Understanding Lustre File System Internals – A Documentation Initiative

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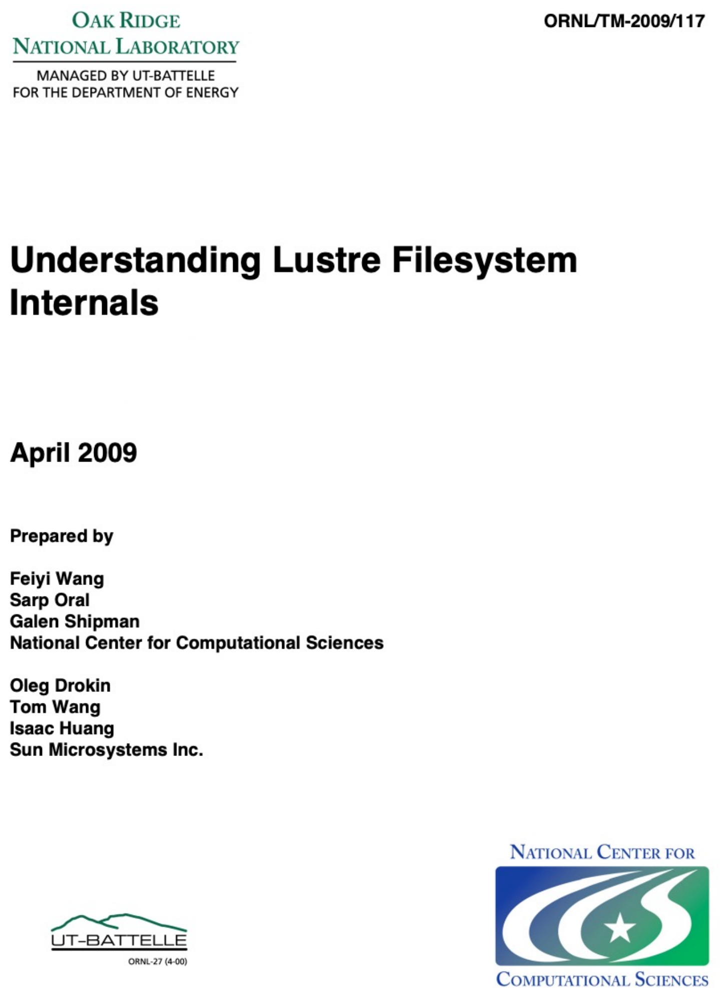
Objectives of the Presentation

- Introduce the new Lustre documentation wiki page to Lustre community
- Provide very brief overview of topics documented in the wiki page
- Invite contributions from the community to extend the documentation
- Provide insights on how to contribute to the documentation

Why Lustre Documentation ?

- Several resources exist to help deploy and configure Lustre
- But none exist to explain the internal workings of Lustre source code for developers
- An ORNL tech-report published in 2009 provided summary on various Lustre subsystem operations
- This tech report is out of date and is based on Lustre 1.6
- Several Lustre subsystems underwent significant code changes
- New features have been added to bring the current version up to 2.15



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Understanding Lustre Filesystem Internals

April 2009

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Figure 1: ORNL tech-report on Lustre internals published in 2009

Limitations with Existing Documentations

- Two main resources for Lustre developers

1. wiki.lustre.org
   - Main community repository for Lustre
   - Major Lustre topics hosted are:
     - Testing, benchmarking, monitoring, development activities and how to guides
   - Various resources that explain Lustre architecture
   - Lustre 101: provides information on Lustre usage on administration
2. Lustre Operations manual
   - Information and procedures to configure Lustre
   - Topics include failover, striping, troubleshooting, configuration and maintenance

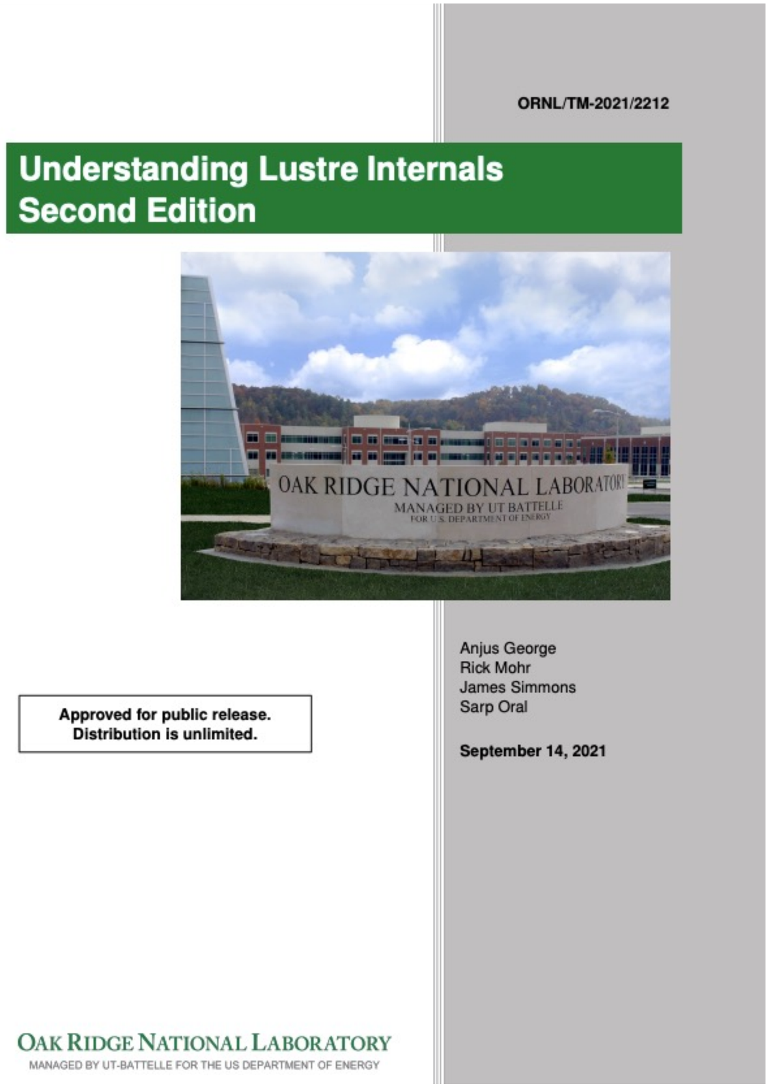
- None cover Lustre source code documentation

The New Documentation Effort

- Need a comprehensive documentation for Lustre internal mechanics for developers
- To prepare the documentation, we planned to explore and study source code for different subsystems
- Scheduled Lustre code deep dive sessions within the team of Lustre developers
- Documented key data structures and APIs pertaining to each subsystem
- Importance was given to interfaces through which subsystems communicate and function call graphs
- Made sure to represent the code flow and data structures wherever possible

ORNL Tech-Report Second Edition

- Published second edition of the ORNL tech-report (https://info.ornl.gov/sites/publications/Files/Pub166872.pdf)
- Aims to document the internal workings of the latest version of Lustre
- More complete and up-to-date information than the previous tech-report
- Key data structures and APIs used for interaction among the various Lustre subsystems
- Details in this document should remain relevant for the foreseeable future


ORNL/TM-2021/2212

Understanding Lustre Internals
Second Edition

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September 14, 2021

Approved for public release.
Distribution is unlimited.

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Figure 2: Latest ORNL tech-report on Lustre internals published in 2021

Wiki page – "Understanding Lustre Internals"

- Hosted in main community repository for Lustre 'wiki.lustre.org'
  - https://wiki.lustre.org/Understanding_Lustre_Internals
- Major sections and subtopics include,
  - Lustre architecture featuring its core components
  - Software stack
  - File layouts
  - Lustre test suite
  - User utilities
  - Core subsystems including,
    - MGC
    - Obdclass
    - Libcfs
    - Fld
    - Fid

Overview of the Topics Documented

1. **Lustre Architecture**
   - Lustre features and scalability and performance numbers
   - Lustre components including management, metadata and object storage servers and targets
   - Lustre file layout describing two categories: Normal and composite layouts

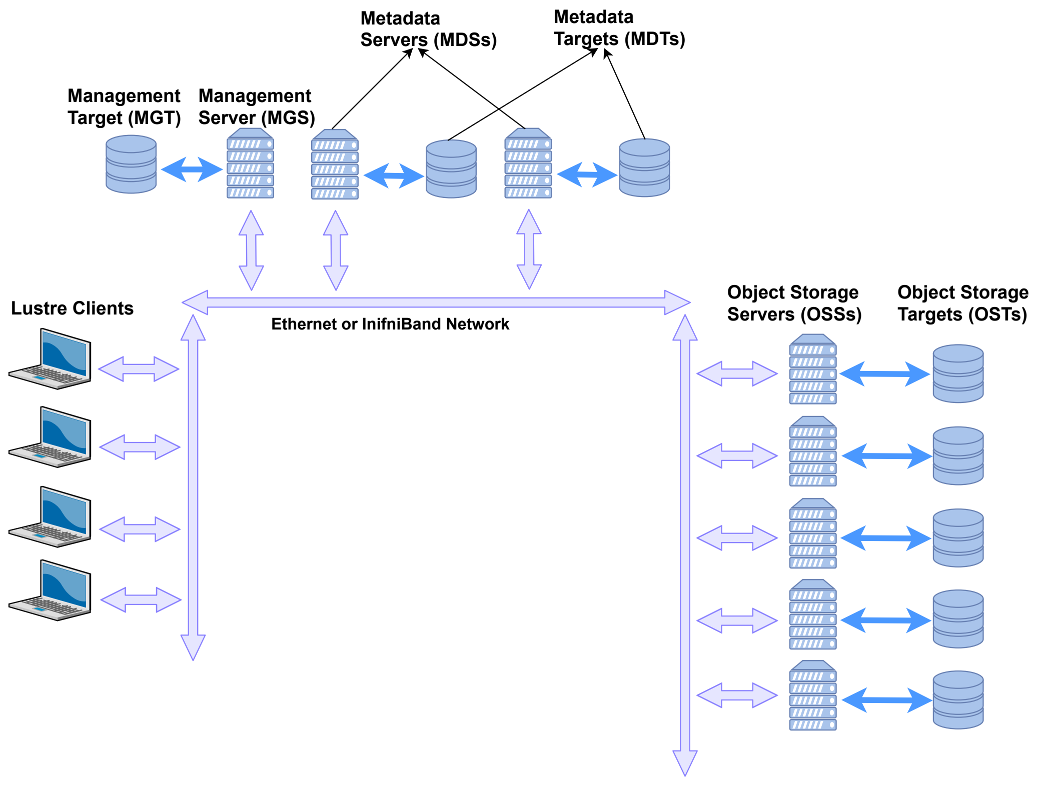

Figure 3: Lustre file system components in a basic cluster[1]

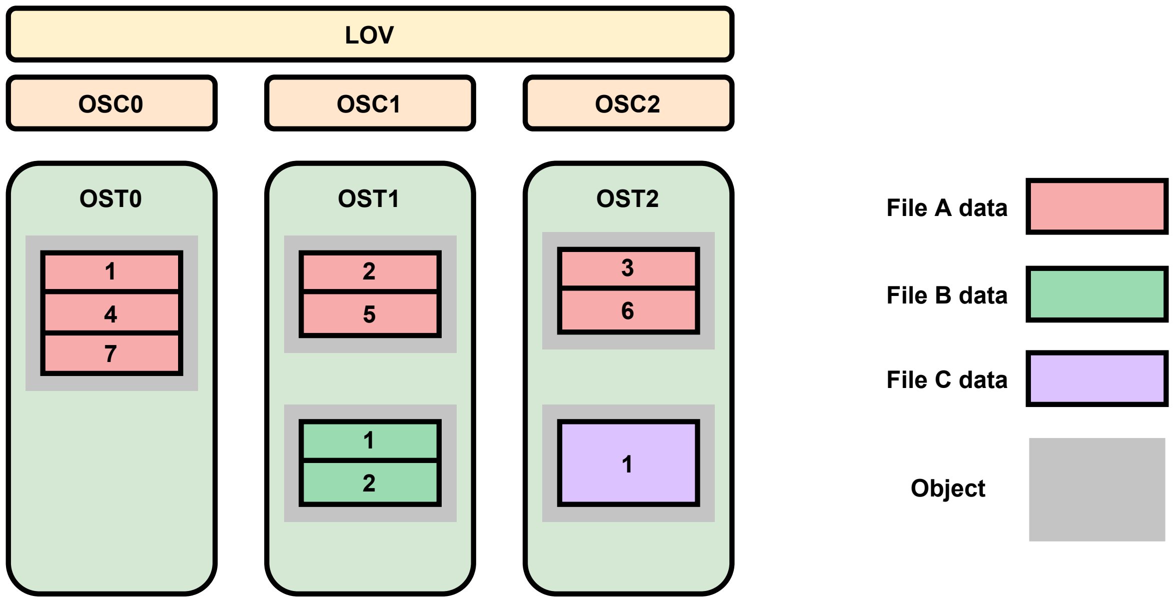

Figure 4: Normal RAID0 file striping in Lustre[1]

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Overview of the Topics Documented

1. Lustre Architecture (cont.)

- Synopsis on distributed namespace, file identifiers and layout attributes
- Basic view of Lustre software stack

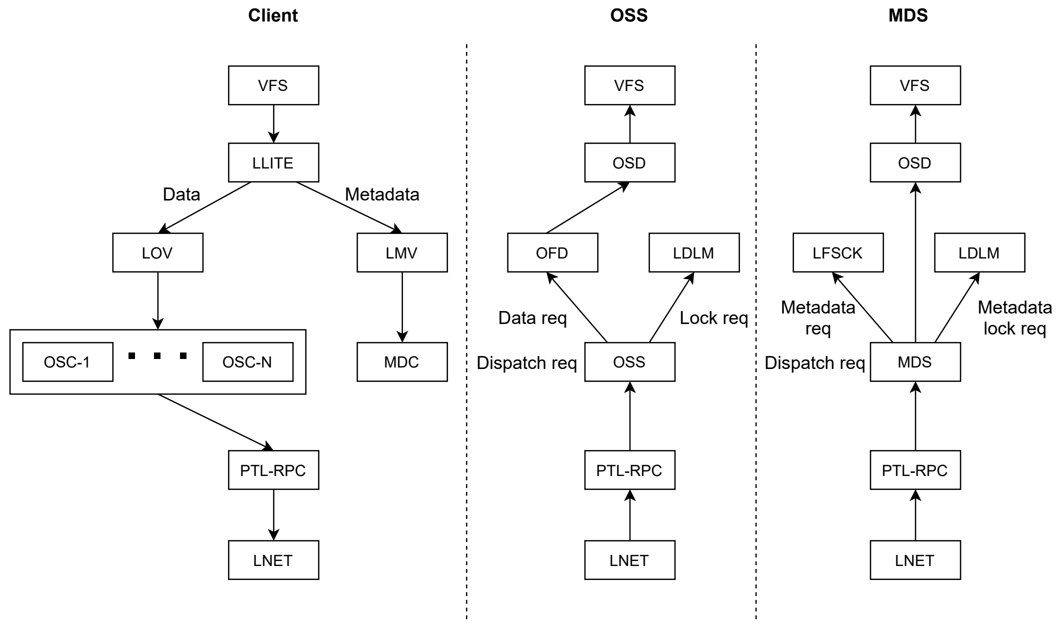


Figure 5: Basic view of the Lustre software stack[1]

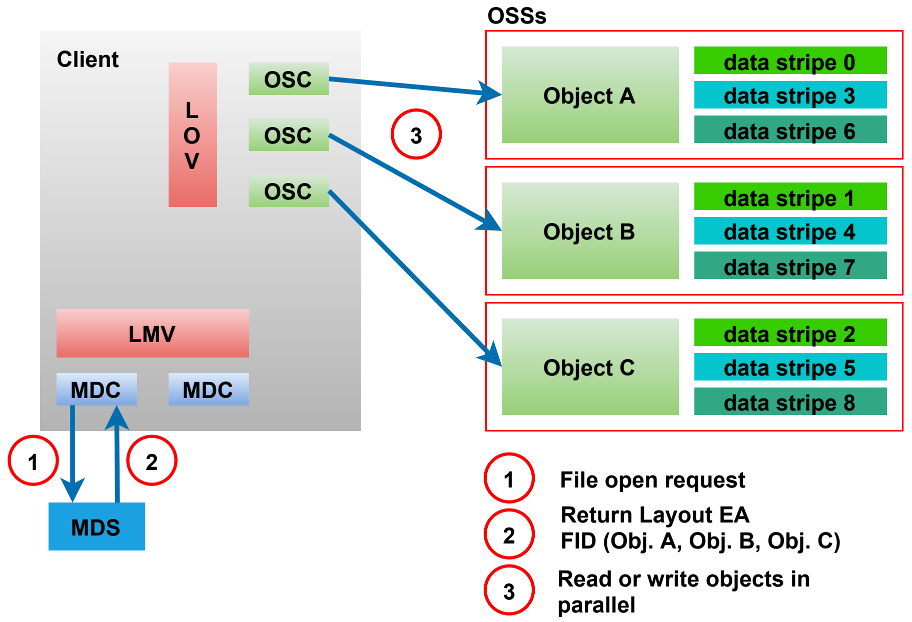


Figure 6: Lustre I/O operation: Lustre client requesting file data[1]

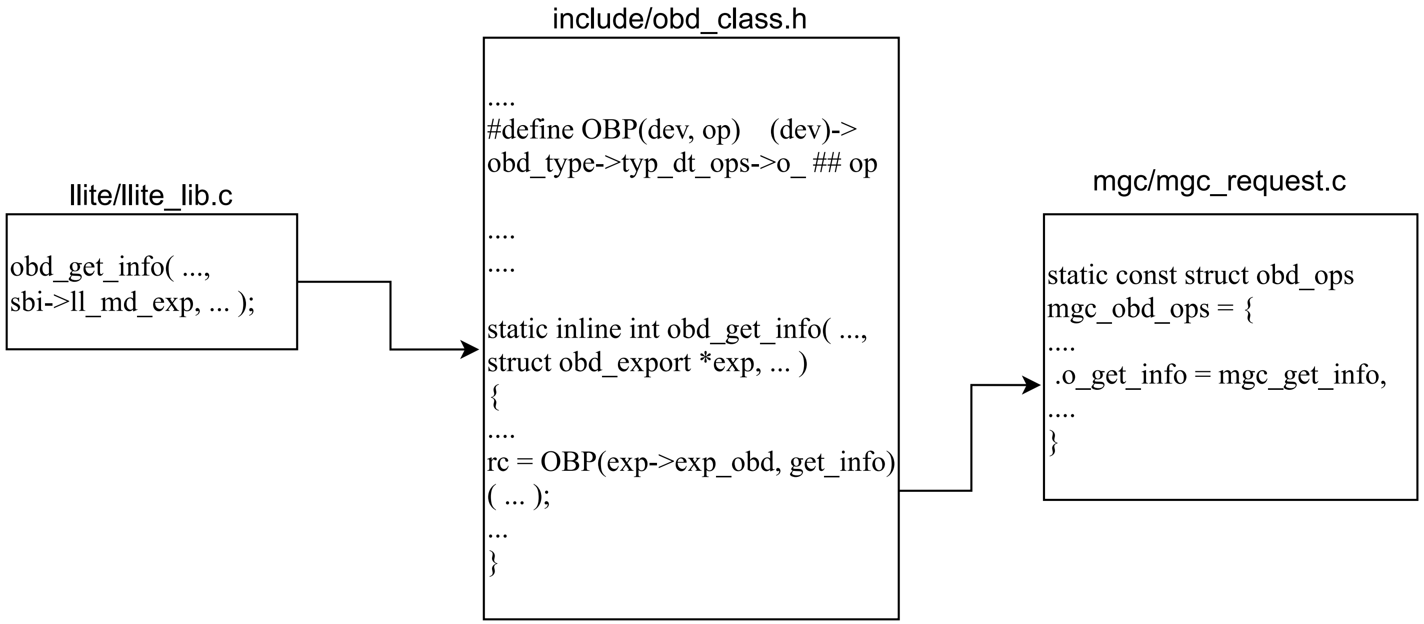
Overview of the Topics Documented

2. **Lustre Tests**
   - Lustre test suite components
   - Various Lustre unit, feature and regression tests
   - Test framework options
   - Acceptance testing on Lustre
   - Lustre tests environment variables
3. **Utils**
   - User utilities including `lfs, lfs_migrate, lctl, llog_reader`
   - `mkfs.lustre, mount.lustre` and `tunefs.lustre`

Overview of the Topics Documented

4. MGC

- Starting from MGC module initialization with registering of MGC obd device
- MGC obd operations with an example of communication between llite and MGC through Obdclass
- Detailed walkthrough of `mgc_setup()`, `mgc_precleanup()`, `mgc_cleanup()` and `mgc_import_event()` methods
- Lustre log handling and log processing in MGC



```
obd_get_info( ...,
sbi->ll_md_exp, ... );
```

```
....
#define OBP(dev, op)    (dev)->
obd_type->typ_dt_ops->o_ ## op

....
....

static inline int obd_get_info( ...,
struct obd_export *exp, ... )
{
....
rc = OBP(exp->exp_obd, get_info)
( ... );
...
}
```

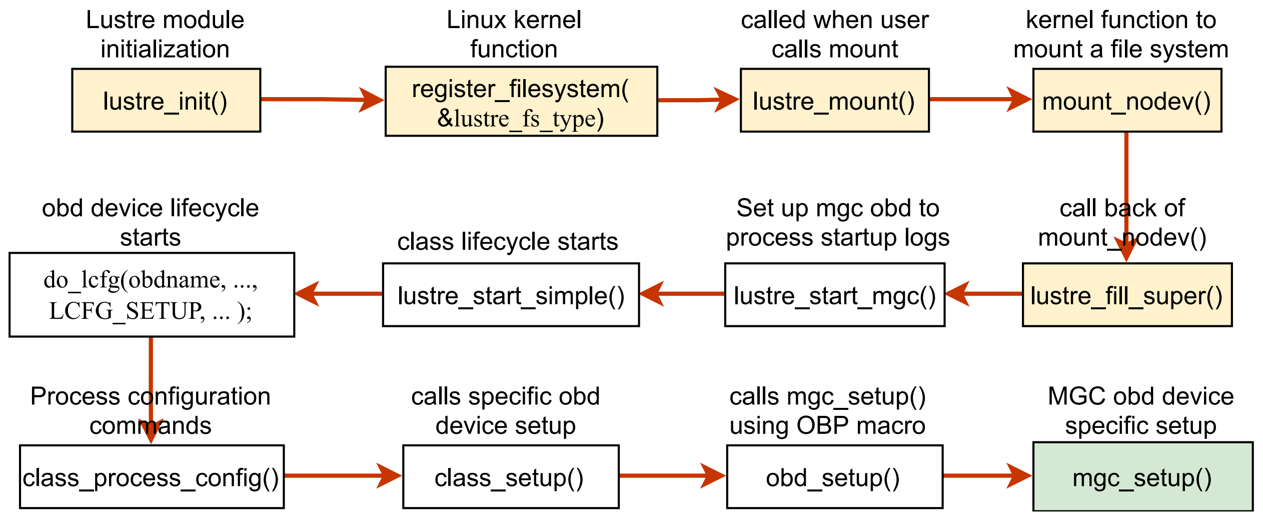
```
static const struct obd_ops
mgc_obd_ops = {
....
 .o_get_info = mgc_get_info,
....
}
```

Figure 7: Communication between llite and mgc through obdclass[1]

Overview of the Topics Documented

4. MGC (cont.)

- `mgc_setup()` with function call graphs
- Comparison of code flow for MGC setup and cleanup processes



Lustre module initialization
lustre_init()
Linux kernel function
register_filesystem(&lustre_fs_type)
called when user calls mount
lustre_mount()
kernel function to mount a file system
mount_nodev()
call back of mount_nodev()
lustre_fill_super()
Set up mgc obd to process startup logs
lustre_start_mgc()
class lifecycle starts
lustre_start_simple()
obd device lifecycle starts
do_lcfg(obdname, ..., LCFG_SETUP, ...);
Process configuration commands
class_process_config()
calls specific obd device setup
class_setup()
calls mgc_setup() using OBP macro
obd_setup()
MGC obd device specific setup
mgc_setup()

Figure 8: mgc_setup() call graph starting from Lustre file system mounting[1]

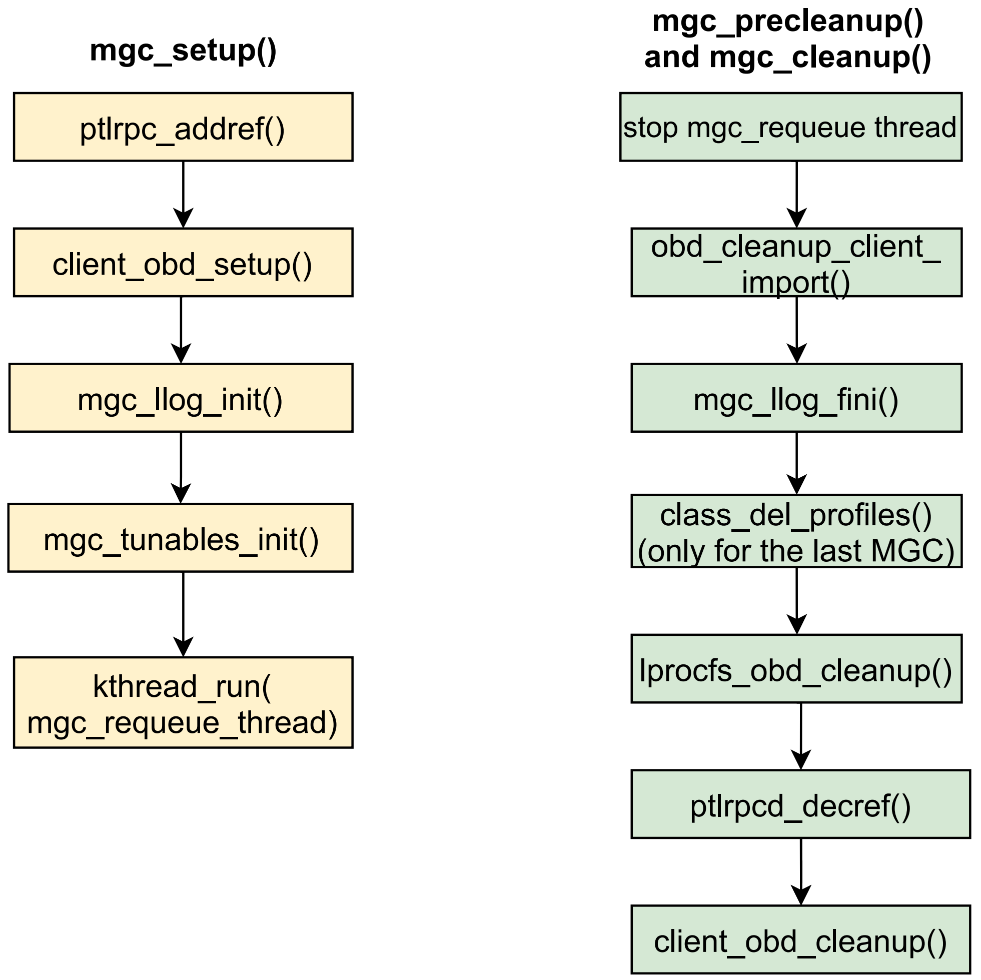


Figure 9: mgc_setup() vs. mgc_cleanup()[1]

Overview of the Topics Documented

5. Obdclass

- `obd_device` structure defining an obd device
- Detailed walkthrough of MGC lifecycle
- Obd device lifecycle through various functions such as `class_attach(), class_setup(), class_precleanup(), class_cleanup()` and `class_detach()`
- Various other data structures including `obd_type, lu_device_type, obd_export, obd_import` and `client_obd`
- Concept of imports and exports through which obd device communication is established

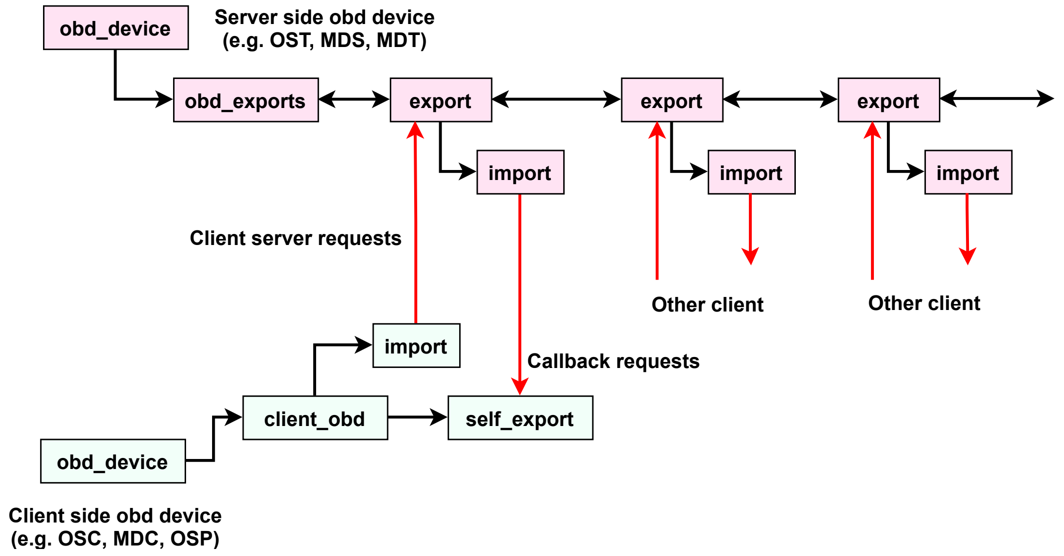


Figure 10: Import and export pair in Lustre[1]

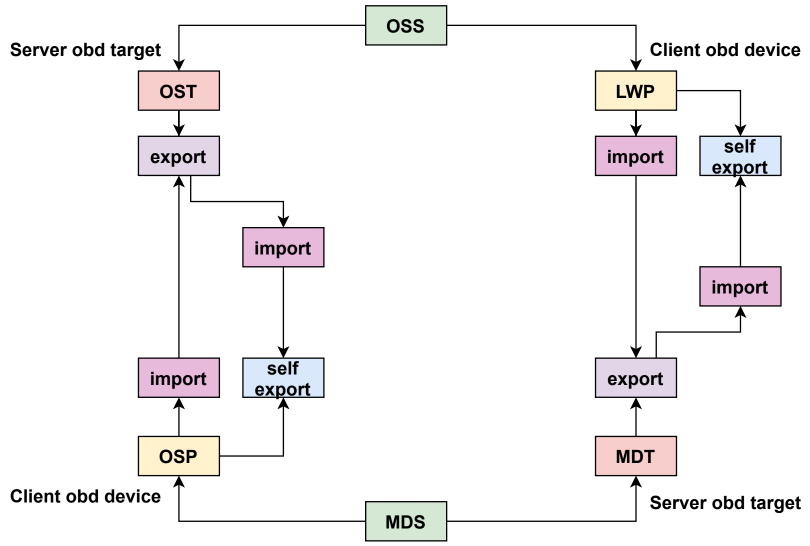


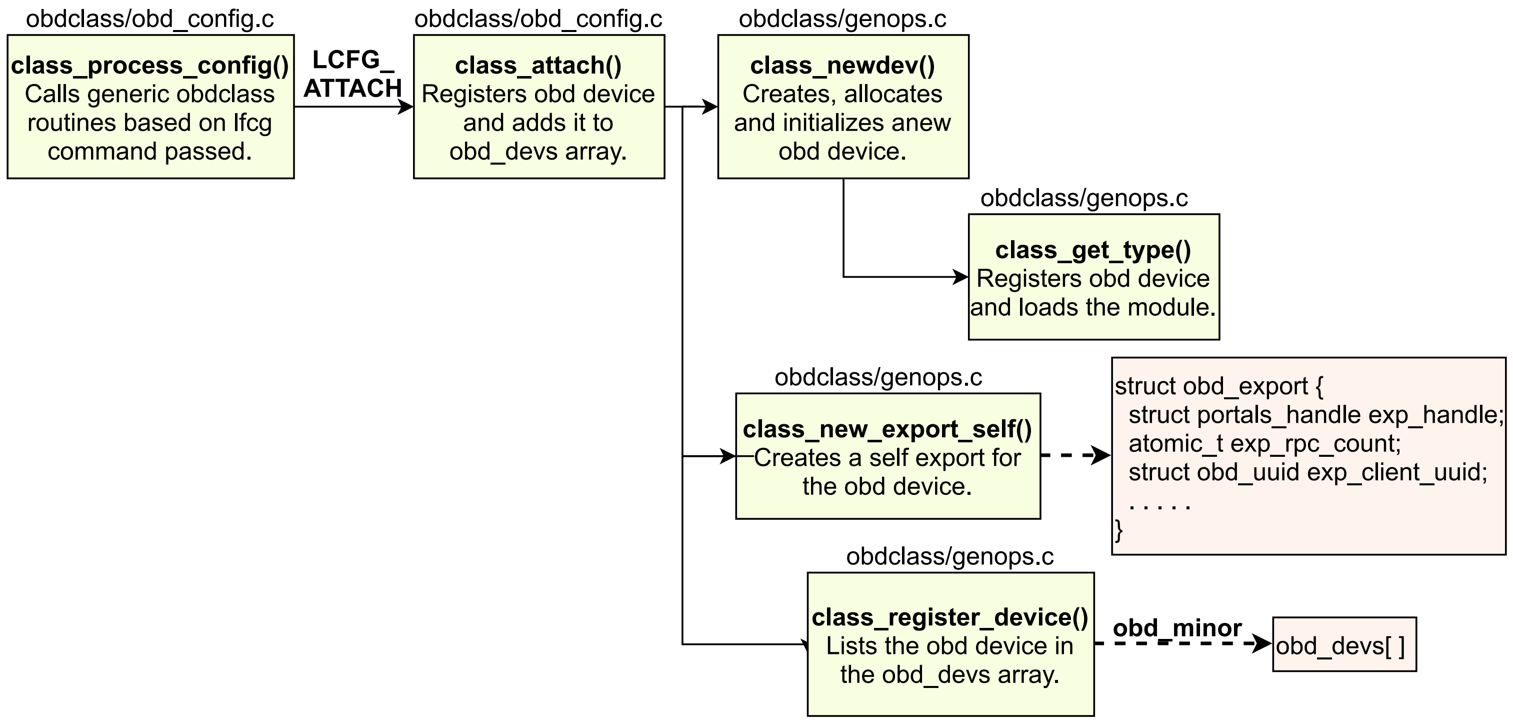
Figure 11: Communication between ost and mdt server obd devices in Lustre[1]

Overview of the Topics Documented

5. **Obdclass**

   – **`class_attach()`**

     - First method in the obd device life cycle
     - Major functionalities are,
       - – Registers and adds the obd device to the list of obd devices
       - – Creates, allocates and initializes a new obd device
       - – Populates `obd_export` structure
       - – Adds the device to `obd_devs` array


obdclass/obd_config.c
class_process_config()
Calls generic obdclass routines based on lfcg command passed.
LCFG_ ATTACH
obdclass/obd_config.c
class_attach()
Registers obd device and adds it to obd_devs array.
obdclass/genops.c
class_newdev()
Creates, allocates and initializes anew obd device.
obdclass/genops.c
class_get_type()
Registers obd device and loads the module.
obdclass/genops.c
class_new_export_self()
Creates a self export for the obd device.
obdclass/genops.c
class_register_device()
Lists the obd device in the obd_devs array.
obd_minor
obd_devs[ ]

```
struct obd_export {
  struct portals_handle exp_handle;
  atomic_t exp_rpc_count;
  struct obd_uuid exp_client_uuid;
  . . . . .
}
```

Figure 13: Workflow of class_attach() function in obd device lifecycle[1]

Overview of the Topics Documented

5. **Obdclass**
   - **`class_setup()`**
     - Create hashtables and self-export
     - Sets the `obd_starting` flag from `obd_device` structure
     - Can view the function call workflow and data structures
     - Data structures involved are `client_obd` and `obd_import`

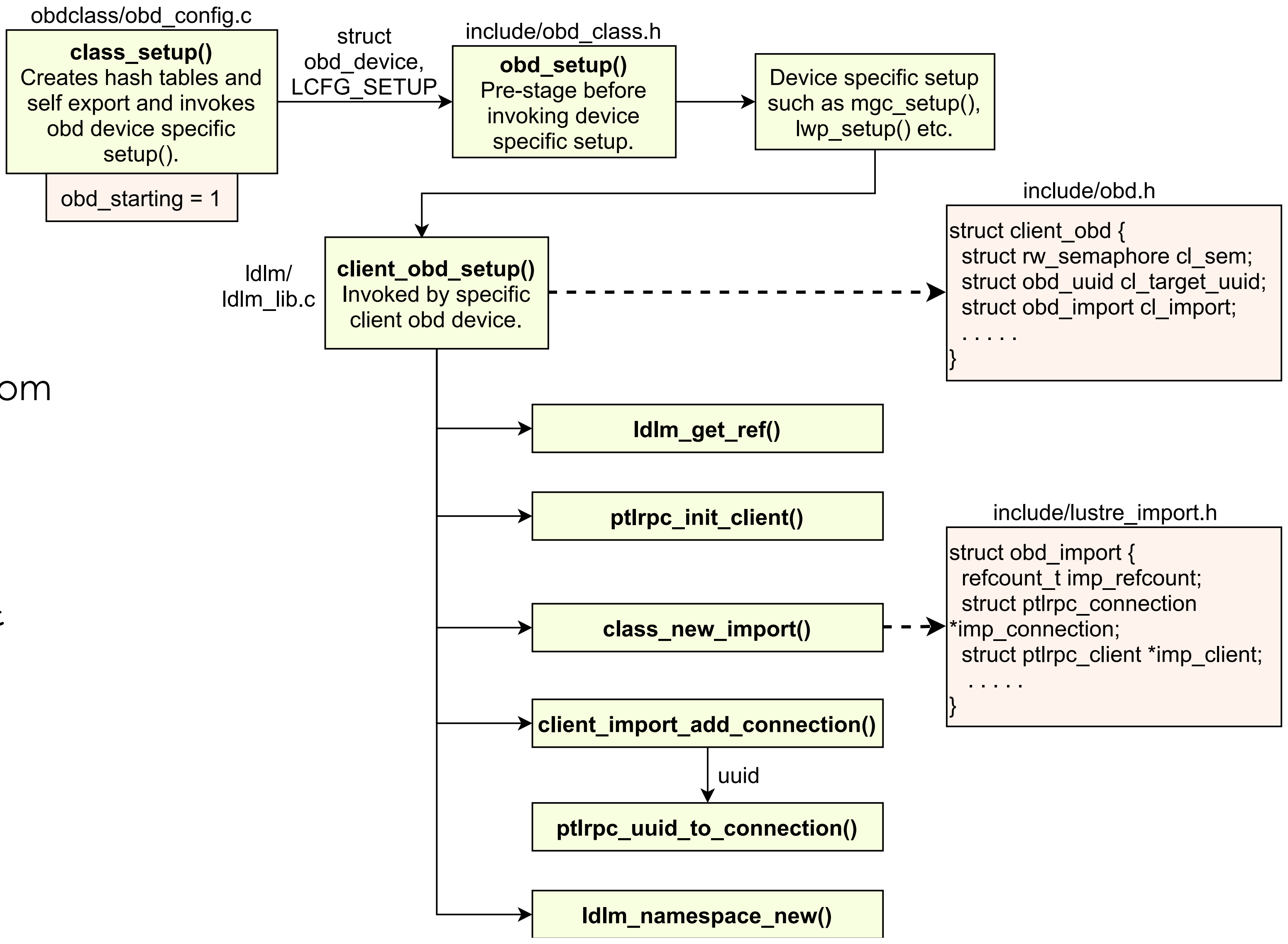

obdclass/obd_config.c
class_setup()
Creates hash tables and self export and invokes obd device specific setup().
obd_starting = 1
struct obd_device, LCFG_SETUP
include/obd_class.h
obd_setup()
Pre-stage before invoking device specific setup.
Device specific setup such as mgc_setup(), lwp_setup() etc.
ldlm/ ldlm_lib.c
client_obd_setup()
Invoked by specific client obd device.
include/obd.h
struct client_obd {
struct rw_semaphore cl_sem;
struct obd_uuid cl_target_uuid;
struct obd_import cl_import;
. . . . .
}
ldlm_get_ref()
ptlrpc_init_client()
include/lustre_import.h
struct obd_import {
refcount_t imp_refcount;
struct ptlrpc_connection *imp_connection;
struct ptlrpc_client *imp_client;
. . . . .
}
class_new_import()
client_import_add_connection()
uuid
ptlrpc_uuid_to_connection()
ldlm_namespace_new()

Figure 14: Workflow of class_setup() function in obd device lifecycle[1]

Overview of the Topics Documented

6. **Libcfs**
   - Data encryption support in Libcfs
     - Two types of encryption capabilities: data on the wire and data at rest
   - CPU partition table management
     - Data structures and definitions for CPU and CPT defined in `libcfs_cpu.c`
   - Debugging support and failure injection
     - Macros that report errors and warnings are defined in `libcfs_debug.h`
   - Additional supporting software in Libcfs
     - Implementation of portable time API, resizable arrays, spin locks, atomic_t for reference counts

Overview of the Topics Documented

7. **File Identifiers, FID Location Database, and Object Index**
   - Detailed description of Lustre file identifiers
     - FID allocation process and description FID structure (`lu_fid`) fields
   - Concept of reserved sequence numbers and object IDs
     - Details on reserved sequence ranges used by Lustre such as IGIF, IDIF, OST_MDT0, LLOG, ECHO, and OST_MDT1
   - Functionality of fid kernel module
     - Fid module initialization, sequence number allocation, cleanup routine
   - Contents related to FID Location Database (FLD) and Object Index (OI)
     - Source code files pertaining to FLD and functions for interacting with OI

Future Extensions to the Wiki Page

Already documented	To be documented
• Lustre Architecture • Subsystems – • TESTS • UTILS • MGC • OBDCLASS • LIBCFS • FLD • FID	• LNET • Subsystems – • LDLM • LLITE • LMV • OSP • PTLRPC • MDC • And a few more …

- Plan to document all subsystems in Lustre

Inviting Community Contributions

- We are interested in making this documentation a community effort
- We invite more contributions from the Lustre community,
  - To extend the documentation by adding contents related more Lustre subsystems
  - To keep the documentation UpToDate with Lustre source code changes
- Lustre users/admins/developers are welcome to contribute towards this documentation

How to Contribute ?

- Create an account in wiki.lustre.org
- wiki.lustre uses Mediawiki in the backend
- Contents can be easily added and are not syntax heavy like latex
- Various extensions are already enabled for adding images, cross referencing etc.
- Source code snippets, figures and tables can be directly added using simplified syntax
- Useful resources for documentation discussion,
  - Jira ticket - LUDOC-498
  - Slack channel - #lustre-internals-document

Acknowledgements

- Thanks to Lustre team at ORNL – James Simmons, Rick Mohr and Sarp Oral
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- Great resources that helped me when I started to learn and document Lustre,
  - wiki.lustre.org
  - Lustre operations manual
  - wiki.whamcloud.com
- References

1. George, Anjus, Mohr, Rick, Simmons, James, and Oral, Sarp. Understanding Lustre Internals Second Edition. United States: N. p., 2021. Web. doi:10.2172/1824954.

Thank you!

Questions?