Next Generation ESX Storage:

A Pluggable Core Storage Architecture

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Motivation

- The current ESX storage stack is highly functional, but limited in flexibility and extensibility.

- The Pluggable Core Storage Architecture addresses these limitations.
  - Implements clear APIs between the various components of the storage stack.
  - Allows third party software vendors to port their proprietary multipathing and load balancing code to the ESX platform.
  - Allows SAN array hardware vendors to write device specific code for ESX that takes advantage of advanced array features without compromising proprietary information.

Audience

- This presentation is focused at software developers and development managers.
- The aim is to describe the current state of the ESX Pluggable Core Storage Architecture and ellicit feedback from our partners and customers about their needs in this area.

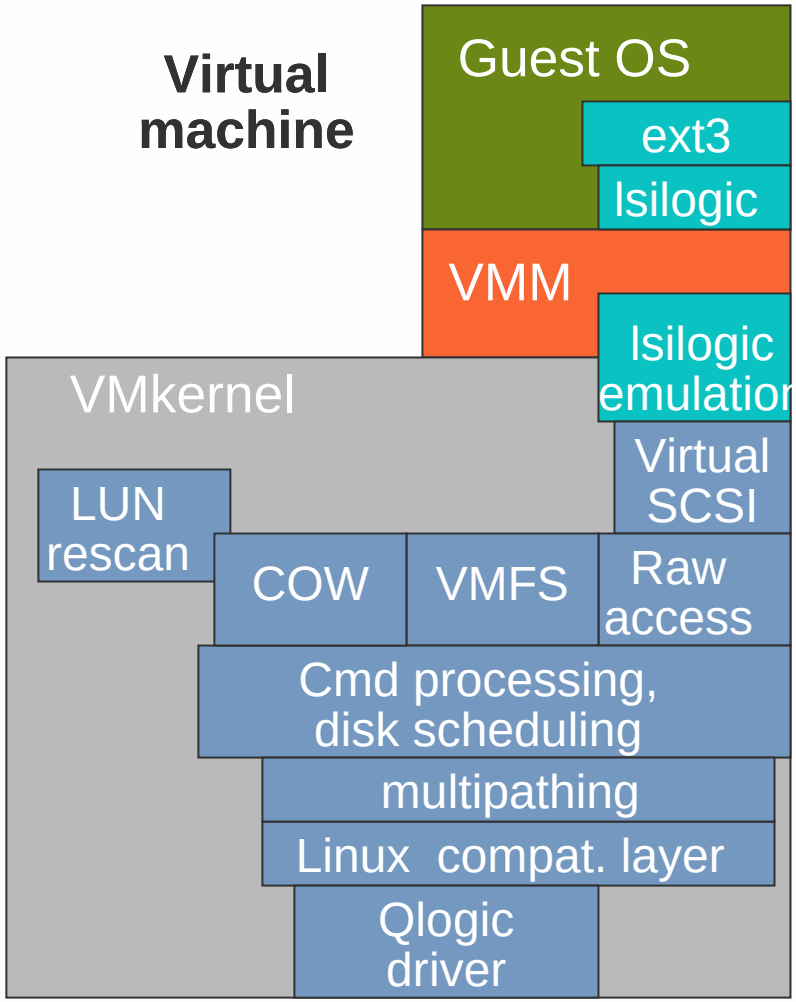
Outline

- Core Storage Architecture Definition
- Motivation For Change
- ESX Storage Architecture
  - Existing Storage Architecture
  - New Storage Architecture
- ESX Storage Plugin
  - Storage Plugin Framework Functionality
  - Storage Plugin Functionality
- Native Multipathing Implementation of an ESX Storage Plugin

Definition

- ESX Core Storage Architecture
  - The part of the storage stack that resides in the ESX operating system (vmkernel)
    - “below” the Virtual SCSI implementation,
    - “above” the Linux compatibility and physical disk driver layers

Core Storage Architecture



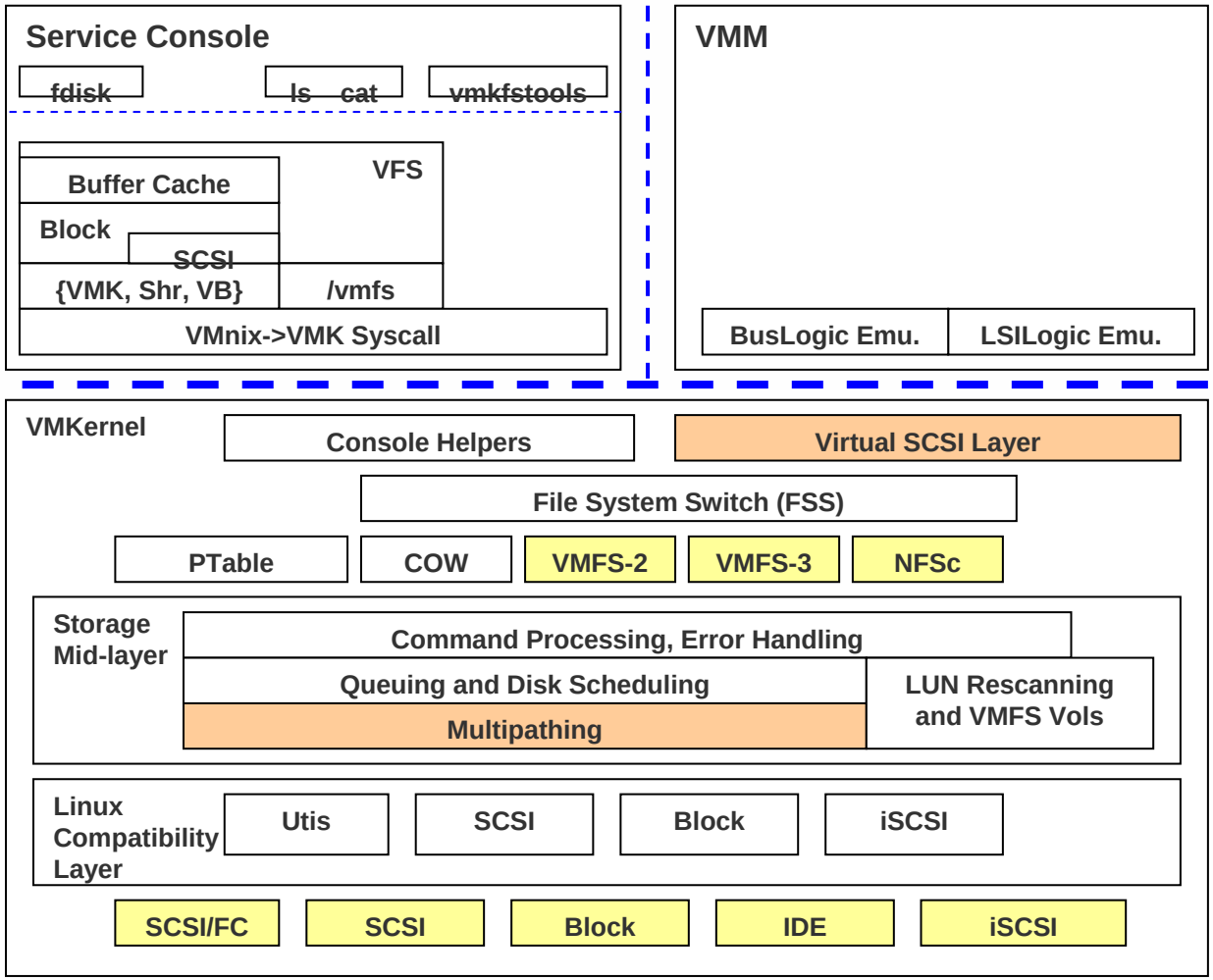
- Common illustration of vmkernel architecture
- Core Storage Architecture Includes
  - Part of command processing
  - Disk scheduling
  - Path scanning
  - Multipathing

Motivation for Changing the Core Storage Architecture

- Enhance the ESX Server infrastructure for storage partner integration
  - Empower Software partners to port their proprietary multipathing products to the ESX platform
  - Allow Storage partners to take full advantage of their device specific functionality within ESX
    - Protect array specific code from regression (recertification)
  - Speed the time to market of the support for new storage arrays
    - Enable asynchronous support for new arrays
  - Promote the proliferation of enhanced load balancing algorithms

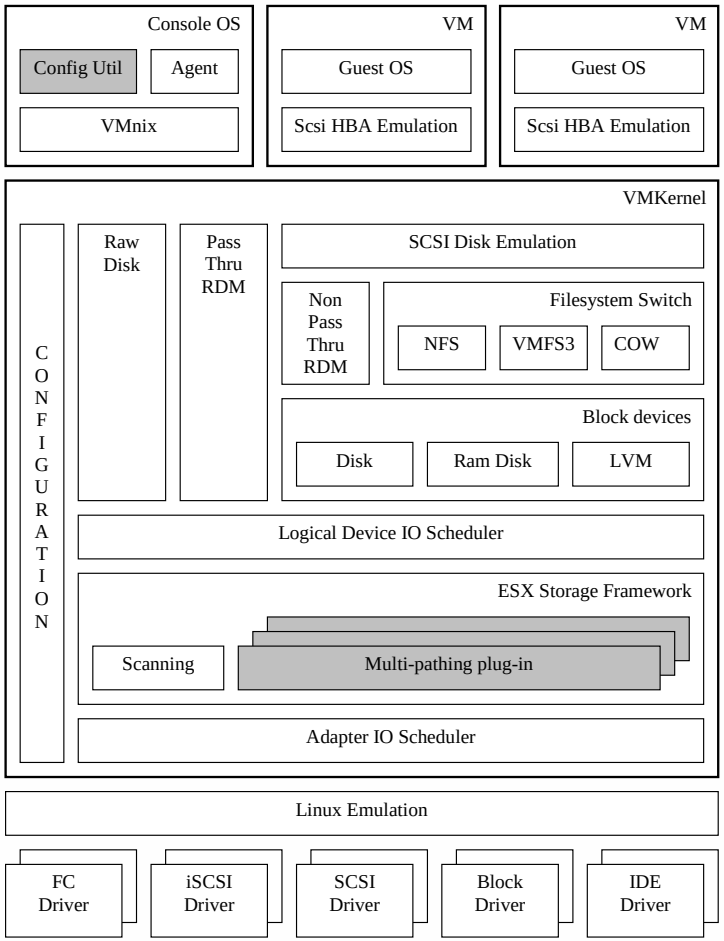
- Pack ESX with more functionality than VMware can provide all by itself!

Existing ESX Storage Stack Architecture



- Monolithic design.
- No support for isolating 3rd party proprietary code.

New ESX Storage Stack Architecture



- Well defined functional layers
- Isolate SCSI emulation code.
- Support multiple file system types
- Support multiple block device types
- Improved path scanning functionality
- Improved storage management
- Provide APIs for
  - Multipathing implementations
  - Device Drivers

Plan To Get To The New Architecture

- Redesign the Storage Stack
  - Introduce functional layers
  - Implement the new ESX Core Storage framework
  - Develop an example of an ESX Storage plugin
- Port ESX native multipathing to the Core Storage framework
  - Modularise the code: core, array plugins, path policy plugins
  - Port the failover engine to the Storage framework
  - Port all array specific plug-ins to the new native multipathing APIs.
  - Develop example array specific and path policy plugins.

Benefits of Using VMkernel Infrastructure APIs

- VMkernel development kit
  - Build environment: compiler, header files, makefiles
  - Code samples and Documentation
  - Debugging environment
- Buildable on standard ESX installation
- Pluggable modules can be shipped from 3rd parties
  - Binary Compatible
  - Versionable
- Headers and sample code available to non-Community Source partners

Components of VMkernel Infrastructure API

- The VMkernel API
  - Library of routines used by both internal and external developers
- The VMkernel SCSI API
  - Library of routines specific to SCSI path/device/I/O manipulation
  - Used to implement a new multipathing algorithm or support for a new SAN device.
- Mechanisms to allow 3rd party software to be shipped separately from an ESX release
  - Init time & configuration integration

VMkernel API

- Functionality – basic OS services
  - Memory: heaps, copy to/from virtual address & physical address
  - Locking: spinlock class, semaphore class
  - Worlds: sleep, wakeup, delay
  - Timers and time conversion
  - Character devices
- Benefits
  - Built on existing code currently used within ESX
  - Self-contained header files
  - Opaque data structures hide ESX specifics

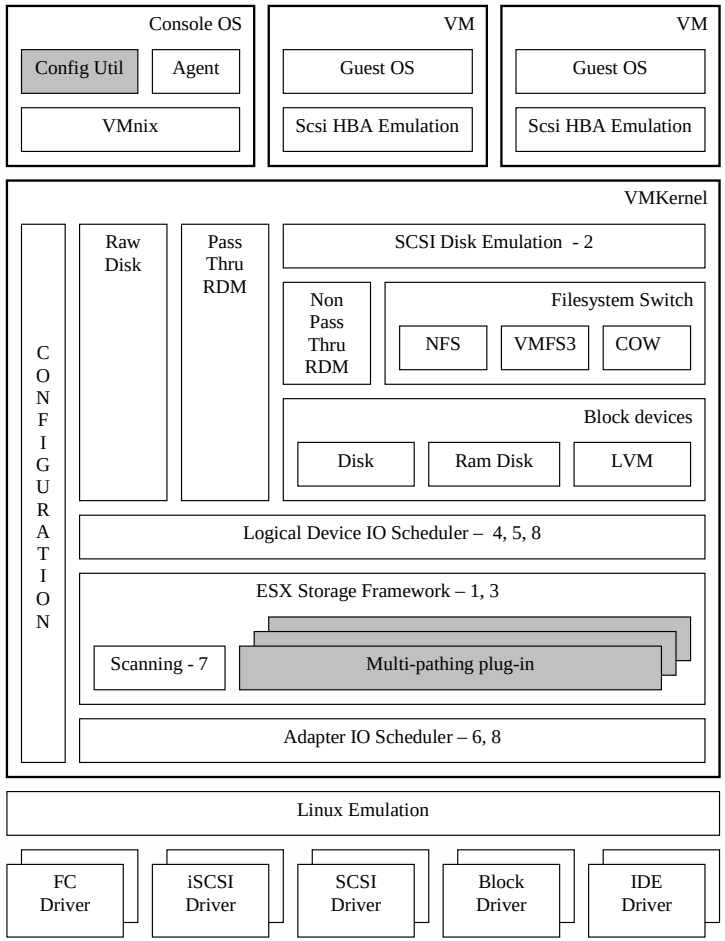
VMkernel SCSI API

- Functionality
  - Plugins: create, register, unregister
  - Device: create, remove, open, close, issue I/O, abort I/O
  - Paths: claim, set state, issue I/O, complete I/O
  - Commands: create, issue sync, issue async
- Benefits
  - Sharing of common code across storage plugin implementations
  - Provide support for Virtual Machine I/O without having to be aware of the Virtual Machines themselves.

Stages of the ESX Boot Process

- Load RAM disk
- Load COS kernel image
- Load Vmkernel
- Load modules
  - vmklinux
  - vmknmpmod
  - Other mp plugins
- Load Device Drivers
- Scan For Physical Devices
  - Scan paths
  - Claim paths
  - Locate boot device
- Boot COS and Start VMs

Core Storage Architecture Functions



- (1) Provide mechanisms to load/manage/unload multiple storage plugins
- (2) Hide Virtual Machine specific activities from the storage plugins
- (3) Route I/O requests for a specific logical device to the appropriate storage plugin
- (4) Handle I/O queuing to the logical devices
- (5) Implement logical device bandwidth sharing between Virtual Machines
- (6) Handle I/O queuing to the physical storage HBAs
- (7) Handle physical path discovery and removal process
- (8) Provide logical device and physical path I/O statistics

Core Storage Plugin Functions

- Manage physical path claiming and unclaiming
- Manage the open and closing of logical devices
- Process I/O requests to logical devices
  - Select an optimal physical path for the request
  - Handle failures and request retries if necessary
    - Specific actions may be required for storage devices.
- Support management tasks such as abort or reset of logical devices

Core Storage Plugin States

- Enabled
  - Logical devices are operational
- Path Claiming
  - In the process of claiming physical paths and exporting logical devices
    - May be different behaviour for active/active and active/passive arrays.
- Disabling
  - In the process of quiescing logical devices
- Disabled
  - Logical devices are not operational

Path Discovery Process

- Path scanning
  - ESX Storage Framework scans the device.
  - Breakout scan process for new path discovery from scan process to remove missing paths.
    - Create/Keep/Destroy
  - The physical paths end up in the pool of unclaimed paths

Storage Plugin Path Claiming Process

- The Storage Framework sends a “start of path claiming” notification to all plugins
- Next the Framework presents the paths to the plugins based on inquiry data and configuration file rules
  - A plugin can claim or reject the path
  - Only a single plugin can claim any given path
- Finally the framework sends an “end of path claiming” notification to all plugins.
  - Now that a plugin has all the paths, it may create a logical device and expose it the Framework.

Path Claiming Rules

- Sample vmkpath.conf
  - Model String “Disk Type A ” Plugin “mpmgmt#1”
  - Model String “Disk Type B ” Plugin “mpmgmt#2”
  - Model String “Disk Type C ” Plugin “mpmgmt#1,mpmgmt#2”
  - Model String “” Plugin “vmware-nmp”
- Default vmkpath.conf:
- Model String “” Plugin “vmware-nmp”
- Reality will very likely be a more complex set of rules

Logical Device Identifiers

- Support multiple Identifiers per logical device
- Legacy unique identifier (UID)
  - Format is ESX proprietary.
  - Needed for backward compatibility/upgrade
    - RDMs, VMFS File system signature
- Standards compliant UID
  - UTF-8 string version:
    - naa.1F92A3E84B4D56C7
    - eui.9A18F7B27E6C54D3
    - iqn.1987-05.com.cisco:01.7fef329e15c8
  - Same UID across all storage plugins
- Storage plugin specific identifiers

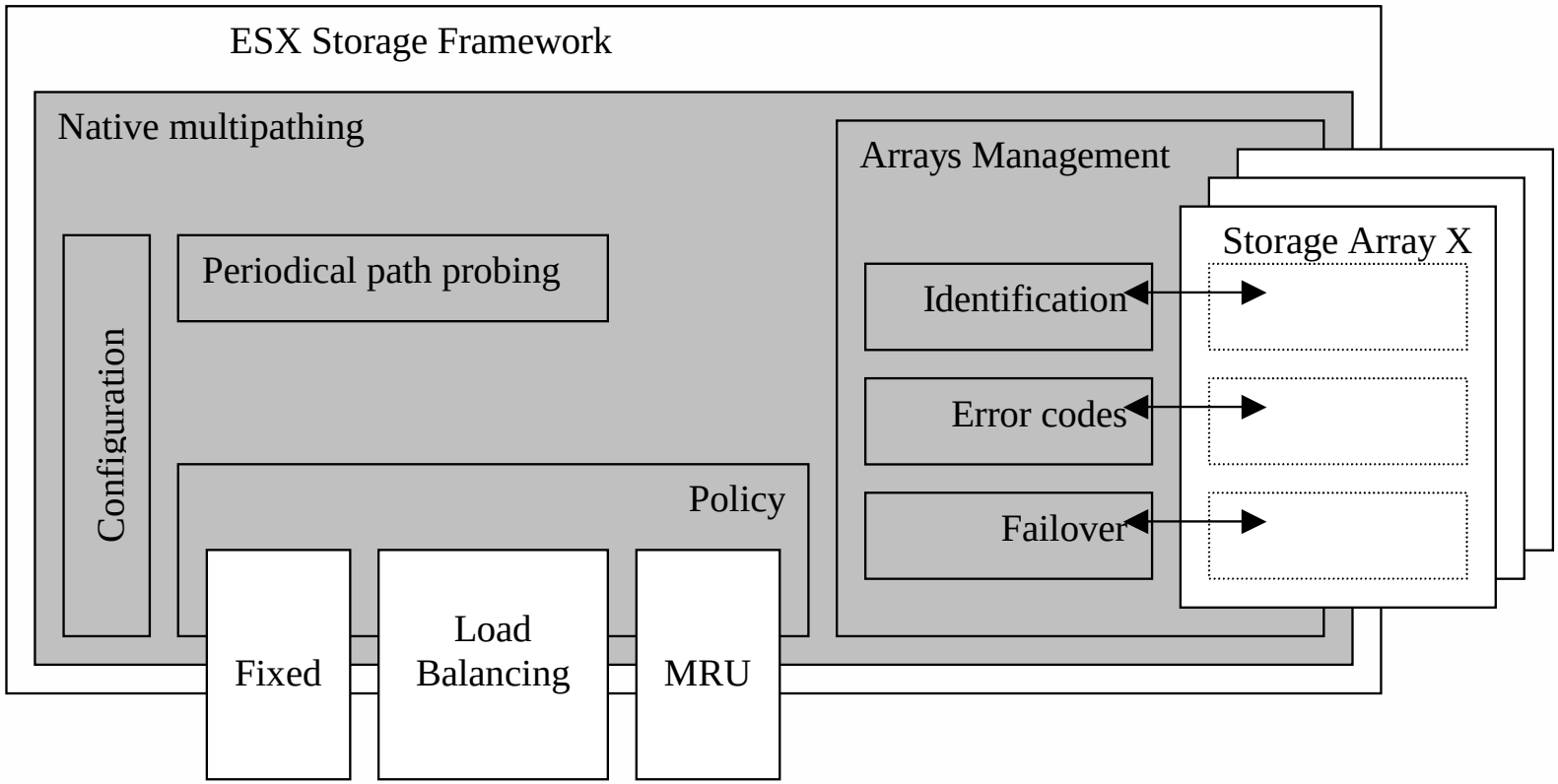
ESX Native Multipathing Plugin Specific Goals

- Replace existing ESX multipathing code
  - Isolate Storage Array Type specific implementations (SAT)
    - active/active
    - active/passive
  - Isolate Path Selection implementations (PS)
    - Fixed path selection
    - Most Recently Used path selection
    - Load Balanced path selection
- Provide public APIs for SAT and PS plugins
- Simultaneously co-exist with other storage plugins
- Support true path load balancing
- Decrease the time and effort involved in supporting new SAN devices.

NMP Initial Scope

- Replace the existing ESX multipathing code
  - Implement as a plugin using the new Core Storage Framework
  - Use only the VMkernel API and VMkernel SCSI APIs.
- Path Selection Specific Plugins (PSP)
  - Fixed
  - MRU
  - Load balanced
- SAN/Storage Array Type Specific Plugins (SATP)
  - All the arrays currently supported by ESX 3.0
- SAT and PS plugins can be shipped separately from an ESX release.

ESX Native Multipathing (NMP)



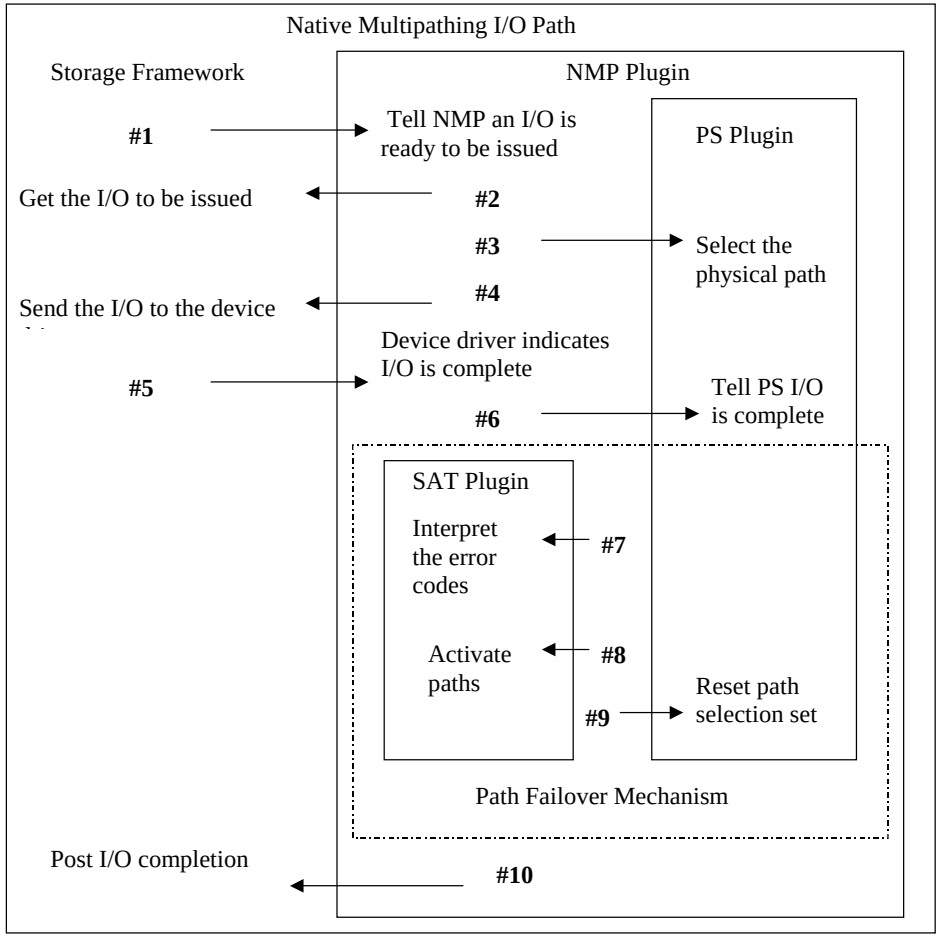
NMP SAT Plugin

- Settable per physical path
- Handle array specific actions
  - For Active/Passive Devices
    - Detect SP failures
    - Activate passive paths
- Called for each I/O request that fails to complete successfully
- Monitor health of each physical path.
- Periodically queried to report the state of each physical path to the NMP plugin
- SATP_UNKN by default

NMP PS Plugin

- Settable per logical device
- Called on each I/O request to a logical device
- Determine which of the physical paths should be used when issuing an I/O request to a logical device.
- PSP_UNKN by default

NMP Flow of I/O



Status

- Work on the new Storage Framework and the NMP plugin is underway
- Storage partners have expressed interest in developing software for this framework

Many Ways to Add Functionality to ESX

- Device Driver Toolkit (DDK)
  - When adding a device driver
- Native Multipath Plugin
  - When adding support for a specific SAN array or path policy
- Storage Stack Plugin
  - When adding support for a complete multipathing mechanism
- Community Source
  - When modifications beyond the scope of the existing APIs is required

Questions?

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The remaining slides are backup information only

- These slides describe how the data structures in the new framework may be defined.
- These slides show how the VMkernel SCSI API routines may be called.
- These slides are only illustrations to describe concepts. The API will evolve before its initial release with ESX.

Data Structures – Reference Counting

- Getting a reference
  - Lookup by name / identifier
    - SCSILookup{Adapter|Path|Device|Plugin}()
  - Iteration over all instances
    - SCSI{Adapter|Path|Device|Plugin}IteratorInit()
      - Returns the first object: takes a reference
    - SCSI{Adapter|Path|Device|Plugin}IteratorNext()
      - Return the next object: takes a reference on the new instance and drops it on the previous instance
    - SCSI{Adapter|Path|Device|Plugin}IteratorDone()
      - Stop iterating: drops the ref on the current object if any
  - Duplicate a reference
    - SCSIRef{Adapter|Path|Device|Plugin}

Data Structures Reference Counting

- Dropping a reference
  - SCSIUnref{Adapter|Path|Device|Plugin}
- Destroying the object
  - Prevent new lookups
  - Sleep until the last reference is dropped
    - Avoids dance with global locks in IO path
  - Returns

Plugin Module Reference Counting

- Always pin a module before accessing it
  - Slow path: acceptable
  - Performance path: not acceptable
    - vmk_ScsiDevice: protected by open/close
      - Device open atomically looks up the device and pins its module
        - *Fails if the module is being unloaded*
    - vmk_ScsiPath: protected by claim/unclaim events
    - vmk_ScsiAdapter: protected by claimed paths

Data Structures – Physical Adapter

- vmk_ScsiAdapter
  - driver name
  - adapter name
  - moduleId
  - capabilities: maxIoSize, maxSgLen, paeCapable
  - entry points: discover, command, taskMgmt, dump
  - dump info: interrupt handler & vector
- ScsiAdapter
  - lock
  - flags
  - useCount
  - Stats

Data Structures – Physical Path

vmk_ScsiPath

- plugin private data

ScsiPath

- Lock
- name
- flags
- useCount
- stats
- inquiry data
- plugin
- Legacy UID

Data Structures – Logical Device

- vmk_ScsiDevice
  - Plugin private data
- ScsiDevice
  - Lock
  - Flags
  - useCount
  - stats
  - plugin
  - device UIDs

Data Structures - Plugin

- vmk_ScsiPlugin
  - Name, moduleId
  - version number, SCSI API revision number
  - entry points:
    - openDevice, closeDevice
    - startCommand, taskMgmt
    - device ioctl, path ioctl, plugin ioctl
- ScsiPlugin
  - lock
  - flags
  - useCount
  - Stats

Data Structures – I/O Command

- vmk_ScsiCommand
  - Issuing Path
    - cdb, cdbLen, sgArray
    - direction, requiredDataLen
    - senseData, senseDataLen
    - done(), doneData
    - worldId
    - commandId: serialNumber, originator
    - timeoutMs
  - Completion Path
    - host status, SCSI status
    - xferredDataLen

Data Structures – Task Management

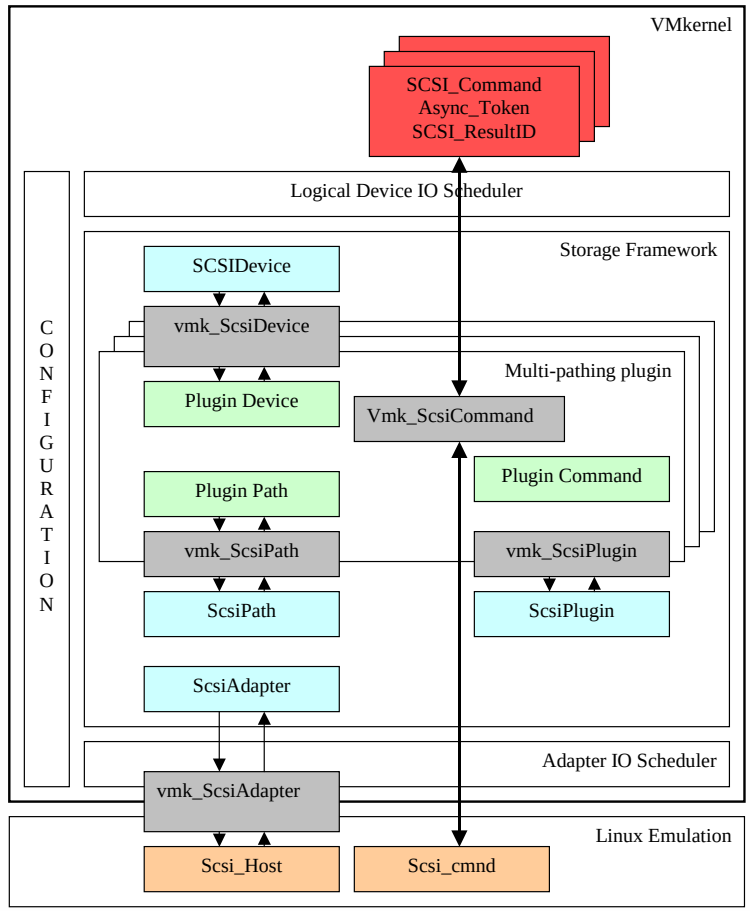
- vmk_ScsiTaskMgmt
  - Task Mgmt Type
  - Completion Status
  - Initiator Id (handle)
  - Serial number

Data Structures

Legacy Structures	VMKAPI	VMKAPI_SCSI
SCSI_Command Async_Token SCSI_ResultID	vmk_ScsiCommand vmk_TaskMgmt	N/A N/A
SCSI_Target	vmk_ScsiDevice	ScsiDevice
N/A	vmk_ScsiPlugin	ScsiPlugin
SCSI_Path	vmk_ScsiPath	ScsiPath
SCSI_Adapter	vmk_ScsiAdapter	ScsiAdapter

I/O Flow through the Data Structures

- SCSI_Command from GOS is converted to a vmk_ScsiCommand
- vmk_ScsiCommand converted to Scsi_Command sent to physical device driver.



I/O Flow Through the Framework