ICS 143 - Principles of Operating Systems

Lectures 14 and 15 - FileSystem Interface and Implementation

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Outline

- File Concept and Structure
- Directory Structures
- File Organizations
- Access Methods
- Protection

File Concept

- Contiguous logical address space
  - OS abstracts from the physical properties of its storage device to define a logical storage unit called file.
  - OS maps files to physical devices.
- Types
  - Data
    - numeric, character, binary
  - Program
    - source, object (load image)
  - Documents

File Structure

- None - sequence of words/bytes
- Simple record structure
  - Lines
  - Fixed Length
  - Variable Length
- Complex Structures
  - Formatted document
  - Relocatable Load File
- Can simulate last two with first method by inserting appropriate control characters
- Who decides
  - Operating System
  - Program

File Attributes

- Name
  - symbolic file-name, only information in human-readable form
- Type -
  - for systems that support multiple types
- Location -
  - pointer to a device and to file location on device
- Size -
  - current file size, maximal possible size
- Protection -
  - controls who can read, write, execute
- Time, Date and user identification
  - data for protection, security and usage monitoring
- Information about files are kept in the directory structure, maintained on disk

File Operations

- A file is an abstract data type. It can be defined by operations:
  - Create a file
  - Write a file
  - Read a file
  - Reposition within file - file seek
  - Delete a file
  - Truncate a file
  - Open(Fi)
    - search the directory structure on disk for entry Fi, and move the content of entry to memory.
  - Close(Fi)
    - move the content of entry Fi in memory to directory structure on disk.

File types - name.extension

File Type	***Possible extension***	***Function***
Executable	Exe,com,bin	Machine language program
Object	Obj, o	Compiled machine lang., not linked
Source code	c, CC, p, java, asm...	Source code in various languages
Batch	Bat, sh	Commands to command interpreter
text	Txt, doc	Textual data, documents
Print, view	ps, dvi, gif	ASCII or binary file
archive	Arc, zip, tar	Group of files, sometimes compressed
Library	Lib, a	Libraries of routines

Directory Structure

- Number of files on a system can be extensive
  - Break file systems into partitions (treated as a separate storage device)
  - Hold information about files within partitions.
- Device Directory: A collection of nodes containing information about all files on a partition.
- Both the directory structure and files reside on disk.
- Backups of these two structures are kept on tapes.

Information in a Device Directory

- File Name
- File Type
- Address or Location
- Current Length
- Maximum Length
- Date created, Date last accessed (for archival), Date last updated (for dump)
- Owner ID (who pays), Protection information
  - Also on a per file, per process basis
    - Current position - read/write position
    - usage count

Operations Performed on Directory

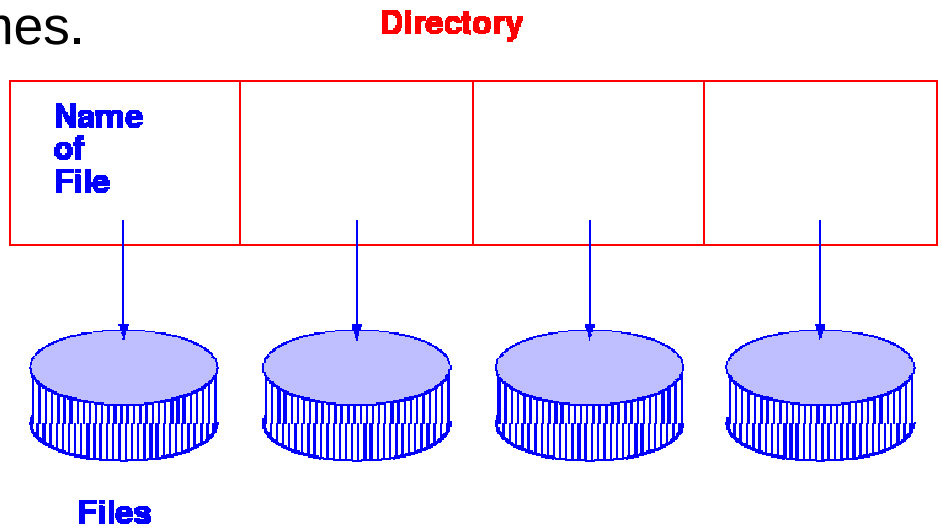
- Search for a file
- Create a file
- Delete a file
- List a directory
- Rename a file
- Traverse the filesystem

Logical Directory Organization -- Goals

- Efficiency - locating a file quickly
- Naming - convenient to users
  - Two users can have the same name for different files.
  - The same file can have several different names.
- Grouping
  - Logical grouping of files by properties (e.g. all Pascal programs, all games…)

Single Level Directory

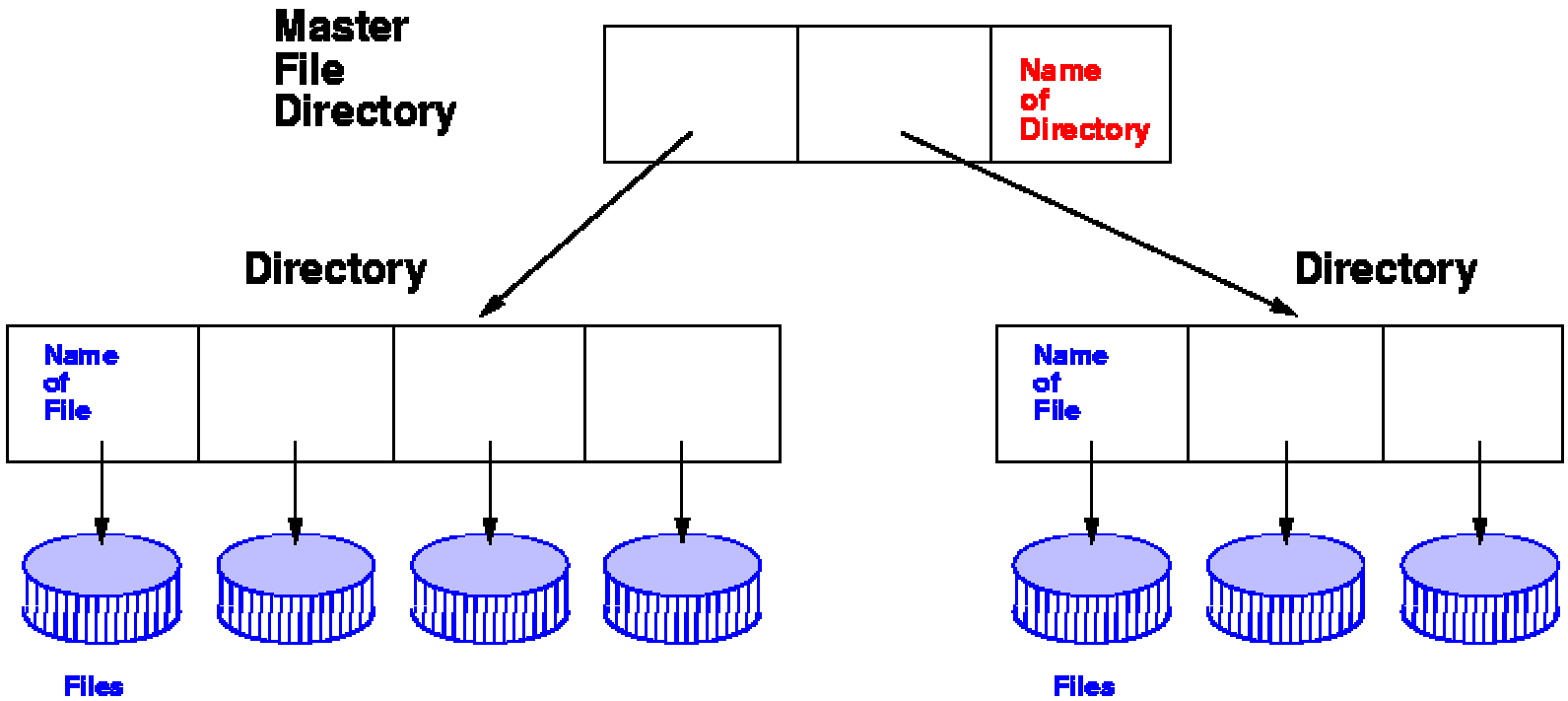
- A single directory for all users
- Naming Problem and Grouping Problem
  - As the number of files increases, difficult to remember unique names
  - As the number of users increase, users must have unique names.



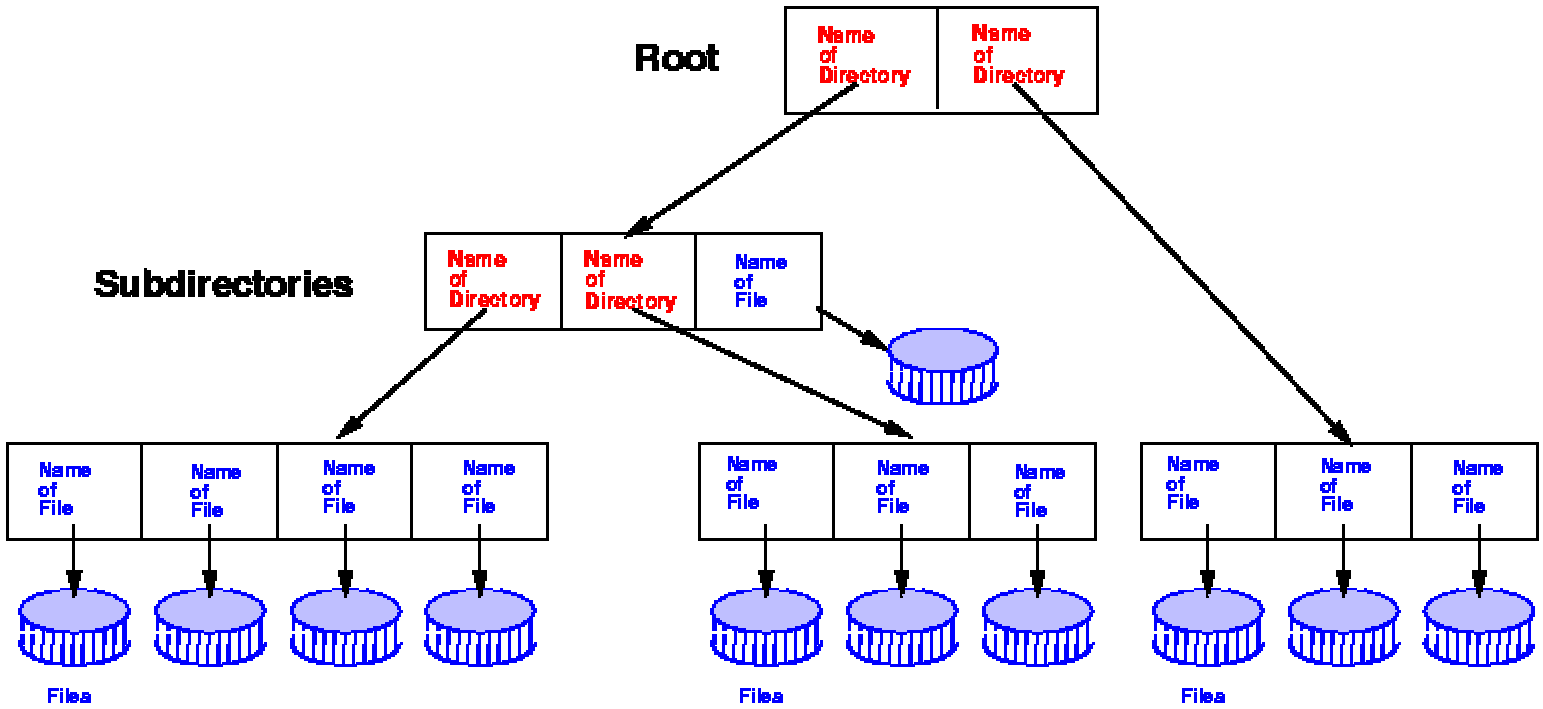
Two Level Directory

- Introduced to remove naming problem between users
  - First Level contains list of user directories
  - Second Level contains user files
  - Need to specify Path name
  - Can have same file names for different users.
  - System files kept in separate directory or Level 1.
  - Efficient searching

Two Level Directory



Tree structured Directories



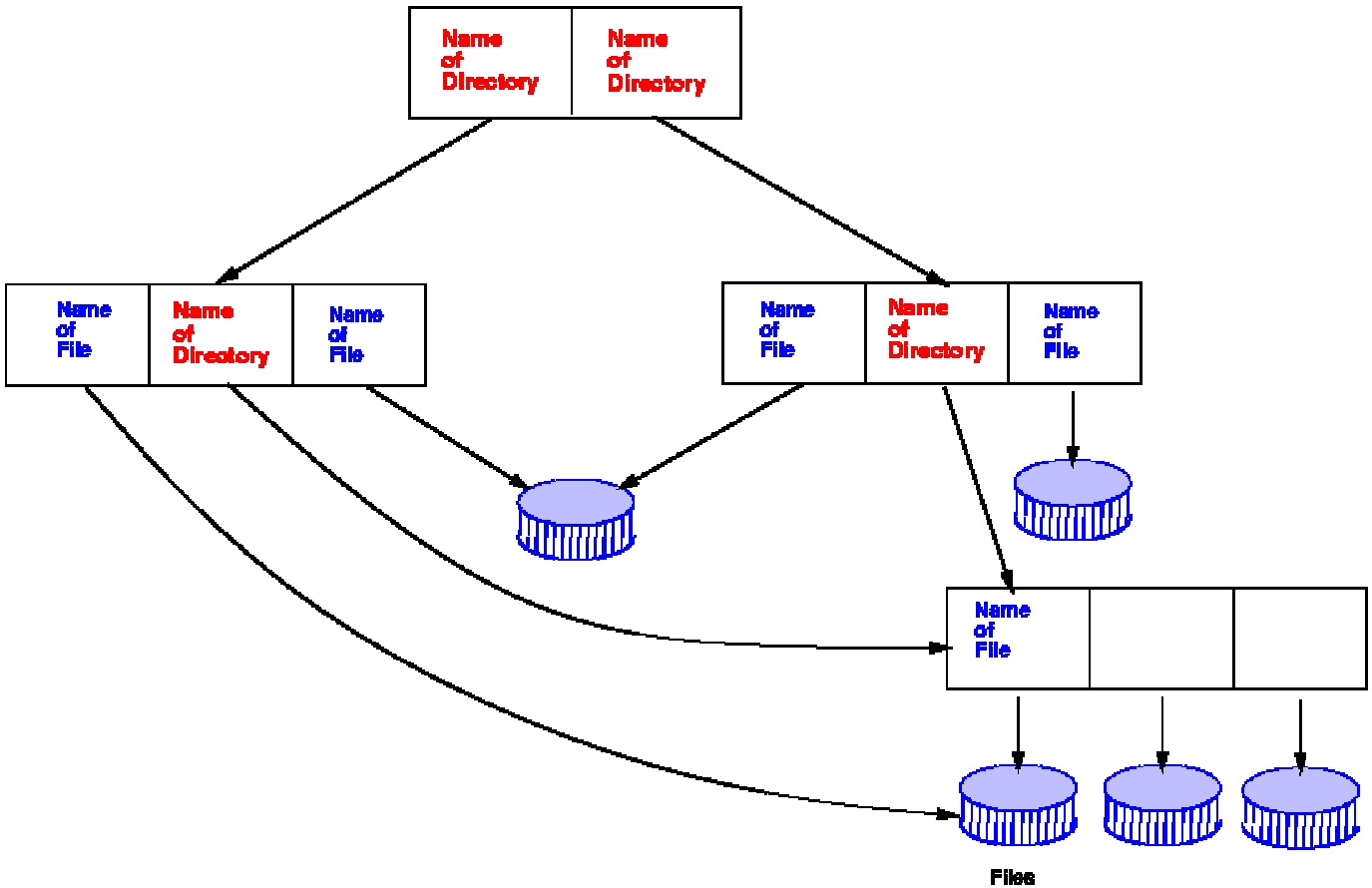
Tree Structured Directories

- Arbitrary depth of directories
  - Leaf nodes are files, interior nodes are directories.
- Efficient Searching
- Grouping Capability
- Current Directory (working directory)
  - cd /spell/mail/prog
  - type list
- MS-DOS uses a tree structured directory

Tree Structured Directories

- Absolute or relative path name
  - Absolute from root
  - Relative paths from current working directory pointer.
- Creating a new file is done in current directory
- Creating a new subdirectory is done in current directory, e.g. mkdir <dir-name>
- Delete a file , e.g. rm file-name
- Deletion of directory
  - Option 1 : Only delete if directory is empty
  - Option 2: delete all files and subdirectories under directory

Acyclic Graph Directories



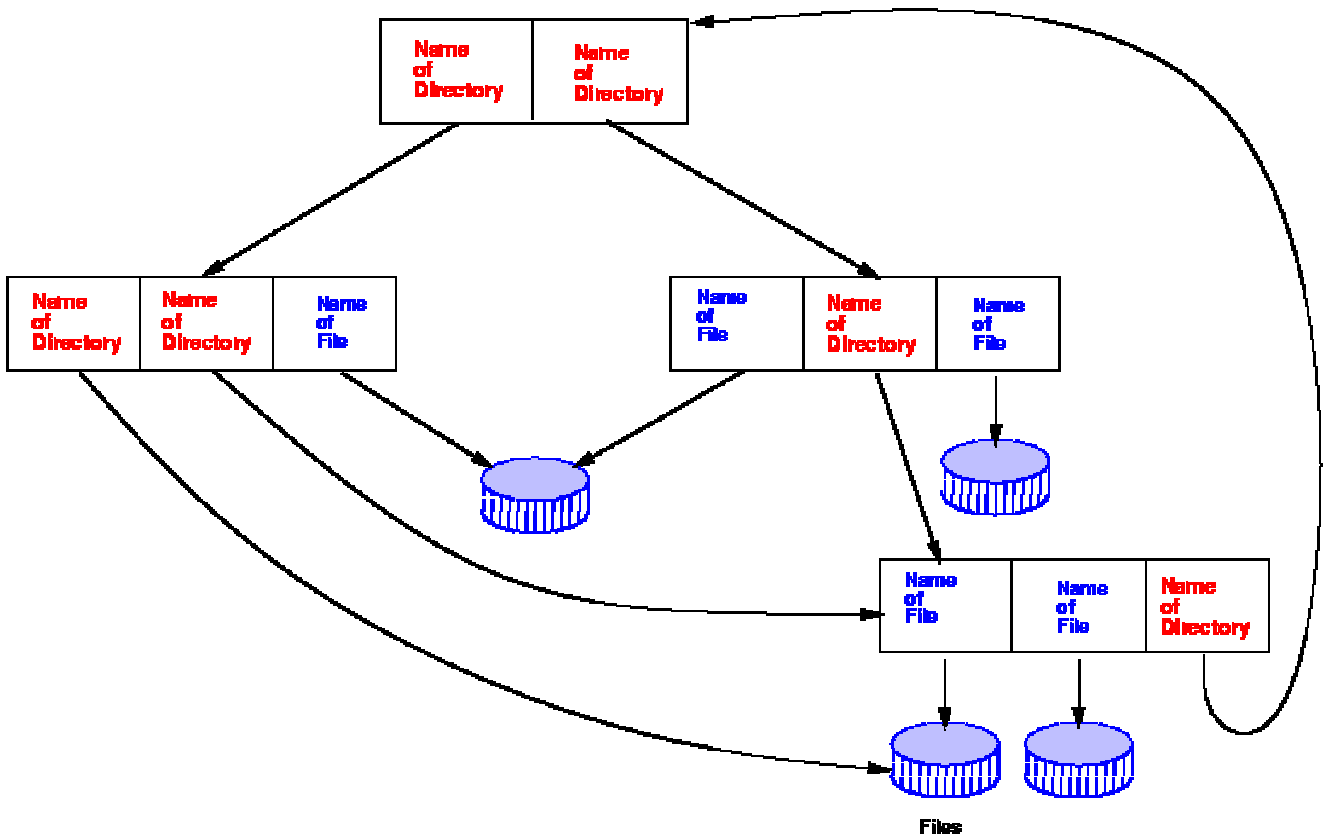
Acyclic Graph Directories

- Acyclic graphs allow sharing
- Implementation by links
  - Links are pointers to other files or subdirectories
  - Symbolic links or relative path name
    - Directory entry is marked as a link and name of real file/directory is given. Need to resolve link to locate file.
- Implementation by shared files
  - Duplicate information in sharing directories
  - Original and copy indistinguishable.
  - Need to maintain consistency if one of them is modified.

Acyclic Graph Directories

- Naming : File may have multiple absolute path names
  - Two different names for the same file
- Traversal
  - ensure that shared data structures are traversed only once.
- Deletion
  - Removing file when someone deletes it may leave dangling pointers.
  - Preserve file until all references to it are deleted
    - Keep a list of all references to a file or
    - Keep a count of the number of references - *reference count.*
    - When count = 0, file can be deleted.

General Graph Directories



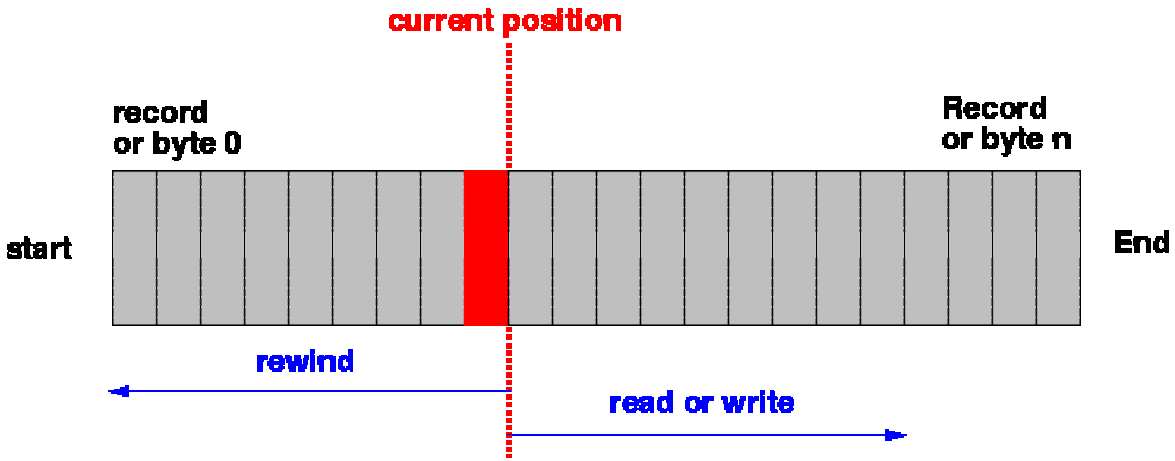
General Graph Directories (cont.)

- How do we guarantee no cycles in a tree structured directory?
  - Allow only links to file not subdirectories.
  - Every time a new link is added use a cycle detection algorithm to determine whether it is ok.
- If links to directories are allowed, we have a simple graph structure
  - Need to ensure that components are not traversed twice both for correctness and for performance, e.g. search can be non-terminating.
- File Deletion - reference count can be non-zero
  - Need garbage collection mechanism to determine if file can be deleted.

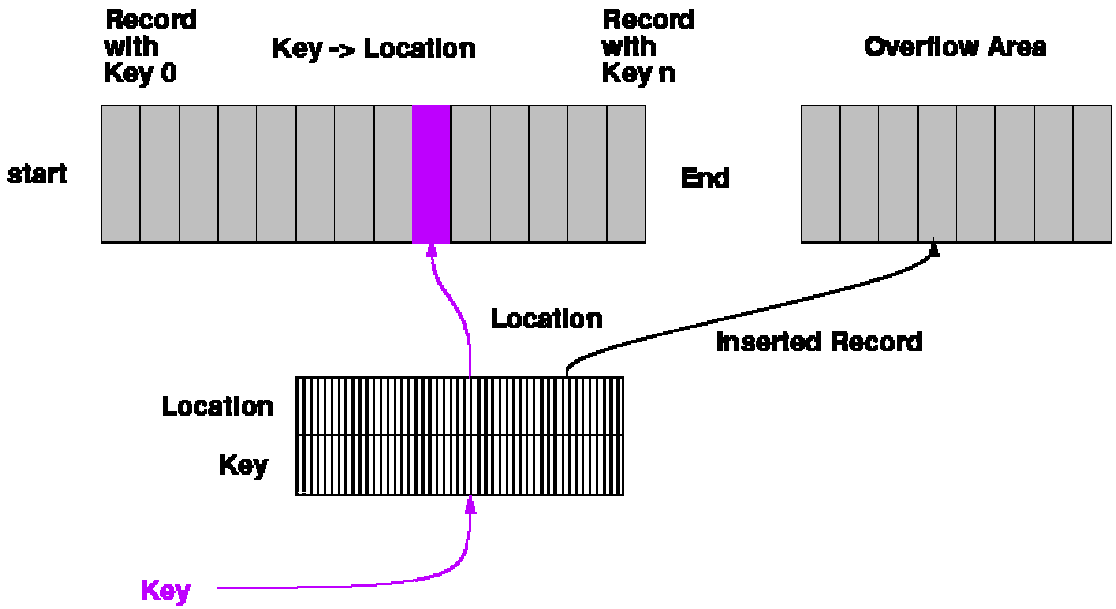
Access Methods

- Sequential Access
  - read next
  - write next
  - reset
  - no read after last write (rewrite)
- Direct Access (n = relative block number)
  - read n
  - write n
  - position to n
    - read next
    - write next
  - rewrite n

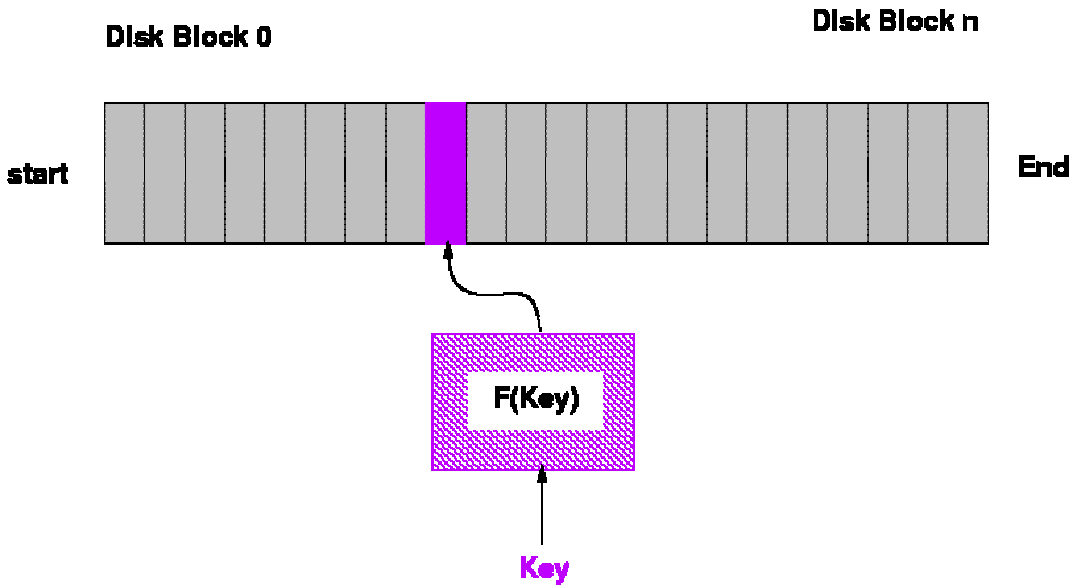
Sequential File Organization



Indexed Sequential or Indexed File Organization



Direct Access File Organization



Protection

- File owner/creator should be able to control
  - what can be done
  - by whom
- Types of access
    - read
    - write
    - execute
    - append
    - delete
    - list

Access lists and groups

- Associate each file/directory with access list
  - Problem - length of access list..
- Solution - condensed version of list
  - Mode of access: read, write, execute
  - Three classes of users
    - owner access - user who created the file
    - groups access - set of users who are sharing the file and need similar access
    - public access - all other users
  - In UNIX, 3 fields of length 3 bits are used.
    - Fields are user, group, others(u,g,o),
    - Bits are read, write, execute (r,w,x).
    - E.g. chmod go+rw file , chmod 761 game

File-System Implementation

- File System Structure
- Allocation Methods
- Free-Space Management
- Directory Implementation
- Efficiency and Performance
- Recovery

File-System Structure

- File Structure
  - Logical Storage Unit with collection of related information
  - File System resides on secondary storage (disks).
    - To improve I/O efficiency, I/O transfers between memory and disk are performed in blocks.
      - Read/Write/Modify/Access each block on disk.
- File system organized into layers.
- *File control block* - storage structure consisting of information about a file.

File System Mounting

- File System must be mounted before it can be available to process on the system
  - The OS is given the name of the device and the mount point (location within file structure at which files attach).
  - OS verifies that the device contains a valid file system.
  - OS notes in its directory structure that a file system is mounted at the specified mount point.

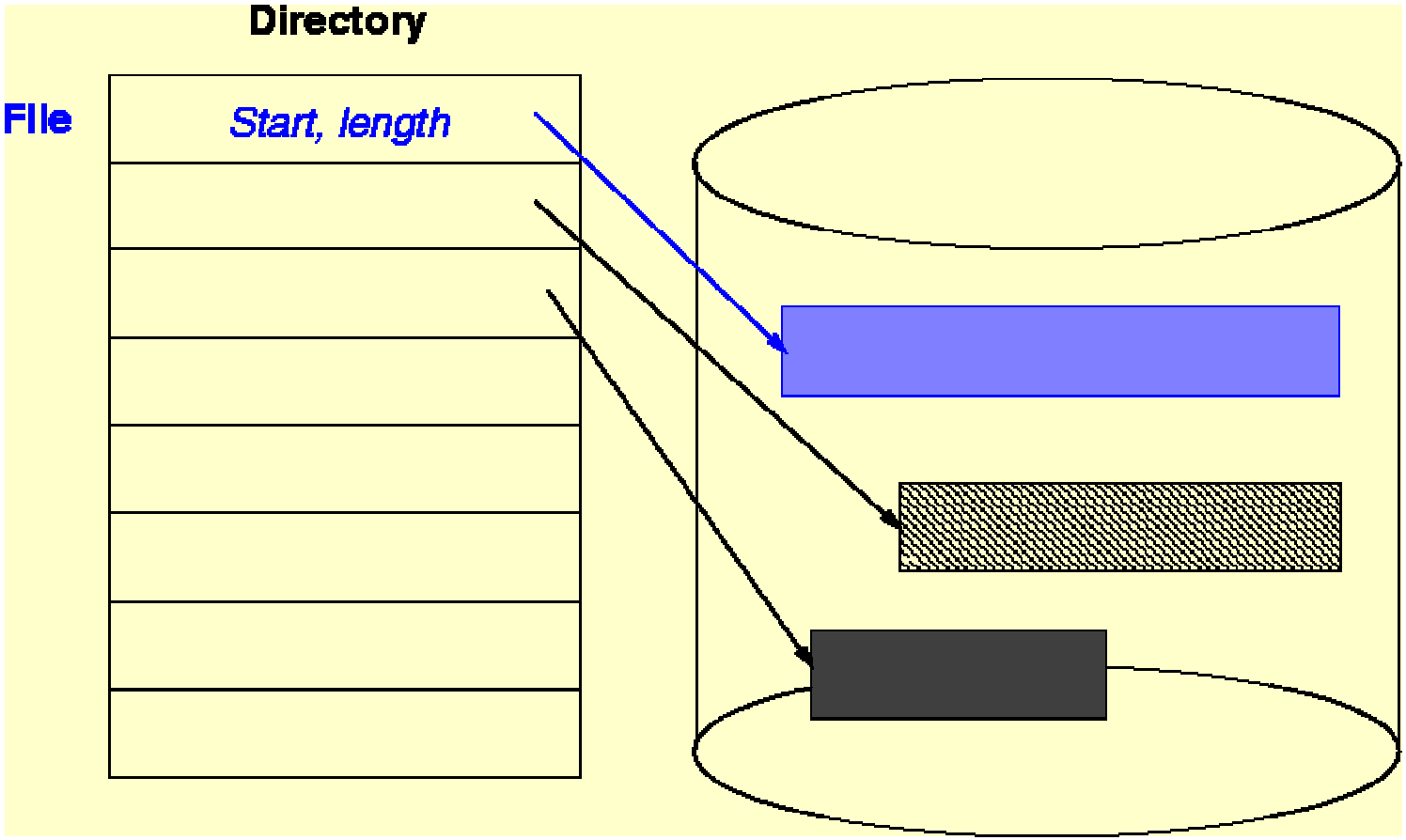
Allocation of Disk Space

- Low level access methods depend upon the disk allocation scheme used to store file data
  - Contiguous Allocation
  - Linked List Allocation
  - Block Allocation

Contiguous Allocation

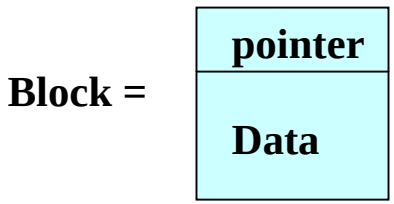
- Each file occupies a set of contiguous blocks on the disk.
  - Simple - only starting location (block #) and length (number of blocks) are required.
  - Suits sequential or direct access.
  - Fast (very little head movement) and easy to recover in the event of system crash.
  - Problems
    - Wasteful of space (dynamic storage-allocation problem). Use first fit or best fit. Leads to external fragmentation on disk.
    - Files cannot grow - expanding file requires copying
    - Users tend to overestimate space - internal fragmentation.
- Mapping from logical to physical - <Q,R>
  - Block to be accessed = Q + starting address
  - Displacement into block = R

Contiguous Allocation

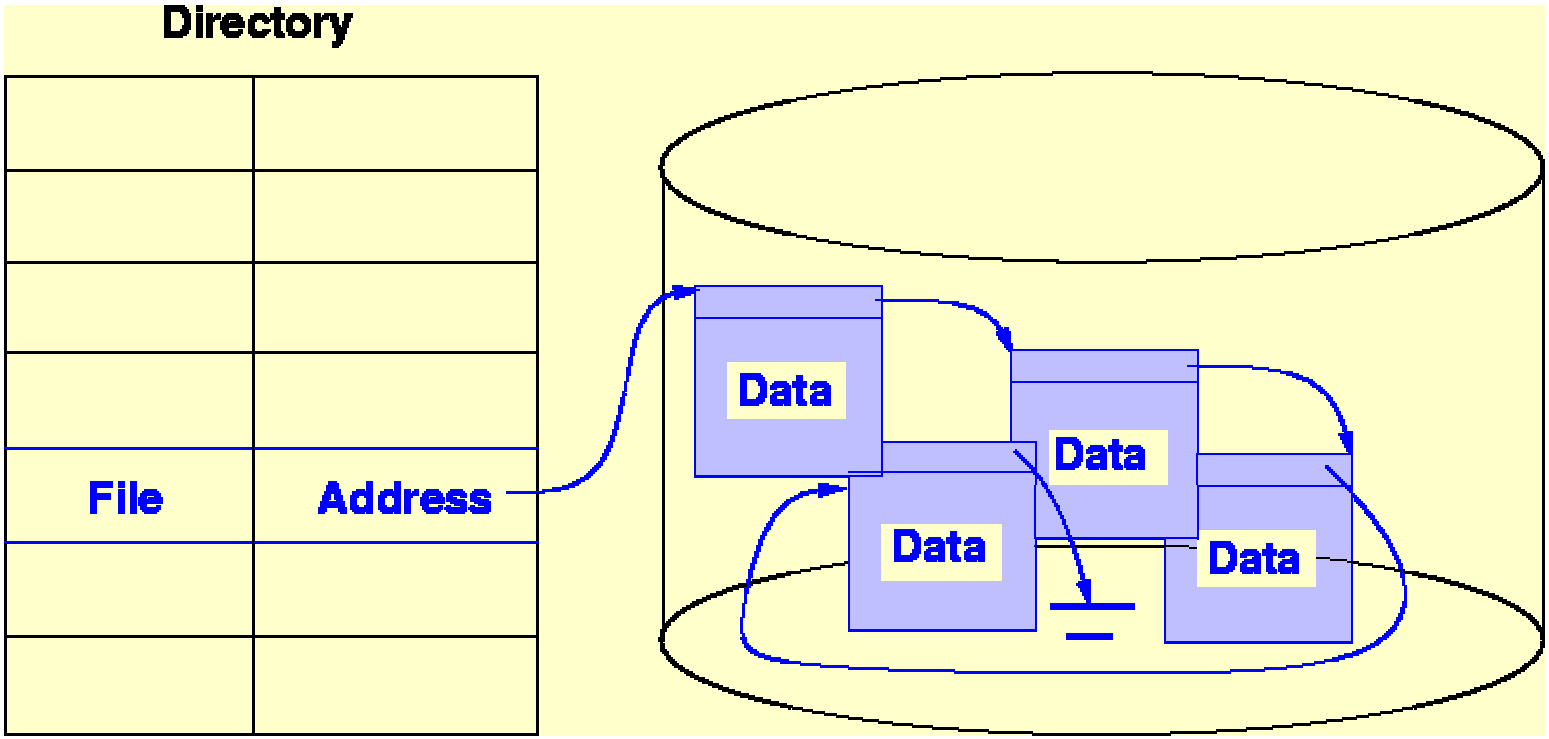


Linked Allocation

- Each file is a linked list of disk blocks
  - Blocks may be scattered anywhere on the disk.
  - Each node in list can be a fixed size physical block or a contiguous collection of blocks.
  - Allocate as needed and then link together via pointers.
    - Disk space used to store pointers, if disk block is 512 bytes, and pointer (disk address) requires 4 bytes, user sees 508 bytes of data.
  - Pointers in list not accessible to user.



Linked Allocation



Linked Allocation

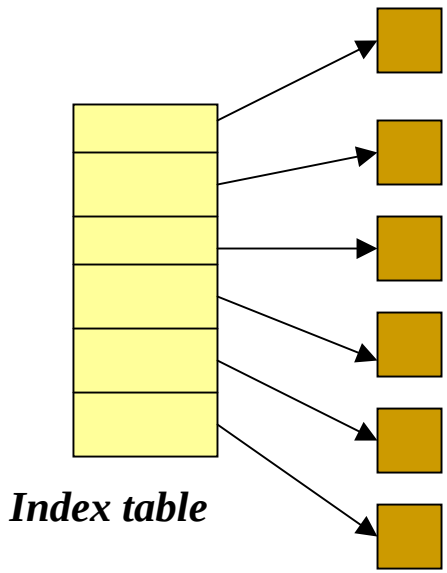
- Simple - need only starting address.
- Free-space management system - space efficient.
  - Can grow in middle and at ends. No estimation of size necessary.
- Suited for sequential access but not random access.
- Directory Table maps files into head of list for a file.
- Mapping - <Q, R>
  - Block to be accessed is the Qth block in the linked chain of blocks representing the file.
  - Displacement into block = R + 1

Linked Allocation (cont.)

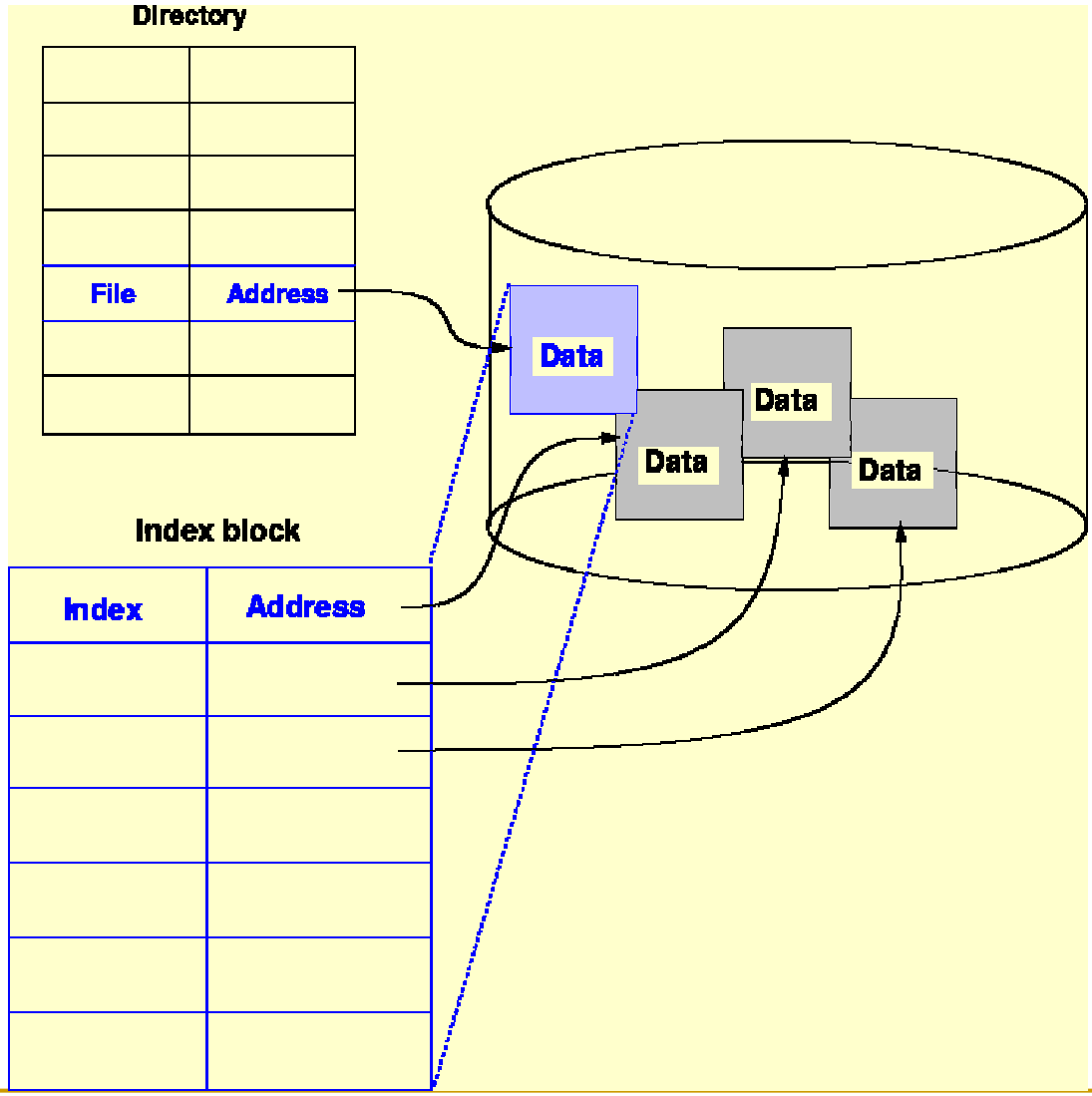
- Slow - defies principle of locality.
  - Need to read through linked list nodes sequentially to find the record of interest.
- Not very reliable
  - System crashes can scramble files being updated.
- Important variation on linked allocation method
  - File-allocation table (FAT) - disk-space allocation used by MS-DOS and OS/2.

Indexed Allocation

- Brings all pointers together into the index block.
- Logical view



Indexed Allocation



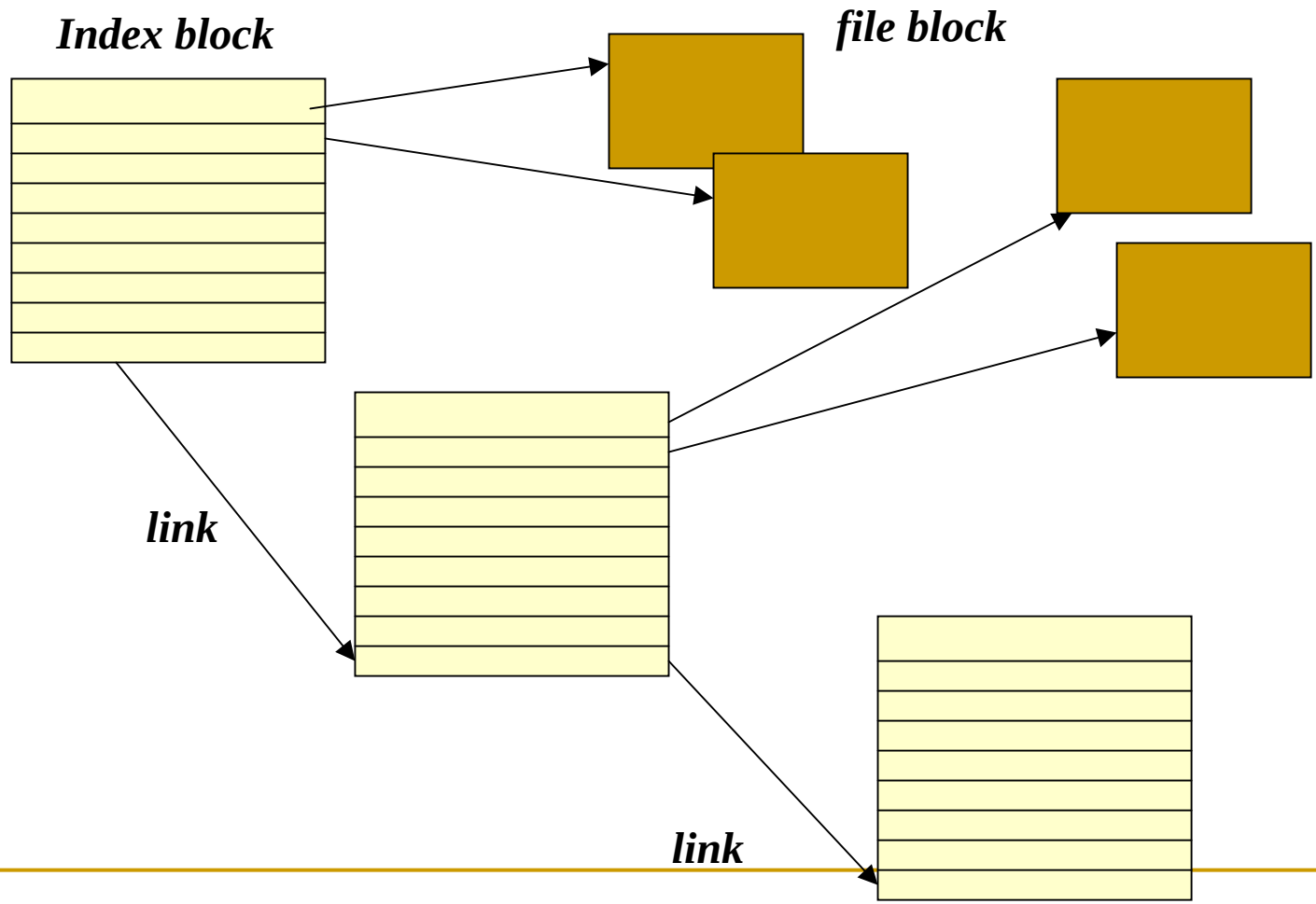
Indexed Allocation (cont.)

- Need index table.
- Supports sequential, direct and indexed access.
- Dynamic access without external fragmentation, but have overhead of index block.
  - Mapping from logical to physical in a file of maximum size of 256K words and block size of 512 words. We need only 1 block for index table.
    - Mapping - <Q,R>
      - Q - displacement into index table
      - R - displacement into block

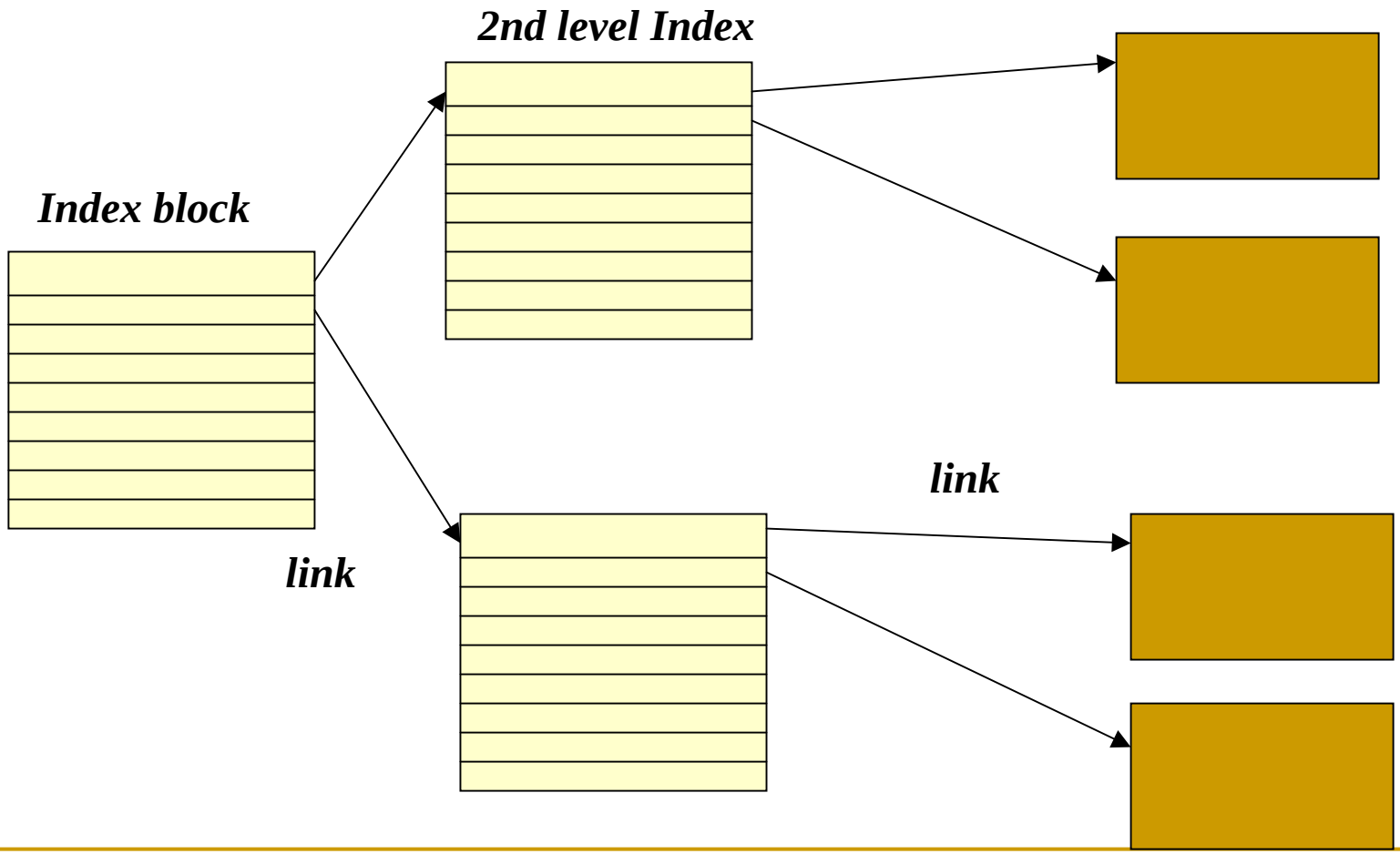
Indexed Allocation - Mapping

- Mapping from logical to physical in a file of unbounded length.
- Linked scheme -
  - Link blocks of index tables (no limit on size)
- Multilevel Index
  - E.g. Two Level Index - first level index block points to a set of second level index blocks, which in turn point to file blocks.
  - Increase number of levels based on maximum file size desired.
  - Maximum size of file is bounded.

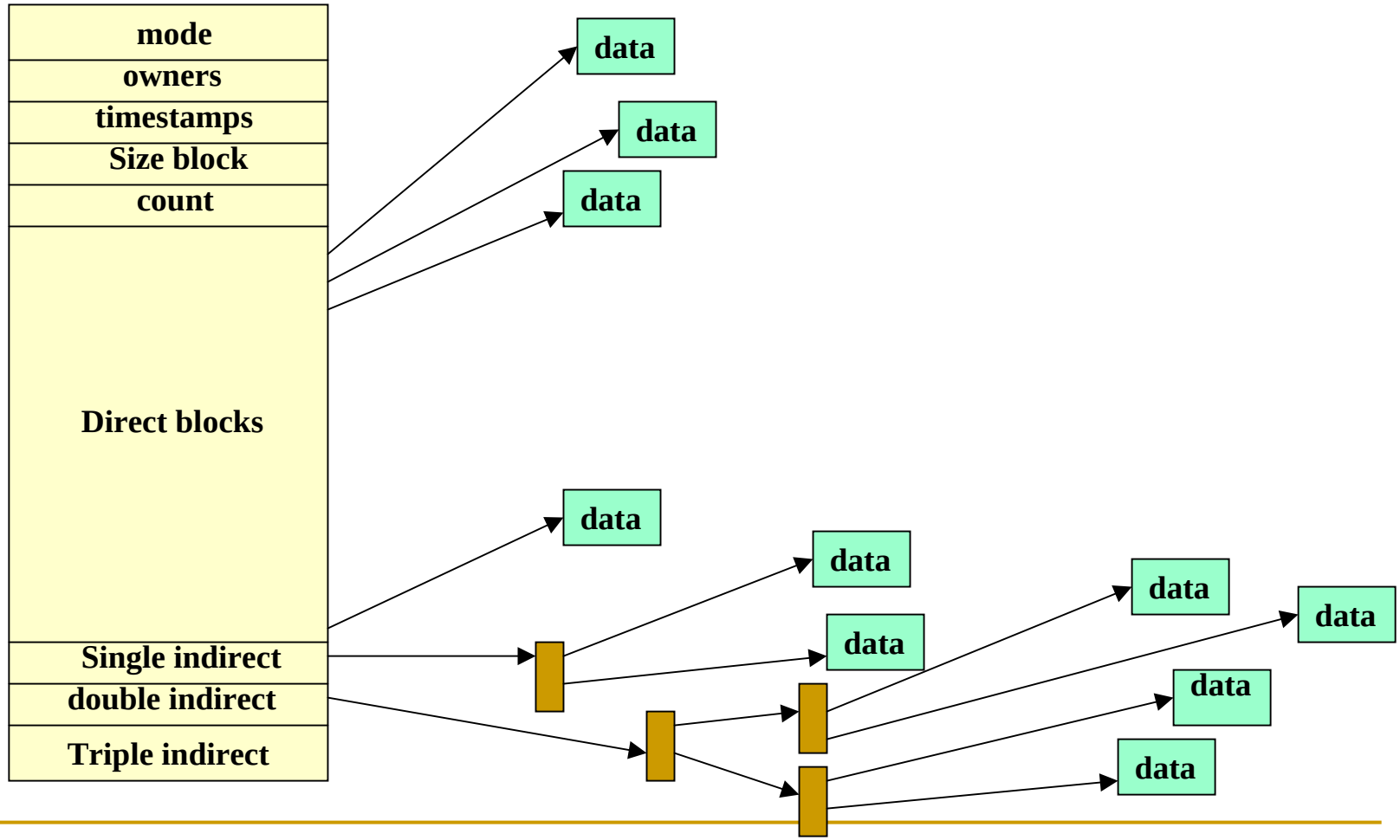
Indexed File - Linked Scheme



Indexed Allocation - Multilevel index

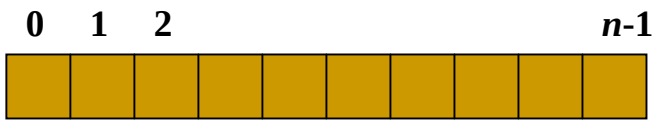


Combined Scheme: UNIX (4K bytes per block)



Free Space Management

- Bit Vector (*n* blocks) - bit map of free blocks



bit[i] = { **0 implies block[i] free**
1 implies block[i] occupied

  - Block number calculation
    (number of bits per word) *
    (number of 0-value words) +
    offset of 1st bit
  - Bit map requires extra space.
    - Eg. Block size = 2^12 bytes, Disk size = 2^30 bytes
      n = 2^30/2^12 = 2^18 bits (or 32K bytes)
  - Easy to get contiguous files
  - Example: BSD File system

Free Space Management

- Linked list (free list)
  - Keep a linked list of free blocks
  - Cannot get contiguous space easily, not very efficient because linked list needs traversal.
  - No waste of space
- Linked list of indices - Grouping
  - Keep a linked list of index blocks. Each index block contains addresses of free blocks and a pointer to the next index block.
  - Can find a large number of free blocks contiguously.
- Counting
  - Linked list of contiguous blocks that are free
  - Free list node contains pointer and number of free blocks starting from that address.

Free Space Management

- Need to protect
  - pointer to free list
  - Bit map
    - Must be kept on disk
    - Copy in memory and disk may differ.
    - Cannot allow for block[i] to have a situation where bit[i] = 1 in memory and bit[i] = 0 on disk
  - Solution
    - Set bit[i] = 1 in disk
    - Allocate block[i]
    - Set bit[i] = 1 in memory.

Directory Implementation

- Linear list of file names with pointers to the data blocks
  - simple to program
  - time-consuming to execute - linear search to find entry.
  - Sorted list helps - allows binary search and decreases search time.
- Hash Table - linear list with hash data structure
  - decreases directory search time
  - collisions - situations where two file names hash to the same location.
  - Each hash entry can be a linked list - resolve collisions by adding new entry to linked list.

Efficiency and Performance

- Efficiency dependent on:
  - disk allocation and directory algorithms
  - types of data kept in the files directory entry
  - Dynamic allocation of kernel structures
- Performance improved by:
  - *On-board cache* - for disk controllers
  - *Disk Cache* - separate section of main memory for frequently used blocks. Block replacement mechanisms
    - LRU
    - *Free-behind* - removes block from buffer as soon as next block is requested.
    - *Read-ahead* - request block and several subsequent blocks are read and cached.
  - Improve PC performance by dedicating section of memory as *virtual disk* or RAM *disk*.

Recovery

- Ensure that system failure does not result in loss of data or data inconsistency.
- Consistency checker
  - compares data in directory structure with data blocks on disk and tries to fix inconsistencies.
- Backup
  - Use system programs to back up data from disk to another storage device (floppy disk, magnetic tape).
- Restore
  - Recover lost file or disk by restoring data from backup.