End-to-End Declarative Data Analytics:

Co-designing Engines, Interfaces, and Cloud Infrastructure

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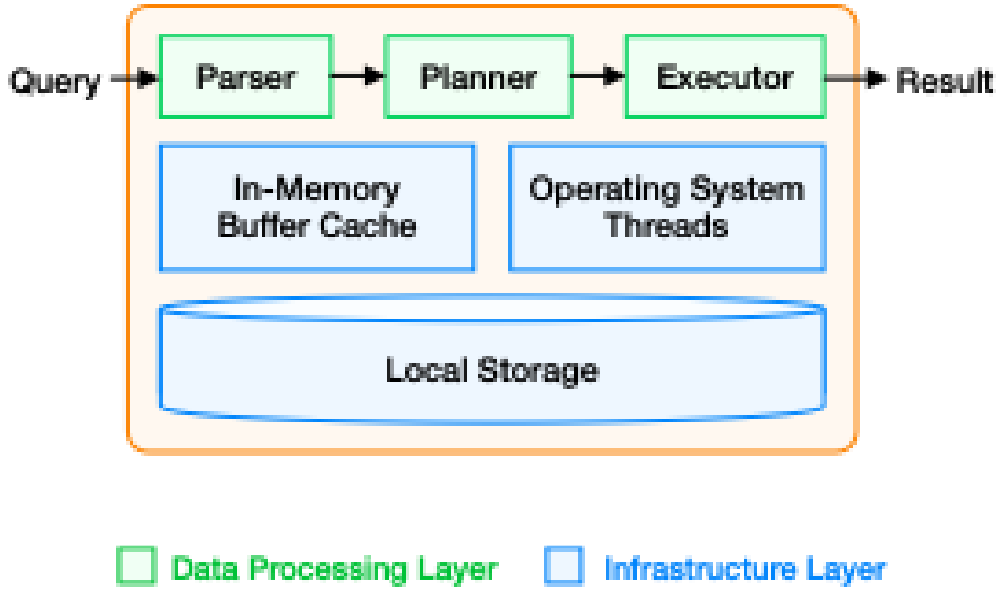
Data Analytics Engine Evolution

A traditional, monolithic engine

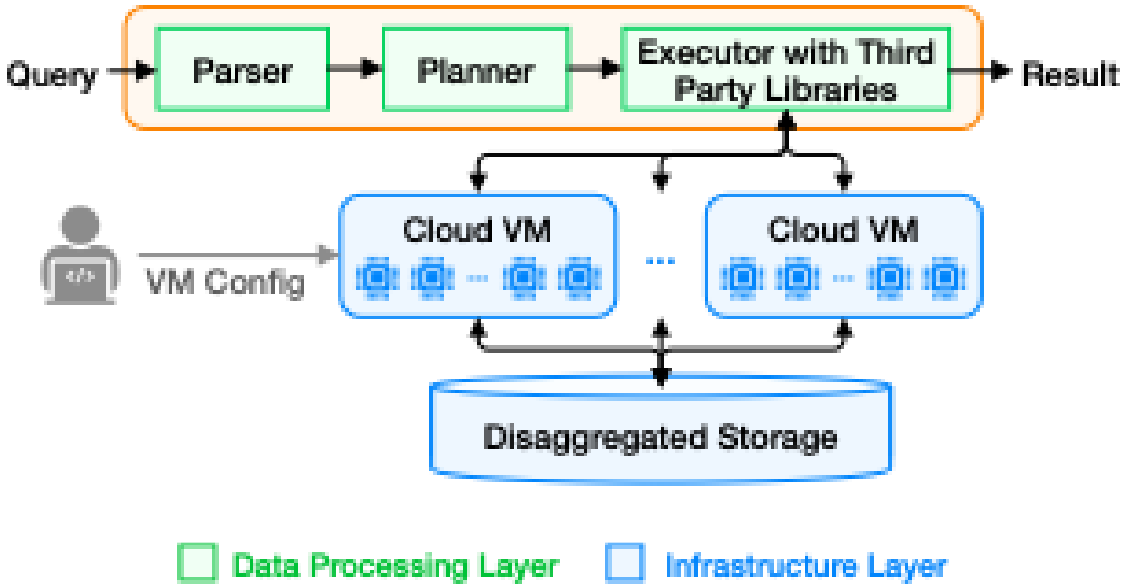
- Assumes full ownership of the data
- Assumes full control of compute and memory



Data Analytics Engine Evolution

A **composite** engine in the **cloud**:

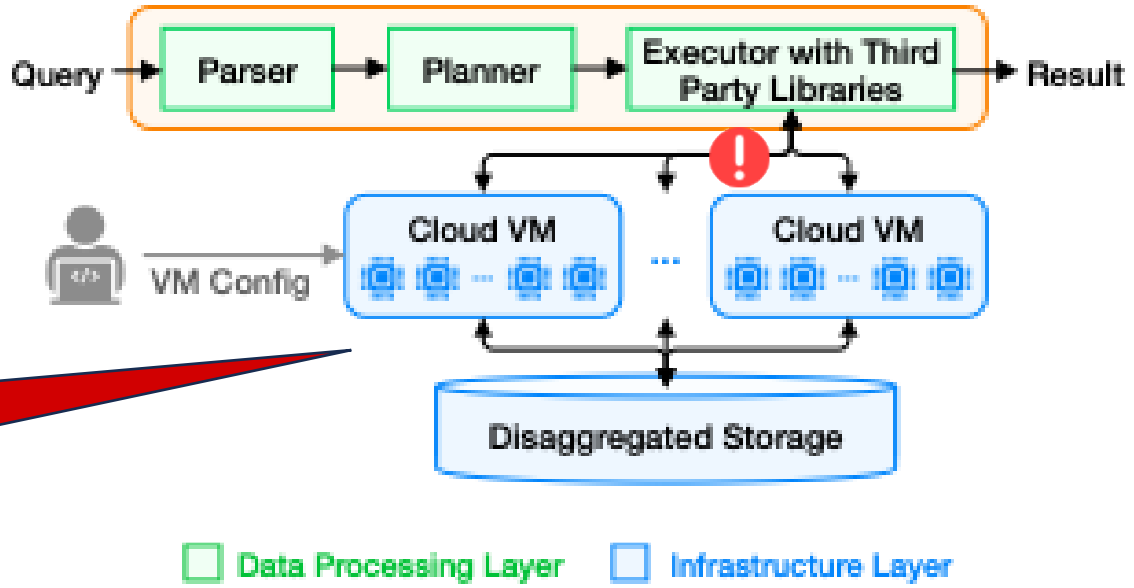
- No longer owns the data
  → stored on data lake
- Many layers of software between the engine and the hardware it runs on



Shortcomings of Today's Cloud Analytics Stack

The declarative nature of data processing ends at query planning/optimization.

- Infrastructure has limited visibility into operators (and their inputs/outputs)



How can the cloud runtime schedule tasks to minimize data movement or decide how to size VMs?

Missing information about query's dataflow and parallelism of the workload!

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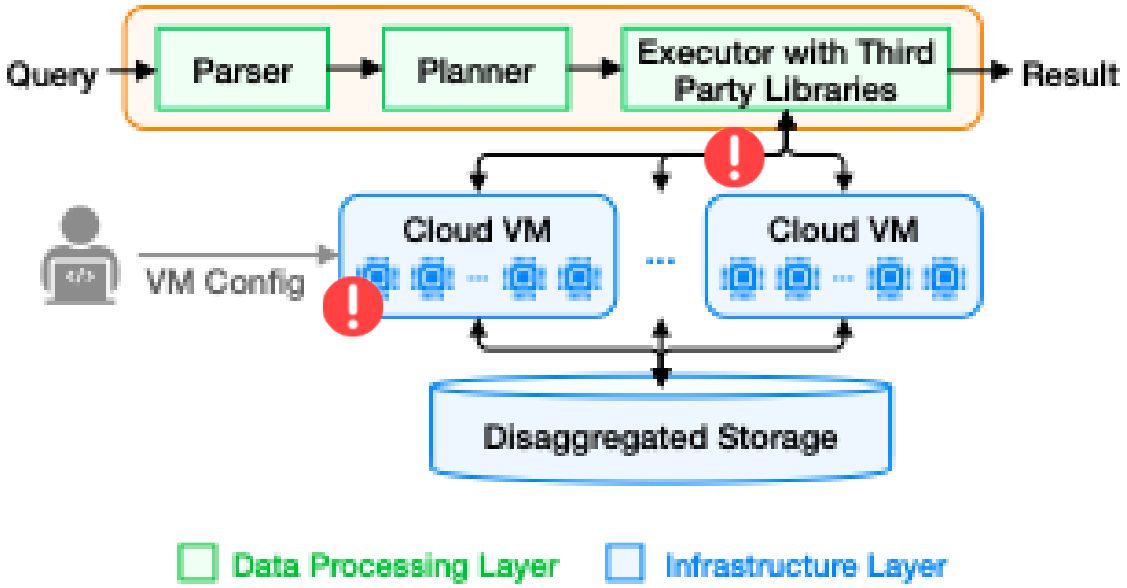

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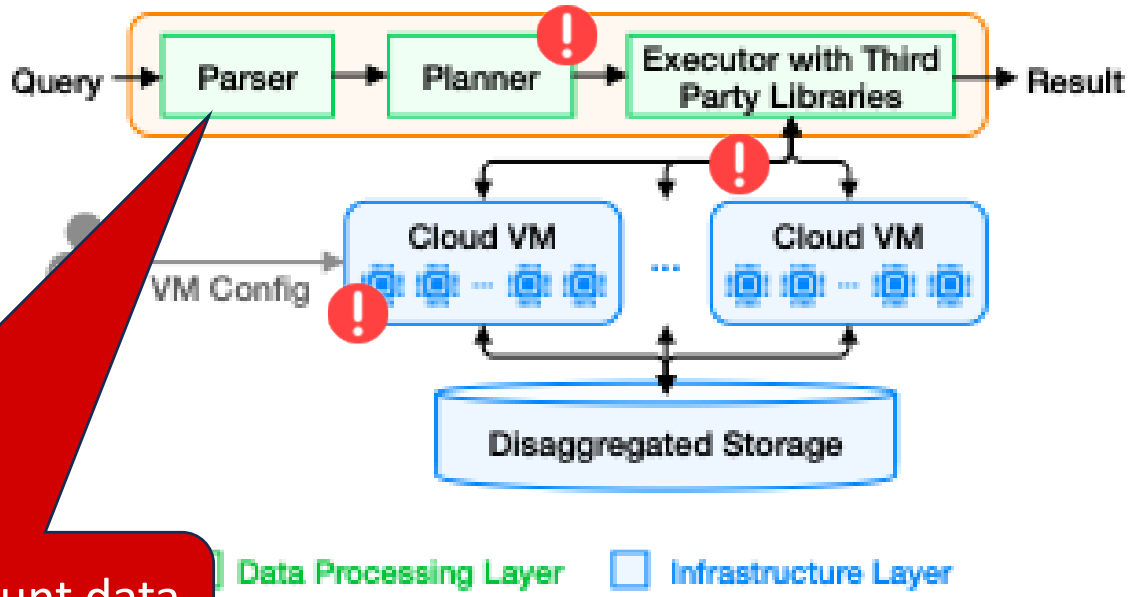

How can the planner take into account data locality and resource contention?

Missing information available at runtime.

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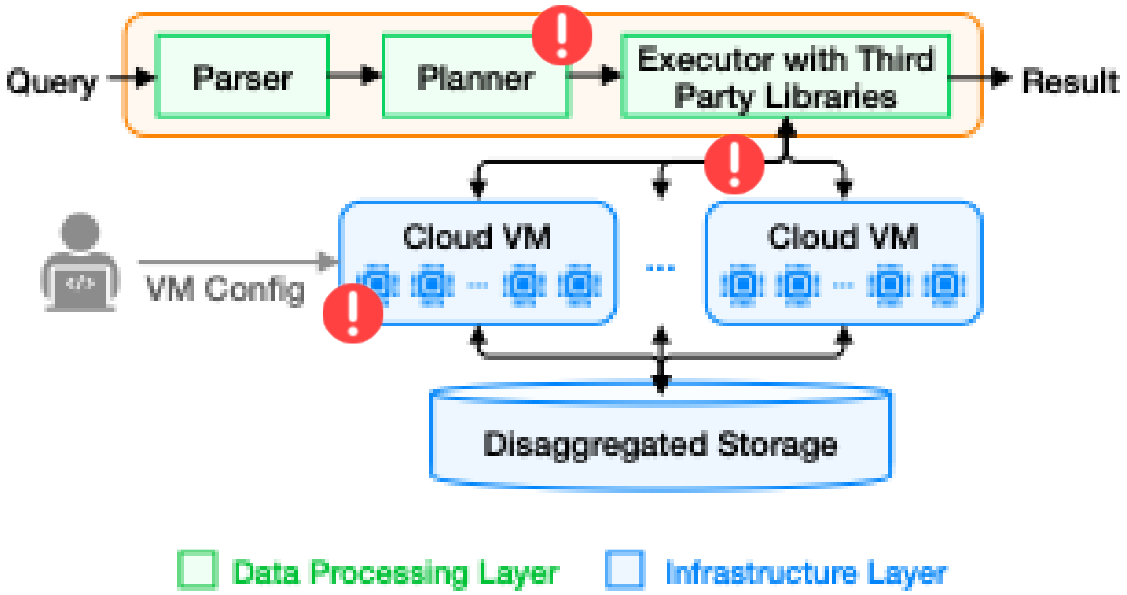
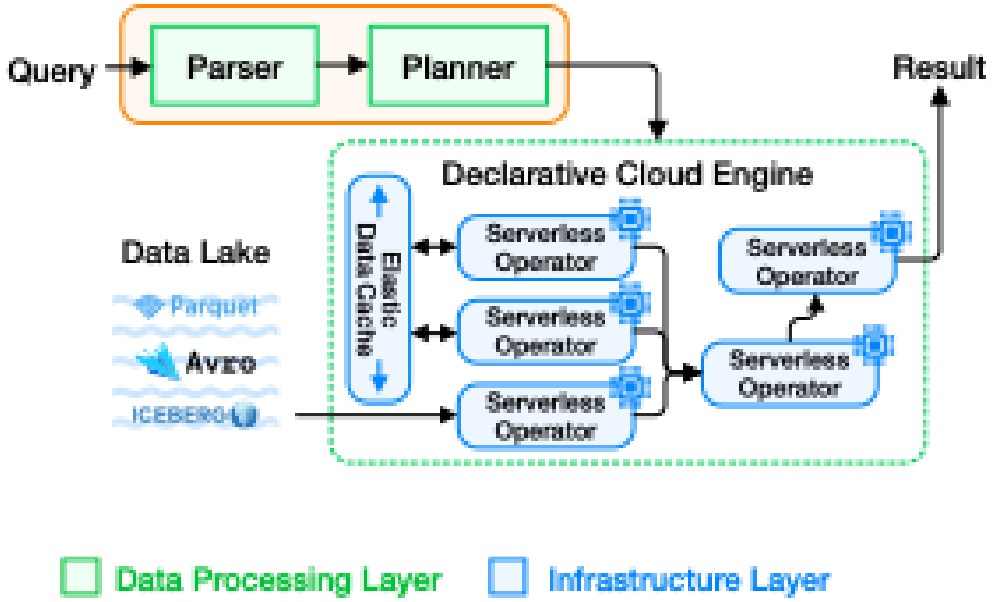


Significant performance & efficiency gains are left on the table!

A Cloud-Native Data Analytics Engine

Co-design the data engine and cloud infrastructure with a *declarative interface.*

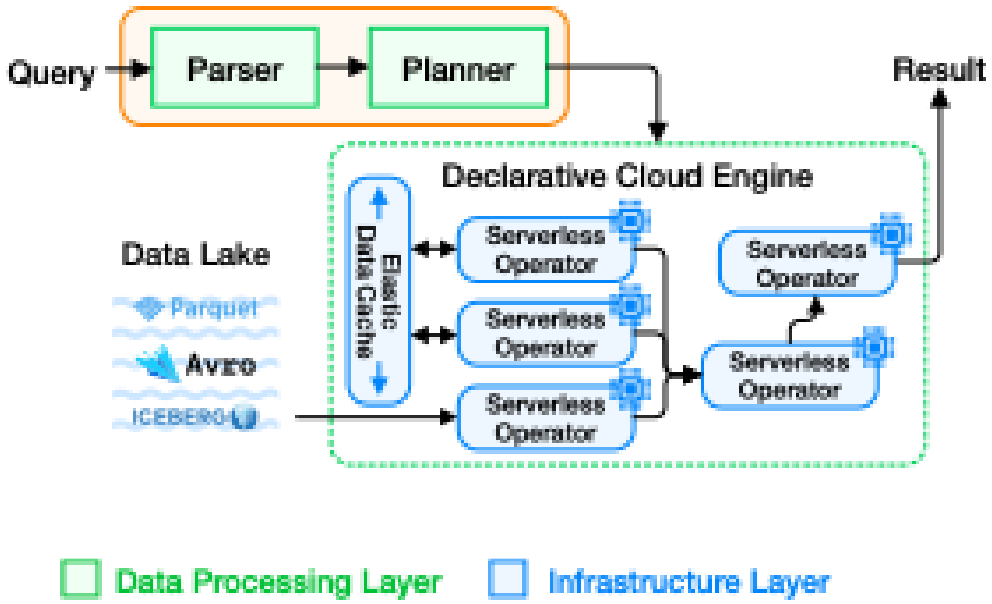
- Expose the query DAG and dataflow to the infrastructure layer
- Infrastructure layer adapts query execution to be hardware-aware and runtime-aware
- Execute query DAG operators with an elastic, declarative serverless runtime



Co-Designing the Data Engine & Cloud Runtime

Data engine decides:

- **Physical plan structure**: predicate pushdown, join order, algorithm choice, etc.
- **Reasonable range of choices** for per-operator degree of parallelism, implementation, etc.



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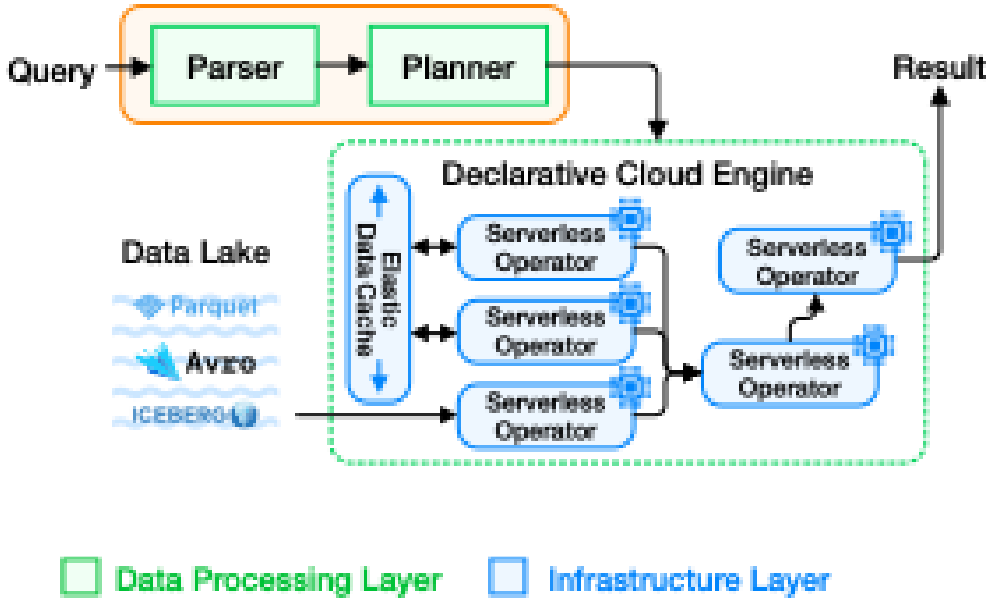
Cloud runtime decides *per-operator*:

- **Elasticity**: degree of parallelism (within bounds)
- **Data caching**: inputs and intermediates to reuse
- **Placement**: where to run, based on data locality
- **Heterogeneous hardware**: CPU type, GPU, etc.
- **More**: degree of isolation, fault recovery, …



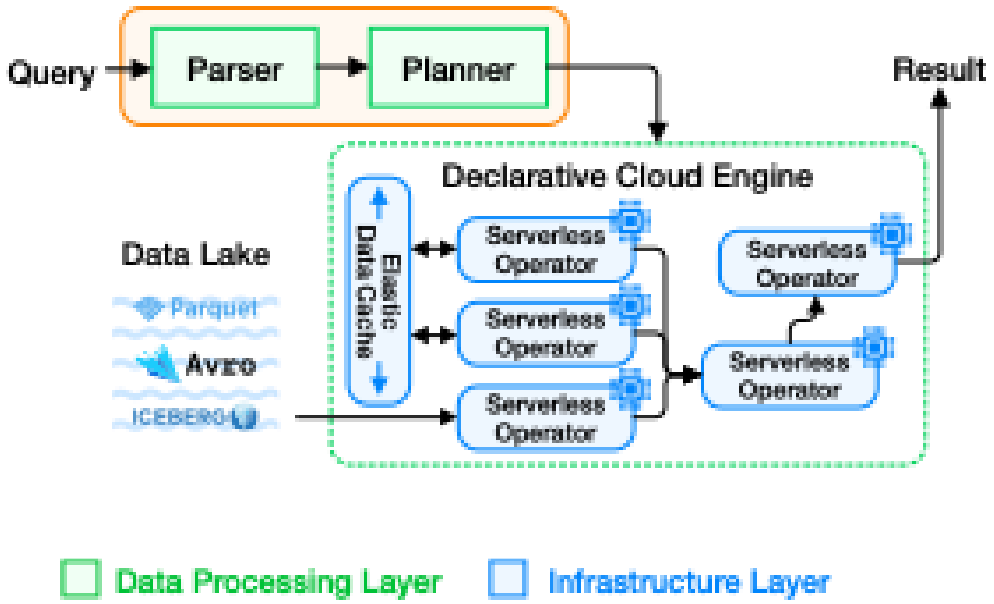
Building a Prototype with Existing Systems

Data Processing Layer: Maximus

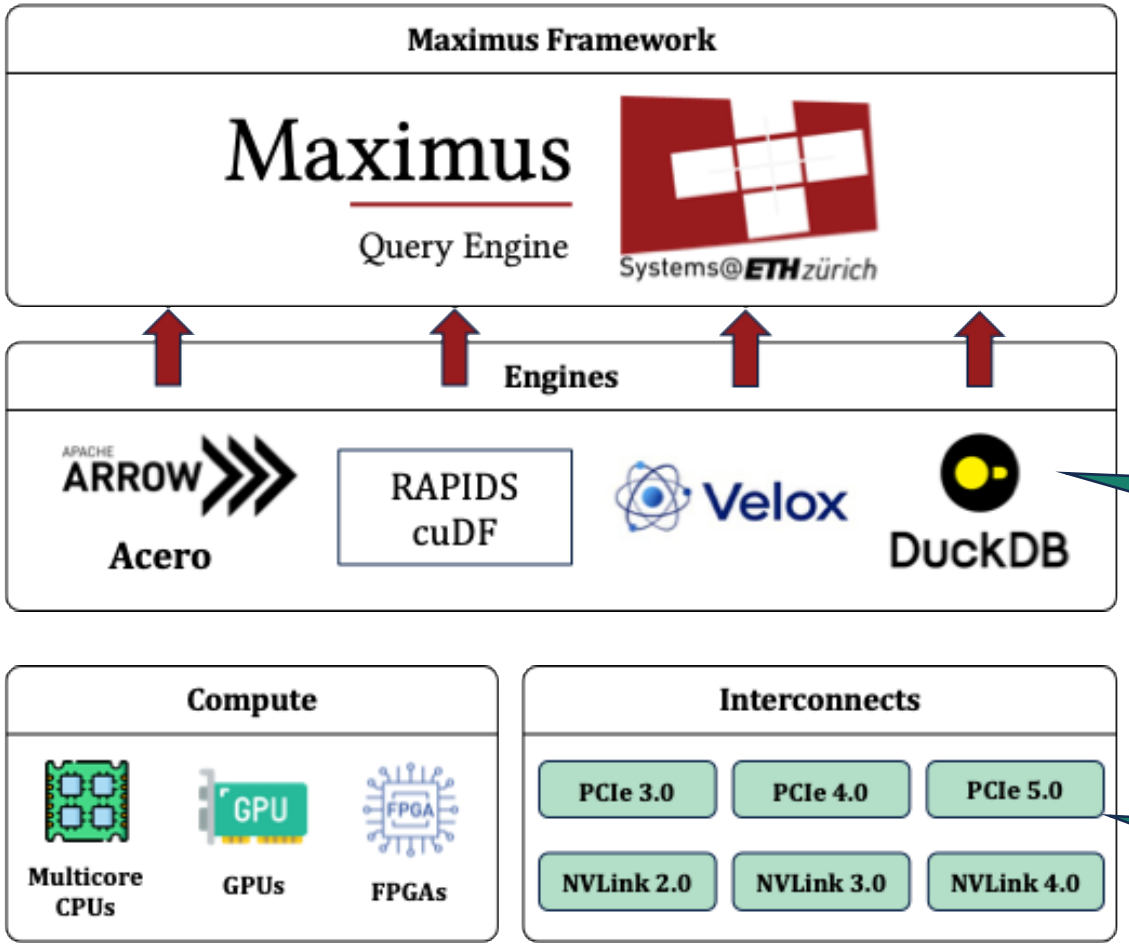
- Composite database engine [SIGMOD'25]
- Allows executing query plans using different backends (CPU, GPU, …)

Infrastructure Layer: Dandelion

- Declarative, serverless cloud runtime [SOSP'25]
- Executes applications as DAGs, which contain two types of operators: pure compute & communication



Why use Maximus as the data engine?



Designed to support a variety of operator libraries

And run on a variety of hardware backends

Why use Dandelion as the cloud runtime?

- DAG interface
- High elasticity
- Strong isolation for multitenancy

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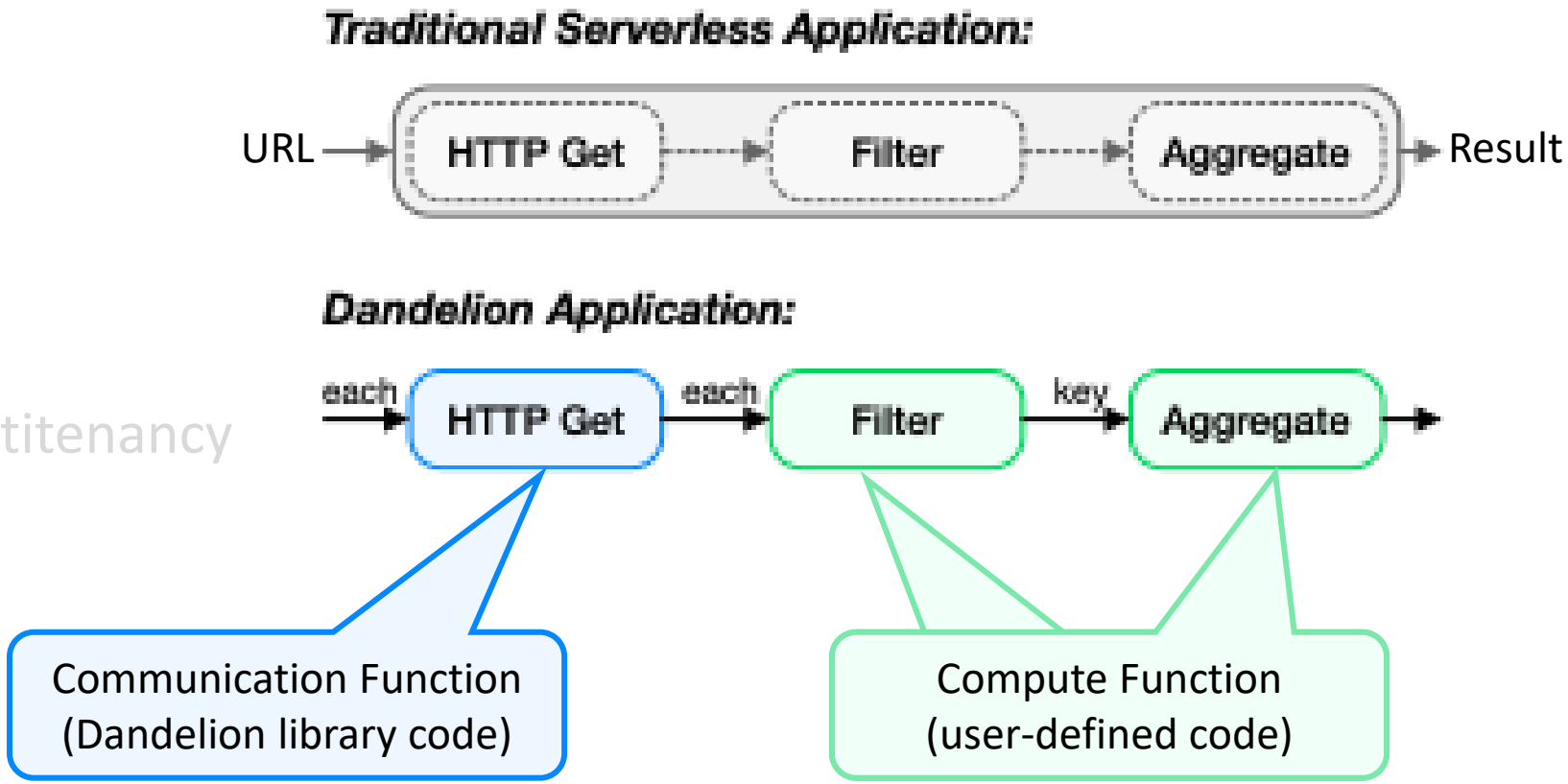

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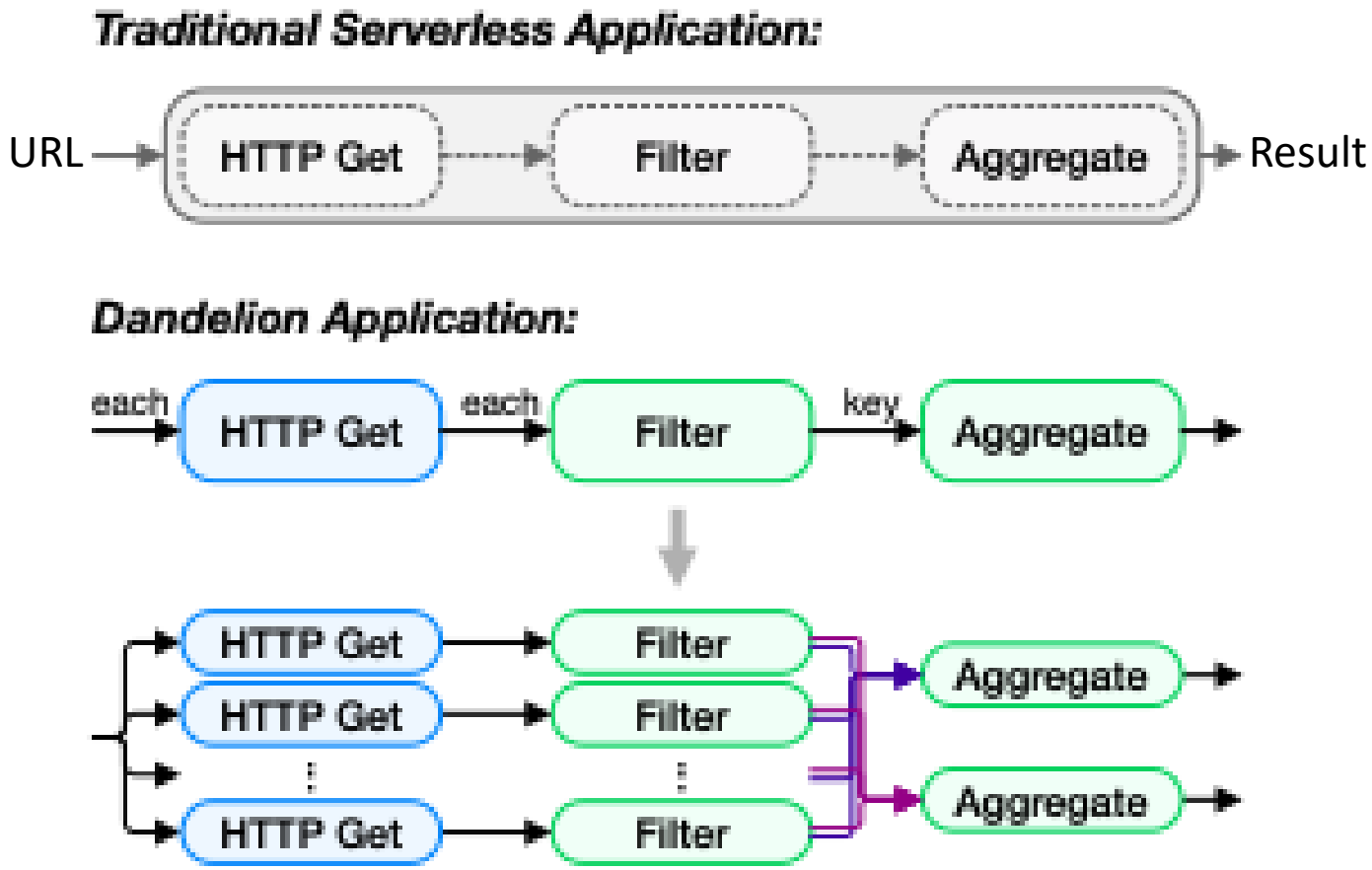
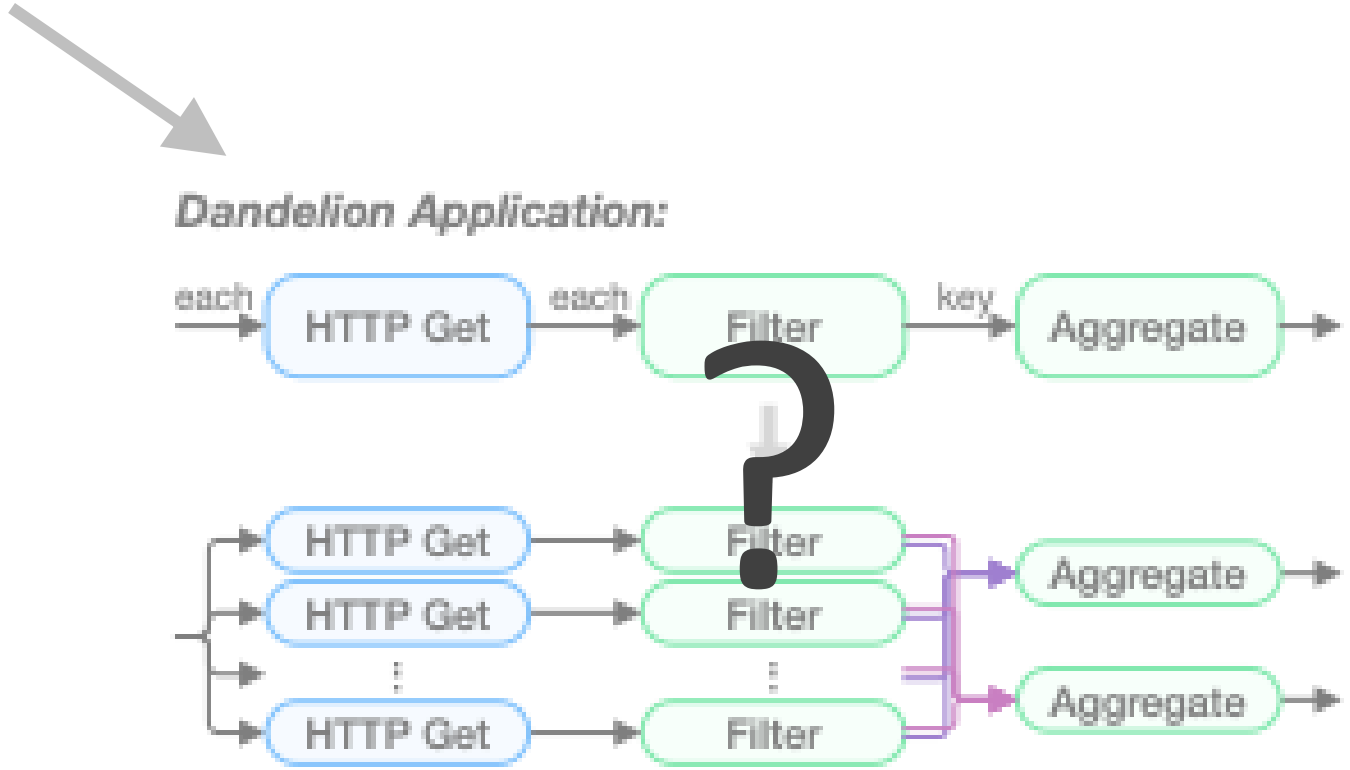


How to map Maximus query → Dandelion DAG?

```
SELECT Name, Age, Country FROM basic.csv WHERE Age > 40
```

SQL



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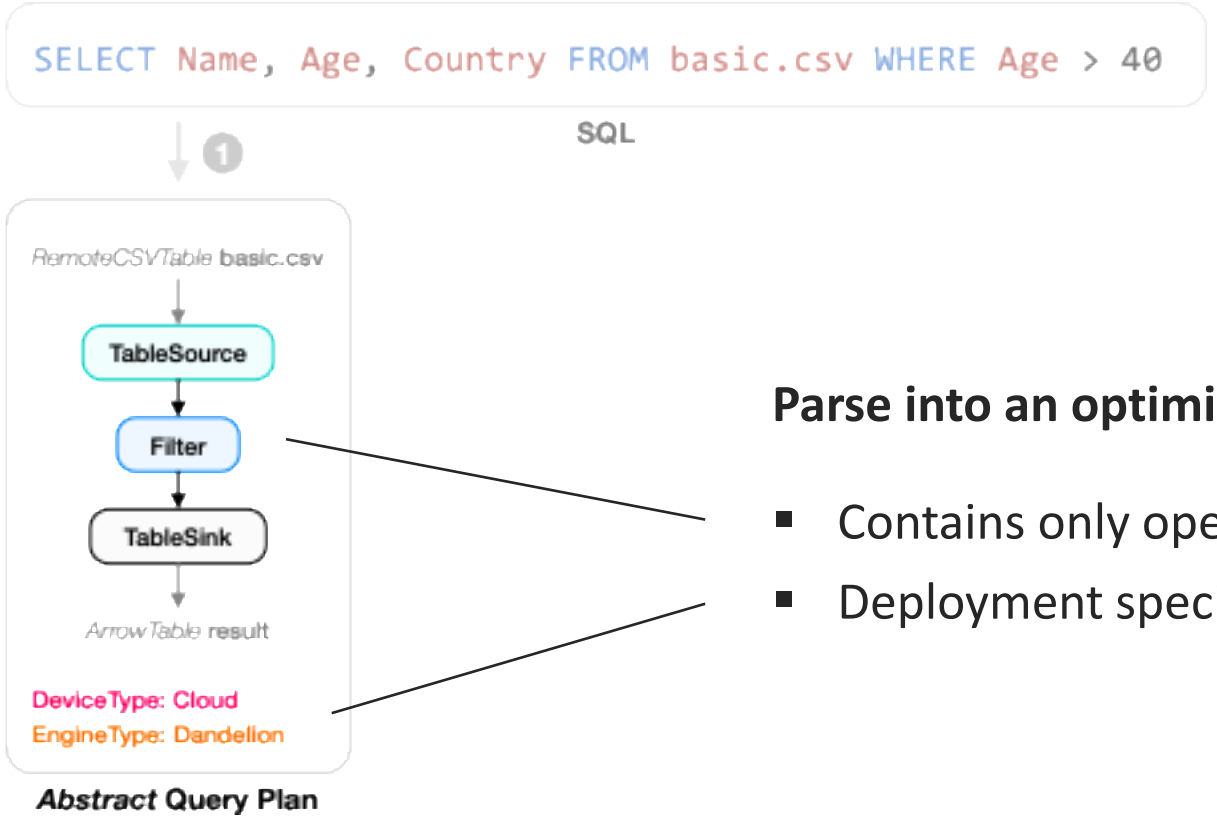

Parse into an optimized *abstract* query plan

- Contains only operator types
- Deployment specification

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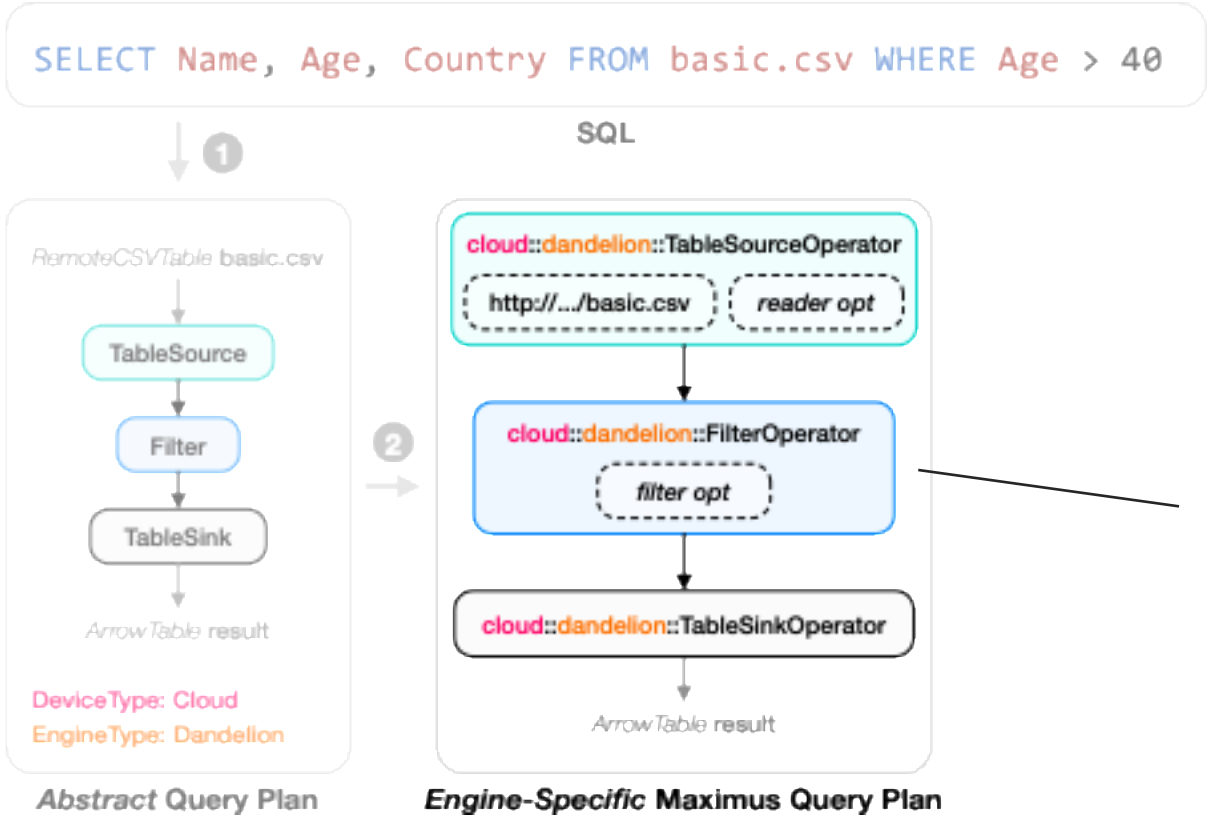

Instantiate Maximus operators

- For the Dandelion engine, they are placeholders that specify the engine options

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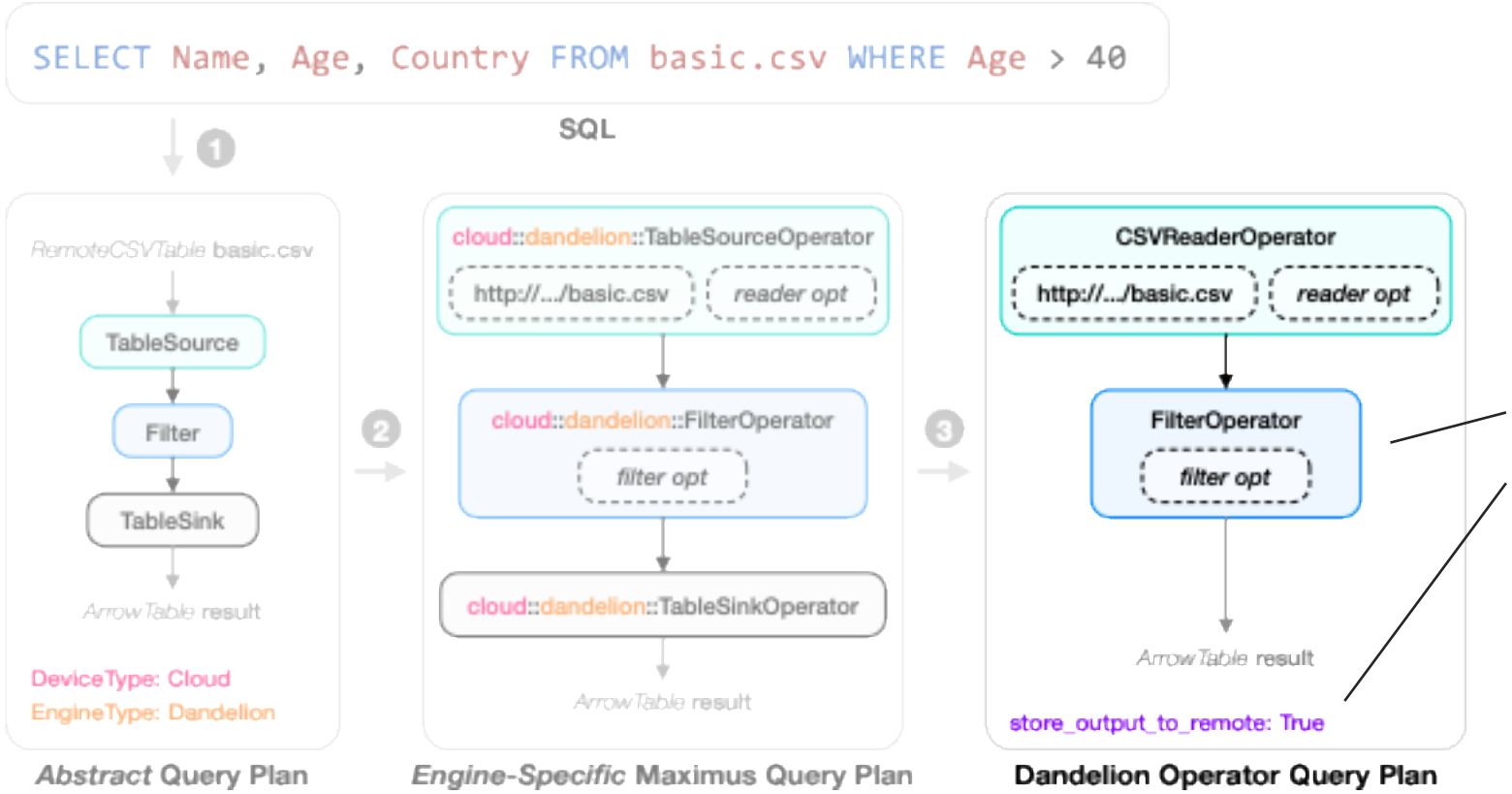

Translate to Dandelion query

- Mostly one-to-one mapping
- Specifies Dandelion specific options (e.g. how data is loaded/stored)

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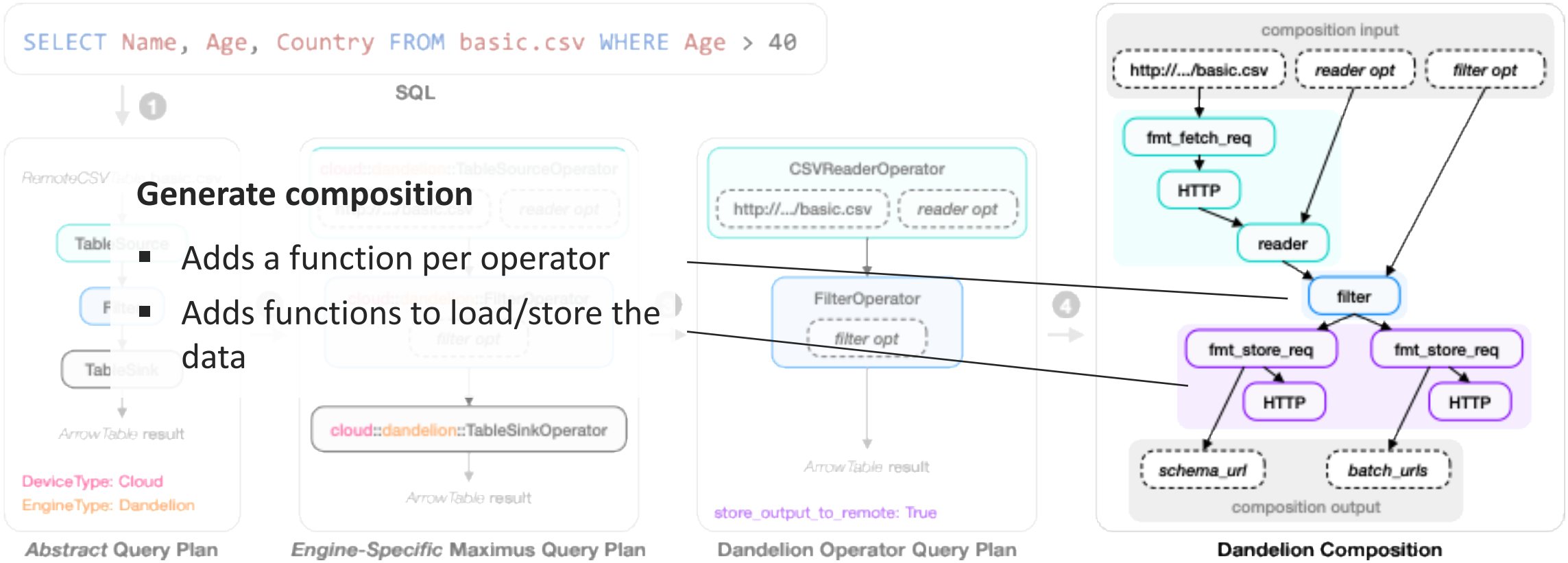
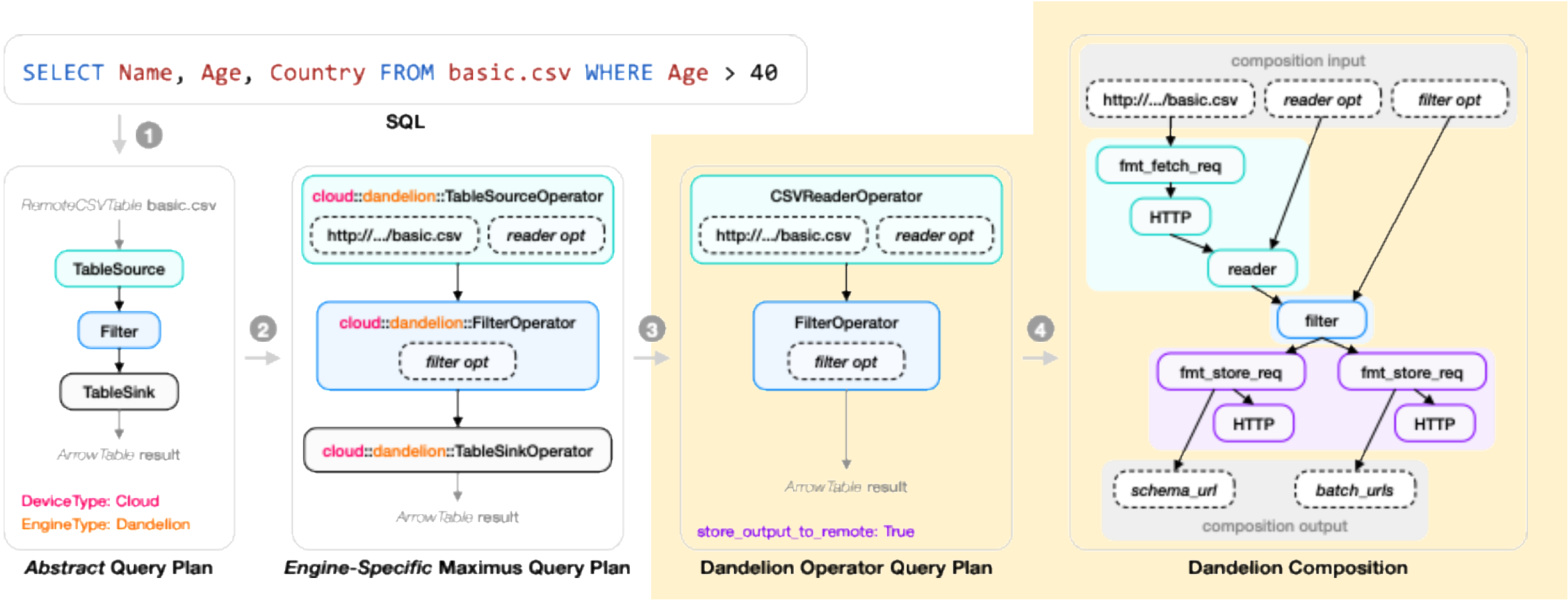


Generate composition

- Adds a function per operator
- Adds functions to load/store the data

How to map Maximus query → Dandelion DAG?



specific to Dandelion

State of our current prototype

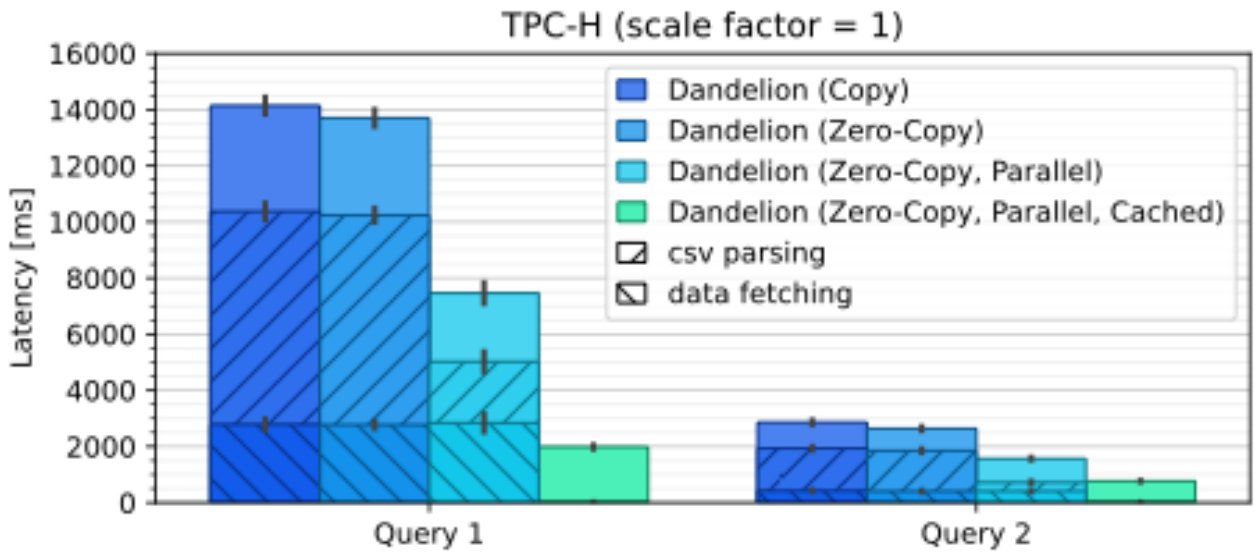
Current focus: basic functionality

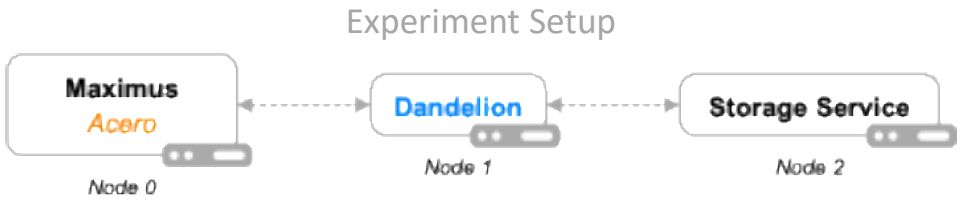
- Data-dependent parallelism (within a node, with manual file partitioning for input data)
- Basic caching support for input and intermediate data
- CPU-only execution for now
- Zero-copy between operators

Future work: performance optimization, scale-out, exploration

- Performance optimization, e.g., vectorization, zero-copy to/from network stack, etc.
- Multi-node support, scheduling policies, data placement
- Distributed cache management
- Explore co-design with storage layer, heterogeneous hardware support, …

Preliminary Feasibility Experiments





- Demonstrate basic support for parallelism, zero-copy data passing, input data caching
- Most of the time is spent fetching and parsing the input CSV data
- Parallelizing the *csv-reader* operator improves performance significantly
- Caching the parsed input data reduces the overall latency

End-to-End Declarative Data Analytics:

Co-designing Engines, Interfaces, and Cloud Infrastructure

- The declarative nature of SQL ends at the query planning/optimization layer in today's engines
- **Goal**: extend the declarative nature of data analytics down to the cloud infrastructure layer
- **Idea**: combine a composite query engine (Maximus) with an elastic, delarative cloud runtime (Dandelion)
- Our early prototype shows feasibility and provides a foundation to explore open questions, e.g., policy interaction across data engine and cloud runtime layers

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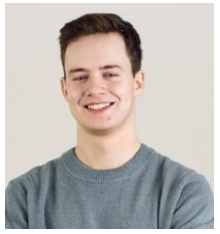
Students at the conference ☺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