Design and Analysis of Operating Systems CSCI 3753

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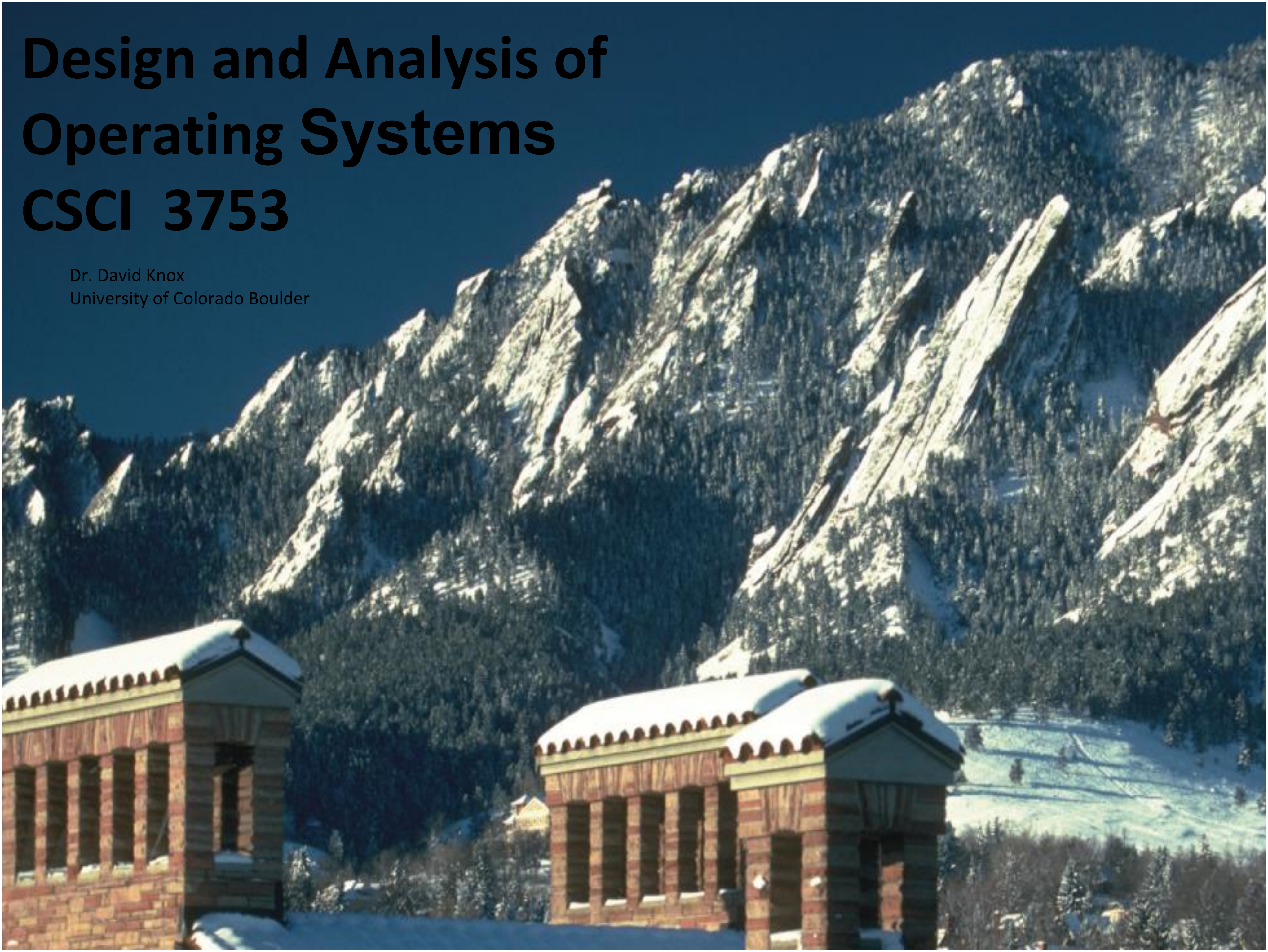

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File Allocation

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File Allocation

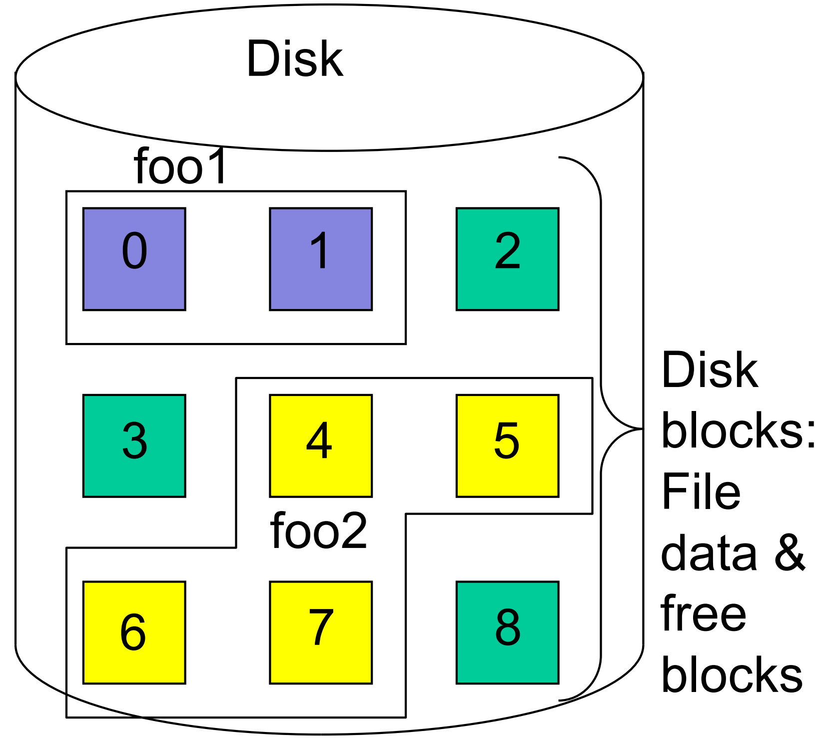
File Allocation

- **Approaches:**
  1. Contiguous file allocation
     - a file is laid out contiguously, i.e. if a file is n blocks long, then a starting address b is selected and the file is allocated blocks b, b+1, b+2, ..., b+n-1
  2. Linked Allocation
     - each file is a linked list of disk blocks
  3. File Allocation Table (FAT) is an important variation of linked lists
     - Don't embed the pointers of the linked list with the file data blocks themselves
     - Instead, separate the pointers out and put them in a special table – the file allocation table (FAT)
     - The FAT is located at a section of disk at the beginning of a volume
  4. Indexed Allocation
     - collect all pointers into a list or table called an *index block*
     - the index j into the list or index block retrieves a pointer to the j'th block on disk

Approach #1: Contiguous File Allocation

File headers

file	start	length
foo1	0	2
foo2	4	4



- **Advantage: fast performance (low seek times because the blocks are all allocated near each other on disk)**

Approach #1: Contiguous File Allocation

- **Disadvantages:**
  - **Problem 1:** external fragmentation (observed same problem fitting into RAM)
    - same solutions apply: first fit, best fit, etc.
    - can also compact memory/defragment disk
    - schedule to be performed in the background late at night, etc.
  - **Problem 2:** May not know size of file in advance
    - allocate a larger size than estimated
    - if file exceeds allocation, have to copy file to a larger free “hole”
  - **Problem 3:** Over-allocation of a “slow growth” file
    - A file may eventually need 1 million bytes of space
    - But initially, the file doesn’t need much
      (may be growing at a very slow rate, e.g. 1 byte/sec)
    - For much of the lifetime of the file, allocating 1 MB wastes allocation

Contiguous File Allocation

- **Disadvantages:**
  - Problem 3: Over-allocation of a “slow growth” file
    - A file may eventually need 1 million bytes of space
    - But initially, the file doesn’t need much, and it may be growing at a very slow rate, e.g. 1 byte/sec
    - So for much of the lifetime of the file, allocating 1 MB wastes allocation
    - This is a “slow growth” problem.

General File Allocation

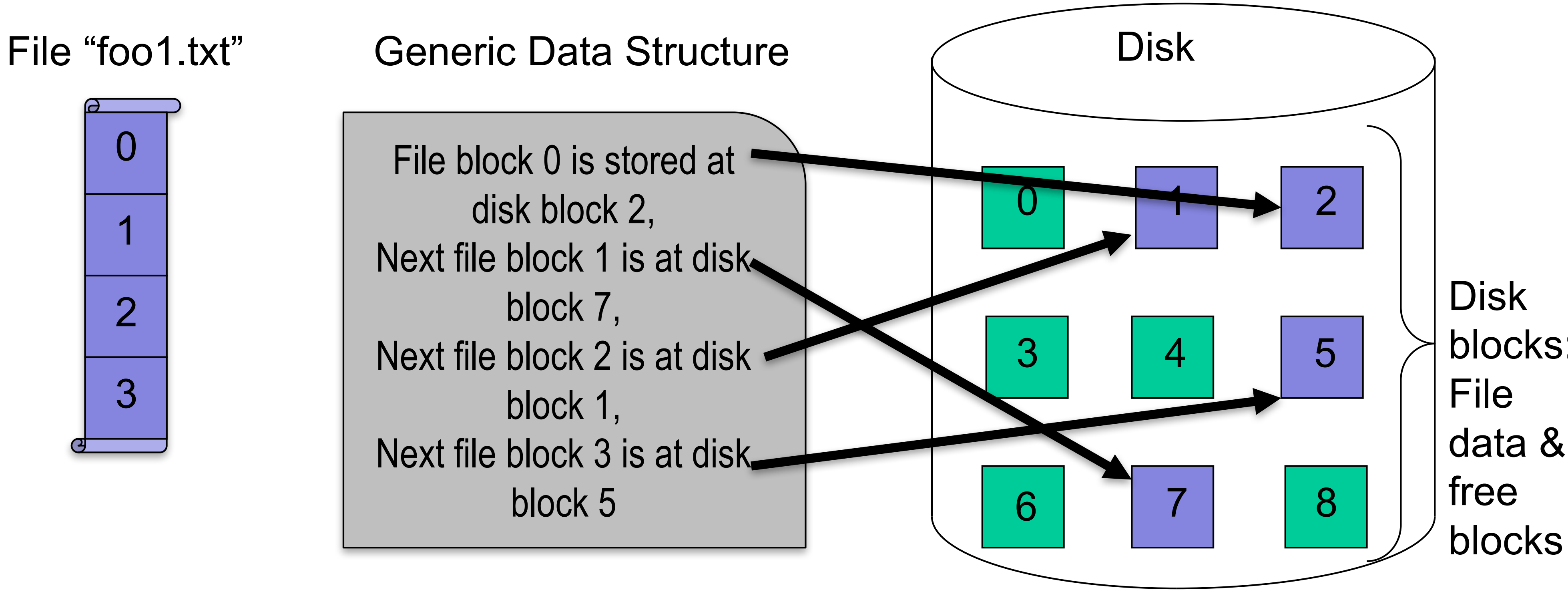
- **Page table solved external fragmentation problem for process allocation**

- **Apply a similar concept to file allocation**
  - Divide disk into fixed-sized blocks, just as main memory was divided into fixed-sized physical frames

  - Allow a file's data blocks to be spread across any collection of disk blocks, not necessarily contiguous

  - *Need a data structure to keep track of what block of a file is stored on which block in disk*

General File Allocation



- **Generic data structure can be:**
  - A Linked list and variants
  - Indexed allocation (somewhat resembles a page table) and variants

General File Allocation

- **General approach to file allocation solves:**
  - External fragmentation problem

  - Problem of not knowing file size in advance and having to over-estimate
    - Allocate exactly number of disk blocks needed
    - As more disk blocks are needed, easy to allocate exactly the additional number of disk blocks needed from pool of free/unallocated disk blocks
    - and these disk blocks can be anywhere on disk, not necessarily contiguous

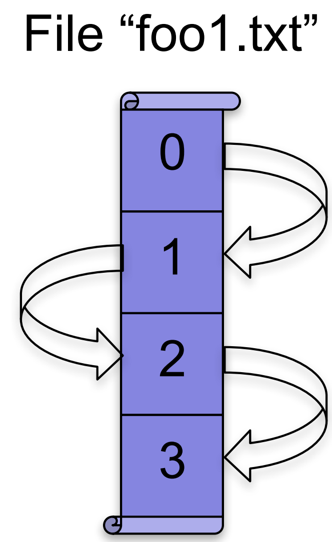
  - Slow growth problem: only allocate exactly as many blocks as a slow growth file needs

General File Allocation

- **Examples:**
  - UNIX FS (UFS, = Berkeley FFS) uses 8 KB blocks.
  - Linux' file system ext2fs uses default 1 KB blocks (though 2 and 4 KB supported (and much larger))

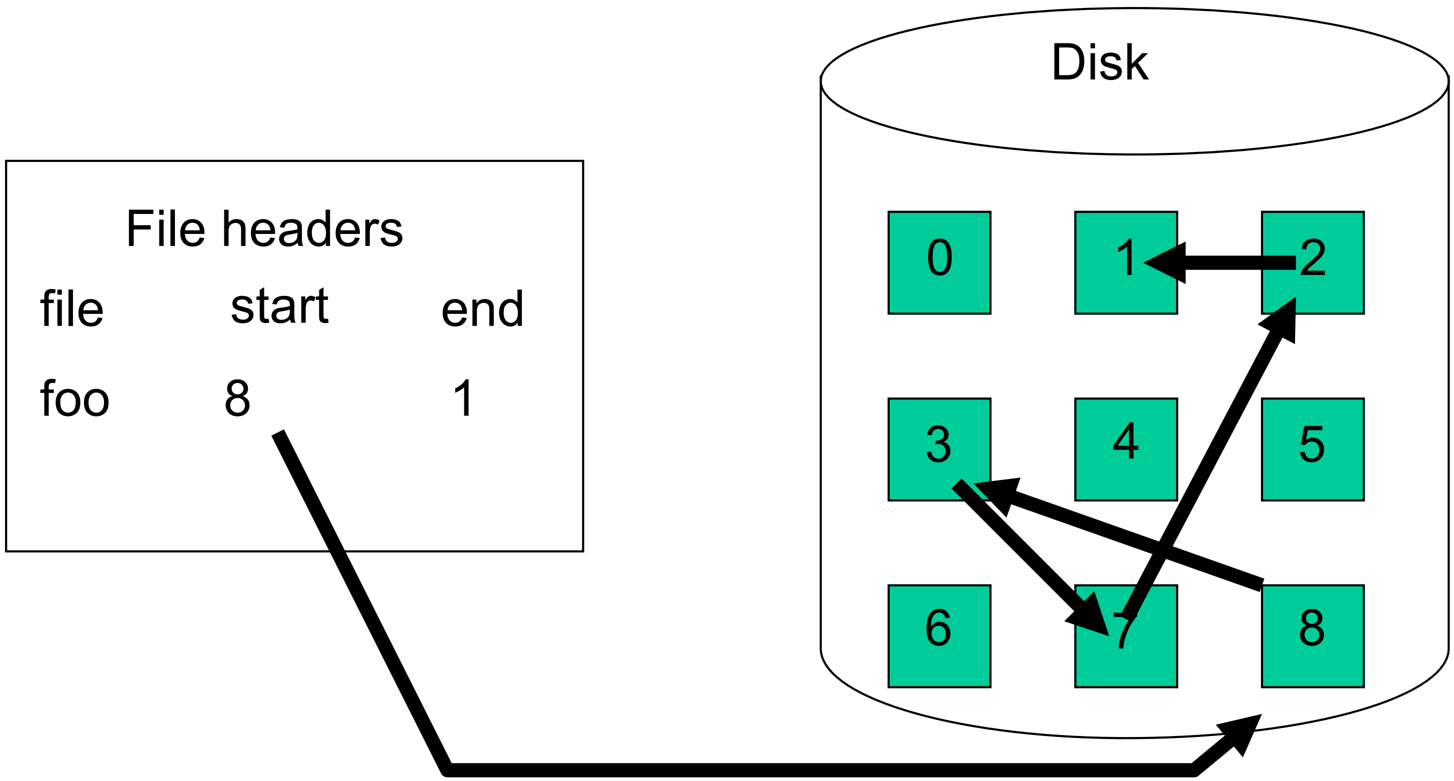
Approach #2: Linked File Allocation

- **Linked Allocation**
  - each file is a linked list of disk blocks
  - to add to a file, just modify the linked list either in the middle or at the tail, depending on where you wish to add a block
  - to read from a file, traverse linked list until reaching the desired data block



Linked File Allocation

- **Linked Allocation**
  - each file is a linked list of disk blocks



Linked File Allocation

- **Advantages:**
  - solves problems of contiguous allocation
    - no external fragmentation
    - don’t need to know size of a file a priori
  - Minimal bookkeeping overhead in file header – just a pointer to start of file on disk
    - Compromise is that all the pointer overhead is stored in each disk block
  - Good for sequential read/write data access
  - Easy to insert data into middle of linked list

Linked File Allocation

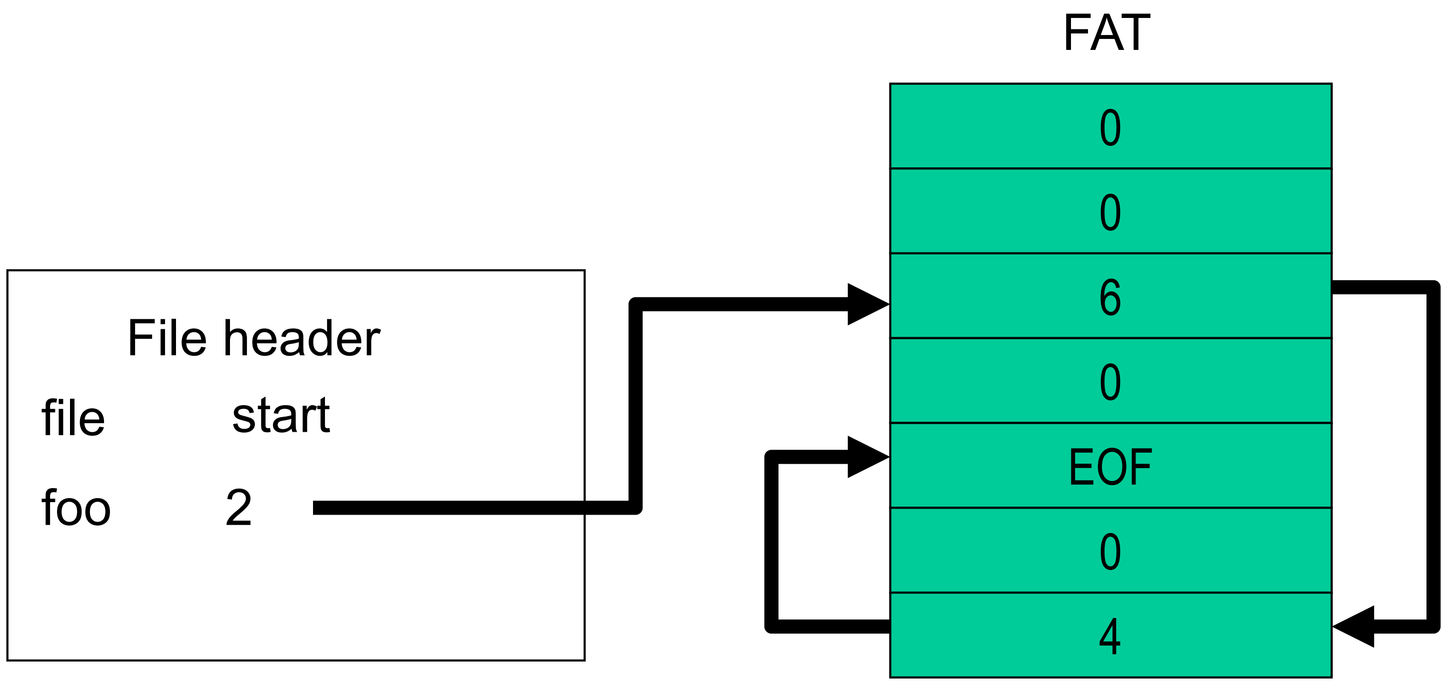
- **Problems:**
  - performance of random (direct) data access is extremely slow for reads/writes
    - because you have to traverse the linked list until indexing into the correct disk block
  - Space is required for pointers on disk in every disk block
  - reliability is fragile
    - if one pointer is in error or corrupted, then lose the rest of the file after that pointer

Approach #3: File Allocation Table (FAT)

- **File Allocation Table (FAT) is an important variation of linked lists**
  - Don't embed the pointers of the linked list with the file data blocks themselves
  - Instead, separate the pointers out and put them in a special table – the file allocation table (FAT)
  - The FAT is located at a section of disk at the beginning of a volume

File Allocation Table

- **entries in the FAT point to other entries in the FAT as a linked list, but their values are interpreted as the disk block number**
- **unused blocks in FAT initialized to 0**



File Allocation Table

- **FAT file systems used in MS-DOS and Win95/98**
  - Bill Gates designed/coded original FAT file system
  - replaced by NTFS (basis of Windows file systems from WinNT through Windows Vista/7)
  - Variants include FAT16, FAT32, etc. FAT16 and FAT32 refer to the size of the address used in the FAT.

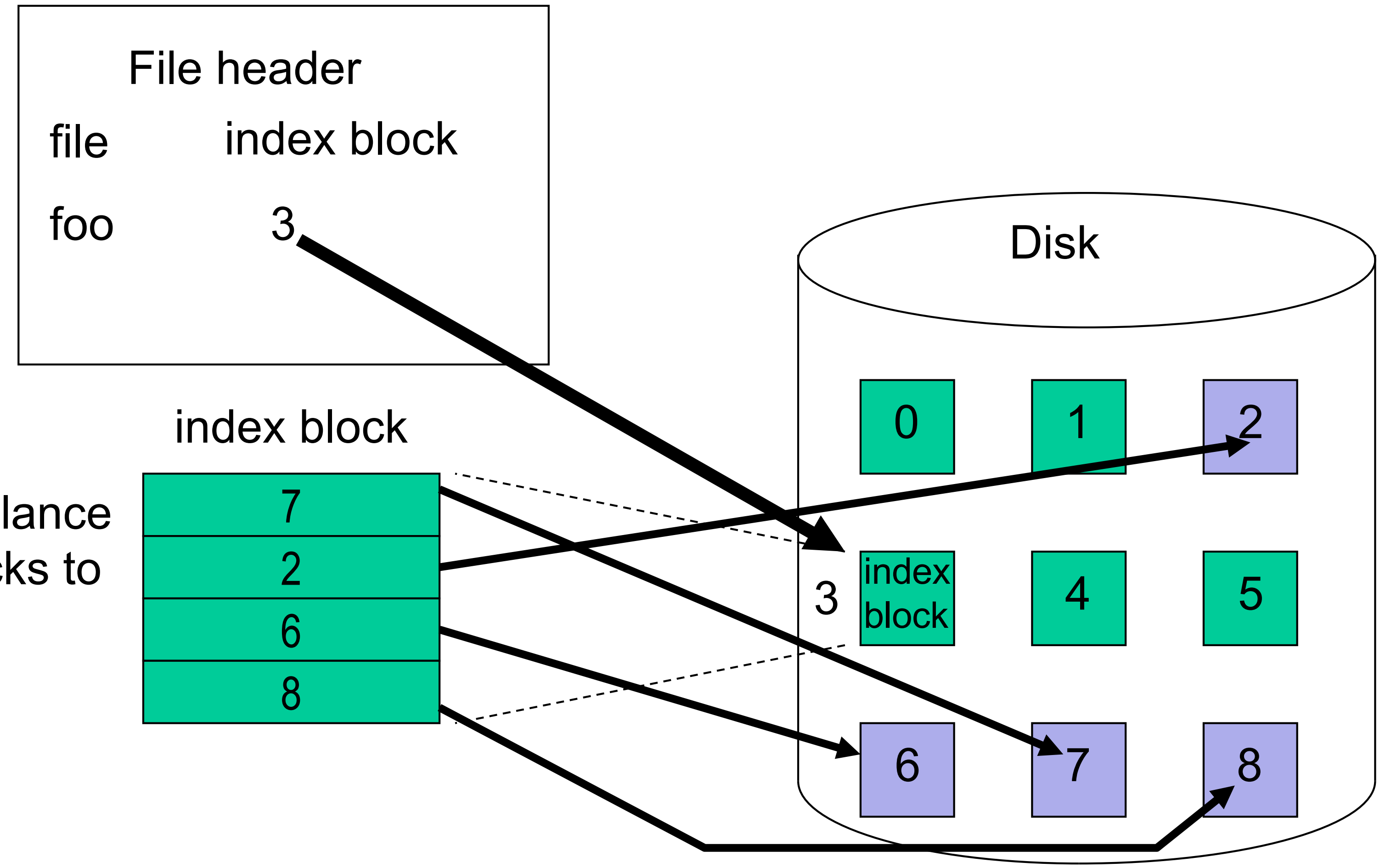
File Allocation Table

- **Linked list for a file is terminated by a special end-of-file EOF value**
- **Allocating a new block is simple - find the first 0-valued block**
- **Advantage: random Reads/Writes faster than pure linked list**
  - the pointers are all colocated in the FAT near each other at the beginning of disk volume - low disk seek time
- **Still have to traverse the linked list to find location of data – this is a slow operation**

Approach #4: Indexed Allocation

- **Conceptually, collect all pointers into a list or table called an *index block***
  - the index j into the list or index block retrieves a pointer to the j'th block on disk
  - Looks kind of like a page table, except it's extensible
- **Unlike the FAT**
  - the index block can be stored in any block on disk, not just in a special section at the beginning of disk
  - the index is just a linear list of pointers

Indexed Allocation



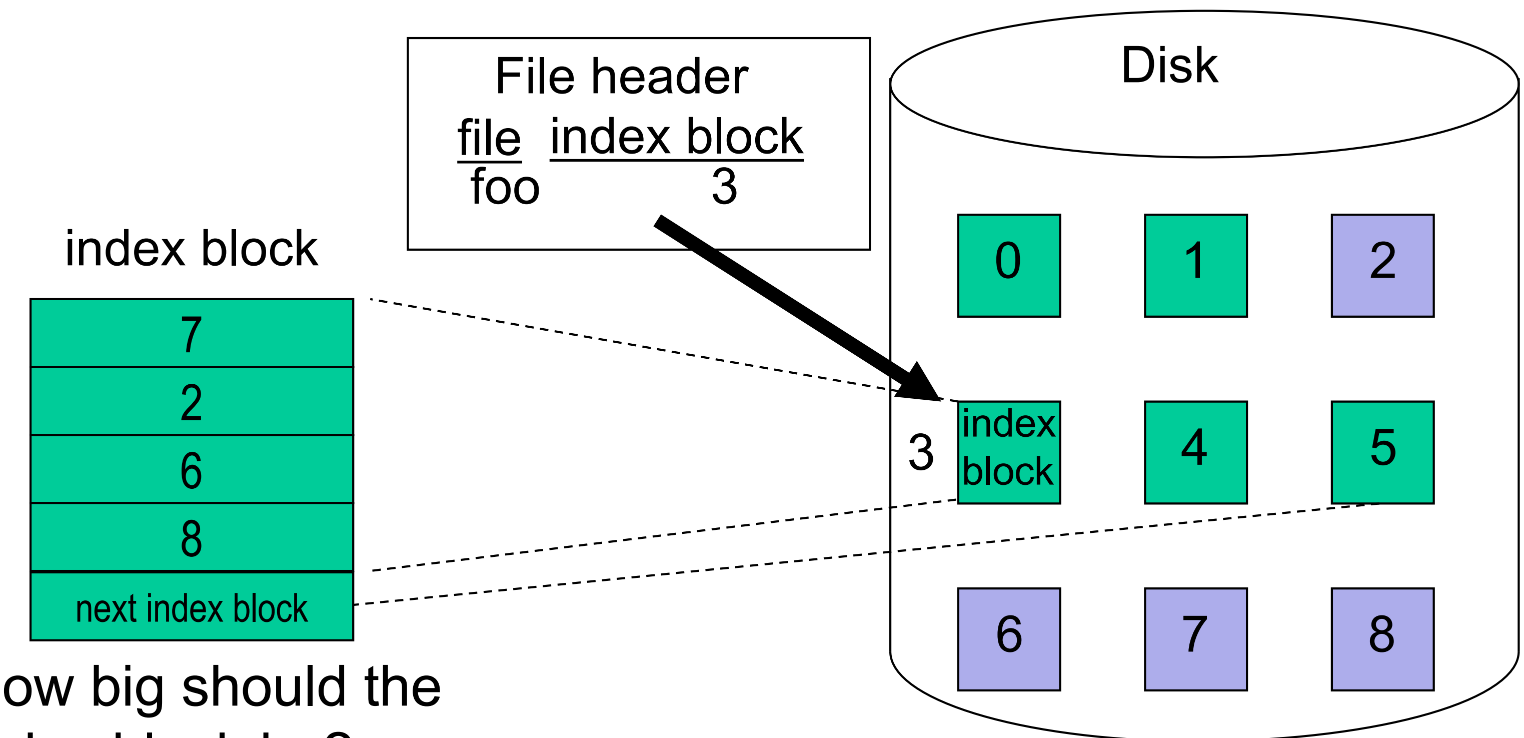
note resemblance of index blocks to page tables!

Indexed Allocation

- **Solves many problems of contiguous and linked list allocation:**
  - no external fragmentation
  - size of file not required a priori
  - don’t have to traverse linked list for random/direct reads/writes
    - just index quickly into the index block

Indexed Allocation

- **Solutions:**
  1. Link together index blocks –
     - each index block has link to next index block
  2. *Multilevel index* (like hierarchical page tables!)
     - First level is list of all index blocks for file
     - Second level is list of all data blocks in that section of the file



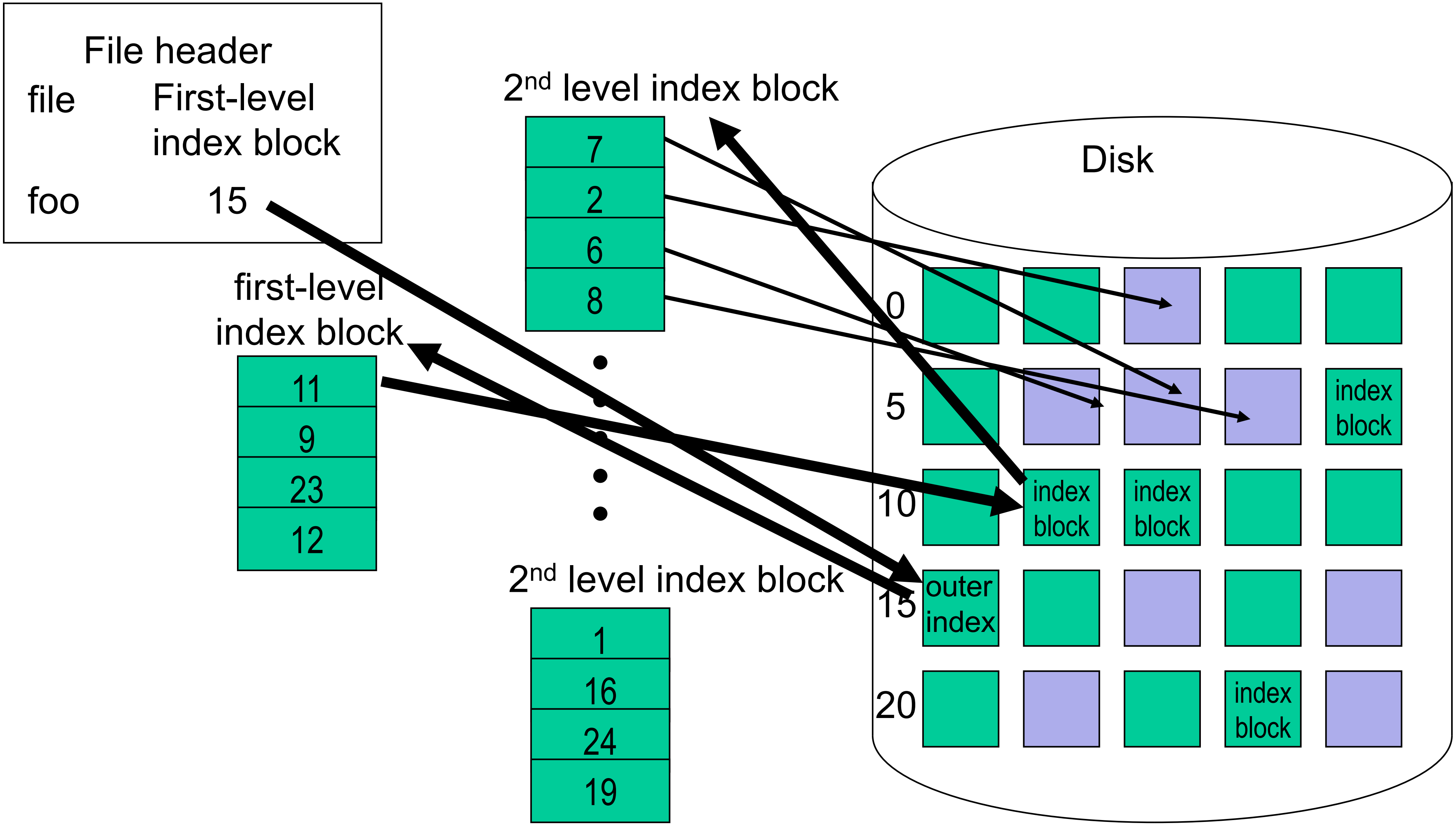
How big should the index block be?

Indexed Allocation

- **Problem: how big should the index block be?**
  - if the index block is too large, then there are many wasted/empty entries for small files
  - if the index block is too small, then there are not enough entries for large files

- **Solutions:**
  - link together index blocks
  - *multilevel index* (like hierarchical page tables!)
    - indexing into the first-level index block provides a pointer to second-level index blocks. Indexing into the second-level index block (using a different offset) retrieves a pointer to the actual file block on disk

Approach #5: Multilevel Indexed Allocation



Multilevel Indexed Allocation

- **Don't have to allocate unused second-level index blocks!**
- **Maximum file size?**

  two levels of index blocks,
  1024 pointer entries/block => 1 million addressable data blocks.

  If each block is 4 KB, then the largest file size is 4 GB.

- **Problems with multi-level indexing:**
  - accessing small files takes just as long as large files
  - have to go through the same # of levels of indexing, hence same # of disk operations
  - accessing the data of a 100 byte file requires at leas 4 block reads

Approach #6: UNIX Multilevel Indexed Allocation

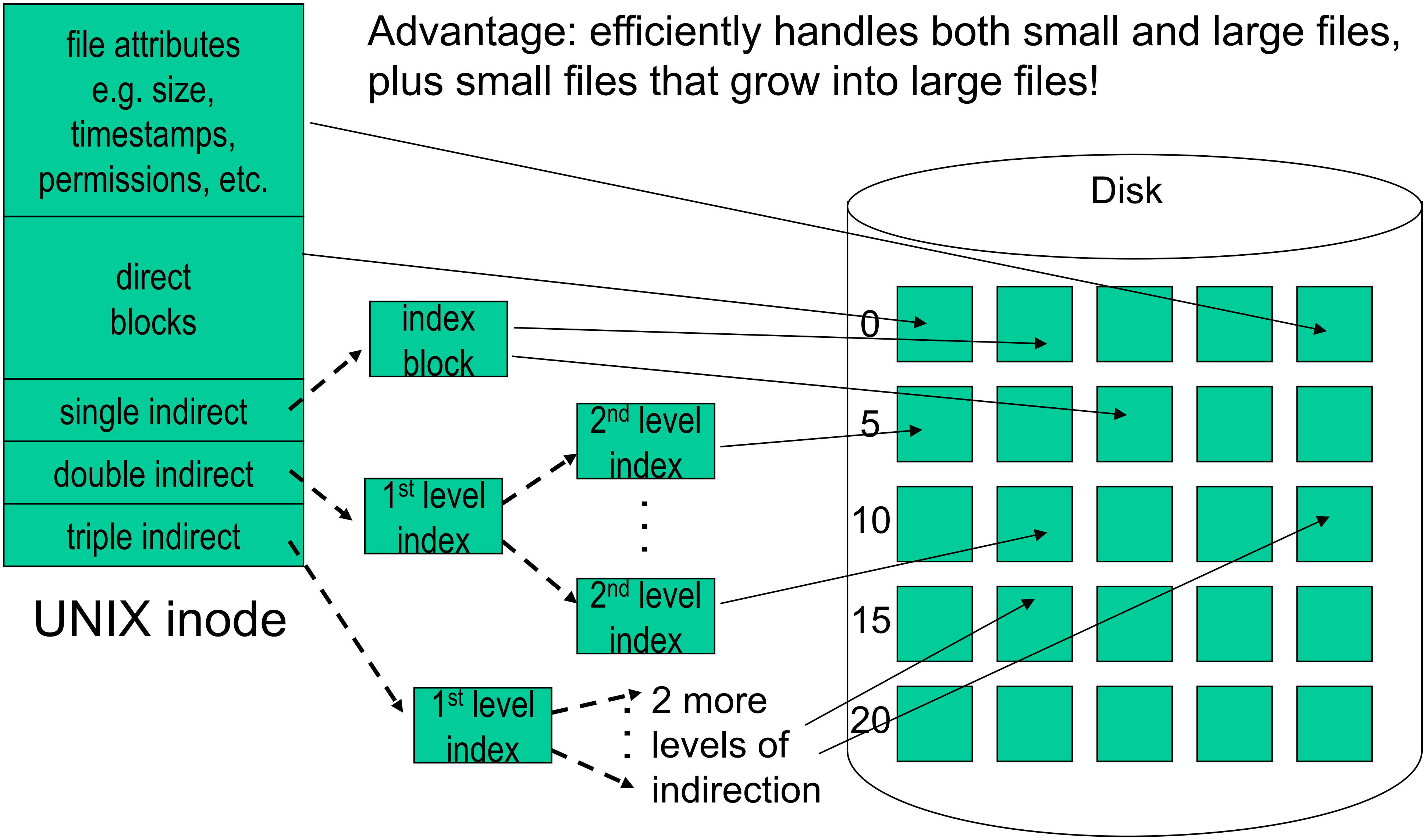
- **UNIX (and Linux ext2fs, ext3fs, etc.) uses this variation of multi-level indexing to accommodate large and small files**
  - Suppose there are 15 entries in the index block
  - the first 12 entries are pointers to direct blocks of file data on disk
  - the 13th pointer points to a singly indirect block, which is an index block pointing to disk blocks
  - the 14th pointer points a *doubly indirect block* (2 levels of index blocks)
  - the 15th pointer points to *a triply indirect block* (3 levels of index blocks)

Approach #6: UNIX Multilevel Indexed Allocation

- UNIX (and Linux ext2fs, ext3fs, etc.) uses this variation of multi-level indexing to accommodate large and small files

UNIX Multilevel Indexed Allocation

Advantage: efficiently handles both small and large files, plus small files that grow into large files!



UNIX Multilevel Indexed Allocation

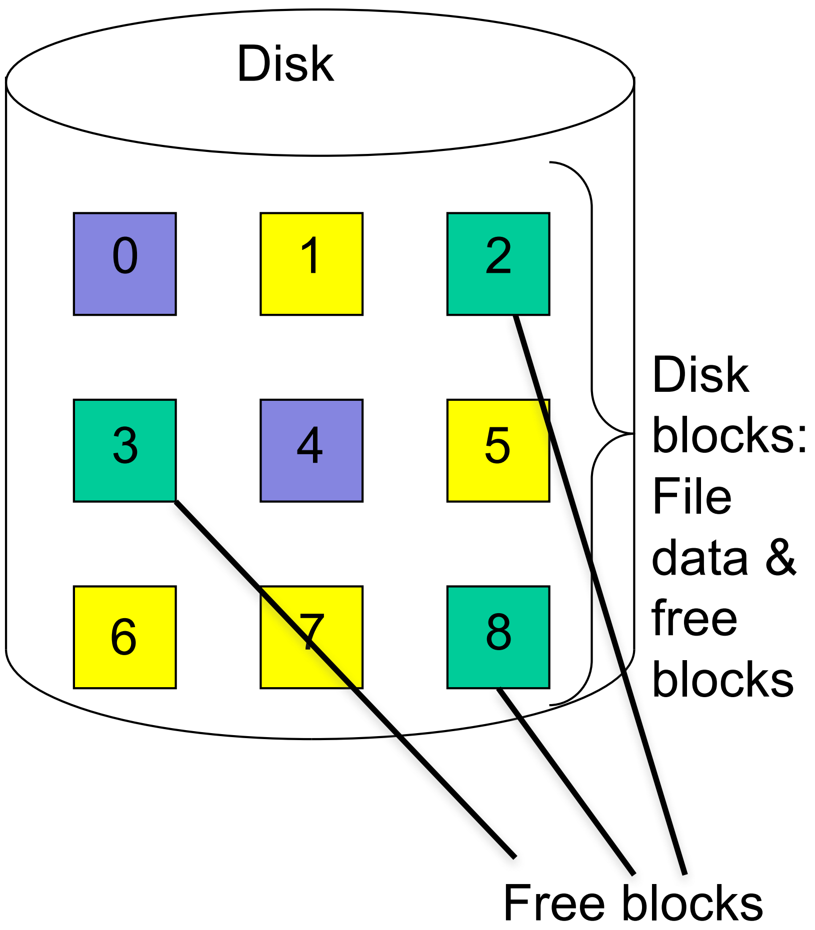
- **for small files**
  - only uses a small index block of 15 entries, so there is very little wasted memory
- **for large files**
  - the indirect pointers allow expansion of the index block to span a large number of disk blocks

Comparing File Allocation with Process Allocation

- **In both cases, mapping an entity to storage**
  - Process address space allocated frames in RAM via page tables
  - File data is allocated to disk/flash
- **Differences:**
  - Address spaces are fixed in size and known in advance,
  - Files grow/contract over time – files need a mapping/allocation system that is more flexible than page tables, which can't grow
  - Address spaces can be sparse and mostly unused, while file data is all "used"

Free Space Management

- **Another aspect of managing a file system is managing free space**
  - the file system needs to keep track of what blocks of disk are free/unallocated
  - keeps a free-space "list"
  - In this example, need to keep track that disk blocks 2, 3 and 8 are free/unallocated



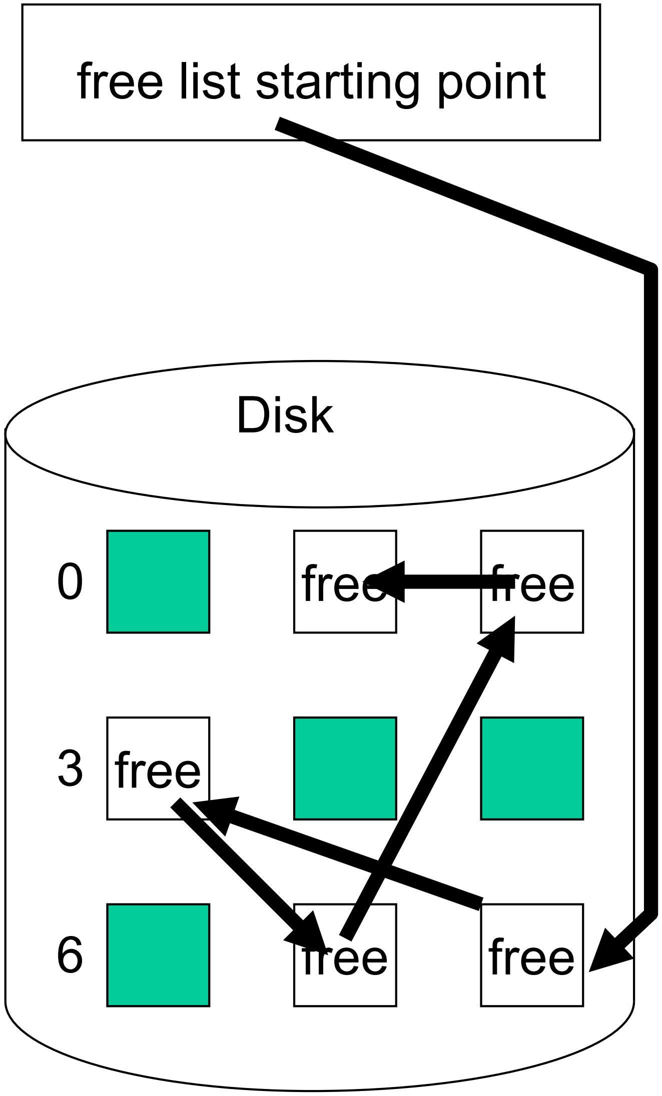
Free Space Management Approaches

1. **Bit Vector or Bit Map**

- **Each block is represented by a bit.**
- **Concatenate all such bits into an array of bits, namely a bit vector.**
  - The j'th bit indicates whether the j'th block has been allocated.
  - if bit = 1, then a block is free, else if bit = 0, then block is allocated

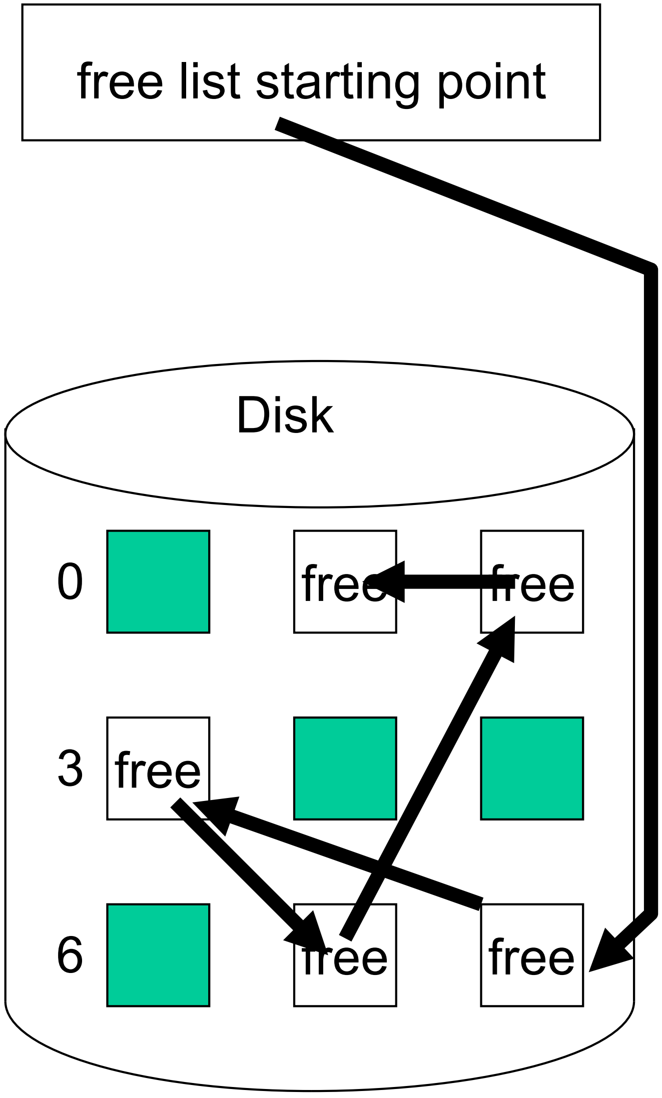
Free Space Management Approaches

2. **Linked List**
   - link together all free blocks
   - efficient - keeps track of only the free blocks.
     - bitmap has the overhead of tracking both free and allocated blocks - this is wasteful if memory is mostly allocated
   - Faster than bitmap – find 1st free block immediately



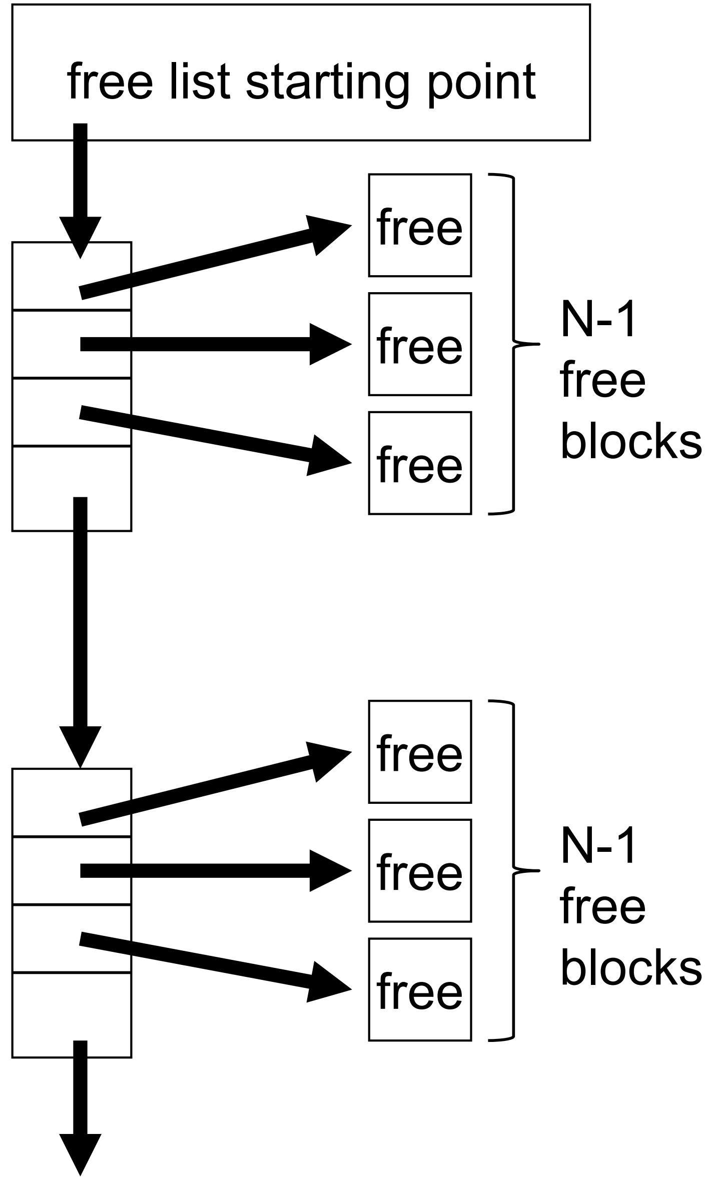
Free Space Management Approaches

- **Problem with Linked List free space management:**
  - traversing the free list is slow if you want to allocate a large number of free blocks all at once
    - hopefully this occurs infrequently



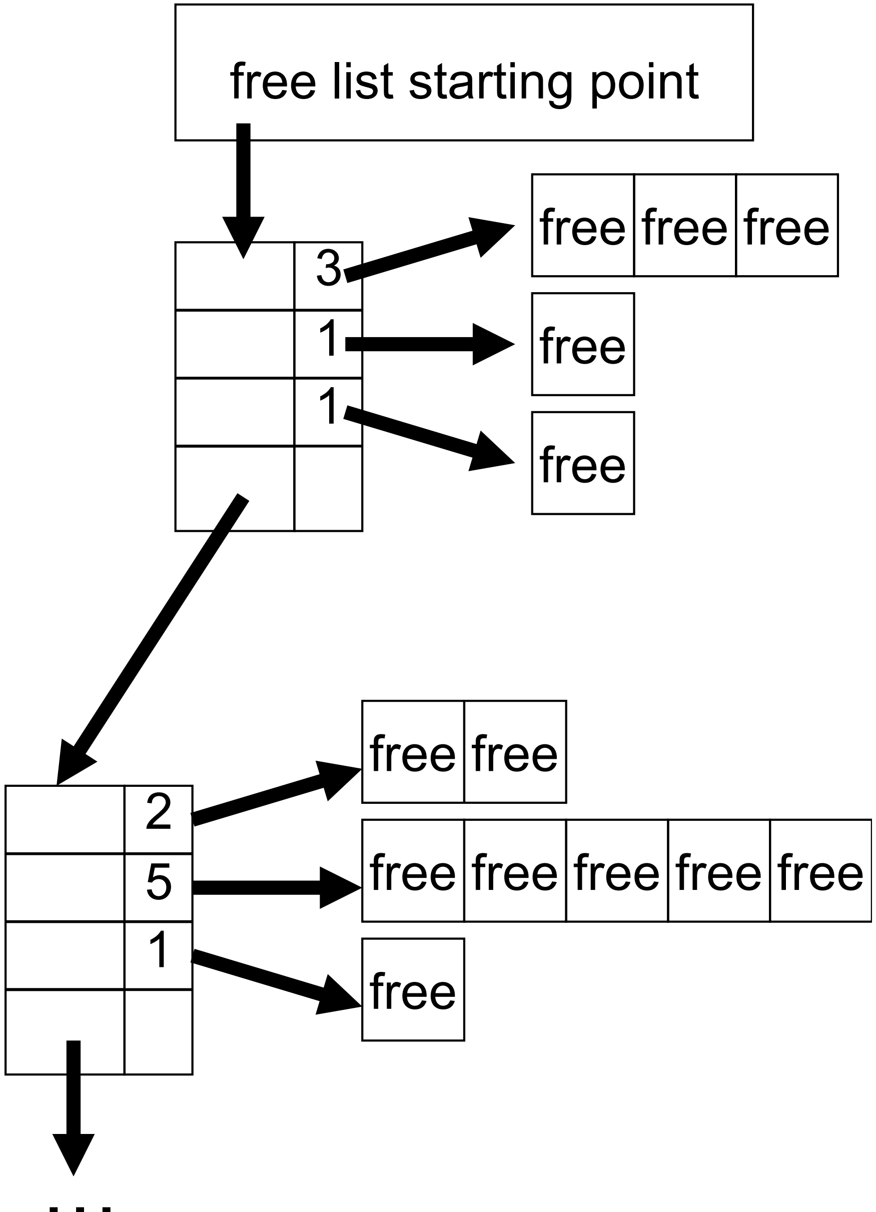
Free Space Management Approaches

3. **Grouping**
   - linked list, except store n-1 pointers to free blocks in each list block
   - the last block points to the next list block containing more free pointers
   - allows faster allocation of larger numbers of free blocks all at once



Free Space Management Approaches

4. **Counting -**
   - grouped linked list, but also add a field to each pointer entry that indicates the number of free blocks immediately after the block pointed to
   - even faster allocation of large #'s of free blocks



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