

# Comparison of PostgreSQL resource consumption at different cache states using a parallelized workload

The following is a test that shows the effects of the Linux filesystem cache being „hot“ or „cold“ (filled with data needed for the job) and the PostgreSQL shared\_buffers caches being „hot“ or „cold“ on job run-time and resource usage profiles.

In particular the CPU load, the ratio between system and user CPU and the storage IO load consumption profiles change when caches are cold versus hot.

## Methods

### Test Work Load

The test job used can be found in Git here:

[<GIT-RA>/adr/services/svc\\_sqlbalancer/examples/rating\\_ereignis\\_summary.sql](https://git-RA.com/adr/services/svc_sqlbalancer/examples/rating_ereignis_summary.sql)

### Clearing PG Caches

1. CHECKPOINT and shutdown PostgreSQL
2. Restart PostgreSQL

### Clearing FS Caches

To clear all filesystem caches in the Linux kernel:

1. CHECKPOINT and shutdown PostgreSQL
2. Drop the Linux filesystem caches:

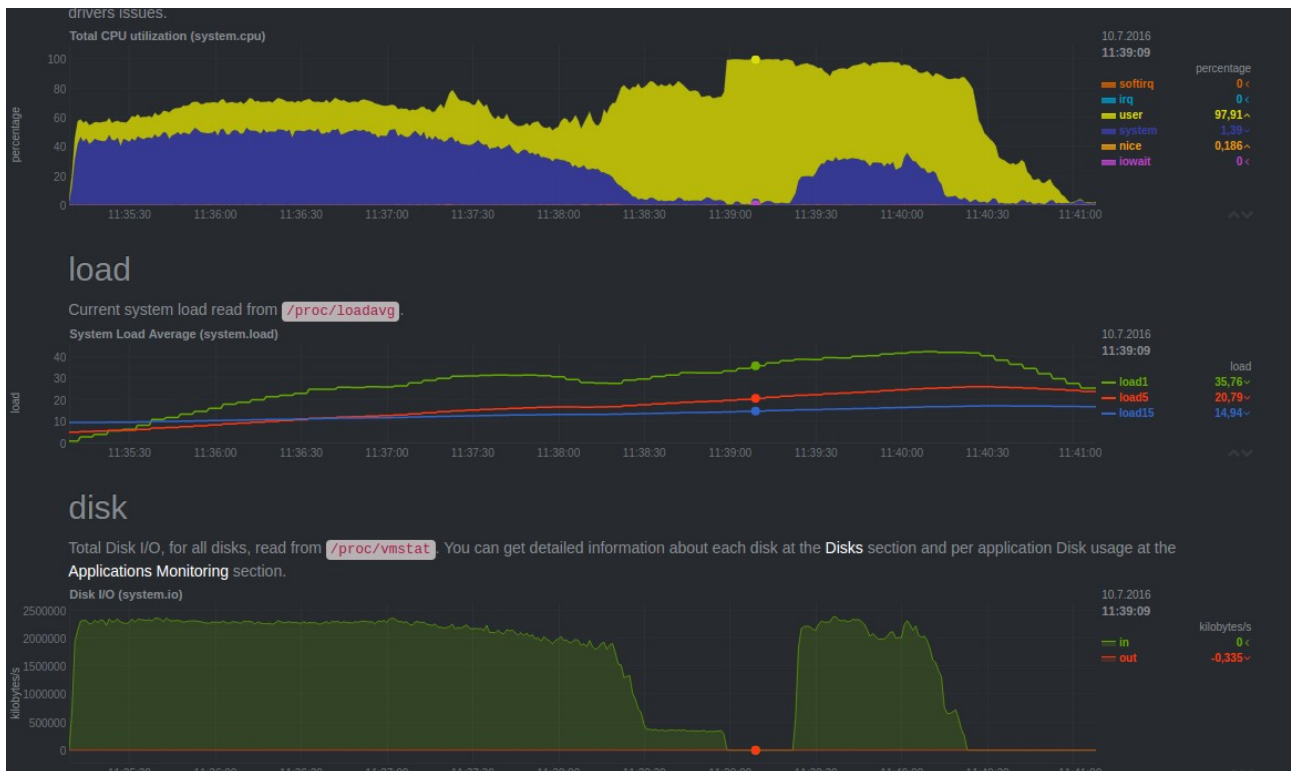
```
console
sudo su
sync
echo 1 > /proc/sys/vm/drop_caches
echo 2 > /proc/sys/vm/drop_caches
echo 3 > /proc/sys/vm/drop_caches
```

3. Restart PostgreSQL

# Results

## PG-Cold / FS-Cold

Here is the CPU/disk load during a complete run of the test job with PostgreSQL cache cold and Filesystem cache cold:



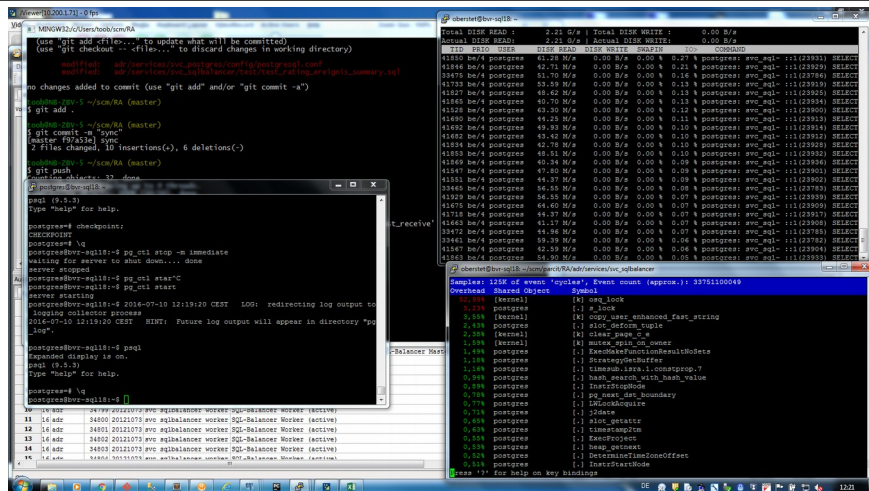
With both the FS and PG caches cold, there are phases with massive storage read IO (> 2.3GB/s). Here, data is read from the NVMe's and brought into the Linux FS and further mapped into the PG shared buffers. During these phases, the system CPU load is also significant. This is expected, as storage IO will run kernel (FS and driver) code.

Here is a snapshot of Linux perf top monitoring a PG background process of a SQL balancer worker running a work unit of the test job:

High system load:

```
oberstet@bvr-sql18: ~  
Samples: 88K of event 'cycles', Event count (approx.): 30523891909  
Overhead Shared Object Symbol  
53.83% [kernel] [k] osq_lock  
5.79% postgres [.] s_lock  
4.03% [kernel] [k] copy_user_enhanced_fast_string  
2.47% [kernel] [k] clear_page_c_e  
2.00% postgres [.] slot_deform_tuple  
1.82% [kernel] [k] mutex_spin_on_owner  
1.36% postgres [.] StrategyGetBuffer  
1.27% postgres [.] ExecMakeFunctionResultNoSets  
0.97% postgres [.] hash_search_with_hash_value  
0.96% postgres [.] timesub.isra.1.constprop.7  
0.78% postgres [.] InstrStopNode  
0.76% postgres [.] LWLockAcquire  
0.70% postgres [.] pg_next_dst_boundary  
0.69% postgres [.] j2date  
0.57% postgres [.] timestamp2tm  
0.54% postgres [.] heap_getnext  
0.50% postgres [.] slot_getattr  
0.50% postgres [.] pg_localtime  
0.48% postgres [.] timestamp2pl_interval  
0.47% postgres [.] DetermineTimeZoneOffset  
0.46% postgres [.] heap_fill_tuple  
0.44% postgres [.] ExecProject  
0.43% [kernel] [k] put_page  
0.41% postgres [.] InstrStartNode  
Press '?' for help on key bindings
```

## High storage IO:



## PG-Cold / FS-Hot

Here is the CPU/disk load during a complete run of the test job with PostgreSQL cache cold and Filesystem cache hot:



The CPU load total and breakdown between user/system CPU look nearly the same as with cold FS caches. However, there is no IO at all. This makes sense as data is fully cached in FS caches already. And it demonstrates that PG will first need to bring data into PG caches for processing.

Here is a snapshot of Linux `perf top` monitoring a PG background process of a SQL balancer worker

running a work unit of the test job:

### Phase 1: bringing data in PG caches

```
oberstet@bvr-sql18: ~  
Samples: 18K of event 'cycles', Event count (approx.): 11299903376  
Overhead Shared Object Symbol  
54,92% [kernel] [k] osq_lock  
6,56% postgres [.] s_lock  
4,30% [kernel] [k] copy_user_enhanced_fast_string  
2,56% postgres [.] slot_deform_tuple  
2,38% [kernel] [k] clear_page_c_e  
1,73% postgres [.] StrategyGetBuffer  
1,73% [kernel] [k] mutex_spin_on_owner  
1,47% postgres [.] hash_search_with_hash_value  
1,25% postgres [.] ExecMakeFunctionResultNoSets  
1,06% postgres [.] timesub.isra.1.constprop.7  
1,04% postgres [.] InstrStopNode  
0,92% postgres [.] LWLockAcquire  
0,63% postgres [.] j2date  
0,62% postgres [.] ExecProject  
0,61% postgres [.] pg_next_dst_boundary  
0,60% postgres [.] timestamptz_pl_interval  
0,58% postgres [.] slot_getattr  
0,57% postgres [.] timestamp2tm  
0,56% postgres [.] InstrStartNode  
0,55% postgres [.] ReadBuffer_common  
0,46% postgres [.] heap_getnext  
0,46% postgres [.] ExecProcNode  
0,45% postgres [.] pg_localtime  
0,44% [kernel] [k] find_get_entry  
Press '?' for help on key bindings
```

### Phase 2: crunching data

```
oberstet@bvr-sql18: ~  
Samples: 431K of event 'cycles', Event count (approx.): 25678782961  
Overhead Shared Object Symbol  
29,26% postgres [.] _bt_checkkeys  
25,08% [kernel] [k] osq_lock  
5,16% postgres [.] s_lock  
4,94% postgres [.] hash_search_with_hash_value  
4,32% [kernel] [k] copy_user_enhanced_fast_string  
4,23% postgres [.] FunctionCall2Coll  
3,76% postgres [.] LWLockAcquire  
1,89% [kernel] [k] mutex_spin_on_owner  
1,84% postgres [.] StrategyGetBuffer  
1,81% [kernel] [k] clear_page_c_e  
1,39% postgres [.] PinBuffer  
1,34% postgres [.] bt_readpage  
1,16% postgres [.] UnlockReleaseBuffer  
1,14% postgres [.] LWLockRelease  
0,95% postgres [.] timestamp_lt  
0,92% postgres [.] timestamp_ge  
0,74% postgres [.] ReadBuffer_common  
0,58% postgres [.] _bt_steppage  
0,43% [kernel] [k] put_page  
0,37% postgres [.] _bt_checkpage  
0,36% [kernel] [k] update_cfs_shares  
0,35% [kernel] [k] effective_load.isra.40  
0,30% [kernel] [k] _raw_spin_lock  
0,27% postgres [.] slot_deform_tuple  
Press '?' for help on key bindings  
  
oberstet@bvr-sql18: ~  
Samples: 889K of event 'cycles', Event count (approx.): 52628687571  
Overhead Shared Object Symbol  
27,34% postgres [.] pg_detoast_datum_packed  
19,32% postgres [.] _bt_checkkeys  
12,12% libc-2.21.so [.] __strcoll_l  
6,02% postgres [.] ExecStoreMinimalTuple  
5,42% postgres [.] qsort_ssup  
3,28% postgres [.] FunctionCall2Coll  
3,09% postgres [.] varstr_cmp  
2,86% postgres [.] bpcharcmp  
1,92% postgres [.] slot_deform_tuple  
1,62% postgres [.] hash_search_with_hash_value  
1,40% postgres [.] comparison_shim  
1,28% postgres [.] LWLockAcquire  
1,04% postgres [.] btint8fastcmp  
0,80% postgres [.] _bt_readpage  
0,75% libc-2.21.so [.] strcoll  
0,62% postgres [.] tuplesort_gettupleslot  
0,59% postgres [.] lc_collate_is_c  
0,58% postgres [.] ExecProject  
0,57% postgres [.] advance_aggregates  
0,56% postgres [.] _bt_steppage  
0,54% postgres [.] timestamp_ge  
0,53% postgres [.] timestamp_lt  
0,53% postgres [.] slot_getattr  
0,43% postgres [.] bpchareq  
Press '?' for help on key bindings
```

### Phase 3: storing results

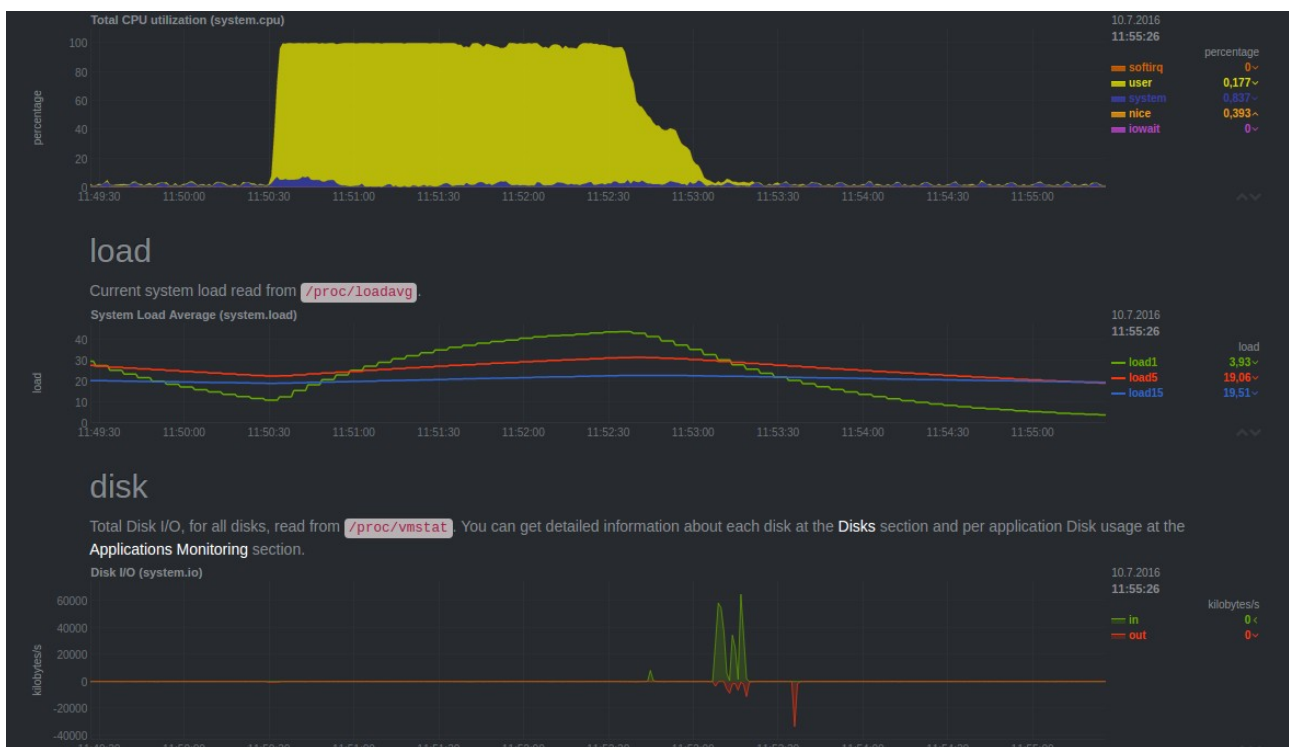
```

oberstet@bvr-sql18: ~
Samples: 953K of event 'cycles', Event count (approx.): 53442218624
Overhead Shared Object Symbol
22,05% postgres [.] ExecStoreMinimalTuple
15,44% postgres [.] qsort_ssaup
9,40% postgres [.] pg_deToast_datum_packed
6,93% postgres [.] slot_deform_tuple
6,54% postgres [.] _bt_checkkeys
6,27% postgres [.] btint8fastcmp
4,10% libc-2.21.so [.] __strcoll_l
2,90% postgres [.] FunctionCall2Coll
1,97% postgres [.] tuplesort_gettupleslot
1,67% postgres [.] ExecProject
1,58% postgres [.] advance_aggregates
1,46% postgres [.] tuplesort_getdatum
1,38% postgres [.] slot_getattr
1,11% postgres [.] bpchareq
1,05% postgres [.] varstr_cmp
1,00% postgres [.] execTuplesMatch
0,97% postgres [.] bpcharcmp
0,96% postgres [.] puttuple_common
0,90% postgres [.] advance_transition_function
0,90% postgres [.] InstrStopNode
0,65% postgres [.] InstrStartNode
0,62% postgres [.] slot_getsomeattrs
0,58% [kernel] [k] clear_page_c_e
0,57% postgres [.] ExecProcNode
Press '?' for help on key bindings

```

## PG-Hot / FS-Hot

Here is the CPU/disk load during a complete run of the test job with PostgreSQL cache hot and Filesystem cache hot:



With both the FS and PG caches hot, time is spent almost exclusively in PG code. The specific functions within PG consuming the most time is changing of the run-time of the test job and depend on the phase in which the job.

Here is a snapshot of Linux perf top monitoring a PG background process of a SQL balancer worker running a work unit of the test job:

Phase 1: accessing source data

oberstet@bvr-sql18: ~

Samples: 117K of event 'cycles', Event count (approx.): 4445114699

Overhead	Shared Object	Symbol
59.38%	postgres	[.] _bt_checkkeys
7.89%	postgres	[.] FunctionCall2Coll
4.91%	postgres	[.] hash_search_with_hash_value
4.55%	postgres	[.] LWLockAcquire
2.35%	postgres	[.] _bt_readpage
1.99%	postgres	[.] timestamp_ge
1.90%	postgres	[.] PinBuffer
1.86%	postgres	[.] timestamp_lt
1.70%	postgres	[.] _bt_steppage
1.45%	postgres	[.] HeapTupleSatisfiesMVCC
1.36%	postgres	[.] slot_deform_tuple
0.74%	postgres	[.] ExecMakeFunctionResultNoSets
0.73%	postgres	[.] _bt_checkpage
0.58%	postgres	[.] timesub.isra.1.constprop.7
0.46%	postgres	[.] InstrStopNode
0.38%	postgres	[.] pg_next_dst_boundary
0.36%	postgres	[.] j2date
0.36%	postgres	[.] timestamp2tm
0.32%	postgres	[.] LWLockRelease
0.31%	postgres	[.] timestampz_pl_interval
0.30%	postgres	[.] ExecProject
0.28%	postgres	[.] DetermineTimeZoneOffset
0.27%	[kernel]	[k] clear_page_c_e
0.26%	postgres	[.] heap_fill_tuple

Press '?' for help on key bindings

## Phase 2: computing result set

oberstet@bvr-sql18: ~

Samples: 458K of event 'cycles', Event count (approx.): 52232857789

Overhead	Shared Object	Symbol
14.98%	postgres	[.] pg_detoast_datum_packed
14.50%	postgres	[.] qsort_ssup
13.39%	postgres	[.] ExecStoreMinimalTuple
8.66%	postgres	[.] _bt_checkkeys
5.52%	libc-2.21.so	[.] __strcoll_l
5.40%	postgres	[.] btint8fastcmp
4.66%	postgres	[.] slot_deform_tuple
3.04%	postgres	[.] FunctionCall2Coll
1.50%	postgres	[.] ExecProject
1.44%	postgres	[.] varstr_cmp
1.36%	postgres	[.] bpcharcmp
1.35%	postgres	[.] slot_getattr
1.28%	postgres	[.] advance_aggregates
1.28%	postgres	[.] tuplesort_gettupleslot
1.06%	postgres	[.] execTuplesMatch
1.05%	postgres	[.] advance_transition_function
1.00%	postgres	[.] bpchareq
0.97%	postgres	[.] tuplesort_getdatum
0.84%	postgres	[.] InstrStopNode
0.82%	[kernel]	[k] copy_page_rep
0.71%	postgres	[.] puttuple_common
0.68%	postgres	[.] comparison_shim
0.67%	postgres	[.] InstrStartNode
0.58%	postgres	[.] ExecClearTuple

Press '?' for help on key bindings

## Phase 3: storing results

oberstet@bvr-sql18: ~

Samples: 496K of event 'cycles', Event count (approx.): 39208347296

Overhead	Shared Object	Symbol
19.34%	postgres	[.] ExecStoreMinimalTuple
17.11%	postgres	[.] qsort_ssup
7.93%	postgres	[.] pg_detoast_datum_packed
6.93%	postgres	[.] btint8fastcmp
6.59%	postgres	[.] slot_deform_tuple
4.53%	postgres	[.] _bt_checkkeys
2.91%	postgres	[.] FunctionCall2Coll
2.89%	libc-2.21.so	[.] __strcoll_l
2.31%	postgres	[.] advance_transition_function
1.80%	postgres	[.] ExecProject
1.58%	postgres	[.] slot_getattr
1.48%	postgres	[.] tuplesort_gettupleslot
1.47%	postgres	[.] advance_aggregates
1.27%	postgres	[.] tuplesort_getdatum
1.22%	postgres	[.] execTuplesMatch
1.20%	postgres	[.] bpchareq
0.99%	postgres	[.] InstrStopNode
0.87%	postgres	[.] puttuple_common
0.80%	[kernel]	[k] copy_page_rep
0.75%	postgres	[.] InstrStartNode
0.75%	postgres	[.] varstr_cmp
0.74%	postgres	[.] finalize_aggregates
0.71%	postgres	[.] bpcharcmp
0.67%	postgres	[.] ExecClearTuple

Press '?' for help on key bindings

**Conclusion:** With data fully cached in PG caches, the whole CPU available on the machine being spent almost exclusively within PG code, not kernel (or other) code means, that any tuning effort can focus tuning at the SQL level, rather than system (Linux) or storage (FS, hardware).