CPSC 410/611: File Management

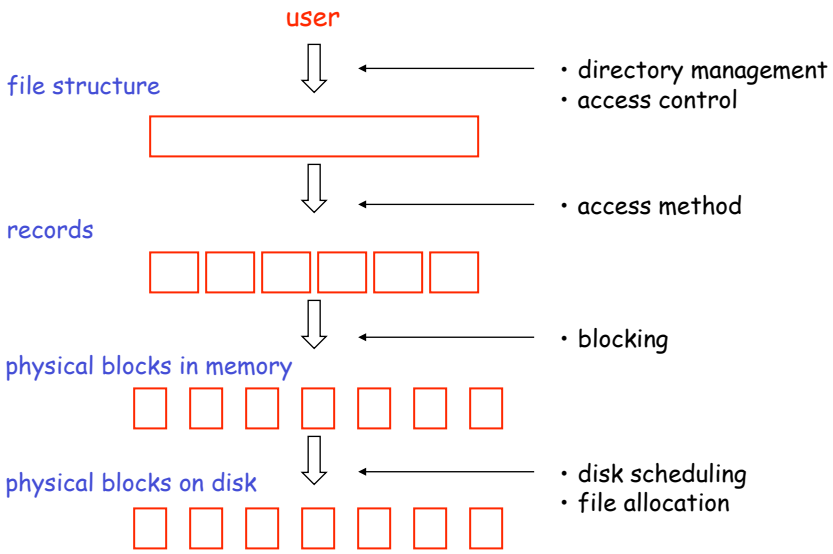
- What is a file?
- Elements of file management
- File organization
- Directories
- File allocation

- *Reading: Silberschatz, Chapter 10, 11*

What is a File?

- A **file** is a collection of data elements, grouped together for purpose of access control, retrieval, and modification
- Often, files are mapped onto physical storage devices, usually nonvolatile.
- Some modern systems define a file simply as a sequence, or stream of data units.
- A **file system** is software responsible for
  - creating, destroying, reading, writing, modifying, moving files
  - controlling access to files
  - management of resources used by files.

The Logical View of File Management

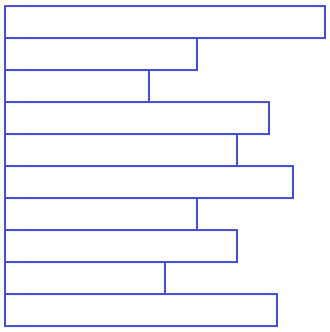


Logical Organization of a File

- A file is perceived as an ordered collection of **records**, R_0, R_1, …, R_n.
- A record is a contiguous block of information transferred during a logical read/write operation.
- Records can be of fixed or variable length.
- Organizations:
  - Pile
  - Sequential File
  - Indexed Sequential File
  - Indexed File
  - Direct/Hashed File

Pile

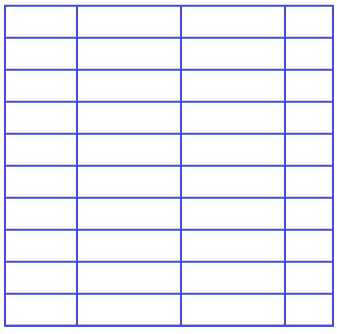
- Variable-length records
- Chronological order
- Random access to record by search of whole file.
- What about modifying records?



Pile File

Sequential File

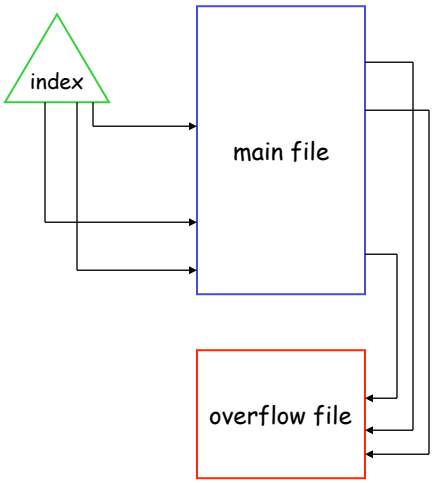
- Fixed-format records
- Records often stored in order of *key field*.
- Good for applications that process all records.
- No adequate support for random access.
- What about adding new record?
- Separate pile file keeps *log file* or *transaction file*.



Sequential File

Indexed Sequential File

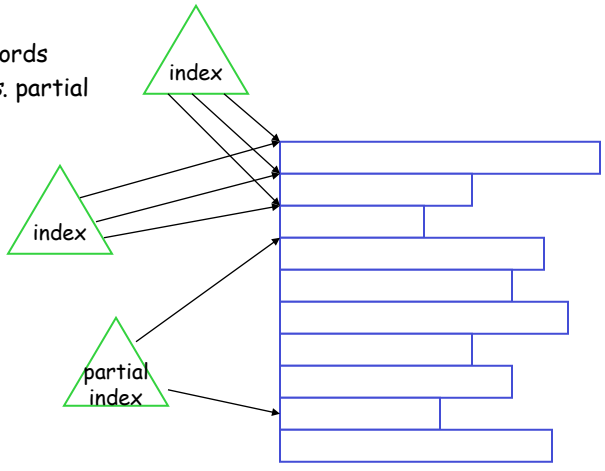
- Similar to sequential file, with two additions.
  - Index to file supports random access.
  - Overflow file indexed from main file.
- Record is added by appending it to overflow file and providing link from predecessor.



Indexed Sequential File

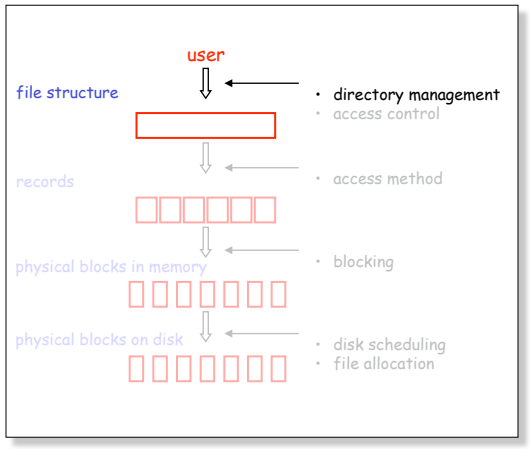
Indexed File

- Multiple indexes
- Variable-length records
- Exhaustive index *vs.* partial index



File Management

- What is a file?
- Elements of file management
- File organization
- Directories
- File allocation
- UNIX file system

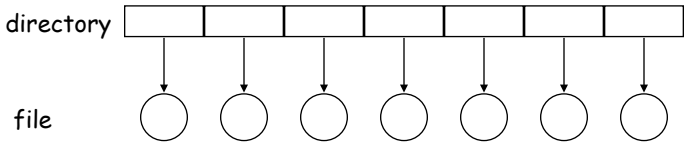


Directories

- Large amounts of data: Partition and structure for easier access.
- High-level structure:
  - *partitions* in MS-DOS
  - *minidisks* in MVS/VM
  - *file systems* in UNIX.
- Directories: Map file name to directory entry (basically a symbol table).
- Operations on directories:
  - search for file
  - create/delete file
  - rename file

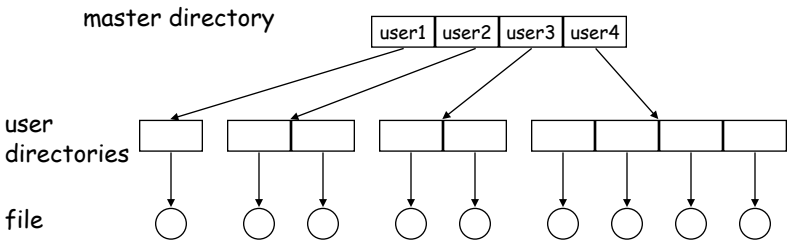
Directory Structures

- Single-level directory:



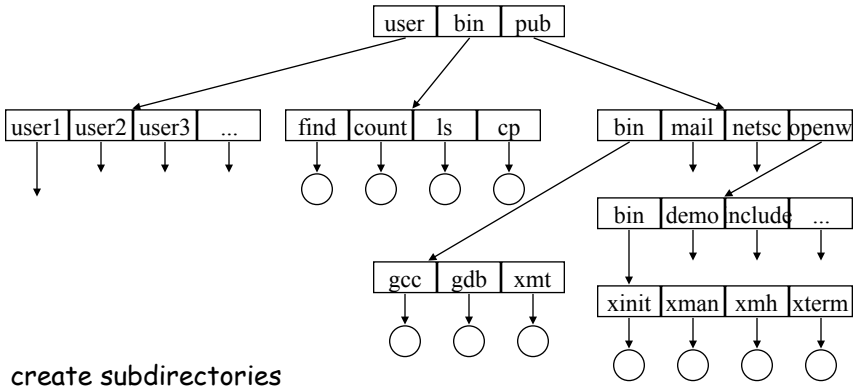
- Problems:
  - limited-length file names
  - multiple users

Two-Level Directories



- Path names
- Location of system files
  - special directory
  - search path

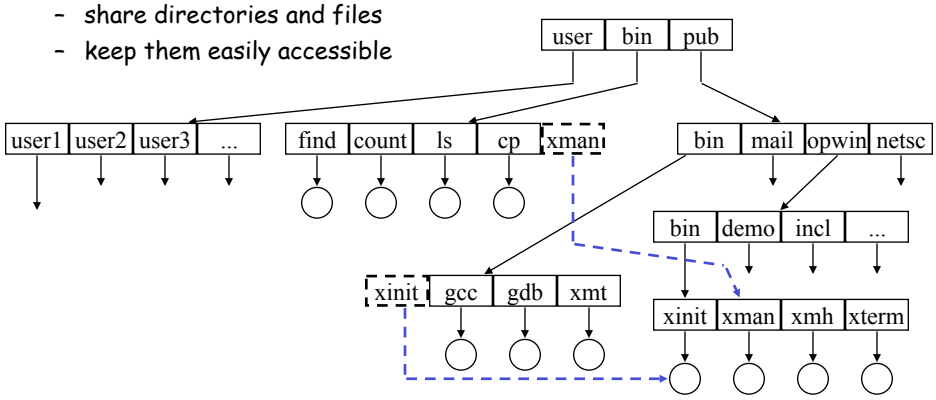
Tree-Structured Directories



- create subdirectories
- current directory
- path names: complete vs. relative

Generalized Tree Structures

- share directories and files
- keep them easily accessible



- Links: File name that, when referred, affects file to which it was linked. (hard links, symbolic links)
- Problems:
  - consistency, deletion
  - Why links to directories only allowed for system managers?

UNIX Directory Navigation: current directory

```
#include <unistd.h>

char * getcwd(char * buf, size_t size);
/* get current working directory */
```

Example:

```
void main(void) {
    char mycwd[PATH_MAX];

    if (getcwd(mycwd, PATH_MAX) == NULL) {
        perror ("Failed to get current working directory");
        return 1;
    }
    printf("Current working directory: %s\n", mycwd);
    return 0;
}
```

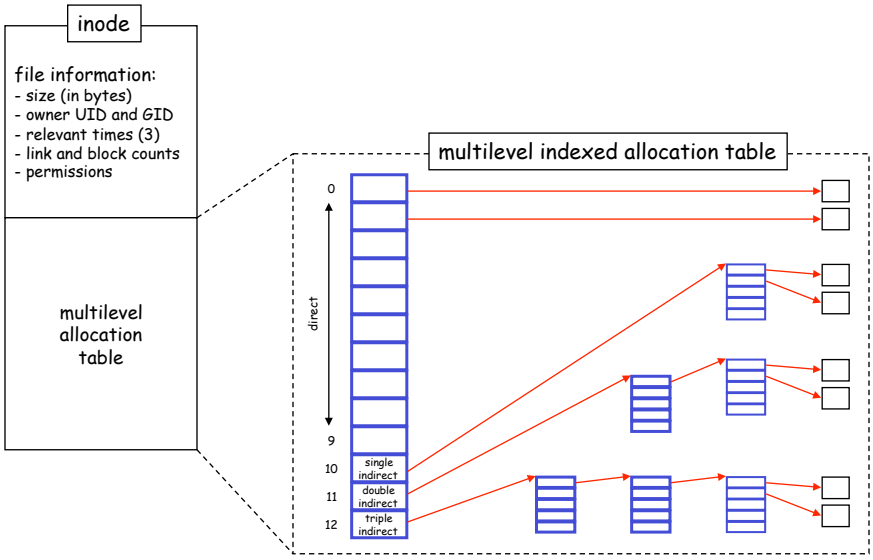
UNIX Directory Navigation: directory traversal

```
#include <dirent.h>

DIR           * opendir(const char * dirname);
        /* returns pointer to directory object          */
struct dirent * readdir(DIR * dirp);
        /* read successive entries in directory 'dirp'  */
int             closedir(DIR *dirp);
        /* close directory stream                       */
void            rewinddir(DIR * dirp);
        /* reposition pointer to beginning of directory */
```

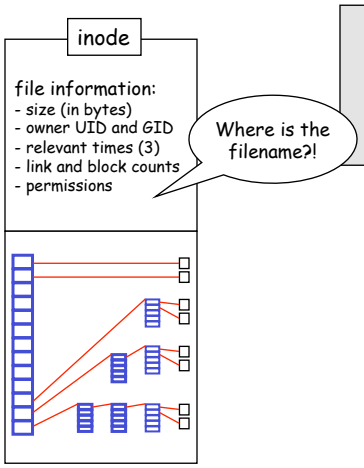
Directory Traversal: Example

```
#include <dirent.h>

int main(int argc, char * argv[]) {
    struct dirent * direntp;
    DIR           * dirp;

    if (argc != 2) {
        fprintf(stderr, "Usage: %s directory_name\n", argv[0]);
        return 1;
    }

    if ((dirp = opendir(argv[1])) == NULL) {
        perror("Failed to open directory");
        return 1;
    }

    while ((dirent = readdir(dirp)) != NULL)
        printf(%s\n", direntp->d_name);
    while((closedir(dirp) == -1) && (errno == EINTR));
    return 0;
}
```

Unix File System Implementation: inodes

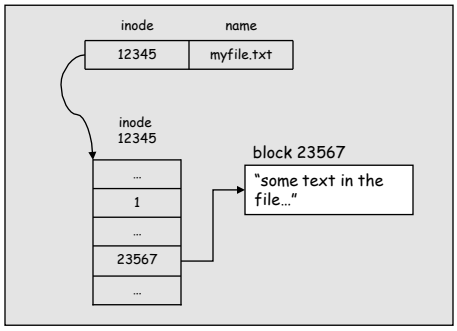


Directory Implementation



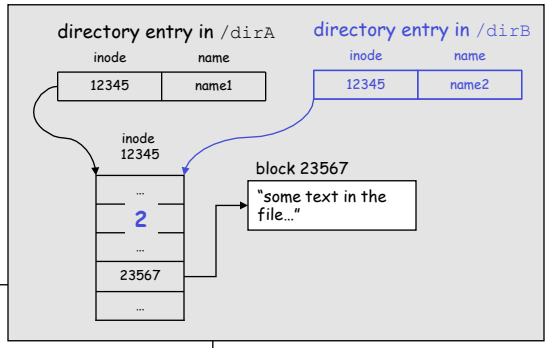
Name information is contained in separate **Directory File**, which contains entries of type:

(name of file , inode[1] number of file)



[1] More precisely: Number of block that contains inode.

Hard Links

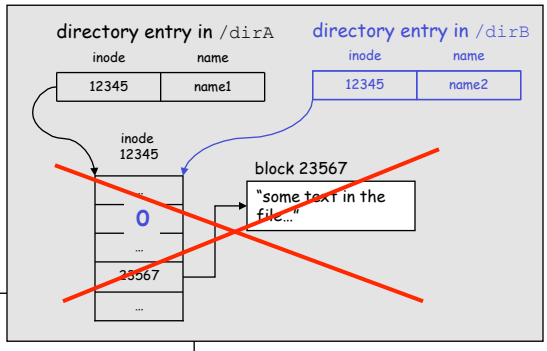


shell command
`ln /dirA/name1 /dirB/name2`

is typically implemented using the **`link`** system call:

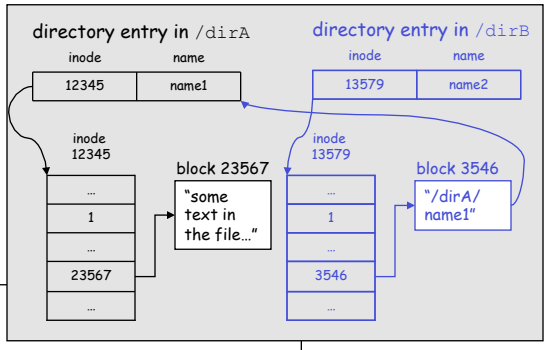
```
#include <stdio.h>
#include<unistd.h>

if (link("/dirA/name1", "/dirB/name2") == -1)
  perror("failed to make new link in /dirB");
```

Hard Links: `unlink`




```
#include <stdio.h>
#include<unistd.h>

if (unlink("/dirA/name1") == -1)
  perror("failed to delete link in /dirA");

if (unlink("/dirB/name2") == -1)
  perror("failed to delete link in /dirB");
```

Symbolic (Soft) Links



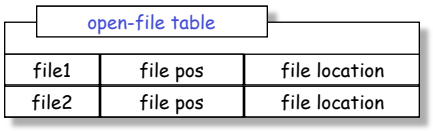
shell command
`ln -s /dirA/name1 /dirB/name2`

is typically implemented using the **`symlink`** system call:

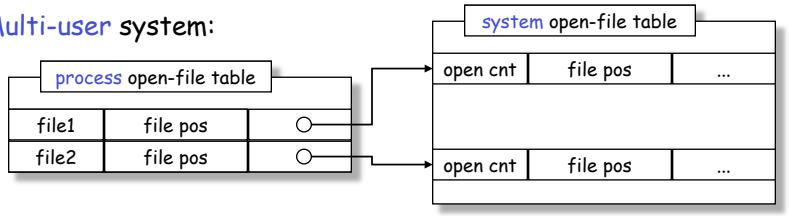
```
#include <stdio.h>
#include<unistd.h>

if (symlink("/dirA/name1", "/dirB/name2") == -1)
  perror("failed to create symbolic link in /dirB");
```

Bookkeeping

- **Open file** system call: cache information about file in kernel memory:
  - location of file on disk
  - file pointer for read/write
  - blocking information
- Single-user system:



- Multi-user system:



Opening/Closing Files

```
#include <fcntl.h>
#include <sys/stat.h>

int open(const char * path, int oflag, …);
/* returns open file descriptor */
```

Flags:
`O_RDONLY, O_WRONLY, O_RDWR`
`O_APPEND, O_CREAT, O_EXCL, O_NOCCTY`
`O_NONBLOCK, O_TRUNC`

Errors:
`EACCESS`: <various forms of access denied>
`EEXIST` `O_CREAT` and `O_EXCL` set, and file exists already.
`EINTR`: signal caught during `open`
`EISDIR`: file is a directory and `O_WRONLY` or `O_RDWR` in flags
`ELOOP`: there is a loop in the path
`EMFILE`: to many files open in calling process
`ENAMETOOLONG`: …
`ENFILE`: to many files open in system
…

Opening/Closing Files

```
#include <unistd.h>

int close(int fildes);
```

Errors:
EBADF: fildes is not valid file descriptor
EINTR: signal caught during close

Example:

```
int r_close(int fd) {
    int retval;

    while (retval = close(fd), ((retval == -1) && (errno == EINTR)));
    return retval;
}
```

Multiplexing: select()

```
#include <sys/select.h>

int select(int              nfds,
           fd_set         * readfds,
           fd_set         * writefds,
           fd_set         * errorfds,
           struct timeval   timeout);
           /* timeout is relative */

void FD_CLR  (int fd, fd_set * fdset);
int  FD_ISSET(int fd, fd_set * fdset);
void FD_SET  (int fd, fd_set * fdset);
void FD_ZERO (fd_set * fdset);
```

Errors:
EBADF: fildes is not valid for one or more file descriptors
EINVAL: <some error in parameters>
EINTR: signal caught during select before timeout or selected event

select() Example: Reading from multiple fd's

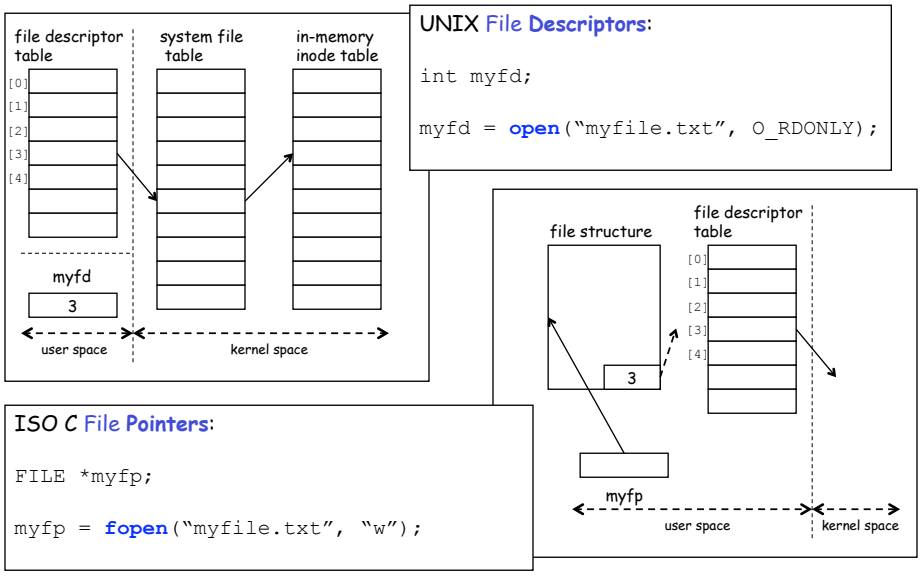
```
FD_ZERO(&readset);
maxfd = 0;
for (int i = 0; i < numfds; i++) {
  /* we skip all the necessary error checking */
  FD_SET(fd[i], &readset);
  maxfd = MAX(fd[i], maxfd);
}
```

```
while (!done) {
  numready = select(maxfd, &readset, NULL, NULL, NULL);
  if ((numready == -1) && (errno == EINTR))
    /* interrupted by signal; continue monitoring */
    continue;
  else if (numready == -1)
    /* a real error happened; abort monitoring */
    break;

  for (int i = 0; i < numfds; i++) {
    if (FD_ISSET(fd[i], &readset)) { /* this descriptor is ready*/
      bytesread = read(fd[i], buf, BUFSIZE);
      done = TRUE;
    }
}
```

select() Example: Timed Waiting on I/O

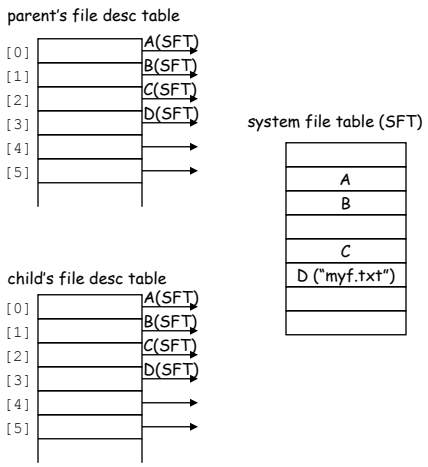
```
int waitfdtimed(int fd, struct timeval end) {
  fd_set         readset;
  int            retval;
  struct timeval timeout;

  FD_ZERO(&readset);
  FDSET(fd, &readset);
  if (abs2reltime(end, &timeout) == -1) return -1;
  while (((retval = select(fd+1,&readset,NULL,NULL,&timeout)) == -1)
           && (errno == EINTR)) {
      if (abs2reltime(end, &timeout) == -1) return -1;
      FD_ZERO(&readset);
      FDSET(fd, &readset);
  }
  if (retval == 0) {errno = ETIME; return -1;}
  if (retval == -1) {return -1;}
  return 0;
}
```

File Representation to User



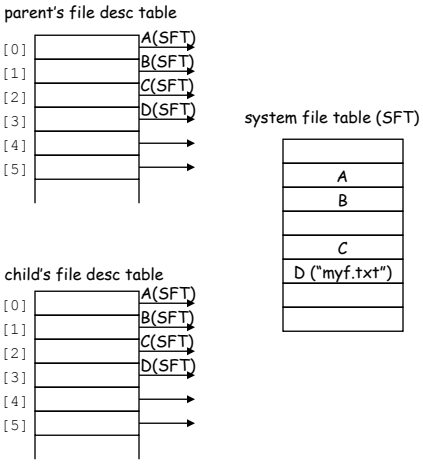
File Descriptors and `fork()`

- With `fork()`, child inherits content of parent's address space, including most of parent's state:
  - scheduling parameters
  - file descriptor table
  - signal state
  - environment
  - etc.



File Descriptors and `fork()` (II)

```
int main(void) {
  char c = '!';
  int myfd;

  myfd = open('myf.txt', O_RDONLY);

  fork();

  read(myfd, &c, 1);

  printf('Process %ld got %c\n',
            (long)getpid(), c);

  return 0;
}
```



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  return 0;
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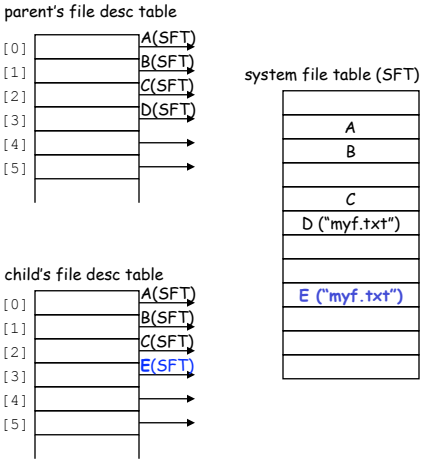

Duplicating File Descriptors: `dup2()`

- Want to redirect I/O from well-known file descriptor to descriptor associated with some other file?
  - e.g. `stdout` to file?

```
#include <unistd.h>

int dup2(int fildes, int fildes2);
```

Errors:
`EBADF`: `fildes` or `fildes2` is not valid
`EINTR`: `dup2` interrupted by signal

Example: redirect standard output to file.

```
int main(void) {
  int fd = open('my.file', <some_flags>, <some_mode>);

  dup2(fd, STDOUT_FILENO);

  close(fd);

  write(STDOUT_FILENO, 'OK', 2);
}
```

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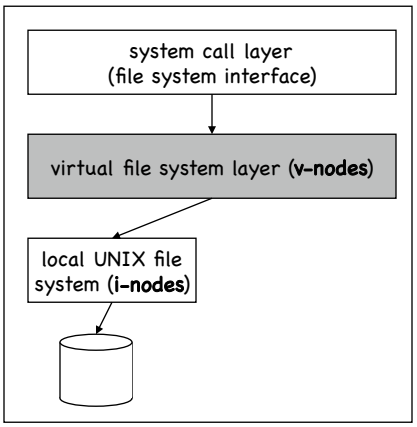
after open		after dup2		after close	
file descriptor table		file descriptor table		file descriptor table	
[0]	standard input	[0]	standard input	[0]	standard input
[1]	standard output	[1]	write to file.txt	[1]	write to file.txt
[2]	standard error	[2]	standard error	[2]	standard error
[3]	write to file.txt	[3]	write to file.txt		

File System Architecture: Virtual File System



Example: Linux Virtual File System (VFS)

- Provides generic file-system interface (separates from implementation)
- Provides support for network-wide identifiers for files (needed for network file systems).

Objects in VFS:

- inode objects (individual files)
- file objects (open files)
- superblock objects (file systems)
- dentry objects (individual directory entries)

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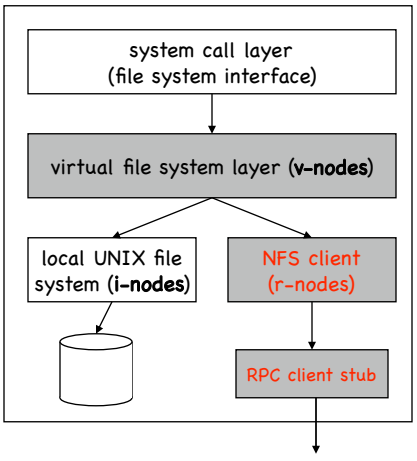

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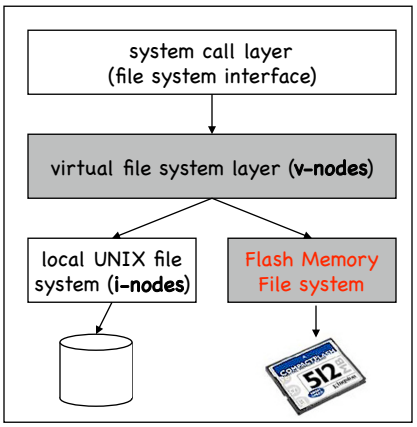
File System Architecture: Virtual File System



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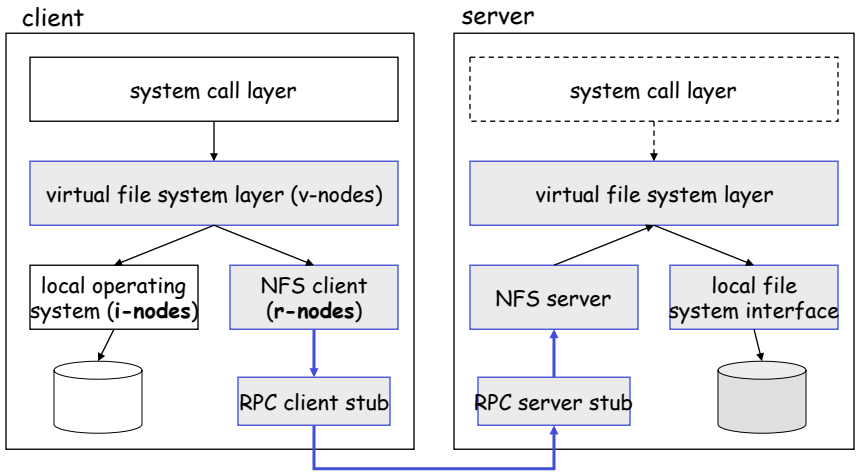
- **inode objects** (individual files)
- **file objects** (open files)
- **superblock objects** (file systems)
- **dentry objects** (individual directory entries)

Sun's Network File System (NFS)

- Architecture:
  - NFS as collection of protocols the provide clients with a distributed file system.
  - **Remote Access Model** (as opposed to **Upload/Download Model**)
  - Every machine can be both a client and a server.
  - Servers export directories for access by remote clients (defined in the `/etc/exports` file).
  - Clients access exported directories by mounting them remotely.
- Protocols:
  - file and directory access
    - Servers are stateless (no `OPEN`/`CLOSE` calls)

NFS: Basic Architecture



NFS Implementation: Issues

- File handles:
  - specify *filesystem* and *i-node number* of file
  - sufficient?
- Integration:
  - where to put NFS on client?
  - on server?
- Server caching:
  - *read-ahead*
  - *write-delayed* with periodic *sync* *vs.* *write-through*
- Client caching:
  - timestamps with validity checks

NFS: File System Model

- File system model similar to UNIX file system model
  - Files as uninterpreted sequences of bytes
  - Hierarchically organized into naming graph
  - NSF supports **hard links** and **symbolic links**
  - Named files, but access happens through **file handles**.
- File system operations
  - NFS Version 3 aims at statelessness of server
  - NFS Version 4 is more relaxed about this
- Lots of details at **http://nfs.sourceforge.net/**

NFS: Client Caching

- Potential for inconsistent versions at different clients.
- Solution approach:
  - Whenever file cached, **timestamp** of last modification on server is cached as well.
  - **Validation**: Client requests latest timestamp from server (*getattributes*), and compares against local timestamp. If fails, all blocks are invalidated.
- Validation check:
  - at file open
  - whenever server contacted to get new block
  - after timeout (3s for file blocks, 30s for directories)
- Writes:
  - block marked dirty and scheduled for flushing.
  - flushing: when file is closed, or a **sync** occurs at client.
- Time lag for change to propagate from one client to other:
  - delay between write and flush
  - time to next cache validation

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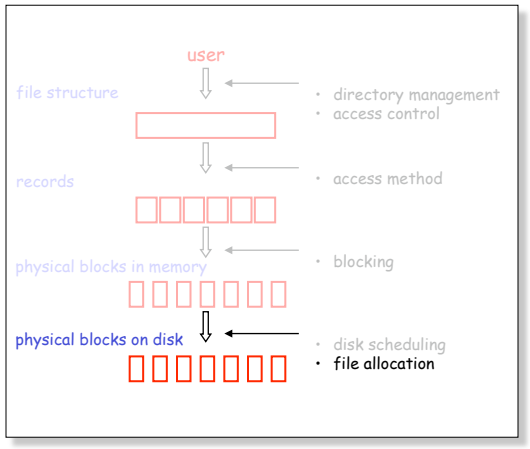
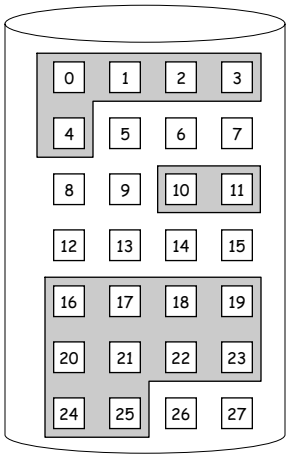


Allocation Methods

- File systems manage disk resources
- Must allocate space so that
  - space on disk utilized effectively
  - file can be accessed quickly
- Typical allocation methods:
  - contiguous
  - linked
  - indexed
- Suitability of particular method depends on
  - storage device technology
  - access/usage patterns

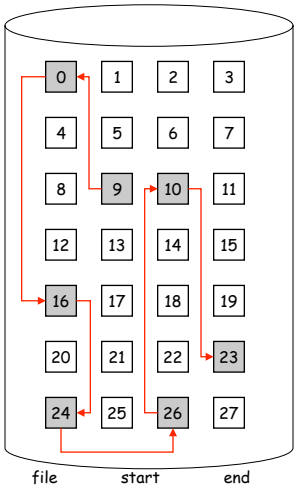
Contiguous Allocation



file	start	length
file1	0	5
file2	10	2
file3	16	10

- Logical file mapped onto a sequence of adjacent physical blocks.
- Advantages:
  - minimizes head movements
  - simplicity of both sequential and direct access.
  - Particularly applicable to applications where entire files are scanned.
- Disadvantages:
  - Inserting/Deleting records, or changing length of records difficult.
  - Size of file must be known *a priori*. (Solution: copy file to larger hole if exceeds allocated size.)
  - External fragmentation
  - Pre-allocation causes internal fragmentation

Linked Allocation

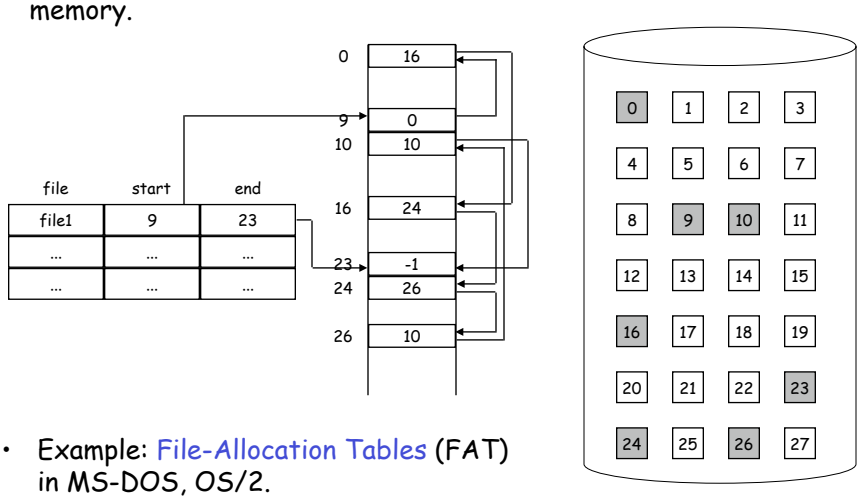


file	start	end
file 1	9	23
...	...	...
...	...	...

- Scatter logical blocks throughout secondary storage.
- Link each block to next one by forward pointer.
- May need a backward pointer for backspacing.
- Advantages:
  - blocks can be easily inserted or deleted
  - no upper limit on file size necessary *a priori*
  - size of individual records can easily change over time.
- Disadvantages:
  - direct access difficult and expensive
  - overhead required for pointers in blocks
  - reliability

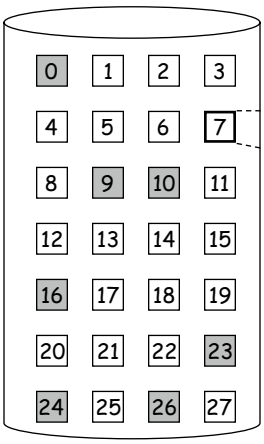
Variations of Linked Allocation

- Maintain all pointers as a separate linked list, preferably in main memory.



- Example: File-Allocation Tables (FAT) in MS-DOS, OS/2.

Indexed Allocation



file	index block
file1	7
...	...
...	...

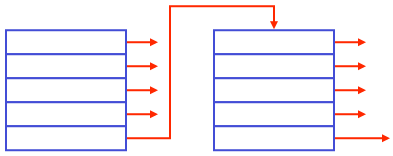
- Keep all pointers to blocks in one location: index block (one index block per file)

9	0	16	24	26	10	23	-1	-1	-1

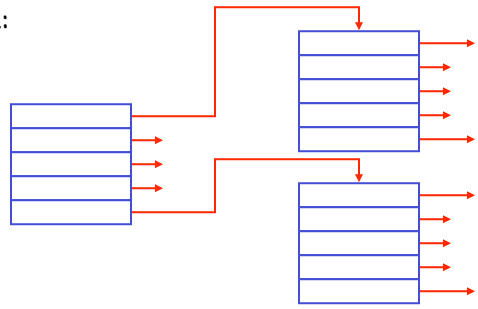
- Advantages:
  - supports direct access
  - no external fragmentation
  - therefore: combines best of continuous and linked allocation.
- Disadvantages:
  - internal fragmentation in index blocks
- Problem:
  - what is a good size for index block?
  - fragmentation *vs.* file length

Solutions for the Index-Block-Size Dilemma

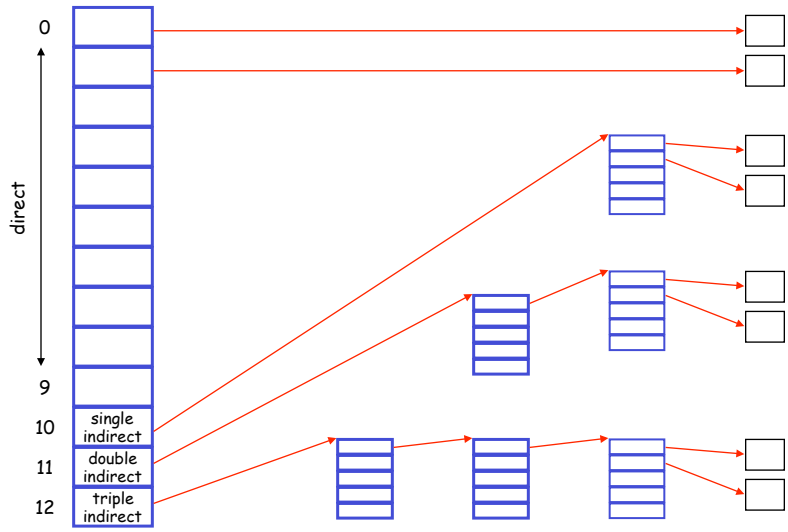
- Linked index blocks:



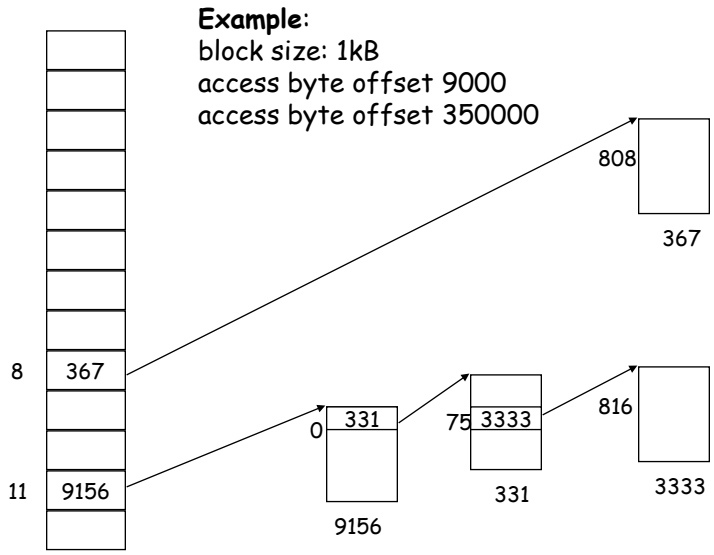
- Multilevel index scheme:



Index Block Scheme in UNIX

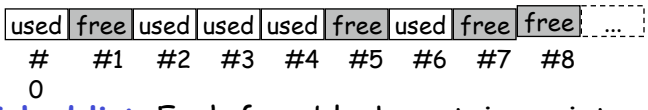


UNIX (System V) Allocation Scheme



Free Space Management

- Must keep track where unused blocks are.
- Can keep information for free space management in unused blocks.
- **Bit vector**:



- **Linked list**: Each free block contains pointer to next free block.
- Variations:
  - **Grouping**: Each block has more than on pointer to empty blocks.
  - **Counting**: Keep pointer of first free block and number of contiguous free blocks following it.