Education

The File Systems Evolution

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Abstract

The File Systems Evolution

File Systems impose structure on the address space of one or more physical or virtual devices. Starting with local file systems over time additional file systems appeared focusing on specialized requirements such as data sharing, remote file access, distributed file access, parallel files access, HPC, archiving, security etc.. Due to the dramatic growth of unstructured data files as the basic units for data containers are morphing into file objects providing more semantics and feature-rich capabilities for content processing. This presentation will categorize and explain the basic principles of currently available file systems (e.g. Local FS, Shared FS, SAN FS, Clustered FS, Network FS, Distributed FS, Parallel FS, ...). It will also explain technologies like Scale-Out NAS, NAS Aggregation, NAS Virtualization, NAS Clustering, Global Namespace, Parallel NFS. All of these files system categories and technologies are complementary. They will be enhanced in parallel with additional value added functionality. New file system architectures will be developed and some of them will be blended in the future.

Check Out Other Tutorials

Check out SNIA Tutorial:

Storage Tiering and the Impact of Flash on File Systems

Check out SNIA Tutorial:

Scale-Out Storage Systems

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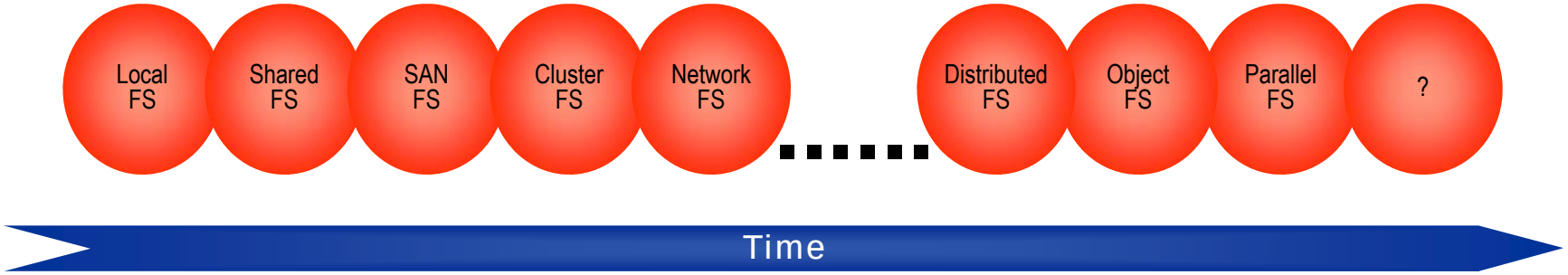
Aspects of Deduplication

Check out SNIA Tutorial:

File Systems for Object Storage Devices

The File Systems Evolution

- File systems evolved over time
- Starting with local file systems over time additional file systems appeared focusing on specialized requirements such as data sharing, remote file access, distributed file access, parallel files access, HPC, archiving, etc.



Note: The picture above does not reflect the exact sequence in which the files system types appeared. Some of them actually appeared in parallel. It is also not the intention to indicate that a new file system replaces its predecessors. Instead they are targeting complimentary objectives.

Agenda

- File System Basics
- File Systems Taxonomy
- Local FS
- Shared FS / Global FS
  - SAN FS, Cluster FS
- Network FS
- Distributed FS
- Distributed Parallel FS
- Scale-Out NAS
  - NAS Aggregation
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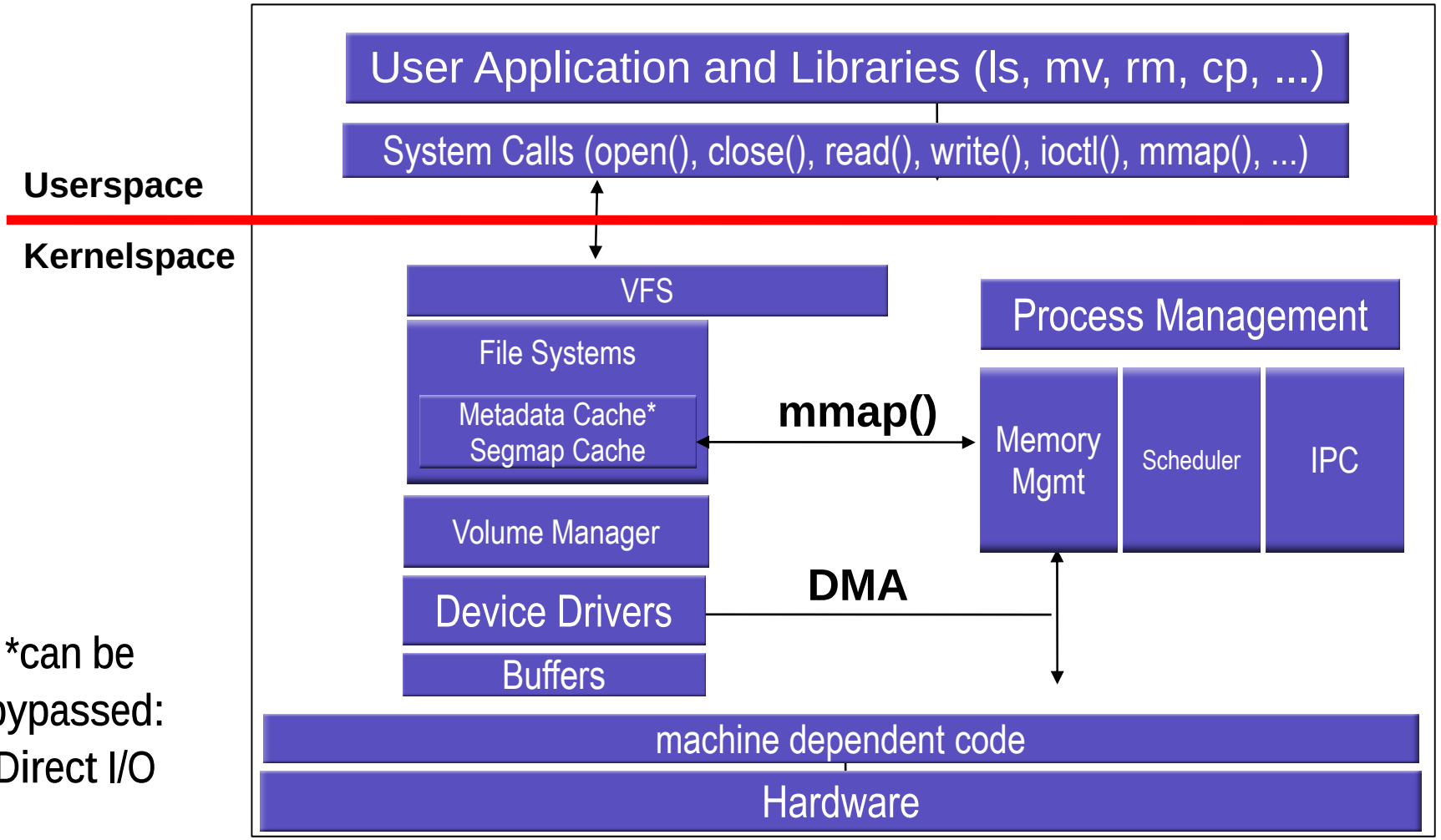
- FS Future Developments

File System & Operating System



*can be bypassed: Direct I/O

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www.wikipedia.org

- ADFS – Acorn's Advanced Disc filing system, successor to DFS
- BFS – the Be File System used on BeOS
- EFS – Encrypted filesystem, An extension of NTFS
- EFS (IRIX) – an older block filing system under IRIX
- Ext – Extended filesystem, designed for Linux system
- Ext2 – Second extended filesystem, designed for Linux systems
- Ext3 – Name for the journalled form of ext2
- FAT – Used on DOS and Microsoft Windows, 12, 16 and 32 bit table depths
- FFS (Amiga) – Fast File System, used on Amiga systems. This FS has evolved over time. Now counts FFS1, FFS Intl, FFS DCache, FFS2
- FFS – Fast File System, used on *BSD systems
- Fossil – Plan 9 from Bell Labs snapshot archival file system
- Files-11 – OpenVMS filesystem
- GCR – Group Code Recording, a floppy disk data encoding format used by the Apple II and Commodore Business Machines in the 5¼" disk drives for their 8-bit computers
- HFS – Hierarchical File System, used on older Mac OS systems

www.wikipedia.org (cont'd)

- HFS Plus – Updated version of HFS used on newer Mac OS systems
- HPFS – High Performance Filesystem, used on OS/2
- ISO 9660 – Used on CD-ROM and DVD-ROM discs (Rock Ridge and Joliet are extensions to this)
- JFS – IBM Journaling Filesystem, provided in Linux, OS/2, and AIX
- LFS – 4.4BSD implementation of a log-structured file system
- MFS – Macintosh File System, used on early Mac OS systems
- Minix file system – Used on Minix systems
- NTFS – Used on Windows NT, Windows 2000, Windows XP and Windows Server 2003 systems
- NSS – Novell Storage Services. This is a new 64-bit journaling filesystem using a balanced tree algorithm. Used in NetWare versions 5.0-up and recently ported to Linux.
- OFS – Old File System, on Amiga. Nice for floppies, but fairly useless on hard drives
- PFS – and PFS2, PFS3, etc. Technically interesting filesystem available for the Amiga, performs very well under a lot of circumstances. Very simple and elegant

www.wikipedia.org (cont'd)

- ReiserFS – Filesystem that uses journaling
- Reiser4 – Filesystem that uses journaling, newest version of ReiserFS
- SFS – Smart File System, journaled file system available for the Amiga platforms
- UDF – Packet based filesystem for WORM/RW media such as CD-RW and DVD.
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- UFS – Unix Filesystem, used on older BSD systems
- UFS2 – Unix Filesystem, used on newer BSD systems
- UMSDOS – FAT filesystem extended to store permissions and metadata, used for Linux
- VxFS – Veritas file system, first commercial journaling file system; HP-UX, Solaris, Linux, AIX
- VSAM
- WAFL – Used on Network Appliance systems
- XFS – Used on SGI IRIX and Linux systems
- ZFS – Used on Solaris

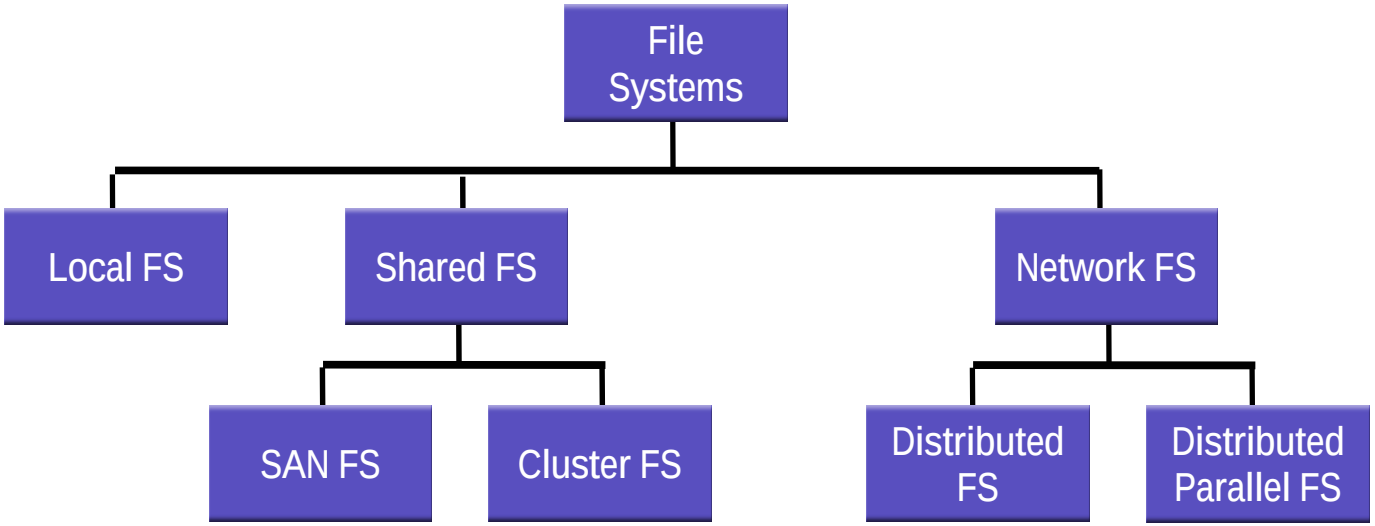
www.wikipedia.org (cont'd)

- 9P The Plan 9 and Inferno distributed file system
- AFS (Andrew File System)
- AppleShare
- Arla (file system)
- Coda
- CXFS (Clustered XFS) a distributed networked file system designed by Silicon Graphics (SGI) specifically to be used in a SAN
- Distributed File System (DCE)
- Distributed File System (Microsoft)
- Freenet
- Global File System (GFS)
- Google File System (GFS)
- IBRIX Fusion™
- InterMezzo
- Isilon OneFS™
- Lustre (Sun Microsystems)

www.wikipedia.org (cont'd)

- NFS
- OpenAFS
- Server message block (SMB) (aka Common Internet File System (CIFS) or Samba file system)
- Xsan (a storage area network (SAN) filesystem from Apple Computer, Inc.)
- archfs (archive)
- cdfs (reading and writing of CDs)
- cfs (caching)
- Davfs2 (WebDAV)
- Devfs
- ftpfs (ftp access)
- fuse (filesystem in userspace, like lufs but better maintained)
- GPFS an IBM cluster file system
- JFFS/JFFS2 (filesystems designed specifically for flash devices)
- LUFS (replace ftpfs, ftp ssh ... access)
- nntpfs (netnews)
- OCFS (Oracle Cluster File System)

File System Taxonomy



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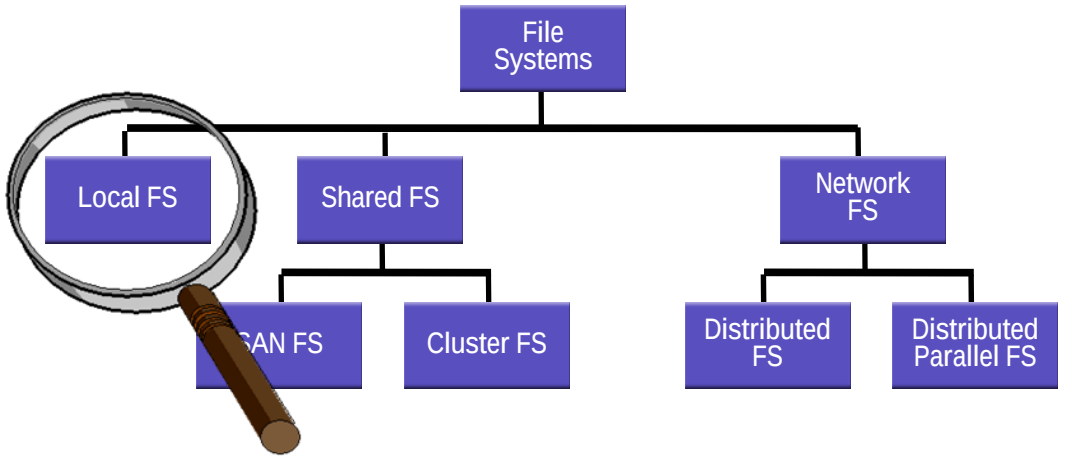
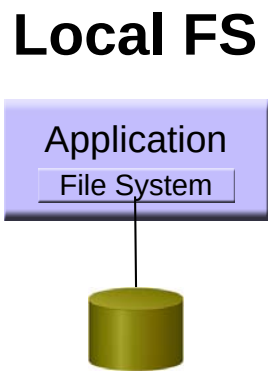


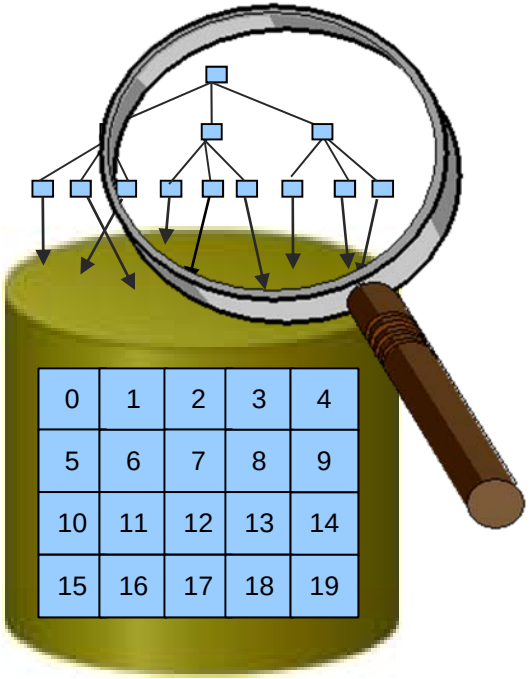
Local FS

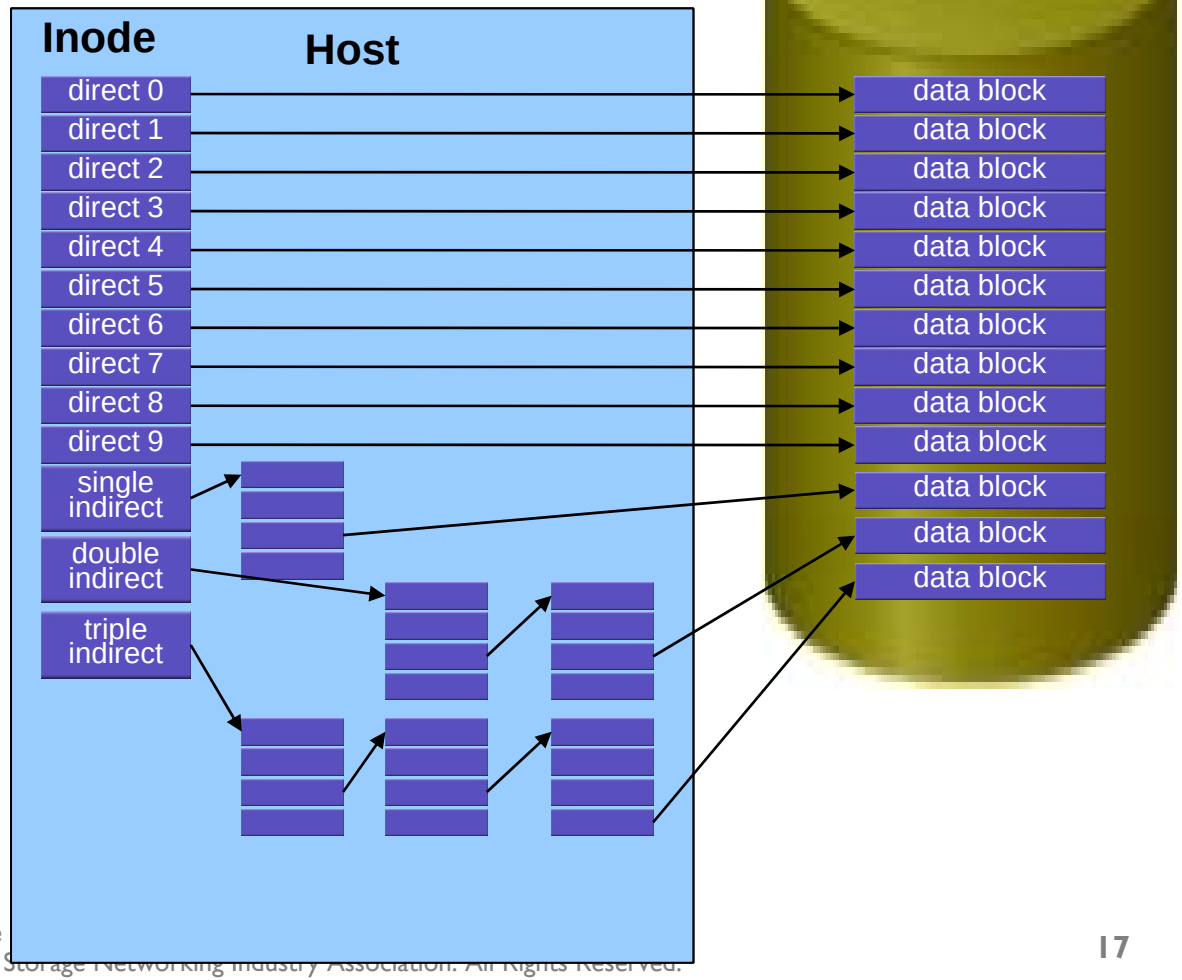


- FS is **co-located** with application server

Traditional File System - Inode

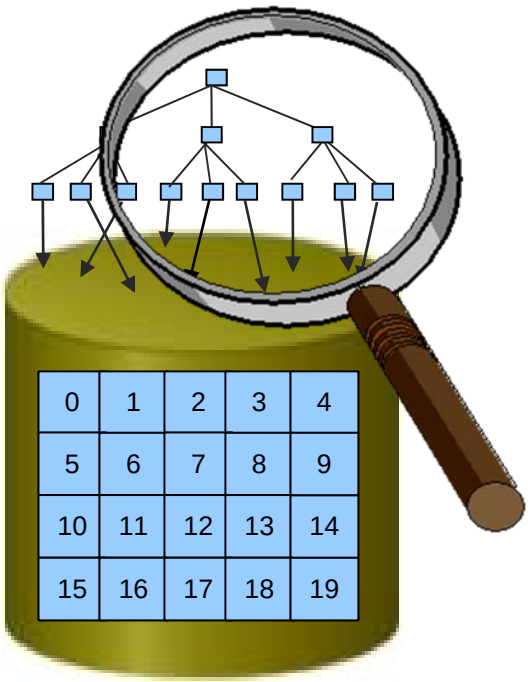
- When a file system is created, data structures that contain information about files are created. Each file has an inode and is identified by an inode number (often referred to as an "i-number" or "inode") in the file system where it resides.

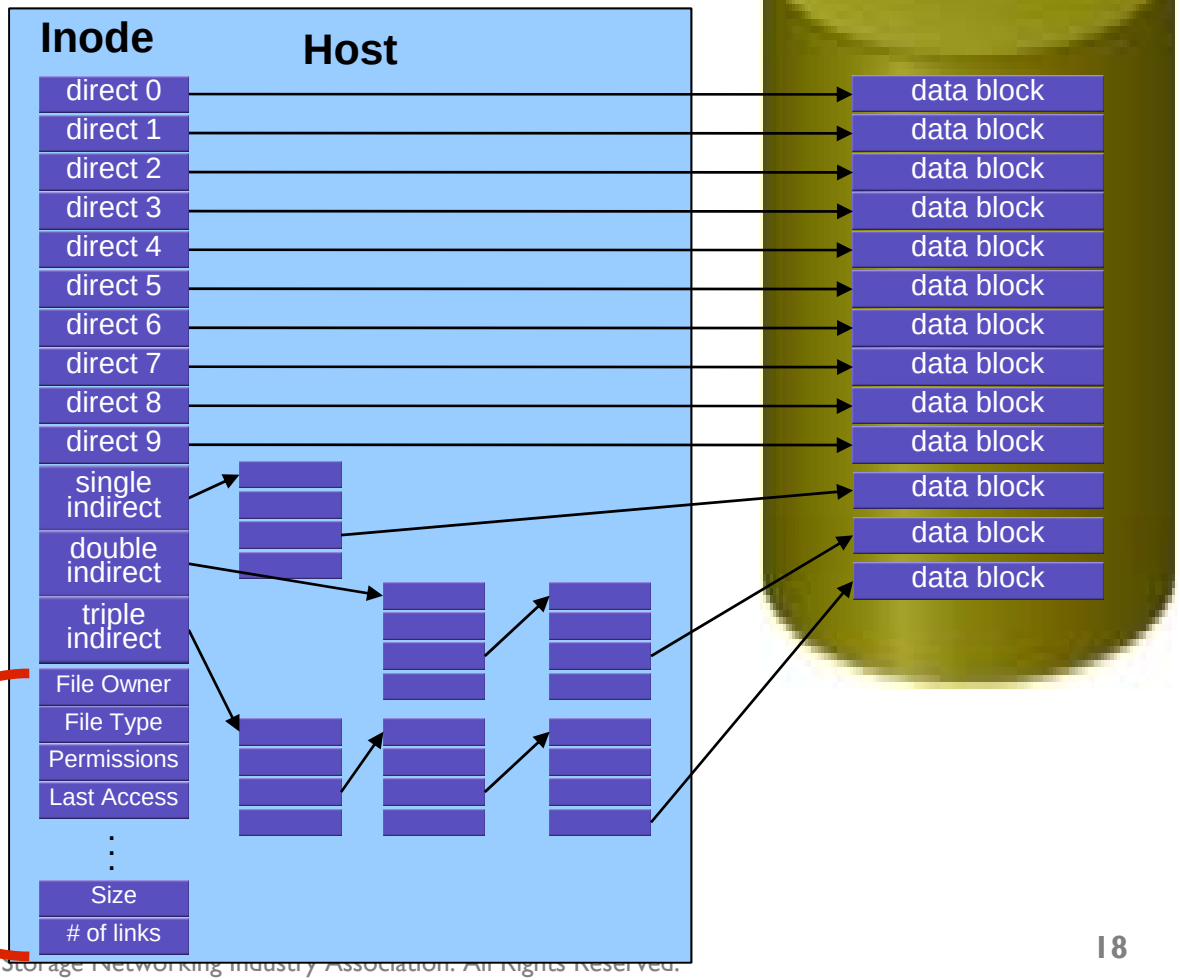




Traditional File System - Inode

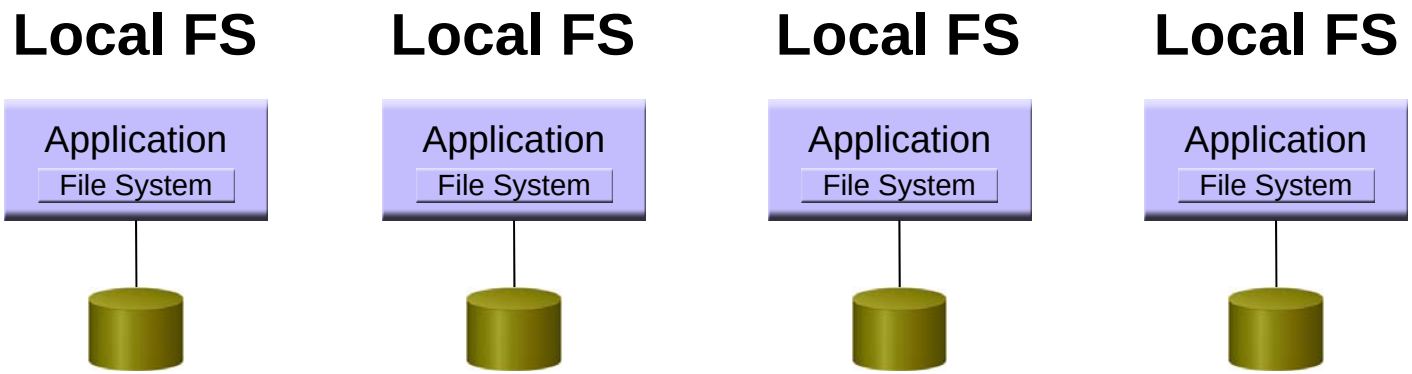
- The inode also contains file attributes...





File Attributes:

Local FS



- **Islands of storage** (no data sharing)

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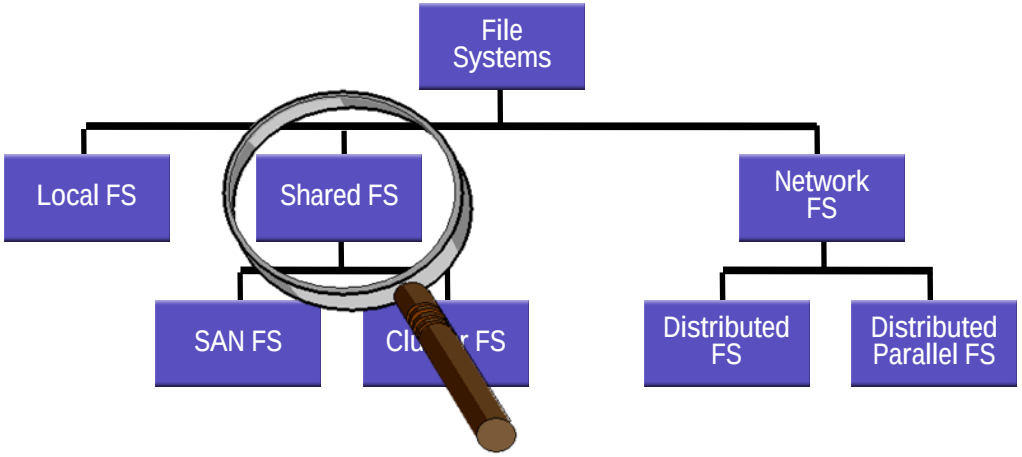
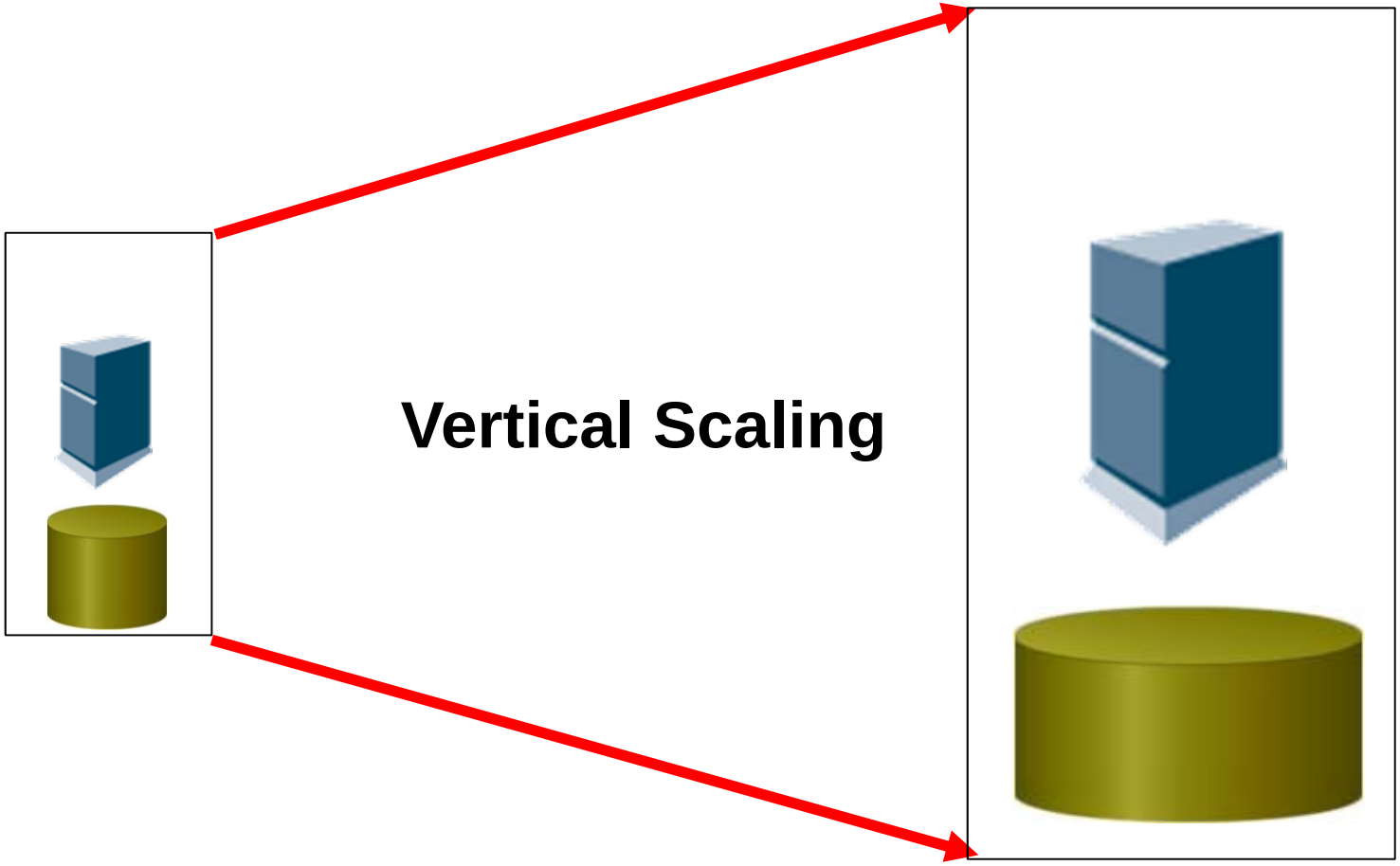
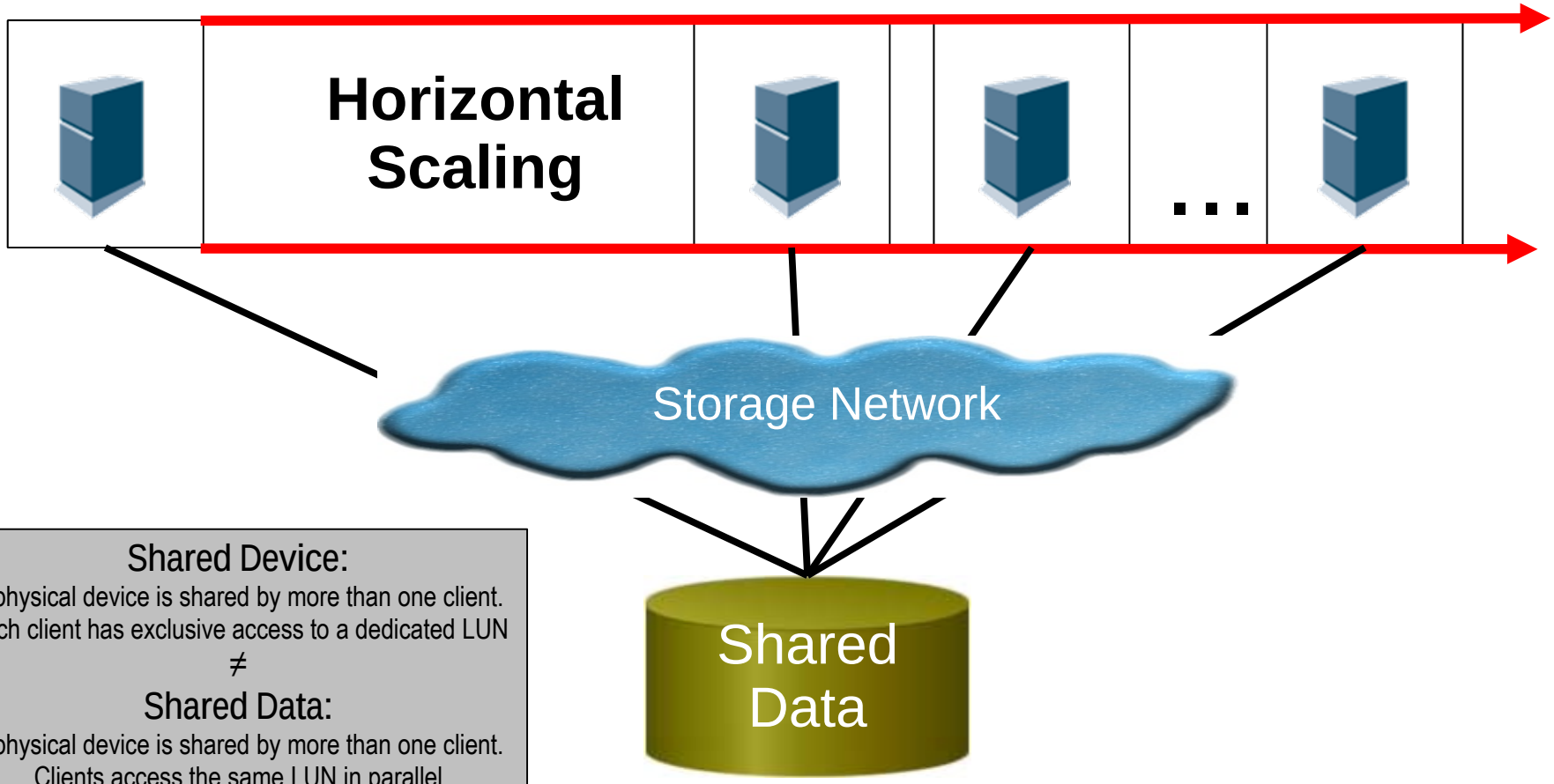


Scale-Up



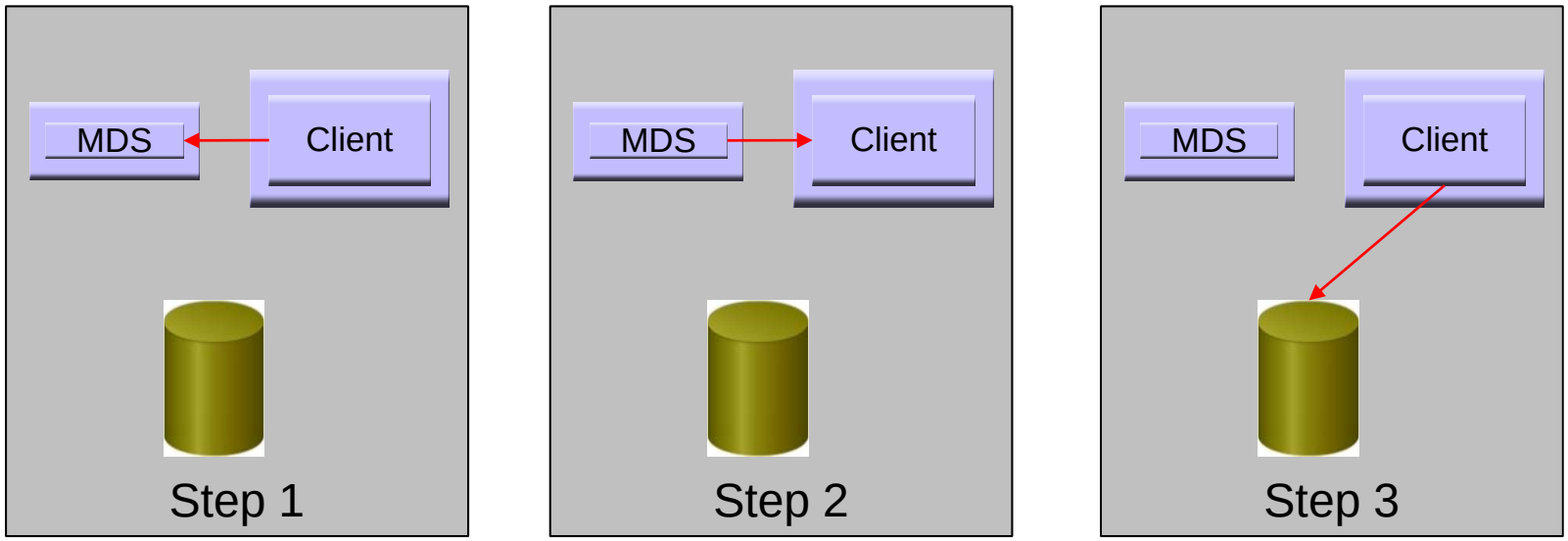
Scale-Out with Shared FS



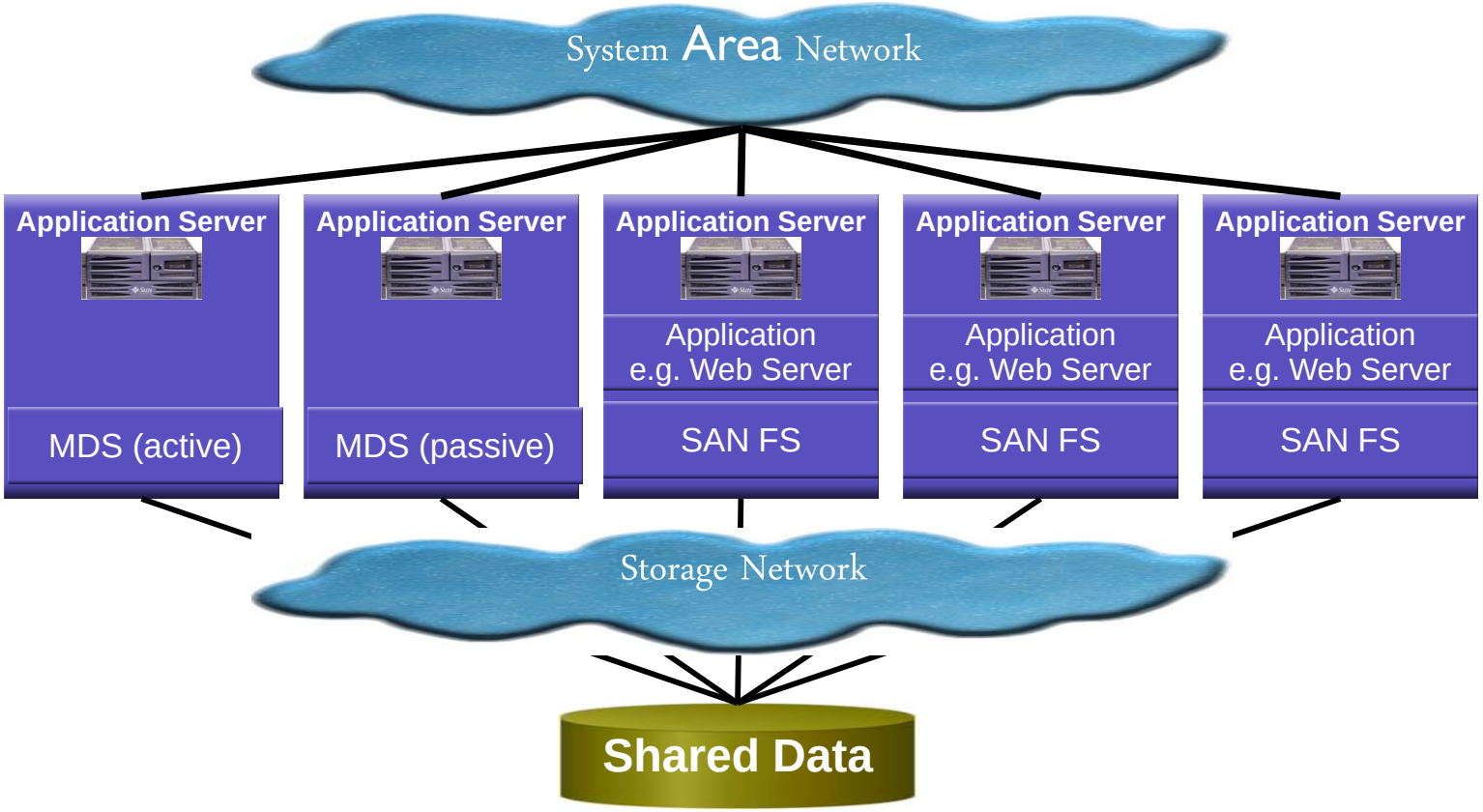
Shared Device:
A physical device is shared by more than one client.
Each client has exclusive access to a dedicated LUN
≠
Shared Data:
A physical device is shared by more than one client.
Clients access the same LUN in parallel

Shared FS/ Gobal FS Data Access

- Separation between logical and physical placement
- Separate Metadata Server (MDS)
- File access is a three-step transaction...

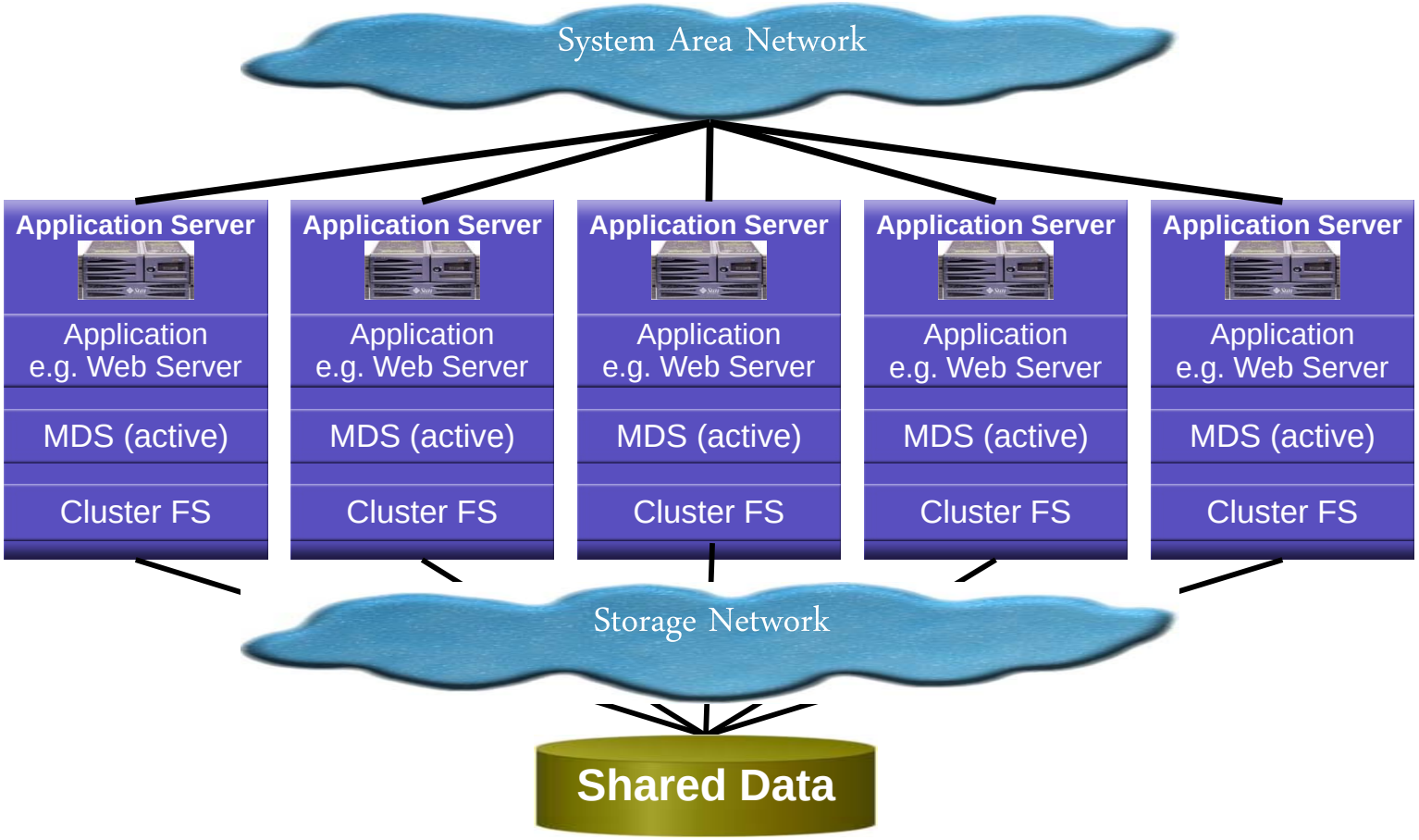


Shared FS / Global FS – SAN FS



- MDS is not part of each node (i.e. master/slave - asymmetric)
- Heterogeneous with unlimited number of nodes
- Unlimited distance between nodes

Shared FS / Global FS – Cluster FS



- MDS is part of each (cluster) node (i.e. peer-to-peer - symmetric)
- Homogeneous with limited number of nodes
- Limited distance between (cluster) nodes

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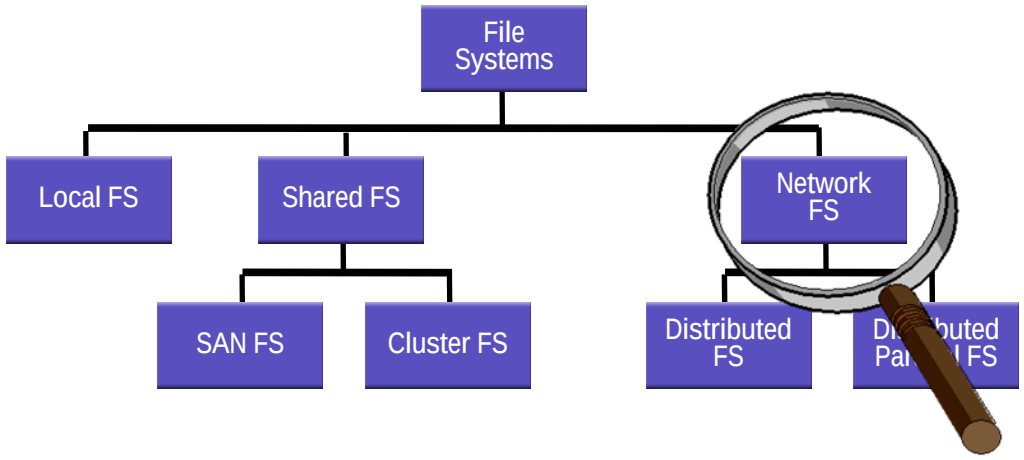
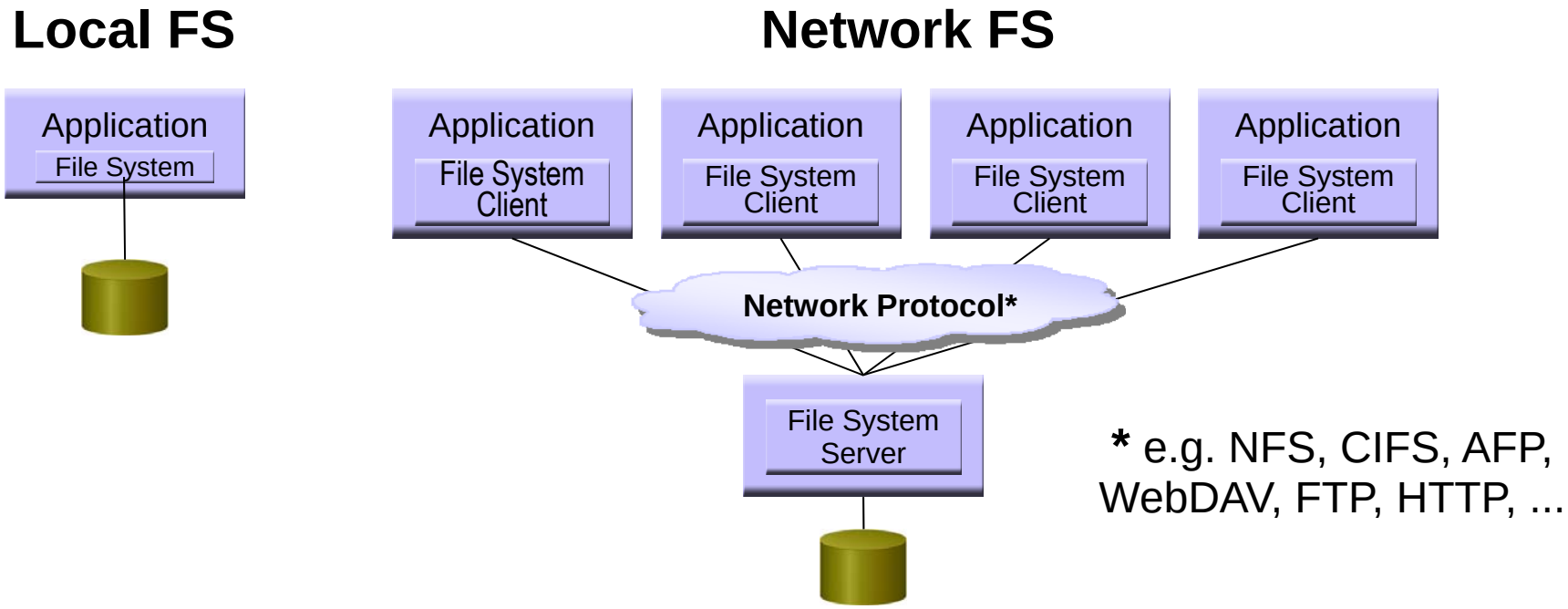
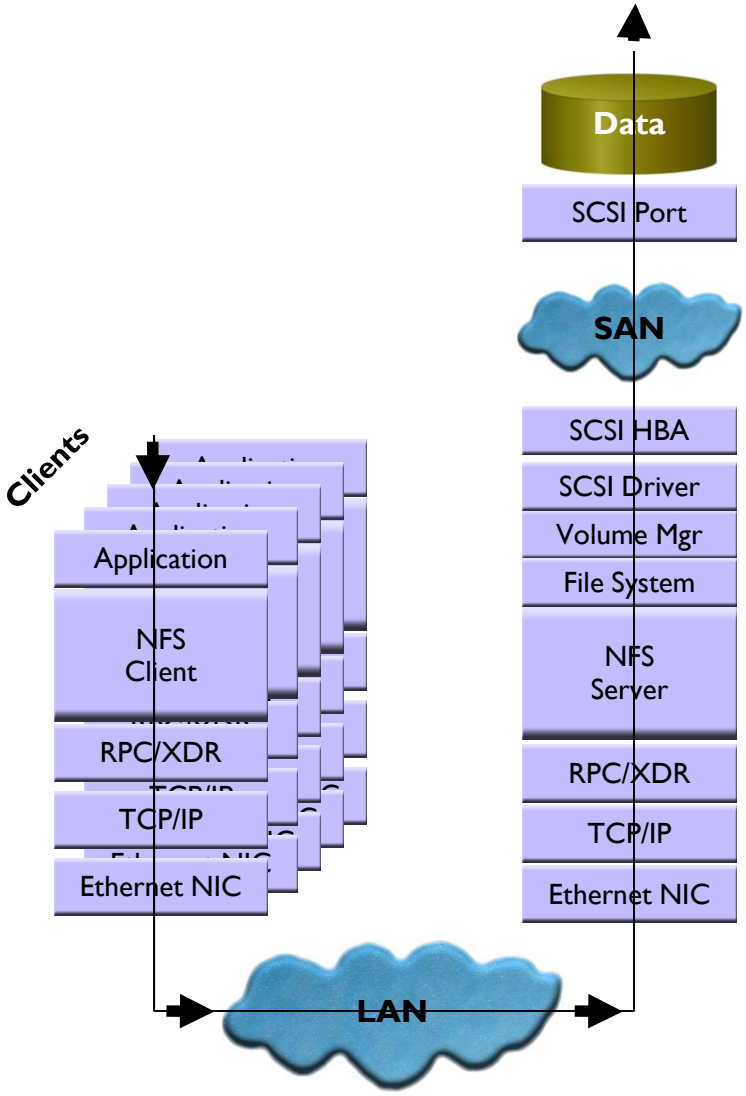


Network File Systems - aka Proxy FS



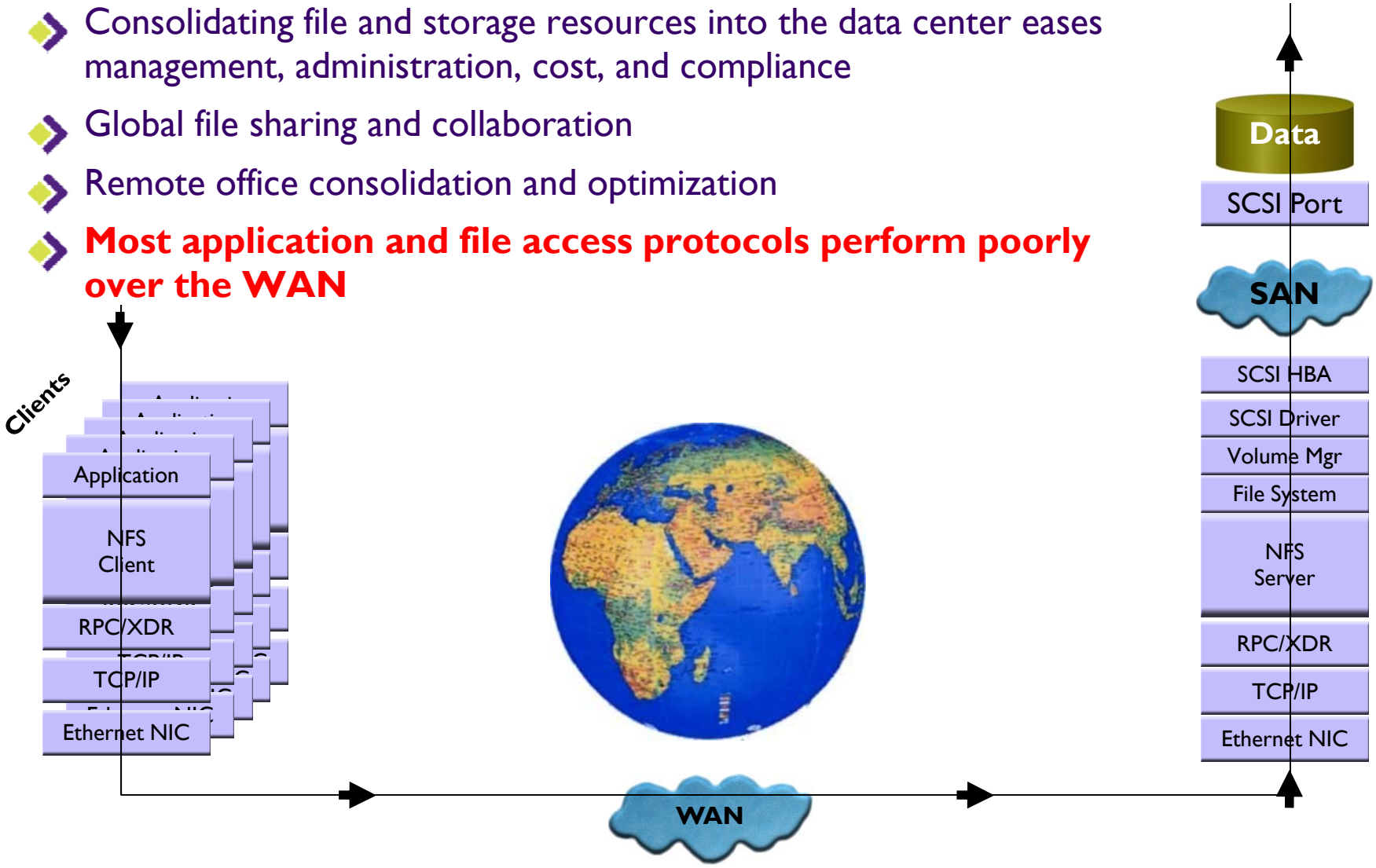
- A network file system is any file system that supports **sharing of files over a computer network protocol between one or more file systems clients and a file system server**

Network FS Stack (e.g. NFS)



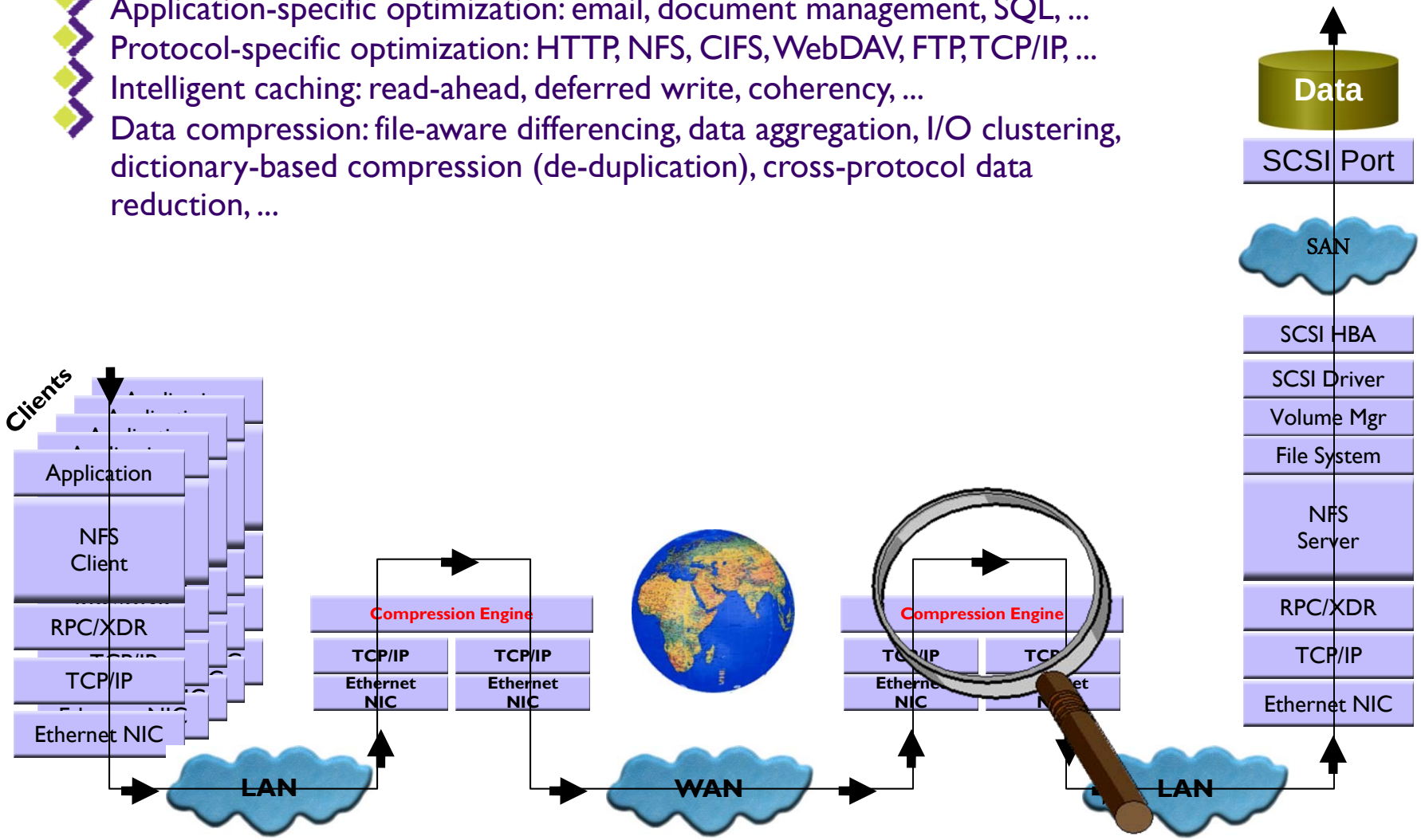
Network FS in a Distributed World

- Consolidating file and storage resources into the data center eases management, administration, cost, and compliance
- Global file sharing and collaboration
- Remote office consolidation and optimization
- **Most application and file access protocols perform poorly over the WAN**



Network Compression

- Application-specific optimization: email, document management, SQL, ...
- Protocol-specific optimization: HTTP, NFS, CIFS, WebDAV, FTP, TCP/IP, ...
- Intelligent caching: read-ahead, deferred write, coherency, ...
- Data compression: file-aware differencing, data aggregation, I/O clustering, dictionary-based compression (de-duplication), cross-protocol data reduction, ...



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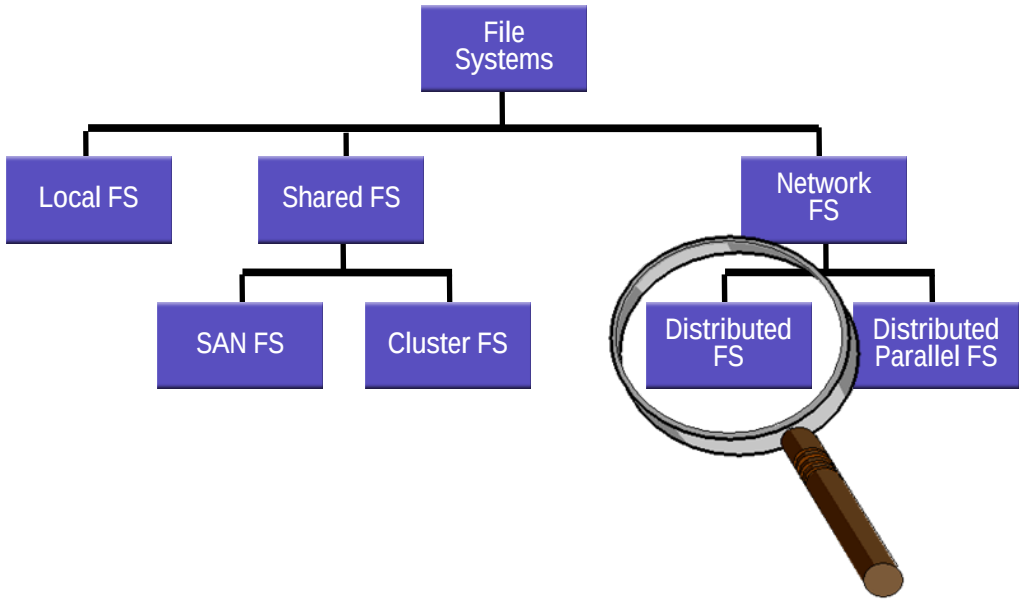
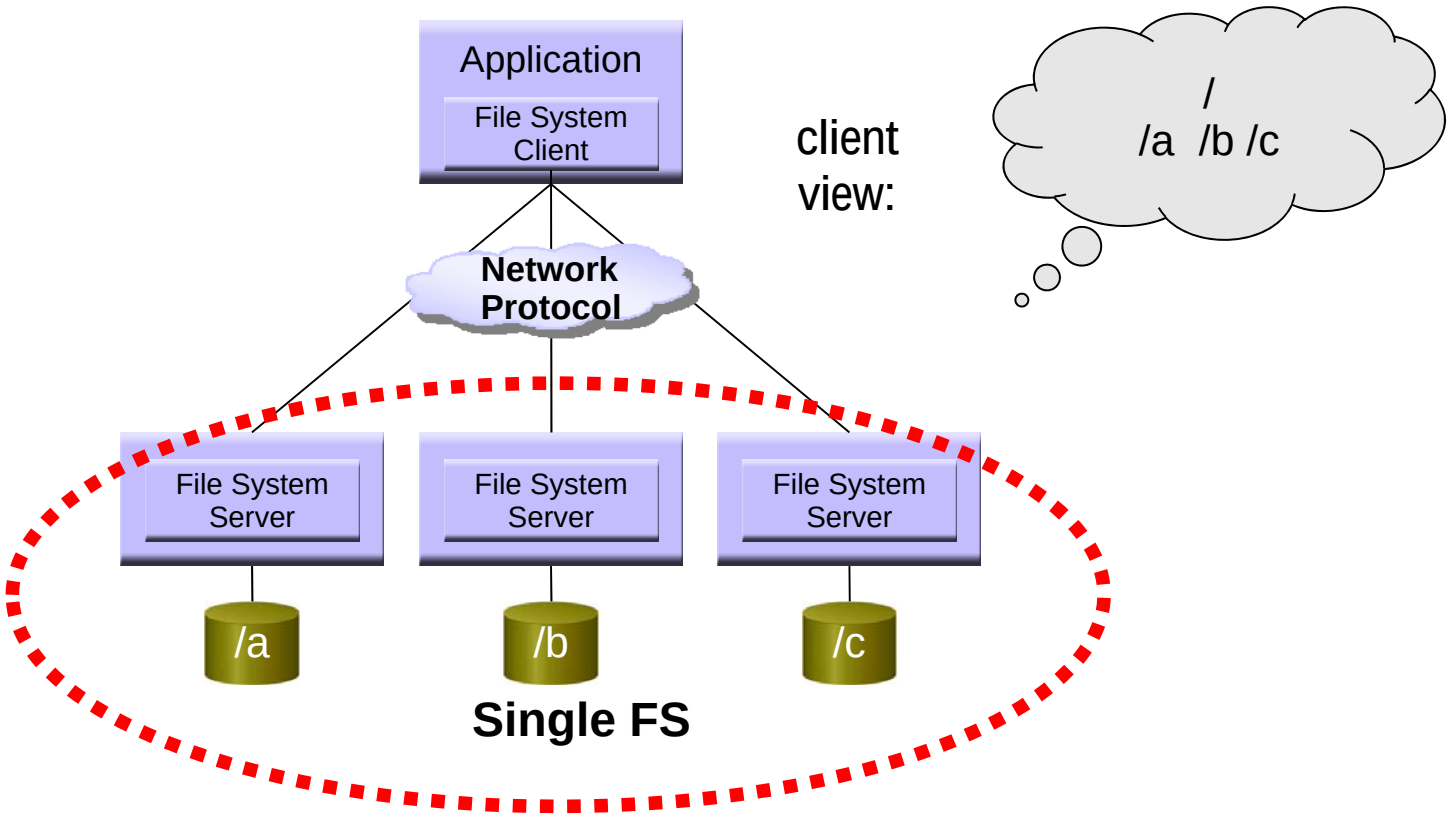


Distributed File System (DFS)



- A distributed file system is a network file system whose files are dispersed across file servers (≠ Parallel FS)

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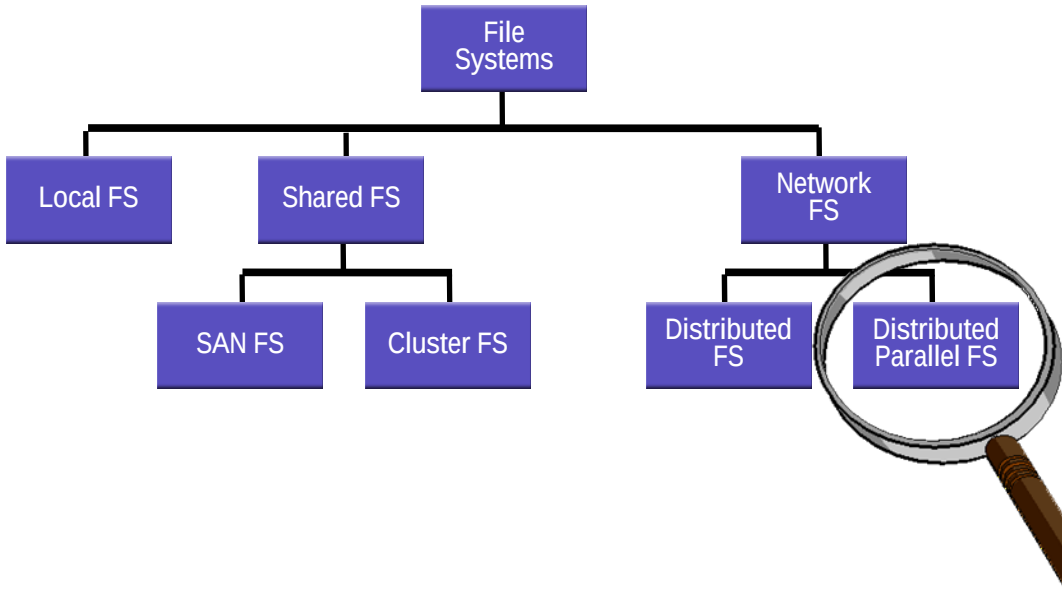
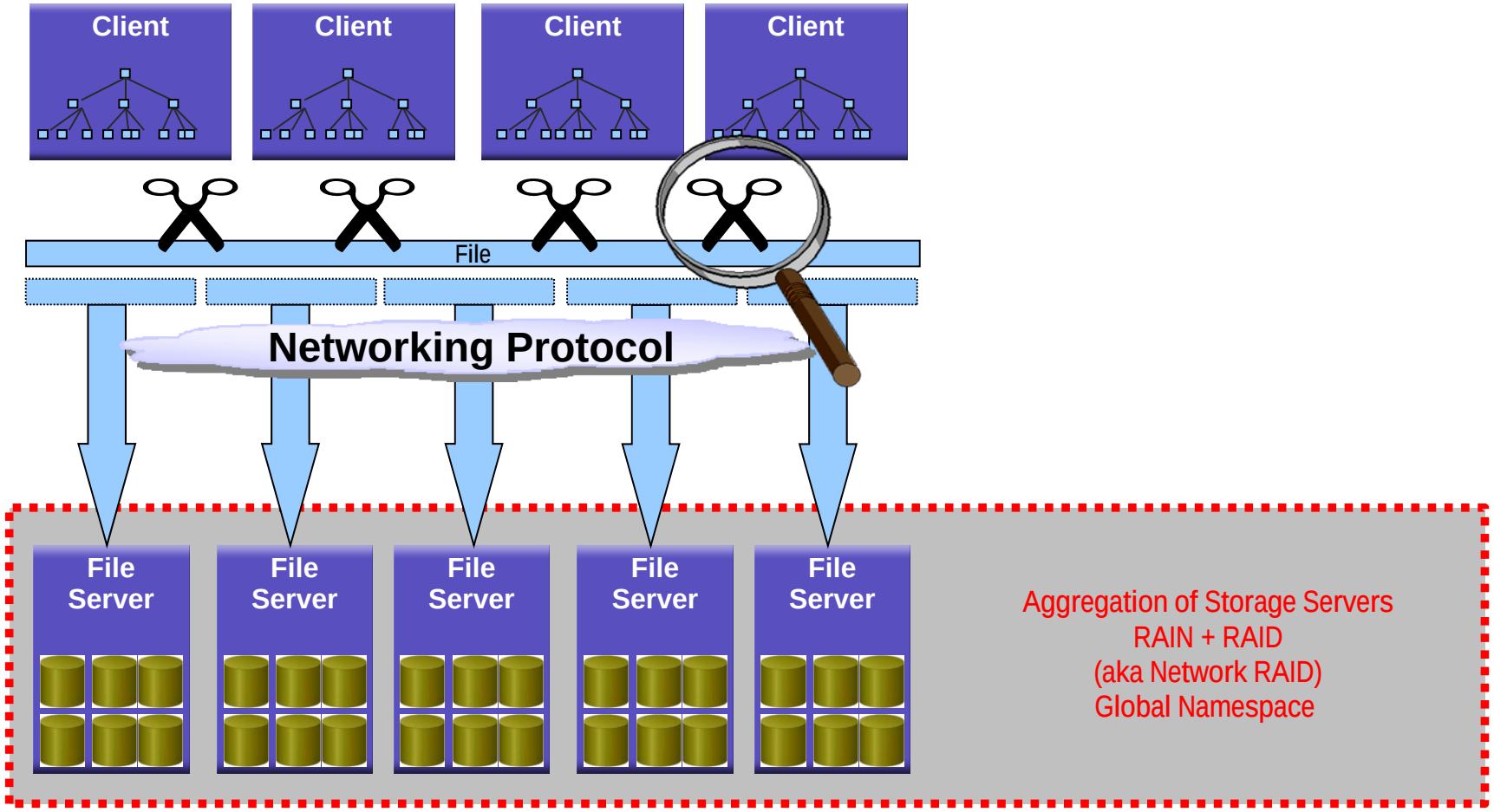


Distributed Parallel File System

- File Segments distributed across storage nodes – Parallel I/Os



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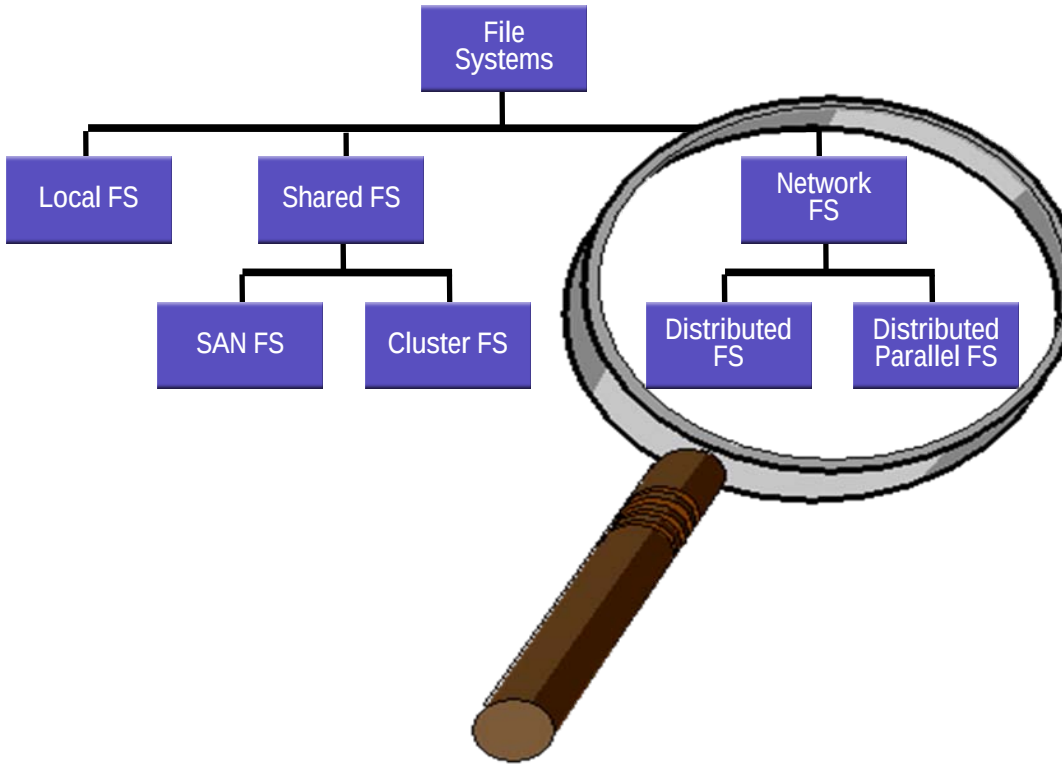

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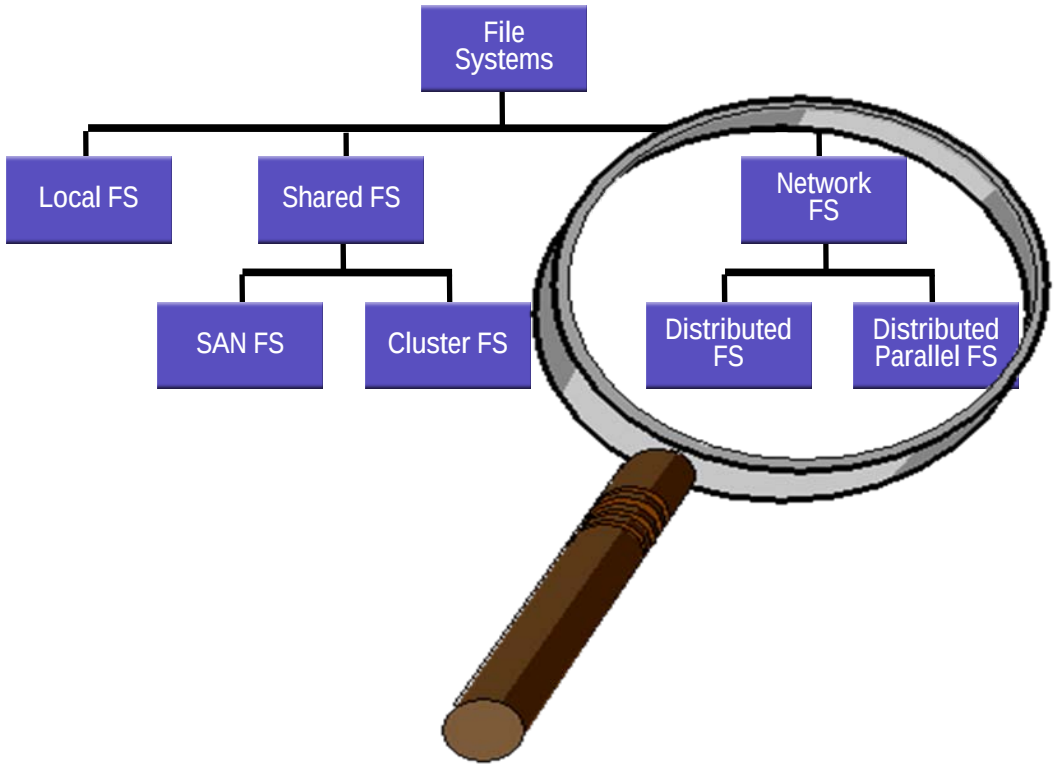
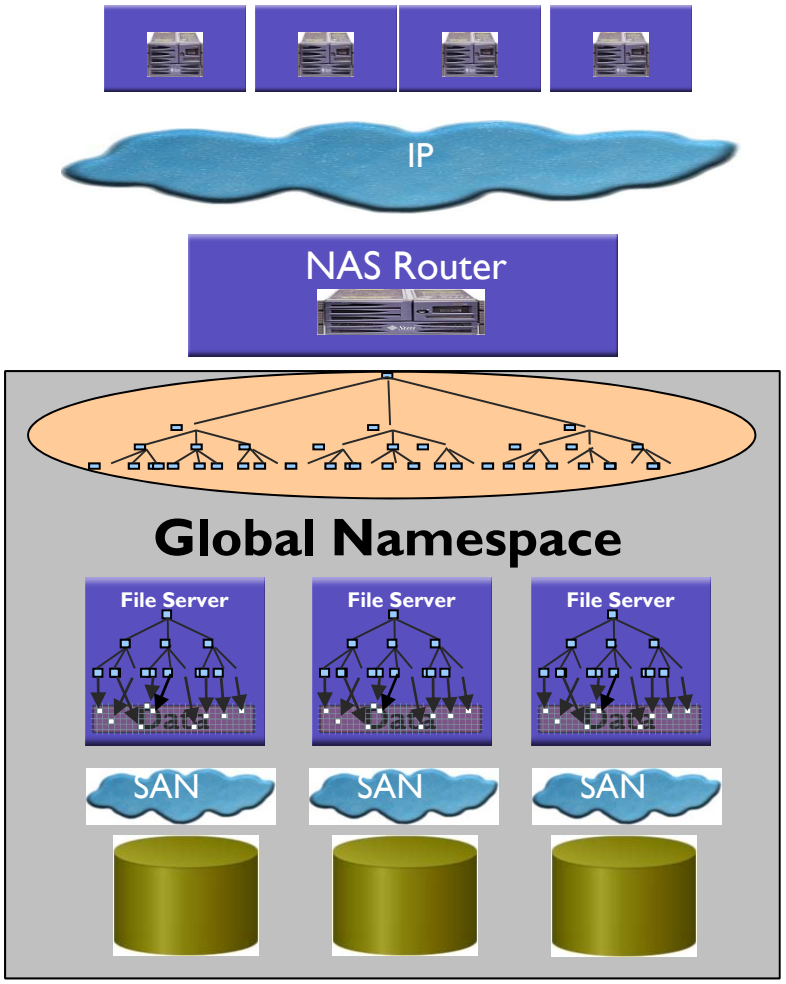


NAS Aggregation & Global Namespace



- In-Band Solution
- Aka NAS Router

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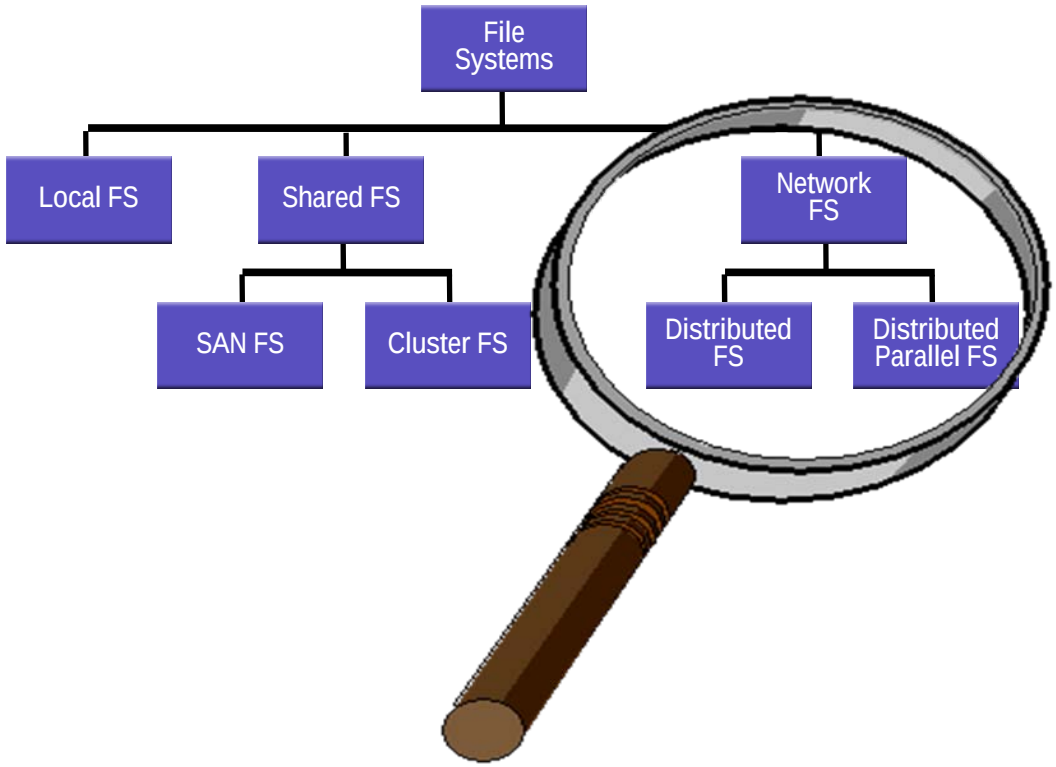
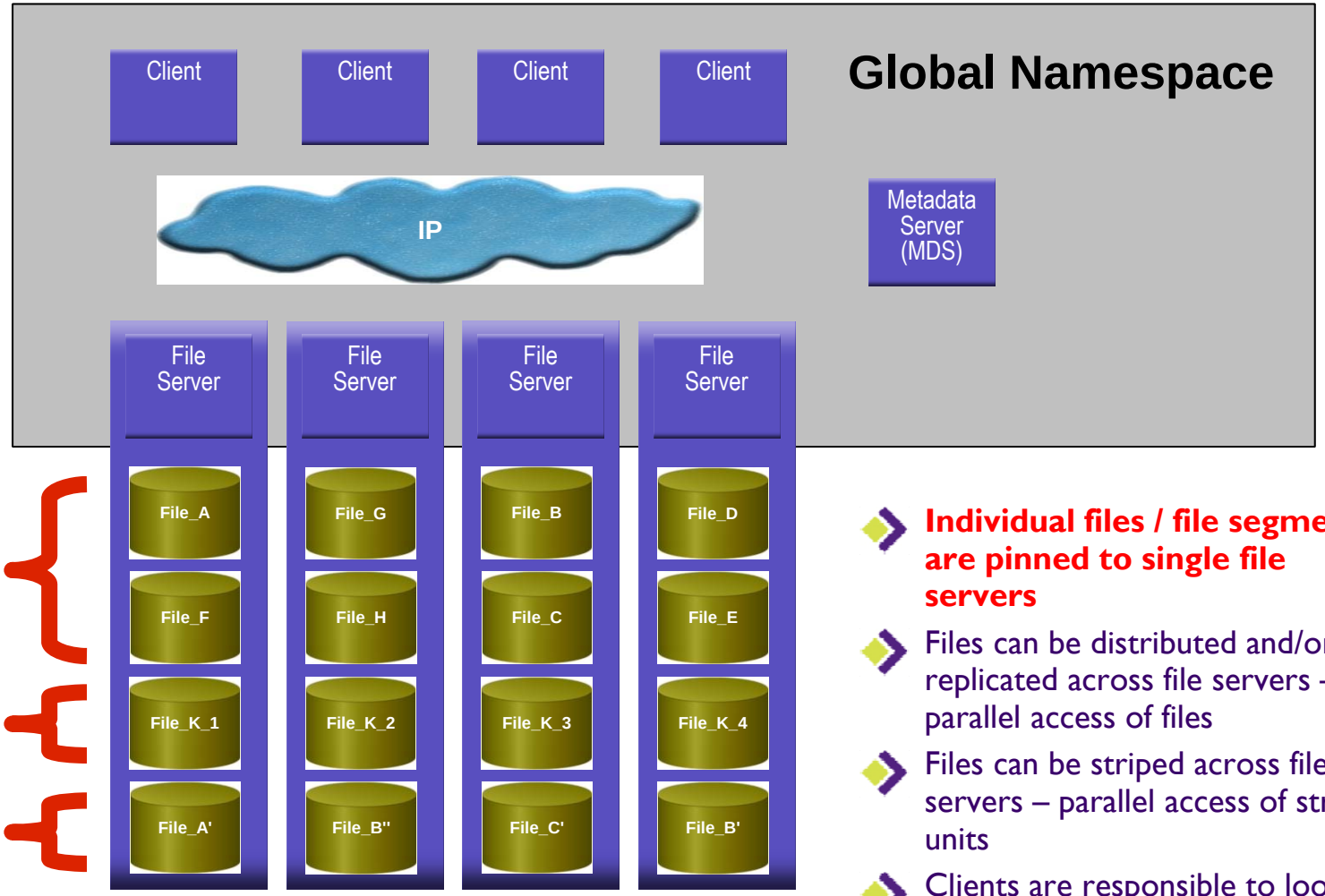
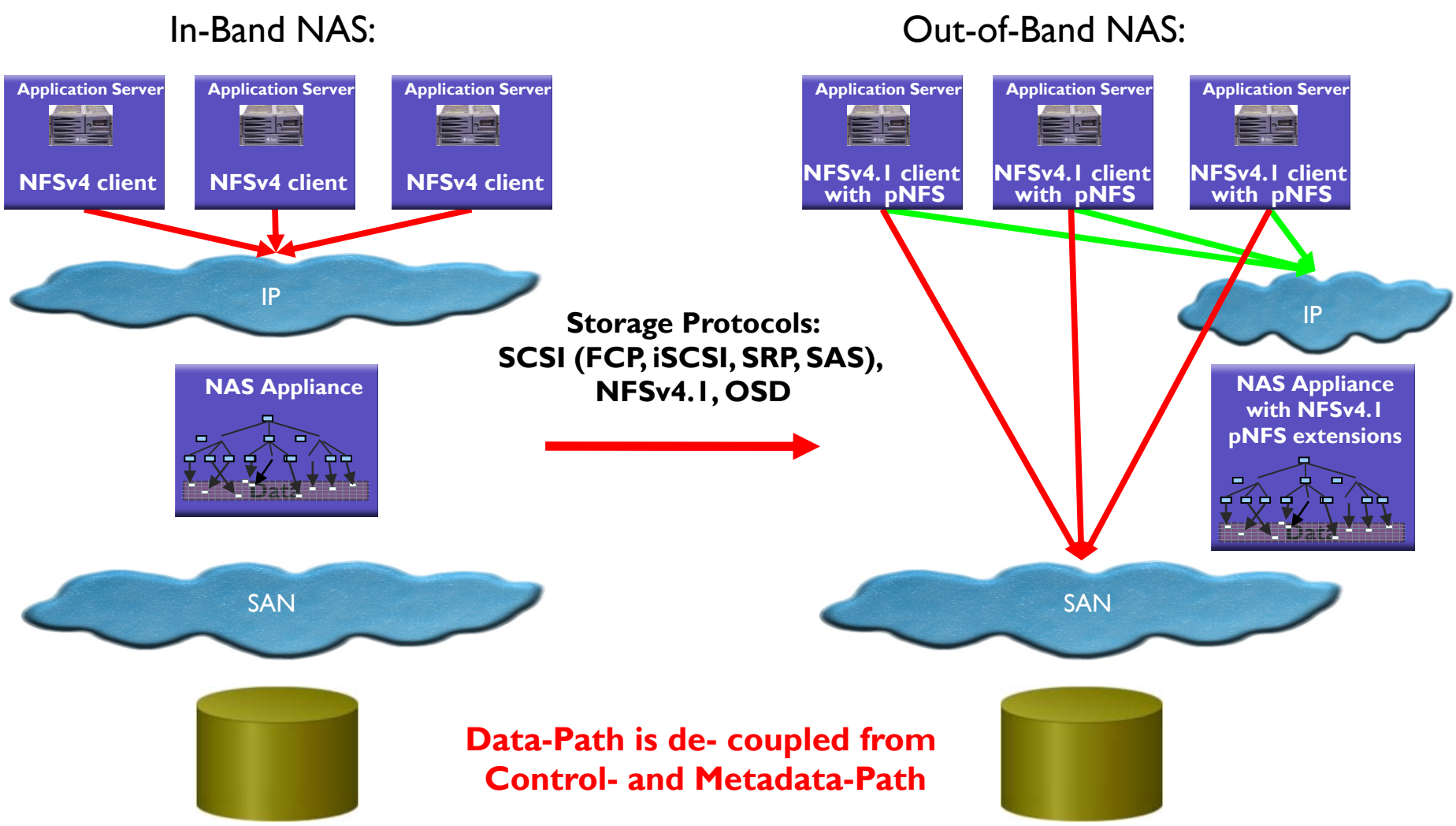


NAS Virtualization - Out-of-Band



- **Individual files / file segments are pinned to single file servers**
- Files can be distributed and/or replicated across file servers – parallel access of files
- Files can be striped across files servers – parallel access of stripe units
- Clients are responsible to lookup the right file server
- e.g. NFSv4.1 pNFS, MS DFS

NAS Virtualization – NFS4.1 pNFS



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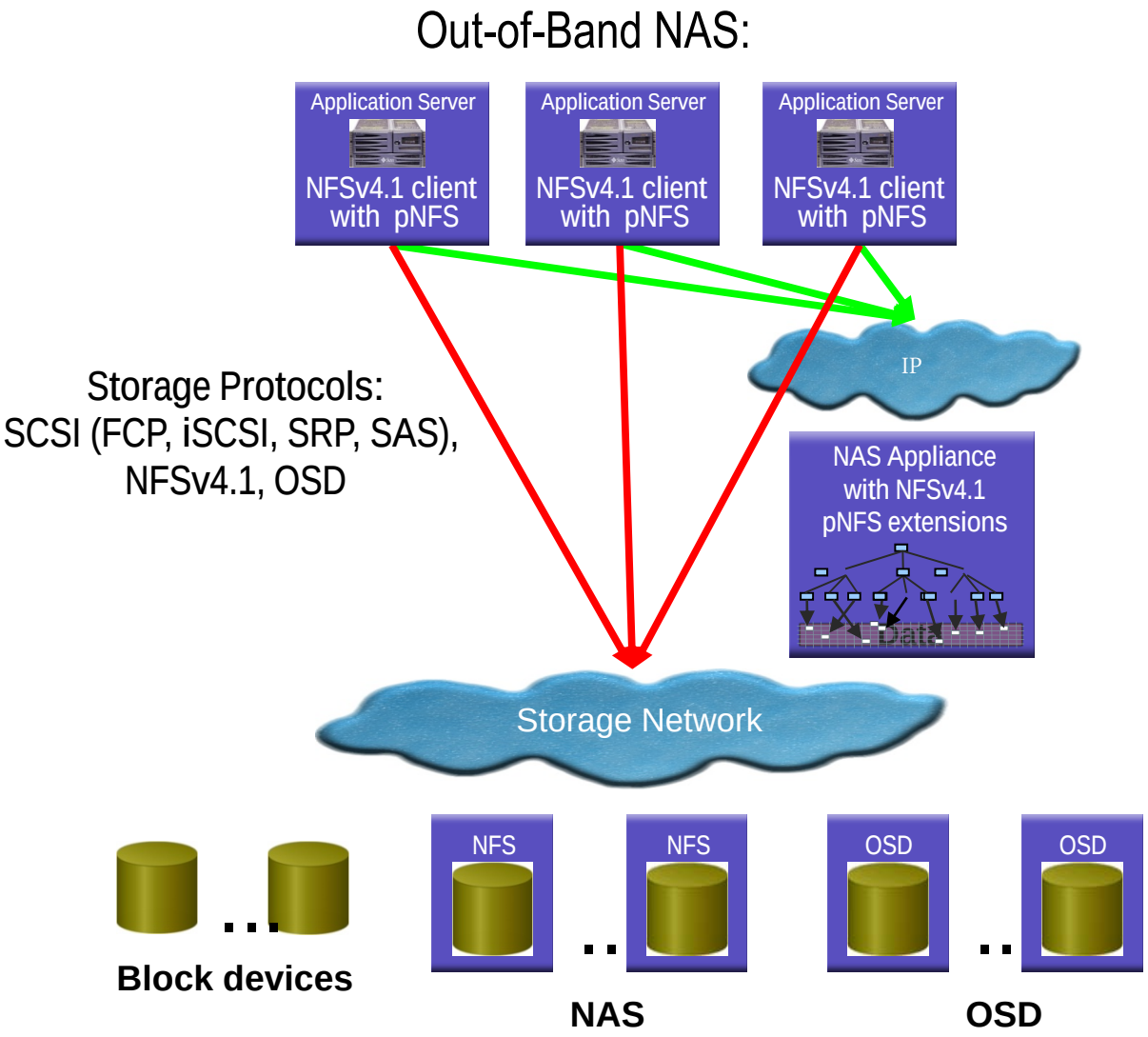
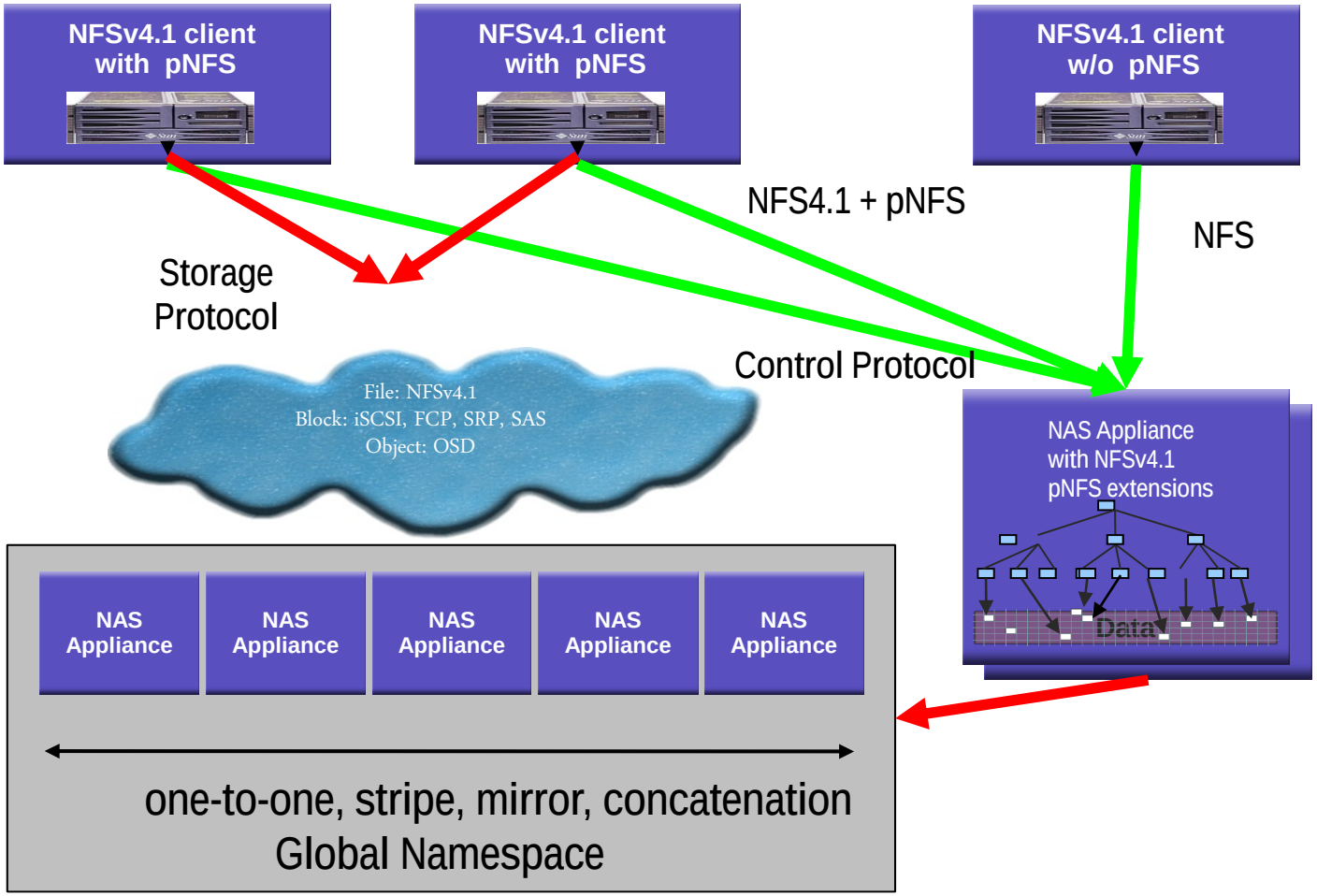


NAS Virtualization – NFS4.1 pNFS



MDS acts as proxy for clients not pNFS enabled

MDS creates Global Namespace

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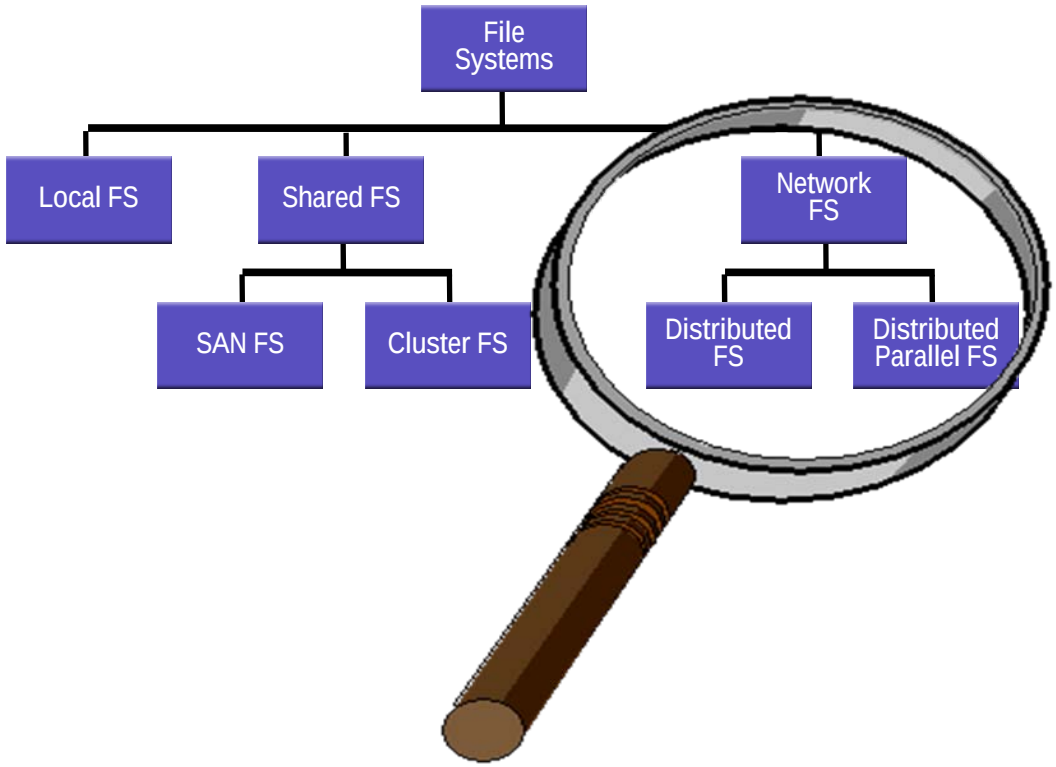
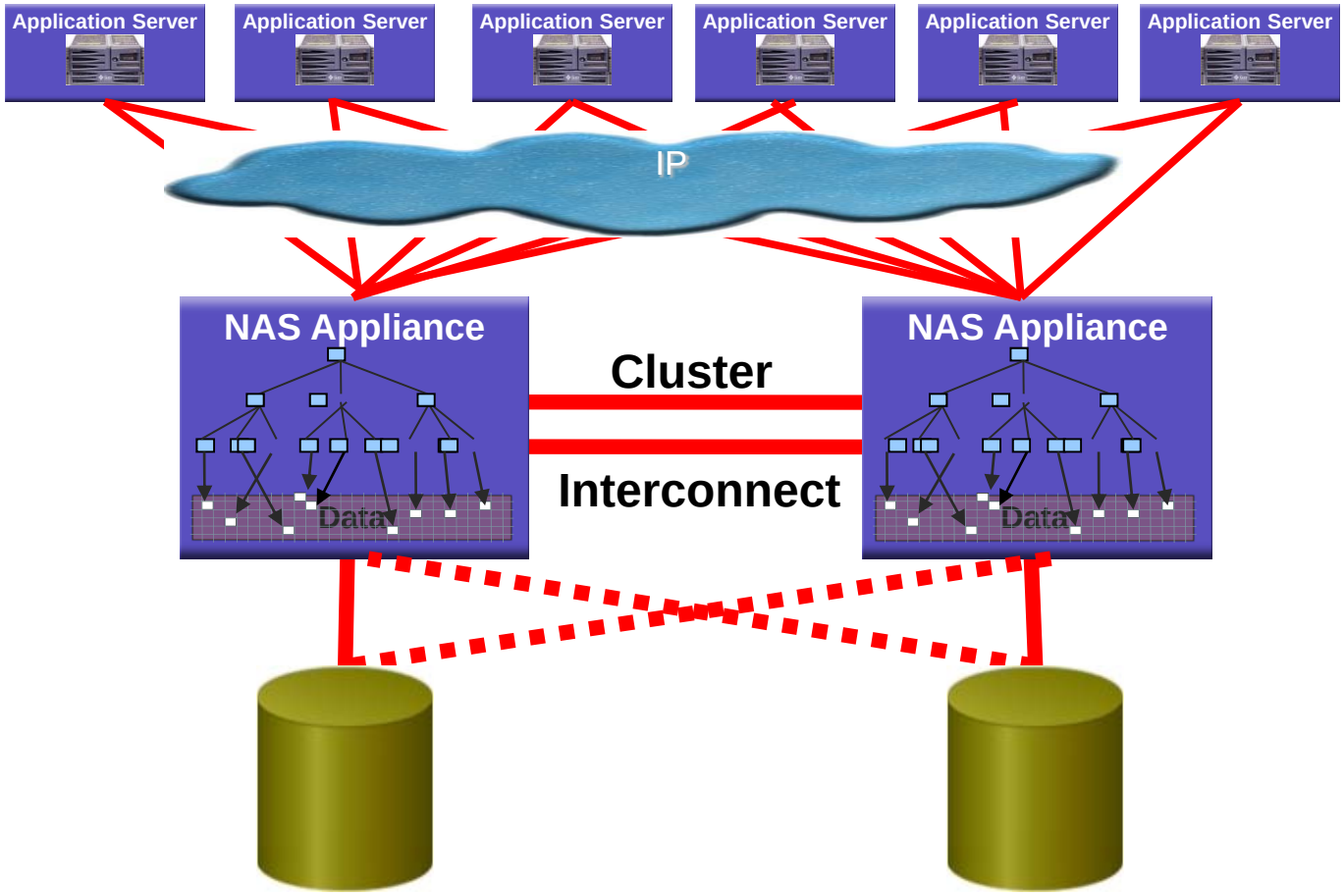
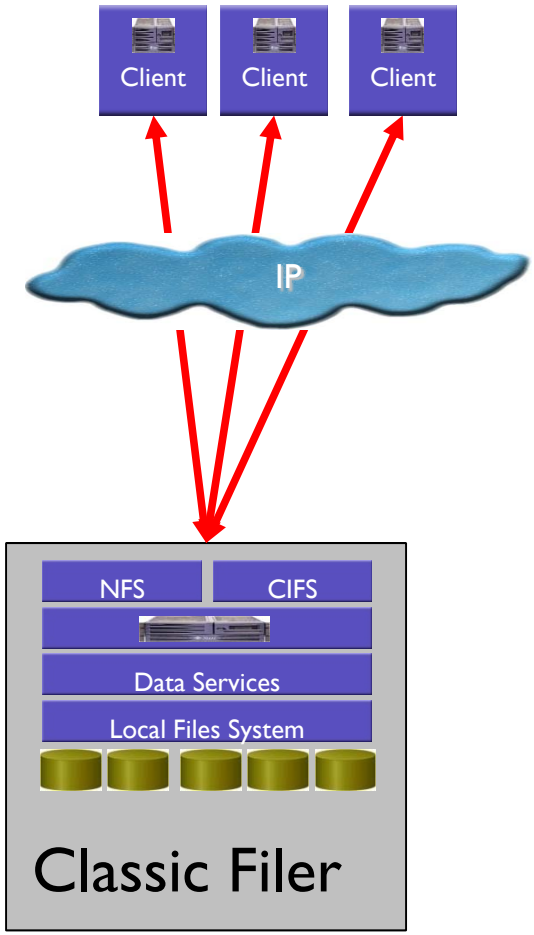


Clustered NAS

- ≠NAS Cluster / NAS Grid

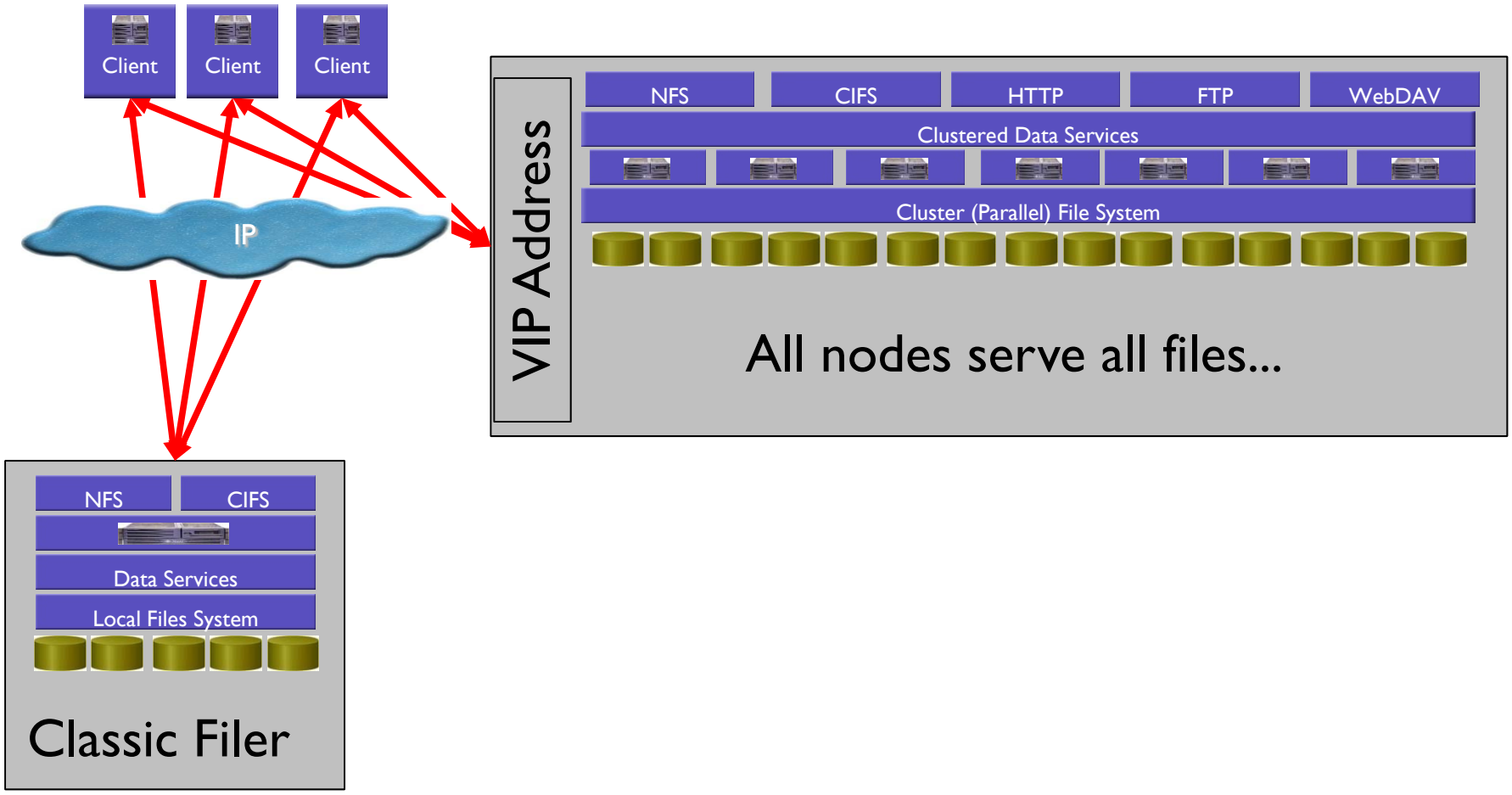


NAS Cluster / NAS Grid (1)



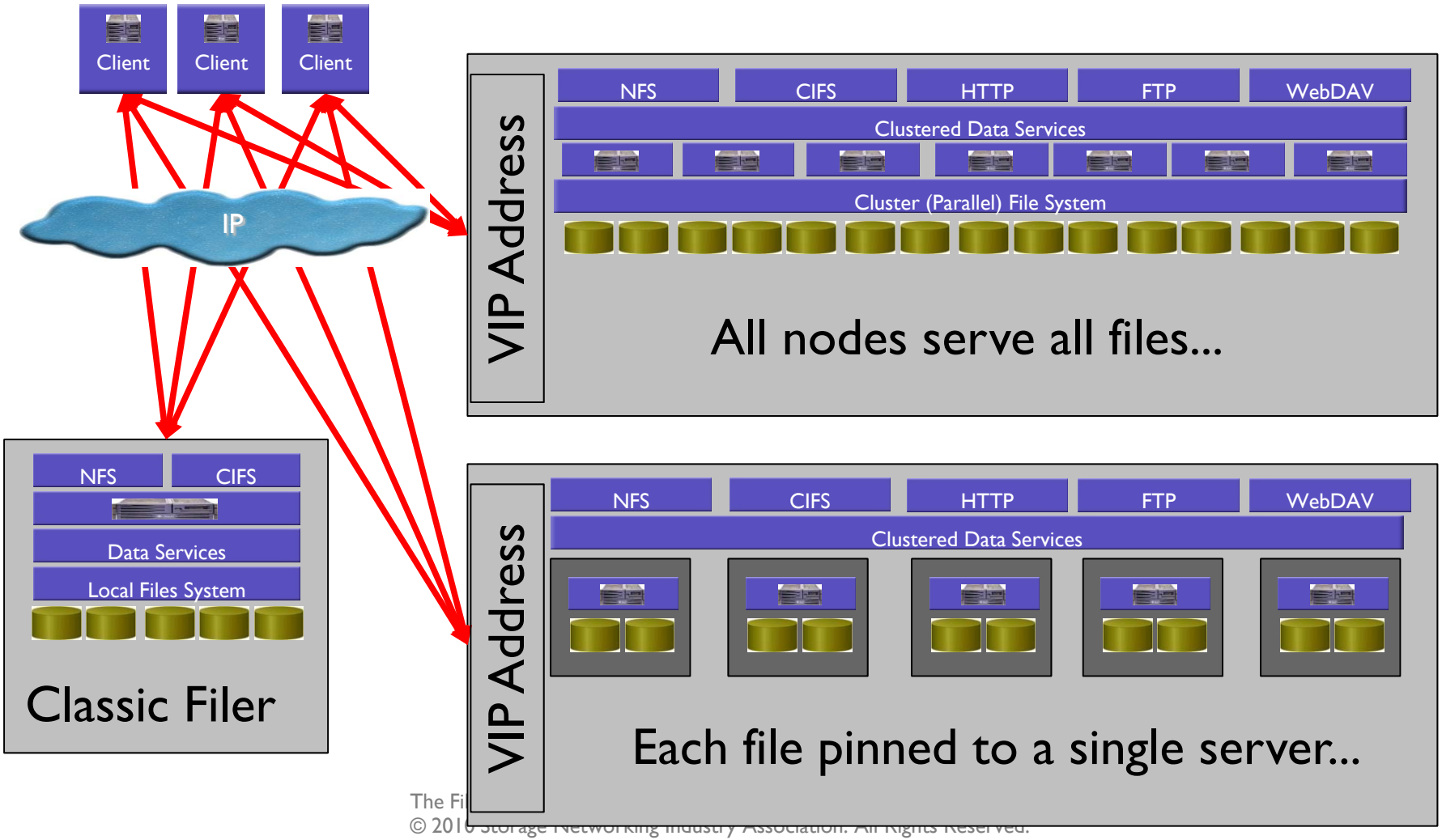
NAS Cluster / NAS Grid (2)

Two flavors:

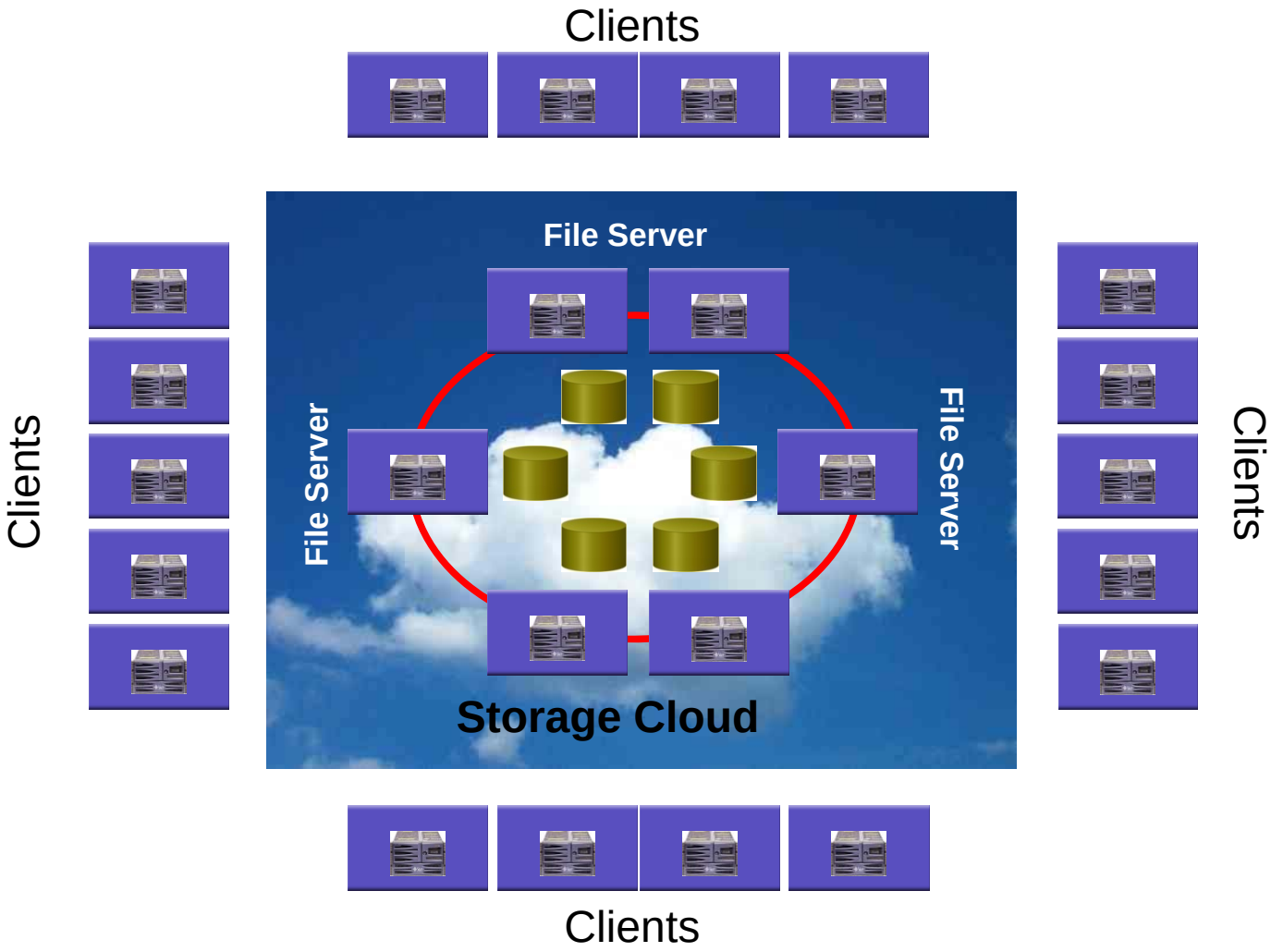


NAS Cluster / NAS Grid (4)

Two flavors:

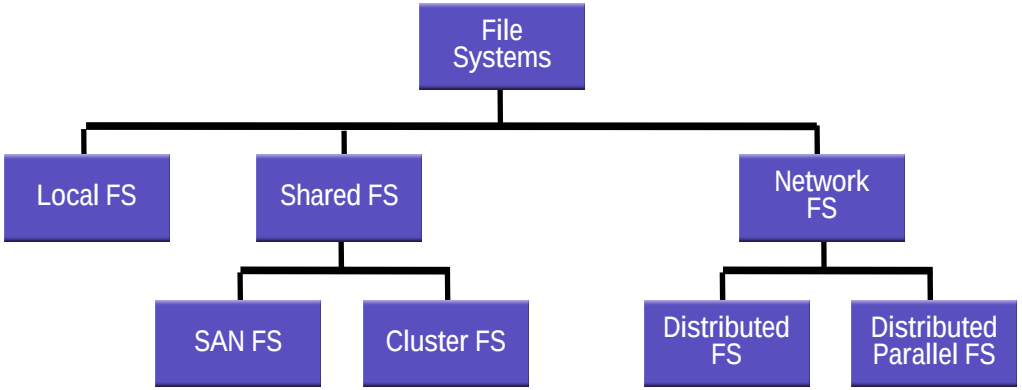


NAS Cluster/Grid & Storage Cloud

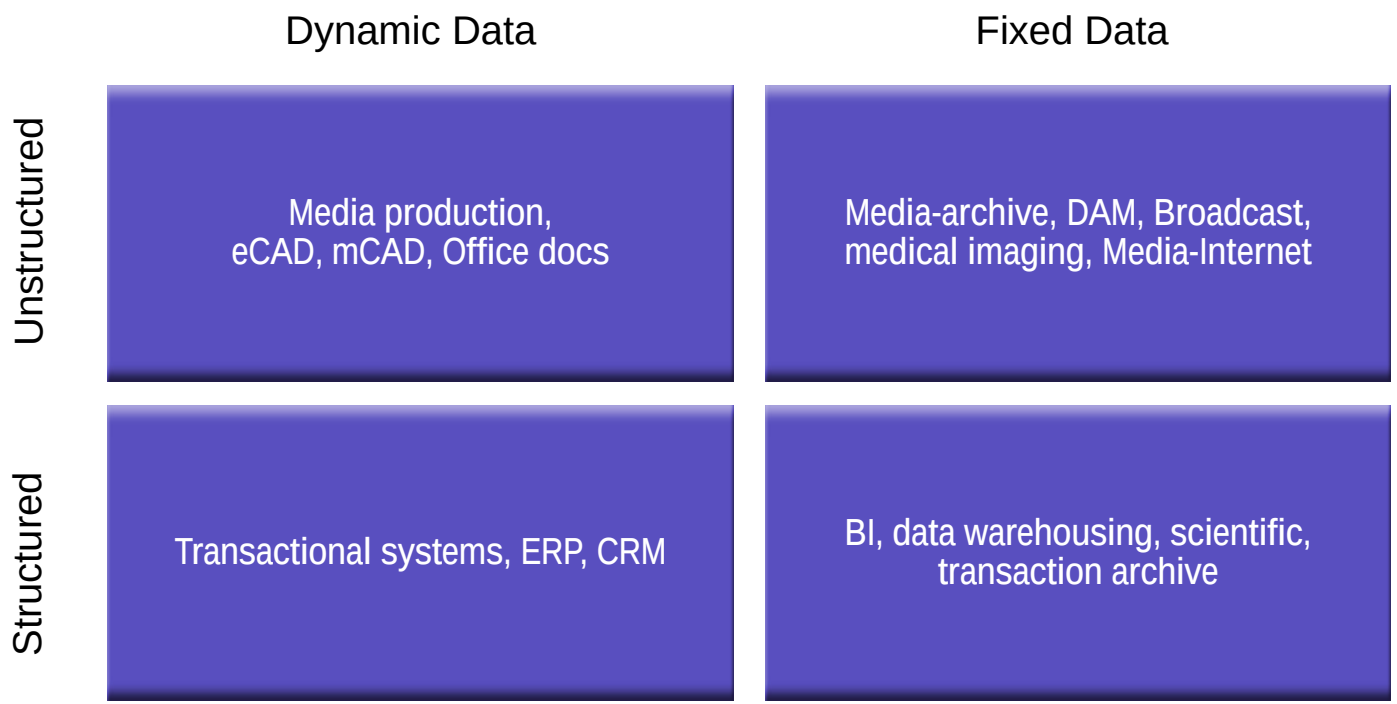


Agenda

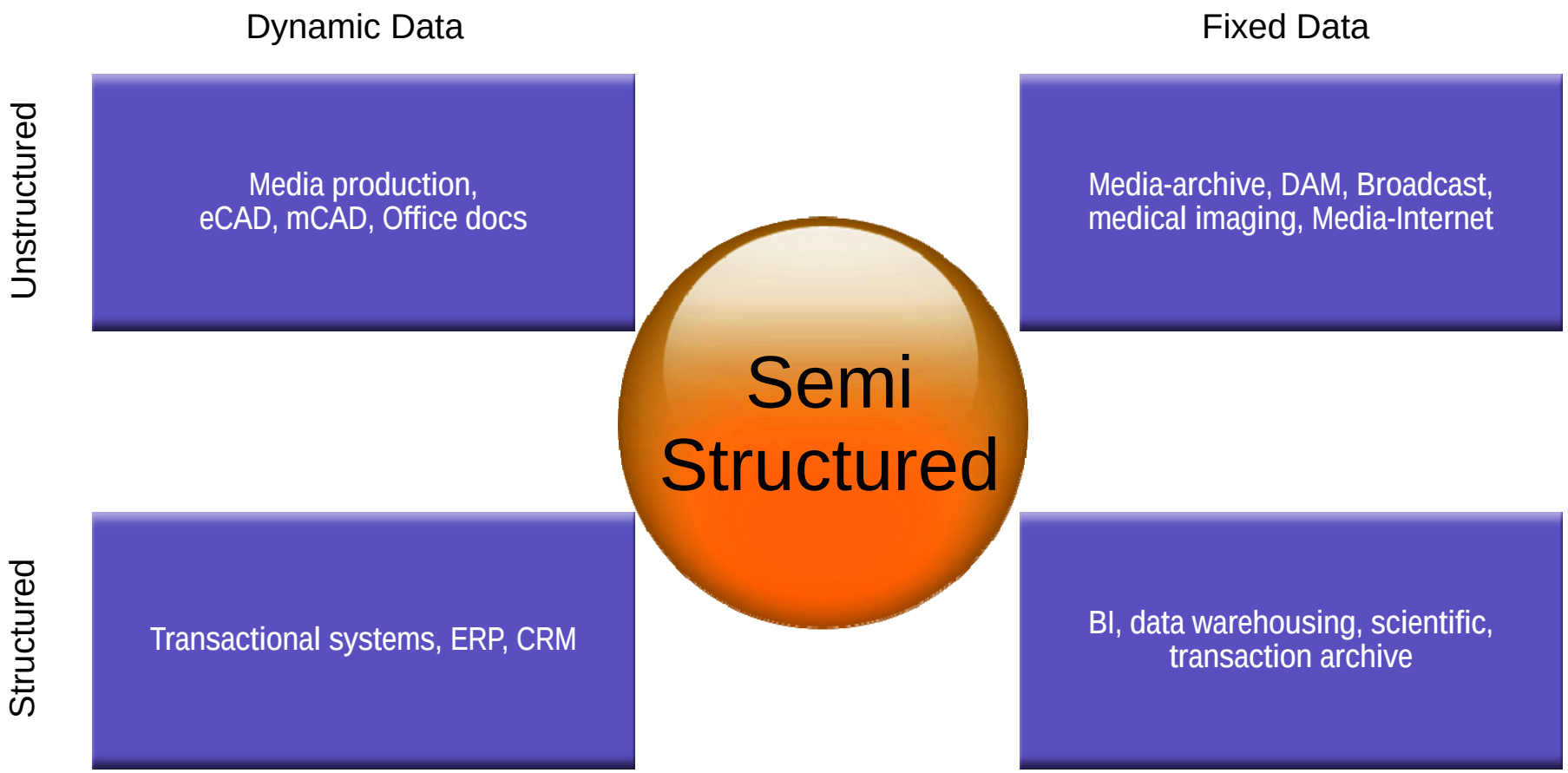
- File System Basics
- File Systems Taxonomy
- Local FS
- Shared FS / Global FS
  - SAN FS, Cluster FS
- Network FS
- Distributed FS
- Distributed Parallel FS
- Scale-Out NAS
  - NAS Aggregation
  - NAS Virtualization
  - NAS Cluster / NAS Grid
- FS Future Developments



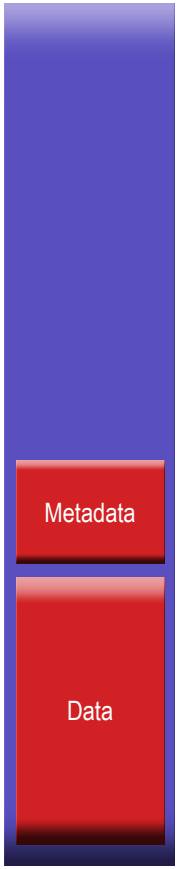
Storage Market Segmentation



Storage Market Segmentation

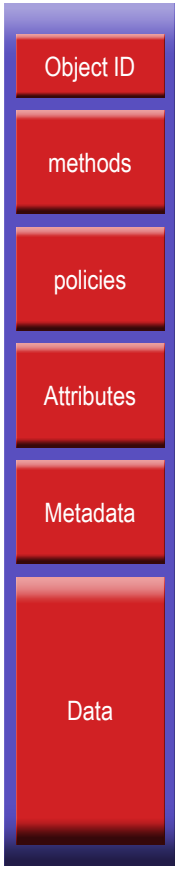


Data For Clouds – File Objects



Owner, permissions, type, last mod. Data, ...

Data For Clouds – File Objects



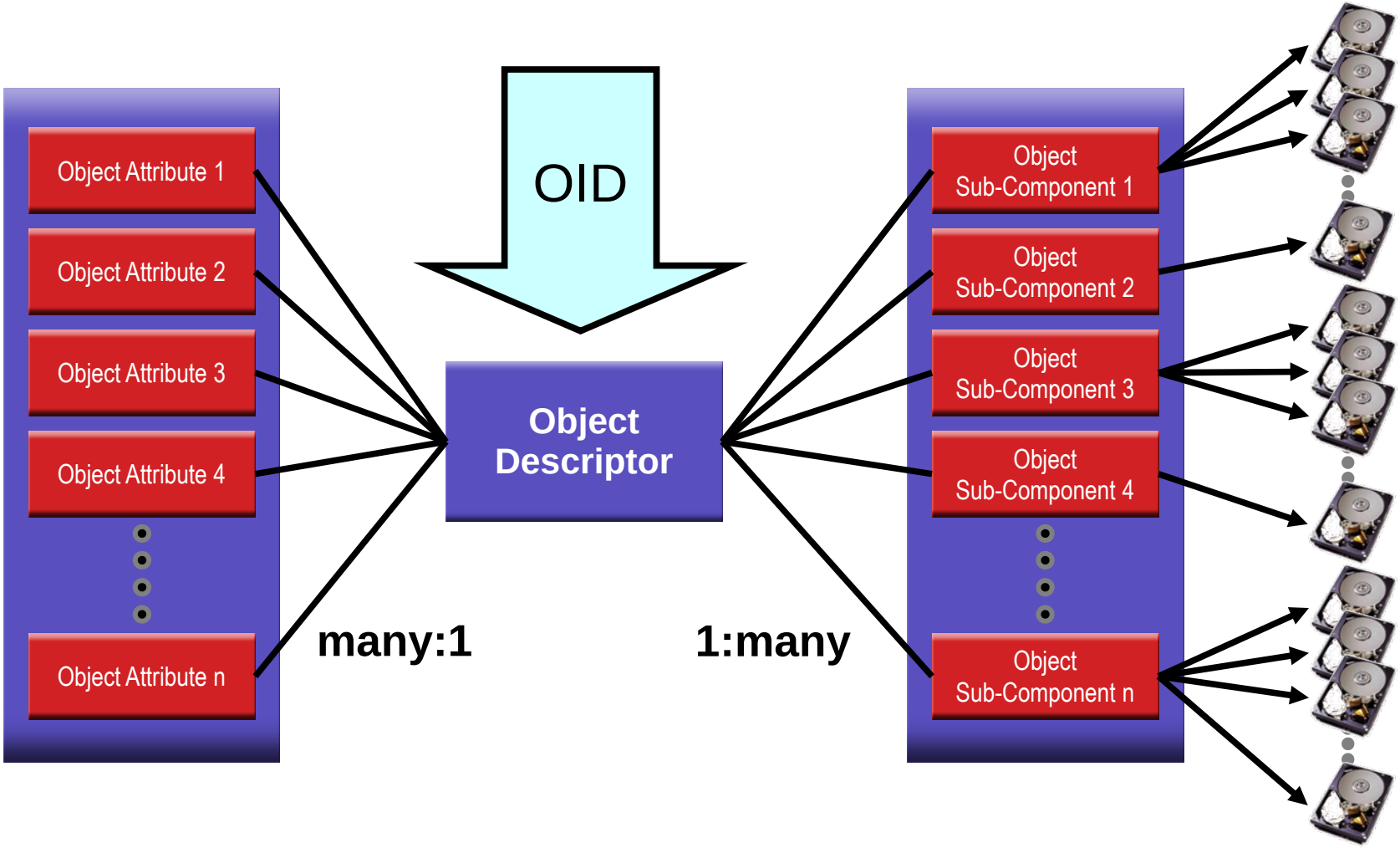
e.g.encryption

e.g. replication

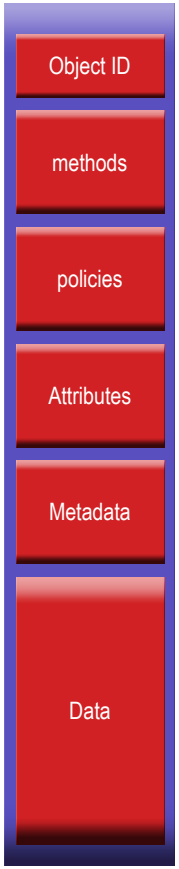
user/application defined

Owner, permissions, type, last mod. Data, ...

Object Model



Data For Clouds – File Objects



e.g.encryption

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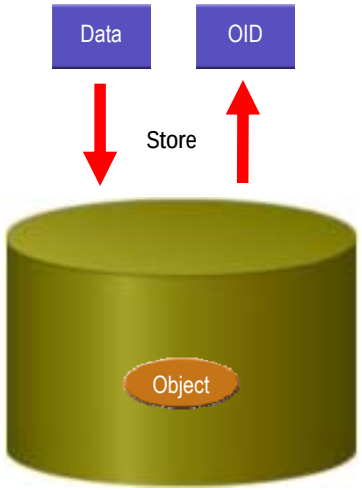
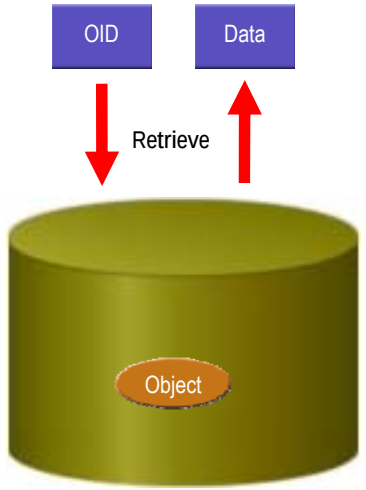
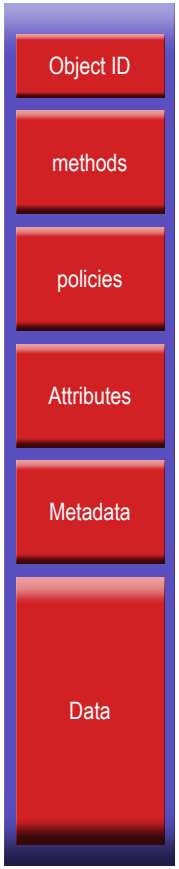




Data For Clouds – File Objects



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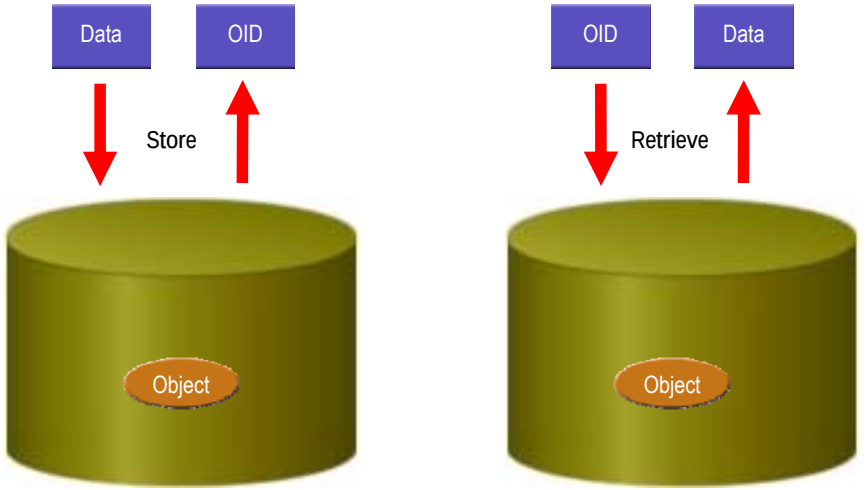
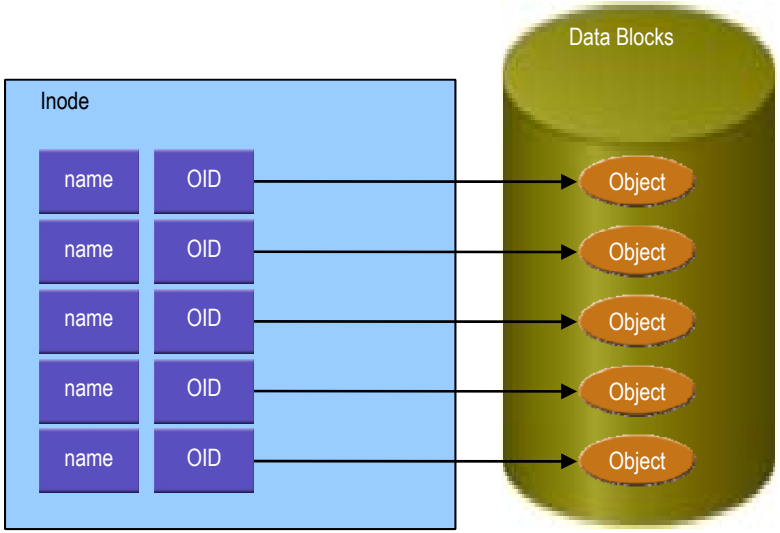
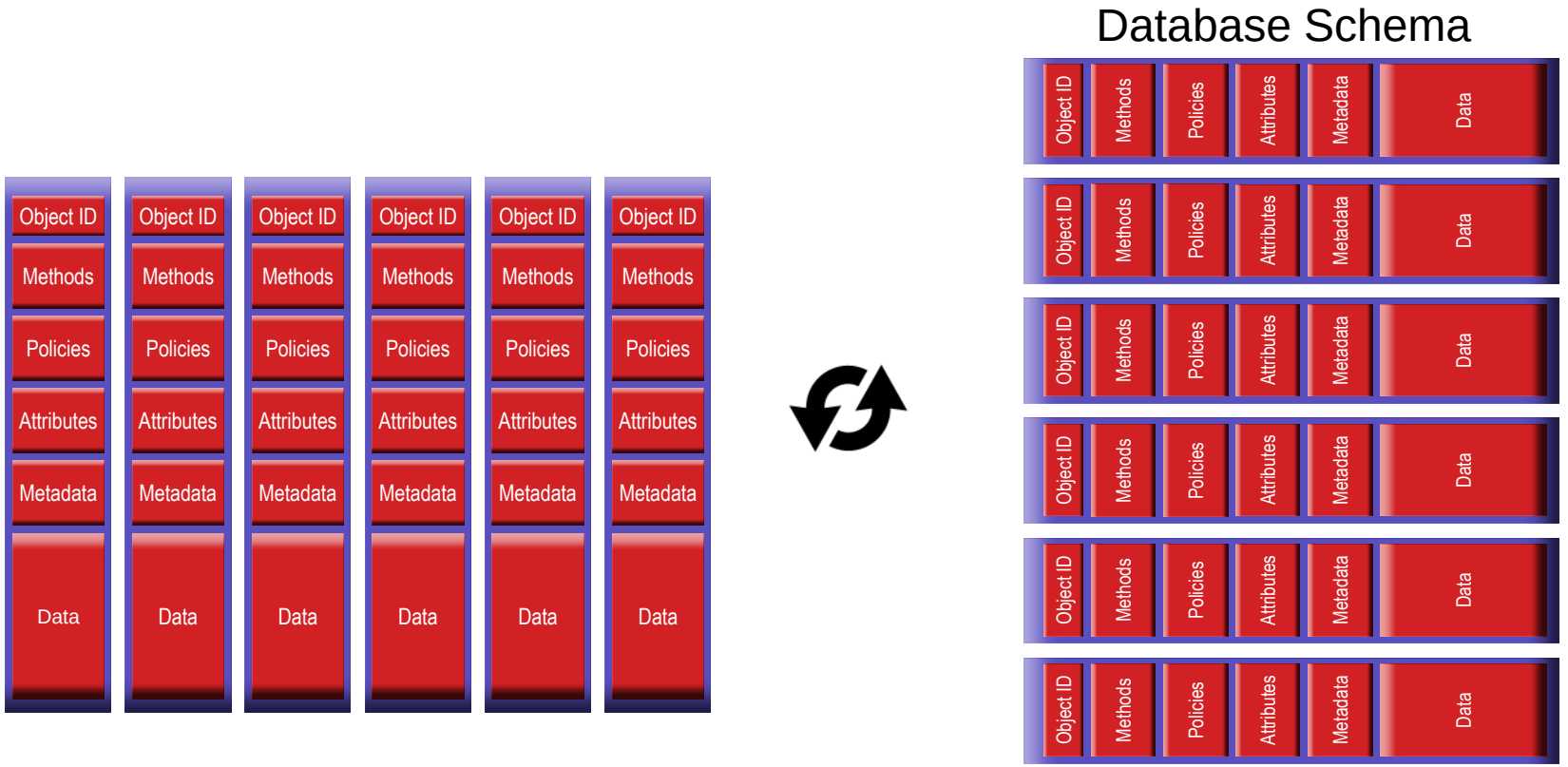


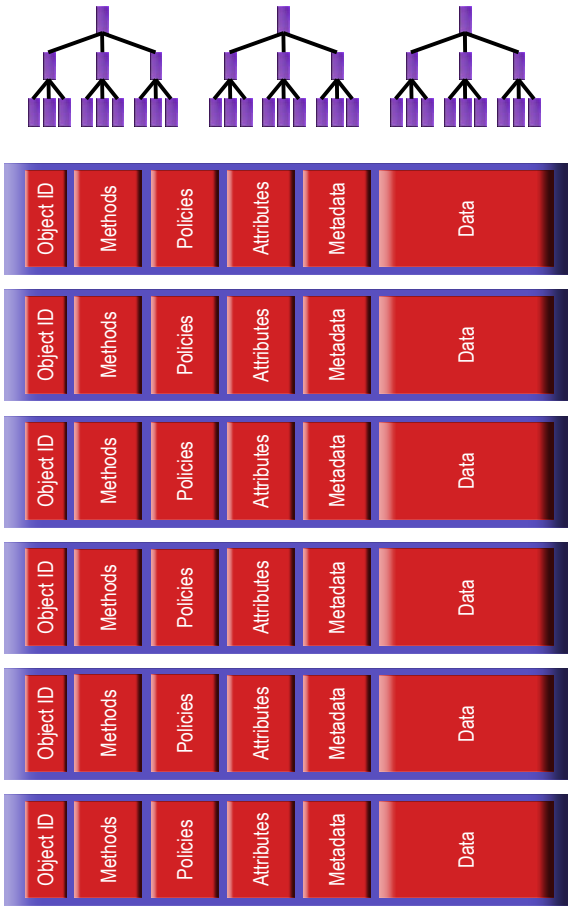


Managing File Objects (1)

- File objects can be managed like records in a relational database with user data as Binary Large Objects (BLOBs)



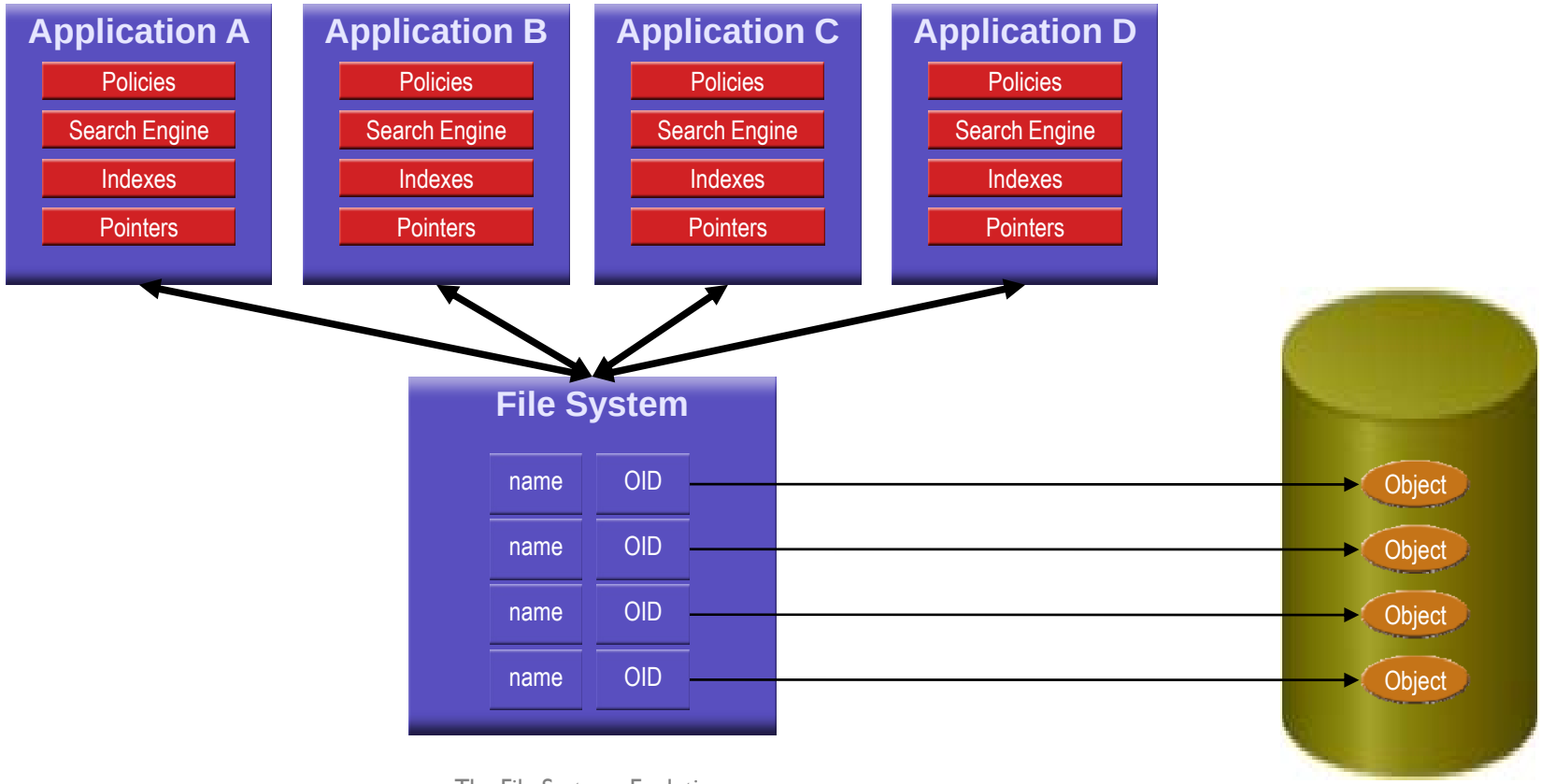
Managing File Objects (2)



- Indexes
- constraints/relationships
- Object search
- Full text search
- Join operations
- Virtual views
- SQL-like requests
- Cursors

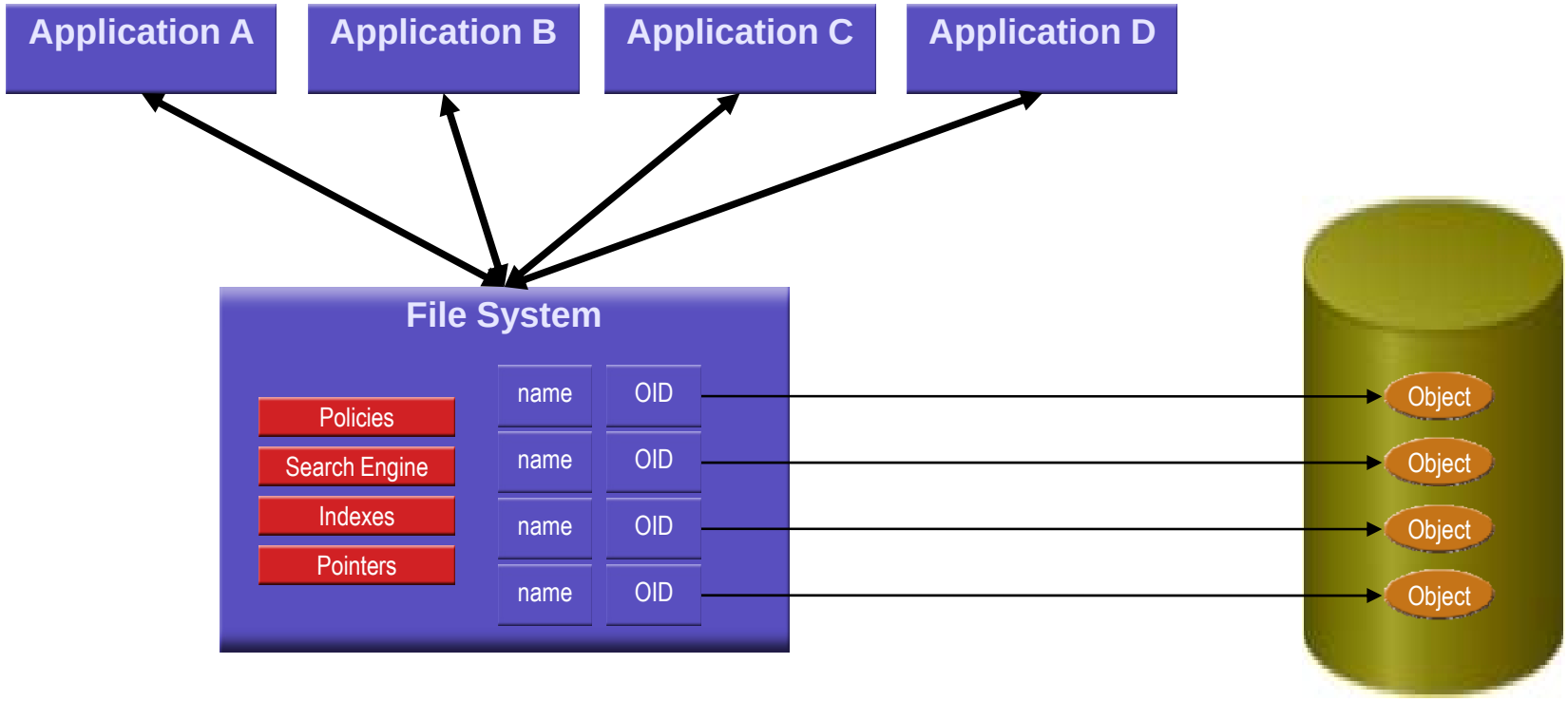
Application Content Repositories

- Combination of application, database, data services and pointers into external file system
- Application specific



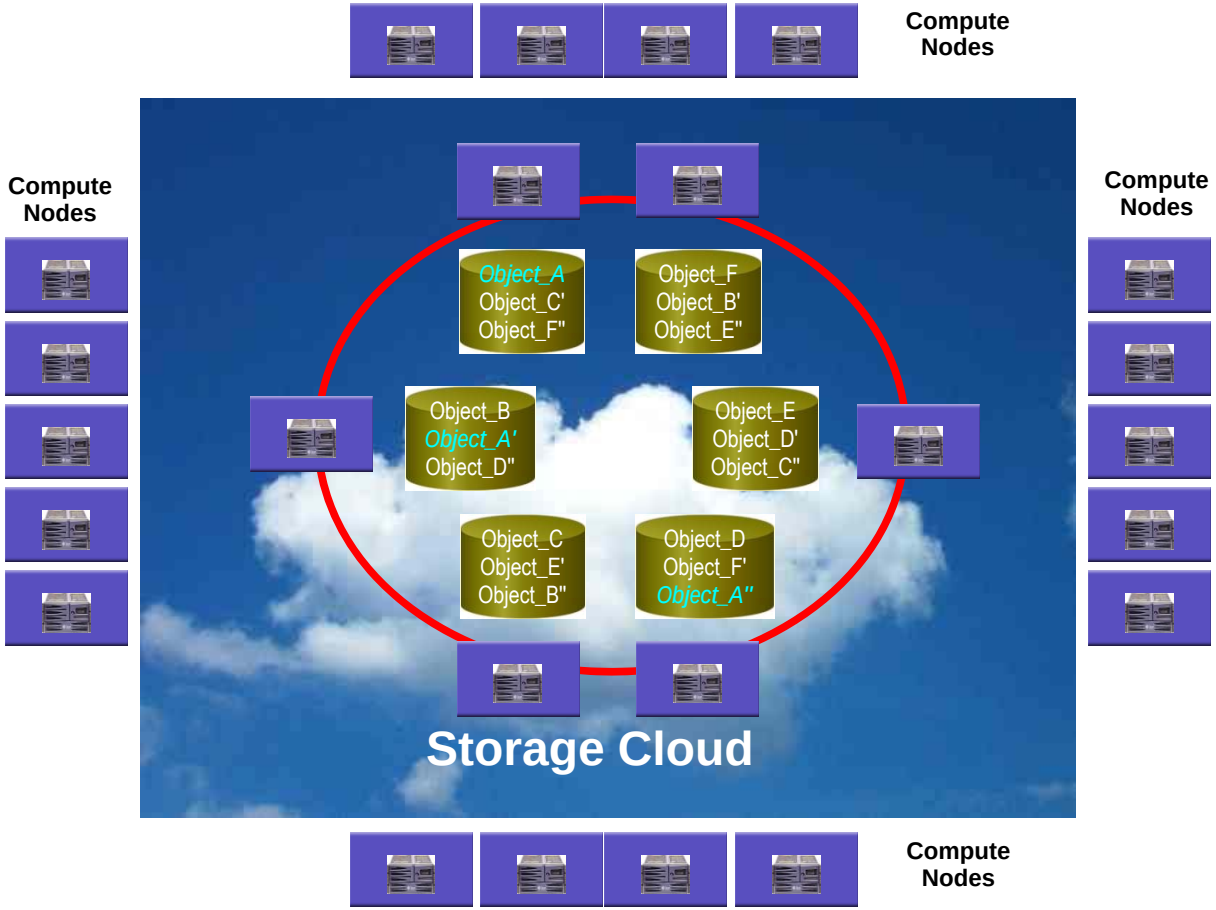
File-Based Content Repositories

- Combination of files system, database and data services
- Application agnostic



File Systems & Objects for Clouds

File Systems morphing into distributed file-based content repositories

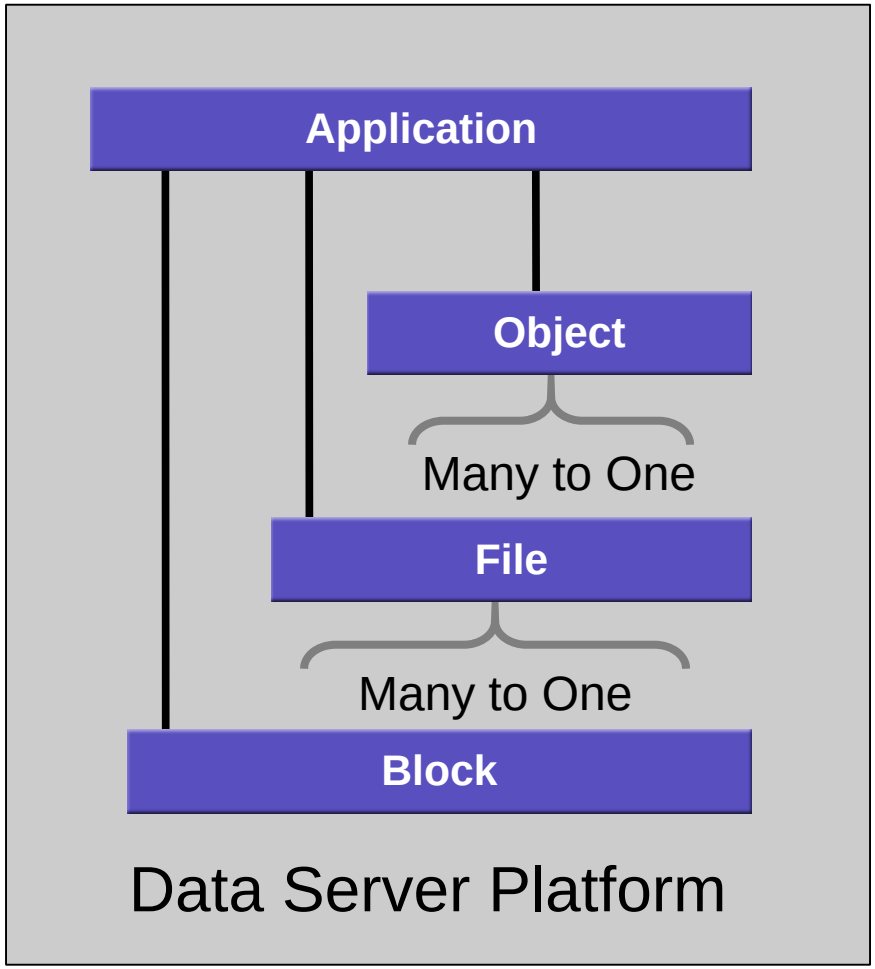


- Availability through file replication
- Sacrifice performance
- Locality of data
- No RAID protection
- Peer-to-peer
- Storage grid
- Mesh topology
- Flat namespace
- Geographically dispersed
- Heterogeneous
- Spontaneous federations

Data Serving Hierarchy

3 Levels of Abstraction

- Application may interface with the storage subsystem in anyone of three layers:
  - Block with highest performance and very little meta data
  - File with medium performance and some meta data
  - Object with medium performance and *rich* meta data



Q&A / Feedback

- Please send any questions or comments on this presentation to SNIA: trackfilemgmt@snia.org

Many thanks to the following individuals for their contributions to this tutorial.

- SNIA Education Committee

Christian Bandulet