The HSF Conditions Database

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Overview

- What is Conditions Data?
- Brief history recap: from idea to ‘HSF project’
- Features, implementation & deployment
- Performance testing
- Experience from experiments: sPHENIX, DUNE, Belle II
- Outlook & conclusion

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

Road to HSF CDB Project - Simplified

- Experts from various experiments get together
  - Describe problem to be solved
  - Write white paper w/ requirements
- Define public API specification, which specific solutions should follow
- Implementation with support from HSF
  - as Affiliated Project or HSF Project (see Liz’s talk)

In reality…

Road to HSF CDB Project - Reality

- sPHENIX@BNL needed a CDB. Belle2's solution, run at BNL, lacked scalability
- HSF white paper suggested scalable DB schema
  - Much input from CMS and ATLAS (Many thanks to Andrea Formica in particular!)
- Started to develop reference implementation according to guidelines of that paper
  - Define use cases & requirements in parallel w/ HSF activity (paper 99% complete)
- Presented implementation and performance results at CHEP
  - Garnered attention and interest from HEP community
- The reference implementation is successfully running in production for sPHENIX
- Drove forward HSF integration, published source code, put it under Apache 2.0 license
  - Now listed as 'HSF project' https://hepsoftwarefoundation.org/projects.html

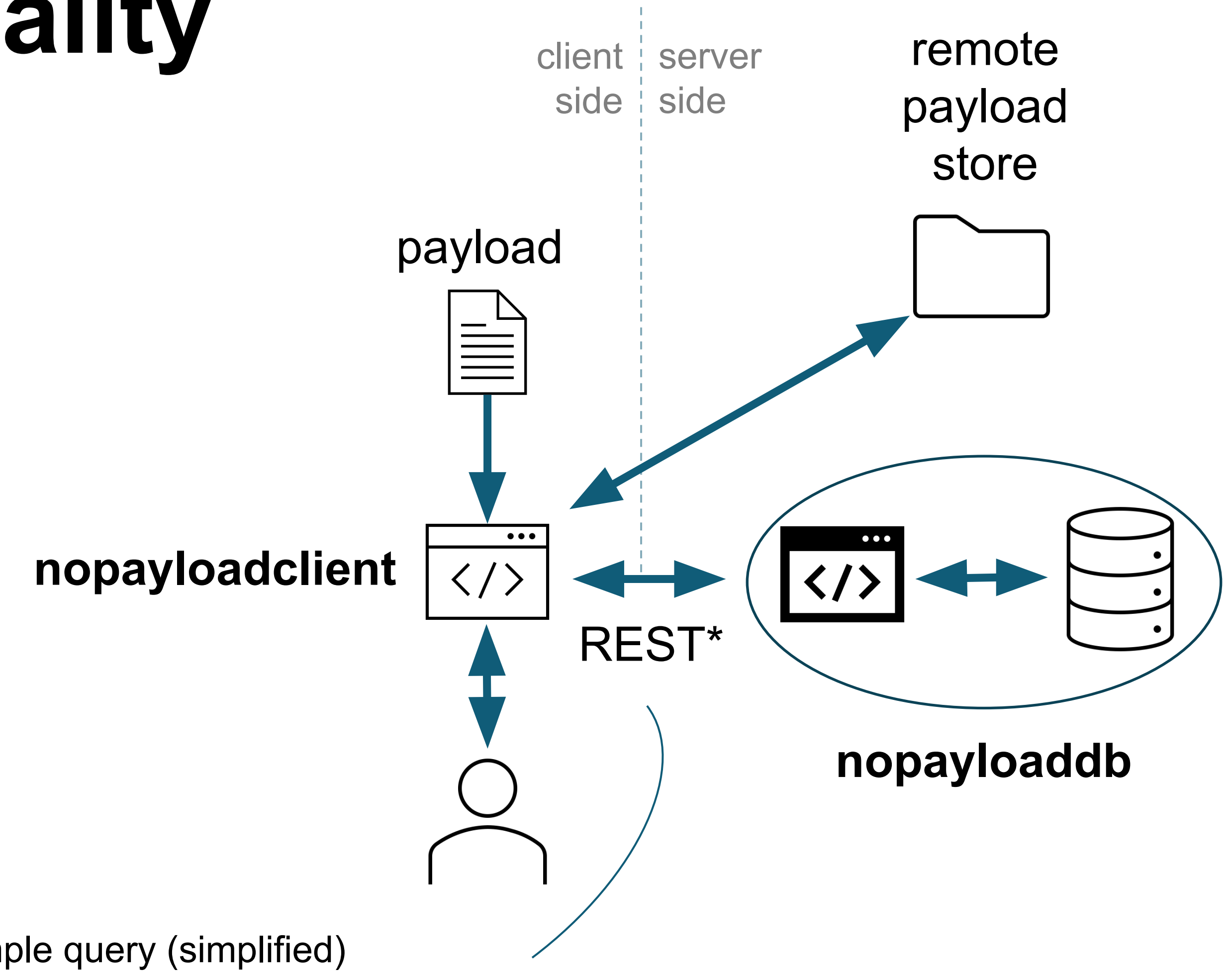
Features & Functionality

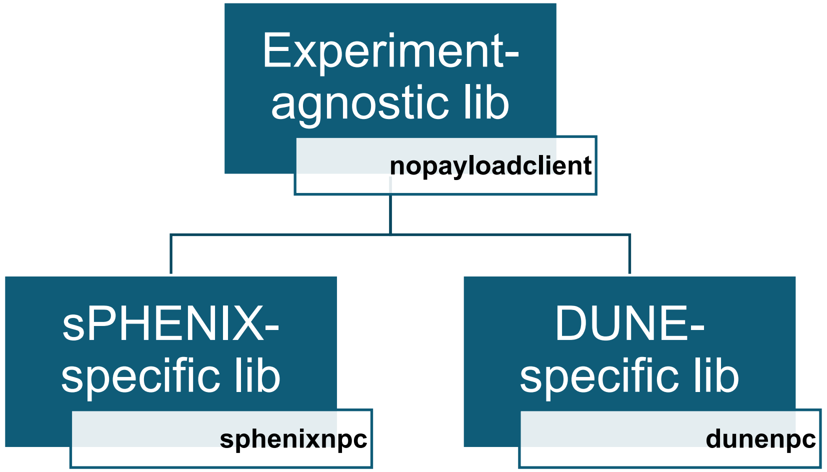
- Payload agnostic by design, loose server-client-coupling (REST Interface)
  - Database only stores the metadata, not the payloads (**nopayloaddb**)
- Proven scalability O(100M) payloads
- Easy deployment, configuration & horizontal scaling
- Standalone CLI & easy-to-integrate C++ client library
- Various caching options
- Based completely on open source software:
  - Postgres, Django python API, C++ client library
  - Deployed on kubernetes and / or OKD, config via helm

Features & Functionality

nopayloadclient:

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

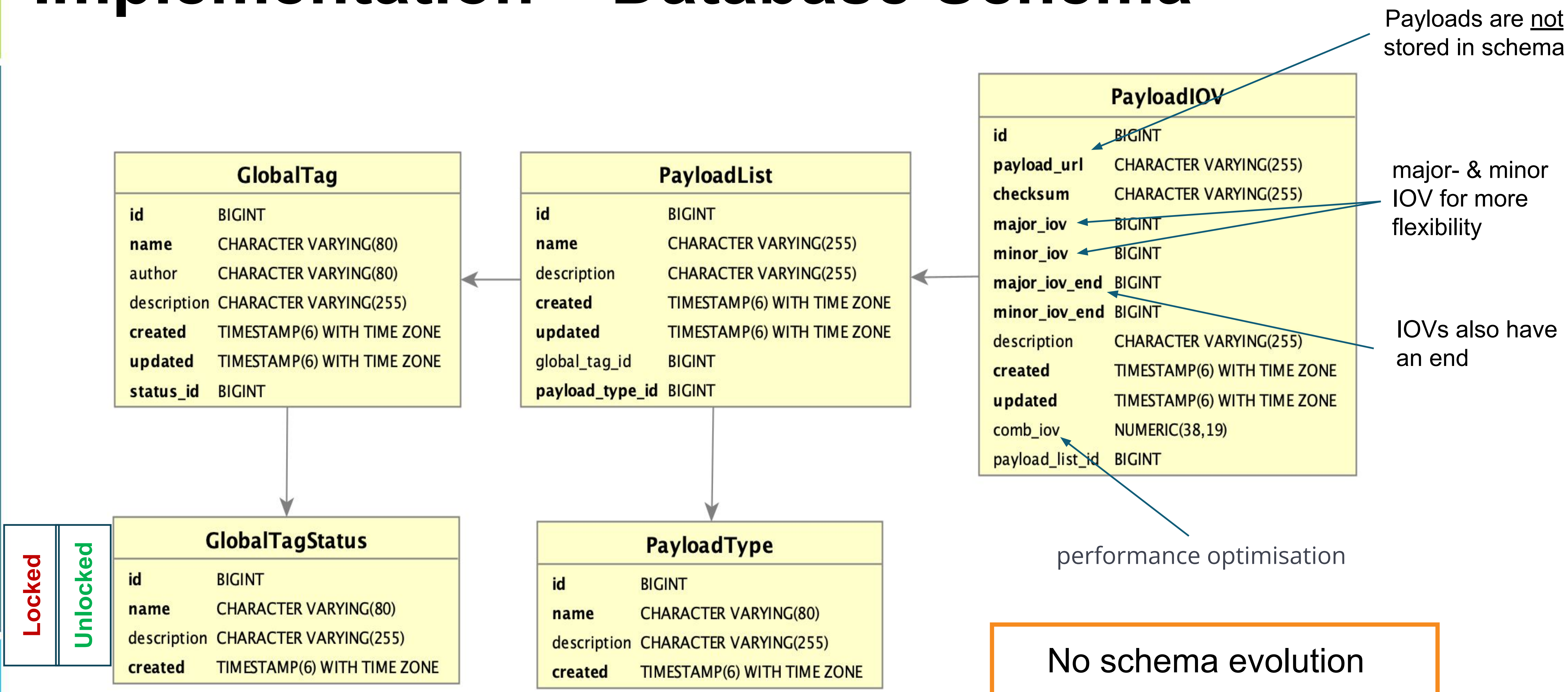




*Example query (simplified)

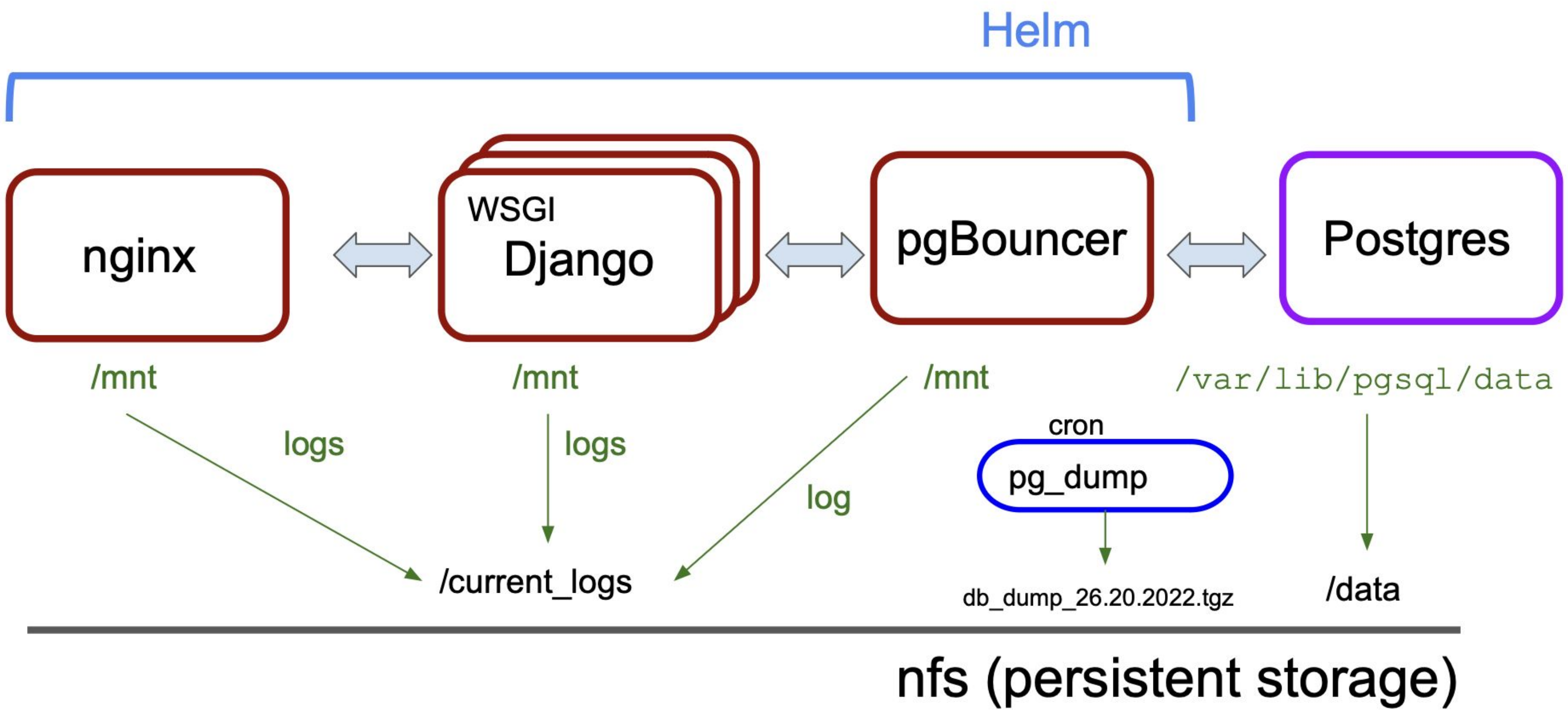
```
curl http://<host>/api/payloadiovs/?gtName=test_gt&iovNum=42
-> {type_1: url_1, type_2: url_2, …}
```

Implementation – Database Schema



No schema evolution

Deployment on OKD



- Classic deployment at VMs also possible
- Single-container image available

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

Easily adoptable for various HEP experiments

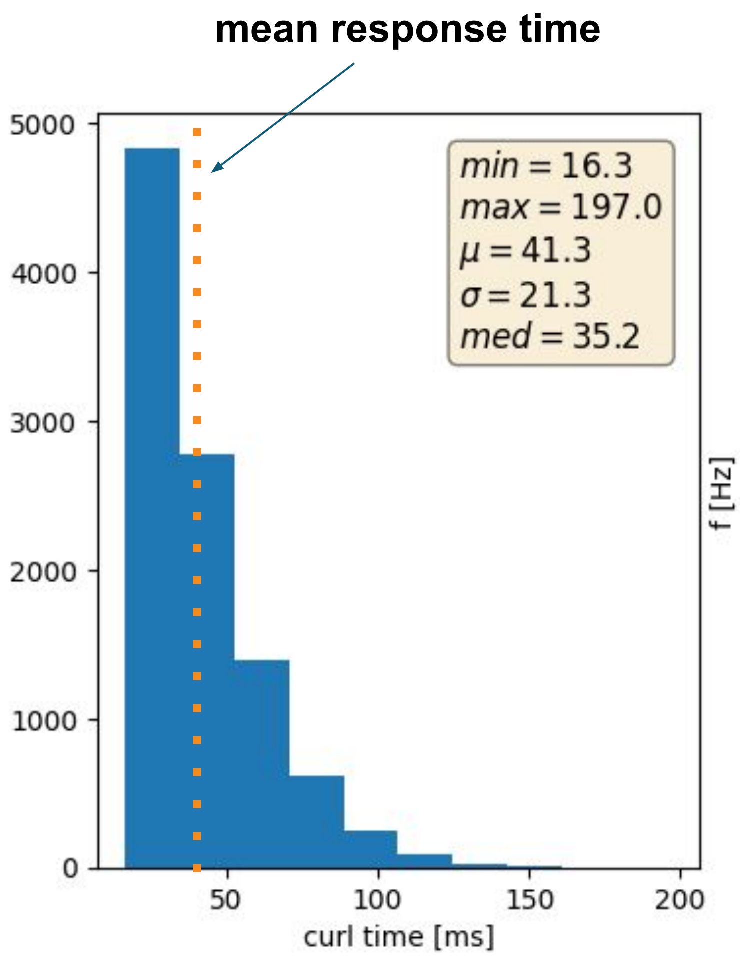
Performance Testing – Strategy

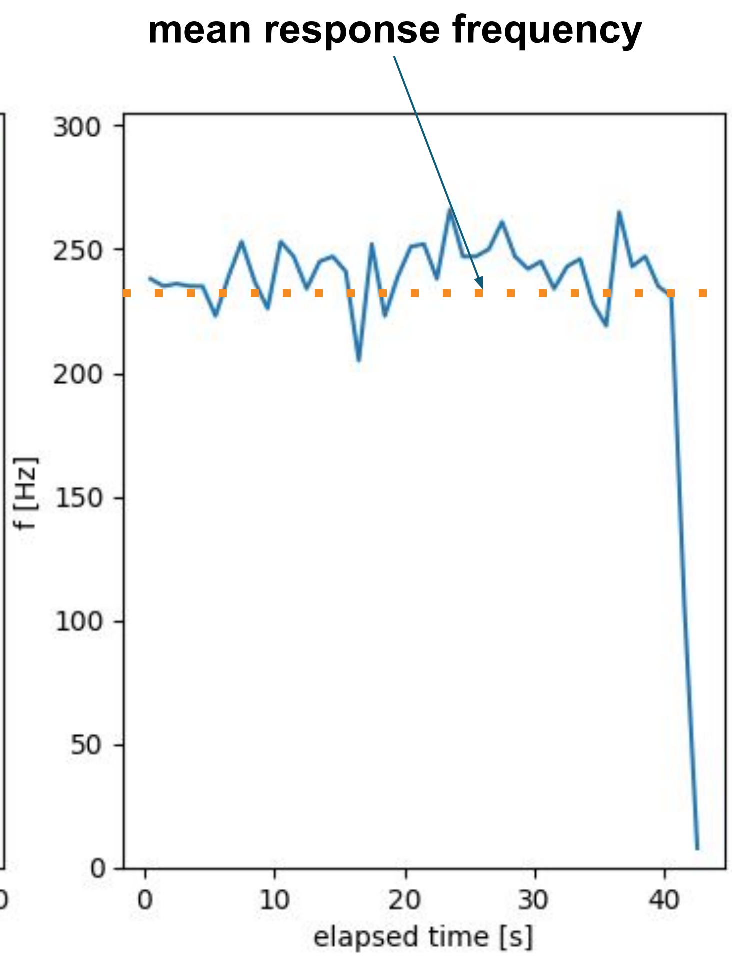
- Simulate expected DB occupancy
- Simulate access patterns
  - Query read API for payload URL
  - Parallel requests via HTC or MT

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

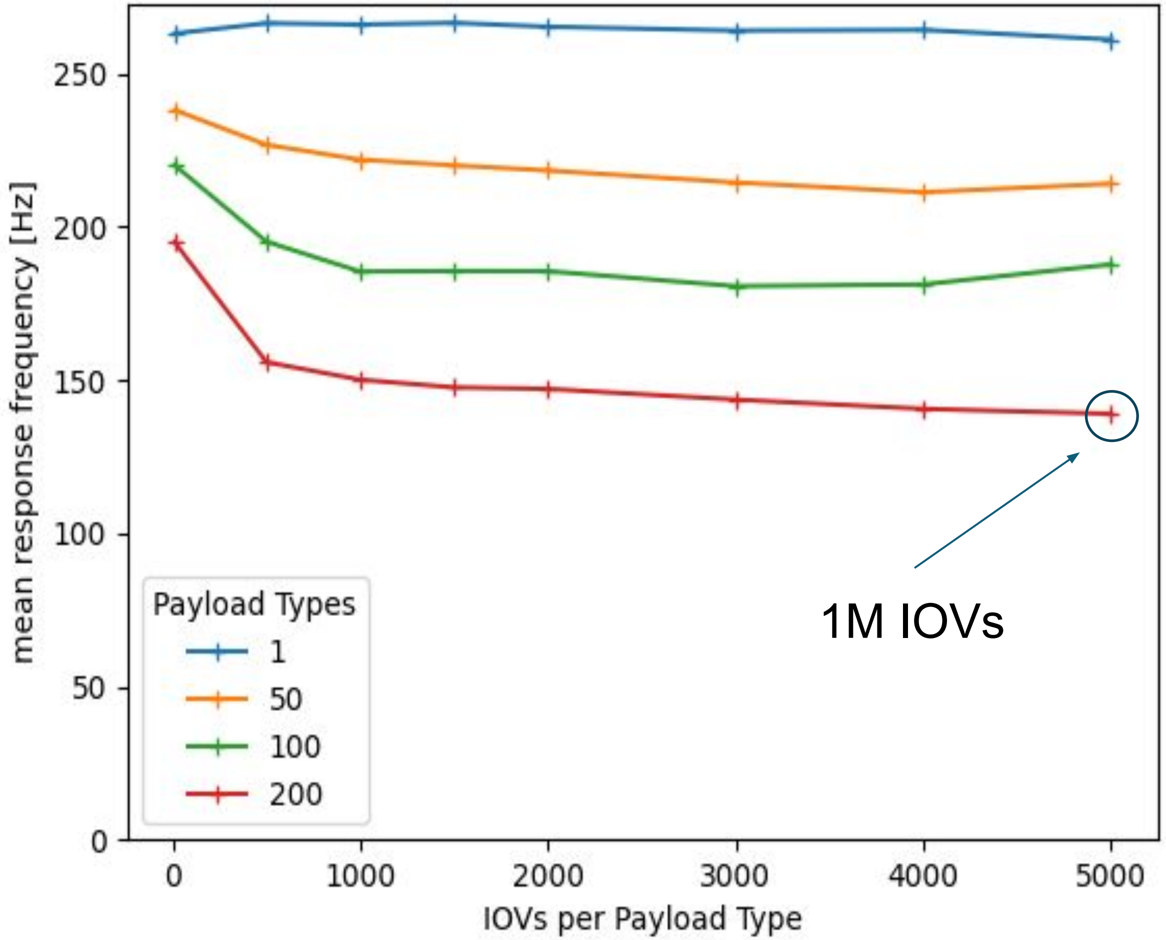




Performance Testing – Scaling

- 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

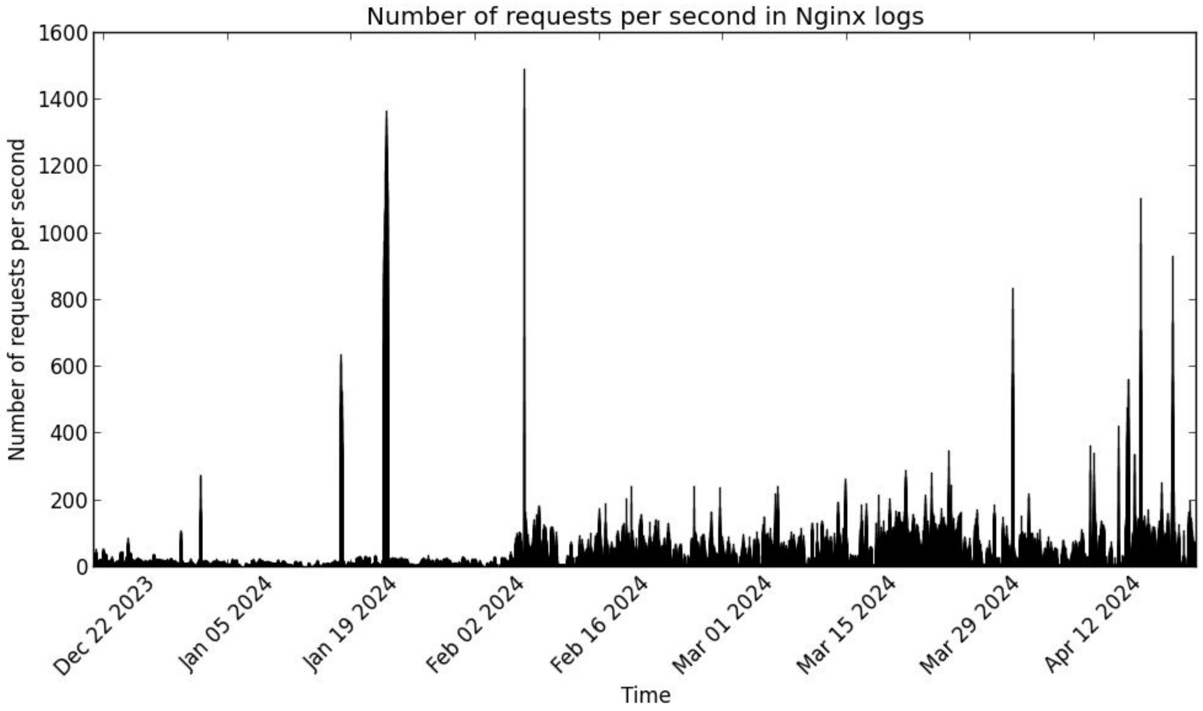
Resp. freq. vs size of queried GT



One Year of Successful Production in sPHENIX

<u>Valuable Experience gathered</u>:

- Bug Fixes regarding retry mechanism, payload file handling, and compiler optimizations
- CDB throughput issue at the level of ~20K almost concurrent jobs
  - Implemented very conservative Nginx caching: 1sec for most used resource call



Since initial bugs were fixed,
successful operations with minimal maintenance effort

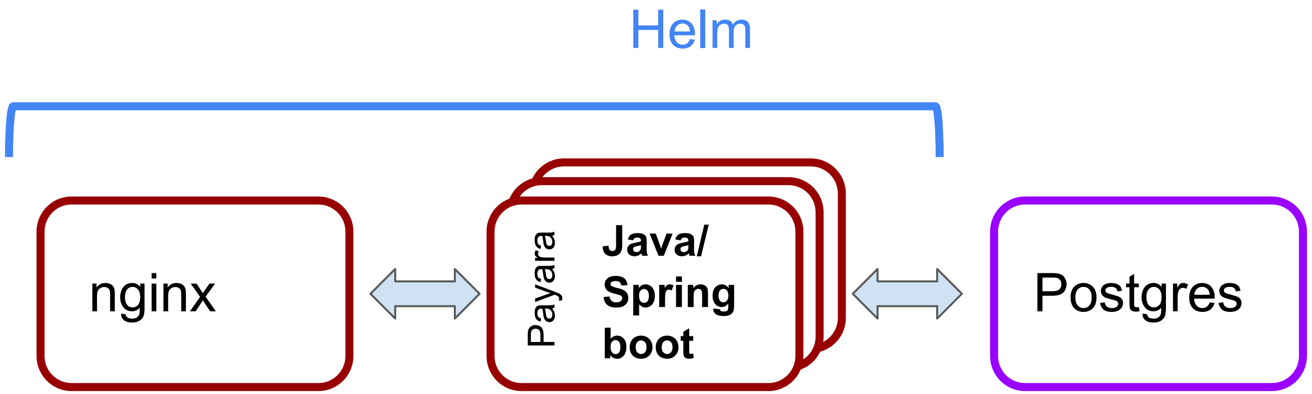
Experience from DUNE

- **nopayloadclient** has been accepted into SciSoft (FNAL)
- Created prototype for DUNE-specific client: **dunenpc**
  - Developed **art** *Service* to interface **dunenpc**
- Deployed test instance of backend @ CERN
  - Apache & bare Django on VM (for integration tests)
  - Created corresponding configuration file

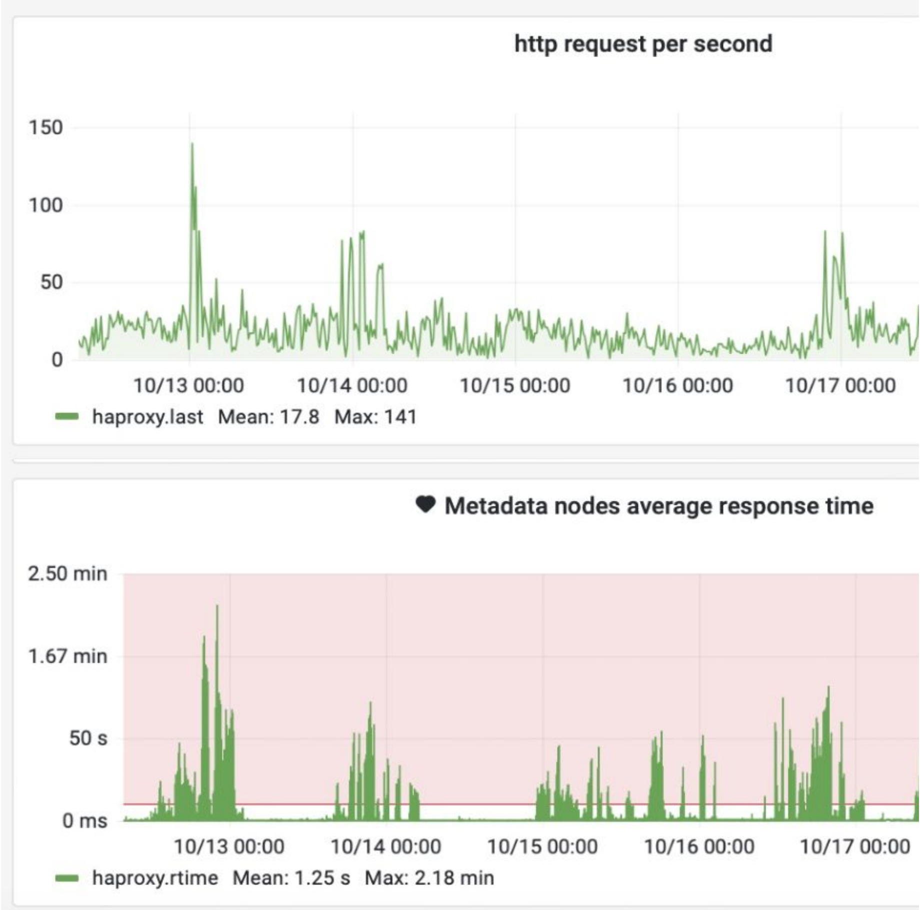
Successfully ran DUNE offline dummy job
w/ access to our DB

Implementation Matters - Experience from Belle II

- Belle II uses a **<u>different schema and implementation</u>** (though the API is similar)
  - Payara/Java/Spring boot
  - Experiencing scalability problems
    - Performance degrades for large tags O(70k)
- Currently testing HSF-like deployment on OKD
- **Considering full migration to the HSF CDB**



performance issues



okd

Outlook & Next Steps

- Transfer git repos to HSF organization (currently in BNLNPPS)
- Meanwhile continuing to work on new features:
  - Client-side configurable server-side caching strategies
  - Single-container kubernetes cluster emulator for local testing of deployment config (IRIS-HEP Fellowship)
  - Support for usage on HPCs
- ePIC (EIC) has picked it up to evaluate
- BNL / NPPS is committed to maintaining the HSF Conditions DB

Conclusion

- Presented experiment-agnostic HSF conditions Database Reference Implementation
  - Scalable, easy-to-adopt, fully open source
  - Successful operation at sPHENIX for a year now
  - Other experiments consider adopting
  - Good example of community software under HSF umbrella
- Its road from an ‘idea’ to a ‘reference implementation’ to ‘HSF project’ (idealized):

  1. Describe the problem 2. Define an API 3. Develop a Reference Implementation

- This could serve as an example for future HSF projects / reference Implementations

Backup

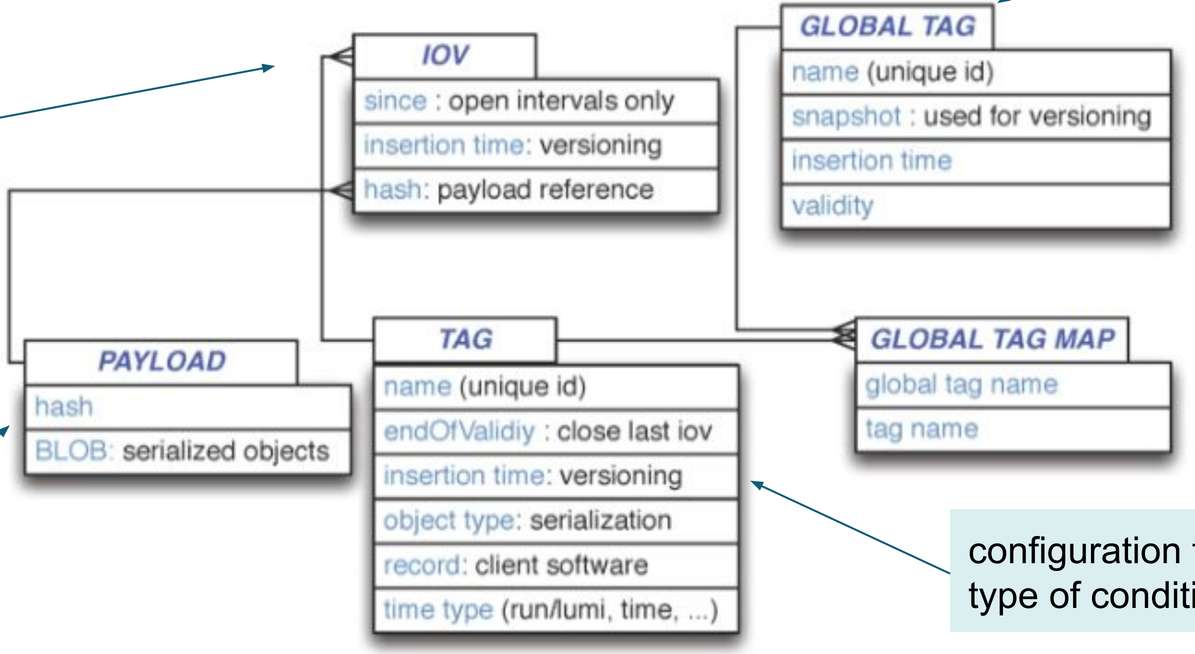
Conditions Data – HSF Recommendations

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)

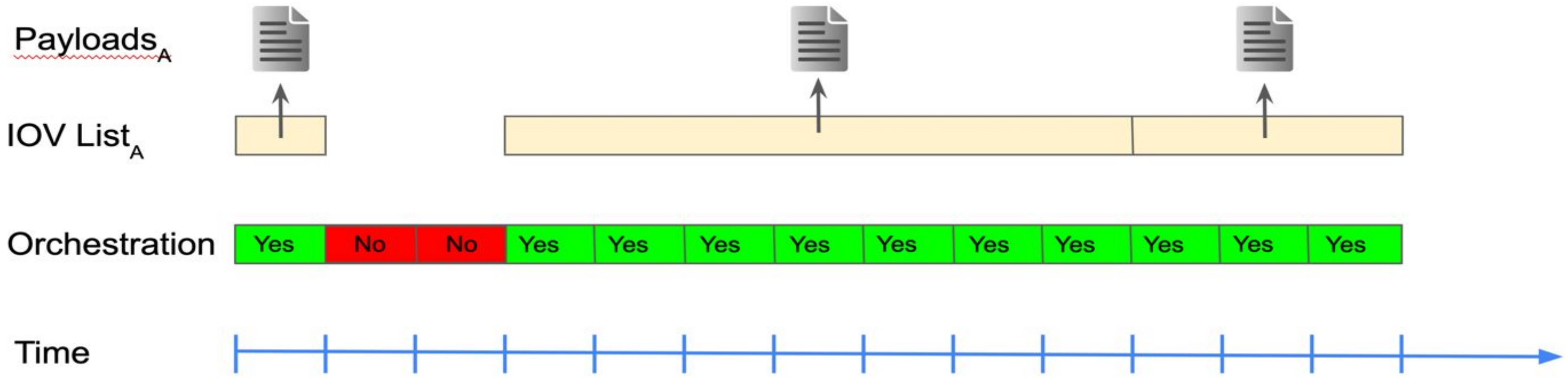
configuration for each type of conditions data

Conditions Data – Use Cases

- HSF Conditions Database meeting: **use cases** https://indico.cern.ch/event/1280790/
- Most can be realised w/ HSF Recomm.
- Special use-case:

  Fast-Processing. Goal:
  - Publish data for analysis fast
  - Maximize physics performance

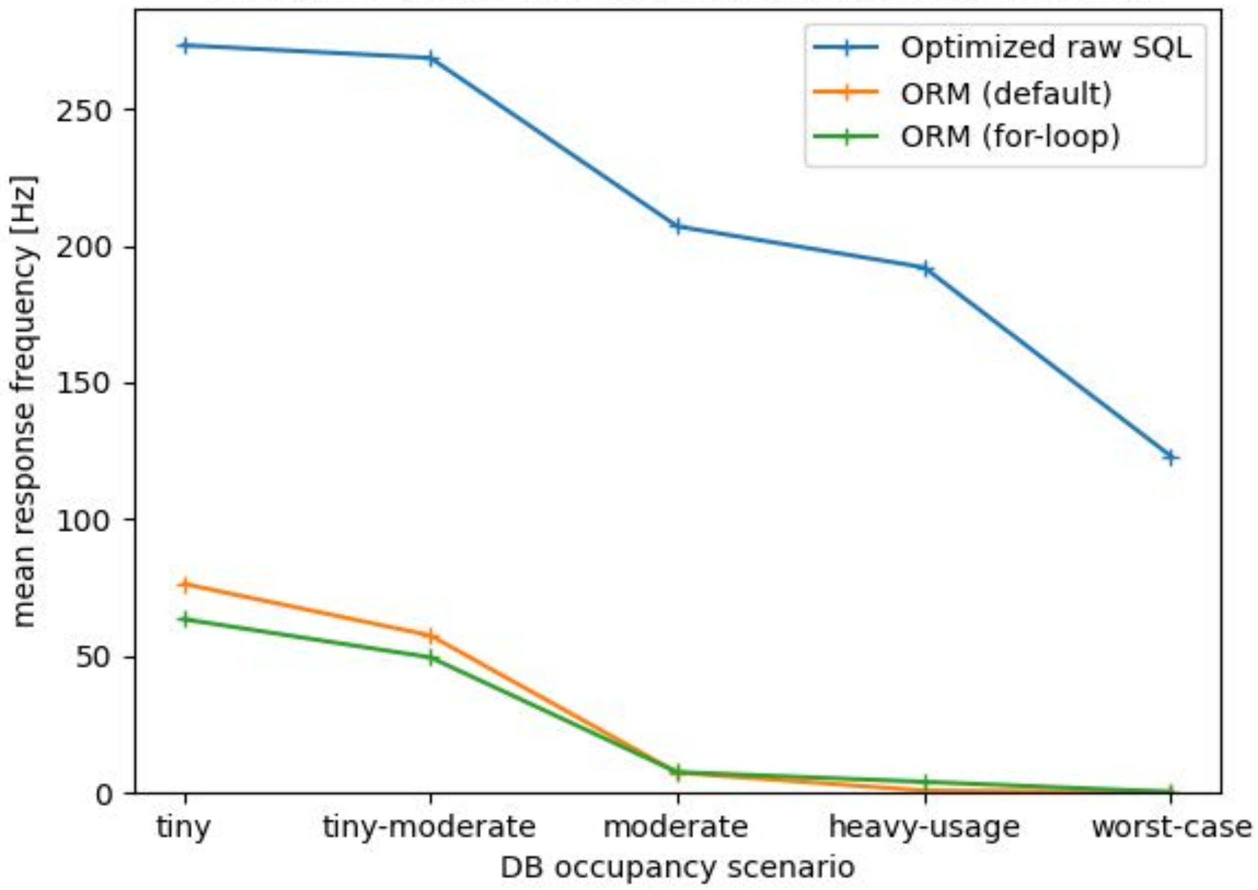
Use case	Example
Online	• High Level Trigger
Reprocessing	• Run reco w/ improved calib.
Analysis	• High level physics analysis
Development	• Test new calib. within existing GT
★ Fast-processing	• Process data w/ just-in-time calib.



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

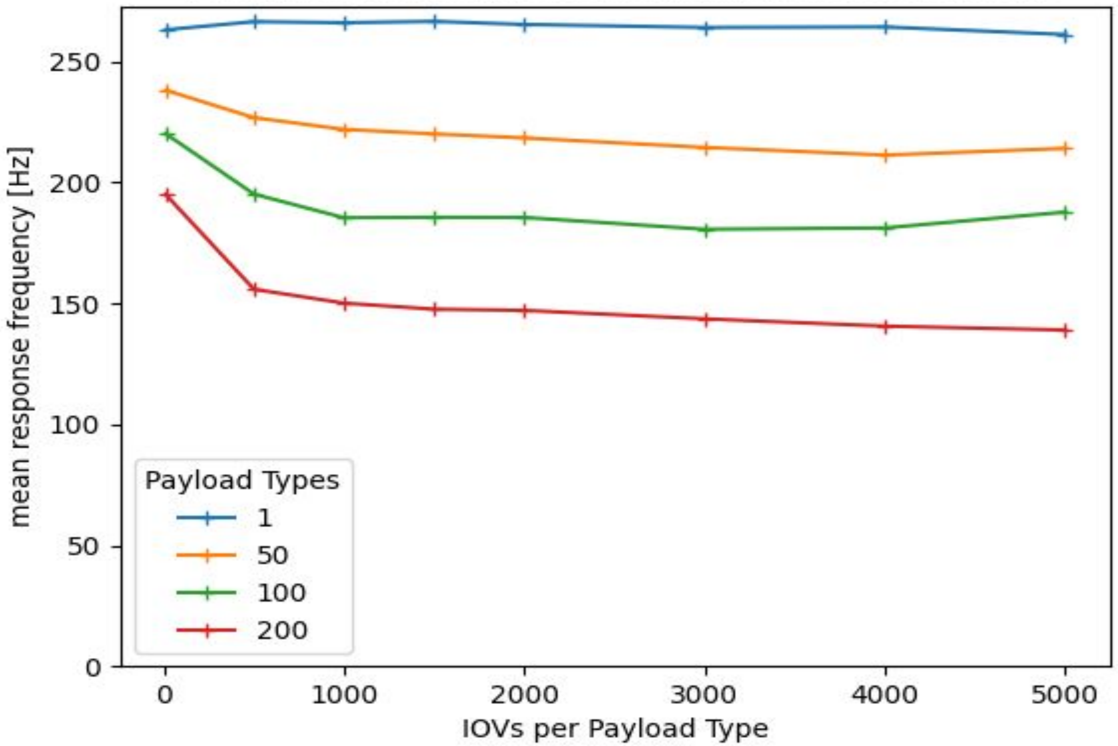
Resp. freq. vs size of queried GT



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

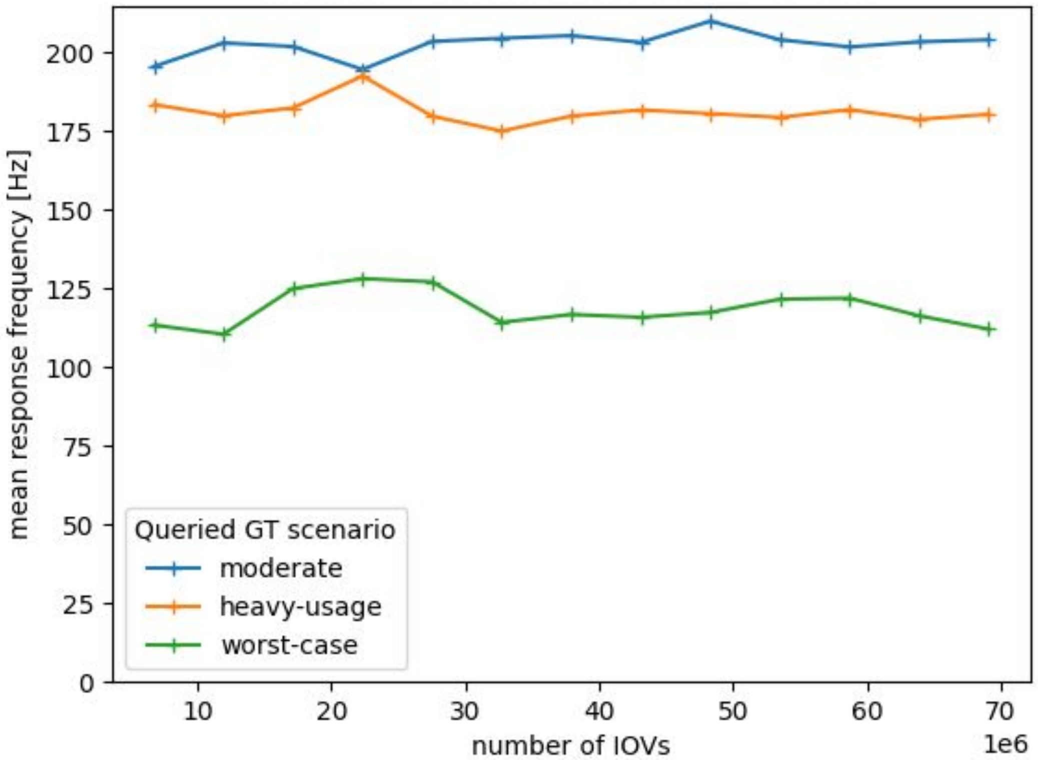
Performance Testing – Scaling

Resp. freq. vs size of queried GT



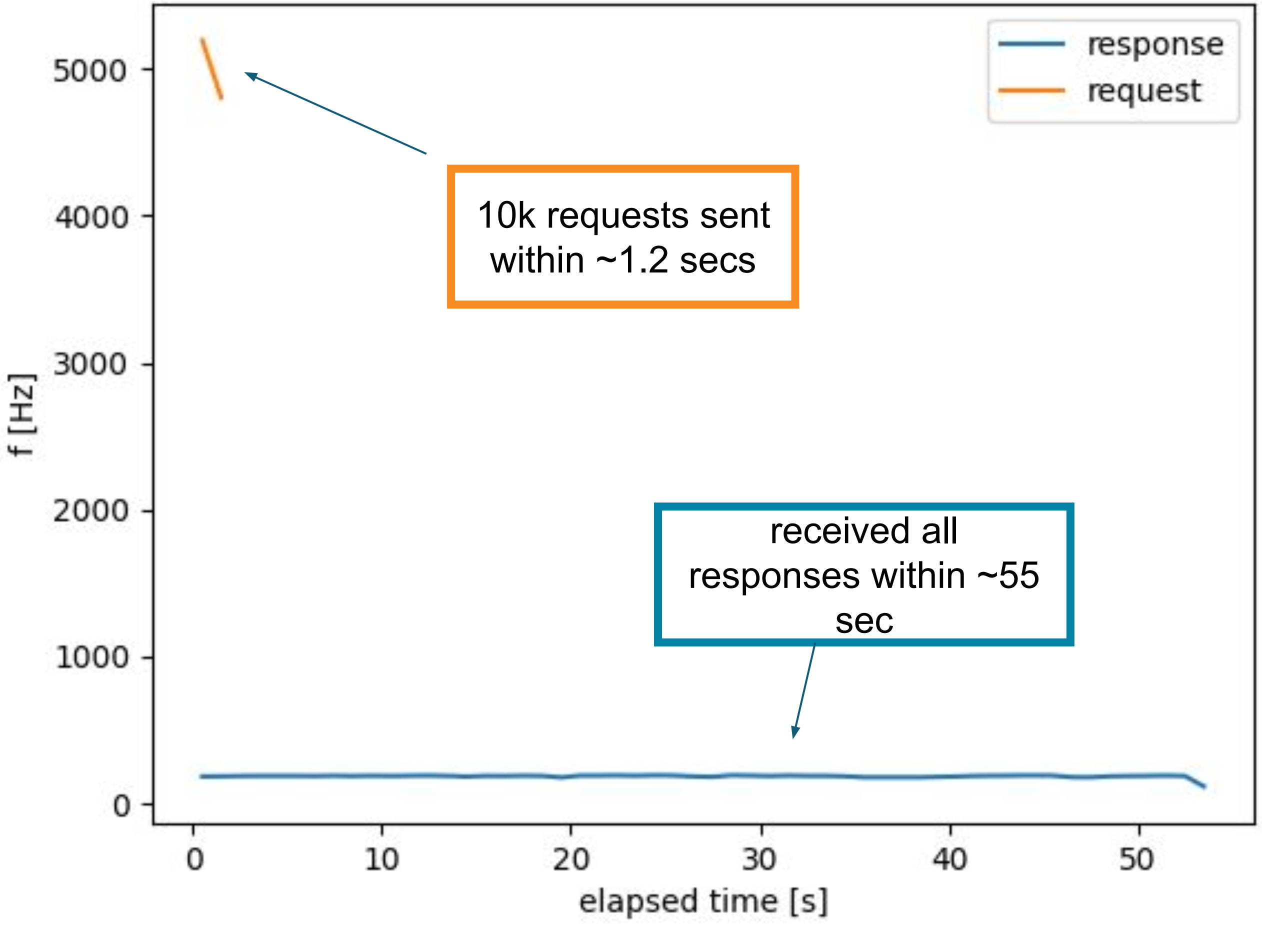
- Scales with number of payload types
- Almost flat w.r.t. number of IOVs

Resp. freq. vs DB size



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

Performance Testing – High Frequency

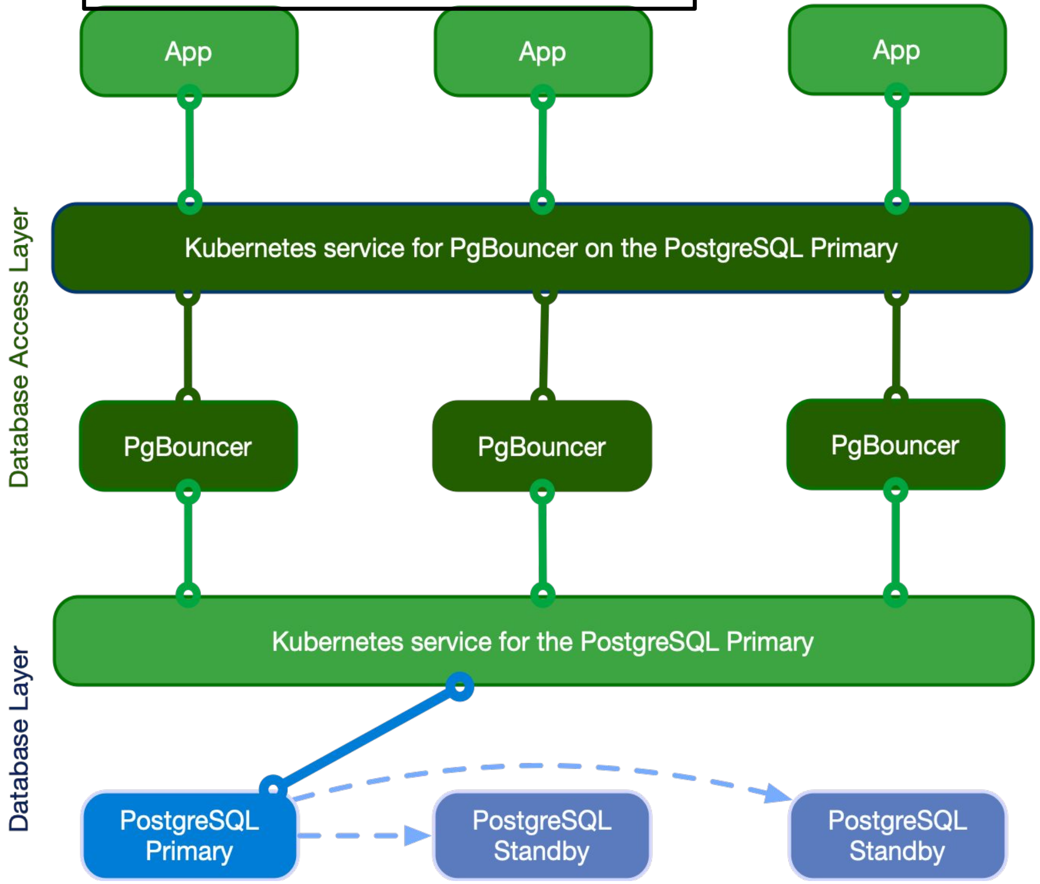


- Simulate offline reco use case
  - Many jobs launched at same time
- Cooperative multithreading (**asynchio**)
  - Send requests firsts
  - Process responses later
- Allows very high peak request frequency
- Server-side queuing of requests works

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

```sql
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

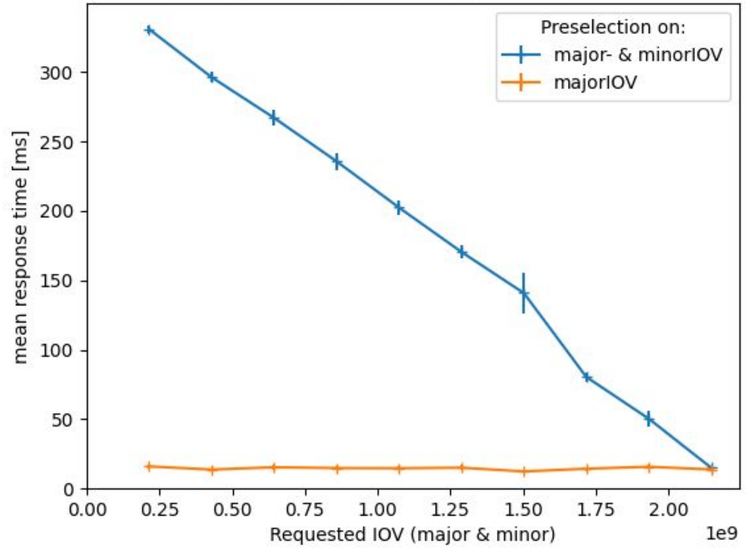
```
->  Limit  (cost=0.56..4.53 rows=1 width=61) (actual time=1.815..1.815 rows=1 loops=201)
      ->  Index Only Scan using combo_covering_idx on "PayloadIOV" pi
              (cost=0.56..3484.55 rows=876 width=61) (actual time=1.815..1.815 rows=1 loops=201)
          Index Cond: (payload_list_id =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

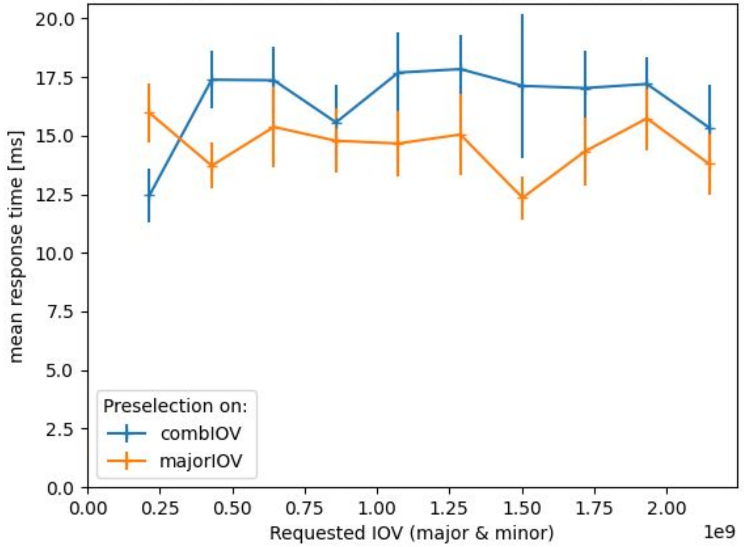
Index Condition & Filter

```
->  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