Operating System Concepts

Lecture 29: File System Abstraction

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MWF 12:00-12:50 VVC 2 215

Today's class

- What is a file system?
  - file abstraction
- File attributes and operations
- Access methods

What's a file system?

- file system is comprised of a collection of files, a directory structure, an index structure, and a free space list
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    - disk I/O is done in blocks; reading or writing less than the block size needs translation and buffering
  - providing a more convenient API (compared to hardware interface) with
    - naming: finding file by name rather than block number
    - sharing: enabling shared access to files
    - protection: enforcing access restriction
    - reliability: keeping file intact despite power cycles, crashes, hardware failures, etc.
    - efficient access: maximizing sequential access and allowing efficient random access

File systems and disks

- disk is an array of blocks, where each block is a fixed-size data array
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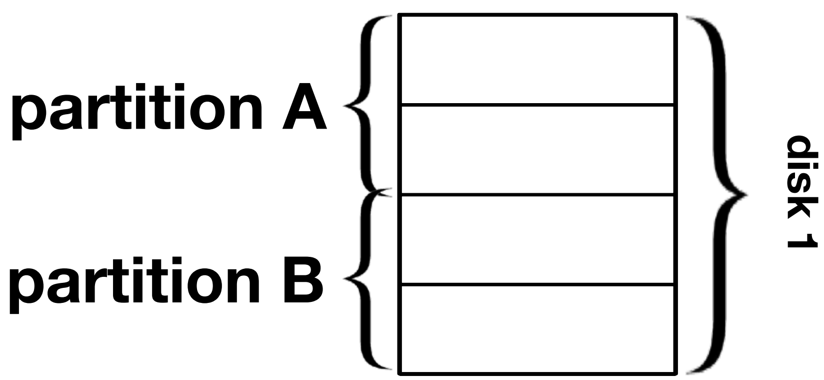
- disk can be partitioned into quarters, each holding a separate file system
  - the volume is a subset of a device or the device is sliced up into several volumes
  - reasons to partition a disk
    - to limit the size of each file system
    - to have multiple file system types on a single disk
    - to leave an unformatted disk space for raw read/write operations



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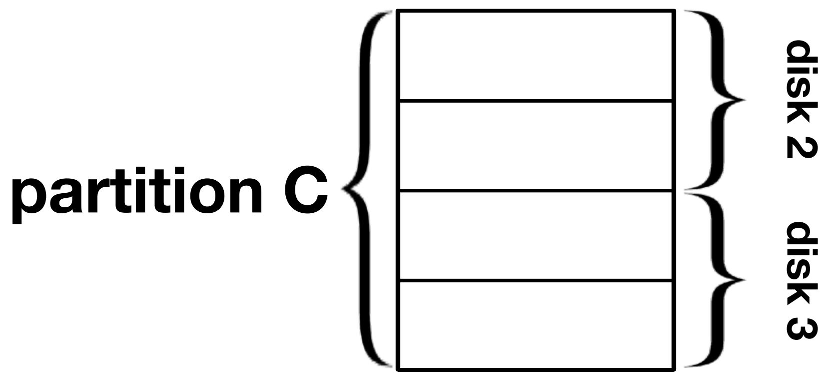
- multiple disks can be linked together to form a RAID set
  - the volume comprises multiple devices



What do hardware and OS provide?

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  - persistence: disks provide **nonvolatile** memory
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  - fast/efficient access: through random access
- Operating System
  - reliability: redundancy allows recovery from some additional failures
  - sharing/protection: read, write, and execute privileges for different users and groups
  - ease of use:
    - associating names with chunks of data (i.e., files)
    - organizing large collections of files into directories
    - transparent mapping of the user's concept of files and directories onto locations on disks
    - search facility in file systems (e.g., SpotLight in Mac OS X)

File system design problems

- how to translate from user-specified names to unique file numbers?
- how to lay out the files on disk?
- how to speed up file operations for small files?
  - since most files are small
- how to support both sequential and random access?
- how to identify data blocks that belong to a file?
  - what is the right data structure to maintain this information?
- how to allocate new blocks to a file?
  - must balance locality with expandability

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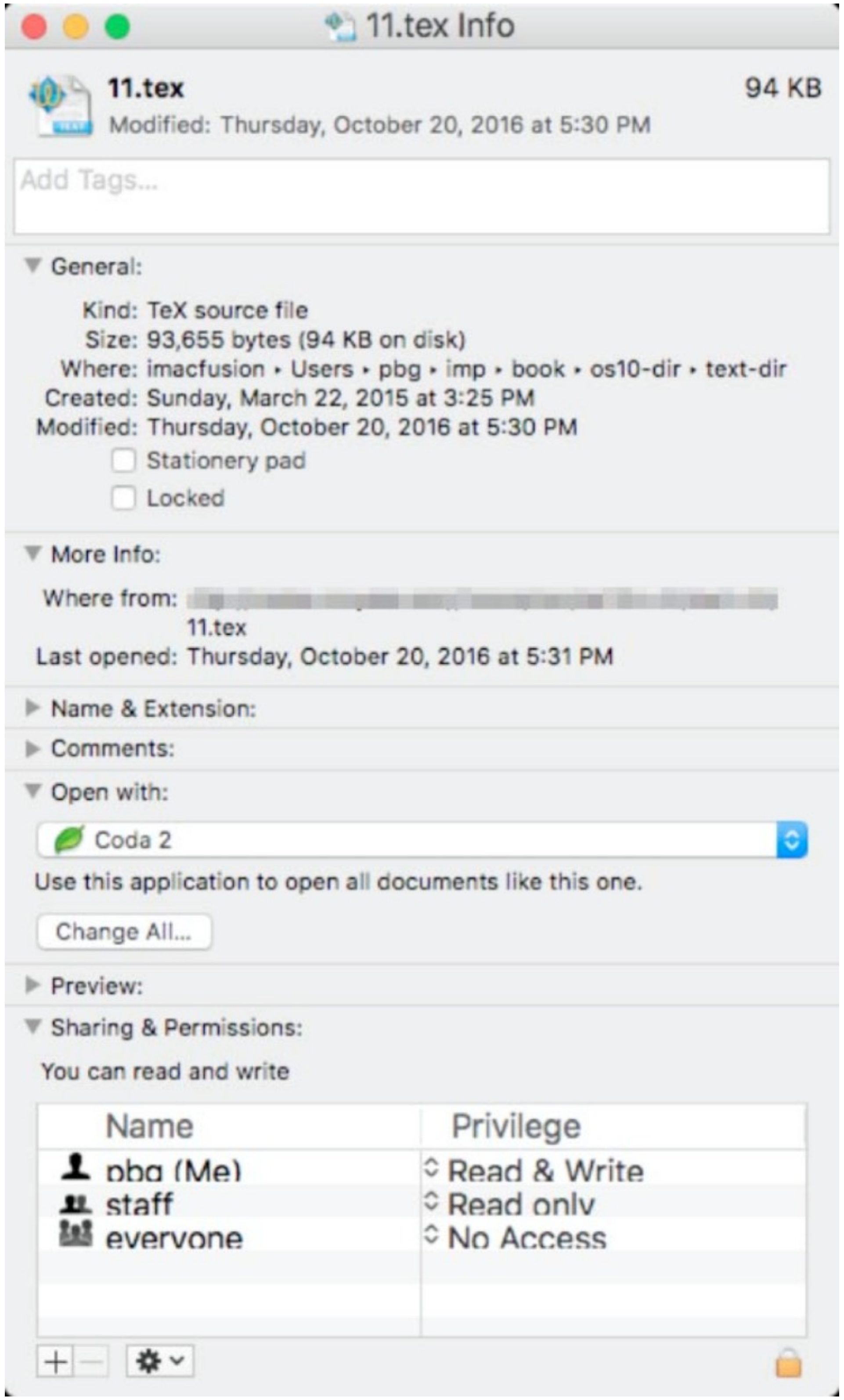
  - files can also be defined as a series of records or objects (structured)
- most Operating Systems impose a minimal number of file structures
  - for example, executable files have a certain structure in UNIX and in Windows

File attributes

- human-readable name
  - constraints: length, legal characters, case sensitiveness, etc.
  - must be unique in a name space



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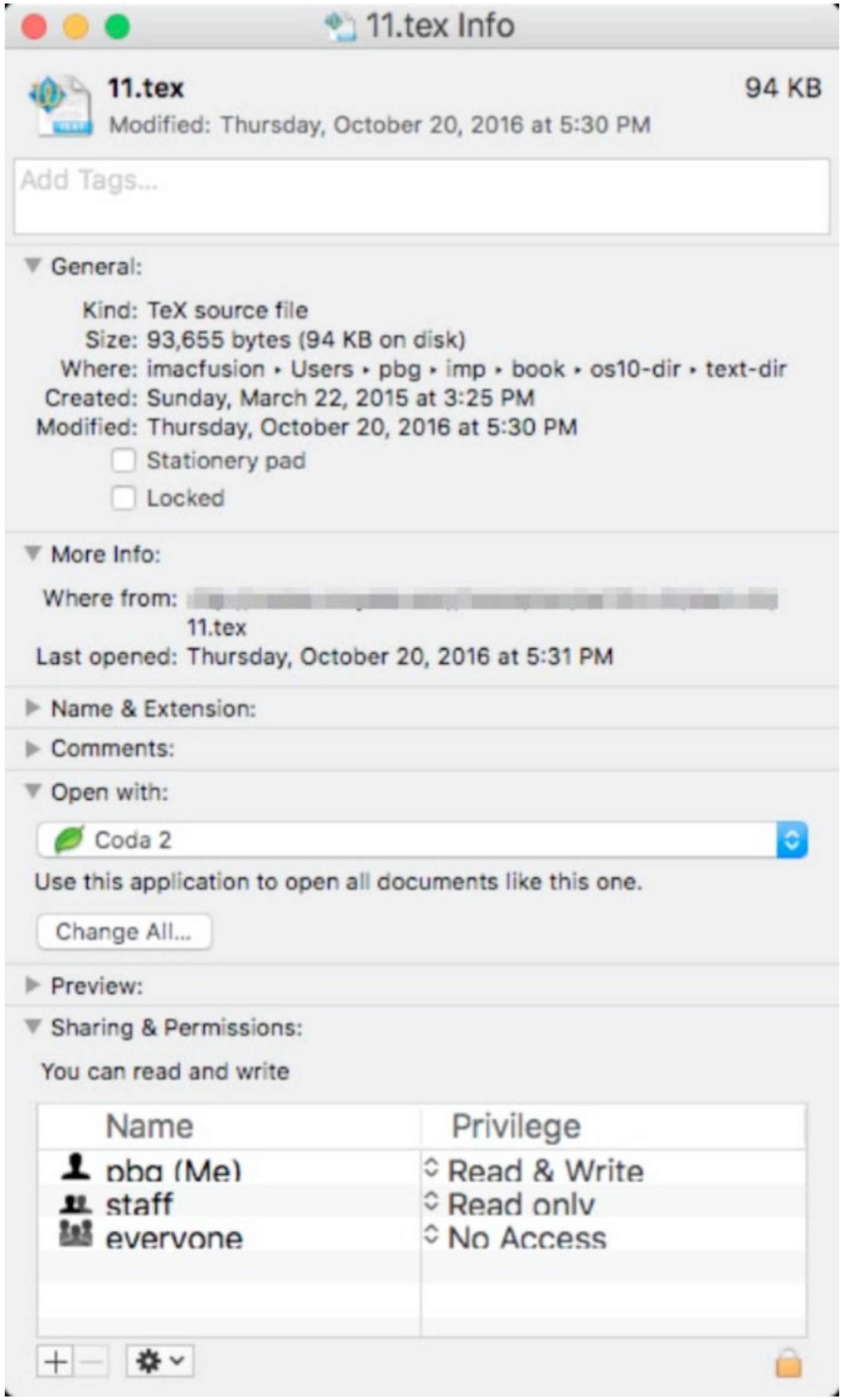

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  - advantage: error detection, default actions, user-friendliness
  - disadvantage: a more complex file system
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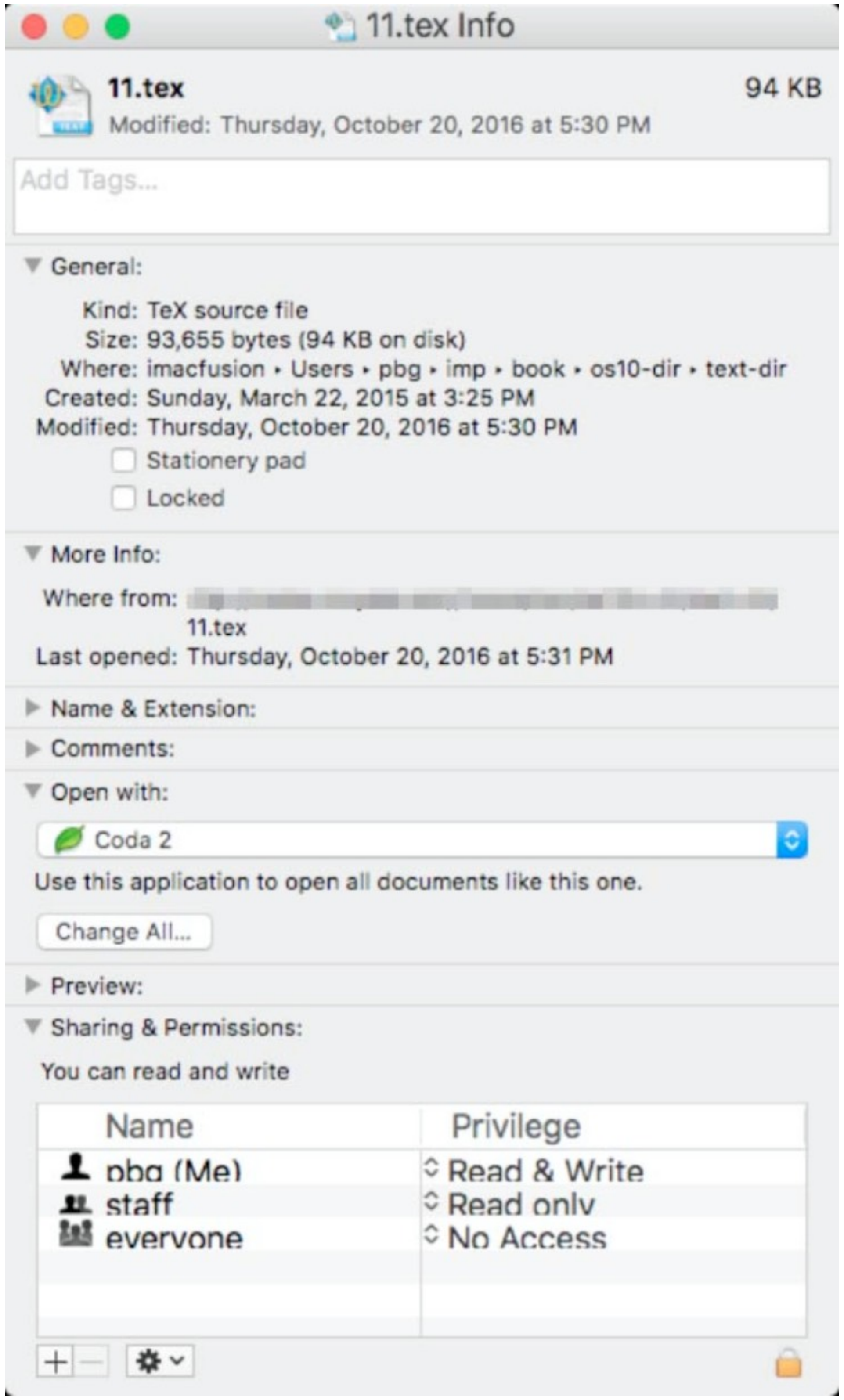
  - in UNIX, file extension is just a hint (not enforced)



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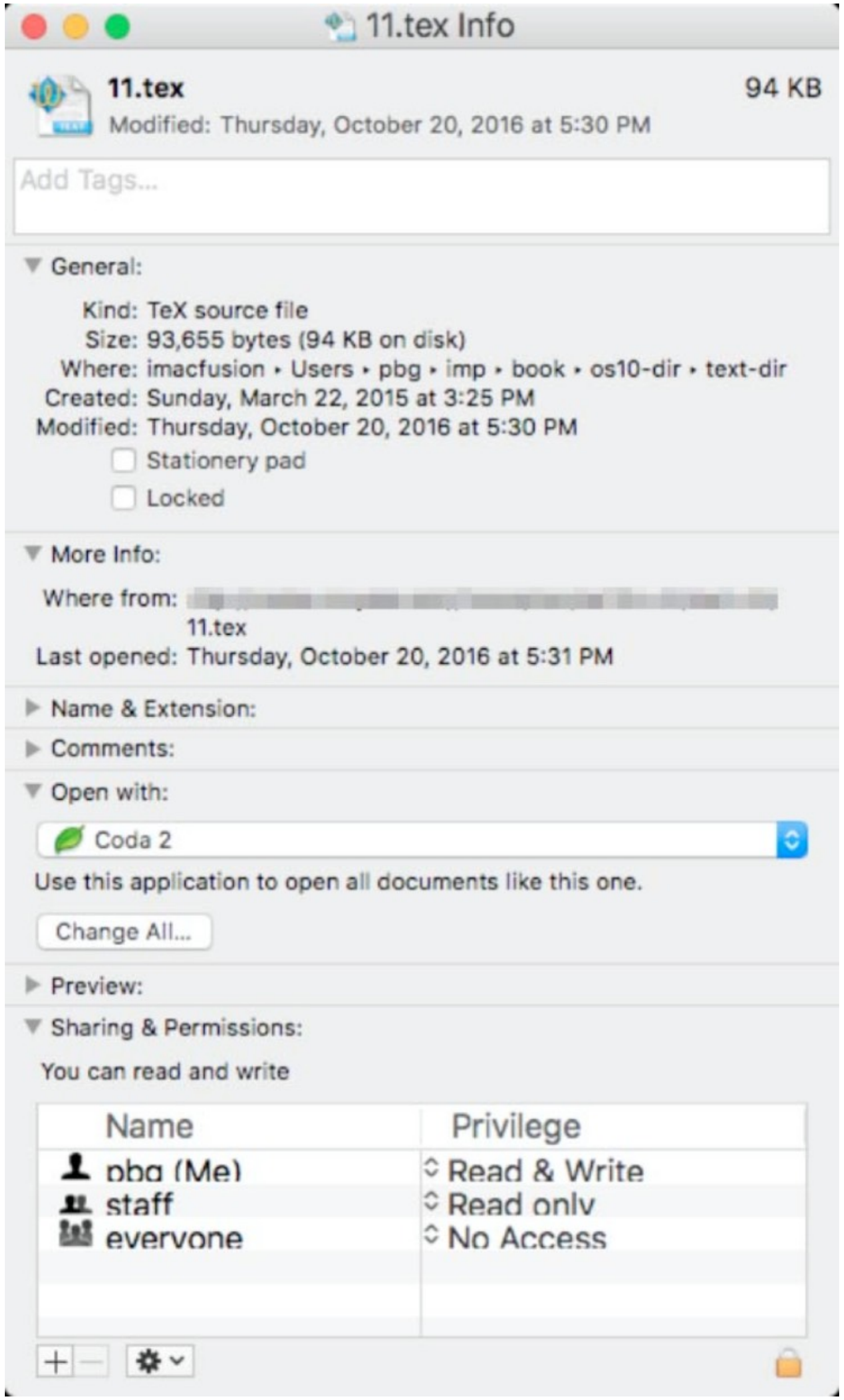
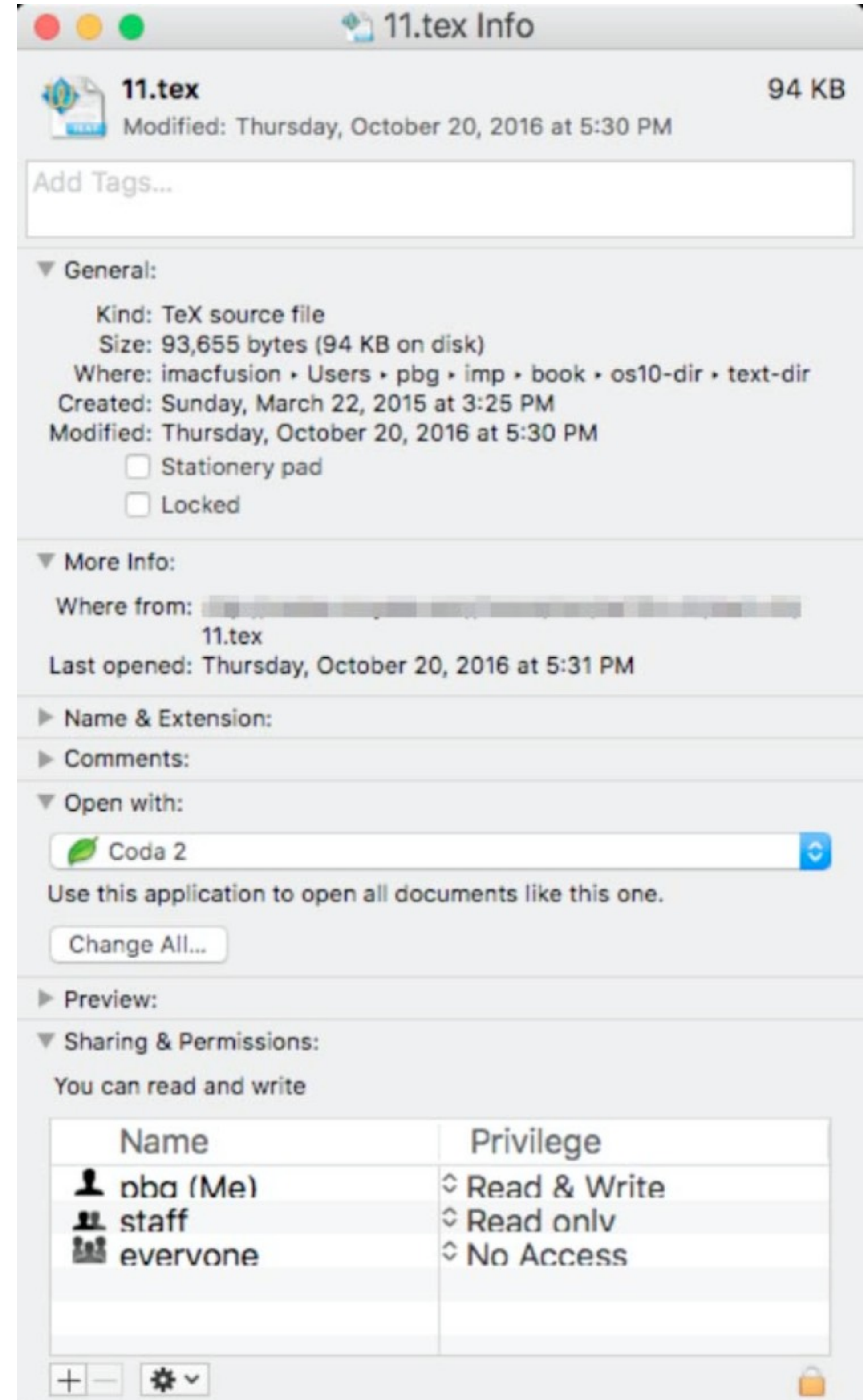
- location: a pointer to the storage device and the file location on that device



File attributes

- size: the current size (in bytes or blocks) and possibly the maximum supported size
  - file size is typically a multiple of block size because disk space is allocated in blocks
  - so some portion of the last block is generally wasted (**internal fragmentation**)
    - all file systems suffer from internal fragmentation



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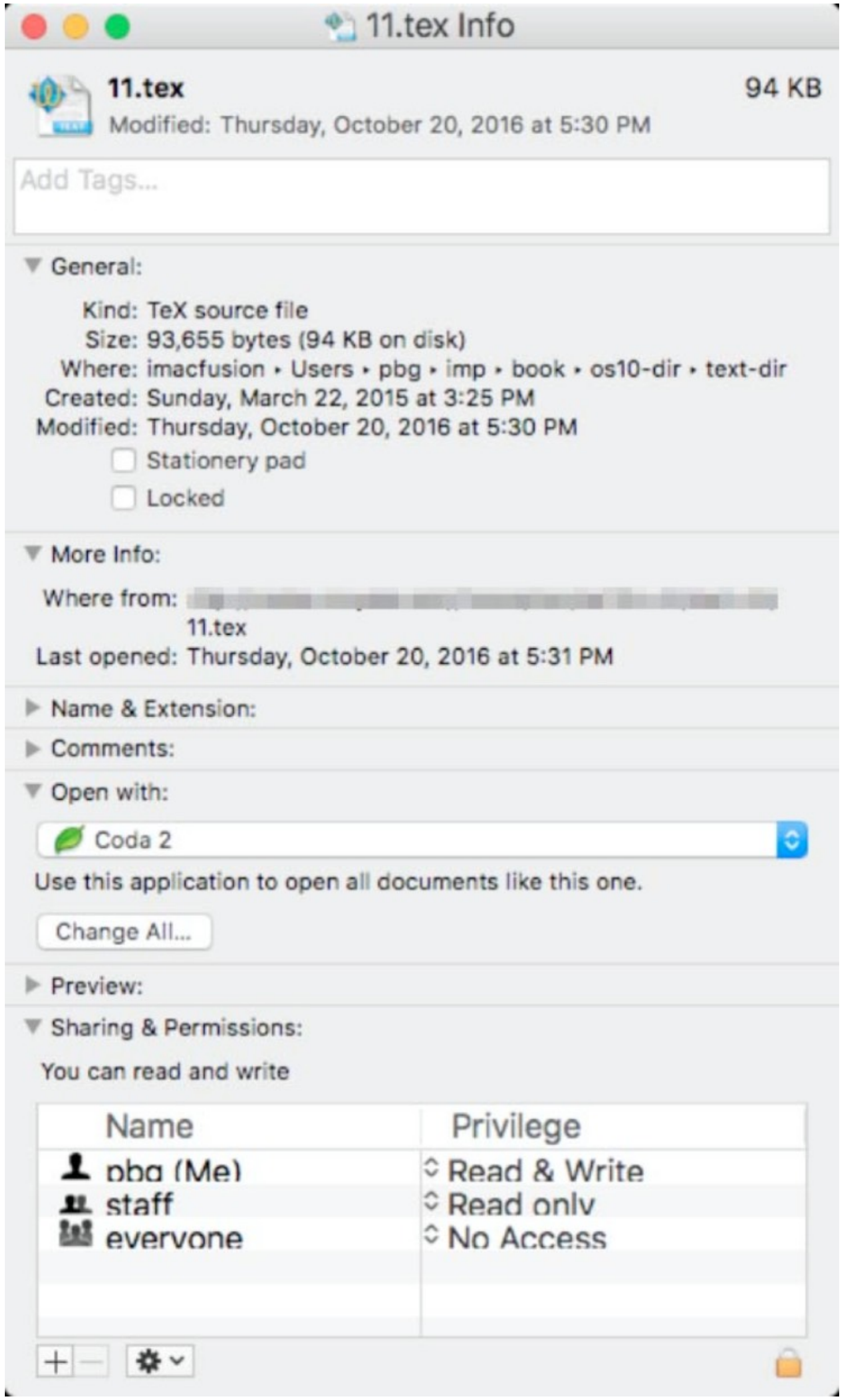

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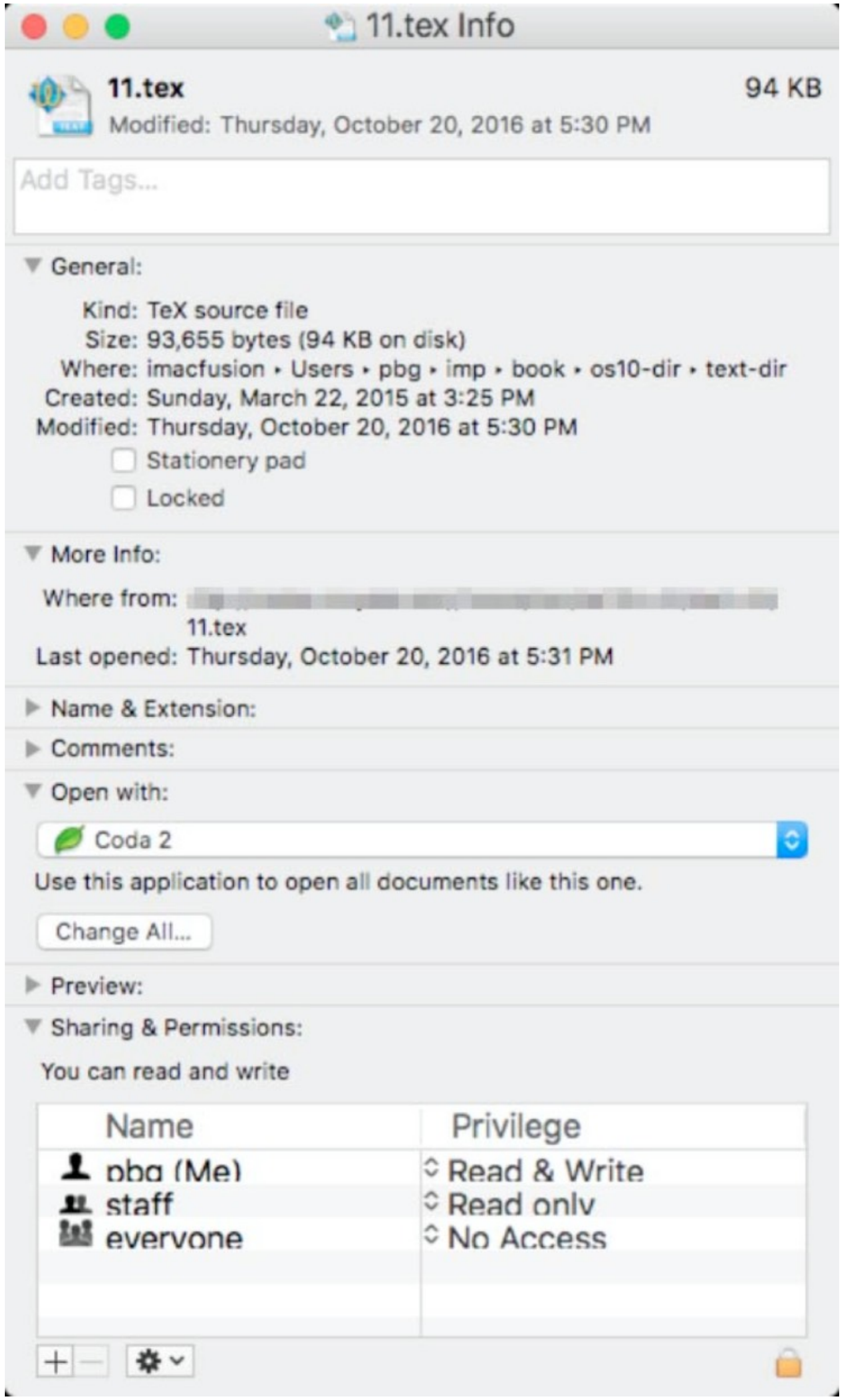

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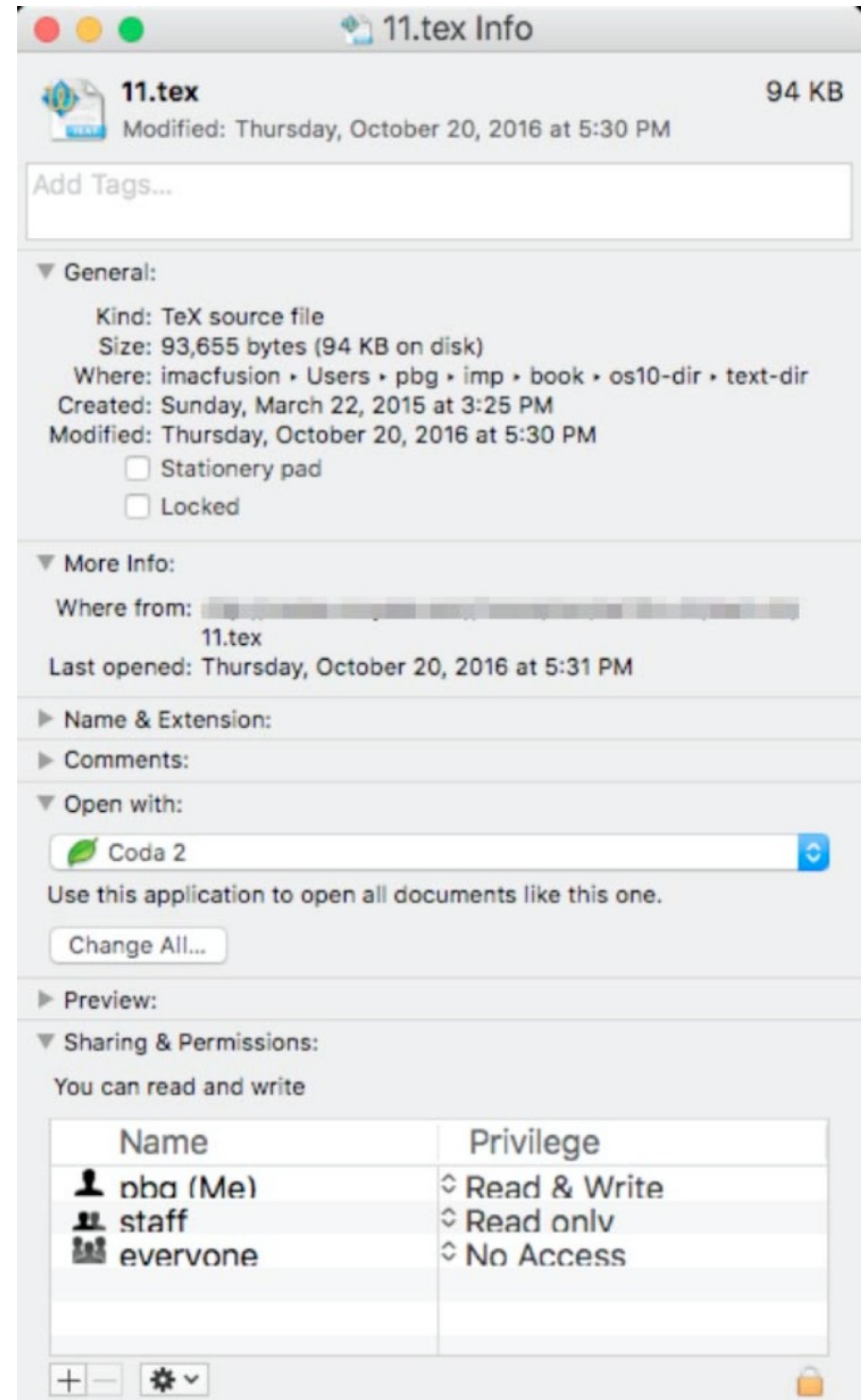

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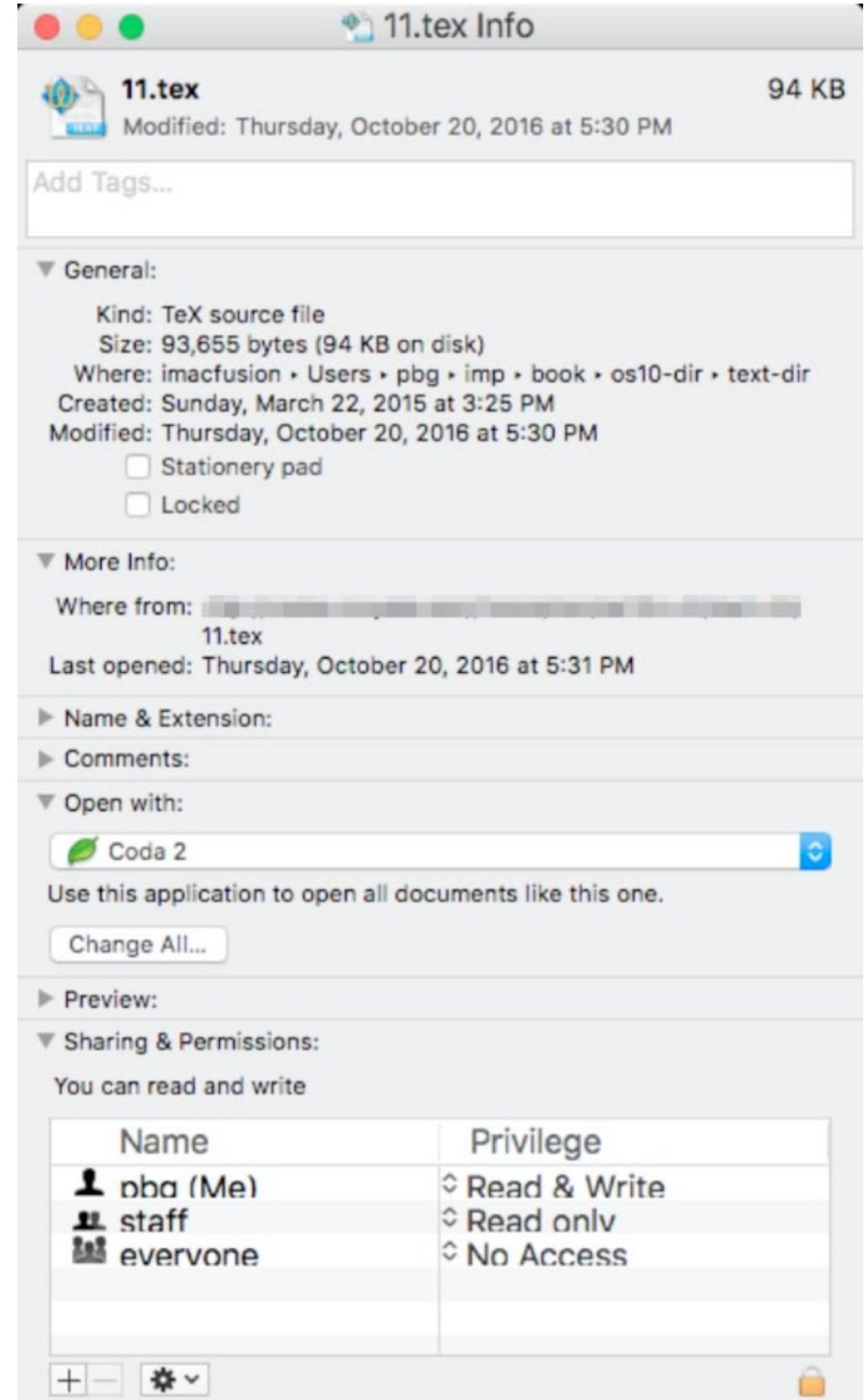
  - such as character encoding, checksum, etc.



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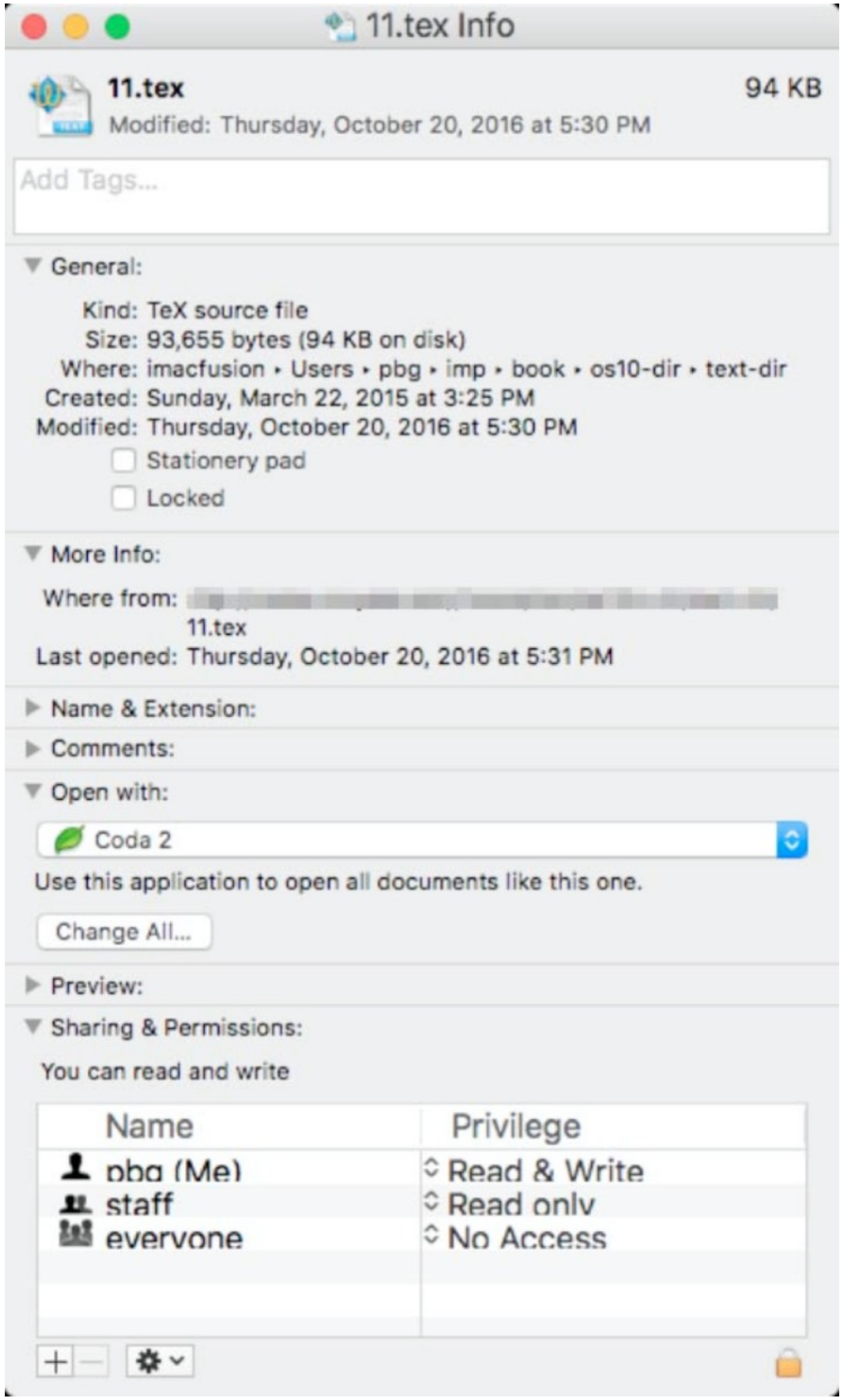
see `struct file` in Linux



How many files are in a typical file system?

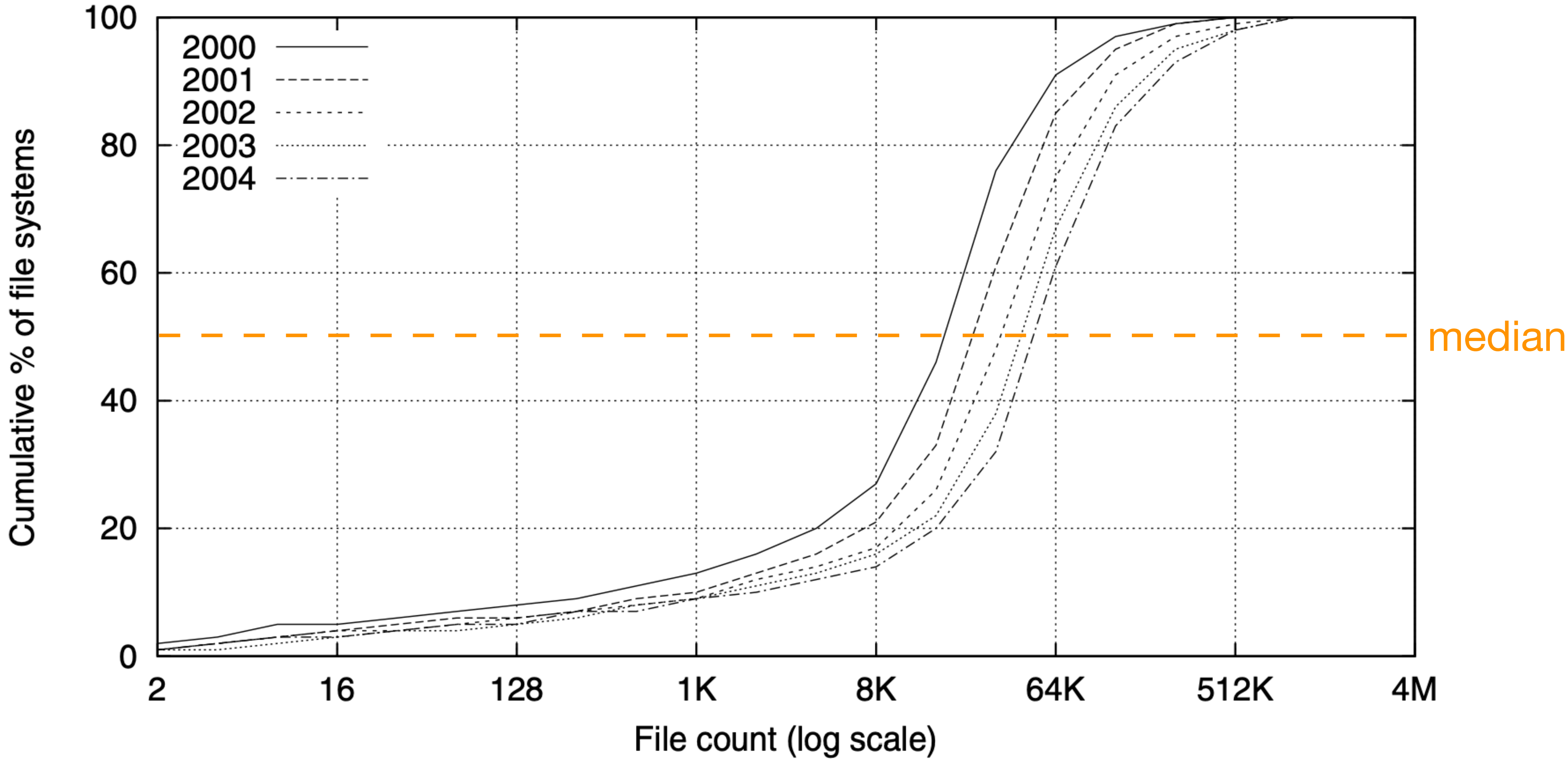


Fig. 1. CDFs of file systems by file count.

over the five-year period, the mean has grown from 30K to 90K files and the median has grown from 18K to 52K files (samples obtained from Microsoft desktops running Windows)

Reference: Nitin Agrawal, William J. Bolosky, John R. Douceur, and Jacob R. Lorch. 2007. A five-year study of file-system metadata. ACM Trans. Storage 3, 3, Article 9 (October 2007)

Most files are small but most disk space is taken up by large files

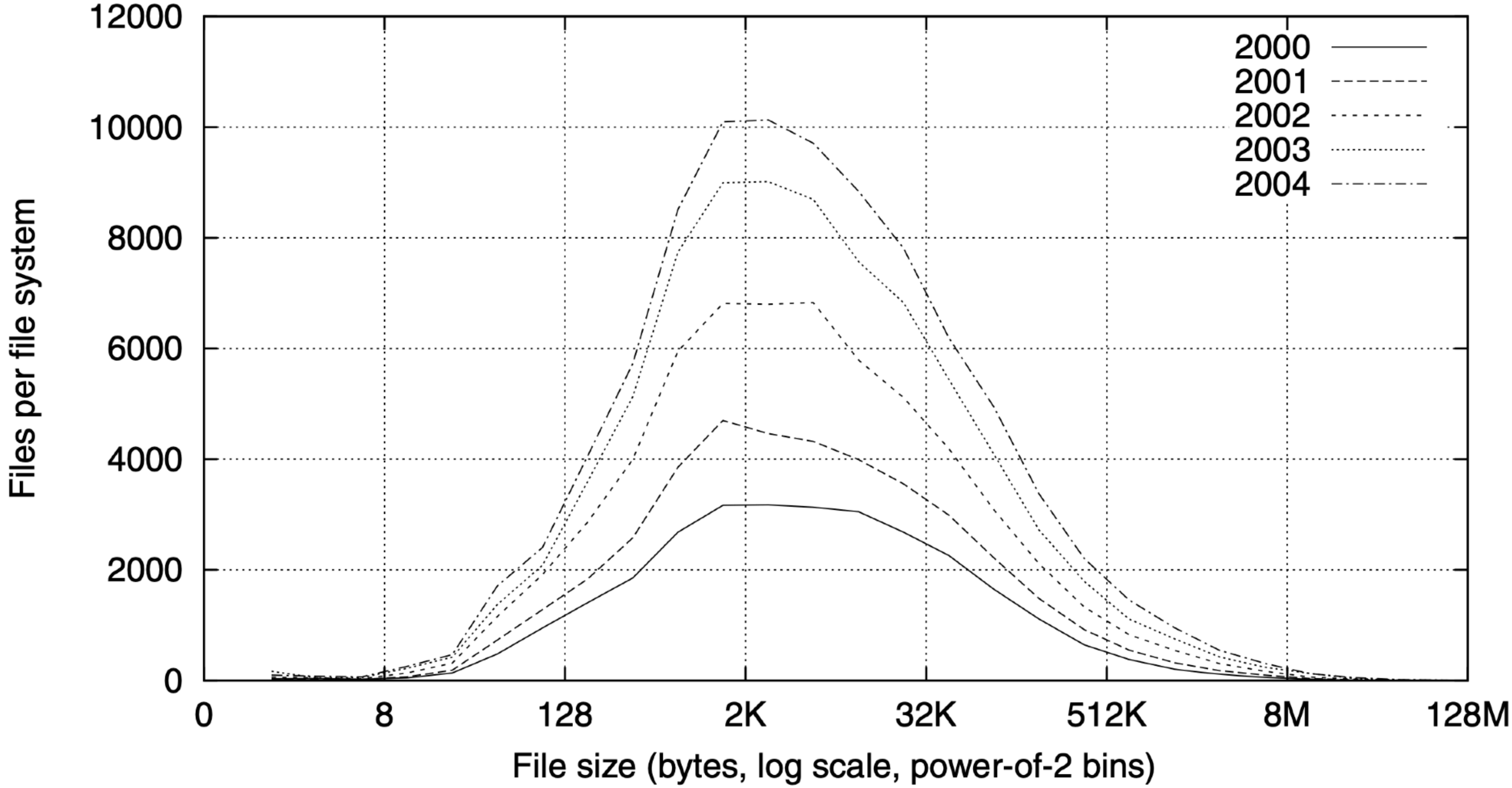


Fig. 2. Histograms of files by size.

thus small file access must be really fast, while large file access should be reasonably efficient

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File system operations

- two categories of file operations
  - basic file system operations (mostly I/O related)
    - `Read(), Write(), Create(), Delete(), Truncate()`
    - `Seek(), Open(), Close()`
  - operations modifying the file attributes
    - `HardLink(), SoftLink(), SetAttribute(), GetAttribute(), Rename(), ChangeMode(), ChangeOwner()`

File operation: create

- take the file name as input
- find and allocate disk space
  - check disk quotas, permissions, etc.
- create a file descriptor (i.e., a handle) for the file
  - include name, location on disk, and all file attributes
- add the file descriptor to the directory that contains the file

File operation: write

- take the file name and data that must be written to the file
- search the directory for the entry associated with the named file
  - then find the file's location on disk
- write data to the file position specified by the **write pointer**
- update the write pointer

File operation: read

- take the file name and a buffer with specific size to read data into it
- search the directory for the named file
  - find the file's location on disk
- read data from the file position specified by the **read pointer** into the buffer
- update the read pointer

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- update the read pointer
- **note:** read and write operations can use the same pointer since a process either reads from or writes to a file at once
  - this pointer is kept as a per-process **current-file-position pointer**

File operation: delete

- take the file name as input
- search the directory for the named file
- free all disk blocks allocated to the file
- remove the file descriptor from the directory
- other operations?
  - reference counting, hard links, etc.

File operation: seek

- take the file name and file offset as input
- search the directory for the named file
- reposition the current-file-position pointer to the given value
    - it does not require any disk I/O, just updates the pointer

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- search the directory for the named file
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- seek is typically used for direct/random access

File operation: truncate

- take the file name as input
- search the directory for the named file
- release all disk blocks allocated to the file
- keep file attributes unchanged, except for its size which is reset to zero
    - truncating is faster than deleting the file and recreating it

Two kernel data structures

- system-wide open-file table: a (doubly linked) list of files in use; shared by all processes with an open file
  - open count (how many processes have the file open)
  - file attributes, including ownership, protection information, access times, file sizes
  - location of file on disk
  - pointers to location of file in memory

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- per-process file descriptor table: a (doubly linked) list of pointers into the open-file table for files opened by the process; it is stored in the process's PCB
  - so for each file opened by the process, there is an entry in this list that contains
    - a pointer to its entry in the system-wide open-file table
    - current-file-position pointer (offset into the file)
    - mode in which the process will access the file (r, w, rw), and file locks (shared & exclusive)
    - accounting information

File operation: open

- take the file name and access mode as input
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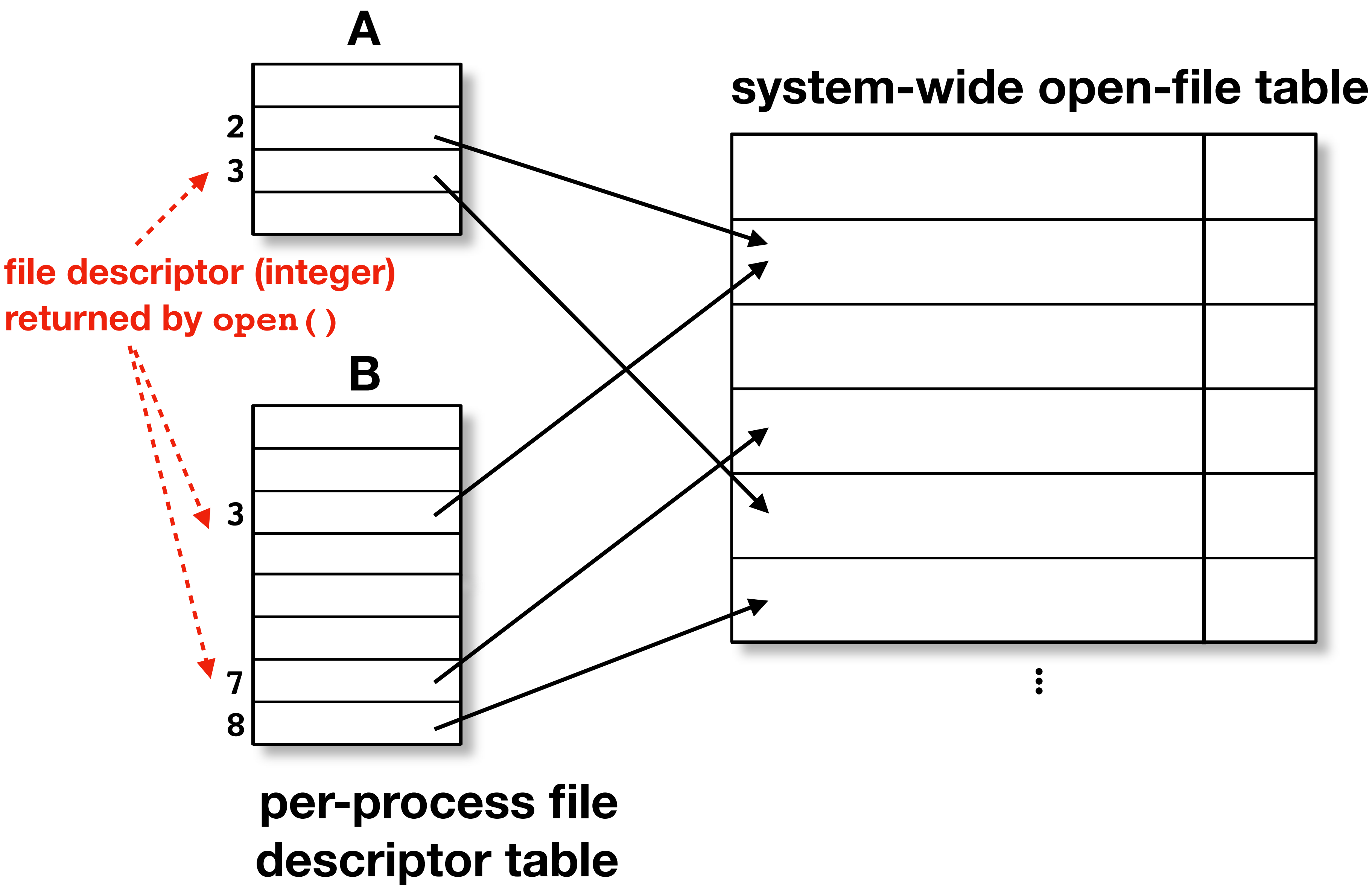
- add a pointer to the open-file table entry to the process file descriptor table
- initialize the current-file-position pointer to the start of the file
- return a pointer to the file entry in the process file descriptor table (referred to as **file descriptor**)
  - so when a file operation is requested, the file is specified via an index into the file descriptor table and locate the corresponding entry in the system-wide open-file table
  - eliminate the need to search the directory for the file entry each time (a one-time cost amortized over many operations)

Kernel's file-related data structures



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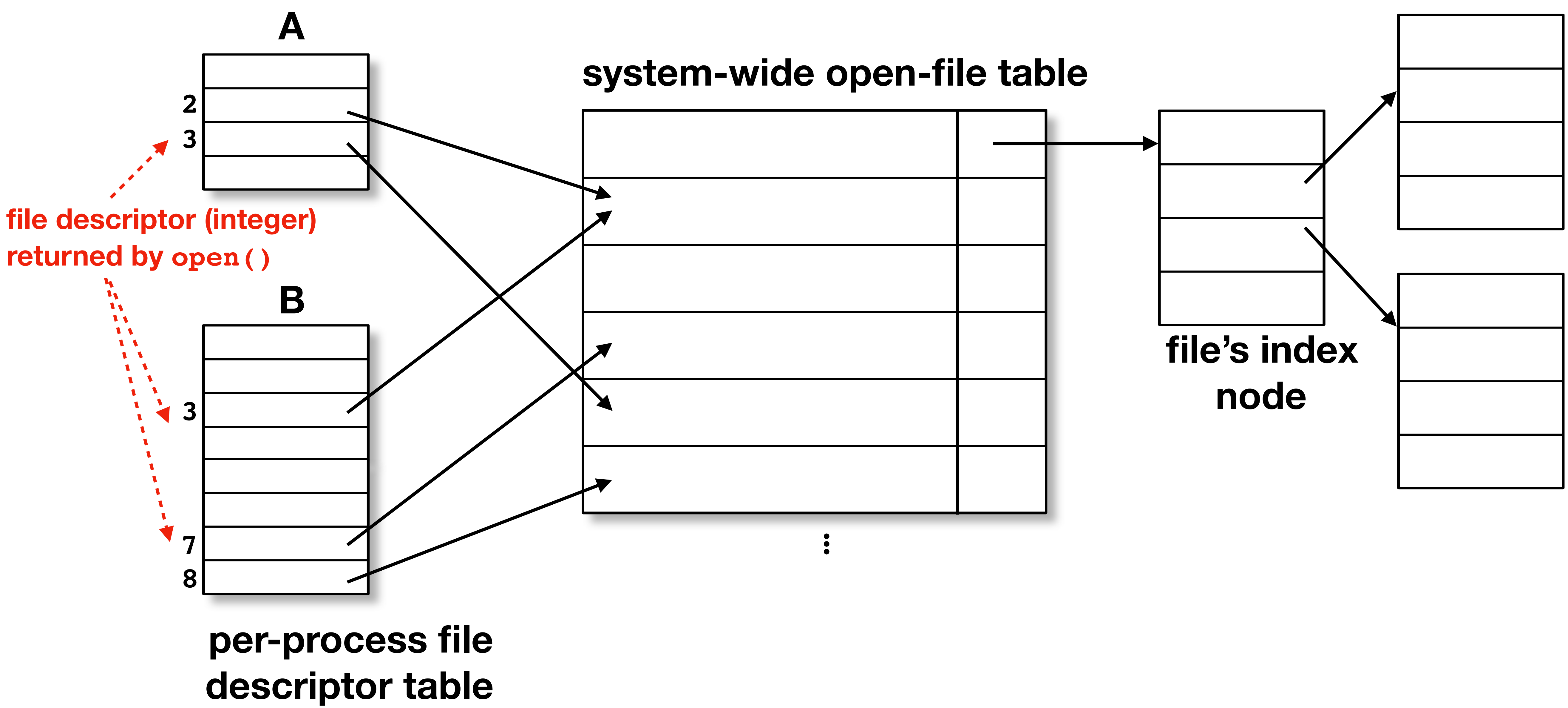


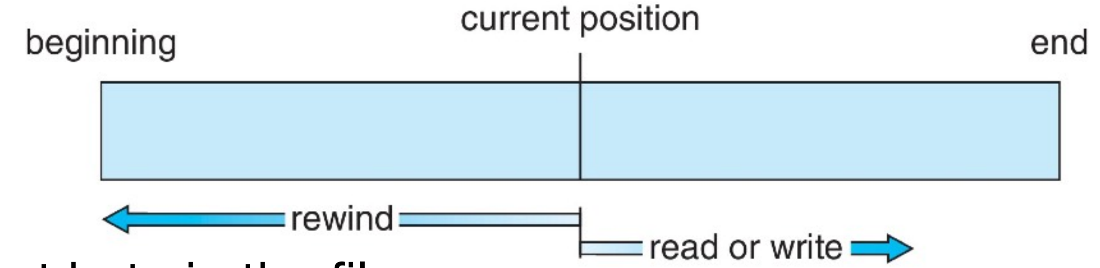
File operation: close

- locate and remove the file's entry from the process file table
- decrement the open count in the system-wide open-file table
- if the open count reaches zero, remove the entry from the system-wide open-file table
  - otherwise the kernel may run out space

Modified operations: using file descriptor

- fd = Open("filename")
- Close(fd)
- Truncate(fd)
- Seek(fd, offset)
- Read(fd, buffer, length)
- Write(fd, buffer, length)

File access methods



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  - is based on the tape model: keep a pointer to the next byte in the file
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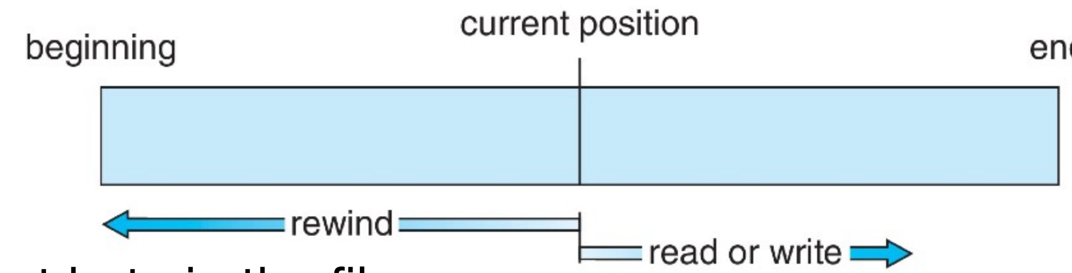

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  - the block number to access is relative to the beginning of the file
    - so the programmer doesn't need to know where the file is stored on disk
  - it is possible to read block 8 then 12 and then 5
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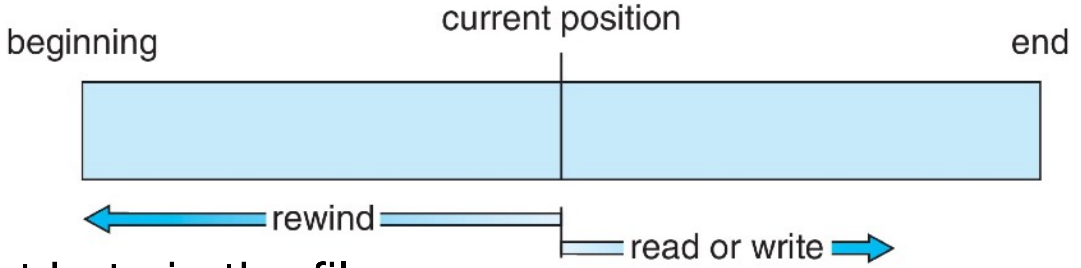

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- some systems only support one access method, some support both methods, and some support only the method declared when the file was created

Simulating sequential access on a direct-access file

sequential access	implementation for direct access
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- simulating direct access on a sequential-access file is extremely inefficient (**why?**)