41. Locality and The Fast File System

Operating System: Three Easy Pieces

Unix operating system

Data structures

- The Good Thing
  - Simple and supports the basic abstractions.
  - Easy to use file system.
- The Problem
  - Terrible performance (2% of available disk bandwidth)

Problem of Unix operating system

- Unix file system treated the disk as a **random-access memory.**
  - Example of random-access blocks with Four files.
    - Data blocks for each file can accessed by going back and forth the disk, because they are are **contiguous.**

A1	A2	B1	B2	C1	C2	D1	D2

    - File b and d is deleted.

A1	A2			C1	C2		

    - File E is created with free blocks. (**spread across** the block)

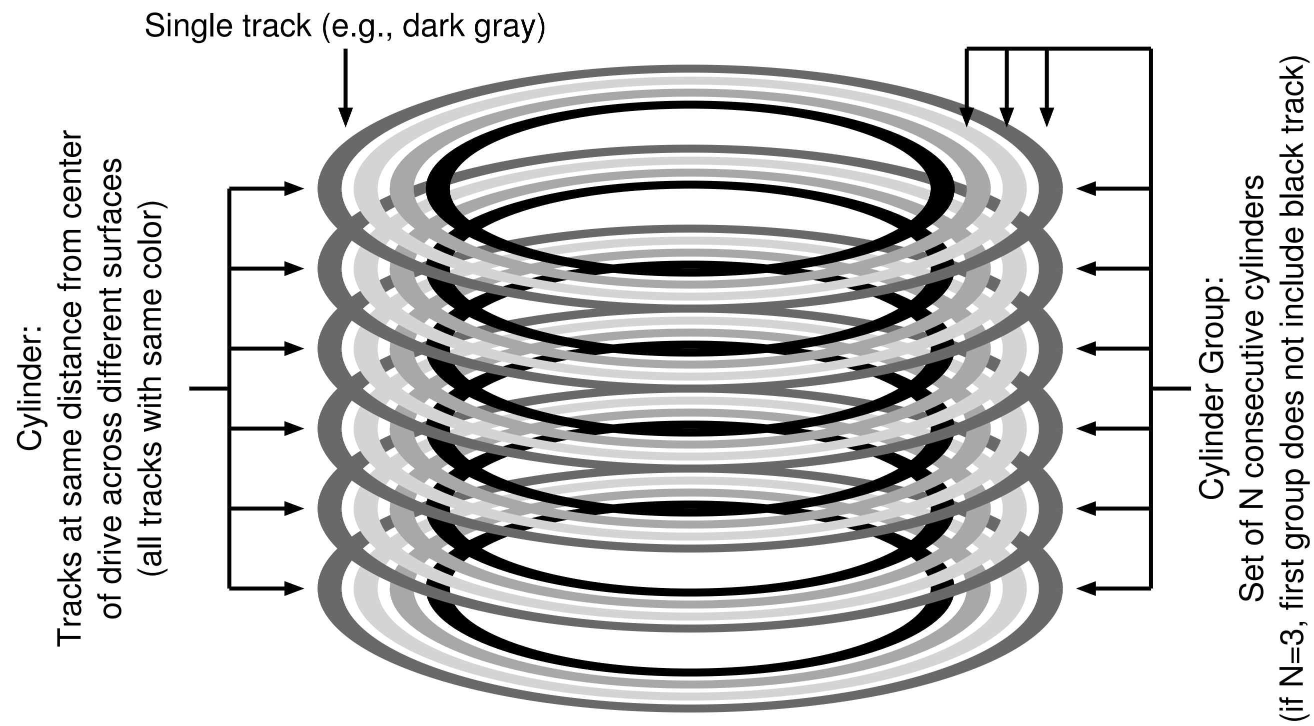
A1	A2	E1	E2	C1	C2	E3	E4

- Other Problem is the original block size was too small(512 bytes)
  - To prevent internal fragmentation (waste within a block)

FFS: Disk Awareness is the solution

- FFS is **Fast File system** designed by a group at Berkeley.
  - The ideas are alive in most modern file system
- The design of FFS is that file system structures and allocation polices to be "disk aware" and improve performance.
  - Keep same API with file system. (`open()`, `read()`, `write()`, etc)
  - Changing the internal implementation (according the physics of the disk)

Mechanical disk internals



Organizing Structure: The Cylinder Group

- FFS divides the disk into a bunch of groups. **(Cylinder Group)**
  - Modern file system call cylinder group as block group.

G0	**G1**	**G2**	**G3**	**G4**	**G5**	**G6**	**G7**	**G8**	**G9**

- These groups are uses to improve seek performance.
  - By placing two files within the same group.
  - Accessing one after the other **will not be long seeks** across the disk.
  - FFS needs to allocate files and directories within each of these groups.

Organizing Structure: The Cylinder Group (Cont.)

- Data structure for each cylinder group.
  - A copy of the **super block(S)** for reliability reason.
  - **inode bitmap(ib)** and **data bitmap(db)** to track free inode and data block.
  - **inodes** and **data block** are same to the previous very-simple file system(VSFS).

How To Allocate Files and Directories?

- Policy is "**keep related stuff together**"
  - i.e. *keep unrelated stuff far apart*

- The placement of directories
  - Find the cylinder group with a low number of allocated directories and a high number of free inodes.
  - Put the directory data and inode in that group.

- The placement of files.
  - Allocate data blocks of a file in the same group as its inode
  - It places all files in the same group as their directory

Example

- Lets suppose we need to create 3 dirs (`/, /a, and /b`) and four files (`/a/c, /a/d, /a/e, /b/f`)

```
group inodes     data
    0 /--------- /---------
    1 acde------ accddee---
    2 bf-------- bff-------
    3 ---------- ----------
    4 ---------- ----------
    5 ---------- ----------
    6 ---------- ----------
    7 ---------- ----------
    ...
```

Files in the same dir are usually accessed sequentially

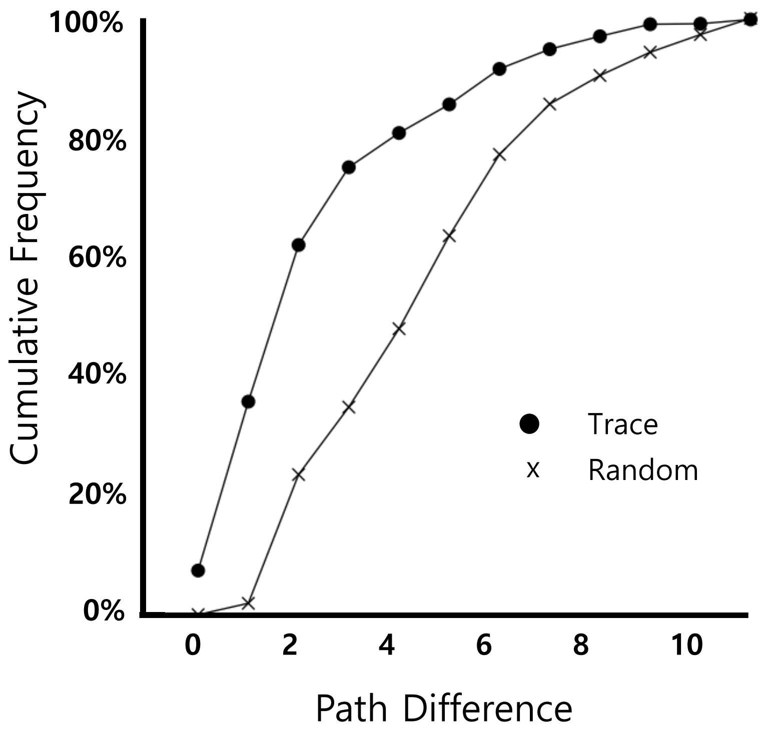
```
group inodes     data
    0 /--------- /---------
    1 a--------- a---------
    2 b--------- b---------
    3 c--------- cc--------
    4 d--------- dd--------
    5 e--------- ee--------
    6 f--------- ff--------
    7 ---------- ----------
    ...
```

Name locality is not preserved

FFS Locality for SEER Traces.

- How "**far away**" file accesses were from one another in the directory tree.

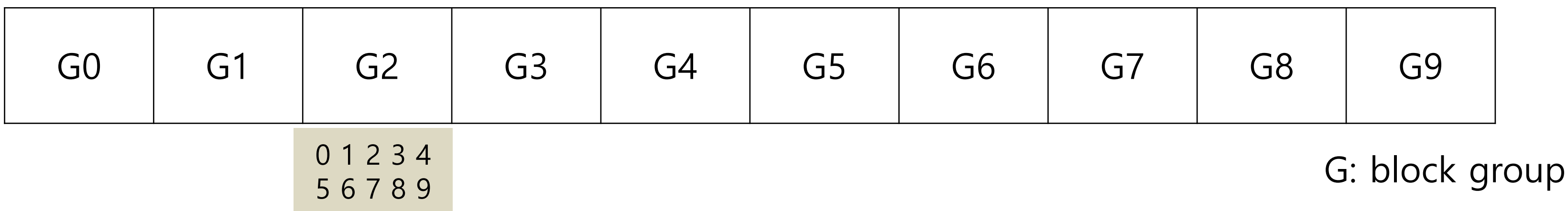
```
proc/src/foo.c
proc/src/bar.c
the distance of two file access is 1

proc/src/foo.c
proc/obj/foo.o
the distance of two file access is 2
```



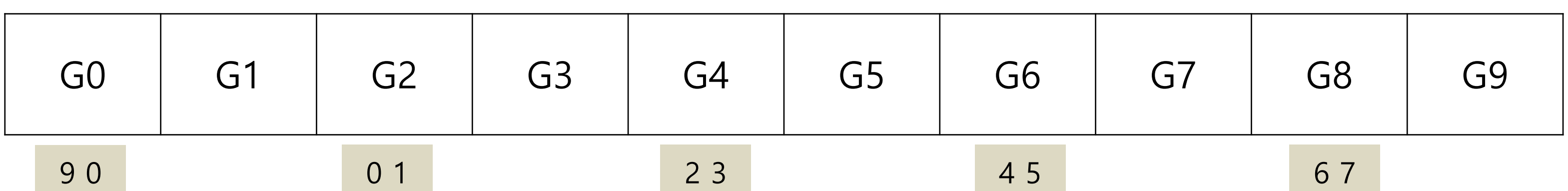
  - 7% of file accesses to the same file
  - Nearly 40% of file accesses in the same directory
  - 25% of file accesses were two distances

The Large-File Exception

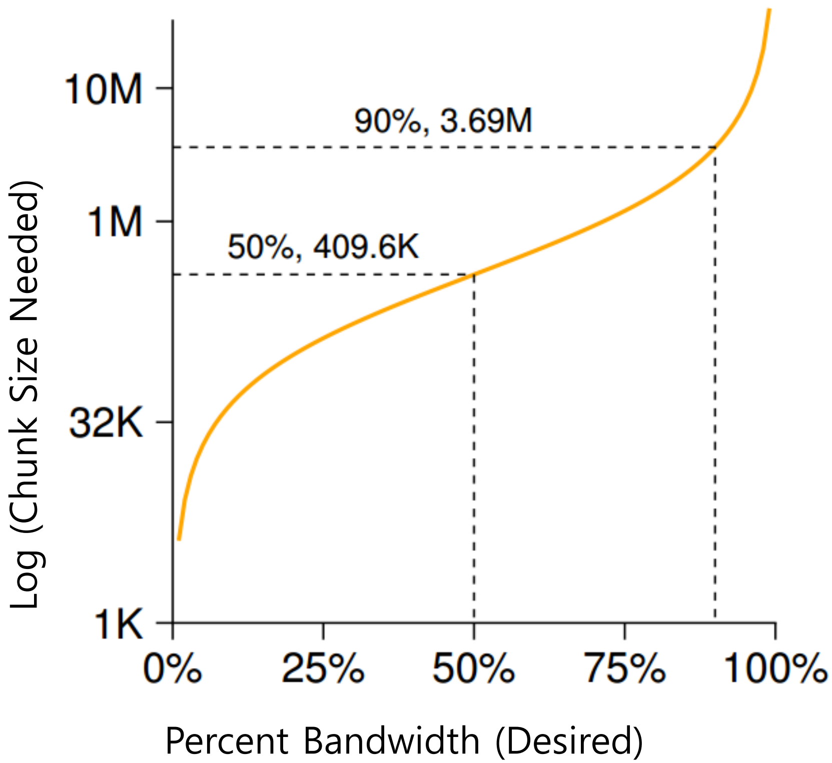
- General policy of file placement
  - Entierly fill the block group it is first place within
  - Hurt file-access locality from “related” file being placed



- For large files, chunks are spread across the disk
  - Hurt performance, but it can be addressed by choosing chunk size
  - **Amortization**: reducing overhead by doing more work



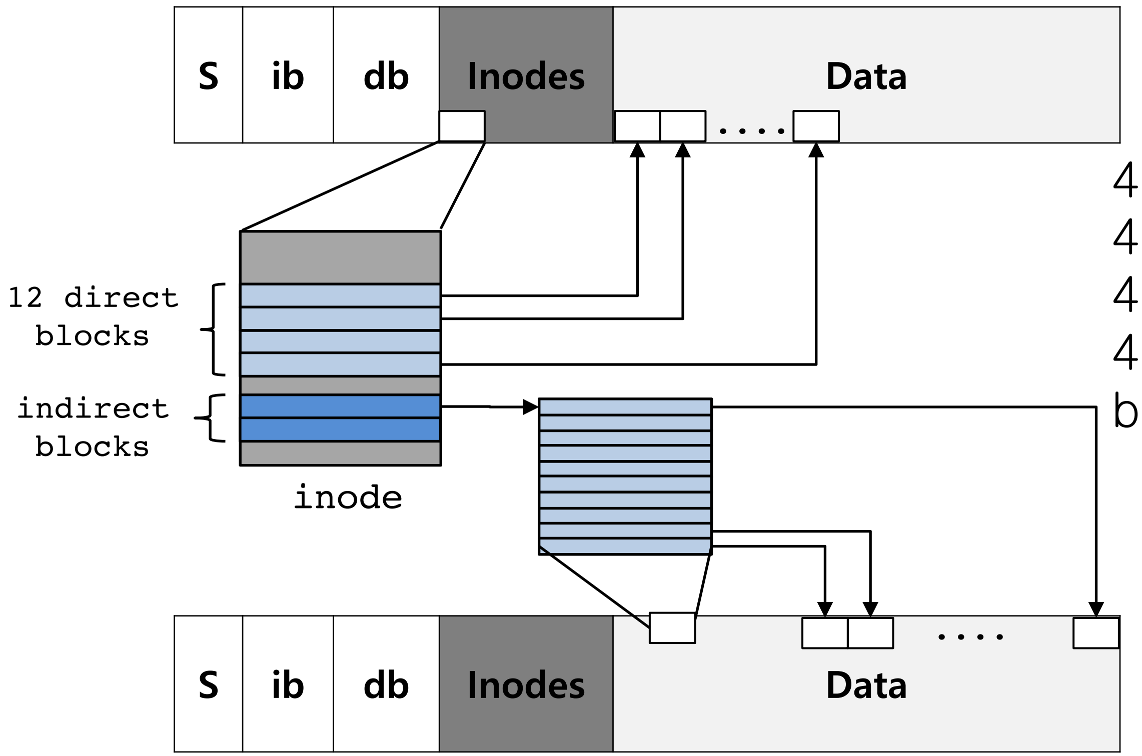
Amortization: How Big Do Chunks Have To Be?



- Computation of the size of chunk
  - Desire 50% of peak disk performance
    - half of time seeking and half of time transferring
  - Disk bandwidth: 40 MB/s
  - Positioning time: 10ms
  - $\frac{40\ \cancel{MB}}{\cancel{sec}} \cdot \frac{1024\ KB}{1\ \cancel{MB}} \cdot \frac{1\ \cancel{sec}}{1000\ \cancel{ms}} \cdot 10\ \cancel{ms} = 409.6\ KB$
    - Transfer only 409.6 KB every time seeking
  - 99% of peak performance on 3.69MB chunk size

The Large-File Exception in FSS

- A simple approach based on the structure of inode
  - Each subsequent **indirect blocks**, and all the **blocks it pointed to**, placed in **a different block group.**
  - Every **1024 blocks (4MB)** of the **file in a separate group (32-bit addr.)**



4MB=
4KB(indirect block size)/
4B (block addr)*
4KB (block ins the second block group)

A few other Things about FFS

- Internal fragmentation
- Sub-blocks
  - Ex) Create a file with 1 KB : use two sub-blocks, not an entire 4-KB blocks
- Parameterization (old disks)
- Track buffer (modern disks)
- Long file names
  - Enabling more expressive names in the file system
- Symbolic link

- Disclaimer: Disclaimer: This lecture slide set is used in AOS course at University of Cantabria by V.Puente. Was initially developed for Operating System course in Computer Science Dept. at Hanyang University. This lecture slide set is for OSTEP book written by Remzi and Andrea Arpaci-Dusseau (at University of Wisconsin)