OAK RIDGE National Laboratory

Advanced Lustre File Layouts

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Overview

This tutorial will cover...

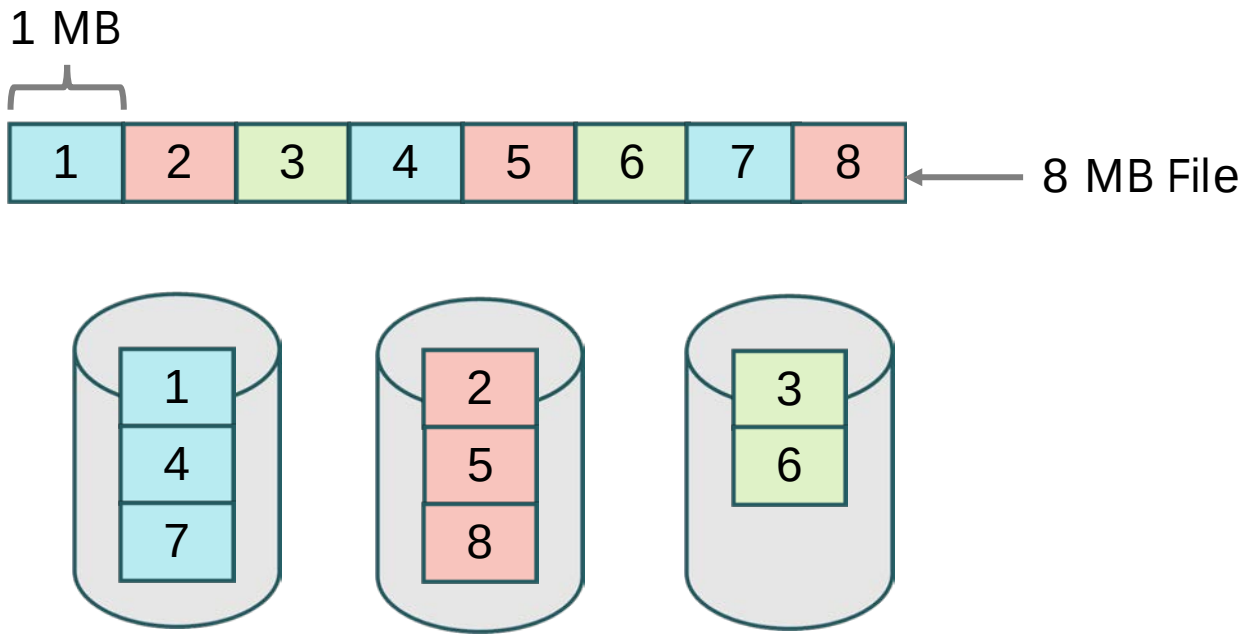
- Normal file layouts
- Progressive File Layouts (PFL)
- Data on MDT (DoM)
- File Level Redundancy (FLR)
- Self-Extending Layouts (SEL)

... but it will NOT cover

- Directory striping
- Choosing file layouts to optimize I/O performance

Normal File Layouts

- File is split into chunks and distributed across selected Object Storage Targets (OSTs) in round-robin fashion
- Splitting is controlled by two main parameters
  - Stripe count
  - Stripe size



Example:

stripe_count = 3

stripe_size = 1 MB

Setting File Stripe Parameters

- File striping is controlled with the `lfs setstripe` command

```
lfs setstripe –c 3 –S 1M data
```

- File must not exist before running `lfs setstripe`

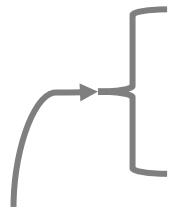
```
lfs setstripe: setstripe error for 'data': stripe already set
```

- Other striping options
  - `-i|--index` = Choose starting OST index for striping (default = -1)
  - `-o|--ost` = Specify OST indices to use
  - `-p|--pool` = Choose OSTs from the specified OST pool (default = none)

Viewing File Stripe Parameters

- Use `lfs getstripe` to view the layout for a file

```
[tmp]# lfs getstripe data
data
lmm_stripe_count:   3
lmm_stripe_size:    1048576
lmm_pattern:        raid0
lmm_layout_gen:     0
lmm_stripe_offset: 2
          obdidx           objid           objid           group
               2           29564         0x737c       0xb00000417
               7           29644         0x73cc       0xc00000403
               6           29662         0x73de       0xe40000414
```

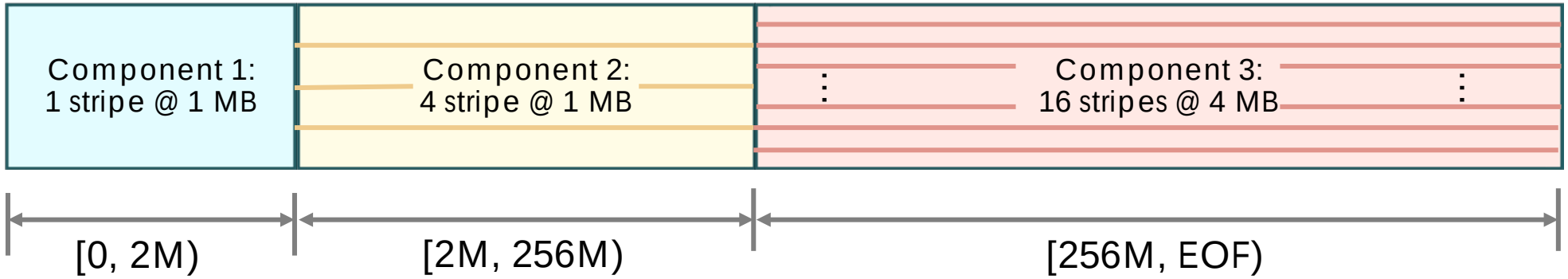


Allocated OSTs

Progressive File Layouts (PFL)

Progressive File Layouts (PFL)

- PFL allows more control over a file's layout
  - Normal layout applies single stripe count and stripe size to entire file
  - PFL can use different normal layouts on different parts of the file (making it one of the types of composite layouts)
  - Potentially optimize IO for files with non-uniform data structures



Creating PFL Layouts

- The `-E|--component-end` option is used to denote different components in the layout
- General format:

```
lfs setstripe -E end1 <stripe_opts> -E end2 <stripe_opts> … <file>
```

- Example:

```
lfs setstripe  -E 2M -c 1  -S 1M \
               -E 256M -c 4  -S 1M \
               -E -1 -c 16  -S 4M \
               data.txt
```

Can also use `-E eof`

Creating PFL Layouts (cont.)

- Components must be specified in order

  First component starts at offset = 0, next component starts where previous component ends

  ```
  lfs setstripe -E eof -c 16 -E 2M -c 1 data.txt
  ```

- First component inherits default values from parent/root directory. Later components inherit values from previous component.

  ```
  lfs setstripe -E 2M -c 1 -S 1M -E 64M -c 4 -E eof –S 4M
  ```

  stripe count = 1
  stripe size = 1M

  stripe count = 4
  stripe size = 1M

  stripe count = 4
  stripe size = 4M

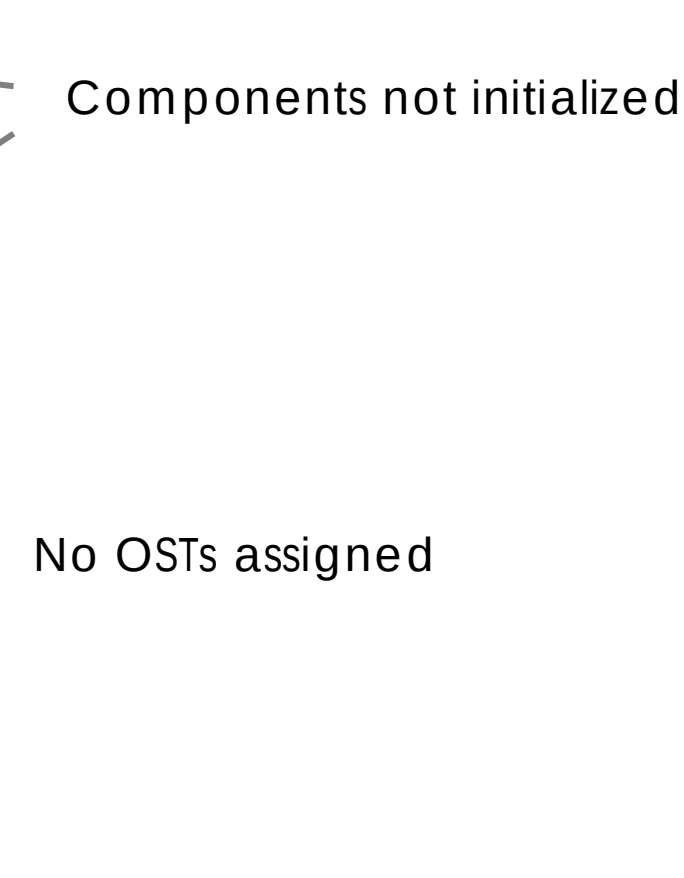
Lazy Initialization

- Lustre always allocates OSTs for the first component, but only allocates OSTs for other components when needed.

```
#> lfs getstripe data.txt
data.txt
  lcm_layout_gen:    3
  lcm_mirror_count:  1
  lcm_entry_count:   3
    lcme_id:             1
    lcme_mirror_id:      0
    lcme_flags:          init
    lcme_extent.e_start: 0
    lcme_extent.e_end:   2097152
      lmm_stripe_count:  1
      lmm_stripe_size:   1048576
      lmm_pattern:       raid0
      lmm_layout_gen:    0
      lmm_stripe_offset: 6
      lmm_objects:
      - 0: { l_ost_idx: 6, l_fid: [0xe40000414:0x7489:0x0] }
```

Lazy Initialization (cont.)

```
lcme_id:                2
lcme_mirror_id:         0
lcme_flags:             0
lcme_extent.e_start:    2097152
lcme_extent.e_end:      268435456
  lmm_stripe_count:     4
  lmm_stripe_size:      1048576
  lmm_pattern:          raid0
  lmm_layout_gen:       0
  lmm_stripe_offset:    -1

lcme_id:                3
lcme_mirror_id:         0
lcme_flags:             0
lcme_extent.e_start:    268435456
lcme_extent.e_end:      EOF
  lmm_stripe_count:     16
  lmm_stripe_size:      4194304
  lmm_pattern:          raid0
  lmm_layout_gen:       0
  lmm_stripe_offset:    -1
```



Lazy Initialization (cont.)

- Writing data will cause components to be initialized on-the-fly

```
# dd if=/dev/zero of=data.txt bs=1M count=4
```

- After 2M is written, Lustre initializes second component

```
lcme_id:              2
lcme_mirror_id:       0
lcme_flags:           init
lcme_extent.e_start:  2097152
lcme_extent.e_end:    268435456
  lmm_stripe_count:   4
  lmm_stripe_size:    1048576
  lmm_pattern:        raid0
  lmm_layout_gen:     0
  lmm_stripe_offset:  7
  lmm_objects:
  - 0: { l_ost_idx: 7, l_fid: [0xc00000403:0x746e:0x0] }
  - 1: { l_ost_idx: 8, l_fid: [0xc4000040e:0x7457:0x0] }
  - 2: { l_ost_idx: 12, l_fid: [0xe80000419:0x2a75:0x0] }
  - 3: { l_ost_idx: 1, l_fid: [0xac000040e:0x74c1:0x0] }
```

Dynamic Layout Changes

- With lazy initialization, only the first component is required to be specified when the file layout is set
- Other components can be added (and even deleted) dynamically using `lfs setstripe`
- There are some caveats:
  - Components can only be deleted starting from the last one
  - Deleting a component will cause all data in that component to be lost
  - Cannot write past the end of the last component

Dynamic Layout Example

```
[tmp]# lfs setstripe -E 2M -c 1 data.txt

[tmp]# dd if=/dev/zero of=data.txt bs=1M count=1
1+0 records in
1+0 records out
1048576 bytes (1.0 MB, 1.0 MiB) copied, 0.00139419 s, 752 MB/s

[tmp]# lfs setstripe --component-add -E 10M -c 4 data.txt

[tmp]# lfs setstripe --component-add -E -1 -c 8 data.txt

[tmp]# dd if=/dev/zero of=data.txt bs=1M count=20
20+0 records in
20+0 records out
20971520 bytes (21 MB, 20 MiB) copied, 0.0671822 s, 312 MB/s

[tmp]# ls -lh data.txt
-rw-r--r-- 1 root root 20M May  2 01:40 data.txt
```

Create initial component...

...then add two more

Data extends Into the third component

Dynamic Layout Example (cont.)

```
[tmp]# lfs setstripe --component-del -I 3 data.txt
```

component index*

Deleting last component...

```
[tmp]# ls -lh data.txt
-rw-r--r-- 1 root root 10M May  2 01:40 data.txt
```

...truncates the file and destroys data in the deleted component

```
[tmp]# dd if=/dev/zero of=data.txt bs=1M count=20
dd: error writing 'data.txt': No data available
11+0 records in
10+0 records out
10485760 bytes (10 MB, 10 MiB) copied, 0.00900609 s, 1.2 GB/s
```

Can't write past end of the last component

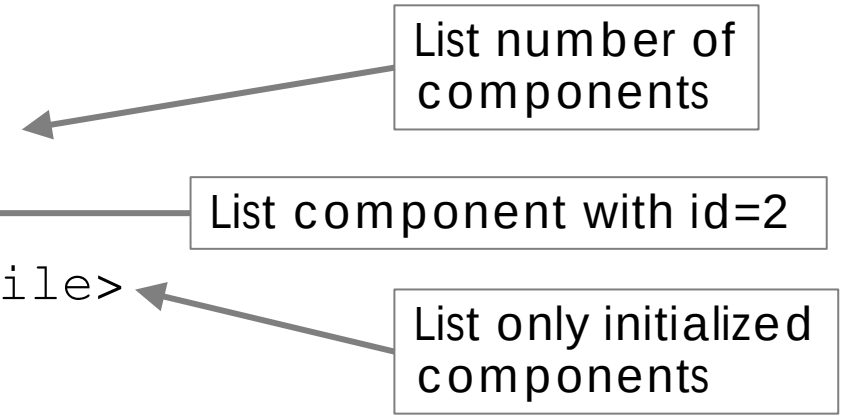
*Not necessarily sequential. Check `lcme_id` field in output from `lfs getstripe`

Other Useful Commands

- Component-related options for `lfs getstripe`

  (Check man page for full set of options)

```
lfs getstripe --component-count <file>
lfs getstripe –I2 <file>
lfs getstripe --component-flag=init <file>
```



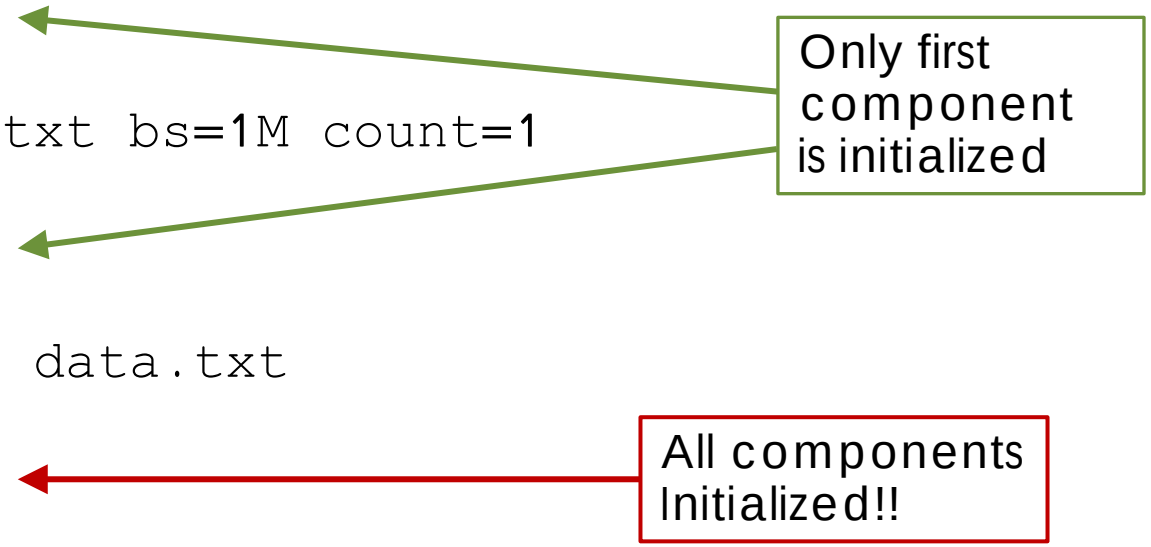
- Use the lfs migrate command to change a normal layout to PFL (and vice versa)

```
lfs setstripe -c 1 data.txt
dd if=/dev/zero of=data.txt bs=1M count=100
lfs migrate -E 2M -c 1 -E 20M -c 4 -E -1 -c 16 data.txt
```

Important Note About File Appends

- Components are normally only initialized when data is written to them…except in the case of file appends

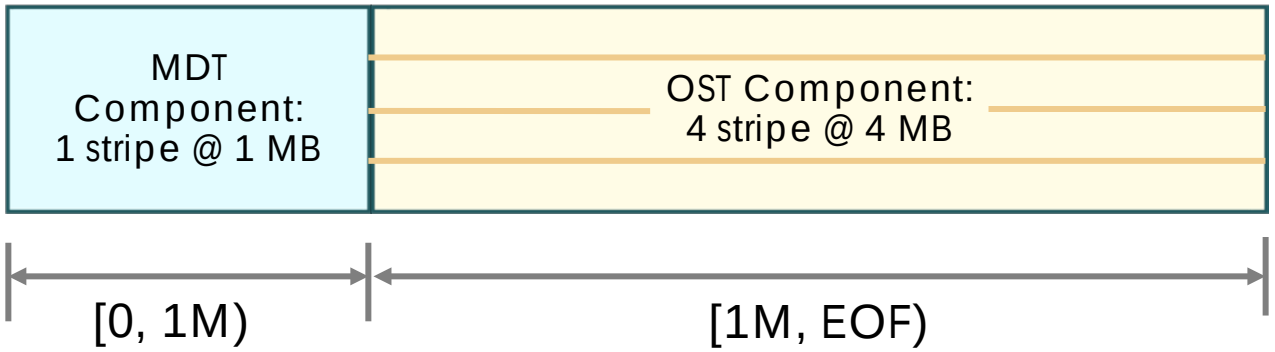
```
[tmp]# lfs setstripe -E 100M -c 1 -E 10G -c 4 -E -1 -c -1 data.txt

[tmp]# lfs getstripe data.txt

[tmp]# dd if=/dev/zero of=file.txt bs=1M count=1

[tmp]# lfs getstripe data.txt

[tmp]# echo ”This is a test” >> data.txt

[tmp]# lfs getstripe data.txt
```



Data on MDT (DoM)

DoM Basics

- DoM layouts are intended to improve small file I/O performance by placing all (or part) of the file on the MDT
- A DoM layout is a composite layout (and is actually just a special case of PFL)
  - Only the first component resides on the MDT
  - The first component always has stripe_count = 1
  - The MDT used for the first component is the same MDT that stores the inode for the file



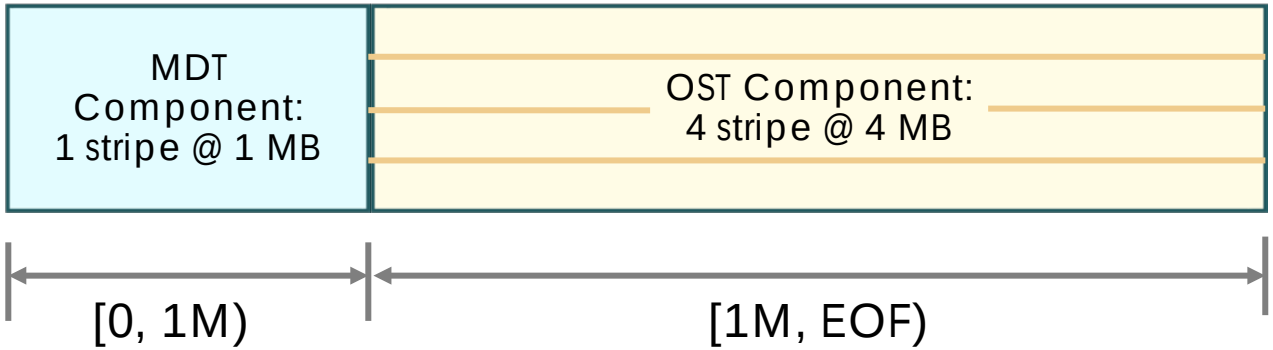
Creating DoM Layout

- DoM layout are created in a similar fashion to PFL layouts

```
lfs setstripe -E <end1> -L mdt -E <end2> [stripe_opts]…
```

- Example:

```
lfs setstripe -E 1M -L mdt -E eof -c 4 -S 4M dom_file
```



Displaying DoM Layout

```
[tmp]# lfs getstripe dom_file

dom_file
  lcm_layout_gen:    2
  lcm_mirror_count:  1
  lcm_entry_count:   2
    lcme_id:                     1
    lcme_mirror_id:              0
    lcme_flags:                  init
    lcme_extent.e_start:         0
    lcme_extent.e_end:           1048576
      lmm_stripe_count:  0
      lmm_stripe_size:   1048576
      lmm_pattern:       mdt
      lmm_layout_gen:    0
      lmm_stripe_offset: 0
```

DoM layout looks nearly identical to a PFL layout

stripe size = extent end

```
lcme_id:                     2
lcme_mirror_id:              0
lcme_flags:                  0
lcme_extent.e_start:         1048576
lcme_extent.e_end:           EOF
  lmm_stripe_count:  4
  lmm_stripe_size:   4194304
  lmm_pattern:       raid0
  lmm_layout_gen:    0
  lmm_stripe_offset: -1
```

Pattern is 'mdt' instead of 'raid0'

DoM for Sys Admins

- System administrators can control the maximum size of the DoM components
- On the MDS server, run

Temporary

```
lctl set_param -n lod.*MDT<index>*.dom_stripesize=<max>
```

or

Persistent

```
lctl set_param -P lod.*MDT<index>.lod.dom_stripesize=<max>
```

- For the `dom_stripesize` value:
  - Default value is 1 MB
  - No smaller than 64 KB and no larger than 1 GB
  - Must be 64 KB aligned

Dom for Sys Admins (cont.)

- DoM can be disabled by setting `dom_stripesize` to 0
  - This can be done on a per-MDT basis as well
- This will disable DoM component creation for any new files or layouts
  - Existing files with DoM components will remain unchanged
  - If a directory has a default layout defined that contains a DoM component, new files in that directory can still be created with DoM components
- DoM files can be identified using `lfs find`

```
lfs find <dir> -L mdt
```

File Creation with DoM Disabled

If DoM is disabled, attempting to create a DoM file will not fail. The layout just gets automatically altered.

```
[tmp]# lfs setstripe -E 1M -L mdt -E eof -c 2 dom_file

[tmp]# lfs getstripe dom_file
dom_file
  lcm_layout_gen:    1
  lcm_mirror_count:  1
  lcm_entry_count:   1
    lcme_id:             1
    lcme_mirror_id:      0
    lcme_flags:          init
    lcme_extent.e_start: 0
    lcme_extent.e_end:   EOF
      lmm_stripe_count:  2
      lmm_stripe_size:   1048576
      lmm_pattern:       raid0
      lmm_layout_gen:    0
      lmm_stripe_offset: 4
      lmm_objects:
      - 0: { l_ost_idx: 4, l_fid: [0xb8000041e:0x743c:0x0] }
      - 1: { l_ost_idx: 10, l_fid: [0xcc000041a:0x73be:0x0] }
```

File Level Redundancy (FLR)

File Level Redundancy (FLR)

- FLR allows users to define one or more mirrors for a file to provide extra data protection.
- When writing to a mirrored file, only one of the mirrors is updated. Other mirrors are marked as stale and need to be resynced.
  - This is the "FLR Delayed Write" implementation
- All mirrors (that are not stale) can be used for reading data
  - Can be used to improve read performance for files that are accessed by many processes in parallel

Creating FLR Layouts

- Unlike other file layouts, this one does not use `lfs setstripe`. Instead, there is a special `lfs mirror` command.

```
lfs mirror create -N[count] [stripe_opts] [--flags=<flags>] … <file>
```

- The mirrors can be either normal layouts, composite layouts, or a mixture of both

```
lfs mirror create -N2 --flags=prefer -c 2 -N -E 10M -c 1 -E eof -c 4 data.txt
```

Two mirrors have the same normal layout

Third mirror uses PFL layout

Displaying FLR Layouts

```
[tmp]# lfs getstripe data.txt
  lcm_mirror_count:  3
  lcm_entry_count:   4
    lcme_mirror_id:         1
    lcme_flags:             init,prefer
    lcme_extent.e_start: 0
    lcme_extent.e_end:   EOF
      lmm_stripe_count:  2
      lmm_stripe_size:   1048576
      lmm_objects:
      - 0: { l_ost_idx: 7, l_fid: [0xc00000403:0x7479:0x0] }
      - 1: { l_ost_idx: 6, l_fid: [0xe40000414:0x7493:0x0] }

    lcme_mirror_id:         2
    lcme_flags:             init,prefer
    lcme_extent.e_start: 0
    lcme_extent.e_end:   EOF
      lmm_stripe_count:  2
      lmm_stripe_size:   1048576
      lmm_objects:
      - 0: { l_ost_idx: 15, l_fid: [0xdc0000419:0x2acf:0x0] }
      - 1: { l_ost_idx: 9, l_fid: [0xc80000405:0x73e4:0x0] }
```

Number of mirrors

Note: Some fields omitted for brevity

Each mirror has unique ID

Displaying FLR Layouts (cont.)

```
lcme_mirror_id:      3
lcme_flags:          init
lcme_extent.e_start: 0
lcme_extent.e_end:   10485760
  lmm_stripe_count:  1
  lmm_stripe_size:   1048576
  lmm_objects:
  - 0: { l_ost_idx: 0, l_fid: [0xe00000416:0x73f9:0x0] }

lcme_mirror_id:      3
lcme_flags:          0
lcme_extent.e_start: 10485760
lcme_extent.e_end:   EOF
  lmm_stripe_count:  4
  lmm_stripe_size:   1048576
  lmm_stripe_offset: -1
```

Only first component of PFL is initialized

All components in the same mirror have identical `lcme_mirror_id` fields

Resync and Verify

- When writing data, the `lcme_flags` field for some components may change to indicate they are out of sync:

```
lcme_flags: init,prefer
```


```
lcme_flags: init,stale,prefer
```

- This is fixed by running

```
lfs mirror resync <file>
```

- Mirrored data can also be checked for consistency

```
lfs mirror verify <file>
```

Extending a Mirrored File

- Additional mirrors can be added to an existing file

```
lfs mirror extend –N[mirror_count] [stripe_options] … <file>
```

  - If the file is not a mirrored file already, it will be converted to one
  - Existing data is copied to the new mirror
- An existing file can also be added as a mirror to another file

```
lfs mirror extend [--no-verify] –N –f victim_file <file>
```

  - The user needs to ensure that victim_file contains the same data

Splitting a Mirrored File

- A specified mirror can be split from a mirrored file into its own separate file

```
lfs mirror split –mirror-id <ID> [-f <new_file>] <mirrored_file>
```

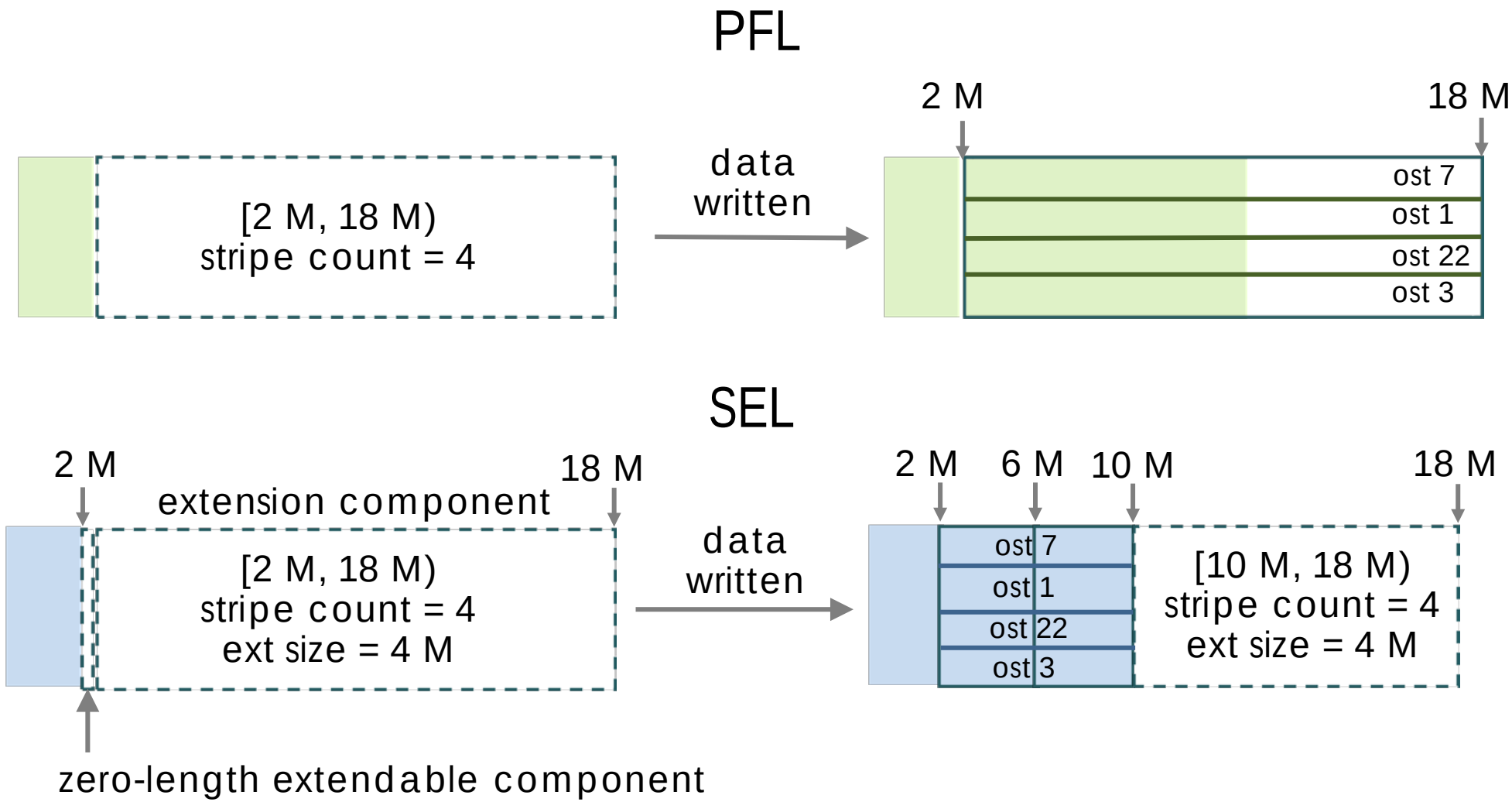
- If the `–f` option is not used, then the default name for the new file will be `<mirrored_file>.<mirror_id>`
- To destroy the mirror instead of splitting into its own file, just use the `–dI--destroy` option instead of `-f`

Self-Extending Layouts (SEL)

Self-Extending Layouts

- SEL is an extension of the PFL feature that allows the MDS to change the PFL layout dynamically if it detects OSTs running low on space
- PFL delays instantiation of some components
- SEL splits non-instantiated components into two parts
  1. An extendable component that is a regular PFL component covering a part of the region
  2. An extension component that is never instantiated and covers the remainder of the region

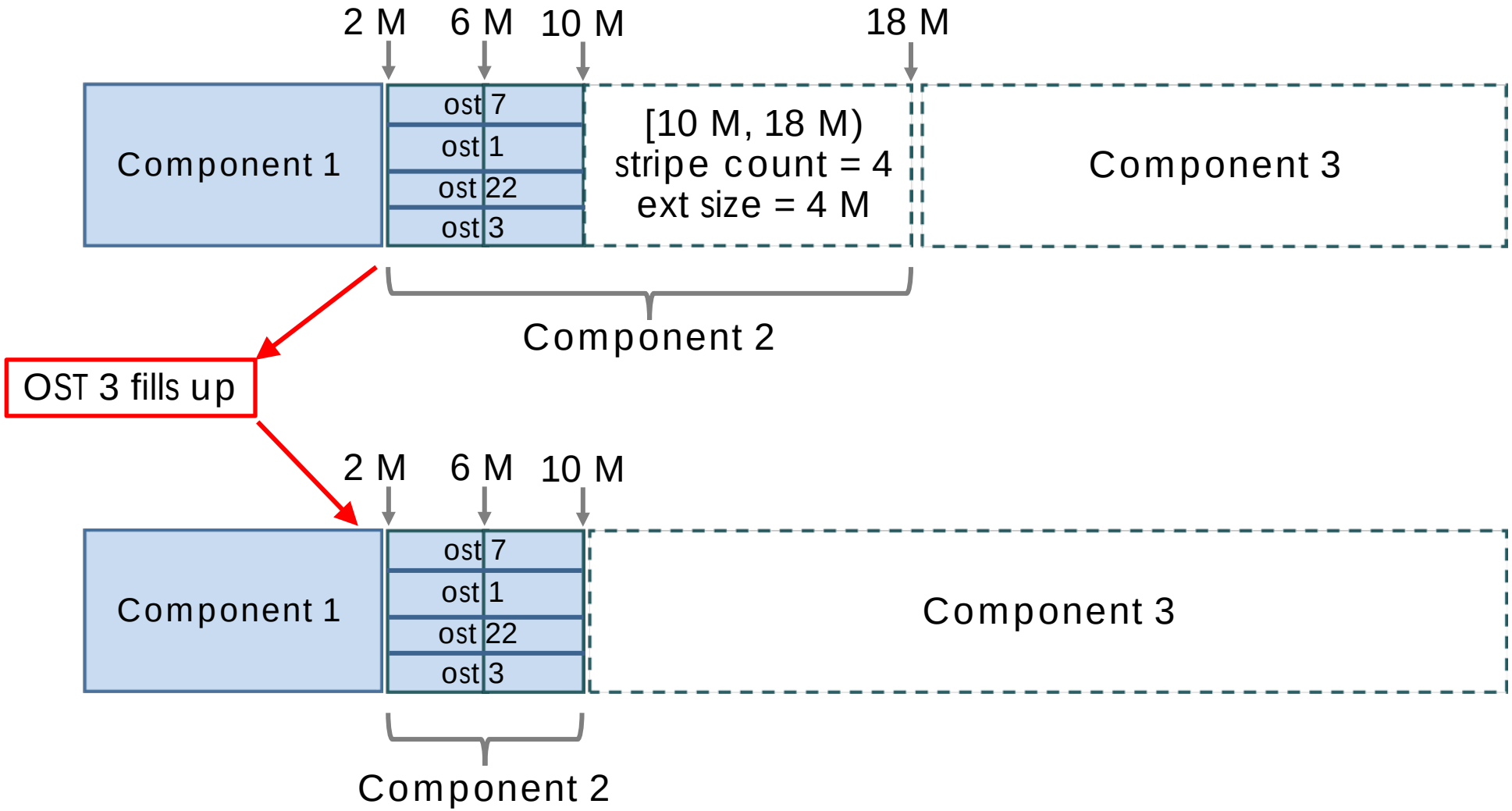
PFL Component vs. SEL Component



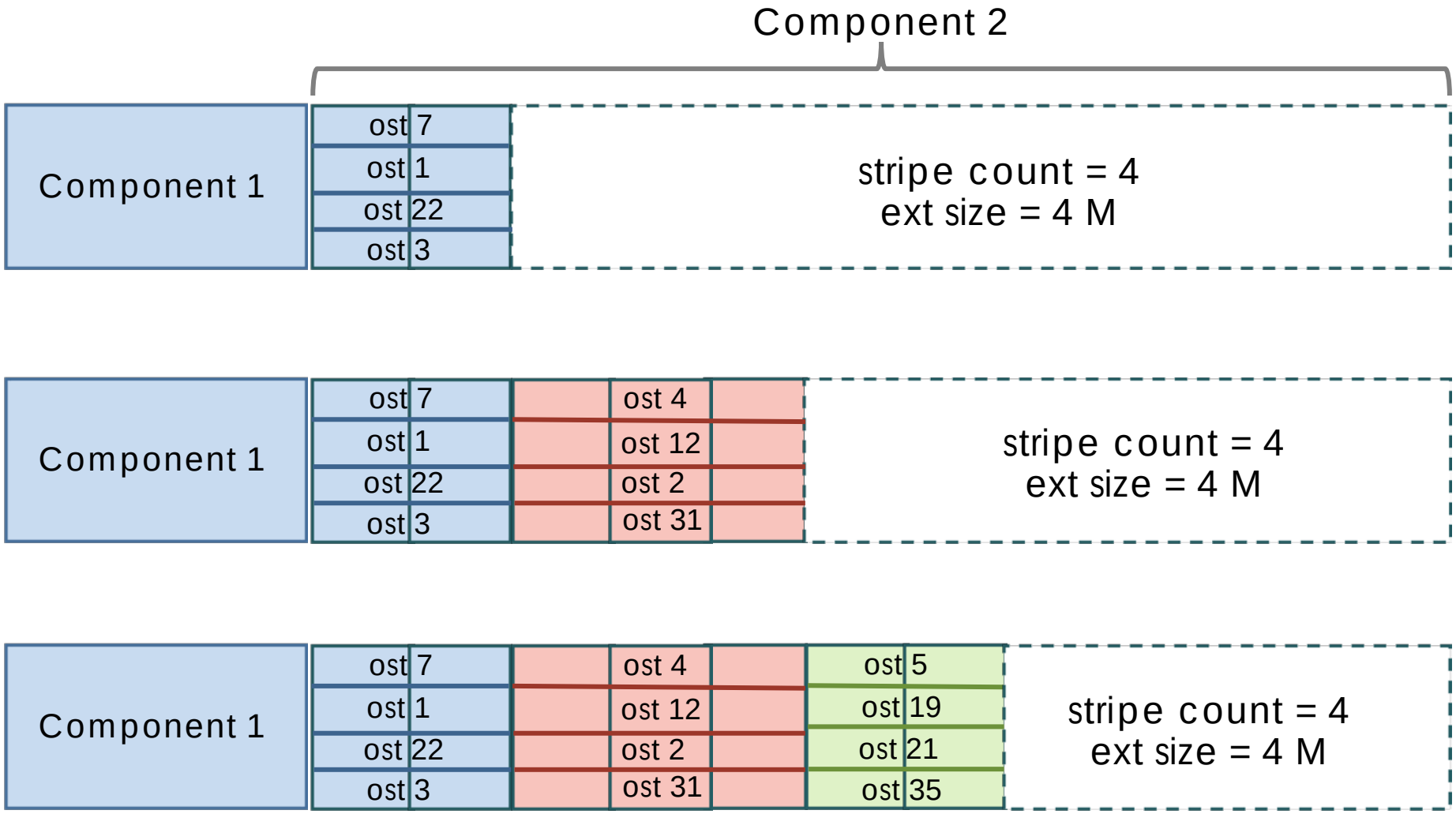
Extension Policies

- The benefit of SEL comes from what it does when an OST starts to fill up. There are four policies that handle various cases:
  1. Extension – When OSTs in current component are not low on space, continue using them (illustrated in the previous slide)
  2. Spill Over – If current component is not the last component, and one of the current OSTs is low on space, switch to next SEL component
  3. Repeating – If current component is the last component and one of the OSTs is low on space, create a new component with the same layout as the current component (but using different OSTs)
  4. Forced extension – If current component is the last component, and an attempt to repeat the layout fails due to low space, just keep using the current OSTs

Spill Over Policy



Repeating Policy



Creating a Self-Extending Layout

- Use the same command as for PFL...

```
lfs setstripe -E end1 <stripe_opts> -E end2 <stripe_opts> … <file>
```

- ...but add a `-z | --extension-size` option with the other stripe options

```
lfs setstripe -E 1G -z 64M -c 1 -E -1 -z 256M -c 4 data.txt
```

Viewing Self-Extending Layout

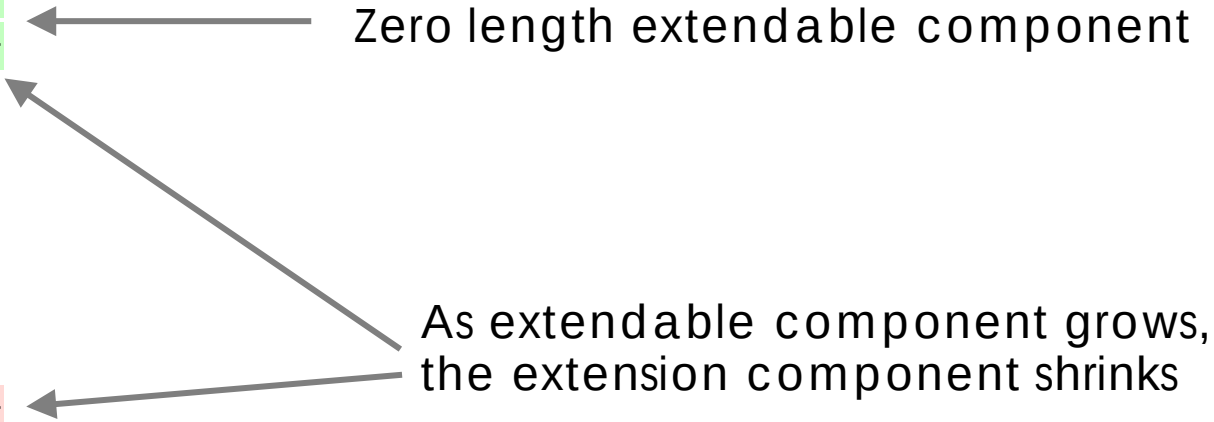
Note: Only some of the output fields are shown for brevity

```
[tmp]# lfs getstripe data.txt
data.txt
  lcm_entry_count:   4
    lcme_id:             1
    lcme_flags:          init
    lcme_extent.e_start: 0
    lcme_extent.e_end:   67108864
      lmm_stripe_count:  1
      lmm_stripe_size:   1048576
      lmm_stripe_offset: 10
      lmm_objects:
      - 0: { l_ost_idx: 10, l_fid: [0xcc000041a:0x73c2:0x0] }

    lcme_id:             2
    lcme_flags:          extension
    lcme_extent.e_start: 67108864
    lcme_extent.e_end:   1073741824
      lmm_stripe_count:  0
      lmm_extension_size: 67108864
      lmm_stripe_offset: -1
```

Denotes extension component

Viewing Self-Extending Layout (cont.)

```
lcme_id:              3
lcme_flags:           0
lcme_extent.e_start:  1073741824
lcme_extent.e_end:    1073741824
  lmm_stripe_count:   4
  lmm_stripe_size:    1048576
  lmm_stripe_offset:  -1

lcme_id:              4
lcme_flags:           extension
lcme_extent.e_start:  1073741824
lcme_extent.e_end:    EOF
  lmm_stripe_count:   0
  lmm_extension_size: 268435456
  lmm_stripe_offset:  -1
```



Acknowledgments

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Questions ?