



# COS 318: Operating Systems

## File Layout and Directories

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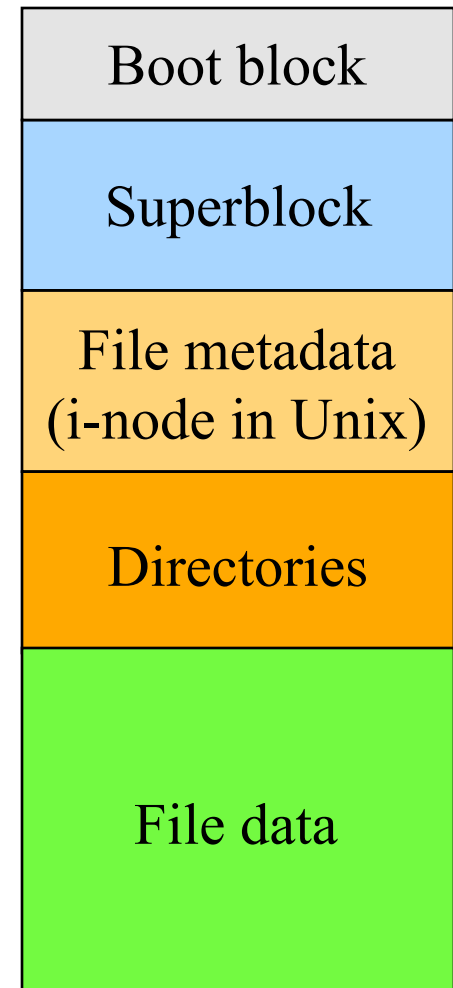
Princeton University

(<http://www.cs.princeton.edu/courses/cos318/>)



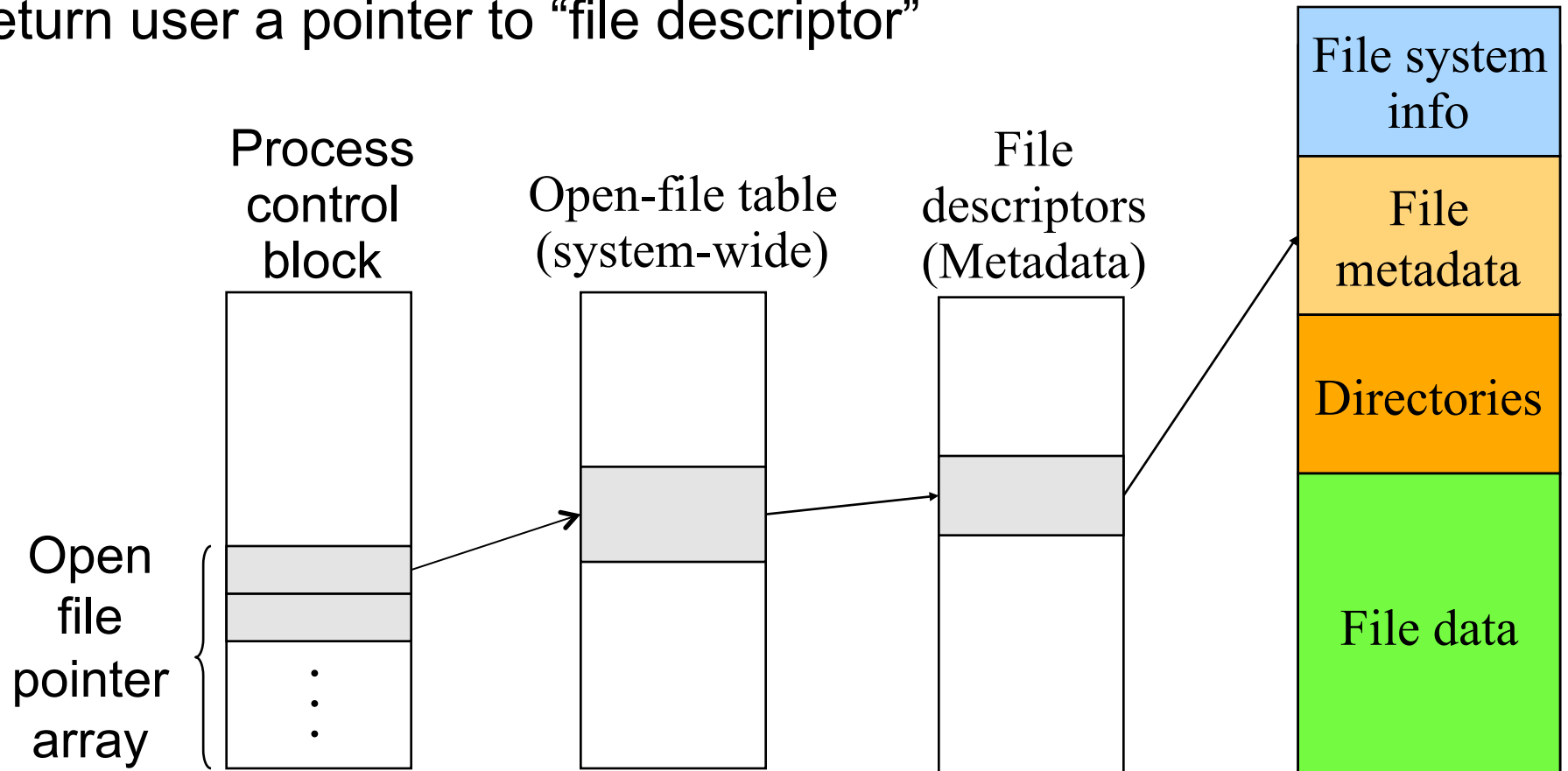
# Typical Physical Layout

- ◆ Boot block
  - Code to boot OS
- ◆ Super-block defines a file system
  - File system info
  - Free blocks, file metadata, root directory
  - File metadata area
  - Permission, etc
- ◆ File metadata
  - Each descriptor describes a file
- ◆ Directories
  - Directory data (directory and file names)
- ◆ File data
  - Data blocks



# Open A File: Open(fd, name, access)

- ◆ Various checking (directory and file name lookup, authenticate)
- ◆ Copy the file descriptors into the in-memory data structure
- ◆ Create an entry in the open file table (system wide)
- ◆ Create an entry in PCB
- ◆ Return user a pointer to “file descriptor”



# Data Structures for Storage Allocation

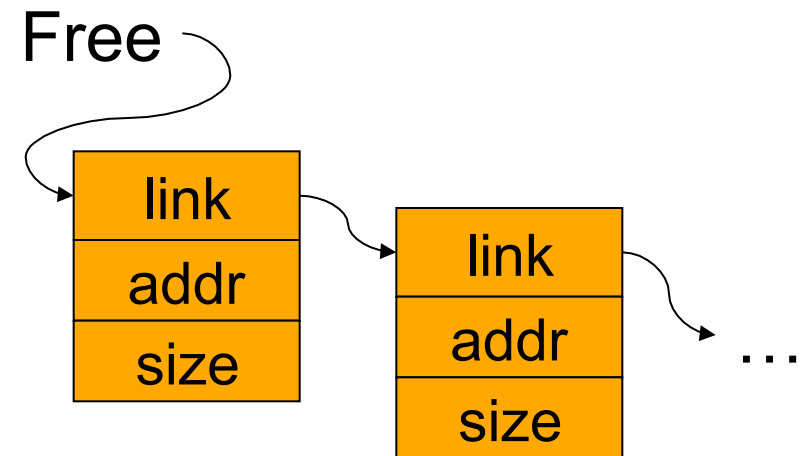
## ◆ A file

- Metadata
- A list of data blocks

## ◆ Free space data structure

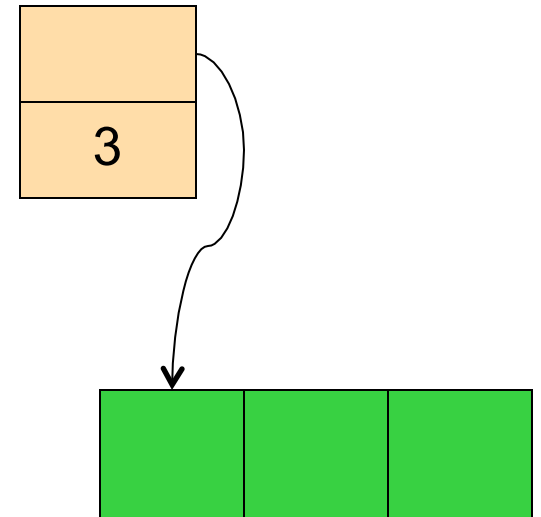
- Bit map indicating the status of disk blocks
- Linked list that chains free blocks together
- Buddy system
- ...

111111111111111111110000000000000000
000001111111111100000000000011111111
⋮
1100000111100011110000000000000000



# Contiguous Allocation

- ◆ Allocate contiguous blocks on storage
  - Bitmap: find N contiguous 0's
  - Linked list: find a region (size  $\geq N$ )
- ◆ File metadata
  - First block in file
  - Number of blocks
- ◆ Pros
  - Fast sequential access
  - Easy random access
- ◆ Cons
  - External fragmentation (what if file C needs 3 blocks)
  - Hard to grow files



# Linked Files (Alto)

## ◆ File structure

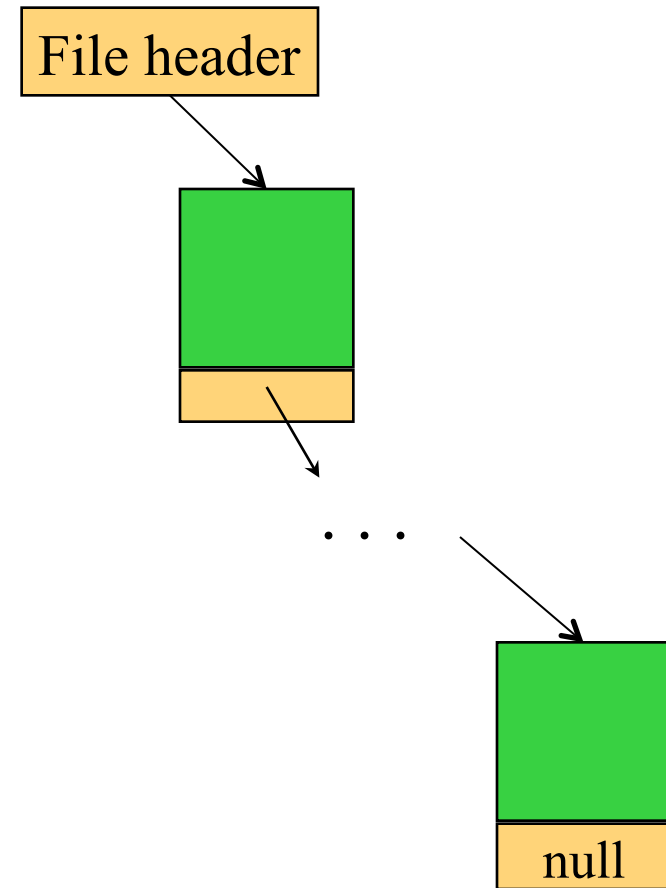
- File metadata points to 1st block on storage
- A block points to the next
- Last block has a NULL pointer

## ◆ Pros

- Can grow files dynamically
- Free list is similar to a file

## ◆ Cons

- Random access: bad
- Unreliable: losing a block means losing the rest



# File Allocation Table (FAT)

- ◆ Allocation table at the beginning of each volume

- ◆ N entries for N blocks

- ◆ File structure

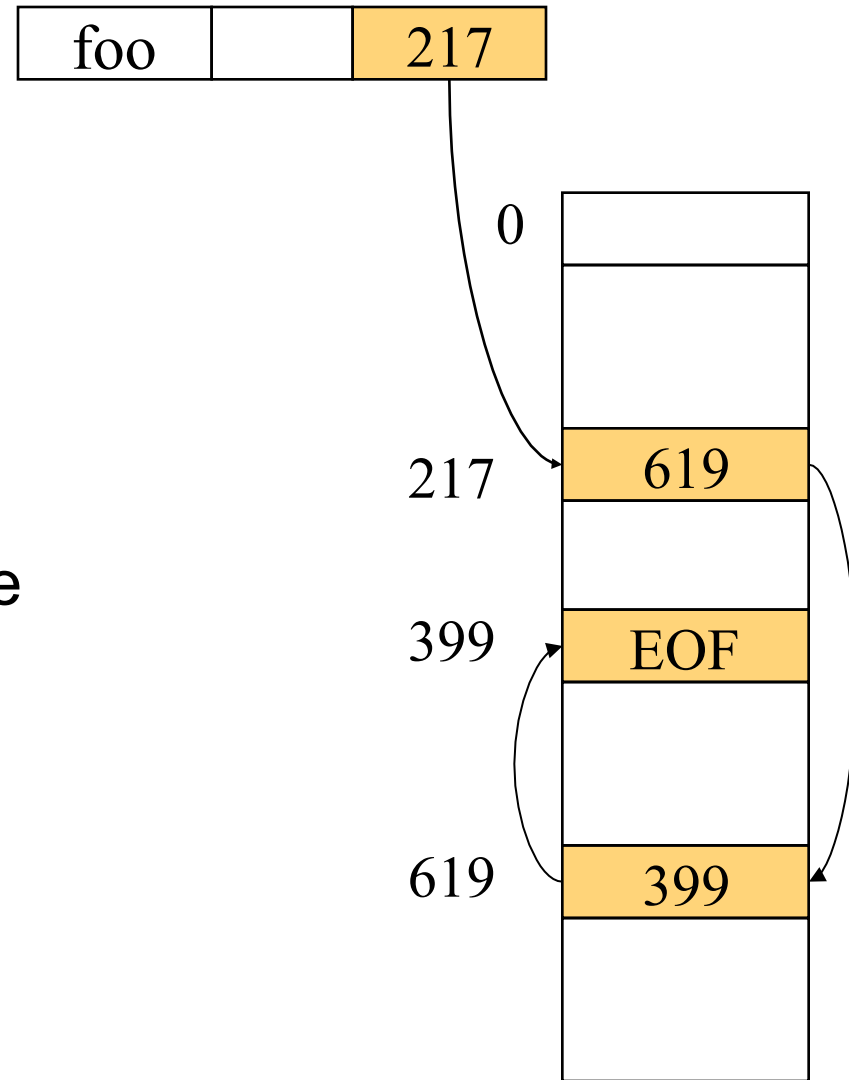
- A file is a linked list of blocks
- File metadata points to the first block of the file
- The entry of first block points to the next, ...

- ◆ Pros

- Simple

- ◆ Cons

- Random access: bad
- Waste space



FAT Allocation Table



# Single-Level Indexed Files

## ◆ File structure

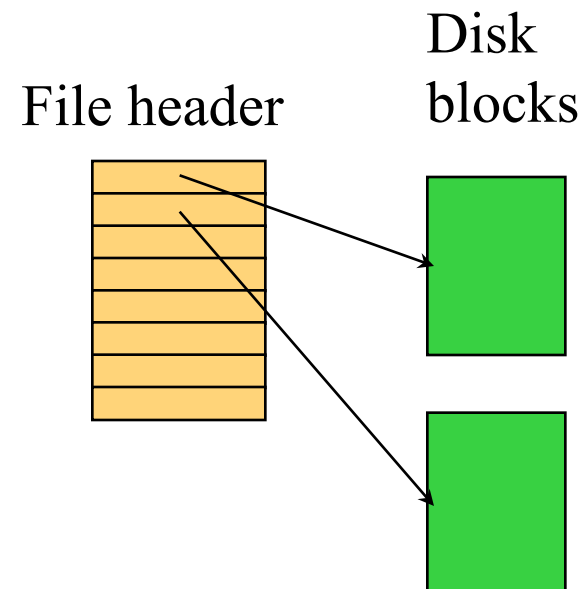
- User declares max size
- A file header holds an array of pointers to point to disk blocks

## ◆ Pros

- Can grow up to a limit
- Random access is fast

## ◆ Cons

- Clumsy to grow beyond the limit





# Multi-Level Indexed Files (Unix)

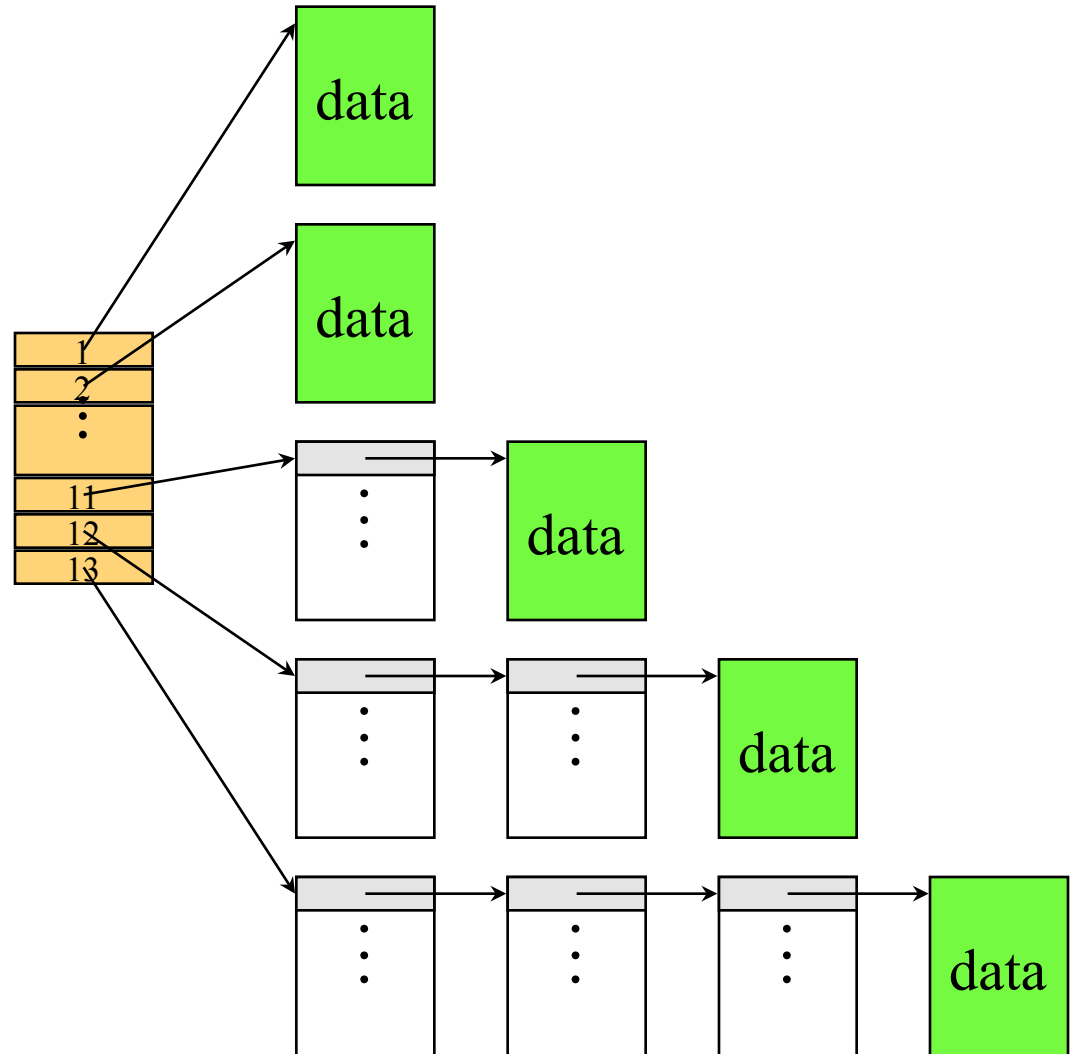
## ◆ 13 Pointers in a header

- 10 direct pointers
- 11: 1-level indirect
- 12: 2-level indirect
- 13: 3-level indirect

## ◆ Pros & Cons

- In favor of small files
- Can grow
- Limit is 16G and lots of seek

## ◆ How to reach block 23, 5, 340?



# Original Unix i-node

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- ◆ Mode: file type, protection bits, setuid, setgid bits
- ◆ Link count: number of directory entries pointing to this
- ◆ Uid: uid of the file owner
- ◆ Gid: gid of the file owner
- ◆ File size
- ◆ Times (access, modify, change)
  
- ◆ 10 pointers to data blocks
- ◆ Single indirect pointer
- ◆ Double indirect pointer
- ◆ Triple indirect pointer



# Naming

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- ◆ Text name
  - Need to map it to index
- ◆ Index (i-node number)
  - Ask users to specify i-node number
- ◆ Icon
  - Need to map it to index or map it to text then to index



# Directory Organization Examples

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## ◆ Flat (CP/M)

- All files are in one directory

## ◆ Hierarchical (Unix)

- /u/cos318/foo
- Directory is stored in a file containing (name, i-node) pairs
- The name can be either a file or a directory

## ◆ Hierarchical (Windows)

- C:\windows\temp\foo
- Use the extension to indicate whether the entry is a directory



# Mapping File Names to i-nodes

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- ◆ Create/delete
  - Create/delete a directory
- ◆ Open/close
  - Open/close a directory for read and write
  - Should this be the same or different from file open/close?
- ◆ Link/unlink
  - Link/unlink a file
- ◆ Rename
  - Rename the directory



# Linear List

## ◆ Method

- <FileName, i-node> pairs are linearly stored in a file
- Create a file
  - Append <FileName, i-node>
- Delete a file
  - Search for FileName
  - Remove its pair from the directory
  - Compact by moving the rest

/u/li/

foo bar ...

veryLongFileName

<foo,1234> <bar,  
1235> ... <very  
LongFileName,  
4567>

## ◆ Pros

- Space efficient

## ◆ Cons

- Linear search
- Need to deal with fragmentation



# Tree Data Structure

## ◆ Method

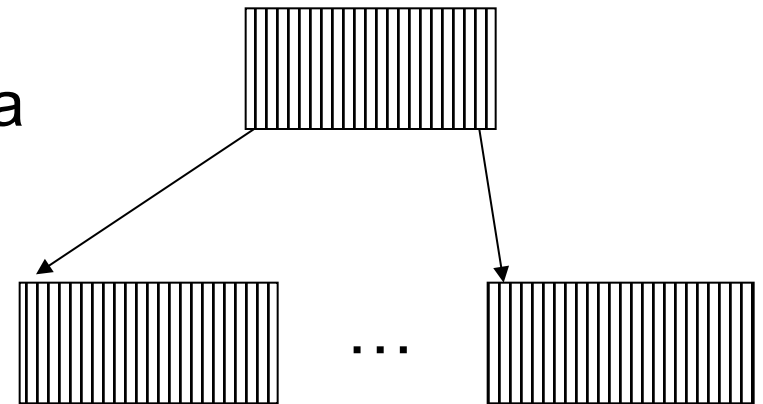
- Store <fileName, i-node> a tree data structure such as B-tree
- Create/delete/search in the tree data structure

## ◆ Pros

- Good for a large number of files

## ◆ Cons

- Inefficient for a small number of files
- More space
- Complex



# Hashing

## ◆ Method

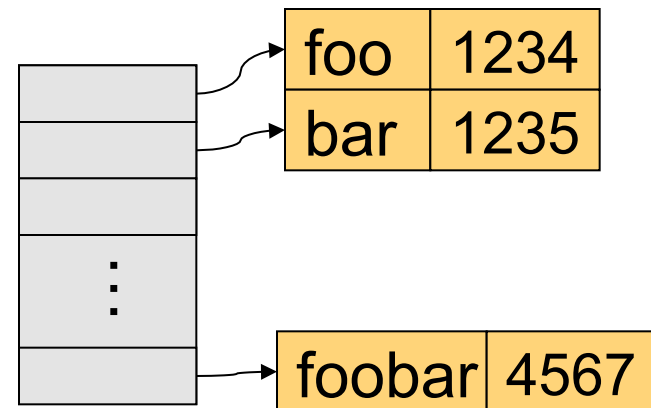
- Use a hash table to map FileName to i-node
- Space for name and metadata is variable sized
- Create/delete will trigger space allocation and free

## ◆ Pros

- Fast searching and relatively simple

## ◆ Cons

- Not as efficient as trees for very large directory (wasting space for the hash table)





# I/Os for Read/Write A File

- ◆ I/Os to access a byte of /u/cos318/foo
  - Read the i-node and first data block of “/”
  - Read the i-node and first data block of “u”
  - Read the i-node and first data block of “cos318”
  - Read the i-node and first data block of “foo”
- ◆ I/Os to write a file
  - Read the i-node of the directory and the directory file.
  - Read or create the i-node of the file
  - Read or create the file itself
  - Write back the directory and the file
- ◆ Too many I/Os to traverse the directory
  - Solution is to use ***Current Working Directory***



# Hard Links

## ◆ Approach

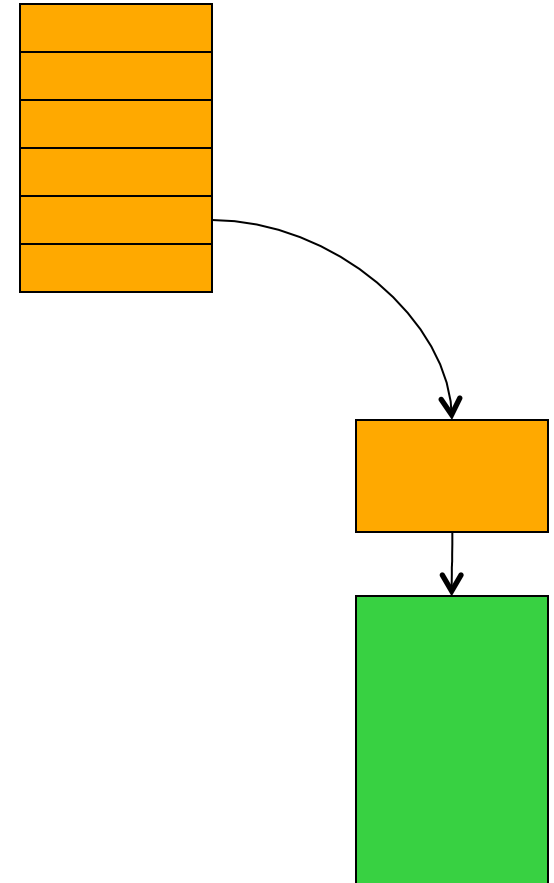
- A link to a file with the same i-node  
`ln source target`
- Delete may or may not remove the  
target depending on whether it is the  
last one (link reference count)

## ◆ Why hard links?

## ◆ How would you implement them?

## ◆ Main issue with hard links?

## Directory



# Symbolic Links

## ◆ Approach

- A symbolic link is a pointer to a file
- Use a new i-node for the link

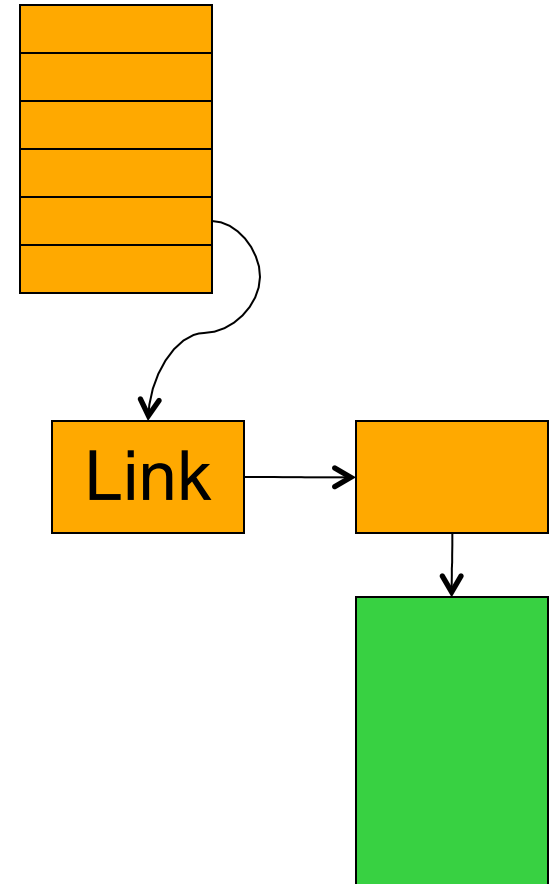
```
ln -s source target
```

## ◆ Why symbolic links?

## ◆ How would you implement them?

## ◆ Main issue with symbolic links?

Directory



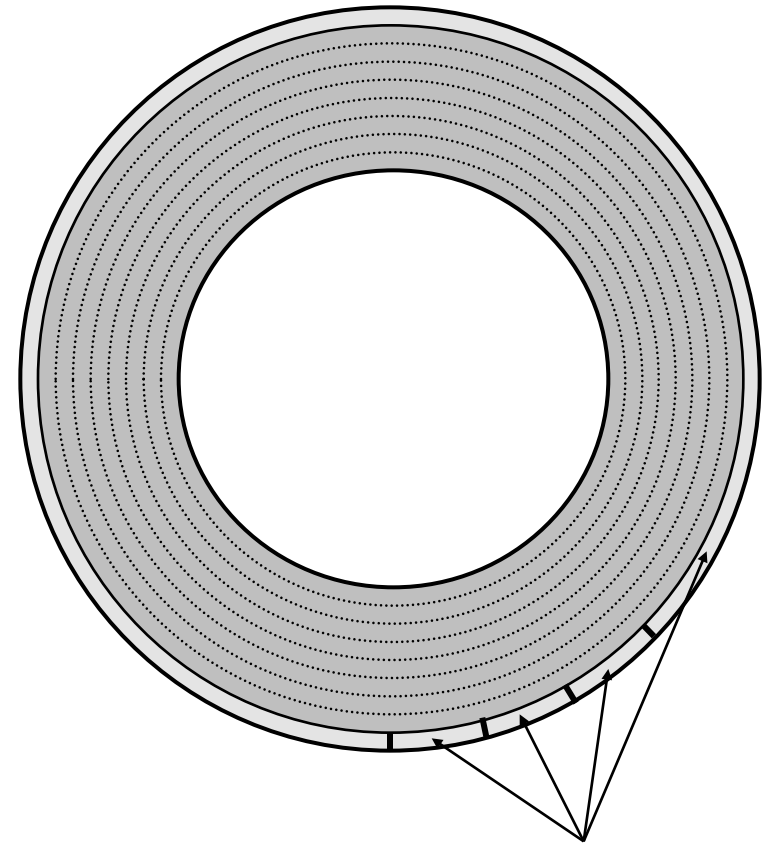
# Original Unix File System

## ◆ Simple disk layout

- Block size is sector size (512 bytes)
- i-nodes are on outermost cylinders
- Data blocks are on inner cylinders
- Use linked list for free blocks

## ◆ Issues

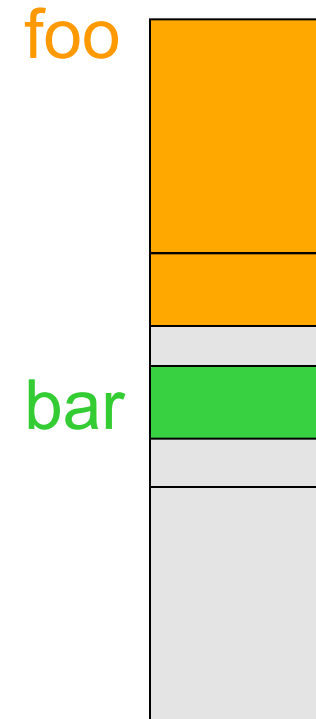
- Index is large
- Fixed max number of files
- i-nodes far from data blocks
- i-nodes for directory not close together
- Consecutive blocks can be anywhere
- Poor bandwidth (20Kbytes/sec even for sequential access!)



**i-node array**

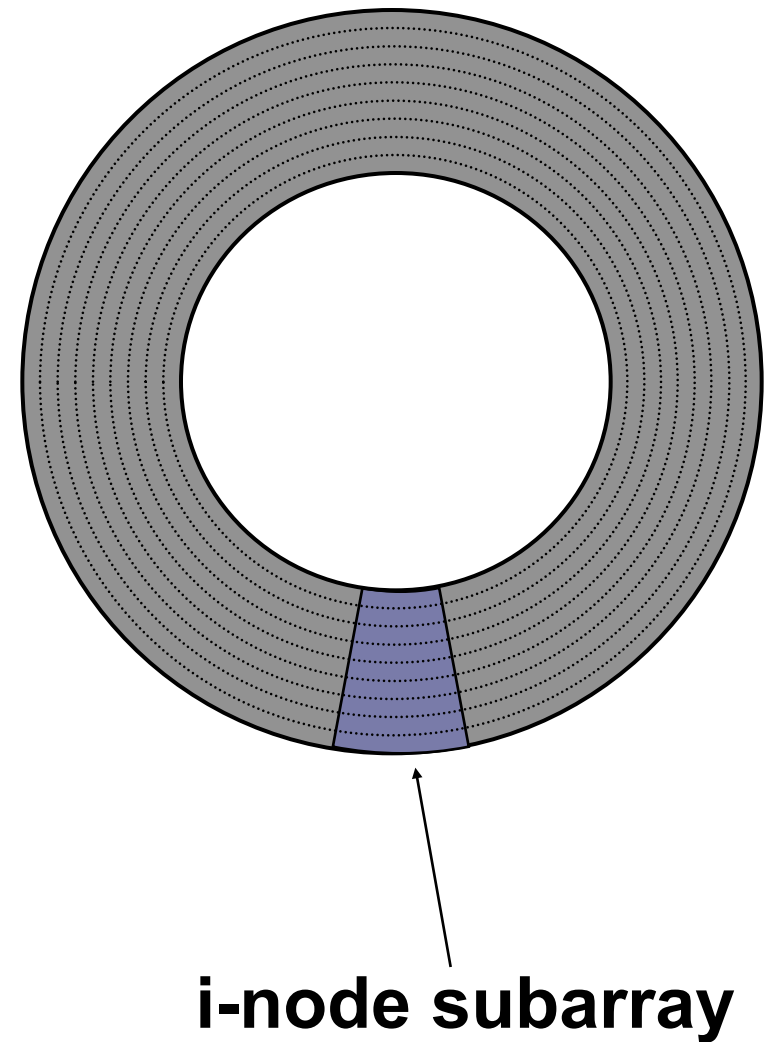
# BSD FFS (Fast File System)

- ◆ Use a larger block size: 4KB or 8KB
  - Allow large blocks to be chopped into fragments
  - Used for little files and pieces at the ends of files
- ◆ Use bitmap instead of a free list
  - Try to allocate contiguously
  - 10% reserved disk space



# FFS Disk Layout

- ◆ i-nodes are grouped together
  - A portion of the i-node array on each cylinder
- ◆ Do you ever read i-nodes without reading any file blocks?
  - 4 times more often than reading together
  - examples: ls, make
- ◆ Overcome rotational delays
  - Skip sector positioning to avoid the context switch delay
  - Read ahead: read next block right after the first



# What Has FFS Achieved?

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## ◆ Performance improvements

- 20-40% of disk bandwidth for large files (10-20x original)
- Better small file performance (why?)

## ◆ We can do better

- Extent based instead of block based
  - Use a pointer and size for all contiguous blocks (XFS, Veritas file system, etc)
- Synchronous metadata writes hurt small file performance
  - Asynchronous writes with certain ordering (“soft updates”)
  - Logging (talk about this later)
  - Play with semantics (/tmp file systems)



# Summary

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- ◆ File system structure
  - Boot block, super block, file metadata, file data
- ◆ File metadata
  - Consider efficiency, space and fragmentation
- ◆ Directories
  - Consider the number of files
- ◆ Links
  - Soft vs. hard
- ◆ Physical layout
  - Where to put metadata and data

