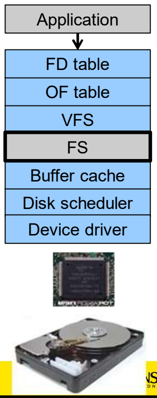
UNIX File Management (continued)

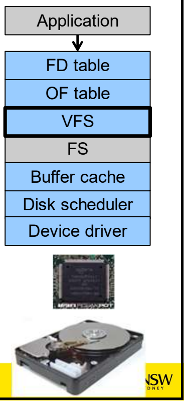
1

OS storage stack (recap)



2

Virtual File System (VFS)



3

Older Systems only had a single file system

•They had file system specific open, close, read, write, … calls.

•However, modern systems need to support many file system types

–ISO9660 (CDROM), MSDOS (floppy), ext2fs, tmpfs

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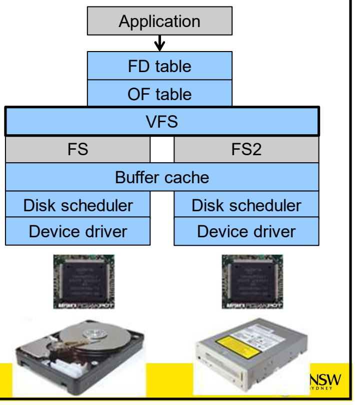
Supporting Multiple File Systems

Alternatives

- Change the file system code to understand different file system types
  - Prone to code bloat, complex, non-solution
- Provide a framework that separates file system independent and file system dependent code.
  - Allows different file systems to be “plugged in”

5

Virtual File System (VFS)



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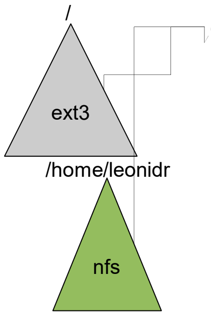
Virtual file system (VFS)


/

ext3

/home/leonidr

nfs

open(“/home/leonidr/file”, …);

Traversing the directory hierarchy may require VFS to issue requests to several underlying file systems

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Virtual File System (VFS)

- Provides single system call interface for many file systems
  - E.g., UFS, Ext2, XFS, DOS, ISO9660,…
- Transparent handling of network file systems
  - E.g., NFS, AFS, CODA
- File-based interface to arbitrary device drivers (`/dev`)
- File-based interface to kernel data structures (`/proc`)
- Provides an indirection layer for system calls
  - File operation table set up at file open time
  - Points to actual handling code for particular type
  - Further file operations redirected to those functions

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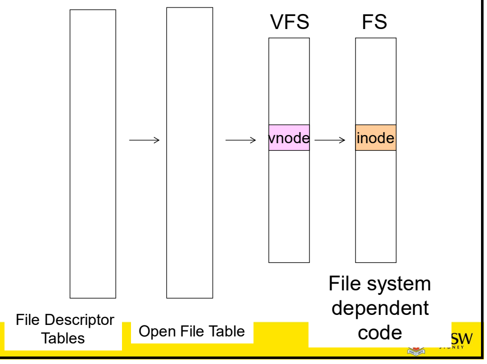
The file system independent code deals with vfs and vnodes


VFS

FS

vnode

inode

File Descriptor Tables

Open File Table

File system dependent code

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VFS Interface

- Reference
  - S.R. Kleiman., *"Vnodes: An Architecture for Multiple File System Types in Sun Unix,"* USENIX Association: Summer Conference Proceedings, Atlanta, 1986
  - Linux and OS/161 differ slightly, but the principles are the same
- Two major data types
  - VFS
    - Represents all file system types
    - Contains pointers to functions to manipulate each file system as a whole (e.g. mount, unmount)
      - Form a standard interface to the file system
  - Vnode
    - Represents a file (inode) in the underlying filesystem
    - Points to the real inode
    - Contains pointers to functions to manipulate files/inodes (e.g. open, close, read, write,…)

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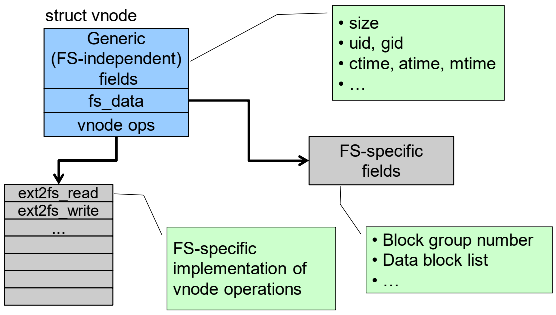
Vfs and Vnode Structures


struct vnode

Generic (FS-independent) fields

fs_data

vnode ops

- size
- uid, gid
- ctime, atime, mtime
- …

FS-specific fields

ext2fs_read

ext2fs_write

…

FS-specific implementation of vnode operations

- Block group number
- Data block list
- …

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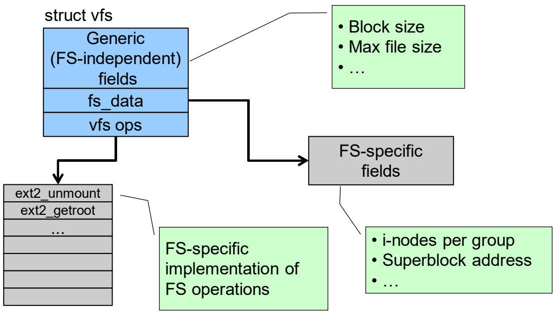
Vfs and Vnode Structures


struct vfs

Generic (FS-independent) fields

fs_data

vfs ops

- Block size
- Max file size
- …

FS-specific fields

ext2_unmount

ext2_getroot

…

FS-specific implementation of FS operations

- i-nodes per group
- Superblock address
- …

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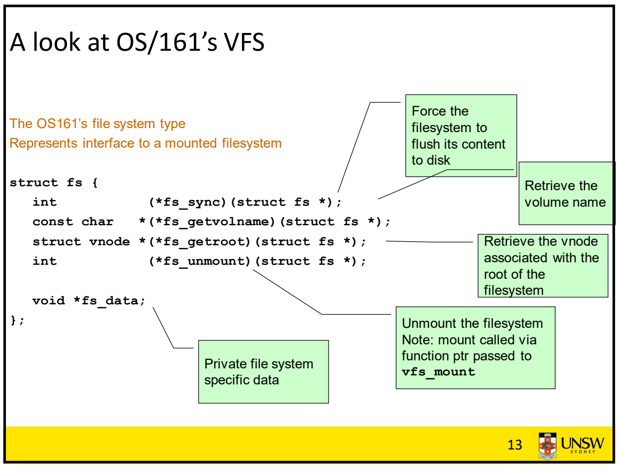

A look at OS/161's VFS

The OS161's file system type
Represents interface to a mounted filesystem

```
struct fs {
   int           (*fs_sync)(struct fs *);
   const char    *(*fs_getvolname)(struct fs *);
   struct vnode *(*fs_getroot)(struct fs *);
   int           (*fs_unmount)(struct fs *);

   void *fs_data;
};
```

Force the filesystem to flush its content to disk

Retrieve the volume name

Retrieve the vnode associated with the root of the filesystem

Unmount the filesystem Note: mount called via function ptr passed to `vfs_mount`

Private file system specific data

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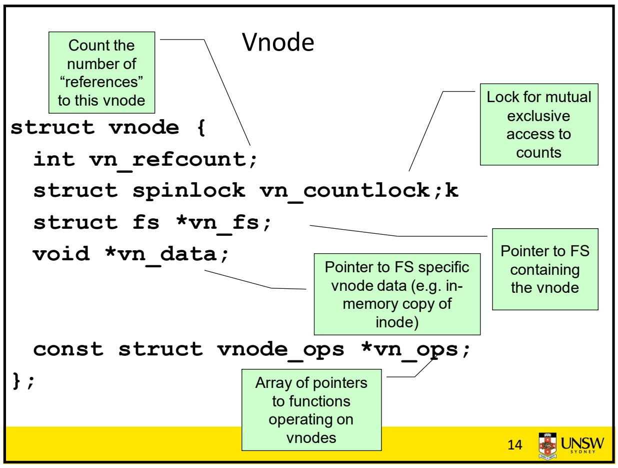

Vnode

```
struct vnode {
  int vn_refcount;
  struct spinlock vn_countlock;k
  struct fs *vn_fs;
  void *vn_data;

  const struct vnode_ops *vn_ops;
};
```

Count the number of "references" to this vnode

Lock for mutual exclusive access to counts

Pointer to FS containing the vnode

Pointer to FS specific vnode data (e.g. in-memory copy of inode)

Array of pointers to functions operating on vnodes

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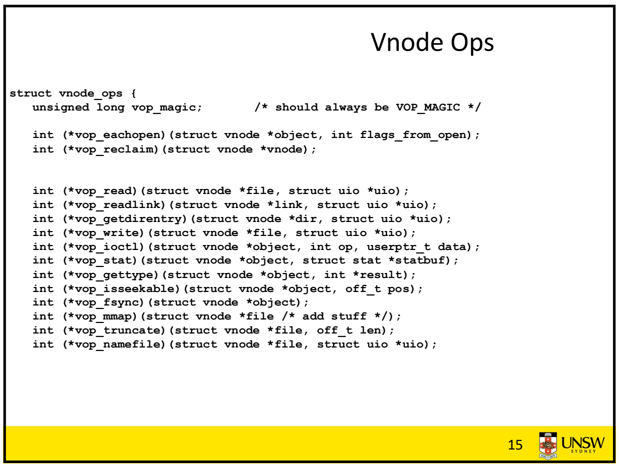

Vnode Ops

```
struct vnode_ops {
   unsigned long vop_magic;       /* should always be VOP_MAGIC */

   int (*vop_eachopen)(struct vnode *object, int flags_from_open);
   int (*vop_reclaim)(struct vnode *vnode);


   int (*vop_read)(struct vnode *file, struct uio *uio);
   int (*vop_readlink)(struct vnode *link, struct uio *uio);
   int (*vop_getdirentry)(struct vnode *dir, struct uio *uio);
   int (*vop_write)(struct vnode *file, struct uio *uio);
   int (*vop_ioctl)(struct vnode *object, int op, userptr_t data);
   int (*vop_stat)(struct vnode *object, struct stat *statbuf);
   int (*vop_gettype)(struct vnode *object, int *result);
   int (*vop_isseekable)(struct vnode *object, off_t pos);
   int (*vop_fsync)(struct vnode *object);
   int (*vop_mmap)(struct vnode *file /* add stuff */);
   int (*vop_truncate)(struct vnode *file, off_t len);
   int (*vop_namefile)(struct vnode *file, struct uio *uio);
```

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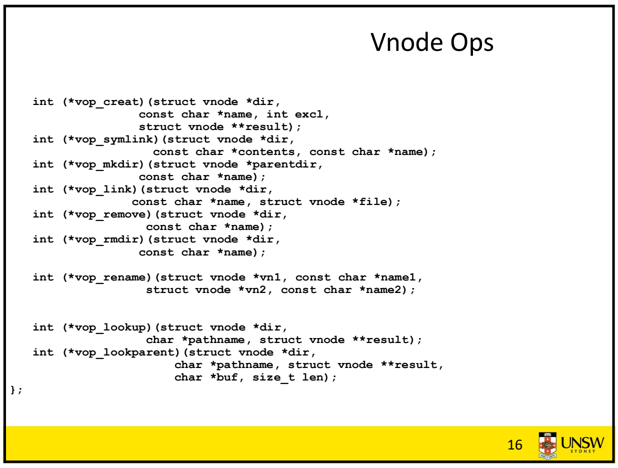

Vnode Ops

```
   int (*vop_creat)(struct vnode *dir,
                    const char *name, int excl,
                    struct vnode **result);
   int (*vop_symlink)(struct vnode *dir,
                      const char *contents, const char *name);
   int (*vop_mkdir)(struct vnode *parentdir,
                    const char *name);
   int (*vop_link)(struct vnode *dir,
                   const char *name, struct vnode *file);
   int (*vop_remove)(struct vnode *dir,
                     const char *name);
   int (*vop_rmdir)(struct vnode *dir,
                    const char *name);

   int (*vop_rename)(struct vnode *vn1, const char *name1,
                     struct vnode *vn2, const char *name2);


   int (*vop_lookup)(struct vnode *dir,
                     char *pathname, struct vnode **result);
   int (*vop_lookparent)(struct vnode *dir,
                         char *pathname, struct vnode **result,
                         char *buf, size_t len);
};
```

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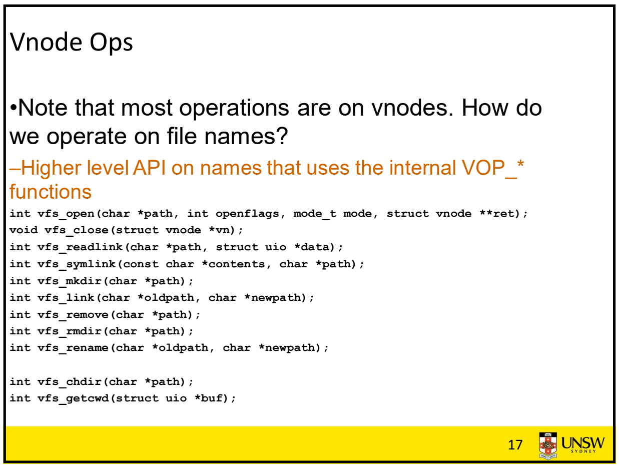

Vnode Ops

- Note that most operations are on vnodes. How do we operate on file names?
  - –Higher level API on names that uses the internal VOP_* functions

```
int vfs_open(char *path, int openflags, mode_t mode, struct vnode **ret);
void vfs_close(struct vnode *vn);
int vfs_readlink(char *path, struct uio *data);
int vfs_symlink(const char *contents, char *path);
int vfs_mkdir(char *path);
int vfs_link(char *oldpath, char *newpath);
int vfs_remove(char *path);
int vfs_rmdir(char *path);
int vfs_rename(char *oldpath, char *newpath);

int vfs_chdir(char *path);
int vfs_getcwd(struct uio *buf);
```

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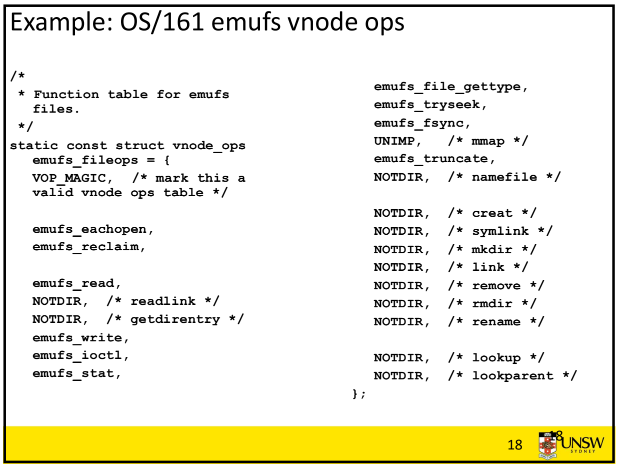

Example: OS/161 emufs vnode ops

```
/*
 * Function table for emufs
   files.
 */
static const struct vnode_ops
   emufs_fileops = {
   VOP_MAGIC,  /* mark this a
   valid vnode ops table */

   emufs_eachopen,
   emufs_reclaim,

   emufs_read,
   NOTDIR,  /* readlink */
   NOTDIR,  /* getdirentry */
   emufs_write,
   emufs_ioctl,
   emufs_stat,
```

```
   emufs_file_gettype,
   emufs_tryseek,
   emufs_fsync,
   UNIMP,   /* mmap */
   emufs_truncate,
   NOTDIR,  /* namefile */

   NOTDIR,  /* creat */
   NOTDIR,  /* symlink */
   NOTDIR,  /* mkdir */
   NOTDIR,  /* link */
   NOTDIR,  /* remove */
   NOTDIR,  /* rmdir */
   NOTDIR,  /* rename */

   NOTDIR,  /* lookup */
   NOTDIR,  /* lookparent */
};
```

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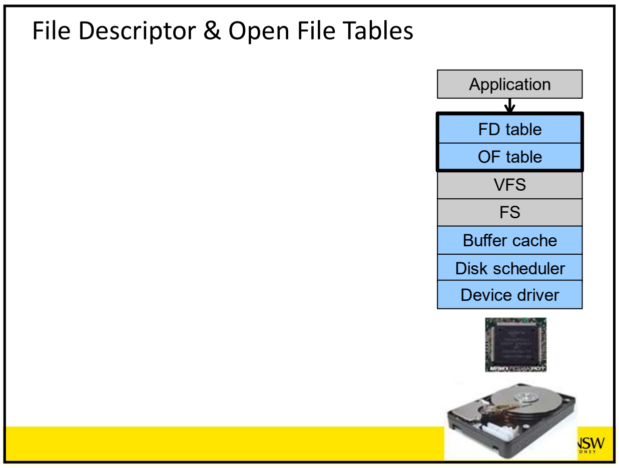

File Descriptor & Open File Tables

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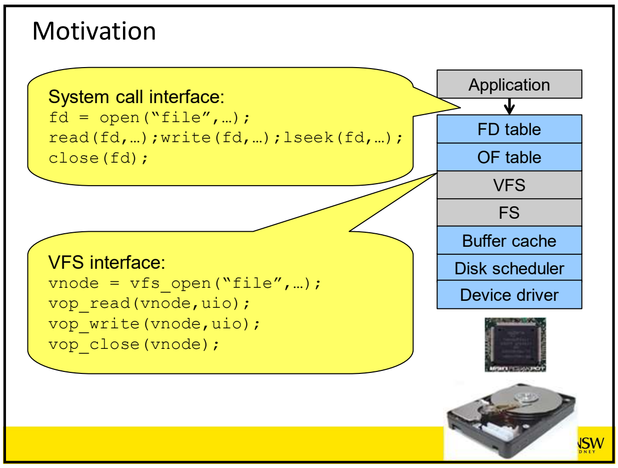

Motivation

System call interface:

```
fd = open("file",…);
read(fd,…);write(fd,…);lseek(fd,…);
close(fd);
```

VFS interface:

```
vnode = vfs_open("file",…);
vop_read(vnode,uio);
vop_write(vnode,uio);
vop_close(vnode);
```

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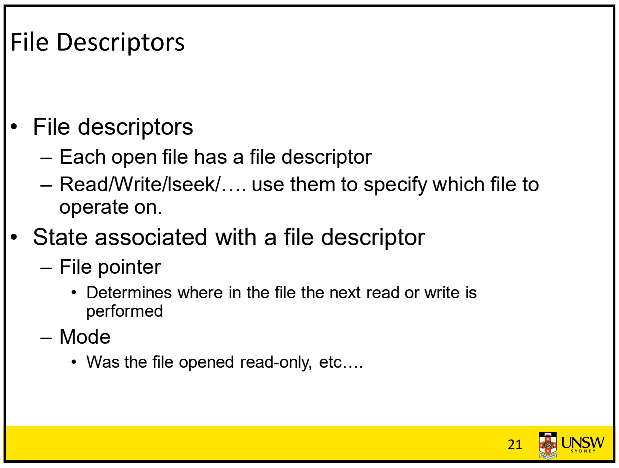

File Descriptors

- File descriptors
  - Each open file has a file descriptor
  - Read/Write/lseek/…. use them to specify which file to operate on.
- State associated with a file descriptor
  - File pointer
    - Determines where in the file the next read or write is performed
  - Mode
    - Was the file opened read-only, etc….

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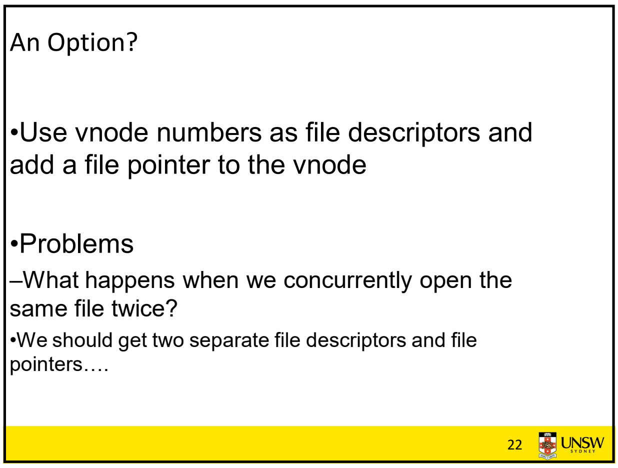

An Option?

•Use vnode numbers as file descriptors and add a file pointer to the vnode

•Problems

–What happens when we concurrently open the same file twice?

•We should get two separate file descriptors and file pointers….

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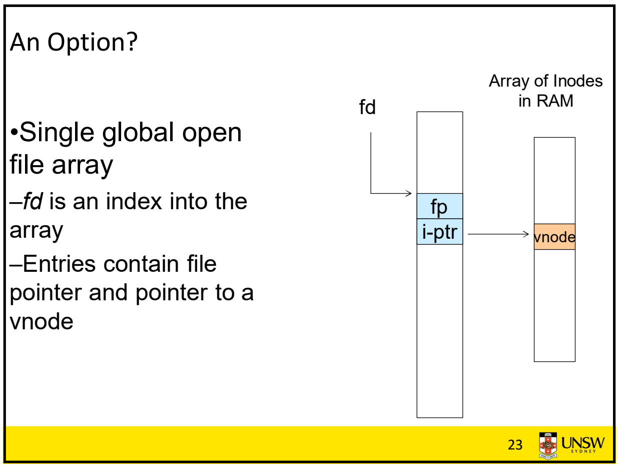

An Option?

•Single global open file array

–*fd* is an index into the array

–Entries contain file pointer and pointer to a vnode

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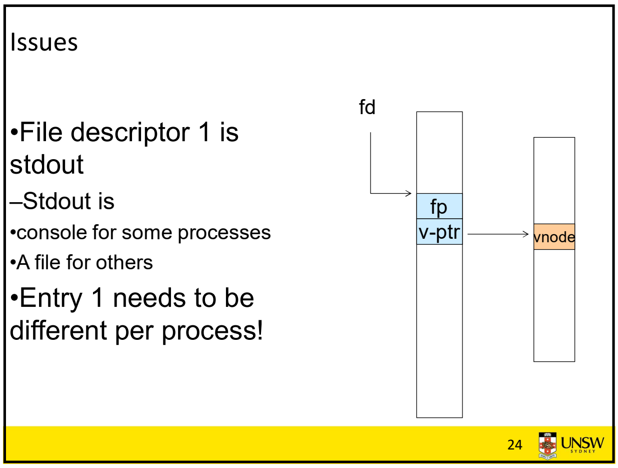

Issues

•File descriptor 1 is stdout

–Stdout is

•console for some processes

•A file for others

•Entry 1 needs to be different per process!

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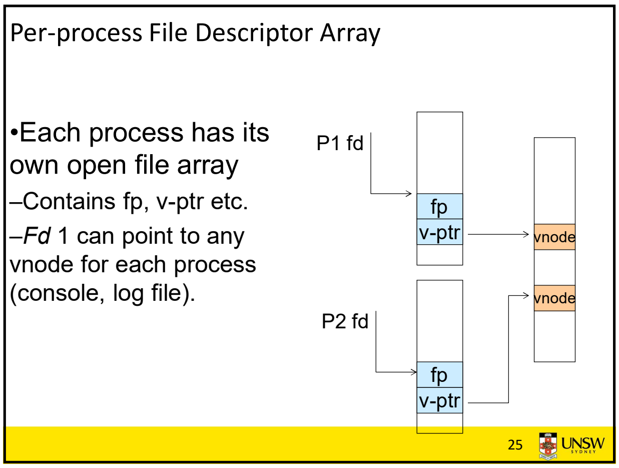

Per-process File Descriptor Array

- Each process has its own open file array
  - Contains fp, v-ptr etc.
  - *Fd* 1 can point to any vnode for each process (console, log file).

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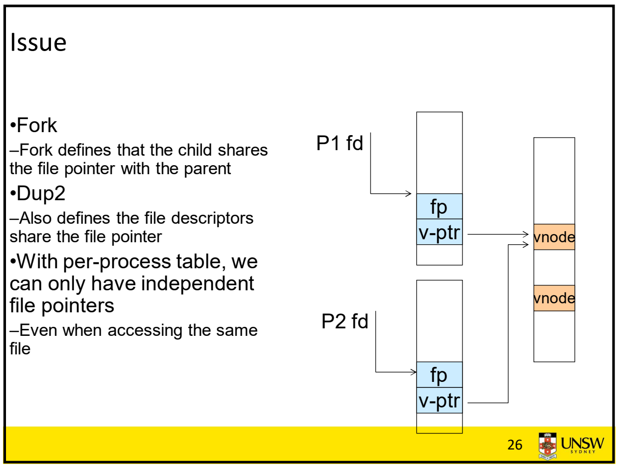

Issue

- Fork
  - Fork defines that the child shares the file pointer with the parent
- Dup2
  - Also defines the file descriptors share the file pointer
- With per-process table, we can only have independent file pointers
  - Even when accessing the same file

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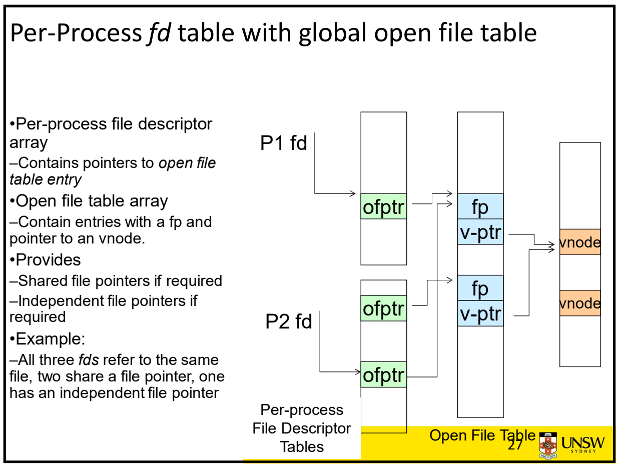

Per-Process *fd* table with global open file table

- Per-process file descriptor array
  - Contains pointers to *open file table entry*
- Open file table array
  - Contain entries with a fp and pointer to an vnode.
- Provides
  - Shared file pointers if required
  - Independent file pointers if required
- Example:
  - All three *fds* refer to the same file, two share a file pointer, one has an independent file pointer

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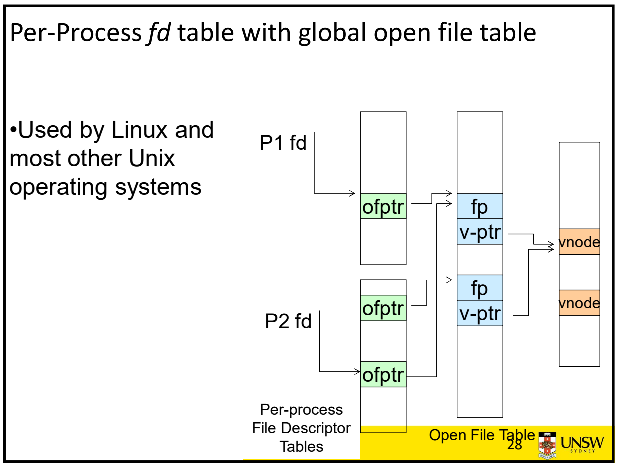

Per-Process *fd* table with global open file table

- Used by Linux and most other Unix operating systems

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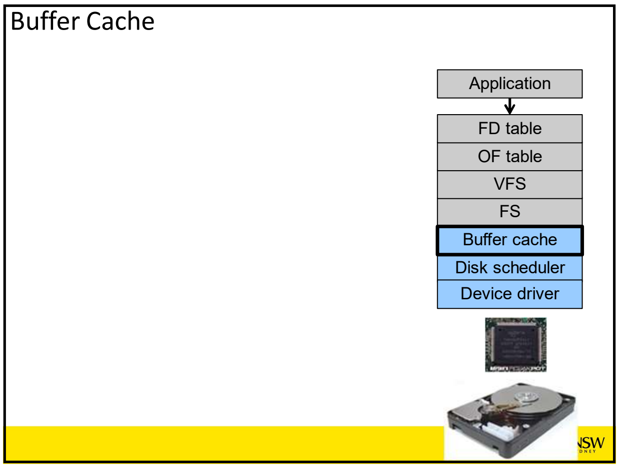

Buffer Cache

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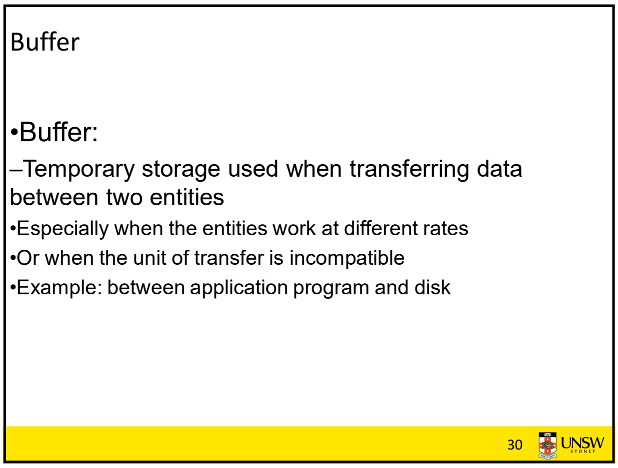

Buffer

- Buffer:
  - Temporary storage used when transferring data between two entities
- Especially when the entities work at different rates
- Or when the unit of transfer is incompatible
- Example: between application program and disk

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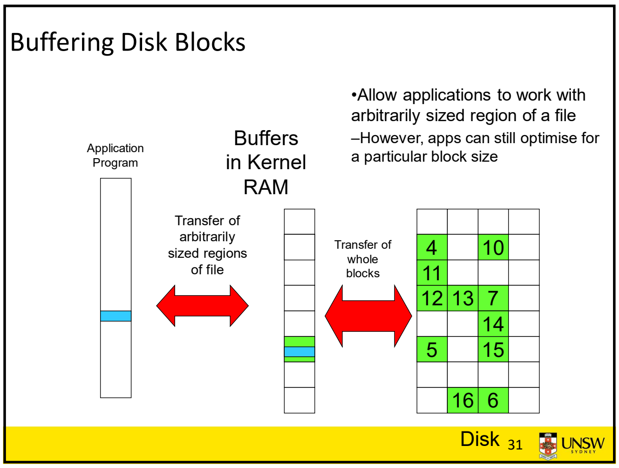

Buffering Disk Blocks

- Allow applications to work with arbitrarily sized region of a file
  - However, apps can still optimise for a particular block size

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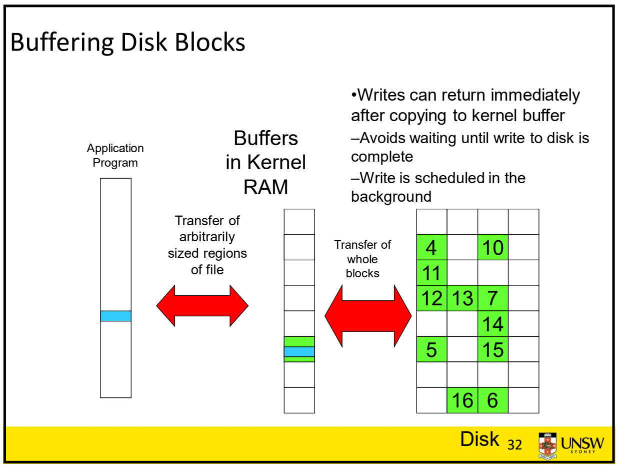

Buffering Disk Blocks

- Writes can return immediately after copying to kernel buffer
  - Avoids waiting until write to disk is complete
  - Write is scheduled in the background

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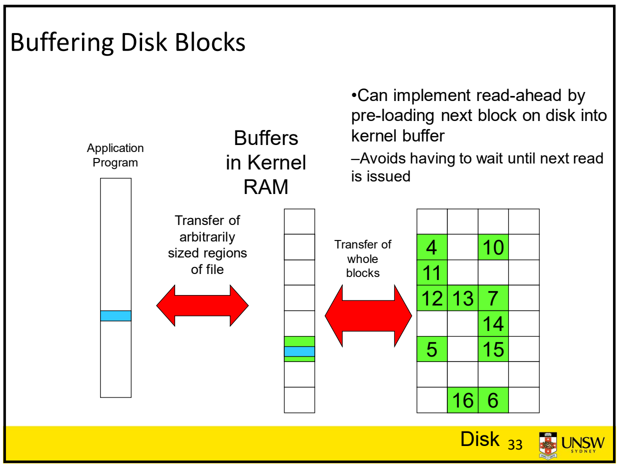

Buffering Disk Blocks

- Can implement read-ahead by pre-loading next block on disk into kernel buffer
  - Avoids having to wait until next read is issued

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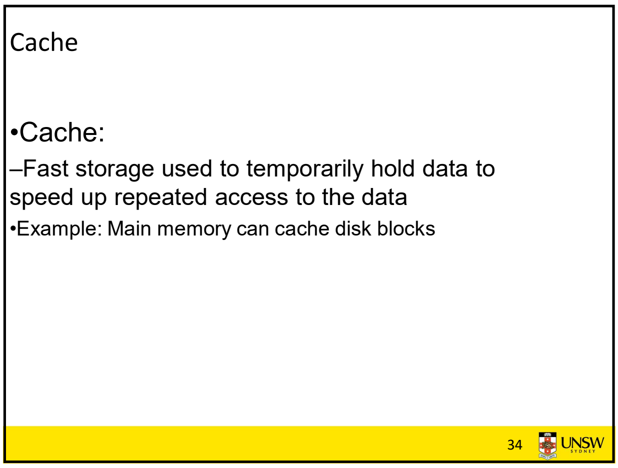

Cache

- Cache:
  - Fast storage used to temporarily hold data to speed up repeated access to the data
- Example: Main memory can cache disk blocks

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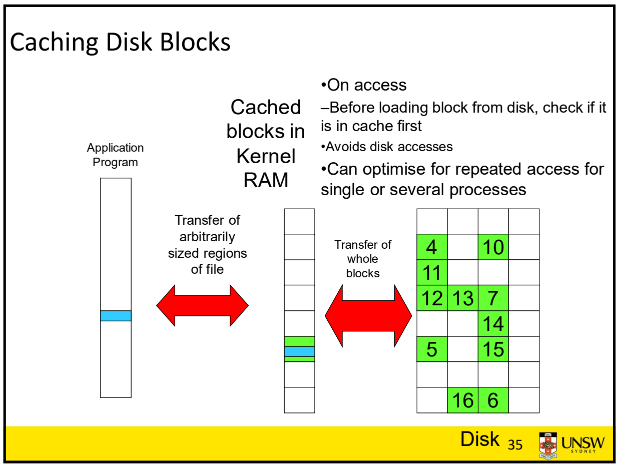
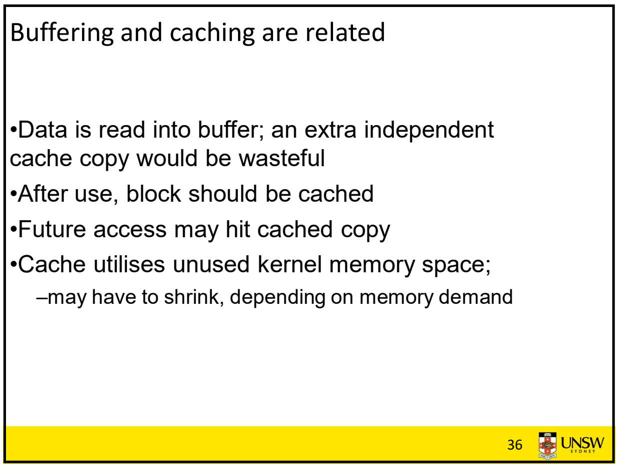


Caching Disk Blocks

- On access
  - Before loading block from disk, check if it is in cache first
    - Avoids disk accesses
- Can optimise for repeated access for single or several processes

Application Program
Cached blocks in Kernel RAM
Transfer of arbitrarily sized regions of file
Transfer of whole blocks
4
10
11
12
13
7
14
5
15
16
6
Disk
35
UNSW

35



Buffering and caching are related

- Data is read into buffer; an extra independent cache copy would be wasteful
- After use, block should be cached
- Future access may hit cached copy
- Cache utilises unused kernel memory space;
  - may have to shrink, depending on memory demand

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Unix Buffer Cache

On read

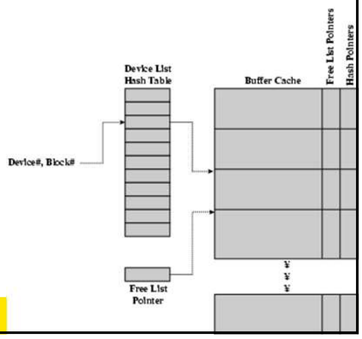
–Hash the device#, block#

–Check if match in buffer cache

–Yes, simply use in-memory copy

–No, follow the collision chain

–If not found, we load block from disk into buffer cache



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Replacement

- What happens when the buffer cache is full and we need to read another block into memory?
  - –We must choose an existing entry to replace
  - –Need a policy to choose a victim
    - •Can use First-in First-out
    - •Least Recently Used, or others.
      - –Timestamps required for LRU implementation
    - • However, is strict LRU what we want?

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File System Consistency

•File data is expected to survive

•Strict LRU could keep modified critical data in memory forever if it is frequently used.

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File System Consistency

•Generally, cached disk blocks are prioritised in terms of how critical they are to file system consistency

–Directory blocks, inode blocks if lost can corrupt entire filesystem

•E.g. imagine losing the root directory

•These blocks are usually scheduled for immediate write to disk

–Data blocks if lost corrupt only the file that they are associated with

•These blocks are only scheduled for write back to disk periodically

•In UNIX, flushd (*flush daemon*) flushes all modified blocks to disk every 30 seconds

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File System Consistency

•Alternatively, use a write-through cache

–All modified blocks are written immediately to disk

–Generates much more disk traffic

- –Temporary files written back
- –Multiple updates not combined

–Used by DOS

•Gave okay consistency when

- »Floppies were removed from drives
- »Users were constantly resetting (or crashing) their machines

–Still used, e.g. USB storage devices

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