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Linux and PostgreSQL in the Multiverse of Connections

Why Are PostgreSQL Connections Expensive?

Josef Machytka <josef.machytka@credativ.de>

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credativ GmbH

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- Founded 1999 in Jülich, Germany
- Close ties to Open-Source Community
- More than 40 Open-Source experts
- Consulting, development, training, support (3rd-level / 24x7)
- Open-Source infrastructure with Linux, Kubernetes, Proxmox
- Open-Source databases with PostgreSQL
- DevSecOps with Ansible, Puppet, Terraform and others
- Since 2025 independent owner-managed company again

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Josef Machytka

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- Professional Service Consultant - PostgreSQL specialist at credativ GmbH
- 33+ years of experience with different databases
- PostgreSQL (13y), BigQuery (7y), Oracle (15y), MySQL (12y), Elasticsearch (5y), MS SQL (5y)
- 10+ years of experience with Data Ingestion pipelines, Data Analysis, Data Lake / Warehouse
- 3+ years of practical experience with LLMs / AI / ML including architecture and principles
- From Czechia, living now 12 years in Berlin

- LinkedIn: linkedin.com/in/josef-machytka
- Medium: medium.com/@josef.machytka
- YouTube: youtube.com/@JosefMachytka

- GitHub: github.com/josmac69/conferences_slides
- ResearchGate: researchgate.net/profile/Josef-Machytka

All My Slides:

Recoded talks:

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Acknowledgement

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Many thanks to the IvorySQL community for supporting my participation in the HOW2026 conference

Many thanks to the Highgo company for the opportunity to test on a Phytium server

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Talk based on Linux 6.x, PostgreSQL 18, and x86_64 architecture

NUMA related facts are relevant mostly for the ARM64 Phytium server, Kylin Linux v10

Diagrams and pictures created by Claude Opus 4.7 and Gemini 3.1 Pro

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PostgreSQL Multi-Process Architecture

PostgreSQL Multi-Process Architecture

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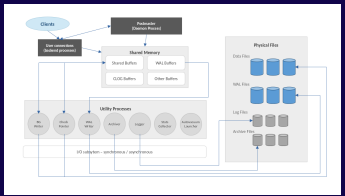
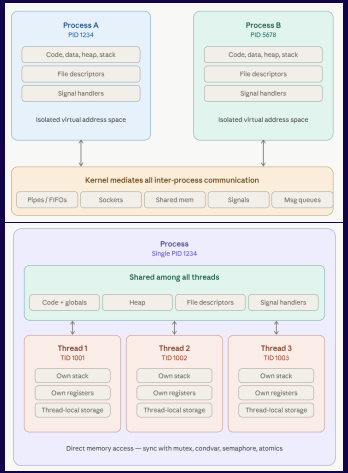
- PostgreSQL uses a multi-process architecture
  - Every connection, every background task is a separate OS process
  - Leads to expensive CPU, memory, and context-switching overhead
  - Inter-process communication (IPC) is necessary via shared memory



- High connection counts (>300–400) degrade performance
  - Too many context switches between processes
  - Too many Translation Lookaside Buffer (TLB) misses
  - Too many resources consumed by idle connections
  - Exponential performance degradation

PostgreSQL Connections

- Each connection is an independent process
- Processes chosen for higher stability in the 1990s
- Reliable threads implemented in Linux 2.6 (2003/2004)
- Main idea: processes are isolated, heavy, but stable
  - Each process has its own isolated memory
  - Great for stability, security, but resource-intensive
  - Starting a new process incurs some overhead
  - But forking has been optimized lately
- Ongoing discussion about switching to threads
  - Threads are now reliable and considered lightweight
  - But handling memory safety depends on developers



Shared Memory on Linux

- Linux implements shared memory for interprocess communication
- Linux philosophy: `Everything is a file`
  - -> `dentry` (directory entry) & `inode` structures
- Shared memory on Linux implemented via `tmpfs` filesystem
  - Filesystem interface to access memory as files
  - Introduced in Linux kernel 2.4 (2001)
  - Successor of older `ramfs`
  - Internally used even if tmpfs is disabled for users
  - Can be used by SysV IPC (shmget, shmat) and mmap interfaces
- PostgreSQL originally used SysV shared memory segments
  - Since PG 9.3 POSIX shared memory via mmap is default on Linux

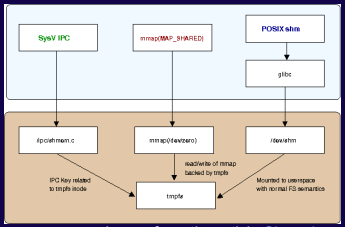


Image from the article Shared memory on Linux

Shared Memory on Linux

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- Users interact with tmpfs via `/dev/shm` directory
  - This filesystem grows and shrinks dynamically as files are created or deleted
  - Size is limited by available RAM and swap space
  - Uses page cache - file I/O is done directly in memory
  - Writing allocates physical memory pages - associated with `dentry` and `inode` structures

- PostgreSQL uses /dev/shm for communication between processes
  - Has a small default on Docker (64MB), can be exhausted quickly - `--shm-size` / `shm_size` parameters
  - If /dev/shm is exhausted, PG reports "`could not resize shared memory segment`" error

```
my-linux ~ $ df -h | grep tmpfs
tmpfs                     3.2G  3.7M  3.1G   1% /run
tmpfs                      16G  543M   15G   4% /dev/shm
tmpfs                     5.0M  8.0K  5.0M   1% /run/lock
tmpfs                     3.2G  140K  3.2G   1% /run/user/1000
```

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PostgreSQL Connections Memory Allocation

Linux Memory Allocation Management

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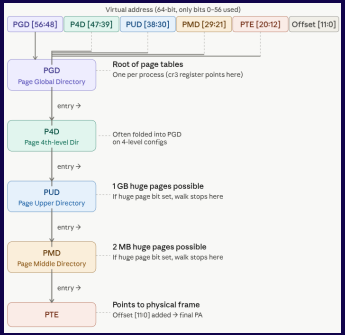
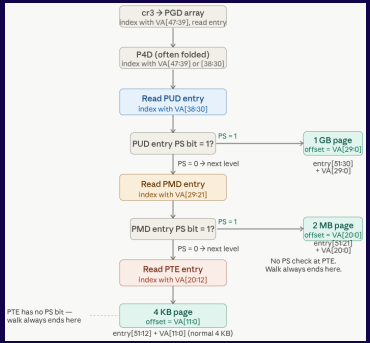
- Linux implements multiple levels of memory mapping tables (4 or 5)
- Mapping translates 64-bit virtual addresses to physical addresses
- Not all 64bits are used for mapping - 48 or 57 bits
  - Page global directory (PGD)
  - Page 4th level directory (P4D) - folded into PGD on 4-level configs
  - Page upper directory (PUD) - 1 GB pages walk ends here
  - Page middle directory (PMD) - 2 MB pages walk ends here
  - Page table entry (PTE) - standard 4 KB pages are stored here
- Tables contain pointers to the next level table or the final mapping
- PUD and PMD have PS bit set when huge pages are used



Standard Pages vs Huge Pages

- Linux fork() does not copy physical memory allocation
  - PTE small when connection starts - around 300 KB
  - Child process fills its tables on TLB Miss
- Shared buffer allocated in standard 4 KB pages
  - The whole hierarchy is traversed on each page access
  - Mapping is found on the last level (PTE)
- Shared buffer allocated in huge pages
  - Mapping of 1GB HugePage is found on PUD level
  - Mapping of 2MB HugePage is found on PMD level
- -> Huge pages significantly improve performance
- -> Reduce overall memory usage



PostgreSQL Connection Memory Allocation

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- Shared buffers allocated as standard pages
  - 1 GB buffers in 4 KB pages = 2 MB PTE table
  - 8 GB buffers in 4 KB pages = 16 MB PTE table
  - 100 connections, 8 GB buffers = 1.6 GB PTE tables
  - 1000 connections, 8 GB buffers = 16 GB PTE tables (!!!)
- Shared buffers allocated as huge pages
  - 1 GB buffers in 2 MB huge pages = 4 KB PMD table
  - 8 GB buffers in 2 MB huge pages = 32 KB PMD table
  - 100 connections, 8 GB buffers in 2MB huge pages = 3.2 MB PMD tables
  - 1000 connections, 8 GB buffers in 2MB huge pages = 32 MB PMD tables
- Why Linux HugePages are Super Important for Database Servers

```
grep -E "PageTables" /proc/meminfo    ## all PTE tables together
grep -E "VmPTE" /proc/<PID>/status    ## connection PTE table
```

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PostgresSQL and NUMA Architectures

PostgreSQL and NUMA Architectures

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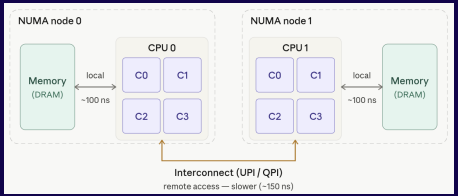
- NUMA (Non-Uniform Memory Access) architectures - divide the system into nodes
- Each node has its own CPU cores and local memory (not always attached to each node)
- Accessing local memory is faster than remote memory in other nodes
- Remote memory access causes higher latency -> NUMA penalty - 2x-3x slower
- Linux kernel offers NUMA balancing mechanisms
  - Automatic memory pages migration or migration of processes between nodes
  - `/proc/sys/kernel/numa_balancing` - 1/0 = on/off
  - Useful for general workloads, but what about PostgreSQL?



PostgreSQL on ARM64 Phytium

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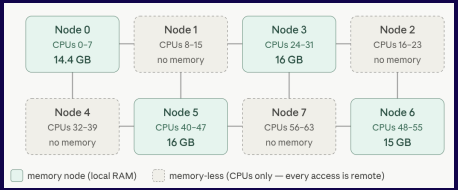
- Server: Phytium FT-2000+/64 - 64 cores ARM64, 62 GB RAM, 8 NUMA nodes
- Kylin Linux Advanced Server v10 (Halberd), kernel 4.19.90 (CentOS 8 lineage)
- Kernel re-spun by KylinSoft - added Chinese hardware support, security patches
- PostgreSQL-IvorySQL 18.3, 4 nodes with memory, 4 nodes without memory



target → / from ↓	0	1	2	3	4	5	6	7
0	10	20	40	30	20	30	50	40
1	20	10	30	20	30	20	40	30
2	40	30	10	20	50	40	20	30
3	30	20	20	10	40	30	30	20
4	20	30	50	40	10	20	40	30
5	30	20	40	30	20	10	30	20
6	50	40	20	30	40	30	10	20
7	40	30	30	20	30	20	20	10

	Node 0 14,403 MB RAM present	Node 3 16,362 MB RAM present	Node 5 16,362 MB RAM present	Node 6 15,317 MB RAM present
Node 0 CPUs 0-7	10 local	30 +200%	30 +200%	50 +400%
Node 1 CPUs 8-15	20 +100%	20 +100%	20 +100%	40 +300%
Node 2 CPUs 16-23	40 +300%	20 +100%	40 +300%	20 +100%
Node 3 CPUs 24-31	30 +200%	10 local	30 +200%	30 +200%
Node 4 CPUs 32-39	20 +100%	40 +300%	20 +100%	40 +300%
Node 5 CPUs 40-47	30 +200%	30 +200%	10 local	30 +200%
Node 6 CPUs 48-55	50 +400%	30 +200%	30 +200%	10 local
Node 7 CPUs 56-63	40 +300%	20 +100%	20 +100%	20 +100%

Pinning PostgreSQL on NUMA nodes

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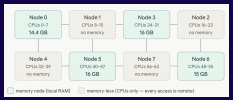
- Forked processes inherit postmaster's bind policy - memory / CPUs
- Pinning both memory and CPUs to specific NUMA node(s)
  - PostgreSQL will use only specified node(s) for everything
  - Specified node(s) must have enough memory for everything
  - Shared buffers, other shared objects (WAL, locks), /dev/shm, connections
  - All processes running on specified node(s), jumping between cores on them
- Pinning just memory to specific NUMA node(s)
  - Processes will jump randomly between all nodes during their run
  - But their memory is pinned to specified node(s)
- Not pinning anything means completely random behavior



Pinning PostgreSQL on NUMA nodes

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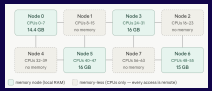
- Pinning memory / CPUs limits PostgreSQL resources to specific node(s)
  - Can be good for isolating workload on specific part of NUMA system
  - Use case for multiple PostgreSQL clusters on one NUMA system



- If size of shared buffers exceeds memory on specified node(s)
  - Buffers will be allocated on available memory, rest stays unmapped
  - Attempt to physically fill whole shared buffers crashes PostgreSQL

- I tested all variants of pinning/ not pinning on Phytium server
  - Differences in benchmarks were between 2 to 6 % and not consistent
  - For typical mainstream workloads pinning is useful only for isolation of PostgreSQL
  - NUMA latency was not significant; the distance table exaggerates

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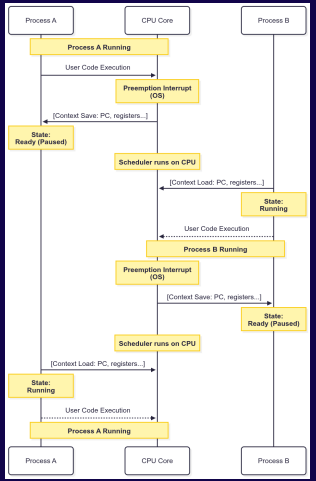
CPU and PostgreSQL Connections

Context Switching Overheads

- But how many ”active connections per core/thread”?
  - Depends on limitations of context switching mechanism
- Context switching brings overheads
  - APIC Interrupt Controller fires timer interrupt
  - APIC is integrated into each individual CPU core or thread
  - On interrupt, CPU saves current process state (context)
  - CPU loads new process state from memory
  - State includes CPU registers, program counter, stack pointer
  - TLB (Translation Lookaside Buffer) may need flush
  - -> TLB entries are newly tagged with process IDs



Linux CPU Schedulers

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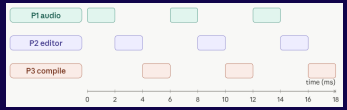
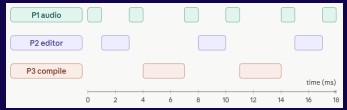
- Completely Fair Scheduler (CFS)
  - Original scheduler used in Linux 2.6+
  - ”Ideal multi-tasking” - N processes, 1/N speed
  - Every process gets an equal share of CPU time
  - In kernel 6.6+ replaced with EEVDF scheduler
- Earliest eligible virtual deadline first (EEVDF)
  - Newer scheduler, since October 2023
  - Introduced small, more frequent bursts of CPU time
  - Can prioritize interactive or latency critical tasks
  - But still should keep fair share of total CPU time
- Ubuntu uses 6.6+ from v24.04
- Debian 12 uses 6.1 -> Debian 13 jumps to 6.12
- RedHat Enterprise 9 uses 5.14 -> v 10 jumps to 6.12
- 6.12 contains many improvements and patches against 6.6+





CFS vs EEVDF

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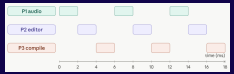
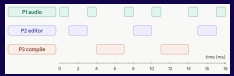
- What switch from CFS to EEVDF means for PostgreSQL connections?
- Typical PG connections are often ”sleeping” - network, data fetch, lock wait
- Some connections are ”bursty” - many small transactions
- CFS can sometimes penalize ”bursty” workloads
  - Context switching storm by waking up many sleeping processes
  - Maintains ”average fairness” for all processes
  - Uniformity, no latency preference, only some preemption for ”sleepers”
- EEVDF can prioritize latency critical tasks
  - ”Bursty” workloads can show better latency - processed earlier
  - Waiting processes should not slow down bursty workloads
  - CPU-heavy workloads will not starve other processes
  - Most likely will improve mixed workloads
  - OLAP only workloads might slightly suffer more context switches
  - For OLAP we can use SCHED_BATCH policy for throughput





Connection Limits Recommendations

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- Rule of thumb: 2 - 4 active OLTP connections per 1 CPU core
  - -> applies only for OLTP workloads on NVMe/SSD storage with huge pages enabled
  - -> sweet spot seems to be 3 active connections per 1 core
  - -> down to 1-2 active connections per 1 core for HDD storage or without huge pages
- OLAP workloads without parallelism -> 1 connection per 1 core
- OLAP workloads with parallelism -> 1 connection per [1+workers] cores
- -> Use PostgreSQL 14+ - allows linear scaling of MVCC
- -> Use PostgreSQL 18+ due to improved relation locking mechanism

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How Much Memory PostgreSQL Connections Use?

PostgreSQL Connection Memory Usage

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- 32GB RAM, PostgreSQL 18, shared_buffers=8GB, effective_cache_size=24GB, work_mem=64MB
- Numbers parsed by script from `/proc/PID/smaps` kernel interface

```
## output of top command
    PID USER      PR  NI    VIRT    RES    SHR S  %CPU  %MEM     TIME+ COMMAND
 190747 postgres  20   0 8701512  20248  16876 S   0.0   0.1   0:00.00 postgres: postgres postgres 172.18.0.1(40278) idle

## python script output - smaps
Path                                                    Size       Rss       Pss  Pss_Dirty  Shr_Clean  Shr_Dirty  Prv_Clean  Prv_Dirty  Swap  SwapPss  Cnt
-------------------------------------------------------------------------------------------------------------------------------------------------------------
/usr/lib/postgresql/18/bin/postgres                     9296      4140      1156         75       3792        168        128         52     0        0    5
[anonymous]                                             1708       660       554        554          0        120          0        540     0        0   21
[heap]                                                  1440      1132       821        821          0        368          0        764     0        0    2
/dev/shm/PostgreSQL.1436672634                          1024       132       130        130          0          4          0        128     0        0    1
/dev/shm/PostgreSQL.3104938386                           112         4         1          1          0          4          0          0     0        0    1
/dev/zero (deleted)                                   8624208     10352      5070       5070          0       9780          0        572     0        0    1
/usr/lib/postgresql/18/lib/auto_explain.so              20         8         0          0          0          8          0          0     0        0    5
/usr/lib/postgresql/18/lib/pg_stat_statements.so        44         8         0          0          0          8          0          0     0        0    5
/usr/lib/locale/locale-archive                        2980        60        19          0         60          0          0          0     0        0    1
/usr/lib/x86_64-linux-gnu/libffi.so.8.1.2               48         8         0          0          0          8          0          0     0        0    5
/usr/lib/x86_64-linux-gnu/libgpg-error.so.0.33.1       160         8         0          0          0          8          0          0     0        0    5
/usr/lib/x86_64-linux-gnu/libgmp.so.10.4.1             516         8         0          0          0          8          0          0     0        0    5
....
/SYSV00ce5741 (deleted)                                  4         0         0          0          0          0          0          0     0        0    1
/usr/lib/x86_64-linux-gnu/ld-linux-x86-64.so.2         208        80        18          9         64          8          0          8     0        0    5
[stack]                                                132        36        27         27          0         12          0         24     0        0    1
[vvar]                                                  16         0         0          0          0          0          0          0     0        0    1
[vdso]                                                   8         4         0          0          4          0          0          0     0        0    1
-------------------------------------------------------------------------------------------------------------------------------------------------------------
Total                                                 8701512     20380      8553       6841       6356      11760        164       2100     0        0  251
```

Let’s Run Some Heavy Query

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- Let’s run some heavy queries and look into `smaps` again

```
## top command output after query run
    PID USER      PR  NI    VIRT    RES    SHR S  %CPU  %MEM     TIME+ COMMAND
 190747 postgres  20   0 8701848   8.2g   8.1g S   0.0  26.3   0:48.67 postgres: postgres postgres 172.18.0.1(40278) idle

## smaps numbers after query run
Path                                          Size        Rss        Pss  Pss_Dirty  Shr_Clean  Shr_Dirty  Prv_Clean  Prv_Dirty      Swap  SwapPss  Cnt
-------------------------------------------------------------------------------------------------------------------------------------------------------
/usr/lib/postgresql/18/bin/postgres         9296       6508       3255         79       4176        164       2112         56         0        0    5
[anonymous]                                 1708        704        598        598          0        120          0        584         0        0   21
[heap]                                      1776       1516       1208       1208          0        364          0       1152         0        0    2
/dev/shm/                                   1136        148        143        143          0          8          0        140       980        0    2
/dev/zero (deleted)                      8624208    8532008    8443508    8443508          0     143376          0    8388632         0        0    1
/usr/lib/postgresql/18/lib/                   64         44         22          8         28          8          0          8         0        0   10
/usr/lib/locale/locale-archive              2980         68         19          0         68          0          0          0         0        0    1
/usr/lib/x86_64-linux-gnu/                 60520       5020       1376        167       3556       1284        156         24         0        0  205
/SYSV00ce5741 (deleted)                        4          0          0          0          0          0          0          0         0        0    1
[stack]                                      132         44         44         44          0          0          0         44         0        0    1
[vvar]                                        16          0          0          0          0          0          0          0         0        0    1
[vdso]                                         8          4          0          0          4          0          0          0         0        0    1
-------------------------------------------------------------------------------------------------------------------------------------------------------
Total                                    8701848    8546064    8450173    8445755       7832     145324       2268    8390640       980        0  251
```

How Much Memory is Really Used?

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- I did some playing with multiple sessions with/without parallelism
- Leading to different RSS numbers in the top command -> Let's dive into `smaps` for all these sessions

```
## top command
    PID USER      PR  NI    VIRT    RES    SHR S  %CPU  %MEM     TIME+ COMMAND
190747 postgres  20   0 8701868   8.1g   8.1g S   0.0  26.2   0:48.69 postgres: postgres postgres 172.18.0.1(40278) idle
206119 postgres  20   0 8702808   4.7g   4.7g S   0.0  15.2   0:21.81 postgres: postgres postgres 172.18.0.1(44010) idle
219065 postgres  20   0 8802384   8.2g   8.1g S   0.0  26.6   2:56.64 postgres: postgres postgres 172.18.0.1(52912) idle
228832 postgres  20   0 8709912   3.4g   3.4g S   0.0  11.1   0:11.10 postgres: postgres postgres 172.18.0.1(60090) idle
230390 postgres  20   0 8701340   8.1g   8.1g S   0.0  26.3   0:51.89 postgres: postgres postgres 172.18.0.1(44802) idle

## smaps summaries with /dev/zero
Path                                           Size         Rss         Pss  Pss_Dirty  Shr_Clean  Shr_Dirty  Prv_Clean  Prv_Dirty       Swap    SwapPss  Cnt
-------------------------------------------------------------------------------------------------------------------------------------------------------------
Total for /proc/190747/smaps                 8701868     8529172     2196188    2195833       2960    8525332          0        880      61784       1116  256
Total for /proc/206119/smaps                 8702808     4928096     1119095    1118712       3120    4924968          0          8      63996       2112  258
Total for /proc/219065/smaps                 8802384     8635640     2296848    2295726       5472    8531892         12      98264      64896       4078  252
Total for /proc/228832/smaps                 8709912     3609444      798269     795595       8660    3590600         60      10124      60936        100  252
Total for /proc/230390/smaps                 8701340     8542712     2202431    2199069       8660    8531564        748       1740      60768         99  251
-------------------------------------------------------------------------------------------------------------------------------------------------------------
                                            43618312    34285064     8611831    8613495      34872   34193356        820      19916     312480      17405 1279
## smaps summaries without /dev/zero
Path                                           Size         Rss         Pss  Pss_Dirty  Shr_Clean  Shr_Dirty  Prv_Clean  Prv_Dirty       Swap    SwapPss  Cnt
-------------------------------------------------------------------------------------------------------------------------------------------------------------
Total for /proc/190747/smaps                   77660        4416        1291        936       2960        576          0        880       3508       1116  255
Total for /proc/206119/smaps                   78600        3708         448         65       3120        580          0          8       5720       2112  257
Total for /proc/219065/smaps                  178176      104316       99427      98305       5472        584         12      98248       6620       4078  251
Total for /proc/228832/smaps                   85704       19420       12853      10179       8660        576         60      10124       2660        100  251
Total for /proc/230390/smaps                   77132       11716        5143       1781       8660        584        748       1724       2492         99  250
-------------------------------------------------------------------------------------------------------------------------------------------------------------
                                              499272      169576      118162     110266      34872       2900        820      19984      18300      17405 1274
```

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Where is work_mem hidden?

Logging smaps for PostgreSQL process

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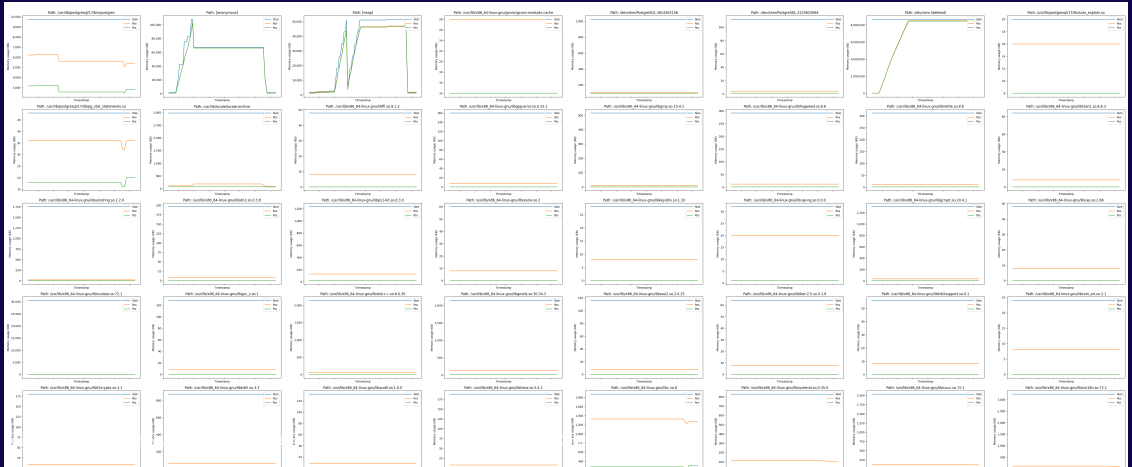
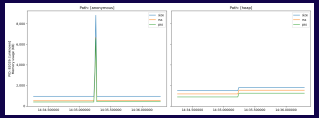
- Scripts scrape smaps data for PostgreSQL connections - each access slows down the process
- Another script parses smaps snapshots and plots a grid (Virt Size, RSS, PSS) for all paths

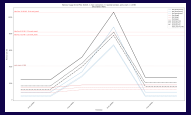


Sorting operation - ORDER BY

- RAM = 32 GB, JIT = off, shared_buffers = ’8GB’, work_mem = ’4MB’

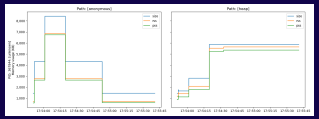
```
SELECT * FROM generate_series(1, 100000) AS t(val) ORDER BY val;
```

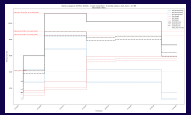




2x work_mem

```
SELECT * FROM generate_series(1, 100000000) AS t(val) ORDER BY val DESC;
```





2.2x work_mem

Why Heap memory stays high after query?

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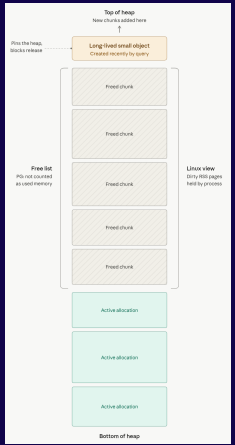
- Heap memory grows by allocating new chunks at the top of the heap
- Deallocation must be done from the top of the heap downwards
- A query can create a long-living small object at the top
- Deallocated lower chunks are only placed on the free list
- PostgreSQL internally does not count this memory as used
- Linux sees them as dirty memory blocks belonging to the process



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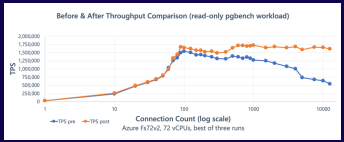
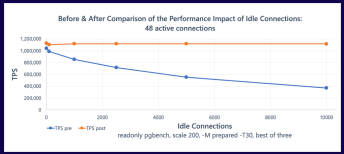
PostgreSQL Internal Limits

MVCC Snapshot Overhead

- MVCC snapshot management scaled very poorly in pre-v14
- Each session has transaction ID horizon / MVCC snapshot
- New transactions needed to check all sessions' snapshots
- Scans of Process Array require ProcArrayLock -> LWLock contention
- Big number of idle sessions degraded throughput of transactions/sec
- v14+ improved this significantly, throughput is now stable
- Each row has "visible since" (xmin) and "visible until" (xmax) XIDs
- Snapshot defines which XIDs are visible to transaction
- More connections -> more XIDs to track -> more overhead

- Improving Postgres Connection Scalability: Snapshots





PostgreSQL Relation Locking Limits

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- Another bottleneck - too many locked objects in the session
- PG 9.2 - v17: hard coded setting FP_LOCK_SLOTS_PER_BACKEND = 16
  - Capacity of ”fast-path” locking mechanism - relations locks are acquired locally
  - Locks over this capacity require accessing central shared lock table
  - Slows down the system due to contention on the shared lock table
  - Increases latency linearly, planning time grows accordingly
  - Causes huge spikes of ”LWLock” waits in pg_stat_activity
  - Good enough for 2010s query patterns with typically few tables per query
  - Limiting for complex schemas of 2020s with many tables/indexes per query
  - Partitioning made it much worse for some types of workloads
- PG 18 increases this limit to max_locks_per_transaction setting (default 64)
- Planning time and latency seems to be more or less flat, no linear increase

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Summary

Summary of Key Takeaways (1/2)

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- **Process Architecture & Memory Overhead**
  - Multi-process model degrades with high connection counts
  - Too many context switches, TLB misses, and heavy memory footprint
  - Interprocess communication relies on Linux `tmpfs`
- **Memory Allocation Management**
  - **Huge Pages** reduce the size of Linux memory mapping tables for large `shared_buffers`
  - Transparent Huge Pages (THP) disabled to prevent reallocation latency
- **NUMA Architecture**
  - Pinning PostgreSQL to specific NUMA nodes mostly useful for workload isolation
  - For mainstream workloads, default Linux NUMA balancing is often sufficient

Summary of Key Takeaways (2/2)

- **CPU Schedulers & Limits**
  - EEVDF scheduler (kernel 6.6+) better handles ”bursty” connections
  - Aim for 2–4 active OLTP connections per CPU core (NVMe/SSD + Huge Pages)
- **Memory Usage & Heap Bloat**
  - Small `work_mem` allocations use heap (`brk()`) -> memory bloat
  - Larger allocations use `mmap()` -> separate anonymous mappings
- **PostgreSQL Internal Bottlenecks Solved**
  - **PG 14+**: Resolved major MVCC snapshot bottlenecks
  - **PG 18+**: Improves fast-path relation locking capacity

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Thank you for your attention!

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Questions?

All my slides

Recorded talks