Tradeoffs in Protecting Storage:

A Meta-Data Comparison of Cryptographic, Backup/Versioning, Immutable/Tamper-Proof, and Redundant Storage Solutions

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Motivation

- System break-ins
  - Attacks are increasingly sophisticated
  - Current payloads are “nice” – this may change
    - “Witty Worm”
- Insider attacks
  - Steal data
  - Cover-up unauthorized activity

More Motivation

- Legal regulations
  - HIPAA
  - Gramm-Leach-Bliley Act
  - Sarbanes-Oxley Act
  - SEC 17A-3 and 17A-4
  - California State Law SB 1386
- User experience
  - System unavailability is intolerable
  - Loss of data isn't either

Tutorial Plan

- Motivation
- **Overview**
- Survey of Protection
- Comparison
- Case Study: Tungsten at NCSA
- Conclusions

Overview - Metrics

- CIA
  - Confidentiality
  - Integrity
  - Availability
- Cost tradeoffs (finite budget)
  - Performance
  - Capital outlay
  - Management effort

Overview – C I A

- Confidentiality
  - Only authorized entities can read data
  - Provided by access control and encryption
- Integrity
  - Only authorized entities can modify data
  - provided by access control, tamper-proofing, immutability
- Availability
  - Security is comparatively easy
    - Unplug the box and bury it!
  - For C & I to be useful, data must be available

Overview – Cost Tradeoffs

- Performance
  - If it's too slow, it can't be used
- Capital outlay
  - Extra space, extra compute, special equipment
- Management effort
  - Imagine manually distributing encryption keys

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  - **Cryptography**
  - Immutability and Tamper-Proofing
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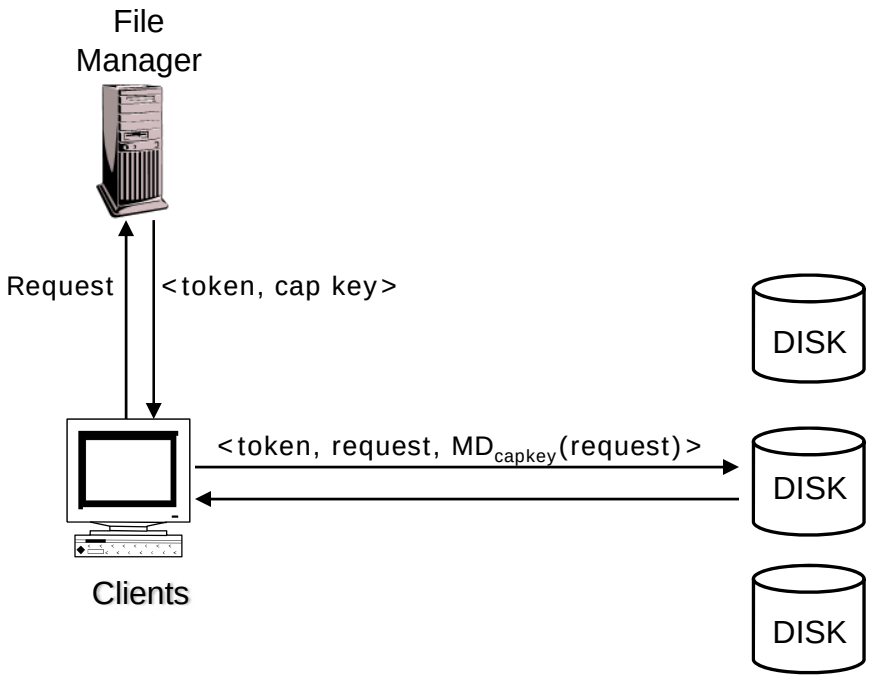
Cryptography - Overview

- Provides Confidentiality (some integrity)
- Emphasis on Key Management
  - Distribution
  - Revocation
  - Granularity

- **NASD** (CMU Parallel Data Lab)
- **SFS-RO** (NYU Secure Computer Systems & MIT Parallel/Distributed OS)
- **Plutus (**HP Labs)
- **SiRiUS** (Stanford Applied Crypto)

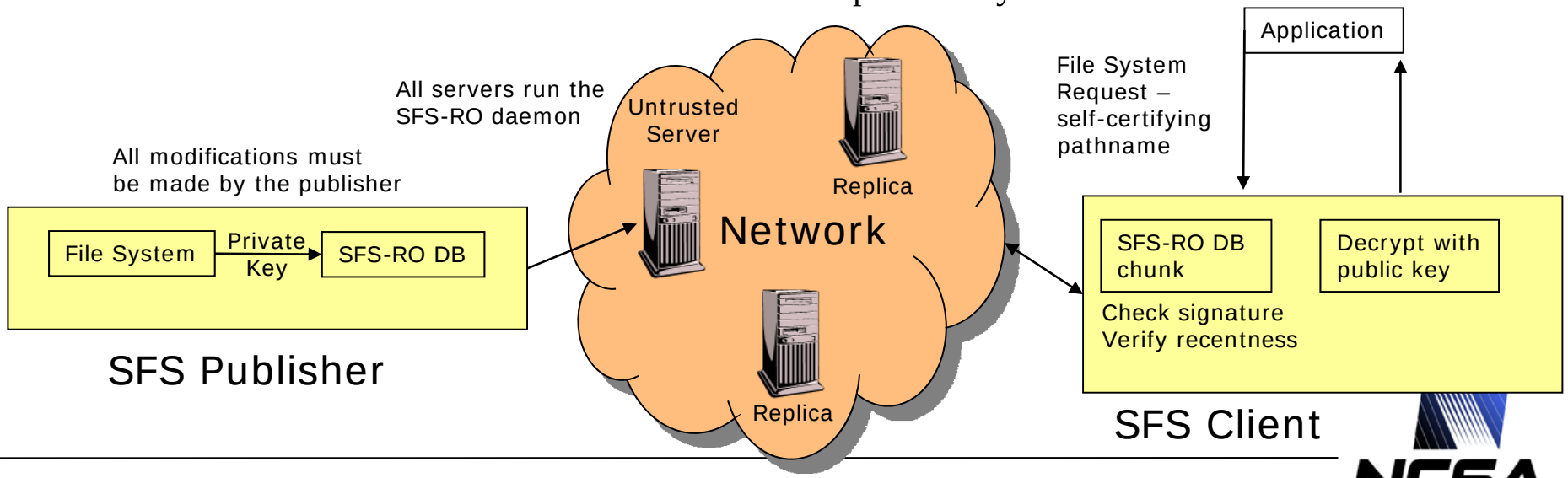
NASD: Network Attached Secure Disks

- Centralized file manager (FM)
- Request to FM results in a *capability object*
  - Token (access rights)
  - Capability key
- FM shares private key with intelligent disks
- User applies capability key to the request and accesses disk directly
- Disk uses secret key and token to verify the request digest
- Immediate revocation is possible with centralized server



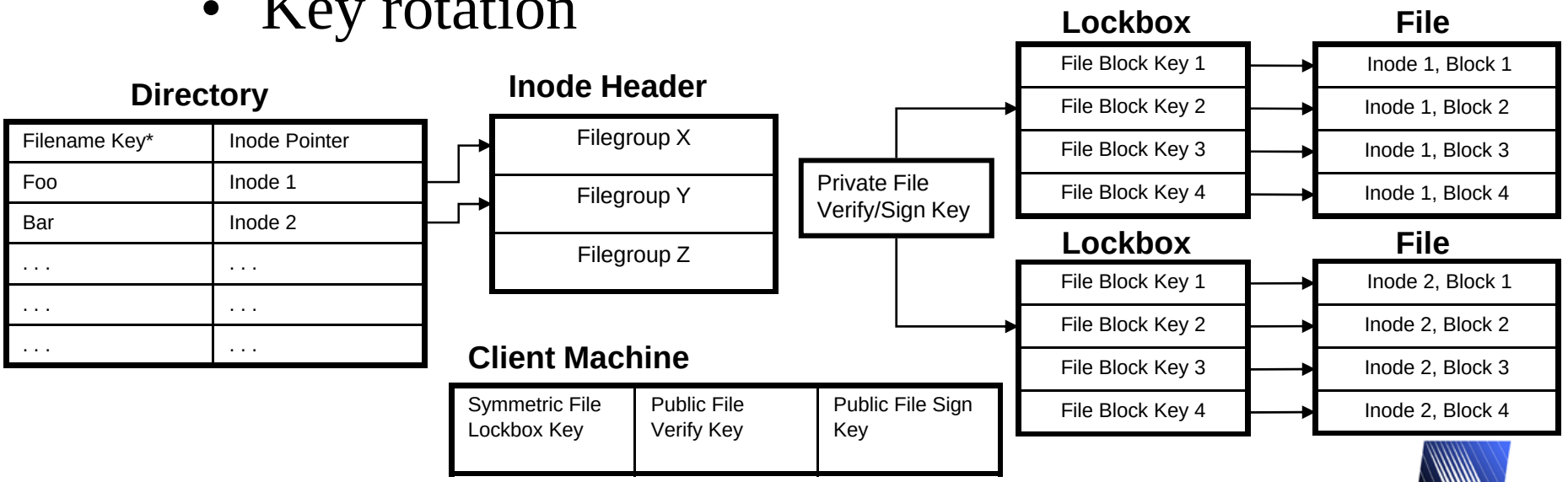
SFS-RO:
Fast and Secure Distributed Read-Only File System

- Encrypt file system contents as signed DB
- Replicate the DB on multiple servers
- Self-Certifying Pathnames
- Key revocation certificates
  - $\{path, location, public\ key\}_{private\ key}$



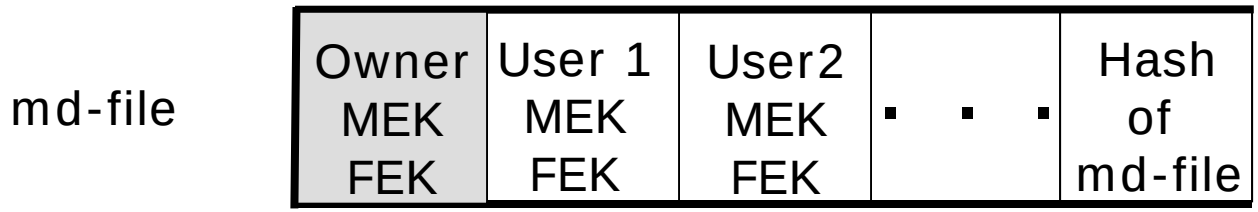
PLUTUS

- Lockbox mechanism for scalable key mgmt
- Manually distribute keys to clients
- File sharing via file groups
- Lazy revocation
- Key rotation



SiRiUS
Securing Remote Untrusted Storage

- Stop-gap security to legacy systems
  - NFS, CIFS, Yahoo, etc.
- Each user has an asymmetric Master Encryption Key
- Metadata file for each file
  - Master encryption for owner
  - File encryption/signing key stored for each user encrypted with MEK of user
  - Hash of contents signed with owner's MEK
- Revocation – simply remove the user's entry from the md-file



Key Management Comparison

System	Distribution	Revocation	Granularity	Duration
NASD	Trusted server	Immediate	Storage object	Session
SFS-RO	User managed	Immediate	File system	Permanent
PLUTUS	Key lockbox	Lazy	Lockbox, group, file, block	Permanent
SiRiUS	User managed	Immediate	Owner, file	Permanent

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Immutability

- **Immutability** means
  - To prevent modification
  - To thwart deletion
  - Brittle, but potentially strong prevention
- **Immutable** file systems allow
  - Appending
  - Writing new data

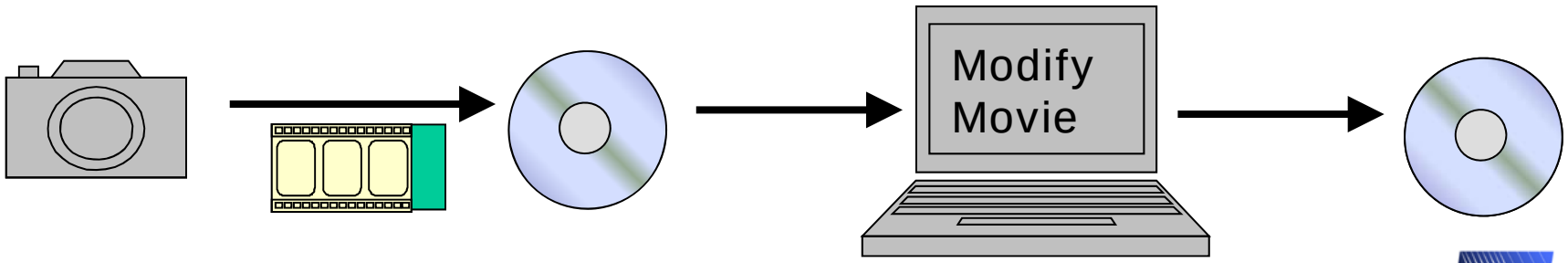
Examples of Immutable Systems

1. Physical WORM (Write Once Read Many)
   - CD-R, magneto-optical
     - Expensive, low capacity, slow
2. Embedded WORM
   - Write-once disk, tape, write-once SAN
     - Limited availability, current implementations not trustworthy
3. Software WORM
   - Write permission attributes, immutable attribute
     - Cheap, fast, easy, weak

Tamper-Proof

aka Tamper-Resistant or Tamper-Evident

- Demonstrate with high reliability that data has not changed improperly
- Not the same as confidentiality
- Not the same as immutability



Examples of Tamper-Proof Systems

1. **SFS-RO**
   - File names contain public keys
   - Blocks/inodes named by hash of content
   - Groups of handles hashed recursively
2. **PASIS**
   - Uses erasure codes, so data can be reconstructed with m of n fragments
   - Uses cross-checksums to identify corrupted data fragments
3. **OceanStore**
   - Restrict server capabilities
   - Erasure code fragmentation

Immutability vs. Tamper-Proof

- Immutability proves something hasn't changed
  - CAN NOT rewrite a CD-R
  - CAN make a new CD-R
- Tamper-Proof proves something is what you think it is
  - CAN NOT forge a signed log file
  - CAN erase a signed log file

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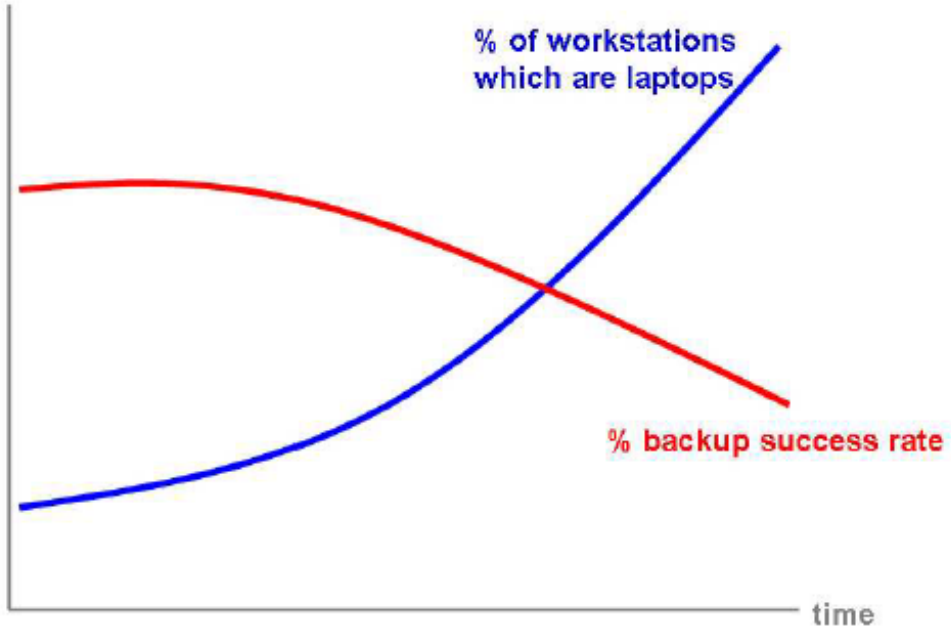
Backup and Versioning

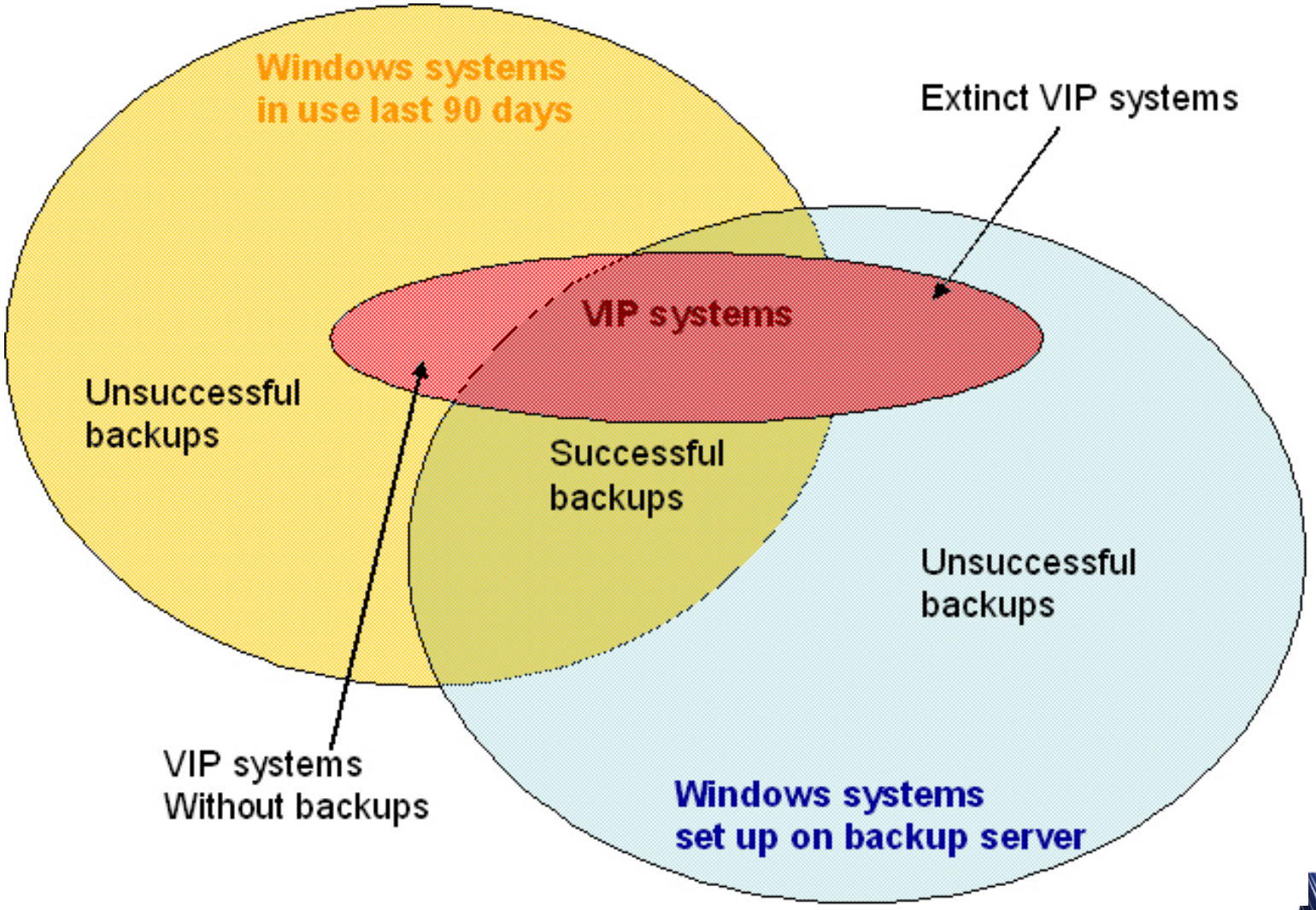
- ***Integrity & Availability***
  - Recovery from corruption **IF** event is known/detected
  - Can actually hurt confidentiality—all of those extra copies floating around
- **Difference is one of *degree* and *technique***
  - Degree in terms of "when"
    - Scheduled is typically backup (very often may be versioning)
    - Interrupt-driven is typically versioning (manual may be backup)
  - technique in terms of "what"
    - Full (typical building block for backup)
    - Differential
    - Incremental (typical for versioning)

Backup

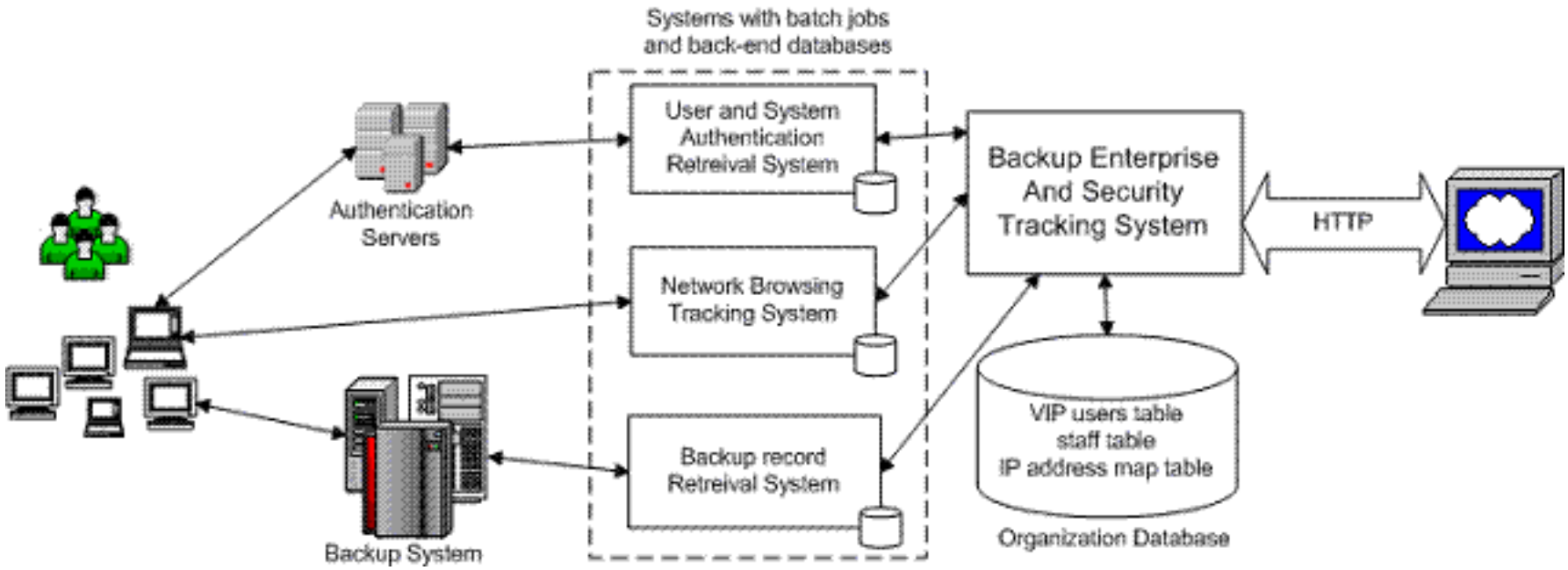
- Understood, now just management issues. Big management issues.
- Traditional backup (Amanda <-> BTS)
- New issues
  - Mobile hosts
  - Transient hosts
  - Restores



Prioritized Backups



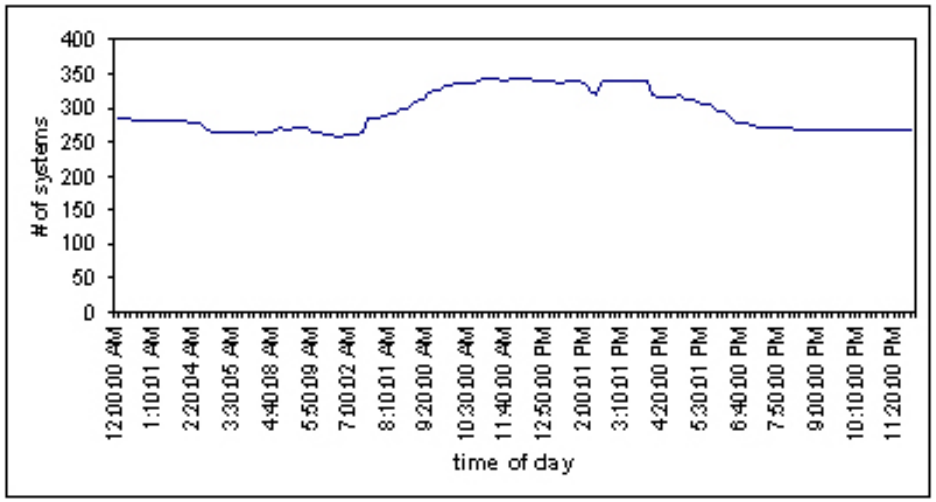
NCSA's Backup Tracking System*

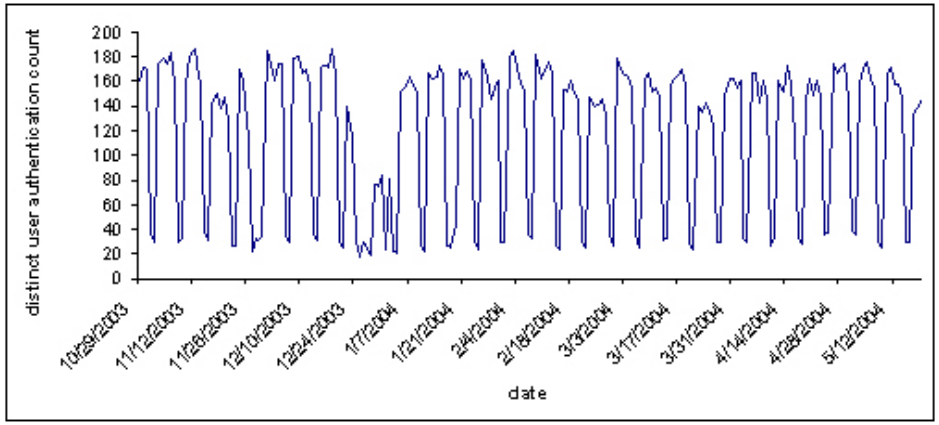


***** G. Pluta, L. Brumbaugh, W. Yurcik, and J. Tucek. "**Who Moved My Data? A Backup Tracking System for Dynamic Workstation Environments**," *Usenix LISA*, 2004.

Backup Data Useful for Other Purposes

Systems





Users

Versioning

- Versioning is *continuous* or *semi-continuous* backup
  - Elephant file system
    - Keep landmark versions (protect yourself)
  - S4
    - Keep everything (protect against others)
  - Recoverable File Service
    - Who did what to whom? (selective roll-back audit trail)

Feasibility of Full Versioning

- Average workstation has 200MB writes/day
  - 73 GB/year, < $300/year
    - What is the cost of lost data?
  - What level of compressability?

- Straw poll—who has .snapshot or OldFiles?

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Redundancy

- Space redundancy protects against
  - 1) Hardware failures
  - 2) Configuration failures
  - 3) Malicious attacks
- Usual technique is RAID
  - Somewhat well known…
  - See Peter Chen's "**RAID: High-Performance, Reliable Secondary Storage**"
  - Has some issues…

RAID Problems

- Only handles hardware failure
- Correlated failures are common
  - Same environment, same load, same disks…
  - Hot spare may not recover in time
  - RAID-6 type techniques are needed
  - Row-diagonal parity
- Some data more important (metadata)
  - D-GRAID
- Hard to manage
  - HP AutoRAID
  - Polus

Other redundancy techniques

- Erasure codes
  - A more complex “parity”
  - Possibly spread across sites
- Byzantine fault-tolerance
  - Don’t trust anybody
  - PASIS (from tamperproof)
- Secret Sharing
- Shortcomings
  - No protection against purposeful corruption
    - Nicely mirrored copies of tampered data
  - Very expensive

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Comparison

Technique	Confidentiality	Integrity	Availability	Cost
Encryption	High	Medium	Negative	CPU
Secret Sharing	High	High	High	CPU, Latency, Space
Tamper-Proof	None	High	None	CPU
Immutability	None	High	High	Latency, Space
Backup	None	Medium	Medium	Bandwidth, Space
Versioning	None	Medium	High	Space
RAID	None	Low	Medium	Space

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Confidentiality is limited to cryptography

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Availability costs in space

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Hardware cost is mostly CPU and space

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Each technique is best at different things

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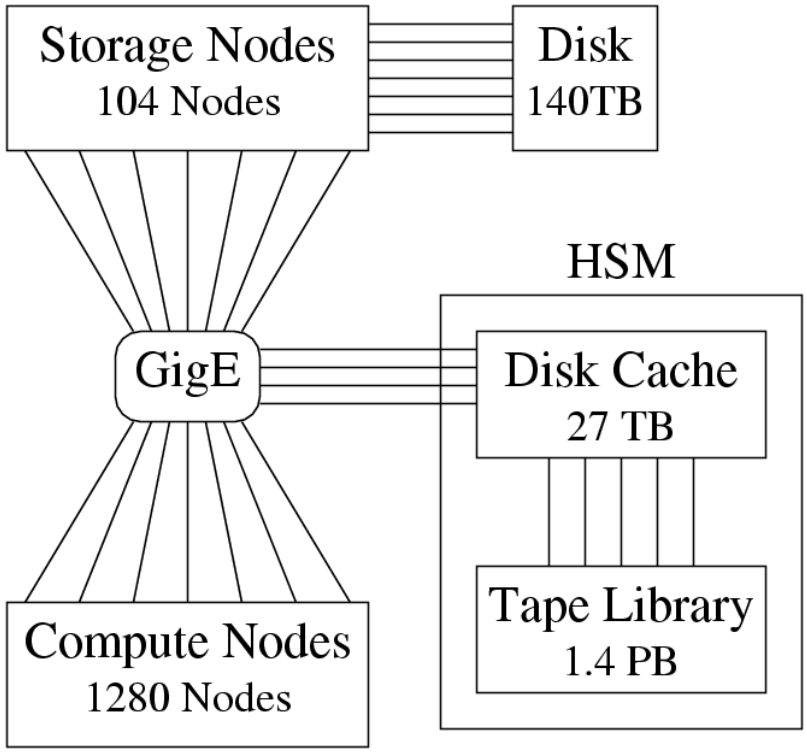
Case Study

- Storage at NCSA
  - Tungsten
    - # 10 on the Top 500
    - 104 storage nodes
    - 140 TB of disk
  - Hierarchical Storage Manager
    - 27 TB disk cache
    - 1.4 PB tape
- Big systems



Specific System Characteristics

- High Performance Work Space (Scratch)
  - 11.1 GB/sec
  - Ephemeral—purge after 14 days
- Mass Storage
  - Write heavy
    - .3:1 ratio of read:write
      - Does anybody even look at it all?
  - Growing (fast)
    - Between 2-20 TB a week

Securing High-Performance Workspace

1. Confidentiality
   - Cryptography is possible
     - Software AES at 50MB/sec
     - Hardware >200MB/Sec
     - Encrypt on-wire loads compute nodes
       - But they're waiting for I/O anyway…
2. Integrity
   - Immutability is impossible
   - Tamper-proof possible, desirable?
3. Availability already sufficient
   - Not time critical

Securing Mass Storage

1. Immutability
   - We sort of already do this (formalize?)
2. Availability
   - No lost files, yet
     - Approaching media limits
   - Tape performance issues
3. Encryption trivial
   - Lower performance requirements

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  1. **Storage Protection > Cryptography**
  2. **No Panacea**
  3. **Mission Possible!**
  4. **Challenges in the Road Ahead**

1. Storage Protection > Cryptography

- Storage security is about more than secrets
  - Secret data isn't useful if it:
    - Is tampered with
    - Is deleted
    - Fails to meet performance goals
    - Costs too much
    - Becomes unavailable

2. No Panacea

Different techniques excel at different things:

Encryption → Confidentiality

Versioning → Integrity

Redundancy → Availability

3. Mission Possible!

It is possible to secure even large, high performance storage systems:

- One must be careful of the design
- Current commercial systems are a bit short—wait a few years

4. Challenges in the Road Ahead

Usability

- Storage is complex, many faults induced by management complexity

Unification with clusters

- Clusters becoming more ubiquitous
- Cluster files systems are (somewhat) feature poor

Leveraging unique properties

- HPC and MSS are different

The End.

Questions?

<http://www.ncassr.org/projects/storage-sec/>