Data Storage - When reality clashes with theory

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Researchers are often guilty of only celebrating the final success

I want to present the carnage that can happen behind the scene

The Research Goal

To create a file system based on a new emerging technology called generalised deduplication

The carnage

We constantly ran out of disk space

But all analytics tools told us that we had ample space left

So what was wrong?

Research Vectors

- Our code
- Something outside our code

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- Our code
    - Full code analysis revealed exactly nothing
    - Follow systems calls, revealed. . . well, nothing

Research Vectors

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- Something outside our code

- Something outside our code
  - We used EXT4 as an external storage
    - It has something called a directory index

EXT 4 Directory index

- An index[1] of all files in a folder
- It is (most often) loaded in to memory
- Used to speed up look up operations
  - `ls`, `stat`, etc.

[1] A Directory Index for Ext2, Daniel Phillips, https://www.kernel.org/doc/ols/2002/ols2002-pages-425-438.pdf

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So what is the problem?

EXT4 vs Directory Index

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Directory Index has a different limit

Relax it gets worse the limit varies between Linux distributions and even version.

The problem

- Directory Index limits a system that should be limited
- The limit is not well defined

OS	Observed limit
Ubuntu 18.04	12mio
Ubuntu 18.04 server	16mio
Fedora 31	32mio
Fedora 31 Server	32mio
Ubuntu 20.04	20mio
Fedora 33	64mio

Solutions

- Disable the directory index
  - That is an option
  - It solves the issue
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- So let us hack away around
- We will turn the disadvantage of the directory index into an advantage
- It is only a "solution".

Hackaround

- Our files all have an SHA-1 identifier
  - 20 bytes or converted to hexadecimal string 40 bytes

Let us use that to create a grouping system.

Hackaround

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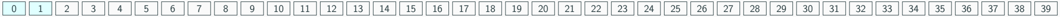
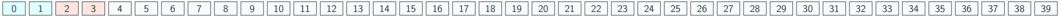
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39

Let us use that to create a grouping system.



0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39

If hash for files shares the 2 first characters, they belong to the same *major group*



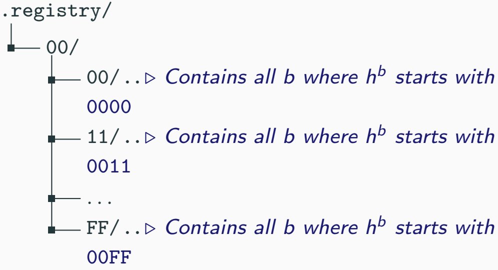
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39

and say files that share the first 4 characters belongs to the same *minor group*

Hackaround

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39

- Then, we create a folder for each major group
- In the major group, we create folders for all minor groups
- Then, we place all files belong to that specific minor group in a folder



```
.registry/
└── 00/
    ├── 00/ ..▷ Contains all b where h^b starts with 0000
    ├── 11/ ..▷ Contains all b where h^b starts with 0011
    ├── ...
    └── FF/ ..▷ Contains all b where h^b starts with 00FF
```

Hackaround

What this does is:

- Reduce the probability of hitting the directory index limit
  - all though still present
- But we retain the power of the directory index
- With minimum damage to storage usage -4kB (minimum per folder)
- Zero impact on RAM usage
- Work also for EXT2, EXT3, and ZFS

A Hackaround there actually would work but cost ram

- Keep a registry in memory of all files stored
- But it increases the RAM consumption of the file system
    - and do you really want your file system to play Google Chrome?

Thank you for your attention