Retrieval Systems for Structured Data

The critical missing  for coupling LLM-powered query interfaces for factual data

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Finding the right data for basic questions or deep analysis is not easy.

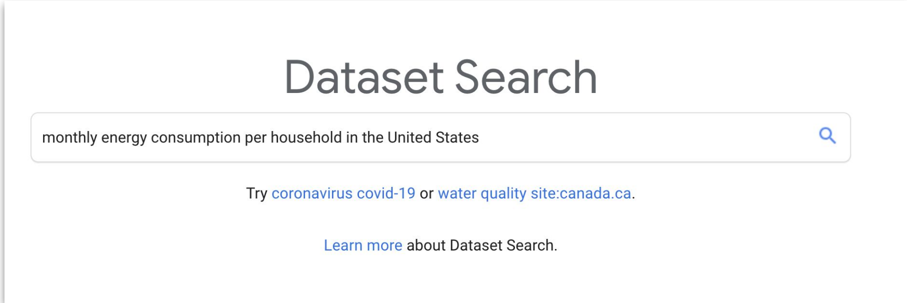
1. How to help data analysts find their data for analytics tasks?
2. How to ground LLM-powered query interfaces in structured data?

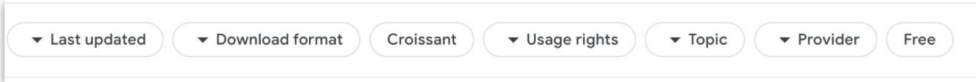
Part 1:
How to help data analysts find their data for analytics tasks?

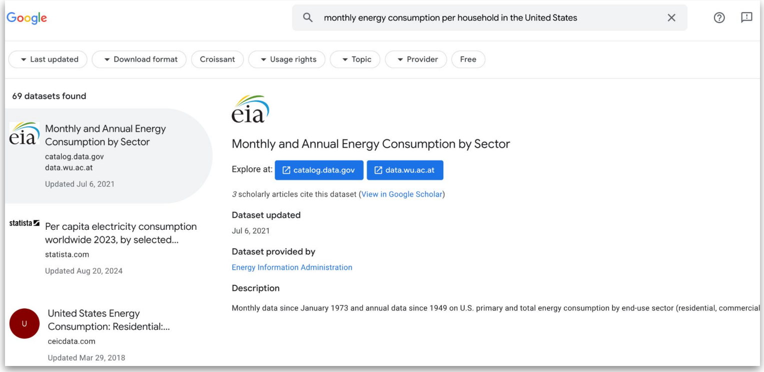
Current dataset search systems for analytics use-cases

Imagine you are looking for a dataset to forecast monthly energy consumption per household until May 2025.

Keyword Search and Metadata Filters







69 datasets… Which one?

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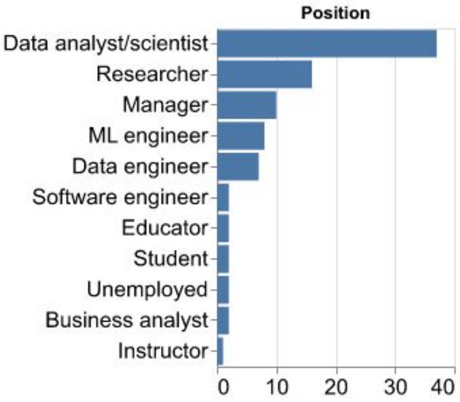
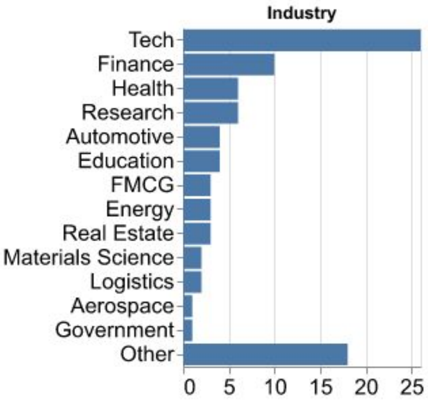
Why is dataset search still so hard in practice?

89 data practitioners recruited through social media & mailing lists

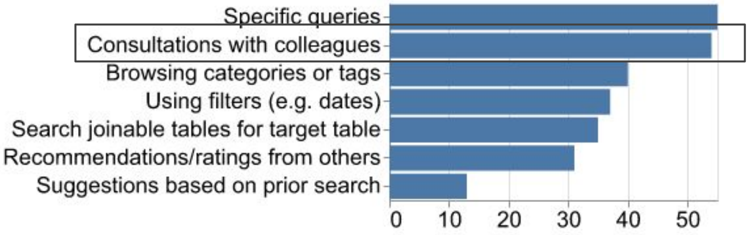




"It took longer than I was expecting": Why is Dataset Search Still So Hard?, Hulsebos, M., Lin, W., Shankar, S., Parameswaran, P., HILDA@SIGMOD 2024.

How do Practitioners Search?

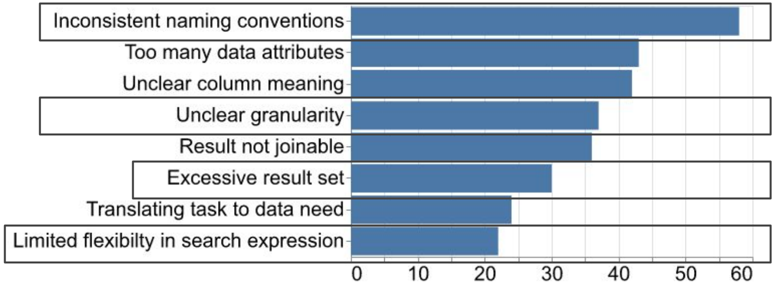
How do you search?



*"…Also, identify **people** who have worked on **similar problems**…"*

*"… I ask more **experienced colleagues which ones are most inherent** to the analysis..."*

Key challenges with existing systems?



*"The biggest challenge I've noticed is **messy variable naming**…."*

*"**Categorical level of detailing** is required..."*

*"There are **too many table results** after the initial search…."*

*"**Not many features to search**/query keywords…"*

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"It took longer than I was expecting": Why is Dataset Search Still So Hard?, Hulsebos, M., Lin, W., Shankar, S., Parameswaran, P., HILDA@SIGMOD 2024.

Towards Next-Generation Dataset Search Systems

Task-driven: explicit **data needs unknown to user**, start from the task

Hybrid: search spans **diff representations** of a table; raw metadata + **semantics**

Iterative: beyond keywords+filters; complex process, need for more pruning

Comprehensibility+diversity: result sets hard to **digest and navigate; IR principles?**

"It took longer than I was expecting": Why is Dataset Search Still So Hard?, Hulsebos, M., Lin, W., Shankar, S., Parameswaran, P., HILDA@SIGMOD 2024.

Task-driven Search with Hypothetical Schema Embeddings

(1) Task-driven query

What data is needed to **train a machine learning model** to **forecast demand for medicines across suppliers?**

(2) Hypothetical Schema generation

```
Instruction: generate schema needed for the given task query.
Query: {task-driven query}
```

LLM output: "`hypothetical_schema`"

```
medication table: medication id, medication name, …
sales table: medication id, supplier id, date, quantity sold, …
```

(3) Embed(`hypothetical_schema`)

(4) Retrieve source tables from vector store similar to `hypothetical_schema`

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Iterative Search through Query Breakdown

Initial complex search query

A dataset to train a **medicine forecast model**, should **contain a, b, c**, and **span 2 years** with a **date range e to b**.
The fact table should be at **r granularity** and contain **20,000 records**.

"A dataset for **task x**,

<retrieved tables>

Retrieve through Hypothetical Schema Embeddings

Data should contain **a , b , c**

<pruned tables>

prune: schema similarity

Data should span **2 years** with a **date range e to b**.

<pruned tables>

prune: metadata **text-to-sql**

The fact table should be at **r granularity** and **contain 20,000 records**."

<pruned tables>

prune: metadata **text-to-sql**

LLM-Assisted Interface for Dataset Search

Things we want from Dataset Search interfaces:

D1 **LLM Elicitation through Proactive Guidance**

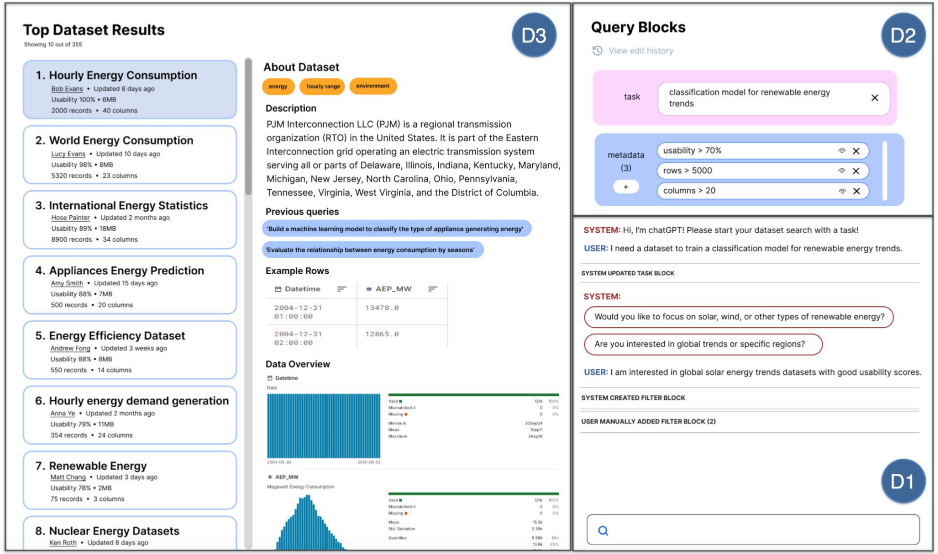
Purpose: Prompt users to share more information about their needs, which will be reflected in the query blocks & search interface.

D2 **Dynamic Query Decomposition**

Purpose: Allow users to see how the LLM is dynamically updating and refining the search space, providing transparency into the search process.

D3 **Allowing Users to Compare Datasets Efficiently**

Purpose: Facilitate high-level exploration of datasets by organizing them into topics and enable users to delve into metadata details of individual datasets as they iteratively build and refine their queries.



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Part 2:
How to ground LLM-powered query interfaces in structured data?

Asking LLMs complex questions

What is the highest eligible free rate for K-12 students in the schools in Alameda County?

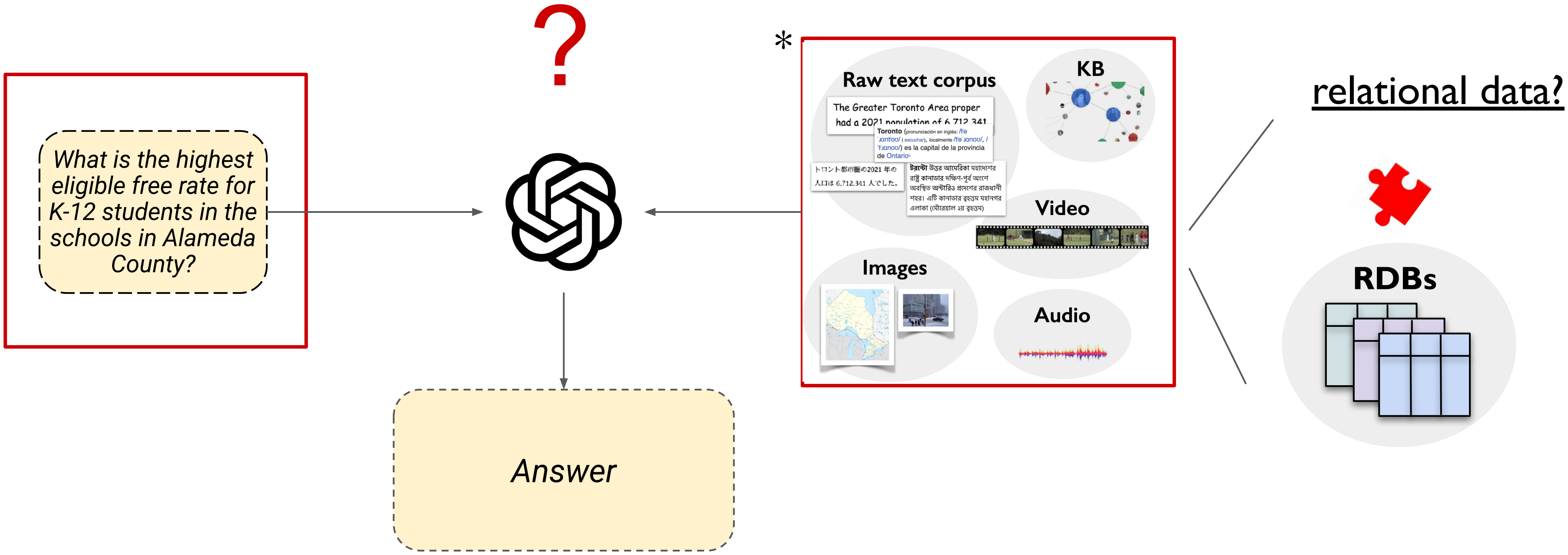
→

→

*"…. To determine the highest free rate specifically in Alameda County schools, **you'd generally need data from specific school districts or schools in the area**, as this rate can vary widely depending on the socio-economic demographics of each district. …" **

*Generated with chatgpt on 6 October 2024

We need “specific” data to ground LLMs



*Retrieval-based Language Models and Applications, Asai, A. et al, Tutorial ACL, 2023.

Why we need RAG over *structured data*

A pattern in practice: "everyone cares about structured data".

Structured data serve **high-value** insights! Up-to-date, domain-specific, facts…

Queries & RAG pipeline

“Which urban Japanese prefecture is not associated with thorny trees?” [table lookup]

“Shane Hall ran a total of 190 races between the year of 1995 - 2008” [aggregate & compare]

“What is the highest eligible free rate for K-12 students in the schools in Alameda County” [aggregate]

- interpret query
- enrich/transform query

how to retrieve tables?

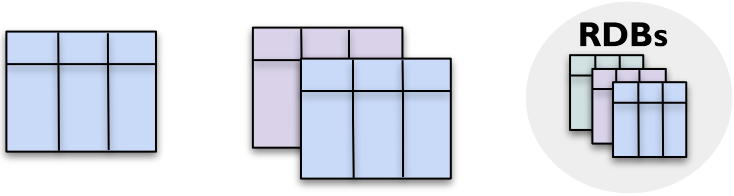
- read table with LLM
- generation & SQL execution

Retrieval is difficult, but crucial…

"... keep in mind that a good RAG system is really **hard to build**.
If your **retrieval system is mediocre**,
the **retrieval can easily distract LLMs** to backfire…
There is still a long way to go." **-** Wenhu Chen (Univ of Waterloo)

Important grounds to explore…

Retrieval/generation complexity depends on query



- What "task" does the **query intend** to do?
- How should we **process** the table(s), relational DBs?
- **What should we embed** of the table(s) and metadata, and **how**?
- Given query and embedded corpus, **how to retrieve relevant table**?
- **Which data source** to retrieve from, and when?
- (How) should methods, models, systems **generalize across tasks, datasets**?

Methods for table retrieval

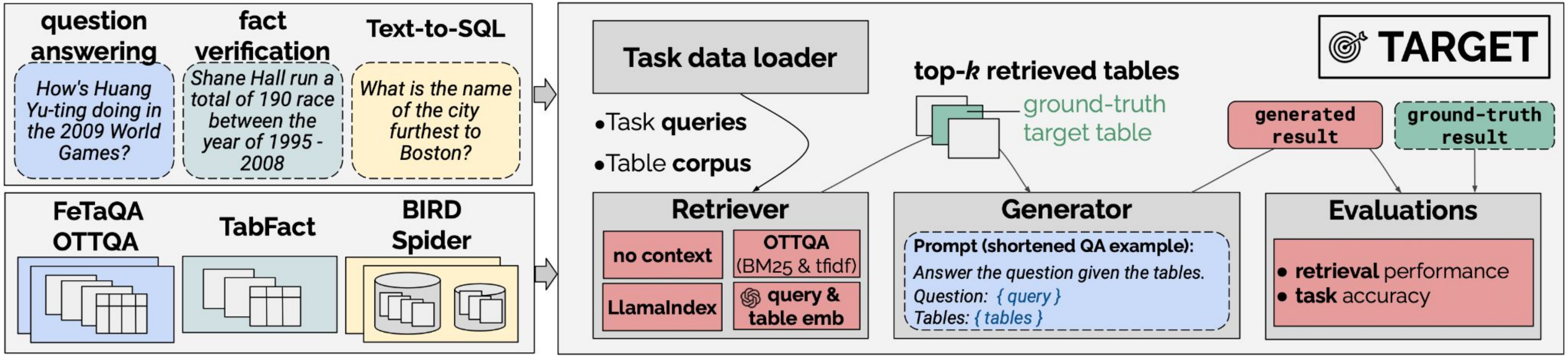
① Embedding of tables in corpus, and input query

- BM25 / TF-IDF (sparse lexical representations)
- Generate summary/metadata → embed summary + table
- "Naive" embedding of table (header / header+rows) and query

② Similarity search (e.g. cosine similarity) to identify top-*k* relevant tables

But how effective are these? How robust across datasets and tasks? No one really knows!

TARGET: Benchmarking Table Retrieval for Generative Tasks



- Diverse: tasks & datasets
- Extensible: easily add new tasks, new datasets
- Adaptable: eval custom retriever, generator

Ji, X, Parameswaran, A., Hulsebos, M., "TARGET: benchmarking Table Retrieval for Generative Tasks", Table Representation Learning workshop NeurIPS, 2024.

TARGET insights

Method	Question Answering						Fact Verification			Text-to-SQL					
	OTTQA			FeTaQA			TabFact			Spider			BIRD		
	R@10	s	SB	R@10	s	SB	R@10	s	P/R/F1	R@1	s	EX	R@1	s	EX
No context	-	-	0.414	-	-	12.495	-	-	0.578/0.42/0.44	-	-	0	-	-	0
OTT-QA BM25	**0.955**	0.001	0.606	0.082	0.001	1.631	0.338	0.001	0.75/0.26/0.39	0.635	0.001	0.385	0.709	0.001	0.181
w/o table title	0.443	0.001	0.529	0.084	0.001	1.555	0.331	0.001	0.75/0.26/0.38	0.5	0.001	0.376	0.535	0.001	0.164
OTT-QA TF-IDF	0.950	0.001	0.425	0.083	0.001	1.639	0.336	0.001	0.75/0.26/0.38	0.622	0.001	0.474	0.640	0.001	0.227
w/o table title	0.43	0.001	0.593	0.083	0.001	1.527	0.322	0.001	0.75/0.25/0.37	0.492	0.001	0.376	0.491	0.001	0.164
LlamaIndex	0.458	0.354	0.507	0.435	0.396	13.745	**0.827**	0.297	0.73/0.34/0.47	0.735	0.198	0.559	0.937	0.228	0.311
OpenAI embedding	0.950	0.190	0.599	**0.722**	0.200	17.64	0.779	0.189	0.76/0.51/0.61	0.768	0.193	0.602	0.926	0.199	0.317
header only	0.950	0.189	0.61	0.718	0.18	17.66	0.781	0.187	0.75/0.48/0.58	**0.833**	0.175	0.646	**0.958**	0.191	0.323

- BM25/TF-IDF less effective, only with *very* descriptive table name.
- Table rows can “distract” embeddings, *particularly in RDBs as seen in practice.*
- Generating summary/metadata can help, but not all tables easy to LLM-summarize.

Ji, X, Parameswaran, A., Hulsebos, M., “TARGET: benchmarking Table Retrieval for Generative Tasks”, Table Representation Learning workshop NeurIPS, 2024.

Still much to explore…

- What is right input of (meta)data to not "distract" embedding?
- How do we route to proper data source, interpret the task, etc?
- The reality in practice is much harder:
  - How do methods perform on more *challenging tasks & datasets*?
  - Closing semantic gap e(query) and e(table); most public datasets relatively "easy" match between query and tables.
  - Relational databases are large → in-DB schema and table retrieval.

Roadmap for TARGET

Ji, X, Parameswaran, A., Hulsebos, M., "TARGET: benchmarking Table Retrieval for Generative Tasks", Table Representation Learning workshop NeurIPS, 2024.

TARGET is out TODAY!

RAG tables over tables with TARGET!

```python
from target_benchmark.retrievers import AbsCustomEmbeddingRetriever
class YourRetriever(AbsCustomEmbeddingRetriever):
    def __init__(self, **kwargs):
        # load your favorite table retriever!

    def retrieve(self, query: str, dataset_name: str, top_k: int):
        # given a query, retrieve the top-k table id

    def embed_corpus(self, dataset_name: str, corpus: Iterable[Dict]):
        # use retriever, embedding models, etc. to embed the corpus!
```

- Ready to eval table retrieval and e2e generation: **input welcome for v2**
- Data on HF, code on GH, `pip install target_benchmark`
- https://target-benchmark.github.io

Ji, X, Parameswaran, A., Hulsebos, M., "TARGET: benchmarking Table Retrieval for Generative Tasks", Table Representation Learning workshop NeurIPS, 2024.

Key takeaways

- Retrieval (RAG, agents, or dataset discovery) is critical to get insights from data.

- Dataset discovery requires co-worker consultation. Existing interfaces are inflexible. We propose lightweight retrieval w **Hypothetical Schema Embeddings**, and a **flexible LLM-assisted interface** that takes a *task* and *doesn't fix metadata filters*.

- To push table retrieval for grounding LLMs in structured data forward, we introduce 🎯 **TARGET: the first benchmark for RAG for structured data**, and uncover deficits of methods that are robust for unstructured text! More to come…