Eat My Data:

How everybody gets file I/O wrong

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What I work on

- MySQL Cluster
- High Availability
- (Shared Nothing) Clustered Database
- with some real time properties

Overview

- Common mistakes that lead to data loss

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- Mistakes by:
  - the application programmer

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Overview

- Common mistakes that lead to data loss
- Mistakes by:
  - the application programmer
  - the library programmer
  - the kernel programmer
- Mostly just concentrating on Linux
  - will mention war stories on other platforms too

In the beginning

- All IO was synchronous

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- When you called write things hit the platter

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- All IO was synchronous
- When you called write things hit the platter
- Turns out that this is slow for a lot of cases

A world without failure

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- computers crash

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  - suspend works, resume doesn't
- When the data is important, live in the world of failure

Data Consistency

- In the event of failure, what state can I expect my data to be in?

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- If there isn't an explicit save (e.g. RSS readers, IM logs) some recent version should be okay.
- Not Acceptable:
  - I hit save, why is none of my work there?
  - Why have all my IM logs disappeared?
  - Why have all my saved passwords disappeared?

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  - Repeatable Read, Read Committed etc
- Very well known consistency issues
  - that lots of people still get wrong
  - different engines have different properties

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- okay at larger objects (BLOBs)
  - named after “The Blob”, not Binary Large Objects
- Accessed by a variety of ways
  - indexes

Easy solution to data consistency

- put it in a database
  - that gives data consistency guarantees
- We'll talk about this later

Revelation #1

- Databases are not file systems!

Revelation #2

- File systems are not databases!

Revelation #3

- A database has different consistency semantics than a file system

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- A database has different consistency semantics than a file system
  - typically file systems a lot more relaxed

Eat my data

- Where can the data be to eat?

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  - application crash = loss of this data

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- Library buffer - glibc
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- Operating System buffer – page/buffer cache
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- on disk
  - disk failure = loss of data

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- OS buffer to disk
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    - Can be **very** delayed with laptop mode
  - fsync(2), fdatasync(2), sync(2)
    - with caveats!

Simple Application: Save==on disk

- User hits “Save” in Word Processor
  - Expects that data to be on disk when “Saved”
- How?

Saving a simple document

```
struct wp_doc {
  char *document;
  size_t len;
};
struct wp_doc d;
...
FILE *f;
f= fopen(“important_document”,”w”);
fwrite(d.document,d.len,1,f);
```

Bug #1

- No fclose(2)
  - Buffers for the stream may not be flushed from libc cache

Word Processor Saving -1 Bug

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struct wp_doc {
   char *document;
   size_t len;
};
struct wp_doc d;
...
FILE *f;
f= fopen(“important_document”,”w”);
fwrite(d.document,d.len,1,f);
fclose(f);
```

Bug #2, 3 and 4

- No error checking!
- fopen
  - Did we open the file
- fwrite
  - did we write the entire file (ENOSPC?)
- fclose
  - did we successfully close the file

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  - **meta**data **only**
  - no data is written to the journal
  - integrity of file system structures
  - not internals of files

Data journaling

- is nothing like a database transaction

Atomic write(2)

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- It isn't
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- A file system with atomic write(2)
  - can't rely on it being there
  - Essentially useless

Eat My Data

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   char *document;
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};
struct wp_doc d;
...
FILE *f;
f= fopen(“important_document”,”w”);
fwrite(d.document,d.len,1,f);  ◄──────   CRASH
fclose(f);
```

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- Old trick of writing to temp file first
- Can catch any errors
  - e.g. ENOSPC
  - don't rename on error
- Idea that if we crash during writing temp file user data is safe
  - although we may leave around a temp file

Temp file, rename

```
struct wp_doc {
    char *document;
    size_t len;
};
struct wp_doc d;
...
FILE *f;
f= fopen(“important_document.temp”,”w”);
if(!f) return errno;
size_t w= fwrite(d.document,d.len,1,f);
if(w<d.len) return errno;
fclose(f);
rename(“important_document.temp”,”important_document”);
```

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Now all is good with the world...

- This is where a lot of people stop
- close(2) and rename(2) do **not** imply sync
- They make no guarantees on when (or in what order) changes hit the platter
- Quite possible (and often) metadata is flushed before data

File System Integrity

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  - other file systems **are** different

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- data=ordered mode on ext3
  - writes data before metadata
  - other file systems **are** different
- ext3 ordered mode is an **exception**, not the rule
  - applications relying on this are not portable and depend on file system behaviour. the **applications** are buggy.

data=ordered

- write()
- close()
- rename()
- Disk order:
  - data from fwrite()
  - inode
  - directory entry

other systems

- write()
- close()
- rename()
- Disk order:
  - any!

flush and sync

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struct wp_doc {
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FILE *f;
f= fopen(“important_document.temp”,”w”);
if(!f) return errno;
size_t w= fwrite(d.document,d.len,1,f);
if(w<d.len) return errno;
if(fflush(f)!=0) return errno;
if(fsync(fileno(f))==-1) return errno;
fclose(f);
rename(“important_document.temp”,”important_document”);
```

Flush the buffers!

Sync to disk **before** rename

A tale of libxml2

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- libxml2 provides utility functions to “write XML to file”
- Nice application developer saves time by using libxml2's function
  - Application developer writes to temp file, renames
  - User looses data after crash
  - Nice application developer has to work around limitations of library

so, replace

- xmlSaveFile(foo)

```
gint common_save_xml(xmlDocPtr doc, gchar *filename) {
        FILE    *fp;
        char    *xmlbuf;
        int     fd, n;

        fp = g_fopen(filename, "w");
        if(NULL == fp)
                return -1;

        xmlDocDumpFormatMemory(doc, (xmlChar **)&xmlbuf, &n, TRUE);
        if(n <= 0) {
                errno = ENOMEM;
                return -1;
        }

        if(fwrite(xmlbuf, sizeof (xmlChar), n, fp) < n) {
                xmlFree (xmlbuf);
                return -1;
        }

        xmlFree (xmlbuf);

        /* flush user-space buffers */
        if (fflush (fp) != 0)
                return -1;

        if ((fd = fileno (fp)) == -1)
                return -1;

#ifdef HAVE_FSYNC
        /* sync kernel-space buffers to disk */
        if (fsync (fd) == -1)
                return -1;
#endif

        fclose(fp);

        return 0;
}
```

Nearing Nirvana

- If any failure during writing, the previously saved copy is untouched and safe
  - User wont get partial or no data

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- On Linux, fsync(2) does actually sync
  - barring enabling write cache
- On MacOS X, not so much

on fsync, POSIX Says...

- If _POSIX_SYNCHRONIZED_IO is not defined, the wording relies heavily on the conformance document to tell the user what can be expected from the system. It is explicitly intended that a null implementation is permitted.

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POSIX compliant fsync

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gcc →

POSIX compliant fsync

```c
int fsync(int fd)
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```

gcc →

```
pushl   %ebp
movl    %esp, %ebp
movl    $0, %eax
popl    %ebp
ret
```

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Tale of a really fast database server

- A while ago (pre MySQL 4.1.9)
- Seeing corruption of InnoDB pages
  - only on MacOS X
- Also, things seemed pretty fast

fsync() doesn't have to sync

- On MacOS X, fsync() doesn't flush drive write cache

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- An extra fcntl is provided to do this

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- Let's see the InnoDB code for ensuring data is synced to disk
  - if this doesn't work, transactions don't work

```
#ifdef HAVE_DARWIN_THREADS
# ifdef F_FULLFSYNC
   /* This executable has been compiled on Mac OS X 10.3 or later.
   Assume that F_FULLFSYNC is available at run-time. */
   srv_have_fullfsync = TRUE;
# else /* F_FULLFSYNC */
   /* This executable has been compiled on Mac OS X 10.2
   or earlier.  Determine if the executable is running
   on Mac OS X 10.3 or later. */
   struct utsname utsname;
   if (uname(&utsname)) {
      fputs("InnoDB: cannot determine Mac OS X version!\n", stderr);
   } else {
      srv_have_fullfsync = strcmp(utsname.release, "7.") >= 0;
   }
   if (!srv_have_fullfsync) {
      fputs("InnoDB: On Mac OS X, fsync() may be"
            " broken on internal drives,\n"
            "InnoDB: making transactions unsafe!\n", stderr);
   }
# endif /* F_FULLFSYNC */
#endif /* HAVE_DARWIN_THREADS */
```

```c
#if defined(HAVE_DARWIN_THREADS)
# ifndef F_FULLFSYNC
        /* The following definition is from the Mac OS X 10.3 <sys/fcntl.h> */
#  define F_FULLFSYNC 51 /* fsync + ask the drive to flush to the media */
# elif F_FULLFSYNC != 51
#  error "F_FULLFSYNC != 51: ABI incompatibility with Mac OS X 10.3"
# endif
        /* Apple has disabled fsync() for internal disk drives in OS X. That
        caused corruption for a user when he tested a power outage. Let us in
        OS X use a nonstandard flush method recommended by an Apple
        engineer. */

        if (!srv_have_fullfsync) {
                /* If we are not on an operating system that supports this,
                then fall back to a plain fsync. */

                ret = fsync(file);
        } else {
                ret = fcntl(file, F_FULLFSYNC, NULL);

                if (ret) {
                        /* If we are not on a file system that supports this,
                        then fall back to a plain fsync. */
                        ret = fsync(file);
                }
        }
#elif HAVE_FDATASYNC
        ret = fdatasync(file);
#else
        /*      fprintf(stderr, "Flushing to file %p\n", file); */
        ret = fsync(file);
#endif
```

Yes, some OS Vendors hate you

- Thanks to all the permutations of reliably getting data to a disk platter, a simple call is now two screens of code

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- Time to start REDO/UNDO logging
  - other cool tricks
- Or not care so much
  - e.g. DVD ripping
- Some video software saves frame-per-file

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- Traditional directory is stored on disk as list of name,inode
- lookup is search through this list
- Allocation of disk space to directories is block-at-a-time, leading to fragmentation
- Directory indexes help
  - some better than others
- Can't always control the file system
  - count on over a few thousand files being **slow**

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- sqlite is ACID with a capital D for Durability
- takes hard work out of things
- Not so good with many clients
- Brilliant for a document format though
- Scales up to “a few dozen GB of data” before not being as efficient as other RDBMs

Performance of Large files

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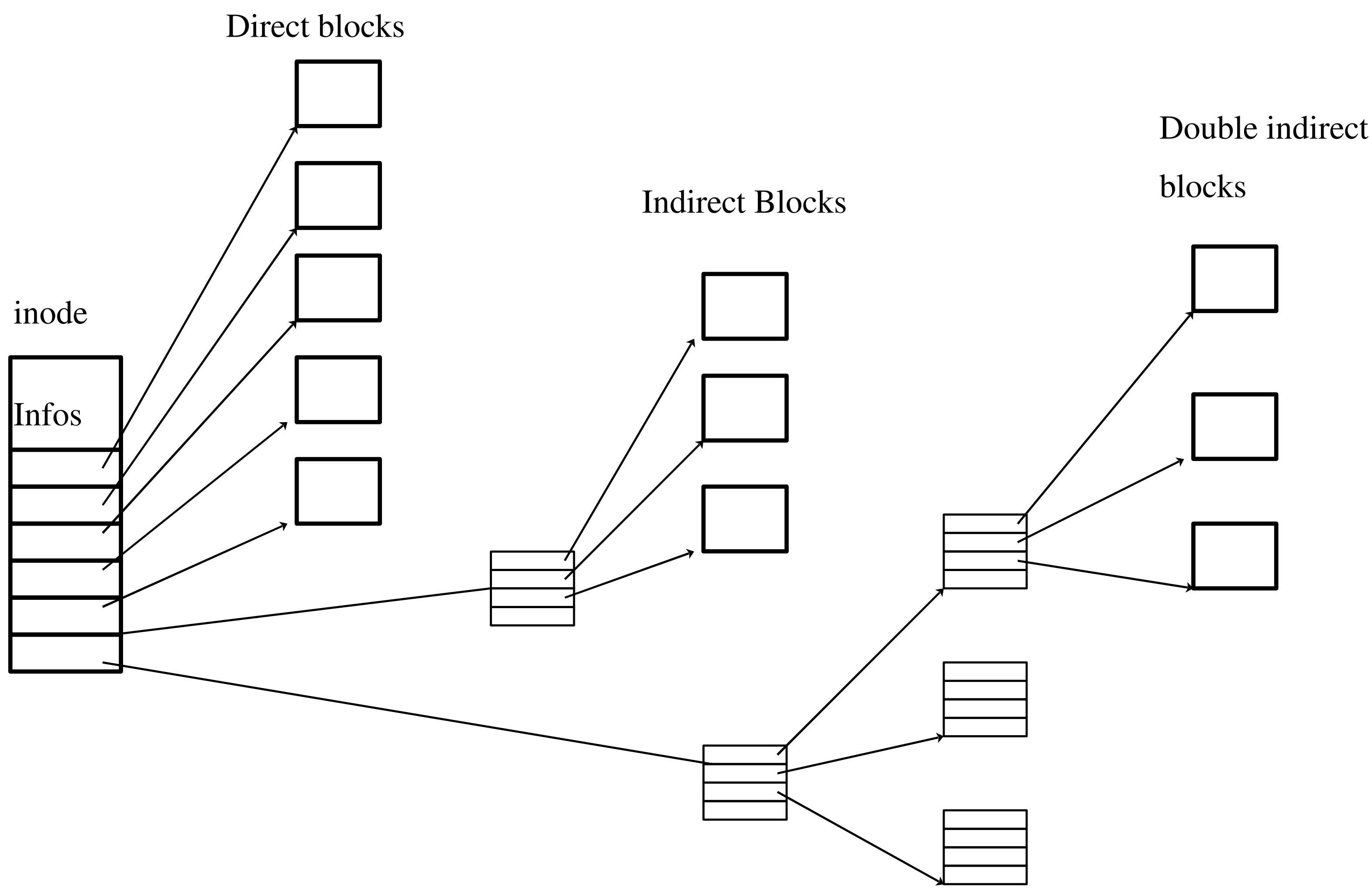
- Extents based file systems much more efficient
- Zeroing takes long time
  - support for unwritten extents means fast zeroing
  - think CREATE TABLESPACE
  - think bittorrent


Direct blocks
Double indirect
blocks
Indirect Blocks
inode
Infos

Extent

- start disk block
- start file block
- length
- flags
  - e.g. unwritten

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- Files can get interweaved ababab
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  - reading performance suffers
  - especially with slow growing files
- Preallocate disk space
  - with no standard way to do it... :(

Preallocation

- Often the file system will do it for you
  - doesn't work as well with O_SYNC
- No (useful) standard way to preallocate space
  - posix_fallocate doesn't work
  - xfsctl for files on XFS

Tablespace allocation in NDB

```
#ifdef HAVE_XFS_XFS_H
    if(platform_test_xfs_fd(theFd))
    {
      ndbout_c("Using xfsctl(XFS_IOC_RESVSP64) to allocate disk
space");
      xfs_flock64_t fl;
      fl.l_whence= 0;
      fl.l_start= 0;
      fl.l_len= (off64_t)sz;
      if(xfsctl(NULL, theFd, XFS_IOC_RESVSP64, &fl) < 0)
        ndbout_c("failed to optimally allocate disk space");
    }
#endif
#ifdef HAVE_POSIX_FALLOCATE
    posix_fallocate(theFd, 0, sz);
#endif
```

Improvements in mysql-test-run

- Would run several nodes on one machine
  - each creating tablespace files
  - all IO is O_SYNC

Improvements in mysql-test-run

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Library Developers

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    int fstat(int filedes, struct stat *buf);
    ```

There is hope

- You can do file IO correctly
- You can prevent data loss
- You can pester people to make life easier

Good Luck!

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- and please don't eat my data