ArchiveSafe LT: Secure Long-term Archiving System

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Introduction and Motivation

Long-Term Secure Archiving

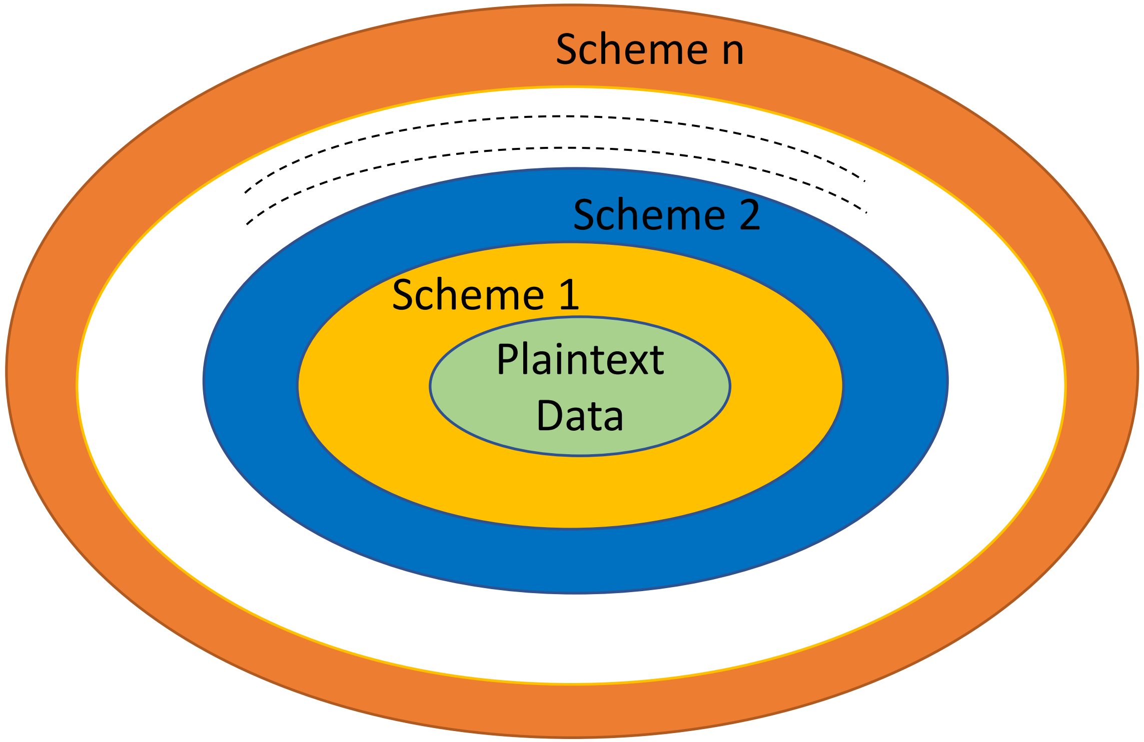
- Every year the amount of digitally stored sensitive information increases significantly.
- Some governmental and legal documents, health and tax records are required to be securely archived for decades to comply with various laws and regulations.
- Regular cryptographic schemes are not guaranteed to stay secure for such long time periods.
- Current solutions rely on information-theoretic techniques e.g.: Multi-server secret sharing.
- They require costly and complicated setup:
    - Private channels for Quantum key distribution (QKD) & One time pads (OTP)
    - Trusted Execution Environments (TEEs)

Gap and Motivation

- **Problem:**
  - Long-Term secure archiving is essential but current solutions are complicated and costly.
- **Thought:**
  - Is there any other way to prolong the lifespan of standard cryptographic schemes?
- **Idea:**
  - Robust Combiners!

Robust Combiners

A **Robust Combiner** is a combination of multiple cryptographic schemes into one so the resulting scheme is robust to the failure of any of the combined ones.



Contributions

Contributions

- We developed ***ArchiveSafe LT***, a framework ensuring long-term integrity and confidentiality without the complexity and cost required by the state-of-the-art systems.

- ***ArchiveSafe LT*** is built on the novel idea of utilizing a pool of computationally-secure schemes to build robust combiners to secure the data.

- ***ArchiveSafe LT*** provides significant performance improvement and cost reduction compared to the currently available systems.

Related Work

- LINCOS (2017)[1] utilizes proactive secret sharing and information-theoretic hiding commitments for integrity and authenticity protection.
- PROPYLA (2018)[2] enables partial data integrity and authenticity checks. Utilizes oblivious random access machine to hide access patterns.
- ELSA (2018)[3] introduces more efficient data integrity and authenticity checks.
- SAFE (2020)[4] Utilizes a trusted execution environment (TEE) provider to perform secret shares generation.

[1] Braun, Johannes, et al. "LINCOS: A storage system providing long-term integrity, authenticity, and confidentiality."
[2] Geihs, Matthias, et al. "Propyla: privacy preserving long-term secure storage."
[3] Muth, Philipp, et al. "ELSA: efficient long-term secure storage of large datasets."
[4] Buchmann, Johannes, et al. "SAFE: A Secure and Efficient Long-Term Distributed Storage System."

ArchiveSafe LT Framework

Framework Overview

- ***ArchiveSafe LT*** defines an archive as a group of data files.

- The framework implements six operations to cover the archive life cycle:
  - `Initialize()`
  - `Update()`
  - `EvolveIntegrity()`
  - `EvolveConfidentiality()`
  - `Retrieve()`
  - `Delete()`

Framework Overview

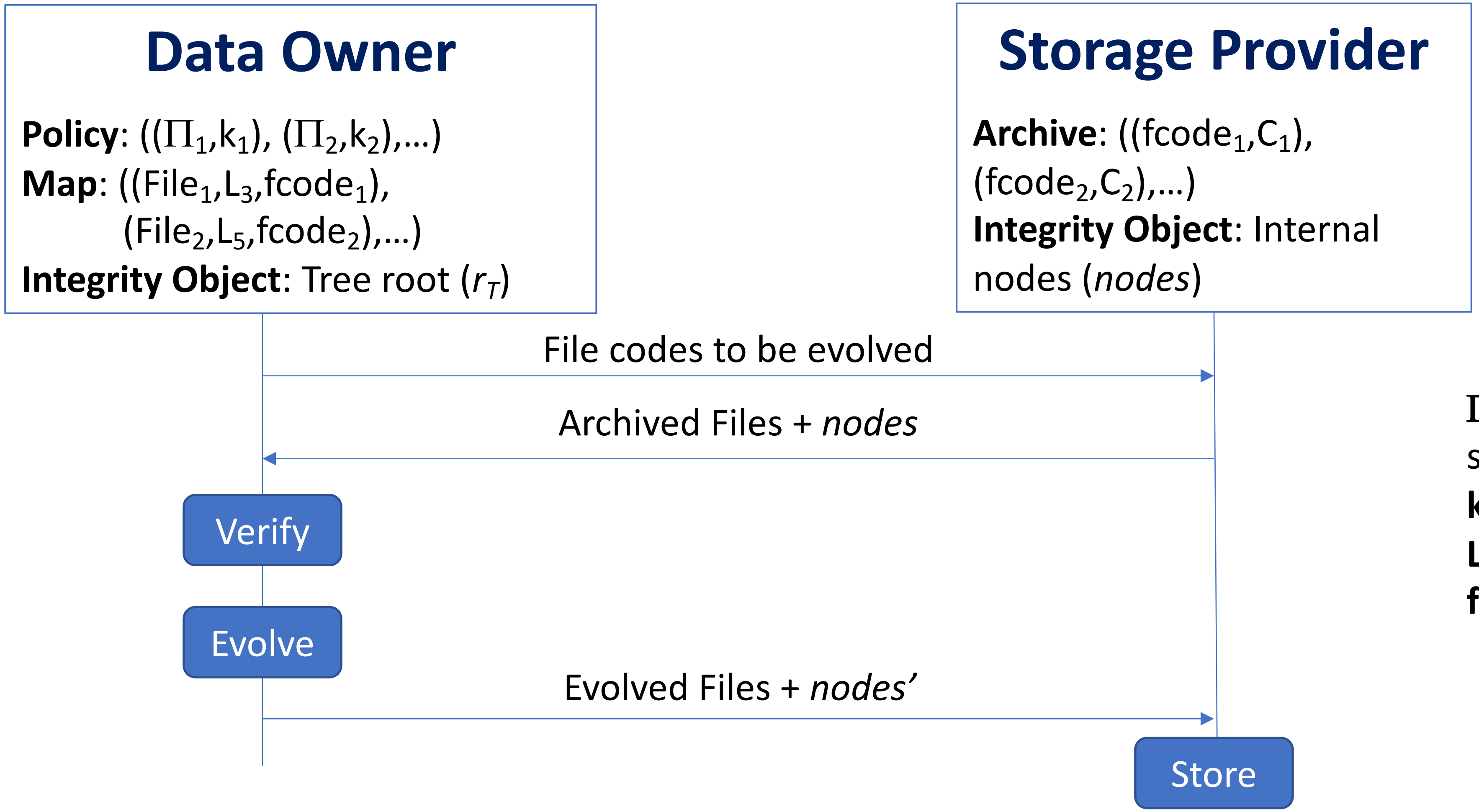
- Files can be updated, deleted or retrieved individually without processing the whole archive. A unique feature of ***ArchiveSafe LT***.
- When a cryptographic scheme is compromised, the Evolution protocol is initiated to strengthen the combiner by adding an additional secure scheme to it.

Designs Overview

- We present two system designs based on the ***ArchiveSafe LT*** framework:

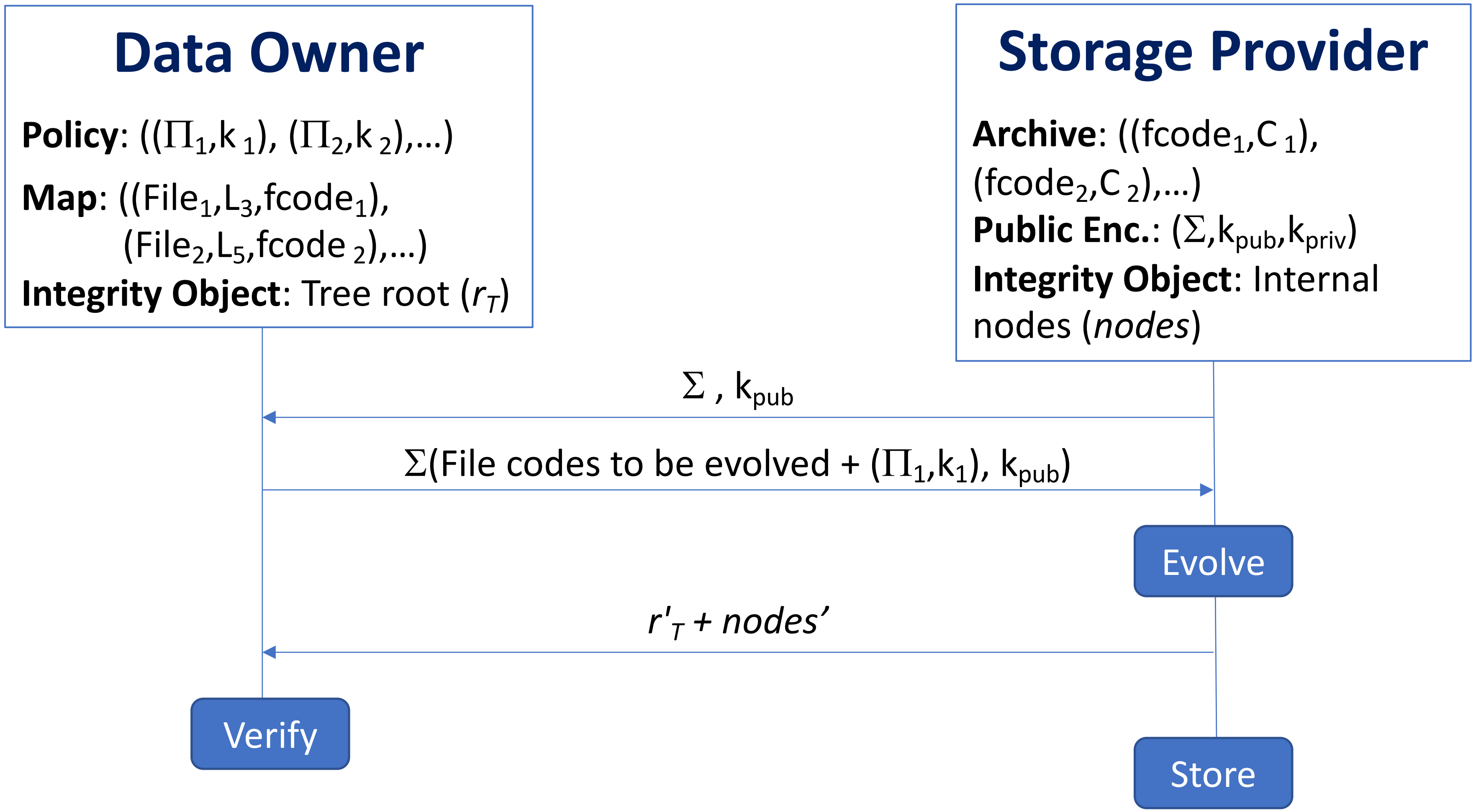
ASLT-D1	ASLT-D2
Untrusted or incapable storage provider	*Trusted* and capable storage provider
Data owner does all processing	Storage provider performs evolution processes

Design I - Evolution



Π: A symmetric encryption scheme
k: secret key
L: Number of evolutions
fcode: File ID

Design II - Evolution



Π: A symmetric encryption scheme

k: secret key

Σ: An asymmetric encryption scheme

k_{pub}: Public key

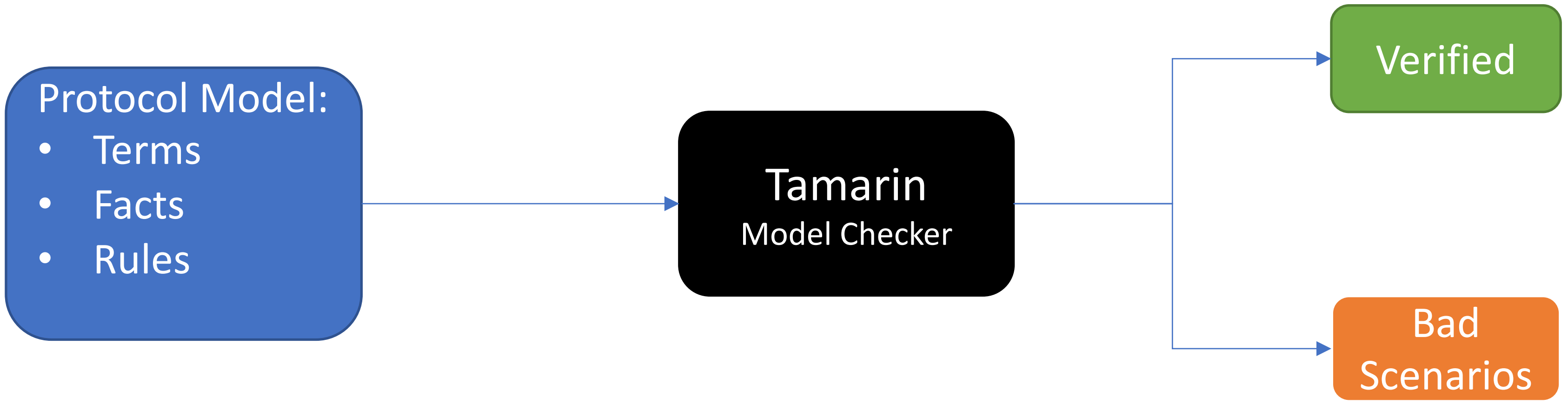
k_{priv}: Private key

L: Number of evolutions

fcode: File ID

Security Proofs - Tamarin

- To ensure no adversarial scenario is missed, we utilized an automatic prover (Tamarin*) for the confidentiality and integrity security proofs.



- Limitation: We modeled up to two evolution processes.

* https://tamarin-prover.github.io/

Tamarin - Model

- **Functions**:
  - KeyGen/2, Lock/3, Unlock/3

Lock(Schema, Key, Plaintext Data)

- **Equations**:
  - Unlock(schemenum, KeyGen(schemenum, sk),
    Lock(schemenum, KeyGen(schemenum, sk), data)) = data

- **Rules**:
  - **Oracles**: OCorruptKey, OUpdate, OEvolve, ODelete, ORetrieve2/3, OForge2/3.
  - **Challenges**: DistinguishChallenge, IntegrityChallenge.

Tamarin – Confidentiality Lemma

```
All fname fcontents #tchallenge
.
ChallengeStored(fname, fcontents) @ #tchallenge
& not(Ex #tr . RetrievedContents(fname, fcontents) @ #tr)
& not(
        (Ex #tga #tc1 #tc2 . GotArchive(fname, '2') @ #tga &
                    Corrupted('1') @ #tc1 & Corrupted('2') @ #tc2)
       |(Ex #tga #tc2 #tc3 . GotArchive(fname, '3') @ #tga &
                    Corrupted('2') @ #tc2 & Corrupted('3') @ #tc3))
 ==>
   not(Ex #tk . K(fcontents) @ #tk)
```

A valid challenge exists

This file was not retrieved by the adversary before

The adversary does not have the secured archive and broke schemes 1 & 2 at the same time

The adversary does not have the secured archive and broke schemes 2 & 3 at the same time

Tamarin – Integrity Lemma

```
All fname layer1 layer2 fcontents #tforgeanswer
.
ForgeAnswer(fname, layer1, layer2, fcontents) @ #tforgeanswer
  ==>
      (Ex fname2 #tstored . Stored(fname2, fcontents) @ #tstored)
    | (Ex #tc1 #tc2 . Corrupted(layer1) @ #tc1 & Corrupted(layer2) @ #tc2)
```

A valid challenge exists

Adversary is not presenting a valid file under a different valid file name

The adversary did not broke schemes 1 & 2 at the same time

Evaluation and Results

Evaluation Experiment

- We measure the system's performance through an experiment mimicking the evolution of an archive:
  - **1992**: Initial creation using DES + 3DES and MD2 + MD5.
  - **2001**: 1st evolution using AES-128 and SHA-256.
  - **2004**: 2nd evolution using AES-192 and SHA-384.
  - **2015**: 3rd evolution using AES-256 and SHA3-512.

Evaluation Experiment Setup

- The experiment was performed using HP Z420 (Ubuntu Linux 20.04.3 LTS, 8-core Intel Xeon CPU E5-1620 3.6 GHz, 32 GiB RAM, 1 TB SSD).
- We performed 100 repetitions of the following tasks:
  - 1000 sample files of each size were randomly generated.
  - We measured times for:
    - Initial creation.
    - Evolution.
    - Retrieval.

Results – Performance & Space I

	LINCOS[1], PROPYLA[2], ELSA[3]	ArchiveSafe LT	Trend
Creation Time	55.2 Hrs.	7.7 Hrs. (± 2%)	Improvement increases with larger archive sizes
Evolution Time	110.4 Hrs.	0.7 Hrs. (± 2%)	Improvement increases with larger archive sizes
Storage Space	3x	1x	Improvement increases with more shares

ArchiveSafe LT **time & space utilization compared to other systems**
On a 158 GB Archive

[1] Braun, Johannes, et al. "LINCOS: A storage system providing long-term integrity, authenticity, and confidentiality."
[2] Geihs, Matthias, et al. "Propyla: privacy preserving long-term secure storage."
[3] Muth, Philipp, et al. "ELSA: efficient long-term secure storage of large datasets."

Results – Performance & Space II

	SAFE[4]	ArchiveSafe LT	Trend
Creation Time	10 Sec.	3.3 Sec. (± 2%)	Improvement increases with larger archive sizes
Evolution Time	109 Sec.	3.2 Sec. (± 2%)	Improvement increases with larger archive sizes
Storage Space	3x	1x	Improvement increases with more shares

***ArchiveSafe LT* time & space utilization compared to SAFE (TEE)**
On a 10 MB Archive

[4] Buchmann, Johannes, et al. "SAFE: A Secure and Efficient Long-Term Distributed Storage System."

Conclusion

Conclusion

- ***ArchiveSafe LT*** provides long-term integrity and confidentiality using standard cryptographic schemes through a robust combiner.

- Compared to state-of-the-art approaches, ***ArchiveSafe LT*** reduces cost and complexity and provides better performance and space utilization.

- ***Future Work:***
  - Improve ***ArchiveSafe LT*** efficiency and robustness in supporting long-term integrity.

ArchiveSafe LT: Secure Long-term Archiving System

- A system providing long-term integrity and confidentiality through robust combiners.
- Utilizes standard cryptographic schemes.
- Can be utilized for in-house or outsourced storage.
- Better performance and space utilization than similar systems.

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Paper: https://dl.acm.org/doi/10.1145/3564625.3564635
Artifacts: https://github.com/samavi/pubs/tree/main/ArchiveSafeLT

Thank you!