File Systems: Memory Management, Naming and Reliability

CS 111

Operating Systems

Peter Reiher

Outline

- Managing disk space for file systems
- File naming and directories
- File volumes
- File system performance issues
- File system reliability

Free Space and Allocation Issues

- How do I keep track of a file system's free space?
- How do I allocate new disk blocks when needed?
  - And how do I handle deallocation?

The Allocation/Deallocation Problem

- File systems usually aren't static
- You create and destroy files
- You change the contents of files
  - Sometimes extending their length in the process
- Such changes convert unused disk blocks to used blocks (or visa versa)
- Need correct, efficient ways to do that
- Typically implies a need to maintain a free list of unused disk blocks

Creating a New File

- Allocate a free file control block
  - For UNIX
    - Search the super-block free I-node list
    - Take the first free I-node
  - For DOS
    - Search the parent directory for an unused directory entry
- Initialize the new file control block
  - With file type, protection, ownership, ...
- Give new file a name
  - Naming issues will be discussed in the next lecture

Extending a File

- Application requests new data be assigned to a file
  - May be an explicit allocation/extension request
  - May be implicit (e.g., write to a currently non-existent block – remember sparse files?)
- Find a free chunk of space
  - Traverse the free list to find an appropriate chunk
  - Remove the chosen chunk from the free list
- Associate it with the appropriate address in the file
  - Go to appropriate place in the file or extent descriptor
  - Update it to point to the newly allocated chunk

Deleting a File

- Release all the space that is allocated to the file
  - For UNIX, return each block to the free block list
  - DOS does not free space
    - It uses garbage collection
    - So it will search out deallocated blocks and add them to the free list at some future time
- Deallocate the file control lock
  - For UNIX, zero inode and return it to free list
  - For DOS, zero the first byte of the name in the parent directory
    - Indicating that the directory entry is no longer in use

Free Space Maintenance

- File system manager manages the free space
- Getting/releasing blocks should be fast operations
  - They are extremely frequent
  - We'd like to avoid doing I/O as much as possible
- Unlike memory, it matters what block we choose
  - Best to allocate new space in same cylinder as file's existing space
  - User may ask for contiguous storage
- Free-list organization must address both concerns
  - Speed of allocation and deallocation
  - Ability to allocate contiguous or near-by space

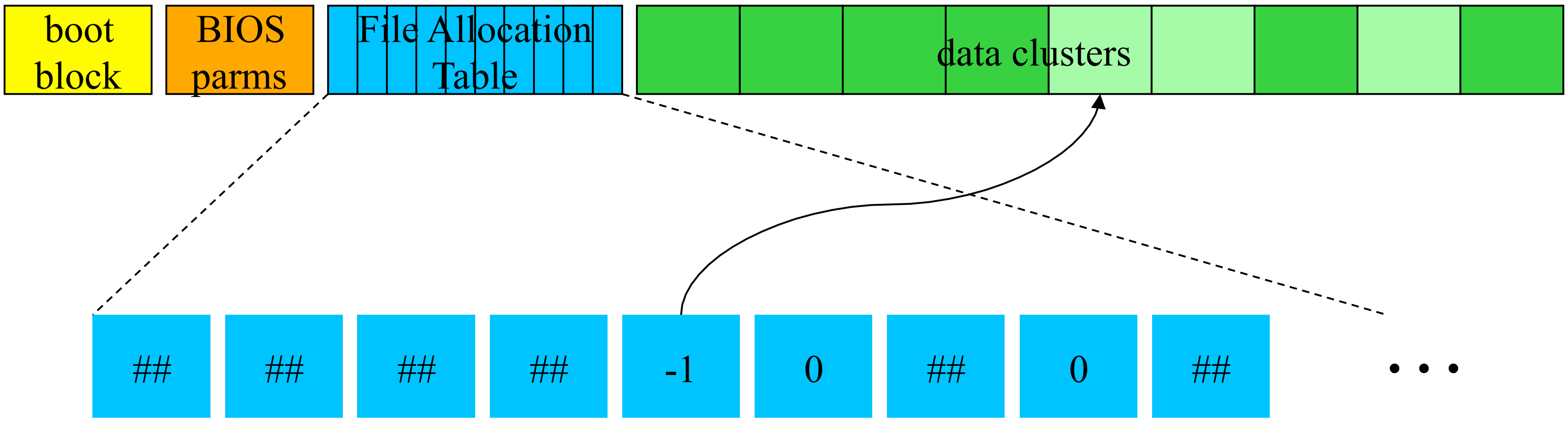
DOS File System Free Space Management

- Search for free clusters in desired cylinder
  - We can map clusters to cylinders
    - The BIOS Parameter Block describes the device geometry
  - Look at first cluster of file to choose the desired cylinder
  - Start search at first cluster of desired cylinder
  - Examine each FAT entry until we find a free one
- If no free clusters, we must garbage collect
  - Recursively search all directories for existing files
  - Enumerate all of the clusters in each file
  - Any clusters not found in search can be marked as free
  - This won't be fast . . .

Extending a DOS File

- Note cluster number of current last cluster in file
- Search the FAT to find a free cluster
  - Free clusters are indicated by a FAT entry of zero
  - Look for a cluster in the same cylinder as previous cluster
  - Put -1 in its FAT entry to indicate that this is the new EOF
  - This has side effect of marking the new cluster as “not free”
- Chain new cluster on to end of the file
  - Put the number of new cluster into FAT entry for last cluster

DOS Free Space



Each FAT entry corresponds to a cluster, and contains the number of the next cluster.

A value of zero indicates a cluster that is not allocated to any file, and is therefore free.

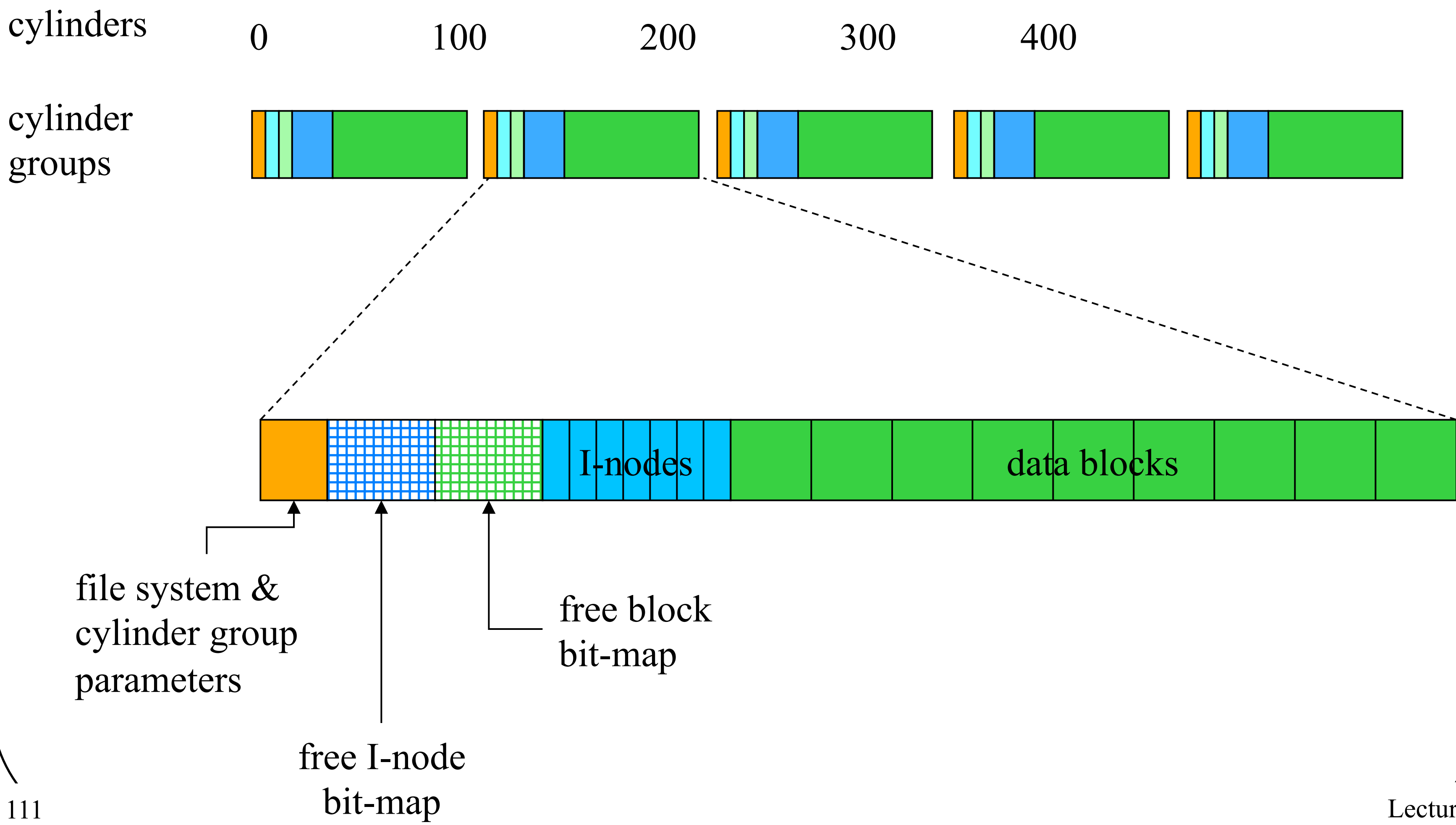
The BSD File System Free Space Management

- BSD is another version of Unix
- The details of its inodes are similar to those of Unix System V
  - As previously discussed
- Other aspects are somewhat different
  - Including free space management
  - Typically more advanced
- Uses bit map approach to managing free space
  - Keeping cylinder issues in mind

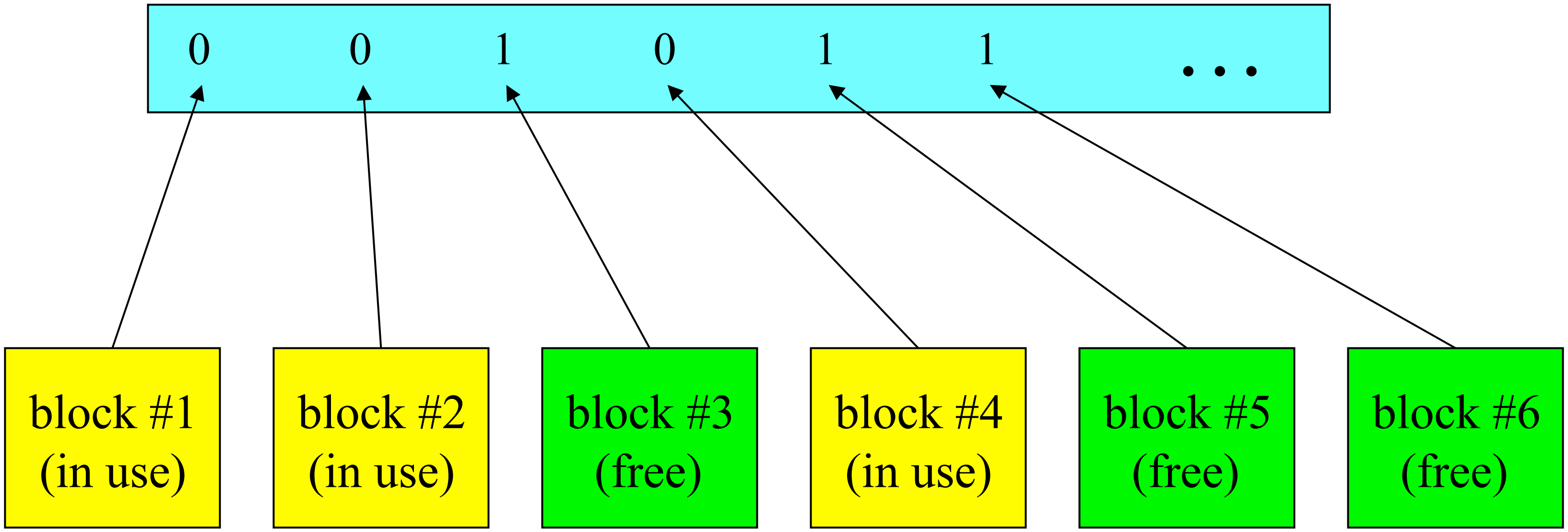
The BSD Approach

- Instead of all control information at start of disk,
- Divide file system into cylinder groups
  - Each cylinder group has its own control information
    - The *cylinder group summary*
  - Active cylinder group summaries are kept in memory
  - Each cylinder group has its own inodes and blocks
  - Free block list is a bit-map in cylinder group summary
- Enables significant reductions in head motion
  - Data blocks in file can be allocated in same cylinder
  - Inode and its data blocks in same cylinder group
  - Directories and their files in same cylinder group

BSD Cylinder Groups and Free Space



Bit Map Free Lists



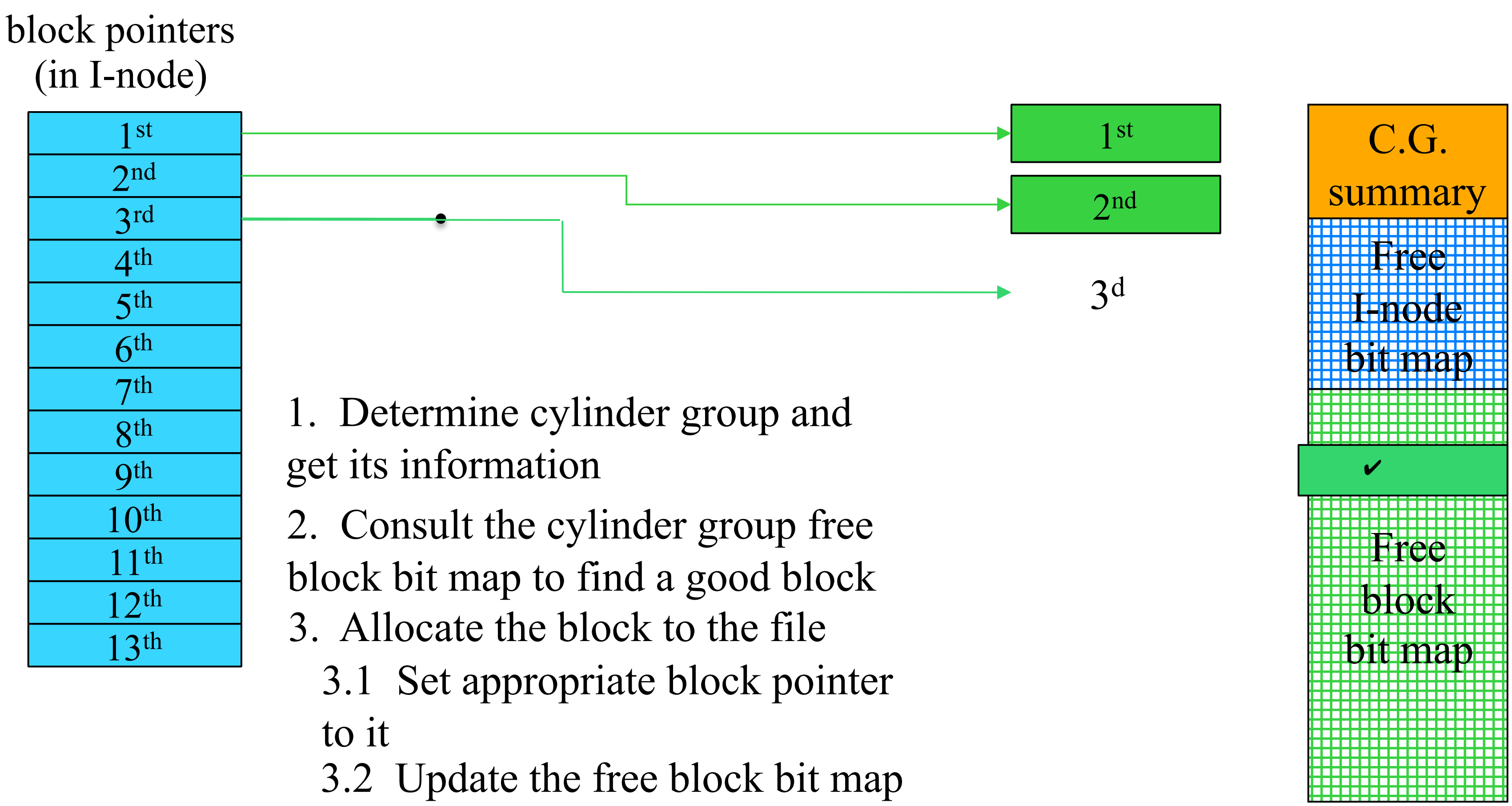
Actual data blocks

BSD Unix file systems use bit-maps to keep track of both free blocks and free I-nodes in each cylinder group

Extending a BSD/Unix File

- Determine the cylinder group for the file's inode
  - Calculated from the inode's identifying number
- Find the cylinder for the previous block in the file
- Find a free block in the desired cylinder
  - Search the free-block bit-map for a free block in the right cylinder
  - Update the bit-map to show the block has been allocated
- Update the inode to point to the new block
  - Go to appropriate block pointer in inode/indirect block
  - If new indirect block is needed, allocate/assign it first
  - Update inode/indirect to point to new block

Unix File Extension



1. Determine cylinder group and get its information
2. Consult the cylinder group free block bit map to find a good block
3. Allocate the block to the file
   3.1 Set appropriate block pointer to it
   3.2 Update the free block bit map

Naming in File Systems

- Each file needs some kind of handle to allow us to refer to it
- Low level names (like inode numbers) aren't usable by people or even programs
- We need a better way to name our files
  - User friendly
  - Allowing for easy organization of large numbers of files
  - Readily realizable in file systems

File Names and Binding

- File system knows files by descriptor structures
- We must provide more useful names for users
- The file system must handle name-to-file mapping
  - Associating names with new files
  - Finding the underlying representation for a given name
  - Changing names associated with existing files
  - Allowing users to organize files using names
- *Name spaces* – the total collection of all names known by some naming mechanism
  - Sometimes all names that *could* be created by the mechanism

Name Space Structure

- There are many ways to structure a name space
  - Flat name spaces
    - All names exist in a single level
  - Hierarchical name spaces
    - A graph approach
    - Can be a strict tree
    - Or a more general graph (usually directed)
- Are all files on the machine under the same name structure?
- Or are there several independent name spaces?

Some Issues in Name Space Structure

- How many files can have the same name?
  - One per file system ... flat name spaces
  - One per directory ... hierarchical name spaces
- How many different names can one file have?
  - A single “true name”
  - Only one “true name”, but aliases are allowed
  - Arbitrarily many
  - What’s different about “true names”?
- Do different names have different characteristics?
  - Does deleting one name make others disappear too?
  - Do all names see the same access permissions?

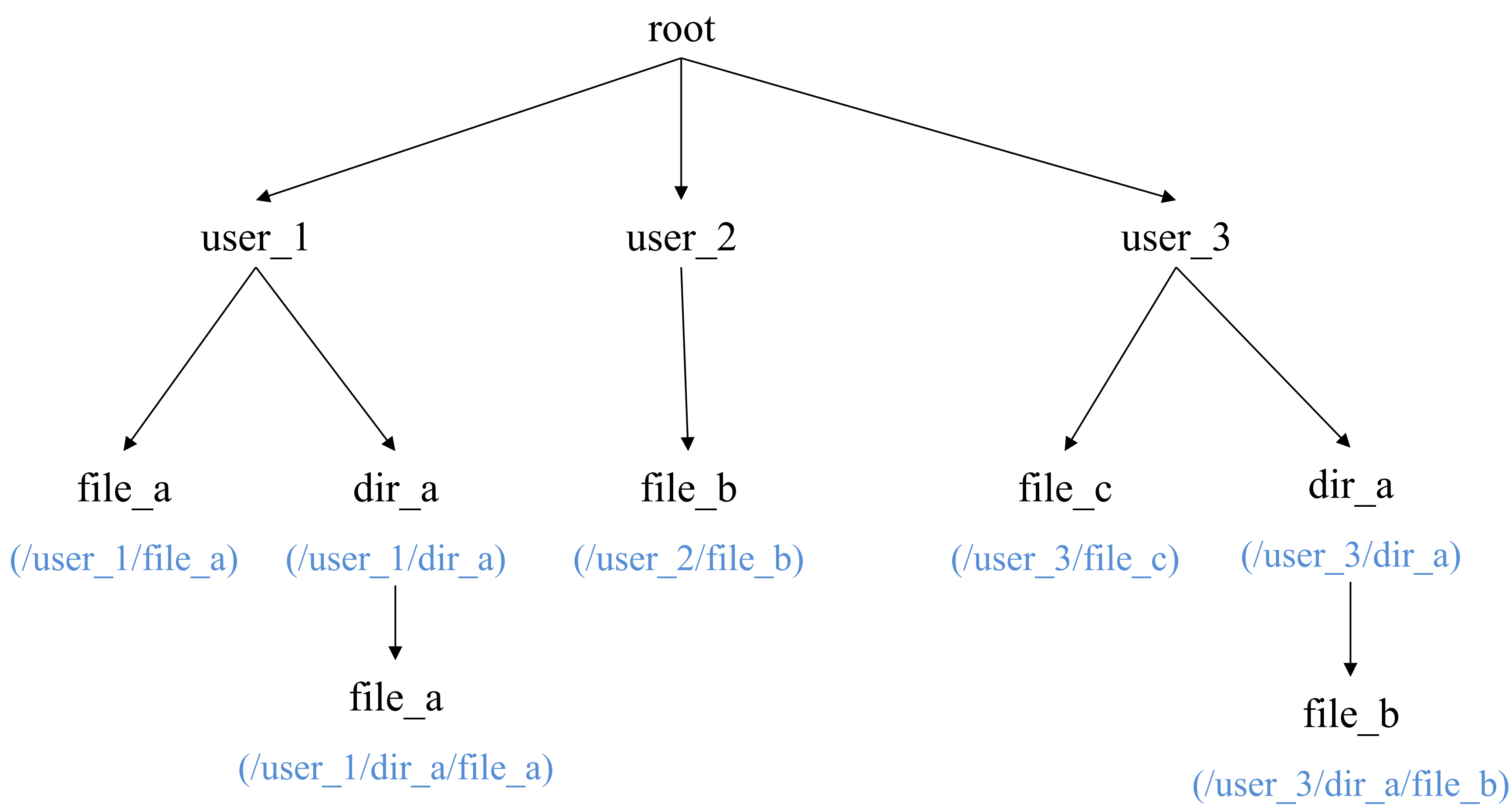
Flat Name Spaces

- There is one naming context per file system
  - All file names must be unique within that context
- All files have exactly one true name
  - These names are probably very long
- File names may have some structure
  - E.g., CAC101.CS111.SECTION1.SLIDES.LECTURE_13
  - This structure may be used to optimize searches
  - The structure is very useful to users but has no meaning to the file system
- Not widely used in modern file systems

Hierarchical Name Spaces

- Essentially a graphical organization
- Typically organized using directories
  - A file containing references to other files
  - A non-leaf node in the graph
  - It can be used as a naming context
    - Each process has a *current directory*
    - File names are interpreted relative to that directory
- Nested directories can form a tree
  - A file name describes a path through that tree
  - The directory tree expands from a “root” node
    - A name beginning from root is called “fully qualified”
  - May actually form a directed graph
    - If files are allowed to have multiple names

A Rooted Directory Tree



Directories Are Files

- Directories are a special type of file
  – Used by OS to map file names into the associated files
- A directory contains multiple directory entries
  – Each directory entry describes one file and its name
- User applications are allowed to read directories
  – To get information about each file
  – To find out what files exist
- Usually only the OS is allowed to write them
  – Users can cause writes through special system calls
  – The file system depends on the integrity of directories

Traversing the Directory Tree

- Some entries in directories point to child directories
  - Describing a lower level in the hierarchy
- To name a file at that level, name the parent directory and the child directory, then the file
  - With some kind of delimiter separating the file name components
- Moving up the hierarchy is often useful
  - Directories usually have special entry for parent
  - Many file systems use the name ".." for that

Example: The DOS File System

- File & directory names separated by back-slashes
  - E.g., `\user_3\dir_a\file_b`
- Directory entries are the file descriptors
  - As such, only one entry can refer to a particular file
- Contents of a DOS directory entry
  - Name (relative to this directory)
  - Type (ordinary file, directory, ...)
  - Location of first cluster of file
  - Length of file in bytes
  - Other privacy and protection attributes

DOS File System Directories

Root directory, starting in cluster #1

file name	type	length	…	1st cluster
user_1	DIR	256 bytes	…	9
user_2	DIR	512 bytes	…	31
user_3	DIR	284 bytes	…	114

Directory /user_3, starting in cluster #114

file name	type	length	…	1st cluster
..	DIR	256 bytes	…	1
dir_a	DIR	512 bytes	…	62
file_c	FILE	1824 bytes	…	102

File Names Vs. Path Names

- In flat name spaces, files had "true names"
  - That name is recorded in some central location
  - Name structure (a.b.c) is a convenient convention
- In DOS, a file is described by a directory entry
  - Local name is specified in that directory entry
  - Fully qualified name is the path to that directory entry
    - E.g., start from root, to user_3, to dir_a, to file_b
  - But DOS files still have only one name
- What if files had no intrinsic names of their own?
  - All names came from directory paths

Example: Unix Directories

- A file system that allows multiple file names
  - So there is no single "true" file name, unlike DOS
- File names separated by slashes
  - E.g., `/user_3/dir_a/file_b`
- The actual file descriptors are the inodes
  - Directory entries only point to inodes
  - Association of a name with an inode is called a *hard link*
  - Multiple directory entries can point to the same inode
- Contents of a Unix directory entry
  - Name (relative to this directory)
  - Pointer to the inode of the associated file

Unix Directories

But what's this "." entry?

It's a directory entry that points to the directory itself!

We'll see why that's useful later

Root directory, inode #1

inode #	file name
1	.
1	..
9	user_1
31	user_2
114	user_3

Directory /user_3, inode #114

inode #	file name
114	.
1	..
194	dir_a
307	file_c

Here's a ".." entry, pointing to the parent directory

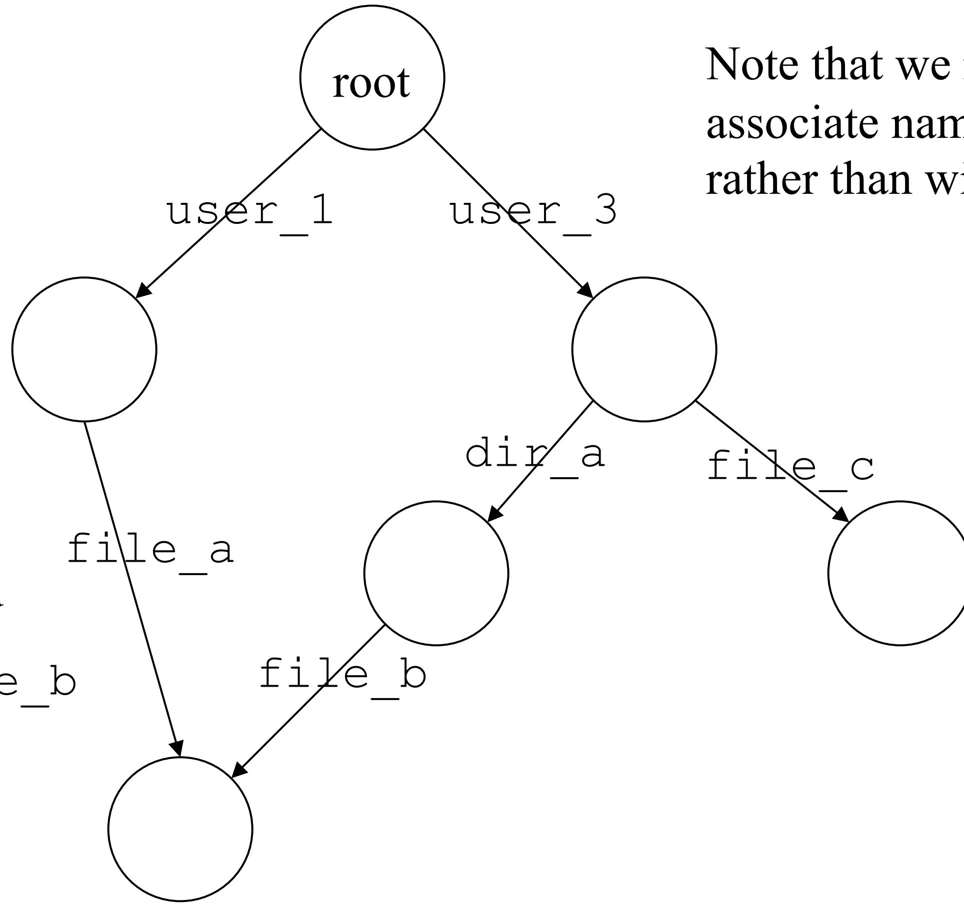
Multiple File Names In Unix

- How do links relate to files?
  - They're the names only
- All other metadata is stored in the file inode
  - File owner sets file protection (e.g., read-only)
- All links provide the same access to the file
  - Anyone with read access to file can create new link
  - But directories are protected files too
    - Not everyone has read or search access to every directory
- All links are equal
  - There is nothing special about the first (or owner's) link

Links and De-allocation

- Files exist under multiple names
- What do we do if one name is removed?
- If we also removed the file itself, what about the other names?
  - Do they now point to something non-existent?
- The Unix solution says the file exists as long as at least one name exists
- Implying we must keep and maintain a reference count of links
  - In the file inode, not in a directory

Unix Hard Link Example



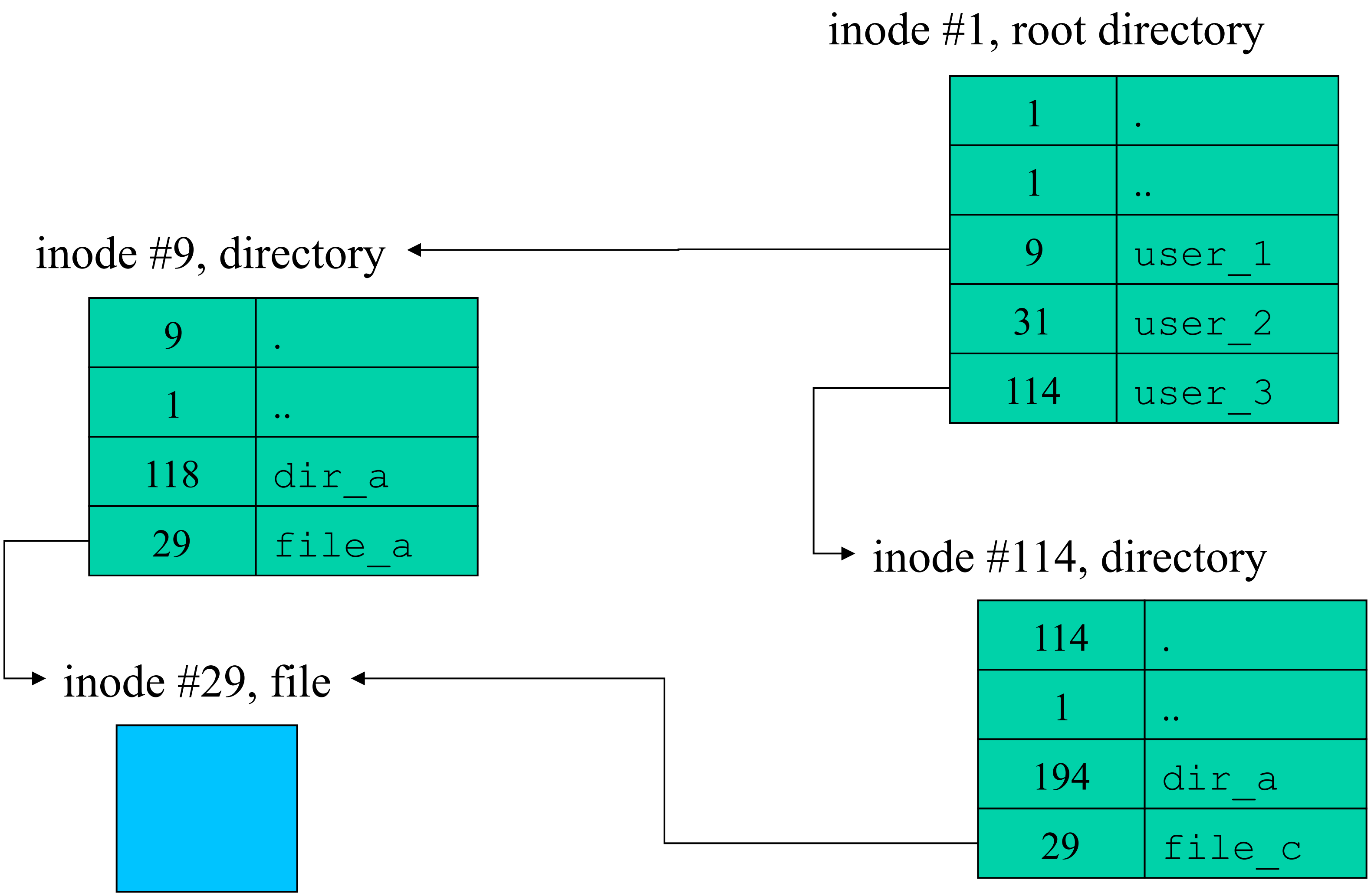
Note that we now associate names with links rather than with files.

`/user_1/file_a` and

`/user_3/dir_a/file_b`

are both links to the same inode

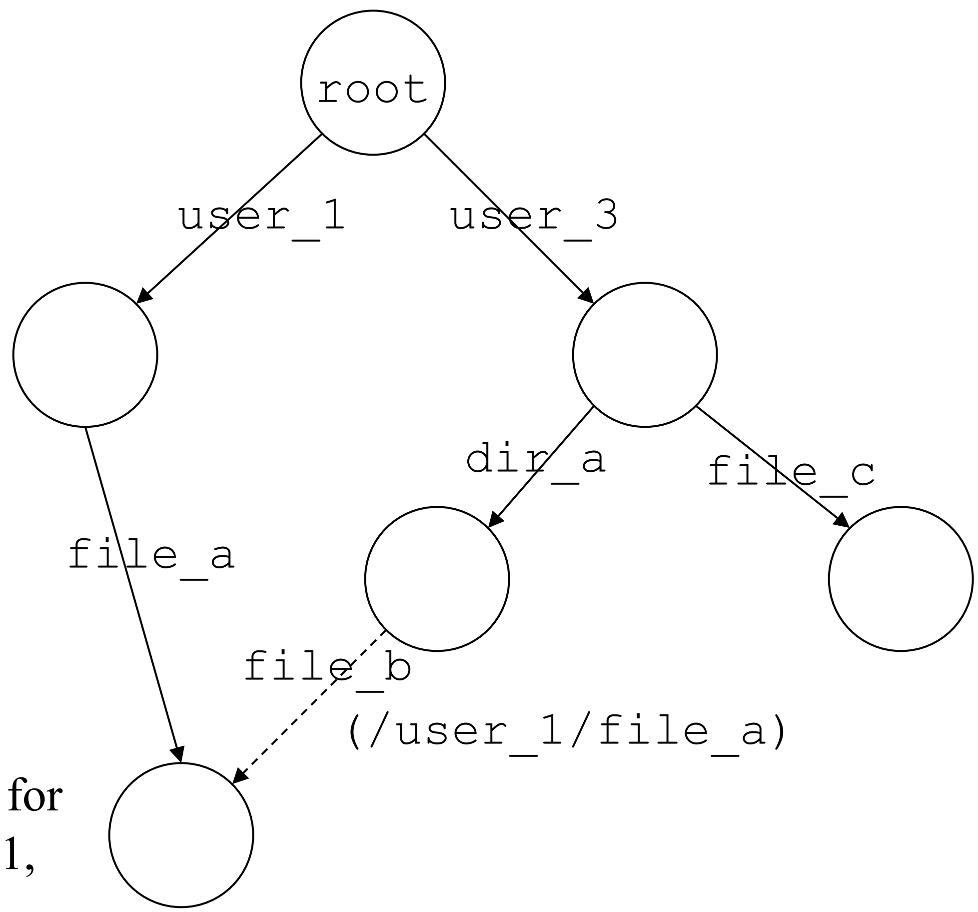
Hard Links, Directories, and Files



Symbolic Links

- A different way of giving files multiple names
- Symbolic links implemented as a special type of file
  - An indirect reference to some other file
  - Contents is a path name to another file
- OS recognizes symbolic links
  - Automatically opens associated file instead
  - If file is inaccessible or non-existent, the open fails
- Symbolic link is <u>not</u> a reference to the inode
  - Symbolic links will not prevent deletion
  - Do not guarantee ability to follow the specified path
  - Internet URLs are similar to symbolic links

Symbolic Link Example



The link count for this file is still 1, though

Symbolic Links, Files, and Directories