Tivoli Storage, IBM Software Group

Data Deduplication and Tivoli Storage Manager

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- This presentation uses the following designations regarding availability of potential product enhancements
  - Planned 5.5: Planned for delivery in TSM v5.5 (2007)
  - Next Release Candidate: Candidate for delivery in the next release after v5.5
  - Future Candidate: Candidate for delivery in future release

Topics

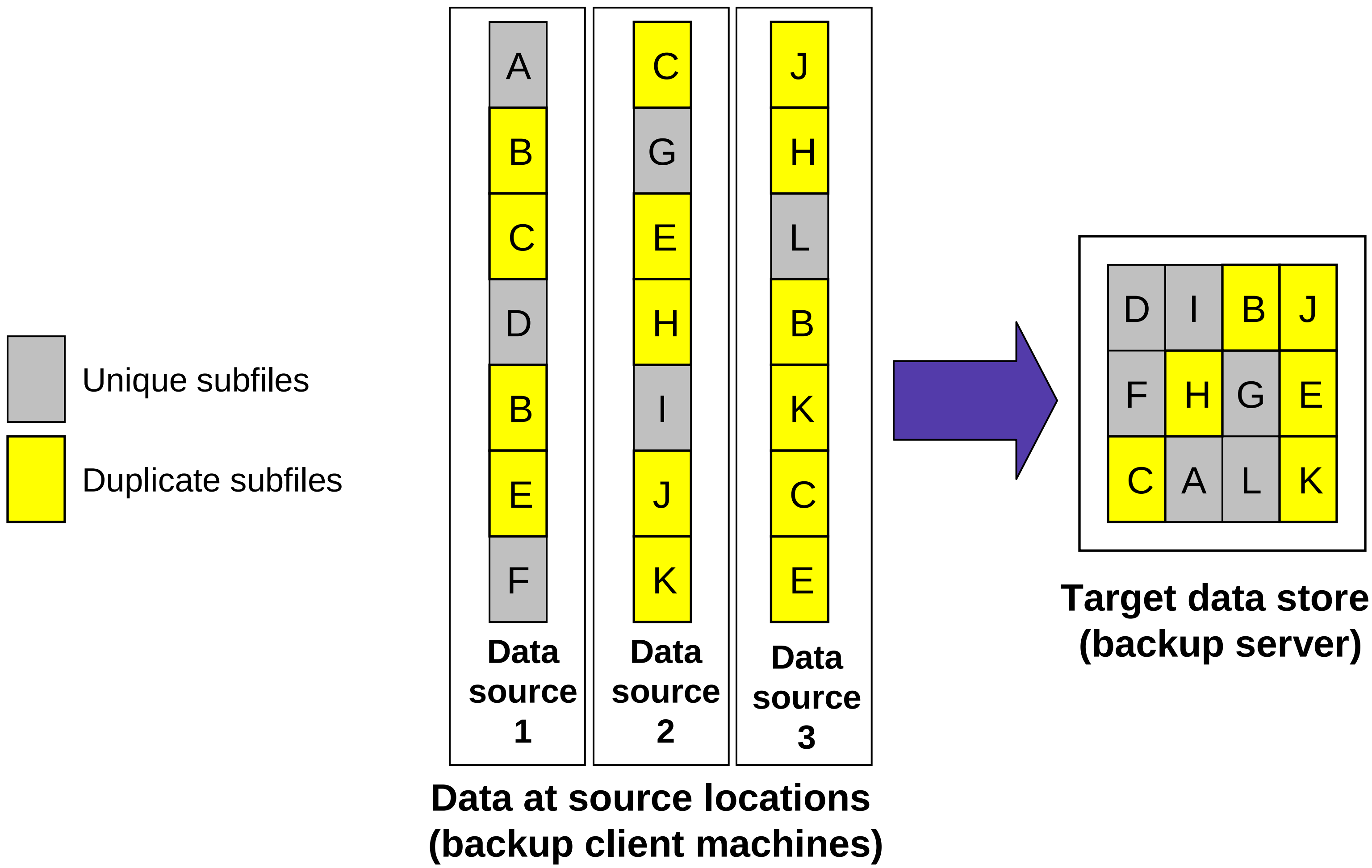
- ➢ Deduplication technology
- Data reduction and deduplication in TSM

Data Reduction Methods

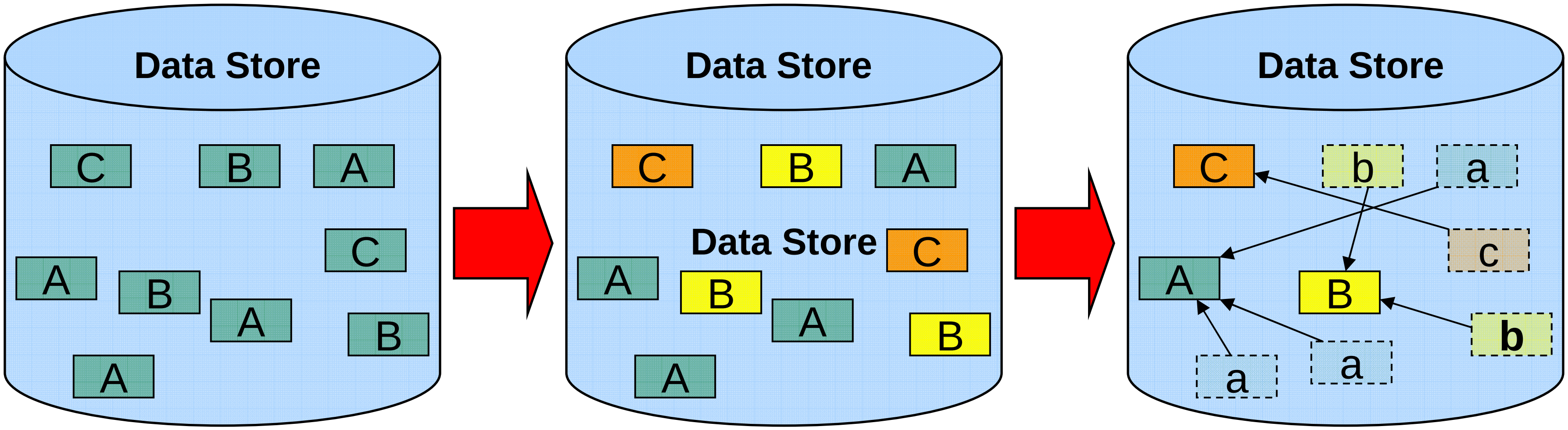
Compression	▪ Encoding of data to reduce size ▪ Typically localized, such as to a single file, directory tree or storage volume
Single instance store (SIS)	▪ A form of compression, usually applied to a large collection of files in a shared data store ▪ Only one instance of a file is retained in the data store ▪ Duplicate instances of the file reference the stored instance ▪ Also known as redundant file elimination
Data deduplication	▪ A form of compression, usually applied to a large collection of files in a shared data store ▪ In contrast to SIS, deduplication often refers to elimination of redundant subfiles (also known as chunks, blocks, or extents) ▪ Only one instance is stored for each common chunk ▪ Duplicate instances of the chunk reference the stored instance

This terminology is not used consistently throughout the industry.
In particular, the terms SIS and deduplication are sometimes used interchangeably.

Deduplication Concept



How Deduplication Works



1. Data chunks are evaluated to determine a unique signature for each

2. Signature values are compared to identify all duplicates

3. Duplicate data chunks are replaced with pointers to a single stored chunk, saving storage space

Data Deduplication Value Proposition

Potential advantages

- Reduced storage capacity required for a given amount of data
- Ability to store significantly more data on given amount of disk
- Restore from disk rather than tape may improve ability to meet recovery time objective (RTO)
- Network bandwidth savings (some implementations)
- Lower storage-management cost resulting from reduced storage resource requirements

Potential tradeoffs/limitations

- Significant CPU and I/O resources required for deduplication processing
- Deduplication might not be compatible with encryption
- Increased sensitivity to media failure because many files could be affected by loss of common chunk
- Deduplication may not be suitable for data on tape because increased fragmentation of data could greatly increase access time

Deduplication Design Considerations

- Source-side vs. target-side
- In-band vs. out-of-band
- Method used for data chunking
- How redundant chunks are identified
- Avoiding false matches
- How redundant chunks are eliminated and tracked

Where Deduplication is Performed

Approach	Advantages	Disadvantages
Source-side (client-side) Deduplication performed at the data source (e.g., by a backup client), before transfer to target location	▪ Deduplication before transmission conserves network bandwidth ▪ Awareness of data usage and format may allow more effective data reduction ▪ Processing at the source may facilitate scale-out	▪ Deduplication consumes CPU cycles on the file/ application server ▪ Requires software deployment at source (and possibly target) endpoints ▪ Depending on design, may be subject to security attack via spoofing
Target-side (server-side) Deduplication performed at the target (e.g., by backup software or storage appliance)	▪No deployment of client software at endpoints ▪Possible use of direct comparison to confirm duplicates	▪ Deduplication consumes CPU cycles on the target server or storage device ▪ Data may be discarded after being transmitted to the target

Note: Source-side and target-side deduplication are not mutually exclusive

When Deduplication is Performed

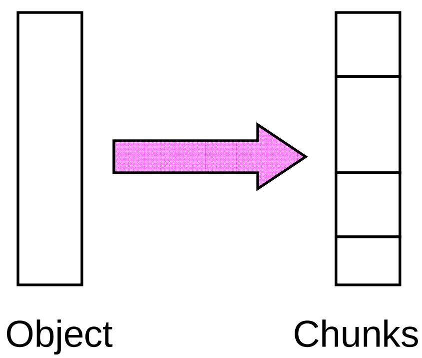
Approach	Advantages	Disadvantages
In-band Deduplication performed during data processing on the source or target	▪Immediate data reduction, minimizing disk storage requirement ▪No post-processing	▪May be bottleneck for data ingestion (e.g., longer backup times) ▪Only one deduplication process for each I/O stream ▪No deduplication of legacy data on the target server
Out-of-band Deduplication performed after data ingestion at the target	▪No impact to data ingestion ▪Potential for deduplication of legacy data ▪Possibility for parallel data deduplication processing	▪Data must be processed twice (during ingestion and subsequent deduplication) ▪Storage needed to retain data until deduplication occurs

Note: In-band and out-of-band deduplication are not mutually exclusive

Generalized Deduplication Processing

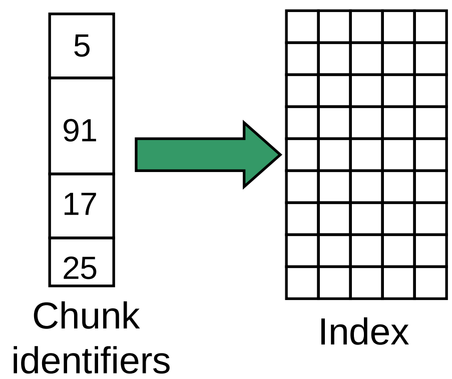
1. Chunk the object

- Divide object into logical segments called chunks



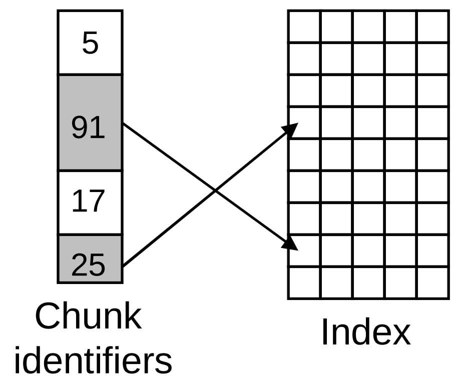
2. Identify duplicate chunks

- Hash each chunk to produce unique identifier
- Compare each chunk identifier with index to determine whether chunk is already stored

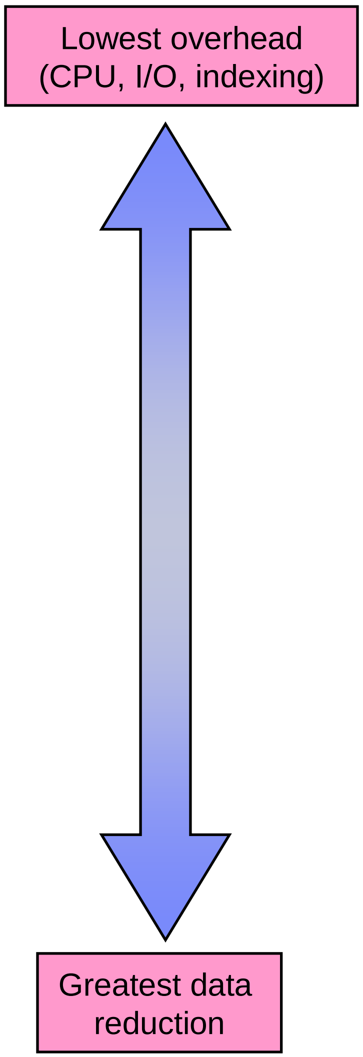


3. Eliminate redundant chunks

- Update index to reference matching chunks
- Deallocate space for redundant chunks



Data Chunking Methods



Whole file chunking

- Each file is treated as a single chunk
- No detection of duplicate data at subfile level

Fixed-size chunking

- Chunk boundaries occur at fixed intervals, irrespective of data content
- Method is unable to detect duplicate data if there is an offset difference
  - Because redundant data has shifted due to insertion/deletion
  - Because redundant data is embedded within another file or contained in a composite structure

Variable-size chunking

- Rolling hash algorithm is used to determine chunk boundaries to achieve an expected average chunk size
- Can detect redundant data, irrespective of offset differences
- Often referred to as fingerprinting (e.g., Rabin fingerprinting)

Format-aware chunking

- In setting chunk boundaries, algorithm considers data format/structure
- Examples: awareness of backup stream formatting; awareness of PowerPoint slide boundaries; awareness of file boundaries within a composite

Identification of Redundant Chunks

- Unique identifier is determined for each chunk
- Identifiers are typically calculated using a hash function that outputs a digest based on the data in each chunk
  - MD5 (message-digest algorithm)
  - SHA (secure hash algorithm)
- For each chunk, the identifier is compared against an index of identifiers to determine whether that chunk is already in the data store
- Selection of hash function involves tradeoffs between
  - Processing time to compute hash values
  - Index space required to store hash values
  - Risk of false matches

False Matches

- Possibility exists that two different data chunks could hash to the same identifier (such an event is called a collision)
- Should a collision occur, the chunks could be falsely matched and data loss could result
- Collision probability can be calculated from the possible number of unique identifiers and the number of chunks in the data store
  - Longer digest ➔ More unique identifiers ➔ Lower probability of collisions
  - More chunks ➔ Higher probability of collisions
- Approaches to avoiding data loss due to collisions
  - Use a hash function that produces a long digest to increase the possible number of unique identifiers
  - Combine values from multiple hash functions
  - Combine hash value with other information about the chunk
  - Perform byte-wise comparison of chunks in the data store to confirm matches

Hash Functions

Hash functions take a message of arbitrary length as input and output a fixed length digest of L bits. They are published algorithms, normally standardized as RFC.

Name	Output size L (bits)	Performance (cycles/byte) Intel Xeon: C / assembly*	Collision chance 50% (or greater) when these many chunks (or more) are generated **	Chance of one collision in a 40 PB archive*** (using 4KB / chunk)	Year of the standard
MD5	128	9.4 / 3.7	$2^{64} \approx 10^{20}$	$0.5*10^{-20}$	1992
SHA-1	160	25 / 8.3	$2^{80} \approx 10^{24}$	$0.5*10^{-28}$	1995
SHA-256	256	39 / 20.6	$2^{128} \approx 10^{40}$	$0.5*10^{-60}$	2002
SHA-512	512	135 / 40.2	$2^{256} \approx 10^{80}$	$0.5*10^{-140}$	2002
Whirlpool	512	112 / 36.5	$2^{256} \approx 10^{80}$	$0.5*10^{-140}$	2003

* "Performance analysis and parallel implementation of dedicated hash functions", Proc. of EUROCRYPT 2002, pp 165-180, 2002.

** The probability of one collision out of k chunks is $p \approx 1-e^{-(k^2)/2*N}$, where $N=2^L$; when p=0.5, we get $k \approx N^{1/2} = 2^{L/2}$ (from birthday paradox).

*** The probability of one hard-drive bit-error is about 10^{-14} .

Probability of collision is extremely low and can be reduced at the expense of performance by using hash function that produces longer digest

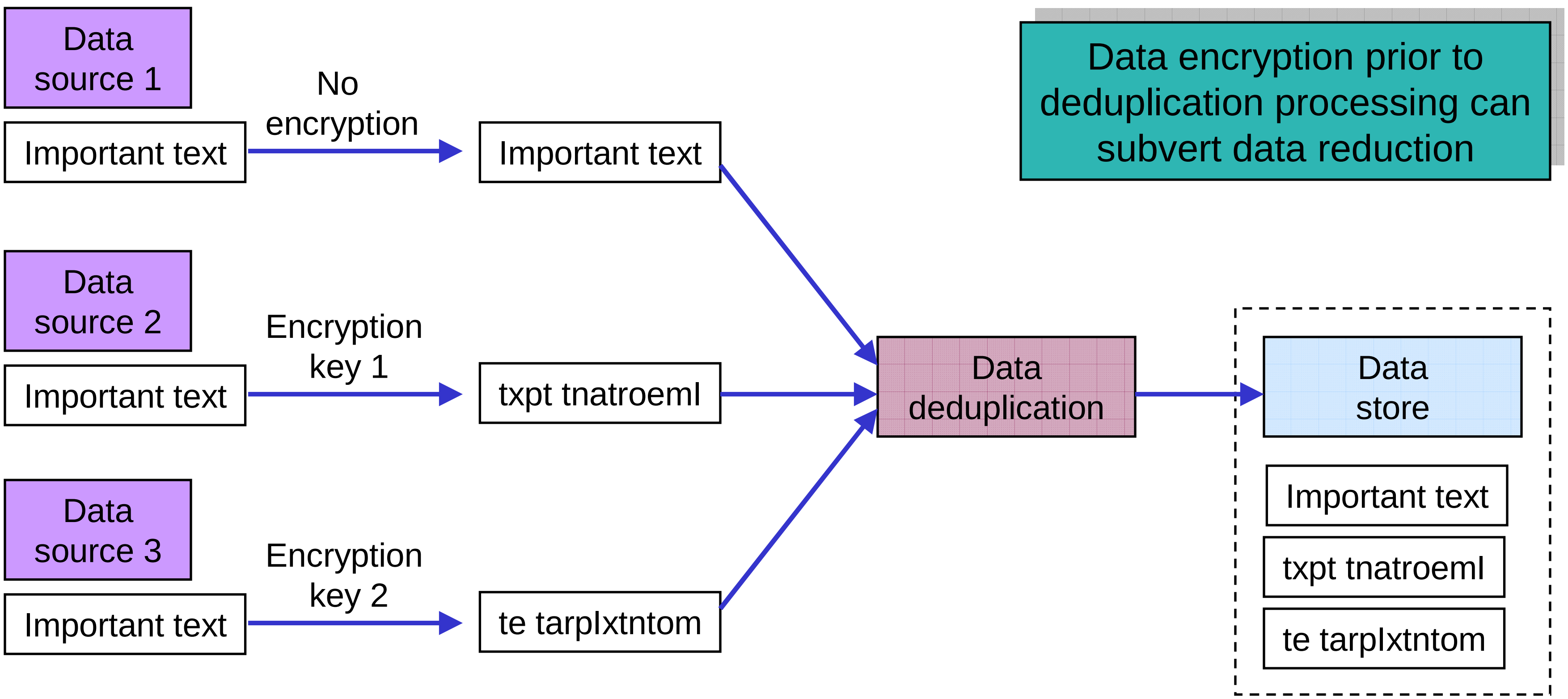
Elimination of Redundant Chunks

- For each redundant chunk, the index is updated to reference the matching chunk
- Index is updated with metadata indicating how to reconstruct the object from chunks, some of which may be shared with other objects
- Any space occupied by the redundant chunks can be deallocated and reused
- Deduplication index is critical
  - Integrity
  - Performance
  - Scalability
  - Protection

Deduplication Ratios

- Used to indicate compression achieved by deduplication
- If deduplication reduces 500 TB of data to 100 TB, ratio is 5:1
- Deduplication vendors claim ratios in the range 20:1 to 500:1
- Ratios reflect design tradeoffs involving performance and compression
- Actual compression ratios will be highly dependent on other variables
  - Data from each source: redundancy, change rate, retention
  - Number of data sources and redundancy of data among those sources
  - Backup methodology: incremental forever, full+incremental, full+differential
  - Whether data encryption occurs prior to deduplication
- Beware of hype

Deduplication and Encryption



1. Three data sources have the same text file

2. After encryption, text files do not match

3. Deduplication processing does not detect redundancy

4. Text files are stored without data reduction

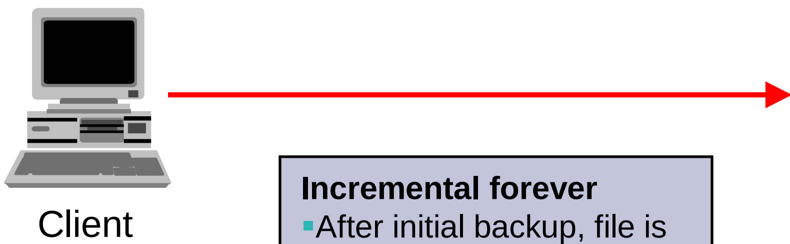
Topics

- Deduplication technology

- Data reduction and deduplication in TSM

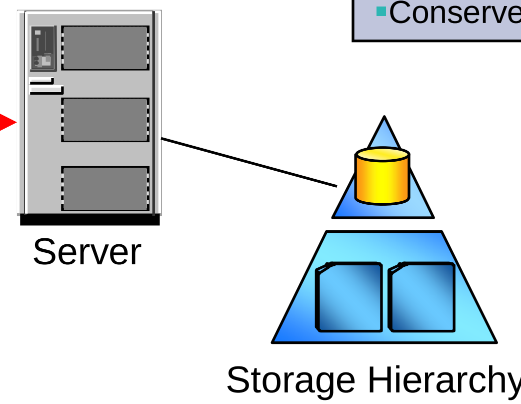
Data Reduction with TSM Today

Client compression
- Files compressed by client before transmission
- Conserves network bandwidth and server storage



Subfile backup
- Only changed portions of files are transmitted
- Conserves network bandwidth and server storage

Incremental forever
- After initial backup, file is not backed up again unless it changes
- Conserves network bandwidth and server storage



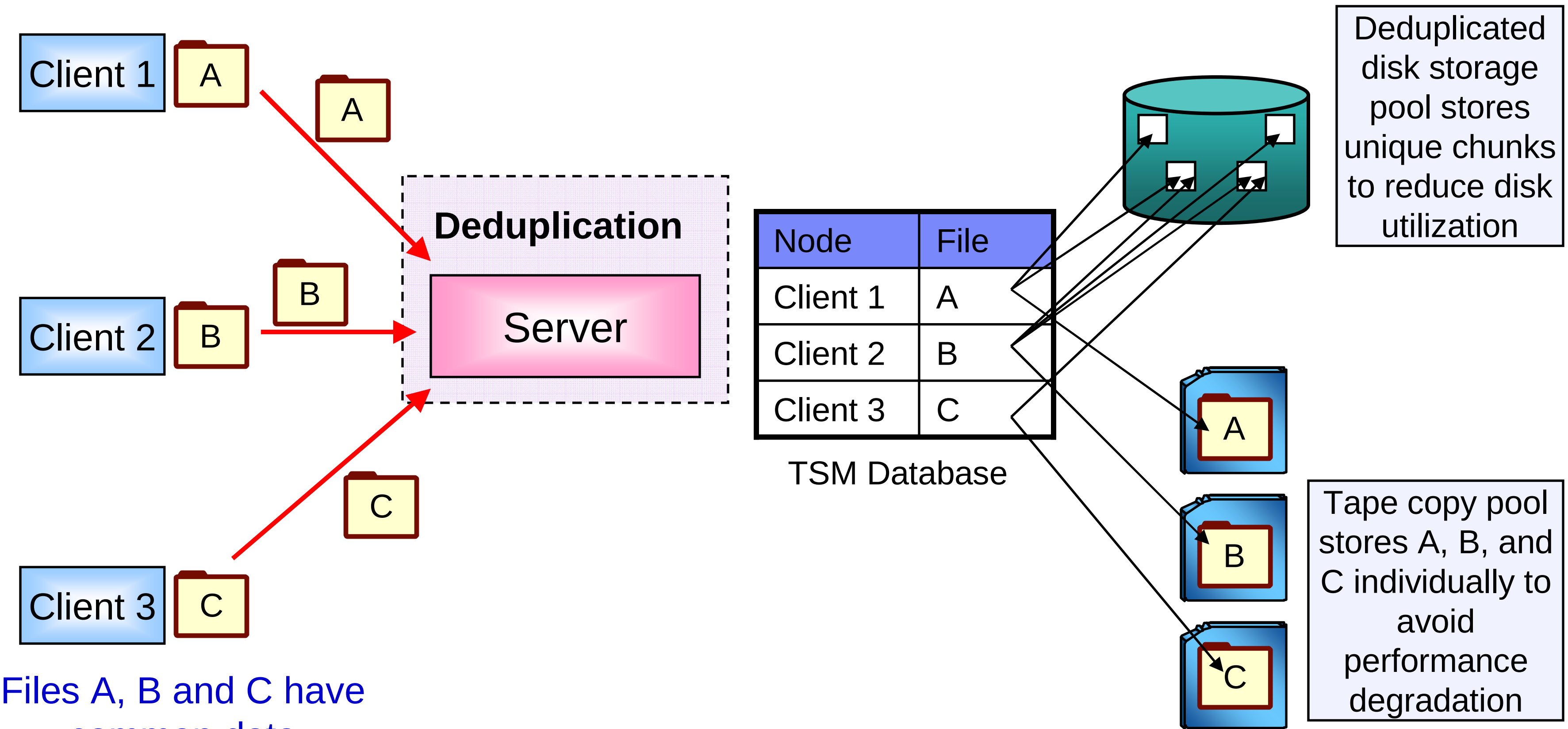
Device compression
- Compression performed by storage hardware
- Conserves server storage

Appliance deduplication
- Deduplication performed by storage appliance (VTL or NAS)
- Conserves server storage

Native Data Deduplication in TSM

- TSM's incremental forever methodology greatly reduces data redundancy as compared to traditional methodologies based on periodic full backups
- Consequently, there is less potential for data reduction via deduplication in TSM as compared to other backup products
- Nevertheless, deduplication is an important function to TSM because it will allow more data objects to be stored on a given amount of disk for fast access
- Native deduplication is a key product enhancement in TSM

TSM Deduplication Overview



Files A, B and C have common data

Allows more objects to be stored on disk for fast access

Next Release Candidate

Design Points for Initial TSM Deduplication Solution

Design point	Comments
Server-side	▪Avoids need for deployment of client software ▪Effective for all types of stored data
Out-of-band	▪Allows deduplication of legacy data in addition to new data ▪Minimizes impact to backup windows ▪Concurrent processing to identify duplicate data
Index maintained in TSM server database (DB2)	Transactional integrity, scalability, performance, disaster protection
Variable-size chunking	▪Rabin fingerprinting with awareness of TSM data format
SHA-generated identifiers for detection of duplicate chunks	▪Probably SHA-1 or SHA-256 ▪Longer identifiers of SHA-256 would reduce collision probability, at the expense of increased processing and database space usage
Average chunk size to be determined	▪ Larger chunks require less database overhead ▪ Larger chunks reduce the total number of chunks required for given amount of data and therefore reduce collision probability ▪ Smaller chunks improve compression
Space occupied by redundant chunks will be recovered during reclamation	▪ Allows coordinated recovery of space occupied by deleted objects and redundant chunks

Expected Deduplication Behavior

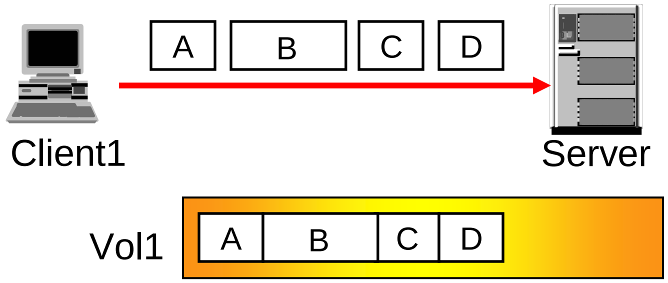
- Disk storage requirement reduced via optional data deduplication for FILE storage pools
- Deduplication processing performed on TSM server and tracked in database
- Reduced redundancy for
  - Identical objects from same or different client nodes (even if names are different)
  - Common data chunks (subfiles, extents) in objects from same or different nodes
- Post-ingestion (out-of-band) detection of duplicate data on TSM server to minimize impact to backup windows
- Space occupied by duplicate data will be removed during reclamation processing
- Allowed for all data types: backup, archive, HSM, TDP, API applications
- Transparent client access to deduplicated objects

Expected Deduplication Behavior

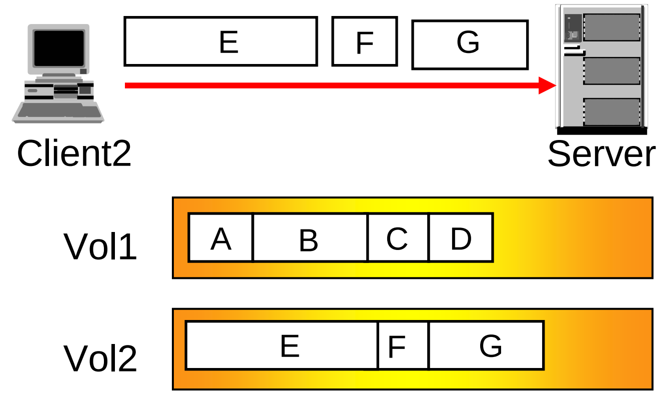
- Deployment of new clients or API applications not required
- Legacy data stored in or moved to enabled FILE storage pools can be deduplicated
- Data migrated or copied to tape will be reduplicated to avoid excessive mounting and positioning during subsequent access
- Ability to control number, duration and scheduling of CPU-intensive background processes for identification of duplicate data
- Reporting of space savings in deduplicated storage pools
- Deduplication will not be effective for client-encrypted data, but should work with storage-device encryption
- Native TSM implementation, with no dependency on specific hardware

Deduplication Example

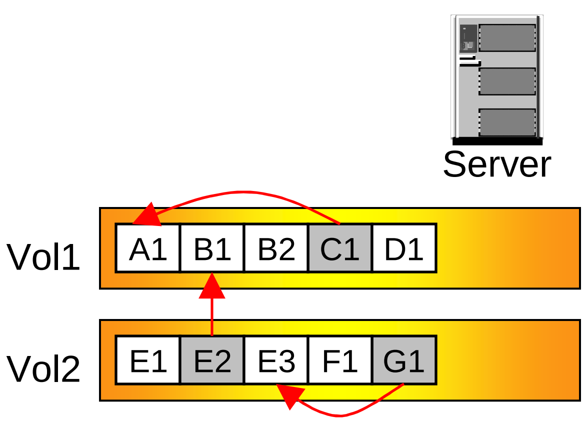
1. Client1 backs up files A, B, C and D. Files A and C have different names, but the same data.



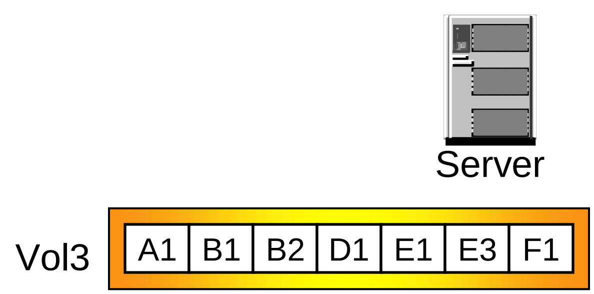
2. Client2 backs up files E, F and G. File E has data in common with files B and G.



3. Server process "chunks" the data and identifies duplicate chunks C1, E2 and G1.



4. Reclamation processing recovers space occupied by duplicate chunks.



Comparison of TSM Data Reduction Methods

	Client compression	Incremental forever	Subfile backup	Deduplication
How data reduction is achieved	Client compresses files	Client only sends changed files	Client only sends changed subfiles	Server eliminates redundant data chunks
Conserves storage pool space?	Yes	Yes	Yes	Yes
Conserves network bandwidth?	Yes	Yes	Yes	No
Data supported	Backup, archive, HSM, API	Backup	Backup (Windows only)	Backup, archive, HSM, API
Scope of data reduction	Redundant data within same file on client node	Files that do not change between backups	Subfiles that do not change between backups	Redundant data from any files in storage pool
Avoids storing identical files renamed, copied, or relocated on client node?	No	No	No	Yes
Removes redundant data for files from different client nodes?	No	No	No	Yes

Considerations for Use of TSM Deduplication

- Consider deduplication if
  - Data recovery would improve by storing more data objects on limited amount of disk
  - Data will remain on disk for extended period of time
  - Much redundancy in data stored by TSM (e.g., for common operating-system or project files)
  - TSM server CPU and disk I/O resources are available for intensive processing to identify duplicate chunks

- Deduplication might not be indicated for
  - Mission-critical data, whose recovery could be delayed by accessing chunks that are not stored contiguously
  - TSM servers that do not have sufficient resources

Potential Follow-on Enhancements

- The initial TSM deduplication solution is designed to allow extensibility
- Depending on business priorities, possible future extensions to this solution could include
  - Option to perform inline deduplication during data ingestion (to achieve immediate compression)
  - Client-side deduplication (to distribute processing and conserve network bandwidth)
  - Option to control which hash function is used (tradeoff between performance and probability of false match)
  - Deduplication support for random-access disk or tape storage pools
  - Policies to control deduplication based on node, filespace, file size, or other criteria

Future Candidates

Summary

- Data deduplication can reduce storage requirements, allowing more data to be retained on disk for fast access
- Deduplication involves tradeoffs relating to degree of compression, performance, risk of data loss and compatibility with encryption
- TSM's incremental forever method avoids periodic full backups, reducing the potential for additional data reduction via deduplication
- Server-side deduplication is a key enhancement in TSM