File System

jnlin(2019-2020, CC BY-SA)

? (1996-2018)

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Handbook and Manual pages

- Official guide and be found at
  - https://www.freebsd.org/doc/en/books/handbook/permissions.html

Files

- $ ls -l

```
drwx--x--x  7 liuyh  gcs      1024 Sep 22 17:25 public_html
```

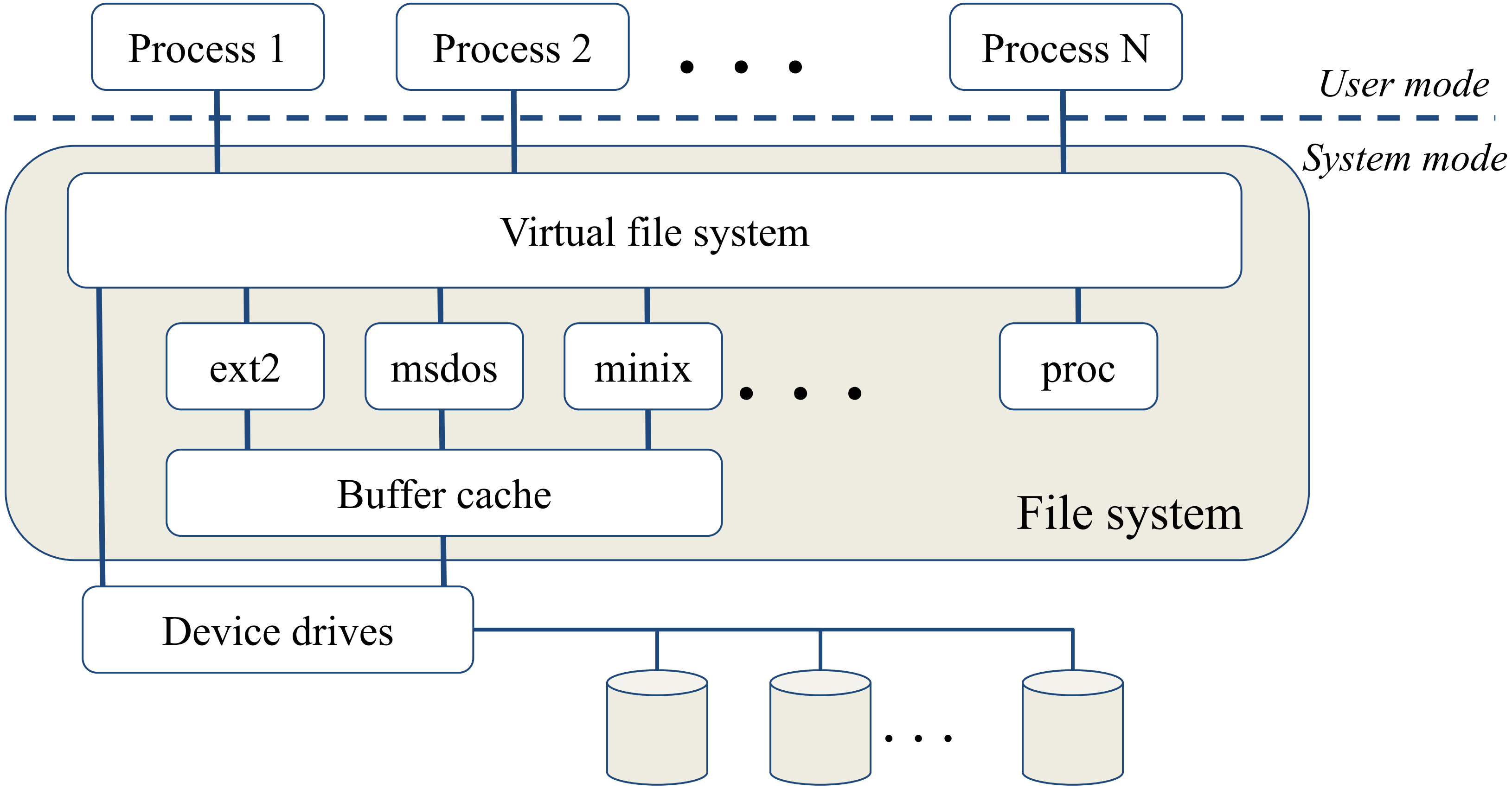
File Type	d
File Access Mode	rwx--x--x
inodes	7
File User Owner	liuyh
File Group Owner	gcs
File Size	1024
File Last Modify Time	Sep 22 17:25
File Name	public_html

Outline

- File System Architecture
  - Pathname
  - File Tree
  - Mounting
  - File Types
- inode and file
  - Link
- File Access Mode
  - Changing File Owner
  - FreeBSD bonus flags

File System Architecture (1)

- Application ↔ Kernel ↔ Hardware
  - Applications call system-calls to request service
  - Kernel invokes corresponding drivers to fulfill this service

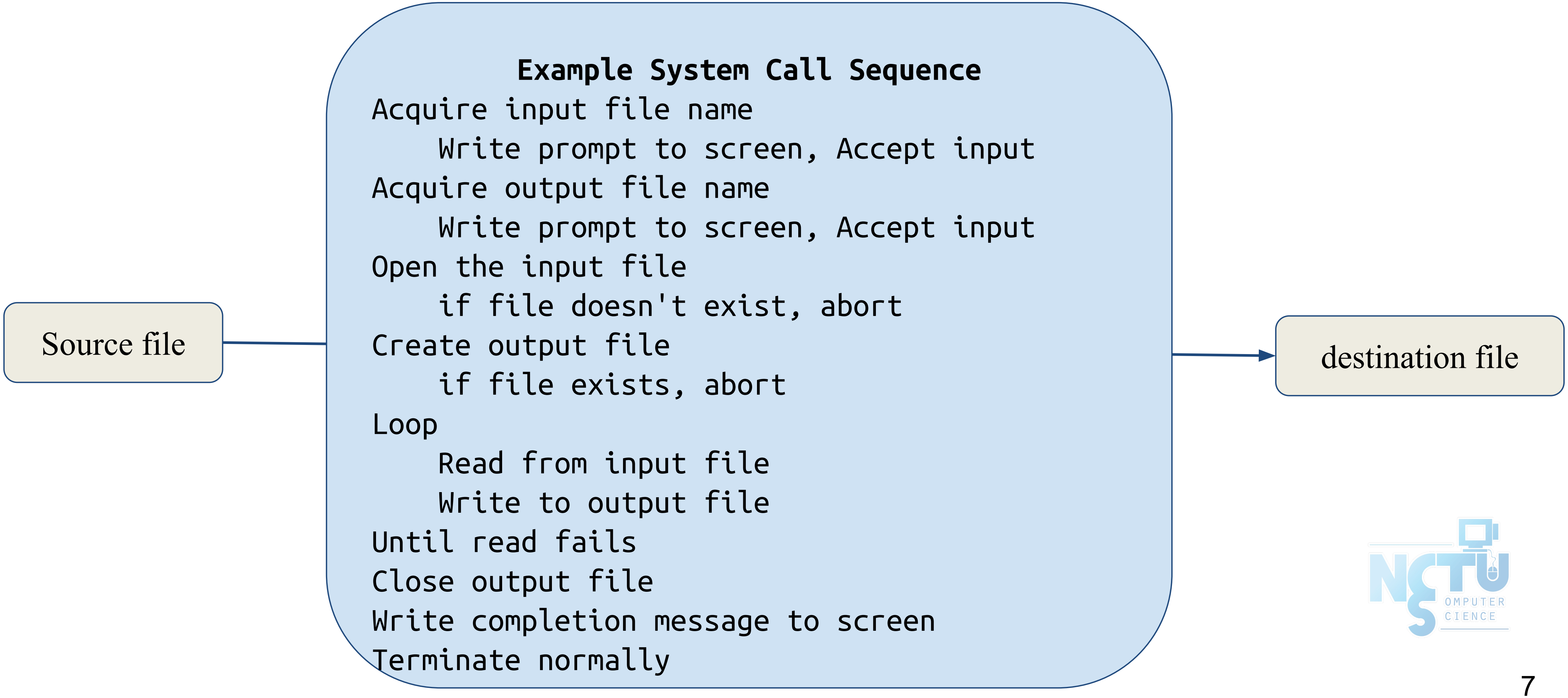


File System Architecture (2)

- The basic purpose of filesystem
  - Represent and organize the system’s storage
  - Four main components:
    - Namespace
      - A way of naming things and arranging them in a hierarchy
    - Application Programming Interface (API)
      - A set of system calls for navigating and manipulating nodes
    - Security model
      - A scheme for protecting, hiding and sharing things
    - Implementation
      - Code that ties the logical model to an actual disk

File System Architecture (2)

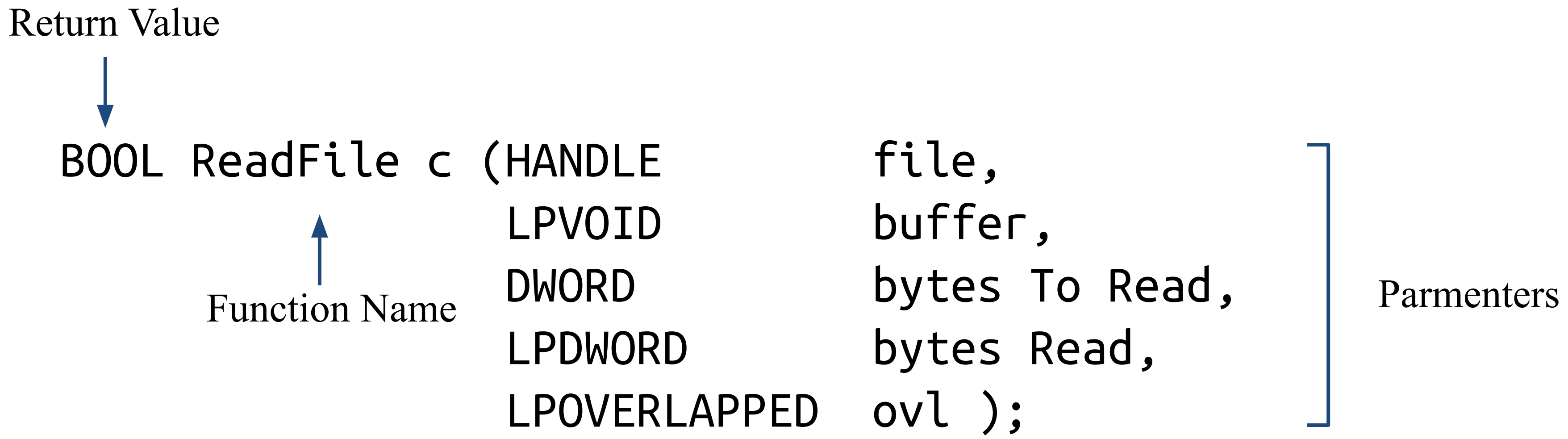
- System call sequence to copy the contents of one file to another file



```
Example System Call Sequence
Acquire input file name
    Write prompt to screen, Accept input
Acquire output file name
    Write prompt to screen, Accept input
Open the input file
    if file doesn't exist, abort
Create output file
    if file exists, abort
Loop
    Read from input file
    Write to output file
Until read fails
Close output file
Write completion message to screen
Terminate normally
```

File System Architecture (2)

- Consider the ReadFile() function in the Win32 API – a function for reading from a file



Return Value

```
BOOL ReadFile c (HANDLE        file,
                 LPVOID        buffer,
                 DWORD         bytes To Read,
                 LPDWORD       bytes Read,
                 LPOVERLAPPED  ovl );
```

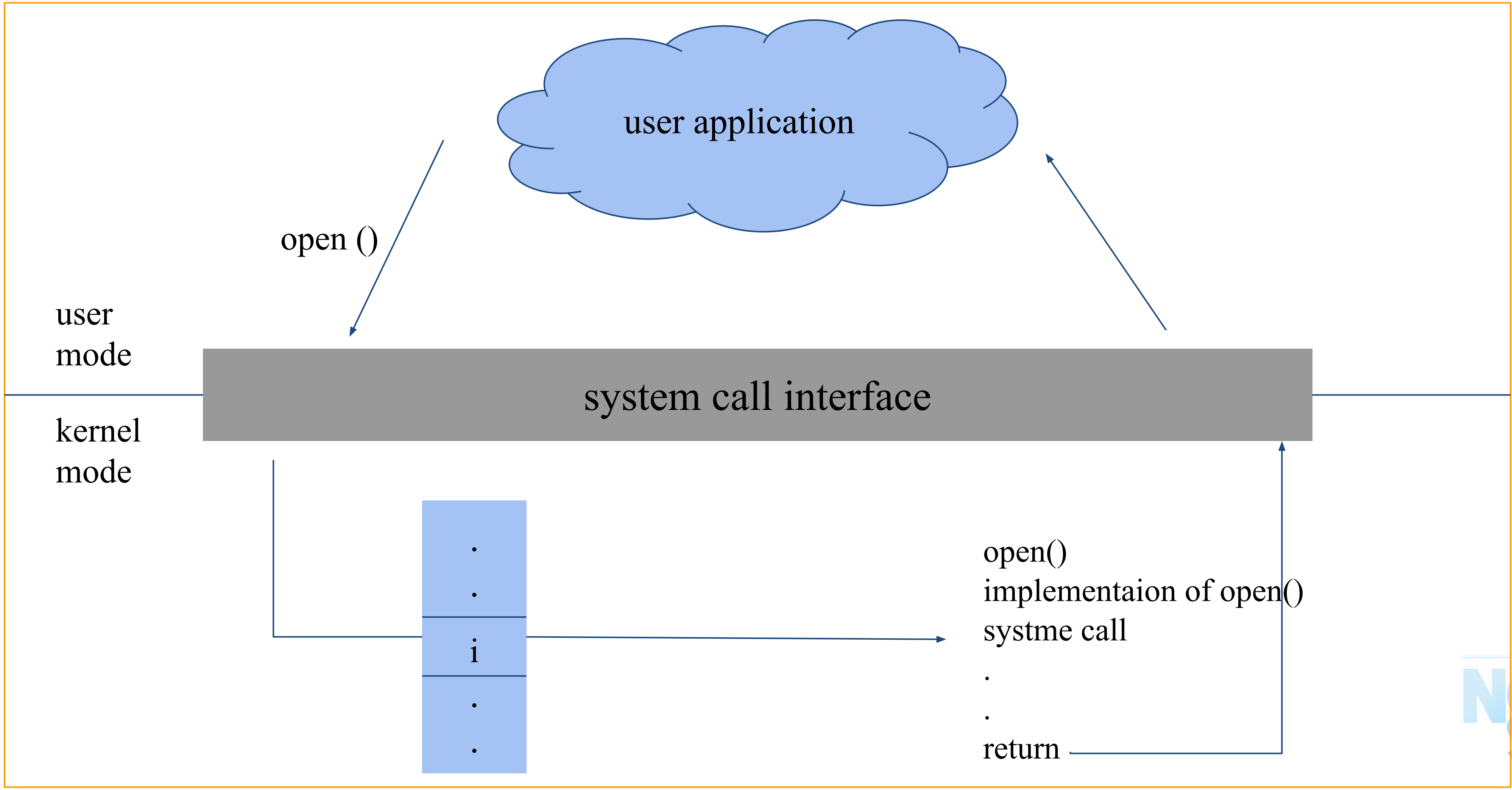
Function Name

Parmenters

- A description of the parameters passed to ReadFile()
  - HANDLE file — the file to be read
  - LPVOID buffer — a buffer where the data will be read into and written from
  - DWORD bytesToRead — the number of bytes to be read into the buffer
  - LPDWORD bytesRead — the number of bytes read during the last read
  - LPOVERLAPPED ovl — indicates if overlapped I/O is being used

File System Architecture (3)

- API – System Call – OS Relationship



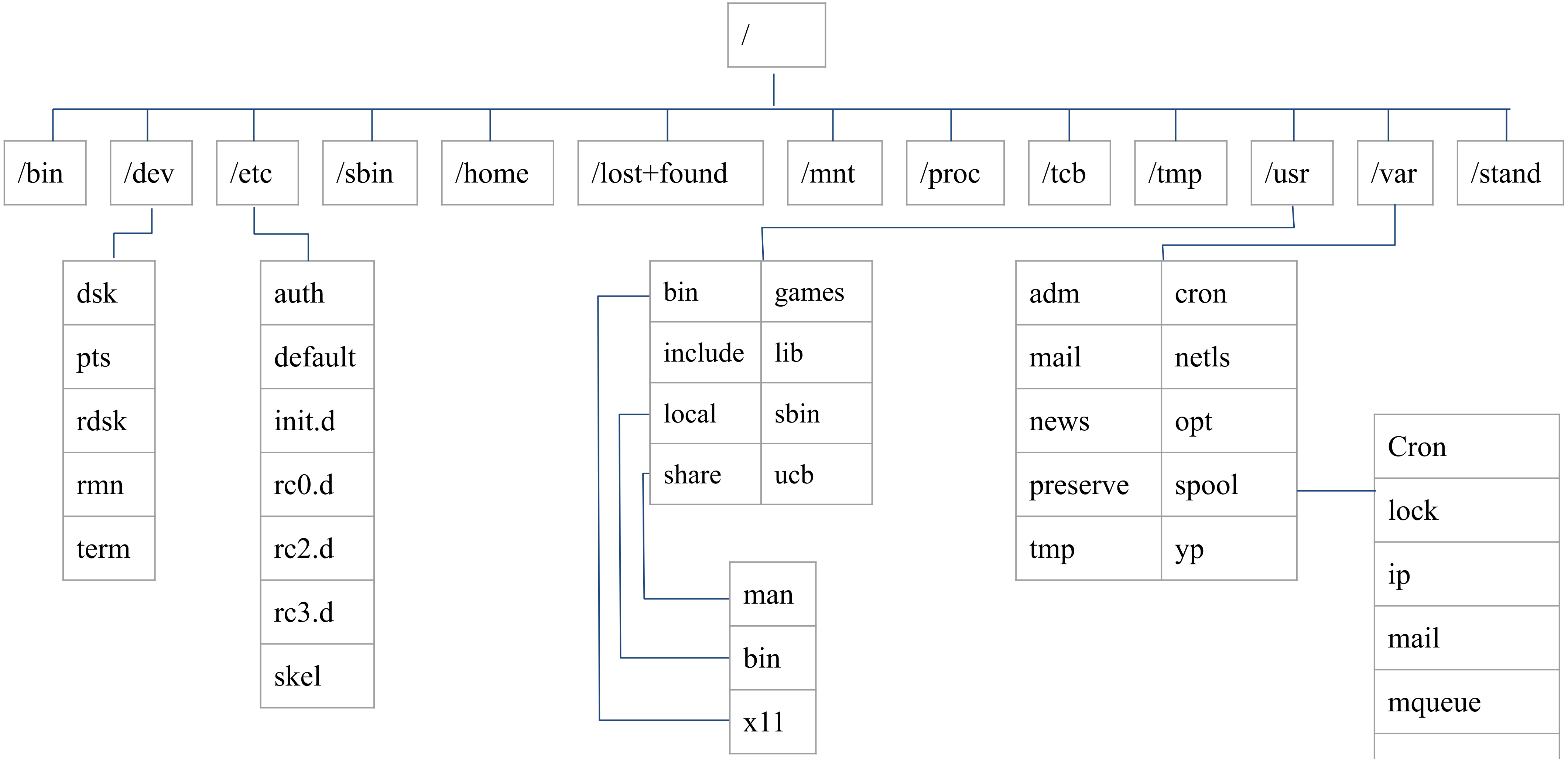
File System Architecture (4)

- Objects in the filesystem:
  - What you can find in a filesystem:
    - Files and directories
    - Hardware device files
    - Processes information
    - Interprocess communication channel (IPC)
    - Shared memory segments (SHM)
  - We can use common file system interface to access such "object"
    - open、read、write、close、seek、ioctl, fcntl, …

Pathname

- Two kinds of path
  - Absolute path → start from /
    - E.g. /u/dcs/109/1091028/test/haha.c
  - Relative path → start from your current directory
    - E.g. test/haha.c
- Constraints of pathname
  - Single component: ≦ 255 characters
  - Single absolute path: ≦ 1023 characters

File Tree


/
/bin
/dev
/etc
/sbin
/home
/lost+found
/mnt
/proc
/tcb
/tmp
/usr
/var
/stand
dsk
pts
rdsk
rmn
term
auth
default
init.d
rc0.d
rc2.d
rc3.d
skel
bin
games
include
lib
local
sbin
share
ucb
man
bin
x11
adm
cron
mail
netls
news
opt
preserve
spool
tmp
yp
Cron
lock
ip
mail
mqueue
uucp
uucppublic

Layout of File Systems (1)

- hier(7)

Path Name	Contents
/	The root directory of the file system
/bin & /sbin	User utilities & system programs fundamental to both single-user and multi-user environments
/usr	User utilities and applications
/usr/bin & /usr/sbin	Local executable
/lib	Shared and archive libraries
/libexec	Critical system utilities needed for binaries in /bin and /sbin
/mnt	Empty directory commonly used by system administrators as a temporary mount point
/tmp	Temporary files that are not guaranteed to persist across system reboots. Also, there is /var/tmp
/usr/lib	Support libraries for standard UNIX programs
/usr/libexec	System daemons & system utilities (executed by other programs)
/usr/include	Libraries Header files
/usr/local	Local executables, libraries, etc

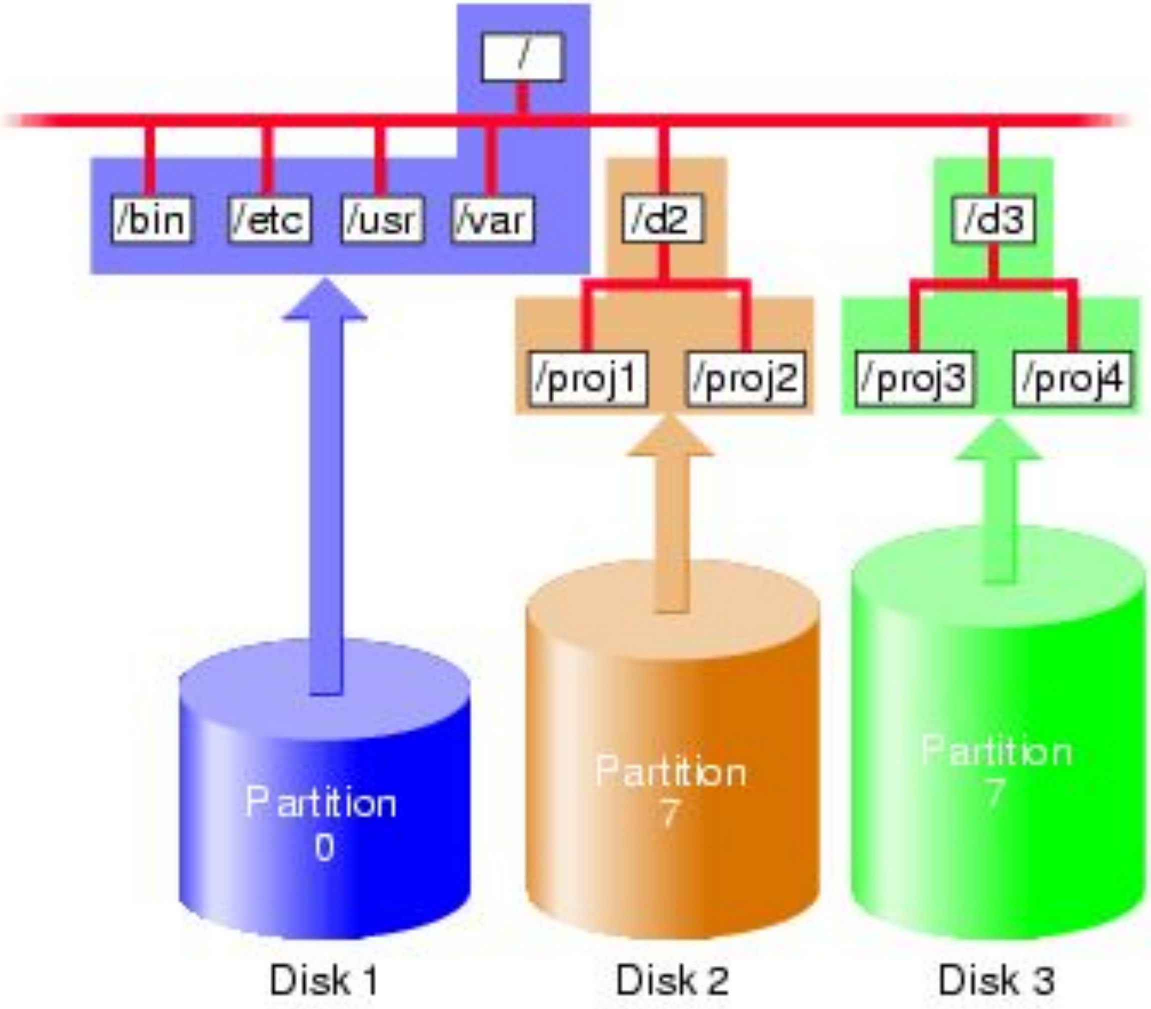
Layout of File Systems (2)

Path Name	Contents
/usr/src	BSD, third-party, and/or local source files
/usr/obj	Architecture-specific target tree produced by building the /usr/src tree
/etc	System configuration files and scripts
/usr/local/etc	/etc of /usr/local, mimics /etc
/dev	Device entries for disks, terminals, modems, etc
/proc	Images of all running process
/var	Multi-purpose log, temporary, transient, and spool files
/var/db	Database files
/var/db/pkg & /var/db/ports	Ports Collection management files. ports(7)
/var/log	Various system log files
/var/mail	User mailbox files
/var/spool	Spooling directories for printers, mails, etc

Mounting file system (1)

- mount(8)
- Common types of file systems
  - Most are disk partitions
  - Network file servers
  - Memory disk emulators
  - Kernel components
  - Etc,…
- "mount" command
  - Map the mount point of the existing file tree to the root of the newly attached filesystem
  - $ mount /dev/ad2s1e /home2
  - The previous contents of the mount point become inaccessible

Mounting file system (2)



Mounting file system (3)

- fstab(5)
- Filesystem table – fstab
  - Automatically mounted at boot time
  - /etc/fstab
    - Filesystem in this file will be checked and mounted automatically at boot time

      Ex:

```
# Device        Mountpoint      FStype  Options         Dump      Pass#
/dev/ad0s1a     /               ufs     rw              1         1
/dev/ad0s1b     none            swap    sw              0         0
```

Mounting file system (4)

- umount(8)
- Unmounting file system
  - "umount" command
    - $ umount { node | device }
      - Ex:

umount /home	umount /dev/ad0s1e

  - Busy file system
    - Someone’s current directory is there or there are opened files
    - Use "umount -f"
    - We can use "lsof" or "fstat" like utilities to figure out who makes it busy

Mounting file system (5)

- fstat(1)

```
liuyh@NASA ~ $ fstat
USER     CMD        PID      FD   MOUNT        INUM    MODE          SZ|DV     R/W
liuyh    fstat      94218    wd   /            234933  drwxr-xr-x    16          r
root     screen     87838    4    /tmp         9947    prwx------    0           r
```

- lsof(8) (/usr/ports/sysutils/lsof) – list open files

```
liuyh@NASA ~ $ lsof
COMMAND     PID    USER      FD     TYPE   SIZE/OFF     NODE    NAME
screen      87838 root      cwd    VDIR          7     522069  /usr/ports/sysutils/screen
screen      87838 root      rtd    VDIR         26          3  /
screen      87838 root      txt    VREG     337968     424757  /usr/local/bin/screen
screen      87838 root      txt    VREG     245976     679260  /libexec/ld-elf.so.1
screen      87838 root      txt    VREG     314504     678109  /lib/libncurses.so.8
screen      87838 root      txt    VREG      64952     678438  /lib/libutil.so.8
screen      87838 root      txt    VREG      33536     677963  /lib/libcrypt.so.5
```

File Types (1)

- File types

Symbol	File types
-	Regular file
b	Block device file
c	Character device file
d	Directory
l	Symbolic link
s	UNIX domain socket
p	Named pipe

File Types (2)

- file command
  - determine file type
    - $ file .tcshrc

      .tcshrc: ASCII text
    - $ file /bin

      /bin: directory
    - $ file /bin/sh

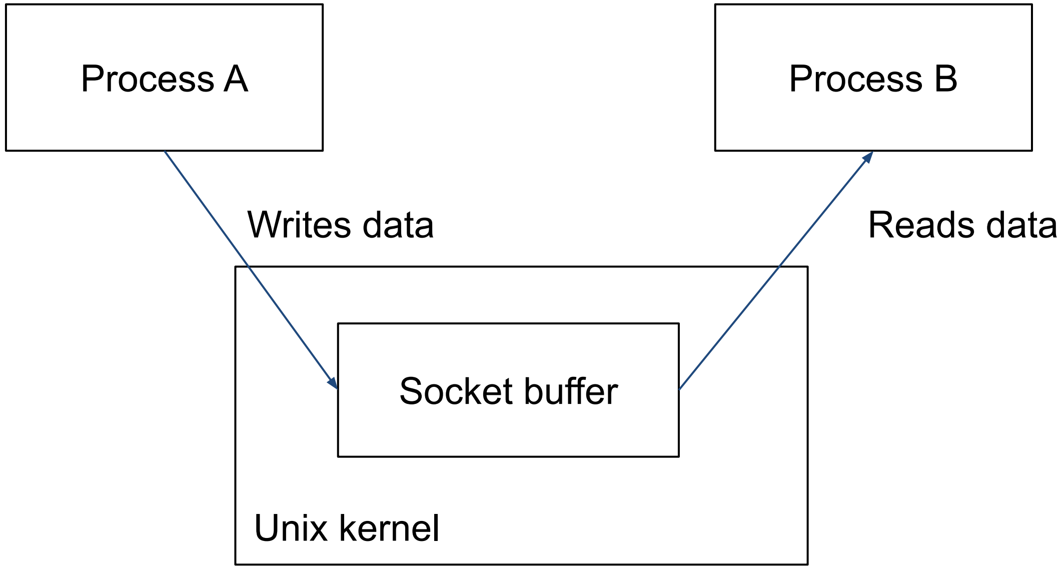
      /bin/sh: ELF 32-bit LSB executable, Intel 80386, version 1 (FreeBSD), dynamically linked (uses shared libs), stripped
  - /usr/ports/sysutils/file

File Types (2)

- Directory
  - . and ..
  - mkdir / rmdir

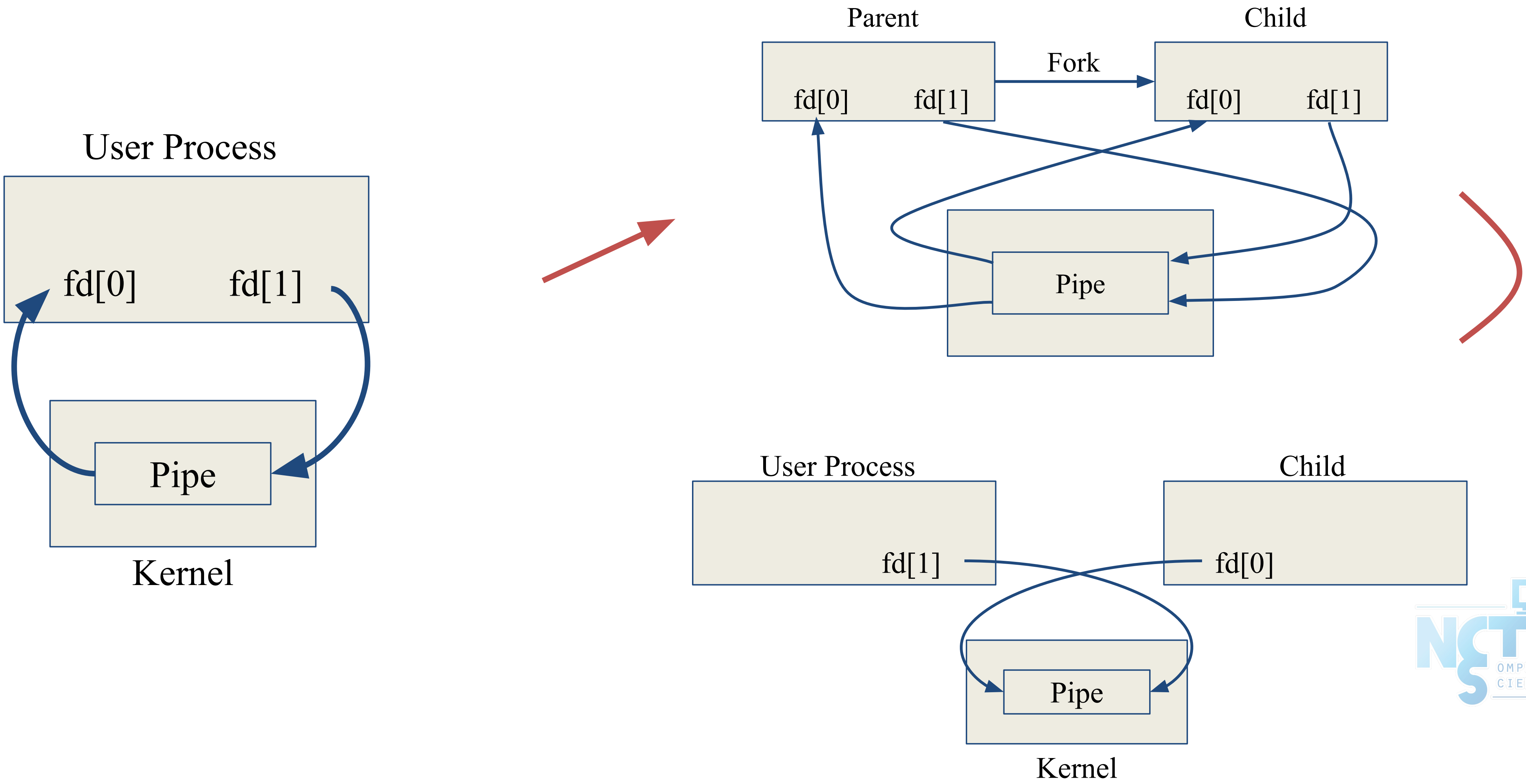
File Types (3)

- UNIX domain socket
  - Created by socket()
  - Local to a particular host
  - Be referenced through a filesystem object rather than a network port



File Types (4)

- Named Pipes
  - Let two processes do "FIFO" communication



File Types (5)

- Named Pipe
  - $ mkfifo [-m mode] fifo_name ...

  - $ mkfifo pipe
  - $ du >> pipe
  - (another process)
  - $ sort -n pipe

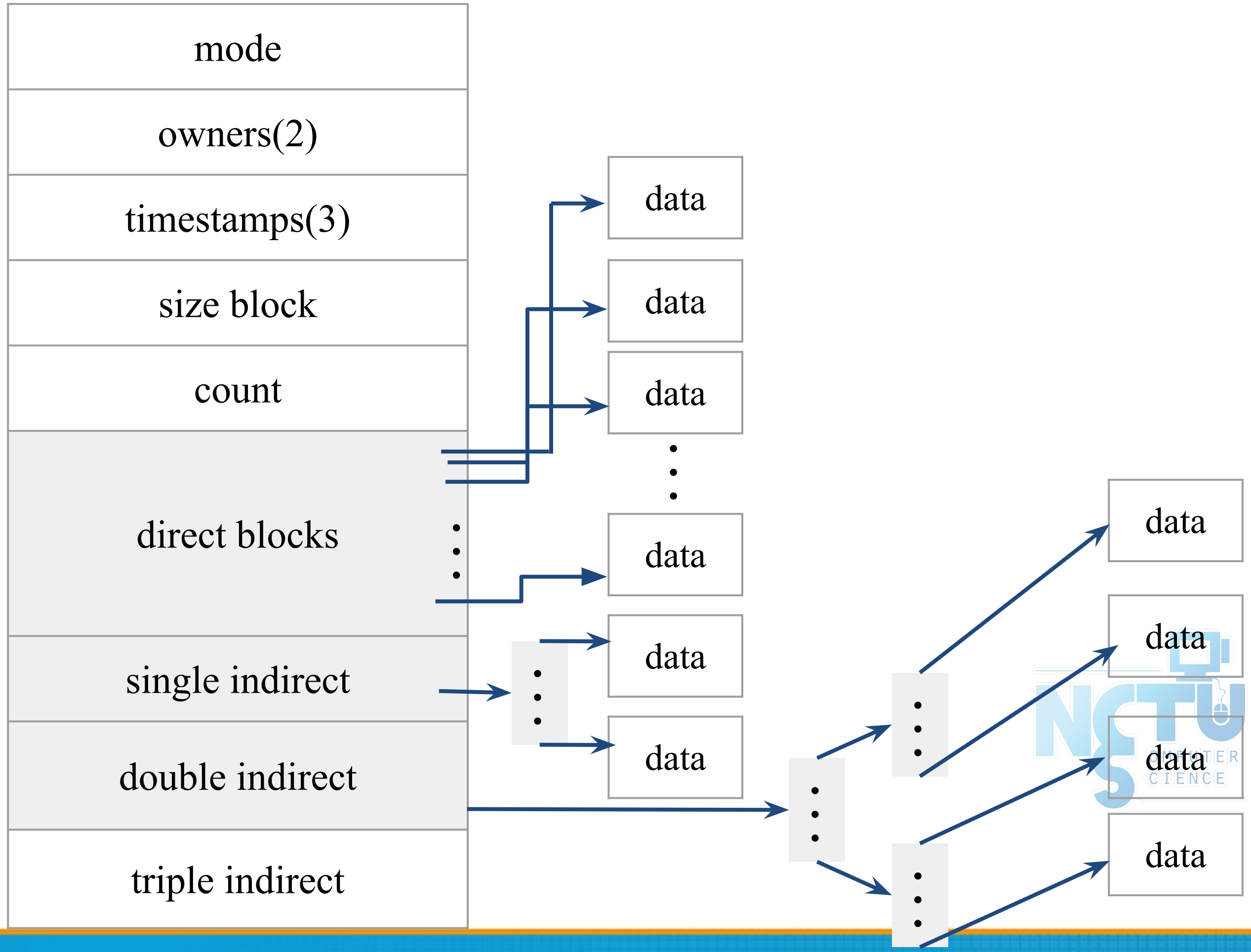
File Types (6)

- Symbolic Link
  - A file which points to another pathname
  - $ ln -s ori-file soft-file
  - Like "short-cut" in Windows

inode and file (1)

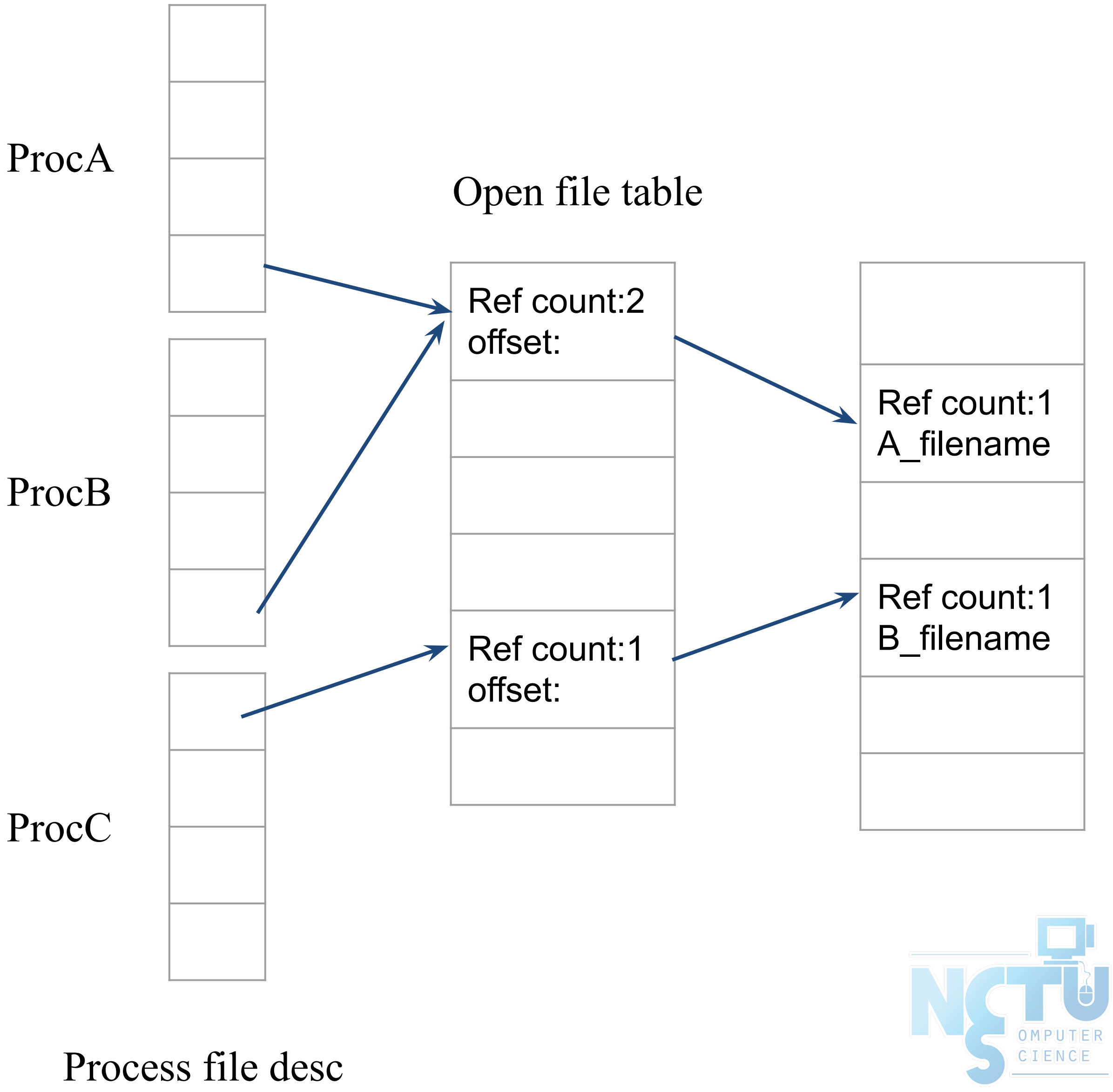
- inode
  - A structure that records information of a file
    - You can use "ls -i" to see each file’s inode number

```
fyli@NASA ~ $ ls -i
```



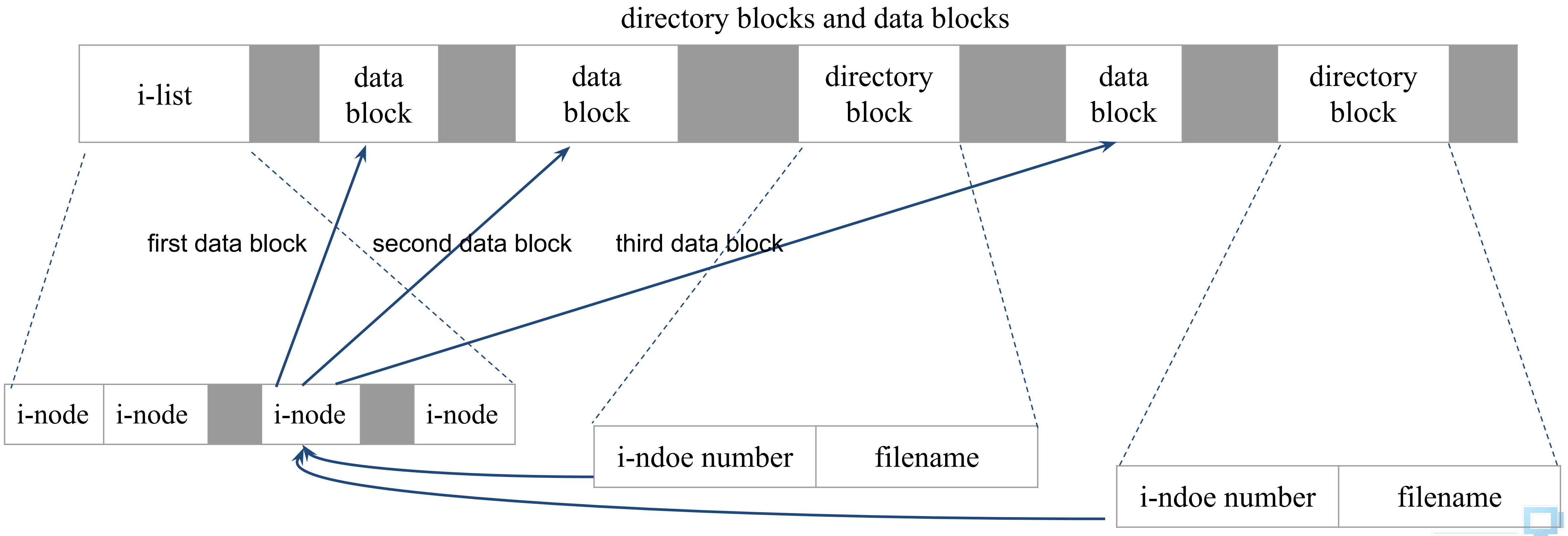
inode and file (2)

- Filesystem
  - Boot blocks
  - Super block
  - Inode list
  - Data block



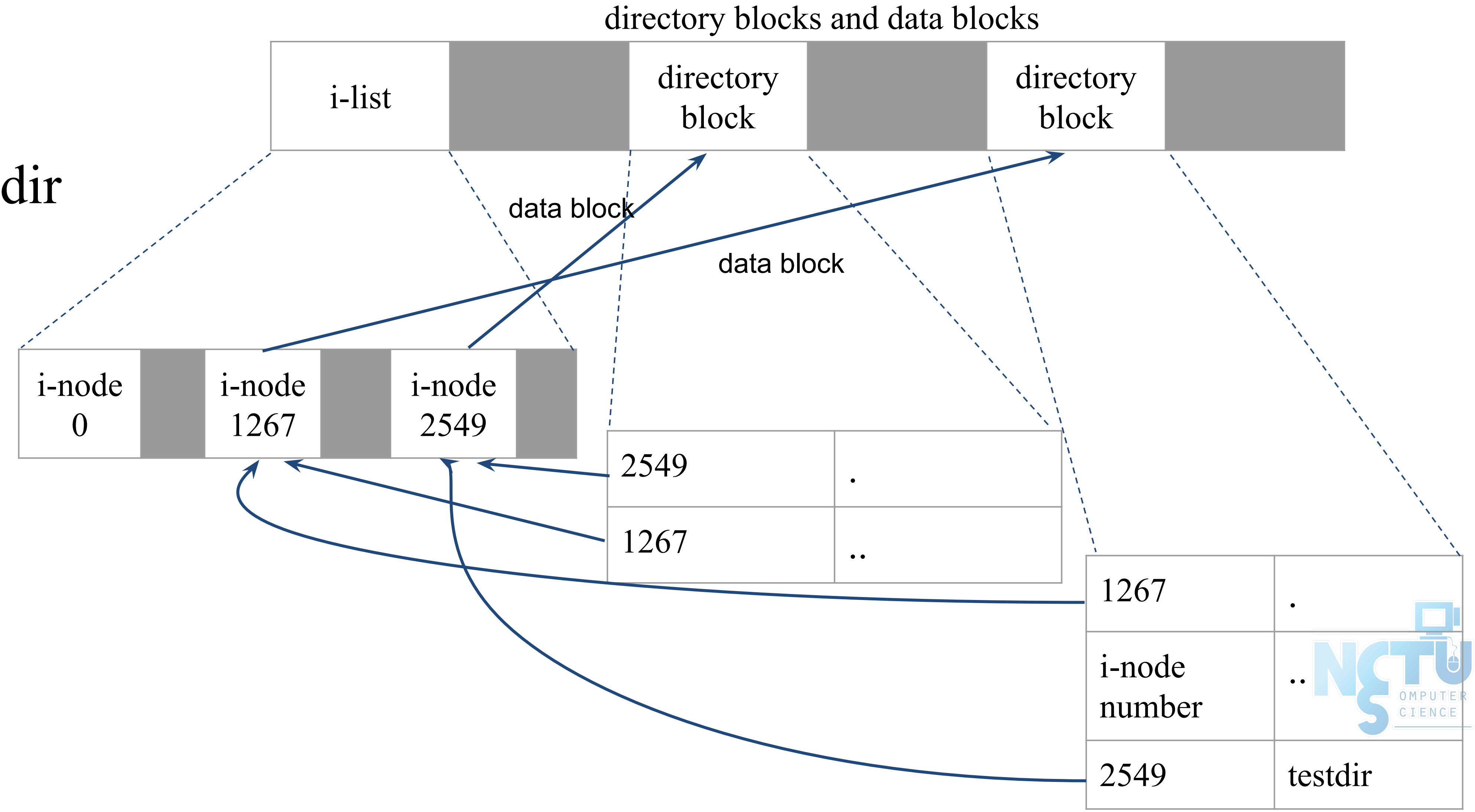
inode and file (3)

- More detail of inode and data block



inode and file (4)

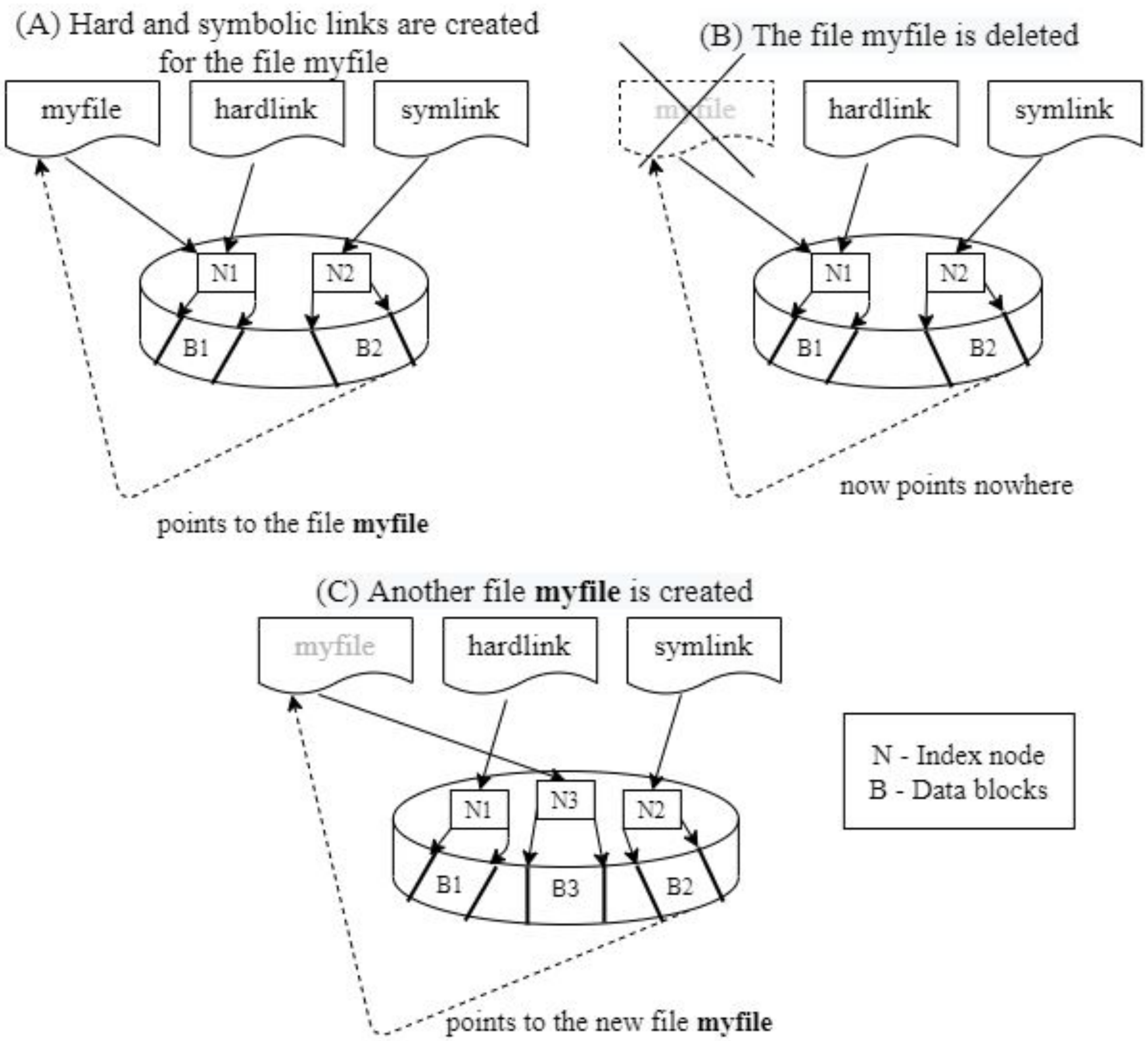
- Example
  - .
  - ..
  - testdir



Hard Link V.S. Symbolic Link (1)

- Link
  - Hard link
    - Associate two or more filenames with the same inode
      - Must in the same partition
    - $ ln ori-file hard-file
  - Soft (symbolic) link
    - A file which points to another pathname
    - $ ln -s ori-file soft-file

Hard Link V.S. Symbolic Link (2)



(A) Hard and symbolic links are created for the file myfile

points to the file **myfile**

(B) The file myfile is deleted

now points nowhere

(C) Another file **myfile** is created

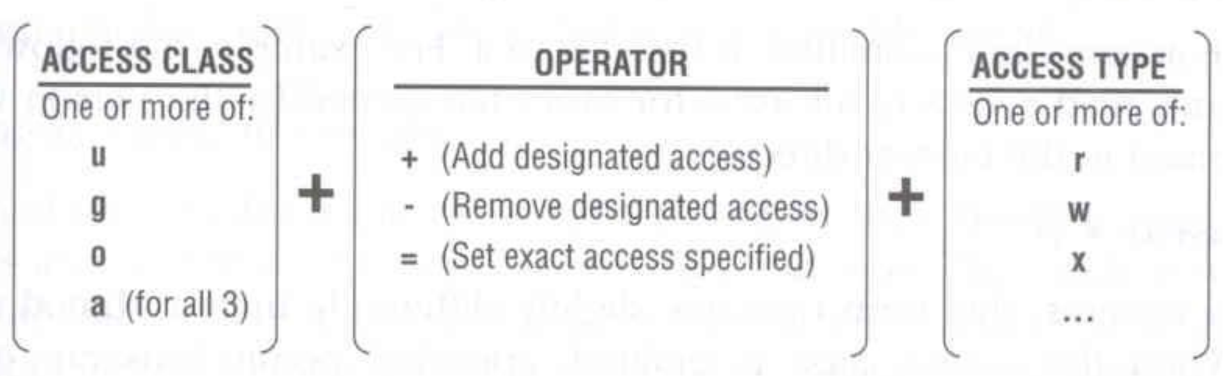
points to the new file **myfile**

N - Index node
B - Data blocks

```
$ touch index
$ ln index hlink
$ ln –s index slink
```

File Access Mode (1)

- rwx r-x r-x
  - User, group, other privileges
- chmod command
  - chmod(1), "MODES" section
  - $ chmod access-string file
    - $ chmod u+x test.sh
    - $ chmod go-w .tcshrc
    - $ chmod u+w,g-w hehe haha
    - $ chmod –R 755 public_html/



ACCESS CLASS

One or more of:

u

g

o

a (for all 3)

+

OPERATOR

+ (Add designated access)

- (Remove designated access)

= (Set exact access specified)

+

ACCESS TYPE

One or more of:

r

w

x

...

File Access Mode (2)

- setuid, setgid, sticky bit
  - setuid, setgid on file
    - The effective uid/gid of resulting process will be set to the UID/GID of the file
    - setuid
    - passwd, chsh, crontab
    - setgid
    - top, fstat, write

File Access Mode (3)

- setgid on directory
  - Cause newly created files within the directory to be the same group as directory
- sticky on directory (/tmp)
  - Do not allow to delete or rename a file unless you are
    - The owner of the file
    - The owner of the directory
    - root

File Access Mode (4)

- Decimal argument of chmod
  - setuid: 4000
  - setgid: 2000
  - sticky : 1000

Mode	Attribute	Mode	Attribute
755	`- rwx r-x r-x`	644	`- rw- r-- r--`
4755	`- rws r-x r-x`	600	`- rw- --- ---`
2755	`- rwx r-s r-x`	400	`- r-- r-- r--`
2775	`d rwx rws r-x`	1777	`d rwx rwx rwt`
755	`d rwx r-x r-x`	4555	`- r-s r-x r-x`
750	`d rwx r-x ---`	711	`- rwx --x --x`
700	`d rwx --- ---`	711	`d rwx --x --x`

File Access Mode (5)

- Assign default permissions: umask
  - Shell built-in command
  - Inference the default permissions given to the files newly created.
  - The newly created file permission:
  - Use full permission bit (file: 666, dir: 777) xor umask value.
  - Ex:

umask	New File	New Dir
022	`- rw- r-- r--`	`d rwx r-x r-x`
033	`- rw- r-- r--`	`d rwx r-- r--`
066	`- rw- --- ---`	`d rwx --x --x`
000	`- rw- rw- rw-`	`d rwx rwx rwx`
477	`- r-- --- ---`	`d r-x --- ---`
777	`- --- --- ---`	`d --- --- ---`

File Protection

Command	Minimum Access Needed	
	On file itself	On directory file is in
cd /home/test		x
ls /home/test/*.c		r
ls -s /home/test/*.c		rx
cat runme	r	x
cat >> runme	w	x
run-binary	x	x
run-script	rx	x
rm rumme		wx

Changing File Owner

- Changing File Owner
  - Commands:
    - chown(8) -- change user owner
    - chgrp(1)   -- change group owner
- Change the file ownership and group ownership

```
$ chown -R fyli /home/fyli
$ chgrp   -R cs /home/fyli
$ chown -R fyli:gcs /home/fyli
$ chown -R :gcs /home/fyli
```

FreeBSD bonus flags

- chflags(1) command
  - ○ schg system immutable flag (root only)
  - ○ sunlnk system undeletable flag (root only)
  - ○ sappnd system append-only flag (root only)
  - ○ uappend user append-only flag (root, user)
  - ○ uunlnk user undeletable flag (root, user)
- ls -ol

```
fyli@NASA ~ $ ls -ol /libexec/
total 1034
-r-xr-xr-x  1 root  wheel  schg    238472 Sep 21 12:50 ld-elf.so.1*
-r-xr-xr-x  1 root  wheel  -       238512 Jul 24 17:15 ld-elf.so.1.old
-r-xr-xr-x  1 root  wheel  schg    212204 Sep 21 12:51 ld-elf32.so.1
-r-xr-xr-x  1 root  wheel  -       212248 Jul 24 17:17 ld-elf32.so.1.old
```

Appendix

Journaling File System

- Write operational logs to the jornal first, then commit it asynchronously.
- If system crashed, check the log
  - fully committed: skip
  - partial committed: rollback or commit
  - non-committed: ignore or commit
- Reduce "fsck" time and data inconsistency
- Example
  - ext3, ext4
  - xfs
  - btrfs

CoW (Copy on Write) File System

- If some data is copied but not modified, they will be referred to the same physical address in the storage
- Pros
  - Reduce the space used
- Cons
  - Data inconsistency (for example, the reference count is not consistent)
  - Not "real" used space on file
- Example
  - ZFS deduplication

File Attribute Extension

- Associate files with metadata not interpreted by the filesystem

- Key-value pairs, saved in the inode

- Example
  - mime_type
  - md5/sha1 checksum
  - security attributes