File System Aging

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Motivation

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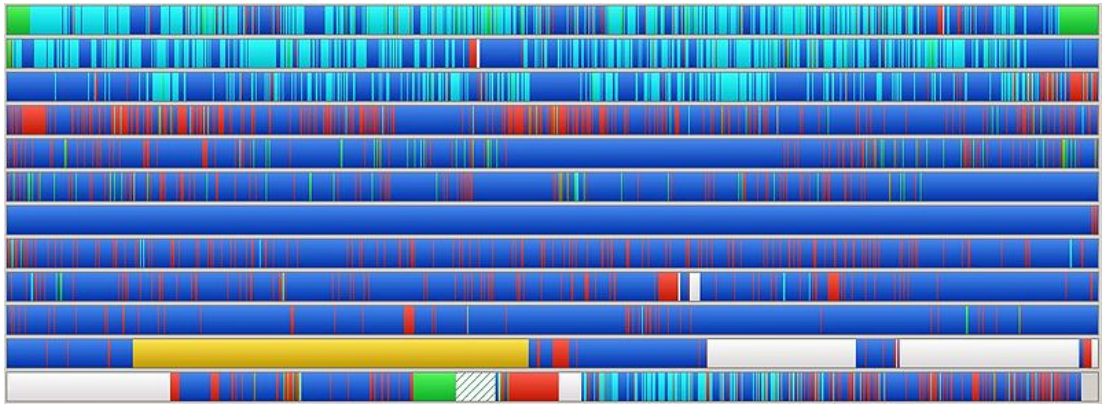
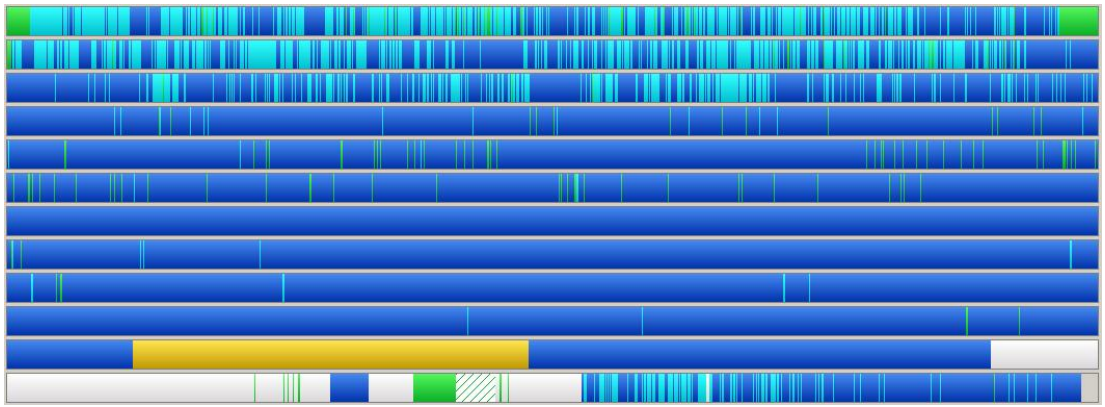


Blue - defragmented files
Red - fragmented files and folders
Yellow - paging file
Green - system files
White - unused space
Green/White - reserved system space
Light Blue - defragmented folders

↓ Defragmentation



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Is this still relevant?

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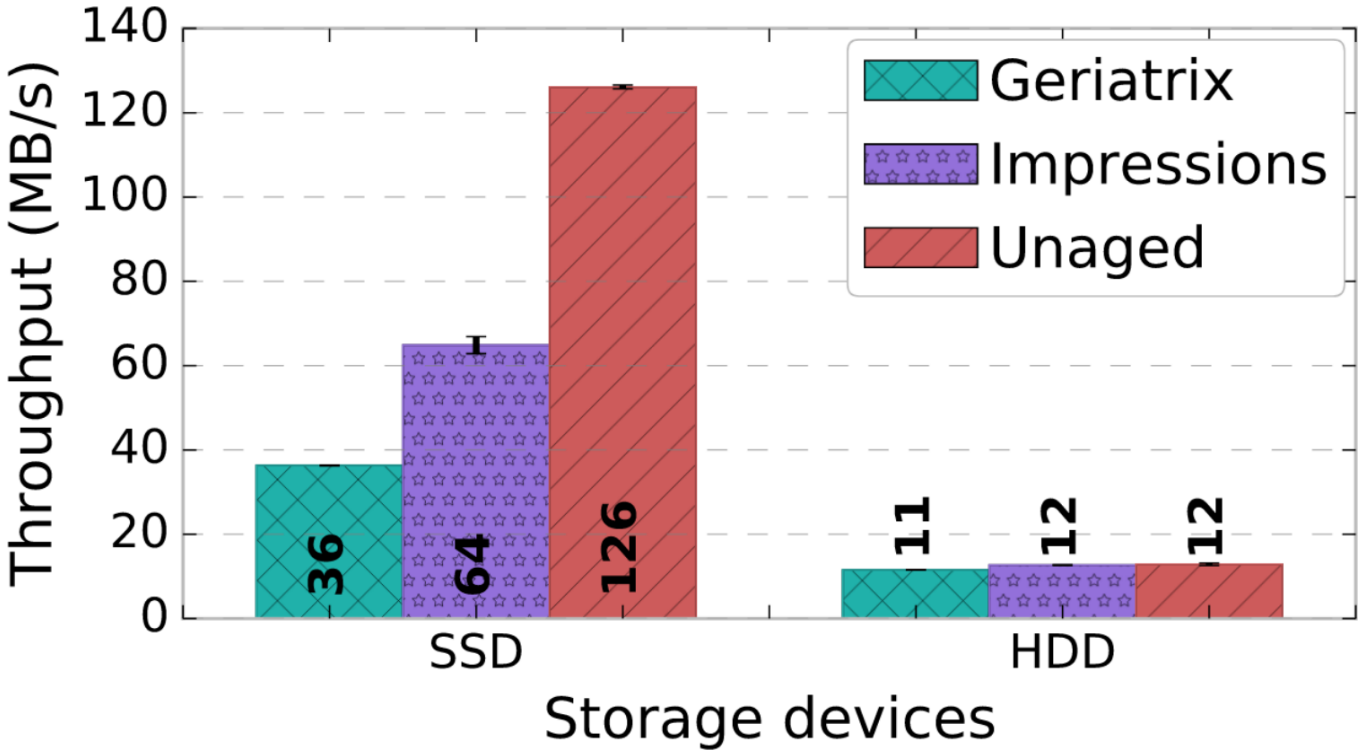

Aging impact on Ext4 atop SSD and HDD. [8]

Overview

Background

Natural Transfer Size (NTS) [4]

- Maximizing read throughput of a device by reading:
  (a) sufficiently **large** chunks of
  (b) **sequential** data

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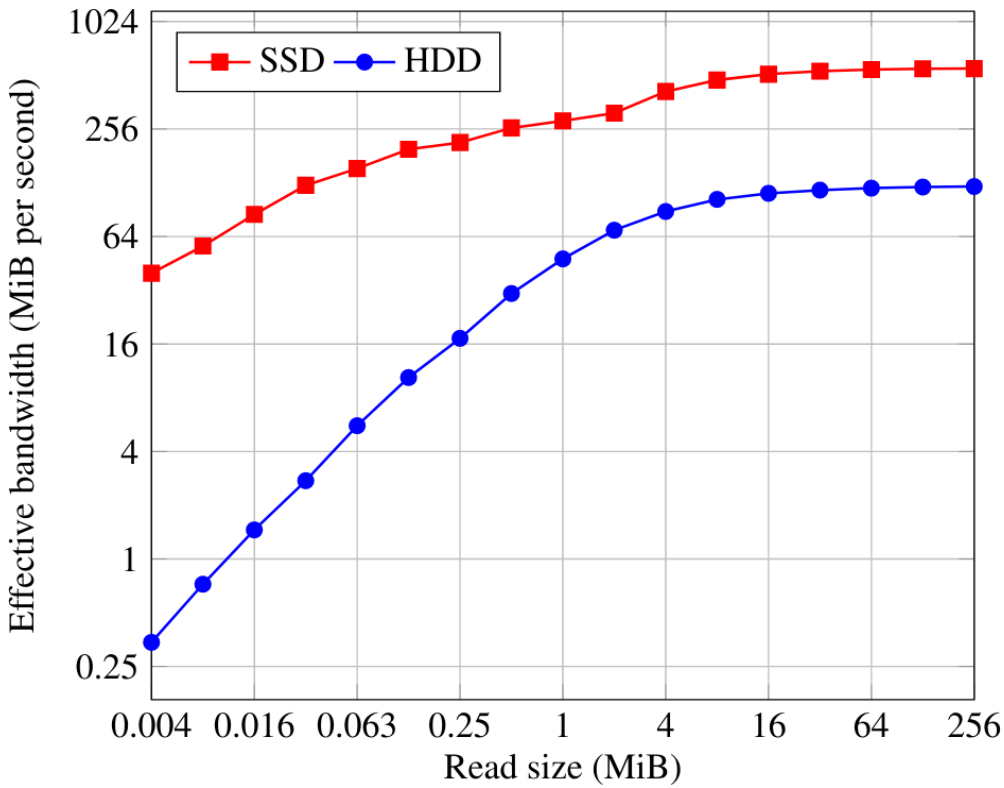
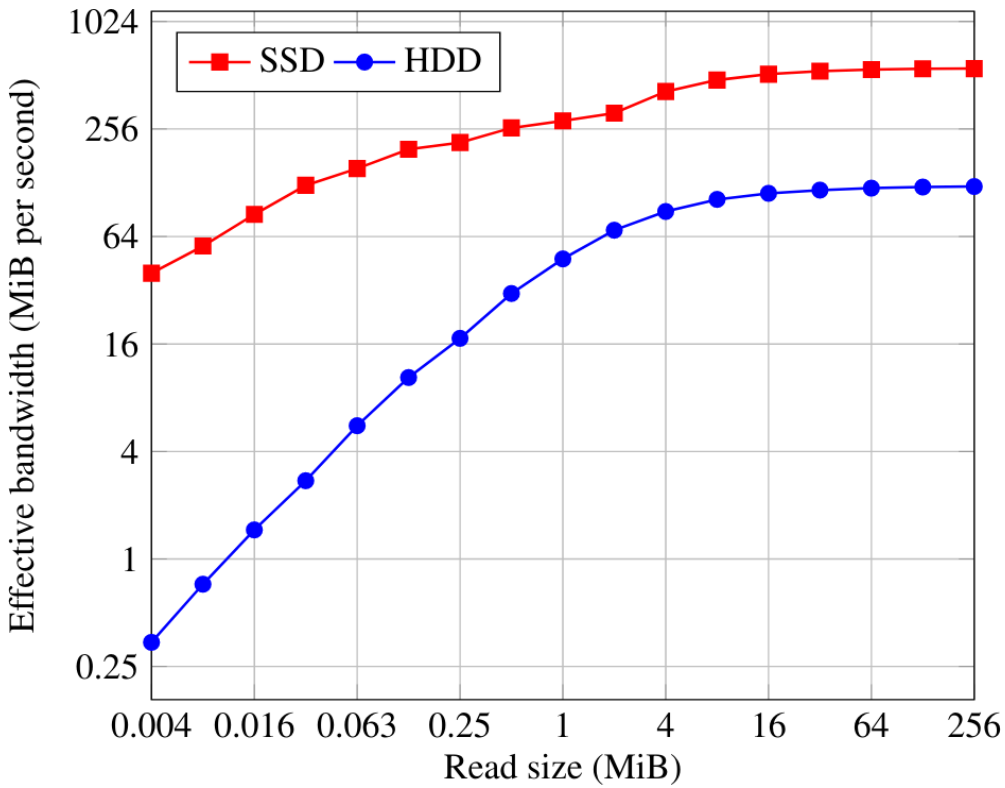


Natural Transfer Size (NTS) [4]

- Maximizing read throughput of a device by reading:
  (a) sufficiently **large** chunks of
  (b) **sequential** data
- How large is sufficient?
  - 4MiB $\rightarrow$ Natural Transfer Size (NTS)



Update-In-Place File Systems

Allocation

- Allocation of space for new files
- Modification of files *updates* them *in-place*

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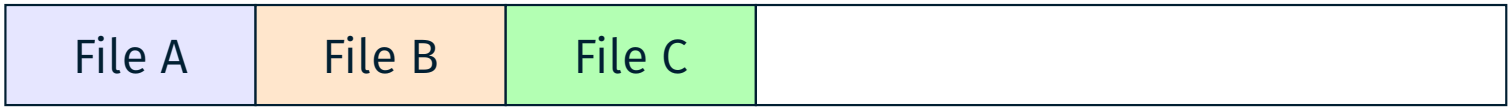
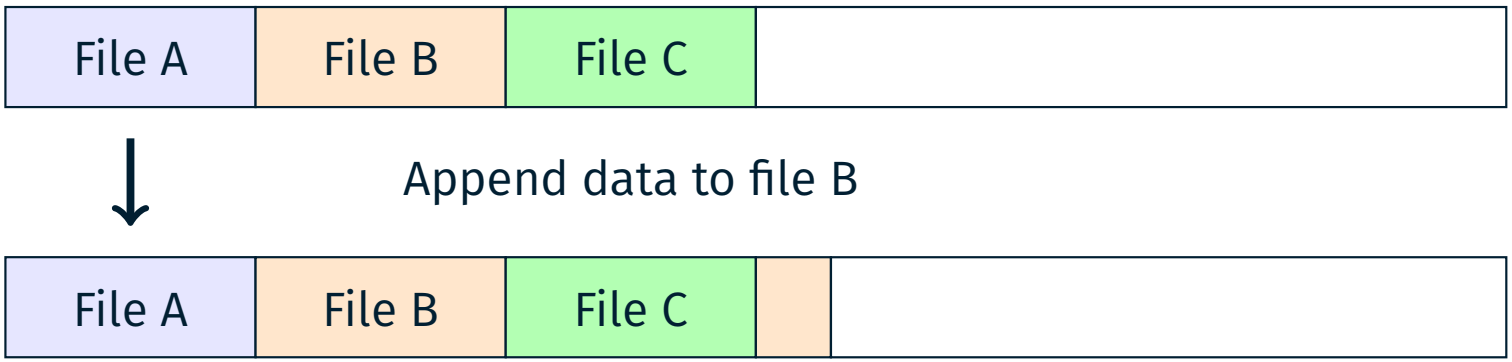
Causes for fragmentation:

- Growth beyond intial allocation
  $\rightarrow$ **intra-file** fragmentation
- Related files are not stored adjacent
  $\rightarrow$ **inter-file** fragmentation


File A
File B
File C


File A
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Append data to file B
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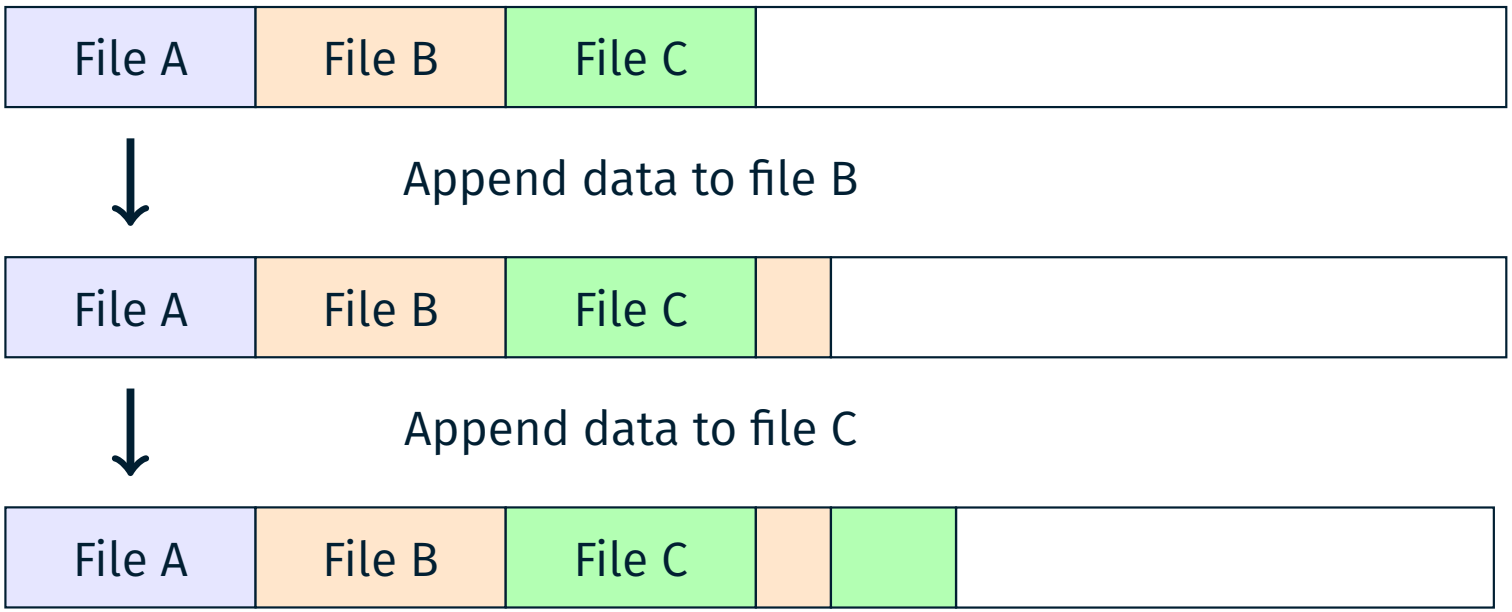
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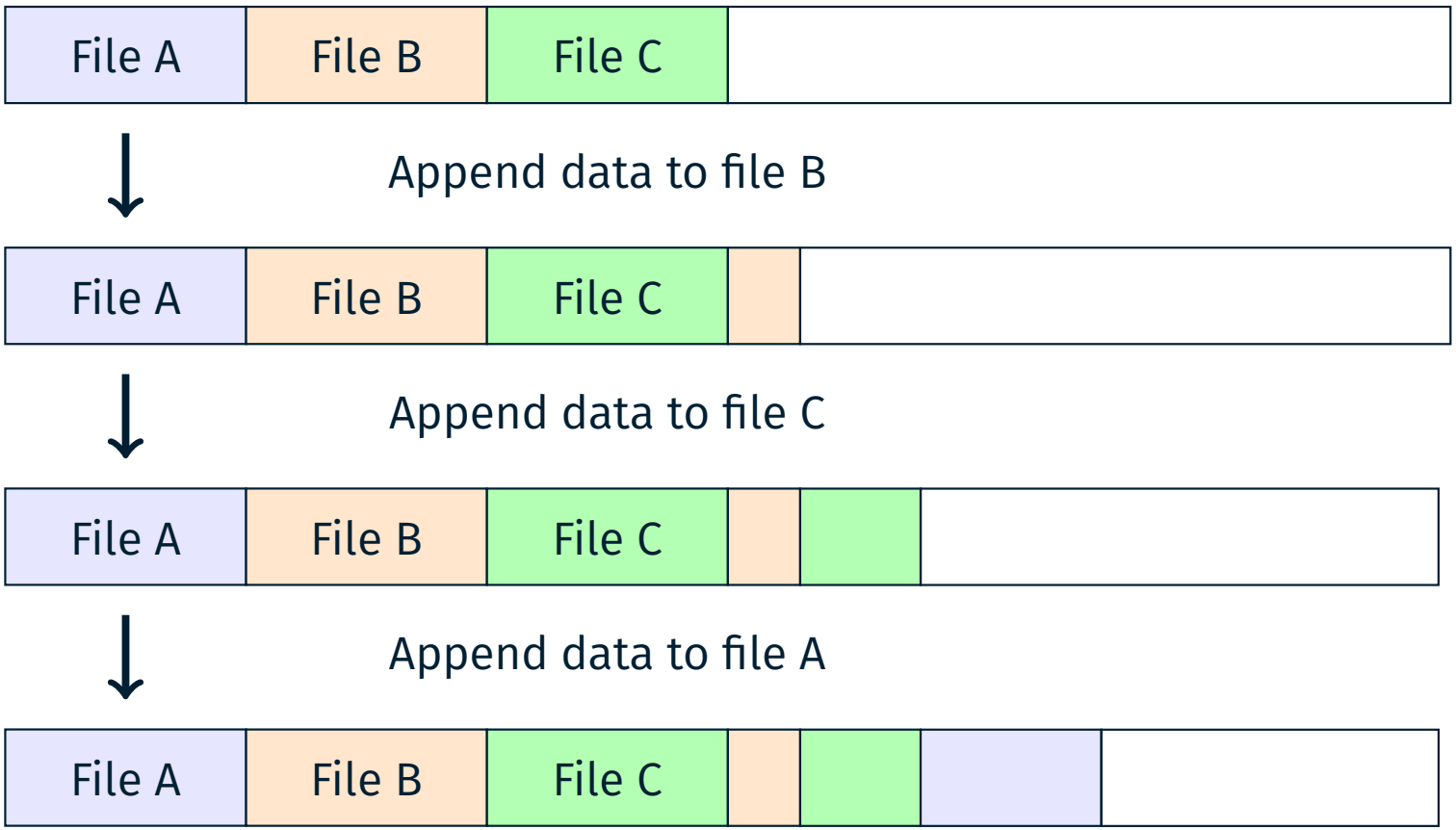
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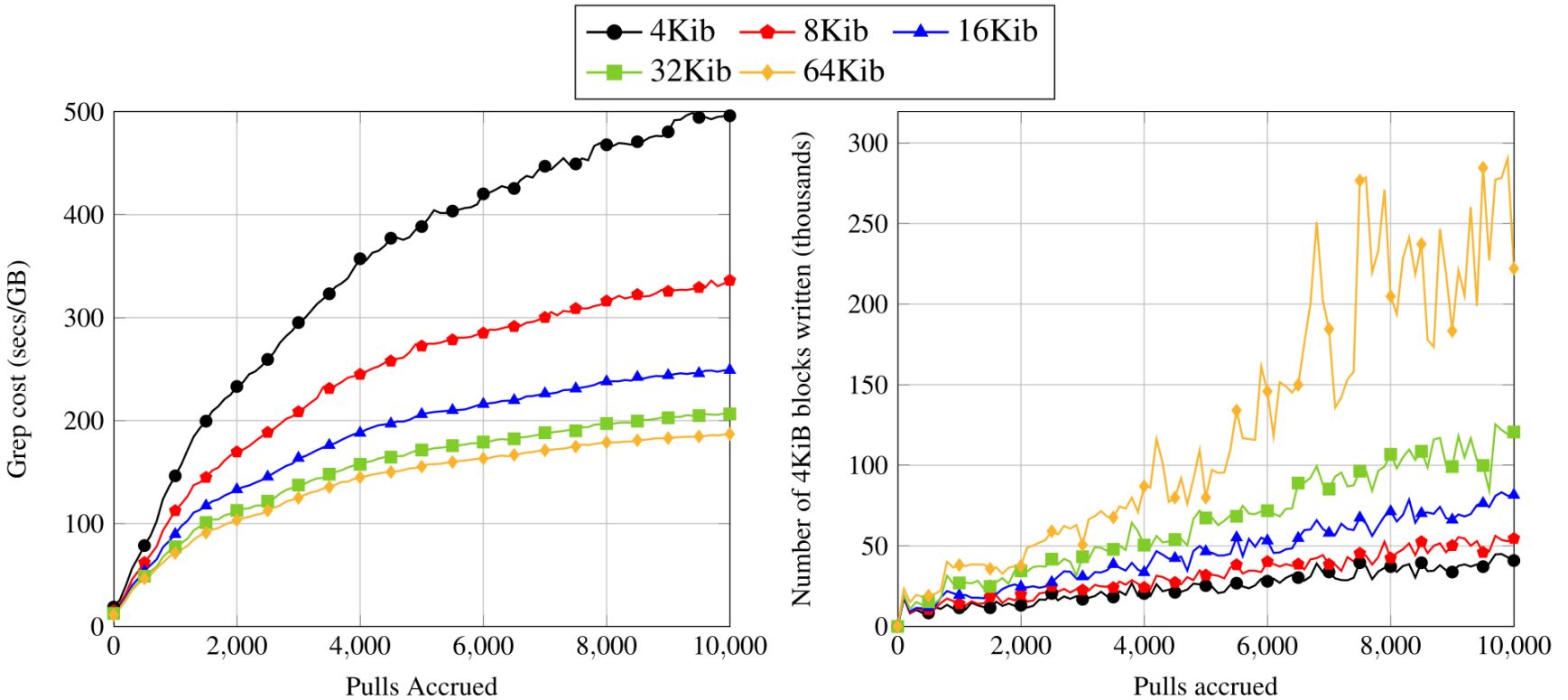
B-Tree based File Systems

Organize some parts or the entire file system in B-Trees

- File insertions and deletetions modify the trees structure and cause fragmentation
- Aging depends on the size of the tree nodes
  - NTS sized nodes reduce aging
  - Smaller nodes reduce write amplification



(a) Grep cost at different node sizes (lower is better).

(b) Write amplification at different node sizes (lower is better).

Aging and write amplification on Btrfs. [4]

Measuring age

Conventional file system benchmarks:

- Operation speed [8]
- Search times [4]

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Measuring fragmentation:

- Layout Score [9]
- Dynamic Layout Score [4]
- Free Space Extents [8]
- Write latency [5]

Actual use:

- Accurate representation
- Long term use required (months or years)

Application based aging:

- Aging specific to one workload
- Cannot replicate all effects of real long term aging [8]

Artificial Aging

Generates an artificial workload from file system snapshots

+ Can closely match months of real aging in hours

- Fails to replicate fragmentation for long aging durations
- Regular snapshots are required

Generates a realistic file system image

+ Can be configured to match characteristics and distributions of aged file systems
- No realistic free space fragmentation [8]

Geriatrix [8]

Ages a file system until it matches an aging profile

+ Creates realistic free space fragmentation
+ Can approximate a realistic aged file system in hours

- Requires aging profiles specific to the file system [8]

Known Countermeasures

Grouping Files

Reduces inter-file fragmentation by

- Storing logically related files physically close
- Reserving space for additional files to be allocated

Which files are related?

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- Created simultaneously

Limitations

- Directories can grow to exceed the reserved space
- Files can be falsely classified as related

Allocating Extents

Extent: Group of sequential blocks

Reduce intra-file fragmentation by

- Allowing files to grow inside the extent
- Ensuring a minimum size for file fragments

What is a good size for extents?

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What is a good size for extents?

- Extent size $>=$ NTS
- More than 90% of files are 1MiB or smaller [3, 6]

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What is a good size for extents?

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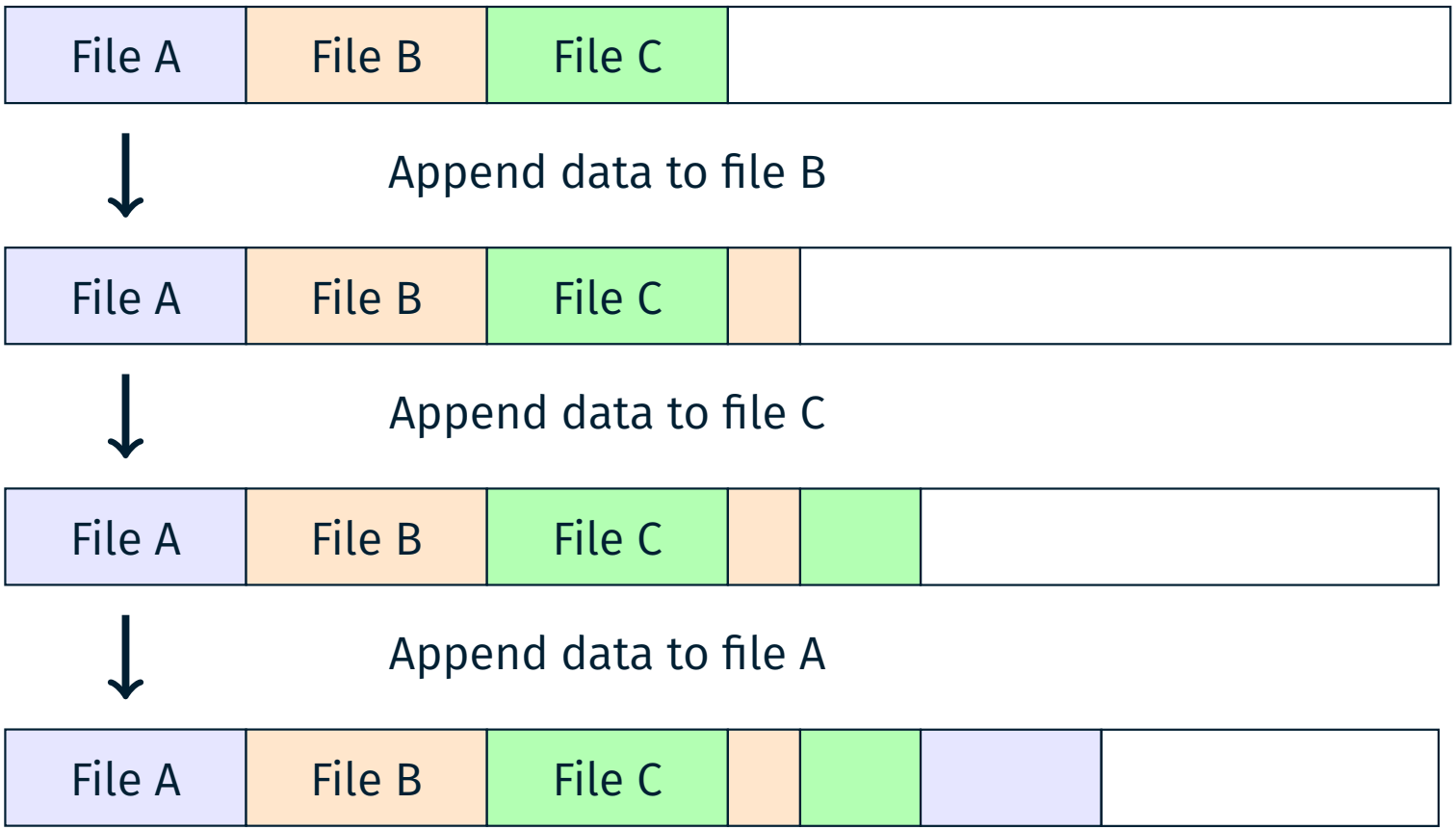
Limitations

- Files growing beyond the extent size fragment

Reminder: Update-In-Place Fragmentation



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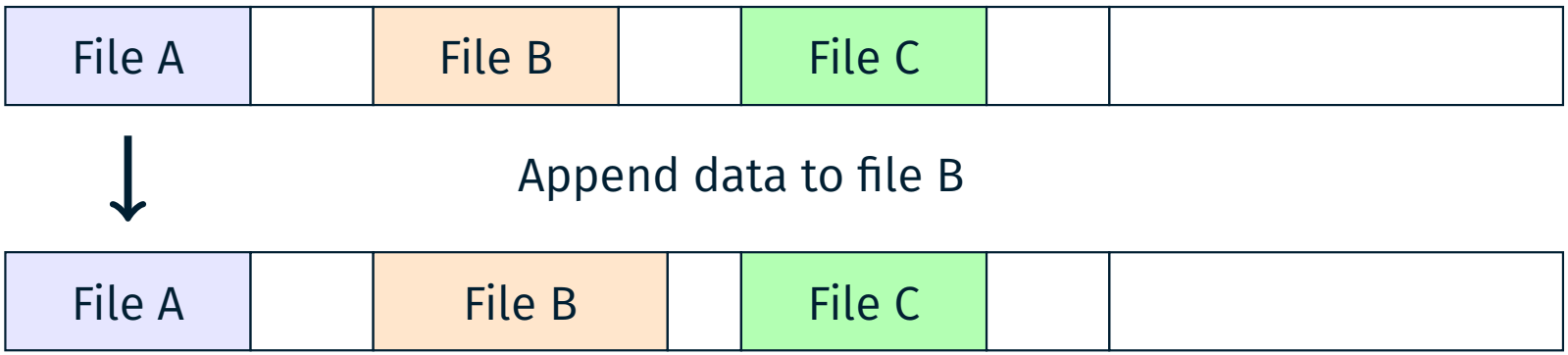

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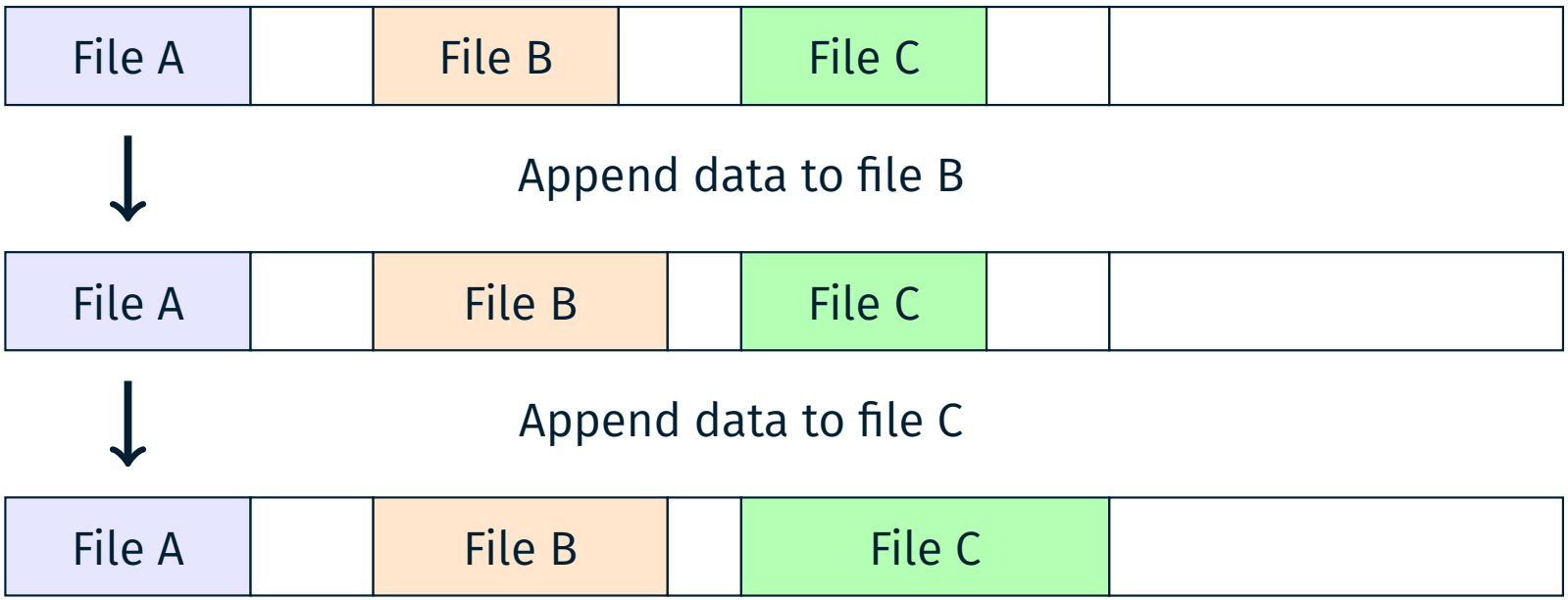

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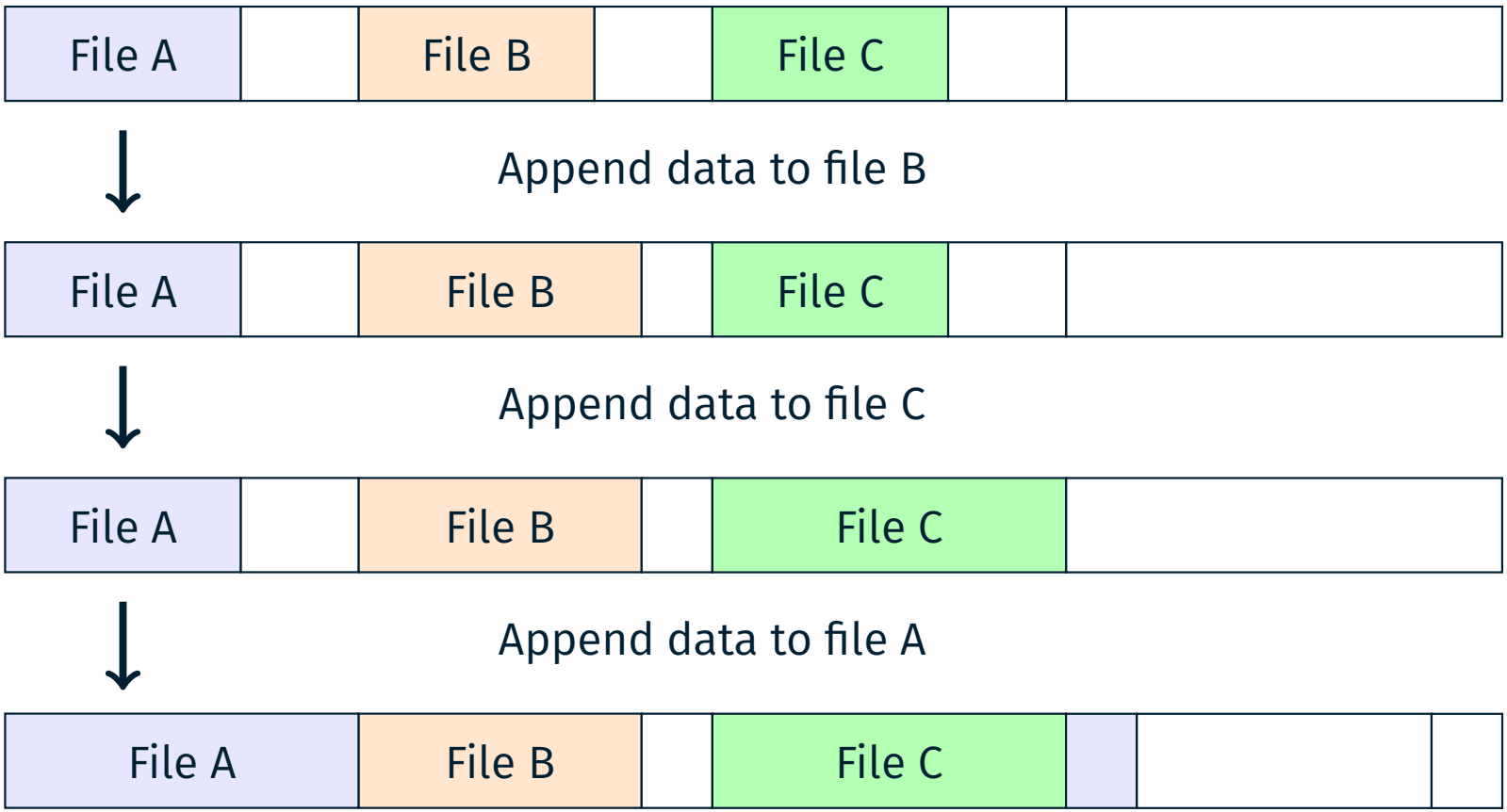

Delayed Allocation

Reduces intra-file fragmentation by

- Delaying allocation after file creation and
- Writing data to a buffer initially and
- Choosing an appropriate extent after the file has reached final size

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- Delaying allocation after file creation and
- Writing data to a buffer initially and
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Limitations:

- Delay can only be a few seconds [4]
- Files growing over a long period of time will still fragment

Packing

Reduces inter-file fragmentation by

- Packing multiple small files into one extent
- Storing metadata in the same extent
- Storing small files directly in the metadata structures

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Limitations:

- Can lead to heavy fragmentation on file growth

Modern File Systems and Aging

Ext4 [1]

Type: Update-In-Place

Countermeasures:

- Grouping
- Packing
- Extents (up to 128MiB)
- Delayed allocation

BtrFS [4]

Type: B-Tree based

Node size: 4KiB (default) to 64KiB (maximum)

Countermeasures:

- Extents
- Delayed allocation
- Packing

BetrFS [7]

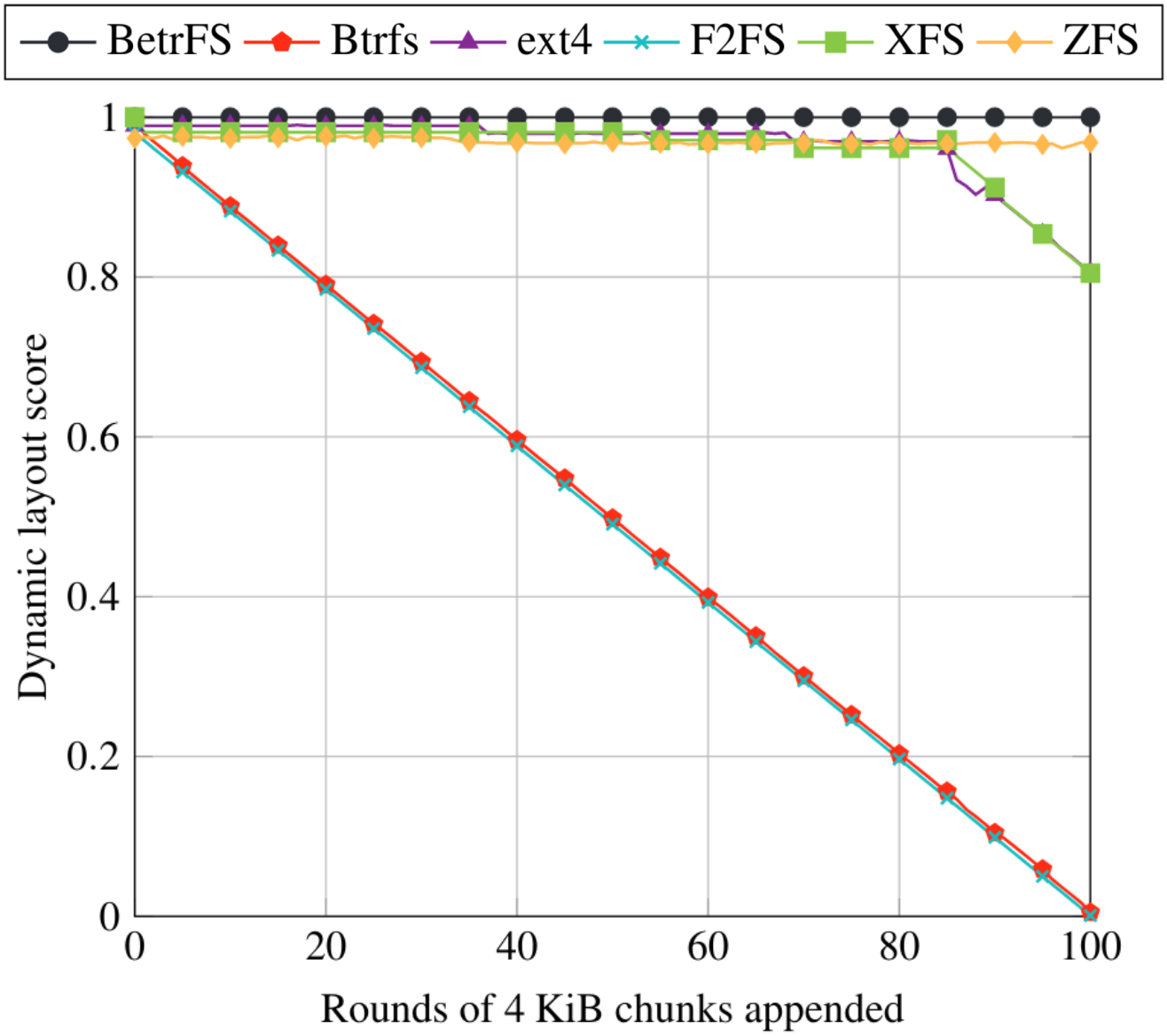
Type: B^{ε}-Tree based

Node size: 4MiB

Countermeasures:

- B^{ε}-Tree
  - Modifications to nodes are buffered
  - Reduced write amplification
- Data is also stored in a B^{ε}-Tree

Comparison: Intra-File Fragmentation [4]



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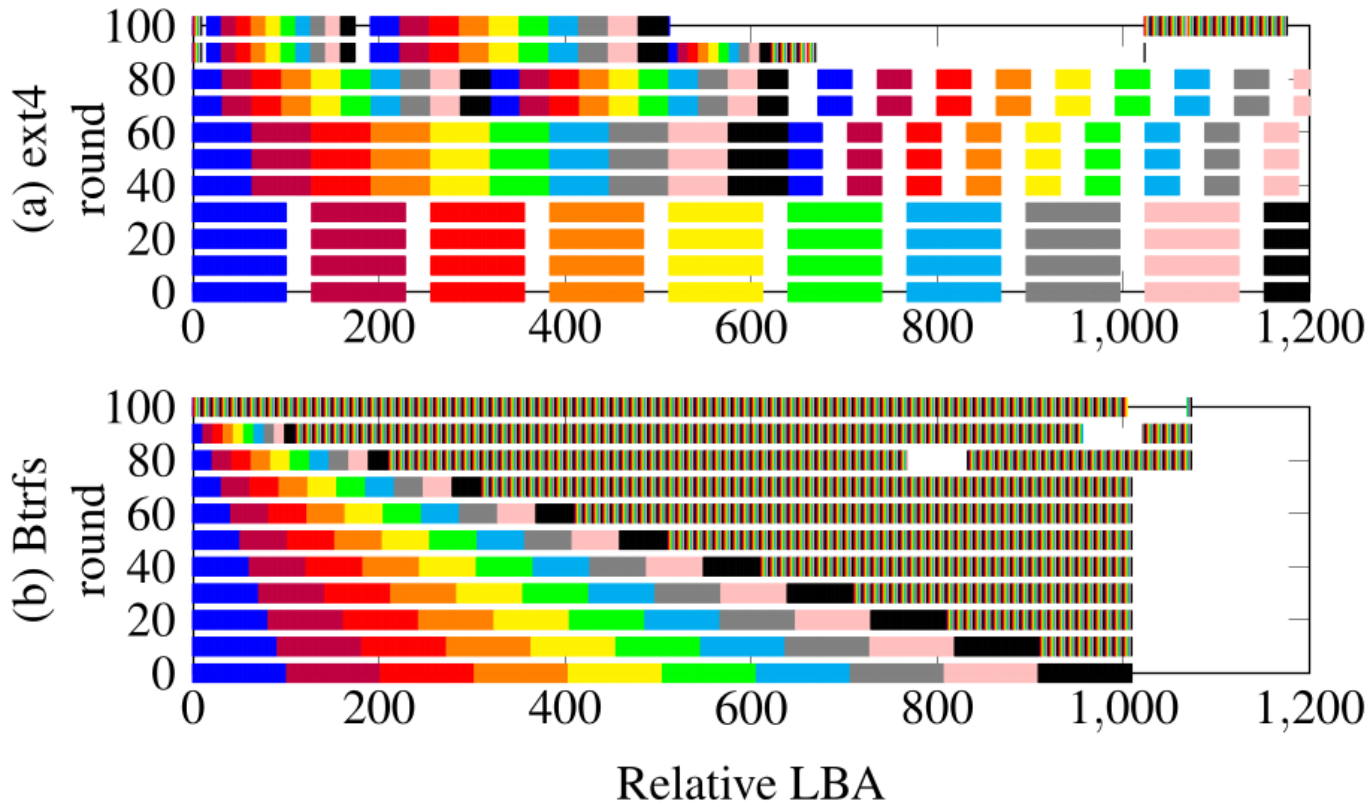
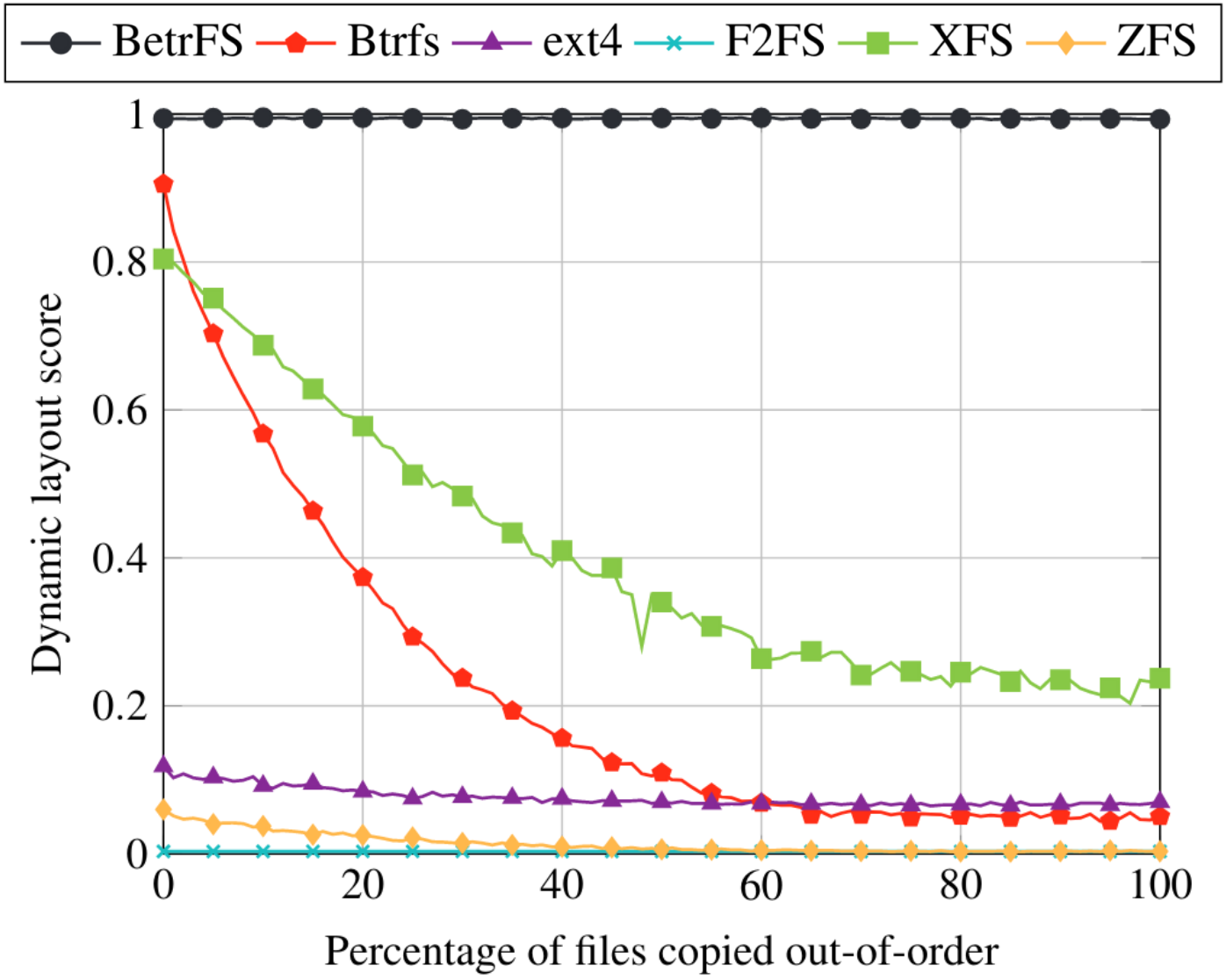


Intrafile benchmark layout visualization. [4]

Comparison: Inter-File Fragmentation [4]



Conclusion

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File System Aging is not a solved problem:

- Ext4 and BtrFS age measurably
- Known countermeasures help but have limitations

Current and future research:

- Aging on non-mechanical drives
- New Filesystems

Questions?

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