PostgreSQL Performance Tuning

Bruce Momjian

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

 http://momjian.us/presentations

Last updated: January, 2017

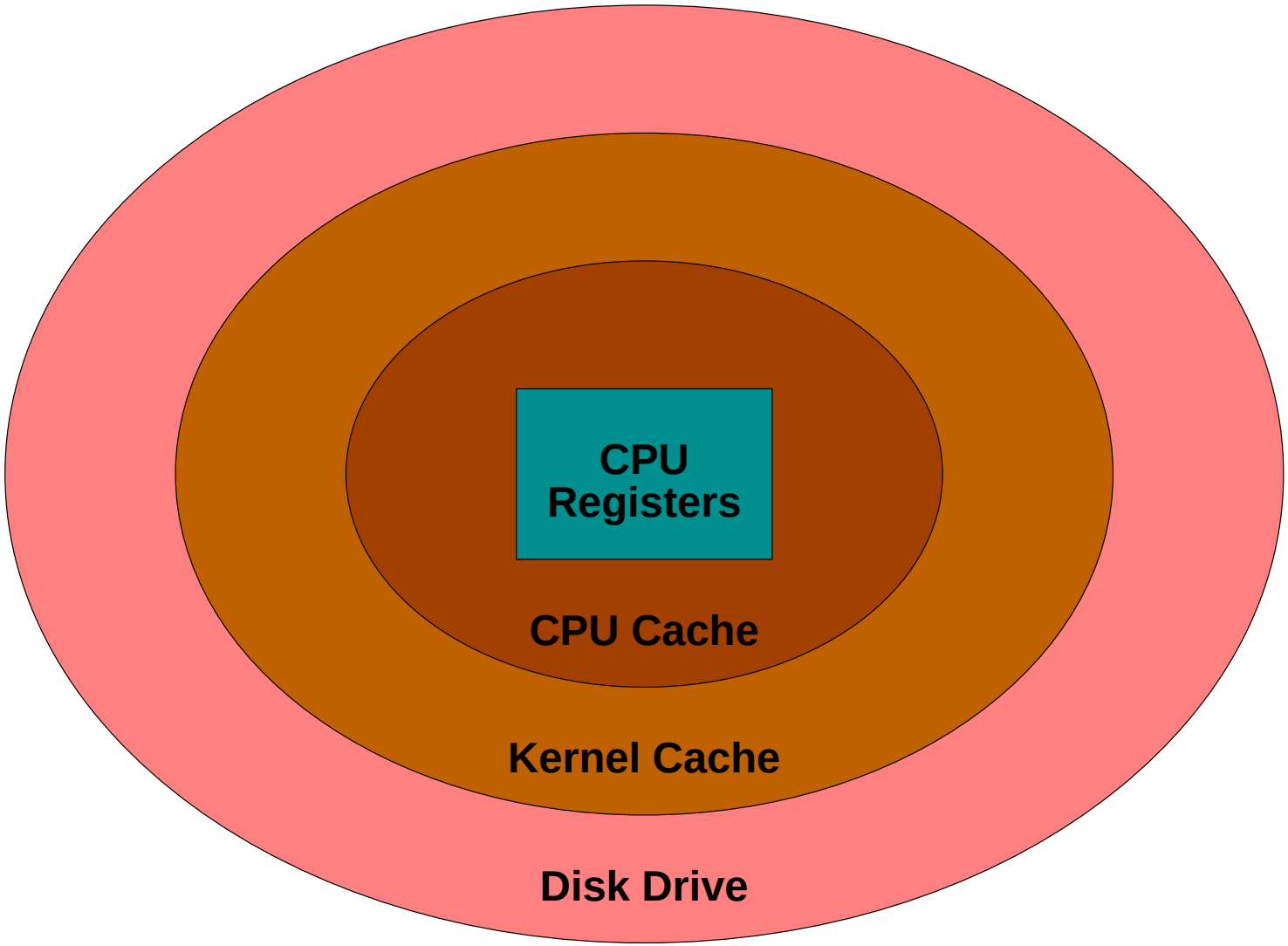
Outline

1. Caching
2. Internals
3. Storage

Caching

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

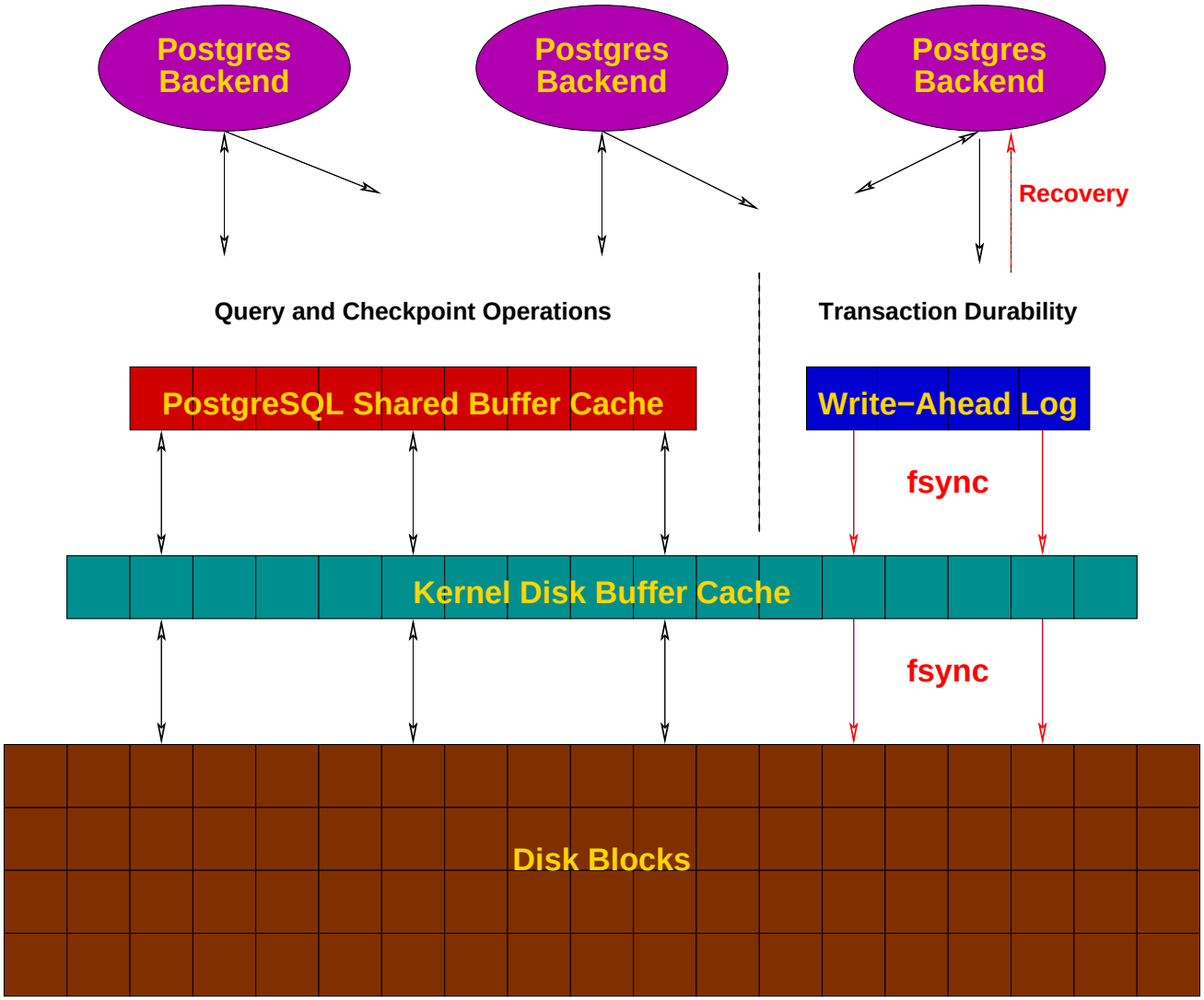
Caches



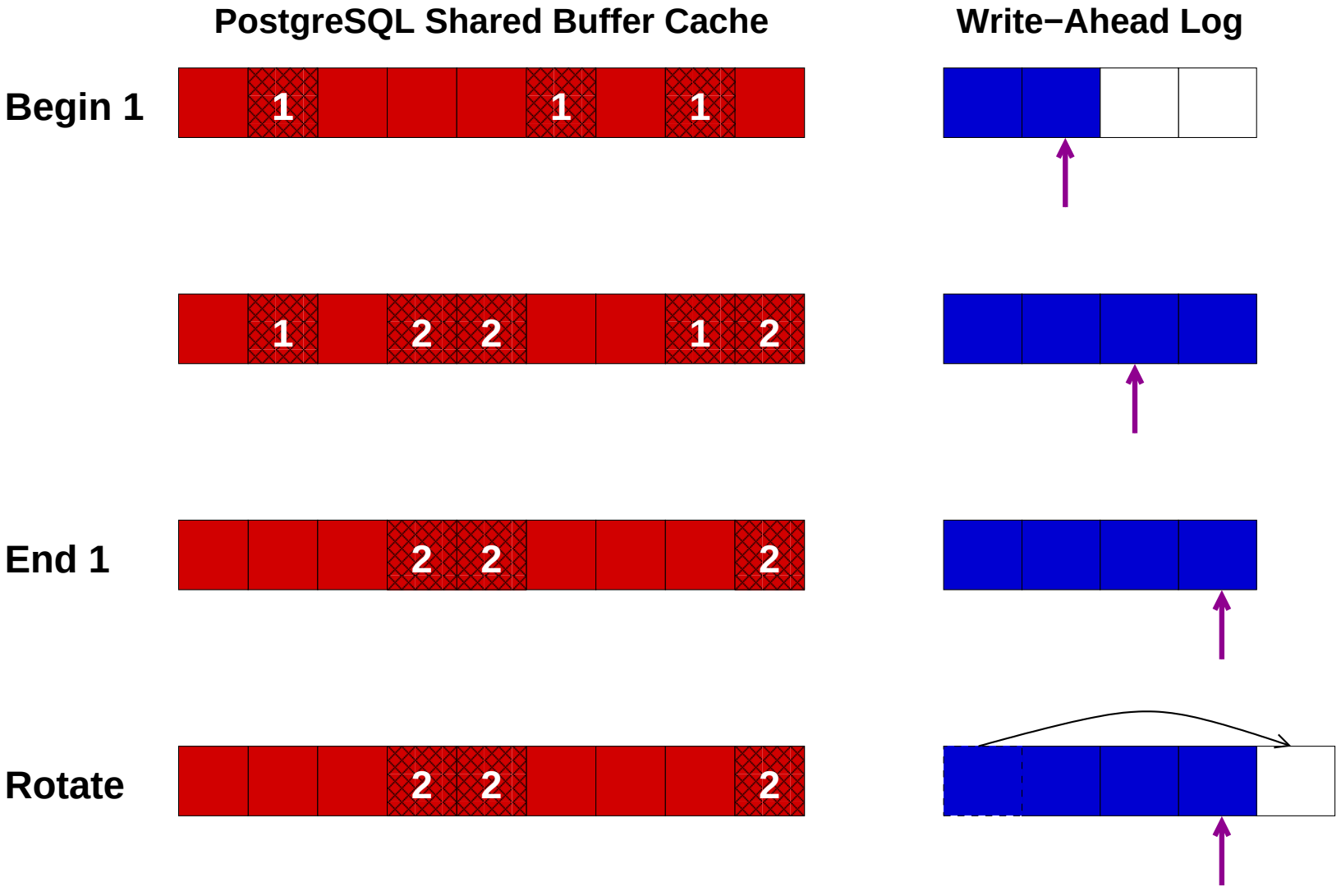
Cache Sizes

Storage Area	Measured in
CPU registers	bytes
CPU cache	megabytes
RAM	gigabytes
disk drives	terabytes

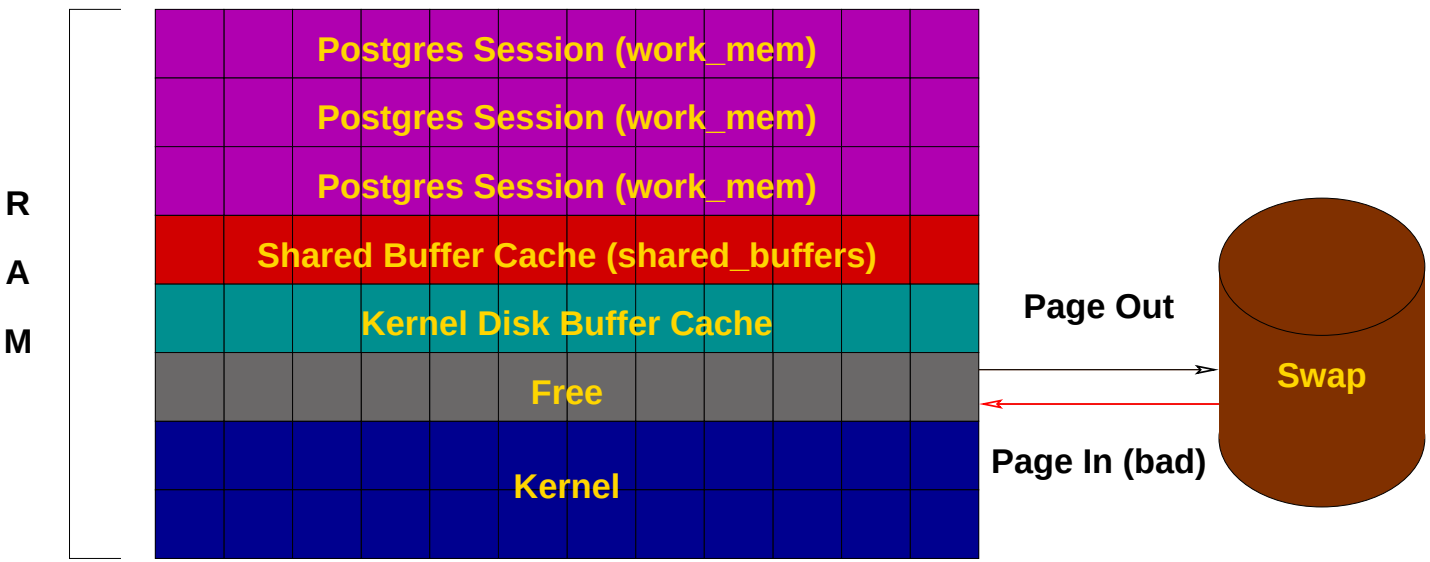
Checkpoints and WAL Files



Buffer / Disk Interaction



Memory Usage



Postgresql.conf Cache Parameters

```
shared_buffers = 32MB                   # min 128kB
                                        # (change requires restart)
#temp_buffers = 8MB                     # min 800kB

#work_mem = 1MB                         # min 64kB
#maintenance_work_mem = 16MB            # min 1MB

#effective_cache_size = 128MB
```

Kernel changes often required.

Internals

The Anatomy Lesson of Dr. Nicolaes Tulp, Rembrandt van Rijn

SQL Query

```
SELECT firstname
FROM friend
WHERE age = 33;
```

Query in Psql

```
test=> SELECT firstname
test-> FROM friend
test-> WHERE age = 33;
    firstname
------------------
 Sandy
(1 row)
```

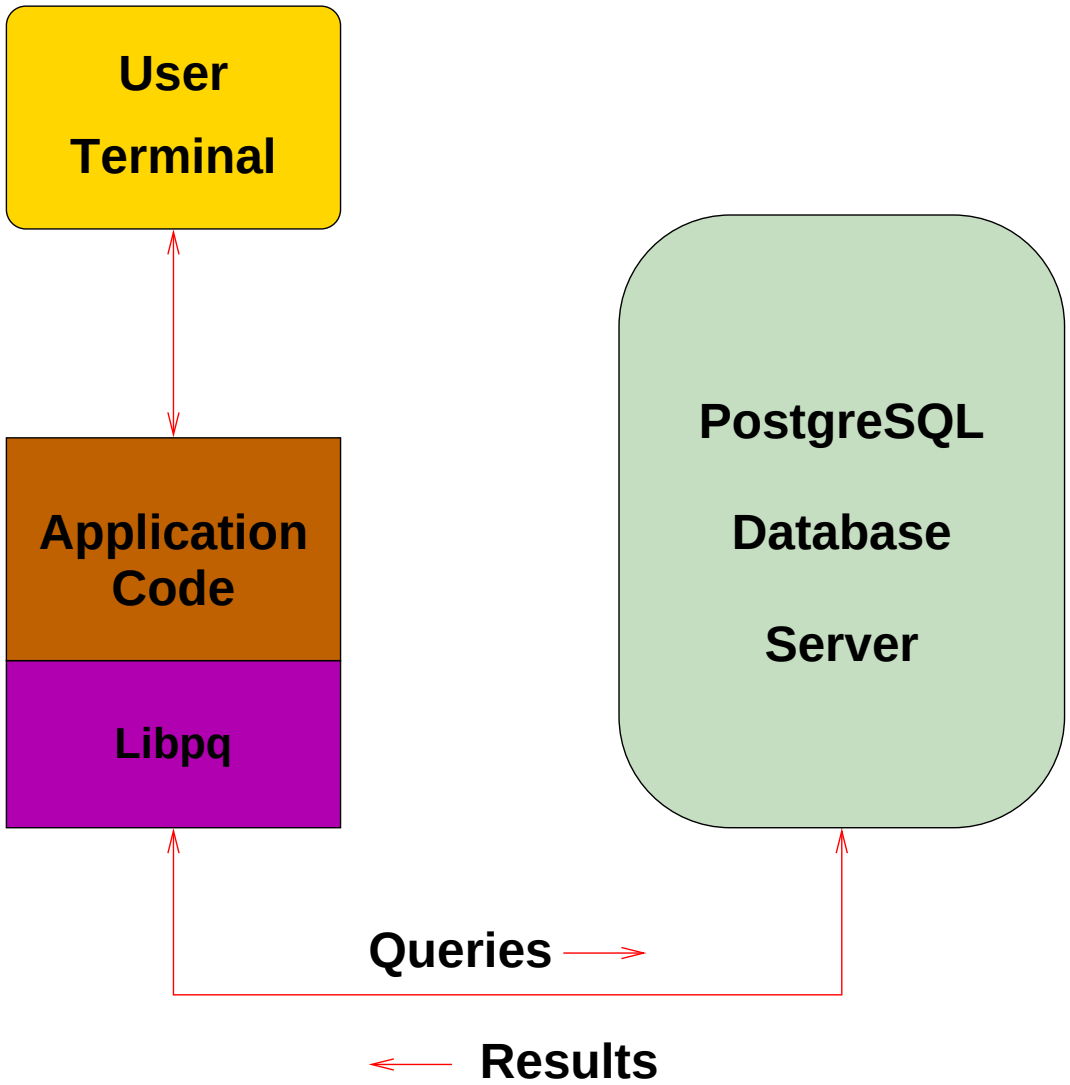
Query Processing

```
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\nFROM friend\nWHERE age = 33
    at fe-exec.c:1195
```

Libpq


User
Terminal
Application
Code
Libpq
PostgreSQL
Database
Server
Queries
Results

TCP/IP Packet

```
17:05:22.715714 family.home.49165 > candle.navpoint.com.5432: P 354:400(46)
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 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;_
```

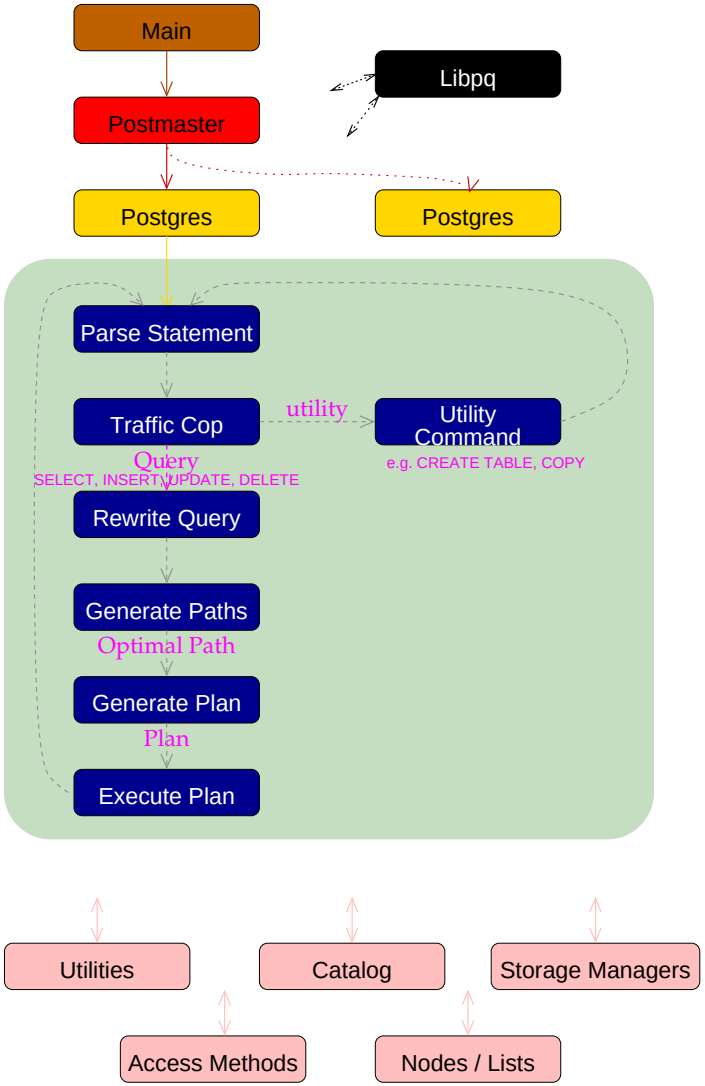
Query Sent
Result Received

```
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)
```

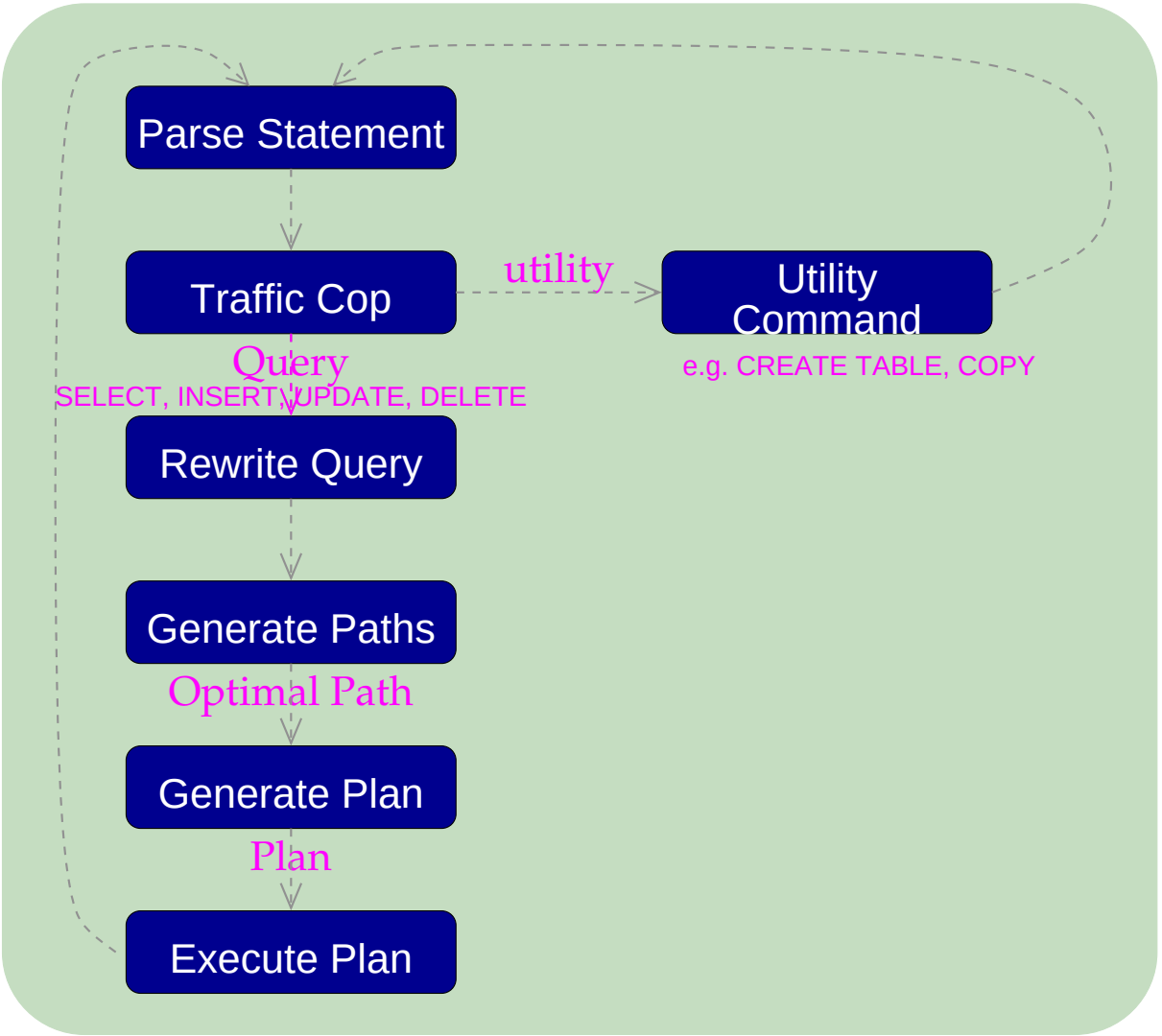
Query Processing

```
FindExec: found "/var/local/postgres/./bin/postmaster" using argv[0]
./bin/postmaster: BackendStartup: pid 3320 user postgres db test socket 5
./bin/postmaster child[3320]: starting with (postgres -d99 -F -d99 -v131072 -p test )
FindExec: found "/var/local/postgres/./bin/postgres" 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 :h
s false :hasSubLinks false :rtable ({ RTE :relname friend :relid 26912  :subquery <> :alias <> :eref { ATTR :relname friend :at
 "firstname"  "lastname"  "city"  "state"  "age" )} :inh true :inFromCl true :checkForRead true :checkForWrite false :check
r 0}) :jointree { FROMEXPR :fromlist ({ RANGETBLREF 1 }) :quals { EXPR :typeOid 16  :opType op :oper { OPER :opno 96 :opid 0 :o
lttype 16 } :args ({ VAR :varno 1 :varattno 5 :vartype 23 :vartypmod -1  :varlevelsup 0 :varnoold 1 :varoattno 5} { CONST :cons
 23 :constlen 4 :constbyval true :constisnull false :constvalue  4 [ 33 0 0 0 ] })}} :rowMarks () :targetList ({ TARGETENTRY :r
 { RESDOM :resno 1 :restype 1042 :restypmod 19 :resname firstname :reskey 0 :reskeyop 0 :ressortgroupref 0 :resjunk false } :ex
VAR :varno 1 :varattno 1 :vartype 1042 :vartypmod 19  :varlevelsup 0 :varnoold 1 :varoattno 1}}) :groupClause <> :havingQual <>
tinctClause <> :sortClause <> :limitOffset <> :limitCount <> :setOperations <> :resultRelations ()}
DEBUG:  rewritten parse tree:
DEBUG:  { QUERY :command 1  :utility <> :resultRelation 0 :into <> :isPortal false :isBinary false :isTemp false :hasAggs false
SubLinks false :rtable ({ RTE :relname friend :relid 26912  :subquery <> :alias <> :eref { ATTR :relname friend :attrs ( "first
   "lastname"  "city"  "state"  "age" )} :inh true :inFromCl true :checkForRead true :checkForWrite false :checkAsUser 0}) :
ree { FROMEXPR :fromlist ({ RANGETBLREF 1 }) :quals { EXPR :typeOid 16  :opType op :oper { OPER :opno 96 :opid 0 :opresulttype
:args ({ VAR :varno 1 :varattno 5 :vartype 23 :vartypmod -1  :varlevelsup 0 :varnoold 1 :varoattno 5} { CONST :consttype 23 :co
n 4 :constbyval true :constisnull false :constvalue  4 [ 33 0 0 0 ] })}} :rowMarks () :targetList ({ TARGETENTRY :resdom { RESD
esno 1 :restype 1042 :restypmod 19 :resname firstname :reskey 0 :reskeyop 0 :ressortgroupref 0 :resjunk false } :expr { VAR :va
 :varattno 1 :vartype 1042 :vartypmod 19  :varlevelsup 0 :varnoold 1 :varoattno 1}}) :groupClause <> :havingQual <> :distinctCl
<> :sortClause <> :limitOffset <> :limitCount <> :setOperations <> :resultRelations ()}
DEBUG:  plan: { SEQSCAN :startup_cost 0.00 :total_cost 22.50 :rows 10 :width 12 :qptargetlist ({ TARGETENTRY :resdom { RESDOM :
 1 :restype 1042 :restypmod 19 :resname firstname :reskey 0 :reskeyop 0 :ressortgroupref 0 :resjunk false } :expr { VAR :varno
rattno 1 :vartype 1042 :vartypmod 19  :varlevelsup 0 :varnoold 1 :varoattno 1}}) :qpqual ({ EXPR :typeOid 16  :opType op :oper
R :opno 96 :opid 65 :opresulttype 16 } :args ({ VAR :varno 1 :varattno 5 :vartype 23 :vartypmod -1  :varlevelsup 0 :varnoold 1
attno 5} { CONST :consttype 23 :constlen 4 :constbyval true :constisnull false :constvalue  4 [ 33 0 0 0 ] })}) :lefttree <> :r
ree <> :extprm () :locprm () :initplan <> :nprm 0  :scanrelid 1 }
DEBUG:  ProcessQuery
DEBUG:  CommitTransactionCommand
DEBUG:  proc_exit(0)
DEBUG:  shmem_exit(0)
DEBUG:  exit(0)
./bin/postmaster: reaping dead processes...
./bin/postmaster: CleanupProc: pid 3320 exited with status 0
```

Backend Flowchart



Backend Flowchart - Magnified



Statistics - Part 1

```
PARSER STATISTICS
  system usage stats:
        0.000002 elapsed 0.000000 user 0.000001 system sec
        [0.009992 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
```

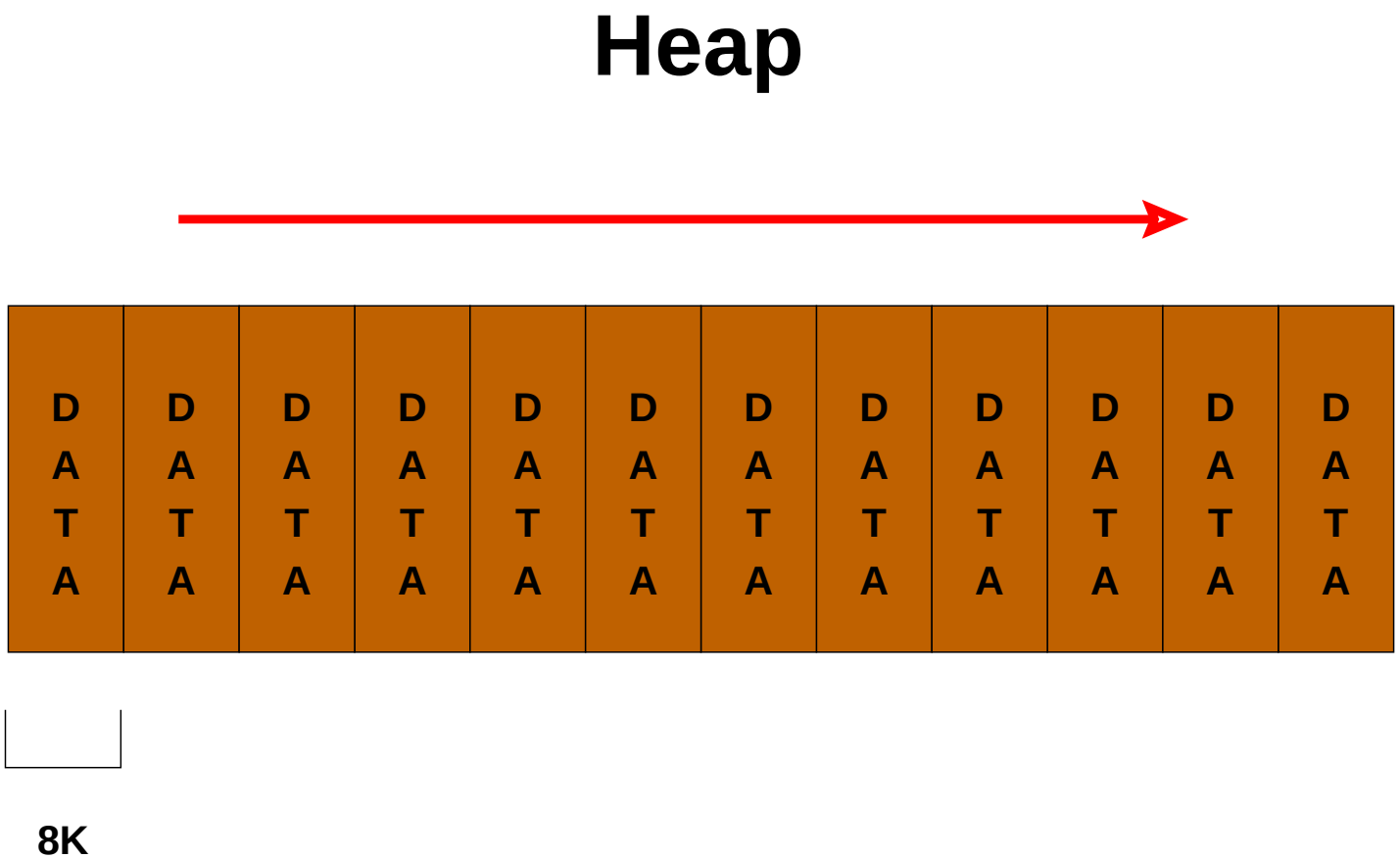
Optimizer

- Scan Methods
- Join Methods
- Join Order

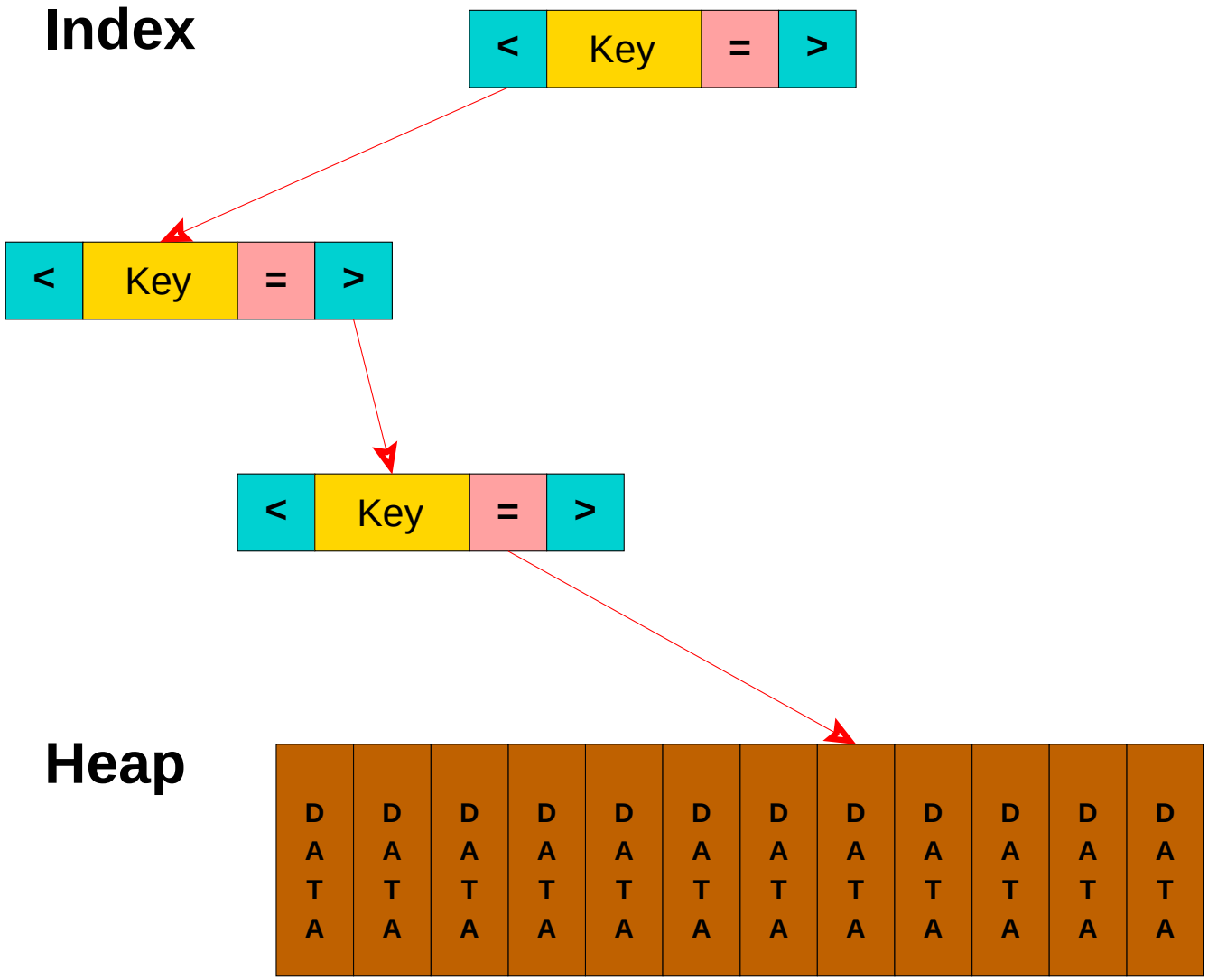
Scan Methods

- Sequential Scan
- Index Scan
- Bitmap Scan

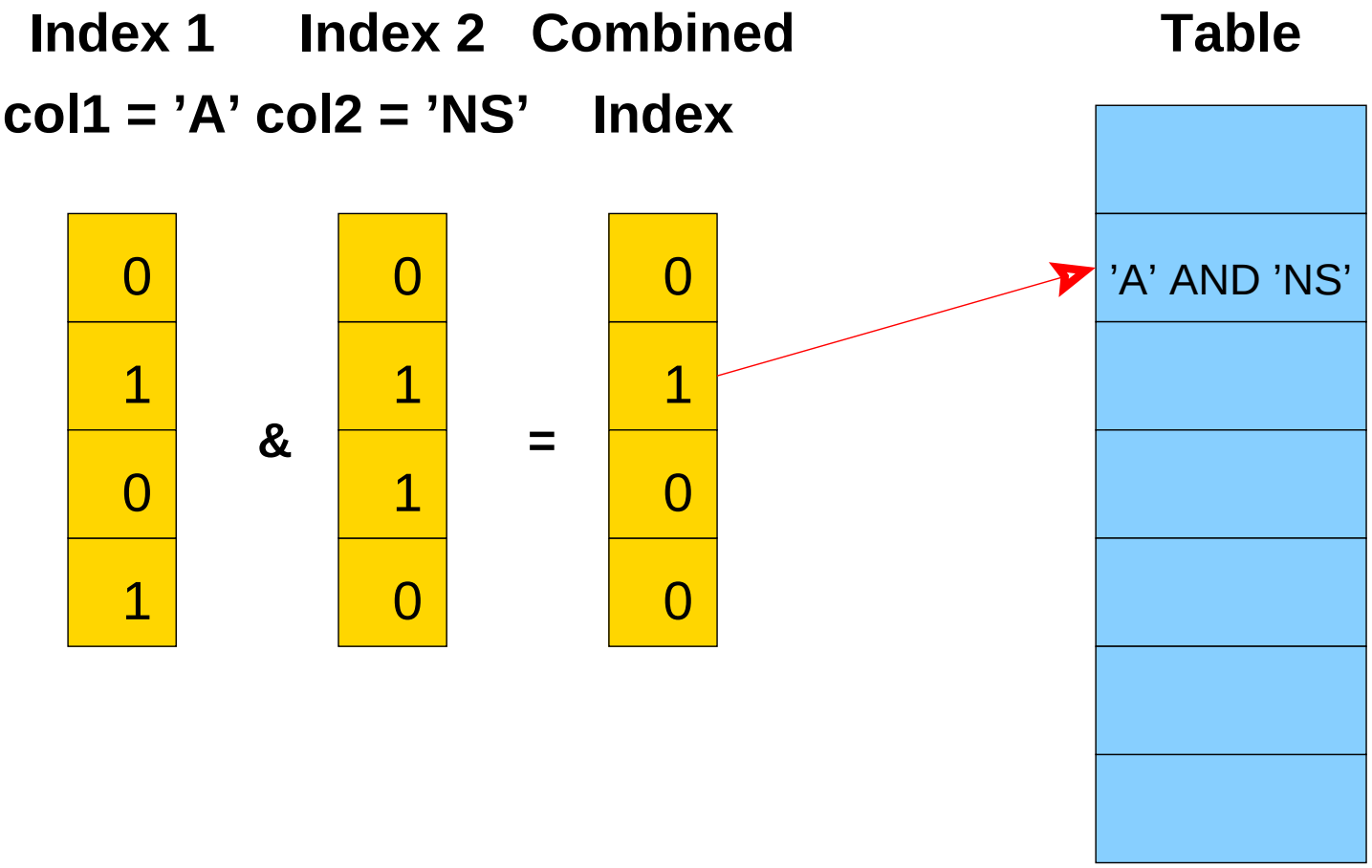
Sequential Scan



Btree Index Scan



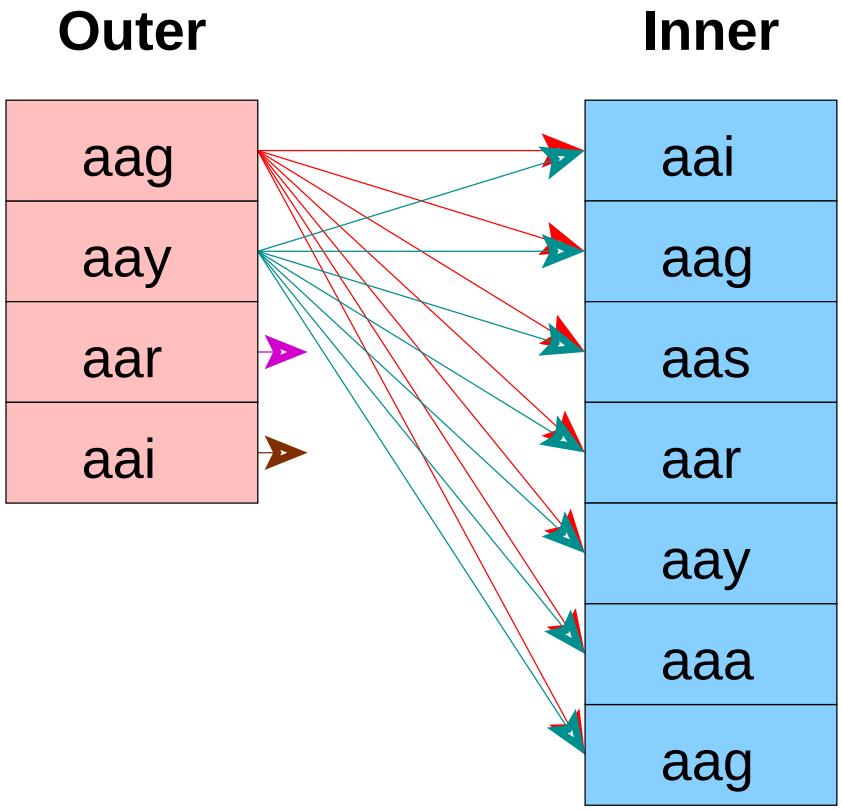
Bitmap Scan


Index 1
col1 = 'A'
Index 2
col2 = 'NS'
Combined
Index
Table
0
1
0
1
&
0
1
1
0
=
0
1
0
0
'A' AND 'NS'

Join Methods

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

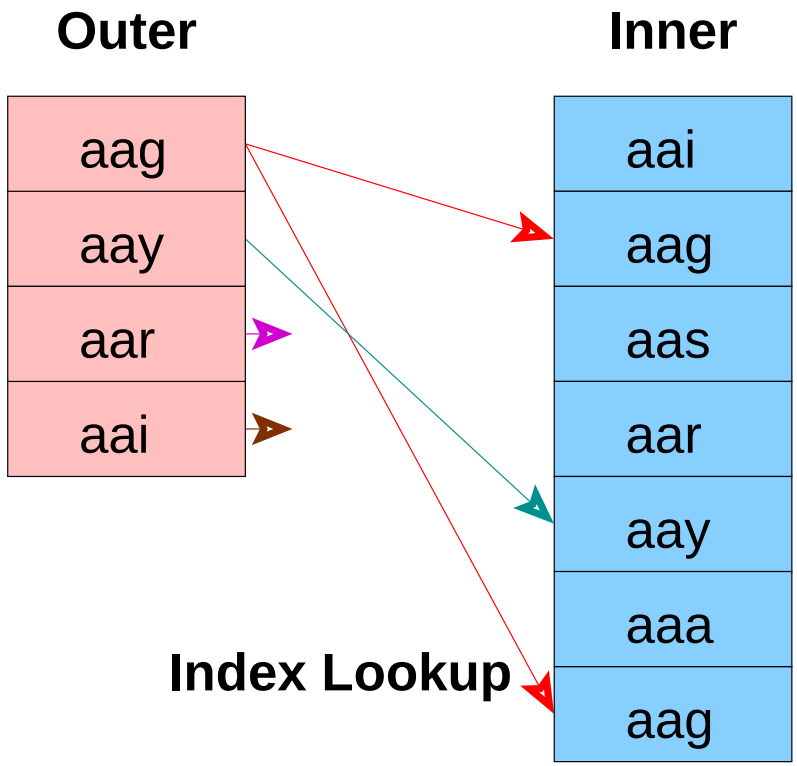
Nested Loop Join with Inner Sequential Scan



No Setup Required

Used For Small Tables

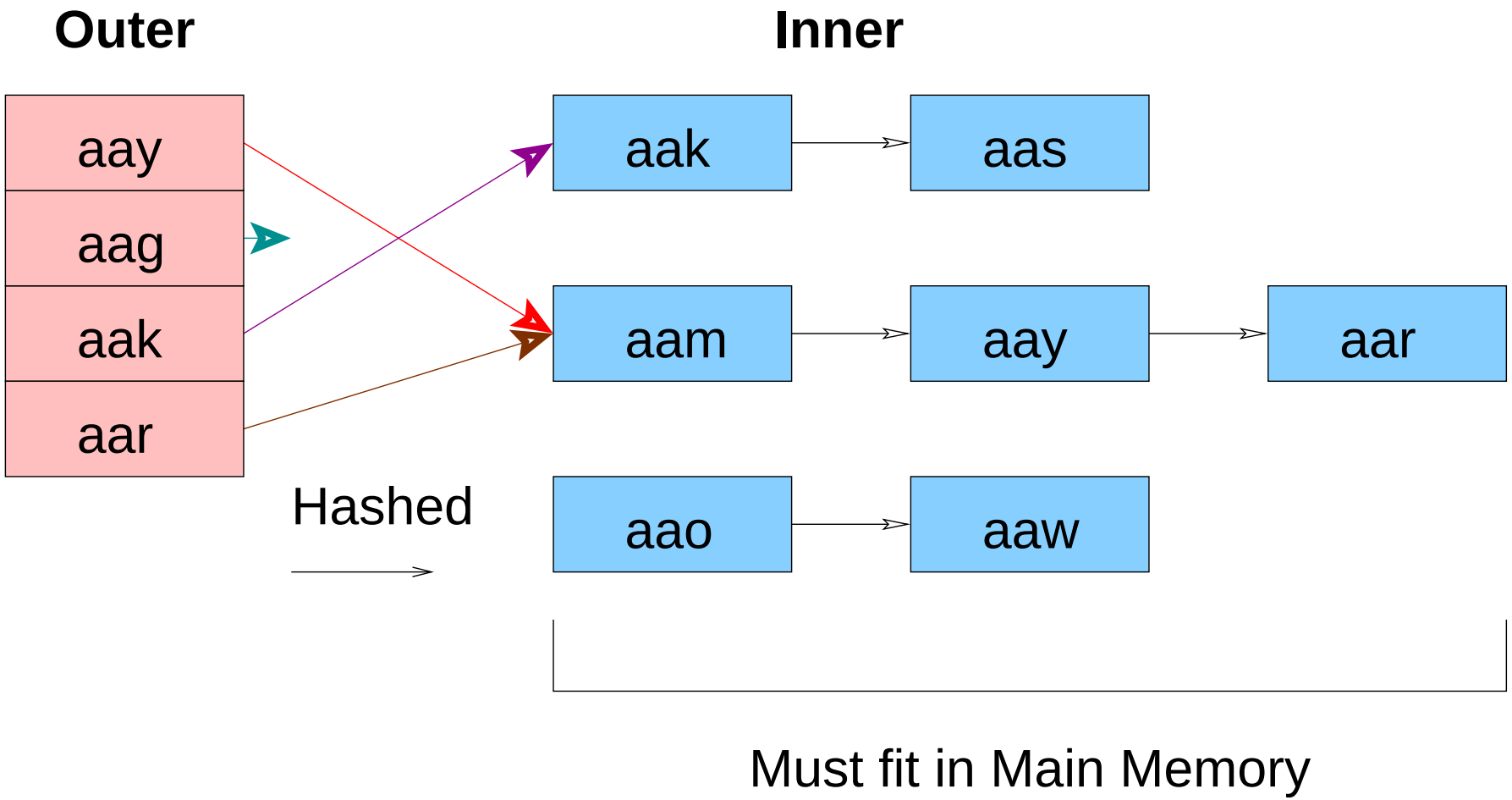
Nested Loop Join with Inner Index Scan



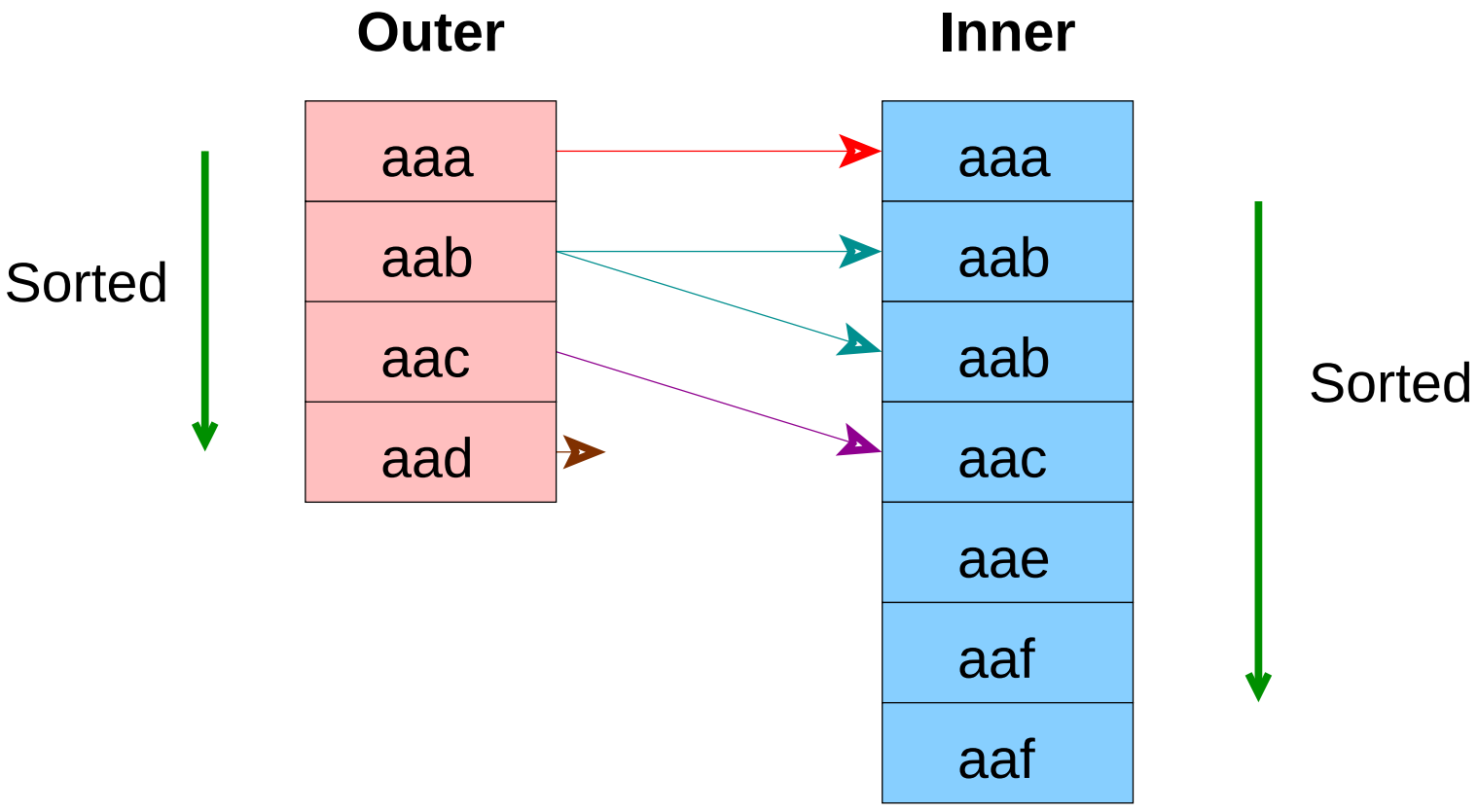
No Setup Required

Index Must Already Exist

Hash Join


Outer
Inner
aay
aag
aak
aar
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

```
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 rows=575 cost=0.00..1229.35
  clauses=(salesorder.customer_id = customer.customer_id)
        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
        IdxScan(1) rows=80 cost=0.00..10.88
          pathkeys=((salesorder.customer_id, customer.customer_id) )

cheapest startup path:
MergeJoin rows=575 cost=0.00..1229.35
  clauses=(salesorder.customer_id = customer.customer_id)
        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
        IdxScan(1) rows=80 cost=0.00..10.88
          pathkeys=((salesorder.customer_id, customer.customer_id) )

cheapest total path:
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
```

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

```
test=> 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
VACUUM
```

Analyze

```
starelid    | 16416
staattnum   | 4
stanullfrac | 0
stawidth    | 22
stadistinct | -0.4244
stakind1    | 1
stakind2    | 2
stakind3    | 3
stakind4    | 0
staop1      | 98
staop2      | 664
staop3      | 664
staop4      | 0
stanumbers1 | {0.146658,0.027904,0.0246593,0.0233615,0.0227125,0.0227125,0.0227125,0.0149254,0.01427
64,0.0123297}
stanumbers2 |
stanumbers3 | {-0.145569}
stanumbers4 |
stavalues1  | {I/O,equal,"not equal",less-than,greater-than,greater-than-or-equal,less-than-or-equal
,subtract,multiply,add}
stavalues2  | {"(Block, offset), physical location of tuple","absolute value","btree less-equal-grea
ter","convert int2 to float4","deparse an encoded expression","format int8 to text","is opclass visi
ble in search path?","matches LIKE expression","print type names of oidvector field",sine,"~18 digit
 integer, 8-byte storage"}
stavalues3  |
stavalues4  |
```

EXPLAIN

```
test=> EXPLAIN SELECT name FROM customer;
NOTICE:  QUERY PLAN:

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

Explain Analyze

```
test=> 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
```

Explain Using ansi Joins

```
test=> EXPLAIN INSERT INTO warehouse_tmp
test-> (uri, expression, n, relevance, spid_measure, size, title, sample)
test-> SELECT d.uri, dn.expression, n.n, dn.relevance, d.spid_measure,
test->        d.size, d.title, dn.sample
test-> FROM document as d
test->      INNER JOIN (document_n_gram AS dn
test(>         INNER JOIN n_gram AS n
test(>         ON (dn.expression = n.expression))
test->         ON (d.uri = dn.uri)
test-> 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
```

Explain Using Subselect In FROM Clause

```
test=> EXPLAIN SELECT cs.entity_id as region, r.name, cs.status, count(*)
test-> FROM region r inner join
test->      (SELECT DISTINCT findregion(entity_id) AS entity_id, status
test(>       FROM current_status
test(>       ORDER BY 1
test(>      ) AS cs on r.region_id = cs.entity_id
test-> 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
                                         with=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)
EXPLAIN
```

Postgresql.conf Optimizer Parameters

```
# - 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)
```

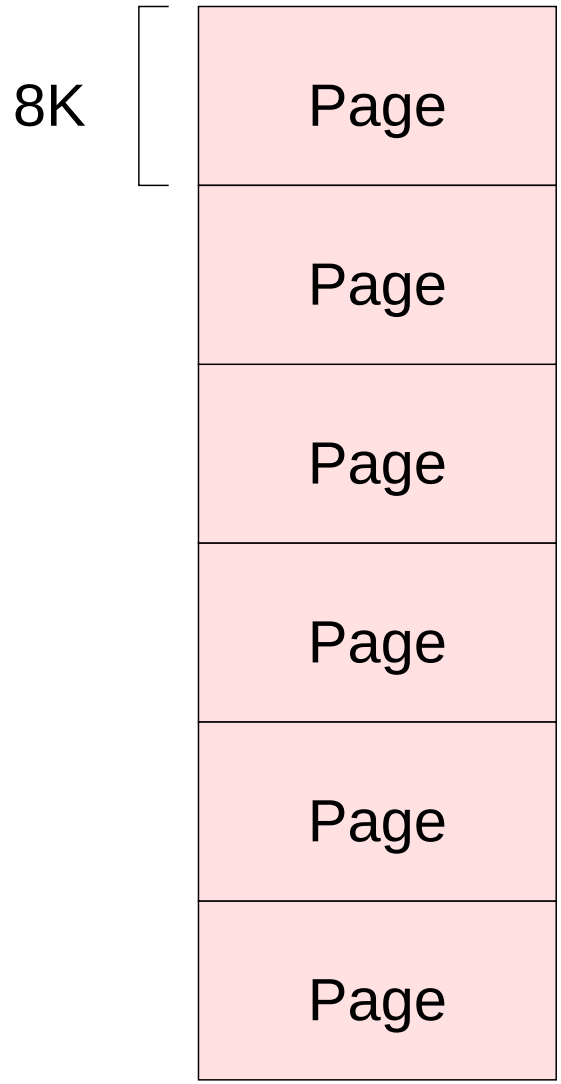
More Postgresql.conf Optimizer Parameters

```
# - 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 # range 1-1000
#from_collapse_limit = 8
#join_collapse_limit = 8        # 1 disables collapsing of explicit JOINs
```

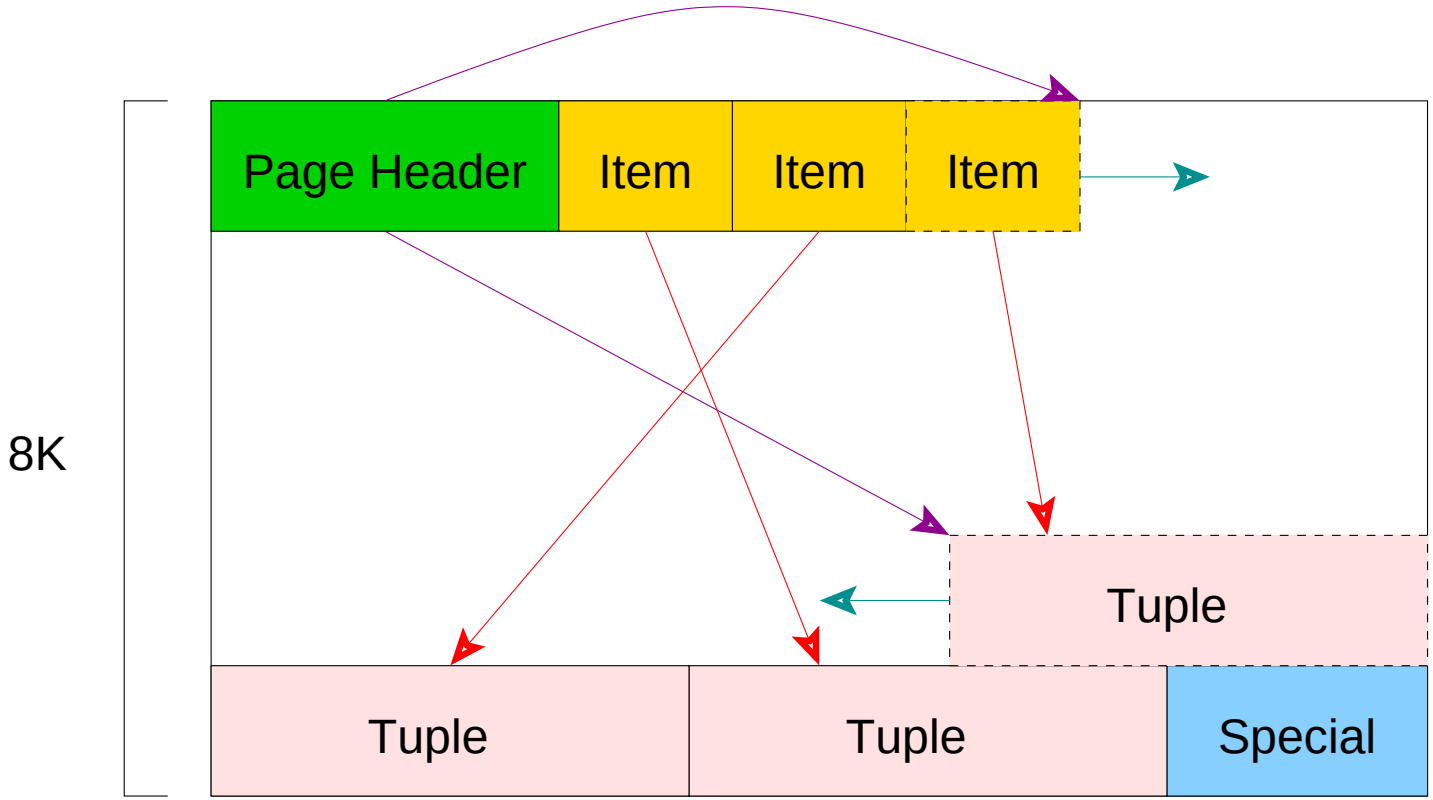
Storage

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

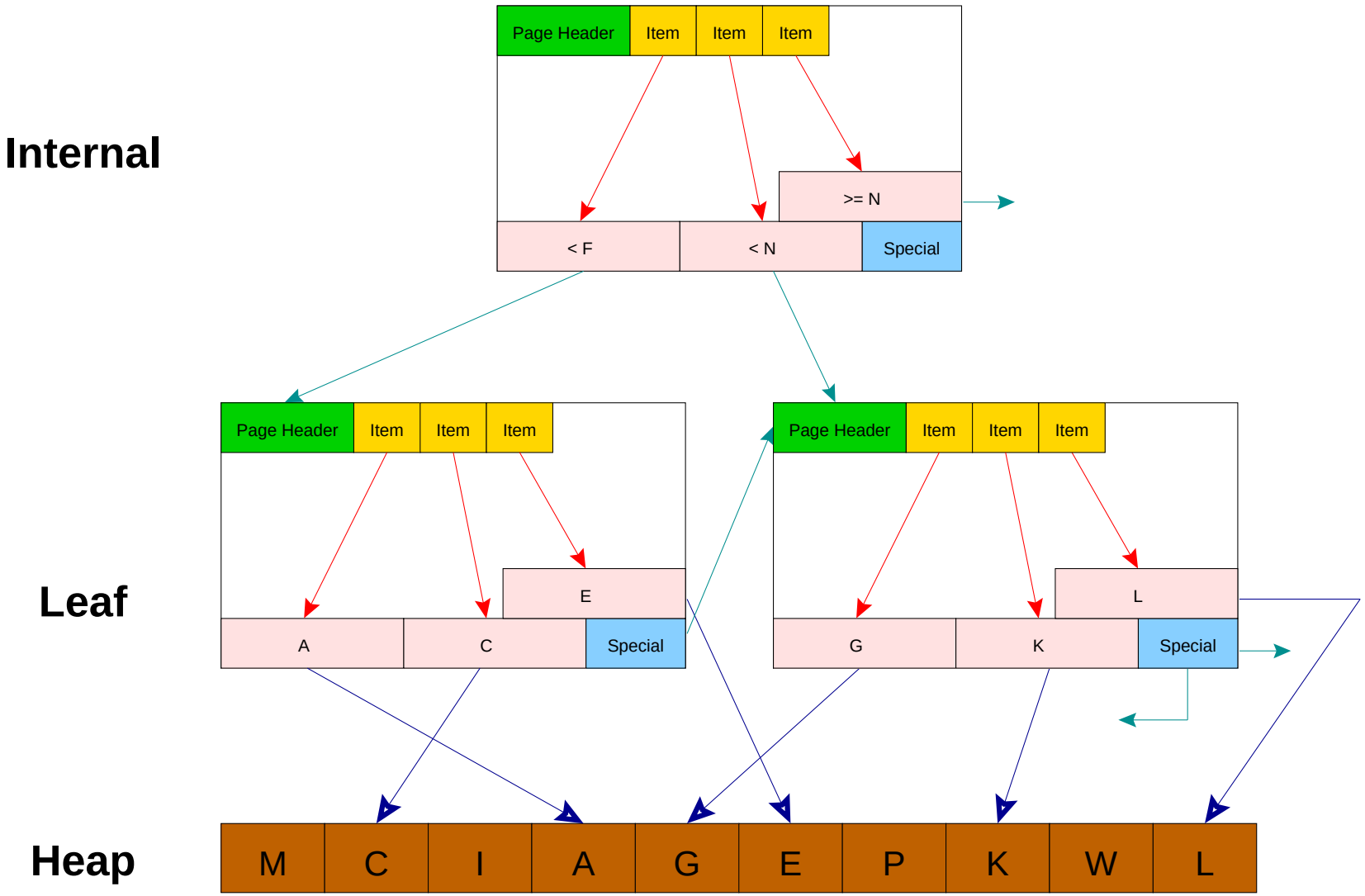
File Structure



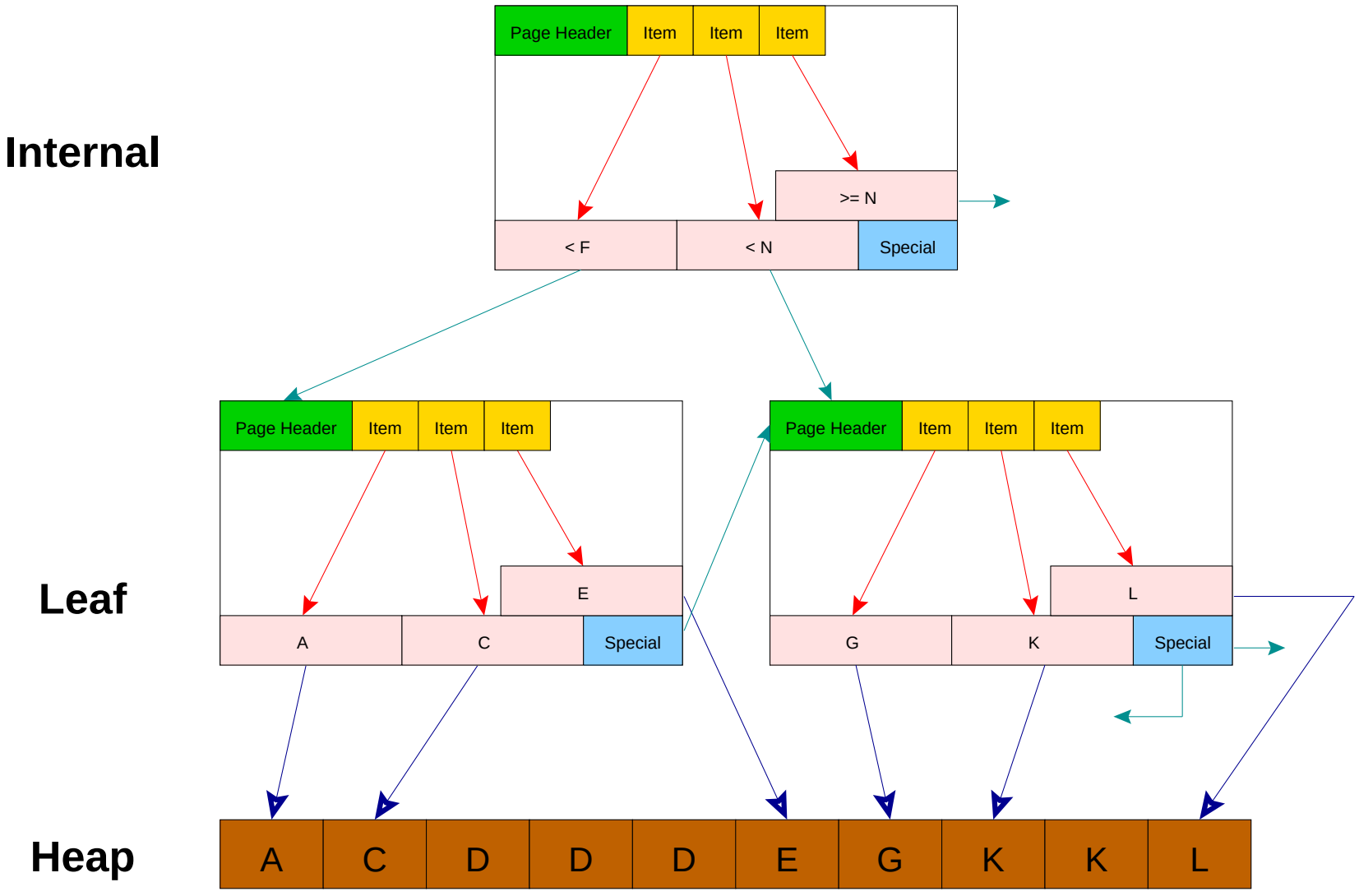
Page Structure



Index Page Structure



Cluster


Internal
Leaf
Heap
Page Header
Item
Item
Item
>= N
< F
< N
Special
Page Header
Item
Item
Item
E
A
C
Special
Page Header
Item
Item
Item
L
G
K
Special
A
C
D
D
D
E
G
K
K
L

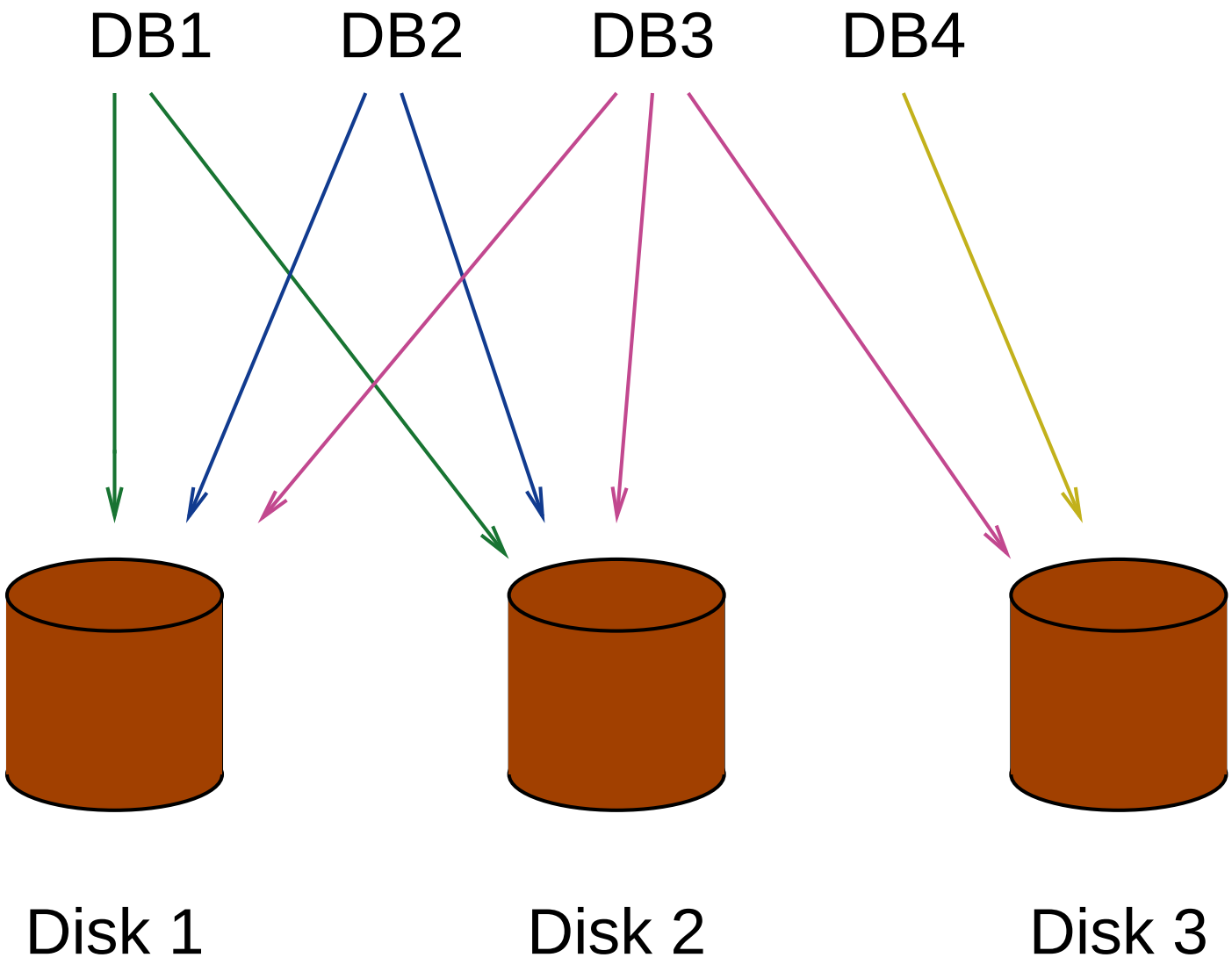
CLUSTER

```
test=> 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);
CREATE INDEX
test=> CLUSTER customer USING customer_id_index;
CLUSTER
```

Index Types (Access Methods)

- Btree
- Hash
- Rtree
- GiST
- GIN

Tablespaces For Database I/O Balancing



Tablespaces For Table and Index I/O Balancing

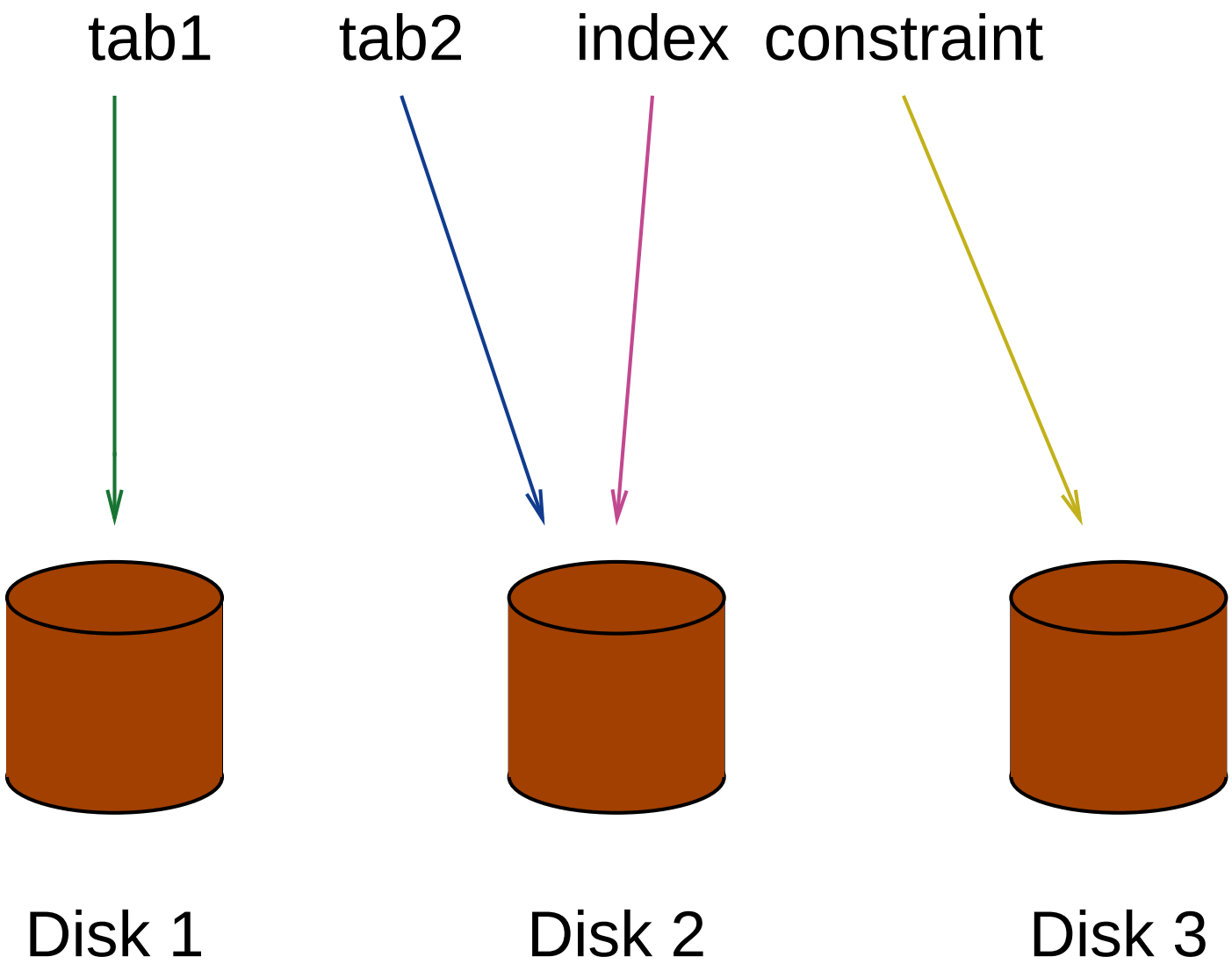
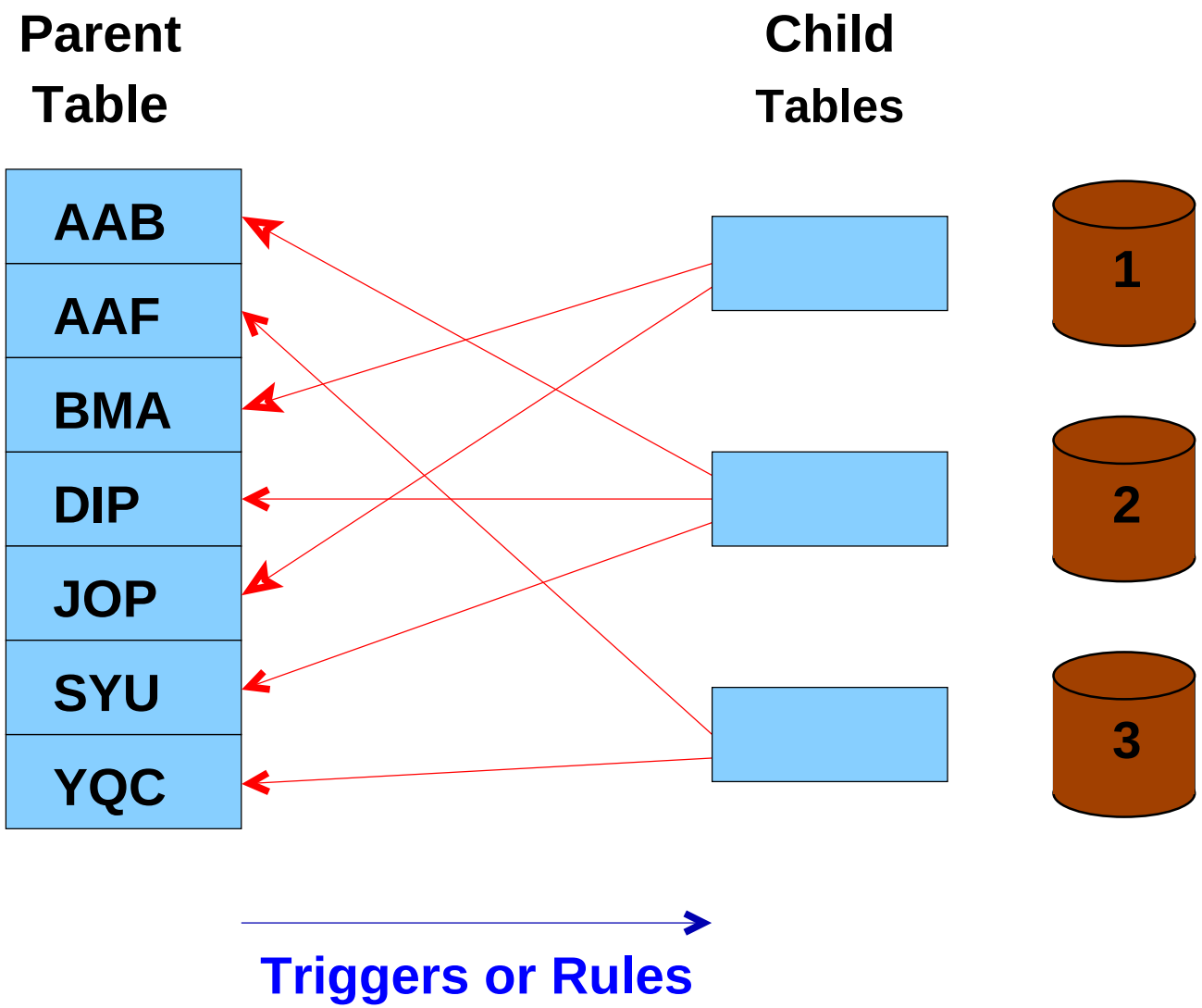


Table I/O Balancing Using constraint_exclusion



Range partitioning is also possible.

Caches

- System Cache
- Relation Information Cache
- File Descriptor Cache

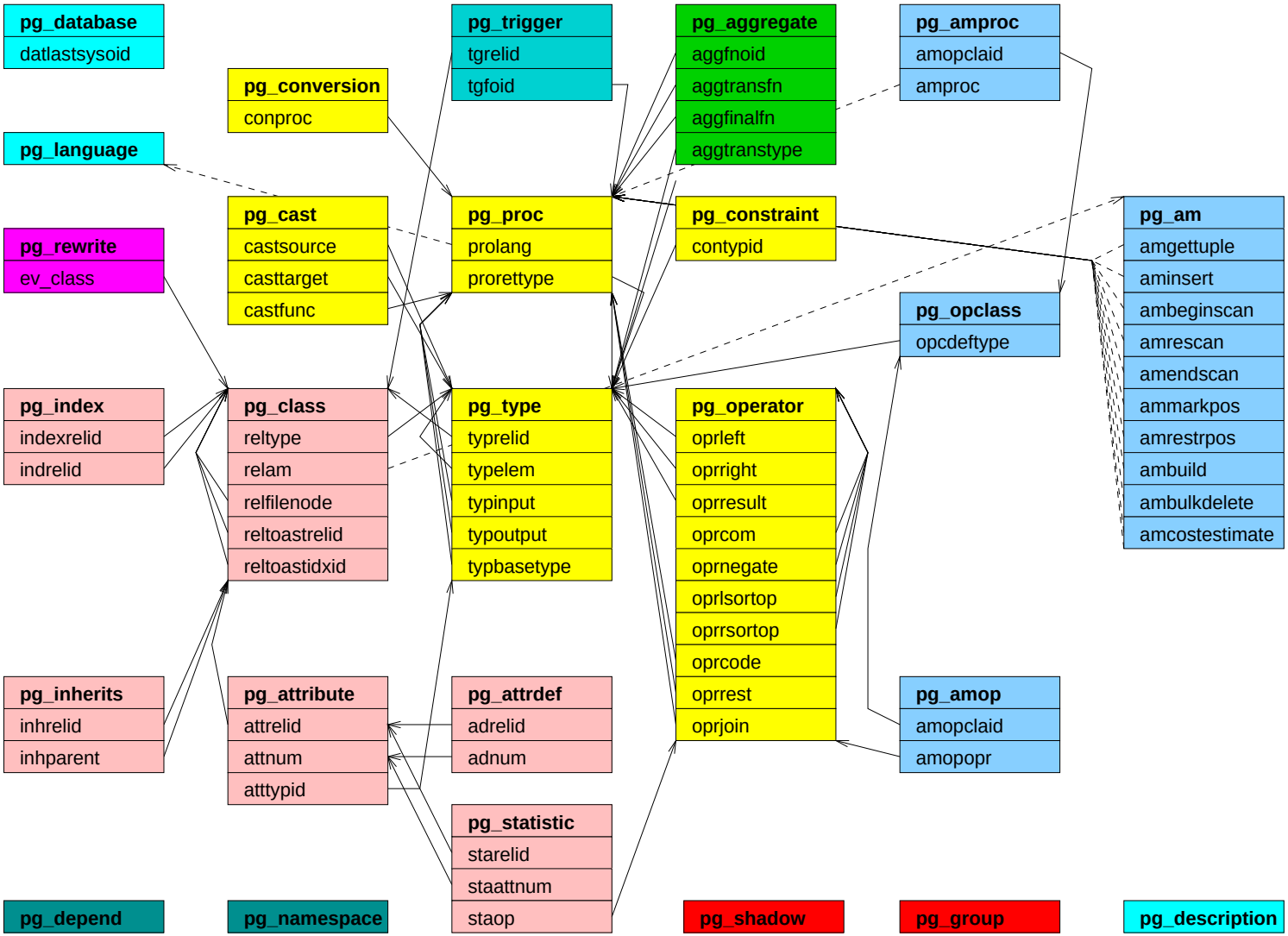
Shared Memory

- 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

System Tables



Conclusion

http://momjian.us/presentations

https://www.flickr.com/photos/143948408@N03/