182 km (113.1 mi) stage and concluded in Milan, on 9 June, with a 136 km (84.5 mi).	

Question: What did Deschanel play in 1983?	
H-STAR: In 1983, Mary Jo Deschanel played the role of Annie Glenn. ✗	TabSQLify: in 1983, deschanel played the role of annie glenn in the movie “the right stuff”. ✓
Answer: In 1983, Deschanel played Annie Glenn in the movie, The Right Stuff.	

Figure 9: Comparison of the outputs with TabSQLify.

A.3 Analysis: Generated Samples

In Table 13, we study H-STAR by considering the total number of samples generated by the LLMs. BINDER and DATER utilize self-consistency techniques to refine their results, while the Chain-of-Table approach adopts a more iterative sample creation process. Specifically, BINDER generates 50 Neural-SQL samples, implementing self-consistency, while DATER employs self-consistency at each step, resulting in 100 samples. In contrast, the Chain-of-Table method opts for a more resource-efficient strategy, producing 25 samples across three steps: ‘Dynamic Plan’, ‘Generate Args’, and ‘Query’. TabSQLify generates the fewest samples, with one generation each for the table decomposition and query steps. Using single outputs can result in a decrease in accuracy when the model fails to return an answer. Thus, H-STAR incorporates self-consistency measures by generating two outputs at each stage to ensure output validity. Each step, except Query, involves two generations for both SQL and Text, i.e., a total of four steps for column and row retrieval. These additional steps serve as a precaution against abnormal LLM generations. Overall, H-STAR is efficient and only uses 6-10 sample generations.

Method	# samples / step	Total # samples
BINDER	Neural SQL: 50	50
DATER	Decompose Table: 40 Generate Cloze: 20 Generate SQL: 20 Query: 20	100
Chain-of-Table	Dynamic Plan ≤ 5 Generate Args ≤ 19 Query: 1	≤ 25
TabSQLify	Table Decompose: 1 Query: 1	2
H-STAR	Column Extraction: 2-4 Row Extraction: 2-4 Query: 2	6-10

Table 13: Number of generated samples for different methods.

A.4 Benefit of using Transposed Table

Table 14 compares H-STAR’s performance using transposed versus original tables for text-based column verification. On TabFact, H-STAR achieves 86.51% accuracy with transposed tables, versus 85.22% with original tables. On WikiTQ, accuracy is 68.62% with transposed tables, compared to 66.59% with original tables.

Method	TabFact	WikiTQ
H-STAR (with transposed table)	86.51	68.62
H-STAR (with original table)	85.22	66.59

Table 14: Comparison between H-STAR using a) transposed table and b) original table for text-based column extraction.

Analysis. Transposing tables leads to better performance than using the original table for column verification. The transposed table approach is more effective for complex datasets like WikiTQ, which are harder to reason upon and contain longer tables.

B Input Table Format

The input table format changes depending on the type of reasoning used. Since H-STAR uses a hybrid approach, the input table format also varies depending on the type of reasoning used. Besides the question and the in-context examples, the table is accompanied by a list of columns and a table caption if available. Providing more context aids in better semantic understanding (Singha et al., 2023; Sui et al., 2024).

B.1 Symbolic Reasoning

We adopt the table prompt format from previous SQL-based methods Text-to-SQL (Rajkumar

et al., 2022; Cheng et al., 2022; Nahid and Rafiei, 2024). We include (1) the table schema containing CREATE TABLE followed by the schema, (2) the table header and all the rows separated by tabs, and (3) the list of columns along with the corresponding query. If the prompt exceeds the context limit, we truncate the table rows to fit within the limit. Example of the input table:

```

CREATE TABLE 2012-13 Exeter City F.C.
season(
    row_id int,
    name text,
    league int,
    total int)
/
All rows of the table:
SELECT * FROM w;
row_id    name    league    total
1    danny coles    3    3
4    john o'flynn   11   12
8    jamie cureton  20   20
/
columns:  ['name', 'league', 'total']

```

B.2 Textual Reasoning

We convert the tables into linear, sequential text. Continuing with the format of previous textual reasoning methods (Ye et al., 2023; Chen, 2023; Wang et al., 2023), we adopt the PIPE encoding i.e. plain text separated by ‘|’. Furthermore, we append the table with the caption and the list of columns similar to the format in Section B.1. Example of the input table:

```

table caption: 2012-13 Exeter City
F.C. season
/
col : name | league | total
row 1: danny coles | 3 | 3
row 4: john o'flynn | 11 | 12
row 8: jamie cureton | 20 | 20
*/
columns: ['name', 'league', 'total']

```

C Comparison with ReAct

While our method appears to be similar to ReAct in terms of combining textual reasoning and tool-based methods, there are significant differences between H-STAR and ReAct:

1. Integration of Symbolic and Semantic Reasoning. H-STAR combines SQL-based and text-based reasoning, while ReAct merges textual reasoning with actions. ReAct uses tools mainly for actions, not reasoning. H-STAR applies SQL for quantitative tasks and text for lexical queries, whereas ReAct focuses more on textual reasoning.

2. Fixed Multi-Stage Approach. ReAct prompts LLMs to alternate between reasoning and actions, allowing interaction with external sources. H-STAR, on the other hand, splits tabular reasoning into two stages: 1) Table Extraction, and 2) Adaptive Reasoning, blending SQL and text reasoning. This hybrid approach sets H-STAR apart from ReAct’s focus on textual reasoning and interaction with the environment.

3. Table Extraction Approach. H-STAR uses a "multi-view" approach for table extraction, identifying relevant columns from both original and transposed tables before selecting rows, reducing irrelevant data, and improving focus. In contrast, ReAct does not employ any extraction method.

4. Adaptive Reasoning Strategy. H-STAR uses SQL to support semantic reasoning for quantitative tasks while relying solely on semantic reasoning for lexical queries. In contrast, ReAct interleaves reasoning and actions without adapting to task type. H-STAR’s hybrid approach, combining SQL logic and text understanding, excels in handling diverse tasks, outperforming ReAct on table reasoning tasks.

D Implementation Details

We provide the implementation details including the hyperparameters and prompt details for each of the individual steps. H-STAR operates in two key stages: 1) Table Extraction and 2) Adaptive Reasoning. The Table Extraction phase includes column extraction (SQL-based: `colsql` and text-based: `coltext`) and row extraction (SQL-based: `rowsql` and text-based: `rowtext`). The Adaptive Reasoning phase consists of SQL-based (`fsql`) and text-based (`ftext`) reasoning components.

D.1 Hyperparameters

Table 15 provides the details of PaLM-2 hyperparameters used for the WikiTQ and TabFact datasets. Table 16 showcases the hyperparameter setting for GPT-3.5-Turbo. The hyperparameters ‘samples’ indicate the number of outputs taken for

each step of the pipeline whereas the ‘examples’ indicate the number of few-shot demonstrations for each step.

Function	temperature	top_p	output_tokens	samples	examples
WikiTQ					
<code>col_{sql}</code>	0.4	1.0	512	2	3
<code>col_{text}</code>	0.7	1.0	512	2	3
<code>row_{sql}</code>	0.4	1.0	512	2	3
<code>row_{text}</code>	0.7	1.0	512	2	2
<code>f_{sql}</code>	0.1	1.0	512	1	3
<code>f_{text}</code>	0.0	1.0	512	1	4
TabFact					
<code>col_{sql}</code>	0.4	1.0	512	2	4
<code>col_{text}</code>	0.7	1.0	512	2	3
<code>row_{sql}</code>	0.4	1.0	512	2	4
<code>row_{text}</code>	0.7	1.0	512	2	3
<code>f_{sql}</code>	0.1	1.0	512	1	3
<code>f_{text}</code>	0.0	1.0	512	1	5

Table 15: Hyperparameter settings for PaLM-2.

Function	temperature	top_p	output_tokens	samples	examples
WikiTQ					
<code>col_{sql}</code>	0.3	1.0	512	2	3
<code>col_{text}</code>	0.4	1.0	512	2	2
<code>row_{sql}</code>	0.3	1.0	512	2	3
<code>row_{text}</code>	0.4	1.0	512	2	3
<code>f_{sql}</code>	0.1	1.0	512	1	4
<code>f_{text}</code>	0.0	1.0	512	1	4
TabFact					
<code>col_{sql}</code>	0.2	1.0	512	2	4
<code>col_{text}</code>	0.4	1.0	512	2	3
<code>row_{sql}</code>	0.4	1.0	512	2	4
<code>row_{text}</code>	0.5	1.0	512	2	3
<code>f_{sql}</code>	0.1	1.0	512	1	4
<code>f_{text}</code>	0.0	1.0	512	1	5

Table 16: Hyperparameter settings for GPT-3.5-Turbo.

D.2 Input Prompts

Figures 10, 11, 12, 13, 14 and 15 illustrate the input prompts containing sample in-context learning examples for the steps `colsql`, `coltext`, `rowsql`, `rowtext`, `fsql`, and `ftext` respectively.

E Error Analysis: Case Study

Figures 16 and 17 showcase how semantic and symbolic approaches can individually fail for the column and row extraction steps. Figures 19, 18, 20 and 21 illustrate error cases for each individual step within H-STAR.

SQL-based Column Extraction

You are given the table schema, and the table along with the corresponding statement. Write a simple SQLite program for selecting the required columns only, to help answer the question correctly. The SQLite program need not directly answer the question. Assume you always have enough information when executing the SQLite. Fuzzy match data if unsure.

1. Plan:

- Identify critical values and ranges from the table related to the statement.
- Make use of your domain knowledge to find the correct approach to solve the question.
- Always select the column with special aggregate values like 'total'.

2. Retrieval:

- Generate a simple SQL program extracting the relevant columns
- SQL: SELECT <COLUMNS> FROM w;
- Evidence: f_col([column names])

Response Format:

Begin your response with 'Output' and include:

- Plan: Write the plan for column extraction along with a reasoning chain

- Retrieval: Write a simple SQL query

Evidence: f_col([column names])

Before you return the answer, review your outputs and make sure you have followed all the given instructions.
Make sure to only select columns.

```

```
<input>
CREATE TABLE Plock Governorate(
 row_id int,
 language text,
 number int,
 percentage (%) text,
 males int,
 females int)
/*
All rows of the table:
SELECT * FROM w;
row_id language number percentage (%) males females
0 polish 447685 80.86 216794 230891
1 yiddish 51215 9.25 24538 26677
2 german 35931 6.49 17409 18522
7 total 553633 100 275652 277981
*/
columns: ['row_id', 'language', 'number', 'percentage (%)', 'males', 'females']
Q: how many male and female german speakers are there?
```

<output>

1. Plan:

- We need to count the number of male and female speakers
- The column 'language' with the aggregate value 'total' must be included
- We then select the 'males', 'females', 'language'

2. Retrieval:

- # SQL format: SELECT <column names> FROM w;
- SQL: SELECT `language`, `males`, `females` FROM w;
- # Only output the column names from the column list
- Evidence: f\_col([language, males, females])

```

Figure 10: Prompt for SQL-based column extraction (col_{sql}).

Text-based Column Extraction

You need to select all the relevant columns from the table and obtain a relevant sub-table to the question. The sub-table should then be used to answer the question. Please ensure that your final answer matches your reasoning. Your task is to perform the following actions

1. Plan:
Identify critical values and ranges from the table related to the question.
2. Retrieval:
Identify all table columns containing question-relevant information. Explain the relevance of each selected piece of evidence.

Response Format: Strictly follow the given format only.

Begin your response with 'Output' and include:

- Plan: Write the plan for column extraction along with a reasoning chain
- Retrieval: Based on the plan, identify the columns followed by a reasoning chain

Evidence: f_col([column names])

...

<input>

/*

row: row 1 | row 2 | row 3 | row 4 | row 5

pick: 1 | 2 | 3 | 4 | 5

player: jay washington | alex cabagnot | dennis miranda | ato ular | kameron vales

country of origin: united states | united states | philippines | philippines | united states

pba team: air21 express | sta lucia realtors | coca-cola tigers | blackwater bossing | converge fiberxers

college: eckerd | hawaii - hilo | feu | mpbl | ateneo

*/

Q: Which college has most players belonging to asian countries?

<output>

1. Plan:

a. Extract data from the 'country of origin' column to create a new column

b. The table columns 'college', and 'player' contain the question-specific information

2. Retrieval:

Explanation: Look at the 'college', and 'player' columns to identify unique colleges and player names. For each row, extract the ethnicity from the 'country of origin' column to create a new column to identify Asian countries.

Evidence: f_col([player, country of origin, college])

...

Figure 11: Prompt for Column-based column verification (`col_text`).

SQL-based Row Extraction

You are given the table schema, and the table along with the corresponding question. Your task is only to write an SQLite program to create a subtable to help answer the question. You must not answer the question but you must only find the relevant suitable. Write a simple but correct SQLite program.

1. Decompose:

Find all the subtasks from the main question.

2. Retrieval:

Generate an SQLite program for each subtask and then combine using only an 'OR' clause.

Response Format:

Begin your response with 'Output: ' and include all the following components:

- Decompose: Divide the question into smaller manageable sub-tasks; one task for each condition
- Retrieval: A basic SQLite program for each condition followed by a combined SQLite

NOTE

- Use the column names as it is as given in the column list.

- Use 'OR' to combine conditions.

- The SQLite program must be only of the format: SELECT <column names> FROM w WHERE <conditions>;

Be very careful, think, and ensure that all the above instructions are followed, and only then return your response.
```

```
<input>
CREATE TABLE British_Records_in_Athletics(
 row_id int,
 event text,
 place text);

/*
3 example rows:
SELECT * FROM British_Records_in_Athletics LIMIT 3;
row_id event place
0 5 km søfteland , norway
1 5 miles york , united kingdom
2 10 km burrator , united kingdom
*/
columns: ['row_id', 'event', 'place']
Q: how many events took place within the united kingdom?
<output>
1. Decompose:
- Part 1: Find all instances of events that took place within the united kingdom
Do not use COUNT() clause
The SQLite program must be only of the format: SELECT <column names> FROM w WHERE <conditions>;
 SELECT event, place FROM w WHERE place LIKE '%united kingdom%';
2. Retrieval:
SQL: SELECT event, place FROM w WHERE place LIKE '%united kingdom%';
```

```

Figure 12: Prompt for SQL-based row selection (row_{sql}).

Text-based Row Extraction

You are provided an initial response containing a response, a table, and a question. Your task is to give feedback about the initial response and find the omitted rows if any.

1. Assessment:
 - Assess the question
2. Feedback: Based on the nature of the question, provide the feedback.
 - a. Calculation/comparison-based question:
 - Check if the comparison is limited to some rows or if it consists of the entire table
 - b. Order/temporal-based question:
 - Check if the response includes the row containing the mentioned entity
 - Check if the response contains relative rows mentioned in the question
 - c. Entity-specific question:
 - Check if any row about the entity in the question are not included

Add rows if not present in the response.

Rows: f_row([rows])

Response Format:

Begin your response with 'Output' and must always include the following:

- Assessment: Assess the question and the response
- Feedback: Provide a step-by step feedback on the suggested answers

Rows: f_row([rows])

Follow all instructions given. Check if all instructions have been followed before returning the answer.

```
...
<input>
/*
col : rank | athlete
row 0 : 1 | Manjeet Kaur
row 1 : 2 | Olga Tereshkova
row 2 : 3 | Pinki Pramanik
row 3 : 4 | Tang Xiaoyin
row 4 : 5 | Marina Maslyonko
*/
Q: tell me who finished immediately after manjeet kaur
Initial Response: ['row 1']
<output>
1. Assessment:
- We are asked to find the athlete after manjeet kaur.
- Thus, we need to return the row for manjeet kaur and the row after it.
2. Feedback:
- Is the row for Manjeet Kaur included in the initial response? A: No; add(row 0)
- What is the row after Manjeet Kaur (row 0)? A: row 1; add(row 1)
- Is the row after Manjeet Kaur included in the initial response? A: Yes
Rows: f_row([row 0, row 1])
...
```

Figure 13: Prompt for text-based row verification (row_{text}).

SQL-based Reasoning

You must carefully understand the table and the corresponding question. Your task is to determine whether you need an SQLite program to solve the question. The final SQLite program must be simple and must be only a single program.

Always remember, that most questions do not need an SQLite program, and you must simply return 'None'.

1. Nature of the Question:

Evaluate the nature of the question. For tasks involving computation, counting, or if the question involves column selection for extensive tables, the solution is again 'SQL'. Make sure to use the SQLite program for mathematical questions.

2. Final Output:

A. Based on your analysis, if the solution is 'SQL', then you must write an SQLite program to extract a subtable to answer the question. The SQLite does not need to directly answer the question. Generate an SQLite that is less complex but ensure that it is correct. Try to use fuzzy-match for values if you are not sure about the values. Generate a step-by-step SQLite program to answer the question.

B. If the solution is not SQL, then simply return 'None'

Response Format:

Begin your response with 'Output: ' and always include the following:

- Nature of the Question: Evaluation based on the nature of the question.
- Final Output: 'None' if SQL is not required otherwise the SQLite program is the solution.

Check if all instructions have been followed before returning the answer.

```
<input>
CREATE TABLE 2008 women 's british open(
    row_id int,
    player text,
    player country text)
/*
3 example rows:
SELECT * FROM w LIMIT 3;
row_id      player      player_country
0          juli inkster united states
1          momoko ueda   japan
2          laura diaz   united states
*/
columns: ['row_id', 'player', 'player country']
statement: count the number of players from united states and japan
<output>
1. Nature of the Question:
- This question involves counting the number of players from a specific countries.
- Counting data points within a table is a task suited for SQL.
2. Final Output: Since the task is SQL,
- Step 1: Group players by country and count the occurrences
    SELECT `player country` , COUNT(*) AS total_players FROM w GROUP BY `player country`;
SQL: SELECT `player country` , COUNT(*) AS total_players_per_country FROM w GROUP BY `player country`;

```

```

Figure 14: Prompt for SQL-based reasoning ( $f_{\text{sql}}$ ).

## Text-based Reasoning

You are an expert on table data. You must use the table data and the additional evidence to answer the given question.

- Divide the main statement into sub-tasks and answer each sub-task
- Based on the answers, check whether the statement is supported by the table

**\*\*NOTE\*\***

Please be extremely careful, pause, make sure all instructions have been followed, and only then output the answer

Response Format:

Begin your response with 'Output: ' and always include the following:

- Decompose: Divide the main question into sub-tasks and answer each sub-task
- Final Answer: Strictly output as a short phrase starting with `therefore, the answer is: "AnswerName1", "AnswerName2"...` form, no other form

- Read the question carefully, understand, and return what the question asks.
- Be careful, make sure you have followed all instructions, and only then return the output.

```
<input>
/*
col : rank | cyclist | team
row 0 : alejandro valverde (esp) | caisse d'epargne
row 1 : alexandr kolobnev (rus) | team csc saxo bank
row 2 : davide rebellin (ita) | gerolsteiner
row 3 : paolo bettini (ita) | quick step
row 4 : franco pellizotti (ita) | liquigas
row 5 : denis menchov (rus) | rabobank
row 6 : samuel sánchez (esp) | euskaltel-euskadi
row 7 : stéphane goubert (fra) | ag2r-la mondiale
row 8 : haimar Zubeldia (esp) | euskaltel-euskadi
row 9 : david moncoutié (fra) | cofidis
*/
columns: ['rank', 'cyclist', 'team']
Q: which country had the most cyclists finish within the top 10?
<output>
```

Here is an additional evidence to help the answering process.

Additional Evidence:

```
/*
col : country | total_cyclists_per_country
row 0 : ita | 3
*/
```

Using the table and the additional evidence to answer the question

1. Decompose:
  - #1: Number of cyclists from Italy in the top 10 = 3
2. Final Answer: Therefore, the answer is: "Italy"

...

Figure 15: Prompt for text-based reasoning ( $f_{text}$ ).

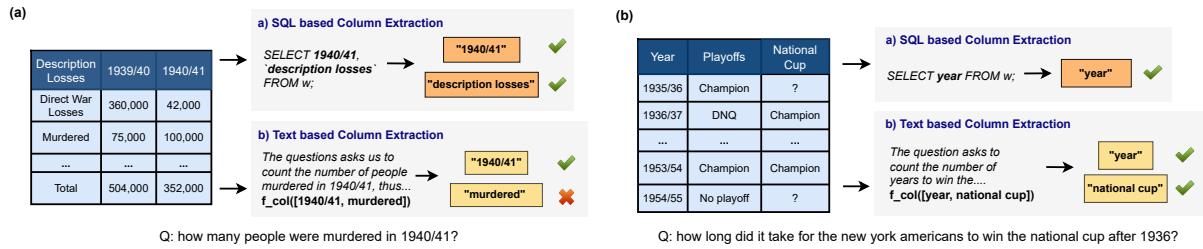


Figure 16: Comparison of SQL-based and text-based column extraction methods for answering table queries: (a) SQL-based selection accurately identifies the columns ("1940/41", "description losses"), while text-based selection mistakenly includes "murdered" as a table column. (b) The text-based method selects both required columns ("year" and "national cup"), while the SQL-based approach overlooks "national cup" as a requirement.

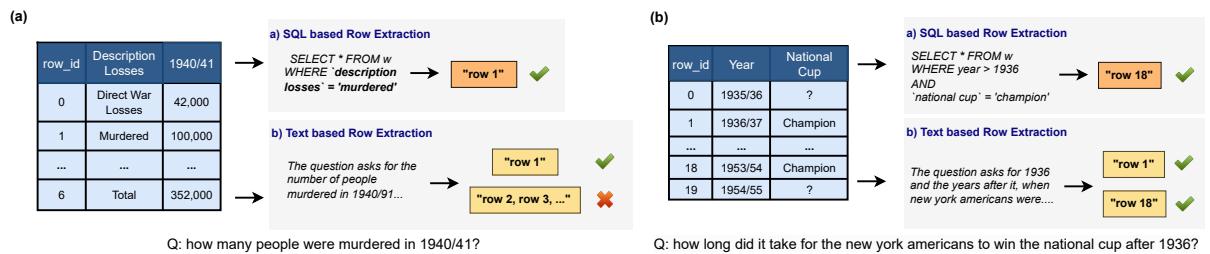


Figure 17: Comparison of SQL-based and text-based row extraction methods for answering table queries. (a) SQL-based selection accurately selects the necessary rows ("Murdered"), while text-based selection incorrectly includes additional rows; (b) Text-based method correctly selects relevant rows ("1953/54", "1936/37"), while SQL-based selection misinterprets the query, including only the row for the year "1953/54".

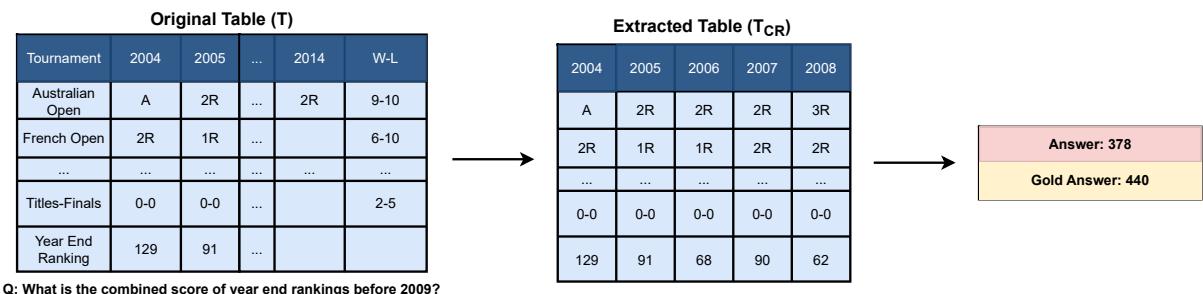
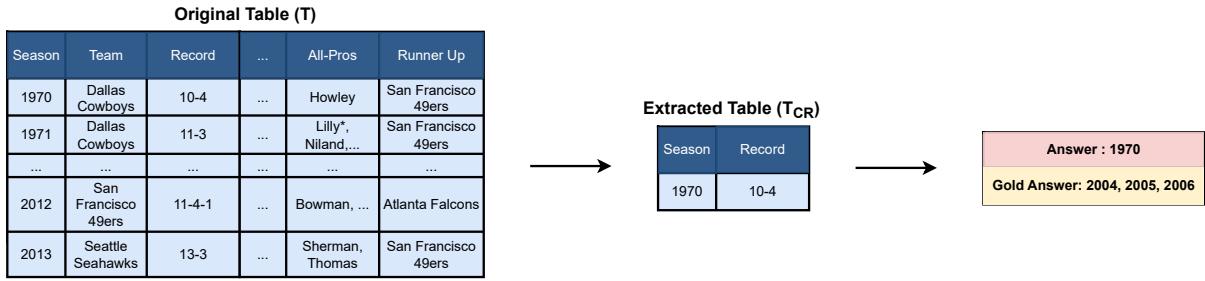
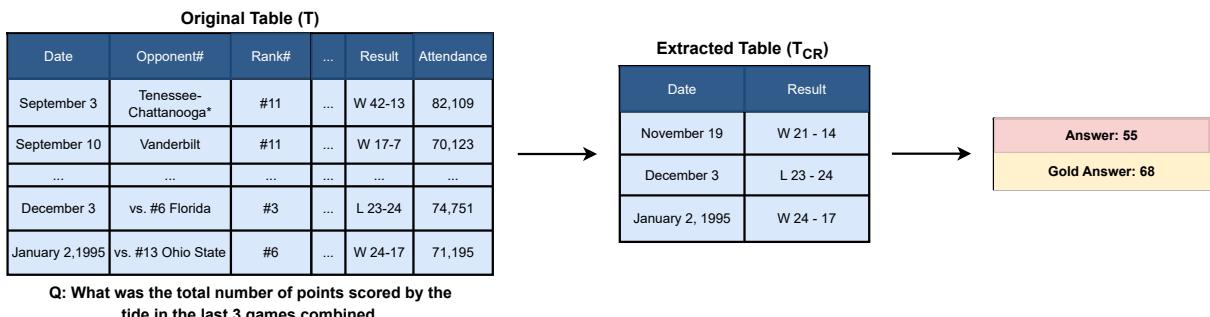


Figure 18: **Case Study: ‘Missing Columns’.** An illustration of the error ‘Missing Columns’. In the above example, the extracted table does not contain the column ‘Tournament’ that contains the ‘Year End Ranking’. The omission of the ‘Tournament’ column affects the downstream steps in the pipeline leading to an insufficient row extraction and reasoning.



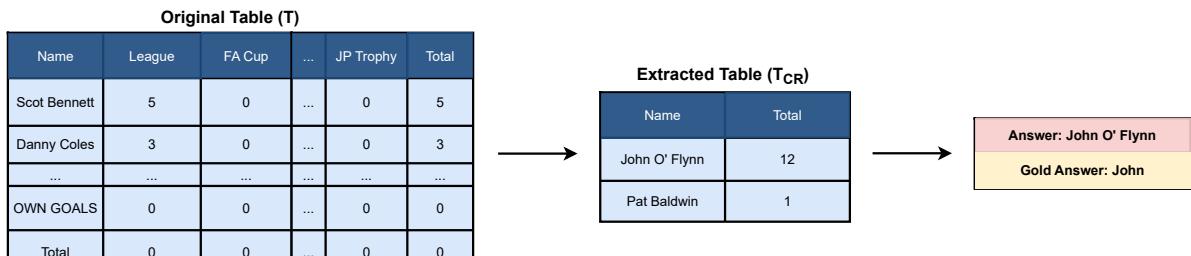
Q: In which three consecutive years was the record the same?

Figure 19: **Case Study: ‘Missing Rows’**. An illustration of the error ‘Missing Rows’. From the above example, it can be seen that while the extracted columns are correct, the row extraction is incorrect. Thus, as the extracted table lacks the necessary information, the final answer is incorrect.



Q: What was the total number of points scored by the tide in the last 3 games combined.

Figure 20: **Case Study: ‘Incorrect Reasoning’**. An illustration of the error ‘Incorrect Reasoning’. Despite the correct question-relevant table being extracted, the model misinterprets the question. It adds up the scores by the opposing team instead thus returning an incorrect answer.



Q: Does pat or john have the highest total?

Figure 21: **Case Study: ‘Incorrect Annotation’**. An illustration of the error ‘Incorrect Annotation’. In the example, the query-specific table is correctly extracted and the final reasoning leads to the correct answer. However, the prediction is penalized for not being an ‘exact match’.