PostgreSQL and RAM usage

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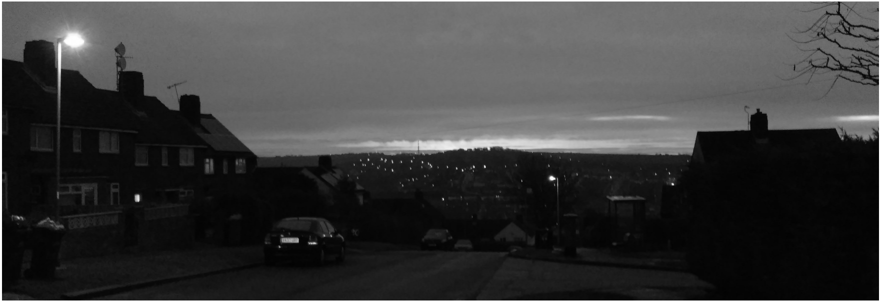
The Skiff, Brighton

One fine day early in the morning



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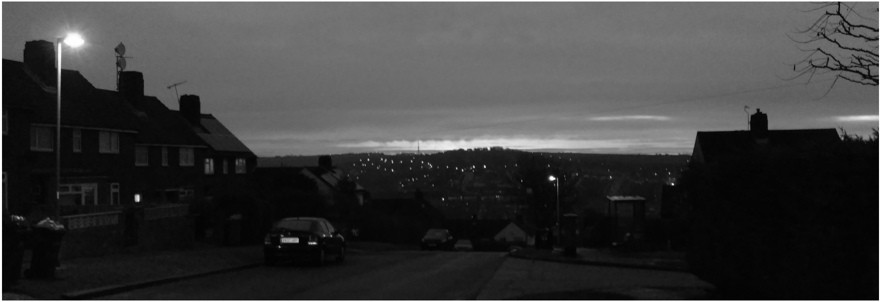

You are woken up by SMS

Bz-z-z! Something is wrong with your live system.

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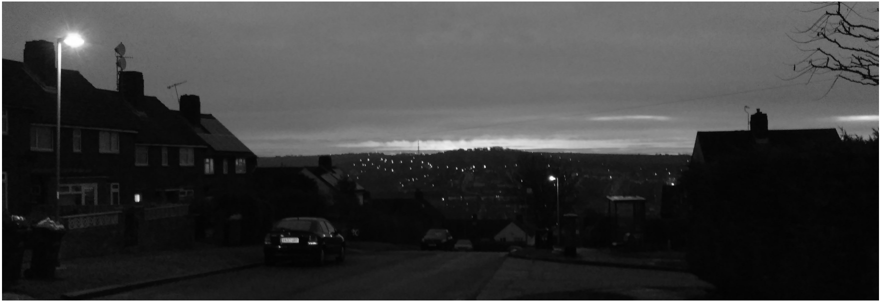

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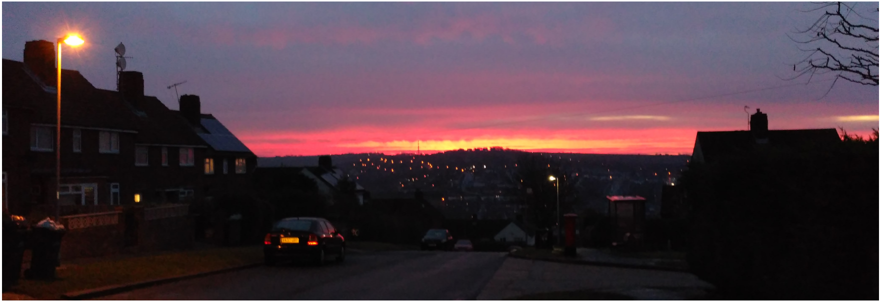
You have a look into the logs . . .

One fine day



DB Log:

```
LOG:  server process (PID 18742) was terminated by signal 9: Killed
DETAIL:  Failed process was running: some query here
LOG:  terminating any other active server processes
FATAL:  the database system is in recovery mode
...
LOG:  database system is ready to accept connections
```

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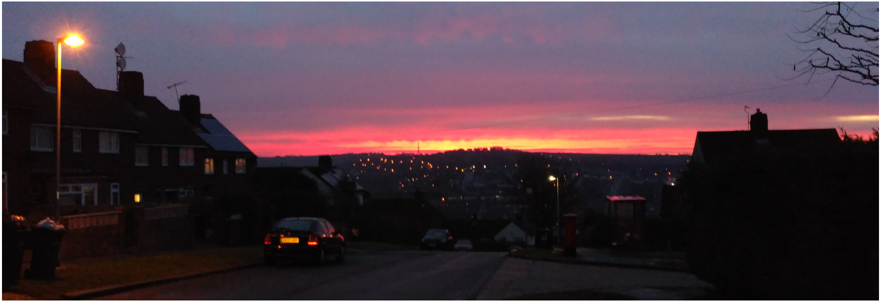

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```

Syslog:

```
Out of memory: Kill process 18742 (postgres) score 669 or sacrifice child
Killed process 18742 (postgres) total-vm:5670864kB, anon-rss:5401060kB, file-rss:1428kB
```

How to avoid such a scenario?

Outline

1. What are postgres server processes?
2. What processes use much RAM and why?
3. What queries require much RAM?
4. How to we measure the amount of RAM used?
5. How is allocated RAM reclaimed?

What are postgres server processes?

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"The" postgres server process aka **postmaster**

- Performs bootstrap
- Allocates shared memory including shared buffers
- Listens to sockets
- Spawns backends and other server processes

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Backend processes: these are the ones that perform queries

- One process per client connection, so no more than **max_connections** of them it total
- A connection pooler can be used between clients and servers to limit the number of server backends
- Standalone ones are Pgpool-II, pgbouncer, crunchydb

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Writer process aka **bgwriter** (8.0+)

- Writes dirty buffer pages to disk using LRU algorithm
- Aims to free buffer pages before backends run out of them
- But under certain circumstances, backends still have to do it by their own

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Checkpointer process (9.2+)

- Checkpoints are forced dirty disk pages flushes. Checkpointer process issues them every so often to guarantee that changes committed before certain point in time have been persisted.
- In case of server crash the recovery process start from the last checkpoint completed.

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WAL Writer process (8.3+)

- Writes and fsyncs WAL segments
- Backends could have done it by their own when **synchronous_commit=on** (and actually did before 8.3)
- When **synchronous_commit=off** – acutal commits get delayed no more than **wal_writer_delay** and processed batchwise

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Autovacuum launcher process launches **autovacuum workers**:

- To VACUUM a table when it contains rows with very old transaction ids to prevent transaction IDs wraparound
- To VACUUM a table when certain number of table rows were updated/deleted
- To ANALYZE a table when certain number of rows were inserted

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Statistic collector handles requests from other postgres processes to write data into **pg_stat_*** system catalogs

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Background workers aka **bgworkers** are custom processes spawned and terminated by postgres. No more than **max_worker_processes** of them. Can be used for

- Parallel query execution: backends launch them on demand
- Logical replication
- Custom add-on background jobs, such as pg_squeeze

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- There might be also **logger** and **archiver** processes present.
- You can use syslog as a log destination, or enable postgres **logging_collector**.
- Similarly you can turn on or off **archive_mode**.

What processes use much RAM and why?

Shared memory

Shared memory is accessible by all postgres server processes.

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- The amount of memory used for table and advisory locks is

  $$\text{about } 270 \times \textbf{max\_locks\_per\_transaction}$$
  $$\times\,(\textbf{max\_connections} + \textbf{max\_prepared\_transactions}) \text{ bytes}$$

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- Same for **max_pred_locks_per_transaction** — predicate locks are used only for non-default transaction isolation levels, make sure not to increase this setting too much.

Autovacuum workers

- No more than **autovacuum_max_workers** workers, each uses **maintenance_work_mem** or **autovacuum_work_mem** of RAM
- Ideally, your tables are not too large and your RAM is not too small, so you can afford setting **autovacuum_work_mem** to reflect your smallest table size
- Practically, you will **autovacuum_work_mem** to cover all the small tables in your DB, whatever that means

Backends and their bgworkers

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- The **work_mem** parameter limits the amount of RAM used **per operation**, i. e. per execution plan node, **not per statement**
- It actually doesn't work reliably ...

What queries require much RAM?

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Each query has an execution plan

```
postgres=# explain select atttypid::regclass, count(*) from pg_class join pg_attribute
postgres-#  on attrelid = pg_class.oid group by 1 order by 2 desc;
                                    QUERY PLAN
-----------------------------------------------------------------------------------
 Sort  (cost=143.51..143.60 rows=39 width=12)
   Sort Key: (count(*)) DESC
   ->  HashAggregate  (cost=142.08..142.47 rows=39 width=12)
         Group Key: (pg_attribute.atttypid)::regclass
         ->  Hash Join  (cost=18.56..129.32 rows=2552 width=4)
               Hash Cond: (pg_attribute.attrelid = pg_class.oid)
               ->  Seq Scan on pg_attribute  (cost=0.00..75.36 rows=2636 width=8)
               ->  Hash  (cost=14.36..14.36 rows=336 width=4)
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So, essentially the question is, what plan nodes can be memory-hungry? Right?
Not exactly. Also we need to track the situations when there are too many nodes in a plan!

What execution plan nodes might require much RAM?

Nodes: stream-like

Some nodes are more or less stream-like. They don't accumulate data from underlying nodes and produce nodes one by one, so they have no chance to allocate too much memory.

Examples of such nodes include

- Sequential scan, Index Scan
- Nested Loop and Merge Join
- Append and Merge Append
- Unique (of a sorted input)

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- Append and Merge Append
- Unique (of a sorted input)

Sounds safe? Even a single row can be quite large.
Maximal size for individual postgres value is around 1GB, so this query requires 5GB:

```
WITH cte_1g as (select repeat('a', 1024*1024*1024 - 100) as a1g)
SELECT *
FROM cte_1g a, cte_1g b, cte_1g c, cte_1g d, cte_1g e;
```

Nodes: controlled

Some of the other nodes actively use RAM but control the amount used. They have a **fallback behaviour** to switch to if they realise they cannot fit **work_mem**.

- Sort node switches from quicksort to sort-on-disk
- CTE and materialize nodes use temporary files if needed
- Group Aggregation with DISTINCT keyword can use temporary files

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Also

- Exact Bitmap Scan falls back to Lossy Bitmap Scan
- Hash Join switches to batchwise processing if it encounters more data than expected

Nodes: unsafe

They are Hash Agg, hashed SubPlan and (rarely) Hash Join can use unlimited amount of RAM.
Optimizer normally avoids them when it estimates them to process huge sets, but it can easily be wrong.

How to make the estimates wrong:

```
CREATE TABLE t (a int, b int);
INSERT INTO t SELECT 0, b from generate_series(1, (10^7)::int) b;
ANALYZE t;
INSERT INTO t SELECT 1, b from generate_series(1, (5*10^5)::int) b;
```

After this, autovacuum won't update stats, as it treats the second insert as small w r. t. the number of rows already present.

```
postgres=# EXPLAIN (ANALYZE, TIMING OFF) SELECT * FROM t WHERE a = 1;
                                    QUERY PLAN
-------------------------------------------------------------------------------------
 Seq Scan on t  (cost=0.00..177712.39 rows=1 width=8) (rows=500000 loops=1)
   Filter: (a = 1)
   Rows Removed by Filter: 10000000
 Planning time: 0.059 ms
 Execution time: 769.508 ms
```

Unsafe nodes: hashed SubPlan

Then we run the following query

```
postgres=# EXPLAIN (ANALYZE, TIMING OFF)
postgres-# SELECT * FROM t WHERE b NOT IN (SELECT b FROM t WHERE a = 1);
                                          QUERY PLAN
-----------------------------------------------------------------------------------------------
Seq Scan on t  (cost=177712.39..355424.78 rows=5250056 width=8) (actual rows=9500000 loops=1)
  Filter: (NOT (hashed SubPlan 1))
  Rows Removed by Filter: 1000000
  SubPlan 1
    ->  Seq Scan on t t_1  (cost=0.00..177712.39 rows=1 width=4) (actual rows=500000 loops=1)
          Filter: (a = 1)
          Rows Removed by Filter: 10000000
Planning time: 0.126 ms
Execution time: 3239.730 ms
```

and get a half-million set hashed.

The backend used 60MB of RAM while **work_mem** was only 4MB.

Sounds not too bad, but . . .

Unsafe nodes: hashed SubPlan and partitioned table

For a partitioned table it hashes the same condition separately for each partition!

```
postgres=# EXPLAIN SELECT * FROM t WHERE b NOT IN (SELECT b FROM t1 WHERE a = 1);
                                QUERY PLAN
--------------------------------------------------------------------------
 Append  (cost=135449.03..1354758.02 rows=3567432 width=8)
   ->  Seq Scan on t  (cost=135449.03..135449.03 rows=1 width=8)
         Filter: (NOT (hashed SubPlan 1))
         SubPlan 1
           ->  Seq Scan on t1 t1_1  (cost=0.00..135449.03 rows=1 width=4)
                 Filter: (a = 1)
   ->  Seq Scan on t2  (cost=135449.03..135487.28 rows=1130 width=8)
         Filter: (NOT (hashed SubPlan 1))
   ->  Seq Scan on t3  (cost=135449.03..135487.28 rows=1130 width=8)
         Filter: (NOT (hashed SubPlan 1))
   ->  Seq Scan on t4  (cost=135449.03..135487.28 rows=1130 width=8)
         Filter: (NOT (hashed SubPlan 1))
   ->  Seq Scan on t5  (cost=135449.03..135487.28 rows=1130 width=8)
         Filter: (NOT (hashed SubPlan 1))
   ->  Seq Scan on t6  (cost=135449.03..135487.28 rows=1130 width=8)
         Filter: (NOT (hashed SubPlan 1))
   ->  Seq Scan on t7  (cost=135449.03..135487.28 rows=1130 width=8)
         Filter: (NOT (hashed SubPlan 1))
   ->  Seq Scan on t8  (cost=135449.03..135487.28 rows=1130 width=8)
         Filter: (NOT (hashed SubPlan 1))
   ->  Seq Scan on t1  (cost=135449.03..270898.05 rows=3559521 width=8)
         Filter: (NOT (hashed SubPlan 1))
```

This is going to be fixed in PostgreSQL 10

Unsafe nodes: hashed SubPlan and partitioned table

For now the workaround is to use dirty hacks:

```
postgres=# explain
postgres-# SELECT * FROM (TABLE t OFFSET 0) s WHERE b NOT IN (SELECT b FROM t1 WHERE a = 1);
                              QUERY PLAN
-------------------------------------------------------------------------
 Subquery Scan on _  (cost=135449.03..342514.44 rows=3567432 width=8)
   Filter: (NOT (hashed SubPlan 1))
   ->  Append  (cost=0.00..117879.62 rows=7134863 width=8)
         ->  Seq Scan on t  (cost=0.00..0.00 rows=1 width=8)
         ->  Seq Scan on t2  (cost=0.00..32.60 rows=2260 width=8)
         ->  Seq Scan on t3  (cost=0.00..32.60 rows=2260 width=8)
         ->  Seq Scan on t4  (cost=0.00..32.60 rows=2260 width=8)
         ->  Seq Scan on t5  (cost=0.00..32.60 rows=2260 width=8)
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         ->  Seq Scan on t7  (cost=0.00..32.60 rows=2260 width=8)
         ->  Seq Scan on t8  (cost=0.00..32.60 rows=2260 width=8)
         ->  Seq Scan on t1  (cost=0.00..117651.42 rows=7119042 width=8)
   SubPlan 1
     ->  Seq Scan on t1 t1_1  (cost=0.00..135449.03 rows=1 width=4)
           Filter: (a = 1)
```

Memory usage was reduced 9 times, also it works much faster.

Unsafe nodes: Hash Aggregation

Estimates for groupping are sometimes unreliable at all. Random numbers chosen by a fair dice roll:

```
postgres=# explain (analyze, timing off) select b, count(*)
postgres-# from (table t union all table t) u group by 1;
                           QUERY PLAN
--------------------------------------------------------------------
 HashAggregate  (... rows=200 ... ) (actual rows=10000000 ...)
   Group Key: t.b
   ->  Append  (... rows=19999954 ...) (actual rows=20000000 ...)
         ->  Seq Scan on t  (... rows=9999977 ... ) (actual ... )
         ->  Seq Scan on t t_1  (... rows=9999977 ... ) (actual ... )
 Planning time: 0.141 ms
 Execution time: 14523.303 ms
```

...and uses several gigs of RAM for the hash table!

Unsafe nodes: Hash Join

Hash Joins can use more memory than expected if there are many collisions on the hashed side:

```
postgres=# explain (analyze, costs off)
postgres-# select * from t t1 join t t2 on t1.b = t2.b where t1.a = 1;
                                        QUERY PLAN
-----------------------------------------------------------------------------------------------
Hash Join (actual time=873.321..4223.080 rows=1000000 loops=1)
  Hash Cond: (t2.b = t1.b)
  ->  Seq Scan on t t2 (actual time=0.048..755.195 rows=10500000 loops=1)
  ->  Hash (actual time=873.163..873.163 rows=500000 loops=1)
        Buckets:  131072 (originally 1024) Batches:  8 (originally 1) Memory Usage:  3465kB
        ->  Seq Scan on t t1 (actual time=748.700..803.665 rows=500000 loops=1)
              Filter: (a = 1)
              Rows Removed by Filter: 10000000

postgres=# explain (analyze, costs off)
postgres-# select * from t t1 join t t2 on t1.b % 1 = t2.b where t1.a = 1;
                                        QUERY PLAN
------------------------------------------------------------------------------------------------
Hash Join (actual time=3542.413..3542.413 rows=0 loops=1)
  Hash Cond: (t2.b = (t1.b % 1))
  ->  Seq Scan on t t2 (actual time=0.053..732.095 rows=10500000 loops=1)
  ->  Hash (actual time=888.131..888.131 rows=500000 loops=1)
        Buckets:  131072 (originally 1024) Batches:  2 (originally 1) Memory Usage:  19532kB
        ->  Seq Scan on t t1 (actual time=753.244..812.959 rows=500000 loops=1)
              Filter: (a = 1)
              Rows Removed by Filter: 10000000
```

And just one more random fact.

array_agg used at least 1Kb per array before a fix in Postgres 9.5

Funny, isn't it: on small arrays **array_agg_distinct** from **count_distinct** extension is faster than built-in **array_agg**.

How to we measure the amount of RAM used?

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top? ps?

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top? ps? htop? atop? No. They show private and shared memory together.

We have to look into /proc filesystem, namely /**proc**/pid/**smaps**

smaps

/proc/7194/smaps comprises a few sections like this

```
....
0135f000-0a0bf000 rw-p 00000000 00:00 0
[heap]
Size:             144768 kB
Rss:              136180 kB
Pss:              136180 kB
Shared_Clean:          0 kB
Shared_Dirty:          0 kB
Private_Clean:         0 kB
Private_Dirty:    136180 kB
Referenced:       114936 kB
Anonymous:        136180 kB
AnonHugePages:      2048 kB
Swap:                  0 kB
KernelPageSize:        4 kB
MMUPageSize:           4 kB
Locked:                0 kB
VmFlags: rd wr mr mw me ac sd
....
```

which is a private memory segment . . .

smaps

...or this

```
....
7f8ce656a000-7f8cef300000 rw-s 00000000 00:04 7334558
/dev/zero (deleted)
Size:               144984 kB
Rss:                 75068 kB
Pss:                 38025 kB
Shared_Clean:            0 kB
Shared_Dirty:        73632 kB
Private_Clean:           0 kB
Private_Dirty:        1436 kB
Referenced:          75068 kB
Anonymous:               0 kB
AnonHugePages:           0 kB
Swap:                    0 kB
KernelPageSize:          4 kB
MMUPageSize:             4 kB
Locked:                  0 kB
VmFlags: rd wr sh mr mw me ms sd
....
```

which looks like part of shared buffers. BTW what is PSS?

smaps: PSS

PSS stands for **proportional set size**

- For each private allocated memory chunk we count its size as is
- We divide the size of a shared memory chunk by the number of processes that use it

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PSS support was added to Linux kernel in 2007, but I'm not aware of a task manager able to display it or sort processes by it.

smaps: Private

Anyway, we need to count only private memory used by a backend or a worker, as all the shared is allocated by postmaster on startup.

We can get the size of private memory of a process this way:

```
$ grep '^Private' /proc/7194/smaps|awk '{a+=$2}END{print a*1024}'
7852032
```

smaps: Private from psql

You even can get amount of private memory used by a backend from itself using SQL:

```
do $do$
declare
    l_command text :=
        $p$ cat /proc/$p$ || pg_backend_pid() || $p$/smaps $p$ ||
        $p$ | grep '^Private' $p$ ||
        $p$ | awk '{a+=$2}END{print a * 1024}' $p$;
begin
    create temp table if not exists z (a int);
    execute 'copy z from program ' || quote_literal(l_command);
    raise notice '%', (select pg_size_pretty(sum(a)) from z);
    truncate z;
end;
$do$;
```

Unfortunately it requires superuser privileges.

Workaround: rewrite as a PL/Python function and mark it SECURITY DEFINER.

How is allocated RAM reclaimed?

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And sometimes this show-me-my-RAM-usage SQL returns much more than zero:

```
postgres=# \i ~/smaps.sql
psql:/home/l/smaps.sql:13: NOTICE:  892 MB
DO
```

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But there is no heavy query running? Does Postgres LEAK?!

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But there is no heavy query running? Does Postgres LEAK?! Well, yes and no.

How is allocated RAM reclaimed?

Postgres operates so-called **memory contexts** — groups of memory allocations. They can be

- Per-row
- Per-aggregate
- Per-node
- Per-query
- Per-backend
- and some other ones I believe

And they are designed to "free" the memory when the correspondent object is destroyed. And they do "free", I've checked it.

How is allocated RAM reclaimed?

Why "free", not free?

Because postgres uses so-called **memory allocator** that optimises malloc/free calls. Sometimes some memory is freed, and it does not free it for to use next time. But not 892MB. They free(3) it, I've checked it.

How is allocated RAM reclaimed?

Why free(3), not free?

Because linux implementation of free(3) uses either heap expansion by **brk()** or **mmap()** syscall, depending on the size requested. And memory got by **brk()** does not get reclaimed.

The threshold for the decision what to use is not fixed as well. It is initially **128Kb** but Linux increases it up to **32MB** adaptively depending on the process previous allocations history.

Those values can be changed, as well as adaptive behaviour could be turned off using **mallopt(3)** or even certain environment variables.

And it turned out that Postgres stopped "leaking" after it.

Questions?

Relevant ads everywhere:
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For your postgres never to run OOM!