Dec 5

TAAF: A Trace Abstraction and Analysis Framework Synergizing Knowledge Graphs and LLMs

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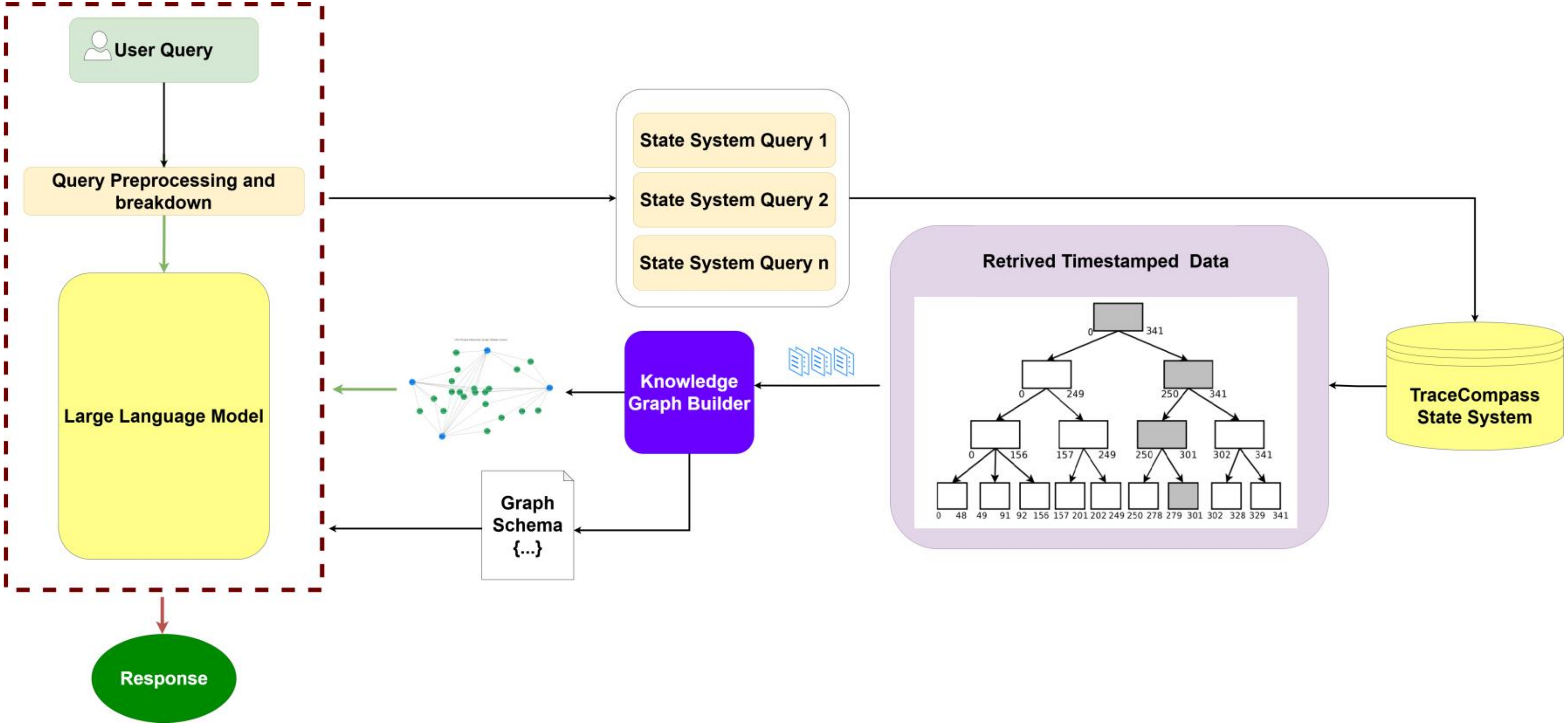
Methodology Architecture



User Query

Query Preprocessing and breakdown

Large Language Model

Response

State System Query 1

State System Query 2

State System Query n

Knowledge Graph Builder

Graph Schema {...}

Retrived Timestamped Data

TraceCompass State System

Research Questions

- **RQ1:** To what extent does the incorporation of a Knowledge Graph improve the accuracy of the TAAF when answering trace-related queries?
- **RQ2:** Does providing the LLM with the graph schema (node types and features) enhance the accuracy of its responses?
- **RQ3:** How does the accuracy and quality of TAAF responses vary across different LLM models (GPT-4 .1 nano (small), GPT-4o, o4-mini (Reasoning))?
- **RQ4:** What is the effect of time interval length on the performance of TAAF's answers?
- **RQ5:** How does TAAF's accuracy vary across different query types (e.g., multiple-choice, true/false, explanatory), and graph structures (single-hub vs. multi-hub)?
- **RQ6:** To what extent does the choice of temporal location (early vs. late in the trace) affect system performance and reasoning accuracy?
- **RQ7:** How does the temperature (sampling randomness) parameter affect the accuracy and consistency of LLM responses within TAAF?

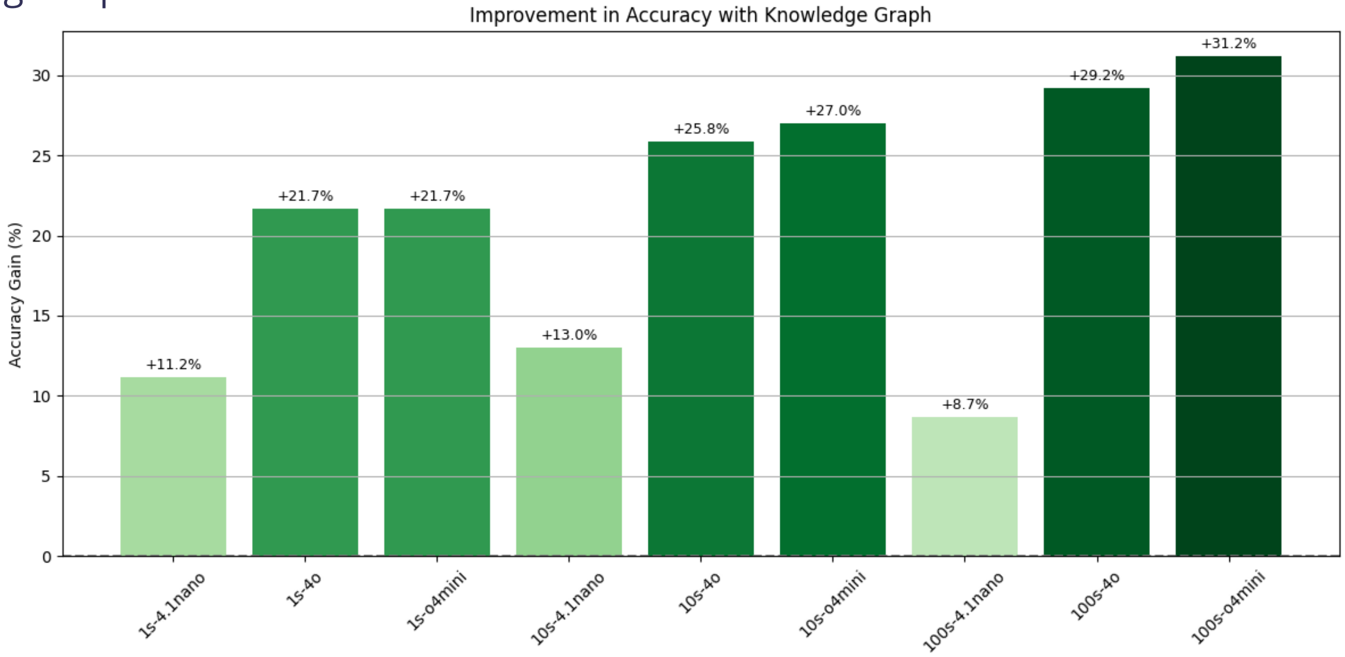
Approach

- We designed **100** unique questions.
- Each question is asked **3 times** under the raw-data condition, yielding **300** data points.
- Each question is also asked three times under the KG-powered condition, adding another **300** data points.
- Therefore, each experiment produces **600** data points in total.
- To date, we've run **10** experiments, resulting in **6,000** data points overall.
- The main Metric we use is **Accuracy:**

$$\frac{(Number\ of\ 0s \times 0)+(Number\ of\ 0.5s \times 0.5)+(Number\ of\ 1s \times 1)}{300} \times 100$$

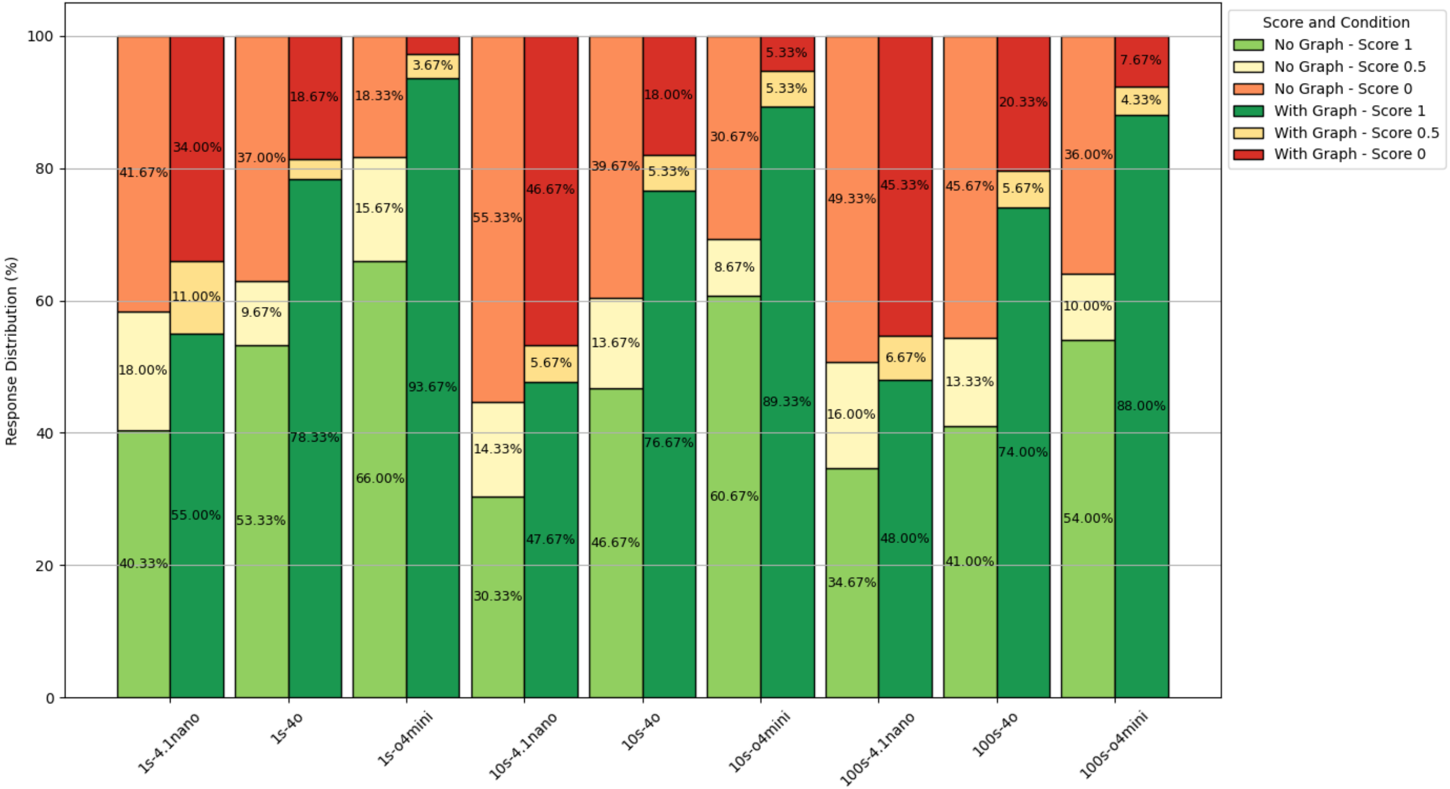
RQ1: To what extent does the incorporation of a Knowledge Graph improve the accuracy of the TAAF when answering trace-related queries?

Min Improvement: +8.7%
Max Improvement: + 31.2%
Average Improvement: +21.5%



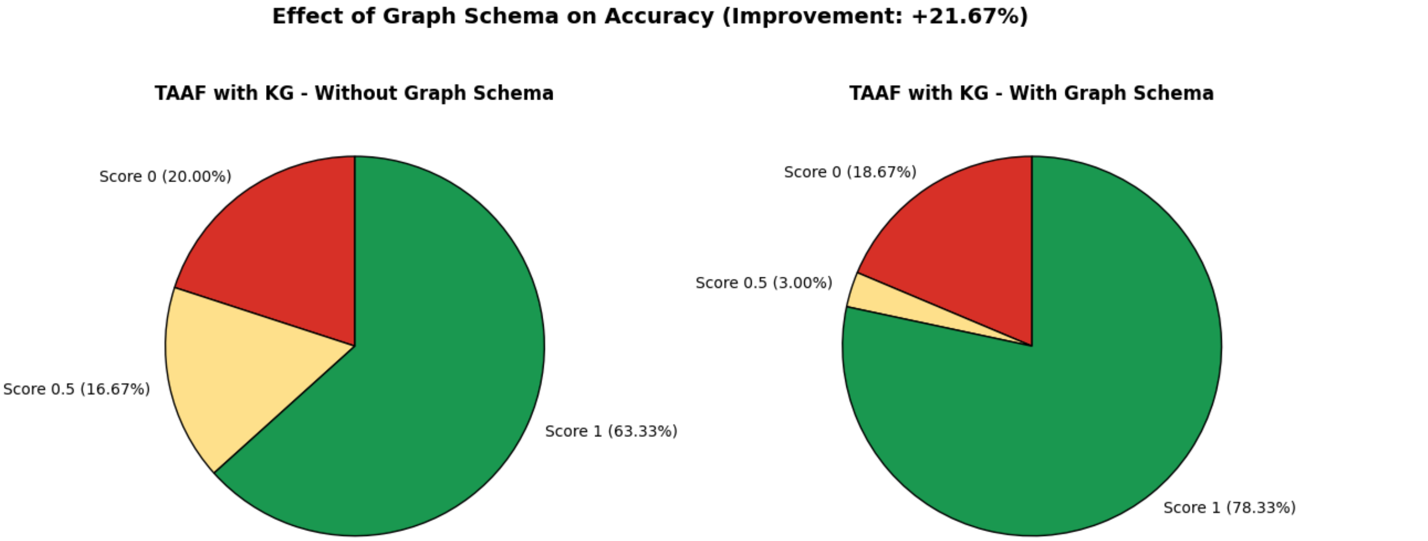
RQ1: To what extent does the incorporation of a Knowledge Graph improve the accuracy of the TAAF when answering trace-related queries?

TAAF Score Breakdown With and Without Knowledge Graph (0 at Top → 1 at Bottom)



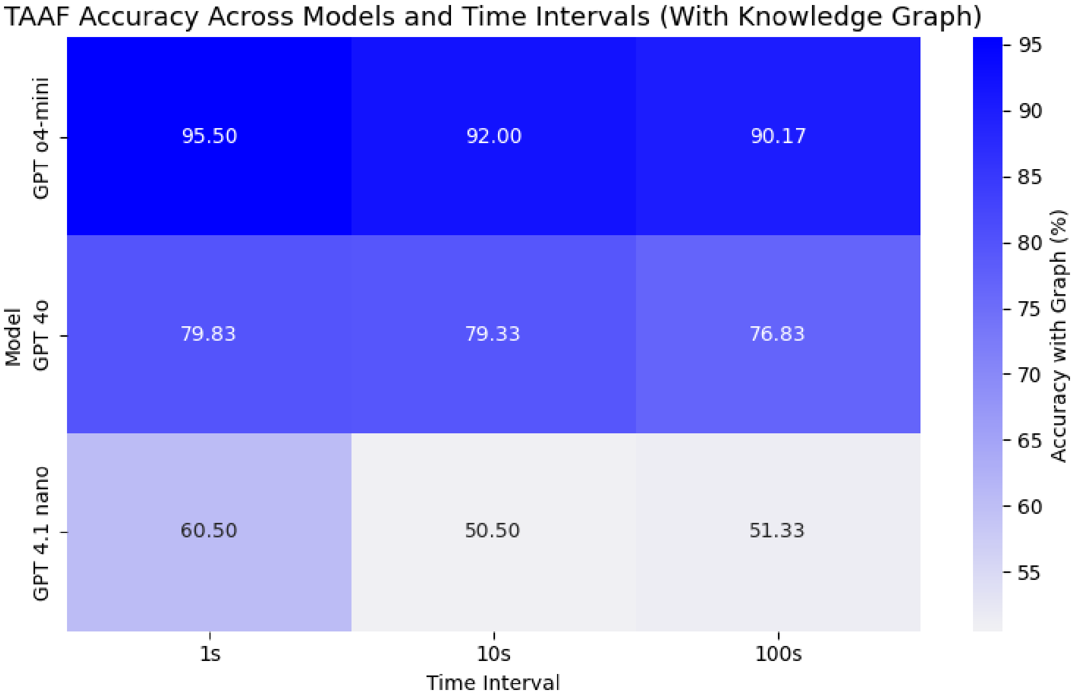
RQ2: Does providing the LLM with the graph schema (node types and features) enhance the accuracy of its responses?

Experiment was done on 1s of data from the mid timestamp with 4o model
+21.67% Improvement

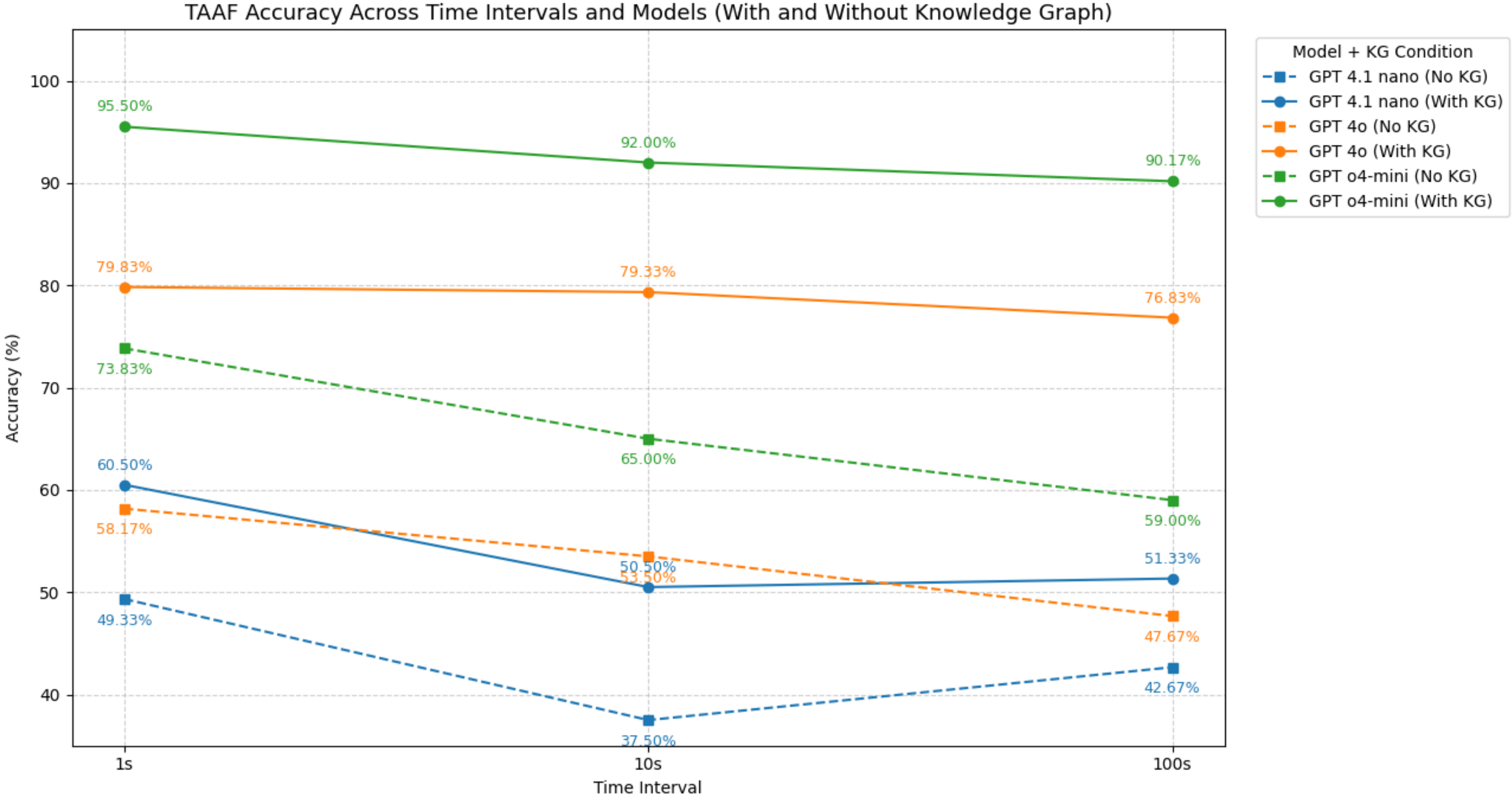


RQ3: How does the accuracy and quality of TAAF responses vary across different LLM models (GPT-4 .1 nano (small), GPT-4o, o4-mini (Reasoning))?

Min Accuracy: 50.50
Max Accuracy: 95.50



RQ4: What is the effect of time interval length on the performance of TAAF's answers?

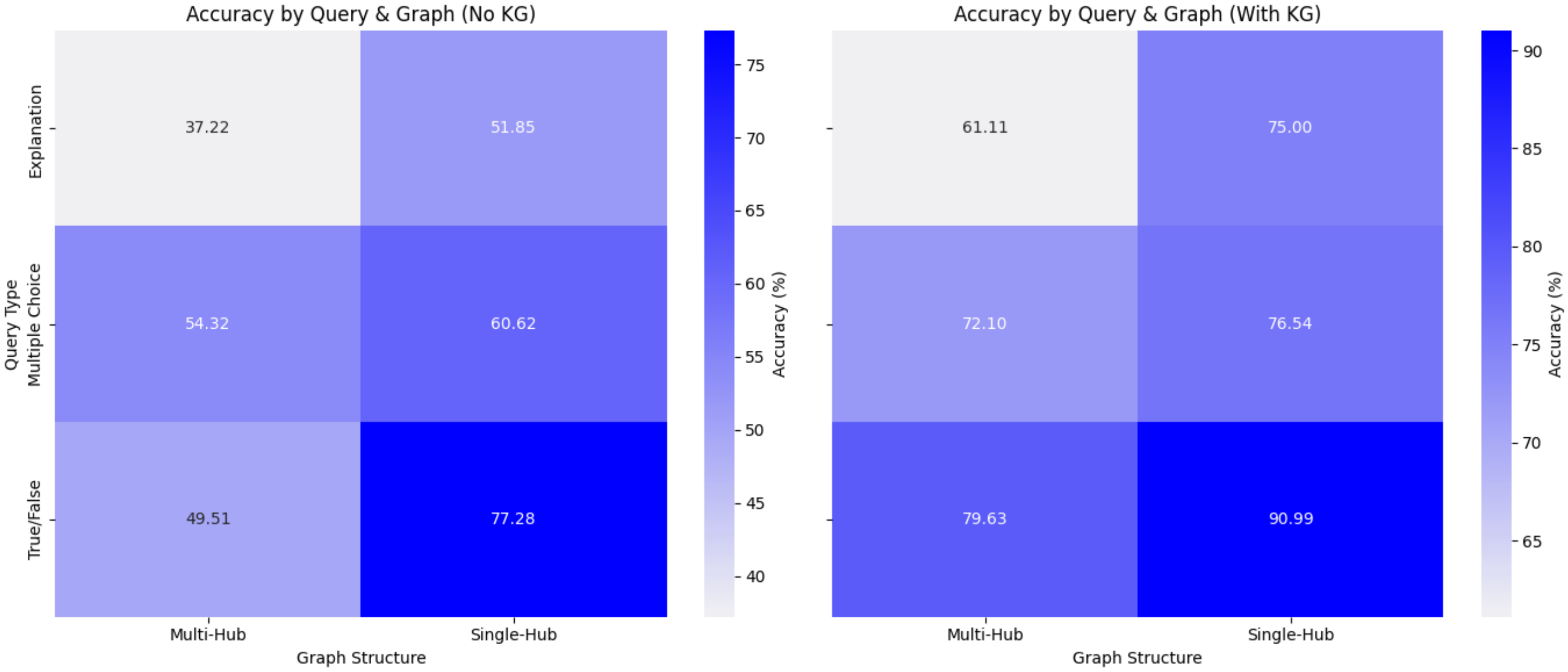


RQ5:How does TAAF's accuracy vary across different query types (e.g., multiple-choice, true/false, explanatory), and graph structures (single-hub vs. multi-hub)?

Note: Aggregated results across all models

TAAF Best Accuracy: True/False Single-Hub 90.99%

TAAF Worst Accuracy: Explanation Multi-Hub 61.11%



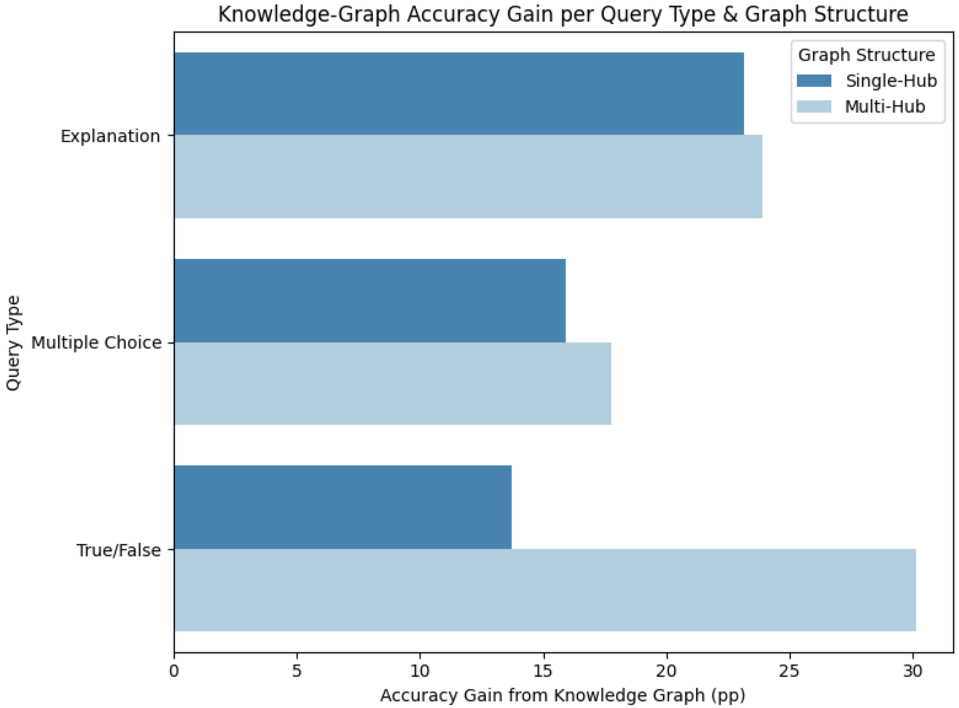
Accuracy by Query & Graph (No KG)

Accuracy by Query & Graph (With KG)

RQ5:How does TAAF's accuracy vary across different query types (e.g., multiple-choice, true/false, explanatory), and graph structures (single-hub vs. multi-hub)?

Note: Aggregated results across all models

TAAF Best Accuracy Gain: True/False Multi-Hub 30%



RQ5:How does TAAF's accuracy vary across different query types (e.g., multiple-choice, true/false, explanatory), and graph structures (single-hub vs. multi-hub)?

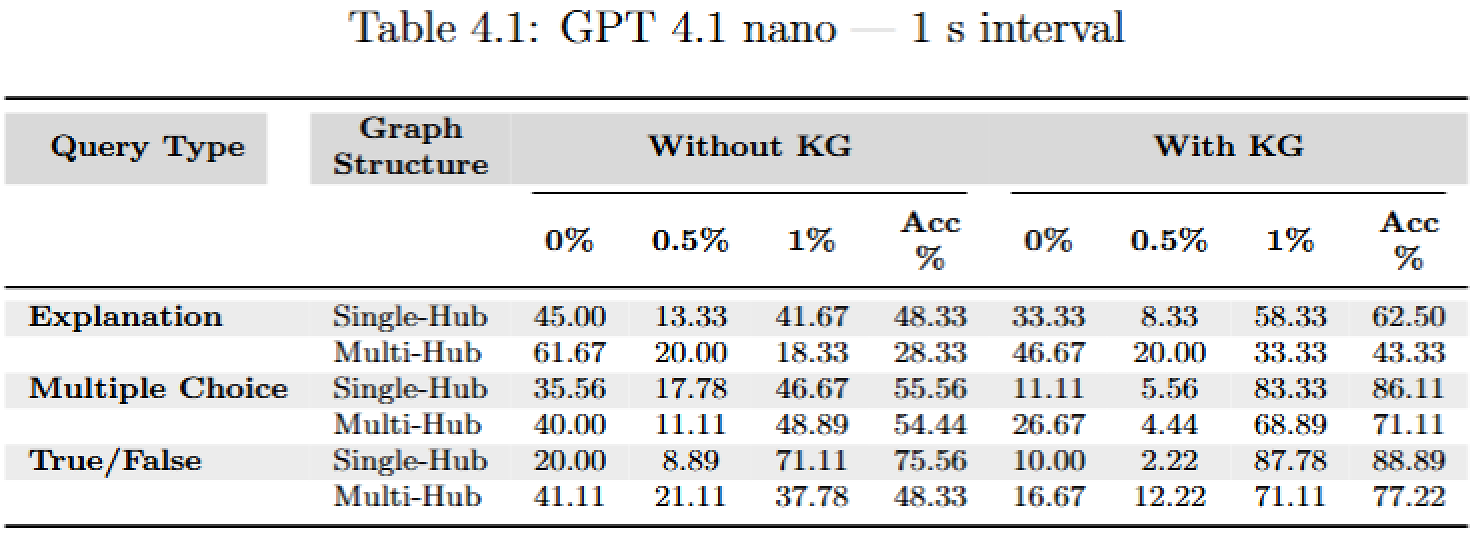
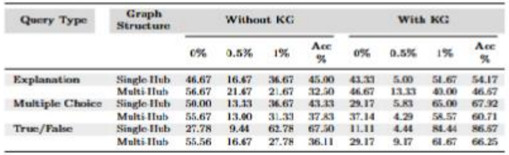


Table 4.1: GPT 4.1 nano — 1 s interval

Query Type	Graph Structure	Without KG				With KG			
		0%	0.5%	1%	Acc %	0%	0.5%	1%	Acc %
Explanation	Single-Hub	45.00	13.33	41.67	48.33	33.33	8.33	58.33	62.50
	Multi-Hub	61.67	20.00	18.33	28.33	46.67	20.00	33.33	43.33
Multiple Choice	Single-Hub	35.56	17.78	46.67	55.56	11.11	5.56	83.33	86.11
	Multi-Hub	40.00	11.11	48.89	54.44	26.67	4.44	68.89	71.11
True/False	Single-Hub	20.00	8.89	71.11	75.56	10.00	2.22	87.78	88.89
	Multi-Hub	41.11	21.11	37.78	48.33	16.67	12.22	71.11	77.22

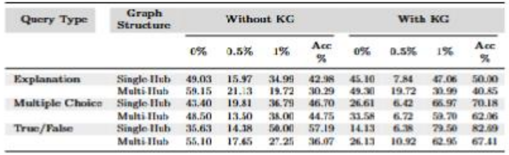
RQ5:How does TAAF's accuracy vary across different query types (e.g., multiple-choice, true/false, explanatory), and graph structures (single-hub vs. multi-hub)?

Table 4.2: GPT 4.1 nano — 10 s interval



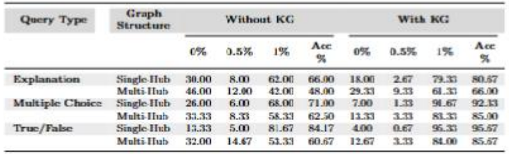
Query Type	Graph Structure	Without KG				With KG			
		0%	0.5%	1%	Acc %	0%	0.5%	1%	Acc %
Explanation	Single-Hub	46.67	16.67	36.67	45.00	43.33	5.00	51.67	54.17
	Multi-Hub	56.67	21.67	21.67	32.50	46.67	13.33	40.00	46.67
Multiple Choice	Single-Hub	50.00	13.33	36.67	43.33	29.17	5.83	65.00	67.92
	Multi-Hub	55.67	13.00	31.33	37.83	37.14	4.29	58.57	60.71
True/False	Single-Hub	27.78	9.44	62.78	67.50	11.11	4.44	84.44	86.67
	Multi-Hub	55.56	16.67	27.78	36.11	29.17	9.17	61.67	66.25

Table 4.3: GPT 4.1 nano — 100 s interval



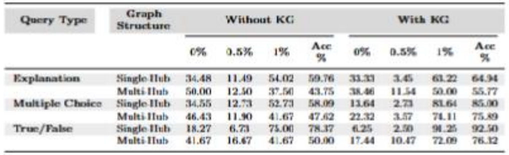
Query Type	Graph Structure	Without KG				With KG			
		0%	0.5%	1%	Acc %	0%	0.5%	1%	Acc %
Explanation	Single-Hub	49.03	15.97	34.99	42.98	45.10	7.84	47.06	50.00
	Multi-Hub	59.15	21.13	19.72	30.29	49.30	19.72	30.99	40.85
Multiple Choice	Single-Hub	43.40	19.81	36.79	46.70	26.61	6.42	66.97	70.18
	Multi-Hub	48.50	13.50	38.00	44.75	33.58	6.72	59.70	62.06
True/False	Single-Hub	35.63	14.38	50.00	57.19	14.13	6.38	79.50	82.69
	Multi-Hub	55.10	17.65	27.25	36.07	26.13	10.92	62.95	67.41

Table 4.4: GPT 4o — 1 s interval



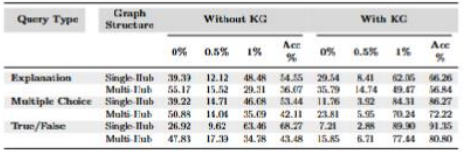
Query Type	Graph Structure	Without KG				With KG			
		0%	0.5%	1%	Acc %	0%	0.5%	1%	Acc %
Explanation	Single-Hub	30.00	8.00	62.00	66.00	18.00	2.67	79.33	80.67
	Multi-Hub	46.00	12.00	42.00	48.00	29.33	9.33	61.33	66.00
Multiple Choice	Single-Hub	26.00	6.00	68.00	71.00	7.00	1.33	91.67	92.33
	Multi-Hub	33.33	8.33	58.33	62.50	13.33	3.33	83.33	85.00
True/False	Single-Hub	13.33	5.00	81.67	84.17	4.00	0.67	95.33	95.67
	Multi-Hub	32.00	14.67	53.33	60.67	12.67	3.33	84.00	85.67

Table 4.5: GPT 4o — 10 s interval



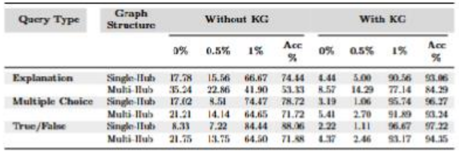
Query Type	Graph Structure	Without KG				With KG			
		0%	0.5%	1%	Acc %	0%	0.5%	1%	Acc %
Explanation	Single-Hub	34.48	11.49	54.02	59.76	33.33	3.45	63.22	64.94
	Multi-Hub	50.00	12.50	37.50	43.75	38.46	11.54	50.00	55.77
Multiple Choice	Single-Hub	34.55	12.73	52.73	58.09	13.64	2.73	83.64	85.00
	Multi-Hub	46.43	11.90	41.67	47.62	22.32	3.57	74.11	75.89
True/False	Single-Hub	18.27	6.73	75.00	78.37	6.25	2.50	91.25	92.50
	Multi-Hub	41.67	16.67	41.67	50.00	17.44	10.47	72.09	76.32

Table 4.6: GPT 4o — 100 s interval



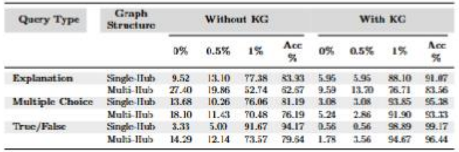
Query Type	Graph Structure	Without KG				With KG			
		0%	0.5%	1%	Acc %	0%	0.5%	1%	Acc %
Explanation	Single-Hub	39.39	12.12	48.48	54.55	29.54	8.41	62.05	66.26
	Multi-Hub	55.17	15.52	29.31	36.07	35.79	14.74	49.47	56.84
Multiple Choice	Single-Hub	39.22	14.71	46.08	53.44	11.76	3.92	84.31	86.27
	Multi-Hub	50.88	14.04	35.09	42.11	23.81	5.95	70.24	72.22
True/False	Single-Hub	26.92	9.62	63.46	68.27	7.21	2.88	89.90	91.35
	Multi-Hub	47.83	17.39	34.78	43.48	15.85	6.71	77.44	80.80

Table 4.7: GPT o4-mini — 1 s interval



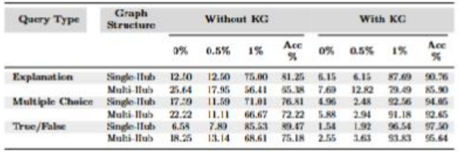
Query Type	Graph Structure	Without KG				With KG			
		0%	0.5%	1%	Acc %	0%	0.5%	1%	Acc %
Explanation	Single-Hub	17.78	15.56	66.67	74.44	4.44	5.00	90.56	93.06
	Multi-Hub	35.24	22.86	41.90	53.33	8.57	14.29	77.14	84.29
Multiple Choice	Single-Hub	17.02	8.51	74.47	78.72	3.19	1.06	95.74	96.27
	Multi-Hub	21.21	14.14	64.65	71.72	5.41	2.70	91.89	93.24
True/False	Single-Hub	8.33	7.22	84.44	88.06	2.22	1.11	96.67	97.22
	Multi-Hub	21.75	13.75	64.50	71.88	4.37	2.46	93.17	94.35

Table 4.8: GPT o4-mini — 10 s interval



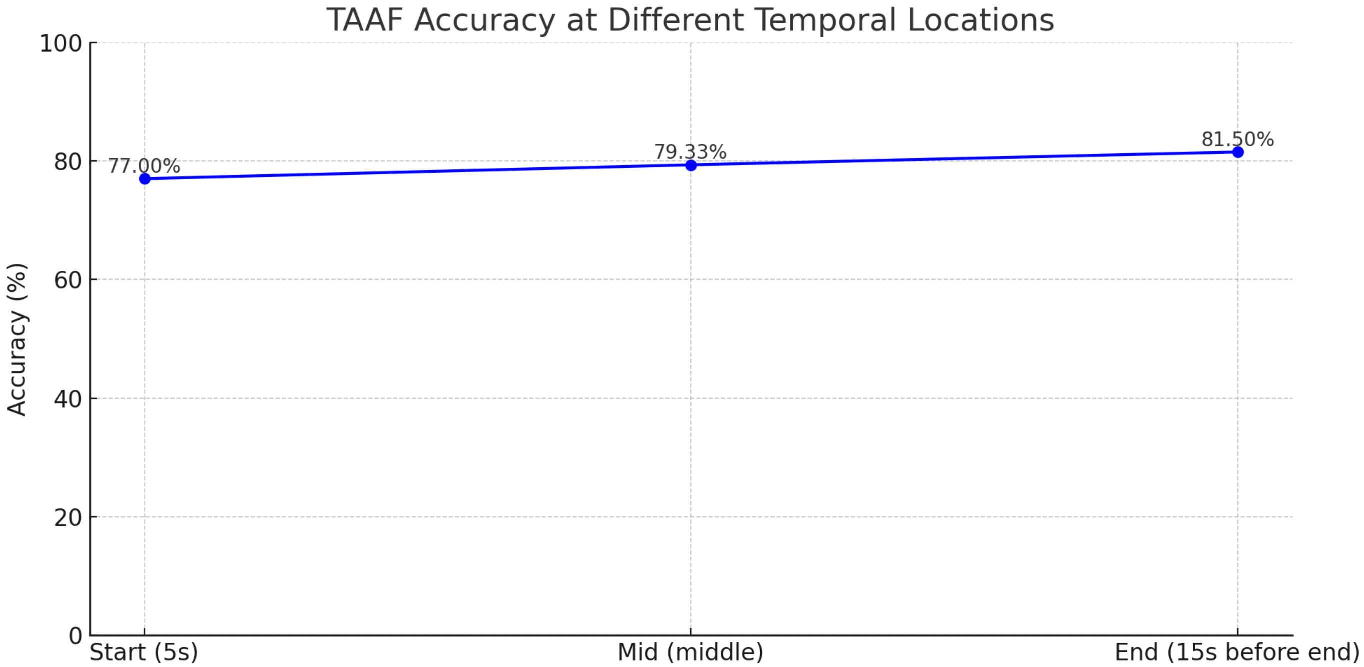
Query Type	Graph Structure	Without KG				With KG			
		0%	0.5%	1%	Acc %	0%	0.5%	1%	Acc %
Explanation	Single-Hub	9.52	13.10	77.38	83.93	5.95	5.95	88.10	91.07
	Multi-Hub	27.40	19.86	52.74	62.67	9.59	13.70	76.71	83.56
Multiple Choice	Single-Hub	13.68	10.26	76.06	81.19	3.08	3.08	93.85	95.38
	Multi-Hub	18.10	11.43	70.48	76.19	5.24	2.86	91.90	93.33
True/False	Single-Hub	3.33	5.00	91.67	94.17	0.56	0.56	98.89	99.17
	Multi-Hub	14.29	12.14	73.57	79.64	1.78	3.56	94.67	96.44

Table 4.9: GPT o4-mini — 100 s interval

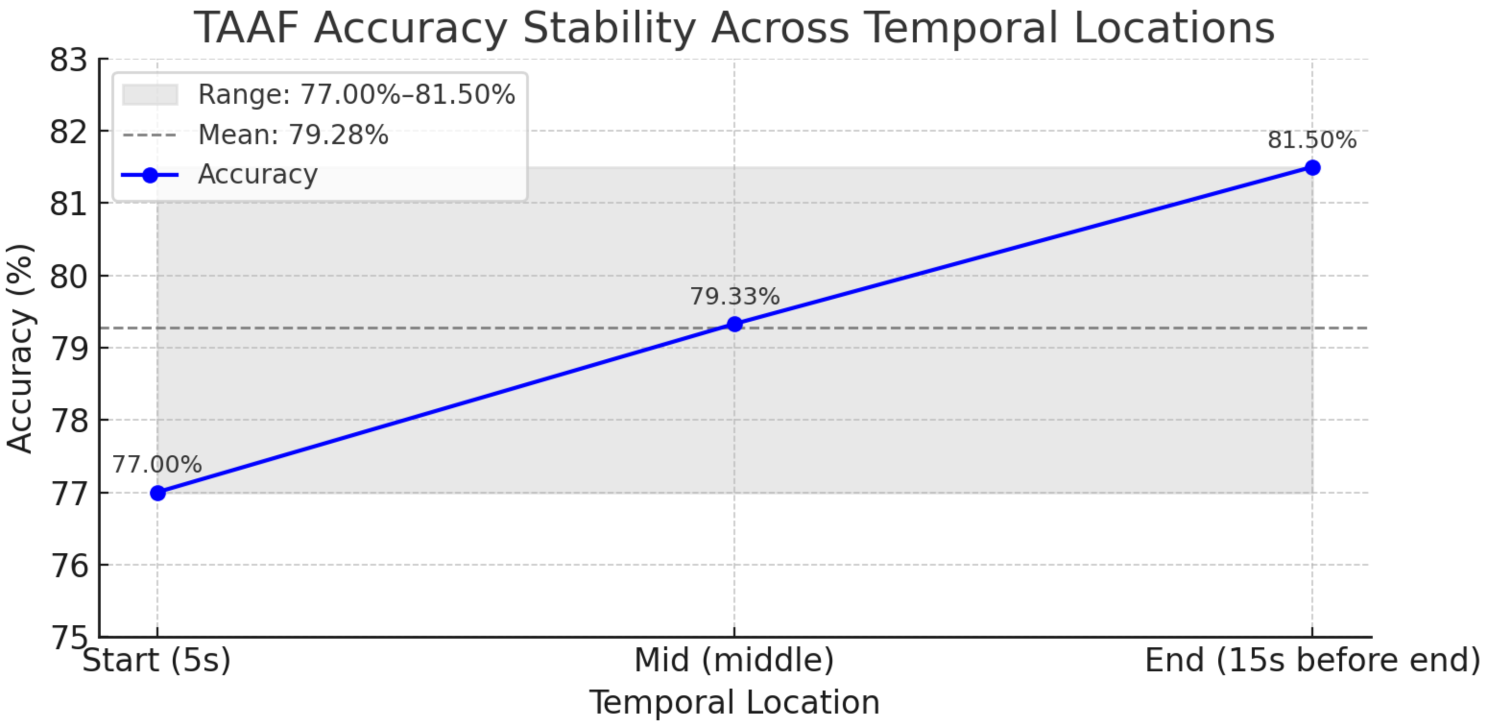


Query Type	Graph Structure	Without KG				With KG			
		0%	0.5%	1%	Acc %	0%	0.5%	1%	Acc %
Explanation	Single-Hub	12.50	12.50	75.00	81.25	6.15	6.15	87.69	90.76
	Multi-Hub	25.64	17.95	56.41	65.38	7.69	12.82	79.49	85.90
Multiple Choice	Single-Hub	17.39	11.59	71.01	76.81	4.96	2.48	92.56	94.05
	Multi-Hub	22.22	11.11	66.67	72.22	5.88	2.94	91.18	92.65
True/False	Single-Hub	6.58	7.89	85.53	89.47	1.54	1.92	96.54	97.50
	Multi-Hub	18.25	13.14	68.61	75.18	2.55	3.63	93.83	95.64

RQ6: To what extent does the choice of temporal location (early vs. late in the trace) affect system performance and reasoning accuracy?

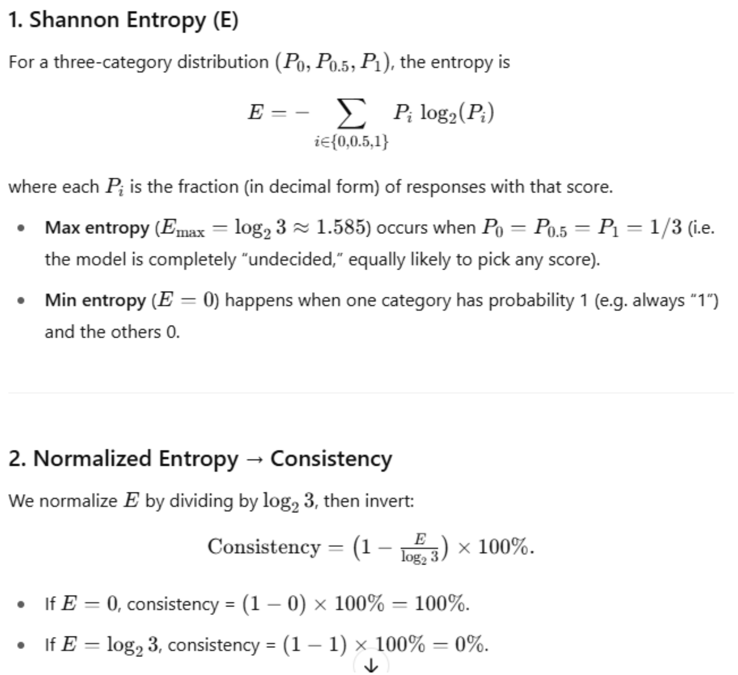


RQ6: To what extent does the choice of temporal location (early vs. late in the trace) affect system performance and reasoning accuracy?



RQ7: How does the temperature (sampling randomness) parameter affect the accuracy and consistency of LLM responses within TAAF?

- **Accuracy:**
  - $\frac{(Number\ of\ 0s \times 0)+(Number\ of\ 0.5s \times 0.5)+(Number\ of\ 1s \times 1)}{300}$
- **Consistency** measures how **peaked** (vs. spread-out) the model's response distribution is. A very **consistent** model almost always gives the same score (e.g. almost always "1"), whereas an **inconsistent** model spreads its answers across 0, 0.5 and 1 in roughly equal measure.



1. Shannon Entropy (E)

For a three-category distribution $(P_0, P_{0.5}, P_1)$, the entropy is

$$E = -\sum_{i\in\{0,0.5,1\}} P_i \log_2(P_i)$$

where each P_i is the fraction (in decimal form) of responses with that score.

- **Max entropy** ($E_{\max} = \log_2 3 \approx 1.585$) occurs when $P_0 = P_{0.5} = P_1 = 1/3$ (i.e. the model is completely "undecided," equally likely to pick any score).
- **Min entropy** ($E = 0$) happens when one category has probability 1 (e.g. always "1") and the others 0.

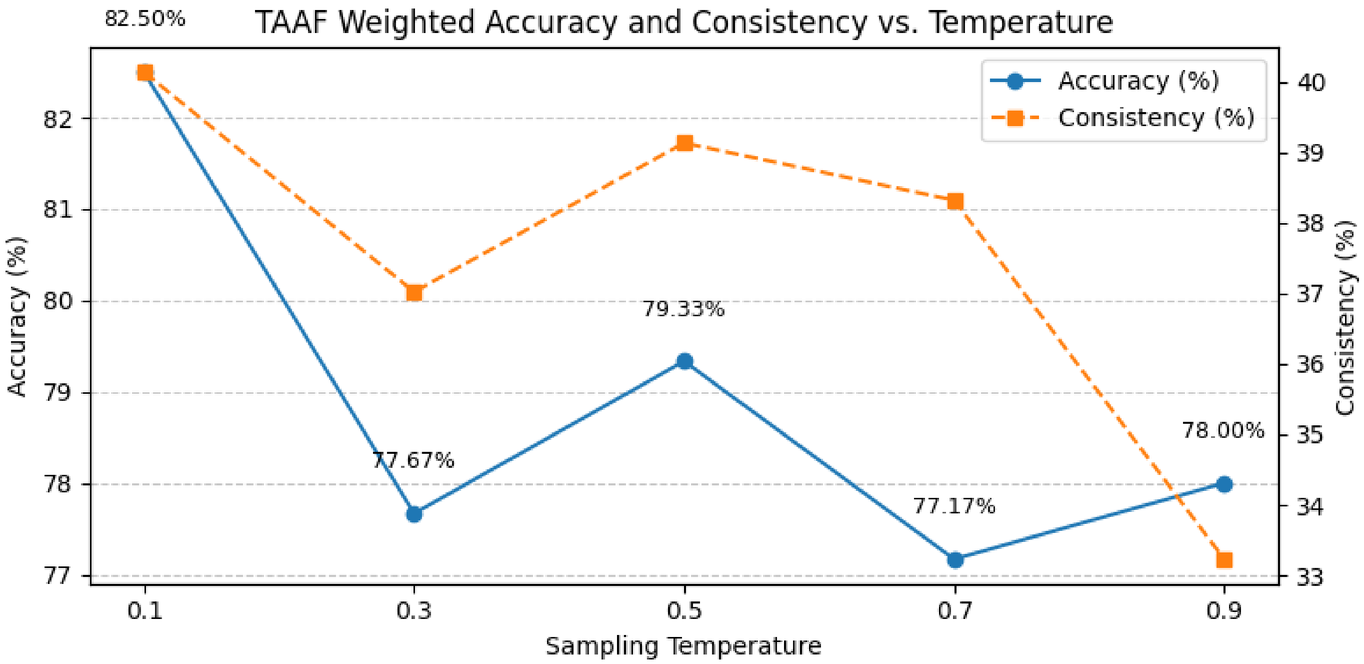
2. Normalized Entropy → Consistency

We normalize E by dividing by $\log_2 3$, then invert:

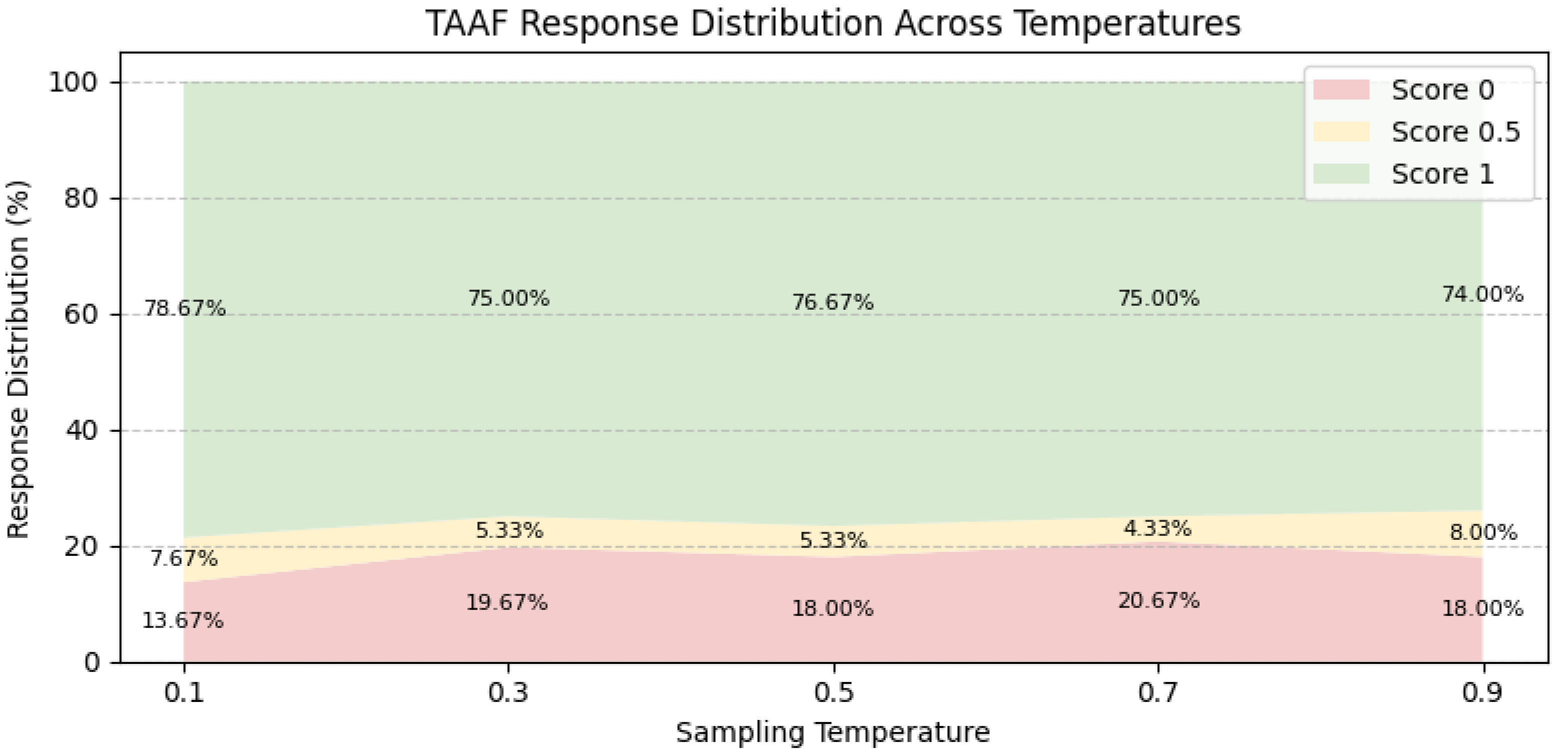
$$\text{Consistency} = \left(1 - \frac{E}{\log_2 3}\right) \times 100\%.$$

- If $E = 0$, consistency = $(1 - 0) \times 100\% = 100\%$.
- If $E = \log_2 3$, consistency = $(1 - 1) \times 100\% = 0\%$.

RQ7: How does the temperature (sampling randomness) parameter affect the accuracy and consistency of LLM responses within TAAF?



RQ7: How does the temperature (sampling randomness) parameter affect the accuracy and consistency of LLM responses within TAAF?



Future Research Questions

- **RQ8:** How does introducing an AI agent (e.g., multi-turn dialogue, clarification loops) improve the interpretability and correctness of TAAF responses?

Thanks!

Do you have any questions?

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