ASSIGNMENT 5

Group 21

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Github Link: https://github.com/Tanmay7404/CS344_OsLab_2024/tree/main/Assignment%204

Part 1: Introduction to the Filesystems and Features

Filesystems Chosen

For this assignment, we selected ZFS and EXT4 to examine two distinctive features:
● **Data Deduplication** – Available in ZFS, which helps eliminate redundant data storage.
● **Large File Creation** – Optimised in EXT4, enhancing performance and storage management for large files.

Overview of ZFS

ZFS is an advanced file system and volume manager developed for the Solaris OS, designed to streamline disk and file management while boosting performance and compatibility. It emphasises data integrity, making it ideal for high-reliability environments. Key features include:

- **Data Deduplication**: Minimises storage by eliminating redundant data at the block level.
- **Checksumming**: Detects and corrects data corruption, enhancing reliability.
- **Copy-on-Write (COW)**: Prevents data loss by writing updates to new locations instead of overwriting existing data.

These features collectively enhance data security, optimise storage, and prevent data corruption.

Overview of EXT4

EXT4 is a popular Linux filesystem designed for scalability and performance, particularly suited for handling large files efficiently. Key features include:

Extents-based Mapping: Reduces fragmentation by allocating larger, contiguous memory regions, improving performance.
Delayed Allocation: Defers physical block allocation until necessary, optimising memory usage.
Multiblock Allocation: Allows multiple contiguous blocks to be allocated in a single operation, minimising fragmentation.

These enhancements make EXT4 ideal for applications with large files and high write throughput.

Deduplication in ZFS

ZFS uses block-level deduplication to reduce storage usage by eliminating redundant data. The process involves:

- **Hashing Data**: Each block's SHA256 hash is compared against a table of existing hashes.
- **Synchronous Deduplication**: Duplicate data blocks aren't stored; instead, references to the existing data block are created in real-time.

This reduces storage needs but increases CPU and memory usage, particularly during high workloads.

Large File Optimization in EXT4

EXT4 optimise large file handling through features like:

- **Extents-Based Mapping**: Maps data in contiguous extents to reduce fragmentation.
- **Multiblock Allocation**: Allocates multiple contiguous blocks in a single operation.
- **Delayed Allocation**: Defers physical block assignment, allowing for larger, contiguous data chunks.

These features boost performance with large files, though they may introduce higher metadata overhead for smaller files.

Comparison

- **ZFS Deduplication**: Reduces storage but requires more CPU and memory.
- **EXT4 Large File Optimization**: Enhances performance for large files, with potential overhead for small files.

Part 2:Installation and Setup for Experiments

To assess these filesystems, ZFS and EXT4 need to be set up on separate drives or partitions to allow for controlled testing and a direct performance comparison of each feature.
● ZFS Installation:
● EXT4 Installation:
After installation, we will perform tests to measure the benefits and trade-offs of each filesystem's unique feature—ZFS's deduplication and EXT4's large file optimization—and assess their performance under identical workloads.

Workload 1

This workload setup defines parameters for testing deduplication, file structure, file operations, and read performance in a ZFS environment.

1. **Deduplication Settings**:
    - **dedupunit=1m**: Deduplicates 1 MB blocks, storing only unique blocks.
    - **dedup ratio=2**: Targets a 2:1 deduplication ratio, expecting to store 1 MB for every 2 MB written.
2. **File System Descriptor (fsd)**:
    - **fsd=fsd1**: File structure reference, with **anchor=$anchor** as the root directory.
    - **depth=2, width=3**: Creates 9 directories with a 2-level hierarchy.
    - **files=50, size=1m**: Generates 50 files of 1 MB each.
3. **File Write Descriptor (fwd)**:
    - **fwd=fwd1**: Describes file handling, linked to **fsd1**.
    - **operation=read, xfersize=4k**: Reads files in 4 KB chunks.
    - **fileio=sequential, fileselect=random**: Sequential I/O with random file selection, using **2 threads** for concurrent access.
4. **Read Descriptor (rd)**:
    - **rd=rd1**: Configures reading, linked to **fwd1**.
    - **fwdrate=max**: Maximises read rate over **30 seconds**, reporting results every second for analysis.

This setup evaluates storage efficiency, file handling, and concurrent read performance under load.

This workload is designed to evaluate ZFS deduplication efficiency, space savings, and performance compared to ext4.

1. **File Creation**:
    - **Structure**: 450 files are created in a two-level directory structure, with each file being 1 MB.
    - **Total Files**: Files are distributed across directories with 50 files per subdirectory.

2. **Data Deduplication**:
    - **Parameters**: The deduplication unit size is set to 1 MB (matching file size), allowing ZFS to detect duplicate files effectively.
    - **Expected Deduplication**: A deduplication ratio of 2 indicates that half of the files are expected to be duplicates, potentially halving storage requirements to 225 MB.
3. **Sequential Read Operations**:
    - **Purpose**: A 30-second sequential read operation assesses read performance without directly impacting the deduplication results.
4. **Anchor Directory**:
    - **Configuration**: The test uses a root directory within a ZFS pool to ensure deduplication functions as expected.

Key Outcomes:

- **Space Savings**: Deduplication in ZFS should result in significant storage reduction.
- **Performance Metrics**: Sequential read speed and responsiveness for both ZFS and ext4 will be analysed.
- **Deduplication Efficiency**: The deduplication ratio will indicate how well ZFS manages redundancy.

The overall purpose is to evaluate ZFS deduplication in saving space and its performance impact compared to ext4, guiding file system choices based on efficiency and speed requirements.

Workload 2

This workload, designed to test large file creation, assesses ext4's performance compared to ZFS.

Workload Details:

1. **File Set Definition (fsd1)**:
    - **Anchor**: Files created in the specified anchor directory (e.g., `/zfs_pool`).
    - **Depth=0, Width=1**: Files are placed directly in the anchor without subdirectories.
    - **Files=2, Size=1G**: Creates two 1 GB files, totaling 2 GB.
2. **File Workload Definition (fwd1)**:
    - **Operation=create**: Files are created sequentially.
    - **File Selection=random**: Files selected randomly for creation.
    - **Threads=2**: Two concurrent threads perform the creation.
3. **Run Definition (rd1)**:
    - **fwdrate=max**: Runs at the maximum rate for 30 seconds.
    - **Format=yes**: Filesystem is formatted before the test.
    - **Interval=1**: Logs performance every second.

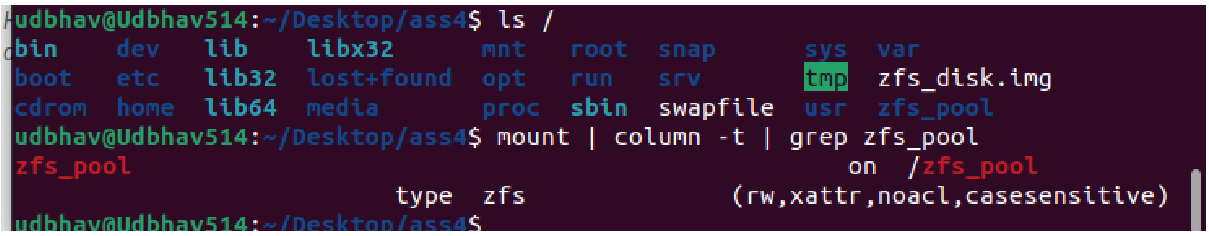
This setup examines the sequential write performance of the filesystem with large files and concurrent threads, providing insight into ext4's large file handling advantages

Finding the Anchors

To run workloads on the file systems, we need to identify the corresponding anchor directories.

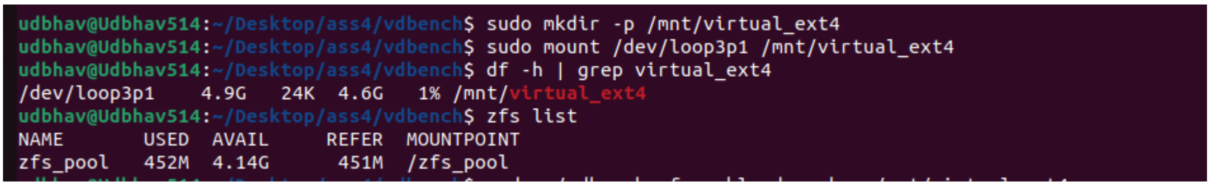
● **ZFS Pool Anchor**: If the ZFS pool is mounted at /zfs_pool, this becomes the anchor.

Anchor: /zfs_pool



● **ext4 Partition Anchor:** If the ext4 partition is mounted at /mnt/virtual_ext4, this becomes the anchor.

Anchor: /mnt/virtual_ext4



Without these anchors, the workloads will not run correctly.

Now we install and run vdbench

- Add both the workload files (workload 1 and workload 2) to your vdbench directory.
- Navigate (cd) to your vdbench directory in the terminal. And run the following commands.

A) ZFS

a. We run this workload on the ZFS file system by setting anchor to the directory of the ZFS Pool (basically the folder pointing to the ZFS Pool):

Workload 1

```
udbhav@Udbhav514:~/Desktop/ass4/vdbench$ sudo ./vdbench -f workload1 anchor=/zfs_pool


Copyright (c) 2000, 2018, Oracle and/or its affiliates. All rights reserved.
Vdbench distribution: vdbench50407 Tue June 05  9:49:29 MDT 2018
For documentation, see 'vdbench.pdf'.

00:26:57.244 Created output directory '/home/udbhav/Desktop/ass4/vdbench/output'
00:26:57.274 input argument scanned: '-fworkload1'
00:26:57.274 input argument scanned: 'anchor=/zfs_pool'
00:26:57.311 Anchor size: anchor=/zfs_pool: dirs:          12; files:          450; bytes:   450.000m (471,859,200)
00:26:57.405 Starting slave: /home/udbhav/Desktop/ass4/vdbench/vdbench SlaveJvm -m localhost -n localhost-10-241030-00.26.57.192 -l localhost-0 -p 5570
00:26:57.635 All slaves are now connected
00:26:59.002 Starting RD=format_for_rd1
00:26:59.339 localhost-0: anchor=/zfs_pool mkdir complete.

Oct 30, 2024 ..Interval.. .ReqstdOps... ...cpu%...  read ....read..... ....write.... ..mb/sec... mb/sec .xfer.. ...mkdir.... ...rmdir.... ...create... ....open.... ...close.... ...delete...
                          rate   resp total  sys   pct   rate   resp   rate   resp  read write  total    size  rate   resp  rate   resp  rate   resp  rate   resp  rate   resp  rate   resp
00:27:00.045            1 1351.0  1.132  51.0 12.2   0.0    0.0  0.000 1351.0  1.132  0.00 168.8 168.88  131072  12.0  1.346   0.0  0.000 168.0 11.676 171.0  1.078 168.0  0.022   0.0  0.000
00:27:01.013            2    0.0  0.000  40.3 6.84   0.0    0.0  0.000    0.0  0.000  0.00  0.00   0.00       0   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:27:02.047            3    0.0  0.000  35.6 3.51   0.0    0.0  0.000    0.0  0.000  0.00  0.00   0.00       0   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:27:03.008            4    0.0  0.000  33.4 4.05   0.0    0.0  0.000    0.0  0.000  0.00  0.00   0.00       0   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:27:04.006            5    0.0  0.000  26.6 2.51   0.0    0.0  0.000    0.0  0.000  0.00  0.00   0.00       0   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:27:05.005            6    0.0  0.000  31.3 2.26   0.0    0.0  0.000    0.0  0.000  0.00  0.00   0.00       0   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:27:06.010            7    0.0  0.000  30.5 2.75   0.0    0.0  0.000    0.0  0.000  0.00  0.00   0.00       0   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:27:07.009            8    0.0  0.000  29.8 3.28   0.0    0.0  0.000    0.0  0.000  0.00  0.00   0.00       0   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:27:08.005            9    0.0  0.000  27.0 2.27   0.0    0.0  0.000    0.0  0.000  0.00  0.00   0.00       0   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:27:09.016           10    0.0  0.000  32.1 4.26   0.0    0.0  0.000    0.0  0.000  0.00  0.00   0.00       0   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:27:10.019           11 1088.0 28.360  29.9 6.28   0.0    0.0  0.000 1088.0 28.360  0.00 136.0 136.00  131072   0.0  0.000   0.0  0.000 136.0 600.38 140.0 362.12 136.0  0.016   0.0  0.000
00:27:11.004           12  228.0  9.926  51.1 17.7   0.0    0.0  0.000  228.0  9.926  0.00 28.50  28.50  131072   0.0  0.000   0.0  0.000  28.0 100.28  26.0 20.021  28.0  0.016   0.0  0.000
00:27:12.005           13    0.0  0.000  44.1 3.78   0.0    0.0  0.000    0.0  0.000  0.00  0.00   0.00       0   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:27:13.018           14  750.0 18.760  86.5 4.74   0.0    0.0  0.000  750.0 18.760  0.00 93.75  93.75  131072   0.0  0.000   0.0  0.000  93.0 244.57  96.0 89.909  93.0  0.015   0.0  0.000
00:27:13.038 localhost-0: anchor=/zfs_pool create complete.
00:27:14.006           15  183.0  1.006  64.3 18.9   0.0    0.0  0.000  183.0  1.006  0.00 22.88  22.88  131072   0.0  0.000   0.0  0.000  25.0  9.540  17.0  0.163  25.0  0.014   0.0  0.000
00:27:14.010     avg_2-15  160.6 21.064  40.2 5.94   0.0    0.0  0.000  160.6 21.064  0.00 20.08  20.08  131072   0.0  0.000   0.0  0.000  20.1 381.01  19.9 214.52  20.1  0.015   0.0  0.000
00:27:14.012     std_2-15  336.3 390.84                                336.3 390.84                                                      41.9 1729.9  43.2 1370.9  41.9  0.009
00:27:14.012     max_2-15 1088.0  10112                               1088.0  10112                                  7.669              136.0  10154 140.0  10136 136.0  0.188
00:27:14.128
00:27:14.129 Miscellaneous statistics:
00:27:14.129 (These statistics do not include activity between the last reported interval and shutdown.)
00:27:14.129 FILE_CREATES        Files created:                               450         30/sec
00:27:14.129 DIRECTORY_CREATES   Directories created:                          12          0/sec
00:27:14.129 WRITE_OPENS         Files opened for write activity:             450         30/sec
00:27:14.129 DIR_EXISTS          Directory may not exist (yet):                 6          0/sec
00:27:14.129 FILE_CLOSES         Close requests:                              450         30/sec
00:27:14.129
00:27:15.000 Starting RD=rd1; elapsed=30; fwdrate=max. For loops: None

Oct 30, 2024 ..Interval.. .ReqstdOps... ...cpu%...  read ....read..... ....write.... ..mb/sec... mb/sec .xfer.. ...mkdir.... ...rmdir.... ...create... ....open.... ...close.... ...delete...
                          rate   resp total  sys   pct   rate   resp   rate   resp  read write  total    size  rate   resp  rate   resp  rate   resp  rate   resp  rate   resp  rate   resp
00:27:16.015            1 240684  0.005  68.4 20.0 100.0 240684  0.005    0.0  0.000 940.1  0.00 940.18    4096   0.0  0.000   0.0  0.000   0.0  0.000 941.0  0.035 939.0  0.005   0.0  0.000
00:27:17.010            2 314314  0.005  87.6 40.7 100.0 314314  0.005    0.0  0.000  1227  0.00 1227.7    4096   0.0  0.000   0.0  0.000   0.0  0.000  1228  0.036  1228  0.004   0.0  0.000
00:27:18.013            3 335943  0.005  97.2 44.1 100.0 335943  0.005    0.0  0.000  1312  0.00 1312.2    4095   0.0  0.000   0.0  0.000   0.0  0.000  1313  0.020  1313  0.003   0.0  0.000
00:27:19.011            4 366012  0.004  97.1 48.2 100.0 366012  0.004    0.0  0.000  1429  0.00 1429.7    4096   0.0  0.000   0.0  0.000   0.0  0.000  1429  0.015  1429  0.003   0.0  0.000
00:27:20.008            5 335460  0.005  99.0 48.2 100.0 335460  0.005    0.0  0.000  1310  0.00 1310.3    4095   0.0  0.000   0.0  0.000   0.0  0.000  1311  0.017  1311  0.004   0.0  0.000
```

```
00:27:20.008            5 335460  0.005  99.0 48.2 100.0 335460  0.005    0.0  0.000  1310  0.00 1310.3    4095   0.0  0.000   0.0  0.000   0.0  0.000  1311  0.017  1311  0.004   0.0  0.000
00:27:21.014            6 326497  0.005  97.5 49.1 100.0 326497  0.005    0.0  0.000  1275  0.00 1275.3    4096   0.0  0.000   0.0  0.000   0.0  0.000  1275  0.027  1275  0.003   0.0  0.000
00:27:22.013            7 318305  0.005  98.0 44.7 100.0 318305  0.005    0.0  0.000  1243  0.00 1243.3    4096   0.0  0.000   0.0  0.000   0.0  0.000  1243  0.015  1243  0.003   0.0  0.000
00:27:23.009            8 348007  0.005  99.7 45.9 100.0 348007  0.005    0.0  0.000  1359  0.00 1359.4    4096   0.0  0.000   0.0  0.000   0.0  0.000  1359  0.012  1359  0.003   0.0  0.000
00:27:24.006            9 379086  0.004  94.6 48.0 100.0 379086  0.004    0.0  0.000  1480  0.00 1480.8    4095   0.0  0.000   0.0  0.000   0.0  0.000  1481  0.014  1481  0.002   0.0  0.000
00:27:25.017           10 332212  0.005  97.5 44.3 100.0 332212  0.005    0.0  0.000  1297  0.00 1297.7    4095   0.0  0.000   0.0  0.000   0.0  0.000  1299  0.016  1299  0.003   0.0  0.000
00:27:26.013           11 369962  0.004  88.3 49.3 100.0 369962  0.004    0.0  0.000  1445  0.00 1445.1    4096   0.0  0.000   0.0  0.000   0.0  0.000  1444  0.011  1444  0.003   0.0  0.000
00:27:27.007           12 304100  0.005  99.5 42.6 100.0 304100  0.005    0.0  0.000  1187  0.00 1187.8    4095   0.0  0.000   0.0  0.000   0.0  0.000  1188  0.015  1188  0.003   0.0  0.000
00:27:28.016           13 370749  0.004  98.5 47.9 100.0 370749  0.004    0.0  0.000  1448  0.00 1448.2    4096   0.0  0.000   0.0  0.000   0.0  0.000  1449  0.012  1449  0.002   0.0  0.000
00:27:29.012           14 358063  0.005  98.5 45.9 100.0 358063  0.005    0.0  0.000  1398  0.00 1398.6    4095   0.0  0.000   0.0  0.000   0.0  0.000  1398  0.014  1398  0.003   0.0  0.000
00:27:30.005           15 360103  0.004  94.8 48.4 100.0 360103  0.004    0.0  0.000  1406  0.00 1406.6    4096   0.0  0.000   0.0  0.000   0.0  0.000  1407  0.012  1407  0.002   0.0  0.000
00:27:31.009           16 334808  0.005  92.0 45.6 100.0 334808  0.005    0.0  0.000  1307  0.00 1307.8    4095   0.0  0.000   0.0  0.000   0.0  0.000  1308  0.013  1308  0.003   0.0  0.000
00:27:32.016           17 371230  0.004  93.3 47.9 100.0 371230  0.004    0.0  0.000  1450  0.00 1450.1    4095   0.0  0.000   0.0  0.000   0.0  0.000  1450  0.012  1450  0.003   0.0  0.000
00:27:33.006           18 351242  0.005  98.7 45.2 100.0 351242  0.005    0.0  0.000  1372  0.00 1372.0    4096   0.0  0.000   0.0  0.000   0.0  0.000  1371  0.012  1371  0.006   0.0  0.000
00:27:34.005           19 365264  0.004  92.4 48.9 100.0 365264  0.004    0.0  0.000  1426  0.00 1426.8    4095   0.0  0.000   0.0  0.000   0.0  0.000  1428  0.014  1428  0.002   0.0  0.000
00:27:35.011           20 385364  0.004  87.8 51.4 100.0 385364  0.004    0.0  0.000  1505  0.00 1505.3    4095   0.0  0.000   0.0  0.000   0.0  0.000  1505  0.011  1505  0.002   0.0  0.000
00:27:36.011           21 370181  0.004  97.5 47.9 100.0 370181  0.004    0.0  0.000  1446  0.00 1446.0    4095   0.0  0.000   0.0  0.000   0.0  0.000  1446  0.013  1446  0.003   0.0  0.000
00:27:37.008           22 356652  0.005  99.5 46.9 100.0 356652  0.005    0.0  0.000  1393  0.00 1393.1    4095   0.0  0.000   0.0  0.000   0.0  0.000  1393  0.012  1393  0.003   0.0  0.000
00:27:38.013           23 273972  0.006  99.8 38.2 100.0 273972  0.006    0.0  0.000  1070  0.00 1070.2    4096   0.0  0.000   0.0  0.000   0.0  0.000  1070  0.019  1070  0.003   0.0  0.000
00:27:39.018           24 336547  0.005  95.7 45.4 100.0 336547  0.005    0.0  0.000  1314  0.00 1314.6    4096   0.0  0.000   0.0  0.000   0.0  0.000  1315  0.014  1315  0.002   0.0  0.000
00:27:40.007           25 361501  0.005  98.5 48.3 100.0 361501  0.005    0.0  0.000  1412  0.00 1412.1    4096   0.0  0.000   0.0  0.000   0.0  0.000  1412  0.012  1412  0.003   0.0  0.000
00:27:41.008           26 340946  0.005  99.0 46.3 100.0 340946  0.005    0.0  0.000  1331  0.00 1331.8    4095   0.0  0.000   0.0  0.000   0.0  0.000  1332  0.013  1332  0.003   0.0  0.000
00:27:42.008           27 367672  0.004  97.7 49.2 100.0 367672  0.004    0.0  0.000  1436  0.00 1436.2    4095   0.0  0.000   0.0  0.000   0.0  0.000  1436  0.012  1436  0.002   0.0  0.000
00:27:43.006           28 354308  0.005  99.2 46.3 100.0 354308  0.005    0.0  0.000  1384  0.00 1384.0    4096   0.0  0.000   0.0  0.000   0.0  0.000  1385  0.012  1385  0.003   0.0  0.000
00:27:44.005           29 365749  0.005  98.2 47.9 100.0 365749  0.005    0.0  0.000  1428  0.00 1428.7    4095   0.0  0.000   0.0  0.000   0.0  0.000  1428  0.012  1428  0.002   0.0  0.000
00:27:45.012           30 257850  0.006 100.0 40.9 100.0 257850  0.006    0.0  0.000  1007  0.00 1007.2    4095   0.0  0.000   0.0  0.000   0.0  0.000  1007  0.016  1007  0.003   0.0  0.000
00:27:45.027     avg_2-30 345244  0.005  96.5 46.3 100.0 345244  0.005    0.0  0.000  1348  0.00 1348.6    4095   0.0  0.000   0.0  0.000   0.0  0.000  1348  0.015  1348  0.003   0.0  0.000
00:27:45.029     std_2-30  29864  0.034                29864  0.034                                                                           116.6  0.070 116.6  0.027
00:27:45.029     max_2-30 385364 18.640               385364 18.640                                                                            1505  5.055  1505  5.017
00:27:45.058 *
00:27:45.059 ******************************************************************
00:27:45.059 * Warning for host=localhost: average processor utilization 96.5%  *
00:27:45.059 * Any processor utilization over 80% could mean that your system   *
00:27:45.059 * does not have enough cycles to run the highest rate possible.    *
00:27:45.062 ******************************************************************
00:27:45.062 *
00:27:45.062 *
00:27:45.062 ***********************************************************************************
00:27:45.062 * Warning: total amount of i/o per second per slave (345,245) greater than 100,000.    *
00:27:45.062 * You may need to adjust your total slave count.                                        *
00:27:45.062 *                                                                                      *
00:27:45.062 * See 'jvms=' in documentation for raw (SD/WD) workloads).                              *
00:27:45.062 * See 'host=' and/or 'clients=' in documentation for file system (FSD/FWD) workloads). *
00:27:45.062 *                                                                                      *
00:27:45.062 * rd=rd1 actively used 1 slaves.                                                       *
00:27:45.062 ***********************************************************************************
00:27:45.062 *
00:27:45.164
00:27:45.164 Miscellaneous statistics:
00:27:45.164 (These statistics do not include activity between the last reported interval and shutdown.)
00:27:45.164 READ_OPENS          Files opened for read activity:          40,051      1,335/sec
00:27:45.164 FILE_BUSY           File busy:                                   76          2/sec
00:27:45.164 FILE_CLOSES         Close requests:                          40,049      1,334/sec
00:27:45.164
00:27:45.323 Vdbench execution completed successfully. Output directory: /home/udbhav/Desktop/ass4/vdbench/output
```

Workload 2:

```
udbhav@Udbhav514:~/Desktop/ass4/vdbench$ sudo ./vdbench -f workload2 anchor=/zfs_pool
[sudo] password for udbhav: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Vdbench distribution: vdbench50407 Tue June 05  9:49:29 MDT 2018
For documentation, see 'vdbench.pdf'.

00:51:12.952 input argument scanned: '-fworkload2'
00:51:12.953 input argument scanned: 'anchor=/zfs_pool'
00:51:12.989 Anchor size: anchor=/zfs_pool: dirs:           0; files:           2; bytes:     2.000g (2,147,483,648)
00:51:13.022 Starting slave: /home/udbhav/Desktop/ass4/vdbench/vdbench SlaveJvm -m localhost -n localhost-10-241030-00.51.12.886 -l localhost-0 -p 5570
00:51:13.235 All slaves are now connected
00:51:14.003 Starting RD=format_for_rd1
00:51:14.613 localhost-0: anchor=/zfs_pool mkdir complete.

Oct 30, 2024 ..Interval.. .ReqstdOps... ...cpu%...  read ....read..... ....write.... ..mb/sec... mb/sec .xfer.. ...mkdir.... ...rmdir.... ...create... ....open.... ...close.... ...delete...
                             rate   resp total  sys   pct   rate   resp   rate   resp  read write  total    size  rate   resp  rate   resp  rate   resp  rate   resp  rate   resp  rate   resp
00:51:15.144           1 1087.0  0.107  20.0 9.44   0.0    0.0  0.000 1087.0  0.107  0.00 135.8 135.88  131072   1.0  0.067  12.0  0.062   0.0  0.000   2.0  3.814   0.0  0.000 450.0  0.118
00:51:16.043           2 1113.0  1.658  41.5 24.8   0.0    0.0  0.000 1113.0  1.658  0.00 139.1 139.12  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:17.075           3 1193.0  2.205  19.3 10.3   0.0    0.0  0.000 1193.0  2.205  0.00 149.1 149.12  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:18.015           4    0.0  0.000  13.4 9.07   0.0    0.0  0.000    0.0  0.000  0.00  0.00   0.00       0   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:19.081           5 1270.0  3.160  16.9 10.6   0.0    0.0  0.000 1270.0  3.160  0.00 158.7 158.75  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:20.011           6    0.0  0.000  15.1 8.67   0.0    0.0  0.000    0.0  0.000  0.00  0.00   0.00       0   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:21.010           7 1195.0  2.399  18.2 15.9   0.0    0.0  0.000 1195.0  2.399  0.00 149.3 149.38  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:22.021           8 1196.0  2.019  22.6 19.6   0.0    0.0  0.000 1196.0  2.019  0.00 149.5 149.50  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:23.007           9 1202.0  2.049  24.2 20.7   0.0    0.0  0.000 1202.0  2.049  0.00 150.2 150.25  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:24.012          10    0.0  0.000   7.3 5.53   0.0    0.0  0.000    0.0  0.000  0.00  0.00   0.00       0   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:25.005          11 1179.0  2.261  19.7 17.7   0.0    0.0  0.000 1179.0  2.261  0.00 147.3 147.38  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:26.019          12 1128.0  2.201  23.3 20.3   0.0    0.0  0.000 1128.0  2.201  0.00 141.0 141.00  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:27.007          13 1083.0  2.559  22.0 17.6   0.0    0.0  0.000 1083.0  2.559  0.00 135.3 135.38  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:28.022          14 1036.0  2.173  21.9 13.3   0.0    0.0  0.000 1036.0  2.173  0.00 129.5 129.50  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:29.080          15  994.0  2.173  17.0 12.4   0.0    0.0  0.000  994.0  2.173  0.00 124.2 124.25  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:30.009          16    0.0  0.000  15.6 9.79   0.0    0.0  0.000    0.0  0.000  0.00  0.00   0.00       0   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:31.004          17  950.0  2.891  23.8 17.4   0.0    0.0  0.000  950.0  2.891  0.00 118.7 118.75  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:32.007          18  913.0  2.674  24.2 22.4   0.0    0.0  0.000  913.0  2.674  0.00 114.1 114.12  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:32.785 localhost-0: anchor=/zfs_pool create complete.
00:51:33.012          19  845.0  2.846   8.3 4.80   0.0    0.0  0.000  845.0  2.846  0.00 105.6 105.62  131072   0.0  0.000   0.0  0.000   2.0  18165   0.0  0.000   2.0  0.059   0.0  0.000
00:51:33.016    avg_2-19  849.8  2.364  19.7 14.5   0.0    0.0  0.000  849.8  2.364  0.00 106.2 106.23  131072   0.0  0.000   0.0  0.000   0.1  18165   0.0  0.000   0.1  0.059   0.0  0.000
00:51:33.016    std_2-19  480.5 54.631                                 480.5 54.631                                                       0.5  7.107               0.5  0.054
00:51:33.016    max_2-19 1270.0 1943.2                                1270.0 1943.2                               0.067        0.098   2.0  18170        3.815   2.0  0.097        2.811
00:51:33.146
00:51:33.146 Miscellaneous statistics:
00:51:33.147 (These statistics do not include activity between the last reported interval and shutdown.)
00:51:33.147 FILE_CREATES        Files created:                              2          0/sec
00:51:33.147 DIRECTORY_CREATES   Directories created:                        1          0/sec
00:51:33.147 FILE_DELETES        Files deleted:                            450         23/sec
00:51:33.147 DIRECTORY_DELETES   Directories deleted:                       12          0/sec
00:51:33.147 WRITE_OPENS         Files opened for write activity:            2          0/sec
00:51:33.147 DIR_EXISTS          Directory may not exist (yet):              3          0/sec
00:51:33.147 FILE_CLOSES         Close requests:                             2          0/sec
00:51:33.147
00:51:34.001 Starting RD=rd1; elapsed=30; fwdrate=max. For loops: None
00:51:34.250
00:51:34.250 Message from slave localhost-0:
00:51:34.251 Anchor: /zfs_pool
```

b. For ext4:

- Navigate to the folder containing the ext4 anchor in the GUI File manager for Ubuntu

Workload 1

```
udbhav@Udbhav514:~/Desktop/ass4/vdbench$ cd /mnt/virtual_ext4
udbhav@Udbhav514:/mnt/virtual_ext4$ xdg-open /mnt/virtual_ext4
```

```
udbhav@Udbhav514:~/Desktop/ass4/vdbench$ sudo ./vdbench -f workload1 anchor=/mnt/virtual_ext4


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Vdbench distribution: vdbench50407 Tue June 05  9:49:29 MDT 2018
For documentation, see 'vdbench.pdf'.

00:43:05.496 input argument scanned: '-fworkload1'
00:43:05.497 input argument scanned: 'anchor=/mnt/virtual_ext4'
00:43:05.531 Anchor size: anchor=/mnt/virtual_ext4: dirs:          12; files:         450; bytes:   450.000m (471,859,200)
00:43:05.562 Starting slave: /home/udbhav/Desktop/ass4/vdbench/vdbench SlaveJvm -m localhost -n localhost-10-241030-00.43.05.454 -l localhost-0 -p 5570
00:43:05.776 All slaves are now connected
00:43:07.002 Starting RD=format_for_rd1
00:43:07.079 localhost-0: anchor=/mnt/virtual_ext4 mkdir complete.
00:43:07.448 localhost-0: anchor=/mnt/virtual_ext4 create complete.

Oct 30, 2024 ..Interval.. .ReqstdOps... ...cpu%...  read ....read..... ....write.... ..mb/sec... mb/sec .xfer.. ...mkdir.... ...rmdir.... ...create... ....open.... ...close.... ...delete...
                             rate   resp total  sys   pct   rate   resp   rate   resp  read write  total    size  rate   resp  rate   resp  rate   resp  rate   resp  rate   resp  rate   resp
00:43:08.043           1 3600.0  0.627  25.9 5.01   0.0    0.0  0.000 3600.0  0.627  0.00 450.0 450.00  131072  12.0  0.107   0.0  0.000 450.0  6.495 450.0  0.754 450.0  0.020   0.0  0.000
00:43:08.064     avg_2-1 NaN  0.000 NaN NaN   0.0 NaN  0.000 NaN  0.000 NaN NaN NaN       0 NaN  0.000 NaN  0.000 NaN  0.000 NaN  0.000 NaN  0.000 NaN  0.000
00:43:08.065     std_2-1
00:43:08.065     max_2-1
00:43:08.179
00:43:08.179 Miscellaneous statistics:
00:43:08.179 (These statistics do not include activity between the last reported interval and shutdown.)
00:43:08.179 FILE_CREATES        Files created:                            450        450/sec
00:43:08.179 DIRECTORY_CREATES   Directories created:                       12         12/sec
00:43:08.180 WRITE_OPENS         Files opened for write activity:          450        450/sec
00:43:08.180 DIR_EXISTS          Directory may not exist (yet):              6          6/sec
00:43:08.180 FILE_CLOSES         Close requests:                           450        450/sec
00:43:08.180
00:43:09.001 Starting RD=rd1; elapsed=30; fwdrate=max. For loops: None

Oct 30, 2024 ..Interval.. .ReqstdOps... ...cpu%...  read ....read..... ....write.... ..mb/sec... mb/sec .xfer.. ...mkdir.... ...rmdir.... ...create... ....open.... ...close.... ...delete...
                             rate   resp total  sys   pct   rate   resp   rate   resp  read write  total    size  rate   resp  rate   resp  rate   resp  rate   resp  rate   resp  rate   resp
00:43:10.038           1 613342  0.001  40.6 10.7 100.0 613342  0.001    0.0  0.000  2395  0.00 2395.9    4096   0.0  0.000   0.0  0.000   0.0  0.000  2397  0.025  2395  0.003   0.0  0.000
00:43:11.010           2 1081823  0.001  83.2 36.1 100.0 1081823  0.001    0.0  0.000  4225  0.00 4225.8    4095   0.0  0.000   0.0  0.000   0.0  0.000  4225  0.011  4226  0.002   0.0  0.000
00:43:12.022           3 1111055  0.001  76.3 36.9 100.0 1111055  0.001    0.0  0.000  4340  0.00 4340.0    4095   0.0  0.000   0.0  0.000   0.0  0.000  4340  0.009  4340  0.001   0.0  0.000
00:43:13.013           4 1118256  0.001  73.0 36.1 100.0 1118256  0.001    0.0  0.000  4368  0.00 4368.1    4096   0.0  0.000   0.0  0.000   0.0  0.000  4369  0.008  4369  0.001   0.0  0.000
00:43:14.005           5 1131860  0.001  77.1 36.7 100.0 1131860  0.001    0.0  0.000  4421  0.00 4421.3    4095   0.0  0.000   0.0  0.000   0.0  0.000  4420  0.008  4420  0.001   0.0  0.000
00:43:15.011           6 1133979  0.001  72.3 37.1 100.0 1133979  0.001    0.0  0.000  4429  0.00 4429.6    4095   0.0  0.000   0.0  0.000   0.0  0.000  4430  0.008  4430  0.001   0.0  0.000
00:43:16.014           7 1133222  0.001  74.0 37.2 100.0 1133222  0.001    0.0  0.000  4426  0.00 4426.6    4096   0.0  0.000   0.0  0.000   0.0  0.000  4427  0.008  4426  0.001   0.0  0.000
00:43:17.010           8 1132729  0.001  72.5 35.5 100.0 1132729  0.001    0.0  0.000  4424  0.00 4424.7    4096   0.0  0.000   0.0  0.000   0.0  0.000  4425  0.008  4425  0.001   0.0  0.000
00:43:18.006           9 1124715  0.001  80.6 45.2 100.0 1124715  0.001    0.0  0.000  4393  0.00 4393.4    4096   0.0  0.000   0.0  0.000   0.0  0.000  4393  0.009  4393  0.001   0.0  0.000
00:43:19.010          10 1134942  0.001  75.1 36.7 100.0 1134942  0.001    0.0  0.000  4433  0.00 4433.3    4096   0.0  0.000   0.0  0.000   0.0  0.000  4434  0.008  4434  0.001   0.0  0.000
00:43:20.006          11 1142716  0.001  74.2 37.9 100.0 1142716  0.001    0.0  0.000  4463  0.00 4463.7    4095   0.0  0.000   0.0  0.000   0.0  0.000  4464  0.008  4464  0.001   0.0  0.000
00:43:21.011          12 1118617  0.001  80.4 37.2 100.0 1118617  0.001    0.0  0.000  4369  0.00 4369.5    4095   0.0  0.000   0.0  0.000   0.0  0.000  4370  0.008  4370  0.001   0.0  0.000
00:43:22.011          13 1136665  0.001  72.6 35.8 100.0 1136665  0.001    0.0  0.000  4440  0.00 4440.0    4095   0.0  0.000   0.0  0.000   0.0  0.000  4440  0.008  4440  0.001   0.0  0.000
00:43:23.008          14 1118798  0.001  75.2 35.8 100.0 1118798  0.001    0.0  0.000  4370  0.00 4370.3    4096   0.0  0.000   0.0  0.000   0.0  0.000  4370  0.009  4370  0.001   0.0  0.000
00:43:24.010          15 1121775  0.001  77.4 36.6 100.0 1121775  0.001    0.0  0.000  4381  0.00 4381.9    4096   0.0  0.000   0.0  0.000   0.0  0.000  4382  0.009  4382  0.001   0.0  0.000
00:43:25.006          16 1123911  0.001  74.7 34.5 100.0 1123911  0.001    0.0  0.000  4390  0.00 4390.2    4095   0.0  0.000   0.0  0.000   0.0  0.000  4390  0.008  4390  0.001   0.0  0.000
00:43:26.012          17 1115061  0.001  73.5 36.2 100.0 1115061  0.001    0.0  0.000  4355  0.00 4355.7    4095   0.0  0.000   0.0  0.000   0.0  0.000  4356  0.008  4356  0.001   0.0  0.000
00:43:27.008          18 1123992  0.001  72.0 35.8 100.0 1123992  0.001    0.0  0.000  4390  0.00 4390.5    4096   0.0  0.000   0.0  0.000   0.0  0.000  4391  0.008  4391  0.001   0.0  0.000
00:43:28.012          19 1134668  0.001  72.3 36.2 100.0 1134668  0.001    0.0  0.000  4432  0.00 4432.2    4095   0.0  0.000   0.0  0.000   0.0  0.000  4432  0.008  4432  0.001   0.0  0.000
00:43:29.005          20 1120017  0.001  72.9 35.9 100.0 1120017  0.001    0.0  0.000  4375  0.00 4375.0    4095   0.0  0.000   0.0  0.000   0.0  0.000  4375  0.008  4376  0.001   0.0  0.000
```

Workload 2:

```
udbhav@Udbhav514:~/Desktop/ass4/vdbench$ sudo ./vdbench -f workload2 anchor=/mnt/virtual_ext4


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Vdbench distribution: vdbench50407 Tue June 05  9:49:29 MDT 2018
For documentation, see 'vdbench.pdf'.

00:53:57.342 input argument scanned: '-fworkload2'
00:53:57.343 input argument scanned: 'anchor=/mnt/virtual_ext4'
00:53:57.414 Anchor size: anchor=/mnt/virtual_ext4: dirs:            0; files:            2; bytes:     2.000g (2,147,483,648)
00:53:57.467 Starting slave: /home/udbhav/Desktop/ass4/vdbench/vdbench SlaveJvm -m localhost -n localhost-10-241030-00.53.57.276 -l localhost-0 -p 5570
00:53:57.803 All slaves are now connected
00:53:59.003 Starting RD=format_for_rd1
00:53:59.520 localhost-0: anchor=/mnt/virtual_ext4 mkdir complete.

Oct 30, 2024 ..Interval.. .ReqstdOps... ...cpu%...  read ....read..... ....write.... ..mb/sec... mb/sec .xfer.. ...mkdir.... ...rmdir.... ...create... ....open.... ...close.... ...delete...
                          rate   resp total  sys   pct   rate   resp   rate   resp  read write  total    size  rate   resp  rate   resp  rate   resp  rate   resp  rate   resp  rate   resp
00:54:00.070            1 4288.0  0.228  25.5 11.7   0.0    0.0  0.000 4288.0  0.228  0.00 536.0 536.00  131072   1.0  0.076  12.0  0.037   0.0  0.000   2.0  4.063   0.0  0.000 450.0 0.150
00:54:01.039            2 1601.0  1.216  31.4 21.0   0.0    0.0  0.000 1601.0  1.216  0.00 200.1 200.12  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:54:02.035            3 1440.0  1.384  30.0 23.6   0.0    0.0  0.000 1440.0  1.384  0.00 180.0 180.00  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:54:03.032            4 1298.0  1.532  27.6 21.6   0.0    0.0  0.000 1298.0  1.532  0.00 162.2 162.25  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:54:04.011            5 1002.0  1.998  25.7 16.4   0.0    0.0  0.000 1002.0  1.998  0.00 125.2 125.25  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:54:05.023            6  934.0  2.136  13.6 8.12   0.0    0.0  0.000  934.0  2.136  0.00 116.7 116.75  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:54:06.018            7  406.0  4.953  14.4 10.0   0.0    0.0  0.000  406.0  4.953  0.00 50.75  50.75  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:54:07.018            8  949.0  2.104  13.2 7.65   0.0    0.0  0.000  949.0  2.104  0.00 118.6 118.62  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:54:08.017            9  786.0  2.529  19.3 16.9   0.0    0.0  0.000  786.0  2.529  0.00 98.25  98.25  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:54:09.017           10  581.0  3.473  21.3 16.6   0.0    0.0  0.000  581.0  3.473  0.00 72.62  72.62  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:54:10.013           11 1480.0  1.342  15.2 6.28   0.0    0.0  0.000 1480.0  1.342  0.00 185.0 185.00  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:54:11.016           12  588.0  3.383  10.6 6.75   0.0    0.0  0.000  588.0  3.383  0.00 73.50  73.50  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:54:12.016           13  531.0  3.778  12.9 9.51   0.0    0.0  0.000  531.0  3.778  0.00 66.38  66.38  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:54:13.014           14  490.0  2.520  12.2 6.89   0.0    0.0  0.000  490.0  2.520  0.00 61.25  61.25  131072   0.0  0.000   0.0  0.000   1.0  12721   0.0  0.000   1.0  0.187   0.0  0.000
00:54:13.034 localhost-0: anchor=/mnt/virtual_ext4 create complete.
00:54:14.010           15    9.0  4.489  20.3 13.9   0.0    0.0  0.000    9.0  4.489  0.00  1.13   1.13  131072   0.0  0.000   0.0  0.000   1.0  13512   0.0  0.000   1.0  0.020   0.0  0.000
00:54:14.014     avg_2-15  863.9  2.083  19.1 13.2   0.0    0.0  0.000  863.9  2.083  0.00 107.9 107.99  131072   0.0  0.000   0.0  0.000   0.1  13117   0.0  0.000   0.1  0.104   0.0  0.000
00:54:14.014     std_2-15  466.4 11.077                                 466.4 11.077                                                  0.4 559.40               0.4  0.118
00:54:14.014     max_2-15 1601.0 617.72                                1601.0 617.72                               0.076        0.074   1.0  13512        4.072   1.0  0.187        1.962
00:54:14.234
00:54:14.234 Miscellaneous statistics:
00:54:14.234 (These statistics do not include activity between the last reported interval and shutdown.)
00:54:14.235 FILE_CREATES        Files created:                              2          0/sec
00:54:14.235 DIRECTORY_CREATES   Directories created:                        1          0/sec
00:54:14.235 FILE_DELETES        Files deleted:                            450         30/sec
00:54:14.235 DIRECTORY_DELETES   Directories deleted:                       12          0/sec
00:54:14.235 WRITE_OPENS         Files opened for write activity:            2          0/sec
00:54:14.236 DIR_EXISTS          Directory may not exist (yet):              4          0/sec
00:54:14.236 FILE_CLOSES         Close requests:                             2          0/sec
00:54:14.236
00:54:17.001 Starting RD=rd1; elapsed=30; fwdrate=max. For loops: None
00:54:17.193
00:54:17.193 Message from slave localhost-0:
00:54:17.193 Anchor: /mnt/virtual_ext4
00:54:17.193 Vdbench is trying to create a new file, but all files already exist,
00:54:17.193 and no threads are currently active deleting files
```

You can view the summary for the last workload run in the summary.html file in the Output folder in the vdbench directory

RESULTS

Workload 1

● ZFS :

Before Workload:

```
NAME        SIZE  ALLOC   FREE  CKPOINT  EXPANDSZ   FRAG    CAP  DEDUP    HEALTH
 ALTROOT
zfs_pool   4.50G   108K  4.50G        -         -     0%     0%  1.00x    ONLINE
 -
```

After Workload:

```
udbhav@Udbhav514:~/Desktop/ass4/vdbench$ zpool list
NAME        SIZE  ALLOC   FREE  CKPOINT  EXPANDSZ   FRAG    CAP  DEDUP    HEALTH  ALTROOT
zfs_pool   4.50G   226M  4.28G        -         -     0%     4%  2.00x    ONLINE  -
```

Data Calculation:

● New Data Added:

The allocated space increased from 108 KB to 226 MB, meaning the new workload added approximately:

226 MB - 108 KB ≈ 225.9 MB

● Intended Space Usage:

The workload was designed to add 450 MB of data (assuming 450 files, each 1 MB in size).

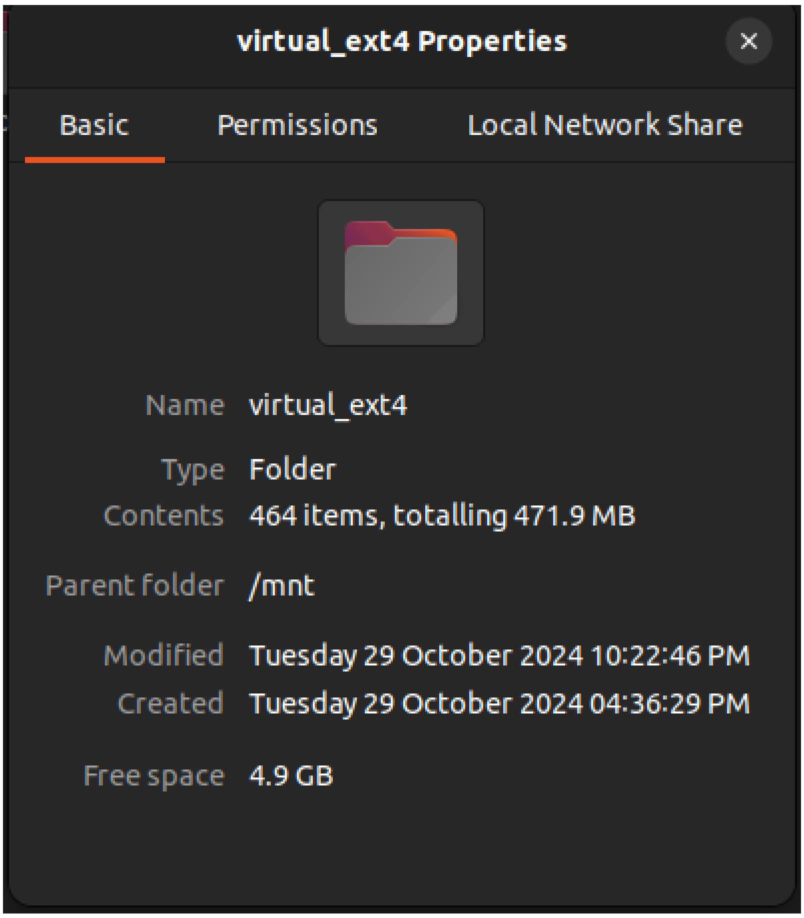
● Actual Space Used: Due to the 2.00x deduplication ratio, only 225.9 MB was required for storage.

● Storage Savings: 450 MB - 225.9 MB = 224.1 MB saved through Deduplication

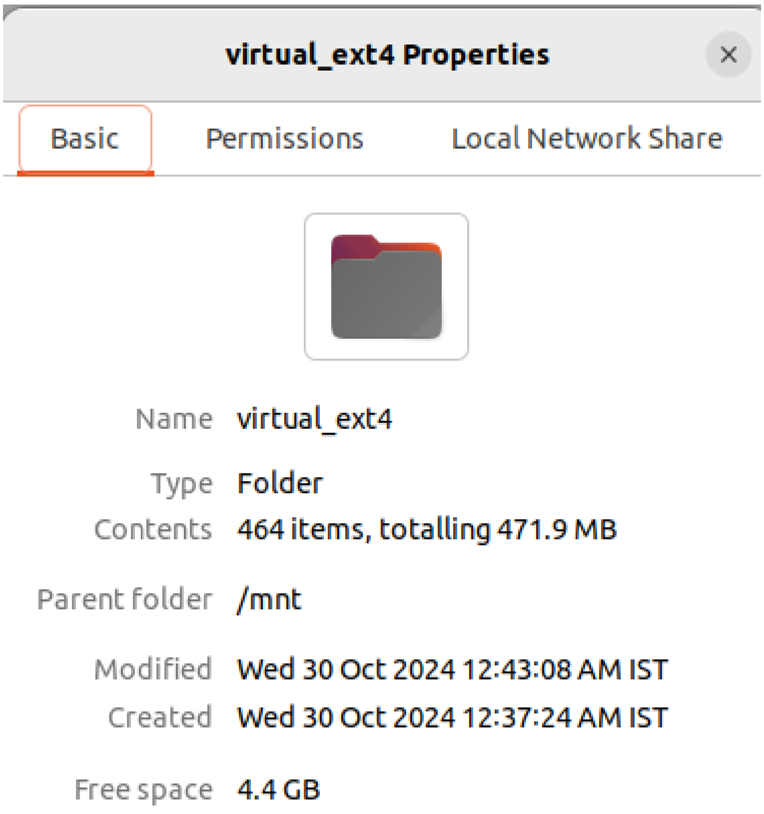
Explanation of Deduplication:
● With a 2.00x deduplication ratio, ZFS reduces the storage required for duplicate data by half.
● Instead of storing identical blocks multiple times, ZFS uses pointers to reference existing blocks, saving space.
● As a result, the actual storage used (226 MB) is much less than the intended space (450 MB).
● This highlights the efficiency of ZFS's deduplication in conserving storage space.
This breakdown explains how ZFS deduplication efficiently manages storage by referencing existing data blocks rather than duplicating them, resulting in substantial space savings.
● Avg CPU Utilisation in ZFS is 40.2% and Write Rate is 160.6 Mb/s. This w

● EXT4

Before Workload



After Workload



Free Space:

● Before the workload, there is 4.9 GB of free space.
● After the workload, the free space has reduced to 4.4 GB. This suggests that the workload has consumed around 500 MB of disk space, which aligns with the overall increase in the size of items within the folder.

Folder Content:

● Both screenshots show the folder containing 464 items totaling 471.9 MB.
● The size of the folder contents remains the same, which could mean that the workload involved read operations, metadata changes, or operations outside the tracked folder, which consumed disk space but did not affect the size or count of items within virtual_ext4.

ext4 Filesystem Behavior:

● On the ext4 filesystem, certain operations, such as creating or modifying files, can consume additional space temporarily due to journaling, metadata updates, or inode table usage.
● If the workload involved creating, modifying, or deleting files, ext4 journaling mechanism might reserve some space temporarily, even if the folder contents appear unchanged.

Workload 2

Zfs: It takes 19 seconds to create the files

```
Oct 30, 2024 ..Interval.. .ReqstdOps... ...cpu%...  read ....read..... ....write.... ..mb/sec... mb/sec .xfer.. ...mkdir.... ...rmdir.... ...create... ....open.... ...close.... ...delete...
                            rate   resp total  sys   pct   rate   resp   rate   resp  read write  total    size  rate   resp  rate   resp  rate   resp  rate   resp  rate   resp  rate   resp
00:51:15.142            1 1087.0  0.107  20.0 9.44   0.0    0.0  0.000 1087.0  0.107  0.00 135.8 135.88  131072   1.0  0.067  12.0  0.062   0.0  0.000   2.0  3.814   0.0  0.000 450.0  0.118
00:51:16.040            2 1113.0  1.658  41.5 24.8   0.0    0.0  0.000 1113.0  1.658  0.00 139.1 139.12  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:17.074            3 1193.0  2.205  19.3 10.3   0.0    0.0  0.000 1193.0  2.205  0.00 149.1 149.12  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:18.014            4    0.0  0.000  13.4 9.07   0.0    0.0  0.000    0.0  0.000  0.00  0.00   0.00       0   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:19.080            5 1270.0  3.160  16.9 10.6   0.0    0.0  0.000 1270.0  3.160  0.00 158.7 158.75  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:20.011            6    0.0  0.000  15.1 8.67   0.0    0.0  0.000    0.0  0.000  0.00  0.00   0.00       0   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:21.010            7 1195.0  2.399  18.2 15.9   0.0    0.0  0.000 1195.0  2.399  0.00 149.3 149.38  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:22.020            8 1196.0  2.019  22.6 19.6   0.0    0.0  0.000 1196.0  2.019  0.00 149.5 149.50  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:23.007            9 1202.0  2.049  24.2 20.7   0.0    0.0  0.000 1202.0  2.049  0.00 150.2 150.25  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:24.012           10    0.0  0.000   7.3 5.53   0.0    0.0  0.000    0.0  0.000  0.00  0.00   0.00       0   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:25.005           11 1179.0  2.261  19.7 17.7   0.0    0.0  0.000 1179.0  2.261  0.00 147.3 147.38  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:26.018           12 1128.0  2.201  23.3 20.3   0.0    0.0  0.000 1128.0  2.201  0.00 141.0 141.00  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:27.007           13 1083.0  2.559  22.0 17.6   0.0    0.0  0.000 1083.0  2.559  0.00 135.3 135.38  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:28.022           14 1036.0  2.173  21.9 13.3   0.0    0.0  0.000 1036.0  2.173  0.00 129.5 129.50  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:29.080           15  994.0  2.173  17.0 12.4   0.0    0.0  0.000  994.0  2.173  0.00 124.2 124.25  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:30.009           16    0.0  0.000  15.6 9.79   0.0    0.0  0.000    0.0  0.000  0.00  0.00   0.00       0   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:31.004           17  950.0  2.891  23.8 17.4   0.0    0.0  0.000  950.0  2.891  0.00 118.7 118.75  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:32.007           18  913.0  2.674  24.2 22.4   0.0    0.0  0.000  913.0  2.674  0.00 114.1 114.12  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000
00:51:33.011           19  845.0  2.846   8.3 4.80   0.0    0.0  0.000  845.0  2.846  0.00 105.6 105.62  131072   0.0  0.000   0.0  0.000   2.0  18165   0.0  0.000   2.0  0.059   0.0  0.000
00:51:33.015     avg_2-19  849.8  2.364  19.7 14.5   0.0    0.0  0.000  849.8  2.364  0.00 106.2 106.23  131072   0.0  0.000   0.0  0.000   0.1  18165   0.0  0.000   0.1  0.059   0.0  0.000
00:51:33.015     std_2-19  480.5 54.631                                 480.5 54.631                                                          0.5  7.107                0.5  0.054
00:51:33.015     max_2-19 1270.0 1943.2                                1270.0 1943.2                                 0.067         0.098   2.0  18170         3.815   2.0  0.097         2.811
```

EXT4 - Takes 15 seconds to create files. Remember, these are 1GB files!

```
00:53:59.003 Starting RD=format_for_rd1

Oct 30, 2024 ..Interval.. .ReqstdOps... ...cpu%...  read ....read..... ....write.... ..mb/sec... mb/sec .xfer.. ...mkdir.... ...rmdir.... ...create... ....open.... ...
                            rate   resp total  sys   pct   rate   resp   rate   resp  read write  total    size  rate   resp  rate   resp  rate   resp  rate   resp  ra
00:54:00.069            1 4288.0  0.228  25.5 11.7   0.0    0.0  0.000 4288.0  0.228  0.00 536.0 536.00  131072   1.0  0.076  12.0  0.037   0.0  0.000   2.0  4.063   0
00:54:01.038            2 1601.0  1.216  31.4 21.0   0.0    0.0  0.000 1601.0  1.216  0.00 200.1 200.12  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0
00:54:02.034            3 1440.0  1.384  30.0 23.6   0.0    0.0  0.000 1440.0  1.384  0.00 180.0 180.00  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0
00:54:03.032            4 1298.0  1.532  27.6 21.6   0.0    0.0  0.000 1298.0  1.532  0.00 162.2 162.25  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0
00:54:04.011            5 1002.0  1.998  25.7 16.4   0.0    0.0  0.000 1002.0  1.998  0.00 125.2 125.25  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0
00:54:05.022            6  934.0  2.136  13.6 8.12   0.0    0.0  0.000  934.0  2.136  0.00 116.7 116.75  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0
00:54:06.018            7  406.0  4.953  14.4 10.0   0.0    0.0  0.000  406.0  4.953  0.00 50.75  50.75  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0
00:54:07.018            8  949.0  2.104  13.2 7.65   0.0    0.0  0.000  949.0  2.104  0.00 118.6 118.62  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0
00:54:08.017            9  786.0  2.529  19.3 16.9   0.0    0.0  0.000  786.0  2.529  0.00 98.25  98.25  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0
00:54:09.017           10  581.0  3.473  21.3 16.6   0.0    0.0  0.000  581.0  3.473  0.00 72.62  72.62  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0
00:54:10.013           11 1480.0  1.342  15.2 6.28   0.0    0.0  0.000 1480.0  1.342  0.00 185.0 185.00  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0
00:54:11.016           12  588.0  3.383  10.6 6.75   0.0    0.0  0.000  588.0  3.383  0.00 73.50  73.50  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0
00:54:12.016           13  531.0  3.778  12.9 9.51   0.0    0.0  0.000  531.0  3.778  0.00 66.38  66.38  131072   0.0  0.000   0.0  0.000   0.0  0.000   0.0  0.000   0
00:54:13.014           14  490.0  2.520  12.2 6.89   0.0    0.0  0.000  490.0  2.520  0.00 61.25  61.25  131072   0.0  0.000   0.0  0.000   1.0  12721   0.0  0.000   1
00:54:14.010           15    9.0  4.489  20.3 13.9   0.0    0.0  0.000    9.0  4.489  0.00  1.13   1.13  131072   0.0  0.000   0.0  0.000   1.0  13512   0.0  0.000   1
00:54:14.013     avg_2-15  863.9  2.083  19.1 13.2   0.0    0.0  0.000  863.9  2.083  0.00 107.9 107.99  131072   0.0  0.000   0.0  0.000   0.1  13117   0.0  0.000   0
00:54:14.014     std_2-15  466.4 11.077                                 466.4 11.077                                                   0.4 559.40                0
00:54:14.014     max_2-15 1601.0 617.72                                1601.0 617.72                                 0.076         0.074   1.0  13512         4.072   1
```

Disadvantages of Deduplication:

1. **Performance Impact**:
    - Deduplication reduces disk space but slows I/O operations due to real-time block comparisons, particularly with large files. Comparing **Write Rates** below
    - In Workload 1: Zfs 160.6 Mb/s, EXT4: 179.2 Mb/s
    - In Workload 2: Zfs 849.8 Mb/s, EXT4: 863.6 Mb/s
    - Also it took 19 sec to create files in ZFS and 15 in EXT4.
    - **Reason**: The system analyses and compares block hashes to detect duplicates, introducing latency.
    - **Impact**: Less suitable for high-speed, low-latency applications like transactional databases.
2. **Higher CPU Utilisation**:
    - Deduplication consumes CPU resources due to hashing, comparison, and indexing for each block. Comparing **CPU Util %** below
    - In Workload 1: Zfs 46.3%, EXT4: 36.8%
    - In Workload 2: Zfs 14.5%, EXT4: 13.2%
    - **Reason**: Hashing and metadata indexing for duplicates add computational overhead.
    - **Impact**: Can bottleneck systems with limited CPU capacity, affecting throughput under heavy load.

Disadvantages of Large File Optimization:

1. **Greater Metadata Overhead for Small Files**:
    - Ext4’s large file optimization increases metadata overhead when handling small files due to extent-based allocation.
    - In ZFS: 224.1 MB used, while 500 MB in EXT4.
    - **Reason**: Extent trees are efficient for large files but inefficient for small, scattered files.
    - **Impact**: Ext4 may be less space-efficient with many small files compared to other filesystems like ZFS.
2. **Lack of Data Recovery Mechanism**:
    - Ext4 optimises large file performance at the cost of data integrity, lacking block-level checksums or recovery mechanisms.
    - **Reason**: Limited metadata for large files limits error detection and correction.
    - **Impact**: Increased vulnerability to undetected data corruption, particularly for large, fragmented files.

Conclusion:

- Deduplication saves space but reduces performance and increases CPU load, making it less ideal for time-sensitive workloads.
- Ext4’s large file optimization enhances performance for large files but adds metadata overhead for small files and limits data recovery. The choice of filesystem should align with workload needs and system requirements.