PostgreSQL

PostgreSQL, the world's most avanced open-source database

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PostgreSQL

- **History**
- **Features**
- **Administration**
- **Tuning**
- **Replication**

History

PostgreSQL

Ingres 1977-1985 – *The beginning*

- Proof of concept for relational databases.
- Michael Stonebraker, professor at Berkeley, California.
- Established the company Ingres in 1980.
- Ingres was bought by Computer Associates in 1994

PostgreSQL

Postgres 1986-1994 – A*s in* "*after Ingres*"

- A project meant to break new ground in database concepts.
- “Objects relational” technologies.
- POSTQUEL query language.
- Rules, procedures, extensible types with indices and object-relational concepts are introduced.
- Code base of Ingres not used as a basis for Postgres.
- Commercialized to become Illustra.
- Bought by Informix.
- Informix was bought by IBM in 2001.

Postgres95 1994-1995 – New life in the OpenSource world

- Two Ph.D. students from Stonebraker's lab, Andrew Yu and Jolly Chen started Postgres95.
- Postgres' POSTQUEL query language replaced with with an extended subset of SQL.
- Departed from academia to a new life in the open source world with a group of dedicated developers outside of Berkeley.
- Establishment of the PostgreSQL Global Development Team.
- Released as PostgreSQL 6.0 in 1996.

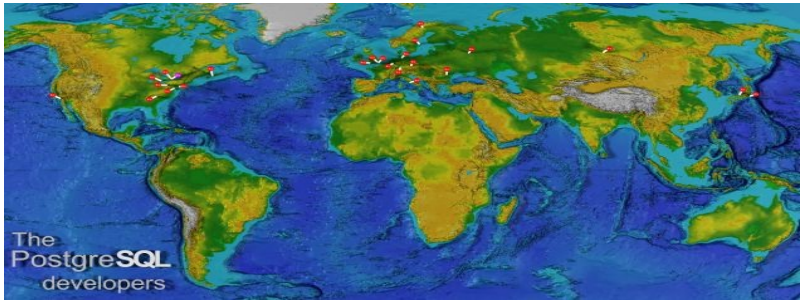
PostgreSQL

Lines of code:	178K	225K	297K	331K	383K	410K	453K	508K		647K	683K
PGSQL version:	6.0	6.[12]	6.[34]	6.5	7.0	7.1	7.[23]	7.4		8.0	8.1
Year:	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	

"Crash" SQL -standards Enterprise - 24/7

- Multiversion Concurrency Control (MVCC)
- Important SQL features
- Improved build-in types
- Speed

- Improved performance
- Improved administration & maintenance
- 24/7 ready



Features

PostgreSQL

Overall features

- Minimal administration
- Stability
- Excellent performance
- Data integrity (ACID)
- Portable
- Extensible
- BSD license

PostgreSQL

General features

- Fully ACID compliance (Atomic, Consistent, Isolated, Durable)
- ANSI SQL 92/99/2003 compliance
- Foreign keys (referential integrity)
- Multi-version concurrency control (MVCC)
- Point-in-time recovery PITR
- Tablespaces
- Savepoints
- Functional and partial indices
- Native SSL support
- Native Kerberos support

- Linux, UNIX (AIX, BSD, HP-UX, SGI, IRIX, Mac OS X, Solaris, SunOS, Tru64), BeOS, Windows.

PostgreSQL

Development features

- Stored procedures, PL/pgSQL, PL/Tcl, PL/Perl, PL/Python
- Native interfaces for ODBC, JDBC, C, C++, PHP, Perl, TCL, ECPG, Python and Ruby
- User defined data types, functions and operators
- Open and documented API.

PostgreSQL

SQL features

- Rules
- Views
- Triggers
- Cursors
- Sequences
- Inheritance
- Outer joins
- Sub-selects
- Support for UNION (ALL/EXCEPT)
- Unicode

Administration

Things we are not going to talk about

- PostgreSQL installation
- PostgreSQL cluster initialization
- Create users
- Create databases
- Create tables, indexes, etc
- Programming

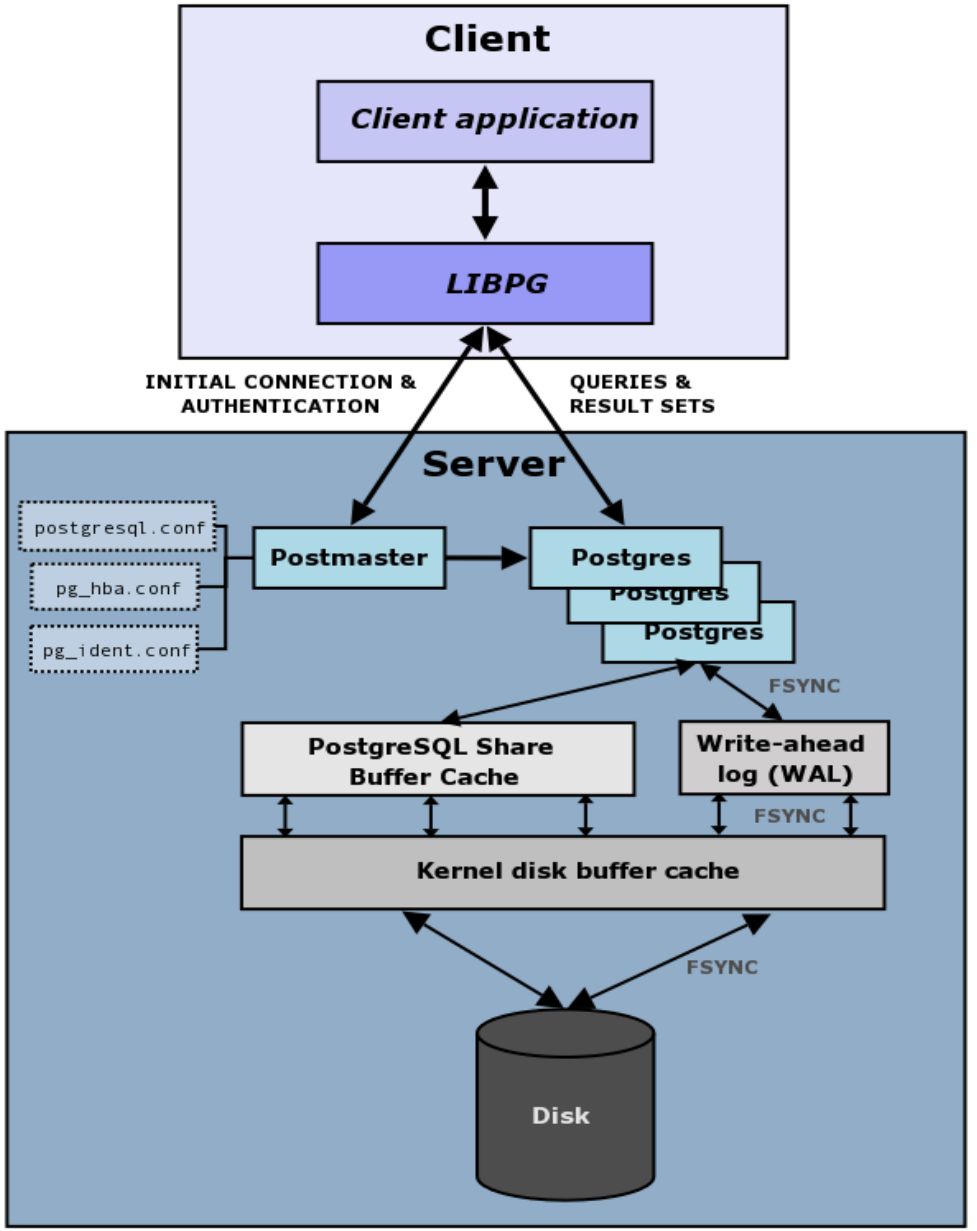
PostgreSQL

Things we are going to talk about

- PostgreSQL overview
- Data directory layout
- pg_hba.conf
- postgresql.conf
- psql ++
- Tablespaces
- Backup / PITR
- Vacuum / Analyze
- System tables

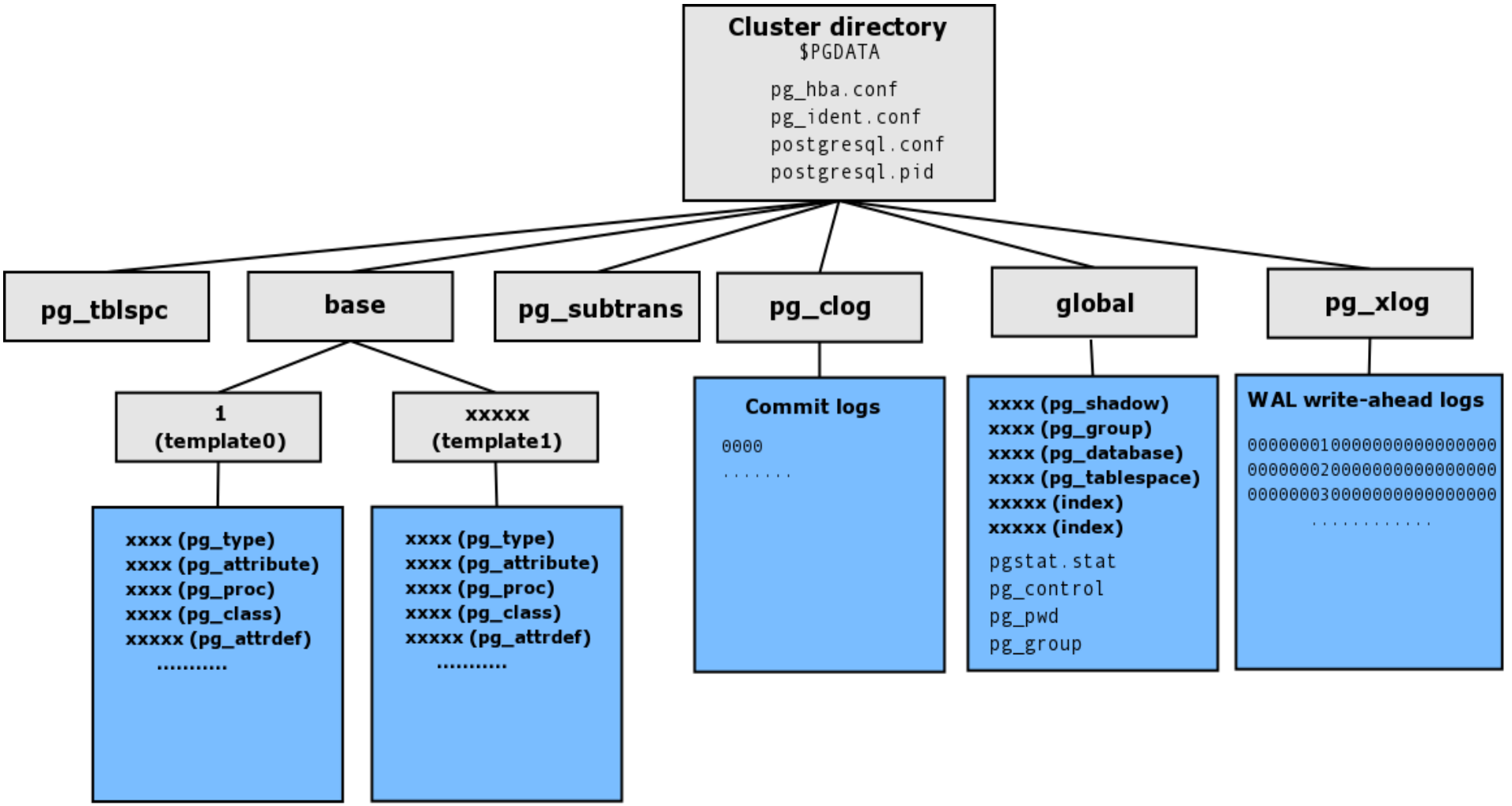
PostgreSQL

- It uses a multi-process model
- It does not use multi-threading.



PostgreSQL

Data directory layout



$PGDATA/pg_hba.conf

The PostgreSQL Client Authentication Configuration file controls:

- Which hosts are allowed to connect
- How clients are authenticated
- Which PostgreSQL user names they can use
- Which databases they can access

A record may have one of these seven formats:

```
local       database  user  authentication-method   [authentication-option]

host        database  user  CIDR-address  authentication-method  [authentication-option]
hostssl     database  user  CIDR-address  authentication-method  [authentication-option]
hostnossl   database  user  CIDR-address  authentication-method  [authentication-option]

host        database  user  IP-address  IP-mask  authentication-method  [authentication-option]
hostssl     database  user  IP-address  IP-mask  authentication-method  [authentication-option]
hostnossl   database  user  IP-address  IP-mask  authentication-method  [authentication-option]
```

authentication-method: trust, reject, md5, crypt, password, krb4, krb5, ident, or pam

$PGDATA/postgresql.conf (I)

The postgreSQL configuration file defines configuration parameters

- Connection and authentication settings
- Resource consumption
- Write Ahead Log (WAL)
- Query planning
- Error reporting and logging
- Runtime statistics
- Client connection defaults
- Lock management
- Version and platform compatibility

PostgreSQL

$PGDATA/postgresql.conf (II)

- Many configuration parameters with full documentation
- Default values are not good for a production system
- Minimum list of parameters that should be activated or changed

```
listen_addresses
max_connections
superuser_reserved_connections

share_buffers
work_mem
maintenance_work_mem

wal_buffers
checkpoint_segments

max_fsm_pages
effective_cache_size

log_directory
log_filename

stats_start_collector
stats_command_string
stats_block_level
stats_row_level
stats_reset_on_server_start
```

PostgreSQL

psql – PostgreSQL interactive terminal (I)

```
Usage:
  psql [OPTIONS]... [DBNAME [USERNAME]]

General options:
  -d DBNAME       specify database name to connect to (default: "postgres")
  -c COMMAND      run only single command (SQL or internal) and exit
  -f FILENAME     execute commands from file, then exit
  -l              list available databases, then exit
  -v NAME=VALUE   set psql variable NAME to VALUE
  -X              do not read startup file (~/.psqlrc)
  --help          show this help, then exit
  --version       output version information, then exit

Input and output options:
  -a              echo all input from script
  -e              echo commands sent to server
  -E              display queries that internal commands generate
  -q              run quietly (no messages, only query output)
  -o FILENAME     send query results to file (or |pipe)
  -n              disable enhanced command line editing (readline)
  -s              single-step mode (confirm each query)
  -S              single-line mode (end of line terminates SQL command)

Output format options:
  -A              unaligned table output mode (-P format=unaligned)
  -H              HTML table output mode (-P format=html)
  -t              print rows only (-P tuples_only)
  -T TEXT         set HTML table tag attributes (width, border) (-P tableattr=)
  -x              turn on expanded table output (-P expanded)
  -P VAR[=ARG]    set printing option VAR to ARG (see \pset command)
  -F STRING       set field separator (default: "|") (-P fieldsep=)
  -R STRING       set record separator (default: newline) (-P recordsep=)

Connection options:
  -h HOSTNAME     database server host or socket directory (default: "local socket")
  -p PORT         database server port (default: "5432")
  -U NAME         database user name (default: "postgres")
  -W              prompt for password (should happen automatically)
```

PostgreSQL

psql – PostgreSQL interactive terminal (II)

```
-bash-2.05b$ psql template1
Welcome to psql 8.0.4, the PostgreSQL interactive terminal.

Type:  \copyright for distribution terms
       \h for help with SQL commands
       \? for help with psql commands
       \g or terminate with semicolon to execute query
       \q to quit

template1=#
```

PostgreSQL

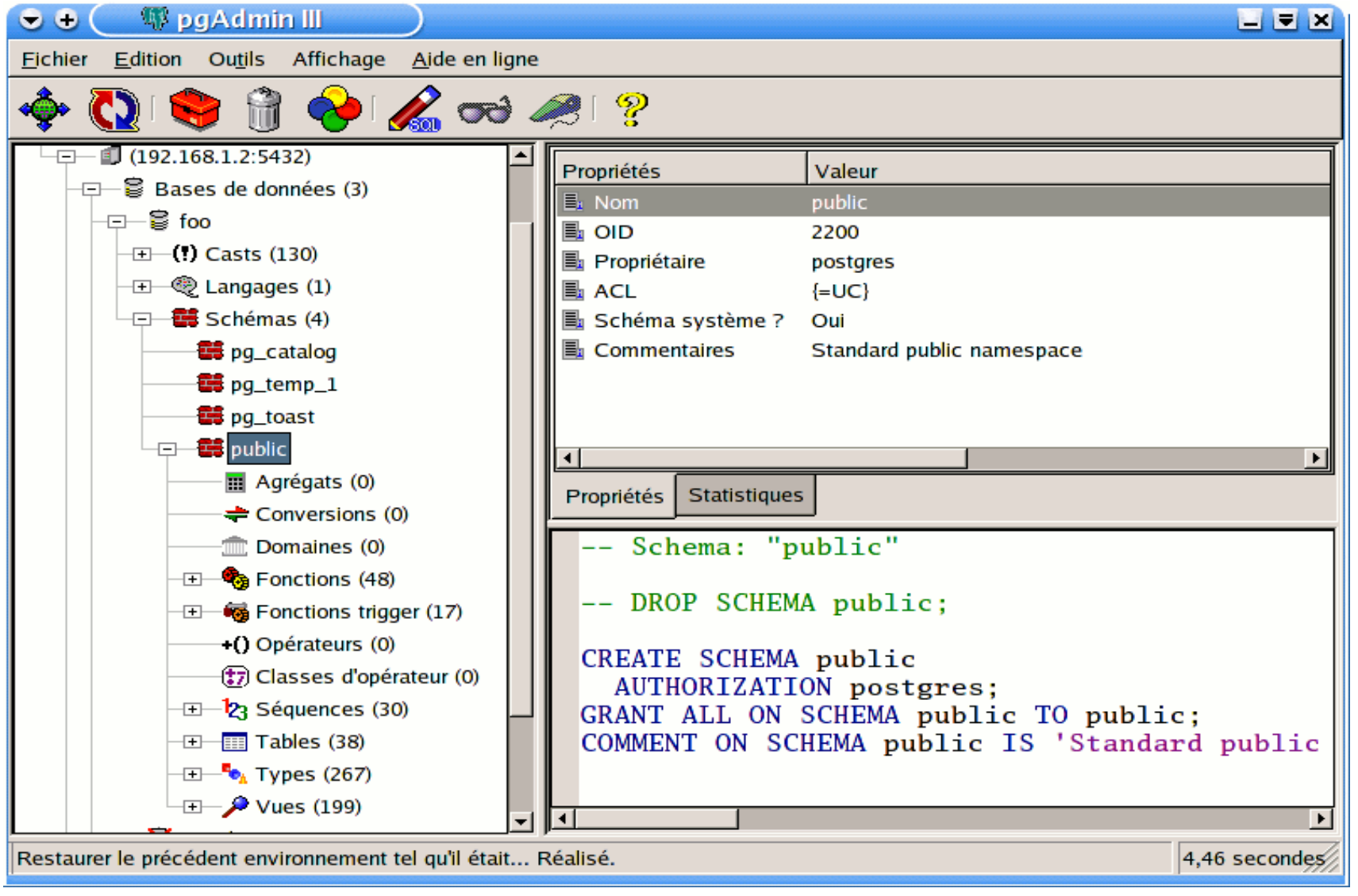
psql – PostgreSQL interactive terminal (III)

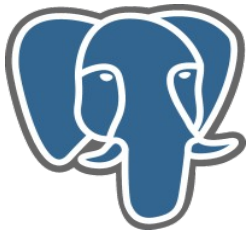
```
template1=# \?
```

```
General
  \c[onnect] [DBNAME|- [USER]]
                connect to new database (currently "template1")
  \cd [DIR]     change the current working directory
  \copyright    show PostgreSQL usage and distribution terms
  \encoding [ENCODING]
                show or set client encoding
  \h [NAME]     help on syntax of SQL commands, * for all commands
  \q            quit psql
  \set [NAME [VALUE]]
                set internal variable, or list all if no parameters
  \timing       toggle timing of commands (currently off)
  \unset NAME   unset (delete) internal variable
  \! [COMMAND]  execute command in shell or start interactive shell

Query Buffer
  \e [FILE]     edit the query buffer (or file) with external editor
  \g [FILE]     send query buffer to server (and results to
                file or |pipe)
  \p            show the contents of the query buffer
  \r            reset (clear) the query buffer
  \s [FILE]     display history or save it to file
  \w FILE       write query buffer to file

Input/Output
  \echo [STRING] write string to standard output
  \i FILE       execute commands from file
  \o [FILE]     send all query results to file or |pipe
  \qecho [STRING]
                write string to query output stream (see \o)

Informational
  \d [NAME]     describe table, index, sequence, or view
  \d{t|i|s|v|S} [PATTERN] (add "+" for more detail)
                list tables/indexes/sequences/views/system tables
  \da [PATTERN] list aggregate functions
  \db [PATTERN] list tablespaces (add "+" for more detail)
  \dc [PATTERN] list conversions
  \dC           list casts
  \dd [PATTERN] show comment for object
  \dD [PATTERN] list domains
  \df [PATTERN] list functions (add "+" for more detail)
  \dg [PATTERN] list groups
  \dn [PATTERN] list schemas (add "+" for more detail)
  \do [NAME]    list operators
  \dl           list large objects, same as \lo_list
  \dp [PATTERN] list table, view, and sequence access privileges
  \dT [PATTERN] list data types (add "+" for more detail)
  \du [PATTERN] list users
  \l            list all databases (add "+" for more detail)
  \z [PATTERN]  list table, view, and sequence access privileges
                (same as \dp)

Formatting
  \a            toggle between unaligned and aligned output mode
  \C [STRING]   set table title, or unset if none
  \f [STRING]   show or set field separator for unaligned query output
  \H            toggle HTML output mode (currently off)
  \pset NAME [VALUE]
                set table output option
                (NAME := {format|border|expanded|fieldsep|footer|null|
                recordsep|tuples_only|title|tableattr|pager})
  \t            show only rows (currently off)
  \T [STRING]   set HTML <table> tag attributes, or unset if none
  \x            toggle expanded output (currently on)

Copy, Large Object
  \copy ...     perform SQL COPY with data stream to the client host
  \lo_export LOBOID FILE
  \lo_import FILE [COMMENT]
  \lo_list
  \lo_unlink LOBOID    large object operations
```

PostgreSQL

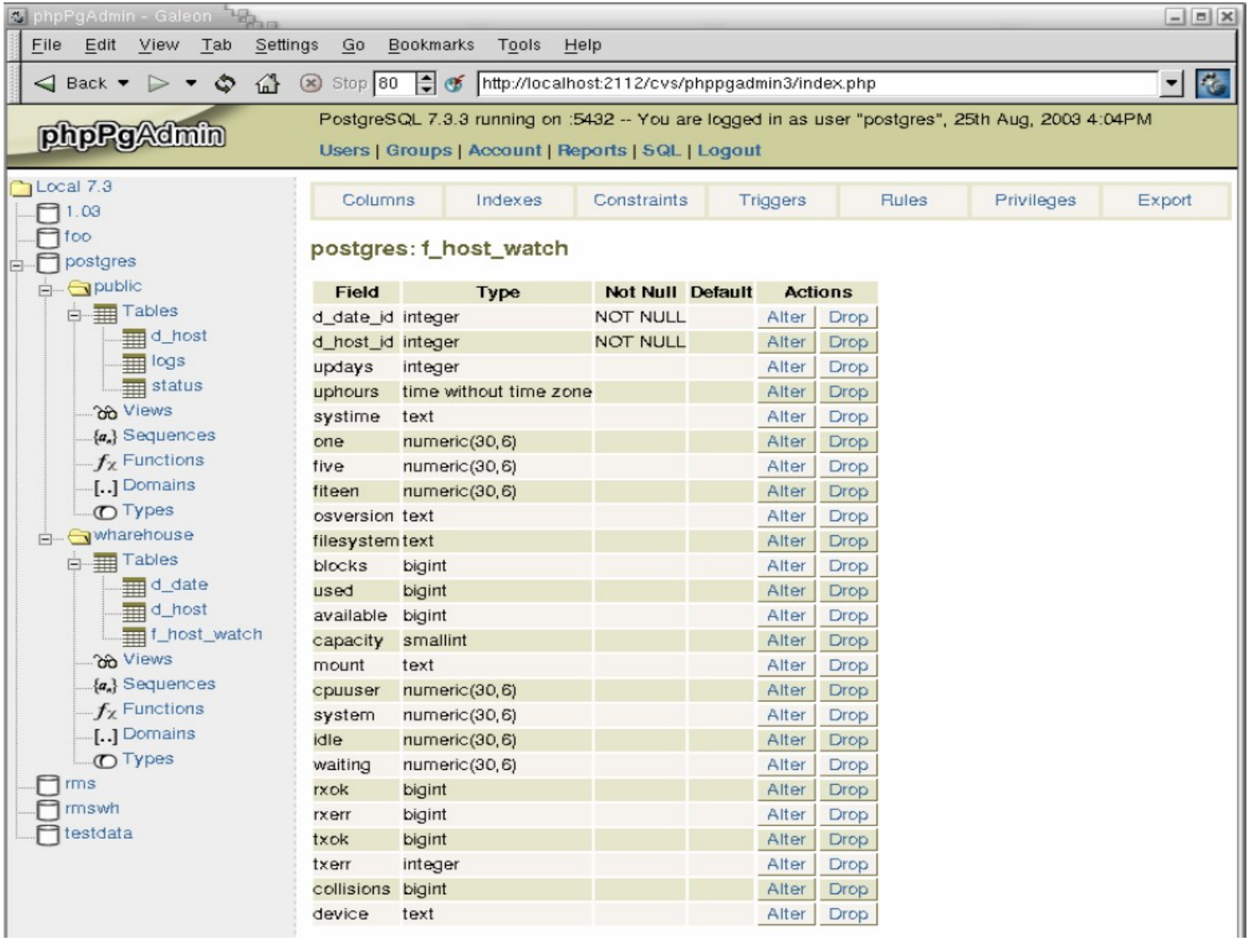
pgAdmin III





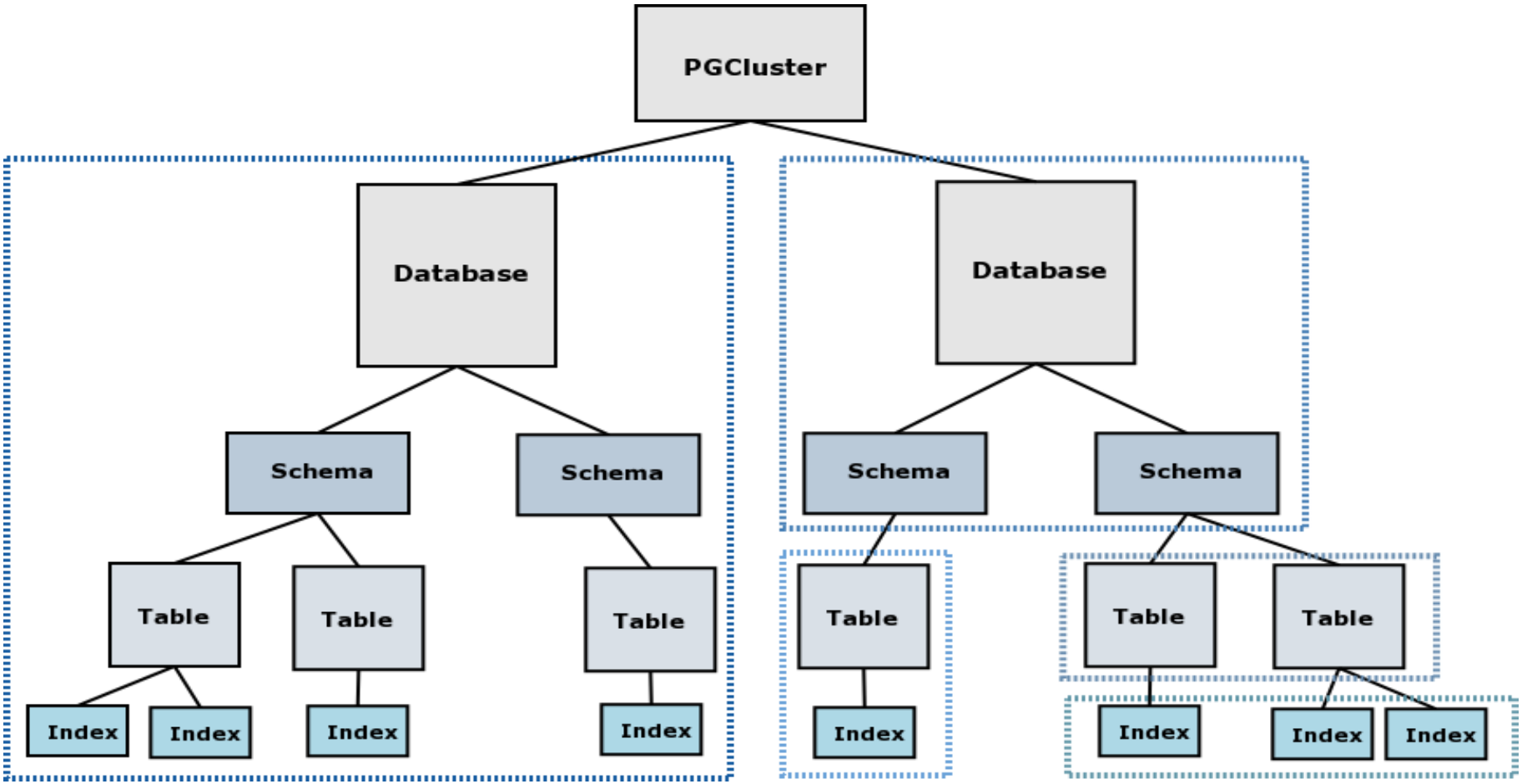
PostgreSQL

phpPgAdmin



PostgreSQL

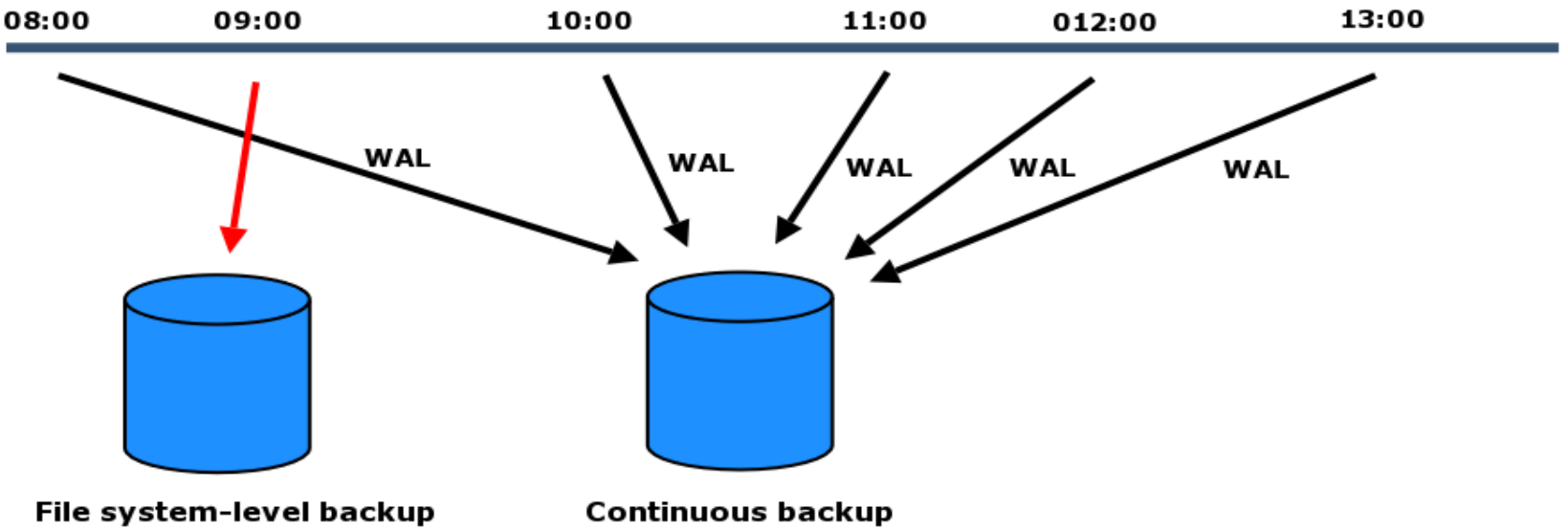
Tablespaces - \db+



- Define locations in the file system where Databases, tables and indexes can be stored
- Control the disk layout of a PostgreSQL installation
- Can be use to optimize performance

PostgreSQL

PITR – Point In Time Recovery



- Hot backup
- Combines a file-system-level backup with backup of WAL files
- The file-system-level backup can be inconsistent
- Only restoration of an entire database cluster can be done
- Enables recover to the time of crash or an arbitrary chosen point in time
  since last file-system-level backup
- More difficult to administrate

Cold / Hot Backup

- **File system-level**

  - Cold backup
  - Tar, cpio while shutdown
  - File system snapshot (inconsistent?)
  - rsync -> shutdown -> rsync -> start

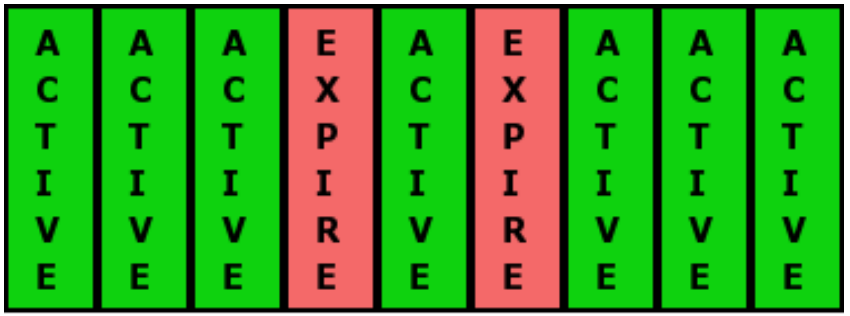
- **pg_dump/pg_dumpall**

  - Hot Backup
  - Extract a schema/data/database or DB cluster into a script/archive fil
  - Consistent backup (MVCC)
  - Non blocking job (read/write)

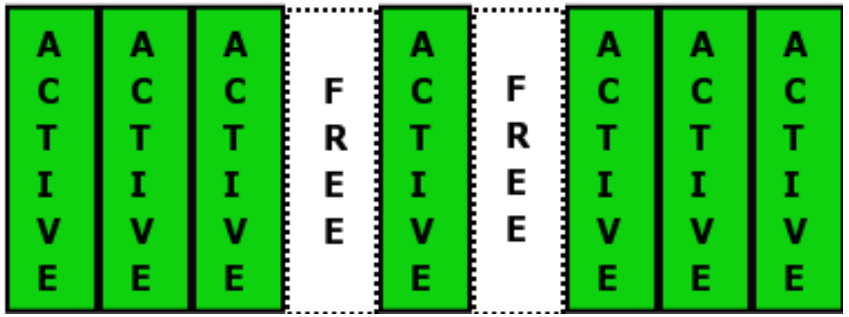
$PGDATA and backup files should be in different disk systems to avoid loss of data

PostgreSQL

Vacuum / Analyze (non blocking)



Original heap
with expired
rows identified

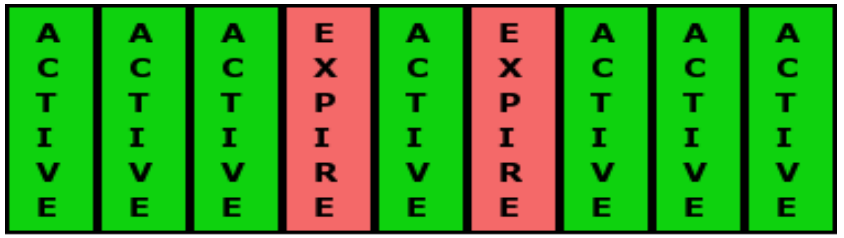


Space reclaimed
for reuse without
truncating the file

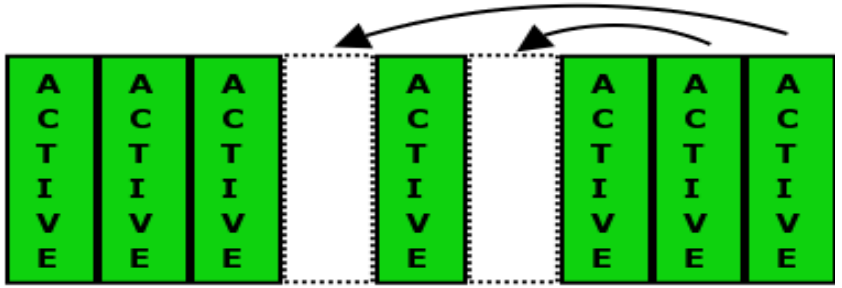
- **analyze** updates the data statistics used by the PostgreSQL query planner
- It can be executed alone or together with vacuum (**vacuum analyze**)

PostgreSQL

Vacuum full (blocking)



Original heap with expired rows identified



Move trailing rows into expired slots

Truncate file

Vacuum prevents also *transaction ID wraparound* failures after 4 billions (4×10^9) transactions

System tables - \dS

- pg_shadow
- pg_settings
- pg_locks
- pg_tablespace
- pg_stat_activity
- pg_stat_*
- pg_statio_*
- pg_class
- .....

Example 1:

```
test001=# SELECT * from pg_shadow ;

 usename  | usesysid | usecreatedb | usesuper | usecatupd |                passwd                | valuntil | useconfig
----------+----------+-------------+----------+-----------+--------------------------------------+----------+-----------
 postgres |        1 | t           | t        | t         |                                      |          |
 pgadmin  |      100 | f           | f        | f         | md55cd31c25de000c28135d138df5690e21 |          |
 rafael   |      101 | f           | f        | f         | md55cd31c76f9470c2abcd8636df5cc6381 |          |
 ola      |      102 | f           | f        | f         | md55cd31c76f94753746bbbbbaa54870e21 |          |
 tomas    |      103 | f           | f        | f         | md55cd31c792637a34bd3234aaadb720e21 |          |
(5 rows)
```

Example 2:

```
ps auxww | grep ^postgres
```

```
postgres 18260  0.0  0.7 370440 14428 pts/1  S    15:30   0:00 /usr/local/bin/postmaster
postgres 18261  0.0  0.0   6036  2036 pts/1  S    15:30   0:00 postgres: logger process
postgres 18263  0.0  0.8 371044 18204 pts/1  S    15:30   0:00 postgres: writer process
postgres 18264  0.0  0.1   7036  2472 pts/1  S    15:30   0:00 postgres: stats buffer process
postgres 18265  0.0  0.1   6748  2712 pts/1  S    15:30   0:00 postgres: stats collector process
postgres 17515  0.0  0.7 371240 10244 pts/1  S    20:39   0:00 postgres: postgres template1 [local] idle
```

master server process

logging

background buffer writer

statistics collector

client connection

postgres: *user database host activity*

```
template1=# SELECT * from pg_stat_activity ;
 datid |  datname  | procpid | usesysid | usename  | current_query |          query_start
-------+-----------+---------+----------+----------+---------------+-------------------------------
     1 | template1 |   17515 |        1 | postgres | <IDLE>        | 2005-10-08 21:15:04.245929+02
```

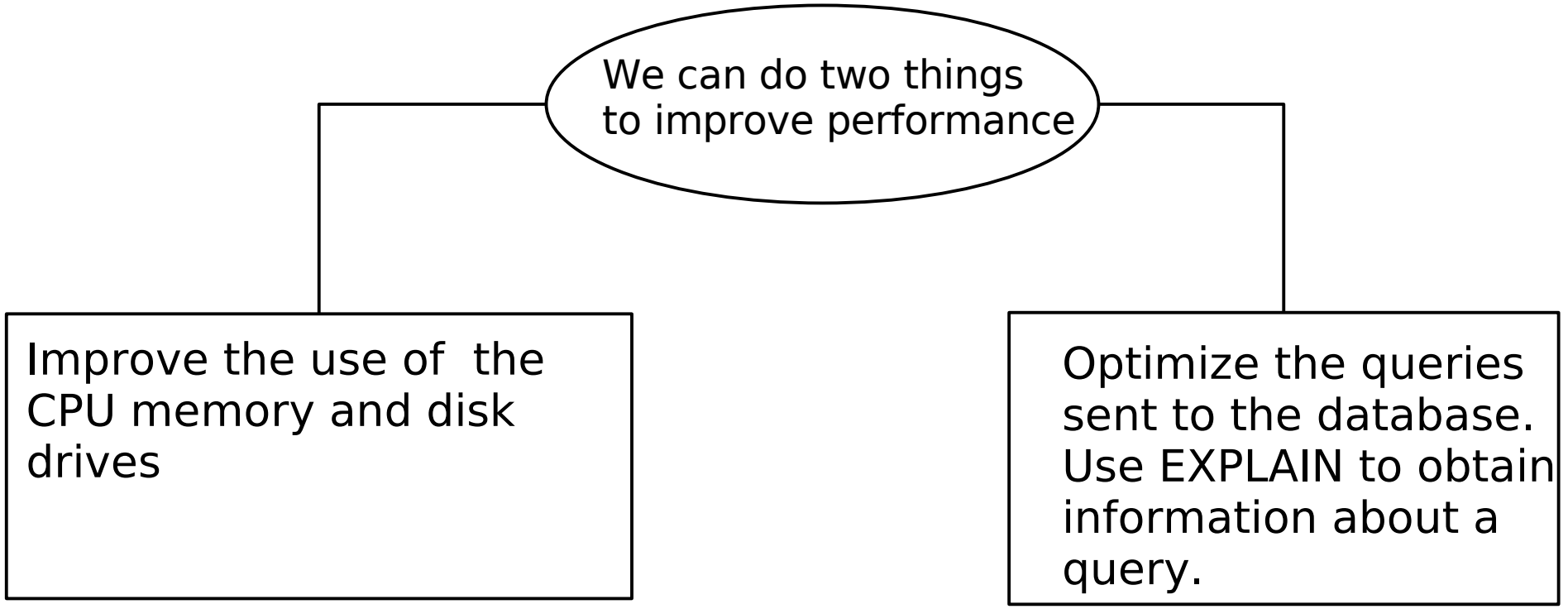
```
template1=# SELECT * from pg_locks ;
 relation | database | transaction |  pid  |      mode       | granted
----------+----------+-------------+-------+-----------------+---------
    16839 |        1 |             | 17515 | AccessShareLock | t
          |          |     9339816 | 17515 | ExclusiveLock   | t
```

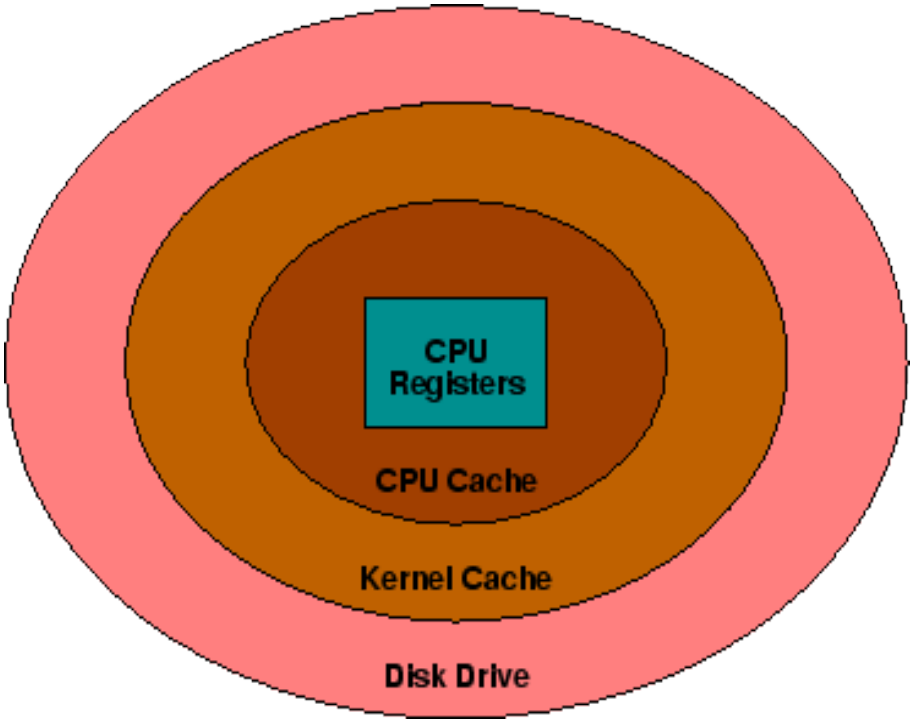
```
template1=# SELECT oid,relname from pg_class where oid ='16839';
  oid  | relname
-------+----------
 16839 | pg_locks
```

Tuning

PostgreSQL

Database performance tuning

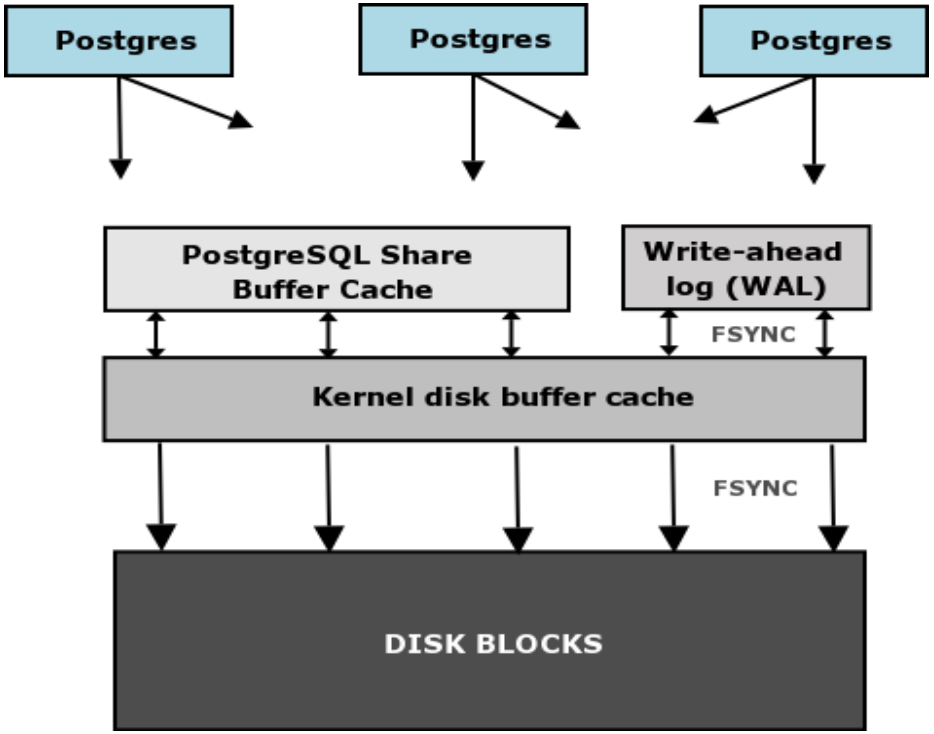




- The most frequently used information is stored next to the CPU
- Less frequently accessed information is stored farther away and brought to the CPU as needed

PostgreSQL

Shared Buffer Cache (`shared_buffers`)



- Large enough to hold most commonly accessed tables
- Small enough to avoid swap pagein activity
- Complex calculation of total RAM, database size, number of connections, and query complexity
- Quick rule --> between 1 000 and 50 000 buffers (8Kb each -> ca.8-400Mb)
- My default is 25% of available RAM
- Never more than 1/3 of available RAM

```
Shared memory values (ie.linux):

kernel.shmmax = ((250 + (8*shared_buffers) + (14*max_connections))*2*1024)
kernel.shmall = (MEMTOTAL/4096)
```

Sort memory batch size (`work_mem`)

- Allocated per operation (non-shared) (ORDER BY, DISTINCT, merge joins, hash joins, IN subqueries)
- Defines a celling on the amount of memory to use before using disk
- Can be adjusted upwards/downwards depending on amount of available RAM, query size and number of connections
- Can be set per connection at query time
- Monitor the PostgreSQL temp-files in `$PGDATA/base/<DB_OID>/pgsql_tmp`

- 2-4% of available RAM if we have just a few big sessions.
- My default is 8192 (size in Kb)

PostgreSQL

Maintenance operation's memory (`maintenance_work_mem`)

- Maximum amount of memory to be used in maintenance operations (VACUUM, ANALIZE, CREATE INDEX, ALTER TABLE, ADD FOREIGN KEY)
- Raise it with large databases and enough RAM
- Can be allocated at runtime so we can increase it temporarily.

- 50-75% of on-size disk of your larger table or index.
- 32-256Mb if this can not be determined
- My default is 131072 (size in Kb)

Free space map (`max_fsm_pages`)

- Sizes the register which tracks partially empty data pages for population with new data
- If set right, makes VACUUM faster and removes the need for VACUUM FULL or REINDEX
- Should be slightly more than the total number of data pages which will be touched by updates and deletes between vacuums

- From VACUUM VERBOSE ANALYZE, example.:

```
[....]
INFO:  free space map: 197 relations, 30363 pages stored; 33568 total pages needed
DETAIL:  Allocated FSM size: 2000 relations + 40000 pages = 354 kB shared memory.
```

This is saying that we need 33568 fsm_pages slots to remember every single page that has a useful amount of free space.

PostgreSQL

Planner cost constants (`effective_cache_size`)

- Tells the query planner the largest possible database object that could be expected to be cached
- Used by the optimizer to estimate the size of the kernel's disk buffer cache used by PostgreSQL

- Around 2/3 in a dedicated server
- My default is 50% of available RAM (8Kb each)

PostgreSQL

Write Ahead Log (`wal_buffers / checkpoints_segments`)

- **`wal_buffers`** defines the number of disk-page buffers allocated in shared memory for WAL data
- Needs only to be large enough to hold the amount of WAL data generated by one typical transaction
- Between 16-64 buffers to be sure

- **`checkpoints_segments`** defines the maximum distance between automatic WAL checkpoints, in log file segments (each segment is normally 16 megabytes)
- The most effective setting for dealing with large updates, data loading, and heavy OLTP activity
- Heavy loads --> 16-32
- Very large write loads (several Gb of data) --> up to 128-256
- My default is 64
- Check logfile for warnings.
- It requires a significant amount of disk space for the `$PGDATA/pg_xlog` directory:

```
( 2 x checkpoint_segments + 1 ) x 16MB
```

Putting the database transaction log `$PGDATA/pg_xlog` on its own dedicated disk resource, will make a big difference in performance on databases with high write activity.

pg_stat* system tables to obtain information

EXAMPLE DATABASE: webmail_stats
PERIOD: 30 days
Statistics for webmail at UiO

```
webmail_stats=# SELECT * from pg_stat_user_tables where schemaname = 'public';
  relid   |schemaname|   relname   | seq_scan| seq_tup_read   | idx_scan | idx_tup_fetch | n_tup_ins | n_tup_upd | n_tup_del
----------+----------+-------------+---------+----------------+----------+---------------+-----------+-----------+-----------
 22516149| public    | users_stats |     593 |         28 962 |        0 |             0 |        96 |         0 |        93
 22516147| public    | login_stats |     983 |         32 294 |        0 |             0 |        64 |       128 |        62
   371003| public    | login_hist  |   6 205 |48 517 780 671  |  729 879 |36 563 060 420 |   978 195 |         0 |   445 161
```

```
webmail_stats=# SELECT * from pg_statio_user_tables where schemaname = 'public';
  relid   | schemaname |   relname   | heap_blks_read | heap_blks_hit | idx_blks_read | idx_blks_hit
----------+------------+-------------+----------------+---------------+---------------+--------------
 22516147 | public     | login_stats |            442 |         1 142 |         3 500 |          490
   371003 | public     | login_hist  |  3 046 174 877 |34 505 800 539 |   123 731 810 |   71 110 729
 22516149 | public     | users_stats |            336 |           632 |         1 580 |          310
```

From disk:

3 046 174 877 blocks x 8Kb/block = 2.436939902 x 10^{10} / 1024 / 1024 = 23 240 Gb
123 731 810 blocks x 8Kb/block = 9.89854480 x 10^{8} / 1024 / 1024 = 944 Gb

From RAM:

34 505 800 539 blocks x 8Kb/block = 2.760464042 x 10^{11} / 1024 / 1024 = 263 258 Gb
71 110 729 blocks x 8Kb/block = 5.68885832 x 10^{8} / 1024 / 1024 = 542 Gb

PostgreSQL

General performance tips

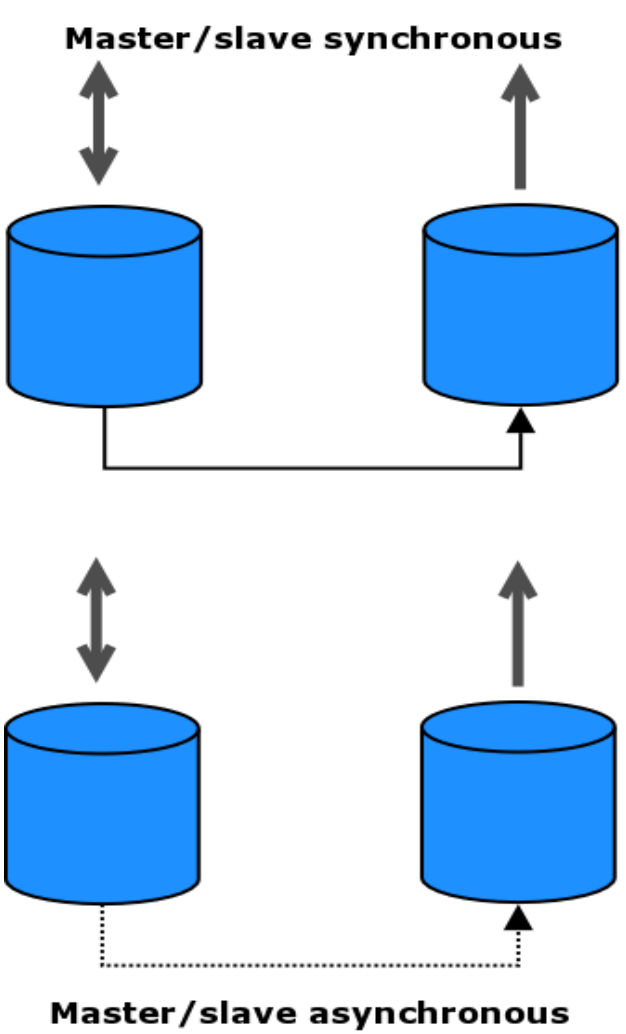
- Run ANALYZE / VACUUM ANALYZE often
- High-performance disk arrays > RAM > CPU
- More disks == better --> Use tablespaces
- RAID 1+0 / 0+1 > RAID 5
- Separate the Transaction Log from the Database - dedicated disk resources
- SCSI is preferred for heavily-used database servers
- Multiple CPUs help to spread multiple database connections among the available CPUs
- Use CLUSTER (or similar method) in heavily-updated tables

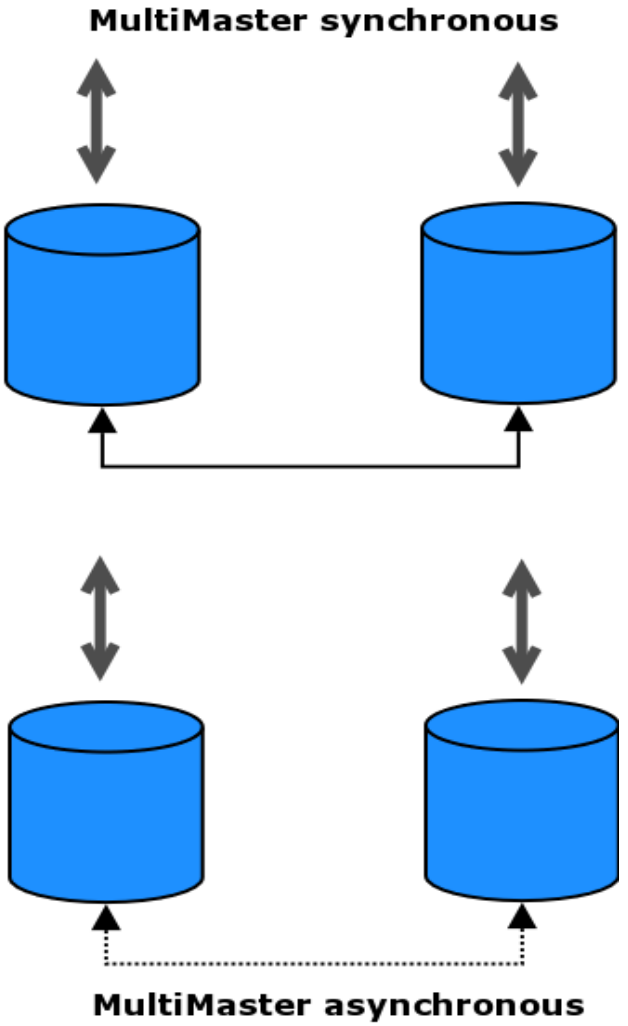
- Populating a Database with a large amount of data:
  - Use copy instead of inserts
  - Remove indexes during population
  - Increase `maintenance_work_mem`
  - Increase `checkpoint_segments`
  - fsync = false / do not forget to change this to true afterwards
  - Run ANALYZE afterwards

- Use LVM / journal-based file systems
- Data and backups on different disk resources
- Run the database in a dedicated server

Replication

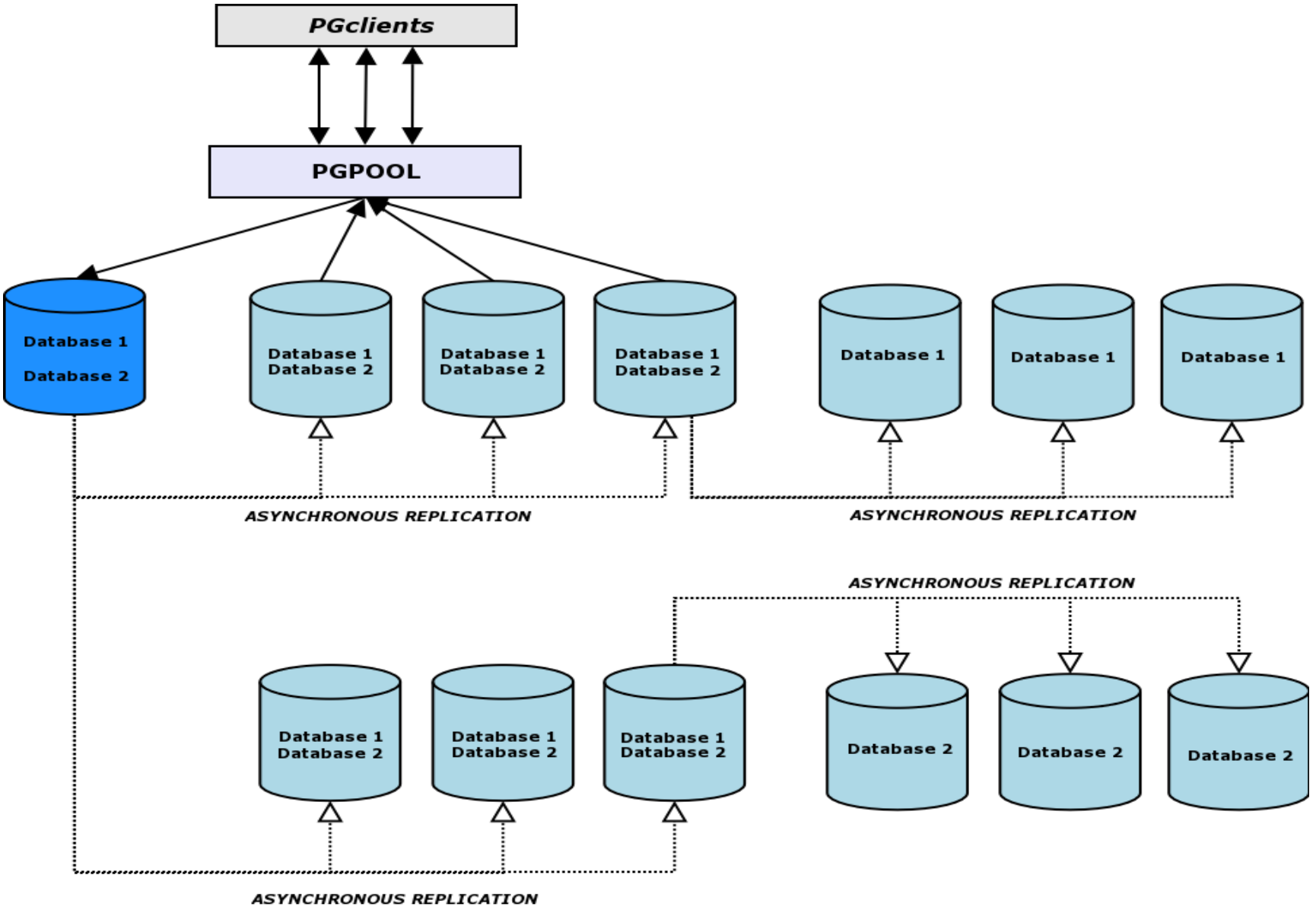

PostgreSQL


Master/slave synchronous
Master/slave asynchronous


MultiMaster synchronous
MultiMaster asynchronous

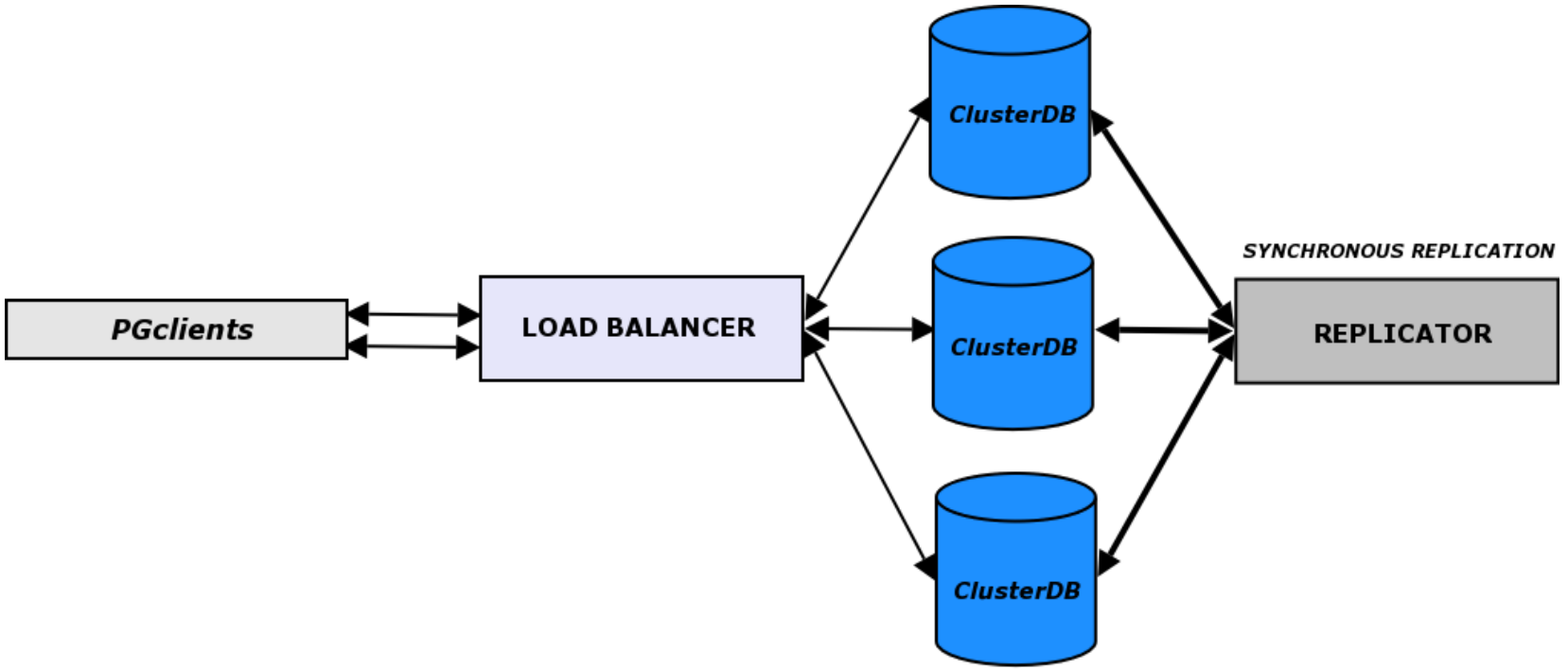
PostgreSQL

Pgpool / Slony -I

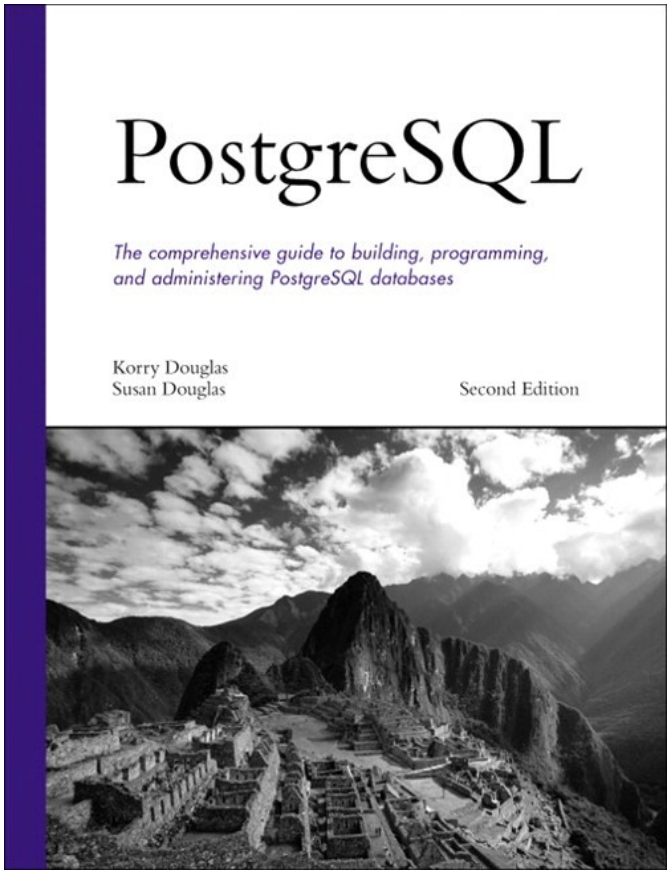


PostgreSQL

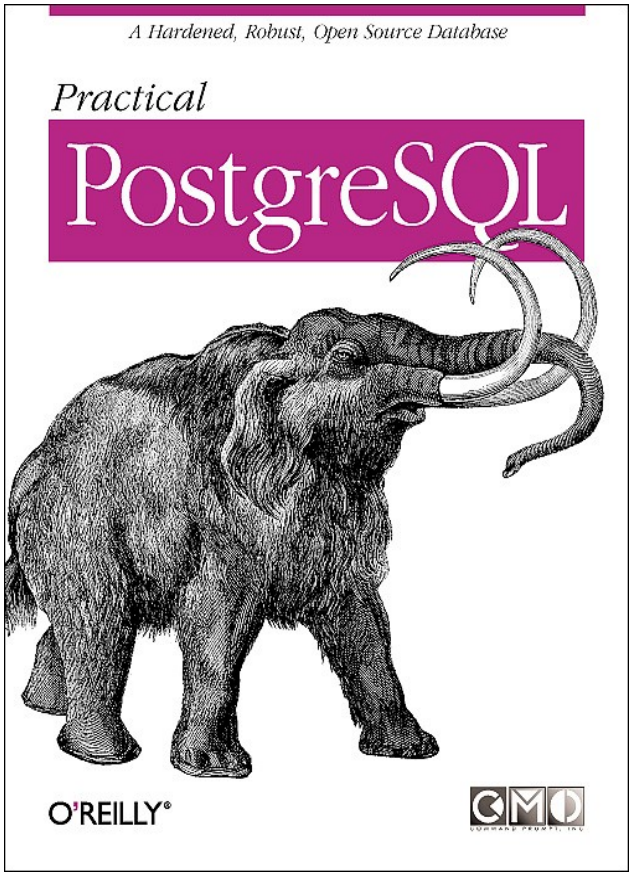
PGCluster



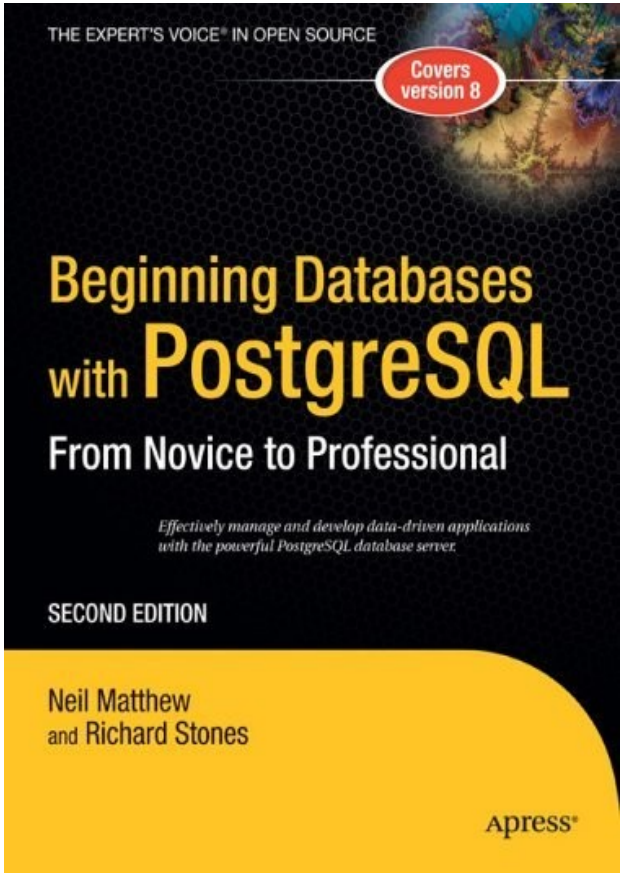
Books



[1]



[2]



[3]

[1] PostgreSQL (second edition), *Korry Douglas & Susan Douglas* – ISBN: 0-672-32756-2
[2] Practical PostgreSQL, *Command Prompt, Joshua Drake & John Worsley* – ISBN: 1-565-92846-6
[3] Beginning databases with PostgreSQL (second edition), *Richard Stones & Neil Matthew* – ISBN: 1-590-59478-9

[1][2]

Resources

- **PostgreSQL**: Official webside. - `http://www.postgresql.org/`
- **pgFoundry**: PG Project side - `http://pgfoundry.org/`
- **Mailing lists**: 20+. Must lists: *pgsql-admin*
  pgsql-general
  pgsql-performance
  pgsql-hackers
- **IRC**: `irc.freenode.net/#postgresql`

PostgreSQL

References

[1] PostgreSQL documentation, 8.0.x online manual - http://www.postgresql.org/docs/

[2] PostgreSQL (second edition), *Korry Douglas / Susan Douglas*, Developer's library.

[3] Beginning databases with PostgreSQL (second edition), *Richard Stones & Neil Matthew*

[4] PostgreSQL mailing lists, http://www.postgresql.org/community/lists/

[5] History of PostgreSQL – presentation, *Bruce Momjian* - *http://candle.pha.pa.us/*

[6] PostgreSQL Performance tunning – presentation, *Bruce Momjian* - http://candle.pha.pa.us/

[7] Mastering PostgreSQL administration – presentation, *Bruce Momjian* - http://candle.pha.pa.us/

[8] Data processing inside postgresql– presentation, *Bruce Momjian* - http://candle.pha.pa.us/

[9] PostgreSQL internals through pictures – presentation, *Bruce Momjian* - http://candle.pha.pa.us/

[10] PostgreSQL replication solutions – presentation, *Bruce Momjian* - http://candle.pha.pa.us/

[11] PostgreSQL: Past, Present, and Future – presentation, *Bruce Momjian* - http://candle.pha.pa.us/

[12] PostgreSQL hardware performance tunning – article, *Bruce Momjian* - http://candle.pha.pa.us/

[13] Get to know PostgreSQL – presentation, *Oddbjørn Steffensen* - http://www.tricknology.org/foilware/

[14] Power PostgreSQL - http://www.powerpostgresql.com/