The HSF Conditions Database Reference Implementation

Andrea Formica[1], Lino Gerlach[2], Giacomo Govi[3],
Paul Laycock[2], Ruslan Mashinistov[2], Chris Pinkenburg[2]

[1]*Université Paris-Saclay (IRFU/CEA, FR)*
[2]*Brookhaven National Lab (US)*
[3]*Fermilab (US)*

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Conditions Data – Introduction

“Conditions data is any additional data needed to process event data”

Changes over time	High access rates	Heterogenous data
• Repeat detector calibration with larger cosmic dataset • Improve calibration algorithms	• Distributed computing jobs access same conditions data simultaneously • Access rates up to ~kHz	• Granularity varies (time indexed, run-indexed, constant) • Structure of payload varies (3D map, time-indexed values, single number, …)
Versioning & configuration	Fast DB queries & effective caching	Payload agnostic by design

Similar challenges for various HEP experiments

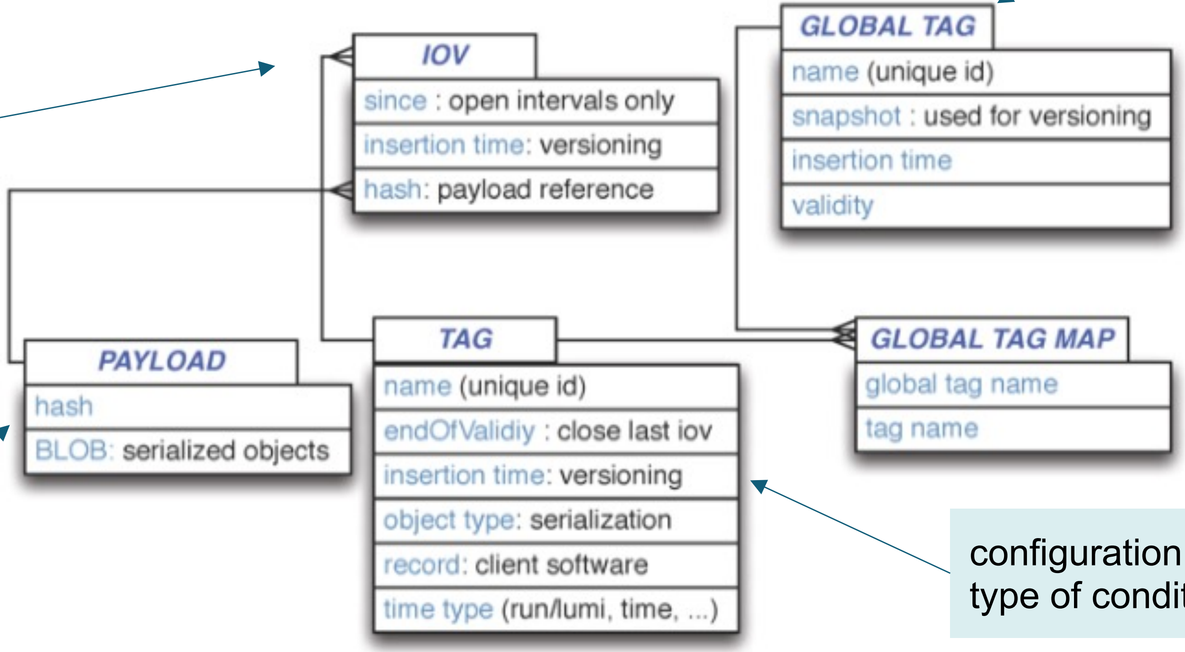
Conditions Data – HSF Recommendations

HEP Software Foundation

- HSF Conditions Databases activity: https://hepsoftwarefoundation.org/activities/conditionsdb.html
  - Discussions across various experiments
- Key recommendations for conditions data handling
  - Separation of payload queries from metadata queries
  - Schema below to organise payloads

top-level configuration of all conditions data

'Interval of Validity': generalized concept of time (begin can be time stamp, run number, lumi block, …)



HEP Software Foundation Community White Paper Working Group – Conditions Data

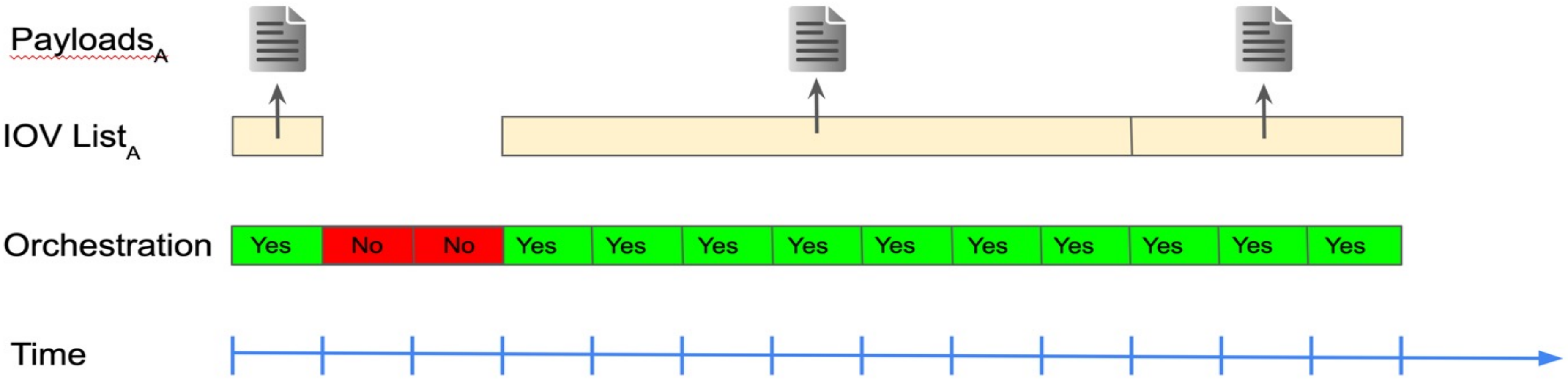
actual data (e.g. in a file)

configuration for each type of conditions data

Conditions Data – Use Cases

- HSF Conditions Database meeting: **use cases** https://indico.cern.ch/event/1280790/
- Most can be realised w/ HSF Recomm.
- Exception: **Fast-Processing**. Goal:
  - Publish data for analysis fast
  - Maximize physics performance

Use case	Example
Online	• High Level Trigger
Reprocessing	• Run reco w/ improved calib.
Analysis	• High level physics analysis
Development	• Test new calib. within existing GT
★ Fast-processing	• Process data w/ just-in-time calib.

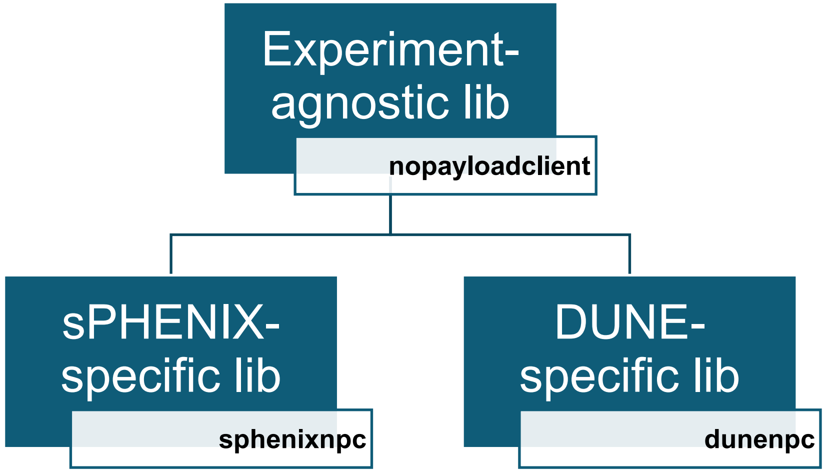


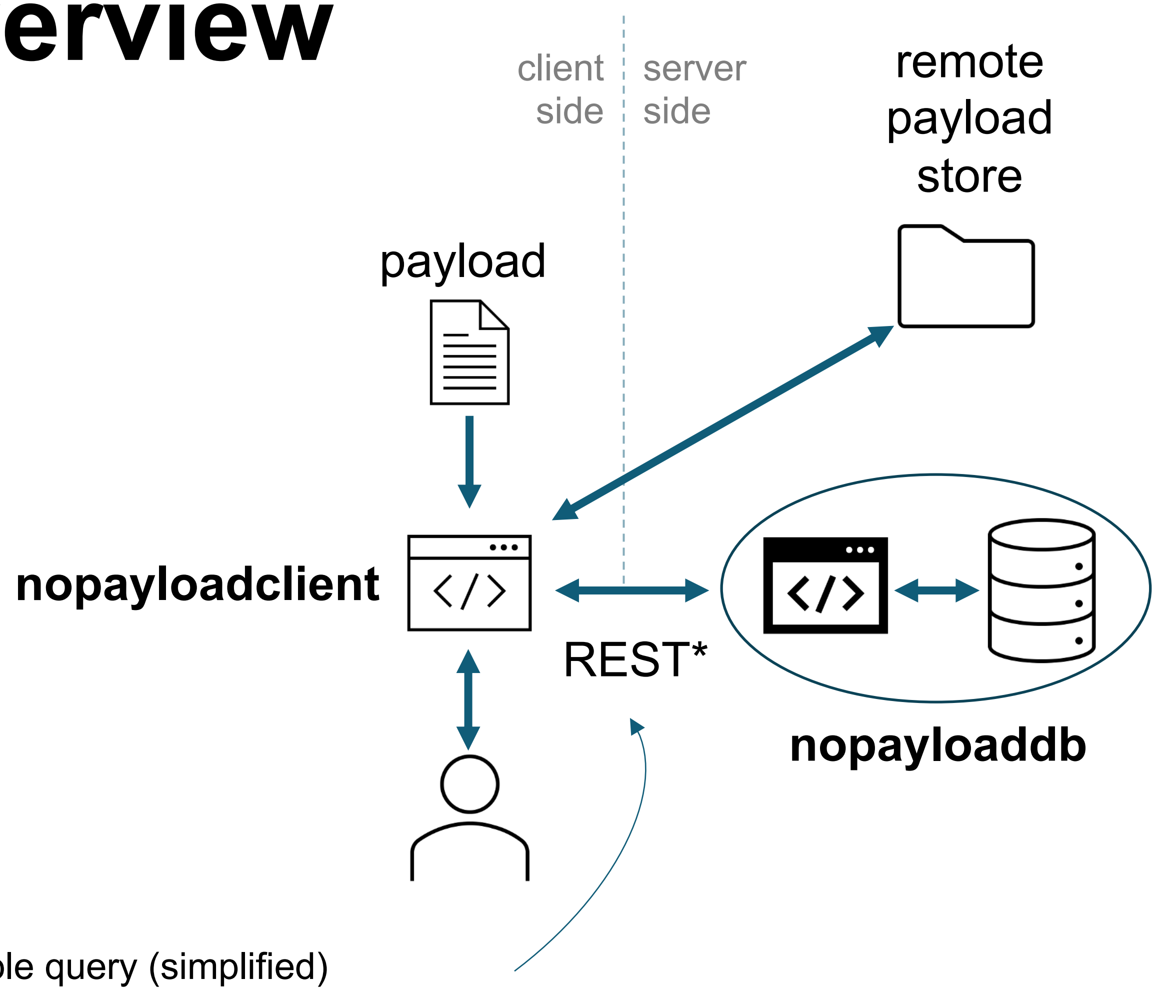
Need additional info: end of IOV

Implementation – Overview

nopayloadclient:

- Client-side stand-alone C++ tool
- Communicates with **nopayloaddb** (server)
- Local caching
- Handling of payloads



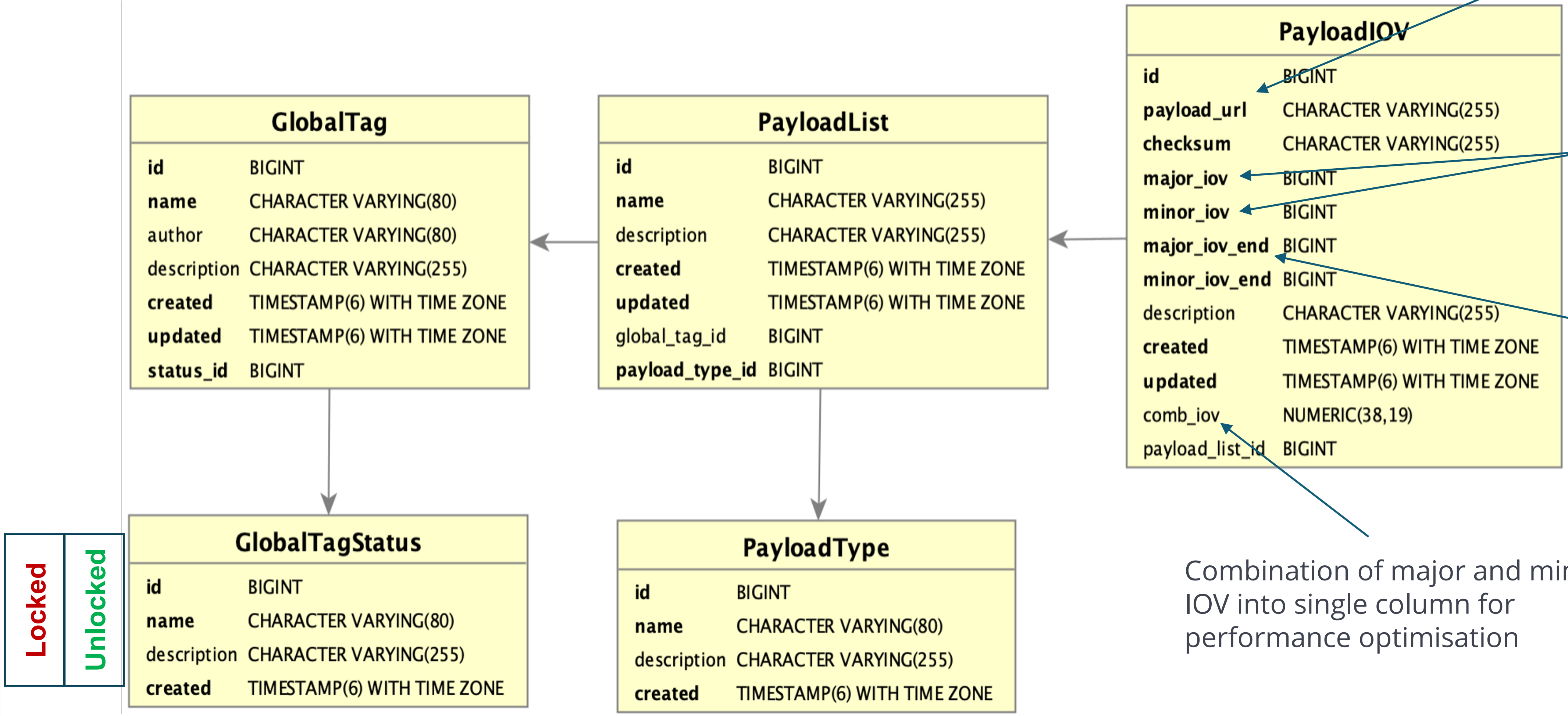


*Example query (simplified)

```
curl http://<host>/api/payloadiovs/?gtName=test_gt&iovNum=42
-> {type_1: url_1, type_2: url_2, …}
```

Implementation – Database Schema

Payloads are not stored in schema

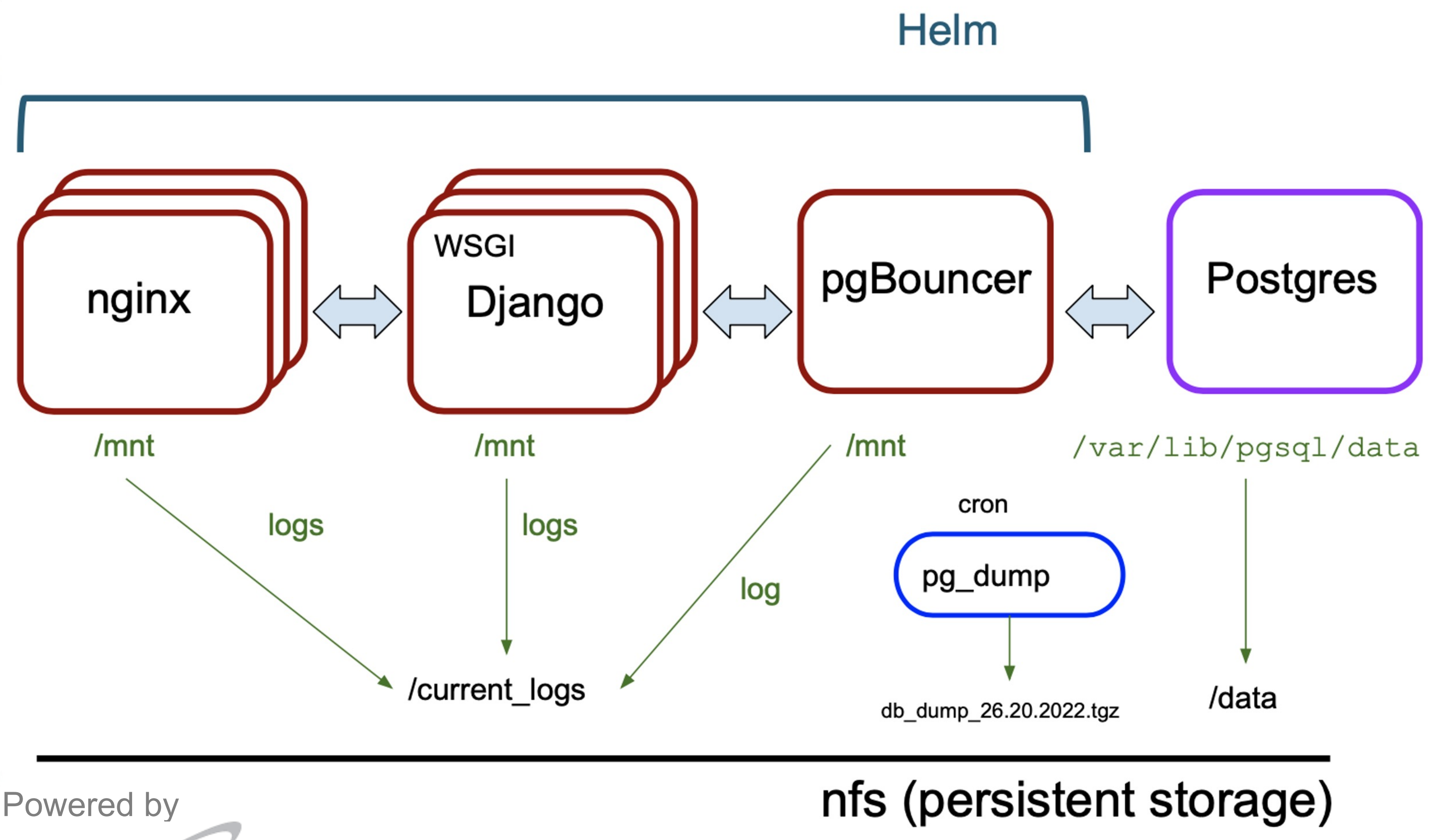


major- & minor IOV for more flexibility

IOVs also have an end

Combination of major and minor IOV into single column for performance optimisation

Deployment on OKD



- Automated deployment on OKD (Helm chart)
- Horizontally scalable
- Open Source only

Easily adoptable for various HEP experiments

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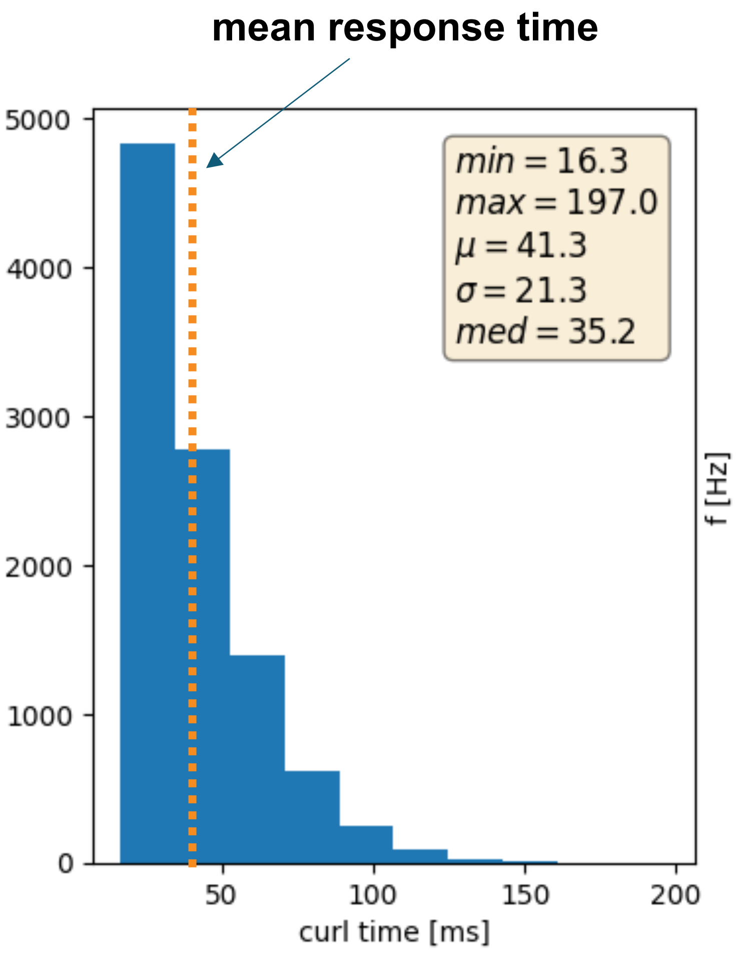
Performance Testing – Strategy

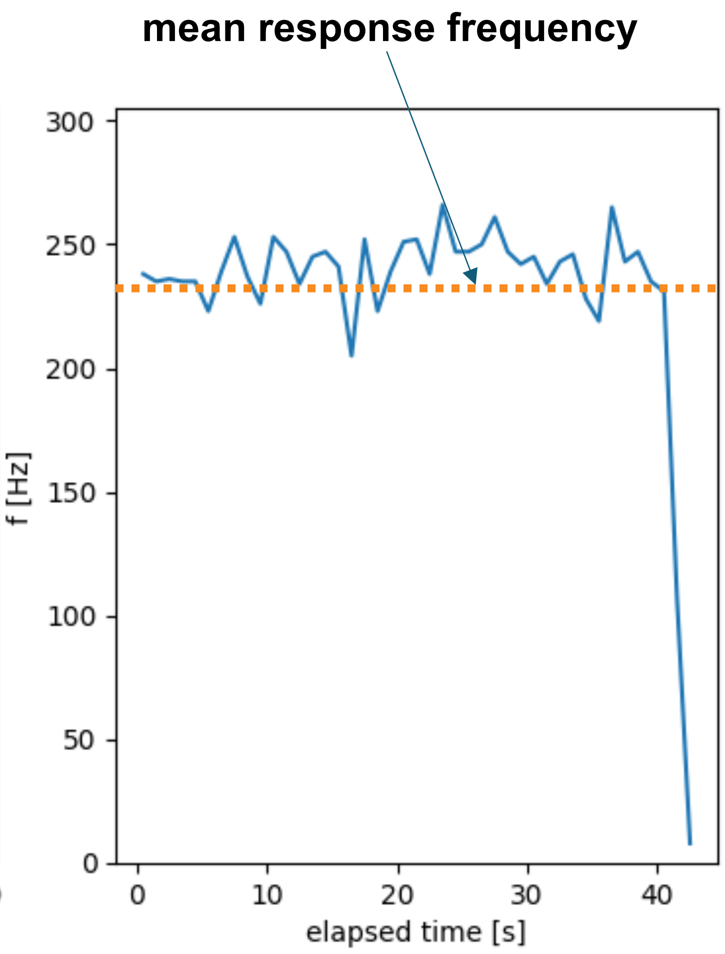
- Simulate expected DB occupancy
- Simulate access patterns
  - Query read API for payload URL
  - Parallel requests via HTC or MT

Scenario	Payload Types	Payload IOVs (per type)
tiny	10	100 (10)
tiny-moderate	10	2000 (200)
moderate	100	20000 (200)
heavy-usage	100	500000 (5000)
worst-case	200	5200000 (26000)

All following tests:

- Random major- and minor IOV, no caching
- Query metadata only, no payloads

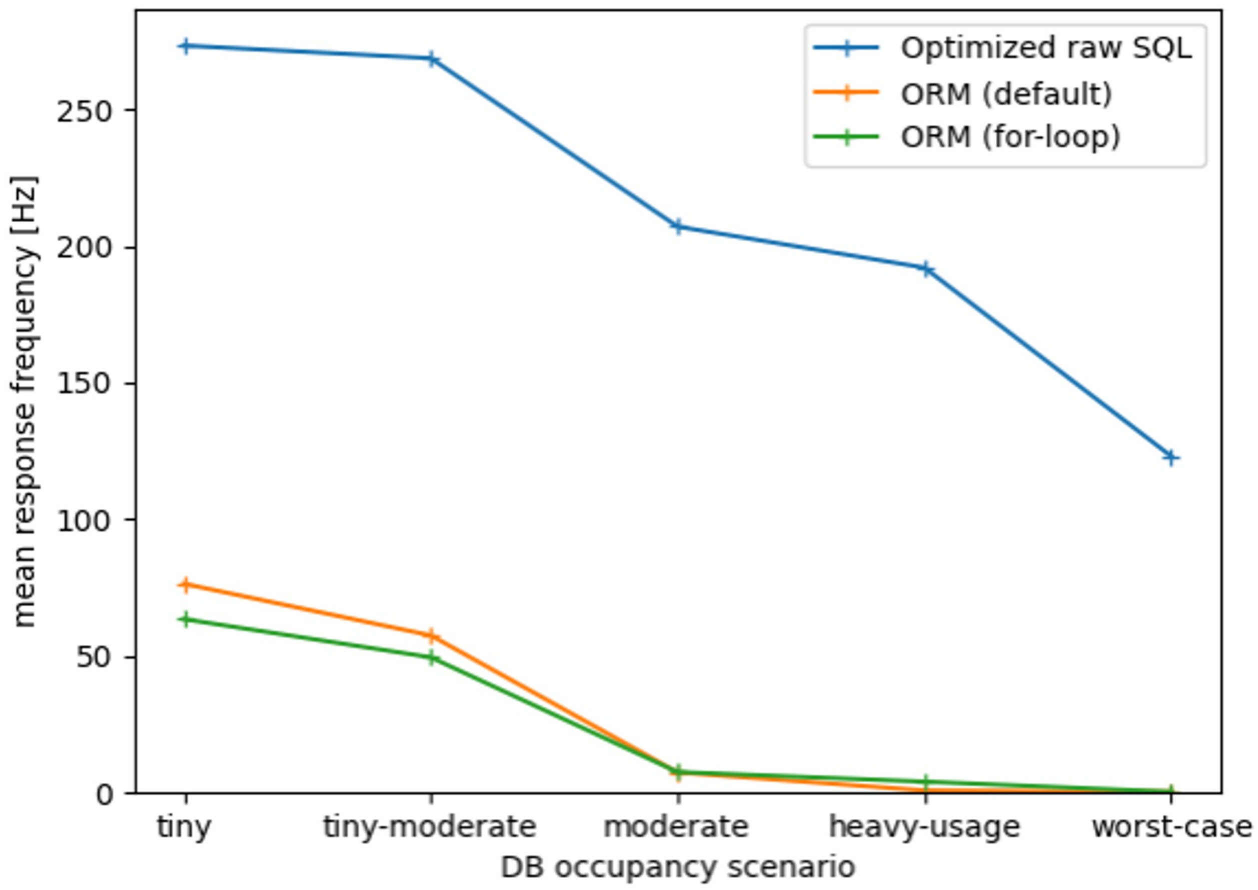




Performance Testing – ORM vs Raw SQL

- High frequency read API workflow:
  - Filter on global tag, major- and minor IOV *
  - Find ‘latest’ IOV for each payload type **
  - Return payload type, file URL, IOV
- Django’s ORM writes query for user
- Optimized raw SQL query
  - Covering index (index-only scan)
  - Combined IOV column <major.minor>
  - Lateral join operation

Resp. freq. vs size of queried GT

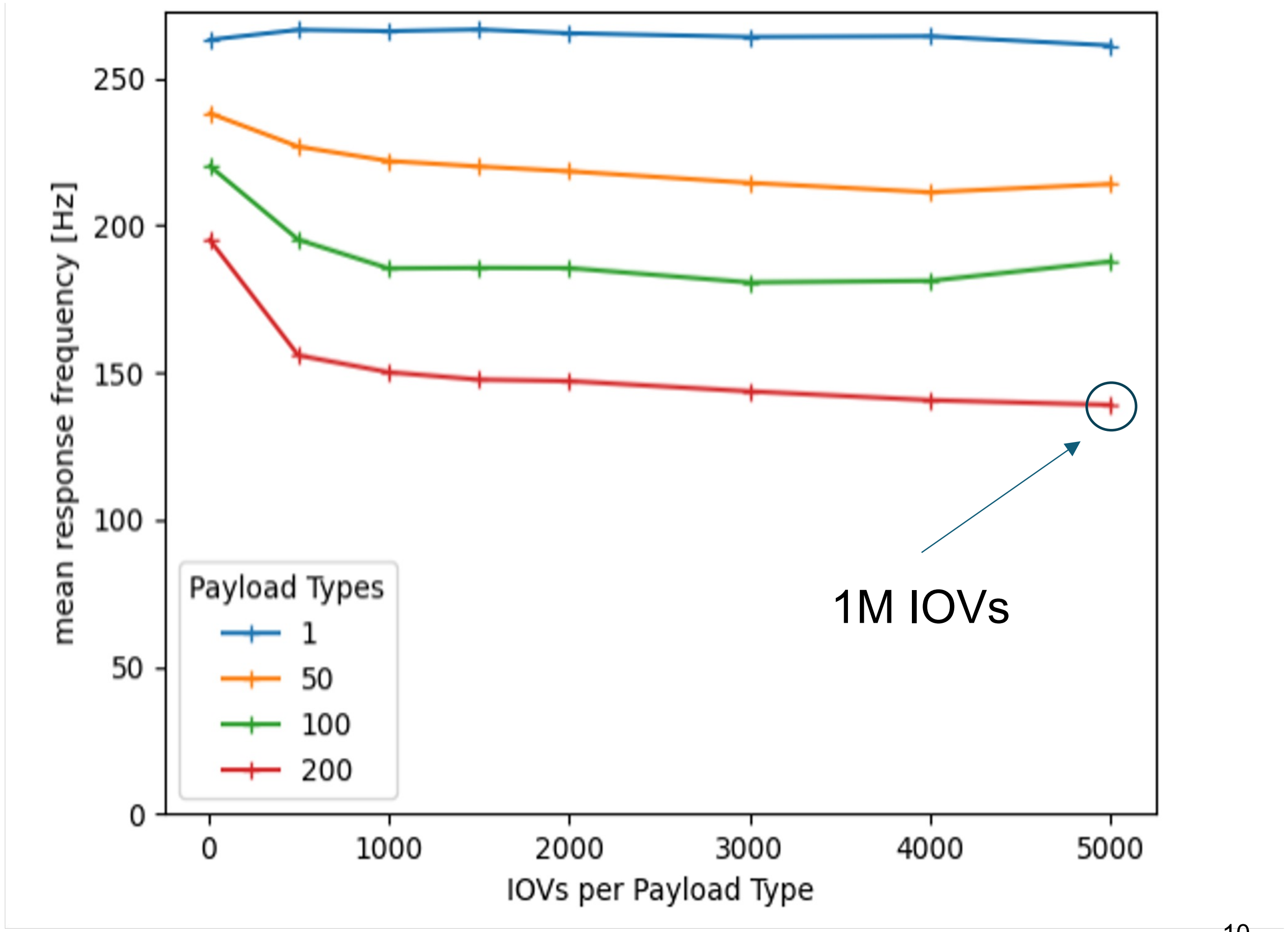


*: my_major<major_iov OR (my_major=major_iov AND my_minor<=minor_iov) **: for max major_iov, find max minor_iov

Performance Testing – Scaling

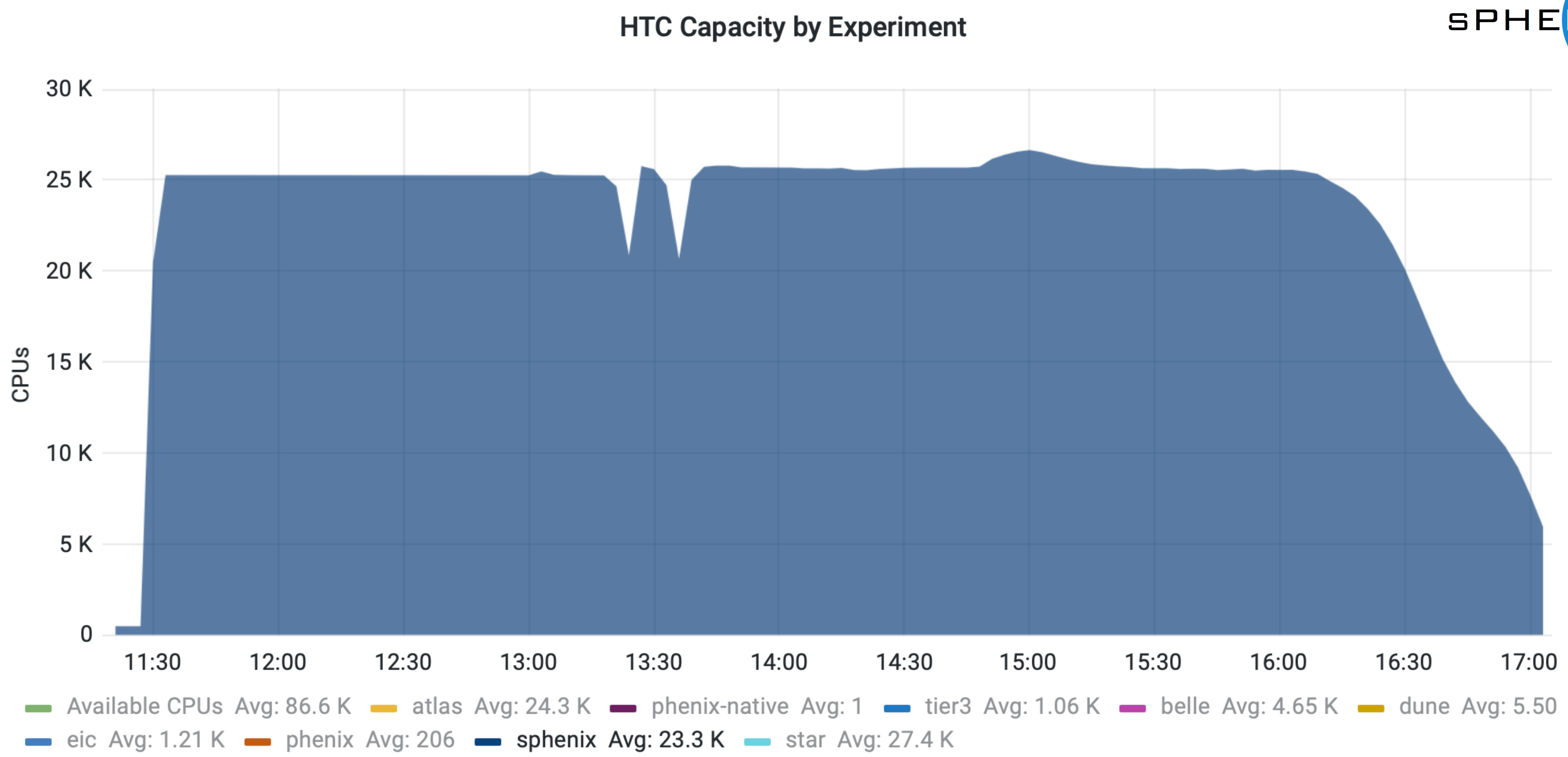
- Investigate scaling w/ size of queried GT
  - Content of DB remains constant
- Measure mean response frequencies
  - Scales with number of payload types
    - More data to sort and return
  - Almost flat vs number of IOVs
    - Index scan (covering index)
- Also tested scaling w.r.t. size of DB
  - No dependence, plot in backup

Resp. freq. vs size of queried GT



Conclusion

- HSF recommends how to handle conditions data
- Presented experiment-agnostic reference implementation
  - Django REST API: **nopayloaddb**
    - Automized deployment on OKD
  - C++ client-side client: **nopayloadclient**
- Performance tests show solid results
  - After raw SQL query optimisation
- Already in use at sPHENIX
- ProtoDUNE planning to deploy as well

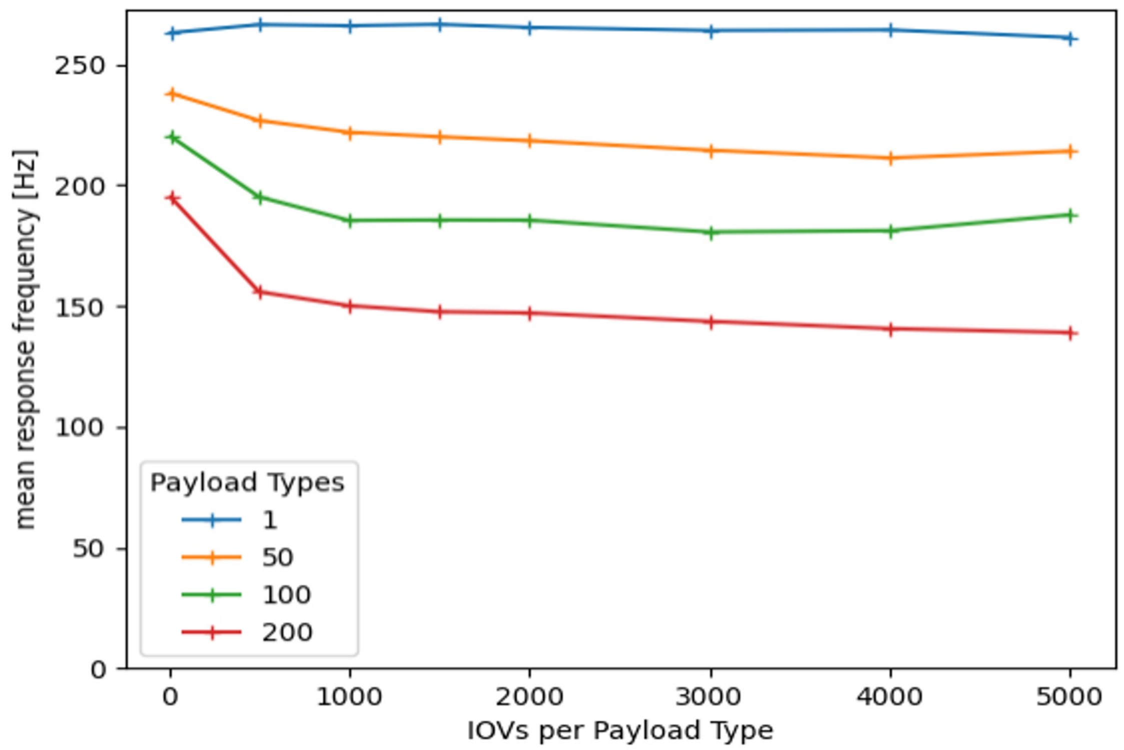


Thank you for your Attention!

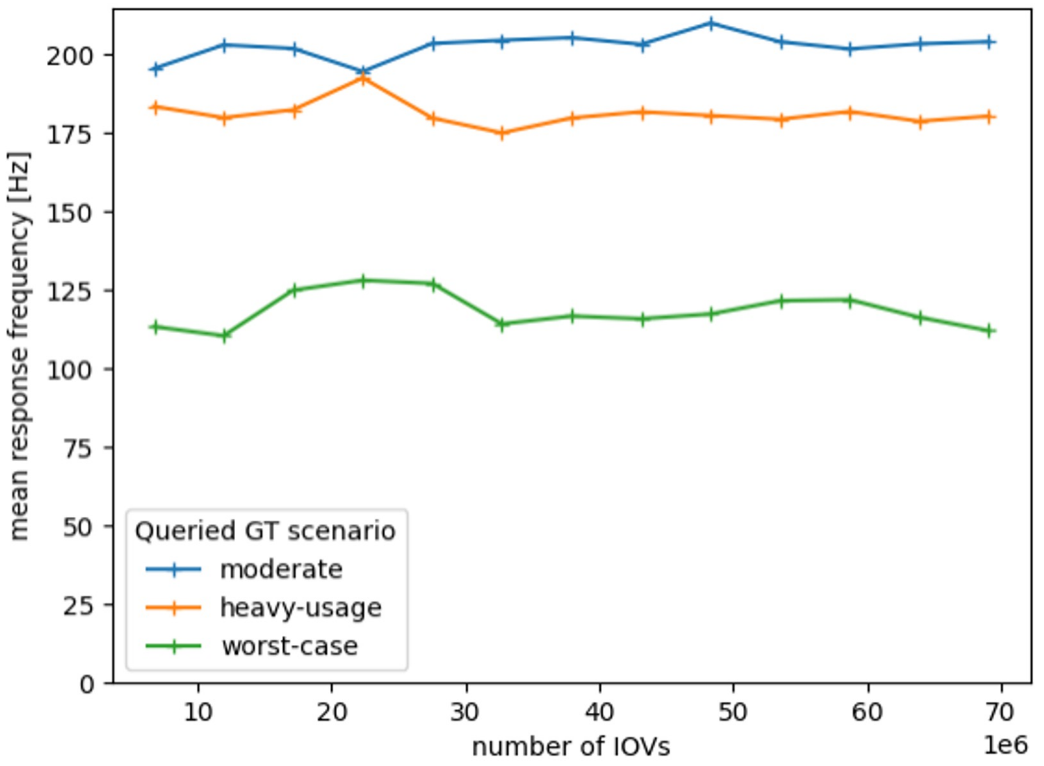
Backup

Performance Testing – Scaling

Resp. freq. vs size of queried GT



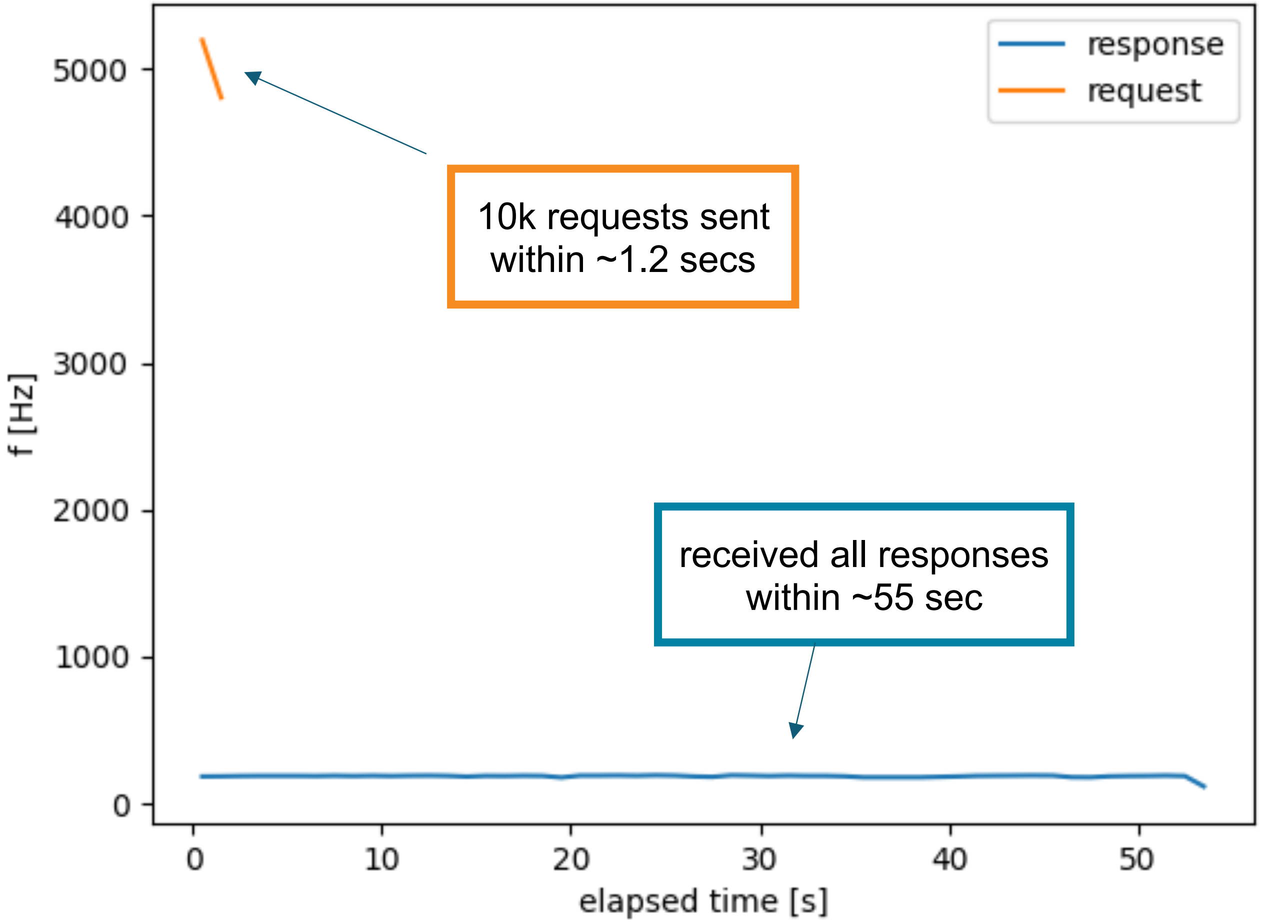
Resp. freq. vs DB size



- Scales with number of payload types
- Almost flat w.r.t. number of IOVs

- Performance depends on size of queried GT
- Additional ‘stuff’ in DB has no significant impact

Performance Testing – High Frequency

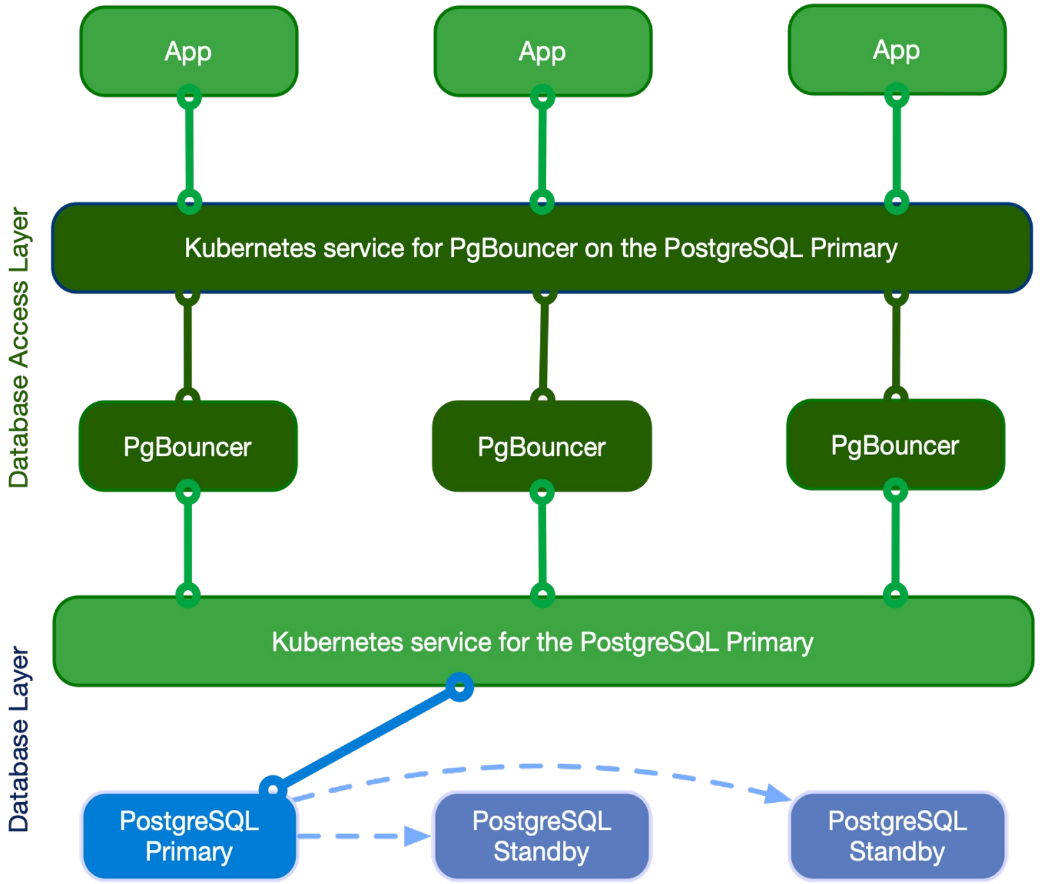


- Simulate offline reco use case
  - Many jobs launched at same time
- Cooperative multithreading (**asynchio**)
  - Send requests firsts
  - Process responses later
- Allows very high peak request frequency
- Server-side queuing of requests works

PostgreSQL High-Availability Cluster

Open source Kubernetes operator for HA PostgreSQL

- Consider DB cluster for high-availability and higher performance
- CloudNativePG:
  - Open source operator (Kubernetes) for PostgreSQL
  - Primary / Standby architecture
  - Native support for pgBouncer connection pooling



PayloadIOV Read API – Raw SQL Query

```
SELECT pi.payload_url, pi.major_iov, pi.minor_iov,
pt.name, …
FROM "PayloadList" pl
JOIN "GlobalTag" gt ON pl.global_tag_id = gt.id AND
gt.name = %(my_gt)s
JOIN LATERAL (
  SELECT payload_url, major_iov, minor_iov, …
  FROM   "PayloadIOV" pi
  WHERE  pi.payload_list_id = pl.id
    AND pi.comb_iov <= CAST(%(my_major_iov)s +
CAST(%(my_minor_iov)s AS DECIMAL(19,0)) / 10E18 AS
DECIMAL(38,19))
  ORDER BY pi.comb_iov DESC
  LIMIT 1
) pi ON true
JOIN "PayloadType" pt ON pl.payload_type_id = pt.id;
```

For each PayloadList (Type)

Get Payloads descending ordered by combined IOV

Limit return to 1 line - latest Payload for a given IOVs

And then append the results of each subquery to create the final output

- LATERAL joining. Without LATERAL, each sub-SELECT is evaluated independently and so cannot cross-reference any other FROM item
- Covering index on Payload table including combined IOV and reference to the PayloadList

Investigating Query Plans - I

```
Hash Join  (cost=7.23..410.15 rows=86 width=70) (actual time=6.111..365.158 rows=200 loops=1)
   Hash Cond: (pl.payload_type_id = pt.id)
   ->  Nested Loop  (cost=0.71..403.40 rows=86 width=69) (actual time=6.017..364.977 rows=200 loops=1)
         ->  Nested Loop  (cost=0.15..11.70 rows=86 width=16) (actual time=0.048..0.133 rows=201 loops=1)
               ->  Seq Scan on "GlobalTag" gt  (cost=0.00..1.09 rows=1 width=8) (actual time=0.023..0.025 rows=1 loops=1)
                     Filter: ((name)::text = 'worst-case'::text)
                     Rows Removed by Filter: 6
               ->  Index Scan using "PayloadList_global_tag_id_2b35c85f" on "PayloadList" pl
                            (cost=0.15..9.75 rows=86 width=24) (actual time=0.022..0.083 rows=201 loops=1)
                     Index Cond: (global_tag_id = gt.id)
         ->  Limit  (cost=0.56..4.53 rows=1 width=61) (actual time=1.815..1.815 rows=1 loops=201)
               ->  Index Only Scan using combo_covering_idx on "PayloadIOV" pi
                            (cost=0.56..3484.55 rows=876 width=61) (actual time=1.815..1.815 rows=1 loops=201)
                     Index Cond: (payload_list_id = pl.id)
                     Filter: ((major_iov < 100000000) OR ((major_iov = 100000000) AND (minor_iov <= 100000000)))
                     Rows Removed by Filter: 24669
                     Heap Fetches: 0
   ->  Hash  (cost=4.01..4.01 rows=201 width=17) (actual time=0.078..0.078 rows=201 loops=1)
         Buckets: 1024  Batches: 1  Memory Usage: 19kB
         ->  Seq Scan on "PayloadType" pt  (cost=0.00..4.01 rows=201 width=17) (actual time=0.018..0.043 rows=201 loops=1)
 Planning Time: 0.996 ms
 Execution Time: 365.221 ms
```

major- & minorIOV

```
Hash Join  (cost=7.23..90.89 rows=86 width=70) (actual time=0.309..3.244 rows=200 loops=1)
   Hash Cond: (pl.payload_type_id = pt.id)
   ->  Nested Loop  (cost=0.71..84.14 rows=86 width=69) (actual time=0.075..2.935 rows=200 loops=1)
         ->  Nested Loop  (cost=0.15..11.70 rows=86 width=16) (actual time=0.028..0.121 rows=201 loops=1)
               ->  Seq Scan on "GlobalTag" gt  (cost=0.00..1.09 rows=1 width=8) (actual time=0.013..0.018 rows=1 loops=1)
                     Filter: ((name)::text = 'worst-case'::text)
                     Rows Removed by Filter: 6
               ->  Index Scan using "PayloadList_global_tag_id_2b35c85f" on "PayloadList" pl
                            (cost=0.15..9.75 rows=86 width=24) (actual time=0.012..0.063 rows=201 loops=1)
                     Index Cond: (global_tag_id = gt.id)
         ->  Limit  (cost=0.56..0.82 rows=1 width=61) (actual time=0.014..0.014 rows=1 loops=201)
               ->  Index Only Scan using combo_covering_idx on "PayloadIOV" pi
                            (cost=0.56..232.55 rows=876 width=61) (actual time=0.013..0.013 rows=1 loops=201)
                     Index Cond: ((payload_list_id = pl.id) AND (major_iov < 100000000))
                     Heap Fetches: 0
   ->  Hash  (cost=4.01..4.01 rows=201 width=17) (actual time=0.073..0.074 rows=201 loops=1)
         Buckets: 1024  Batches: 1  Memory Usage: 19kB
         ->  Seq Scan on "PayloadType" pt  (cost=0.00..4.01 rows=201 width=17) (actual time=0.008..0.036 rows=201 loops=1)
 Planning Time: 0.645 ms
 Execution Time: 3.299 ms
```

Only majorIOV

Investigating Query Plans - II

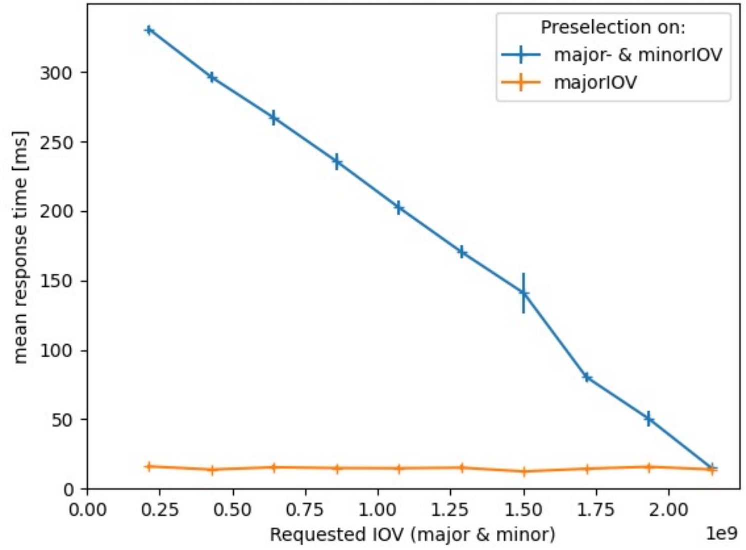
```
->  Limit  (cost=0.56..4.53 rows=1 width=61) (actual time=1.815..1.815 rows=1 loops=201)
      ->  Index Only Scan using combo_covering_idx on "PayloadIOV" pi
                   (cost=0.56..3484.55 rows=876 width=61) (actual time=1.815..1.815 rows=1 loops=201)
            Index Cond: (payload_list_id = pl.id)
            Filter: ((major_iov < 100000000) OR ((major_iov = 100000000) AND (minor_iov <= 100000000)))
            Rows Removed by Filter: 24669
            Heap Fetches: 0
```

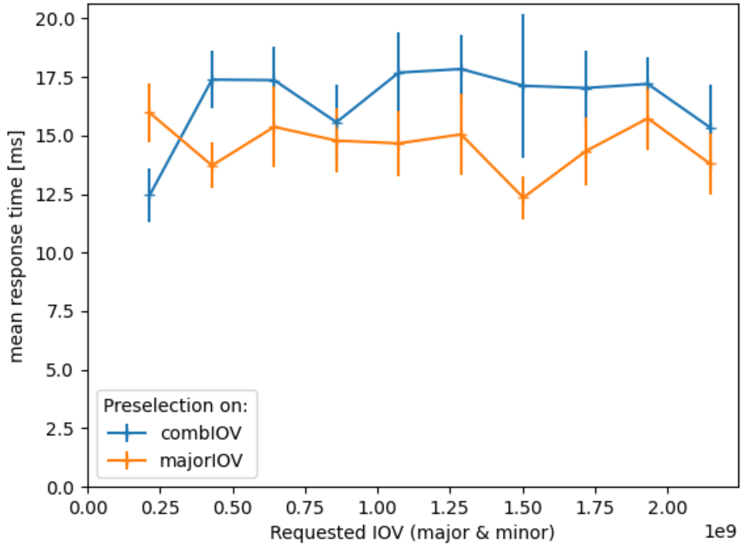
Index Condition & Filter

```
->  Limit  (cost=0.56..0.82 rows=1 width=61) (actual time=0.014..0.014 rows=1 loops=201)
      ->  Index Only Scan using combo_covering_idx on "PayloadIOV" pi
                   (cost=0.56..232.55 rows=876 width=61) (actual time=0.013..0.013 rows=1 loops=201)
            Index Cond: ((payload_list_id = pl.id) AND (major_iov < 100000000))
            Heap Fetches: 0
```

Index Condition Only

Raw SQL - Combined IOV Column





- Preselection on major- & minor IOV (AND / OR)
  - Scales with entries to consider
  - Query uses ‘Filter’
- Preselection on single column (<=)
  - Constant time
  - Query uses ‘Index Condition’
- Combine major- and minor IOV into single column:

major_iov	minor_iov	comb_iov
477658914	1001747433	477658914.0000000001001747433
23283443	1525747152	23283443.0000000001525747152
1834979804	648013294	1834979804.0000000000648013294
bigint	bigint	decimal(38, 19)

- Fast across all values while selecting on both