TrueErase: Full-storage-data-path Per-file Secure Deletion

Sarah Diesburg · Christopher Meyers · Mark Stanovich

Michael Mitchell · Justin Marshall · Julia Gould

An-I Andy Wang

Florida State University

Geoff Kuenning

Harvey Mudd College

Overview

- Problem
  - Per-file secure-deletion is difficult to achieve
    - Important for expired data, statute of limitations, etc.
- Existing solutions tend to be
  - Limited to a segment of legacy storage data path
  - File-system- or storage-medium-specific
- TrueErase
  - Storage-data-path-wide solution
  - Works with common file systems & storage media

The Problem

- Most users believe that files are deleted once
  - Files are no longer visible
  - The trash can is emptied
  - The partition is formatted
- In reality
  - Actual data remains

Are you sure you want to delete kittah?
Yes/No
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'Sensitive' data found on returned hard drive

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BY SARAH SCHMIDT, CANWEST NEWS SERVICE   MARCH 23, 2009

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by Rich Bowden - Jan 27 2009, 04:43

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OCT 7 2008

Mobile phones can never be totally wiped clean of data

Posted by admin in Sci-Tech

1 Comment

GIZMODO
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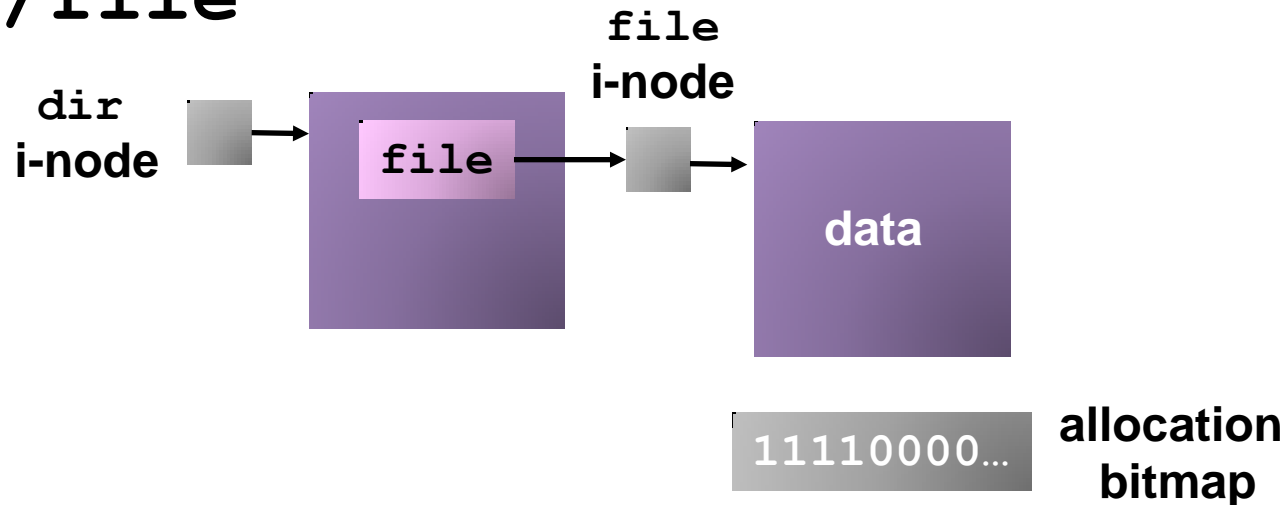Display · | Condensed · | search | Most recent ·

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IPHONE

Refurbished iPhones Might Still Have Previous Owners' Personal Data, No Way to Erase It

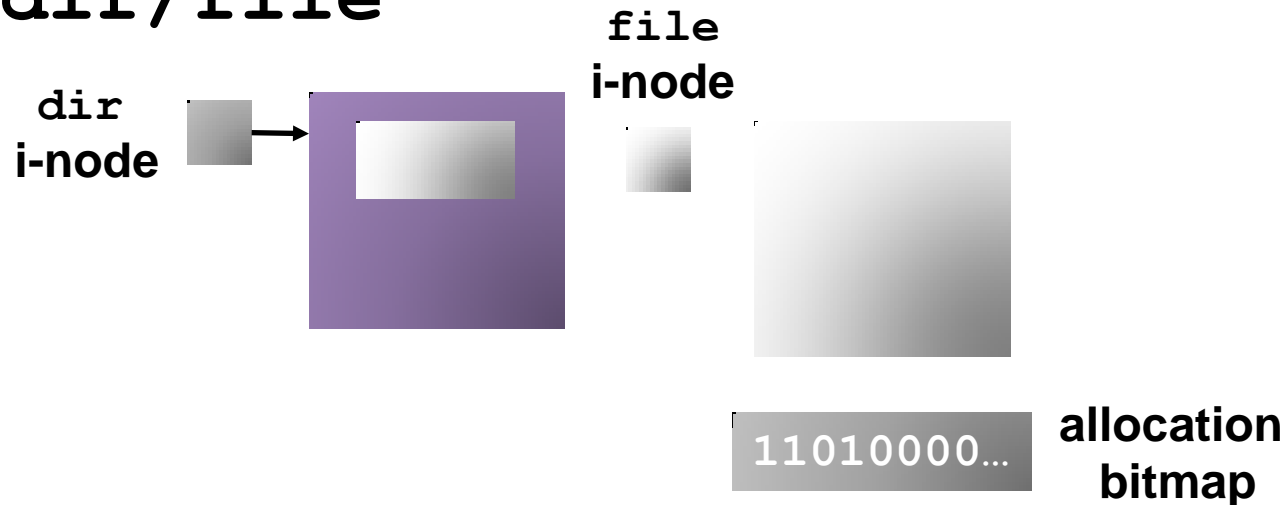By matt buchanan, 11:20 AM on Tue May 20 2008, 21,636 views

What is *secure deletion*?

- Rendering a file's deleted content and metadata (e.g., name) irrecoverable
- **/dir/file**

What is *secure deletion*?

- Rendering a file's deleted content and metadata (e.g., name) irrecoverable
- **rm /dir/file**

dir i-node → [purple block]

file i-node [block]

`11010000…` **allocation bitmap**

How hard can this be?

- Diverse threat models
  - ❑ Attacks on backups, live systems, cold boot attacks, covert channels, policy violations, etc.
- Our focus
  - ❑ Dead forensic attacks on local storage
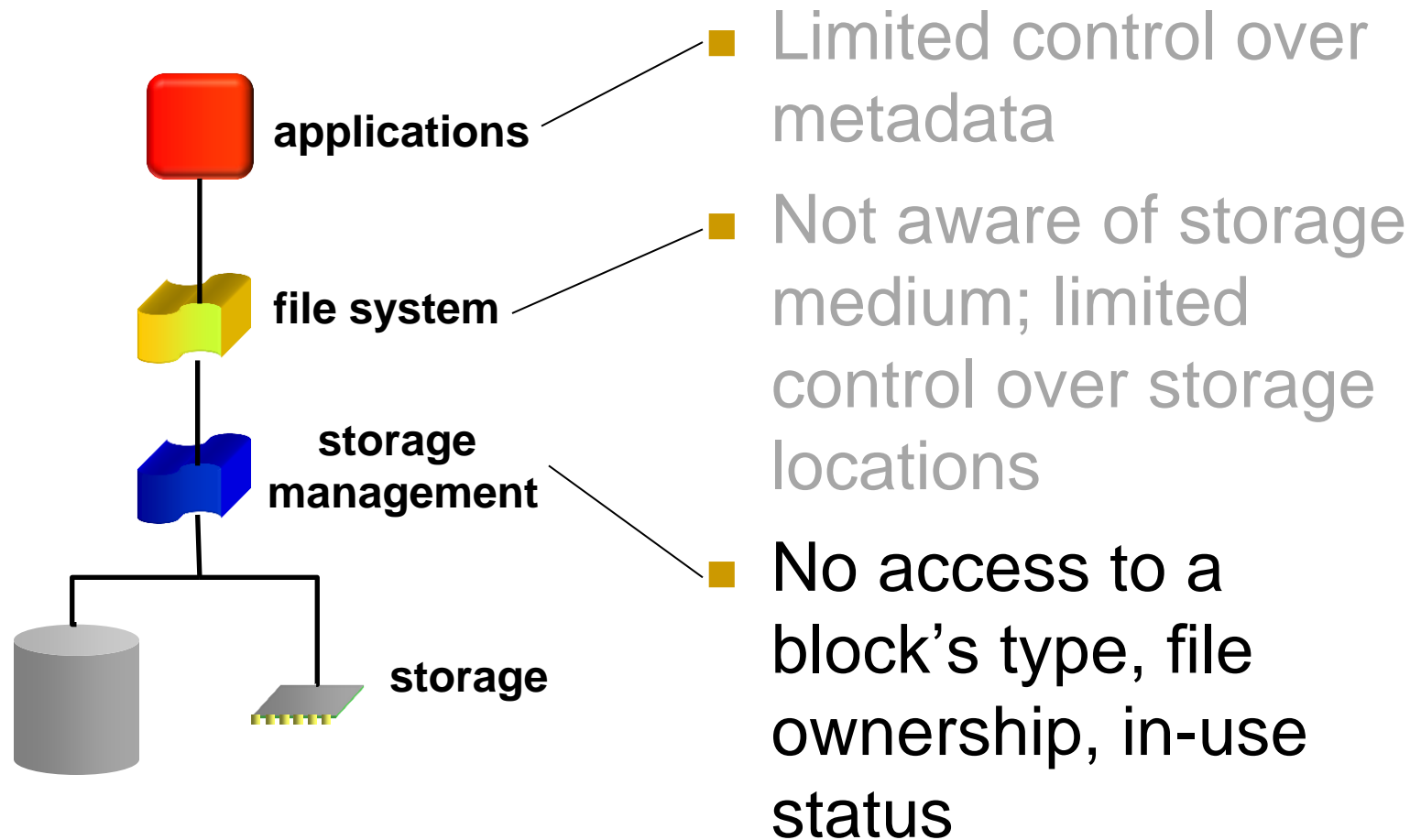   - ■ Occur after the computer has been shut down properly

Basic Research Question

- Under the most benign environments
- What can we design and build to ensure that the secure deletion of a file is honored?
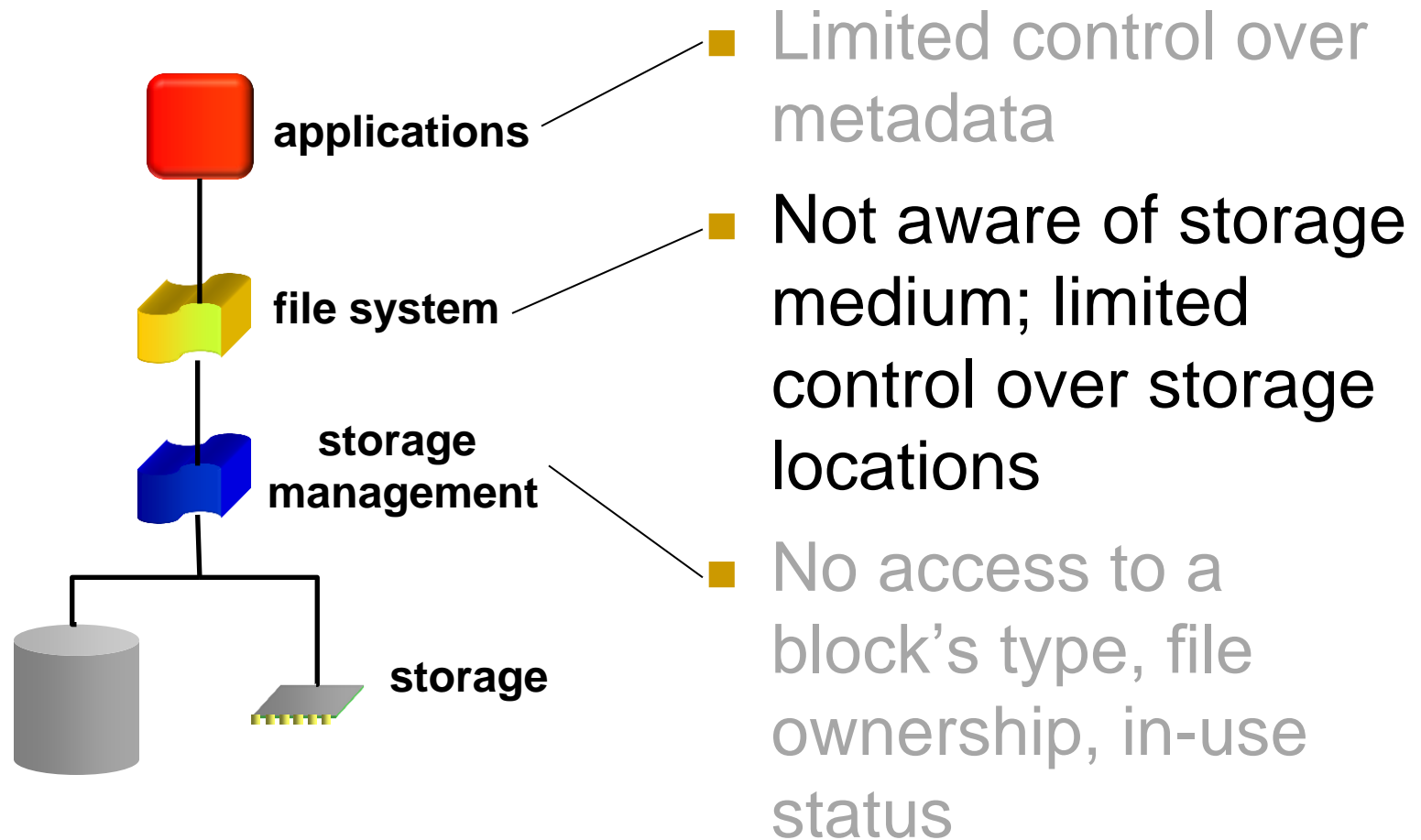 - Throughout the legacy storage data path

TrueErase: A Storage-data-path-wide Framework

- Irrevocably deletes data and metadata
- Offers a unique combination of properties
  - Compatible with legacy apps, file systems, and storage media
  - Per-file deletion granularity
  - Solution covers the entire data path
  - Can survive common system failures
  - Core logic systemically verified

Legacy Storage Data Path
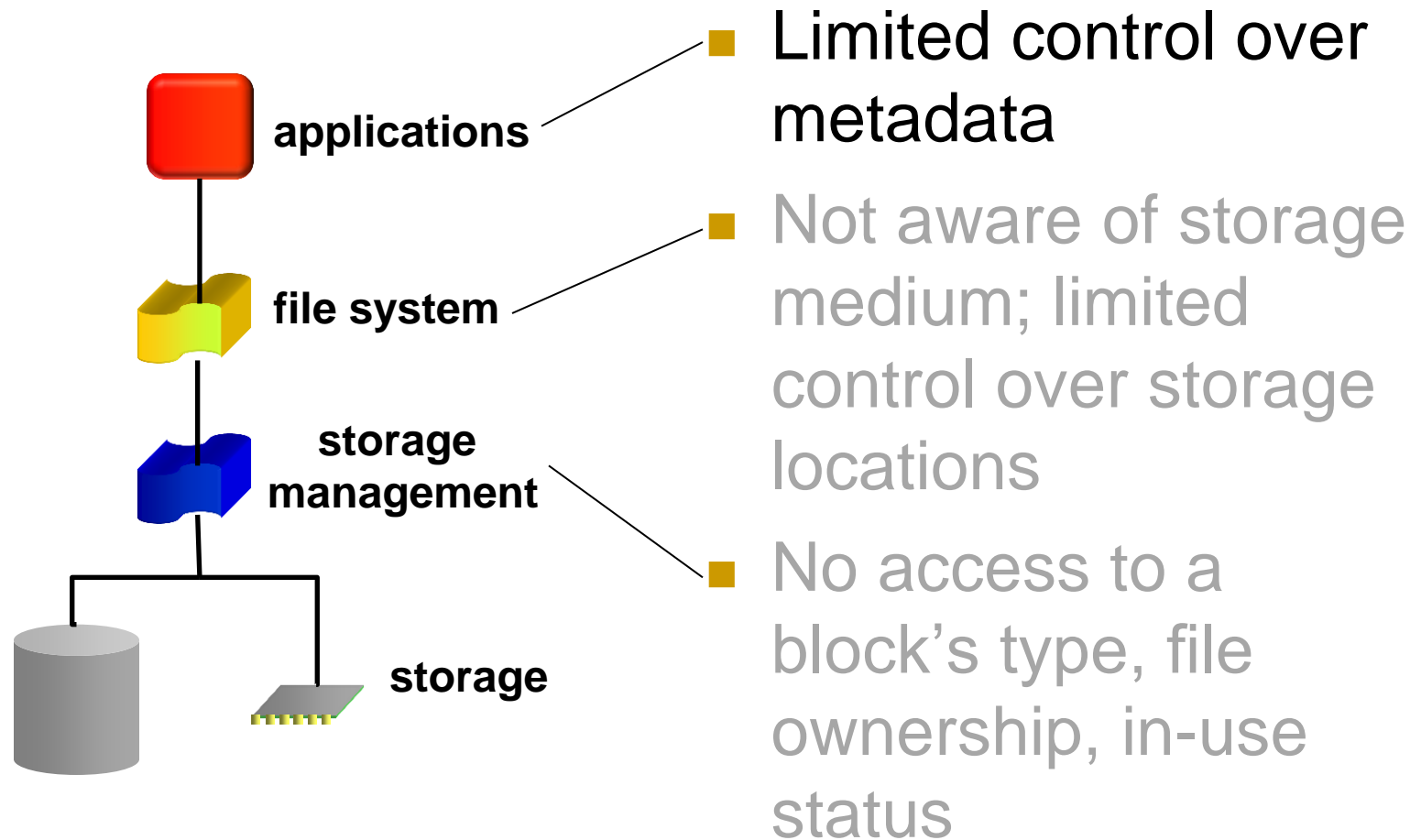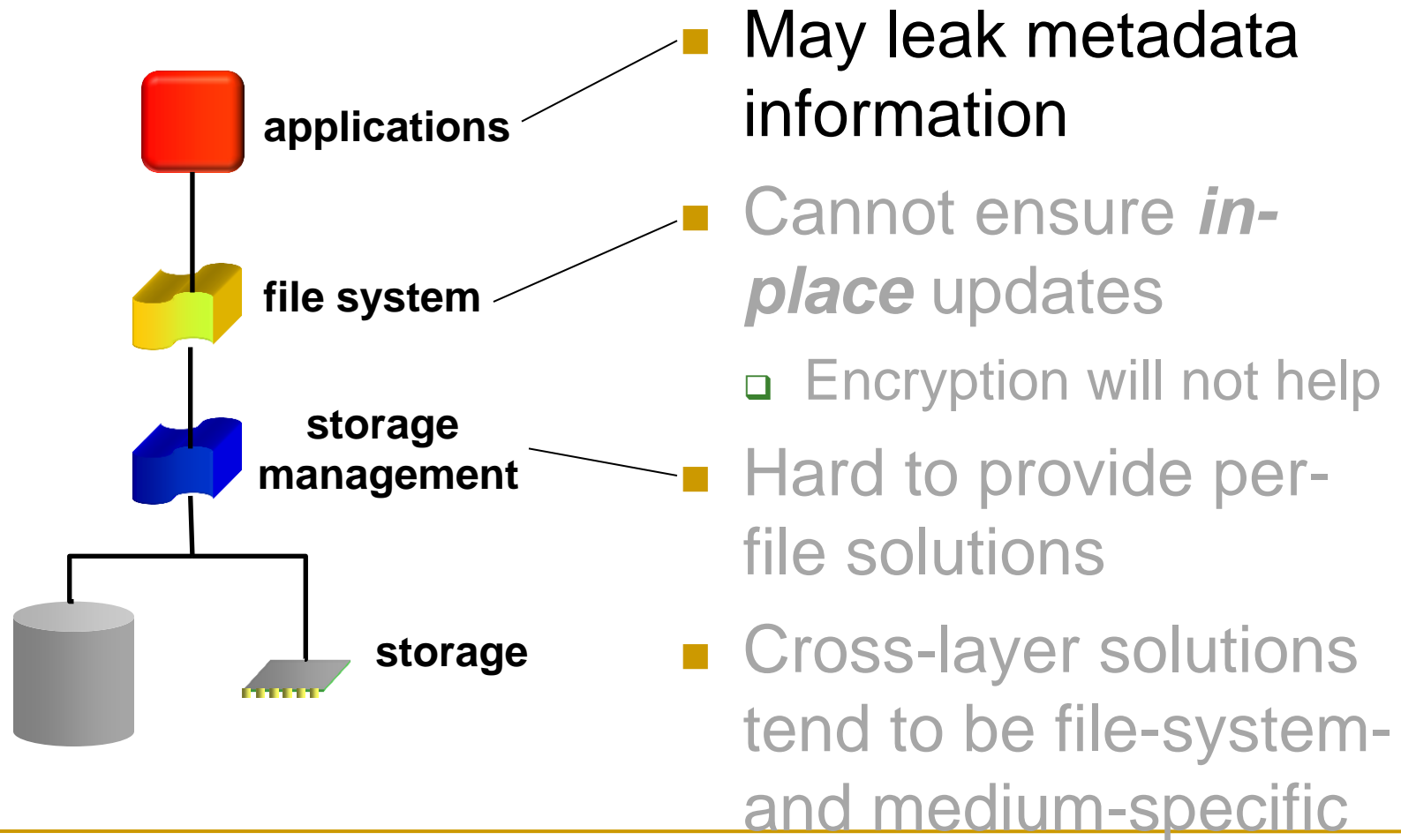
applications

file system

storage management

storage

- Limited control over metadata
- Not aware of storage medium; limited control over storage locations
- No access to a block's type, file ownership, in-use status

Legacy Storage Data Path

applications

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storage

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Legacy Storage Data Path

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Existing Secure-deletion Solutions

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storage

- May leak metadata information
- Cannot ensure *in-place* updates
  - ❑ Encryption will not help
- Hard to provide per-file solutions
- Cross-layer solutions tend to be file-system- and medium-specific

Existing Secure-deletion Solutions

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Existing Secure-deletion Solutions

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storage

- May leak metadata information

- Cannot ensure *in-place* updates
  - □ Encryption will not help

- Hard to provide per-file solutions

- Cross-layer solutions tend to be file-system- and medium-specific

Other Secure-deletion Challenges

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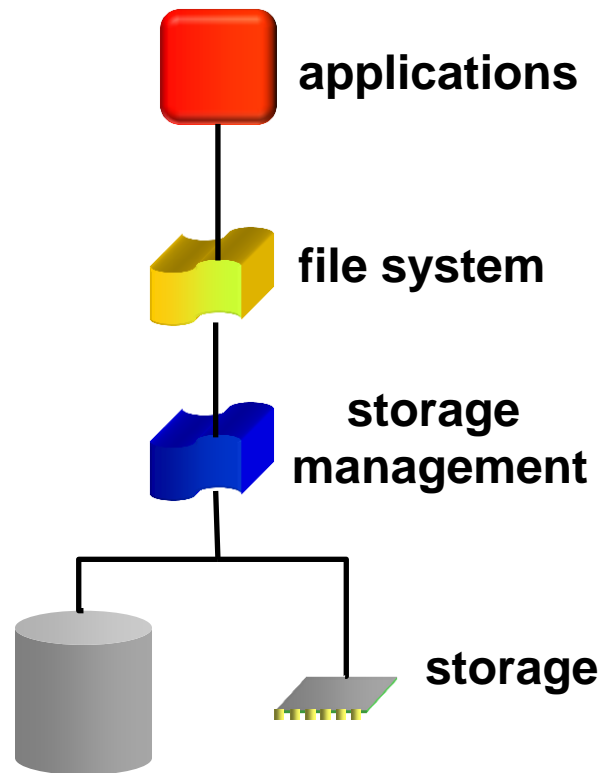
- No legacy requests to delete data blocks
  - For performance
- Legacy optimizations
  - Requests can be split, reordered, cancelled, consolidated, buffered, with versions in transit
- Lack of global IDs
- Crashes/verification

TrueErase Overview

- A centralized, per-file secure-deletion framework

applications

user model

file system

TAP

storage management

secure-deletion commands

storage
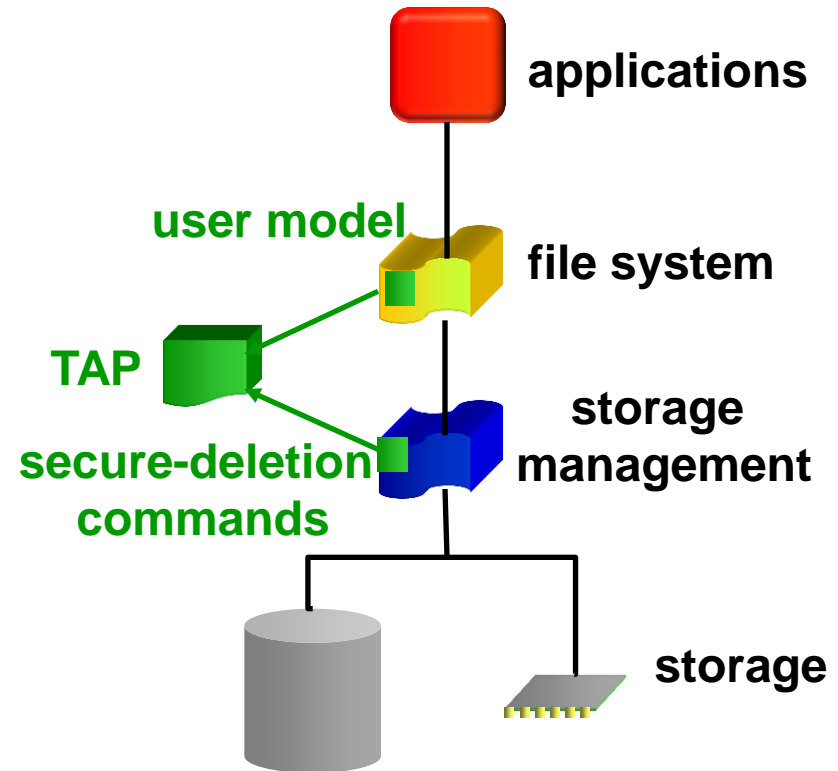
TrueErase Overview

- **User model**
  - Use extended attributes to specify files/dirs for secure deletion
  - Compatible to legacy applications

applications

user model

file system

TAP

storage management

secure-deletion commands
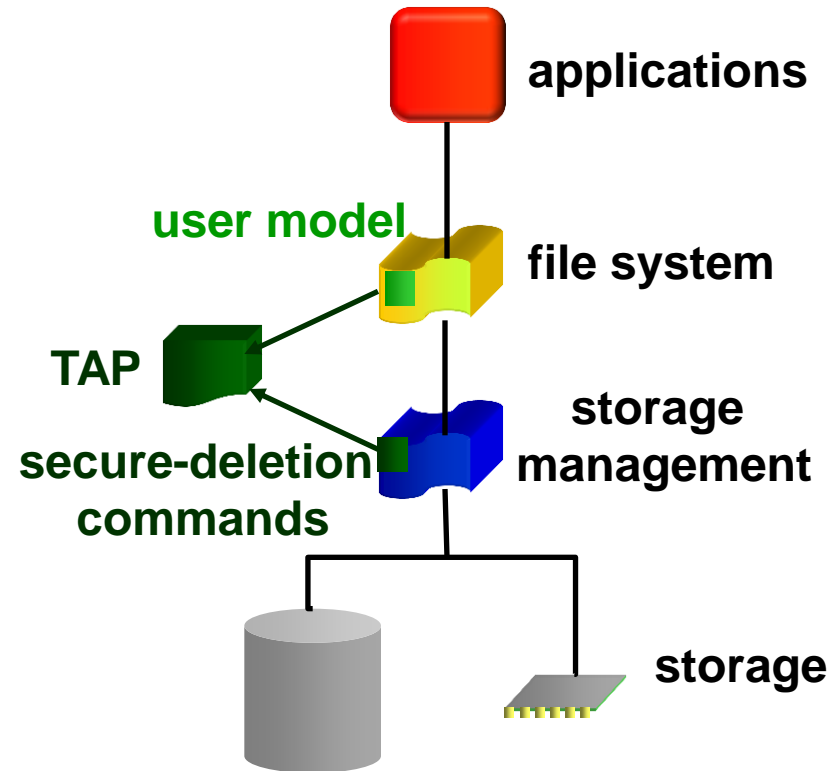
storage

TrueErase Overview

- **Type/attribute propagation module (*TAP*)**
  - ❑ File system reports pending updates
    - ◾ Uses global unique IDs to track versions
  - ❑ Tracks only soft states
   - ◾ No need for mechanisms to recover states

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user model

file system

TAP

secure-deletion commands

storage management
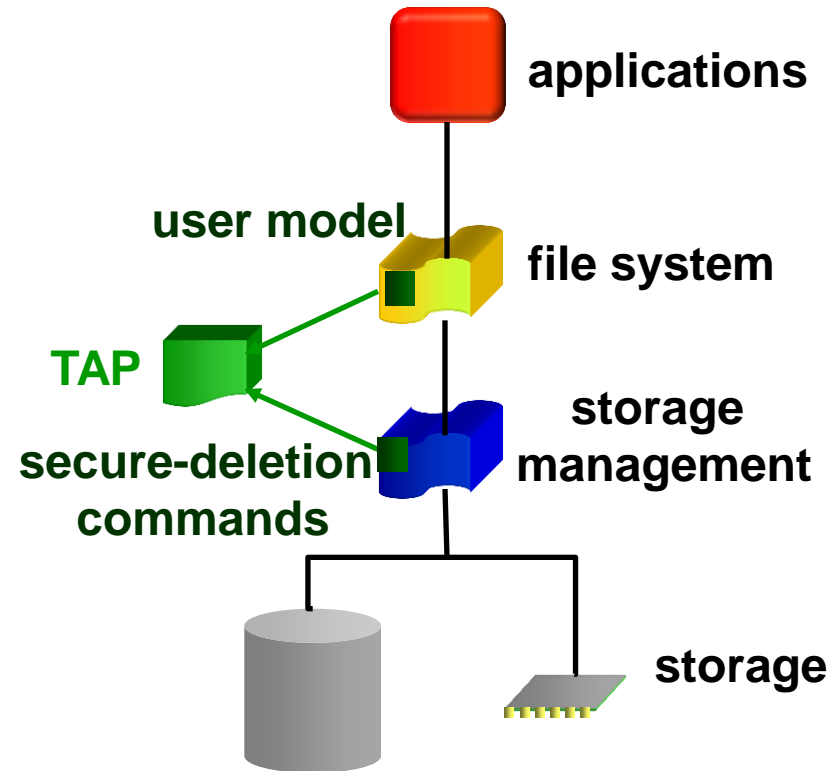
storage

TrueErase Overview

- **Enhanced storage-management layer**
  - Can inquire about file-system-level info
  - Added secure-deletion commands for various storage media
  - Disabled some optimizations (e.g., storage-built-in cache)

applications

user model

file system

TAP

secure-deletion commands

storage management
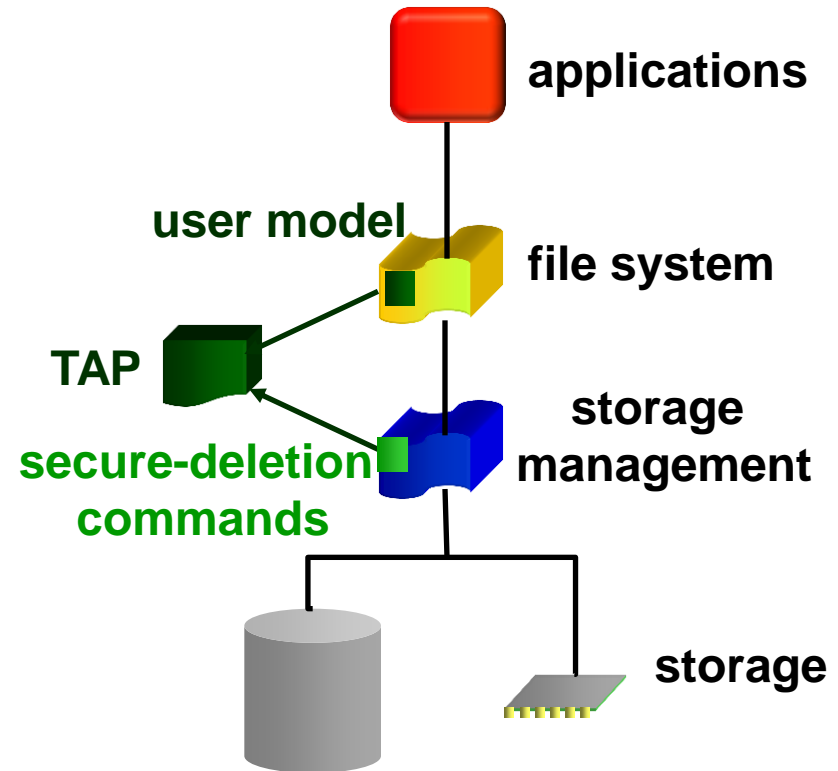
storage

TrueErase Overview

- **After a crash**
  - All replayed and reissued deletions are done securely
  - All data/metadata in the storage data path from prior session will be securely deleted

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user model

file system

TAP

secure-deletion commands

storage management
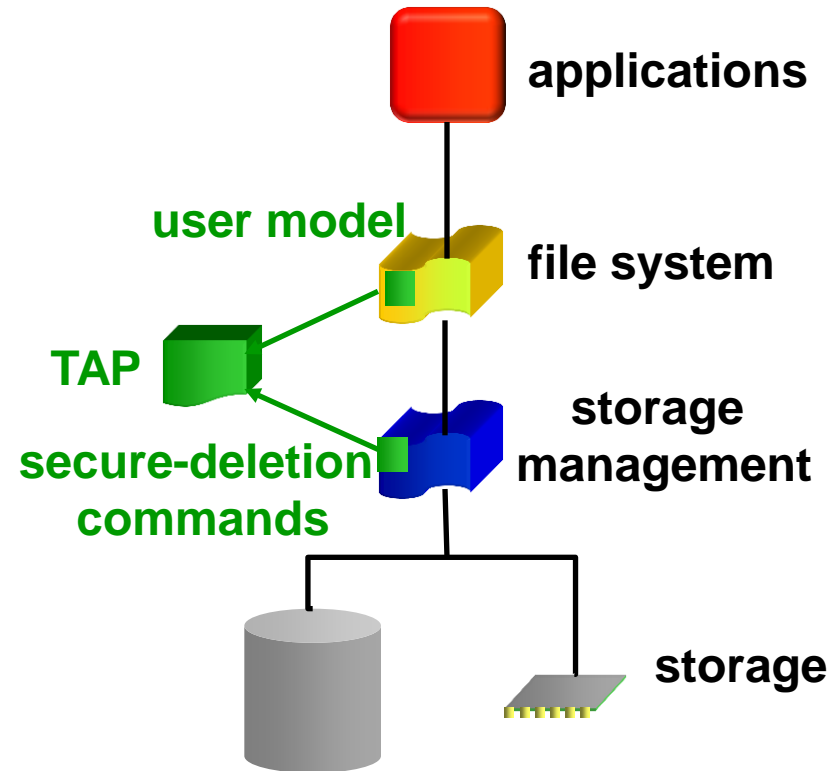
storage

TrueErase Assumptions

- Benign personal computing environment
  - Laptops, cellular phones
  - Uncompromised, single-user, single-file-system, non-RAID, non-distributed system
- Dead forensics attacks
- Full control of storage data path
- Journaling file systems that adhere to the consistency properties specified in [SIVA05]
- All updates are reported

TrueErase Design

- User model

- TAP

- Enhanced storage-management layer

- Exploiting file-system-consistency properties to identify and handle corner cases

User Model

- Ideally, use traditional file-system permission semantics

  - Use extended-attribute-setting tools to mark files/dirs *sensitive*

    - Which will be securely deleted from the entire storage data path
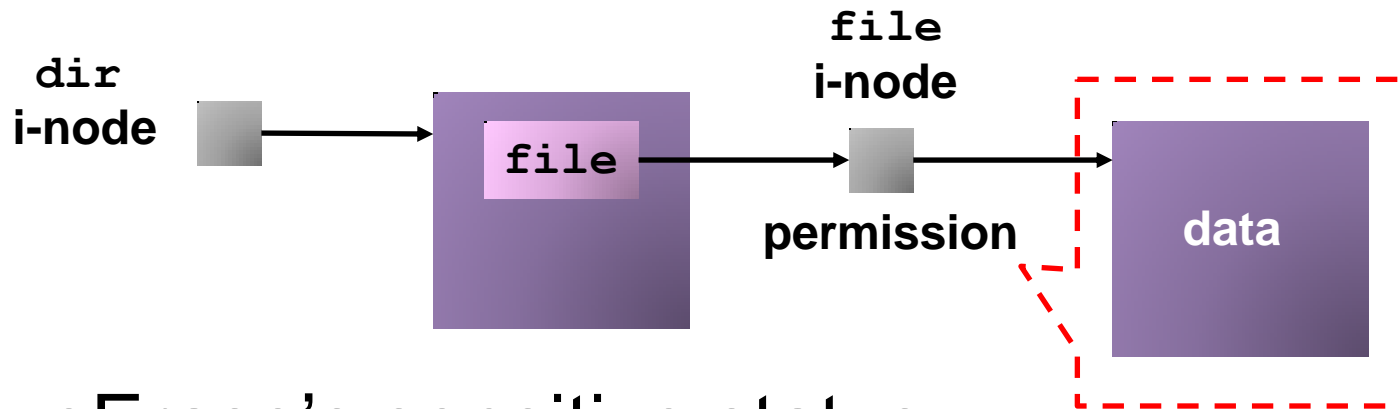
  - Legacy apps just operate on specified files/dirs

Name Handling

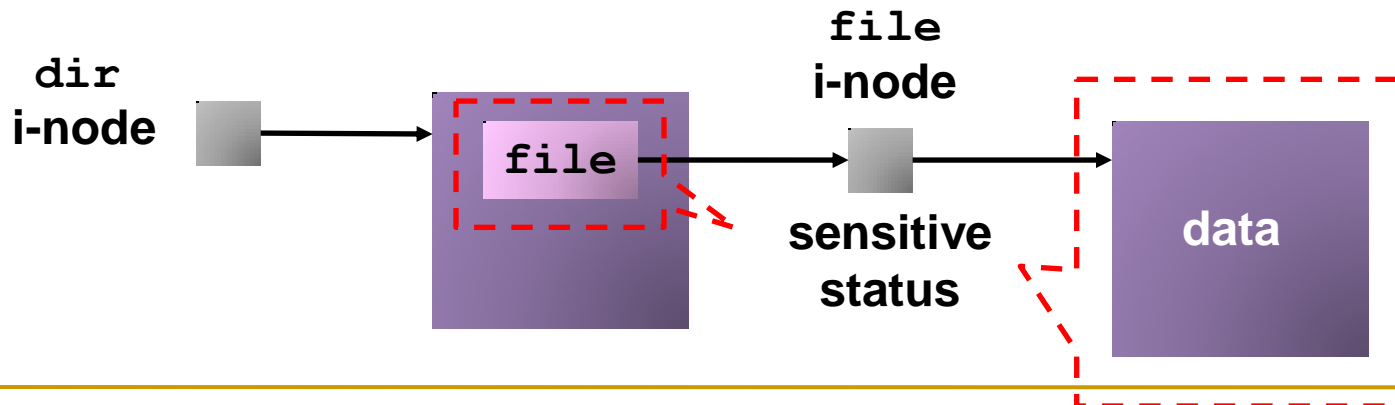- Legacy file-permission semantics

Name Handling

- ## Legacy file-permission semantics

dir i-node → [ ] → (purple box with **file**) → **file i-node** [permission] → (**data**)
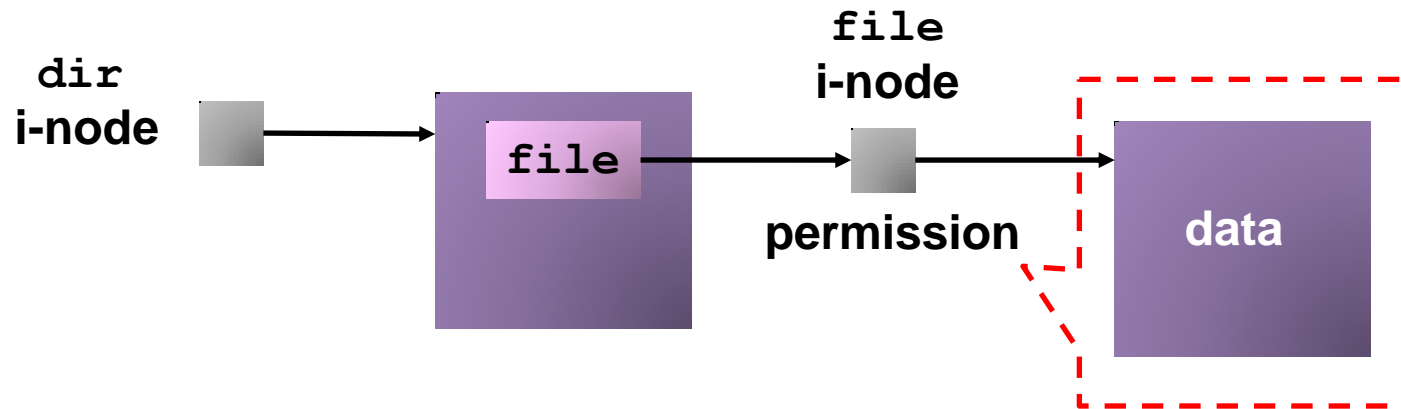
permission

- ## TrueErase's sensitive status

dir i-node → [ ] → (purple box with **file**) → **file i-node** [ ] → (**data**)

sensitive status

Toggling of the Sensitive Status

- Implications
  - Tracking update versions for all files at all times
  - Or, removing old versions for all files at all times
- TrueErase
  - Enforces secure deletions for files/dirs that have stayed sensitive since their creation

Name Handling

- ## By the time one can set attributes of a file
  - ❑ File name may already be stored non-sensitively
- ## Some remedies
  - ❑ Inherit the sensitive status
    - Creating a file under a sensitive directory
  - ❑ smkdir wrapper script
    - Creates a temporary name, marks it sensitive, and renames it to the sensitive name

TAP Module

- Tracks and propagates info from file-system layer to storage-management layer
- Challenges
  - Where to instantiate the deletion requests to file content?
 - What and how to track?
  - How to interact with TAP?

Where to instantiate deletion requests to file content?

□ Can a file system just issue zeroed blocks?

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file system

TAP

storage management

0s

data   storage   data

Where to instantiate deletion requests to file content?

- Can a file system just issue zeroed blocks?

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TAP

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0s ← data

storage

data (X) 0s
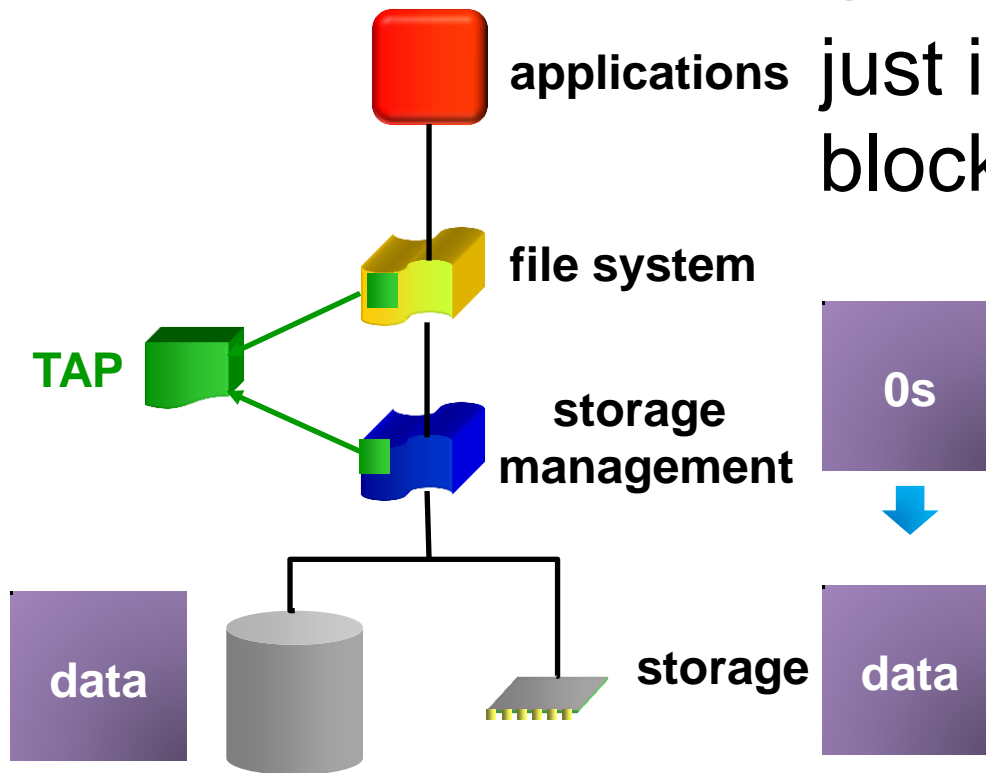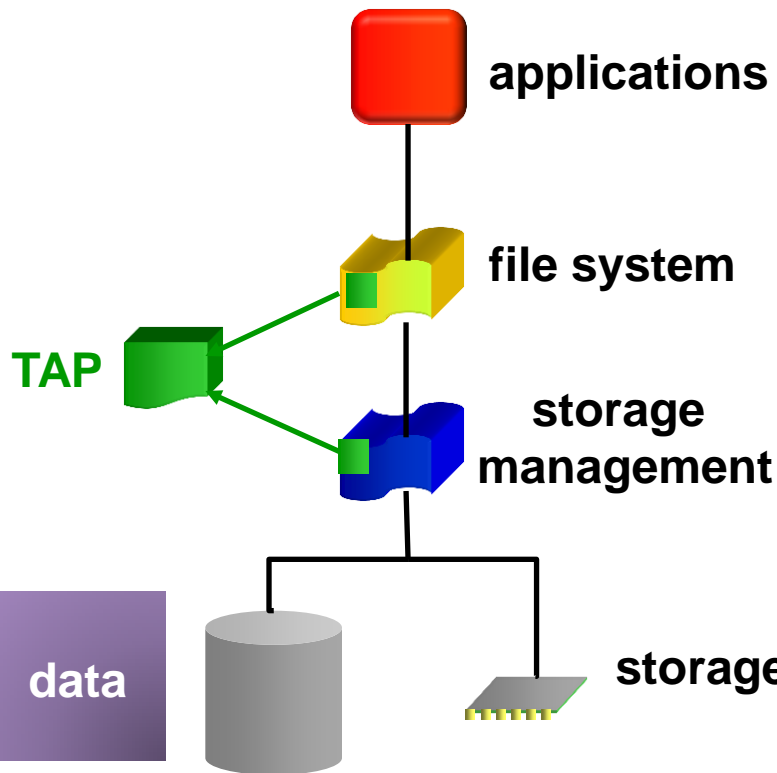
Where to instantiate deletion requests to file content?

- **Instead**
  - A file system attaches deletion reminders to other deletion requests (zeroing allocation bits)

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file system

TAP

storage management

data

storage

data

Where to instantiate deletion requests to file content?

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0/1s ← data

storage

explicit erase

data →
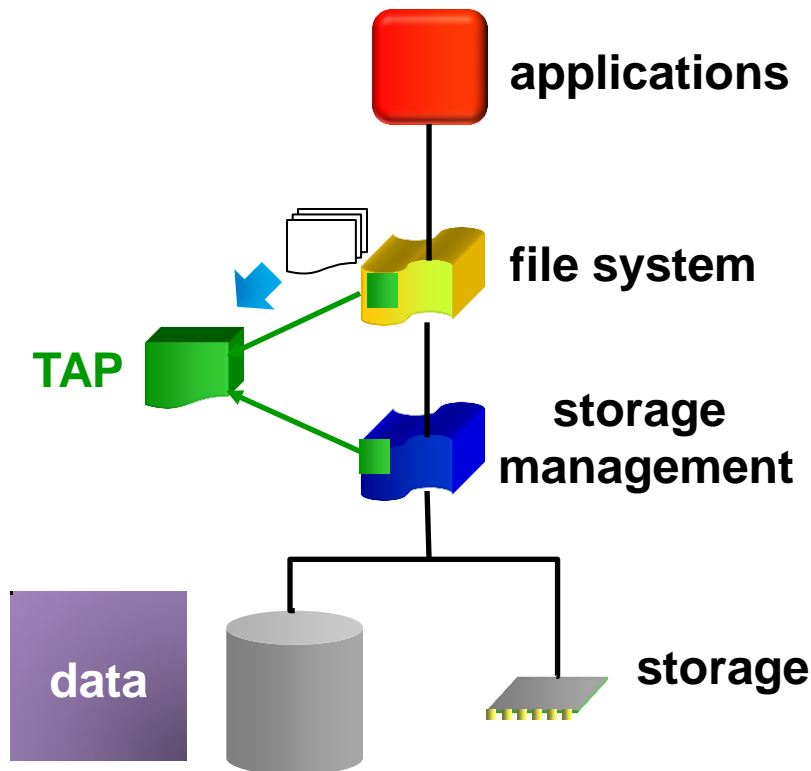
- ❑ Storage-management layer can choose secure-deletion methods
  - ▪ Match the underlying storage medium
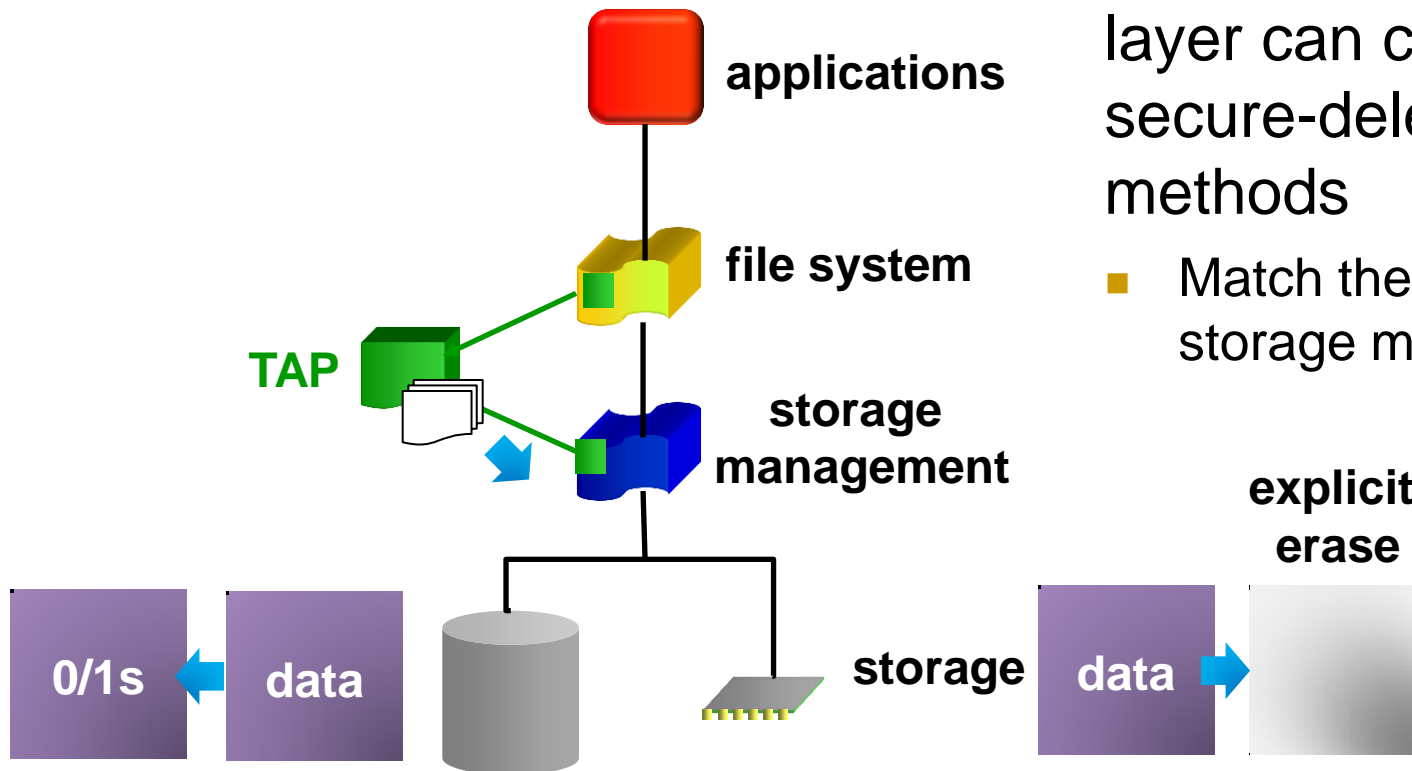
What to track?

- **Tracking deletion is not enough**
  - At the secure-deletion time
    - Versions of a file's blocks may have been stored
    - Metadata may not reference to old versions
      - Need additional persistent states to track old versions
- **TrueErase deletes old versions along the way**
  - Overwriting a sensitive data

    = Secure deletion + update (*secure write*)
  - Tracks all in-transit sensitive updates

What to track?

- Tracking sensitive updates is still not enough
  - ❑ Metadata items are small
  - ❑ A metadata block can be shared by files with mixed sensitive status
    - A non-sensitive request can make sensitive metadata appear in the storage data path
- TrueErase tracks all in-transit updates
  - ❑ For simplicity and verification

How to track?

- Challenges
  - Reuse of name space (i-node number), data structures, memory addresses
  - Versions of requests in transit
- TrueErase
  - Global unique page ID per memory page

Tracking Granularity

- TrueErase tracks physical sector numbers (e.g., 512B)
  - Smallest update unit
  - GUID: global unique page ID + sector number

How to interact with TAP?

- Report_write() creates a per-sector tracking entry

- Report_delete() attaches deletion reminders to a tracking entry

- Report_copy() clones a tracking entry and transfers reminders

- Cleanup_write() deletes a tracking entry

- Check_info() retrieves the sensitive status of a sector and its reminders

Enhanced Storage-management Layer

- Decide which secure-deletion method to use
  - Based on the underlying storage medium
  - We used NAND flash for this demonstration

NAND Flash Basics

- Writing is slower than reading
  - Erasure can be much slower
- NAND reads/writes in *flash pages*
  - Deletes in *flash blocks*
    - Consisting of contiguous pages

NAND Flash Basics

- **In-place updates are not allowed**
  - Flash block containing the page needs to be erased before being written again
    - In-use pages are migrated elsewhere
- **Each location can be erased 10K -1M times**

Flash Translation Layer (FTL)

- ## To optimize performance

  - *FTL* remaps an overwrite request to an erased empty page

- ## To prolong the lifespan

  - *Wear leveling* evenly spreads the number of erasures across storage locations

Added NAND Secure-deletion Commands

- Secure_delete(pages)
  - Copies other in-use pages from the current flash block to elsewhere
  - Issue erase command on the current block
- Secure_write(page)
  - Write the new page
  - Call Secure_delete() on the old (if applicable)

Crash Handling

- A crash may occur during a secure operation
    - Page migration may not complete
- Since copies are done first
    - No data loss; but potential duplicates
    - Journal recovery mechanisms will reissue the request, and secure operations will continue

Wear Leveling

- ## When flash runs low on space
  - Wear leveling compacts in-use pages into fewer flash blocks
- ## Problem: internal storage reorganization
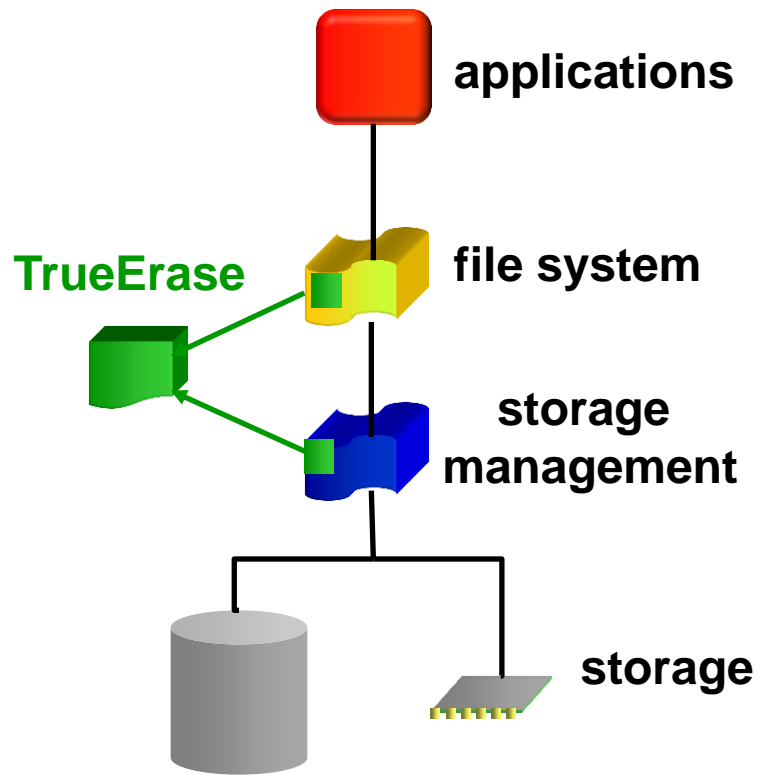 - No respect for file boundaries, sensitive status

Wear Leveling

- ## TrueErase

  - Stores a sensitive-status bit in per-page control areas

    - Used to enforce secure-deletion semantics

  - May not always be in sync with the file-system-level sensitive status

    - E.g., short-lived files

    - When the bit disagrees with file system's secure status, mark the bit sensitive and treat it as such
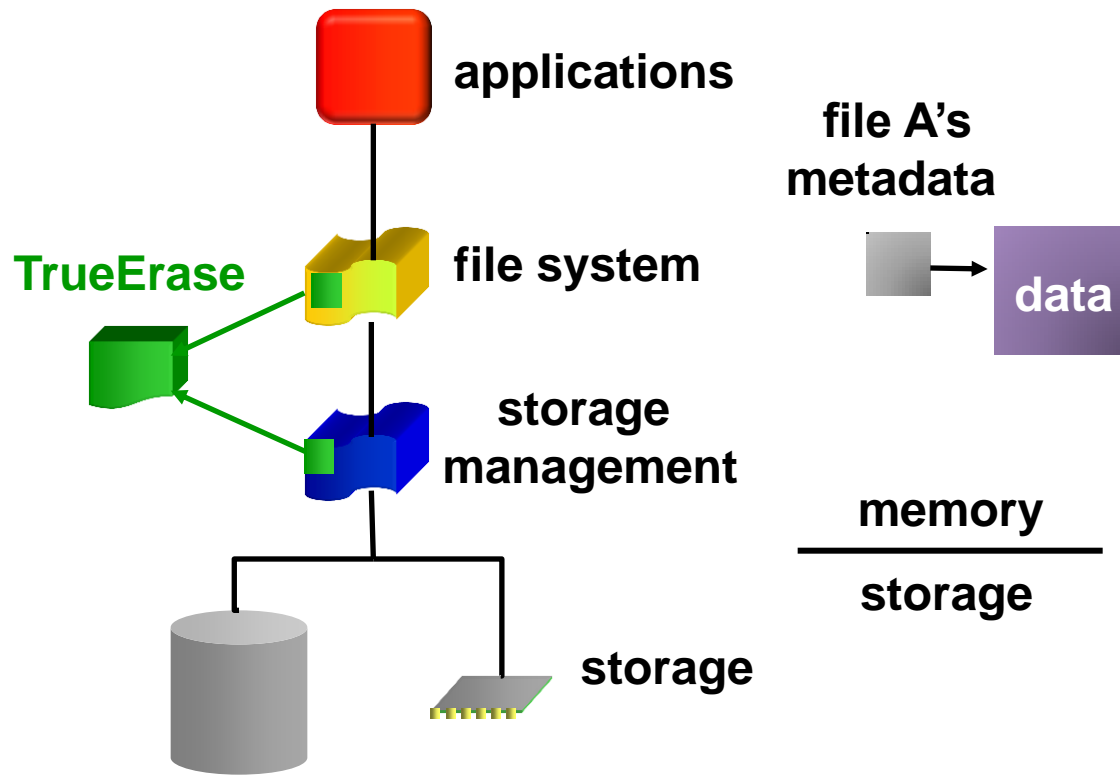
File-system-consistency Properties and Secure Deletion

- **File-system-consistency properties**
  - A file's metadata reference the right data and metadata versions throughout the data path
- **For non-journaling file systems**
  - *Reuse-ordering* & *pointer-ordering properties*
  - Without both (e.g., ext2), a file may end up with blocks from another file
- **For journaling file systems**
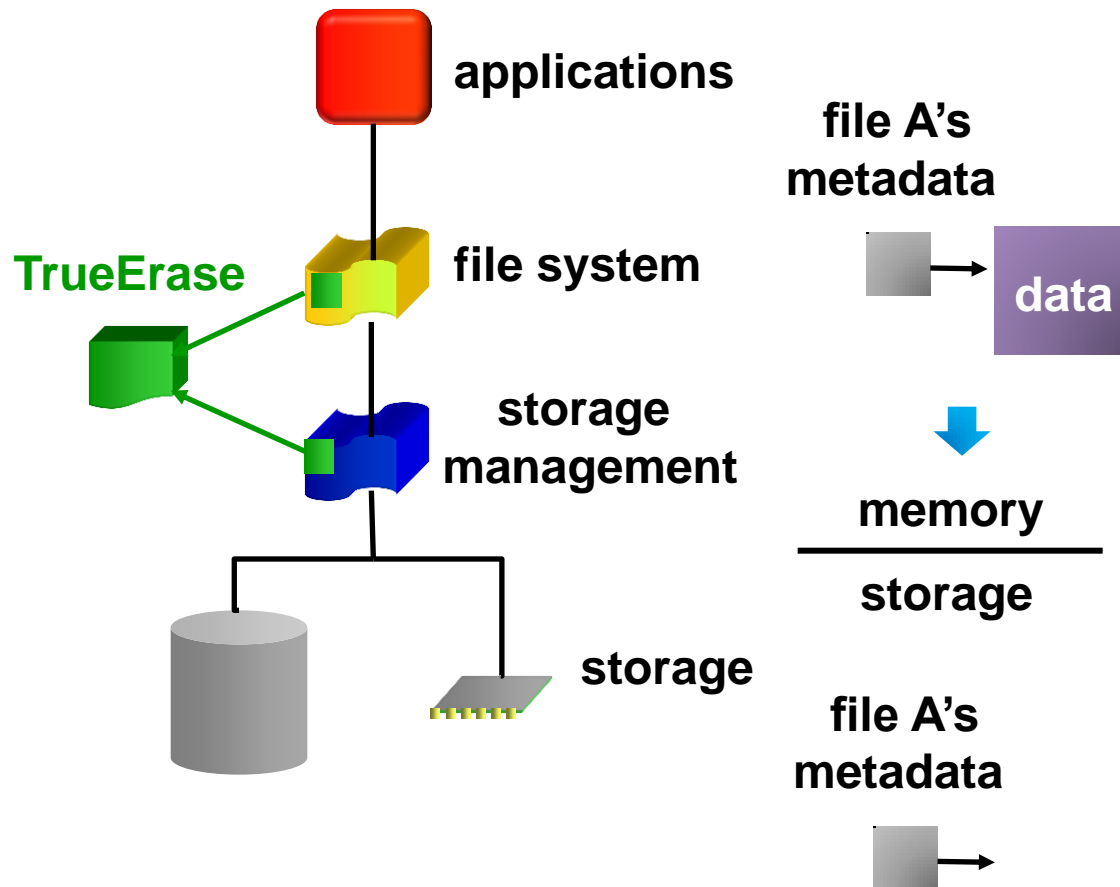 - *Non-rollback property*
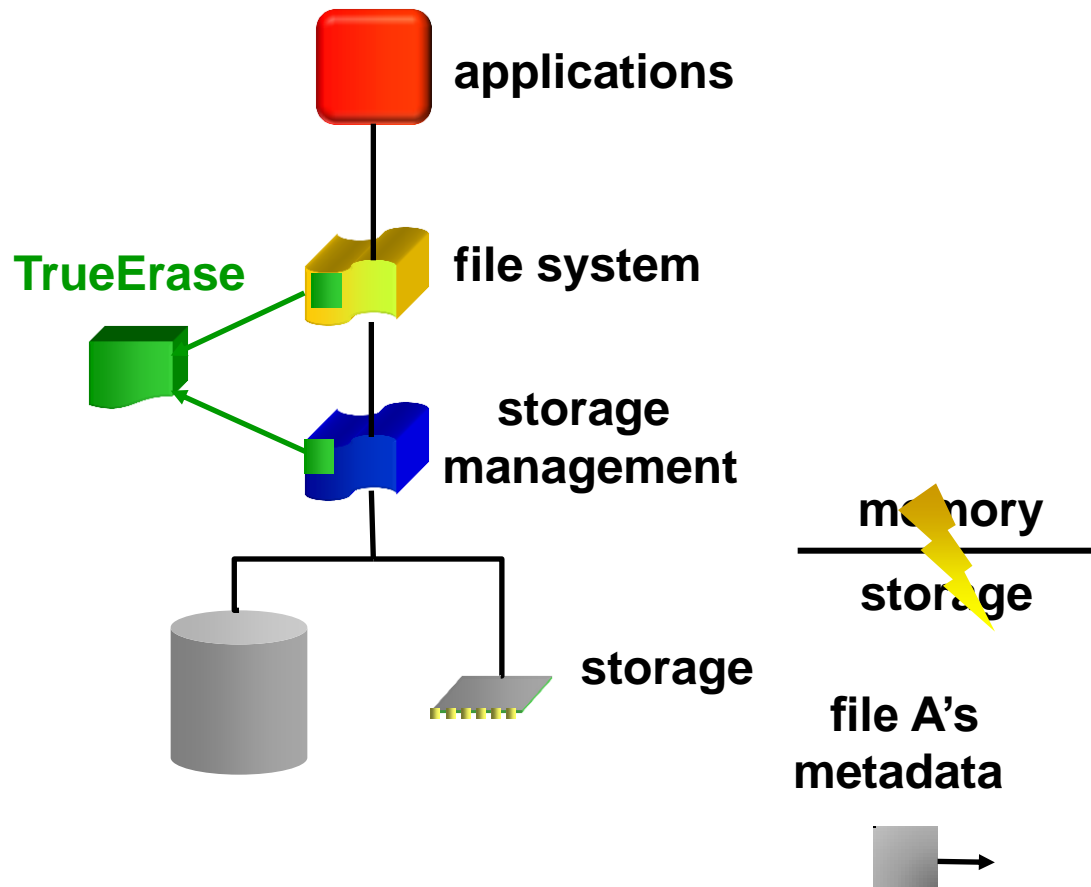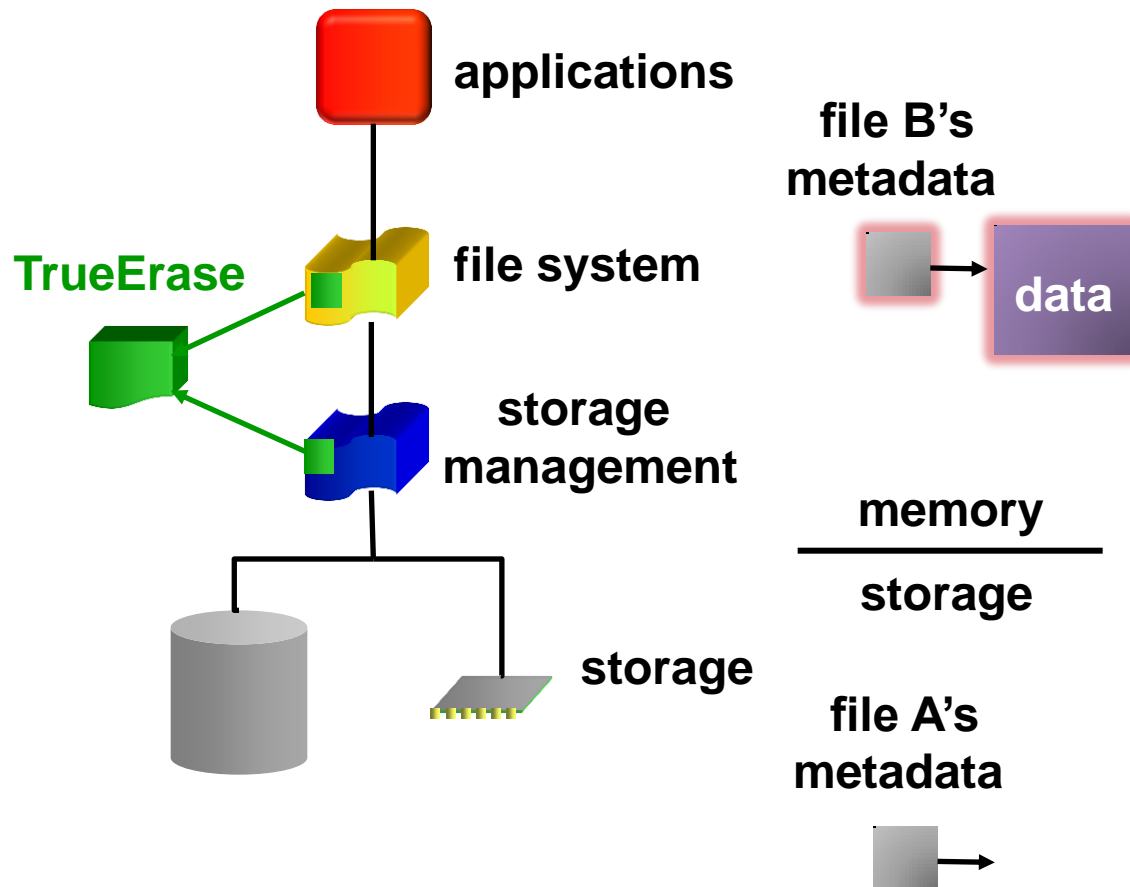
Without Pointer-ordering Property

applications

TrueErase

file system

storage management

storage

Without Pointer-ordering Property

applications

file A's
metadata

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Without Pointer-ordering Property

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Without Pointer-ordering Property

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TrueErase

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file A's metadata

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- **Secure deletion of A can end up deleting B's block**

Pointer-ordering Property

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Pointer-ordering Property

applications

file A's metadata

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- Data blocks are propagated first

Pointer-ordering Property

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TrueErase

storage management

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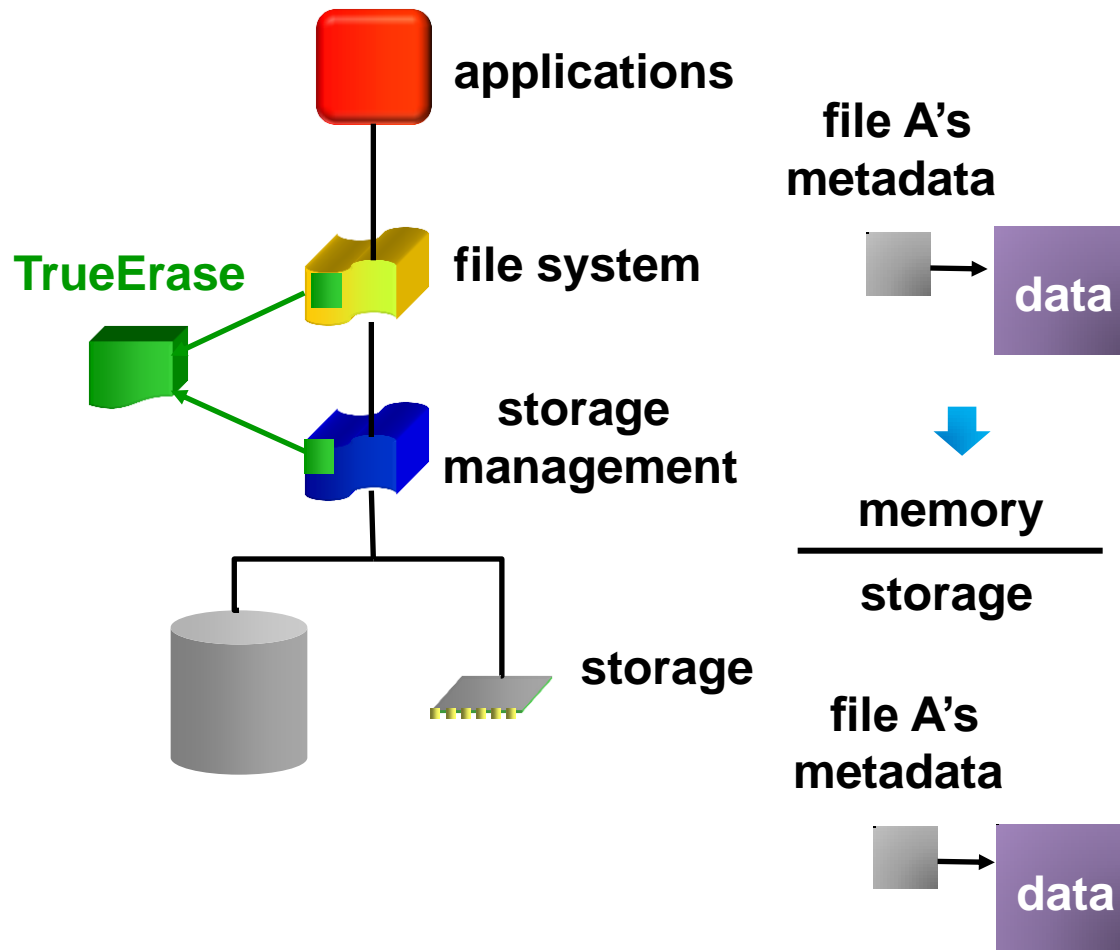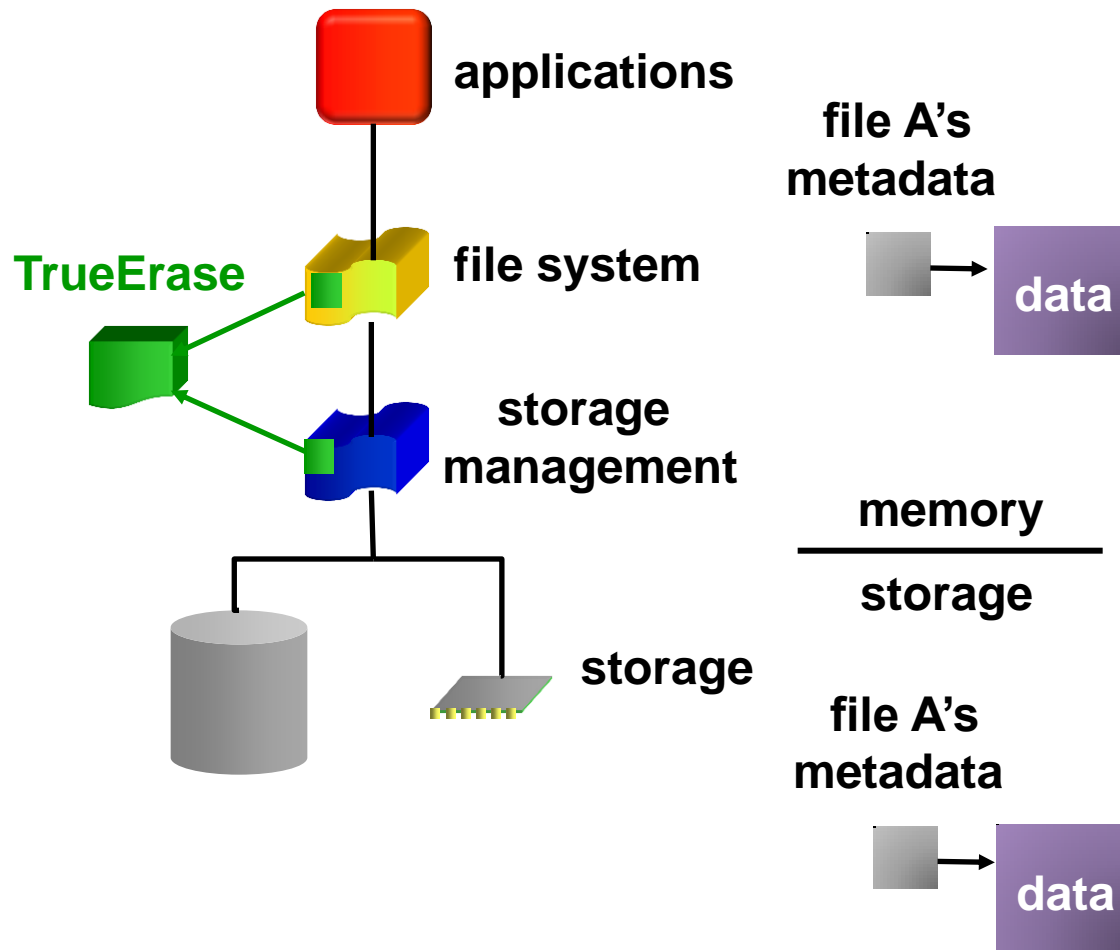storage

data
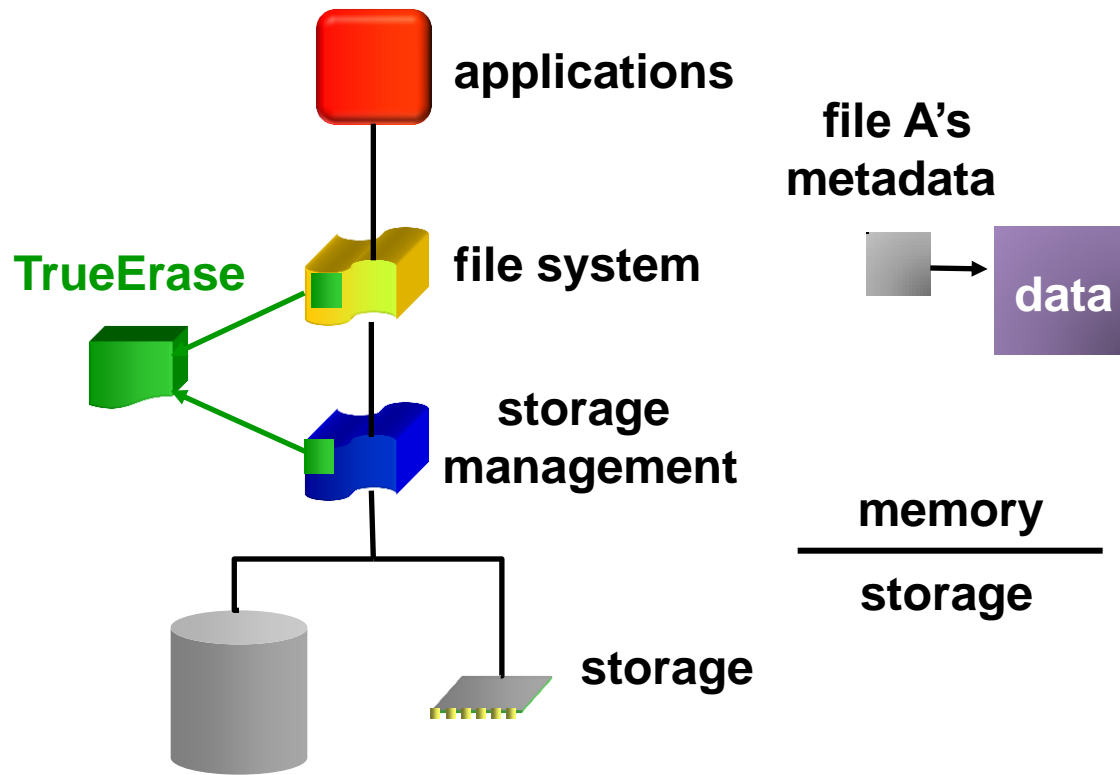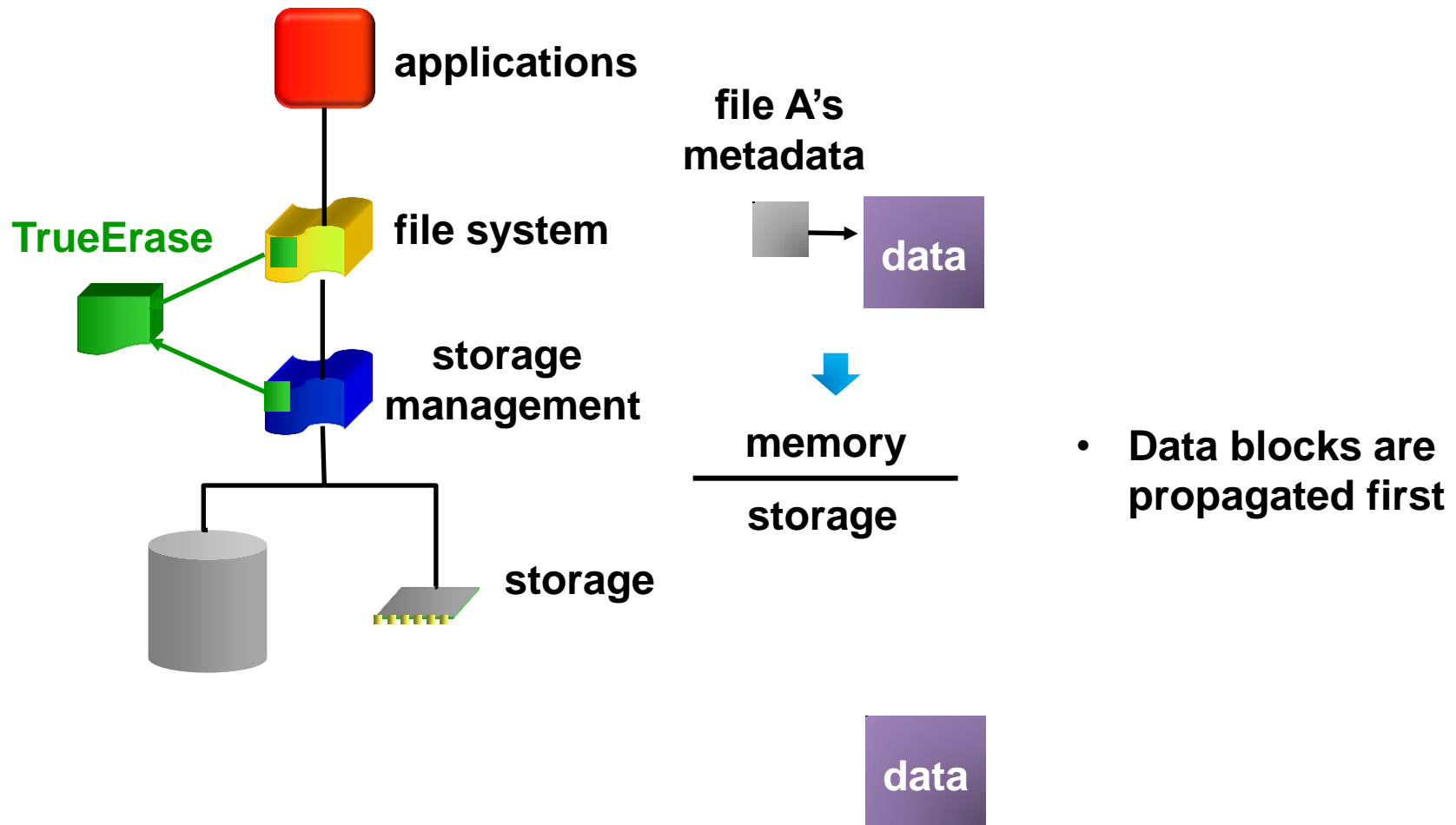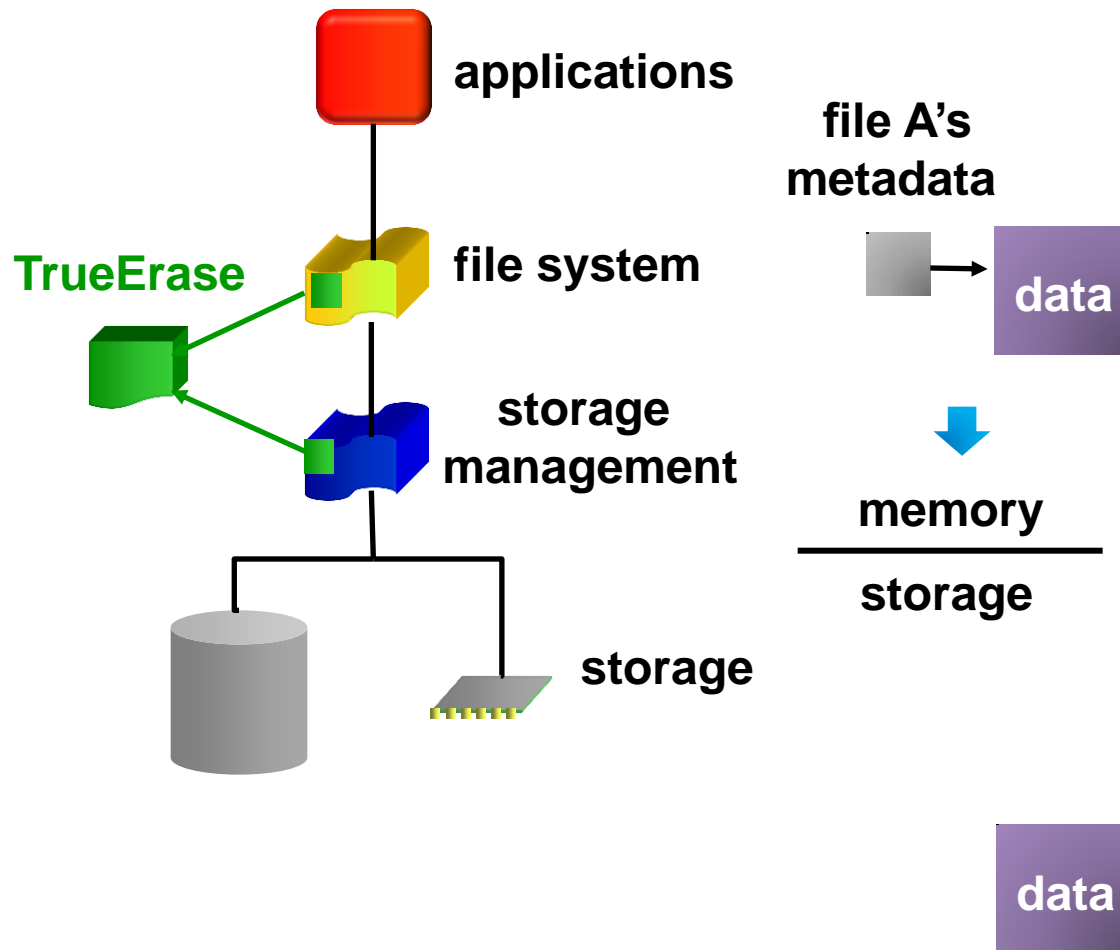
- **May need to perform secure write**

- **Need to handle crash at this point (remove unreferenced sensitive blocks at recovery time)**

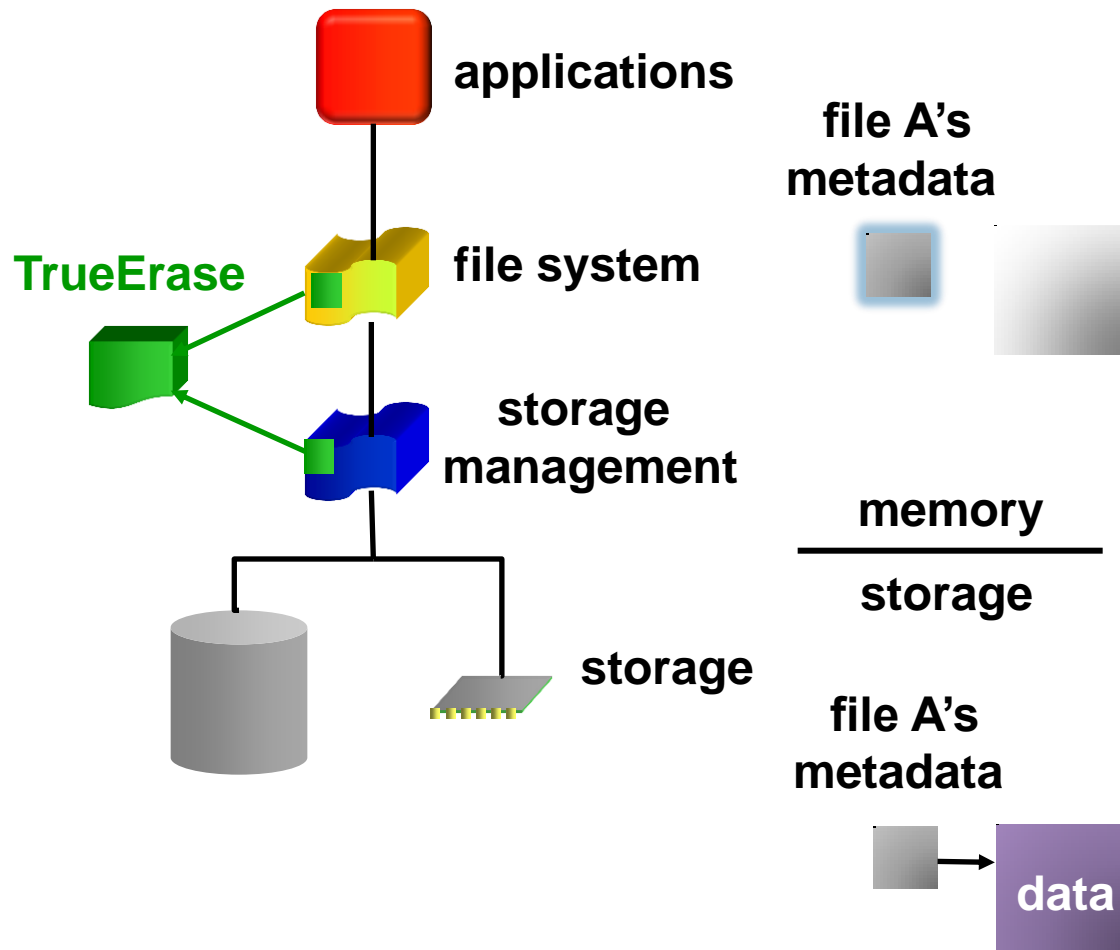- **Need to ensure persistence (e.g., disabling storage-built-in caches)**
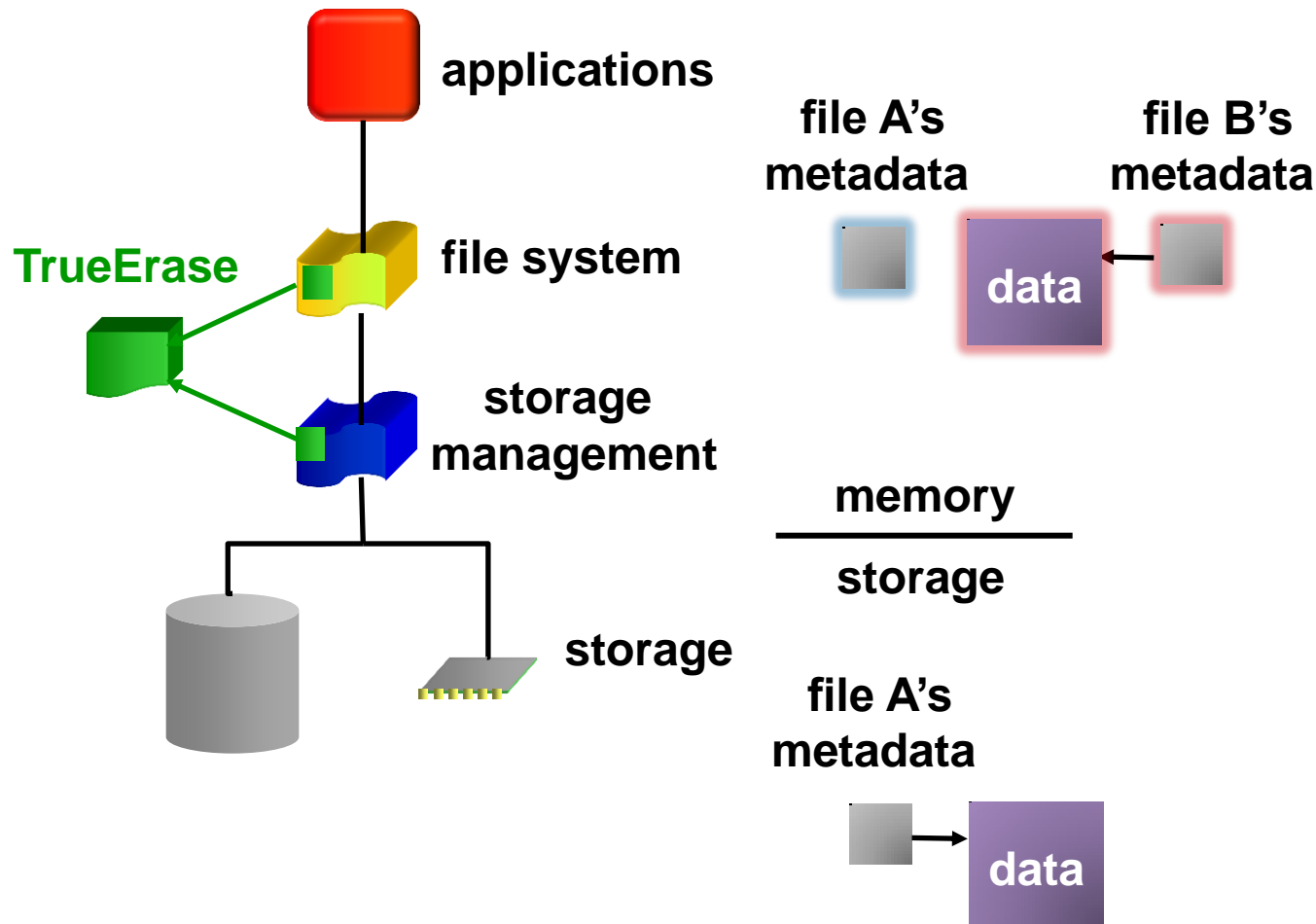
58

Pointer-ordering Property

applications

file A's metadata

TrueErase

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file A's metadata

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Without Reuse-ordering Property

applications

file A's metadata

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Without Reuse-ordering Property

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- **Secure deletion of A can end up deleting B's block**

Reuse-ordering Property

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Reuse-ordering Property

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TrueErase

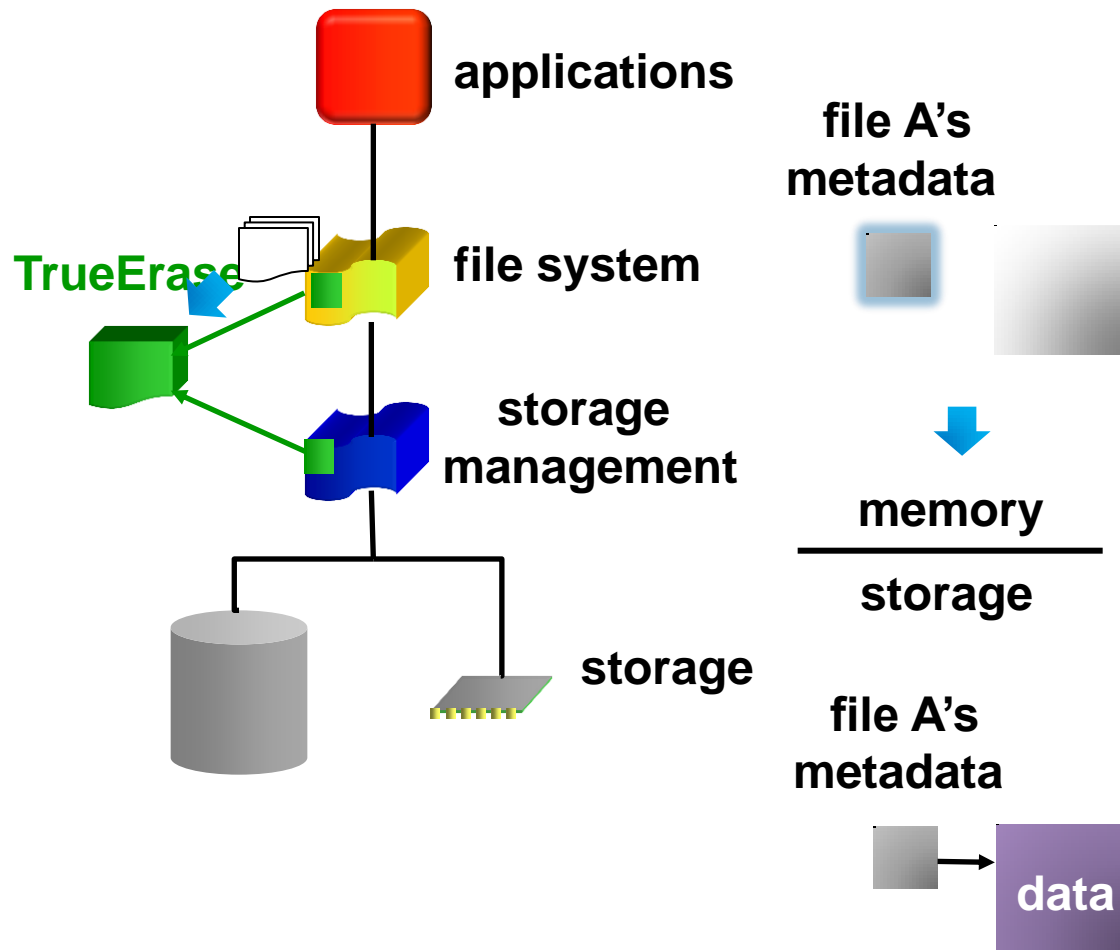storage management

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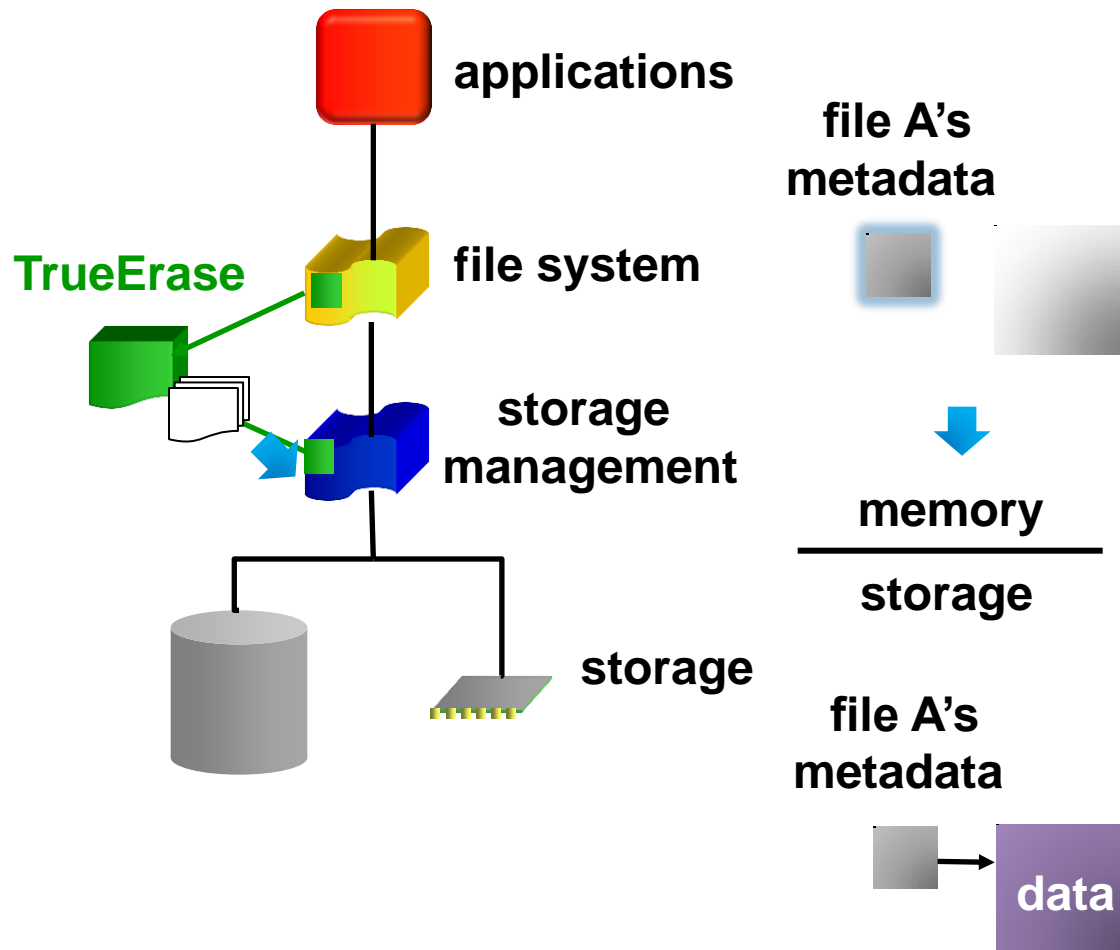
storage

file A's metadata

data

- A block cannot be reused until its free status is persistent

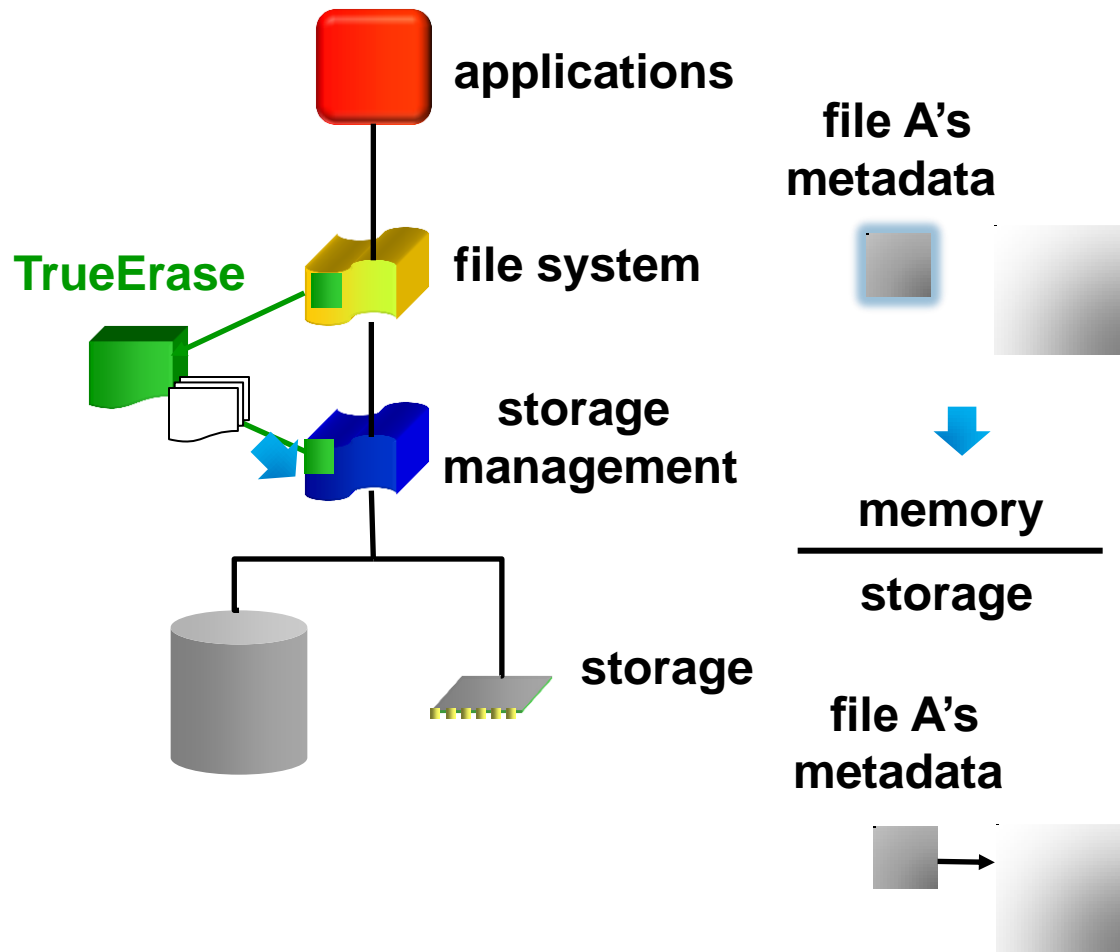# Reuse-ordering Property

- **Pending updates to the unreferenced data block should not be written**

- **Unreferenced in-memory data blocks need to be wiped**

Reuse-ordering Property

applications

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file system

storage management

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file A's metadata

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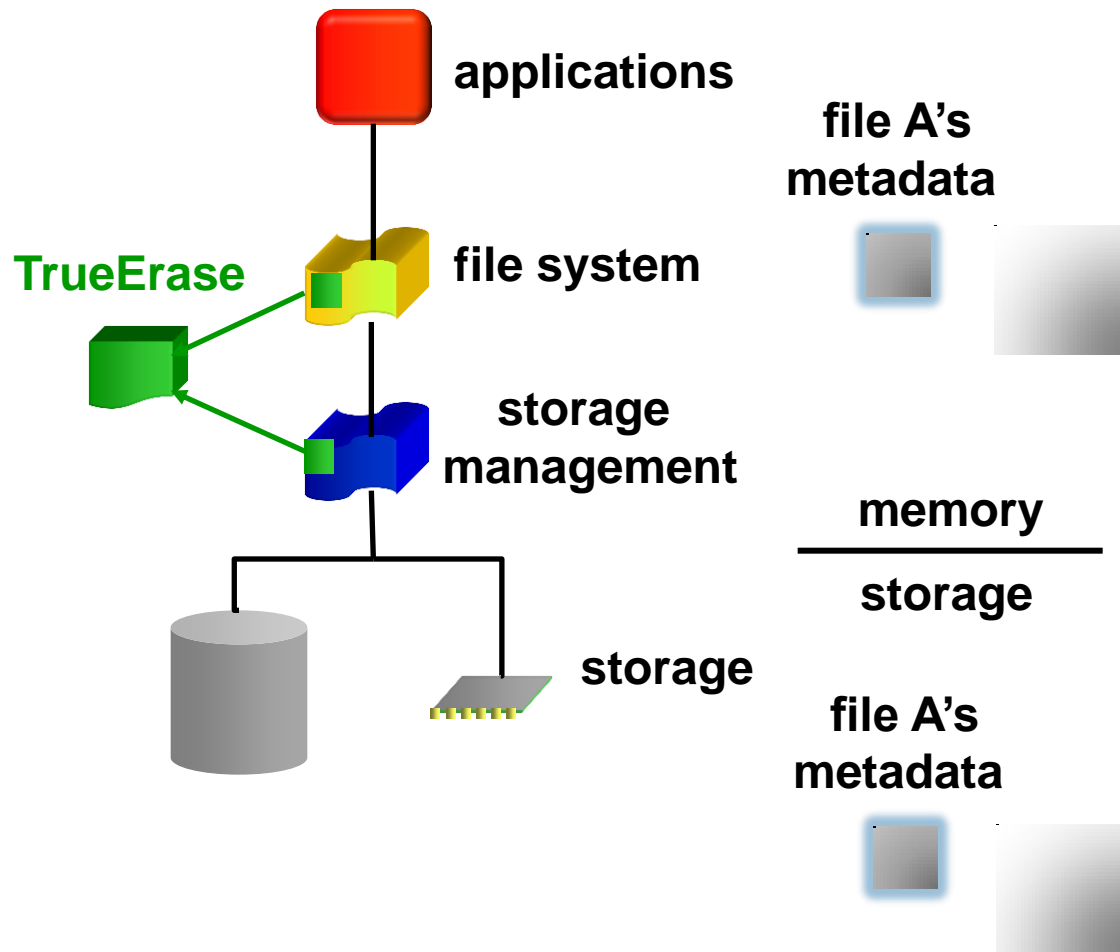
file A's metadata

data

- **By pointer ordering, all prior data updates are flushed**

- **Secure delete the data block before making its free status persistent**

Reuse-ordering Property

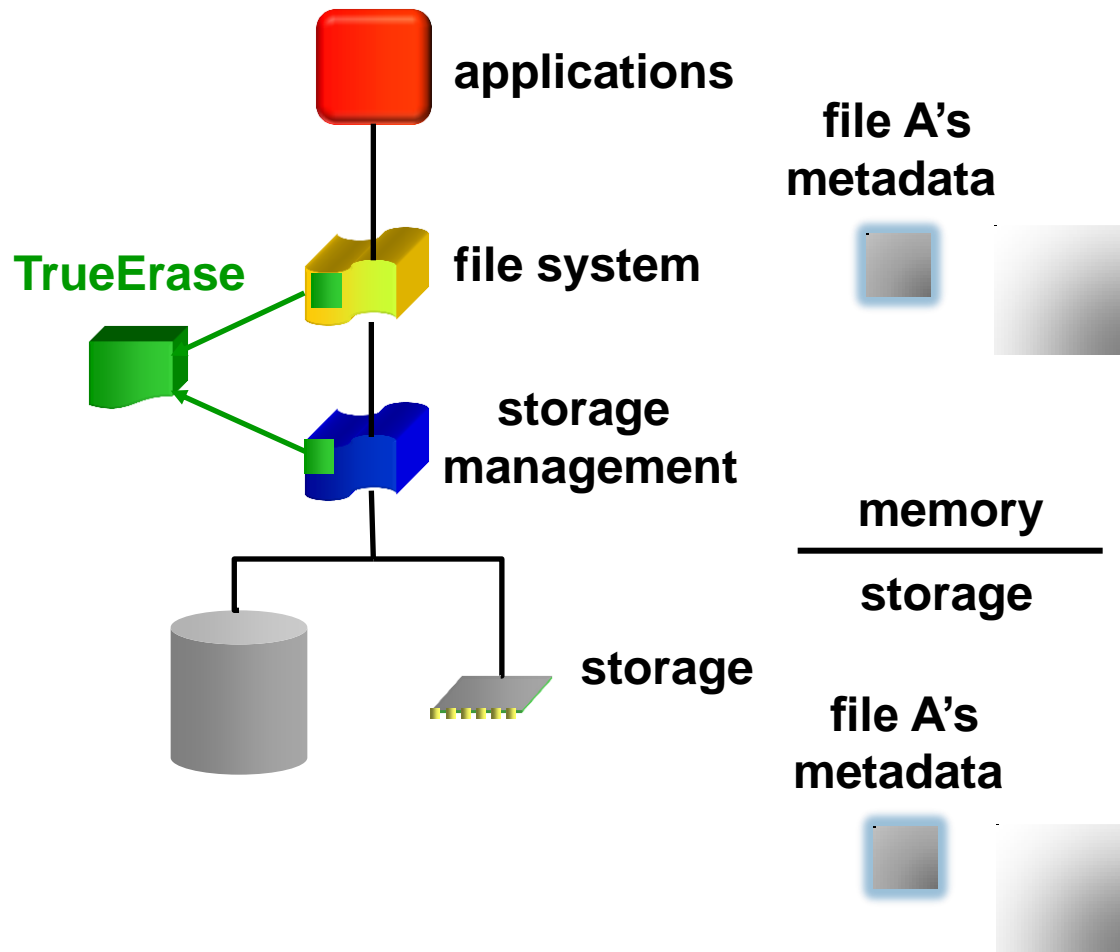

- **A crash will show secure deletion in progress**

- **Recovery mechanism will reissue file deletion**

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Reuse-ordering Property

applications

file A's metadata

TrueErase

file system

storage management

memory

storage

storage

file A's metadata

• **Need to ensure persistence (e.g., disabling storage-built-in caches)**

Reuse-ordering Property

applications

file A's metadata

TrueErase — file system

storage management

memory
storage

file A's metadata

storage

- **Static file types and ownerships for in-transit blocks**

- **Still need GUIDs to track versions**

- **Need to handle dynamic sensitive mode changes (once marked sensitive, always sensitive)**

Reuse-ordering Property

applications

TrueErase

file system

storage management

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file A's metadata

file B's metadata

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file A's metadata
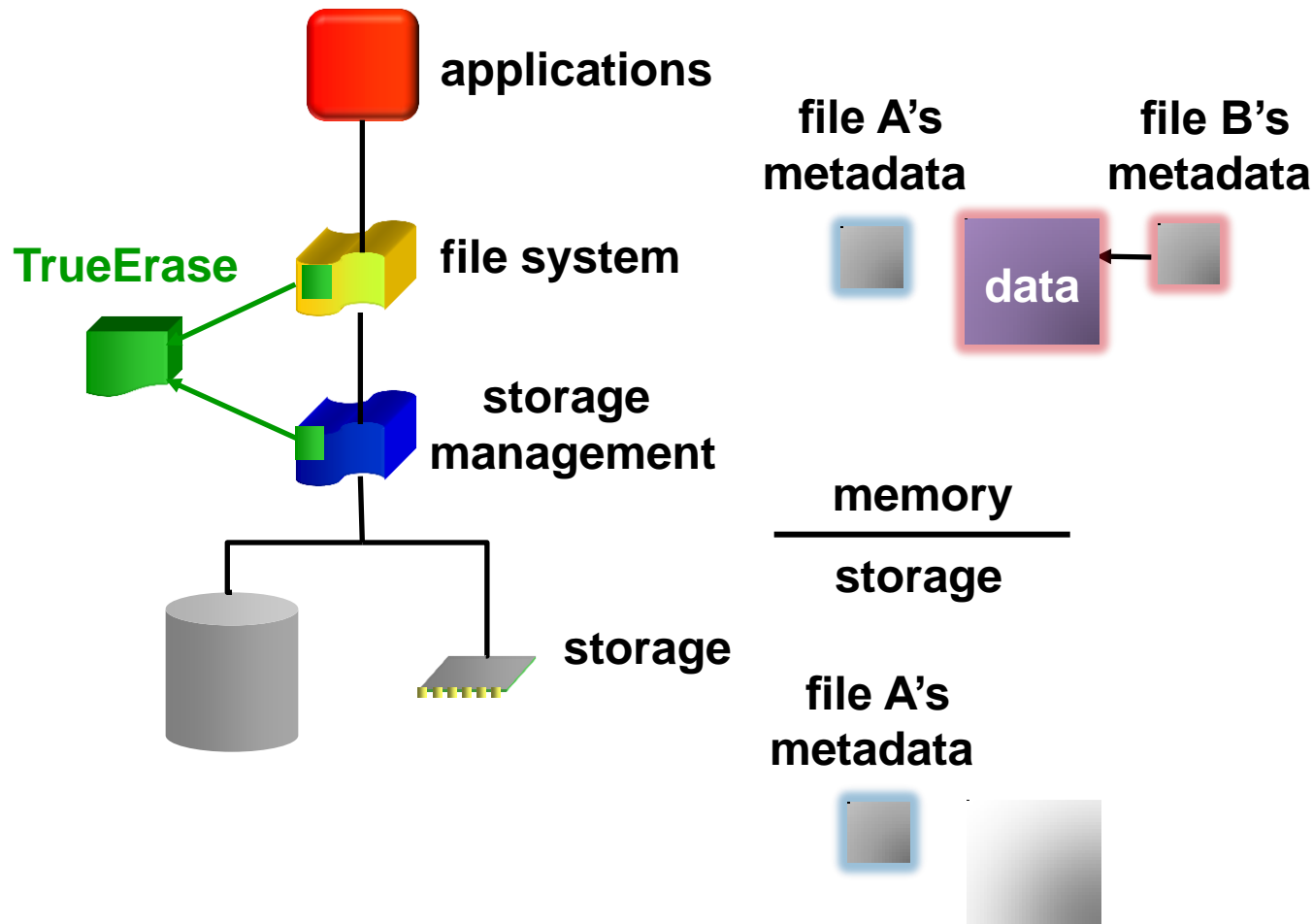
Non-rollback Property

- Older versions of updates will not overwrite newer versions persistently

- Implications

  - An update followed by a secure deletion will be applied in the right order

  - Need to disable some optimizations at the storage-management layer (e.g., built-in cache)

  - Merging/splitting requests okay (we track sectors)

  - A consolidated update is sensitive, if one is sensitive

Structure of Corner Cases

- Ensuring that a secure deletion occurs before a block is persistently declared free

- Hunting down the persistent sensitive blocks left behind after a crash

- Making sure that secure deletion is not applied to the wrong file

- Making sure that a securely deleted block is not overwritten by a buffered unref block

- Handling versions of requests in transit

Crash Handling

- ## At recovery time
  - Replay journal and reissue incomplete deletion operations, with all operations handled securely
  - For flash, securely delete the journal and sensitive blocks not referenced by the file system
  - For disk, securely overwrite journal and all free space

TrueErase Implementation

- Linux 2.6.25

- File system: ext3 with its jbd journaling layer
  - Proven to adhere to the file-system-consistency properties [SIVA05]

- NAND flash: SanDisk's DiskOnChip
  - Lack of access to flash development environ.
  - Dated hardware, but the same design principle

- Storage-management layer: Inverse NAND File Translation Layer (INFTL)

Implementation-level Highlights

- Steps in deletion sequence can be expressed in secure write/delete data/metadata

- Exploited group-commit semantics

    - Reduced the number of secure operations

- Handled buffer/journal copies

- Handled consolidation within and across journal transactions

Verification

- **Basic cases**
  - Sanity checks
  - PostMark with 20% sensitive files
  - Reporting of all updates
  - File-system-consistency-based corner cases
- **TAP state-space verification**

TAP State-space Verification

- **State-space enumeration**
  - Tracked down ~10K unique reachable states, ~2.7M state transitions
  - Reached depth of 16 in the state-space tree
- **Used two-version programming for verification**
  - One based on conceptual rules
  - One based on the TAP kernel module
  - Identified 4 incorrect rules and 3 bugs

Empirical Evaluation

- Workloads
  - PostMark
    - Modified with up to 10% of sensitive files
      - Sensitive files can be chosen randomly
    - Each file operation takes < 0.17 seconds
      - Good enough for interactive use
  - OpenSSH `make +` sync with 27% of files that are newly created marked sensitive
    - Overhead within a factor of two

Related Work

- TRIM command
- FADED
- Type-safe disk
- Modified YAFFS with secure-deletion support

- TrueErase
  - Legacy-compatible, persistent-state-light, centralized info-propagation channel

Lessons Learned

- Retrofitting security features is more complex than we thought

- The general lack of raw flash access and development environments
  - Vendors try to hide complexities
  - File-system consistency and secure deletion rely on exposed controls/details for data layout/removal

Lessons Learned

- A holistic solution would not be possible
  - Without expertise across layers and research fields

- Highlights the importance of knowledge integration

Conclusion

- We have presented the design, implementation, evaluation, and verification of TrueErase

    - Legacy-compatible, per-file, secure-deletion framework

- A secure-deletion solution that can withstand diverse threats remains elusive

    - TrueErase is a promising step toward this goal

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Questions?

- Google keyword: TrueErase

Thank you for your attention!