PostgreSQL is an open-source, full-featured relational database. This presentation gives an overview of PostgreSQL performance tuning.

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Last updated: August, 2019
Outline

1. Caching
2. Internals
3. Storage
Caching

https://www.flickr.com/photos/storm-crypt/
Caches

- Disk Drive
- Kernel Cache
- CPU Cache
- CPU Registers
# Cache Sizes

<table>
<thead>
<tr>
<th>Storage Area</th>
<th>Measured in</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU registers</td>
<td>bytes</td>
</tr>
<tr>
<td>CPU cache</td>
<td>megabytes</td>
</tr>
<tr>
<td>RAM</td>
<td>gigabytes</td>
</tr>
<tr>
<td>disk drives</td>
<td>terabytes</td>
</tr>
</tbody>
</table>
Checkpoints and WAL Files

Query and Checkpoint Operations

Transaction Durability

PostgreSQL Shared Buffer Cache

Write-Ahead Log

Kernel Disk Buffer Cache

Disk Blocks

Postgres Backend

Postgres Backend

Postgres Backend

Recovery

fsync

fsync
Buffer / Disk Interaction

PostgreSQL Shared Buffer Cache

Write-Ahead Log

Begin 1

End 1

Rotate
<table>
<thead>
<tr>
<th>RAM</th>
<th>Postgres Session (work_mem)</th>
<th>Postgres Session (work_mem)</th>
<th>Postgres Session (work_mem)</th>
<th>Shared Buffer Cache (shared_buffers)</th>
<th>Kernel Disk Buffer Cache</th>
<th>Free</th>
<th>Kernel</th>
</tr>
</thead>
</table>

- **Kernel Disk Buffer Cache**
- **Free**
- **Kernel**

**Memory Usage**

- **Page In (bad)**
- **Page Out**

- **Swap**
Postgresql.conf Cache Parameters

shared_buffers = 32MB
#temp_buffers = 8MB
#work_mem = 1MB
#maintenance_work_mem = 16MB
#effective_cache_size = 128MB

Kernel changes often required.
SQL Query

```
SELECT firstname
FROM friend
WHERE age = 33;
```
test=> \textbf{SELECT} firstname

\texttt{test-> FROM friend}

\texttt{test-> WHERE age = 33;}

\begin{verbatim}
  firstname
\end{verbatim}

\begin{verbatim}
  Sandy
\end{verbatim}

\texttt{(1 row)}
test=> SELECT firstname
     test-> FROM friend
     test-> WHERE age = 33;

[ query is processed ]

firstname
-------------------
Sandy
(1 row)
Query in Libpq

test=> SELECT firstname
    test-> FROM friend
    test-> WHERE age = 33;

Breakpoint 1, PQexec (conn=0x807a000,
    query=0x8081200 "SELECT firstname
FROM friend
WHERE age = 33"
    at fe-exec.c:1195
Libpq

User Terminal

Application Code

Libpq

Queries

Results

PostgreSQL Database Server
TCP/IP Packet

ack 61 win 8760 <nop,nop,timestamp 137847 7276138> (DF)

0000: 00 d0 b7 b9 b6 c8 00 02   b3 04 09 dd 08 00 45 00  ________ ______E_
0010: 00 62 45 31 40 00 40 06 b1 fe ac 14 00 02 a2 21 _bE1@_ ________!
0020: f5 2e c0 0d 15 38 1c af 94 34 a8 1a 1e 39 80 18 _._8__ _4__9__
0030: 22 38 19 d5 00 00 01 01 08 0a 00 02 1a 77 00 6f "8_____ _____w_o
0040: 06 6a 51 53 45 4c 45 43 54 06 6a 51 53 45 4c 45 43 54 20 66 69 72 73 74 6e _jQSELEC T firstn
0050: 61 6d 65 0a 46 52 4f 4d 20 66 72 69 65 6e 64 0a ame_FROM  friend_   
0060: 57 48 45 52 45 20 61 67 65 20 3d 20 33 33 3b 00 WHERE ag e = 33_;
FindExec: found "/var/local/postgres/.bin/postgres" using argv

DEBUG: connection: host=[local] user=postgres database=test
DEBUG: InitPostgres
DEBUG: StartTransactionCommand
DEBUG: query: SELECT firstname
   FROM friend
   WHERE age = 33;

[ query is processed ]

DEBUG: ProcessQuery
DEBUG: CommitTransactionCommand
DEBUG: proc_exit(0)
DEBUG: shmem_exit(0)
DEBUG: exit(0)
Query Processing

FindExec: found "/var/local/postgres/.bin/postmaster" using argv[0]

FindExec: found "./var/local/postgres/.bin/postmaster" using argv[0]

DEBUG: connection: host=[local] user=postgres database=test
DEBUG: InitPostgres
DEBUG: StartTransactionCommand
DEBUG: query: SELECT firstname FROM friend
WHERE age = 33;
DEBUG: parse tree: { QUERY :command 1 :utility <> :resultRelation 0 :into <> :isPortal false :isBinary false :isTemp false :hasSubLinks false :rtable (( RTE :relname friend :relid 26912 :subquery <> :alias <> :eref ( ATTR :relname friend :attrs ( "firstname" "city" "state" "age" )) ) ) ) :inh true :inFromCl true :checkForRead true :checkForWrite false :checkAsUser () )

DEBUG: rewritten parse tree:

DEBUG: ProcessQuery
DEBUG: CommitTransactionCommand
DEBUG: shmem_exit(0)
DEBUG: exit(0)

./bin/postmaster: CleanupProc: pid 3320 exited with status 0
Backend Flowchart

Main

Postmaster

Postgres

Libpq

Parse Statement

Traffic Cop

Utility Command

Utility

Command

Storage Managers

Catalog

Utilities

Access Methods

Nodes / Lists

e.g. CREATE TABLE, COPY

Query

SELECT, INSERT, UPDATE, DELETE

Generate Paths

Optimal Path

Generate Plan

Execute Plan
Backend Flowchart - Magnified

1. Parse Statement
2. Traffic Cop
3. Rewrite Query
4. Generate Paths
5. Optimal Path
6. Generate Plan
7. Execute Plan
8. Utility
9. Utility Command
10. Query [SELECT, INSERT, UPDATE, DELETE]
11. e.g. CREATE TABLE, COPY

Flowchart:
- Parse Statement -> Traffic Cop
- Traffic Cop -> Rewrite Query
- Rewrite Query -> Generate Paths
- Generate Paths -> Optimal Path
- Optimal Path -> Generate Plan
- Generate Plan -> Execute Plan
- Utility Command
- Query [SELECT, INSERT, UPDATE, DELETE]
- Utility
Statistics - Part 1

PARSER STATISTICS
system usage stats:
  0.000002 elapsed 0.000000 user 0.000001 system sec
  [0.009999 user 0.049961 sys total]
  0/0 [0/1] filesystem blocks in/out
  0/0 [0/0] page faults/reclaims, 0 [0] swaps
  0 [0] signals rcvd, 0/0 [2/2] messages rcvd/sent
  0/0 [2/6] voluntary/involuntary context switches

postgres usage stats:
  Shared blocks: 0 read, 0 written, buffer hit rate = 0.00%
  Local blocks: 0 read, 0 written, buffer hit rate = 0.00%
  Direct blocks: 0 read, 0 written

PARSE ANALYSIS STATISTICS
system usage stats:
  0.000002 elapsed 0.000001 user 0.000002 system sec
  [0.009993 user 0.049965 sys total]
  0/0 [0/1] filesystem blocks in/out
  0/0 [0/0] page faults/reclaims, 0 [0] swaps
  0 [0] signals rcvd, 0/0 [2/2] messages rcvd/sent
  0/0 [2/6] voluntary/involuntary context switches

postgres usage stats:
  Shared blocks: 1 read, 0 written, buffer hit rate = 96.88%
  Local blocks: 0 read, 0 written, buffer hit rate = 0.00%
  Direct blocks: 0 read, 0 written
Statistics - Part 2

REWRITER STATISTICS

system usage stats:
0.000002 elapsed 0.000000 user 0.000002 system sec
[0.009993 user 0.049968 sys total]
0/0 [0/1] filesystem blocks in/out
0/0 [0/0] page faults/reclaims, 0 [0] swaps
0 [0] signals rcvd, 0/0 [2/2] messages rcvd/sent
0/0 [2/6] voluntary/involuntary context switches

postgres usage stats:
Shared blocks: 0 read, 0 written, buffer hit rate = 0.00%
Local blocks: 0 read, 0 written, buffer hit rate = 0.00%
Direct blocks: 0 read, 0 written

PLANNER STATISTICS

system usage stats:
0.009974 elapsed 0.009988 user -1.999985 system sec
[0.019982 user 0.049955 sys total]
0/0 [0/1] filesystem blocks in/out
0/0 [0/0] page faults/reclaims, 0 [0] swaps
0 [0] signals rcvd, 0/0 [2/2] messages rcvd/sent
0/0 [2/6] voluntary/involuntary context switches

postgres usage stats:
Shared blocks: 5 read, 0 written, buffer hit rate = 96.69%
Local blocks: 0 read, 0 written, buffer hit rate = 0.00%
Direct blocks: 0 read, 0 written

EXECUTOR STATISTICS

system usage stats:
0.040004 elapsed 0.039982 user 0.000013 system sec
[0.059964 user 0.049970 sys total]
0/0 [0/1] filesystem blocks in/out
0/0 [0/0] page faults/reclaims, 0 [0] swaps
0 [0] signals rcvd, 0/2 [2/4] messages rcvd/sent
2/2 [4/8] voluntary/involuntary context switches

postgres usage stats:
Shared blocks: 2 read, 0 written, buffer hit rate = 83.33%
Local blocks: 0 read, 0 written, buffer hit rate = 0.00%
Direct blocks: 0 read, 0 written
Optimizer

- Scan Methods
- Join Methods
- Join Order
Scan Methods

- Sequential Scan
- Index Scan
- Bitmap Scan
Sequential Scan

Heap

```
D A
D A
D A
D A
D A
D A
D A
D A
D A
D A
D A
D A
D A
D A
D A
```

8K
Btree Index Scan

Index

< Key = >

Heap

DATA DATA DATA DATA DATA DATA DATA DATA DATA
Bitmap Scan

Index 1  Index 2  Combined
col1 = 'A'  col2 = 'NS'  Index

|   0   |   0   |   0   |
|   1   |   1   |   1   |
|   0   |   1   |   0   |
|   1   |   0   |   0   |

&  =  

Table

'A' AND 'NS'
Join Methods

- Nested Loop
  - With Inner Sequential Scan
  - With Inner Index Scan
- Hash Join
- Merge Join
Nested Loop Join with Inner Sequential Scan

No Setup Required

Used For Small Tables
Nested Loop Join with Inner Index Scan

No Setup Required

Index Must Already Exist
Hash Join

Outer

aay
aag
aak
aar

Inner

aak
aas
aam
aay
aar
aao
aaw

Hashed

Must fit in Main Memory
Merge Join

Ideal for Large Tables
An Index Can Be Used to Eliminate the Sort
Three-Table Join Query

```sql
SELECT part.price 
FROM customer, salesorder, part 
WHERE customer.customer_id = salesorder.customer_id AND salesorder.part = part.part_id
```
Three-Table Join, Pass 1, Part 1

(2 3): rows=575 width=76

path list:
HashJoin rows=575 cost=3.57..41.90
clauses=(salesorder.part_id = part.part_id)
  SeqScan(2) rows=575 cost=0.00..13.75
  SeqScan(3) rows=126 cost=0.00..3.26
Nestloop rows=575 cost=0.00..1178.70
  SeqScan(2) rows=575 cost=0.00..13.75
  IdxScan(3) rows=126 cost=0.00..2.01
Nestloop rows=575 cost=0.00..1210.28
  pathkeys=((salesorder.customer_id, customer.customer_id) )
    IdxScan(2) rows=575 cost=0.00..45.33
      pathkeys=((salesorder.customer_id, customer.customer_id) )
    IdxScan(3) rows=126 cost=0.00..2.01

cheapest startup path:
Nestloop rows=575 cost=0.00..1178.70
  SeqScan(2) rows=575 cost=0.00..13.75
  IdxScan(3) rows=126 cost=0.00..2.01

cheapest total path:
HashJoin rows=575 cost=3.57..41.90
clauses=(salesorder.part_id = part.part_id)
  SeqScan(2) rows=575 cost=0.00..13.75
  SeqScan(3) rows=126 cost=0.00..3.26
Three-Table Join, Pass 1, Part 2

(1 2 ): rows=575 width=76
path list:
HashJoin  rows=575 cost=3.00..40.75
clauses=(salesorder.customer_id = customer.customer_id)
  SeqScan(2) rows=575 cost=0.00..13.75
  SeqScan(1) rows=80 cost=0.00..2.80
MergeJoin  rows=575 cost=0.00..64.39
clauses=(salesorder.customer_id = customer.customer_id)
  IdxScan(1) rows=80 cost=0.00..10.88
    pathkeys=((salesorder.customer_id, customer.customer_id) )
  IdxScan(2) rows=575 cost=0.00..45.33
    pathkeys=((salesorder.customer_id, customer.customer_id) )

cheapest startup path:
MergeJoin  rows=575 cost=0.00..64.39
clauses=(salesorder.customer_id = customer.customer_id)
  IdxScan(1) rows=80 cost=0.00..10.88
    pathkeys=((salesorder.customer_id, customer.customer_id) )
  IdxScan(2) rows=575 cost=0.00..45.33
    pathkeys=((salesorder.customer_id, customer.customer_id) )

cheapest total path:
HashJoin  rows=575 cost=3.00..40.75
clauses=(salesorder.customer_id = customer.customer_id)
  SeqScan(2) rows=575 cost=0.00..13.75
  SeqScan(1) rows=80 cost=0.00..2.80
Three-Table Join, Pass 2, Part 1

(2 3 1): rows=575 width=112
path list:
  HashJoin rows=575 cost=6.58..68.90
    clauses=(salesorder.customer_id = customer.customer_id)
  HashJoin rows=575 cost=3.57..41.90
    clauses=(salesorder.part_id = part.part_id)
      SeqScan(2) rows=575 cost=0.00..13.75
      SeqScan(3) rows=126 cost=0.00..3.26
  SeqScan(1) rows=80 cost=0.00..2.80
  HashJoin rows=575 cost=3.57..92.54
    clauses=(salesorder.part_id = part.part_id)
      MergeJoin rows=575 cost=0.00..64.39
        clauses=(salesorder.customer_id = customer.customer_id)
          IdxScan(1) rows=80 cost=0.00..10.88
            pathkeys=((salesorder.customer_id, customer.customer_id) )
          IdxScan(2) rows=575 cost=0.00..45.33
            pathkeys=((salesorder.customer_id, customer.customer_id) )
      SeqScan(3) rows=126 cost=0.00..3.26
  HashJoin rows=575 cost=3.00..1205.70
    clauses=(salesorder.customer_id = customer.customer_id)
      Nestloop rows=575 cost=0.00..1178.70
        SeqScan(2) rows=575 cost=0.00..13.75
        IdxScan(3) rows=126 cost=0.00..2.01
      SeqScan(1) rows=80 cost=0.00..2.80
Three-Table Join, Pass 2, Part 2

MergeJoin $\text{rows}=575$  $\text{cost}=0.00..1229.35$
  clauses=$\text{(salesorder.customer_id} = \text{customer.customer_id})$

Nestloop $\text{rows}=575$  $\text{cost}=0.00..1210.28$
  pathkeys=$\text{((salesorder.customer_id, customer.customer_id))}$
    IdxScan (2)  $\text{rows}=575$  $\text{cost}=0.00..45.33$
      pathkeys=$\text{((salesorder.customer_id, customer.customer_id))}$
    IdxScan (3)  $\text{rows}=126$  $\text{cost}=0.00..2.01$
    IdxScan (1)  $\text{rows}=80$  $\text{cost}=0.00..10.88$
      pathkeys=$\text{((salesorder.customer_id, customer.customer_id))}$

cheapest startup path:
MergeJoin $\text{rows}=575$  $\text{cost}=0.00..1229.35$
  clauses=$\text{(salesorder.customer_id} = \text{customer.customer_id})$

Nestloop $\text{rows}=575$  $\text{cost}=0.00..1210.28$
  pathkeys=$\text{((salesorder.customer_id, customer.customer_id))}$
    IdxScan (2)  $\text{rows}=575$  $\text{cost}=0.00..45.33$
      pathkeys=$\text{((salesorder.customer_id, customer.customer_id))}$
    IdxScan (3)  $\text{rows}=126$  $\text{cost}=0.00..2.01$
    IdxScan (1)  $\text{rows}=80$  $\text{cost}=0.00..10.88$
      pathkeys=$\text{((salesorder.customer_id, customer.customer_id))}$

cheapest total path:
HashJoin $\text{rows}=575$  $\text{cost}=6.58..68.90$
  clauses=$\text{(salesorder.customer_id} = \text{customer.customer_id})$

HashJoin $\text{rows}=575$  $\text{cost}=3.57..41.90$
  clauses=$\text{(salesorder.part_id} = \text{part.part_id})$
    SeqScan (2)  $\text{rows}=575$  $\text{cost}=0.00..13.75$
    SeqScan (3)  $\text{rows}=126$  $\text{cost}=0.00..3.26$
    SeqScan (1)  $\text{rows}=80$  $\text{cost}=0.00..2.80$
Result Returned

test=>  SELECT  firstname
   test->  FROM  friend
   test->  WHERE  age = 33;

   1:  firstname  (typeid = 1042, len = -1, typmod = 19, byval =
              
   1:  firstname  =  "Sandy"  (typeid = 1042, len = -1, typmod = 19, byval =
              
   firstname
   ------------------
   Sandy
(1 row)
VACUUM ANALYZE

VACUUM ANALYZE VERBOSE customer;
INFO: vacuuming "pg_catalog.pg_depend"
INFO: index "pg_depend_depender_index" now contains 3616 row versions in 19 pages
DETAIL: 0 index pages have been deleted, 0 are currently reusable.
CPU 0.00s/0.00u sec elapsed 0.00 sec.
INFO: index "pg_depend_reference_index" now contains 3616 row versions in 23 pages
DETAIL: 0 index pages have been deleted, 0 are currently reusable.
CPU 0.00s/0.00u sec elapsed 0.00 sec.
INFO: "pg_depend": found 0 removable, 3616 nonremovable row versions in 25 pages
DETAIL: 0 dead row versions cannot be removed yet.
There were 9 unused item pointers.
0 pages are entirely empty.
CPU 0.00s/-1.99u sec elapsed 0.00 sec.
INFO: analyzing "pg_catalog.pg_depend"
INFO: "pg_depend": 25 pages, 3000 rows sampled, 3625 estimated total rows
<table>
<thead>
<tr>
<th>Attribute</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>starelid</td>
<td>16416</td>
</tr>
<tr>
<td>staattnum</td>
<td>4</td>
</tr>
<tr>
<td>stanullfrac</td>
<td>0</td>
</tr>
<tr>
<td>stawidth</td>
<td>22</td>
</tr>
<tr>
<td>stadistinct</td>
<td>-0.4244</td>
</tr>
<tr>
<td>stakind1</td>
<td>1</td>
</tr>
<tr>
<td>stakind2</td>
<td>2</td>
</tr>
<tr>
<td>stakind3</td>
<td>3</td>
</tr>
<tr>
<td>stakind4</td>
<td>0</td>
</tr>
<tr>
<td>staop1</td>
<td>98</td>
</tr>
<tr>
<td>staop2</td>
<td>664</td>
</tr>
<tr>
<td>staop3</td>
<td>664</td>
</tr>
<tr>
<td>staop4</td>
<td>0</td>
</tr>
<tr>
<td>stanumbers1</td>
<td>[0.146658, 0.027904, 0.0246593, 0.0233615, 0.0227125, 0.0227125, 0.0227125, 0.0149254, 0.0142764, 0.0123297]</td>
</tr>
<tr>
<td>stanumbers2</td>
<td></td>
</tr>
<tr>
<td>stanumbers3</td>
<td>{-0.145569}</td>
</tr>
<tr>
<td>stanumbers4</td>
<td></td>
</tr>
<tr>
<td>stavalues1</td>
<td>{I/O, equal,&quot;not equal&quot;, less-than, greater-than, greater-than-or-equal, less-than-or-equal, subtract, multiply, add}</td>
</tr>
<tr>
<td>stavalues2</td>
<td>{&quot;(Block, offset), physical location of tuple&quot;,&quot;absolute value&quot;,&quot;btree less-equal-greater&quot;,&quot;convert int2 to float4&quot;,&quot;deparse an encoded expression&quot;,&quot;format int8 to text&quot;,&quot;is opclass visible in search path?&quot;,&quot;matches LIKE expression&quot;,&quot;print type names of oidvector field&quot;,sine,&quot;~18 digit integer, 8-byte storage&quot;}</td>
</tr>
<tr>
<td>stavalues3</td>
<td></td>
</tr>
<tr>
<td>stavalues4</td>
<td></td>
</tr>
</tbody>
</table>
EXPLAIN

EXPLAIN SELECT name FROM customer;
NOTICE: QUERY PLAN:

Seq Scan on customer (cost=0.00..225.88 rows=12288 width=34)
EXPLAIN ANALYZE

```
EXPLAIN ANALYZE SELECT name FROM customer;
NOTICE: QUERY PLAN:

Seq Scan on customer (cost=0.00..225.88 rows=12288 width=34) (actual time=0.21..205.20 rows=12288 loops=1)
Total runtime: 249.10 msec
```
EXPLAIN INSERT INTO warehouse_tmp
(uri, expression, n, relevance, spid_measure, size, title, sample)
SELECT d.uri, dn.expression, n.n, dn.relevance, d.spid_measure,
   d.size, d.title, dn.sample
FROM document as d
   INNER JOIN (document_n_gram AS dn
                 INNER JOIN n_gram AS n
                     ON (dn.expression = n.expression))
       ON (d.uri = dn.uri)
ORDER BY dn.expression, n.n;
NOTICE: QUERY PLAN:
Subquery Scan *SELECT* (cost=3895109.07..3895109.07 rows=1009271 width=886)
  -> Sort (cost=3895109.07..3895109.07 rows=1009271 width=886)
     -> Hash Join (cost=1155071.81..2115045.12 rows=1009271 width=886)
        -> Merge Join (cost=1154294.92..1170599.85 rows=1009271 width=588)
           -> Sort (cost=1001390.67..1001390.67 rows=1009271 width=439)
              -> Seq Scan on document_n_gram dn
                 (cost=0.00..49251.71 rows=1009271 width=439)
           -> Sort (cost=152904.25..152904.25 rows=466345 width=149)
              -> Seq Scan on n_gram n (cost=0.00..12795.45 rows=466345 width=149)
              -> Hash (cost=767.71..767.71 rows=3671 width=298)
                 -> Seq Scan on document d (cost=0.00..767.71 rows=3671 width=298)
EXPLAIN SELECT cs.entity_id as region, r.name, cs.status, count(*)
FROM region r inner join
    (SELECT DISTINCT findregion(entity_id) AS entity_id, status
     FROM current_status
     ORDER BY 1
    ) AS cs on r.region_id = cs.entity_id
GROUP BY region, r.name, cs.status;

NOTICE: QUERY PLAN:
Aggregate (cost=13688.40..14338.40 rows=6500 width=24)
  -> Group (cost=13688.40..14175.90 rows=65000 width=24)
    -> Sort (cost=13688.40..13688.40 rows=65000 width=24)
      -> Merge Join (cost=7522.19..7674.94 rows=65000 width=24)
        -> Index Scan using region_pkey on region r
          (cost=0.00 59.00 rows=1000 width=16)
        -> Sort (cost=7522.19..7522.19 rows=6500 width=8)
          -> Subquery Scan cs (cost=6785.54..7110.54
            rows=65 width=8)
            -> Unique (cost=6785.54..7110.54 rows=6500
              width=8)
              -> Sort (cost=6785.54..6785.54 rows=650
                width=8)
                -> Seq Scan on current_status
                  (st=0.00..1065.00 rows=65000 width=8)
# - Planner Method Enabling -

#enable_hashagg = true
#enable_hashjoin = true
#enable_indexscan = true
#enable_mergejoin = true
#enable_nestloop = true
#enable_seqscan = true
#enable_sort = true
#enable_tidscan = true

# - Planner Cost Constants -

#effective_cache_size = 1000 # typically 8KB each
#random_page_cost = 4 # units are one sequential page fetch cost
#cpu_tuple_cost = 0.01 # (same)
#cpu_index_tuple_cost = 0.001 # (same)
#cpu_operator_cost = 0.0025 # (same)
# - Genetic Query Optimizer -

#geqo = true
#geqo_threshold = 11
#geqo_effort = 1
#geqo_generations = 0
#geqo_pool_size = 0
   # default based on tables in statement,
   # range 128-1024
#geqo_selection_bias = 2.0
   # range 1.5-2.0

# - Other Planner Options -

#default_statistics_target = 10
#from_collapse_limit = 8
#join_collapse_limit = 8
   # 1 disables collapsing of explicit JOINs
Storage

https://www.flickr.com/photos/mirandala/
File Structure

8K

Page
Page
Page
Page
Page
Index Page Structure

Internal

Leaf

Heap
Cluster
CREATE TABLE customer (id SERIAL, name TEXT);
NOTICE: CREATE TABLE will create implicit sequence 'customer_id_seq' for SERIAL column 'customer.id'
test=> CREATE INDEX customer_id_index ON customer (id);

CLUSTER customer USING customer_id_index;
Index Types
(Access Methods)

- Btree
- Hash
- Rtree
- GiST
- GIN
Tablespaces For Database I/O Balancing

DB1  DB2  DB3  DB4

Disk 1  Disk 2  Disk 3
Tablespaces For Table and Index I/O Balancing

Disk 1  
Disk 2  
Disk 3
Range partitioning is also possible.
Caches

- System Cache
- Relation Information Cache
- File Descriptor Cache
Shared Memory

- Proc structure
- Lock structure
- Buffer structure
- Free space map
Query Tips

- COPY vs. INSERT
- LIMIT vs. CURSOR
- TRUNCATE vs. DELETE
- Expression indexes
- Partial indexes
- Prepared queries
- INTERSECT vs. AND (selfjoin)
- UNION vs. OR
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