Measuring and Reducing Postgres Transaction Latency

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Subject

Small OLTP — *OnLine Transaction Processing*

- CRUD queries — `... WHERE pk=?`
- data fit in shared buffers — *small, few GB*
- RW, RO — *pgbench builtins*

Focus — *and Motivation*

- performance with emphasis on latency — *interactive web app*
- experiments & measures — *do not assume!*

latency performance : RW $\times 63$**, RO** $\times 219$

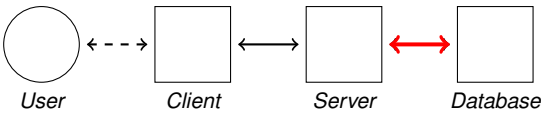
Typical Web Application

3-Tier Architecture

Client user acts on user-agent, sends to

Server process request, database operations to

Database stores and retrieves data



Database Operations

- Connection — *TCP/IP, SSL & AAA*
- Request-Response **cycles** — *transfer, parse, plan, execute, transfer back*

Transaction Performance

Definitions *time & operations*

Throughput operations per time unit *tx/s*
usual approach, load measured in ***tps***

Latency time for one operation *ms/tx*
must fit application requirements

Comments

- correlated *and contradictory*
- max vs enough *and vice-versa*
- sensitive to many settings *net, soft & hard*
- throughput bottleneck & latency additivity *deep voodoo!*

Postgres Performance Swiss Army Knife

Available Features

input	SQL-like scripts with minimal client-side language
options	time to run, prepared, reconnections, ...
parallelism	threads, clients, asynchronous calls
output	statistical performance data

Caveats

- long enough — *warm-up, checkpoint and vacuum*
- several times — *reproducibility*
- pedal-to-the-metal max speed test — *not representative*

Default TPC-B-like Transaction

`pgbench -b tcpb-like`

- TPC-B-like banking transaction

```
-- random ids and amount
\set aid random(1, 100000 * :scale)
\set bid random(1, 1 * :scale)
\set tid random(1, 10 * :scale)
\set delta random(-5000, 5000)
-- actual transaction
BEGIN;
UPDATE pgbench_accounts
  SET abalance = abalance + :delta WHERE aid = :aid;
SELECT abalance
  FROM pgbench_accounts WHERE aid = :aid;
UPDATE pgbench_tellers
  SET tbalance = tbalance + :delta WHERE tid = :tid;
UPDATE pgbench_branches
  SET bbalance = bbalance + :delta WHERE bid = :bid;
INSERT INTO pgbench_history (tid, bid, aid, delta, mtime)
  VALUES (:tid, :bid, :aid, :delta, CURRENT_TIMESTAMP);
END;
```

Pattern

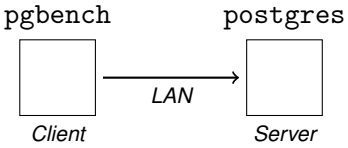
- 3 updates
- 1 insert
- 1 select

Performance Comparisons

Two Connection Costs

Connection Costs

`pgbench -C`



- Client — *8 cores, 16 GB*
- LAN — *1 Gbps*
- Server — *16 cores, 32 GB, HDD*

Initialization and Benchmarks — *Postgres 9.6.1*

`pgbench -i -s 100`	*1.5 GB*
`pgbench -T 2000 -C "host=server sslmode=require"`	*36.1 tps*
`pgbench -T 2000 -C "host=server sslmode=disable"`	*56.4 tps*
`pgbench -T 2000 "host=server sslmode=disable"`	*105.4 tps*

- connection AAA — **8.2 ms**
- SSL negociation — **10.0 ms**
- transfers and transactions — **9.5 ms**

Performance Comparisons

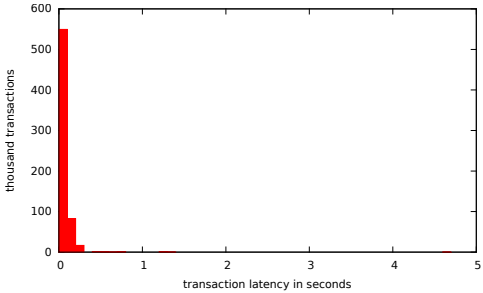
Latency Pitfalls

Latency Comparison – 9.5 vs 9.6

`pgbench -j 4 -c 8`

Version 9.5.5

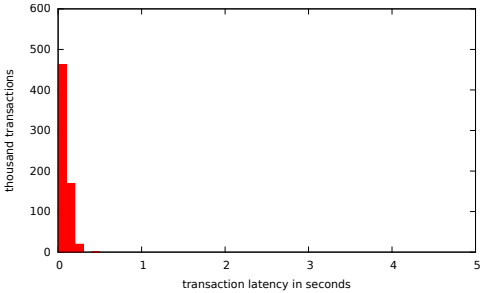
- throughput 329.4 tps
- average latency 24.3 ms



- latency std. dev. 79.5 ms

Version 9.6.1

- throughput 326.4 tps
- average latency 24.4 ms

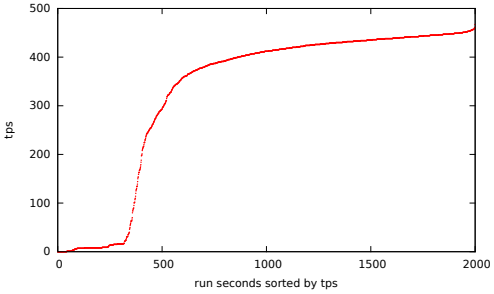


- latency std. dev. 20.3 ms

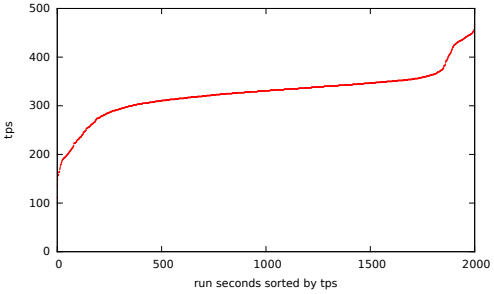
Latency Comparison – 9.5 vs 9.6

Instant TPS

Version 9.5.5



Version 9.6.1



What is happening?

Buy Now, Pay Later!

- transaction surges are absorbed — *in-memory + WAL*
- then data are written disk — *checkpoint*

Postgres 9.5 Checkpoint

- data writes spread over some time — *random I/O*
- OS choose when to actually write — *30s delay on Linux*
- until `fsync` is called... — ***I/O storm – on low-end HDD***

Postgres 9.6 Checkpoint

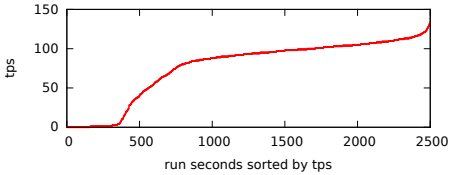
- **sorted** data writes spread over some time — *sequential I/O*
- **flush** instructions sent regularly (256 kB) — *checkpoint_flush_after*
- when `fsync` is called — *ok!*

Performance Comparisons

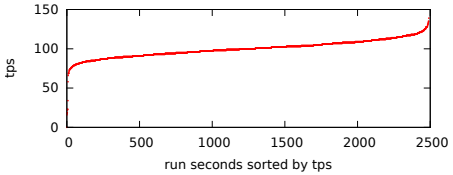
Benchmarking with Rate and Limit

Rate (tps) and Limit (ms) `pgbench -R 100 -L 100 -N`

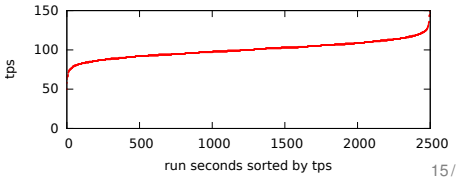
Pg 9.5	*basic checkpoint*
slow & skipped	*24.0%*
latency	*15.6 ± 158.3 ms*



Pg 9.6	*sorted checkpoint*
slow & skipped	*2.7%*
latency	*3.6 ± 24.6 ms*



Pg 9.6	*sorted & flushed checkpoint*
slow & skipped	*0.5%*
latency	*2.6 ± 13.8 ms*



Performance Comparisons

Three Storage Options

FILLFACTOR Storage Parameter

```
CREATE TABLE pgbench_accounts(...) WITH (FILLFACTOR = 100);
```

FILLFACTOR Usage

- MVCC: UPDATE = DELETE + INSERT — *up to 3 pages changes*
- some free space available in page — *1 inside page change*
- **but** more pages/costs for other operations — *trade-off*

FILLFACTOR = 100

- throughput — *406.9 tps*
- latency — *19.7 ± 12.3 ms*

FILLFACTOR = 95

- throughput — *416.8 tps*
- latency — *19.2 ± 8.3 ms*

Hard Disk Drive

- mechanics
- fast sequential I/O
- **slow** random I/O

vs

Solid State Disk

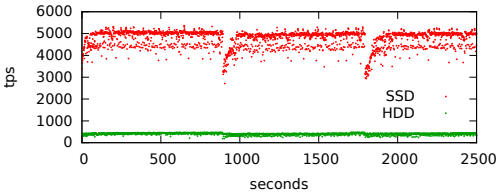
- electronics
- fast sequential I/O
- **fast** random I/O

```
pgbench -j 4 -c 8 -T 2500 -M prepared ...
```

Postgres 9.6

HDD	406.9 tps	*19.7 ± 12.3 ms*
SSD	4,764.9 tps	*1.7 ± 2.4 ms*

checkpoint full page write effect



UNLOGGED TABLE

Can you loose your data?

```
CREATE UNLOGGED TABLE pgbench_accounts(...);
```

Standard	*ACID*
throughput	*406.9 tps*
latency	*19.7 ± 12.3 ms*

UNLOGGED	*good luck!*
throughput	*5,310.7 tps*
latency	*1.5 ± 0.3 ms*

NO!

Performance Comparisons

Two Protocol Impacts

Read-Only In-Cache Test

ro3.sql

```
\set aid random(1, 100000 * :scale)
\set tid random(1, 10 * :scale)
\set bid random(1, :scale)
BEGIN;
SELECT abalance FROM pgbench_accounts WHERE aid=:aid;
SELECT tbalance FROM pgbench_tellers WHERE tid=:tid;
SELECT bbalance FROM pgbench_branches WHERE bid=:bid;
COMMIT;
```

Operations	*Queries on 3 tables*
1 transfers	*network protocol*
2 parse query	*syntax analysis*
3 plan query	*optimization*
4 execute query	*cheap if in cache*

Protocol

SSL or not

SSL Costs — *time & €*

- negotiation and re-negotiation
- cryptographic functions
- certificate?

Benefits — *Snake Oil!*

- Confidentiality
- Integrity
- Authentication

```
pgbench -j 1 -c 1 -D scale=100 -f ro3.sql -T 30 "host=server ..."
```

`sslmode=require` — *SSL*

- throughput — *709.7 tps*
- latency — *1.407 ± 0.132 ms*

`sslmode=disable` — *clear*

- throughput — *781.6 tps*
- latency — *1.277 ± 0.034 ms*

Protocol

Simple vs Prepared

```
-- prepare once in session
PREPARE Abal(INT) AS
  SELECT abalance
  FROM pgbench_accounts
  WHERE aid=$1;
-- execute multiple times...
EXECUTE Abal(1);
EXECUTE Abal(5432);
EXECUTE Abal(18);
```

Prepare

- temporary one-cmd function
- factor out *parse* cost
- keep *plan* and *execute*
- `pgbench -M prepared ...`

`ro3.sql` *simple*

- throughput *709.7 tps*
- latency *1.407 ± 0.132 ms*

`ro3.sql` *prepared*

- throughput *860.0 tps*
- latency *1.161 ± 0.082 ms*

Performance Comparisons

Four Query Combination Tricks

Query Combination

UPDATE & SELECT

```
-- update table
UPDATE pgbench_accounts
  SET abalance = abalance + :delta
  WHERE aid = :aid;

-- get updated data
SELECT abalance
  FROM pgbench_accounts
  WHERE aid = :aid;
```

```
-- combined
UPDATE pgbench_accounts
  SET abalance = abalance + :delta
  WHERE aid = :aid
  RETURNING abalance;
```

UPDATE RETURNING Option

- return updated rows
- one parse, plan, execute

Standard

- throughput *406.9 tps*
- latency *19.7 ± 12.3 ms*

Combined Update

- throughput *408.2 tps*
- latency *19.6 ± 8.7 ms*

Client-combined SQL Queries

```
-- "ro3c.sql" pgbench script
\set aid random(1, 100000 * :scale)
\set tid random(1, 10 * :scale)
\set bid random(1, :scale)
BEGIN \;
SELECT abalance FROM
 pgbench_accounts WHERE aid=:aid \;
SELECT tbalance FROM
 pgbench_tellers WHERE tid=:tid \;
SELECT bbalance FROM
 pgbench_branches WHERE bid=:bid \;
COMMIT;
```

Combine *with \;*

- embedded semi-colon ;
- request with multiple queries
- response with list of results
- avoid request-response loop

ro3.sql *standard*

- throughput *709.7 tps*
- latency *1.407 ± 0.132 ms*

ro3c.sql *combined*

- throughput *1,311.5 tps*
- latency *0.748 ± 0.132 ms*

Server-Side SQL queries

```
CREATE TYPE Balances
  AS (abal INT, tbal INT, bbal INT);

CREATE FUNCTION getBalSQL(INT, INT, INT)
  RETURNS Balances AS $$
  SELECT
    (SELECT abalance
     FROM pgbench_accounts WHERE aid=$1),
    (SELECT tbalance
     FROM pgbench_tellers WHERE tid=$2),
    (SELECT bbalance
     FROM pgbench_branches WHERE bid=$3)
$$ LANGUAGE SQL;
```

```
-- "ro3sf.sql" pgbench script
\set aid random(1, 100000 * :scale)
\set tid random(1, 10 * :scale)
\set bid random(1, :scale)
SELECT getBalSQL(:aid, :tid, :bid);
```

ro3.sql	*standard*
throughput	*709.7 tps*
latency	*1.407 ± 0.132 ms*

ro3sf.sql	*SQL call*
throughput	*1,395.4 tps*
latency	*0.712 ± 0.075 ms*

Server-Side PL/pgSQL queries

```
CREATE FUNCTION
    getBalPL(a INT, t INT, b INT)
  RETURNS Balances AS $$
  DECLARE
    abal INT; tbal INT; bbal INT;
  BEGIN
    SELECT abalance INTO abal
      FROM pgbench_accounts WHERE aid=a;
    SELECT tbalance INTO tbal
      FROM pgbench_tellers WHERE tid=t;
    SELECT bbalance INTO bbal
      FROM pgbench_branches WHERE bid=b;
    RETURN (abal, tbal, bbal)::Balances;
  END;
$$ LANGUAGE PLpgSQL;
```

```
-- "ro3pf.sql" pgbench script
\set aid random(1, 100000 * :scale)
\set tid random(1, 10 * :scale)
\set bid random(1, :scale)
SELECT getBalPL(:aid, :tid, :bid);
```

PL/pgSQL caches plans!

ro3.sql	*standard*
throughput	*709.7 tps*
latency	*1.407 ± 0.132 ms*

ro3pf.sql	*PL/pgSQL call*
throughput	*2,485.5 tps*
latency	*0.400 ± 0.055 ms*

Performance Comparisons

Reducting Server Distance

Client-Server Distance

Interconnection

LAN	Local Area Network	*Ethernet*
LO	loopback interface	`localhost`
IPC	Inter-Process Communication	*Unix domain socket*

TPC-B-Like		*on SSD*
LAN	*403.8 tps*	*2.4 ms*
LO	*1,133.3 tps*	*0.9 ms*
IPC	*1,243.1 tps*	*0.8 ms*

Read-Only 3		
LAN	*709.7 tps*	*1.4 ms*
LO	*2,515.3 tps*	*0.4 ms*
IPC	*3,607.6 tps*	*0.3 ms*

Performance Comparisons

Performance Scalability

Read-Only 3 – remote SSL simple queries

Best Throughput

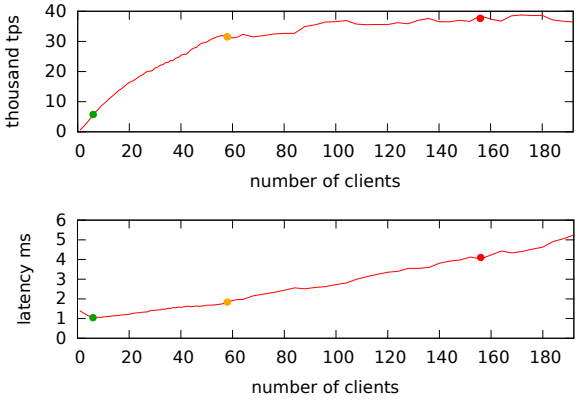
37,639 tps 4.103 ms *156/4*

Best Latency

5,748 tps **1.042 ms** *6/1*

Compromise

31,494 tps 1.837 ms *58/4*



Read-Only 3 – remote noSSL prepared PL call

Best Throughput

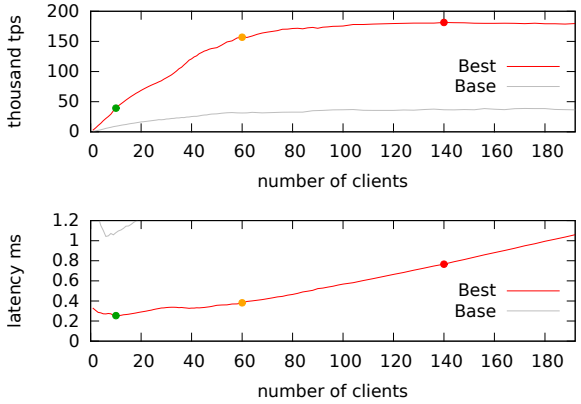
181,503 tps 0.766 ms *140/4*

Best Latency

39,232 tps **0.254 ms** *10/2*

Compromise

156,945 tps 0.381 ms *60/4*



Performance Comparisons

Miscellaneous Settings

Application *framework?*

connection persistence

cache Memcached Redis

Postgres configuration *change defaults*

disk *block_size random_page_cost*

memory *shared_buffers effective_cache_size huge_pages*

checkpoint *_timeout _completion_target _flush_after*

wal *max_wal_size*

Miscellaneous Settings

OS & Hardware

OS

tweak and choose

FS **XFS** ext4 ~~Btrfs~~ ~~ZFS~~, `mount` options

IO io scheduler, queue length, write delay, dirty bytes...

others NUMA, ...

Hardware

expensive is (probably) better

diskS tables wal logs, HDD-with-cache, SSD

tweaking read ahead, write flush

RAID with large caches, BBU

Conclusion

Wrap-up

`pgbench -j 1 -c 1 ...`

	TPC-B-like		*Read-Only 3*	
	tps	*ms*	*tps*	*ms*
HDD -C SSL	36.1	27.7	52.7	18.96
HDD -C noSSL	56.4	17.7	110.1	9.08
HDD SSL	105.4	9.5	709.7	1.41
SSD SSL	403.8	2.47	695.1	1.44
SSD noSSL	465.4	2.15	820.1	1.22
... + prepared	548.1	1.82	974.0	1.02
– returning	529.4	1.89	–	–
... + prepared	681.2	1.47	–	–
– combined	857.8	1.15	1,536.4	0.64
– SQL func	940.3	1.06	1,818.1	0.55
... + prepared	957.9	1.04	2,144.7	0.46
– PL func	1,279.4	0.78	2,778.0	0.36
... + prepared	1,323.2	0.75	3,040.4	0.33
localhost	1,907.6	0.52	10,006.8	0.10
socket	2,273.1	0.44	11,545.5	0.09

- connection
- HDD to SSD
- SSL to none
- simple to prepared
- combinations...
- remote to local

$\times$ **63 to** $\times$ **219**

- *and scaling effects*

Lessons

Things to Bring Home		*in-memory OLTP load*
NoTPS	not only TPS latency-throughput compromise	*latency matters!*
Performance	experiment and measure `pgbench` is improving...	*do not assume!*
Postgres	version sorted and flushed checkpoints	*9.6!*
High	costs	*network, parse & plan*
RW load	ACID	$SSD \gg HDD$
RO load	pg as a cache manager	$SSD = HDD$

Contributions

provided or provoked

About Core

& Andres Freund

- sorted checkpoints
- flushed checkpoints

About `pgbench`

& Robert Haas

- expressions — `\set ...`
- mixed and weighted scripts and builtins — `-b/-f ...@...`
- better statistics — *stddev, per script...*
- improved usability — `-c/-j -P...`
- rate and limit load — `-R -L`
- debug...

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pgDay Paris – March 23, 2017