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PostgreSQL File Manager

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- Relations as Files
- File Descriptor Pool
- File Manager

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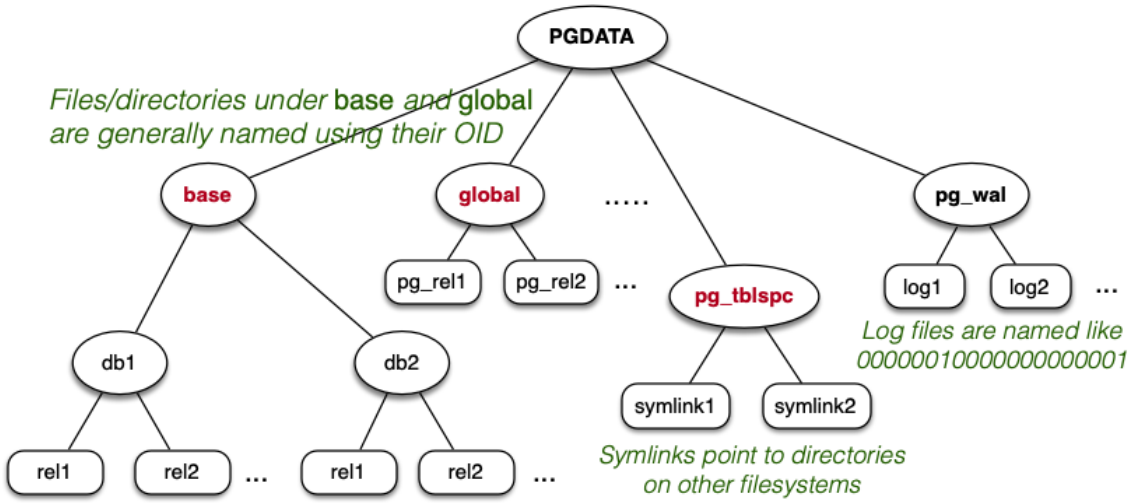
❖ PostgreSQL File Manager

PostgreSQL uses the following file organisation ...



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❖ PostgreSQL File Manager (cont)

Components of storage subsystem:

- mapping from relations to files (**`RelFileNode`**)
- abstraction for open relation pool (**`storage/smgr`**)
- functions for managing files (**`storage/smgr/md.c`**)
- file-descriptor pool (**`storage/file`**)

PostgreSQL has two basic kinds of files:

- heap files containing data (tuples)
- index files containing index entries

Note: **`smgr`** designed for many storage devices; only disk handler provided

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❖ Relations as Files

PostgreSQL identifies relation files via their OIDs.

The core data structure for this is **`RelFileNode`**:

```
typedef struct RelFileNode {
    Oid  spcNode;  // tablespace
    Oid  dbNode;   // database
    Oid  relNode;  // relation
} RelFileNode;
```

Global (shared) tables (e.g. **`pg_database`**) have

- **`spcNode == GLOBALTABLESPACE_OID`**
- **`dbNode == 0`**

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❖ Relations as Files (cont)

The **relpath** function maps **RelFileNode** to file:

```
char *relpath(RelFileNode r)  // simplified
{
   char *path = malloc(ENOUGH_SPACE);

   if (r.spcNode == GLOBALTABLESPACE_OID) {
      /* Shared system relations live in PGDATA/global */
      Assert(r.dbNode == 0);
      sprintf(path, "%s/global/%u",
              DataDir, r.relNode);
   }
   else if (r.spcNode == DEFAULTTABLESPACE_OID) {
      /* The default tablespace is PGDATA/base */
      sprintf(path, "%s/base/%u/%u",
              DataDir, r.dbNode, r.relNode);
   }
   else {
      /* All other tablespaces accessed via symlinks */
      sprintf(path, "%s/pg_tblspc/%u/%u/%u", DataDir
              r.spcNode, r.dbNode, r.relNode);
   }
   return path;
}
```

❖ File Descriptor Pool

Unix has limits on the number of concurrently open files.

PostgreSQL maintains a pool of open file descriptors:

- to hide this limitation from higher level functions
- to minimise expensive **`open()`** operations

File names are simply strings: **`typedef char *FileName`**

Open files are referenced via: **`typedef int File`**

A **`File`** is an index into a table of "virtual file descriptors".

❖ File Descriptor Pool (cont)

Interface to file descriptor (pool):

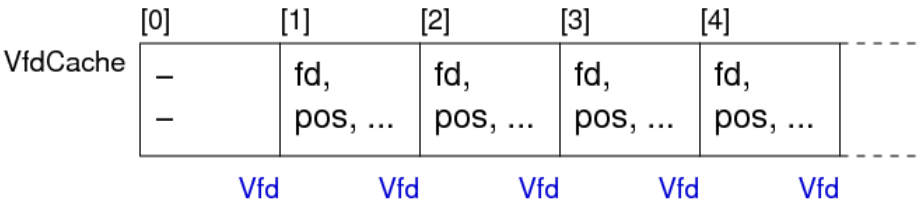
```
File FileNameOpenFile(FileName fileName,
                      int fileFlags, int fileMode);
     // open a file in the database directory ($PGDATA/base/...)
File OpenTemporaryFile(bool interXact);
     // open temp file; flag: close at end of transaction?
void FileClose(File file);
void FileUnlink(File file);
int  FileRead(File file, char *buffer, int amount);
int  FileWrite(File file, char *buffer, int amount);
int  FileSync(File file);
long FileSeek(File file, long offset, int whence);
int  FileTruncate(File file, long offset);
```

Analogous to Unix syscalls **`open()`**, **`close()`**, **`read()`**, **`write()`**, **`lseek()`**, ...

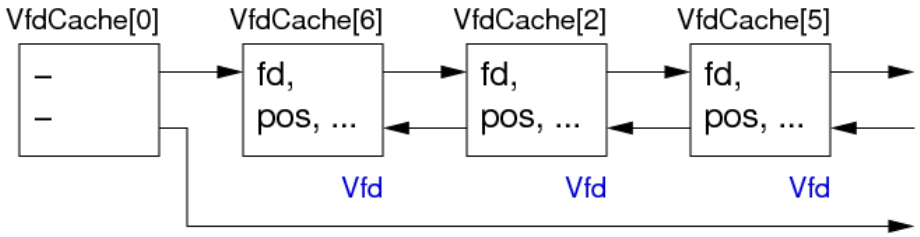
❖ File Descriptor Pool (cont)

Virtual file descriptors (**`Vfd`**)

- physically stored in dynamically-allocated array



- also arranged into list by recency-of-use



`VfdCache[0]` holds list head/tail pointers.

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❖ File Descriptor Pool (cont)

Virtual file descriptor records (simplified):

```
typedef struct vfd
{
    s_short  fd;                // current FD, or VFD_CLOSED if none
    u_short  fdstate;           // bitflags for VFD's state
    File     nextFree;          // link to next free VFD, if in freelist
    File     lruMoreRecently;   // doubly linked recency-of-use list
    File     lruLessRecently;
    long     seekPos;           // current logical file position
    char     *fileName;         // name of file, or NULL for unused VFD
    // NB: fileName is malloc'd, and must be free'd when closing the VFD
    int      fileFlags;         // open(2) flags for (re)opening the file
    int      fileMode;          // mode to pass to open(2)
} Vfd;
```

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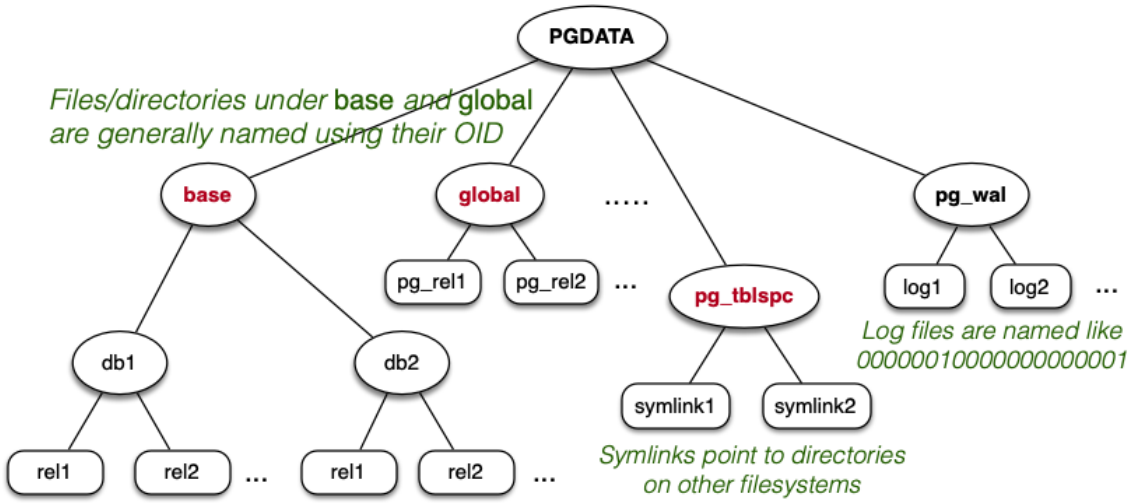
❖ File Manager

Reminder: PostgreSQL file organisation



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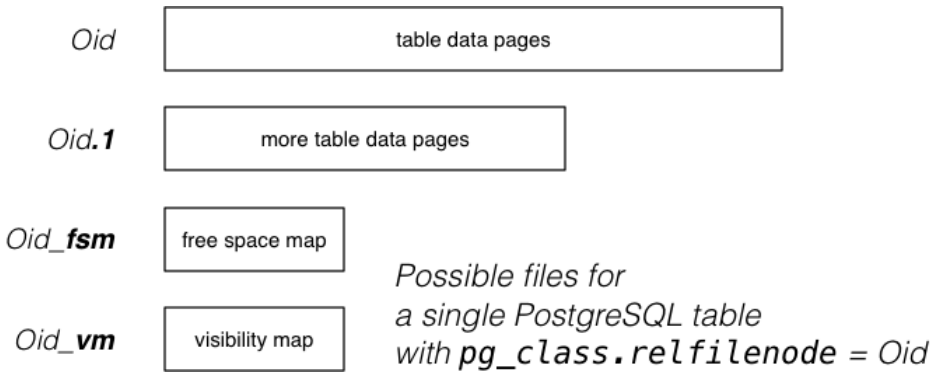
❖ File Manager (cont)

PostgreSQL stores each table

- in the directory ***PGDATA*/pg_database.oid**
- often in multiple files (aka *forks*)



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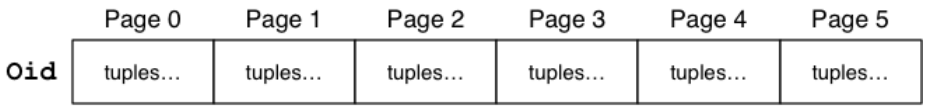
❖ File Manager (cont)

Data files (*Oid*, *Oid*.1, ...):

- sequence of fixed-size blocks/pages (typically 8KB)
- each page contains tuple data and admin data (see later)
- max size of data files 1GB (Unix limitation)



PostgreSQL Data File (Heap)

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❖ File Manager (cont)

Free space map (*Oid*_`fsm`):

- indicates where free space is in data pages
- "free" space is only free after **`VACUUM`**
  (**`DELETE`** simply marks tuples as no longer in use **`xmax`**)

Visibility map (*Oid*_`vm`):

- indicates pages where all tuples are "visible"
  (*visible* = accessible to all currently active transactions)
- such pages can be ignored by **`VACUUM`**

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❖ File Manager (cont)

The "magnetic disk storage manager" (**`storage/smgr/md.c`**)

- manages its own pool of open file descriptors (Vfd's)
- may use several Vfd's to access data, if several forks
- manages mapping from **`PageID`** to file+offset.

PostgreSQL **`PageID`** values are structured:

```
typedef struct
{
    RelFileNode rnode;     // which relation/file
    ForkNumber  forkNum;   // which fork (of reln)
    BlockNumber blockNum; // which page/block
} BufferTag;
```

❖ File Manager (cont)

Access to a block of data proceeds (roughly) as follows:

```
// pageID set from pg_catalog tables
// buffer obtained from Buffer pool
getBlock(BufferTag pageID, Buffer buf)
{
    Vfd vf;  off_t offset;
    (vf, offset) = findBlock(pageID)
    lseek(vf.fd, offset, SEEK_SET)
    vf.seekPos = offset;
    nread = read(vf.fd, buf, BLOCKSIZE)
    if (nread < BLOCKSIZE) ... we have a problem
}
```

`BLOCKSIZE` is a global configurable constant (default: 8192)

❖ File Manager (cont)

```
findBlock(BufferTag pageID) returns (Vfd, off_t)
{
   offset = pageID.blockNum * BLOCKSIZE
   fileName = relpath(pageID.rnode)
   if (pageID.forkNum > 0)
      fileName = fileName+"."+pageID.forkNum
   if (fileName is not in Vfd pool)
      fd = allocate new Vfd for fileName
   else
      fd = use Vfd from pool
   if (pageID.forkNum > 0) {
      offset = offset - (pageID.forkNum*MAXFILESIZE)
   }
   return (fd, offset)
}
```

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