Queues in PostgreSQL

PGDay Australia 2017

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Who am I?

- EnterpriseDB Database Server team member
- PostgreSQL contributor
- First PostgreSQL patch was **`SKIP LOCKED`** in release 9.5 (topic of this talk)
- Currently working on parallelism and new storage formats

What's a Queue?

Why Put One in an RDBMS?

Example Use Cases

Implementation

Problems

What Could We Do Better?

queue /kjuː/

noun

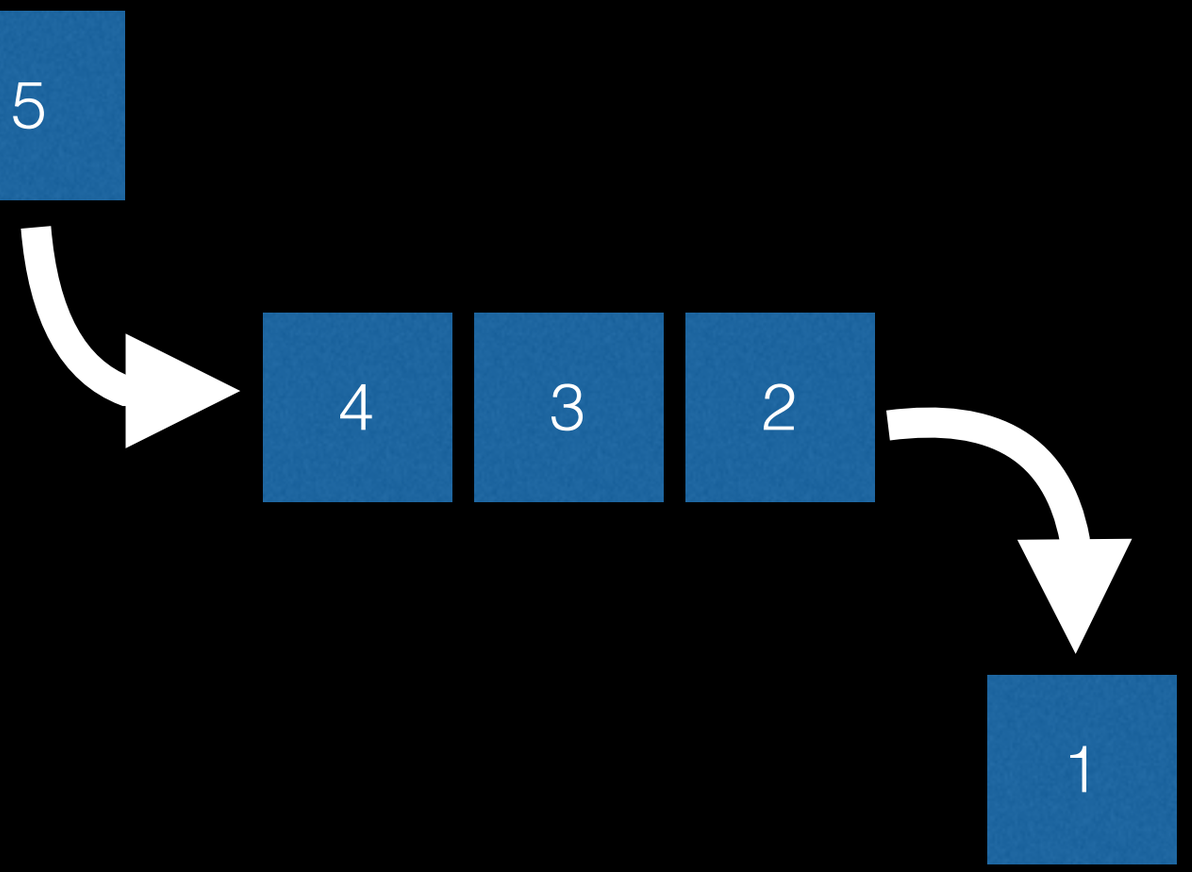
1. *Chiefly British* A line or sequence of people or vehicles awaiting their turn to be attended to or to proceed.

Definition: Oxford Dictionary
Image: paphotos.co.uk

queue /kjuː/

noun

2. *Computing* A list of data items, commands, etc., stored so as to be retrievable in a **definite order**, usually the order of insertion.



Definition: Oxford Dictionary

Informal Taxonomy

- Queues

  1. FIFO: First-in-first-out queues
  2. Priority queues

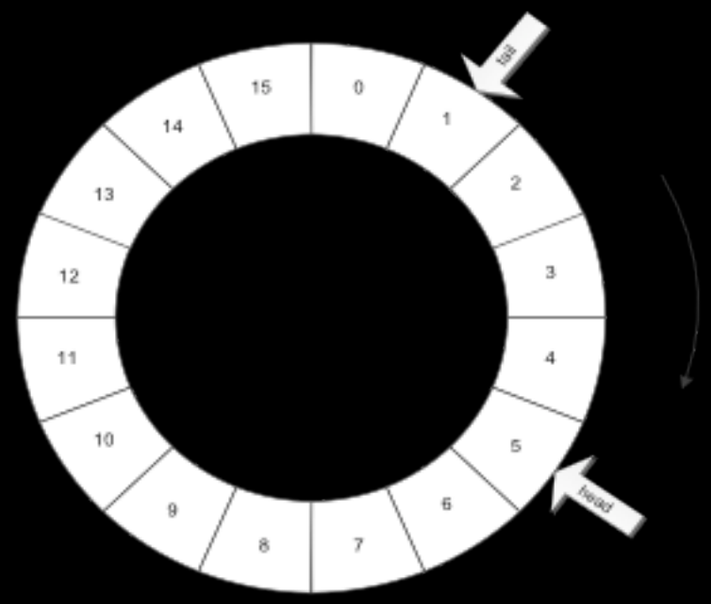
- “Queues”

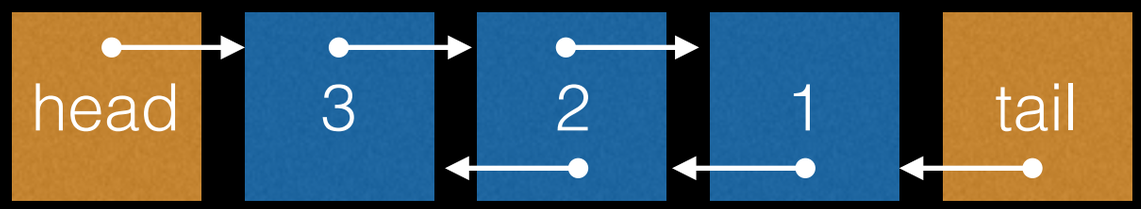
  3. Specialised queues (merging, reordering)
  4. Unordered/approximately ordered queues

1. FIFO Queues

- The order most people think of when they hear the word “queue”

- Often used in low level code because the implementation is simple and fast: physical layout reflects logical ordering





2. Priority Queues

- Sometimes a different explicit logical order is needed
- Implementation techniques include sets of FIFO queues, **trees** and other data structures associated with sorting

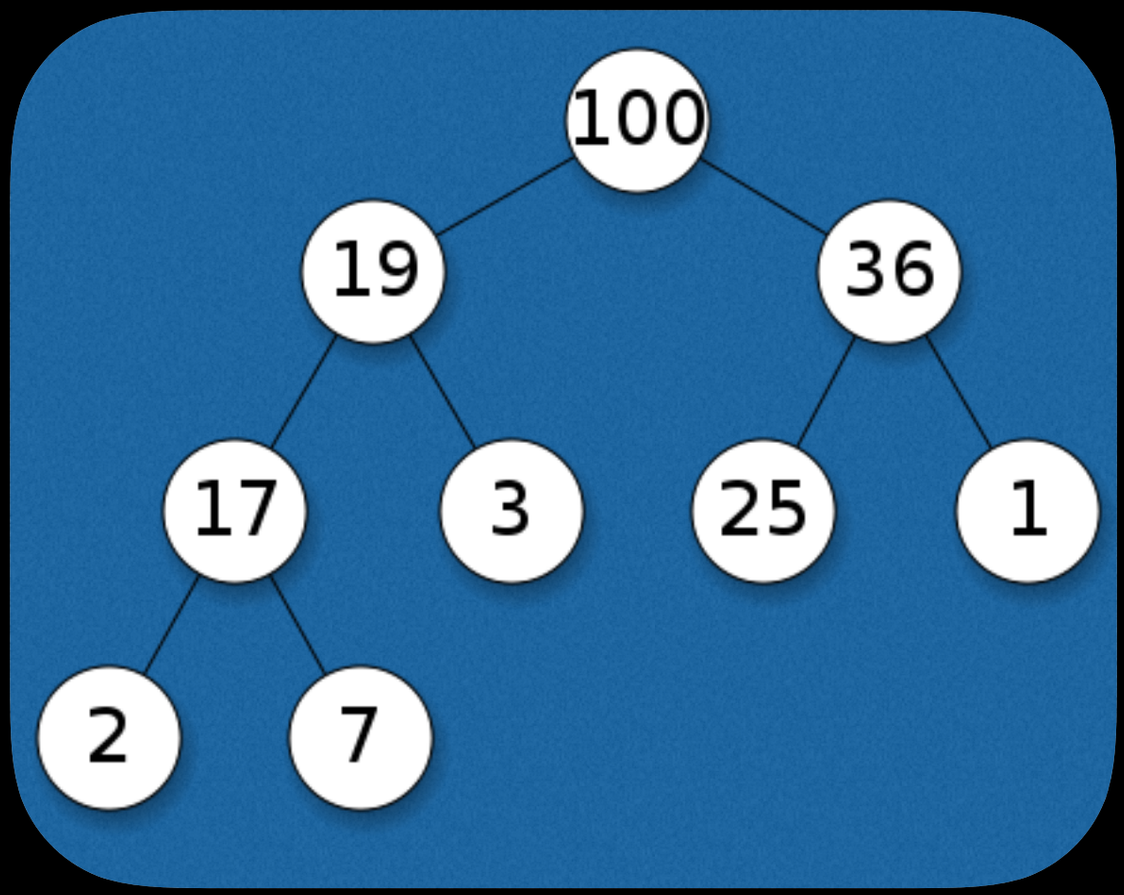


Image: Wikipedia

3. Specialised “Queues”

- Sometimes we use the word queue more loosely to describe something that gives up strict logical ordering to meet some other goal

- Operating system IO schedulers and elevators/lifts allegedly improve global efficiency by merging and reordering queued requests

Image: epicioci pixabay.com

4. Unordered & Approximately Ordered “Queues”

- Sometimes we don’t care about the order that items are retrieved in at all, we just want to process them as quickly as possible

- … but usually we want at least approximate time ordering for fairness (no arbitrarily stuck messages), but don’t need strict global ordering for correctness

- Transactional and concurrent systems blur the order of both insertion and retrieval

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“Meh, why not use RabbitMQ/Redis/PGQ/ *<thing>*?”

Free clipart: pngimg.com

You might consider using a plain old database if…

- … you want reliable persistent message processing that is atomic with respect to other database work (without the complications of distributed transactions)
- … you don’t want the maintenance, backups, failover and risks of new moving parts (message broker daemons)
- … your message rates and number of consumers are in the range that PostgreSQL and your hardware can handle
- … you like PostgreSQL enough to attend a conference

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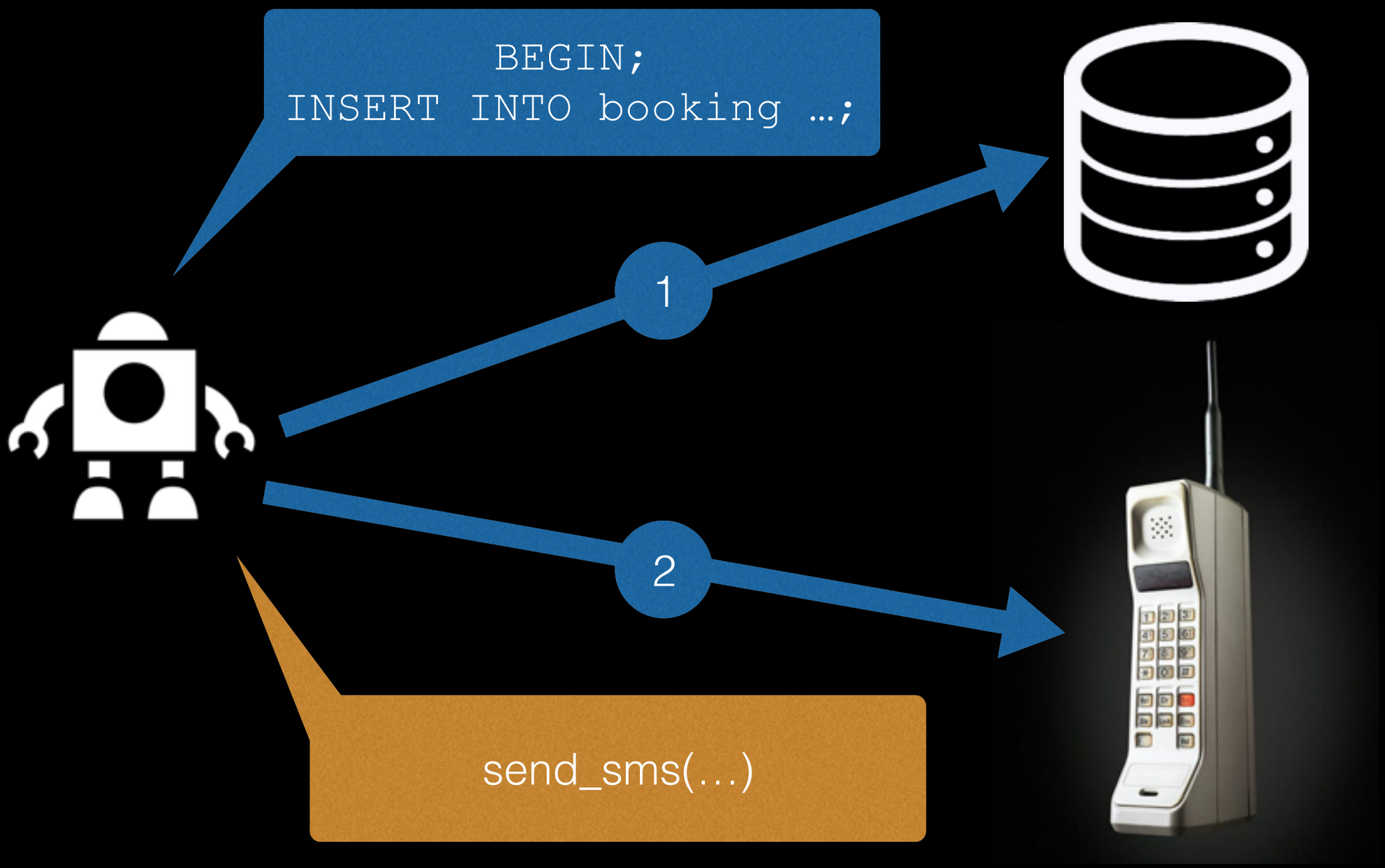
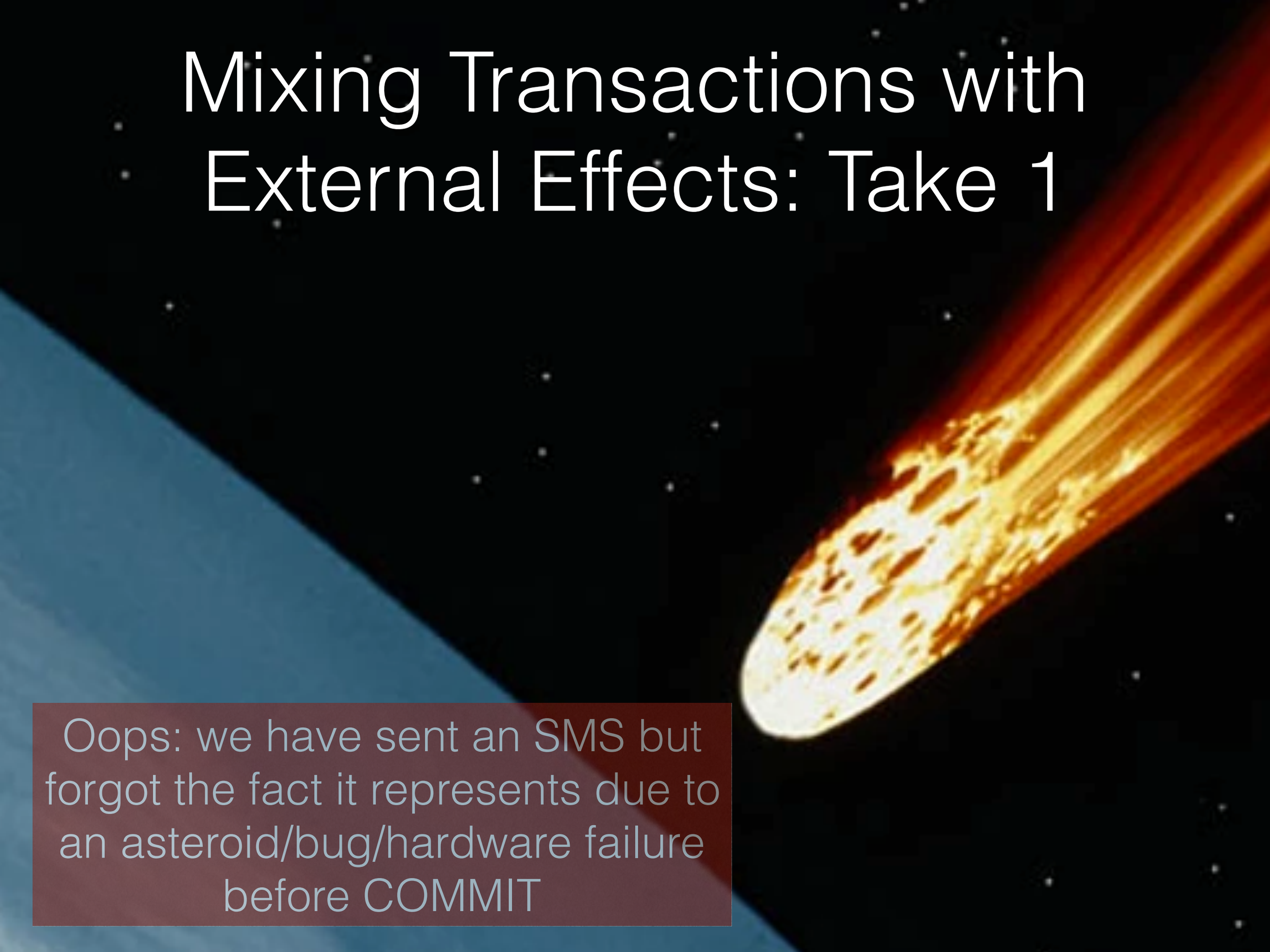
Mixing Transactions with External Effects

- We want to book a seat on a plane
- We also want to send an SMS message with confirmation of the booking and seat number

Mixing Transactions with External Effects: Take 1



Mixing Transactions with External Effects: Take 1

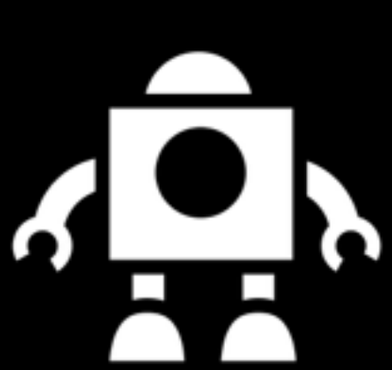


Oops: we have sent an SMS but forgot the fact it represents due to an asteroid/bug/hardware failure before COMMIT

Mixing Transactions with External Effects: Take 2

```
BEGIN;
INSERT INTO booking …;
COMMIT;
```

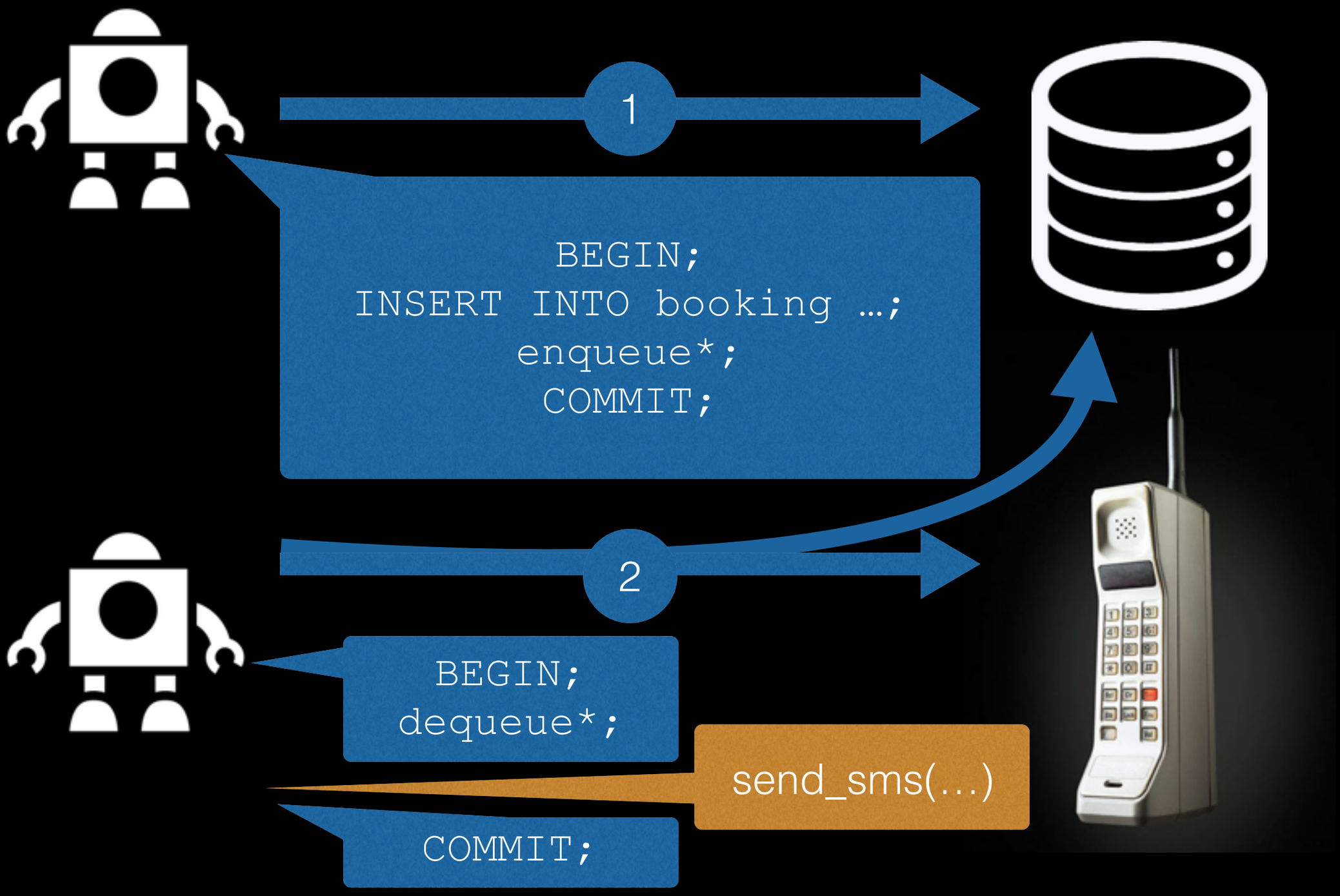
1



Mixing Transactions with External Effects: Take 2

Oops: we have committed the fact, but failed to send an SMS due to flood/transient network failure/SMS provider downtime

Mixing Transactions with External Effects: Take 3

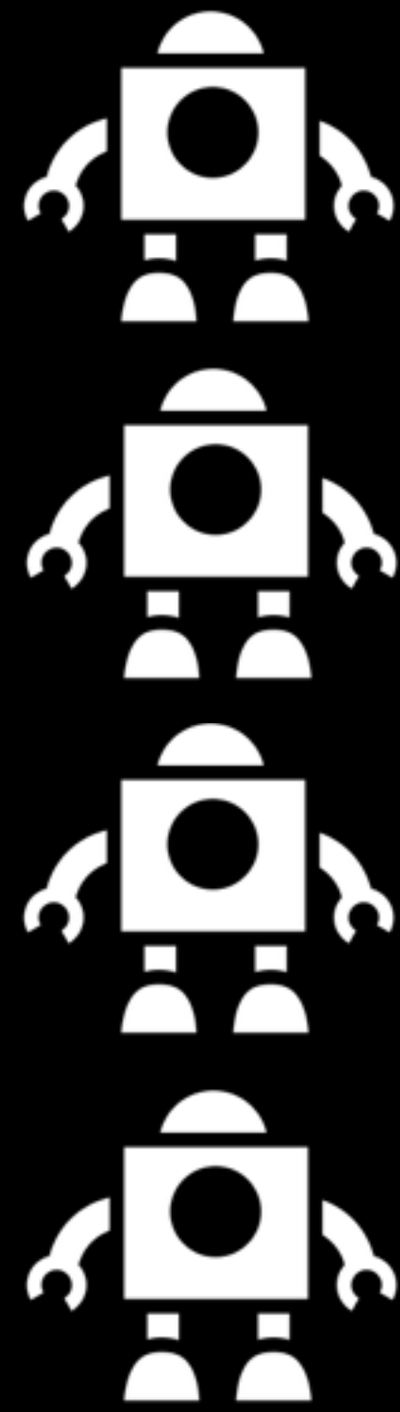


Mixing Transactions with External Effects

- We establish a new fact (the booking) and record our intention to notify the customer (the entry in the SMS queue) **atomically**
- We remove the queued item after sending successfully (and probably have a retry system if the SMS service is temporarily failing)
- The SMS sending operation should ideally be **idempotent** so that if we fail after sending but before committing the dequeue operation, sending the same message again won't be problematic

Distributed Computing

- Job control for farming out expensive external computation to worker processes
- Job control for database aggregation work moved out of interactive transactions



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Ingredients

- Messages: Rows in plain old tables
- Priority ordering: `ORDER BY`
- Signalling: `NOTIFY` & `LISTEN`
- Concurrency:
  - None, course grained locking or `SERIALIZABLE`
  - … or explicit fine grained locking

No Physical FIFO

- The relational model (and therefore its approximate earthly embodiment SQL) doesn't expose details of physical ordering or insertion order to the user

- Ordering will therefore need to be a function of values in records supplied at `INSERT` time, and explicitly requested with `ORDER BY` when they are retrieved (it's always a "priority queue"), or unordered

Enqueue Protocol

- ```
  BEGIN;
  — any other work
  INSERT INTO sms_queue (…)
  VALUES (…);
  NOTIFY sms_queue_broadcast;
  COMMIT;
  ```

- Note: if inserting transactions overlap, then it is difficult to generate a key that increases monotonically with respect to commit/ transaction visibility order!
  ```

Dequeue Protocol: Take 1

- `LISTEN sms_queue_broadcast;`

- ```
  BEGIN;
  SELECT message_uuid, destination, body
    FROM sms_queue
   ORDER BY insert_time
   LIMIT 1;
  — if found, do something (internal or
  — external + idempotent) and then:
  DELETE FROM sms_queue
   WHERE message_uuid = $1;
  COMMIT;
  ```

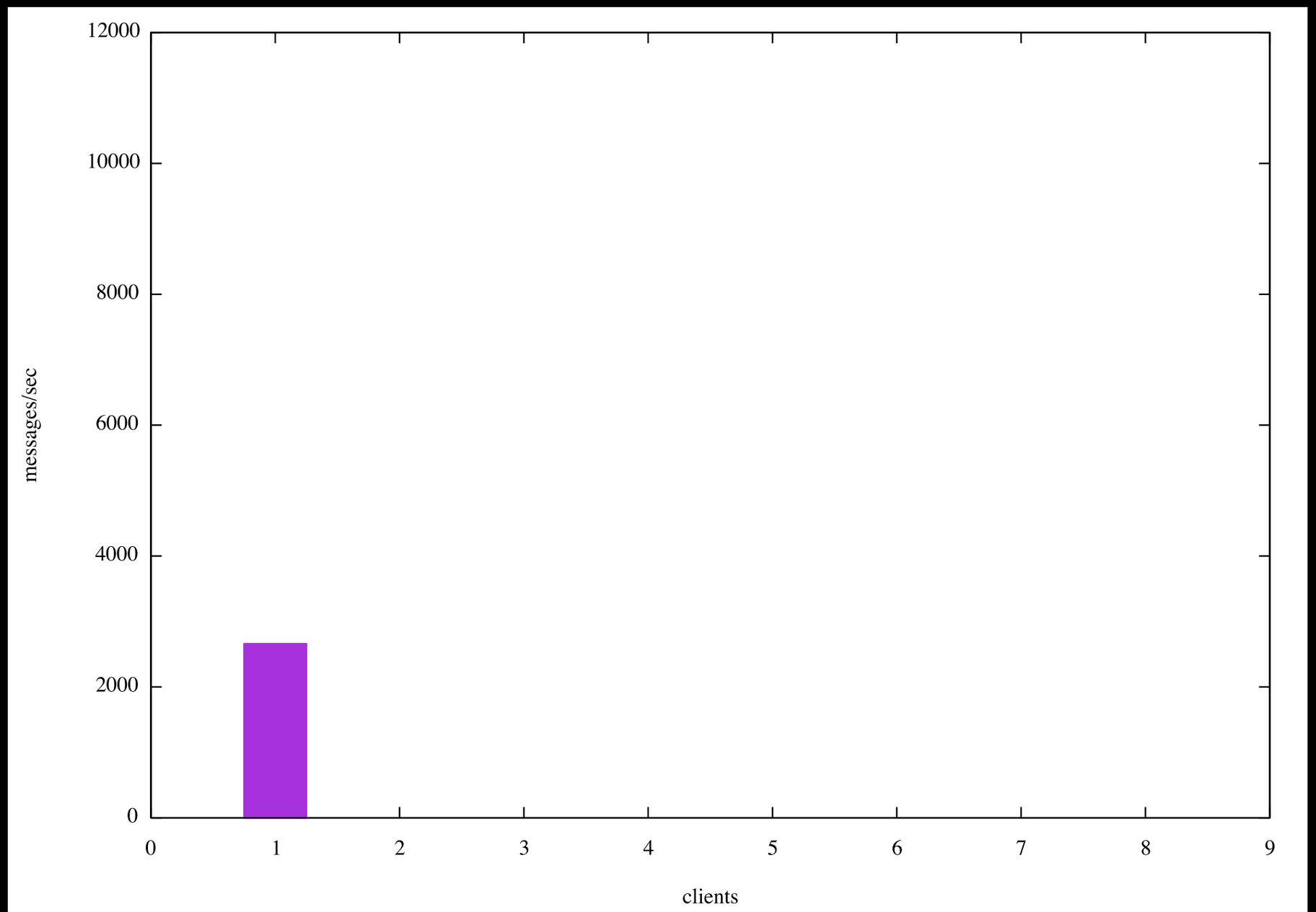
- — repeat previous step until nothing found

- — wait for notifications before repeating
  ```

Dequeue Protocol: Take 1

- At isolation levels below SERIALIZABLE, this protocol won't work correctly if there are concurrent sessions dequeuing
- At SERIALIZABLE level, at most one such overlapping session can succeed (worst case workload for SERIALIZABLE)

Dequeue Protocol: Take 1



Dequeue Protocol: Take 2

- LISTEN sms_queue_broadcast;

- BEGIN;
  SELECT message_uuid, destination, body
    FROM sms_queue
     FOR UPDATE
     ORDER BY insert_time
     LIMIT 1;
  — if found, do something (internal or
  — external + idempotent) and then:
  DELETE FROM sms_queue
   WHERE message_uuid = $1;
  COMMIT;

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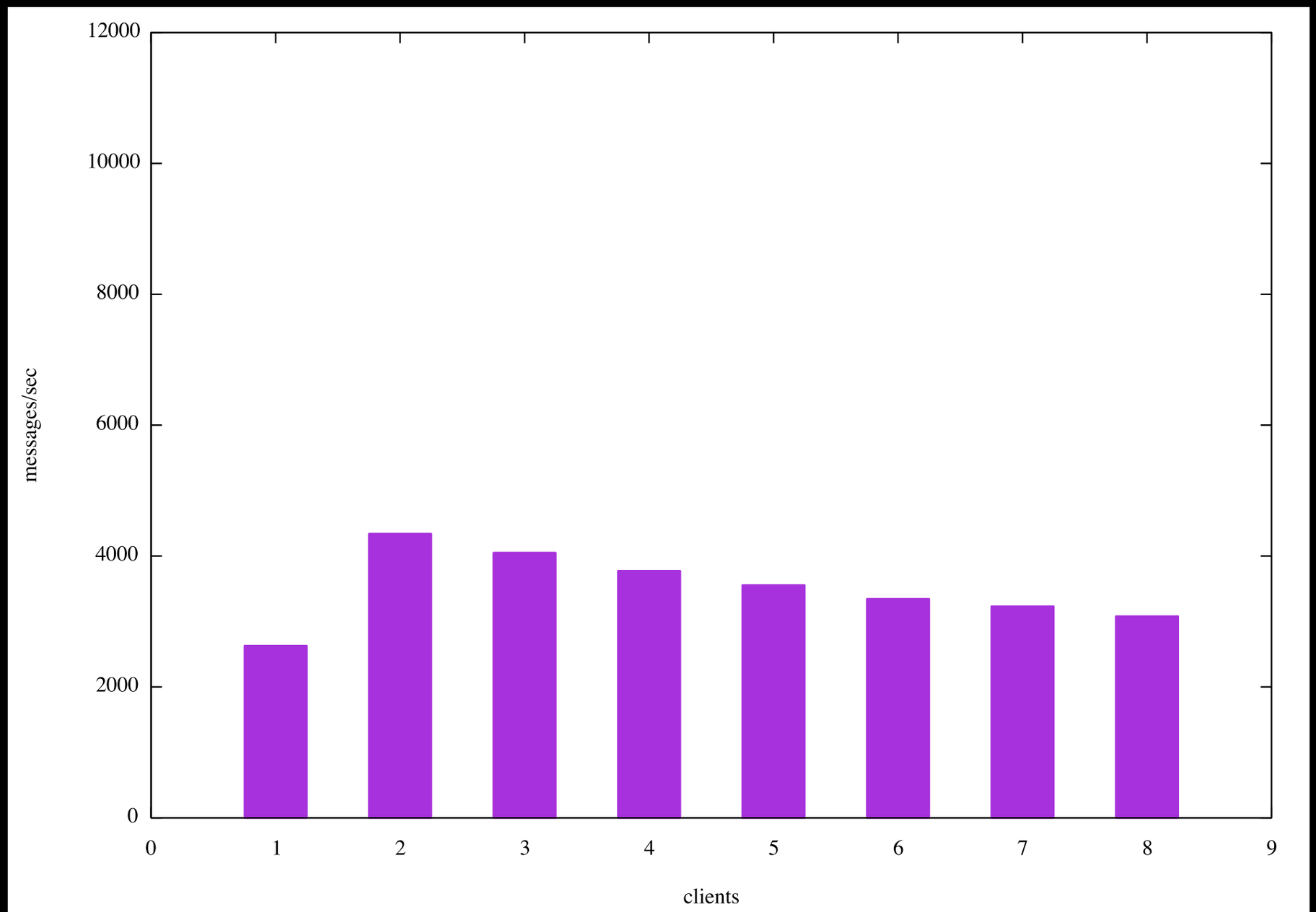
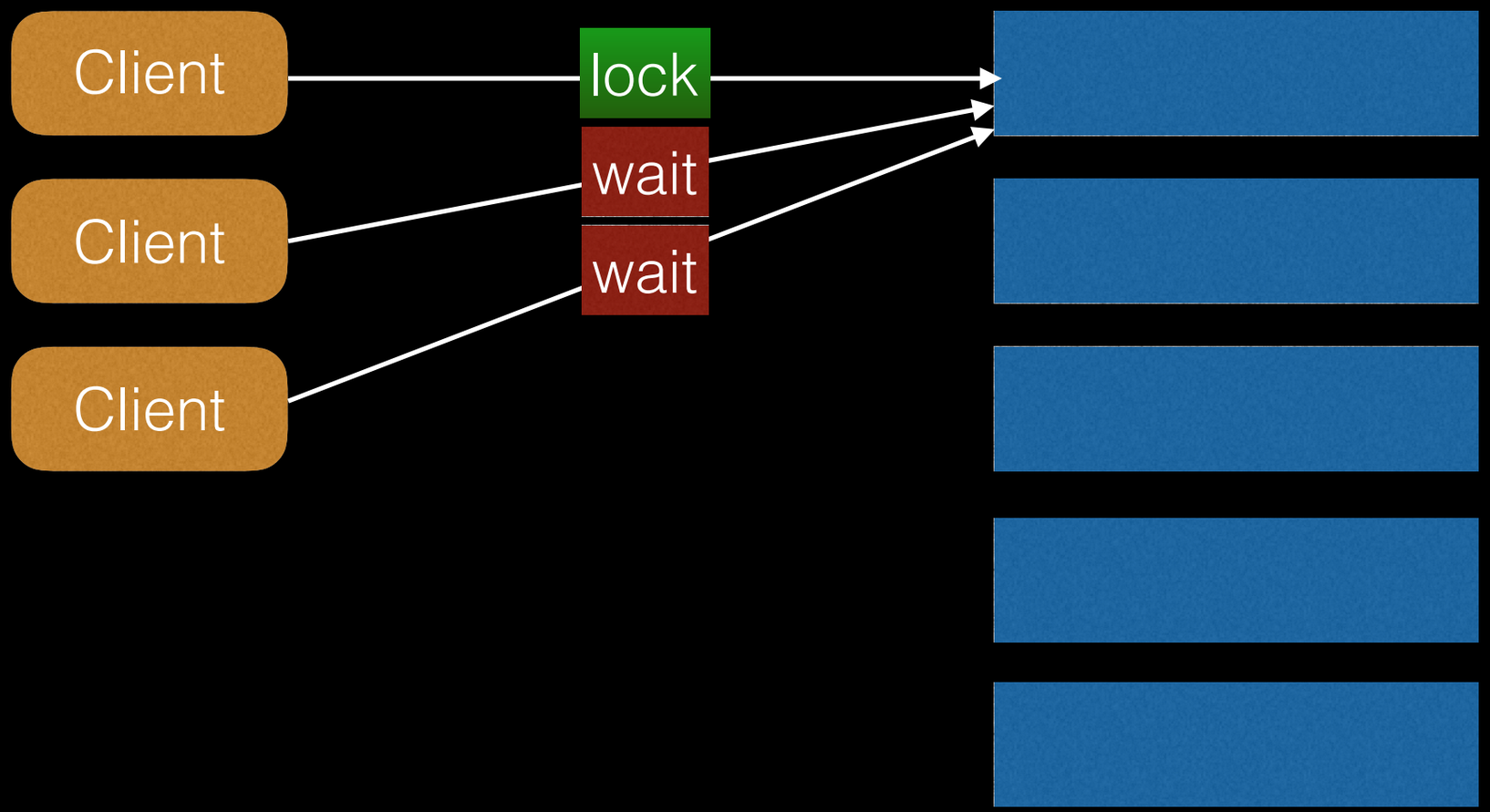
Dequeue Protocol: Take 2



Dequeue Protocol: Take 2

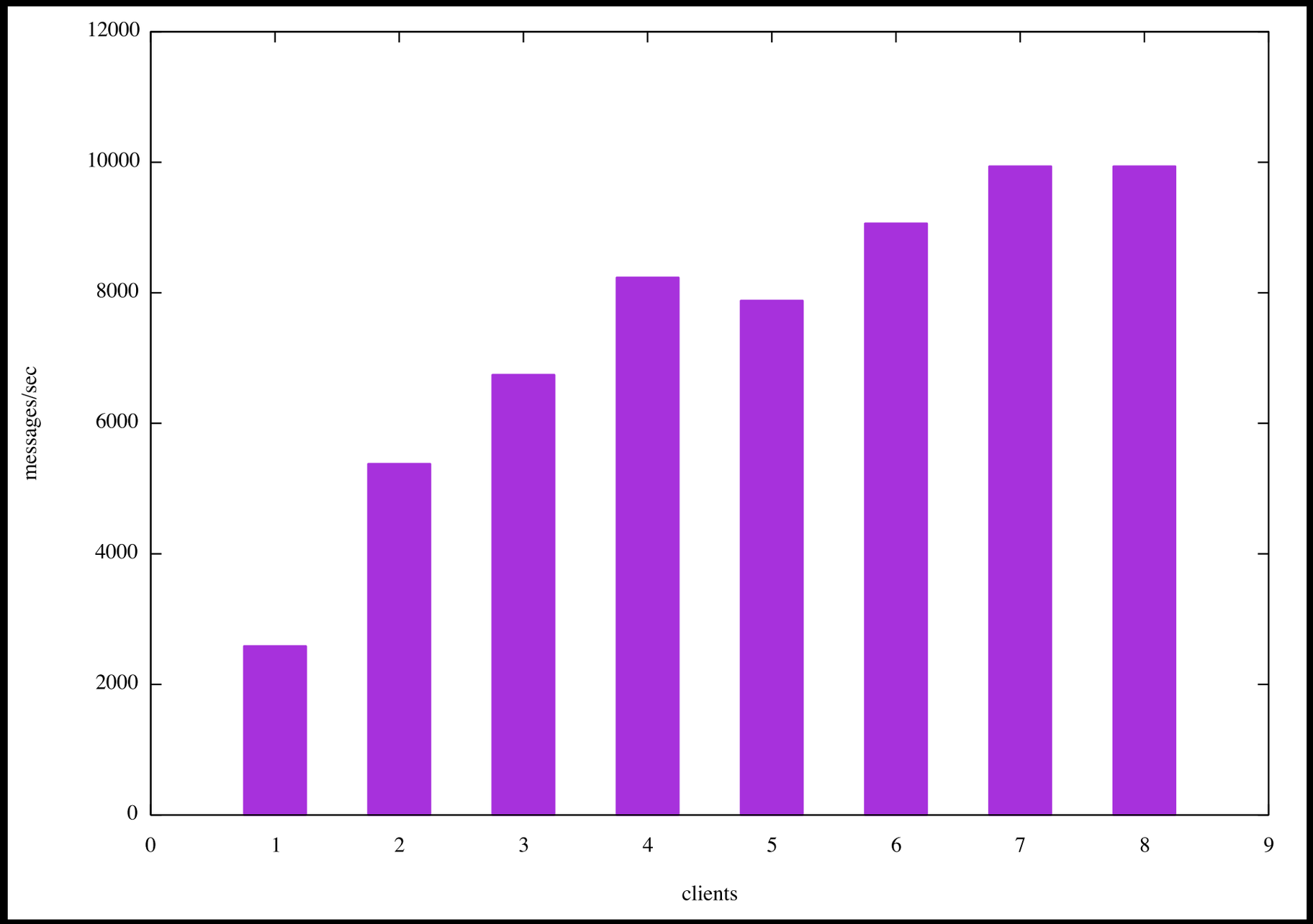


Dequeue Protocol: Take 3

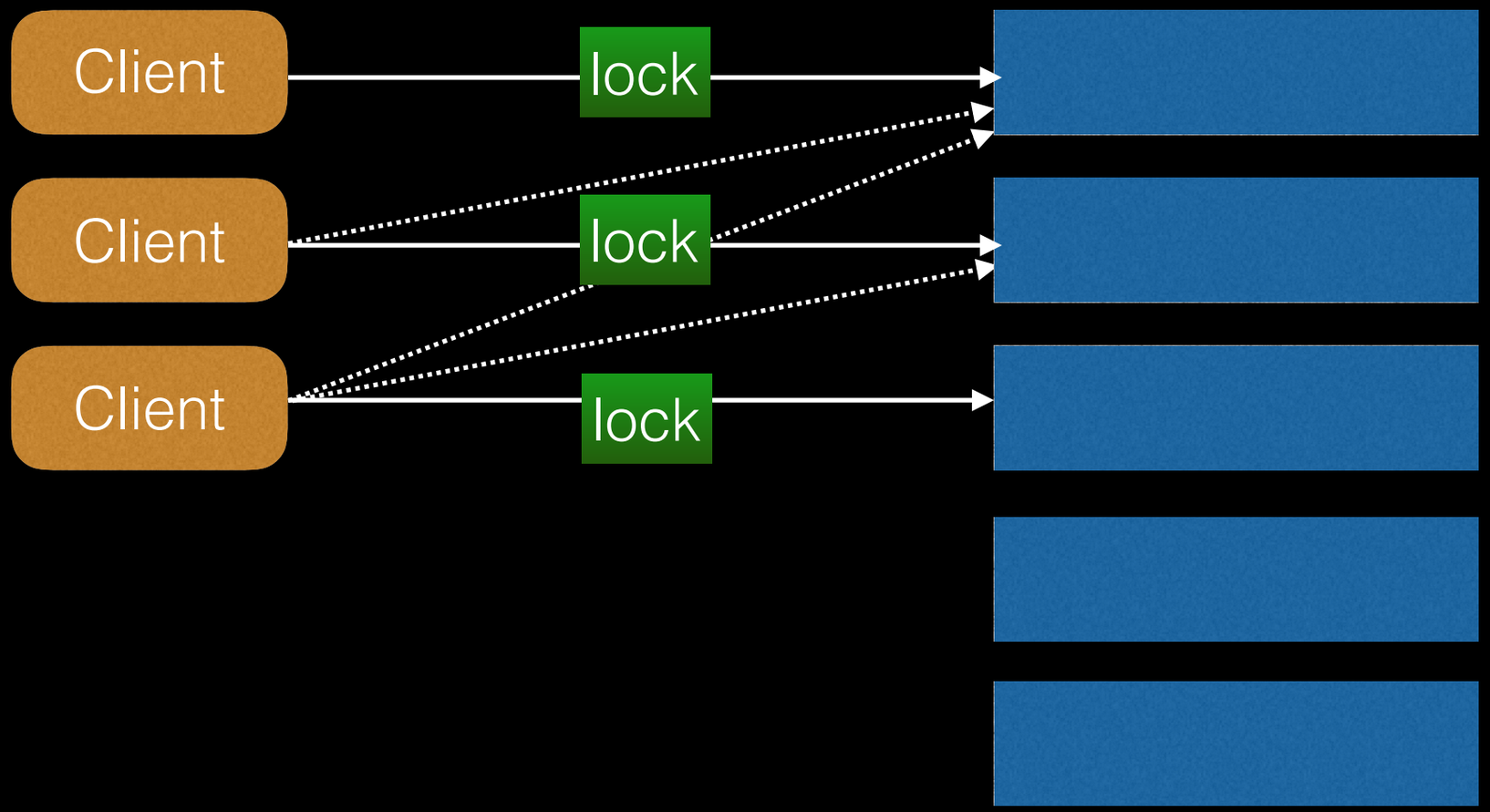
- `LISTEN sms_queue_broadcast;`
- ```
  BEGIN;
  SELECT message_uuid, destination, body
    FROM sms_queue
     FOR UPDATE SKIP LOCKED
   ORDER BY insert_time
   LIMIT 1;
  — if found, do something (internal or
  — external + idempotent) and then:
  DELETE FROM sms_queue
   WHERE message_uuid = $1;
  COMMIT;
  ```
- `— repeat previous step until nothing found`
- `— wait for notifications before repeating`

In PostgreSQL 9.4 and earlier which don't have SKIP LOCKED, use pg_try_advisory_lock(x) in the WHERE clause, where x is somehow derived from the message ID
  ```

Dequeue Protocol: Take 3



Dequeue Protocol: Take 3



Dequeue Protocol: Take 3

- The `ORDER BY` clause is still controlling the time we **start** processing each item, but no longer controlling the order we commit
- Dequeuing transactions that roll back cause further perturbation of the processing order
- Looser ordering is good for concurrency while still approximately fair to all messages
- Stricter ordering is needed for some replication-like workloads with a semantic dependency between messages

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Problems

- Transient failures can be managed with retry counters and two-transaction protocol
- Watch out for ID space running out (32 bit integers)
- If using a SEQUENCE to generate a strict order, be careful of cycling and be aware of behaviour when transactions overlap
- Btrees not correlated with insert/delete order can develop a lot of bloat in high churn tables

Problems

- Statistics for volatile tables might cause trouble (CF DB2 VOLATILE)
- If there is no ordering requirement at all, in theory you might not even need an index on a queue table (you could use ctid to refer to arbitrarily selected locked rows)
- Default vacuum settings may be insufficient, depending on your workload, leading to bloat and unstable performance

old version

row

old version

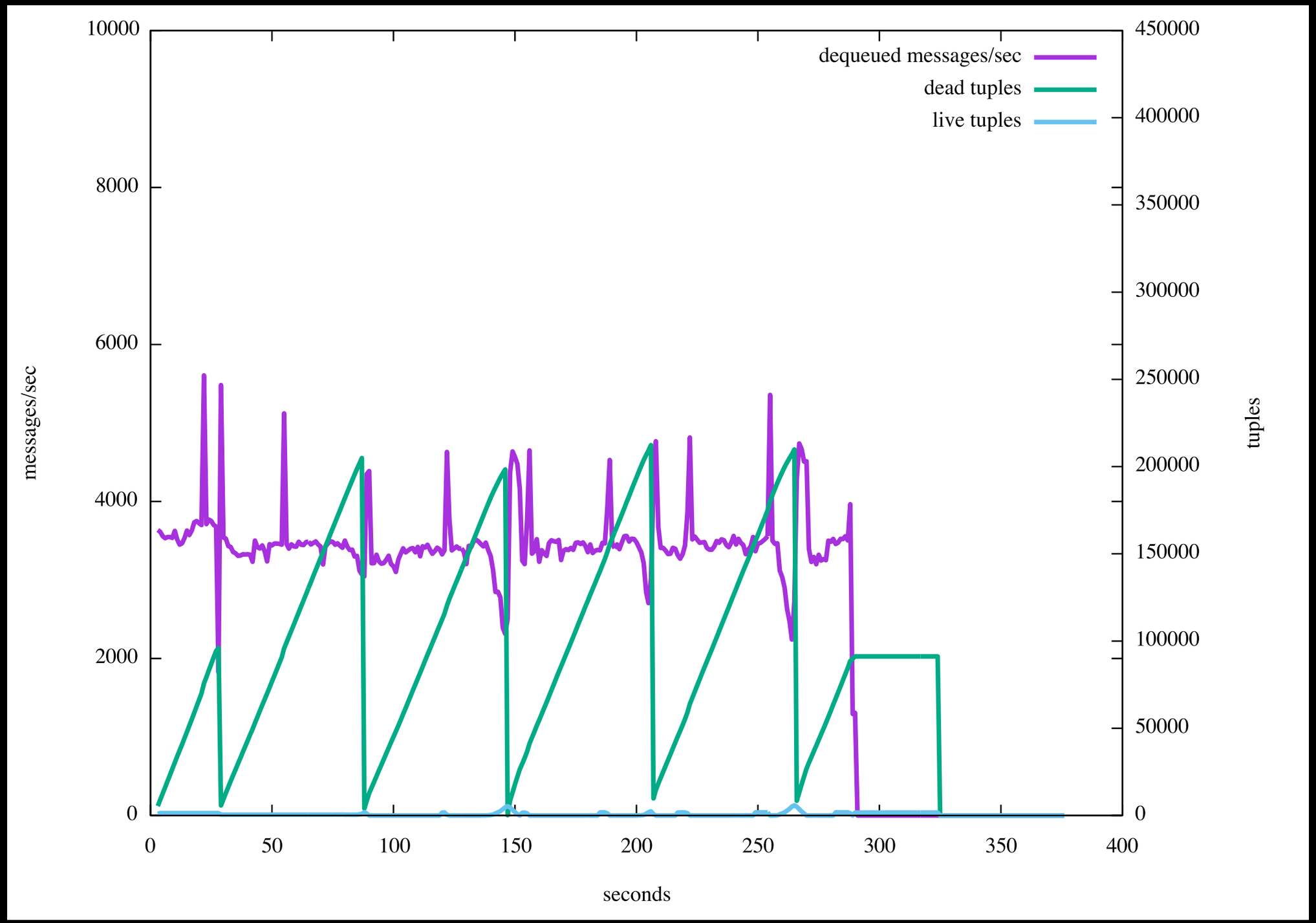
old version

old version

free space

row

Vacuuming


dequeued messages/sec
dead tuples
live tuples
messages/sec
tuples
seconds
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8000
10000
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100000
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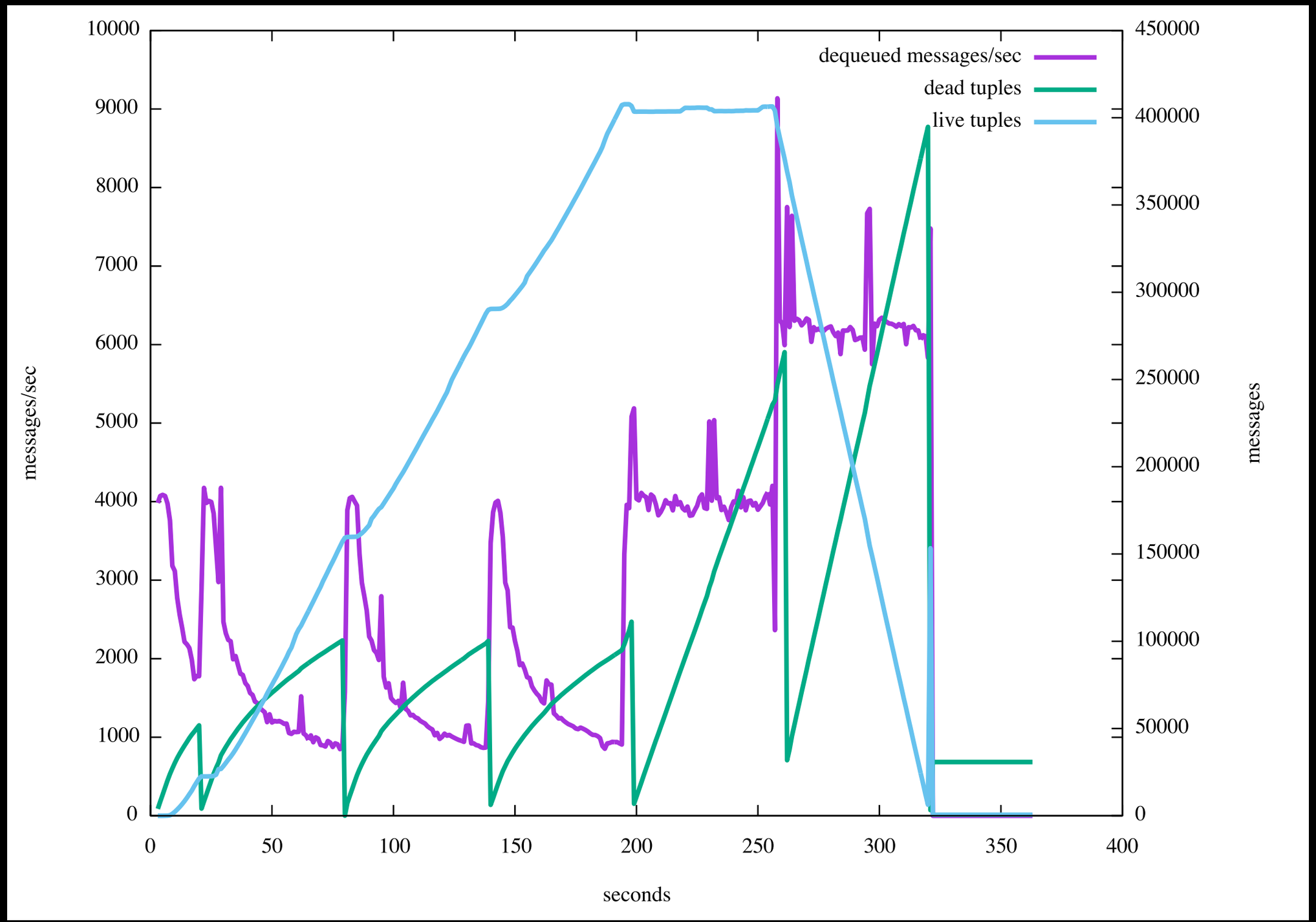
400

Vacuuming


dequeued messages/sec
dead tuples
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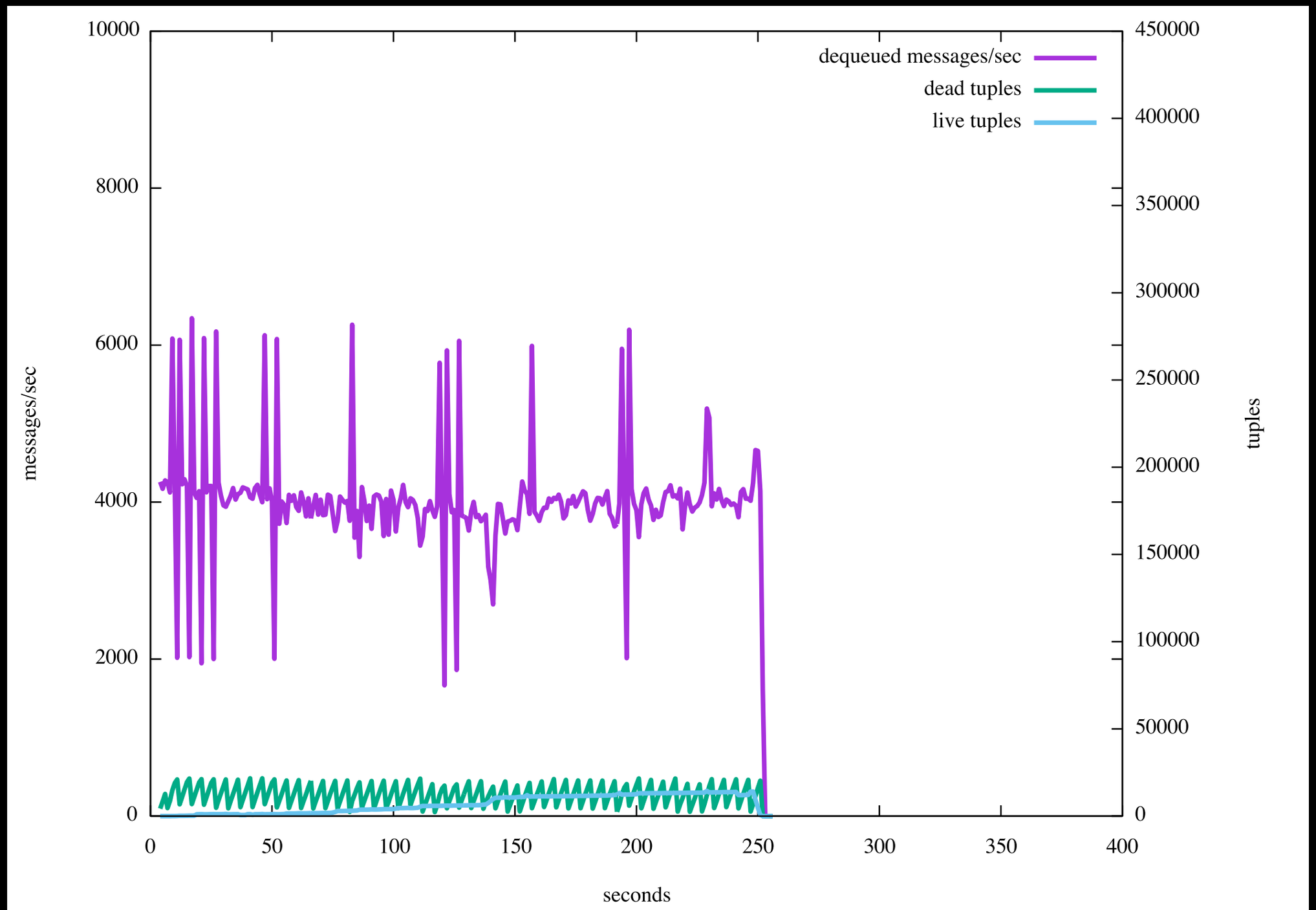
Vacuuming


dequeued messages/sec
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300
350
400

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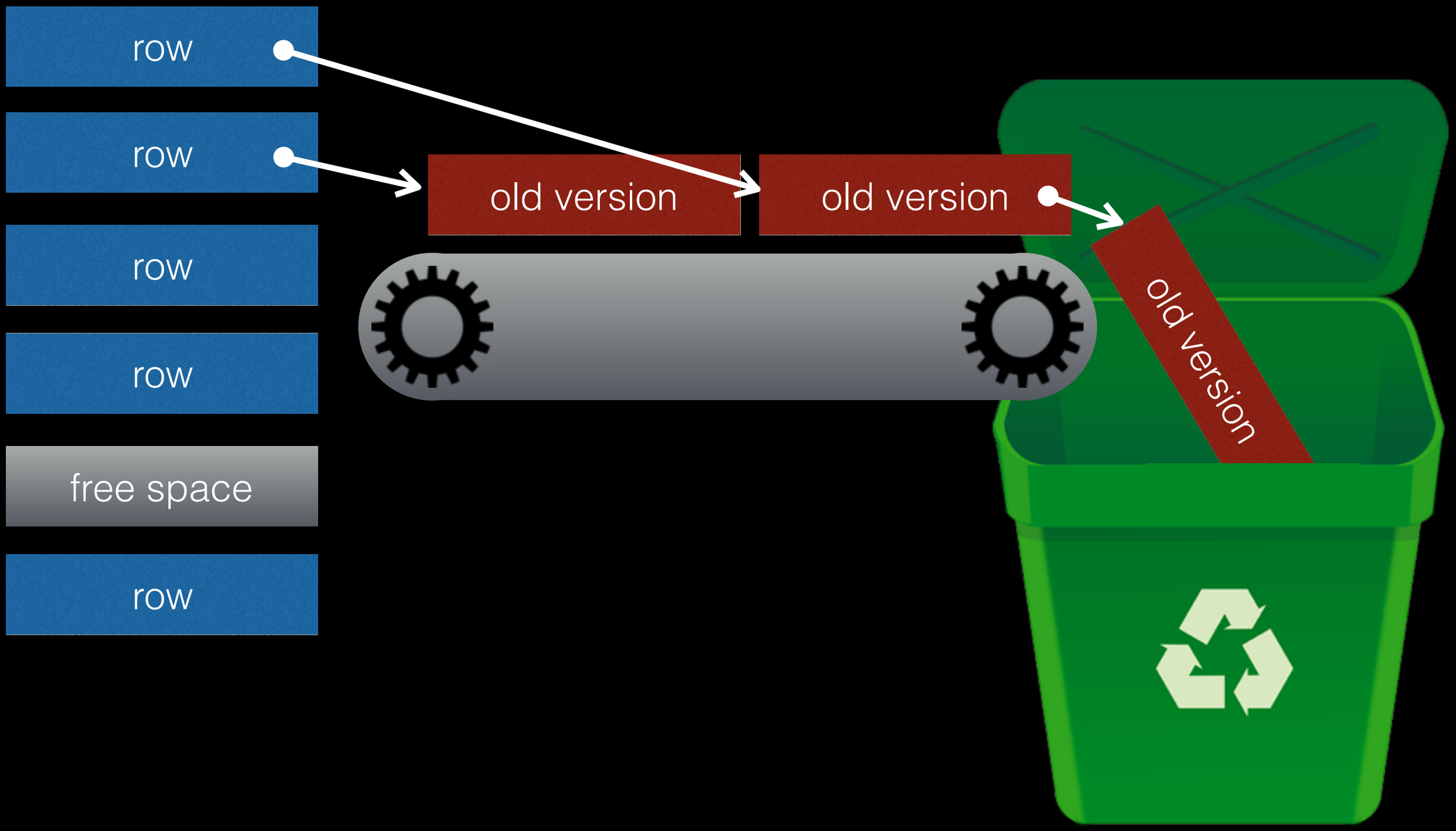
Undo

- Undo-log based MVCC would provide continuous recycling of space, avoiding bloat and giving smoother performance

- Key question: where should we keep old and deleted versions of rows, so that concurrent transactions that still need them can find them?

- Watch this space — active development area


row
row
row
row
free space
row
old version
old version
old version

Notifications

- It would be nice to have a new wait/notify feature that could handle ‘broadcast’ like NOTIFY, but also ‘notify one’: to avoid stampedes of otherwise idle recipients when only one item has been enqueued

- It might be better to do that with a blocking ‘wait’ function rather than the NOTIFY asynchronous message approach (?)

Serializable

- Queue-like workloads are the worst case for SERIALIZABLE
- The executor could in theory consider returning tuples in a different order when there is a LIMIT, no [complete] ORDER BY, and another transaction has SIREAD locks on a tuple being returned
- Perhaps this could reduce conflicts in such workloads, allowing higher throughput without giving up the benefits of SERIALIZABLE

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