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Using the DLM as a Distributed In-Memory Database

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Overview

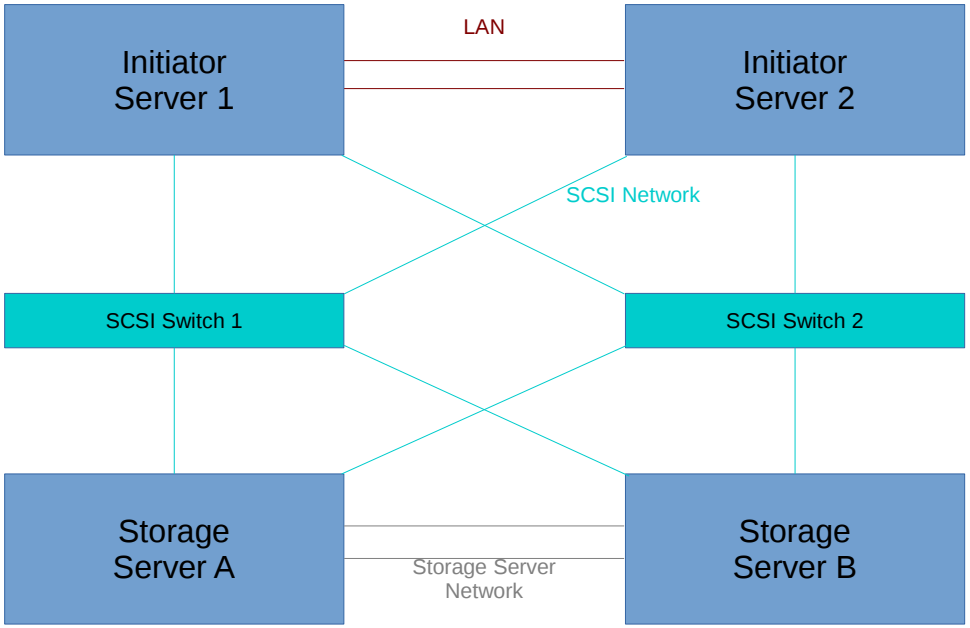
- Introduction
- Initiator-side Clustering
- Persistent Reservation Support for HA Arrays
- Distributed Lock Manager (DLM)
- Using the DLM to Implement PR Support

Introduction

- SCSI specs require that all nodes in a multi-node array report the same state information.
- Many people build a H.A. storage array with iSCSI target software + H.A. software + data replication software.
- Complies to most SCSI requirements except:
  - Persistent reservations (PR).
  - Mode pages.
- Proper PR support is required for initiator-side clustering.

Initiator-side Clustering

- Redundant initiator and storage systems.
- Witness disk is used to decide initiator server master role.
- Witness disk ownership via SCSI persistent reservations.



Persistent Reservation Support for HA Arrays

- Multiple storage servers but …
- Single persistent reservation state.
- Challenges:
  - Implement single PR state efficiently.
  - Handle node join, power cycle, split-brain etc. correctly.

Distributed Lock Manager (DLM)

- A distributed lock manager (DLM) provides distributed software applications with a means to synchronize their accesses to shared resources.
- Was added in 2006 to the Linux kernel as a kernel driver.
- Core component for GFS2, OCFS2, CLVM, …
- Features
  - Supports user space and kernel applications.
  - Allows to serialize access to shared resources.
  - Provides reader/writer lock objects.
  - One lock value block per lock object.
  - Supports remote procedure calls.

DLM Lock Objects

- Each lock object exists in a DLM lockspace.
- Maximum lockspace name length: 64.
- Maximum lock object name length: 32.
- Lock Value Block (LVB)
  - Length must be a multiple of 8.
  - Max. 32 bytes for user space applications.
  - Kernel code can use larger LVB's.

DLM Lock Modes

Mode	Requesting Process	Other Processes
Null (NL)	No access	Read or write access
Concurrent Read (CR)	Read access only	Read or write access
Concurrent Write (CW)	Read or write access	Read or write access
Protected Read (PR)	Read access only	Read access only
Protected Write (PW)	Read or write access	Read access only
Exclusive (EX)	Read or write access	No access

DLM API

- dlm_lock()
  - Asynchronously convert to a higher or lower lock mode.
  - Optionally invoke a callback function on each other node that holds a lock that blocks this conversion (BAST = blocking AST).
  - Optionally invoke a callback function on the local node when the new lock mode is granted (AST = asynchronous system trap).
  - After the new mode has been granted, reports whether or not the LVB is valid (DLM_SBF_VALNOTVALID flag).
- dlm_cancel(): cancel a conversion requested via dlm_lock().
- dlm_unlock(): discard a DLM lock object and also its LVB.
- The LVB is invalidated:
  - If a node holding a lock object in EX or PW mode fails.
  - If a node joins the cluster as master and only NL/CR locks are left.

Lock Value Block (LVB) Propagation

- Converting to a higher mode returns the LVB to the caller (e.g. CR → EX).
- Converting to a lower mode updates the LVB on all nodes (e.g. EX → CR).
- Using the DLM as a distributed in-memory database is possible:
  - By using the namespace + lock object name as key.
  - By using the LVB as value.
  - By using e.g. the CR → EX conversion to read the LVB and the EX → CR conversion to publish a modified LVB.

DLM and Read Access

- Two approaches are possible to obtain the latest contents of the LVB:
  - Obtain read access on the lock object associated with the LVB (best for infrequent reads).
  - Use the BAST mechanism to keep all LVB copies up-to-date all the time (best for frequent reads).

DLM - Implementing Update Notifications

- Create pre.<n> and post.<n> notification lock objects where <n> is the node ID assigned by the cluster management software.
- Initialize pre.<n> to EX and post.<n> to the NL state.
- Associate a BAST with each of these lock objects.
- Send a notification and wait until remote data copies have been updated by converting lock object pre.<n> first to PR and next to NL. Subsequently convert lock object post.<n> to PR and next to NL.
- In the pre.<n> BAST, convert the post.<n> lock object from NL to EX mode and the pre.<n> lock object from EX to NL mode.
- In the post.<n> BAST, convert the pre.<n> lock object from NL to EX mode, make a local copy of the updated data and convert the post.<n> lock object from EX to NL mode.
- Advantage: cluster membership changes are handled transparently.
- Disadvantage: certain cluster membership changes result in data loss.

DLM - Implementing Update Notifications

Updater	Every node i
	Initialize pre.<i> to EX; post.<i> to NL
Update LVB	
for i in (all other nodes): request pre.<i> → PR	
	Convert post.<i> NL → EX
	Convert pre.<i> EX → NL
pre.<i> PR → NL	
request post.<i> → PR	
	Convert pre.<i> NL → EX
	Make a local copy of the updated LVB
	Convert post.<i> EX → NL
post.<i> PR → NL	

Implementing Persistent Reservations (1/2)

- One DLM lockspace per LUN.
- One lock object per LUN for which the LVB contains:
  - Number of registrants
  - Whether or not the device has been reserved persistently.
  - Persistent reservation type.
  - Persistent reservation scope.
  - Value of APTPL (activate persistence through power loss).
- One lock object per LUN and per reservation key containing:
  - Reservation key.
  - Relative target ID.
  - Transport ID (up to 228 bytes for iSCSI).

Implementing Persistent Reservations (2/2)

- A lock object per LUN that serializes PR data changes.
- Propagating PR data changes via notifications.
- Each node persists APTPL reservations locally and reapplies these during boot.
- Result: an efficient and resilient SCSI PR implementation for clusters.

Cluster Node ID Discovery

- Notification mechanism needs to know node IDs of other cluster nodes.
- Node IDs are discovered by reading contents of /sys/kernel/config/dlm/cluster/comms directory.
- Node IDs are read during initialization, after an update has been published and also after an update notification has been received.

Handling Cluster Membership Changes

- If a node leaves the cluster
  - DLM handles this transparently.
- If a node joins the cluster
  - New node copies PR state from LVB's into local state.
  - If one or more of the LVB's were invalid, trigger an LVB update.
- LVB update
  - Send an LVB update notification to other nodes.
  - Each node that receives this notification copies its PR state to LVB's.
  - These LVB updates are serialized – last update takes effect.

Handling Split-Brain

- Cluster manager must stop one of the two partitions
- After the split-brain has been resolved, the same procedure is applied as when a node joins the cluster.
- If a node joins the cluster
  - New node copies PR state from LVB's into local state.
  - If one or more of the LVB's were invalid, trigger an LVB update.
- LVB update
  - Send an LVB update notification to other nodes.
  - Each node that receives this notification copies its PR state to LVB's.
  - These LVB updates are serialized – last update takes effect.

Possible Alternatives for the DLM

- Google's Chubby Lock Service
  - Userspace only
  - userspace / kernel barrier would have to be crossed twice for each distributed lock operation.
  - Strict ordering of updates is not needed for PR.
  - *design emphasis is on availability and reliability, as opposed to high performance* [Bu06].
- Zookeeper
  - Closely related to Chubby according to [Vi11].

References

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Any questions or comments ?

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