Observatories:

Collection, Preservation, Metadata, and Provenance for Active Measurement

Brian Trammell, ETH Zürich

Repeatability and Comparability in Measurement (RCM) Tutorial

ACM SIGCOMM 2018, Budapest, 20 August 2018

mami

measurement and architecture for a middleboxed internet

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Scaling Up Active Measurement

- Remembering what you did and how is almost as important as trying to do the right thing in the first place,
- Remembering what you did a thousand times requires good tooling.

- Here, we'll present a general model for scaling up, supporting repeatability and comparability.
- We call these *observatories.*

Role of an observatory

- Provides a central data repository to store data together with metadata, tracking provenance.
- Makes it easier to share interemediate and final results.

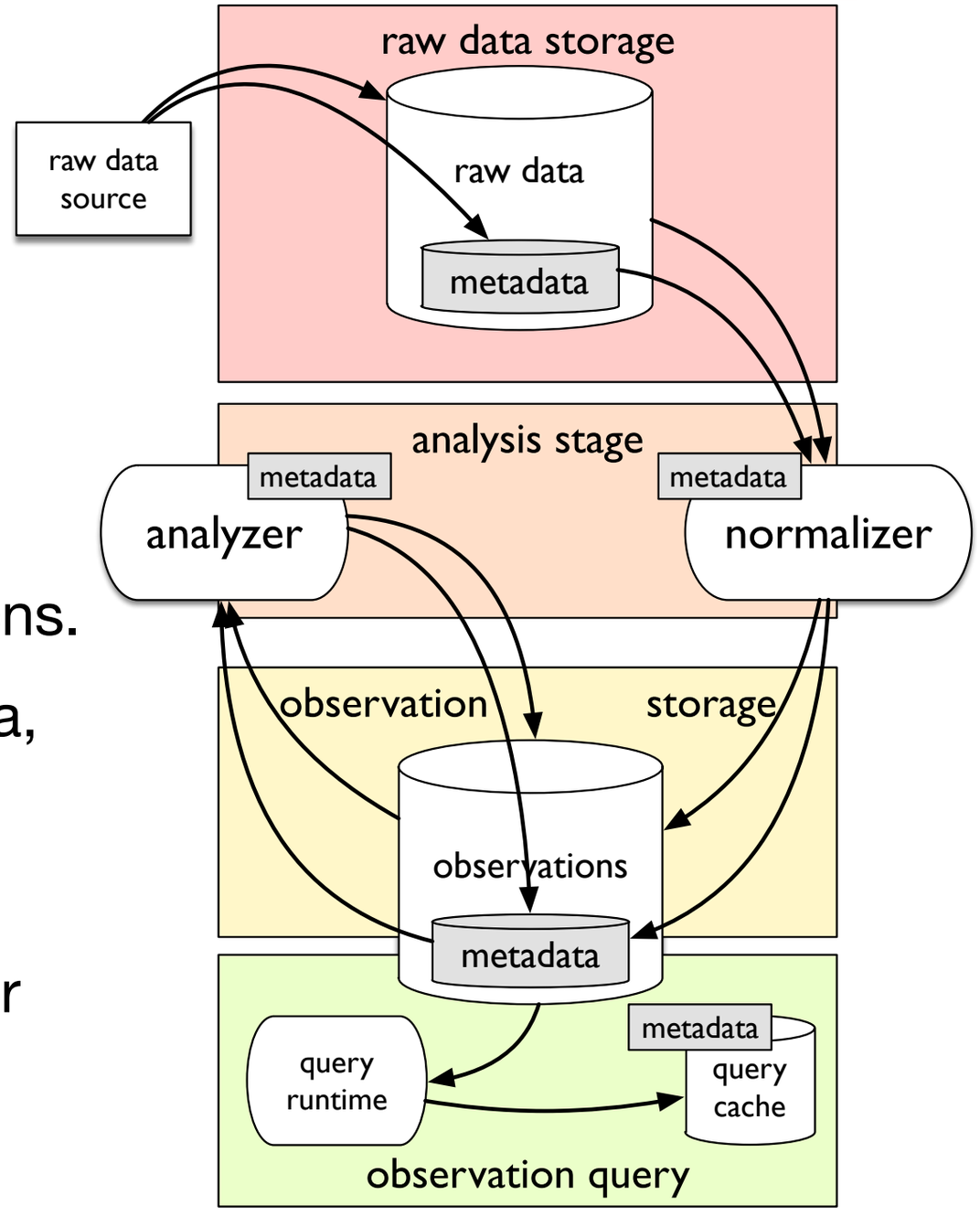
Design Goals

Measurement data observatories can support better science through the following design goals:

- ***Comparability***: allow the results from diverse tools to be expressed in the same vocabulary so they can be compared.
- ***Repeatability***: keep enough metadata around so that future users of the data know how to repeat the experiment.
- ***Protection***: reduce information in raw data to only that needed for a particular analytical task.

Generalized Observatory Workflow

- Raw data submitted to observatory
  - ...by value or reference
- Normalizers convert raw data to observations, controlled by raw metadata
- Analyzers create derived/combined observations from (lower-level) observations.
- Observations stored in a common schema, grouped into sets that share metadata
- Queries over observations are always temporally scoped, and can be cached for permanent reference.



What does an observatory do?

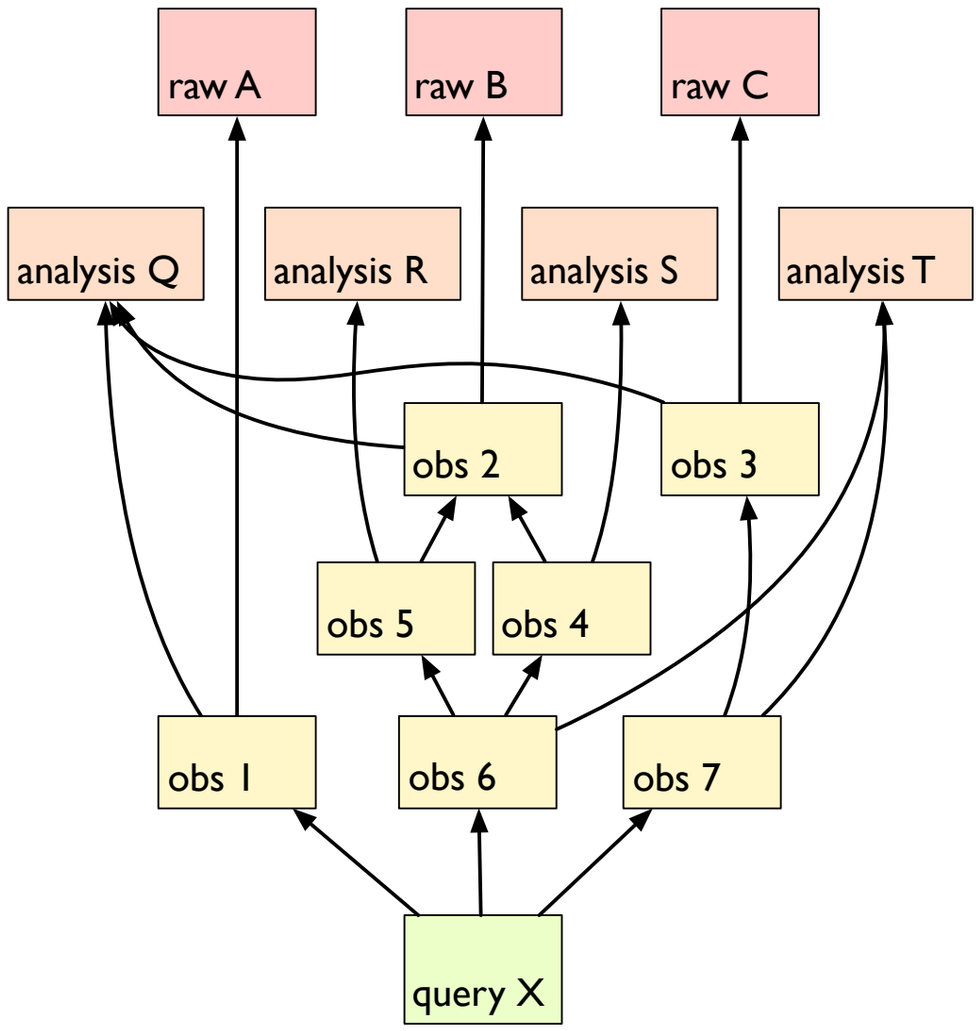
- ***Collect***: take data from multiple tools at multiple vantage points in multiple formats, centralizing it for analysis.
- ***Preserve***: keep raw data in its original form and control access to it.
- ***Normalize***: produce ***observations*** from raw measurement data in a simple schema designed for a specific measurement purpose.
- ***Analyze***: combine observations for higher-level insight.
- ***Query***: allow arbitrary queries over observations.
- Track ***Metadata***: Annotate raw data and observations with arbitrary user-defined information.
- Track ***Provenance***: Provide information about raw and intermediate data sources for all objects/queries in the observatory.

Supporting Comparability: Observations

- Diversity of tools/methods can make comparison difficult.
- Normalizing raw data into *observations* with simple semantics can push this difficulty to the edge.

- An observation schema is specific to the measurement goal...
  - ...should consist of a small set of classes, each containing information elements derived from input data and useful for analysis.
  - e.g. a topology-centered observatory's core object could be a "hop"
  - e.g. a performance observatory could store latency and bandwidth samples

Supporting Repeatability: Provenance



- Every object refers to its antecedents
- Following these links back from a query or observation set results in a **provenance tree.**
- This provenance tree is, in effect, a set of instructions for recreating a given observation set.

Our instance: The Path Transparency Observatory

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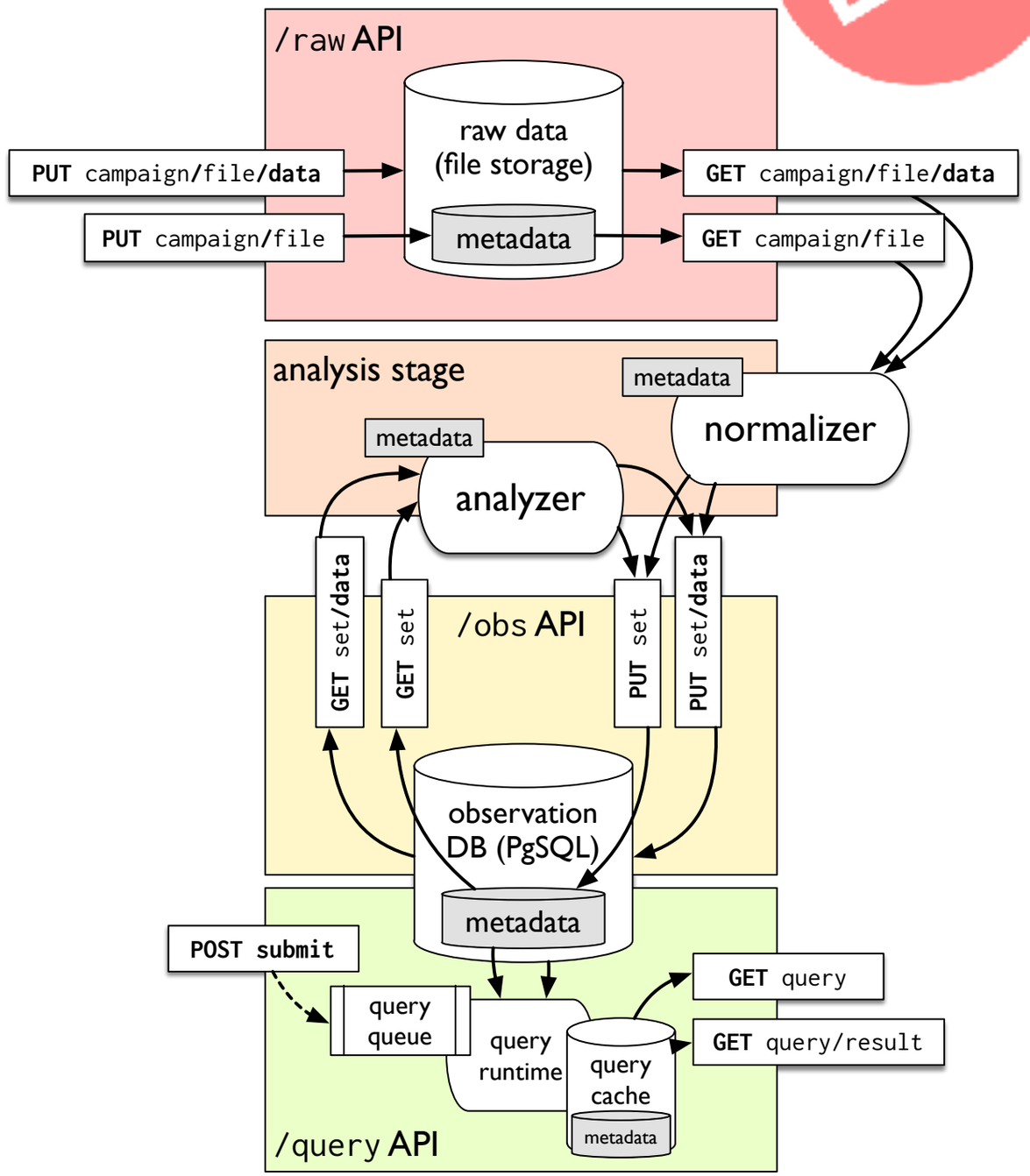
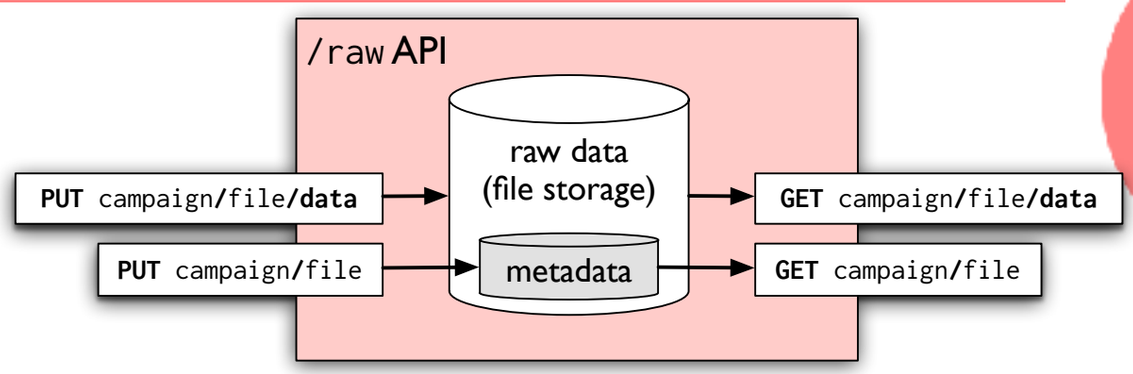
PTO design

- Built around a RESTful API
- ***Raw data*** is stored as *files* in original output format of each tool/ source
  - "metadata first"
- ***Analysis*** stage derives ***observations*** in a common schema
  - organized into sets sharing provenance and other metadata
- Flexible ***query*** engine to access observation storage
  - allows query results to be cached and annotated for publication



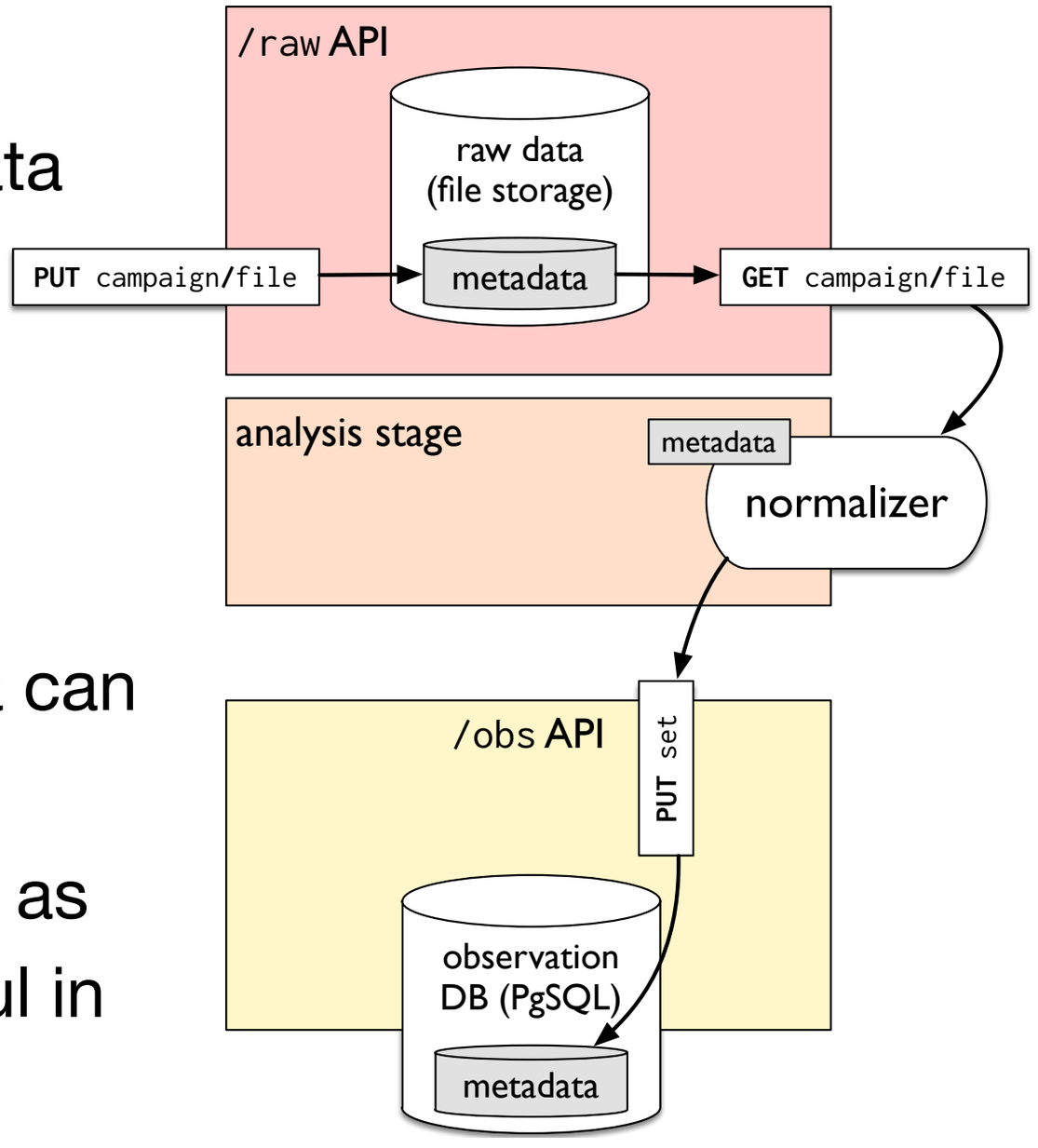
Raw Data Files and Campaigns



- Raw data files are grouped into ***campaigns***
- Every campaign and datafile is associated with metadata
  - Metadata must be created before data is uploaded
  - Metadata mutable, data is not
    - Raw files inherit metadata from campaigns
- ***System metadata*** required for every file:
  - `_time_start, _time_end:` time interval covered by measurements
  - `_owner`: who owns the raw data (and should be contacted for questions about it), as email address or URI.
  - `_file_type`: format of the raw data file
- ***User metadata*** is freeform

Metadata Flow

- PTO's design is **metadata-first:**
  - All additions consist of a metadata phase, then a data phase.
  - Normalizers and analyzers are controlled indirectly by raw and observation set metadata.
  - Data is immutable, but metadata can be updated.
- Arbitrary metadata: we don't know as well as the users what will be useful in the future.



Upload: creating a campaign

- First, set up your environment: you'll need your API key and campaign name:

```
$ export TOKEN="your API key"
$ export CAMPAIGN="your campaign name"
```

- Then, create (edit) your campaign metadata file (`campaign.json`):

```
{
    "_owner": "your email address",
    "_file_type": "pathspider-v2-ndjson-bz2"
}
```

Upload: creating a campaign

- ```
  $ curl -X PUT
         -H "Content-type: application/json"
         -H "Authorization: APIKEY $TOKEN"
         https://rcm.pto.mami-project.eu/raw/$CAMPAIGN
         --data-binary @campaign.json
  ```

- Now we have a campaign. Next, let's upload some data into it...
  ```

Upload: Create and upload metadata

- Data files need at least a time range (`_time_start, _time_end`) in their metadata.
  - We can extract this from PATHspider output:

```
$ python3 extract_pathspider_metadata.py result.ndjson
$ cat result.ndjson.meta.json
```

- Now we can upload metadata for each file:

```
$ curl -X PUT
       -H "Content-type: application/json"
       -H "Authorization: APIKEY $TOKEN"
       https://rcm.pto.mami-project.eu/raw/$CAMPAIGN/result.ndjson
       --data-binary @result.ndjson.meta.json
```

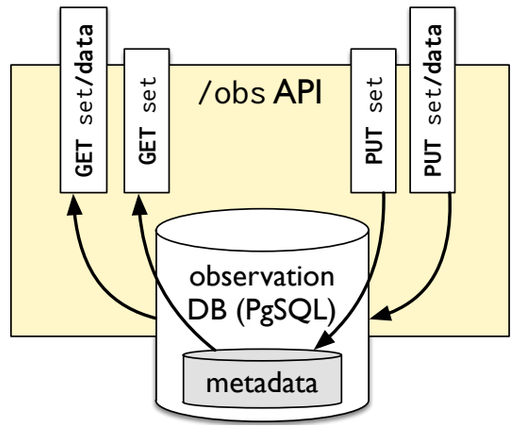
- ***yes, you're uploading metadata at the url identifying the datafile: metadata first!***

Upload: upload raw data

- And finally, data. Compress it first:

```
$ bzip2 result.ndjson
$ curl -X PUT
-H "Content-type: application/bzip2"
-H "Authorization: APIKEY $TOKEN"
https://rcm.pto.mami-project.eu/raw/$CAMPAIGN/result.ndjson/data
--data-binary @result.ndjson.bz2
```

Observation Data Model

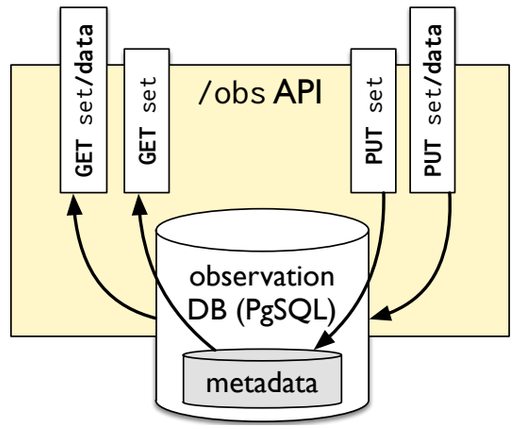


- Raw data is important for provenance and repeatability, but before we can query our data, we need to normalize it into observations.
- A PTO observation is an assertion that at a given **time**, a given **condition**, held on a given **path:**

```
["0","2014-08-28T22:41:02Z","2014-08-28T22:46:25Z",
  "* 82.192.86.197","ecn.multipoint.connectivity.works","3"]
```

  - ***This schema is what makes our observatory a PTO.***
- Observations are organized into **sets**, which share metadata and provenance.

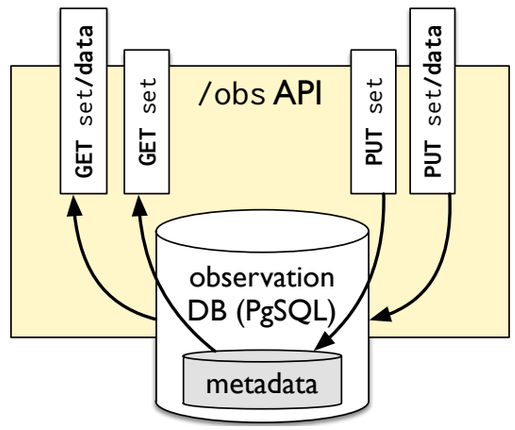
Conditions for Path Transparency



- A condition is some **state** of an **aspect** of a **feature** observed on a network:
  - e.g. **ecn**.**connectivity**.**works** or **ecn**.**negotiation**.**reflected**

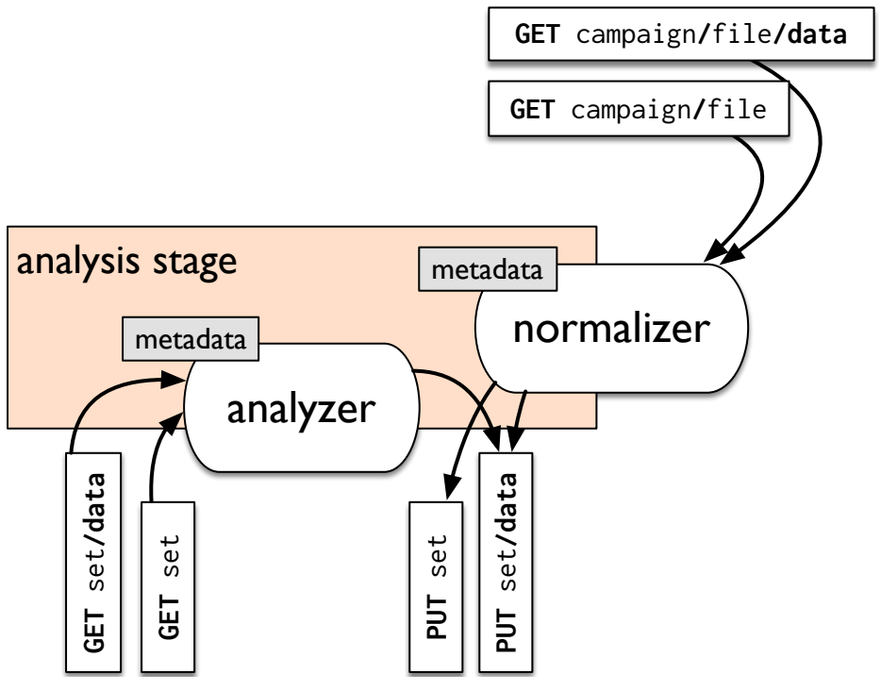
- Feature: what protocol or feature are we trying to use?
- Aspect: what question are we asking about the feature?
- State: what happens when we try to use it?
  - States mutually exclusive for a given aspect on a path at a given time.

Paths



- A path is a **sequence of path elements** (IP addresses, prefixes, AS numbers, pseudonyms, or wildcard) on which an observation was taken
- For active measurement: first path element is the **source** or device sending traffic, last path element is the **target** or device under test.
- e.g. `[digitalocean-ams3 * 104.24.127.228]` or `[128.10.18.52 * 209.200.170.230 204.106.55.245 * 159.45.6.20]`

Normalizers and Analyzers



- *Normalize* raw data and metadata into observations:
- **`ptonorm normalizer campaign file > obs.ndjson`**
  - takes data on stdin, metadata on fd 3
  - produces data + metadata on stdout
- **`ptoload obs.ndjson`**
  - loads resulting observation set
- **`autonorm`**
  - normalizes new files in a campaign according to simple rules

- *Analyze* observation sets into new observation sets:
- **`ptocat set₀ ... setₙ | analyzer > obs.ndjson`**

Step two: normalize raw data to observations

- Normalization and analysis take place on the PTO server itself.
- We'll run **`autonorm`** to kick off the pathspider normalizer.

- This is usually semi-manual:
  - Normalizers are provided by data owners, run by the observatory operator
  - Resulting observation sets are vetted by the owner and operator before loading

Step three: additional analysis

- Let's look for path dependency: different results for the same target from different sources. First, we need a list of sets to analyze:

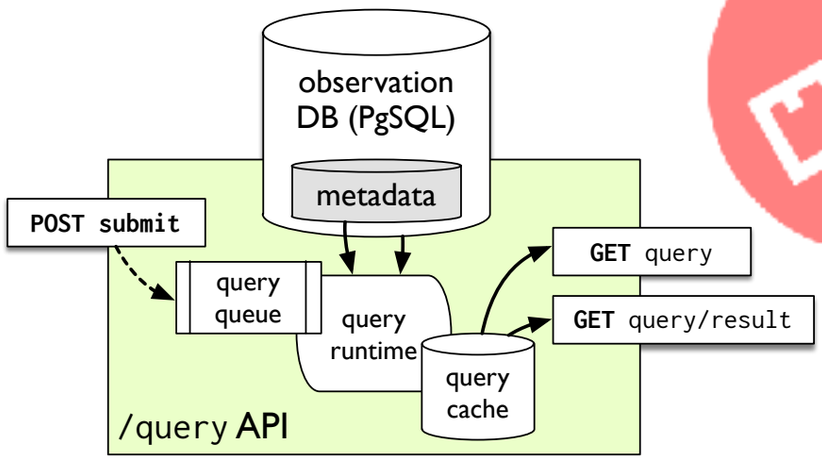
```
$ curl https://rcm.pto.mami-project.eu/obs/by_metadata?\
      analyzer=https://raw.githubusercontent.com/\
      mami-project/pto3-ecn/master/normalize_pathspider/\
      normalize_pathspider.json | jq `.["sets"]`
```

Step three: additional analysis

- Now we can analyze all these sets, comparing results for the same target:

- `ptocat \`cat SETS\` | ecn_pathdep > pathdep.obs`
- `ptoload pathdep.obs`

Queries



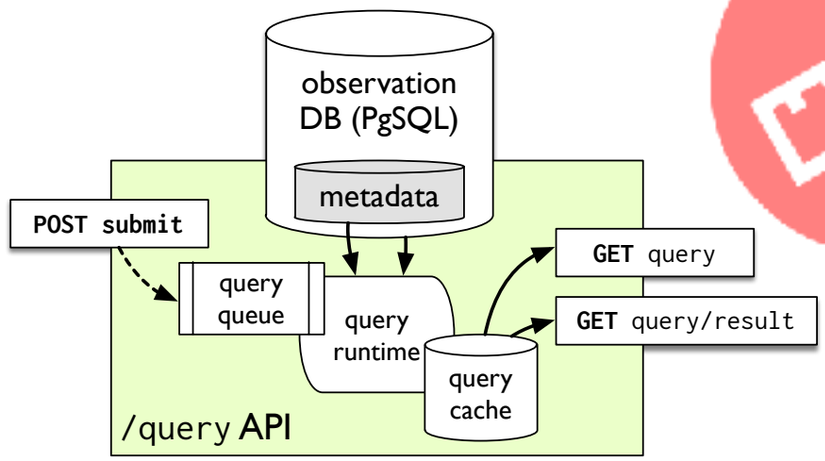
- Queries select or aggregate observations across observation sets based on predicates given in the query parameters.
- Queries are associated with metadata, and arbitrary metadata may be added to them.
- Queries might take a while, so result retrieval is separate from metadata management.
  - Query results are cached temporarily, and may be made permanent by adding an external reference to them.

Step four: aggregate queries

- Queries can also be issued from curl...
- ...but we also supply a Python client library meant for working with queries and query results in Pandas

- We'll switch to a notebook running on this for illustrating queries...

Query Parameters



Parameter	Semantics	Meaning
`time_start`	temporal	Select observations starting at or after the given start time
`time_end`	temporal	Select observations ending at or before the given end time
`set`	select	Select observations with in the given set ID
`on_path`	select	Select observations with the given element in the path
`source`	select	Select observations with the given element at the start of the path
`target`	select	Select observations with the given element at the end of the path
`condition`	select	Select observations with the given condition, with wildcards
`group`	group	Group observations and return counts by group
`option`	options	Specify a query option

PTO: what we've seen

- a metadata-first observatory for supporting comparable and repeatable network measurements: this is a general design pattern you should consider in your future work.
  - See `https://github.com/mami-project/pto3-go`.

- a data model and set of analysis and query tools for pulling path transparency measurements together into a single place, demonstrating the general design pattern.

PTO: lessons learned from our implementation

- Simple interfaces for analysis are way more flexible
  - Prior versions of the PTO were big-data-heavy, required all analysis to be written to specific Apache frameworks.
- Thinking hard about your observatory data model pays off
  - Few changes in the core schema since project start.
  - Structured data allows us to dispense with NoSQL.
- For many tasks, medium data suffices
  - Our PTO instance stores ~1T of data, built on flat files and PostgreSQL on one large host (40-core, 256G/40T).