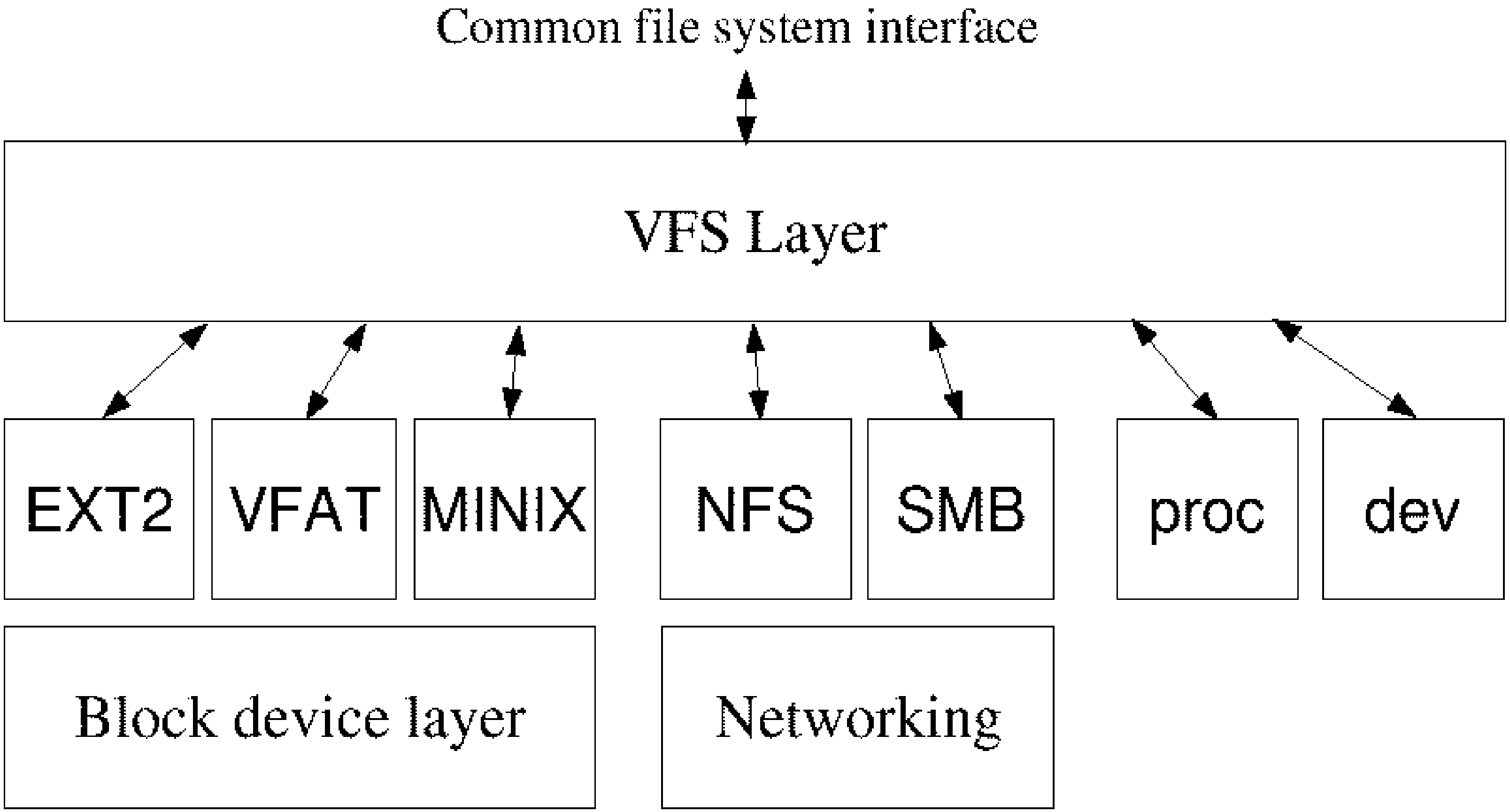
Ausgewählte Betriebssysteme

Filesystem

File Systems

- Name space
  - Hierarchical tree structure
- Simple I/O API
  - `open, close, read, write`
- Uniform interface
  - Persistent storage
  - I/O devices
  - Interprocess communication
  - Kernel-user communication

File System types



File System Types (2)

- Persistent
  - Block device based (disk)
    - Ext2, VFAT ....
  - Network based
    - NFS, coda, AFS
- Virtual
  - Provide information through file API
    - procfs, sysfs, devfs, usbfs...

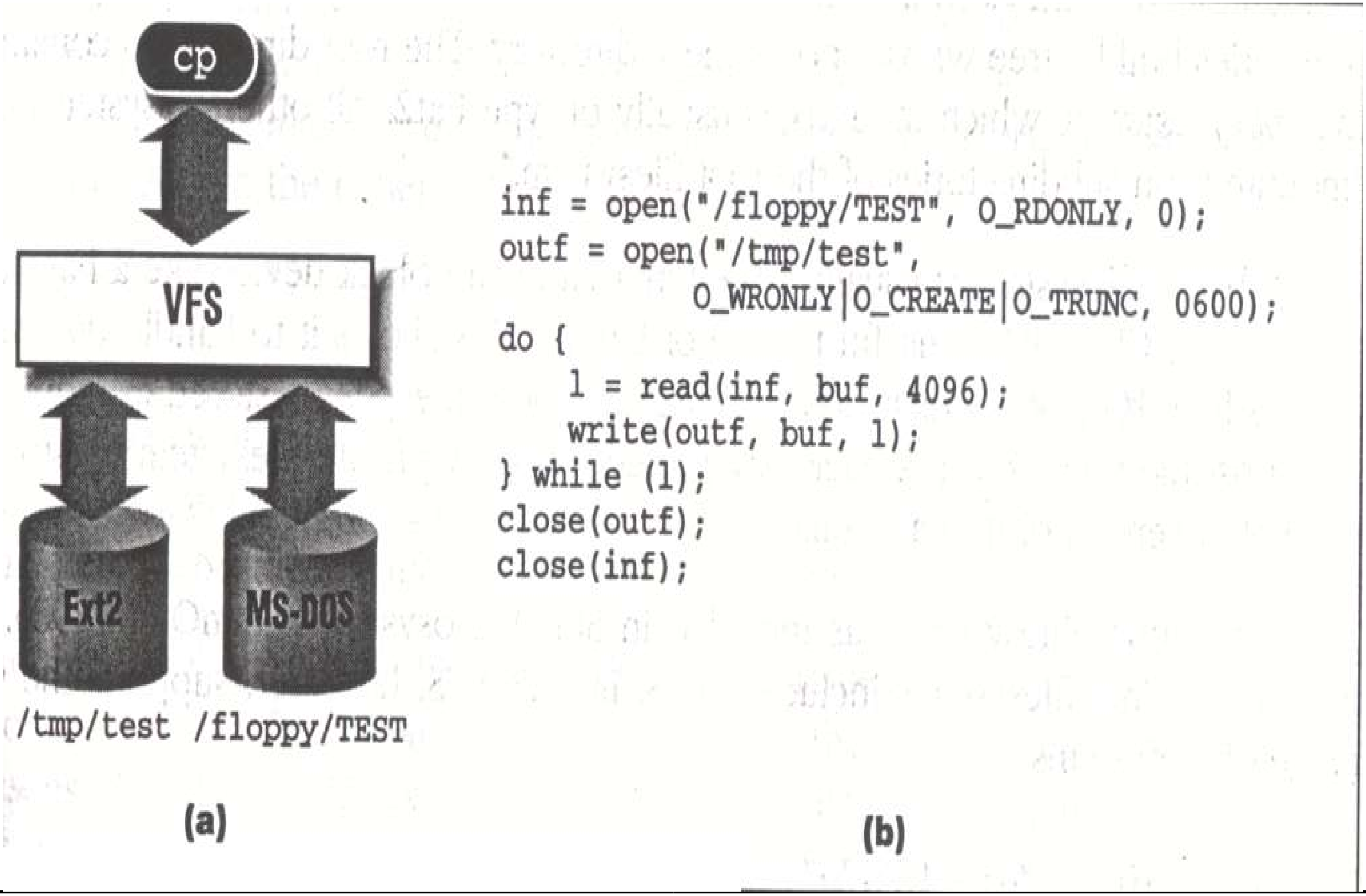
File systems (3)

```
peter@krypton:~> uname -a
Linux krypton 2.5.67 #1 SMP Tue Apr 8 00:17:05 CEST 2003 i686 unknown
peter@krypton:~> cat /proc/filesystems
nodev   sysfs
nodev   rootfs
nodev   bdev
nodev   proc
nodev   sockfs
nodev   usbfs
nodev   usbdevfs
nodev   futexfs
nodev   tmpfs
nodev   pipefs
nodev   eventpollfs
nodev   binfmt_misc
nodev   devpts
        ext3
        ext2
nodev   ramfs
        iso9660
nodev   nfs
nodev   nfsd
nodev   autofs
        reiserfs
nodev   oprofilefs
nodev   rpc_pipefs
```

VFS Layer

- Virtual Filesystem Switch
- Kernel abstraction for different file system implementations
- Framework
  - Define usage model
  - Implement common functionality
  - Provide hooks for specific implementations

User view



```
inf = open("/floppy/TEST", O_RDONLY, 0);
outf = open("/tmp/test",
            O_WRONLY|O_CREATE|O_TRUNC, 0600);
do {
    l = read(inf, buf, 4096);
    write(outf, buf, l);
} while (l);
close(outf);
close(inf);
```

Common File Model

- Mirrors UNIX file model strictly
- Features not available in a particular FS must be emulated
  - Directories as files (UNIX) vs. special tables (FAT)
- Indirection layer associated with objects
  - Pointer to function pointer table

Commen File Model (2)

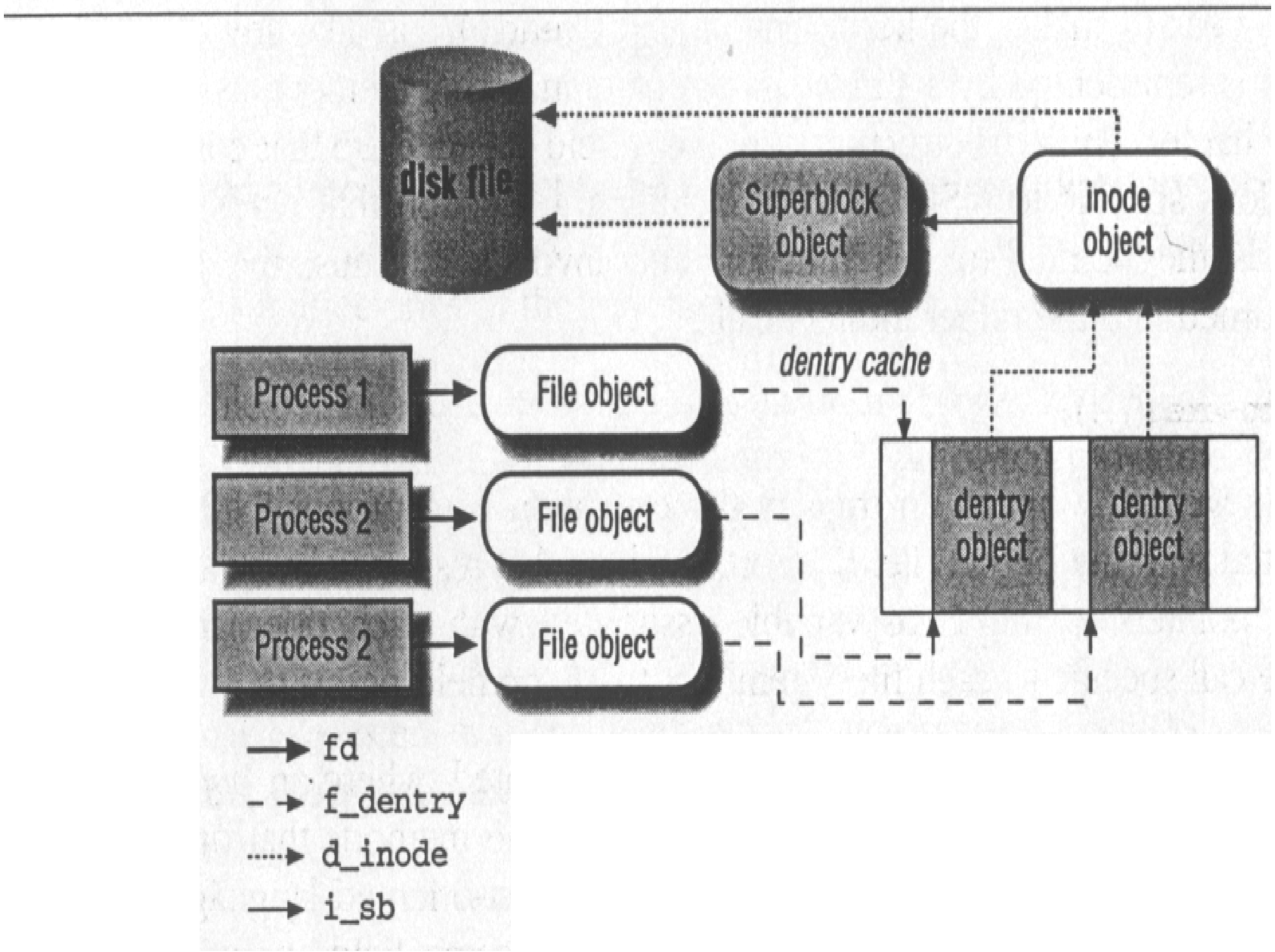
- Superblock (whole fs instance)
  - Represents a whole mounted file system
- Inode (unique entity for an object in a fs)
  - Manages properties of that particular object on disk
- Dentry (directory structure)
  - Represents an entry in a directory
  - Supports path-name to inode mapping
- File (file as seen by a task)
  - Session specific

Object indirection

- Each object has an function pointer table associated with it
- VFS framework calls customized function

  -
    ```
    size_t (*read)(struct file *, char * size_t loff_t *);
    if (file->f_op && (read = file-f_op-read) != NULL)
       ret = read(file, buf, count , &file-f_ops);
    ```
- Actual functions provided by file system implementation
- Operation table filled upon object creation or initialization

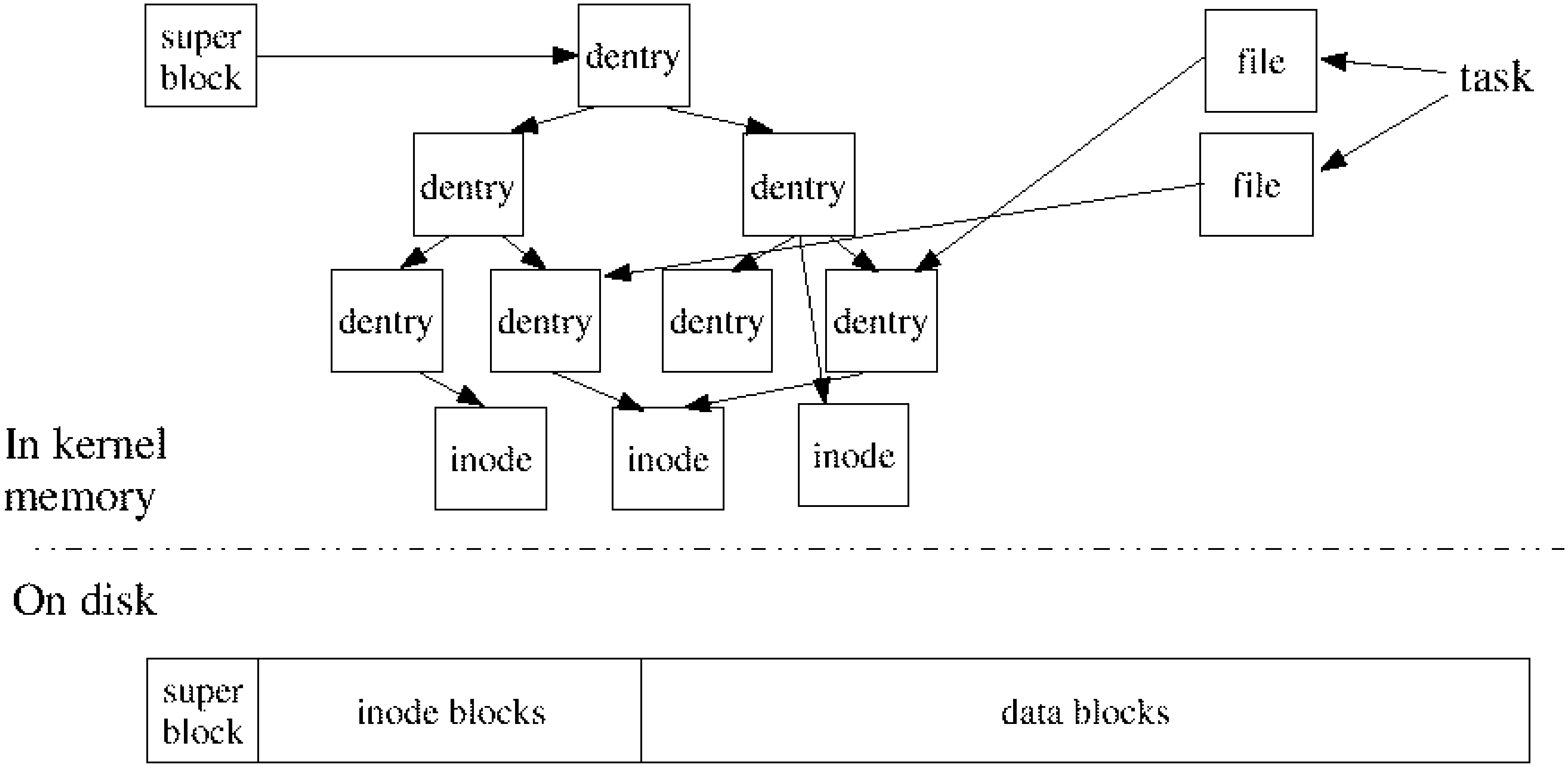
VFS objects


disk file
Superblock object
inode object
dentry cache
Process 1
File object
Process 2
File object
Process 2
File object
dentry object
dentry object
fd
f_dentry
d_inode
i_sb

Memory objects

- VFS objects are cached in memory
- Read from disk when needed
- Slab allocator for each object type

Disk and memory objects



super block

dentry

dentry

dentry

dentry

dentry

dentry

dentry

file

file

task

inode

inode

inode

In kernel memory

On disk

super block

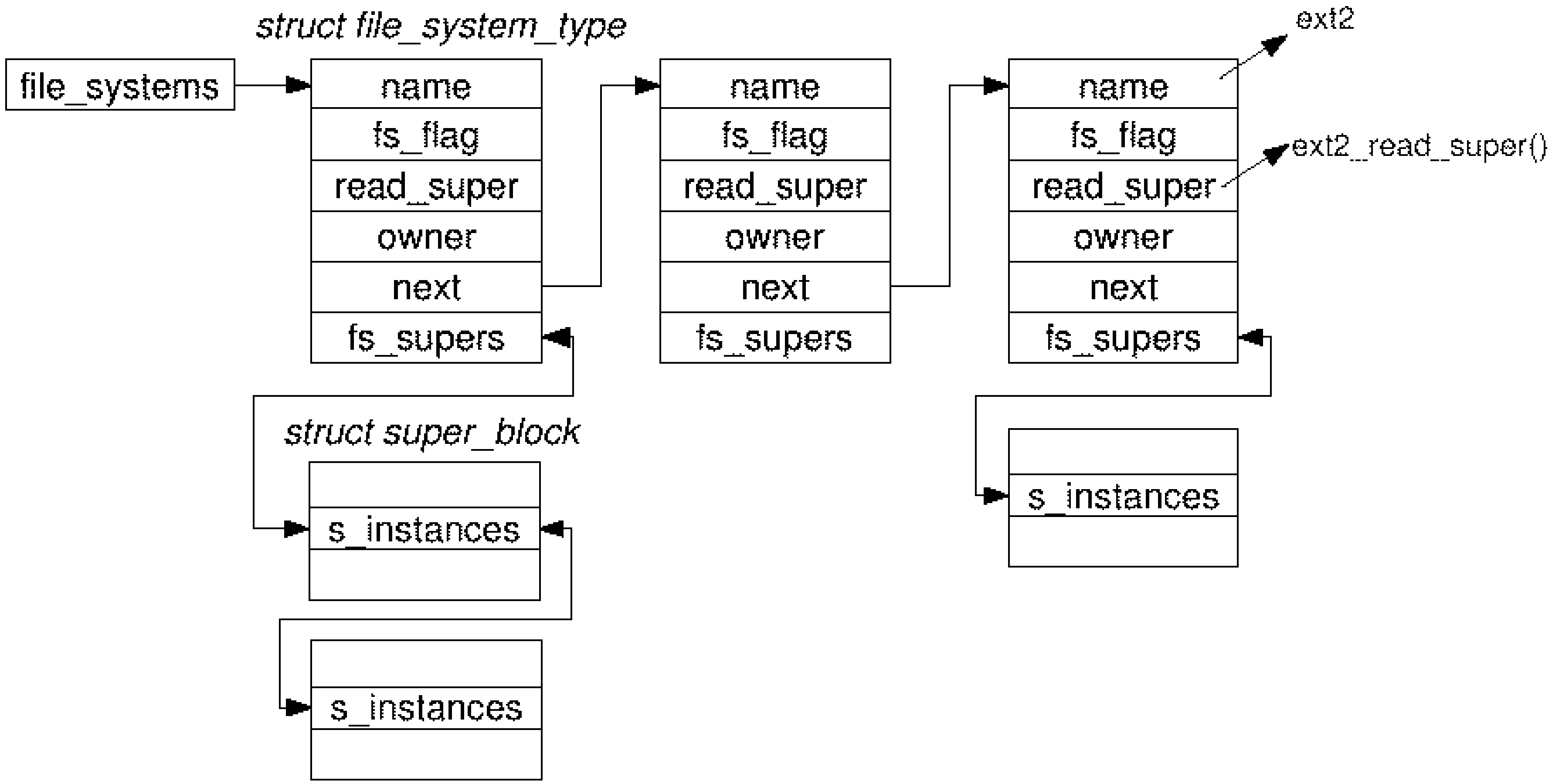
inode blocks

data blocks

File system types

- Structure for each particular file system
  - Populated during system startup or module loading
  - Upon mounting each registered file system probes partition unless the type is explicitly provided
- Important properties
  - `name` identifying name
  - `read_super` file system specific function
  - `fs_supers` all mounted file systems in a list
  - `owner` module that provides the implementation

Registered file systems



FS registration

```
/* file: fs/ext2/super.c */

static struct file_system_type ext2_fs_type =
{
      .owner     = THIS_MODULE,
      .name      = "ext2",
      .get_sb    = ext2_get_sb,
      .kill_sb   = kill_block_super,
      .fs_flags  = FS_REQUIRES_DEV,
};
```

```
static int __init init_ext2_fs(void)
{
      int err = init_ext2_xattr();
      if (err)
            return err;
      err = init_inodecache();
      if (err)
            goto out1;
        err = register_filesystem(&ext2_fs_type);
      if (err)
            goto out;
      return 0;
out:
      destroy_inodecache();
out1:
      exit_ext2_xattr();
      return err;
}
static void __exit exit_ext2_fs(void)
{
      unregister_filesystem(&ext2_fs_type);
      destroy_inodecache();
      exit_ext2_xattr();
}
module_init(init_ext2_fs)
module_exit(exit_ext2_fs)
```

Superblock

- Kernel data structure for a mounted fs
  - Data type: `struct super_block` (include/linux/fs.h)
- Important fields
  - fs parameters: `s_blocksize, s_maxsize`
  - fs type: `s_type`
  - Pointer to method array: `s_op`
  - File system specific data: `s_fs_info`
  - root dentry: `s_root`

Superblock (2)

- `struct super_operations` include/linux/fs.h
  - – Load inode object from disk: `read_inode`
  - – Write inode object to disk: `write_inode`
  - – Decrement reference count: `put_inode`
  - – Decrement superblock object: `put_super`
  - – Delete inode (with file content): `delete_inode`

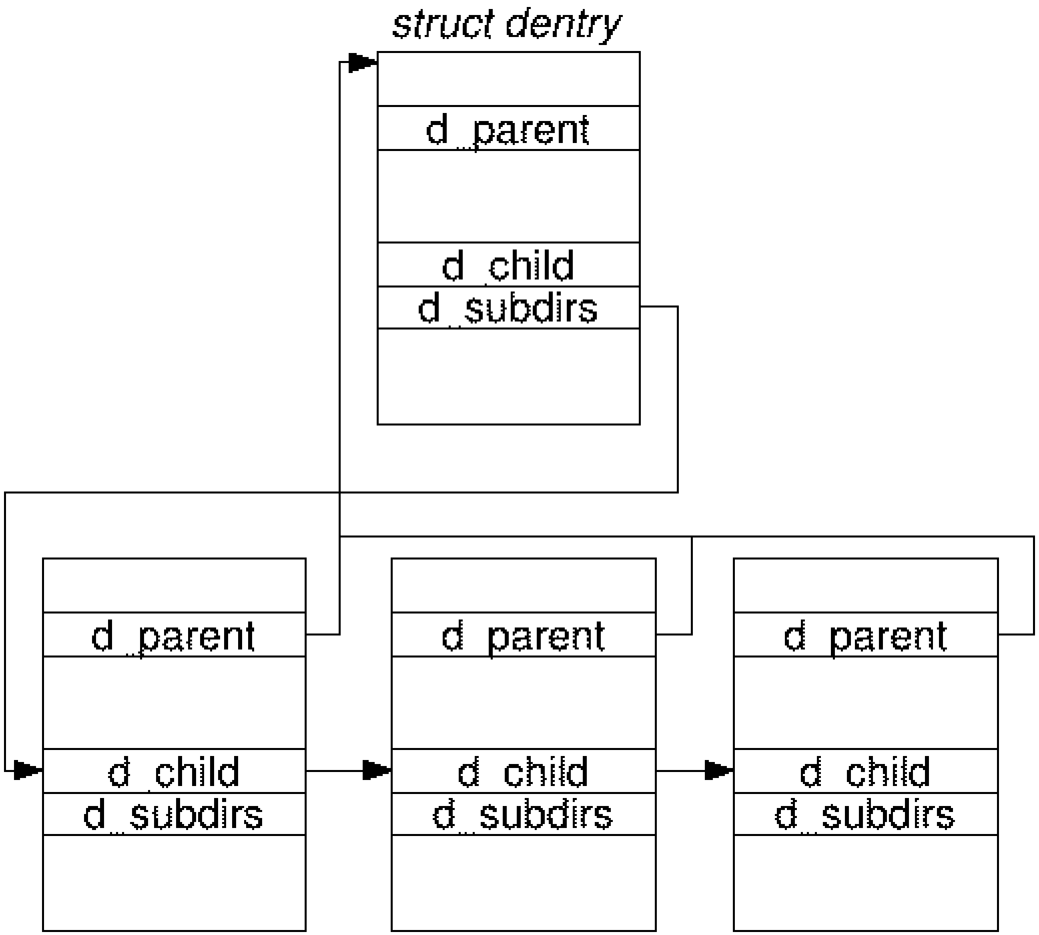
dentry

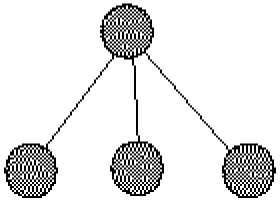
- Kernel data structure for directory entry
  - Associates name with inode object
    - Several dentries can refer to the same inode
  - No corresponding disk data structure
    - Directories are files with special interpreted content (UNIX)
- dentry cache
  - Recently used (looked up) dentry object will be kept in a slab cache

dentry lists

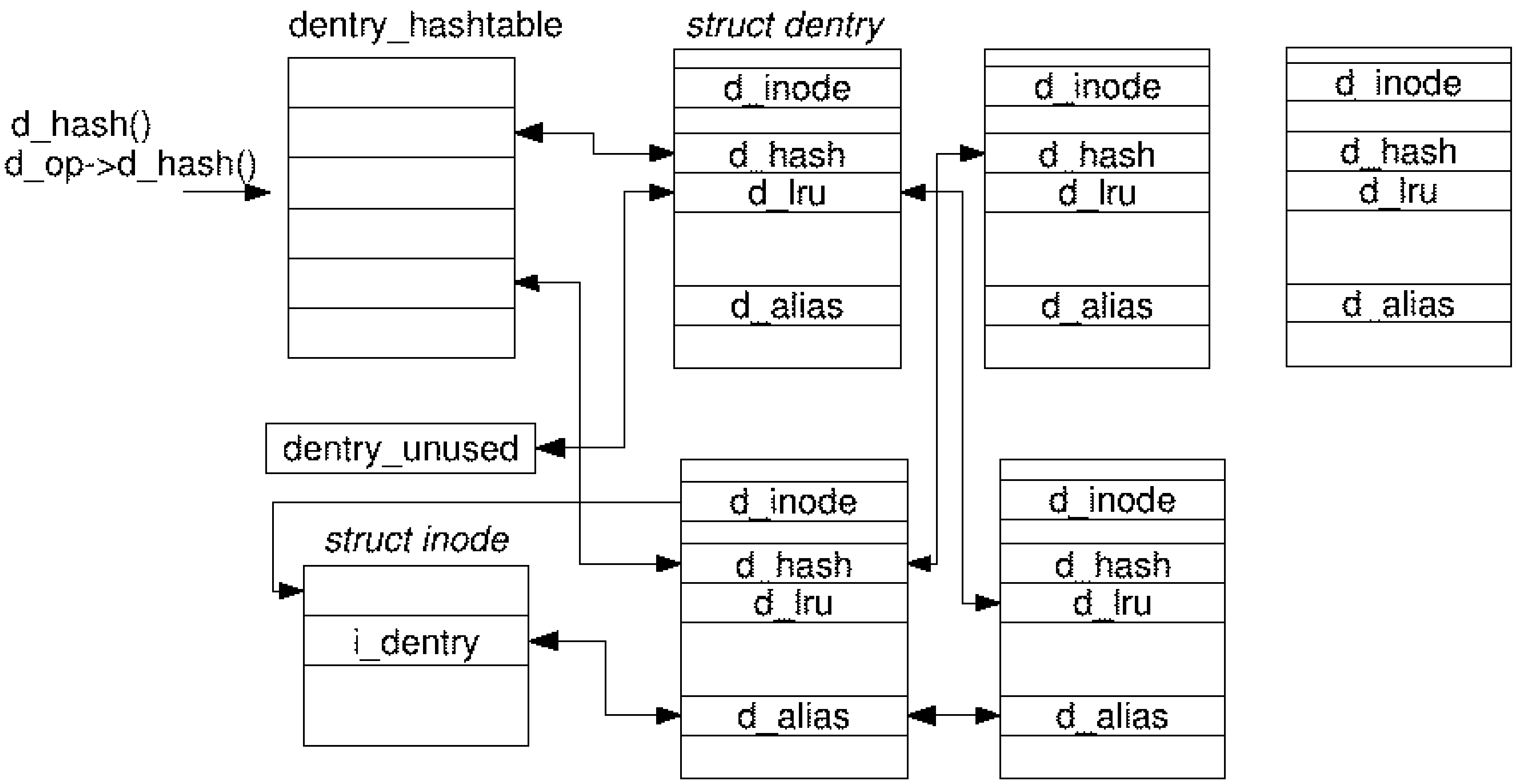
- Tree layout
  - Reflecting the directory layout
- Hash table
  - Fast lookup from filename to dentry object
- List of unused dentry objects
- List of aliases
  - Same inode, different dentries (hardlinks)

dentry tree


struct dentry
d_parent
d_child
d_subdirs
d_parent
d_child
d_subdirs
d_parent
d_child
d_subdirs
d_parent
d_child
d_subdirs



dentry lists (2)



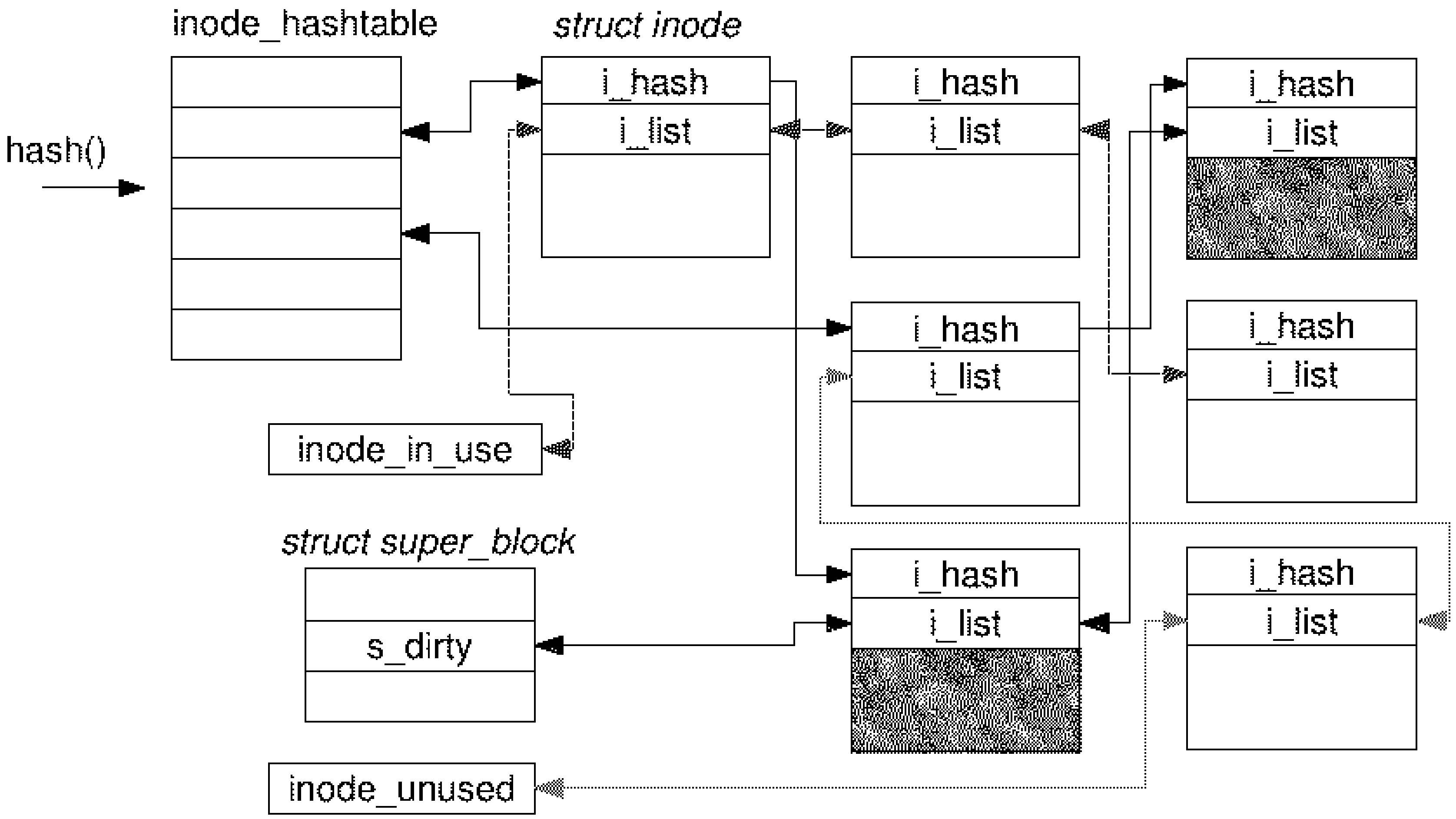
inode

- Kernel data structure for a file (or directory)
  - Inode number is unique per fs
  - Names are not (hard links)
- To access a file
  - Allocate inode object in memory
  - Initialize it with data from disk
- Inode cache
  - Recently used objects (in memory) are kept for further reference

Inode data structure

- `Struct inode` (include/linux/fs.h)
- Important fields
  - Number, superblock: `i_ino, i_sb`
  - Reference counter: `i_count`
  - File information: `i_mode, i_nlink, i_uid, i_gid, i_size,i_atime, i_mtime, i_ctime, i_blksize, i_blocks`
  - Inode methods: `i_op`
  - Default file methods: `i_fop`
  - Inode lists: `i_hash, i_list`
  - Referring dentries: `i_dentry`

inode (2)


inode_hashtable
struct inode
hash()
i_hash
i_list
i_hash
i_list
i_hash
i_list
i_hash
i_list
i_hash
i_list
inode_in_use
struct super_block
s_dirty
i_hash
i_list
i_hash
i_list
inode_unused

inode methods

- `struct inode_operations` (include/linux/fs.h)
- fs dependent operations on inode
  - Create a new inode (and a new file): `create`
  - Find by name: `lookup`
  - Create, remove hardlink: `link, unlink`
  - Create, remove directory: `mkdir, rmdir`
  - Special cases: `symlink, mknod`

file objects

- Kernel data structure for a file opened by a task
  - `struct file` (include/linux/fs.h)
- Important fields
  - dentry object: `f_dentry`
  - File operations: `f_op`
  - Current file pointer: `f_pos`
  - Reference count: `f_count`
  - List link: `f_list`
  - Device driver data: `private_data`

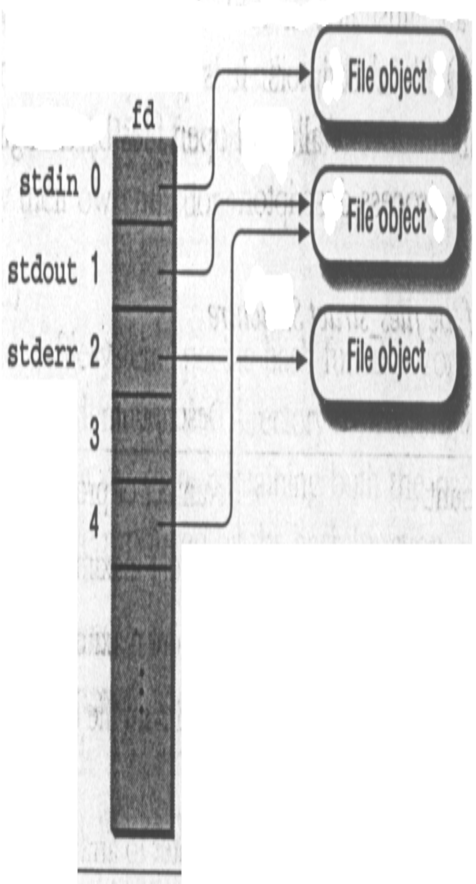
File operations

```
struct file_operations {
    struct module *owner;
    loff_t (*llseek) (struct file *, loff_t, int);
    ssize_t (*read) (struct file *, char __user *, size_t, loff_t *);
    ssize_t (*aio_read) (struct kiocb *, char __user *, size_t, loff_t);
    ssize_t (*write) (struct file *, const char __user *, size_t, loff_t *);
    ssize_t (*aio_write) (struct kiocb *, const char __user *, size_t, loff_t);
    int (*readdir) (struct file *, void *, filldir_t);
    unsigned int (*poll) (struct file *, struct poll_table_struct *);
    int (*ioctl) (struct inode *, struct file *, unsigned int, unsigned long);
    int (*mmap) (struct file *, struct vm_area_struct *);
    int (*open) (struct inode *, struct file *);
    int (*flush) (struct file *);
    int (*release) (struct inode *, struct file *);
    int (*fsync) (struct file *, struct dentry *, int datasync);

    int (*aio_fsync) (struct kiocb *, int datasync);
    int (*fasync) (int, struct file *, int);
    int (*lock) (struct file *, int, struct file_lock *);
    ssize_t (*readv) (struct file *, const struct iovec *, unsigned long, loff_t *);
    ssize_t (*writev) (struct file *, const struct iovec *, unsigned long, loff_t *);
    ssize_t (*sendfile) (struct file *, loff_t *, size_t, read_actor_t, void *);
    ssize_t (*sendpage) (struct file *, struct page *, int, size_t, loff_t *, int);
    unsigned long (*get_unmapped_area)(struct file *, unsigned long, unsigned long, unsigned long,
unsigned long);
};
```

Tasks and files

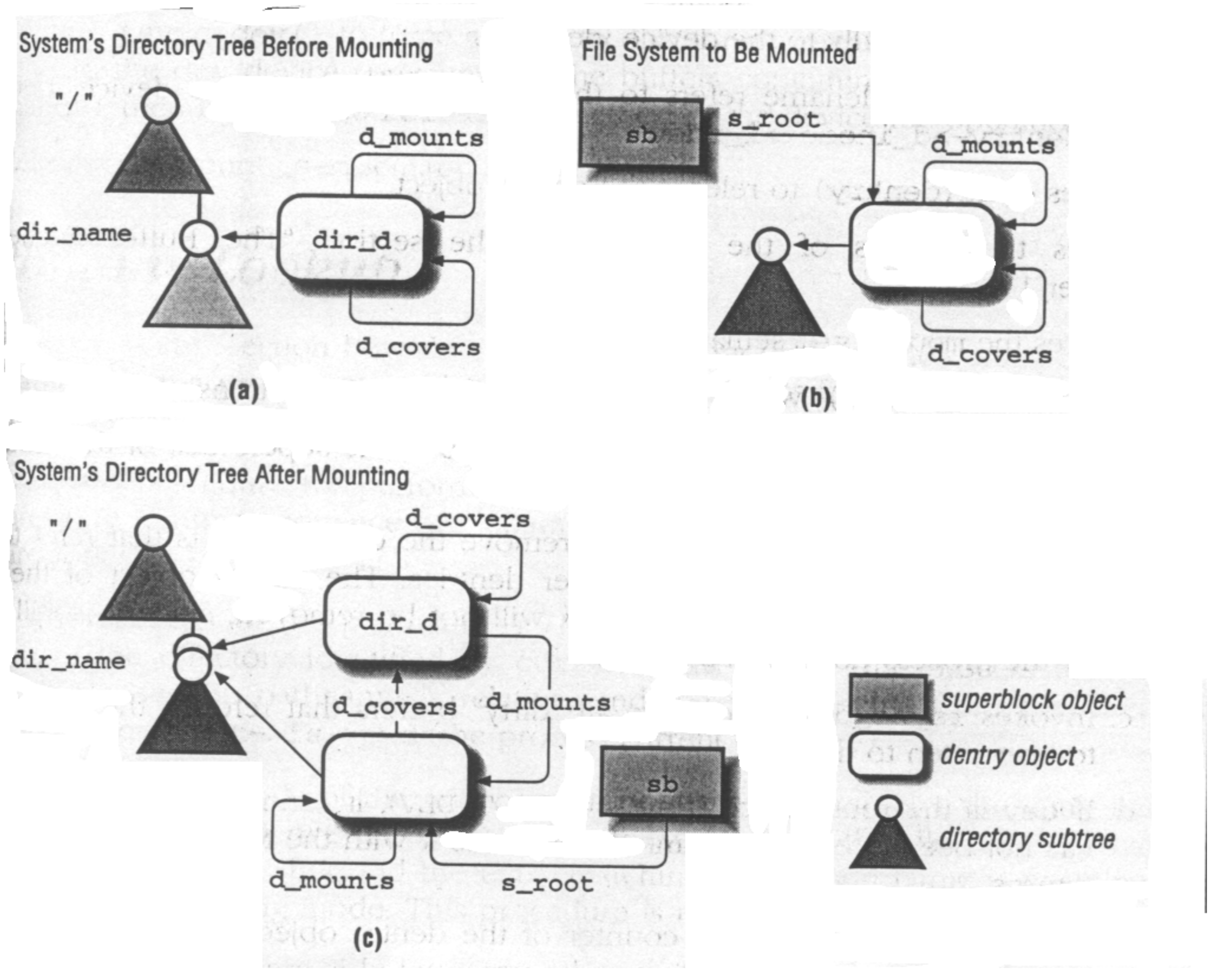
- Fields in `task_struct`
- `struct fs_struct *fs`
  - fs related information
    - `struct dentry *root`
    - `sturct dentry *pwd`
- `struct files_struct *files`
  - Currently open files
  - `t->files->fd[i]` to access file for file descriptor i



Mounting a file system

- Filesystem mounting
  - Each fs can be represented by a tree structure
  - Mounting: graft the root of one filesystem tree to the leaf of another to get a bigger tree
- Terminologies
  - Mount point: leave of a file system where the next fs gets appended
  - Root file system: root fs, by magic on the top
  - Root directory of a mounted fs
- Data structure: struct vfsmount
  - Representing a mounted fs instance

Mount anatomy



Walking a path

- Find the inode for a given pathname
  - Common problem, used frequently
- Starting point dentry:
  - Leading '/': current->fs->root
  - Otherwise: current->fs->pwd
- Special handling when walking a path
  - Symbolic links (loop detection)
  - Access permission
  - Crossing a mount point into another filesystem

Path Walking procedure

- Two relevant functions
  - Lookup path, lock final dentry: `path_lookup(name, flags, nd)`
  - Decrement reference counts: `path_release(nd)`
- `struct nameidata nd` is the context used for walking
  - Field `struct dentry *dentry`: the current (last used) dentry
  - Field `struct vfsmount *mnt`: current file system

`path_lookup` preparation

- Set up the nameidata object before walking
  - Set dentry and mnt to the starting point
  - Initialize flags and other fields
  - If name starts with '/'

    -
      ```
      nd->mnt = mntget(current->fs->rootmnt);
      nd->dentry = dget(current->fs->root);
      ```
  - If name does not start with '/'

    -
      ```
      nd->mnt = mntget(current->fs->pwdmnt);
      nd->dentry = dget(current->fs->pwd);
      ```

Walking further

- Actual work done in `link_path_walk`
- For each real path component
  - Check for permission: `permission`
  - Calculate hash value
  - Check for special component name (like '.', '..')
  - Lookup from the dcache: `cached_lookup`
  - Lookup from disk if not cached: `real_lookup`
  - Check mountpoint, symbolic links, errors etc.
  - Set the dentry in `nd` down to the new component

dentry cache lookup

- Look up the dentry in dcache
  - Call `d_lookup` to return the dentry
  - Call `dentry->d_op->d_revalidate` if defined
    - Usually in network fs for stale files
- Routine d_lookup
  - Find the hash bucket with `d_hash`
  - Search the list for matching parent and filename
  - Use `parent->d_op->d_compare` if defined to match the filename

Real lookup

- Load dentry from the disk
  - Called when cached_lookup fails to return the dentry
- Essentially
  - Get a free dentry (from dcache) and set the filename

    ```
    struct dentry *dentry = d_alloc(parent, name)
    ```
  - Call parent inodes lookup method to file the dentry

    ```
    struct inode *dir = parent->d_inode
    dir->i_op->lookup(dir,dentry)
    ```
  - Filesystem-specific `lookup` involves searching the directory content, and perhaps loading a new inode