Storage Tradeoffs in a Collaborative Backup Service for Mobile Devices

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Context

The MoSAIC Project

- **3-year project** started in Sept. 2004: IRISA, Eurecom and LAAS-CNRS
- supported by the French national program for Security and Informatics (ACI S&I)

Target

- **communicating mobile devices** (laptops, PDAs, cell phones)
- **mobile ad-hoc networks**, spontaneous, peer-to-peer-like interactions

Dependability Goals

- improving **data availability**
- guarantee **data integrity & confidentiality**

- **Goals and Issues**
  - Fault Tolerance for Mobile Devices
  - Challenges
- Storage Mechanisms
- Preliminary Evaluation of Storage Mechanisms

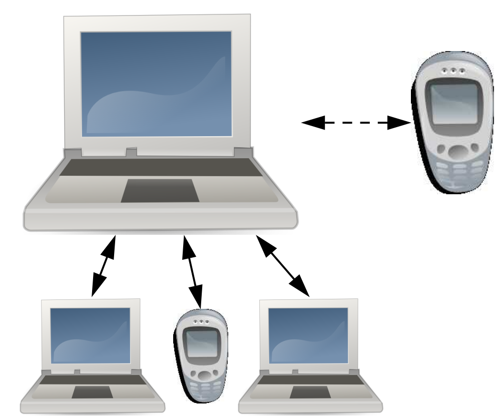
Fault Tolerance for Mobile Devices

Costly and Complex Backup

- only **intermittent access** to one's desktop machine
- potentially **costly communications** (e.g., GPRS, UMTS)

Our Approach: *Cooperative* Backup (illustrated)

- leverage encounters, **opportunistically**
- high **throughput**, low **energetic cost** (Wifi, Bluetooth, etc.)
- leverage **excess resources**
- variety of **independent failure modes**
- hopefully **self-managed** mechanism



Challenges

Secure Cooperation

- participants have **no *a priori* trust relationship**
- protect against **DoS attacks**: data retention, selfishness, flooding
- ideas from P2P: **reputation** mechanism, **cooperation incentives**, etc.

Trustworthy Data Storage

- ensure data **confidentiality**
- data **integrity**
- data **authenticity**
- more requirements...

- Goals and Issues
- **Storage Mechanisms**
  - Constraints Imposed on the Storage Layer
  - Maximizing Storage Efficiency
  - Chopping Data Into Small Blocks
  - Providing a Suitable Meta-Data Format
  - Providing Data Confidentiality, Integrity, and Authenticity
  - Enforcing Backup Atomicity
  - Replication Using Erasure Codes
- Preliminary Evaluation of Storage Mechanisms

Constraints Imposed on the Storage Layer

Scarce Resources (energy, storage, CPU)

- maximize **storage efficiency**
- but **avoid CPU-intensive techniques** (compression, encryption)

Short-lived and Unpredictable Encounters

- **fragment** data into small blocks & **disseminate** it among contributors
- yet, **retain transactional semantics** of the backup (ACID)

Lack of Trust Among Participants

- **replicate data fragments**
- enforce data **confidentiality**, verify **integrity & authenticity**

Maximizing Storage Efficiency

Single-Instance Storage

- ⇒ **reduce redundancy** across files/file blocks
- ⇒ idea: **store only once** any given datum
- ⇒ used in: peer-to-peer **file sharing**, **version control**, etc.

Generic Lossless Compression

- **well-known benefits** (e.g., *gzip*, *bzip2*, etc.)
- **unclear resource requirements**

Techniques Not Considered

- **differential compression**: CPU- and memory-intensive, weakens data availability
- **lossy compression**: too specific (image, sound, etc.)

Chopping Data Into Small Blocks

Natural Solution: Fixed-Size Blocks

- **simple and efficient**
- similar data streams *might* yield **common blocks**

Finding More Similarities Using Content-Based Chopping

- see Udi Manber, *Finding Similar Files in a Large File System*, USENIX, 1994
- identifies **identical sub-blocks** among different data streams
- to be **coupled with single-instance storage**
- $\Rightarrow$ improves **storage efficiency**? under **what circumstances**?

Providing a Suitable Meta-Data Format

Design Principle: Separation of Concerns

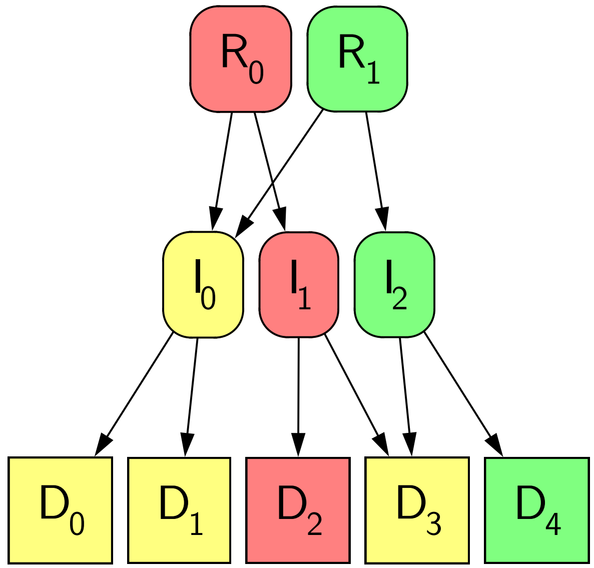
- separate **data** from **meta-data**
- separate **stream meta-data** from **file meta-data**

Indexing Individual Blocks

- avoid block **name clashes**
- block IDs must remain **valid in time and space**

Indexing Sequences of Blocks (illustrated)

- produce a **vector of block IDs**
- recursively **chop it and index it**



Providing Data Confidentiality, Integrity, and Authenticity

Enforcing Confidentiality

- **encrypt** both data & meta-data
- use **energy-economic algorithms** (e.g., symmetric encryption)

Allowing For Integrity Checks

- protect against both **accidental and malicious modifications**
- $\Rightarrow$ store **cryptographic hashes of (meta-)data blocks** (e.g., SHA1, RIPEMD-160)
- $\Rightarrow$ use hashes as a **block naming scheme** (*content-based indexing*)
- $\Rightarrow$ eases implementation of **single-instance storage**

Allowing For Authenticity Checks

- **cryptographically sign** (part of) the meta-data

Enforcing Backup Atomicity

Comparison With Distributed and Mobile File Systems

- backup: only a **single writer and reader**
- thus, **no consistency issues due to parallel accesses**

Using *Write-Once* Semantics

- data is **always appended, not modified**
- previous **versions are kept**
- allows for **atomic insertion of new data**
- used in: peer-to-peer file sharing, version control

Replication Using Erasure Codes

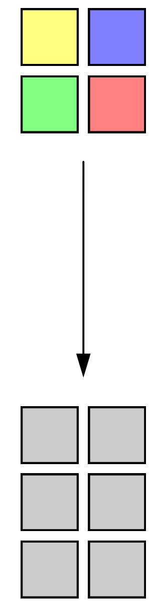
Erasure Codes at a Glance

- b-block message $\longrightarrow b \times S$ coded blocks
- m blocks suffice to recover the message, $b < m < S \times b$
- $S \in \Re$: **stretch factor**, **overhead**
- **failures tolerated**: $S \times b - m$
- $\Rightarrow$ **More storage-efficient** than simple replication

Questions

- Impact on **data availability**?
- Compared to **simple replication**?

b source blocks



$S \times b$ coded blocks

- Goals and Issues
- Storage Mechanisms
- **Preliminary Evaluation of Storage Mechanisms**
  - Our Storage Layer Implementation: `libchop`
  - Experimental Setup
  - Algorithmic Combinations
  - Storage Efficiency & Computational Cost Assessment
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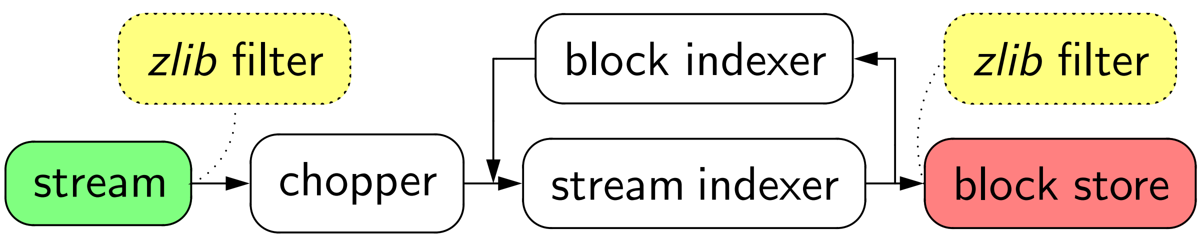
Our Storage Layer Implementation: `libchop`

Key Components

- **chopper**, block & stream **indexers**, **keyed block store**
- provides **several implementations of each component**

Strong Focus on Compression Techniques

- **single-instance storage** (SHA-1-based block indexing)
- **content-based chopping** (Manber's algorithm)
- ***zlib* compression filter** (similar to *gzip*)



Experimental Setup

Measurements

- **storage efficiency**
- **computational cost** (throughput)
- ... for different **combinations of algorithms**

File Sets

- **a single mailbox file** (low entropy)
- **C program, several versions** (low entropy, high redundancy)
- **Ogg Vorbis files** (high entropy, hardly compressable)

Algorithmic Combinations

Config.	Single Instance?	Chopping Algo.	Expected Block Size	Input Zipped?	Blocks Zipped?
A_1	no	—	—	yes	—
A_2	yes	—	—	yes	—
B_1	yes	Manber's	1024 B	no	no
B_2	yes	Manber's	1024 B	no	yes
B_3	yes	fixed-size	1024 B	no	yes
C	yes	fixed-size	1024 B	yes	no

Storage Efficiency & Computational Cost Assessment

Config.	**Summary**	**Resulting Data Size**			**Throughput (MiB/s)**		
		C files	Ogg	mbox	C files	Ogg	mbox
A_1	(without single instance)	26%	100%	55%	21	15	18
A_2	(with single instance)	13%	100%	55%	22	15	17
B_1	Manber	25%	102%	88%	12	6	15
B_2	Manber + zipped blocks	**11%**	103%	**58%**	**7**	5	**10**
B_3	fixed-size + zipped blocks	18%	103%	71%	11	5	18
C	fixed-size + zipped input	**13%**	102%	**57%**	**22**	5	**21**

Storage Efficiency & Computational Cost Assessment

Single-Instance Storage

- mostly beneficial in the **multiple version case** (50% improvement)
- computationally **inexpensive**

Content-Defined Blocks (Manber)

- mostly beneficial in the **multiple version case**
- **computationally costly**

Lossless Compression

- **inefficient on high-entropy data** (Ogg files)
- **otherwise, always beneficial** (block-level or whole-stream-level)

Conclusions

Implementation of a Flexible Prototype

- allows the **combination of various storage techniques**

Assessment of Compression Techniques

$\Rightarrow$ **tradeoff** between storage efficiency & computational cost

$\Rightarrow$ most suitable: lossless input compression + fixed-size chopping + single-instance storage

Six Essential Storage Requirements

- storage efficiency
- small data blocks
- backup atomicity
- error detection
- encryption
- backup redundancy

On-Going & Future Work

Improved Energetic Cost Assessment

- build on the **computational cost measurements** (execution time ≈ energy)
- see Barr et al. *Energy-Aware Lossless Data Compression*, ACM Trans. on Comp. Sys., Aug. 2006

Algorithmic Evaluation

- identify **tradeoffs in the replication/dissemination** processes (Markov chain analysis)
- develop algorithms to **dynamically adapt** to the environment (?)

Design & Implementation

- finalize the **overall architecture**
- integrate required technologies: **service discovery**, **authentication**, etc.
- interface with **trust management** mechanisms

Thank you!

Questions?

http://www.laas.fr/mosaic/

http://www.hidenets.aau.dk/