

# POSTGRESQL AT LOW LEVEL

STAY CURIOUS!

DMITRY DOLGOV

17-05-2019





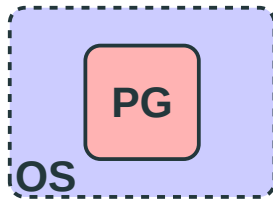
patroni & postgres-operator

pg\_stat\_\*

PG

pg\_stat\_\*

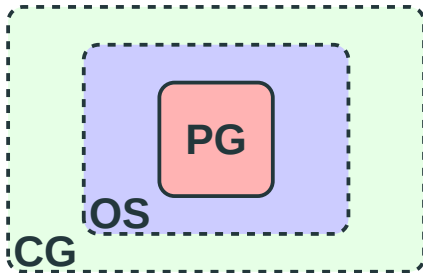
CPU/IO



pg\_stat\_\*

CPU/IO

???

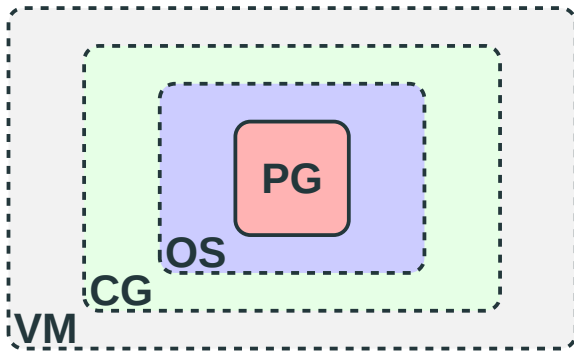


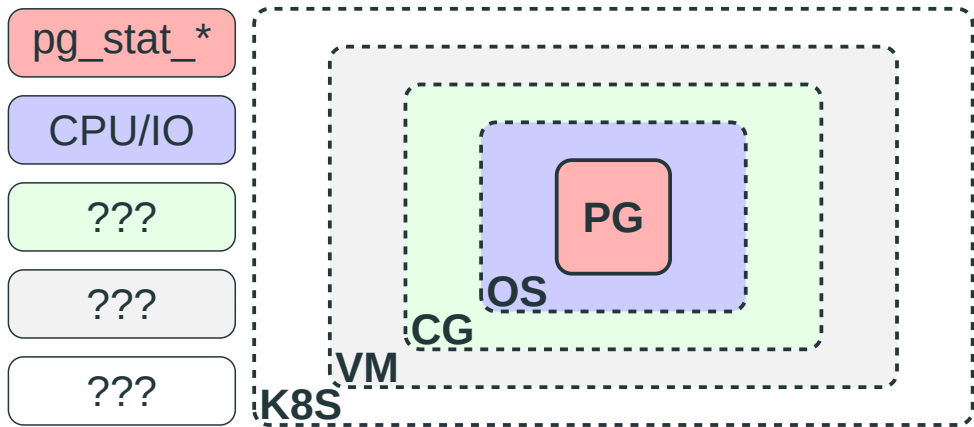
pg\_stat\_\*

CPU/IO

???

???







**All right, then. Keep your secrets**



**Plan?**

# A bit chaotic



## Info sources

source code

strace/GDB/Perf

procfs/sysfs

BPF/eBPF/BCC

## Shared memory

```
ERROR:  could not resize shared memory segment  
"/PostgreSQL.699663942" to 50438144 bytes:  
No space left on device
```

```
# strace -k -p PID
openat(AT_FDCWD, "/dev/shm/PostgreSQL.62223175"
ftruncate(176, 50438144) = 0
fallocate(176, 0, 0, 50438144) = -1 ENOSPC
> libc-2.27.so(posix_fallocate+0x16) [0x114f76]
> postgres(dsm_create+0x67) [0x377067]
...
> postgres(ExecInitParallelPlan+0x360) [0x254a80]
> postgres(ExecGather+0x495) [0x269115]
> postgres(standard_ExecutorRun+0xfd) [0x25099d]
...
> postgres(exec_simple_query+0x19f) [0x39afdf]
```

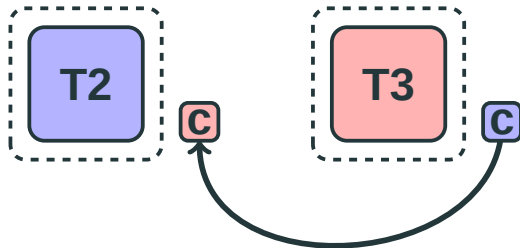
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# strace -k -p PID
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> postgres(ExecGather+0x495) [0x269115]
> postgres(standard_ExecutorRun+0xfd) [0x25099d]
...
> postgres(exec_simple_query+0x19f) [0x39afdf]
```

# vDSO

```
# strace -k -p PID on XEN  
gettimeofday({tv_sec=1550586520, tv_usec=313499}, NULL) = 0  
> [vdso]() [0xef0]
```

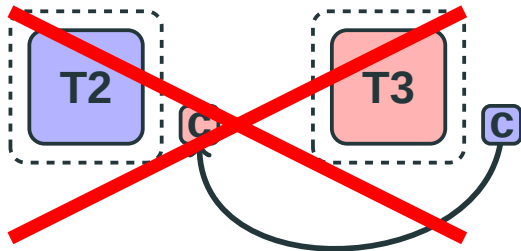
Two frequently used system calls are 77% slower on AWS EC2

# Scheduling





# Scheduling





Andres Freund: New intel MDS vulnerability mitigations cause measurable slowdown

## MDS

# Children	Self	Symbol
# .....	.....	.....
<b>71.06%</b>	<b>0.00%</b>	[.] __libc_start_main
<b>71.06%</b>	<b>0.00%</b>	[.] PostmasterMain
<b>56.82%</b>	<b>0.14%</b>	[.] exec_simple_query
<b>25.19%</b>	<b>0.06%</b>	[k] entry_SYSCALL_64_after_hwframe
<b>25.14%</b>	<b>0.29%</b>	[k] do_syscall_64
<b>23.60%</b>	<b>0.14%</b>	[.] standard_ExecutorRun

## MDS

# Children	Self	Symbol
# .....	.....	.....
71.06%	0.00%	[.] __libc_start_main
71.06%	0.00%	[.] PostmasterMain
56.82%	0.14%	[.] exec_simple_query
25.19%	0.06%	[k] entry_SYSCALL_64_after_hwframe
25.14%	0.29%	[k] <b>do_syscall_64</b>
23.60%	0.14%	[.] standard_ExecutorRun

# MDS

```
# Percent      Disassembly of kcore for cycles
# .....
  0.01% :      nopl      0x0(%rax,%rax,1)
28.94% :      verw      0xffe9e1(%rip)
  0.55% :      pop      %rbx
  3.24% :      pop      %rbp
```

# MDS

```
# Percent      Disassembly of kcore for cycles
# .....
  0.01% :      nopl      0x0(%rax,%rax,1)
28.94% :      verw      0xffe9e1(%rip)
  0.55% :      pop       %rbx
  3.24% :      pop       %rbp
```

# MDS

#	Overhead	Symbol
#	.....	.....
	<b>25.19%</b>	<b>[k]</b> native_safe_halt

## MDS

```
static inline __cpuidle void native_safe_halt(void)
{
    mds_idle_clear_cpu_buffers();
    asm volatile("sti; hlt" : : : "memory");
}
```



## MDS

```
static inline __cpuidle void native_safe_halt(void)
{
    mds_idle_clear_cpu_buffers();
    asm volatile("sti; hlt" : : : "memory");
}
```

## Huge pages

transparent vs classic

TLB misses are faster and less frequent

# Huge pages

```
# perf record -e dTLB-loads,dTLB-stores -p PID
```

```
# huge_pages on
```

```
Samples: 832K of event 'dTLB-load-misses'
```

```
Event count (approx.): 640614445 : ~19% less
```

```
Samples: 736K of event 'dTLB-store-misses'
```

```
Event count (approx.): 72447300 : ~29% less
```

```
# huge_pages off
```

```
Samples: 894K of event 'dTLB-load-misses'
```

```
Event count (approx.): 784439650
```

```
Samples: 822K of event 'dTLB-store-misses'
```

```
Event count (approx.): 101471557
```

# Huge pages

```
# perf record -e dTLB-loads,dTLB-stores -p PID
```

```
# huge_pages on
```

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Samples: 832K of event 'dTLB-load-misses'
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Event count (approx.): 640614445 : ~19% less
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```
# huge_pages off
```

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Samples: 894K of event 'dTLB-load-misses'
```

```
Event count (approx.): 784439650
```

```
Samples: 822K of event 'dTLB-store-misses'
```

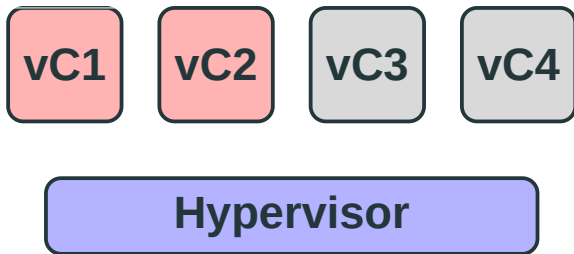
```
Event count (approx.): 101471557
```

# VM

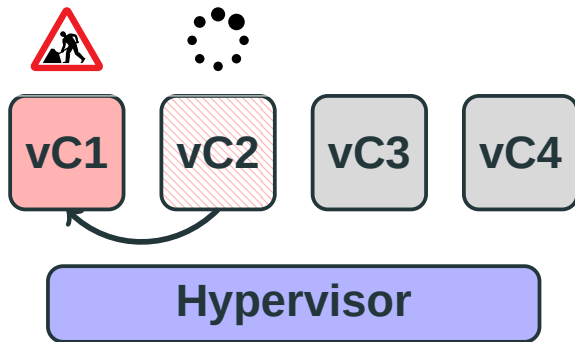
- Lock holder preemption problem
- Lock waiter preemption problem
- Intel PLE (pause loop exiting)
- PLE\_Gap, PLE\_Window

Intel® 64 and IA-32 Architectures Software Developer's Manual, Vol. 3

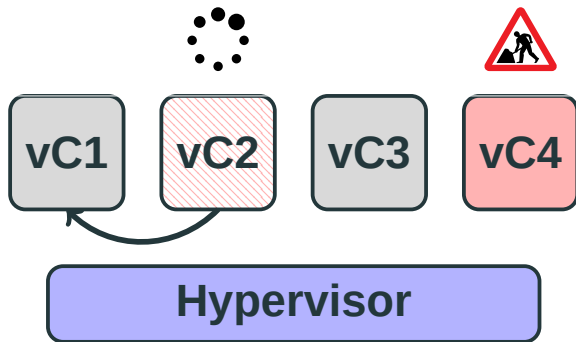
# vCPU



## vCPU



# vCPU





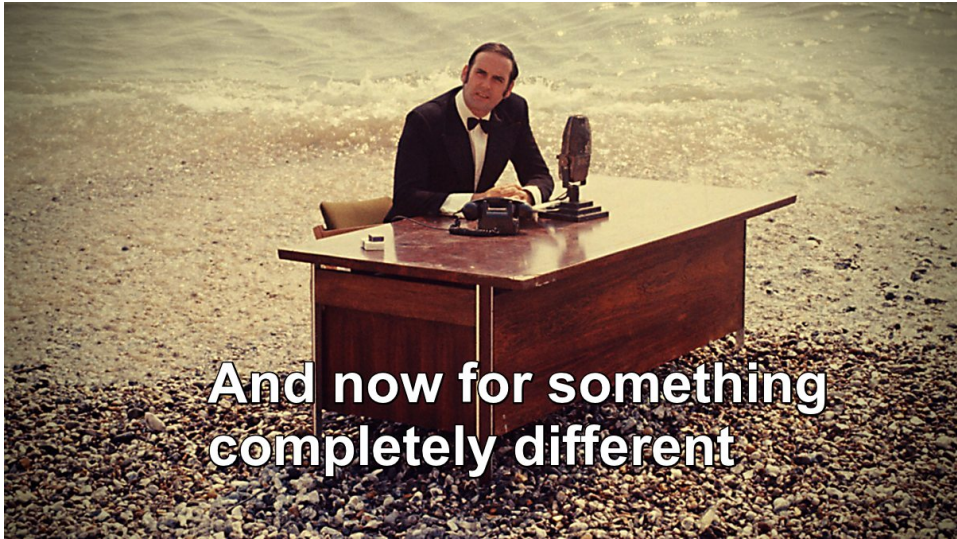
```
# latency average = 17.782 ms  
=> modprobe kvm-intel ple_gap=128  
=> perf record -e kvm:kvm_exit  
reason PAUSE_INSTRUCTION 306795
```

```
# latency average = 17.782 ms  
=> modprobe kvm-intel ple_gap=128  
=> perf record -e kvm:kvm_exit  
reason PAUSE_INSTRUCTION 306795
```

```
# latency average = 16.858 ms  
=> modprobe kvm-intel ple_gap=0  
=> perf record -e kvm:kvm_exit  
reason PAUSE_INSTRUCTION 0
```

```
# latency average = 17.782 ms  
=> modprobe kvm-intel ple_gap=128  
=> perf record -e kvm:kvm_exit  
reason PAUSE_INSTRUCTION 306795
```

```
# latency average = 16.858 ms  
=> modprobe kvm-intel ple_gap=0  
=> perf record -e kvm:kvm_exit  
reason PAUSE_INSTRUCTION 0
```



**And now for something  
completely different**

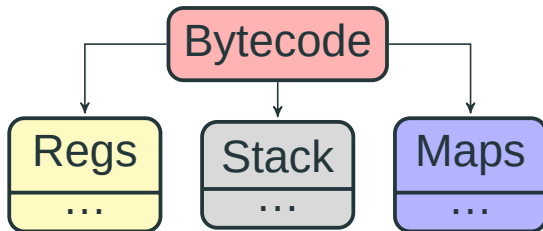
# Userspace

---

Bytecode

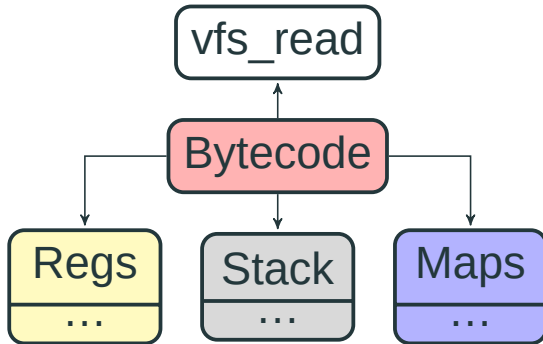
# Userspace

---



# Userspace

---



## Tunables

```
# from /proc/sys/kernel/  
sched_wakeup_granularity_ns  
# default = 1 msec * (1 + ilog(ncpus))
```



# pgbench and pg\_dump

usecs	: count	distribution	:
0 -> 1	: 16	:	:
2 -> 3	: 4604	: **	:
4 -> 7	: 6812	: ****	:
8 -> 15	: 14888	: ****	:
16 -> 31	: 19267	: ****	:
32 -> 63	: 65795	: ****	:
64 -> 127	: 50454	: ****	:
128 -> 255	: 16393	: ****	:
256 -> 511	: 5981	: ***	:
512 -> 1023	: 12300	: ****	:
1024 -> 2047	: 48	:	:
2048 -> 4095	: 0	:	:

user	1m9.127s
sys	0m2.066s
real	1m38.990s

# pgbench and pg\_dump

usecs	: count	distribution	:
0 -> 1	: 16	:	:
2 -> 3	: 4604	: **	:
4 -> 7	: 6812	: ****	:
8 -> 15	: 14888	: ****	:
16 -> 31	: 19267	: ****	:
32 -> 63	: 65795	: ****	:
64 -> 127	: 50454	: ****	:
128 -> 255	: 16393	: ****	:
256 -> 511	: 5981	: ***	:
512 -> 1023	: 12300	: ****	:
1024 -> 2047	: 48	:	:
2048 -> 4095	: 0	:	:

user	1m9.127s
sys	0m2.066s
real	1m38.990s

# pgbench and pg\_dump

usecs	: count	distribution	:
0 -> 1	: 1	:	:
2 -> 3	: 8	:	:
4 -> 7	: 25	:	:
8 -> 15	: 46	: *	:
16 -> 31	: 189	: *****	:
32 -> 63	: 119	: *****	:
64 -> 127	: 96	: ***	:
128 -> 255	: 93	: ***	:
256 -> 511	: 238	: *****	:
512 -> 1023	: 323	: *****	:
1024 -> 2047	: 1012	: *****	:
2048 -> 4095	: 47	: *	:

user 1m8.559s  
sys 0m1.641s  
real 1m32.030s

# pgbench and pg\_dump

usecs	count	distribution	
0 -> 1	: 1	:	:
2 -> 3	: 8	:	:
4 -> 7	: 25	:	:
8 -> 15	: 46	: *	:
16 -> 31	: 189	: *****	:
32 -> 63	: 119	: ****	:
64 -> 127	: 96	: ***	:
128 -> 255	: 93	: ***	:
256 -> 511	: 238	: *****	:
512 -> 1023	: 323	: *****	:
1024 -> 2047	: 1012	: *****	:
2048 -> 4095	: 47	: *	:

user	1m8.559s
sys	0m1.641s
real	1m32.030s

[github.com/iovisor/bcc/](https://github.com/iovisor/bcc/)

[github.com/erthalion/postgres-bcc](https://github.com/erthalion/postgres-bcc)

# Cache

=> llcache\_per\_query.py bin/postgres

PID	QUERY	CPU	REFERENCE	MISS	HIT%
<b>9720</b>	UPDATE pgbench_tellers ...	<b>0</b>	<b>2000</b>	<b>1000</b>	<b>50.00%</b>
<b>9720</b>	SELECT abalance FROM ...	<b>2</b>	<b>2000</b>	<b>100</b>	<b>95.00%</b>
...					

Total References: **3303100** Total Misses: **599100** Hit Rate: **81.86%**

## Shared memory

```
ERROR: could not resize shared memory segment  
"/PostgreSQL.699663942" to 50483144 bytes:  
No space left on device
```

5

Remember?



# Shared memory

=> shmem.py bin/postgres

mmap:

**[20439]**: 142M

anon shm:

**[20439]**: 56B

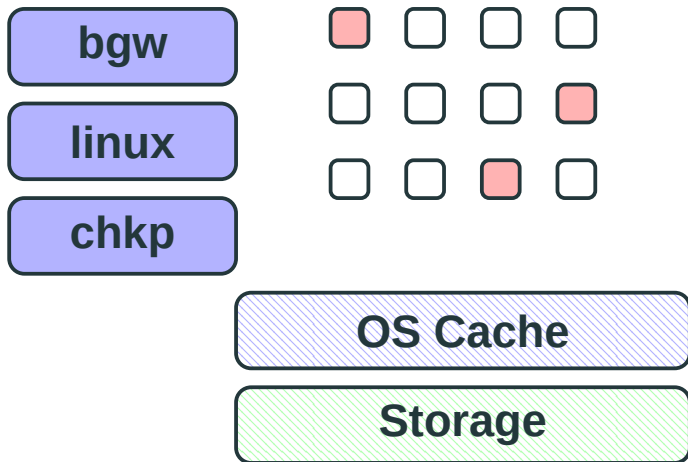
shm:

**[postmaster.opts]**: 0B

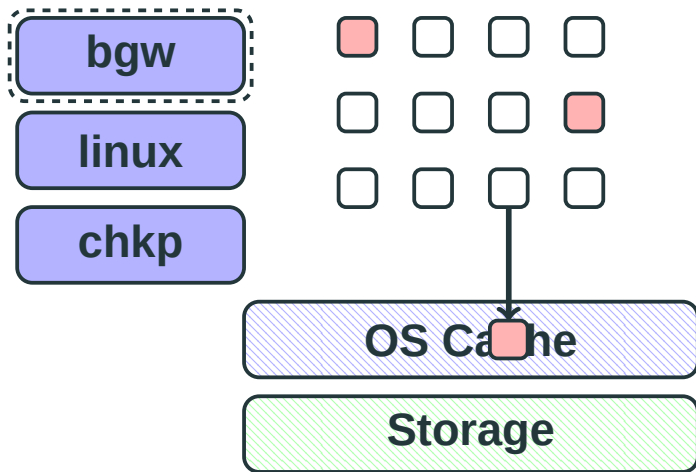
**[PostgreSQL.57332071]**: 7K



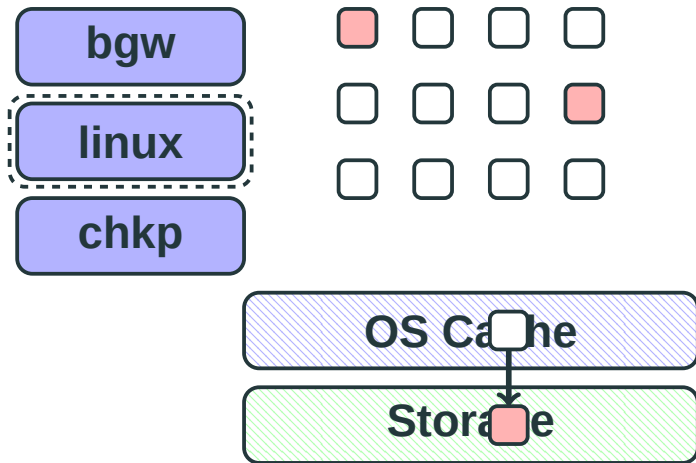
## Dirty pages



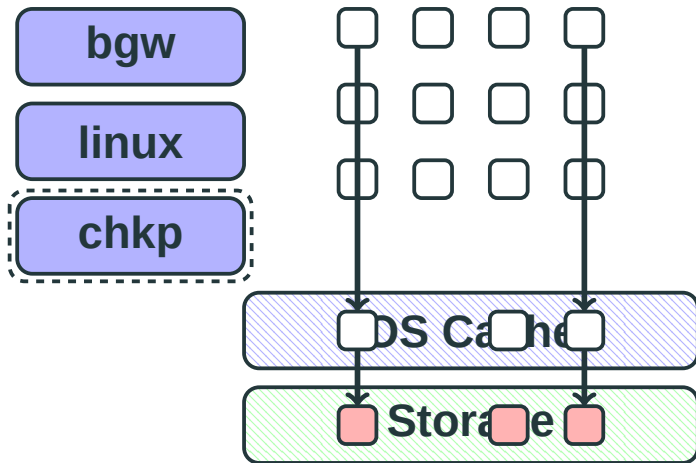
# Dirty pages



# Dirty pages



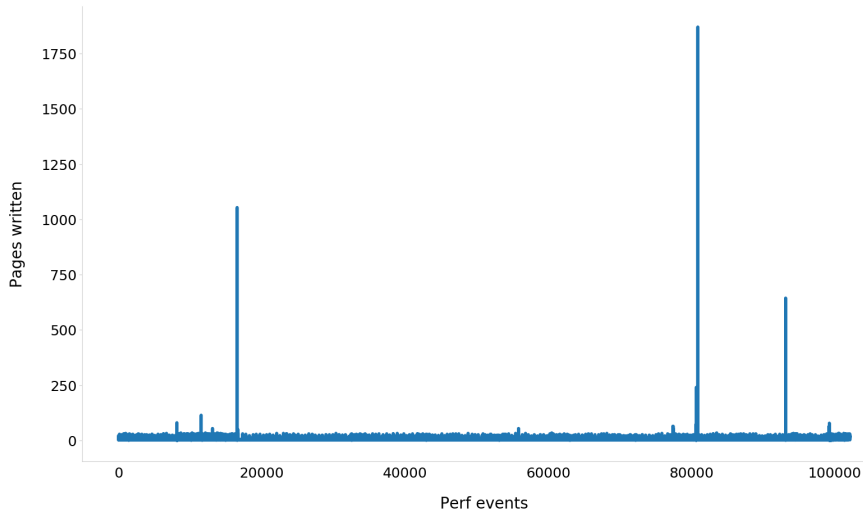
# Dirty pages



## Writeback (cgroup v1)

```
/* vmscan.c */  
/* The normal page dirty throttling mechanism  
 * in balance_dirty_pages() is completely broken  
 * with the legacy memcg and direct stalling in  
 * shrink_page_list() is used for throttling instead,  
 * which lacks all the niceties such as fairness,  
 * adaptive pausing, bandwidth proportional  
 * allocation and configurability.  
 */  
static bool sane_reclaim(struct scan_control *sc)
```

# Pages written, kernel



# Writeback

```
=> perf record -e writeback:writeback_written
```

```
kworker/u8:1 reason=periodic    nr_pages=101429  
kworker/u8:1 reason=background  nr_pages=MAX_ULONG  
kworker/u8:3 reason=periodic    nr_pages=101457
```

# Writeback

```
# pgbench insert workload
```

```
=> io_timeouts.py bin/postgres
```

```
[18335] END: MAX_SCHEDULE_TIMEOUT
```

```
[18333] END: MAX_SCHEDULE_TIMEOUT
```

```
[18331] END: MAX_SCHEDULE_TIMEOUT
```

```
[18318] truncate pgbench_history: MAX_SCHEDULE_TIMEOUT
```



# Kubernetes

**resources:**

**requests:**

**memory:** "64Mi"

**cpu:** "250m"

**limits:**

**memory:** "128Mi"

**cpu:** "500m"

# Kubernetes

**resources:**

**requests:**

**memory:** "64Mi"

**cpu:** "250m"

**limits:**

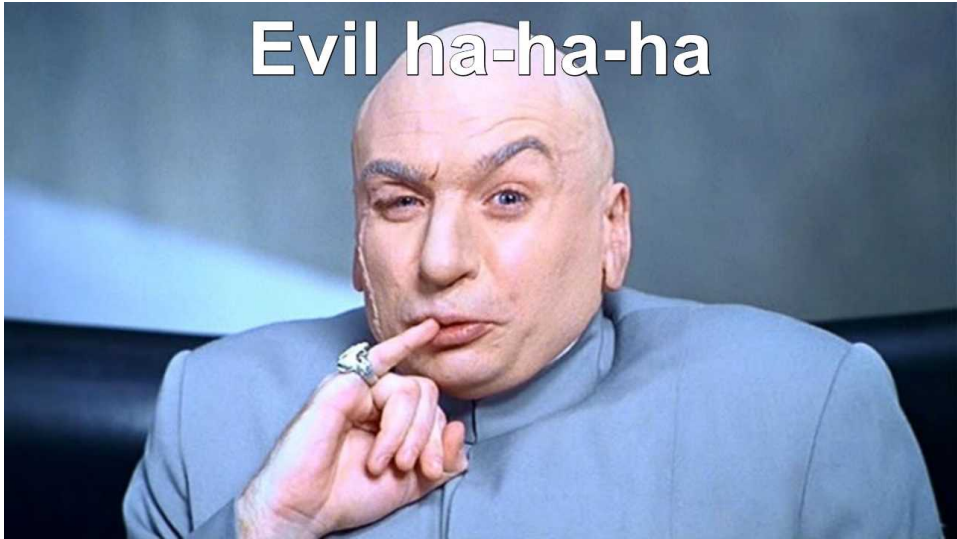
**memory:** "128Mi"

**cpu:** "500m"

soft\_limits\_in\_bytes

limits\_in\_bytes

Evil ha-ha-ha



# Kubernetes

**resources:**

**requests:**

**memory:** "64Mi"

**cpu:** "250m"

**limits:**

**memory:** "128Mi"

**cpu:** "500m"

~~soft\_limits\_in\_bytes~~



limits\_in\_bytes

# Memory reclaim

# only under the memory pressure

=> `page_reclaim.py --container 89c33bb3133f`

**[7382]** postgres: 928K

**[7138]** postgres: 152K

**[7136]** postgres: 180K

**[7468]** postgres: 72M

**[7464]** postgres: 57M

**[5451]** postgres: 1M

## How to run?

```
# bcc + postgres-bcc
```

```
CONFIG_BPF=y
```

```
CONFIG_BPF_SYSCALL=y
```

```
CONFIG_NET_CLS_BPF=m
```

```
CONFIG_NET_ACT_BPF=m
```

```
CONFIG_BPF_JIT=y
```

```
CONFIG_BPF_EVENTS=y
```

```
debugfs on /sys/kernel/debug type debugfs (rw)
```

## How to run: container?

```
# sometimes you also need to let perf know  
# where to find debugging symbols, e.g. copy  
# from /usr/lib/.debug/  
docker run  
    --privileged  
    --net=container:<container-id>  
    --ipc=container:<container-id>
```

## How to run: K8S?

**spec:**

**serviceAccountName:** "bcc"

**hostPID:** true

**containers:**

- **name:** "bcc"

**securityContext:**

**privileged:** true

# 4 \* 65536 + 14 \* 256 + 96

=> export BCC\_LINUX\_VERSION\_CODE **265824**



## How to break?

```
# unsafe access
```

```
=> perf probe -x bin/postgres --funcs
```

```
=> perf probe -x bin/postgres 'ExecCallTriggerFunc trigdata->?'
```

```
=> perf record probe_postgres:ExecCallTriggerFunc
```

## How to break?

# non interruptible sleep

=> perf probe -x bin/postgres --funcs

=> perf probe -x bin/postgres 'XLogInsertRecord fpw\_lsn'

# How to break?

iovisor / bcc

Watch 410 ★ Uns

<> Code ⓘ Issues 266 🔗 Pull requests 21 📁 Projects 0 📖 Wiki 📊 Insights

## Ubuntu xenial kernel panic in bpf\_map\_update\_elem using ext4slower #1678


**Closed** stefreak opened this issue on Apr 12, 2018 · 13 comments


## Questions?

 [github.com/erthalion](https://github.com/erthalion)

 [github.com/erthalion/postgres-bcc](https://github.com/erthalion/postgres-bcc)

 [@erthalion](https://twitter.com/erthalion)

 [dmitrii.dolgov at zalando dot de](mailto:dmitrii.dolgov@zalando.de)

 [9erthalion6 at gmail dot com](mailto:9erthalion6@gmail.com)