MO809/MC964
Tópicos em Computação Distribuída

Sistemas de arquivos distribuídos

Islene Calciolari Garcia

Instituto de Computação - Unicamp

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Sumário

Referência:

Prof. Paul Krzyzanowski
Material do curso Distributed Systems
Rutgers University
Outono de 2014
`http://www.cs.rutgers.edu/~pxk/417/`

Revisão de Arquiteturas

Para pensarmos nos problemas de *caching* e acesso remoto

Building and classifying parallel and distributed systems

Fonte: Prof. Paul Krzyzanowski

Flynn's Taxonomy (1966)

Number of instruction streams and number of data streams

SISD

- traditional uniprocessor system

SIMD

- array (vector) processor
- Examples:
  - GPUs – Graphical Processing Units for video
  - AVX: Intel's Advanced Vector Extensions
  - GPGPU (General Purpose GPU): AMD/ATI, NVIDIA

MISD

- Generally not used and doesn't make sense
- Sometimes (rarely!) applied to classifying redundant systems

MIMD

- multiple computers, each with:
  - program counter, program (instructions), data
- **parallel and distributed systems**

Fonte: Prof. Paul Krzyzanowski

Subclassifying MIMD

memory

- shared memory systems: multiprocessors
- no shared memory: networks of computers, multicomputers

interconnect

- bus
- switch

delay/bandwidth

- tightly coupled systems
- loosely coupled systems

Fonte: Prof. Paul Krzyzanowski

Parallel Systems: Multiprocessors

- Shared memory
- Shared clock
- All-or-nothing failure

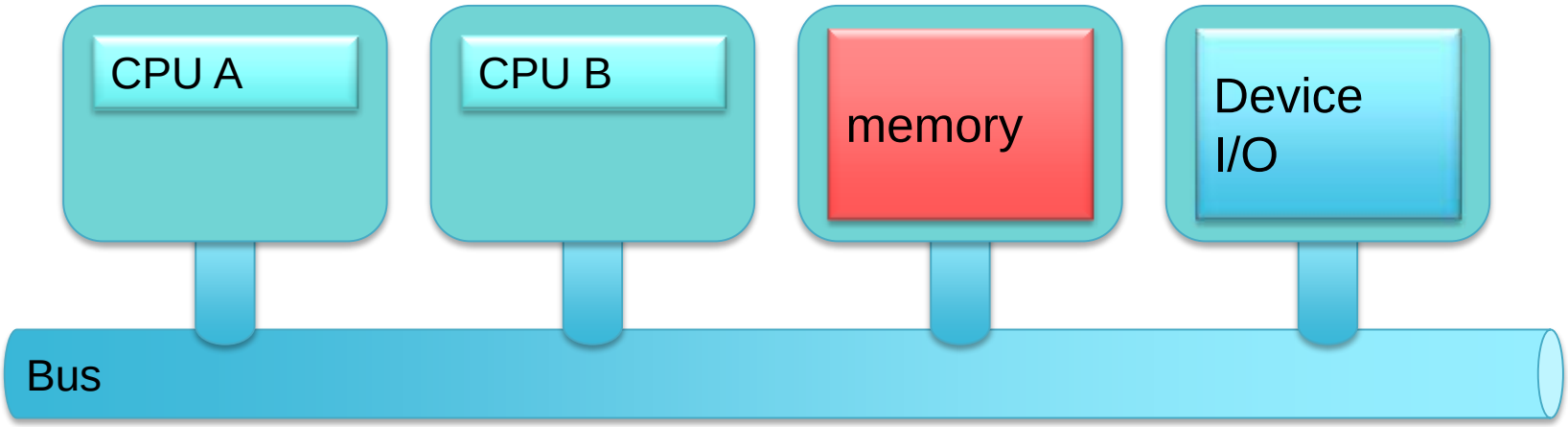
Fonte: Prof. Paul Krzyzanowski

Bus-based multiprocessors

SMP: Symmetric Multi-Processing

All CPUs connected to one bus (backplane)

Memory and peripherals are accessed via shared bus. System looks the same from any processor.

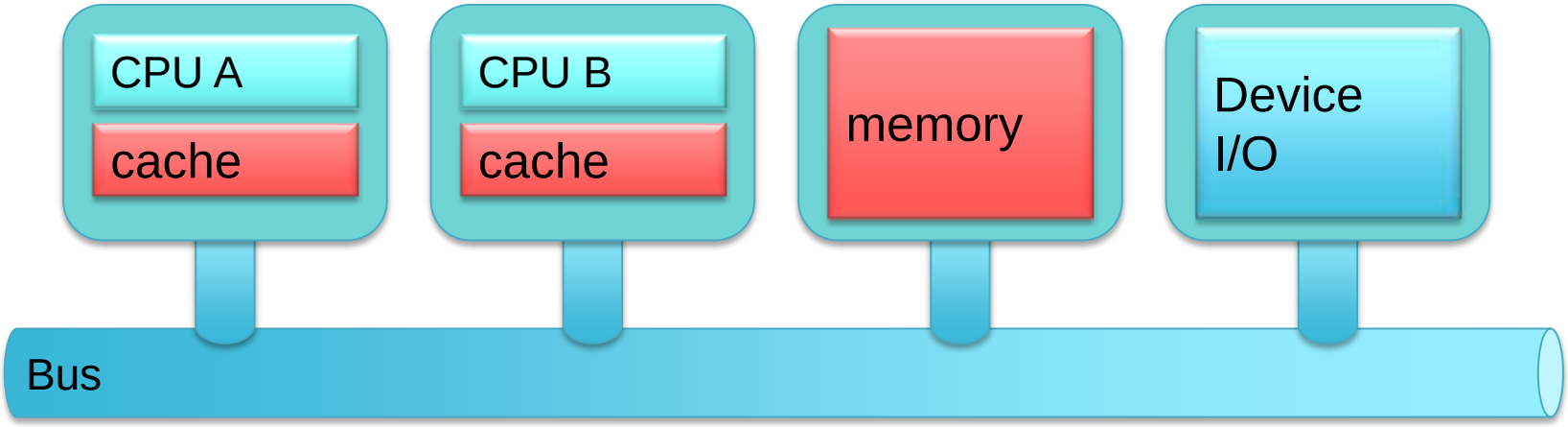


The bus becomes a point of congestion … limits performance

Fonte: Prof. Paul Krzyzanowski

Bus-based multiprocessors

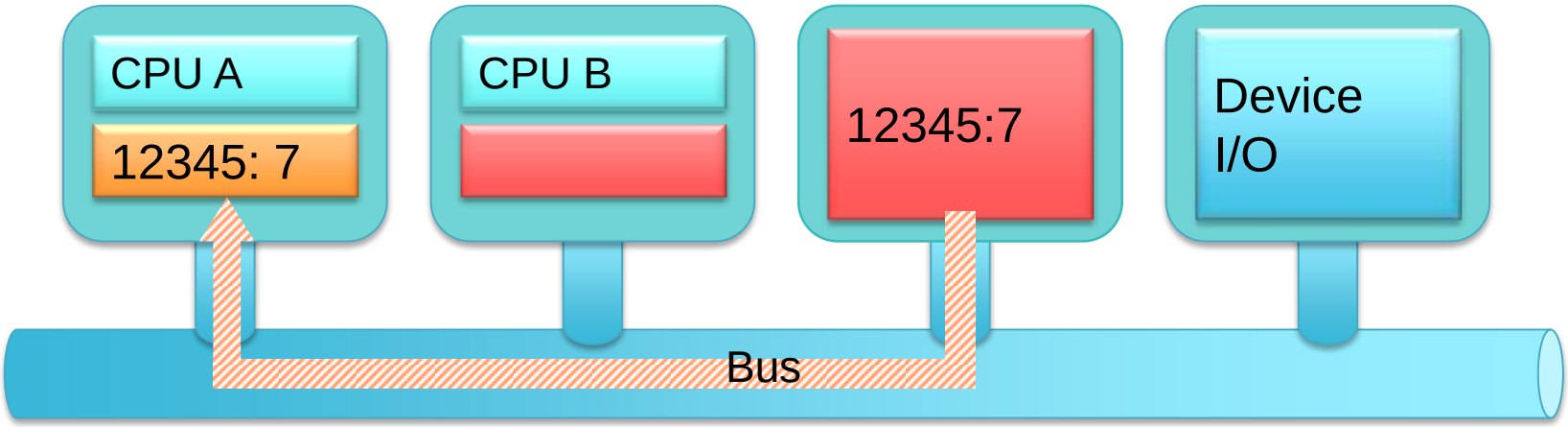
- The cache: great idea to deal with bus overload & memory contention
  - Memory that is local to a processor
- CPU performs I/O to cache memory
  - Access main memory only on cache miss



Fonte: Prof. Paul Krzyzanowski

Working with a cache

CPU A reads location 12345 from memory

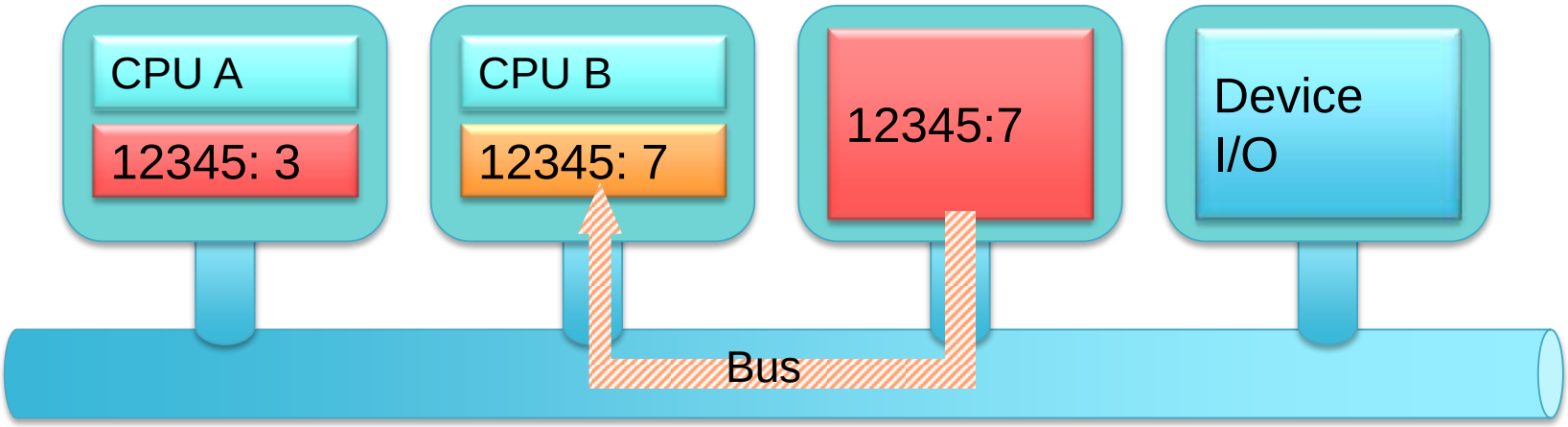


Fonte: Prof. Paul Krzyzanowski

Working with a cache

Gets old value

Memory not coherent!

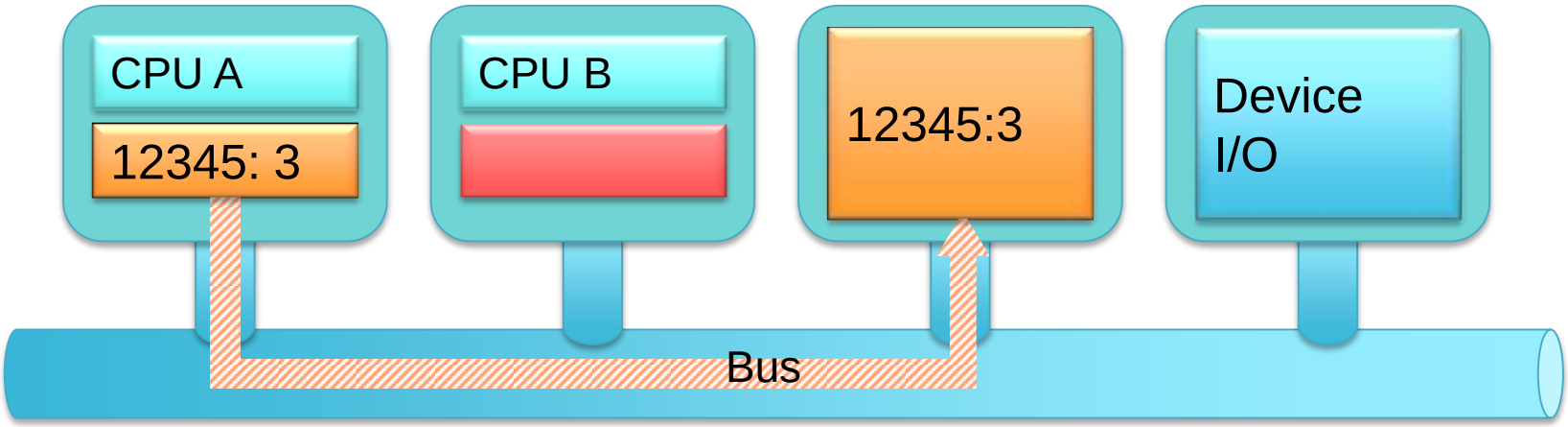


Fonte: Prof. Paul Krzyzanowski

Write-through cache

Fix coherency problem by writing all values through bus to main memory

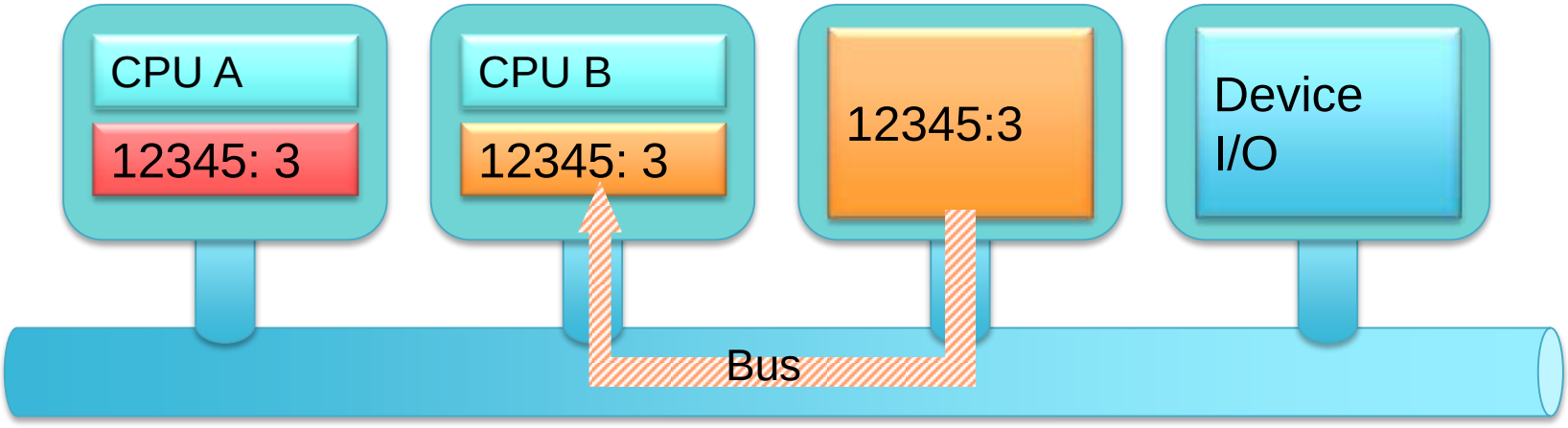
CPU A modifies location 12345 – ***write-through***
main memory is now coherent



Fonte: Prof. Paul Krzyzanowski

Write-through cache … continued

CPU B reads location 12345 from memory
- loads into cache

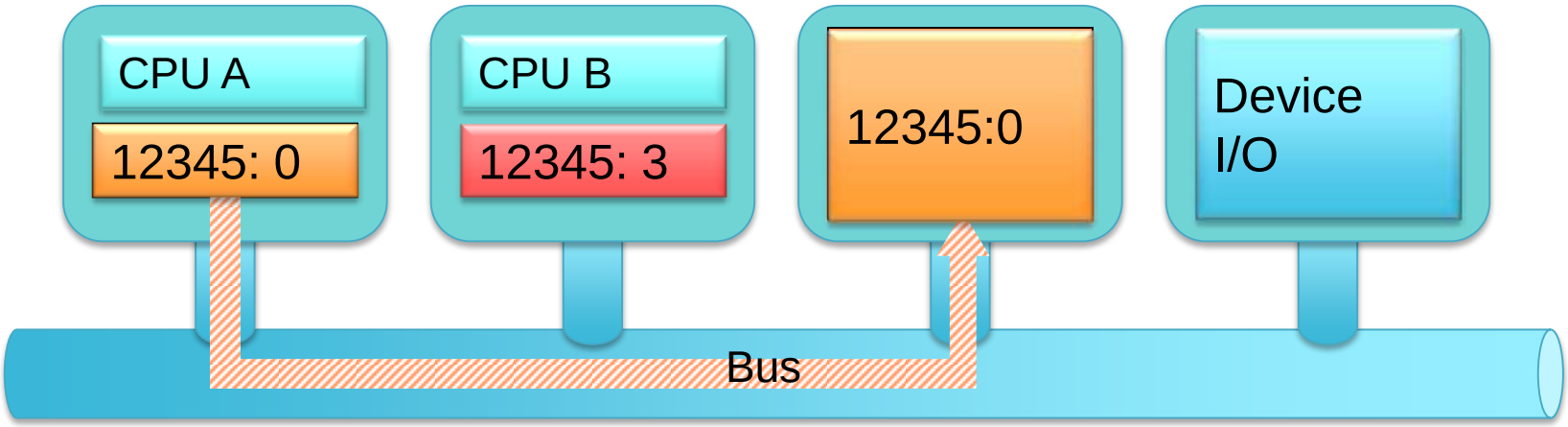


Fonte: Prof. Paul Krzyzanowski

Write-through cache

CPU A modifies location 12345
- write-through

Cache on CPU B not updated
Memory not coherent!



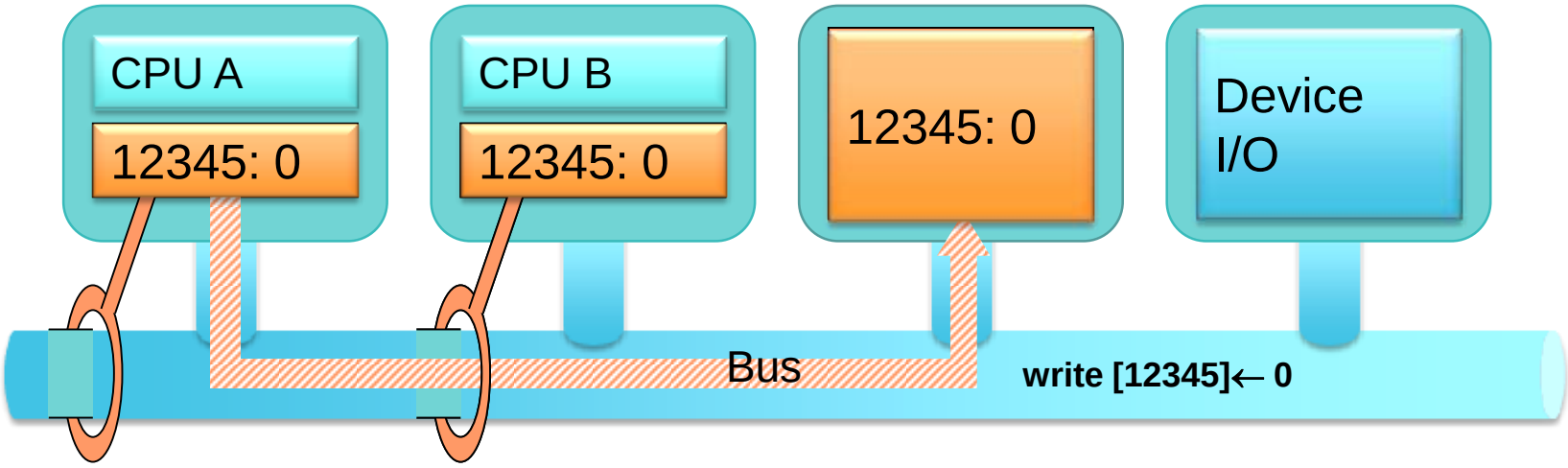
Fonte: Prof. Paul Krzyzanowski

Snoopy cache

Add logic to each cache controller:

monitor the bus for writes to memory

Virtually all bus-based architectures use a snoopy cache



Fonte: Prof. Paul Krzyzanowski

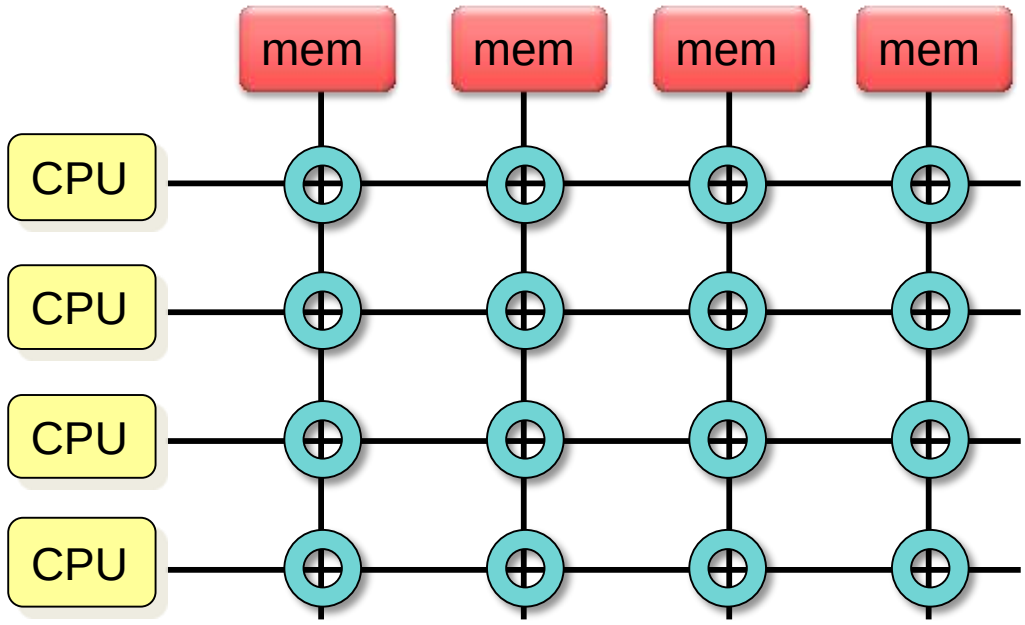
Switched multiprocessors

- Bus-based architecture does not scale linearly to large number of CPUs (e.g., beyond 8)

Fonte: Prof. Paul Krzyzanowski

Switched multiprocessors

Divide memory into groups and connect chunks of memory to the processors with a **crossbar switch**



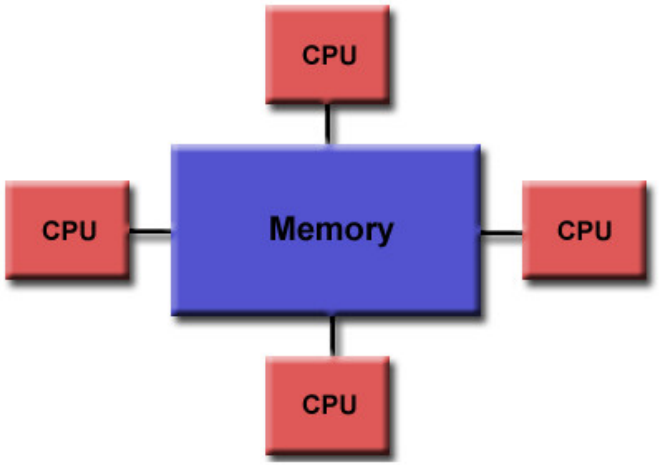
n^2 crosspoint switches – expensive switching fabric

We still want to cache at each CPU – but we cannot snoop!

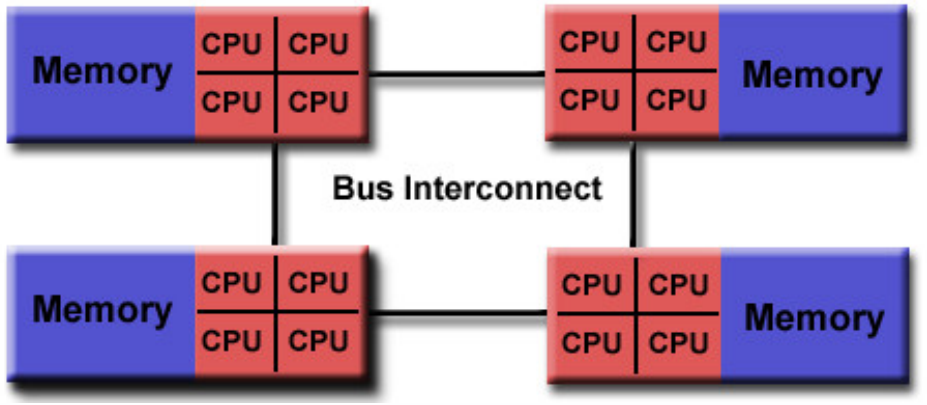
Fonte: Prof. Paul Krzyzanowski

UMA versus NUMA

Uniform Memory Architecture



Non-Uniform Memory Architecture



Fonte:
https://computing.llnl.gov/tutorials/parallel_comp

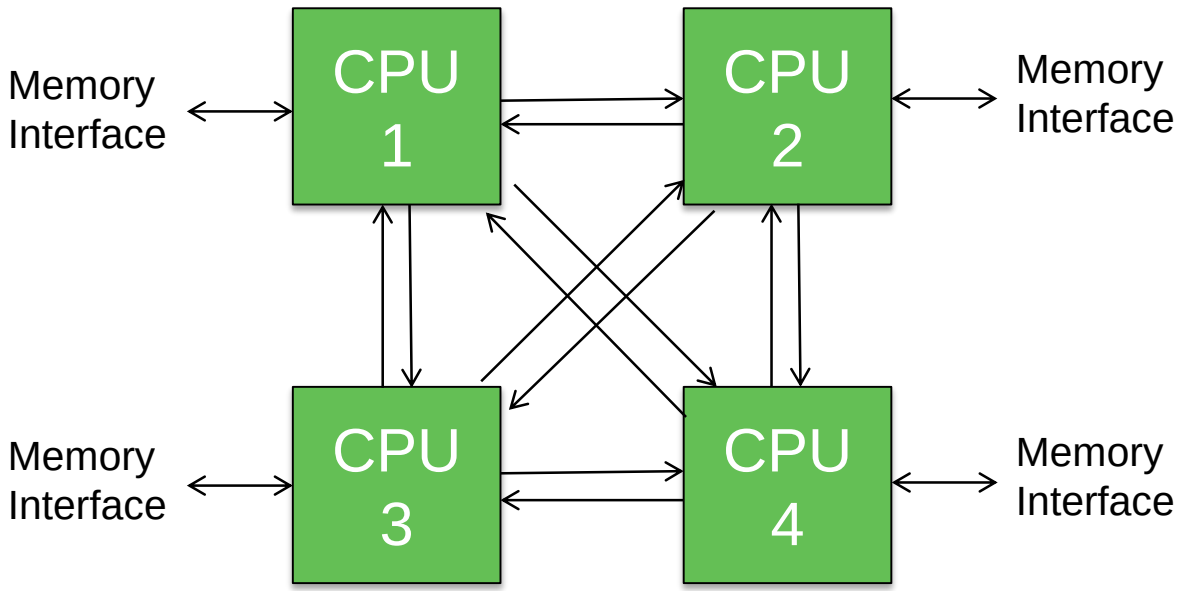
NUMA

- Hierarchical Memory System
- All CPUs see the same address space
- Each CPU has local connectivity to a region of memory
  - fast access
- Access to other regions of memory – slower
- Placement of code and data becomes challenging
  - Operating system has to be aware of memory allocation and CPU scheduling

Fonte: Prof. Paul Krzyzanowski

NUMA Cache Coherence NUMA: Intel Example

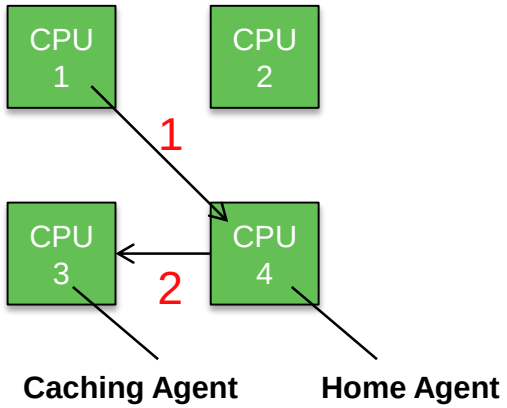
- Home Snoop: *Home-based consistency protocol*
  - Each CPU is responsible for a region of memory
  - It is the "home agent" for that memory
    - Each home agent maintains a directory (table) that track of who has the latest version



Fonte: Prof. Paul Krzyzanowski

NUMA Cache Coherence NUMA: Intel Example

1. CPU sends request to home agent
2. Home agent requests status from the CPU that may have a cached copy (caching agent)

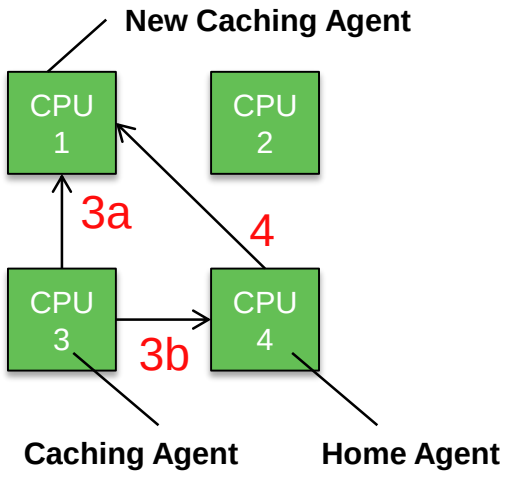


Fonte: Prof. Paul Krzyzanowski

NUMA Cache Coherence NUMA: Intel Example

3. (a) Caching agent sends data update to new caching agent
   (b) Caching agent sends status update to home agent

4. Home agent resolves any conflicts & completes transaction



Fonte: Prof. Paul Krzyzanowski

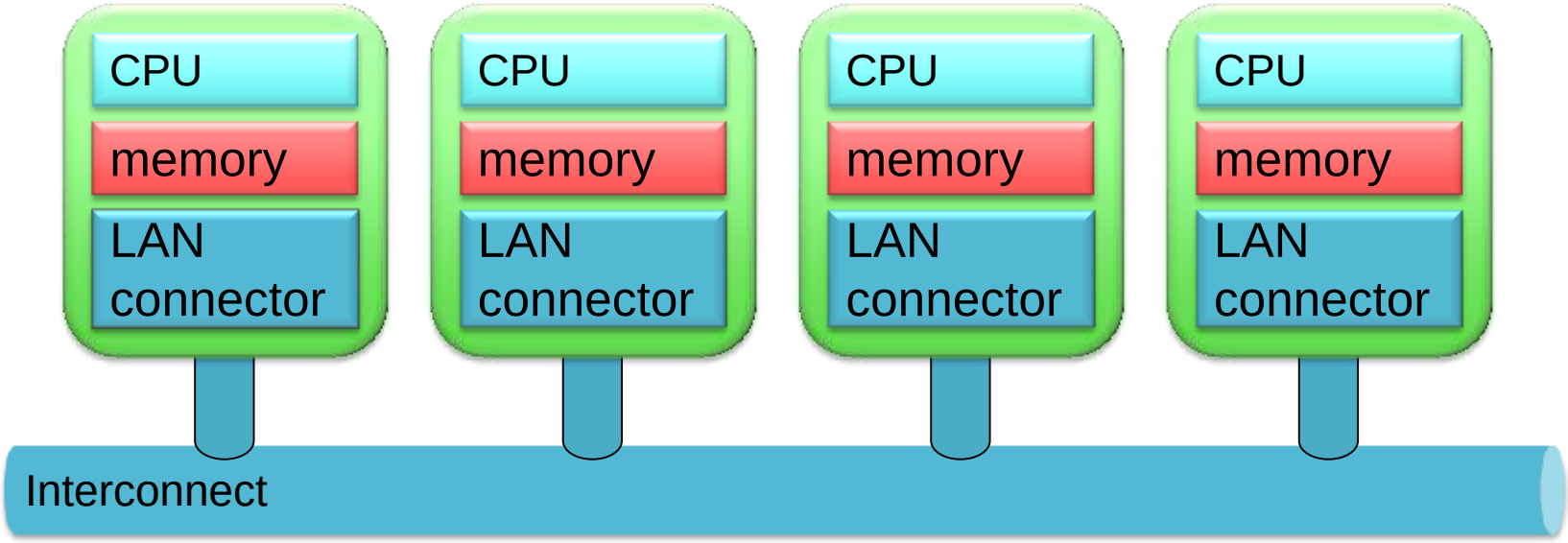
Networks of computers

- Eventually, other bottlenecks occur
  - Network, disk
- We want to scale beyond multiprocessors
  - Multicomputers
- No shared memory, no shared clock
- Communication mechanism needed
  - Traffic much lower than memory access
  - Network

Fonte: Prof. Paul Krzyzanowski

Bus-based multicomputers

Collection of workstations on a LAN

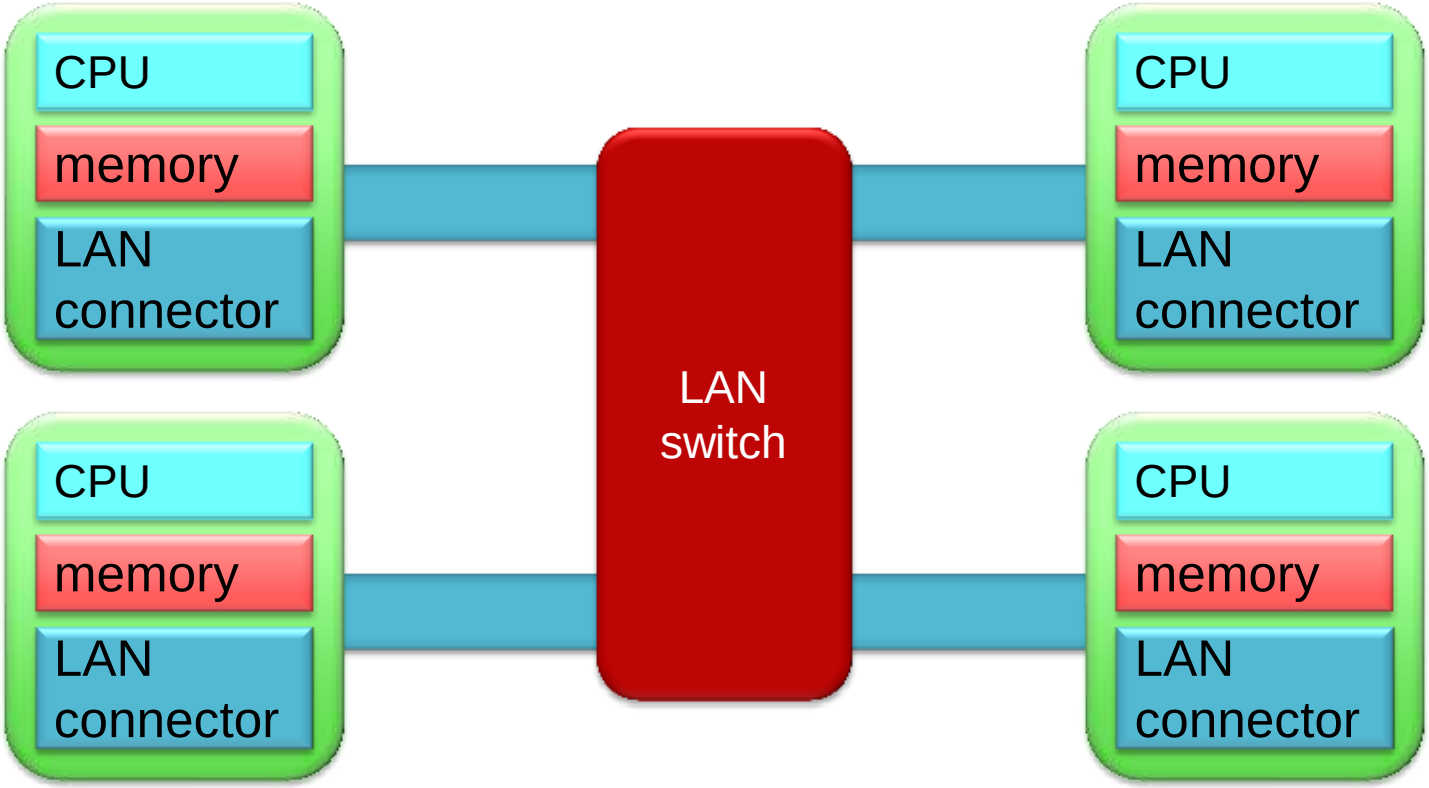


A shared bus-based interconnect gives us the option of *snooping*

Fonte: Prof. Paul Krzyzanowski

Switched multicomputers

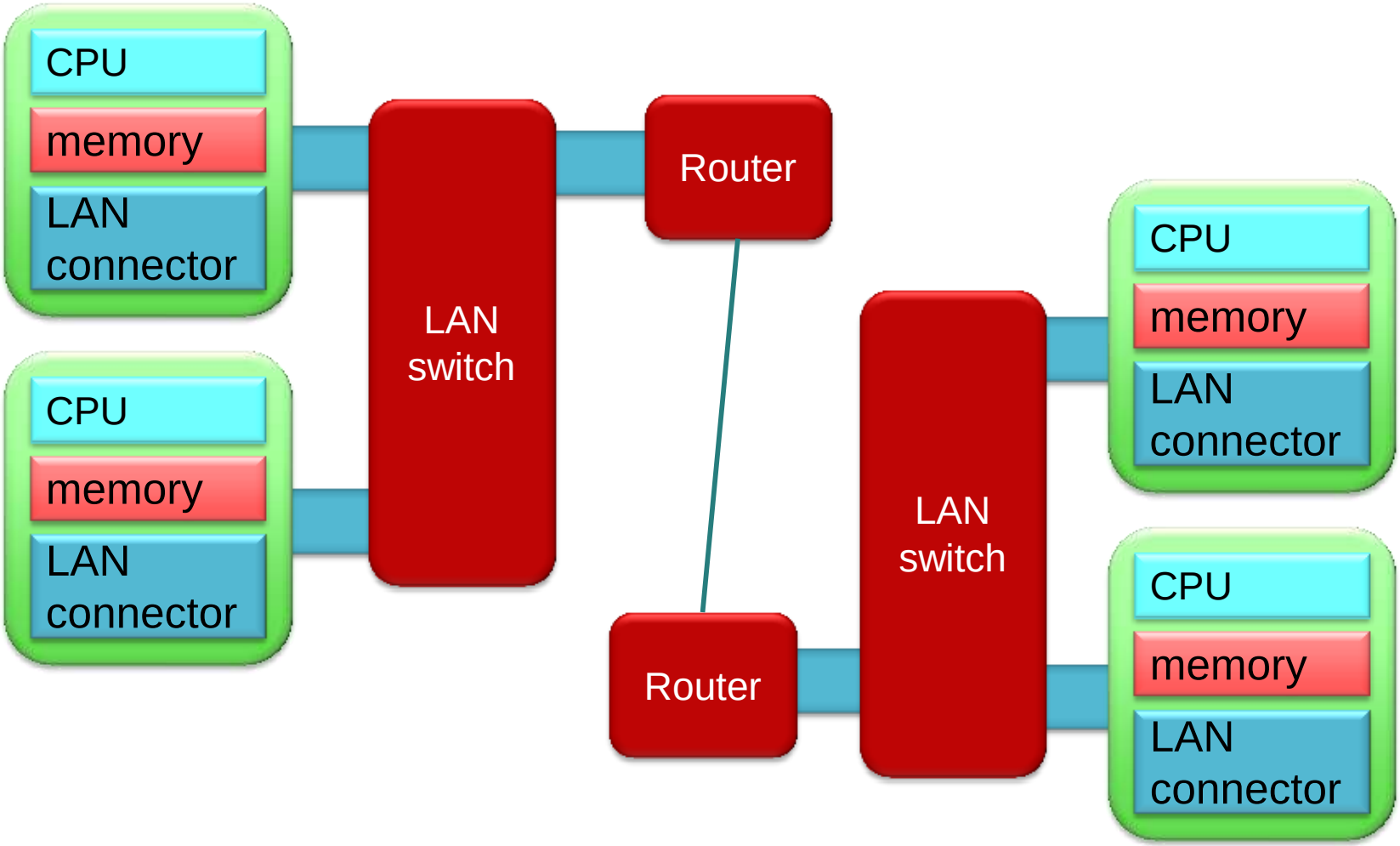
Collection of workstations on a LAN



A switched interconnect does not allow snooping

Fonte: Prof. Paul Krzyzanowski

Wide Area Distribution



Don’t expect to snoop on data traffic

Fonte: Prof. Paul Krzyzanowski

What is a Distributed System?

A collection of independent, autonomous hosts connected through a communication network.

- No shared memory (must use the network)
- No shared clock

Fonte: Prof. Paul Krzyzanowski

Sistemas de arquivos baseados em rede

Distributed Systems

15. Network File Systems

Paul Krzyzanowski

Rutgers University

Fall 2014

Fonte: Prof. Paul Krzyzanowski

Accessing files

File sharing with socket-based programs

HTTP, FTP, telnet:

- Explicit access
- User-directed connection to access remote resources

We want more transparency

- Allow user to access remote resources just as local ones

NAS: Network Attached Storage

Fonte: Prof. Paul Krzyzanowski

File service models

Upload/Download model

– *Read file:* copy file from server to client
– *Write file:* copy file from client to server

Advantage
– **Simple**

Problems
– **Wasteful**: what if client needs small piece?
– **Problematic**: what if client doesn't have enough space?
– **Consistency**: what if others need to modify the same file?

Remote access model

File service provides functional interface:
– *create, delete, read bytes, write bytes, etc…*

Advantages:
– Client gets only what's needed
– Server can manage coherent view of file system

Problem:
– Possible server and network **congestion**
  • Servers are accessed for duration of file access
  • Same data may be requested repeatedly

Fonte: Prof. Paul Krzyzanowski

Semantics of file sharing

Sequential Semantics

Read returns result of last write

Easily achieved *if*

- Only one server
- Clients do not cache data

BUT

- Performance problems if no cache
  - Obsolete data
- We can ***write-through***
  - Must notify clients holding copies
  - Requires extra state, generates extra traffic

Session Semantics

Relax the rules

- Changes to an open file are initially visible only to the process (or machine) that modified it.
- Need to hide or lock file under modification from other clients
- Last process to modify the file wins.

Fonte: Prof. Paul Krzyzanowski

Remote File Service

File Directory Service

– Maps textual names for file to internal locations that can be used by file service

File service

– Provides file access interface to clients

Client module (driver)

– Client side interface for file and directory service

– if done right, helps provide access transparency

e.g. implement the file system under the VFS layer

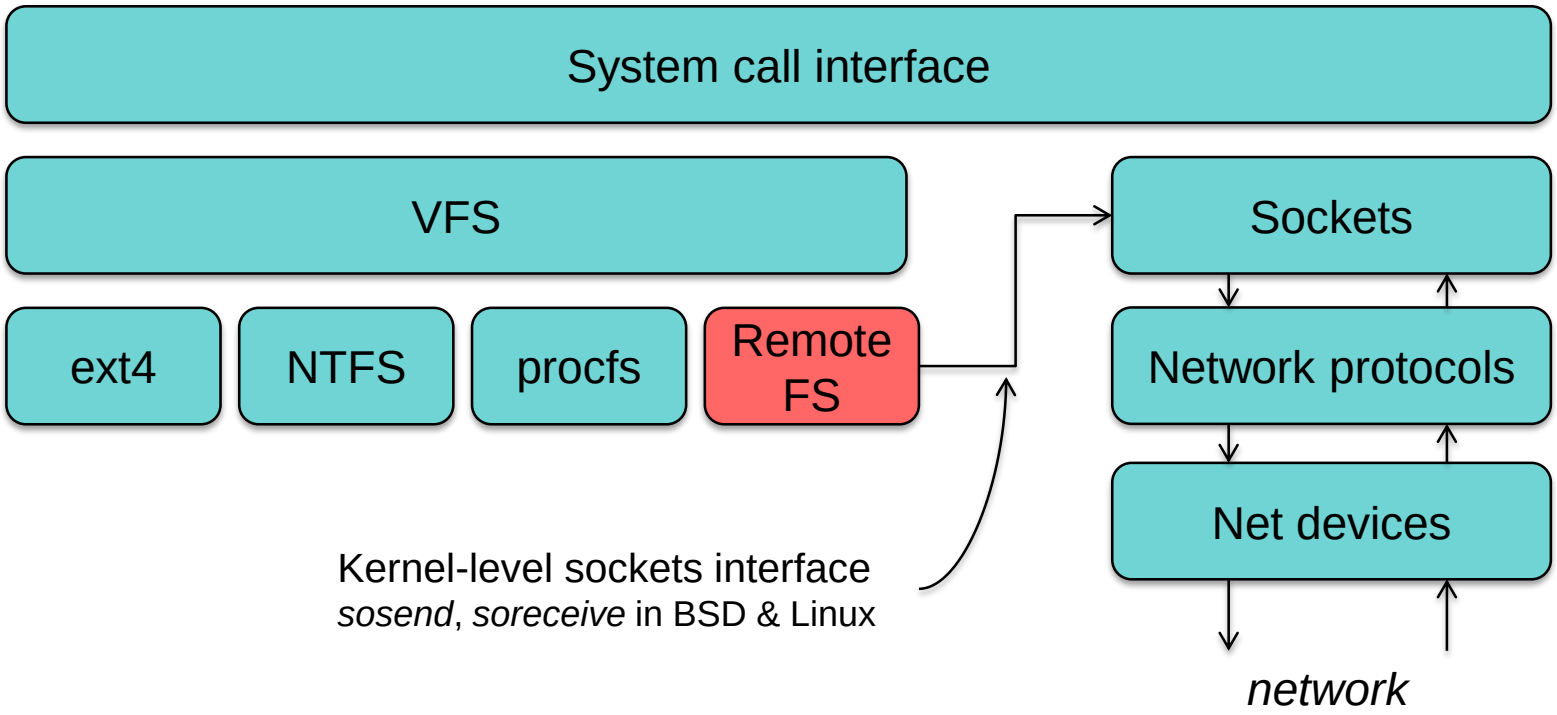
Fonte: Prof. Paul Krzyzanowski

System design issues

Fonte: Prof. Paul Krzyzanowski

Accessing Remote Files

For maximum transparency, implement the client module as a file system type under VFS



Fonte: Prof. Paul Krzyzanowski

Stateful or Stateless design?

Stateful

Server maintains client-specific state

- Shorter requests
- Better performance in processing requests
- Cache coherence is possible
  - Server can know who's accessing what
- File locking is possible

Stateless

Server maintains no information on client accesses

- Each request must identify file and offsets
- Server can crash and recover
  - No state to lose
- Client can crash and recover
- No open/close needed
  - They only establish state
- No server space used for state
  - Don't worry about supporting many clients
- Problems if file is deleted on server
- File locking not possible

Fonte: Prof. Paul Krzyzanowski

Caching

Hide latency to improve performance for repeated accesses

Four places

- Server's disk
- Server's buffer cache
- Client's buffer cache
- Client's disk

WARNING:
risk of cache consistency problems

Fonte: Prof. Paul Krzyzanowski

Approaches to caching

- Write-through
  - What if another client reads its own (out-of-date) cached copy?
  - All accesses will require checking with server
  - Or … server maintains state and sends invalidations

- Delayed writes (write-behind)
  - Data can be buffered locally
    (watch out for consistency – others won't see updates!)
  - Remote files updated periodically
  - One bulk wire is more efficient than lots of little writes
  - Problem: semantics become ambiguous

Fonte: Prof. Paul Krzyzanowski

Approaches to caching

- Read-ahead (prefetch)
  - Request chunks of data before it is needed.
  - Minimize wait when it actually is needed.
- Write on close
  - Admit that we have session semantics.
- Centralized control
  - Keep track of who has what open and cached on each node.
  - Stateful file system with signaling traffic.

Fonte: Prof. Paul Krzyzanowski

NFS

Network File System

Sun Microsystems

Fonte: Prof. Paul Krzyzanowski

Artigo original (1988)

Design and Implementation of the Sun Network Filesystem

Russel Sandberg
David Goldberg
Steve Kleiman
Dan Walsh
Bob Lyon

Sun Microsystems, Inc.
2550 Garcia Ave.
Mountain View, CA. 94110
(415) 960–7293

Introduction

The Sun Network Filesystem (NFS) provides transparent, remote access to filesystems. Unlike many other remote filesystem implementations under UNIX†, the NFS is designed to be easily portable to other operating systems and machine architectures. It uses an External Data Representation (XDR) specification to describe protocols in a machine and system independent way. The NFS is implemented on top of a Remote Procedure Call package (RPC) to help simplify protocol definition, implementation, and maintenance.

NFS Design Goals

Transport Protocol

Initially NFS ran over UDP using Sun RPC

Why was UDP chosen?

- Slightly faster than TCP
- No connection to maintain (or lose)
- NFS is designed for Ethernet LAN environment – relatively reliable
- UDP has error detection (drops bad packets) but no retransmission

NFS retries lost RPC requests

Fonte: Prof. Paul Krzyzanowski

Decisões de projeto

The Hard Issues

Several hard design issues were resolved during the development of the NFS. One of the toughest was deciding how we wanted to use the NFS. Lots of flexibility can lead to lots of confusion.

Concurrent Access and File Locking

The NFS does not support remote file locking. We purposely did not include this as part of the protocol because we could not find a set of locking facilities that everyone agrees is correct. Instead we plan to build separate, RPC based file locking facilities. In this way people can use the locking facility with the flavor of their choice with minimal effort.

Related to the problem of file locking is concurrent access to remote files by multiple clients. In the local filesystem, file modifications are locked at the inode level. This prevents two processes writing to the same file from intermixing data on a single write. Since the server maintains no locks between requests, and a write may span several RPC requests, two clients writing to the same remote file may get intermixed data on long writes.

NFS Design Goals

- Any machine can be a client or server
- Must support diskless workstations
  - Device files refer back to local drivers
- Heterogeneous systems
  - Not 100% for all UNIX system call options
- Access transparency: normal file system calls
- Recovery from failure:
  - Stateless, UDP, client retries
  - Stateless → no locking!
- High Performance
  - use caching and read-ahead

Fonte: Prof. Paul Krzyzanowski

NFS Protocols

Mounting protocol

Request access to exported directory tree

Directory & File access protocol

Access files and directories
(read, write, mkdir, readdir, …)

Fonte: Prof. Paul Krzyzanowski

Mounting Protocol

static mounting

– mount request contacts server

Server: edit `/etc/exports`

Client: `mount fluffy:/users/paul /home/paul`

Fonte: Prof. Paul Krzyzanowski

Mounting Protocol

- Send pathname to server
- Request permission to access contents

client:	parses pathname contacts server for file handle

- Server returns file handle
  - File device #, inode #, instance #

client:	create in-memory VFS inode at mount point. internally points to **rnode** for remote files - *Client keeps state, not the server*

Fonte: Prof. Paul Krzyzanowski

Directory and file access protocol

- First, perform a *lookup* RPC
  - returns file handle and attributes
- lookup is ***not*** like *open*
  - No information is stored on server
- handle passed as a parameter for other file access functions
  - e.g. `read(handle, offset, count)`

Fonte: Prof. Paul Krzyzanowski

Directory and file access protocol

NFS has 16 functions

– (version 2; six more added in version 3)

null
lookup

create
remove
rename

read
write

link
symlink
readlink

mkdir
rmdir
readdir

getattr
setattr

statfs

Fonte: Prof. Paul Krzyzanowski

NFS Performance

- Usually slower than local
- Improve by caching at client
  - Goal: reduce number of remote operations
  - Cache results of
    read, readlink, getattr, lookup, readdir
  - Cache file data at client (buffer cache)
  - Cache file attribute information at client
  - Cache pathname bindings for faster lookups
- Server side
  - Caching is “automatic” via buffer cache
  - All NFS writes are *write-through* to disk to avoid unexpected data loss if server dies

Fonte: Prof. Paul Krzyzanowski

Inconsistencies may arise

Try to resolve by validation

- Save timestamp of file
- When file opened or server contacted for new block
  - Compare last modification time
  - If remote is more recent, invalidate cached data

- Always invalidate data after some time
  - After 3 seconds for open files (data blocks)
  - After 30 seconds for directories

- If data block is modified, it is:
  - Marked *dirty*
  - Scheduled to be written
  - Flushed on file close

Fonte: Prof. Paul Krzyzanowski

Improving read performance

- Transfer data in large chunks
  - 8K bytes default (*that used to be a large chunk!*)
- Read-ahead
  - Optimize for sequential file access
  - Send requests to read disk blocks before they are requested by the application

Fonte: Prof. Paul Krzyzanowski

Problems with NFS

- File consistency
- Assumes clocks are synchronized
- Open with append cannot be guaranteed to work
- Locking cannot work
  - Separate lock manager added (but this adds stateful behavior)
- No reference counting of open files
  - You can delete a file you (or others) have open!
- Global UID space assumed

Fonte: Prof. Paul Krzyzanowski

Problems with NFS

- File permissions may change
  - Invalidating access to file
- No encryption
  - Requests via unencrypted RPC
  - Authentication methods available
    - Diffie-Hellman, Kerberos, Unix-style
  - Rely on user-level software to encrypt

Fonte: Prof. Paul Krzyzanowski

Improving NFS: version 2

- User-level lock manager
  - Monitored locks: introduces *state* at server (but runs as a separate user-level process)
    - status monitor: monitors clients with locks
    - Informs lock manager if host inaccessible
    - If server crashes: status monitor reinstates locks on recovery
    - If client crashes: all locks from client are freed
- NV RAM support
  - Improves write performance
  - Normally NFS must write to disk on server before responding to client *write* requests
  - Relax this rule through the use of non-volatile RAM

Fonte: Prof. Paul Krzyzanowski

Improving NFS: version 2

- Adjust RPC retries dynamically
  - Reduce network congestion from excess RPC retransmissions under load
  - Based on performance
- Client-side disk caching
  - cacheFS
  - Extend buffer cache to disk for NFS
    - Cache in memory first
    - Cache on disk in 64KB chunks

Fonte: Prof. Paul Krzyzanowski

Support Larger Environments: Automounter

Problem with mounts

- If a client has many remote resources mounted, boot-time can be excessive
- Each machine has to maintain its own name space
  - Painful to administer on a large scale

Automounter

- Allows administrators to create a global name space
- Support *on-demand* mounting

Fonte: Prof. Paul Krzyzanowski

Automounter

- Alternative to static mounting
- Mount and unmount in response to client demand
  - Set of directories are associated with a local directory
  - None are mounted initially
  - When local directory is **referenced**
    - OS sends a message to **each** server
    - First reply wins
  - Attempt to unmount every 5 minutes
- Automounter maps
  - Describes how file systems below a mount point are mounted

Fonte: Prof. Paul Krzyzanowski

Automounter maps

Example:

```
automount /usr/src srcmap
```

srcmap contains:

```
cmd    -ro doc:/usr/src/cmd
kernel -ro frodo:/release/src \
            bilbo:/library/source/kernel
lib    -rw sneezy:/usr/local/lib
```

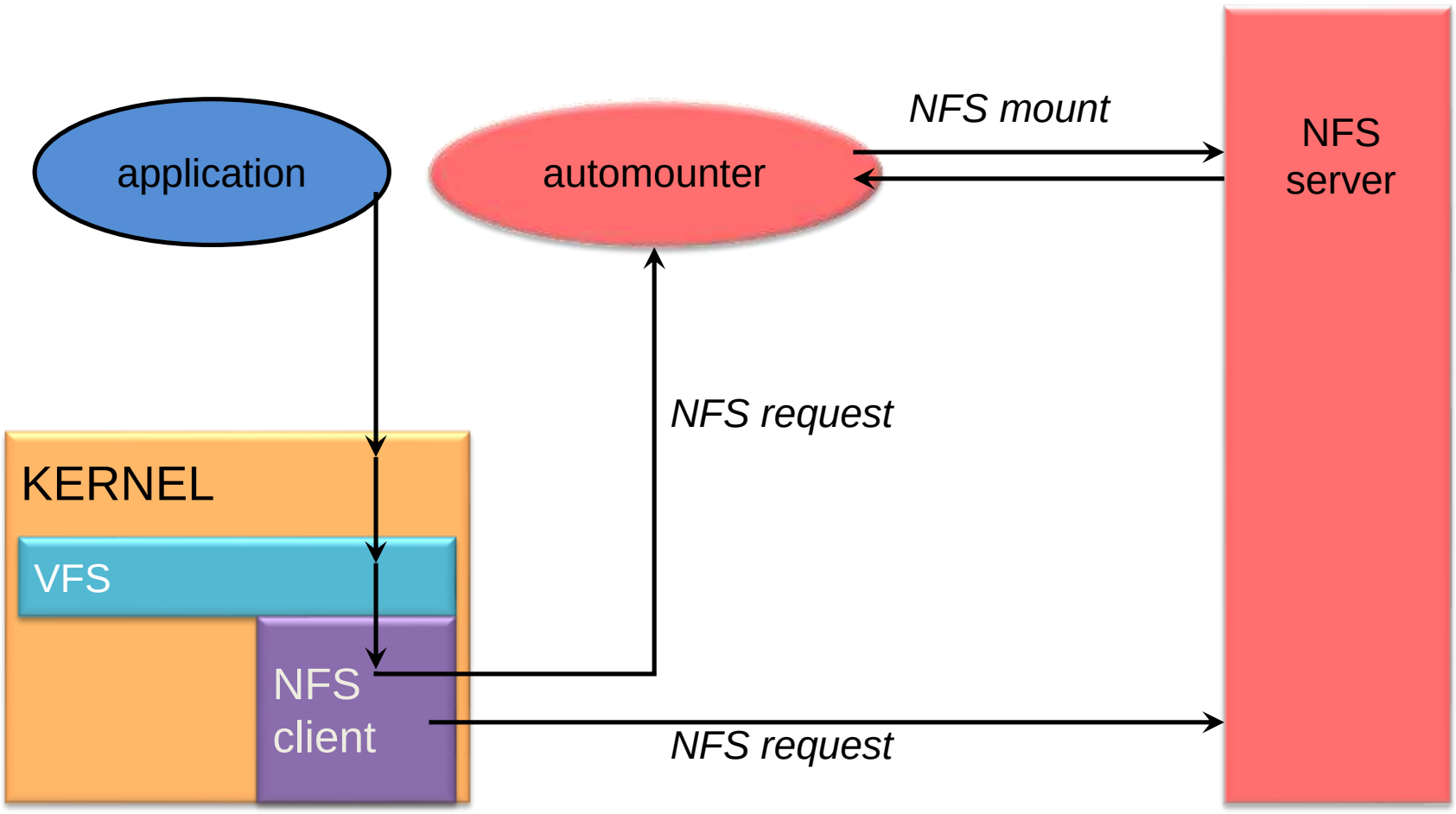
Access **/usr/src/cmd**: request goes to doc

Access **/usr/src/kernel**:

ping frodo and bilbo, mount first response

Fonte: Prof. Paul Krzyzanowski

The automounter



Fonte: Prof. Paul Krzyzanowski

More improvements… NFS v3

- Updated version of NFS protocol
- Support 64-bit file sizes
- TCP support and large-block transfers
  - UDP caused more problems on WANs (errors)
  - All traffic can be multiplexed on one connection
    - Minimizes connection setup
  - No fixed limit on amount of data that can be transferred between client and server
- Negotiate for optimal transfer size
- Server checks access for entire path from client

Fonte: Prof. Paul Krzyzanowski

More improvements… NFS v3

- New *commit* operation
  - Check with server after a *write* operation to see if data is committed
  - If *commit* fails, client must **resend** data
  - Reduce number of *write* requests to server
  - Speeds up *write* requests
    - Don't require server to write to disk immediately
- Return file attributes with each request
  - Saves extra RPCs to get attributes for validation

Fonte: Prof. Paul Krzyzanowski

AFS

Andrew File System

Carnegie Mellon University

c. 1986(v2), 1989(v3)

Fonte: Prof. Paul Krzyzanowski

AFS

- Design Goal
  - Support information sharing on a *large* scale
    e.g., 10,000+ clients

- History
  - Developed at CMU
  - Became a commercial spin-off: Transarc
  - IBM acquired Transarc
  - Open source under IBM Public License
  - OpenAFS (openafs.org)

Fonte: Prof. Paul Krzyzanowski

AFS Assumptions

- Most files are small
- Reads are more common than writes
- Most files are accessed by one user at a time
- Files are referenced in bursts (locality)
  - Once referenced, a file is likely to be referenced again

Fonte: Prof. Paul Krzyzanowski

AFS Design Decisions

Whole file serving

- Send the entire file on *open*

Whole file caching

- Client caches entire file on local disk
- Client writes the file back to server on *close*
  - if modified
  - Keeps cached copy for future accesses

Fonte: Prof. Paul Krzyzanowski

AFS Design

- Each client has an AFS disk cache
  - Part of disk devoted to AFS (e.g. 100 MB)
  - Client manages cache in LRU manner
- Clients communicate with set of trusted servers
- Each server presents one identical name space to clients
  - All clients access it in the same way
  - Location transparent

Fonte: Prof. Paul Krzyzanowski

AFS Server: cells

- Servers are grouped into administrative entities called cells

- Cell: collection of
  - Servers
  - Administrators
  - Users
  - Clients
- Each cell is autonomous but cells may cooperate and present users with one **uniform name space**

Fonte: Prof. Paul Krzyzanowski

AFS Server: volumes

Disk partition contains

file and directories

Grouped into volumes

Volume

- Administrative unit of organization
  - E.g., user's home directory, local source, etc.
- Each volume is a directory tree (one root)
- Assigned a name and ID number
- A server will often have 100s of volumes

Fonte: Prof. Paul Krzyzanowski

Namespace management

Clients get information via cell directory server (Volume Location Server) that hosts the Volume Location Database (VLDB)

Goal:

everyone sees the same namespace

/afs/cellname/path

/afs/mit.edu/home/paul/src/try.c

Fonte: Prof. Paul Krzyzanowski

Communication with the server

- Communication is via RPC over UDP
- Access control lists used for protection
  - Directory granularity
  - UNIX permissions ignored (except execute)

Fonte: Prof. Paul Krzyzanowski

AFS cache coherence

On open:

- Server sends entire file to client

  and provides a callback promise:
- *It will notify the client when any other process modifies the file*

If a client modified a file:

- Contents are written to server on *close*

When a server gets an update:

- it notifies *all* clients that have been issued the callback promise
- Clients invalidate cached files

Fonte: Prof. Paul Krzyzanowski

AFS cache coherence

If a client was down

- On startup, contact server with timestamps of all cached files to decide whether to invalidate

If a process has a file open

- It continues accessing it even if it has been invalidate
- Upon close, contents will be propagated to server

AFS: Session Semantics

(vs. sequential semantics)

Fonte: Prof. Paul Krzyzanowski

AFS replication and caching

- Read-only volumes may be replicated on multiple servers
- Whole file caching not feasible for huge files
  - AFS caches in 64KB chunks (by default)
  - Entire directories are cached
- Advisory locking supported
  - Query server to see if there is a lock
- Referrals
  - An administrator may move a volume to another server
  - If a client accesses the old server, it gets a *referral* to the new one

Fonte: Prof. Paul Krzyzanowski

AFS key concepts

- Single global namespace
  - Built from a collection of volumes
  - Referrals for moved volumes
  - Replication of read-only volumes
- Whole-file caching
  - Offers dramatically reduced load on servers
- Callback promise
  - Kkeeps clients from having to poll the server to invalidate cache

Fonte: Prof. Paul Krzyzanowski

AFS summary

AFS benefits

- AFS scales well
- Uniform name space
- Read-only replication
- Security model supports mutual authentication, data encryption

AFS drawbacks

- Session semantics
- Directory based permissions
- Uniform name space

Fonte: Prof. Paul Krzyzanowski

CODA

COnstant Data Availability

Carnegie-Mellon University

c. 1990-1992

Fonte: Prof. Paul Krzyzanowski

CODA Goals

Descendant of AFS

CMU, 1990-1992

Goals

1. Provide better support for replication than AFS
   – support shared read/write files

2. Support mobility of PCs

Fonte: Prof. Paul Krzyzanowski

CODA

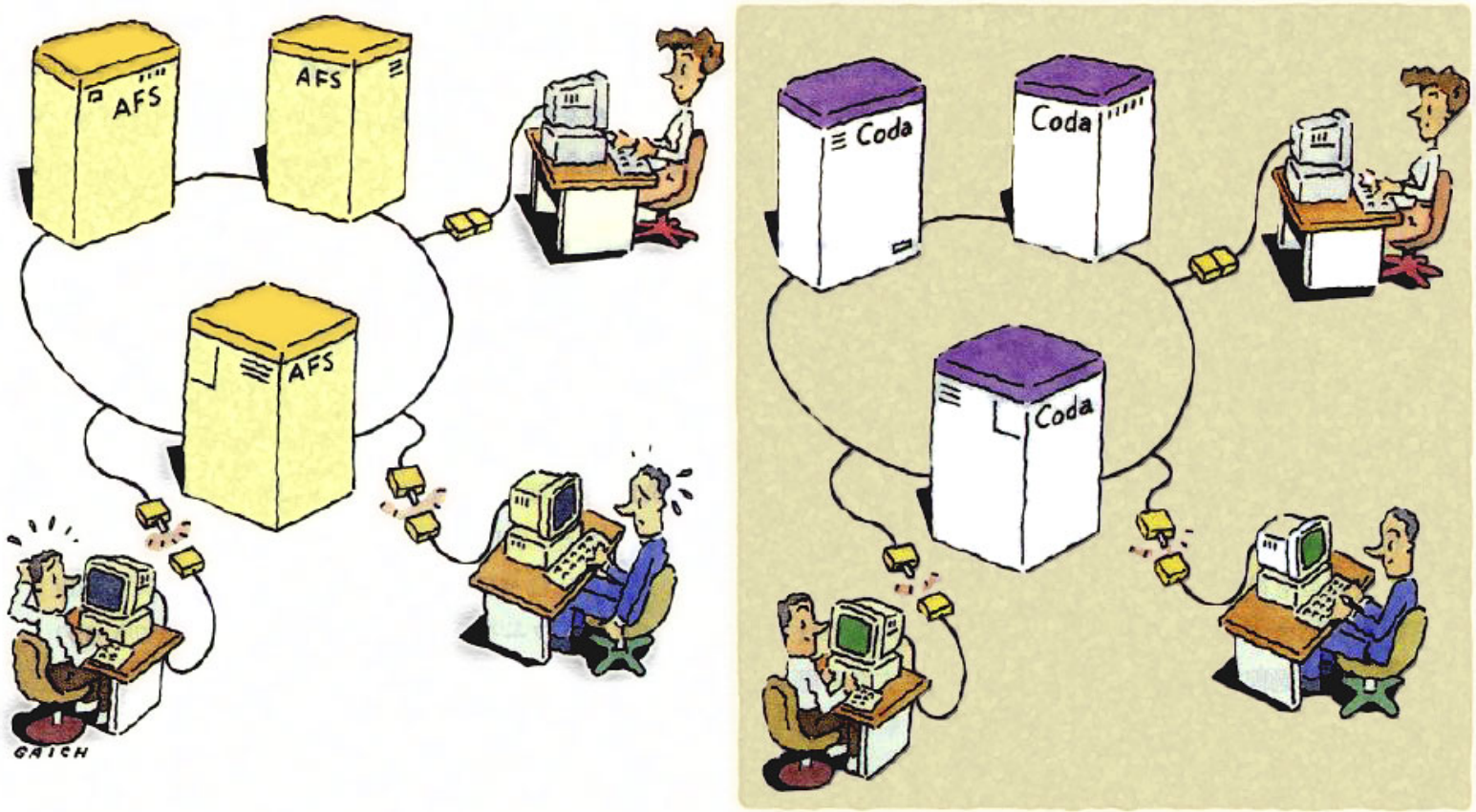


図 1　Coda のディスコネクテッド・オペレーション　Coda ではネットワークに障害が発生しても処理を続けることができる。ユーザは障害が発生したことに気づかない。

Veja também: http://www.coda.cs.cmu.edu/about.html

Mobility

- Goal: Improve fault tolerance
- Provide **constant** data availability in disconnected environments
- Via **hoarding** (user-directed caching)
  - Log updates on client
  - Reintegrate on connection to network (server)

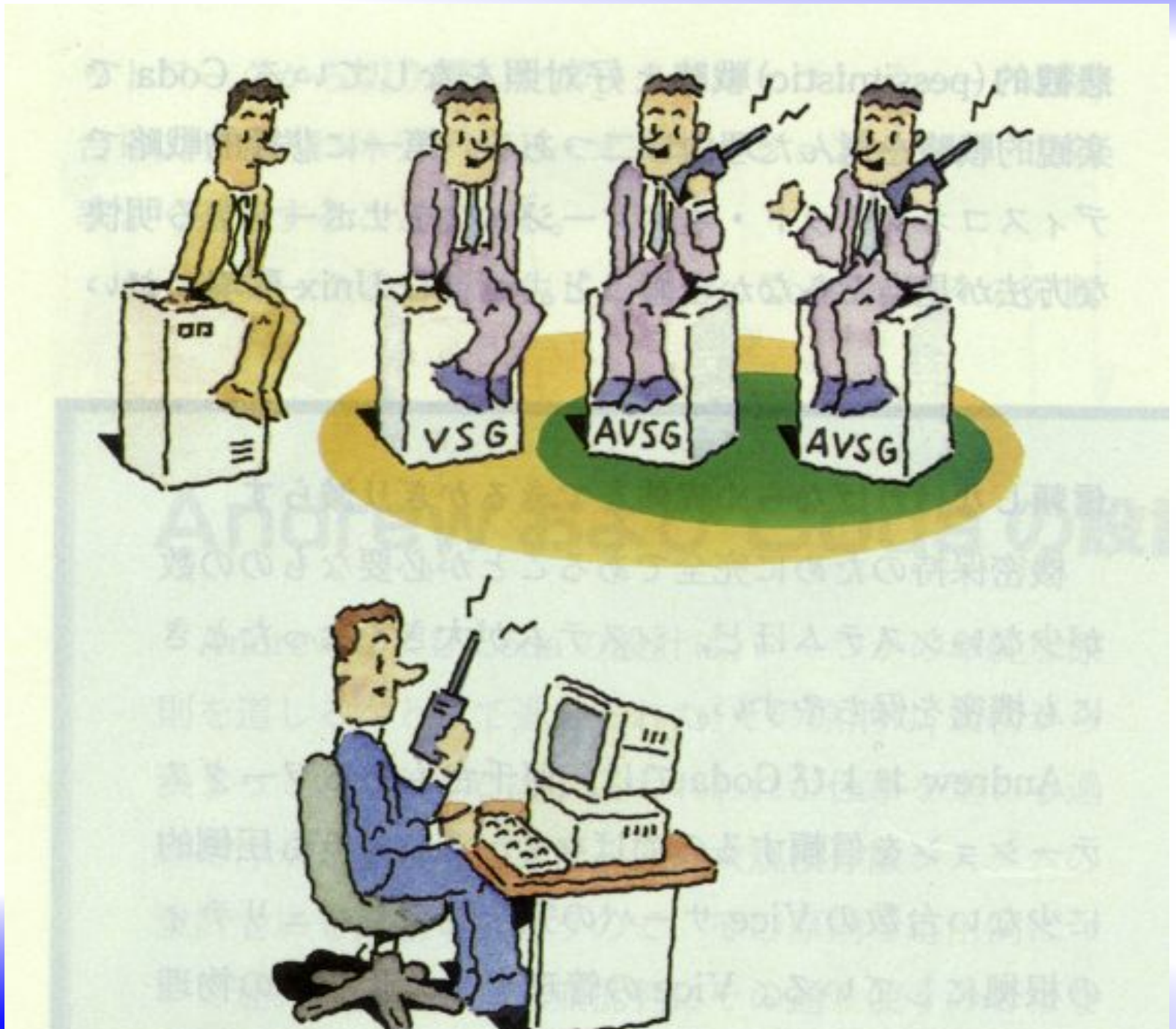
Fonte: Prof. Paul Krzyzanowski

Modifications to AFS

- Support replicated file volumes
- Extend mechanism to support disconnected operation
- A volume can be replicated on a group of servers
  - **Volume Storage Group (VSG)**
- Replicated volumes
  - Volume ID used to identify files is a Replicated Volume ID
  - One-time lookup
    - Replicated volume ID → list of servers and *local* volume IDs
    - Cache results for efficiency
  - Read files from *any* server
  - Write to **all available servers**

Fonte: Prof. Paul Krzyzanowski

CODA



Disconnected volume servers

AVSG: Accessible Volume Storage Group

– Subset of VSG

What if some volume servers are down?

On first download, contact everyone you can and get a version timestamp of the file

Fonte: Prof. Paul Krzyzanowski

Reconnecting disconnected servers

If the client detects that some servers have old versions

- Some server resumed operation

- Client initiates a **resolution process**
  - Updates servers: notifies server of stale data
  - Resolution handled entirely by servers
  - Administrative intervention may be required (if conflicts)

Fonte: Prof. Paul Krzyzanowski

AVSG = Ø

- If no servers are accessible
  - Client goes to **disconnected operation mode**
- If file is not in cache
  - Nothing can be done… fail
- Do not report failure of update to server
  - Log update locally in **Client Modification Log** (CML)
  - User does not notice

Fonte: Prof. Paul Krzyzanowski

Reintegration

Upon reconnection

– Commence **reintegration**

Bring server up to date with CML **log playback**

– Optimized to send latest changes

Try to resolve conflicts automatically

– Not always possible

Fonte: Prof. Paul Krzyzanowski

Support for disconnection

Keep important files up to date

- Ask server to send updates if necessary

Hoard database

- Automatically constructed by monitoring the user's activity
- And user-directed prefetch

Fonte: Prof. Paul Krzyzanowski

CODA summary

- Session semantics as with AFS
- Replication of read/write volumes
  - Clients do the work of writing replicas (extra bandwidth)
  - Client-detected reintegration
- Disconnected operation
  - Client modification log
  - Hoard database for needed files
    - User-directed prefetch
  - Log replay on reintegration

Fonte: Prof. Paul Krzyzanowski

DFS
Distributed File System
Open Group

Fonte: Prof. Paul Krzyzanowski

DFS

- Goal
  - AFS: scalable performance but session semantics were hard to live with
  - Create a file system similar to AFS but with a strong consistency model
- History
  - Part of Open Group's Distributed Computing Environment
  - Descendant of AFS - AFS version 3.x
  - Development stopped c. 2005
  - Dead for all practical purposes (but its ideas live on)
- Assume (like AFS):
  - Most file accesses are sequential
  - Most file lifetimes are short
  - Majority of accesses are whole file transfers
  - Most accesses are to small files

Fonte: Prof. Paul Krzyzanowski

DFS Tokens

Cache consistency maintained by **tokens**

Token

– Guarantee from server that a client can perform certain operations on a cached file

- *Open* tokens
  - Allow token holder to open a file
  - Token specifies access (read, write, execute, exclusive-write)
- *Data* tokens
  - Applies to a byte range
  - *read* token - can use cached data
  - *write* token - write access, cached writes
- *Status* tokens
  - *read*: can cache file attributes
  - *write*: can cache modified attributes
- *Lock* tokens
  - Holder can lock a byte range of a file

Fonte: Prof. Paul Krzyzanowski

Living with tokens

- Server grants and revokes tokens
  - Multiple *read* tokens OK
  - Multiple *read* and a *write* token or multiple *write* tokens not OK if byte ranges overlap
    - Revoke all other *read* and *write* tokens
    - Block new request and send revocation to other token holders

Fonte: Prof. Paul Krzyzanowski

DFS key points

- Caching
  - Token granting mechanism
    - Allows for long term caching and strong consistency
  - Caching sizes: 8K – 256K bytes
  - Read-ahead (like NFS)
    - Don’t have to wait for entire file before using it as with AFS
- File protection via access control lists (ACLs)
- Communication via authenticated RPCs
- Essentially AFS v2 with server-based token granting
  - Server keeps track of who is reading and who is writing files
  - Server must be contacted on each open and close operation to request token

Fonte: Prof. Paul Krzyzanowski

SMB

Server Message Blocks

Microsoft

c. 1987

Fonte: Prof. Paul Krzyzanowski

SMB Goals

- File sharing protocol for Windows 9x/NT/20xx/ME/XP/Vista/Windows 7/Windows 8/Windows 10 …
- Protocol for sharing:

  Files, devices, communication abstractions (named pipes), mailboxes

- Servers: make file system and other resources available to clients
- Clients: access shared file systems, printers, etc. from servers

Design Priority:

locking and consistency over client caching

Fonte: Prof. Paul Krzyzanowski

SMB Design

- Request-response protocol
  - Send and receive ***message blocks***
    - name from old DOS system call structure
  - Send *request* to server (machine with resource)
  - Server sends response
- Connection-oriented protocol
  - Persistent connection – “session”
- Each message contains:
  - Fixed-size header
  - Command string (based on message) or reply string

Fonte: Prof. Paul Krzyzanowski

Message Block

- Header: [fixed size]
  - Protocol ID
  - Command code (0..FF)
  - Error class, error code
  - Tree ID – unique ID for resource in use by client (handle)
  - Caller process ID
  - User ID
  - Multiplex ID (to route requests in a process)
- Command: [variable size]
  - Param count, params, #bytes data, data

Fonte: Prof. Paul Krzyzanowski

SMB commands

- Files
  - Get disk attributes
  - create/delete directories
  - search for file(s)
  - create/delete/rename file
  - lock/unlock file area
  - open/commit/close file
  - get/set file attributes
- Print-related
  - Open/close spool file
  - write to spool
  - Query print queue
- User-related
  - Discover home system for user
  - Send message to user
  - Broadcast to all users
  - Receive messages

Fonte: Prof. Paul Krzyzanowski

Protocol Steps

- Establish connection

Fonte: Prof. Paul Krzyzanowski

Protocol Steps

- Establish connection
- Negotiate protocol
  - ***negprot*** SMB
  - Responds with version number of protocol

Fonte: Prof. Paul Krzyzanowski

Protocol Steps

- Establish connection
- Negotiate protocol
- Authenticate/set session parameters
  - Send ***sesssetupX*** SMB with username, password
  - Receive NACK or UID of logged-on user
  - UID must be submitted in future requests

Fonte: Prof. Paul Krzyzanowski

Protocol Steps

- Establish connection
- Negotiate protocol - *negprot*
- Authenticate - *sesssetupX*
- Make a connection to a resource (similar to *mount*)
  - Send *tcon* (tree connect) SMB with name of shared resource
  - Server responds with a **tree ID** (TID) that the client will use in future requests for the resource

Fonte: Prof. Paul Krzyzanowski

Protocol Steps

- Establish connection
- Negotiate protocol - *negprot*
- Authenticate - *sesssetupX*
- Make a connection to a resource – *tcon*
- Send open/read/write/close/… SMBs

Fonte: Prof. Paul Krzyzanowski

Caching and Server Communication

- Increase effective performance with
  - Caching
    - Safe if multiple clients reading, nobody writing
  - read-ahead
    - Safe if multiple clients reading, nobody writing
  - write-behind
    - Safe if only one client is accessing file
- Minimize times client informs server of changes

Fonte: Prof. Paul Krzyzanowski

Oplocks

Server grants **opportunistic locks** (**oplocks**) to client

- Oplock tells client how/if it may cache data
- Similar to DFS tokens (but more limited)

Client must request an oplock

- oplock may be
  - Granted
  - Revoked by the server at some future time
  - Changed by server at some future time

Fonte: Prof. Paul Krzyzanowski

Level 1 oplock (exclusive access)

- Client can open file for exclusive access
- Arbitrary caching
- Cache lock information
- Read-ahead
- Write-behind

If another client opens the file, the server has former client *break its oplock*:

- Client must send server any lock and write data and acknowledge that it does not have the lock
- Purge any read-aheads

Fonte: Prof. Paul Krzyzanowski

Level 2 oplock (one writer)

- Level 1 oplock is replaced with a Level 2 lock if another process tries to read the file
- Request this if expect others to read
- Multiple clients may have the same file open as long as none are writing
- Cache reads, file attributes
  - Send other requests to server
- Level 2 oplock revoked if another client opens the file for writing

Fonte: Prof. Paul Krzyzanowski

Batch oplock (remote open even if local closed)

- Client can keep file open on server even if a local process that was using it has closed the file
  - Exclusive R/W open lock + data lock + metadata lock
- Client requests batch oplock if it expects programs may behave in a way that generates a lot of traffic (e.g. accessing the same files over and over)
  - Designed for Windows batch files
- Batch oplock revoked if another client opens the file

Fonte: Prof. Paul Krzyzanowski

Filter oplock (allow preemption)

- Open file for read or write
- Allow clients with *filter oplock* to be suspended while another process preempted file access.
  - E.g., indexing service can run and open files without causing programs to get an error when they need to open the file
    - Indexing service is notified that another process wants to access the file.
    - It can abort its work on the file and close it or finish its indexing and then close the file.

Fonte: Prof. Paul Krzyzanowski

No oplock

- All requests must be sent to the server
- Can work from cache only if byte range was locked by client

Fonte: Prof. Paul Krzyzanowski

Naming

- Multiple naming formats supported:
  - `N:\junk.doc`
  - `\\myserver\users\paul\junk.doc`
  - `file://grumpy.pk.org/users/paul/junk.doc`

Fonte: Prof. Paul Krzyzanowski

Microsoft Dfs

- "Distributed File System"
  - Provides a logical view of files & directories
  - Organize multiple SMB shares into one file system
  - Provide location transparency & redundancy

- Each computer hosts volumes

```
\\servername\dfsname
```

  Each Dfs tree has one root volume and one level of leaf volumes.

- A volume can consist of multiple shares
  - Alternate path: load balancing (read-only)
  - Similar to Sun's automounter

- Dfs = SMB + naming/ability to mount server shares on other server shares

Fonte: Prof. Paul Krzyzanowski

Redirection via referrals

- A share can be replicated (read-only) or moved through Microsoft's Dfs

- Client opens old location:
  - Receives STATUS_DFS_PATH_NOT_COVERED
  - Client requests referral:
    TRANS2_DFS_GET_REFERRAL
  - Server replies with new server

Fonte: Prof. Paul Krzyzanowski

SMB (CIFS) Summary

- Stateful model with strong consistency
- Oplocks offer flexible control for distributed consistency
  - Oplocks mechanism supported in base OS: Windows NT/XP/Vista/7/8.9, 20xx
- Dfs offers namespace management

Fonte: Prof. Paul Krzyzanowski

SMB2 and SMB3

- SMB was…
  - Chatty: common tasks often required multiple round trip messages
  - Not designed for WANs
- SMB2
  - Protocol dramatically cleaned up
  - New capabilities added
  - SMB2 is the default network file system in Apple Mavericks (10.9)
- SMB3
  - Added RDMA and multichannel support; end-to-end encryption
  - Windows 8 / Windows Server 2012: SMB 3.0
  - SMB3 default on Apple Yosemite (10.10)

Fonte: Prof. Paul Krzyzanowski

SMB2 Additions

- Reduced complexity
  - From >100 commands to 19
- Pipelining support
  - Send additional commands before the response to a previous one is received
  - Credit-based flow control
    - Goal: keep more data in flight and use available network bandwidth
    - Server starts with a small # of “credits” and scales up as needed
    - Server sends credits to client
    - Client needs credits to send a message and decrements credit balance
    - Allows server to control buffer overflow
    - Note: TCP uses congestion control, which yields to data loss and wild oscillations in traffic intensity

Fonte: Prof. Paul Krzyzanowski

SMB2 Additions

- Compounding support
  - Avoid the need to have commands that combine operations
  - Send an arbitrary set of commands in one request
  - E.g., instead of *RENAME*:
    - CREATE (create new file or open existing)
    - SET_INFO
    - CLOSE
- Larger reads/writes
- Caching of folder & file properties
- “Durable handles”
  - Allow reconnection to server if there was a temporary loss of connectivity

Fonte: Prof. Paul Krzyzanowski

Benefits

- Transfer 10.7 GB over 1 Gbps WAN link with 76 ms RTT
  - SMB: 5 hours 40 minutes: rate = 0.56 MB/s
  - SMB2: 7 minutes, 45 seconds: rate = 25 MB/s

Fonte: Prof. Paul Krzyzanowski

SMB3

- Key features
  - Multichannel support for network scaling
  - Transparent network failover
  - “SMBDirect” – support for Remote DMA in clustered environments
    - Enables direct, low-latency copying of data blocks from remote memory without CPU intervention
  - Direct support for virtual machine files
    - Volume Shadow Copy
    - Enables volume backups to be performed while apps continue to write to files.
  - End-to-end encryption

Fonte: Prof. Paul Krzyzanowski

NFS version 4
Network File System
Sun Microsystems

Fonte: Prof. Paul Krzyzanowski

NFS version 4 enhancements

- Stateful server
- Compound RPC
  - Group operations together
  - Receive set of responses
  - Reduce round-trip latency
- Stateful open/close operations
  - Ensures atomicity of share reservations for windows file sharing (CIFS)
  - Supports exclusive creates
  - Client can cache aggressively

Fonte: Prof. Paul Krzyzanowski

NFS version 4 enhancements

- create, link, open, remove, rename
  - Inform client if the directory changed during the operation
- Strong security
  - Extensible authentication architecture
- File system replication and migration
  - Mirror servers can be configured
  - Administrator can distribute data across multiple servers
  - Clients don't need to know where the data is: server will send referrals
- No concurrent write sharing or distributed cache coherence

Fonte: Prof. Paul Krzyzanowski

NFS version 4 enhancements

- Improved caching
  - Server can delegate specific actions on a file to enable more aggressive client caching
  - Similar to CIFS oplocks
- Callbacks
  - Notify client when file/directory contents change

Fonte: Prof. Paul Krzyzanowski

Review: Core Concepts

- NFS
  - RPC-based access – initially stateless
  - large block reads, read-ahead
- AFS
  - Long-term caching
- CODA
  - Read/write replication & disconnected operation
- DFS
  - AFS + tokens for consistency and efficient caching
- SMB
  - RPC-like access with strong consistency
  - Oplocks (tokens) to support caching
  - Dfs: add-on to provide a consistent view of volumes (AFS-style)

Fonte: Prof. Paul Krzyzanowski