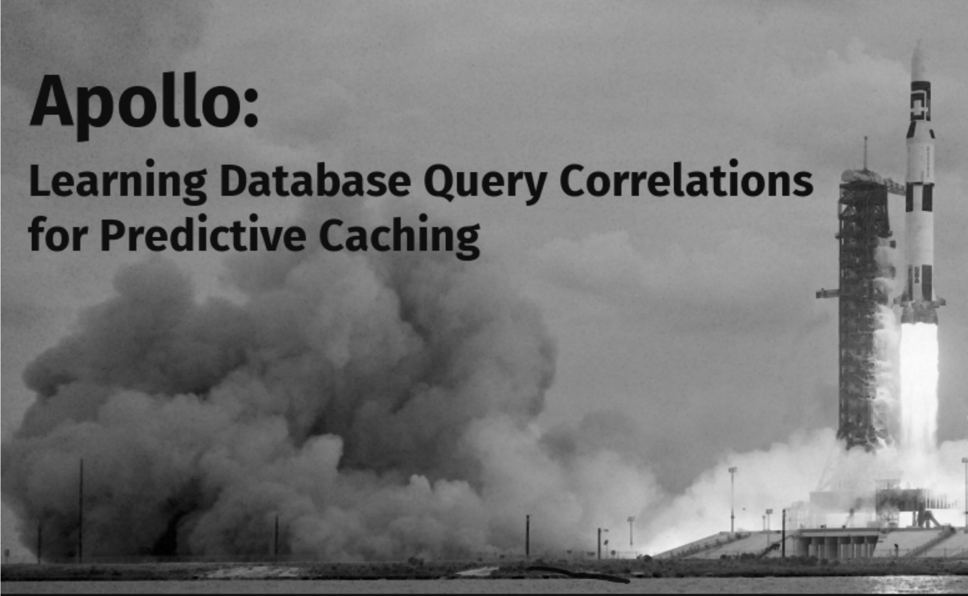


Apollo:

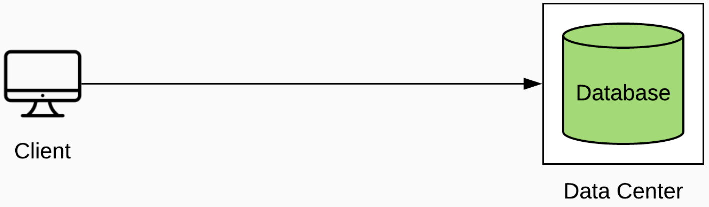
Learning Database Query Correlations for Predictive Caching

Brad Glasbergen

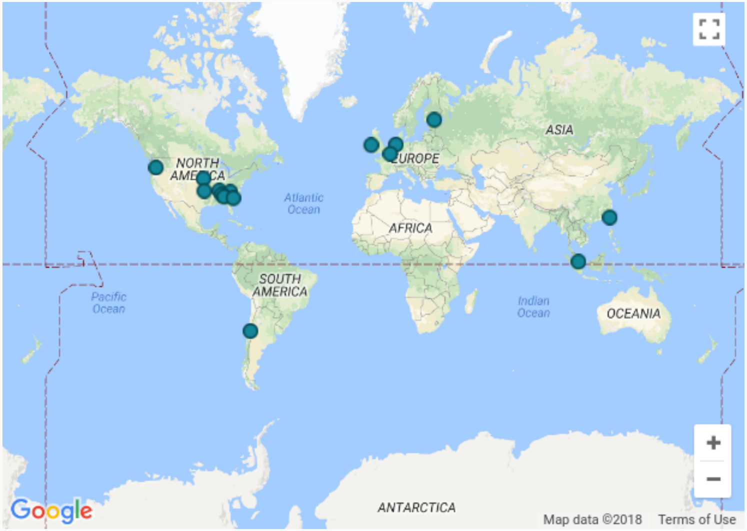
brad.glasbergen@uwaterloo.ca

@bglasber

Simple Web Application Architecture



Worldwide Client/Data Center Distribution



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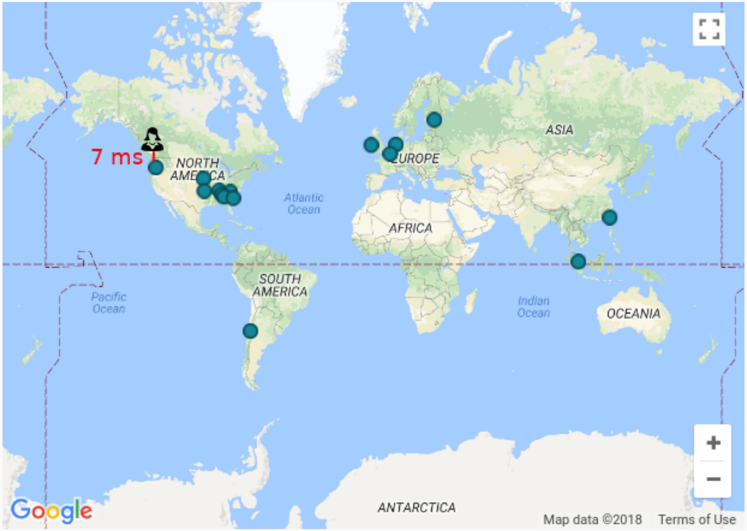
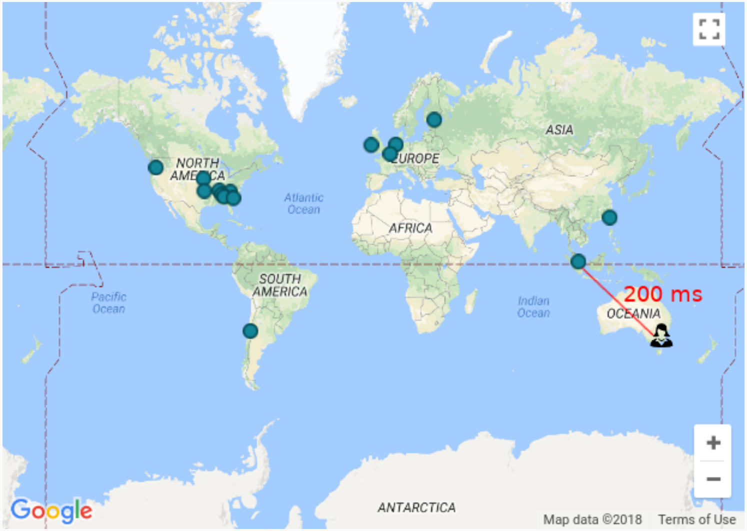


Worldwide Client/Data Center Distribution

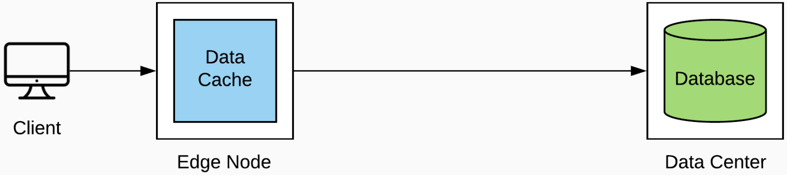


Latency Effects on Clients

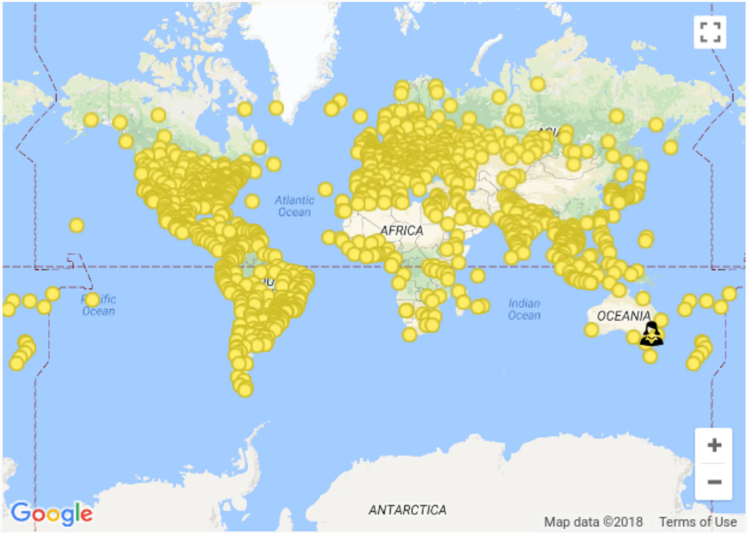
Increased latency reduces user engagement, and consequently revenue!

Schurman et al., “Performance Related Changes and Their User Impact”. *Velocity*, 2009.

Edge Caching (Content Delivery Networks)



Worldwide Client/Edge Node Distribution



Map of metros where at least one Edge node (GGC) is present.

A Problem

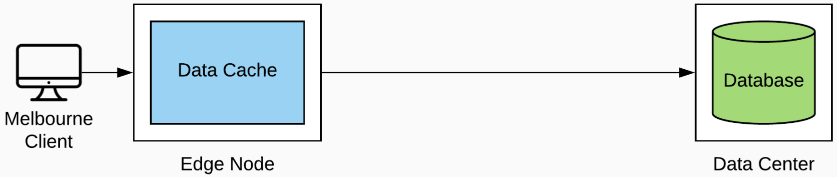
- Limited support for non-static data!

A Problem

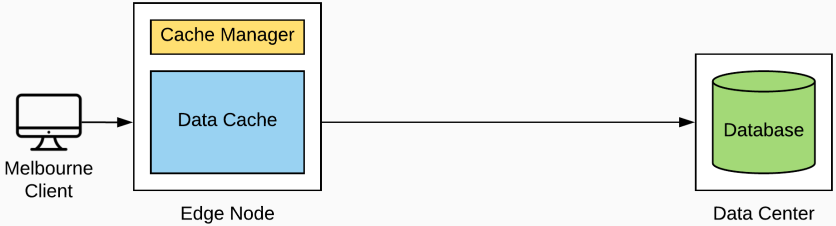
- Limited support for non-static data!
- A majority of webpages rely on personalization and changing data!

Amiri et al., “DBProxy: a dynamic data cache for web applications,” *ICDE*, 2003.

Static Data Edge Cache Architecture



Extending Edge Cache Support



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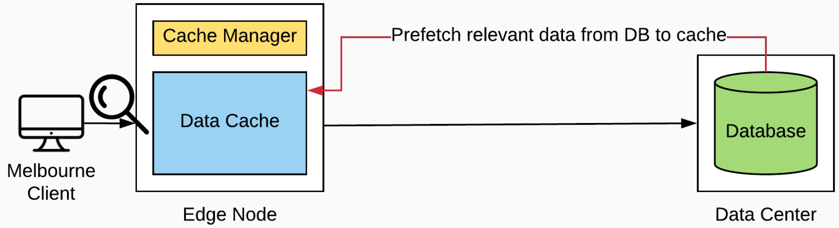


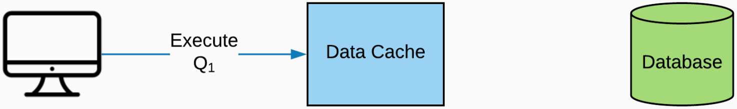
Query Patterns

Execution of a query informs which queries will execute next, and with what parameters.

Dynamic Data Requests (TPC-W Benchmark)

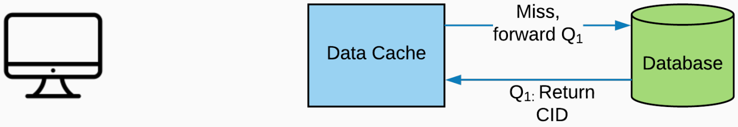
```
1. SELECT  C_ID  FROM CUSTOMER WHERE
C_UNAME = @C_UN and C_PASSWD = @C_PAS

2. SELECT MAX(O_ID) FROM ORDERS WHERE
O_C_ID =  @C_ID
```

Predictive Caching



Q_1: Look up customer ID
Q_2: Look up last order for customer ID

Predictive Caching



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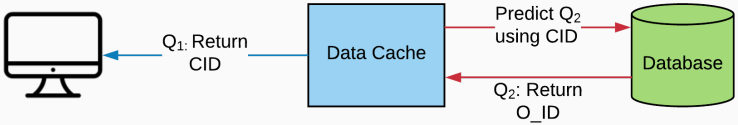
Predictive Caching



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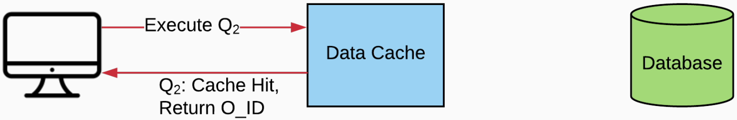

Q_1: Look up customer ID
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Apollo: Caching Dynamic Data

We developed Apollo, a middleware system that:

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- Predictively executes and caches query results using these patterns to reduce client response time.

Apollo: Caching Dynamic Data

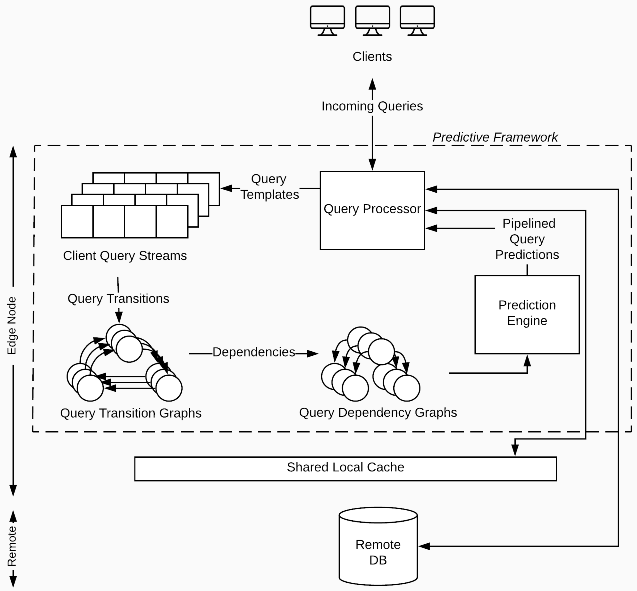
We developed Apollo, a middleware system that:

- Uses online learning to discover client query patterns.
- Predictively executes and caches query results using these patterns to reduce client response time.
- Employs a computationally efficient means of managing updates to cached data.

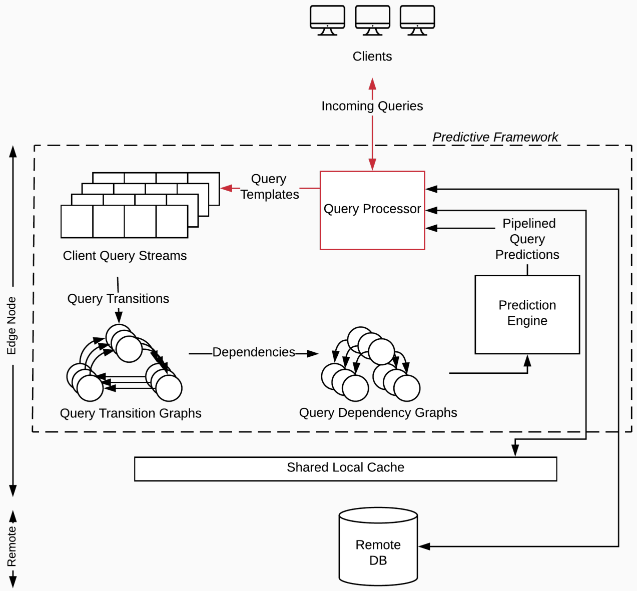
Table of contents

Predictive Query Model

Apollo Overview



Apollo Overview



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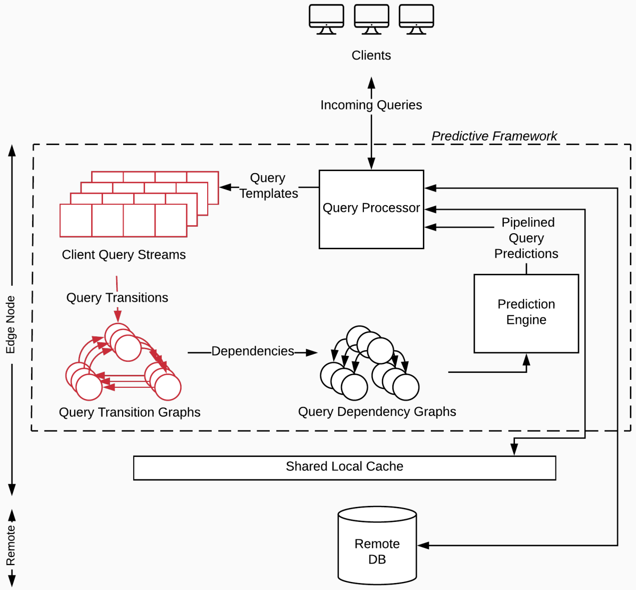

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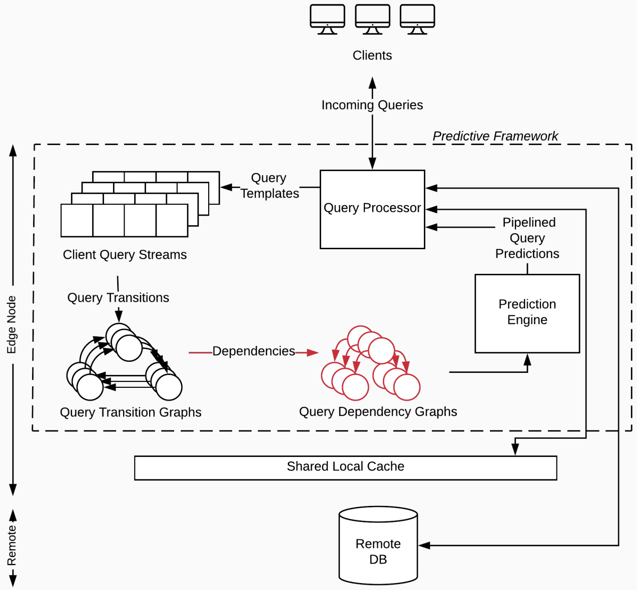

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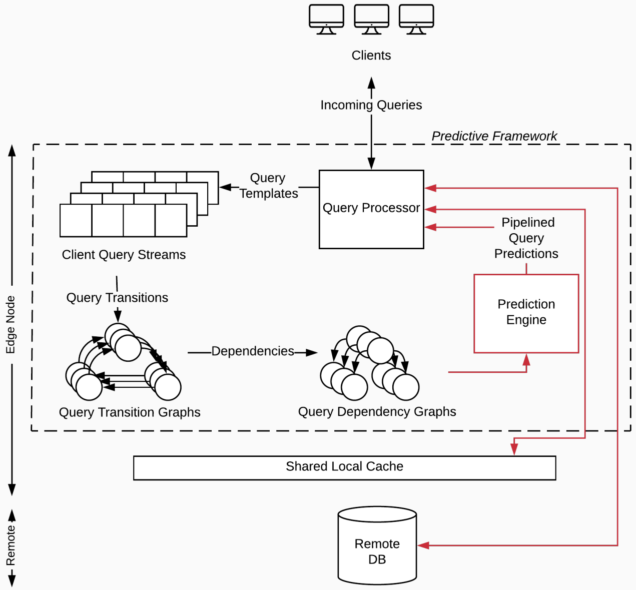

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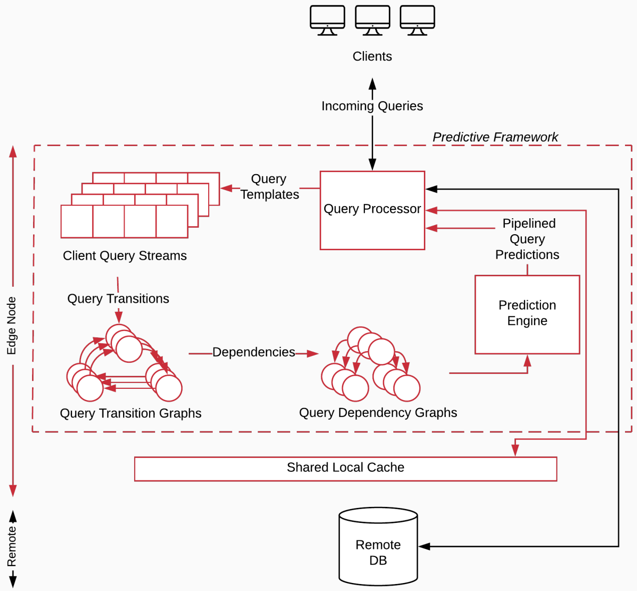

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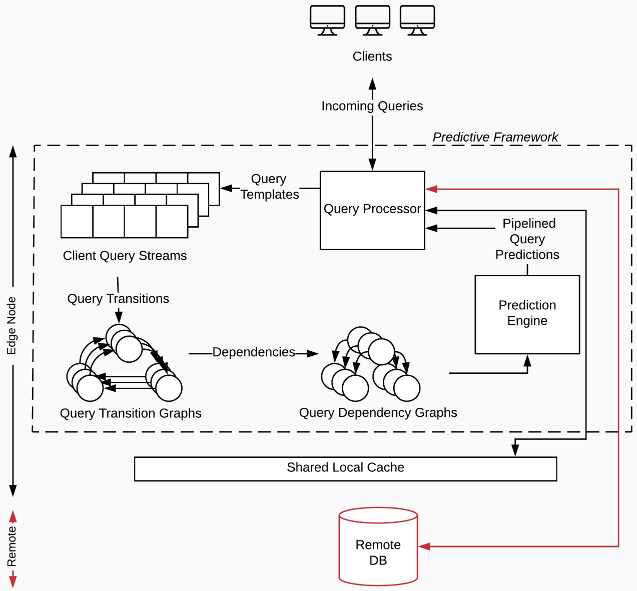


A Query Submission

SELECT $\boxed{\text{C\_ID}}$ FROM CUSTOMER WHERE C_UNAME = 'Alice' and C_PASSWD = 'pass'

SELECT MAX(O_ID) FROM ORDERS WHERE O_C_ID = $\boxed{3}$

Query Templates

Two query instances, Q_1, Q_2 share the same query template if they have the same query text modulo *parameterizable constants*.

Abstracting Query Instances to Query Templates

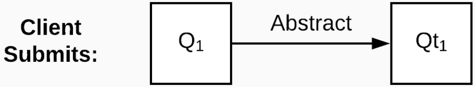
SELECT $\boxed{\text{C\_ID}}$ FROM CUSTOMER WHERE C_UNAME = **?** and C_PASSWD = **?**

SELECT MAX(O_ID) FROM ORDERS WHERE O_C_ID = $\boxed{\textbf{?}}$

Client Query Streams

Client Submits:
Q_1

Client Query Streams



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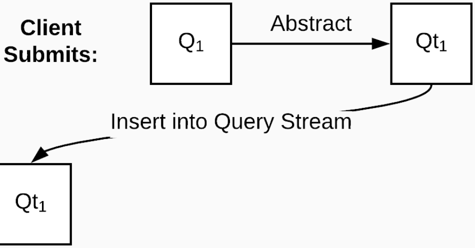

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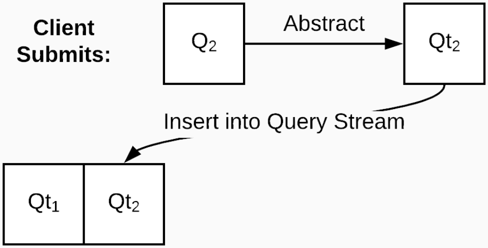

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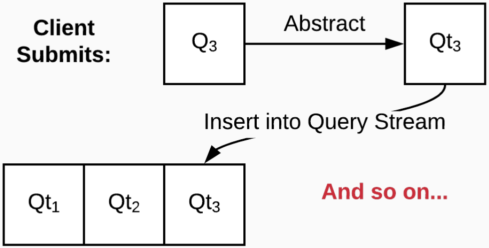
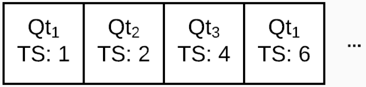


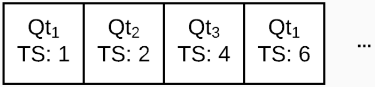
And so on...

Client Query Streams



Client Query Streams

Window Size: 3



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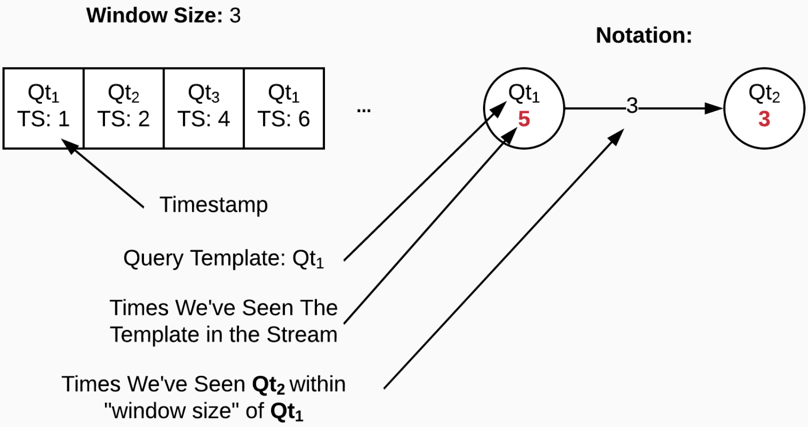

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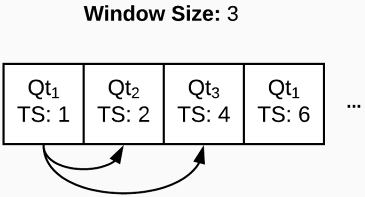

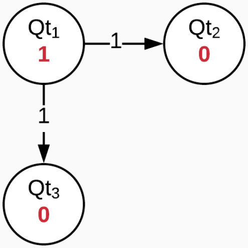

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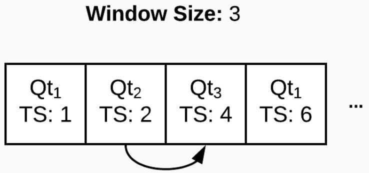

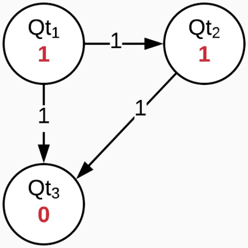

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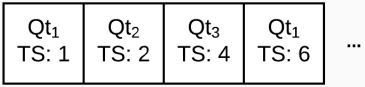

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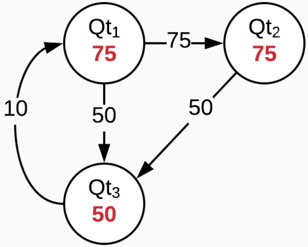
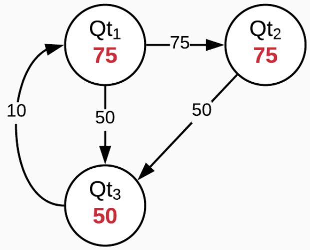


Query Transition Graph



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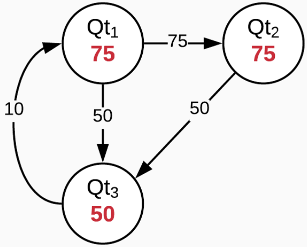

Probability of seeing Qt_2 within sliding window after we've seen Qt_1:

$$P(Qt_2|Qt_1; T \leq \Delta t) = \frac{\text{times } Qt_2 \text{ executed within window of } Qt_1}{\text{times } Qt_1 \text{ executed}} = \frac{75}{75} = 1$$

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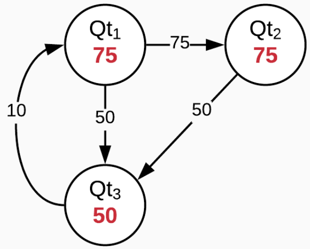

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$P(Qt_1|Qt_3; T \leq \Delta t) = \frac{10}{50} = \frac{1}{5}$

Query Transition Graph

The query transition graphs tells us:

- How often a query template is executed

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- How often a query template is executed
- Which query templates are correlated with each other. If correlation is sufficiently high ($>$ correlation threshold), then we monitor input and output sets for the queries.

Need parameter mappings for predictive caching!

Client Query Streams

SELECT $\boxed{\text{C\_ID}}$ FROM CUSTOMER WHERE C_UNAME = **?** and C_PASSWD = **?**

SELECT MAX(O_ID) FROM ORDERS WHERE O_C_ID = $\boxed{\textbf{?}}$

Client Query Streams

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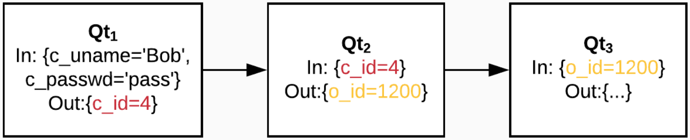
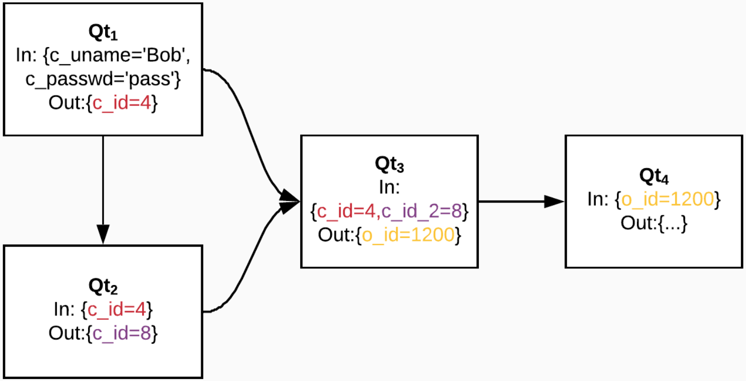
Query Dependency Graph



Core Prediction Routine



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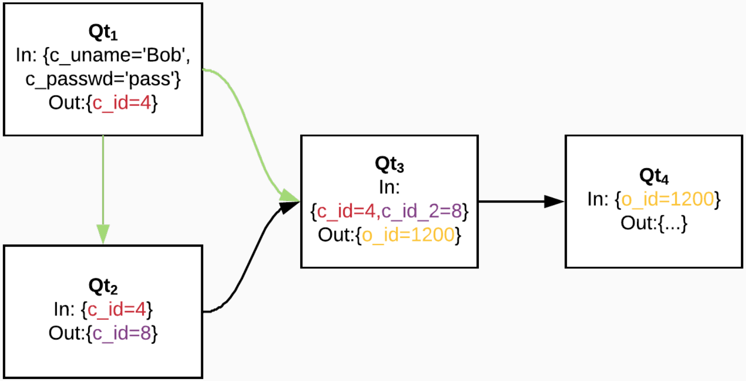

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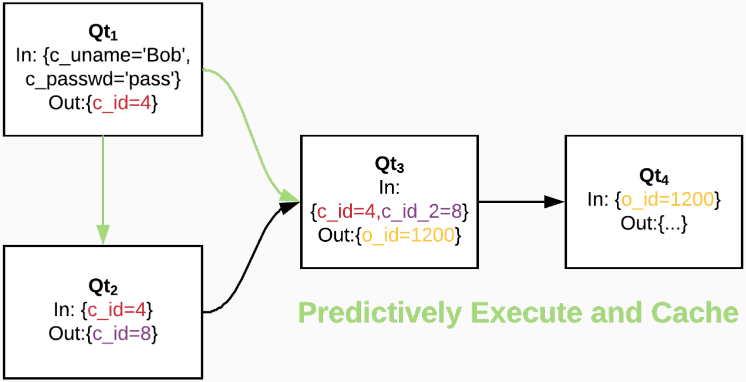
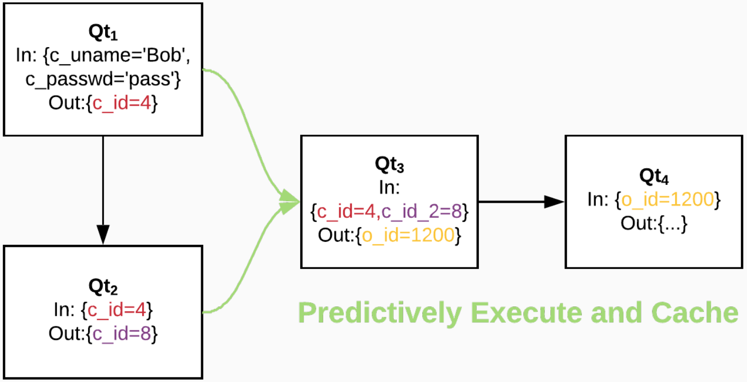


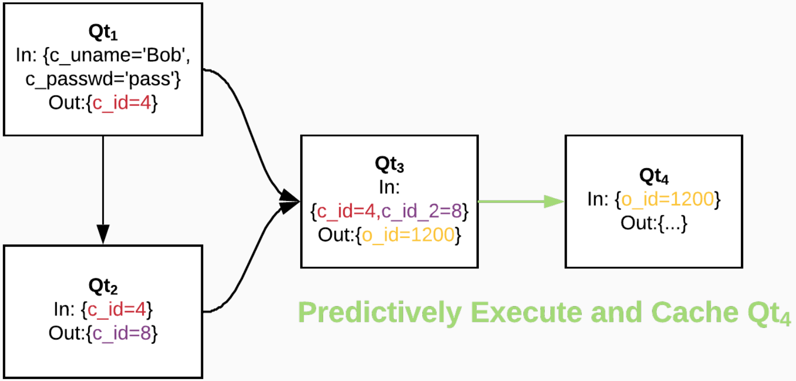
Predictively Execute and Cache Qt_2

Core Prediction Routine

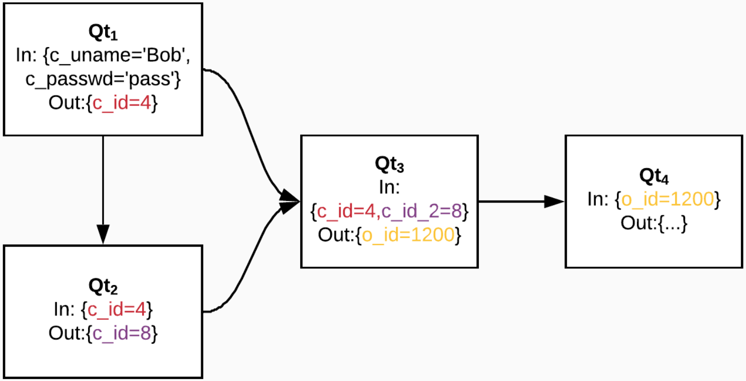


Predictively Execute and Cache Qt_3

Core Prediction Routine



Core Prediction Routine



Predicting Write Queries

Although some write queries (INSERT/UPDATE/DELETE) could be predicted, incorrect predictive executions of such queries would result in modified database state that would need to be undone later.

By predictively executing only read queries, we keep our caching behaviour strictly complementary.

Always Defined Queries

An always defined query is a query whose inputs are always satisfied.

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The query can be executed and cached at any time!

Reloading Always Defined Queries

Reload an always defined query after executing a write query if:

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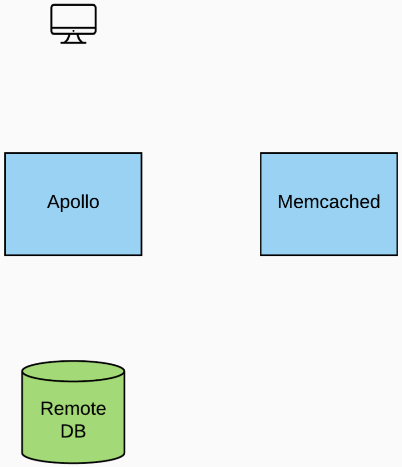
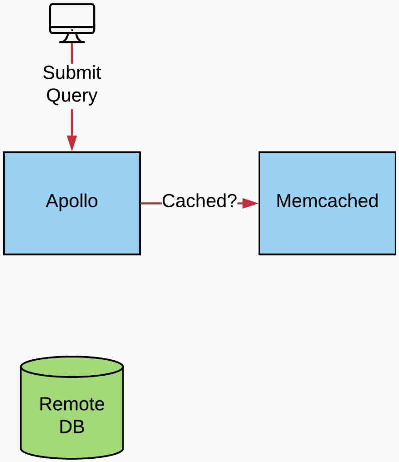
- The query was invalidated!
- The query is considered valuable:
  $\mathit{likelihood\_of\_query}(Qt) \cdot \mathit{avg\_response\_time}(Qt) \geq \text{reload threshold}$

Apollo

Apollo Architecture



Apollo Architecture



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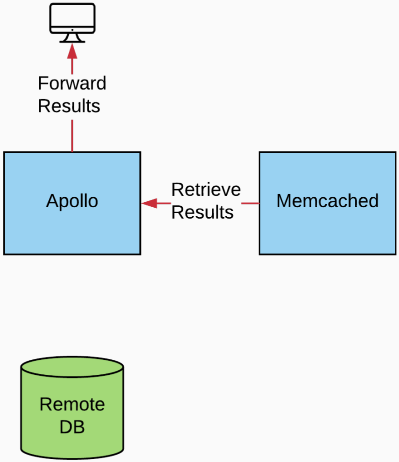

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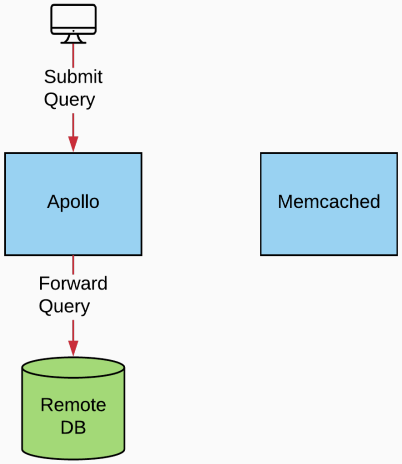

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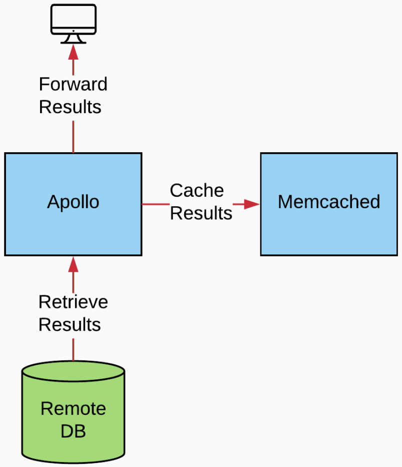

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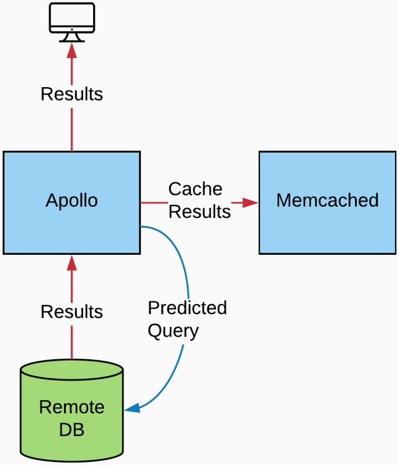

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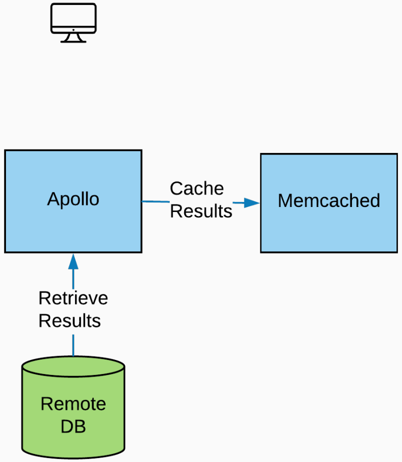

Publish—Subscribe Model

Concurrent requests for the same query will wait until the first query executes and returns its results. That query's result set will be forwarded to the others.

Client Sessions

Clients are guaranteed to see state at least as recent as what they last read/wrote.

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- Client-centric approach to caching!

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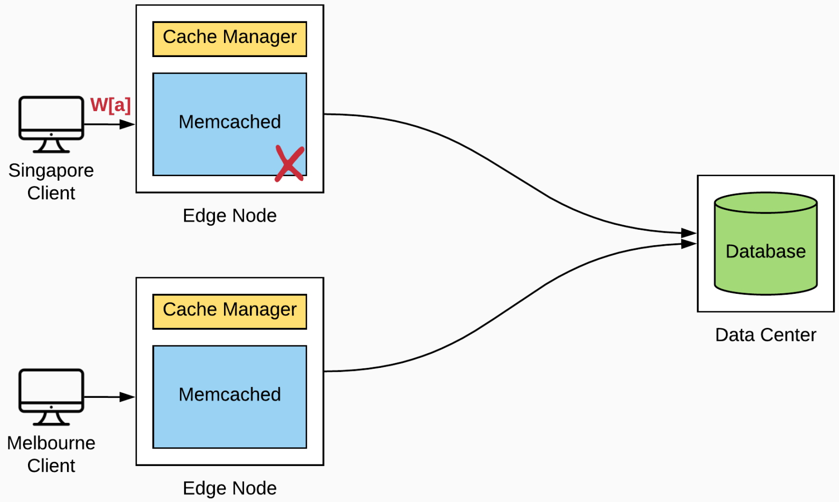
Clients are guaranteed to see state at least as recent as what they last read/wrote.

- Client-centric approach to caching!
- Only writes and reads of “fresher” data cause invalidations!

Benefits

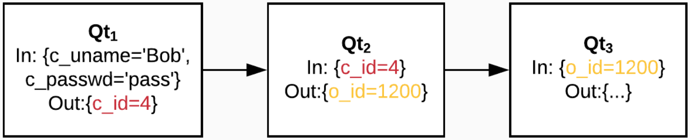


W[a]
Singapore Client
Cache Manager
Memcached
Edge Node
Melbourne Client
Cache Manager
Memcached
Edge Node
Database
Data Center

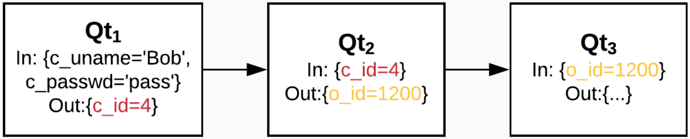
Benefits

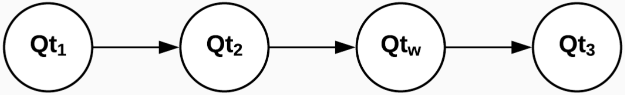
- No global cache invalidations.
- Can predict whether a prefetched query result will be used before invalidation!

Prediction Invalidation Detection



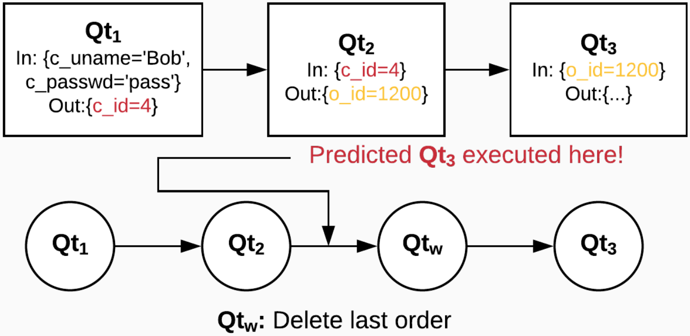
Prediction Invalidation Detection





Qt$_w$: Delete last order

Prediction Invalidation Detection



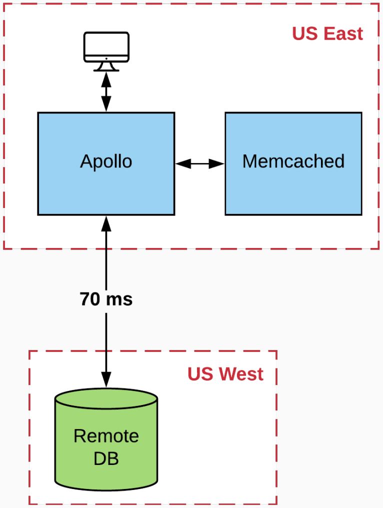
Prediction Invalidation Caching

Prediction Invalidation Caching

- Maintain multiple client transition graphs with different window widths
- Consult client query transition to see if a query is likely to occur that would invalidate the results of our predictively executed query

Experiments

Experiment Configuration



Experiment Configuration

Three configurations:

- Apollo configuration: as described in prior sections.
- Memcached configuration: LRU cache — Apollo with predictive features turned off
- Fido configuration: Use Fido predictive engine instead of Apollo's predictive features!

Fido

$$\underbrace{Q_1, Q_2, Q_3}_{\text{Prefix}}$$

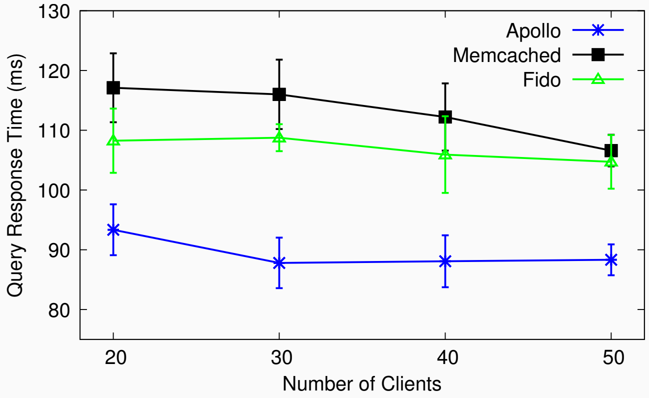
Fido

$$\underbrace{Q_1,Q_2,Q_3}_{\text{Prefix}} \quad \underbrace{Q_4,\ Q_5}_{\text{Suffix}}$$

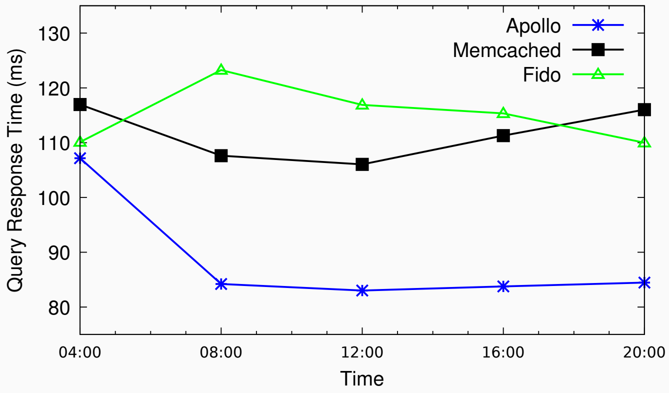
Fido

- Query instance based predictions, instead of query templates.
- Prefix length: 3, Suffix Length: 2
- Requires offline training (Supplied 40 minutes of data).

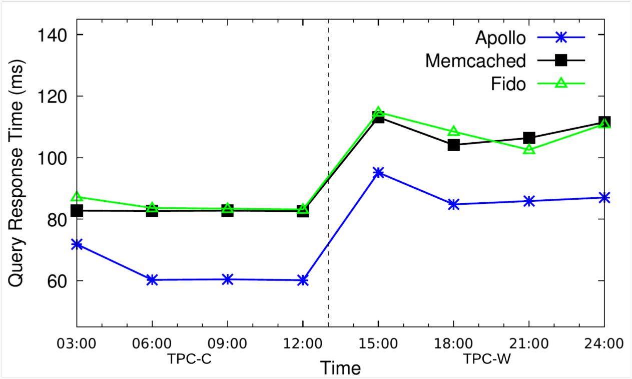
TPC-W Results



Learning Over Time



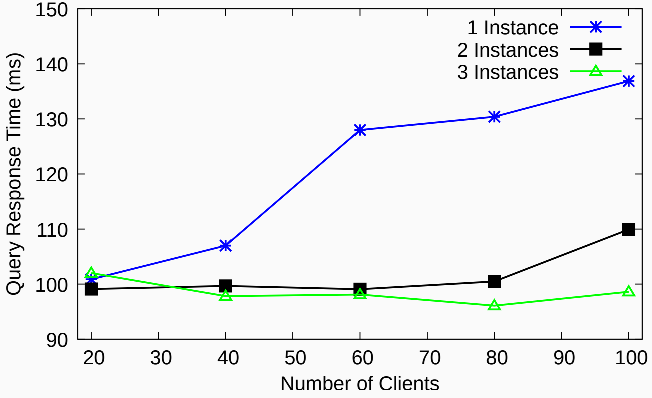
Workload Change



Thanks

Questions?

Multiple Apollo Instances



Parameter Settings (TPC-W)

Parameter	Setting
Window Width	15s
Correlation Threshold	0.99
Reload Threshold	0
Cache Size	5% of DB

Related Work (Systems)

Similarities and Differences Among Related Work

System	Similarities	Differences
Scalpel	• Prefetching via templates	• Offline training • Write Handling • Client-side • Query Rewriting
Fido	• Prefetching • Server-side/middleware	• Offline training • Query Instances • Write Handling

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In *Proceedings 19th International Conference on Data Engineering (Cat. No.03CH37405)*, pages 821–831, March 2003.

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Velocity, 2009.