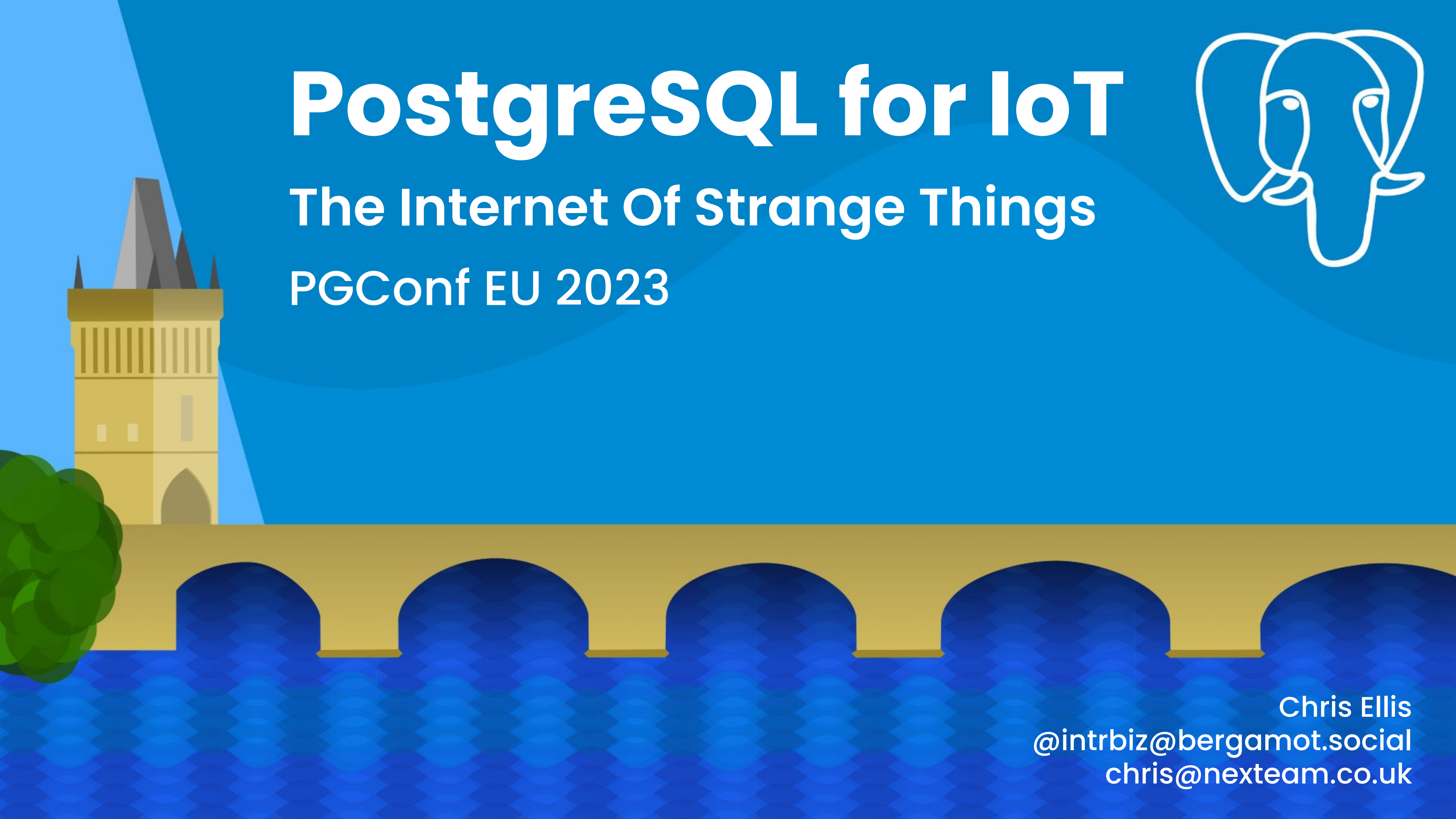
PostgreSQL for IoT

The Internet Of Strange Things

PGConf EU 2023



Chris Ellis
@intrbiz@bergamot.social
chris@nexteam.co.uk

Hello!

- I'm Chris
  - IT jack of all trades, studied Electronic Engineering
- Been using PostgreSQL for about 18 years
- Recently released pgVis (pgVis.org)
  - Build simple visualisation dashboards from SQL
- Worked on various PostgreSQL and IoT projects
  - Connected TV Set top boxes
  - Smart energy meter analytics
  - IoT Kanban Board
  - IoT CHP Engines
  - Mixes of OLTP and OLAP workloads
  - Scaled PostgreSQL in various ways for various situations

IoT

MON 19:25
ON
20° TARGET
18° ACTUAL
Status
Central heating

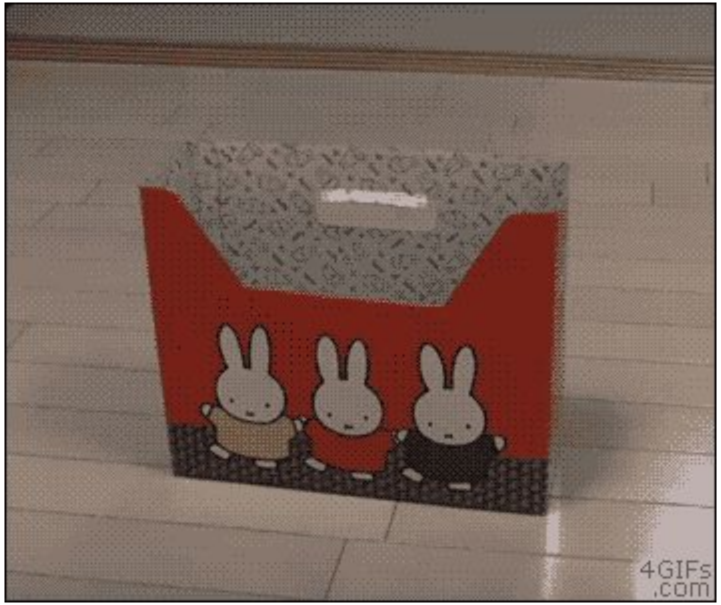
nest
18
HEATING
20

TP-LINK

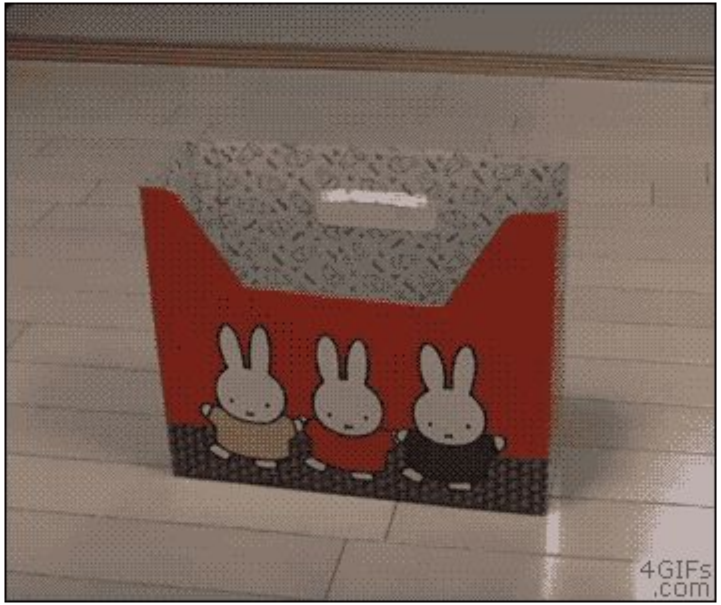
PHILIPS

PHILIPS Hue White and color
PHILIPS Hue White and color
PHILIPS Hue White and color

One size fits all?

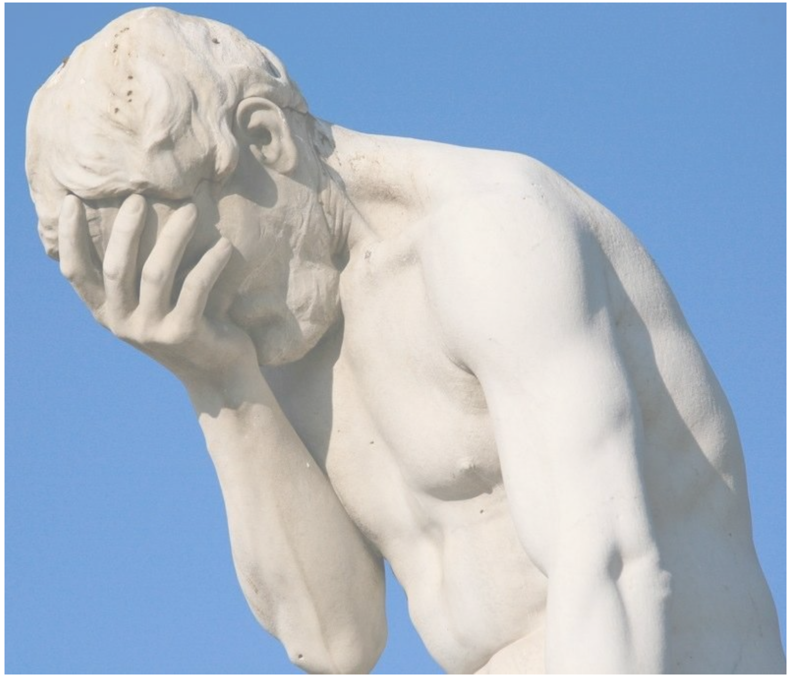


One size fits all?



Time series databases

- Lots of specialised time series datastores
  - Single use case solutions
  - Have their own querying languages
  - Limited data types
- Often surrounded by FUD
  - That you need a dedicated DB for time series
  - That GP DBs can't perform well enough
  - Don't forget the developer time too
    - SQL is very powerful, quickly
  - Managing data at scale is hard, regardless of your database choice
  - Not every business is actually 'big' data



Why PostgreSQL?

- The same reason I constantly go back to PostgreSQL
  - We don’t call it the `world’s most advanced Open Source relational database` without just cause
  - It’s flexible
  - It’s extensible
  - It puts up with you
  - It cares
- IoT is not a simple, one size fits all problem
  - It’s not just time series data
  - I find single solution data stores, a bit, pointless

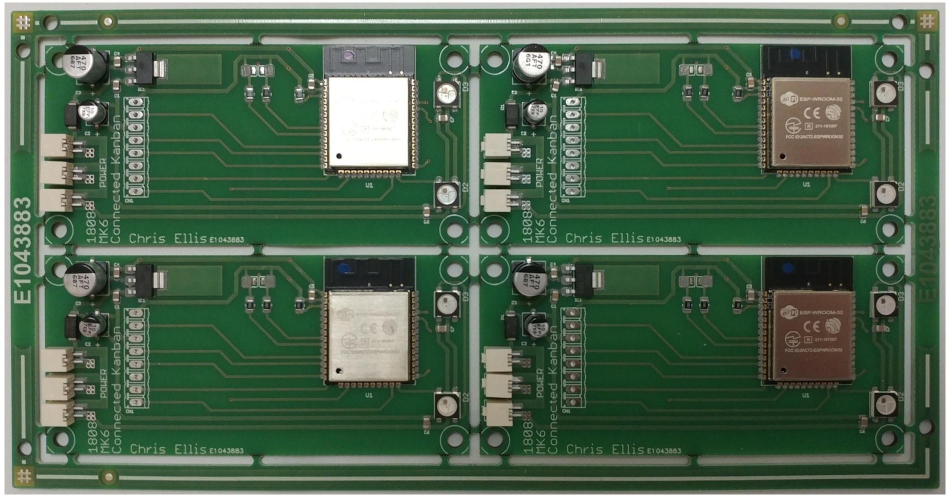
Why PostgreSQL?

- PostgreSQL makes it easy to combine your time series data with other data
    - You know: a join!
- Find me the average energy consumption of Shropshire?
- Find me the monthly average energy consumption for 4 bed houses during the summer?
- Find me the monthly average, min, max energy consumption for 4 bed houses during summer in Shropshire for a half hourly period?
- What is the monthly average energy consumption for houses within x miles of my house?

The Source

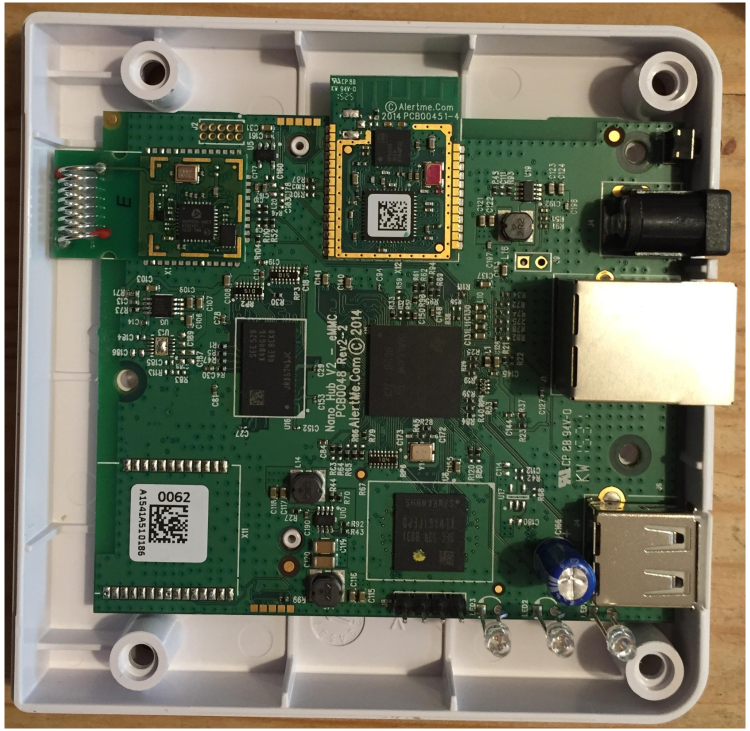
The Source

- The source of your data is usually a small embedded system
  - That often have very variable capabilities
    - From not enough to far to much



- ESP-32
  - Dual core 32bit @ upto 240MHz
  - 520KiB SRAM (D&I)
  - Typically 4MiB SPI Flash ROM
  - WiFi, TCP/IP stack
  - Runs FreeRTOS

The Source



- Some devices can be pretty powerful with good RAM and storage
- Smart Home Hub
    - Single Core 1GHz ARM Cortex-A8
    - 512 MiB RAM
    - 4 GiB Flash eMMC Storage
    - WiFi + Ethernet
    - Zigbee
    - Runs Linux

The Source

- Other devices can be even stranger
  - Whole string of controllers and modules
  - Fairly busy control system, connectivity is not a priority

- Industrial Control
  - Single Core 200MHz ARM7
  - 128 MiB RAM
  - >8GB SD Card
  - Ethernet
  - Lots of CAN
  - Runs a RTOS, hard real time
  - Doing other very important things

Collecting Data

Collecting Data - Device ←→ Platform

- Probably using MQTT between device and platform
  - Seen AMQP to platform (terrible idea)
    - And some strange reinventions of TCP over UDP and DNS
  - Most likely sending binary data, especially if low end device
- Consumer devices might need to be careful of
  - Bandwidth utilisation
  - Power consumption
- Devices operating in remote environments
  - Need to be careful with battery usage
    - Eg: Gas meters must be battery powered
  - GPRS backhaul, slow, expensive during daytime

Collecting Data - Device ←→ Platform

- Be selective about how you send data
  - A lot of use cases don’t need low latency real time data feeds
    - Can switch to a fast mode when you need it
  - In the cloud you often get charged per message
    - Cheaper to send 1 big message than lots of small messages
- Business model
  - IoT products are quite often hero products, one off income (especially in consumer)
  - Yet you have recurring directly coupled costs
- Can be difficult to authenticate devices
  - TLS client auth often used, certs can be extracted and usually cover lots of devices
  - Low end devices harder to do certificates
  - Huge risk of people being able to fake data or do fun things

Storing Data

Storing Data

```sql
CREATE TABLE iot.alhex_reading (
  device_id   UUID NOT NULL,
  read_at     TIMESTAMP NOT NULL,
  temperature REAL,
  light       REAL,
  PRIMARY KEY (device_id, read_at)
);
```

Storing Data - Range Types

```
CREATE TABLE iot.alhex_reading (
  device_id   UUID NOT NULL,
  read_range  TSRANGE NOT NULL,
  temperature REAL,
  light       REAL,
  PRIMARY KEY (device_id, read_range)
);
```

Storing Data - Metadata

```
CREATE TABLE iot.alhex_reading (
  device_id   UUID NOT NULL,
  read_at     TIMESTAMP NOT NULL,
  temperature REAL,
  meta        JSONB,
  PRIMARY KEY (device_id, read_at)
);
```

Storing Data - Rolling On Up

```
CREATE TABLE iot.daily_reading (
  meter_id       UUID NOT NULL,
  read_range     DATERANGE NOT NULL,
  energy         BIGINT,
  energy_profile BIGINT[],
  PRIMARY KEY (device_id, read_range)
);
```

Storing Data - Rolling On Up

t_xmin	t_xmax	t_cid	t_xvac	t_ctid	t_infomask 2	t_infomask	t_hoff
4	4	4	4	6	2	2	1

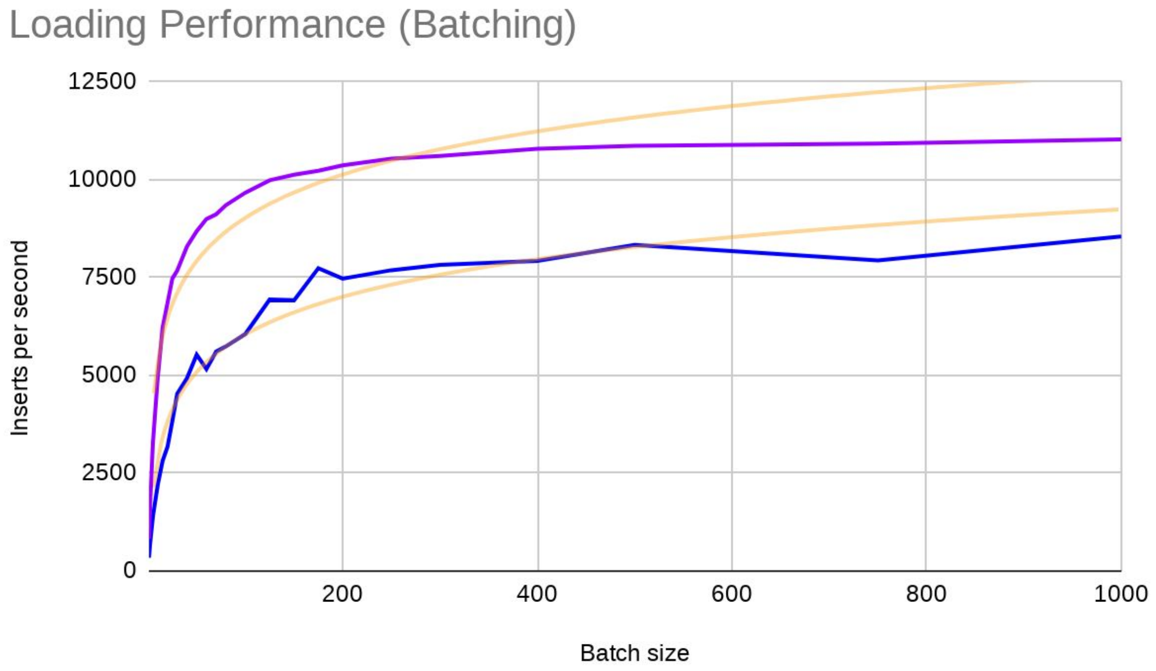
24 bytes

device_id	read_at	temperature	light
16	8	4	4

32 bytes

Loading Data

Loading Data - Batching

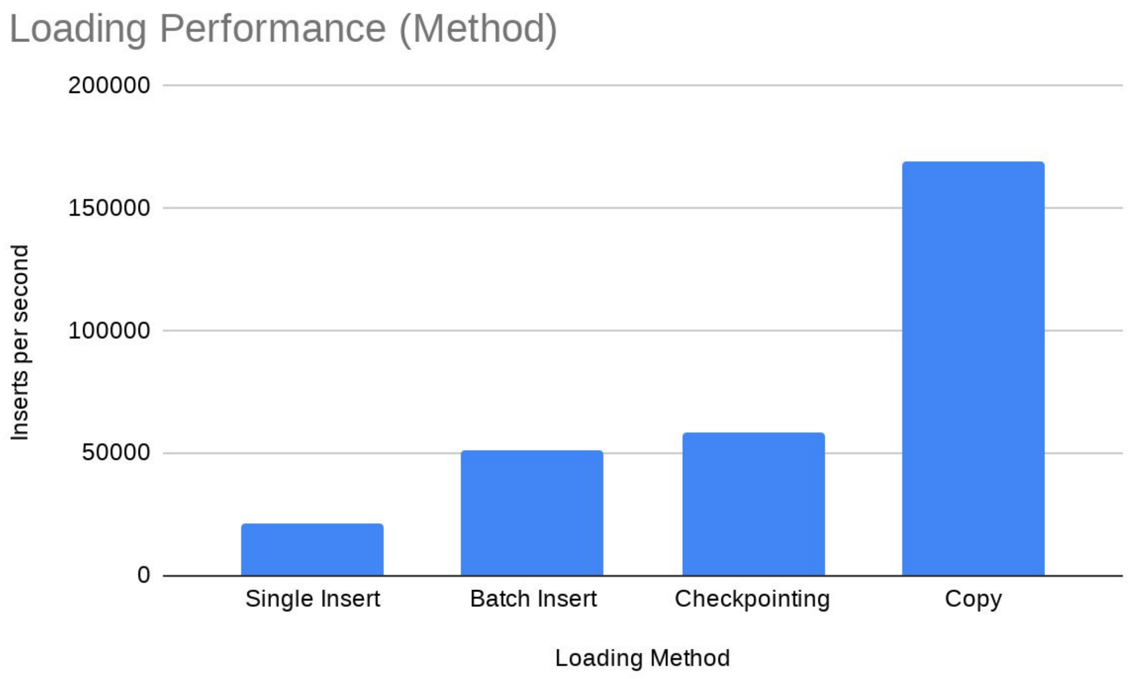


- Load in batches
- Don’t use autocommit
- Batching ramps up fast:
  - Autocommit: 300 /s
  - Batch of 10: 2k2 /s
  - Batch of 50: 5k5 /s
  - Batch of 100: 6k /s
  - Batch of 300: 8k /s
- Batching gives ~ 20x performance gain

Loading Data - Batching

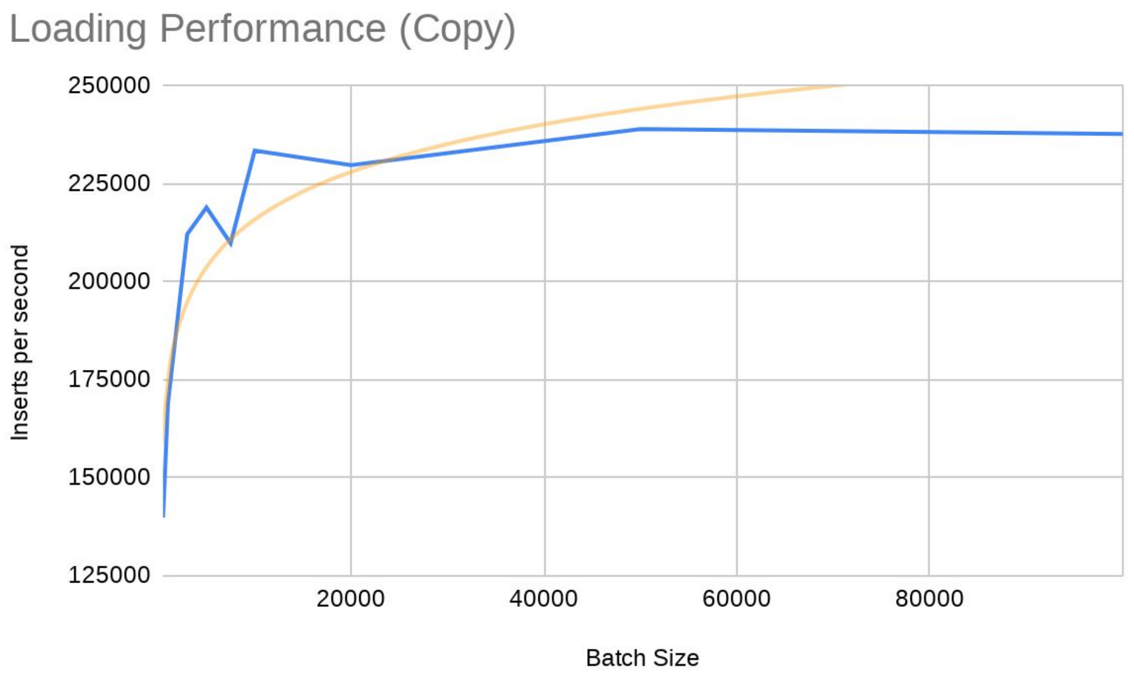
```
connection.setAutoCommit(false);
try {
  try (PreparedStatement stmt = connection.prepareStatement("INSERT INTO ....")) {
     for (T record : batch) {
       stmt.setString(1, record.getId().toString());
       stmt.setTimestamp(2, record.getTimestamp());
       stmt.setFloat(3, record.getTemperature());
       stmt.addBatch();
     }
     stmt.executeBatch();
  }
  connection.commit();
} catch (SQLException e) {
     connection.rollback();
} finally {
     connection.setAutoCommit(true);
}
```

Loading Data - Comparing Loading Methods



- Batched inserts offer a big gain over single insert statements
- Copy has a huge speed up over even batched inserts with the same batch size
- Checkpointing is useful to keep latency consistent

Loading Data - Copy Performance

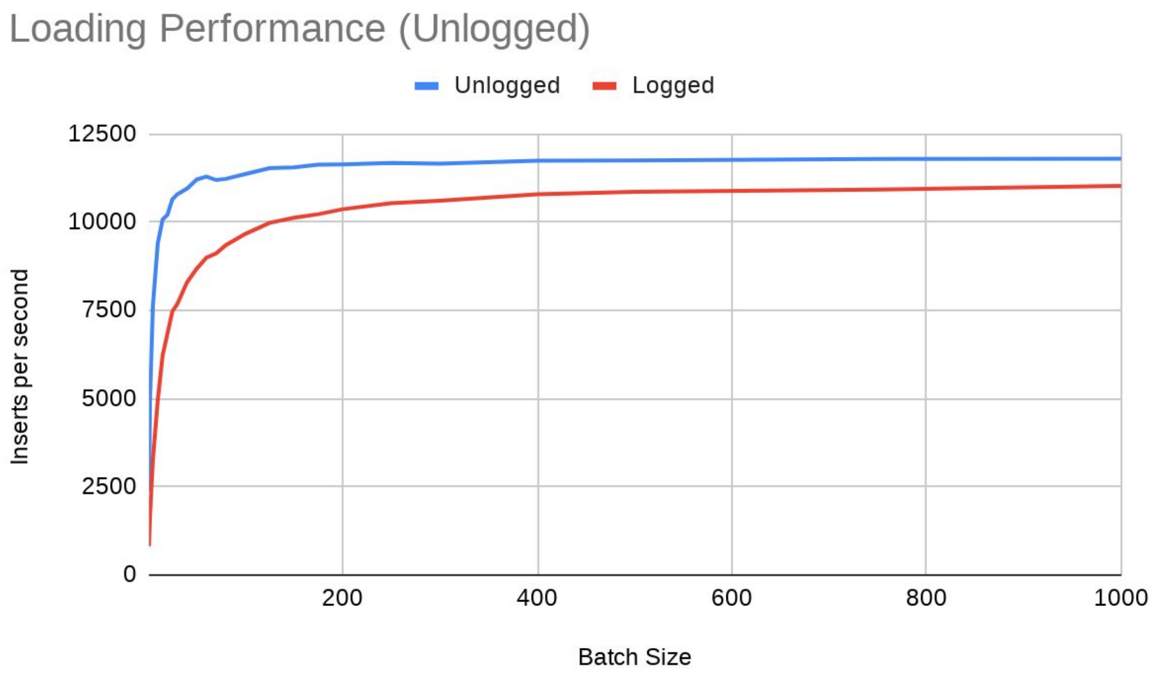


- Copy starts fast and ramps up quickly with batch size
-

Loading Data - ON CONFLICT

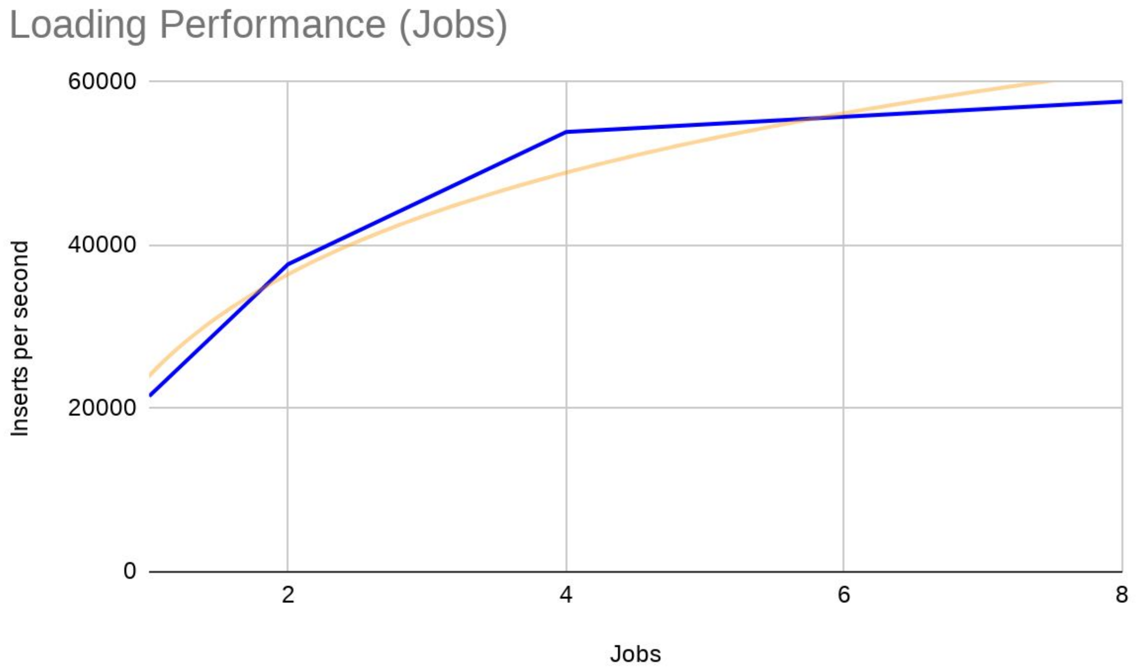
- Use ON CONFLICT
- Your data will be crap
  - Duplicate PKs
  - Out of order
- Nothing worse than having your batch abort
  - Need to deal with savepoints, application buffers
  - Gets rather complex
  - Retransmits, duplicate messages
  - Reprocessing

Loading Data - Unlogged



- UNLOGGED tables will ramp up faster than LOGGED tables with respect to batch sizes
- Little improvement over optimized batch loading

Loading Data - Parallel



- Loading in parallel will let you push more in
- Roughly linear until you hit CPU or Storage limits

Loading Data - Never Sleeping

- IoT data is often constant, never sleeping, never lets up
    - Thankfully PostgreSQL doesn't really have an issue with append only workloads
- Replication can often be the bottleneck
    - Regardless of sync vs async replication
    - You need to ensure that your replicas can keep up with the constant torrent of data
        - Replication replay is single threaded, this can have a huge impact on lagging
- Maintenance windows become hard
    - Need to be careful with backup scheduling and impact
        - Don't really have an overnight quiet time
    - Maintenance jobs might need more planning
        - Might need login in application layers to switch DBs etc to help with this

Loading Data - When Thing Go Wrong

Loading Data - When Thing Go Wrong

- Devices should skew times and back off when things go wrong
  - Can be very easy to trigger congestive collapse
    - Only needs a minor trigger
  - Don’t forget this is more about comms, rather than sampling time
- Your devices should still do sensible things without your platform
- Your data loading system should throttle inserts
  - Don’t want impact of devices taking your DB out, and thus most of the platform
  - It’s probably better to drop data or buffer more than fall flat on your face

Managing Data

Managing Data - Partitioning

Managing Data - Partitioning

```
CREATE TABLE iot.alhex_reading (
  device_id   UUID NOT NULL,
  read_at     TIMESTAMP NOT NULL,
  temperature REAL,
  light       REAL,
  PRIMARY KEY (device_id, read_at)
) PARTITION BY RANGE (read_at);
```

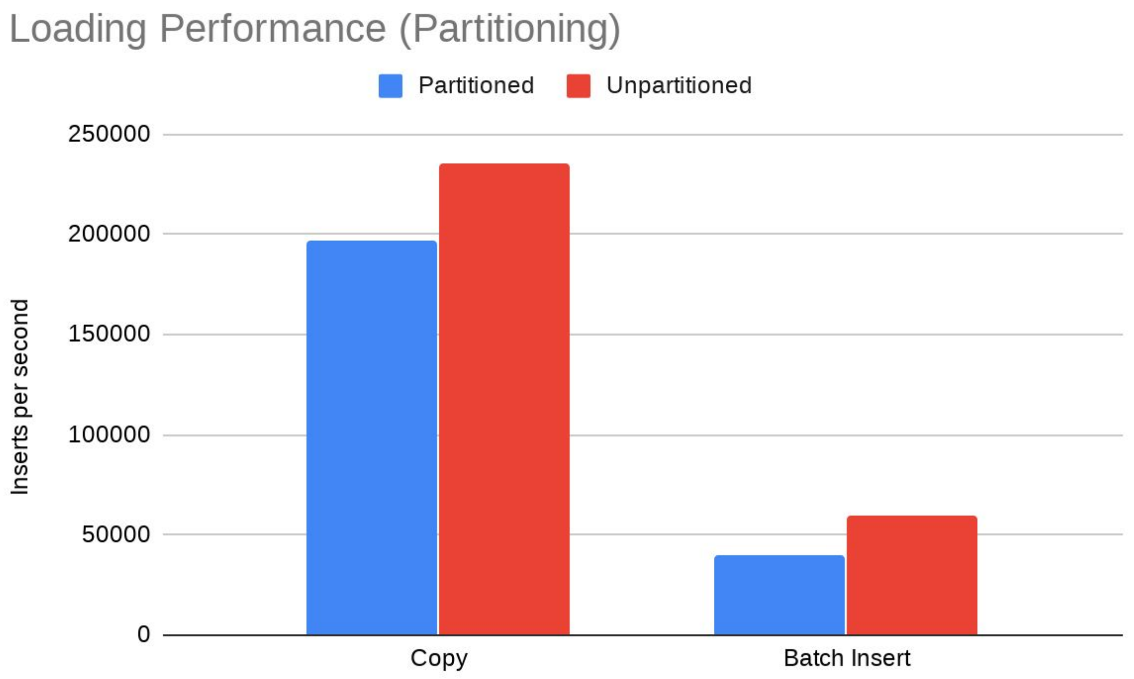
Managing Data - Partitioning

```
CREATE TABLE iot.alhex_reading_202210
  PARTITION OF iot.alhex_reading
  FOR VALUES FROM ('2022-10-01') TO ('2022-11-01');

...

CREATE TABLE iot.alhex_reading_202302
  PARTITION OF iot.alhex_reading
  FOR VALUES FROM ('2023-02-01') TO ('2023-03-01');
```

Managing Data - Partition Loading Performance



- Insert into partition parent table
- Inserts need to be directed to the correct partition
- This has a slight performance drop

Managing Data - Partition Retention

```
ALTER TABLE iot.alhex_reading_202210
  DETACH PARTITION iot.alhex_reading;

-- Archive old partition
COPY iot.alhex_reading_202210
  TO ‘archive/alhex_reading_202210’;

DROP TABLE iot.alhex_reading_202210;
```

Managing Data - Tablespaces

```
CREATE TABLESPACE archive
  LOCATION ‘/data/slow/archive’;

-- Move old data to our archive tablespace
ALTER TABLE iot.alhex_reading_202210
  SET TABLESPACE TO archive;
```

Managing Data - BRIN

Managing Data - BRIN

```sql
CREATE TABLE iot.alhex_reading_history (
  device_id   UUID NOT NULL,
  read_at     TIMESTAMP NOT NULL,
  temperature REAL,
  light       REAL
);

CREATE INDEX alhex_reading_history_read_at_idx
  ON iot.alhex_reading_brin USING BRIN(read_at);
```

Managing Data - BRIN

```
-- Relation size: 1321 MB, 23,000,000 rows

SELECT * FROM iot.alhex_reading_history
WHERE device_id = 'a3e06bcf-429d-43ff-9e46-55aee2ddd86a'
AND read_at >= '2022-10-17 07:10:31'
AND read_at <= '2022-10-18 07:10:31';

-- Seq Scan: 1239 ms          No Index
-- BRIN:       148 ms      80 kB Index
-- BTREE:     0.73 ms     891 MB Index
```

Processing Data

Processing Data - Putting Stuff Together

```
SELECT avg(r.kwh), min(r.kwh),
       max(r.kwh), count(*)
FROM reading_monthly r
JOIN meter m ON (m.id = r.meter_id)
JOIN property p ON (m.property_id = p.id)
WHERE p.bedrooms = 4
AND r.month BETWEEN ‘2023-06-01’ AND ‘2023-09-01’
```

Processing Data - Putting Stuff Together

```
SELECT date_trunc(‘month’, r.day) AS month,
  avg(r.kwh), min(r.kwh), max(r.kwh)
FROM reading r
JOIN meter m ON (m.id = r.meter_id)
JOIN postcode p ON st_dwithin(m.location,
                       p.location, 2000)
WHERE p.postcode = ‘SY2 6ND’
GROUP BY 1;
```

Processing Data - Presenting Data

```
SELECT r.device_id, t.time, array_agg(r.read_at),
       avg(r.temperature), avg(r.light)
FROM generate_series(
   '2022-10-06 00:00:00'::TIMESTAMP,
   '2022-10-07 00:00:00'::TIMESTAMP, '10 minutes') t(time)
JOIN iot.alhex_reading r
   ON (r.device_id = '26170b53-ae8f-464e-8ca6-2faeff8a4d01'::UUID
       AND r.read_at >= t.time
       AND r.read_at < (t.time + '10 minutes'))
GROUP BY 1, 2
ORDER BY t.time;
```

Processing Data - Window Functions

Processing Data - Counters

```
SELECT
 day,
 energy,
 energy - coalesce(lag(energy)
    OVER (ORDER BY day), 0) AS consumed
FROM iot.meter_reading
ORDER BY day;
```

Processing Data - Rolling Along

```
WITH consumption AS (
  … from previous slide …
)
SELECT *, sum(consumed) OVER
 (PARTITION BY date_trunc('week', day))
   AS weekly_total
FROM consumption;
```

Processing Data - Moving On Up

```
SELECT *, avg(consumed) OVER
 (ORDER BY day
  ROWS BETWEEN 2 PRECEDING
  AND CURRENT ROW)
   AS weekly_total
FROM consumption;
```

Processing Data - Mind The Gap!

Processing Data - Mind The Gap

```sql
WITH days AS (
  SELECT t.day::DATE
  FROM generate_series('2017-01-01'::DATE,
'2017-01-15'::DATE, '1 day') t(day)
), data AS (
   SELECT *
   FROM iot.meter_reading
   WHERE day >= '2017-01-01'::DATE
   AND   day <= '2017-01-15'::DATE
)
```

Processing Data - Mind The Gap

```
SELECT day,
       coalesce(energy,
         (((next_read - last_read)
            / (next_read_time - last_read_time))
            * (day - last_read_time))
            + last_read) AS energy_interpolated
FROM (
    … from next slide …
) q
ORDER BY day
```

Processing Data - Mind The Gap

```
SELECT t.day, d.energy,
  last(d.day)    OVER lookback    AS last_read_time,
  last(d.day)    OVER lookforward AS next_read_time,
  last(d.energy) OVER lookback    AS last_read,
  last(d.energy) OVER lookforward AS next_read
FROM days t
LEFT JOIN data d ON (t.day = d.day)
WINDOW
  lookback AS (ORDER BY t.day),
  lookforward AS (ORDER BY t.day DESC)
```

Processing Data - Mind The Gap

```
CREATE FUNCTION last_agg(anyelement, anyelement)
RETURNS anyelement LANGUAGE SQL IMMUTABLE STRICT AS $$
      SELECT $2;
$$;

CREATE AGGREGATE last (
      sfunc = last_agg,
      basetype = anyelement,
      stype = anyelement
);
```

Any Questions?

chris@nexteam.co.uk https://nexteam.co.uk

Appendix - Mind The Gap

```
WITH days AS (
  SELECT t.day::DATE
  FROM generate_series('2017-01-01'::DATE, '2017-01-15'::DATE, '1 day') t(day)
), data AS (
       SELECT *
       FROM iot.meter_reading
       WHERE day >= '2017-01-01'::DATE AND day <= '2017-01-15'::DATE
)
SELECT day, coalesce(energy_import_wh, (((next_read - last_read) / (next_read_time - last_read_time)) * (day -
last_read_time)) + last_read) AS energy_import_wh_interpolated
FROM (
  SELECT t.day, d.energy_import_wh,
       last(d.day) OVER lookback AS last_read_time,
       last(d.day) OVER lookforward AS next_read_time,
       last(d.energy_import_wh) OVER lookback AS last_read,
       last(d.energy_import_wh) OVER lookforward AS next_read
  FROM days t
  LEFT JOIN data d ON (t.day = d.day)
  WINDOW
       lookback AS (ORDER BY t.day),
       lookforward AS (ORDER BY t.day DESC)
) q  ORDER BY q.day
```