A Libre Architecture for Verifiable Data Collection and Proof-of-Check Timestamping

Building Trust and Non-Repudiable Evidence in Distributed Systems

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Abstract

Establishing trusted, time-stamped records of system states in distributed environments presents a significant challenge for maintaining accountability and security. Organizations often struggle to produce non-repudiable proof that a specific check was performed or that a system was in a particular state at a precise moment in time. SCANDALE is a libre software solution designed to address this challenge by providing a robust backend architecture for collecting data from distributed probes and storing immutable proofs of those checks. Its core components include a high-performance HTTP API with real-time capabilities, an agent-based backend built on the Smart Python Agent Development Environment (SPADE) for scalable probe management, and a dedicated service for cryptographic timestamping in compliance with RFC 3161. The platform's primary value is its capacity to transform abstract operational data into concrete, non-repudiable evidence, providing a verifiable and cryptographically secured audit trail.

1 Related Work

Multi-agent systems (MAS) have long been proposed as a suitable paradigm for distributed monitoring and security enforcement. Guemkam et al. (Guemkam et al. 2011) describe a trusted MAS architecture for alert detection in financial critical infrastructures, highlighting the benefits of agent autonomy, contextual awareness, and authenticated communications. Their work demonstrates that MAS-based architectures can significantly enhance trust and resilience in distributed environments.

Institution-oriented approaches such as UTOPIA, introduced by Schmitt et al. (Schmitt, Bonhomme, and Gâteau 2010), further emphasize the importance of formal agent organization, norms, and interaction rules. These concepts influenced the design philosophy of SCANDALE, particularly in the separation of agent roles and the explicit modeling of responsibilities within the system.

From a middleware perspective, SPADE 3 represents a major evolution of Python-based MAS platforms. Palanca et al. (Palanca et al. 2020) describe how SPADE 3 addresses scalability, lifecycle management, and asynchronous communication using XMPP. These features are directly leveraged by SCANDALE to manage large fleets of probes reliably and securely.

2 Introduction: The Imperative for Verifiable System Audits

In modern cybersecurity and IT operations, the ability to produce verifiable data is of strategic importance. Proving that a specific action was taken or that a system was in a particular state at a precise time is critical, especially during incident response, compliance audits, or contractual disputes. Without a

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mechanism for creating tamper-evident records, organizations are left vulnerable to misrepresentation and lack the concrete evidence needed to enforce accountability.

SCANDALE is a novel, open-source platform engineered to create a verifiable and non-repudiable audit trail. It provides a comprehensive architecture for collecting data from a network of distributed probes and cryptographically timestamping the results to generate an authoritative "proof of check." This ensures that the existence of a given piece of data at a specific time can be proven without question.

The platform is composed of three primary components:

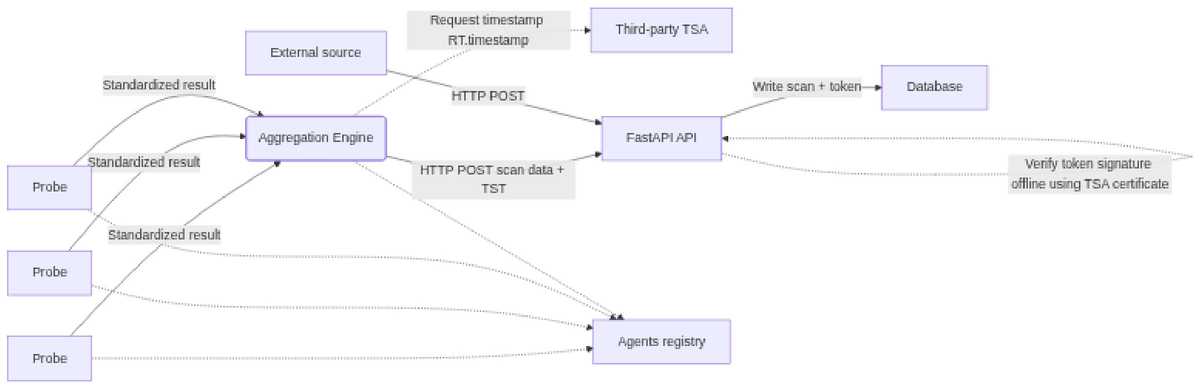
- A documented HTTP API featuring a Pub/Sub mechanism for real-time data dissemination.
- A backend based on the Smart Python Agent Development Environment (SPAD) for deploying and monitoring a network of probes.
- A service to timestamp collected data with a third party according to RFC 3161 standards(Zuccherato et al. 2001), providing cryptographic proof.

This document provides a detailed examination of the system's architecture, its core mechanisms, and its practical applications in establishing digital trust.

3 System Architecture and Core Components

The SCANDALE architecture is designed for scalability and reliability, orchestrating data collection, aggregation, and verification through a set of specialized, interoperable components. This modular design ensures that each part of the system can perform its function efficiently while contributing to the overall goal of creating a trusted audit log. This section deconstructs the architecture and clarifies the role of each component.

3.1 Architectural Overview and Data Flow



The system's data flow provides multiple ingress paths, ensuring flexibility for both agent-based and external data sources. The primary operational flows are as follows:

1. Data Collection: A distributed network of Probes conducts localized scans. These agents execute their tasks and transmit normalized, standardized results to the Aggregation Engine.
2. Aggregation & Timestamping: The Aggregation Engine consolidates data from the probe network. It can then request a cryptographic timestamp from a third-party RFC 3161 service for the consolidated data before forwarding it for storage.
3. Storage & Retrieval: A high-performance FastAPI-based API serves as the primary data interface. It receives data via HTTP POST from the Aggregation Engine or directly from an External source, writes the information to a database, and provides services for retrieval. This API component can also independently request timestamps from the third-party service for data it receives.

3.2 Analysis of Core Components

3.2.1 Probe Agents

These agents are the primary data collectors distributed across the monitored environment. They are responsible for executing scans and feeding the results back into the system. Their two main responsibilities are embedding various scanning tools (probes) and normalizing the output from these tools into a standardized format before transferring the data. Probe agents operate in two distinct modes:

- One-shot: Designed for punctual tasks that are often triggered by a user action. For large-scale jobs, the system can parallelize multiple one-shot agents to handle an extensive list of tasks efficiently.
- Periodic: Configured to execute a specific task at scheduled intervals, enabling continuous and automated monitoring of system states.

3.2.2 Aggregation Engine

The Aggregation Engine acts as the central consolidator of data from the entire probe network. Its main responsibility is to collect and centralize data from the various scanning tools. As an additional critical function, this agent is also responsible for managing the Time-Stamp Protocol (TSP) process as defined by RFC 3161. By interacting with a trusted third-party provider (e.g., freetsa.org), it can obtain a cryptographic timestamp for the collected data.

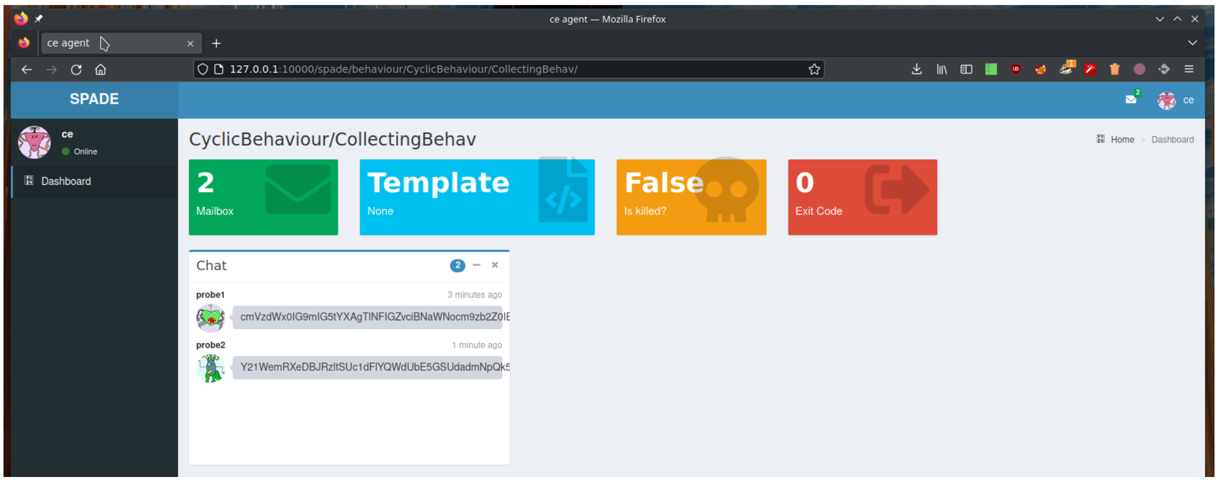
3.2.3 HTTP API

The API is the central hub for all data interaction within the SCANDALE platform. It is built on the high-performance FastAPI framework, a choice made to support high-throughput data ingestion and provide asynchronous capabilities essential for real-time services like the Pub/Sub mechanism. The API's key functions include collecting data, verifying the integrity and format of incoming data using Pydantic models, and providing robust services for the storage and retrieval of all checks and their corresponding proofs.

3.3 The SPADE Agent-Based Framework

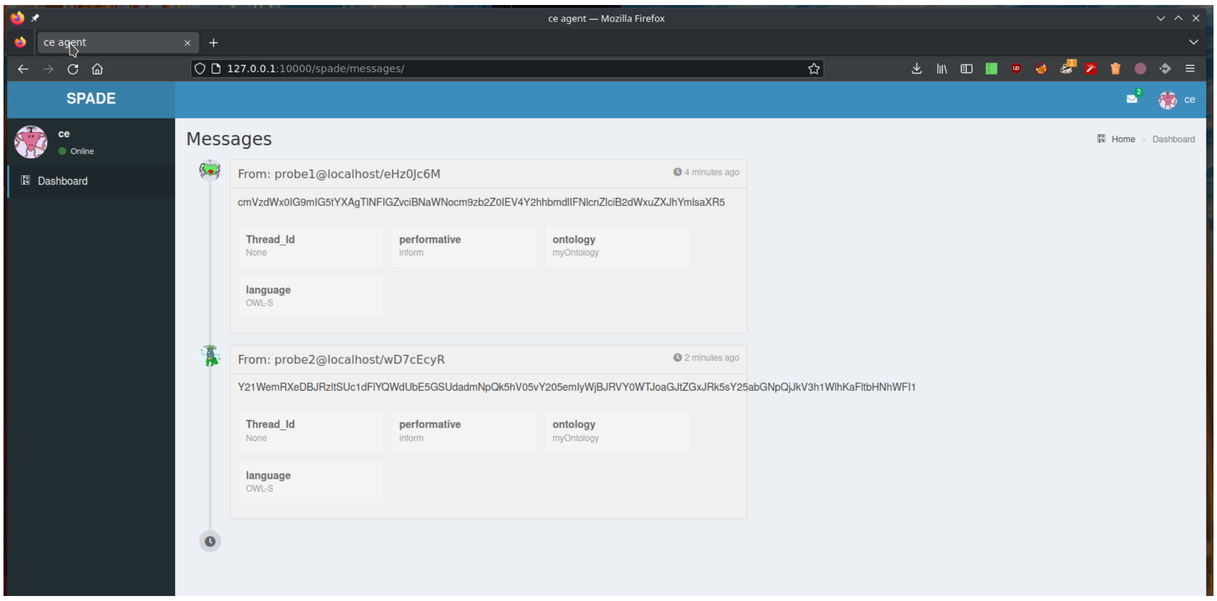
The entire backend architecture for deploying and managing the probe network relies on the Smart Python Agent Development Environment (SPADE). The strategic decision to build on a mature, agent-based framework offloads the complexity of agent lifecycle management, allowing SCANDALE to focus on its core mission of data collection and verification rather than reinventing foundational distributed systems infrastructure. Within this framework, each agent is an independent entity whose lifecycle is managed by the platform; each agent is authenticated, registered, and declares its availability via a presence notification system. This model provides a flexible and scalable foundation for orchestrating complex data collection tasks across a distributed environment.

Having detailed the architectural components, the following section will explore the specific mechanisms and data formats that enable the system's core functionality.


ce agent — Mozilla Firefox
ce agent
127.0.0.1:10000/spade/behaviour/CyclicBehaviour/CollectingBehav/
SPADE
ce
Online
Dashboard
CyclicBehaviour/CollectingBehav
Home
Dashboard
2
Mailbox
Template
None
False
Is killed?
0
Exit Code
Chat
2

probe1 3 minutes ago
cmVzdWx0IG9mIG5tYXAgTlNFIGZvciBNaWNocm9zb2Z0IE

probe2 1 minute ago
Y21WemRXeDBJRzltSUc1dFlYQWdUbE5GSUdadmNpQk5



Messages

From: probe1@localhost/eHz0Jc6M 4 minutes ago

cmVzdWx0IG9mIG5tYXAgTlNFIGZvciBNaWNocm9zb2Z0IEV4Y2hhbmdlIFNlcnZlciB2dWxuZXJhYmlsaXR5

Thread_Id	performative	ontology
None	inform	myOntology

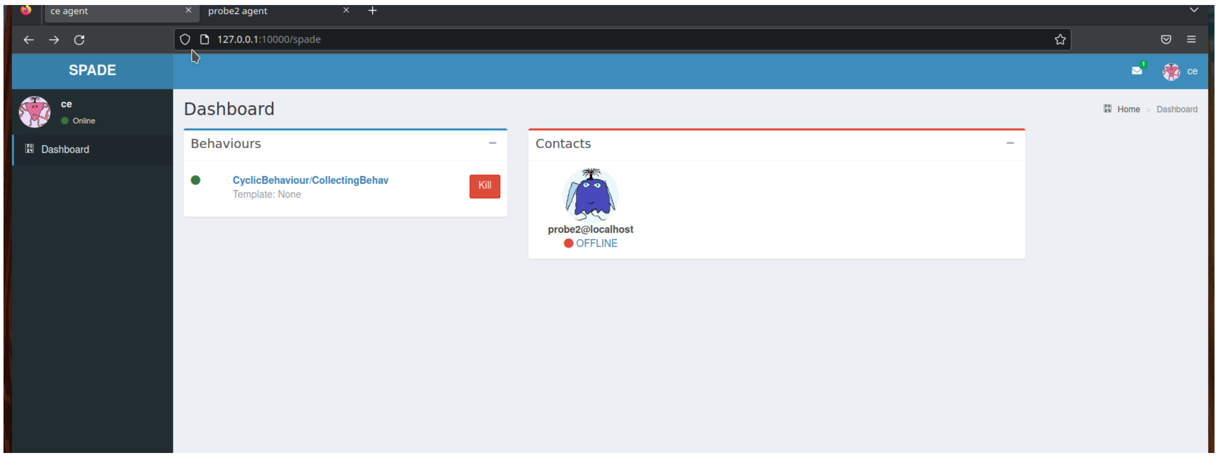
language
OWL-S

From: probe2@localhost/wD7cEcyR 2 minutes ago

Y21WemRXeDBJRzltSUc1dFlYQWdUbE5GSUdadmNpQk5hV05vY205emIyWjBJRVY0WTJoaGJtZGxJRk5sY25abGNpQjJkV3h1WlhKaFltbHNhWFI1

Thread_Id	performative	ontology
None	inform	myOntology

language
OWL-S



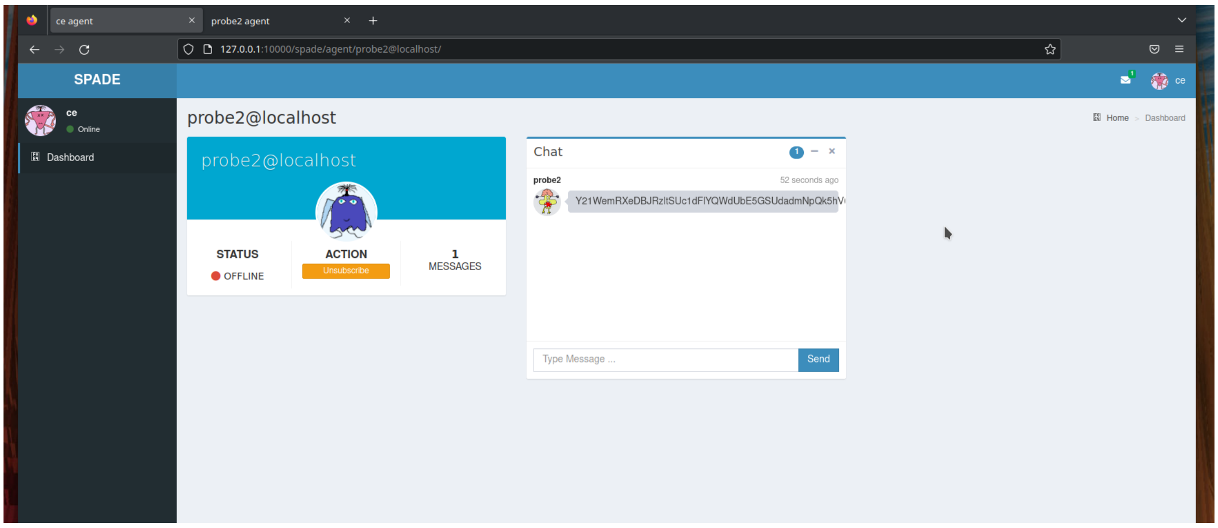
Dashboard

Behaviours

CyclicBehaviour/CollectingBehav
Template: None
Kill

Contacts

probe2@localhost
OFFLINE



probe2@localhost

probe2@localhost

STATUS	ACTION	1
OFFLINE	Unsubscribe	MESSAGES

Chat

probe2 52 seconds ago

Y21WemRXeDBJRzltSUc1dFlYQWdUbE5GSUdadmNpQk5oV

Type Message ... Send

4 Implementation Details and Key Mechanisms

The robustness and utility of the SCANDALE platform are rooted in its specific technical implementations. These mechanisms ensure data integrity, facilitate real-time communication, and maintain interoperability through standardized data formats. This section explores these core technical features.

4.1 Data Integrity via RFC 3161 Timestamping

The cornerstone of SCANDALE's integrity model is its use of a third-party, RFC 3161 compliant timestamping service. The critical benefit of this approach is that the resulting proof is verifiable independently of the SCANDALE system itself. By sending a hash of the collected data to a trusted Time-Stamping Authority (TSA), the system receives a signed token that cryptographically binds the data's hash to a specific point in time. This provides non-repudiable proof of the check's existence, as any third party can validate the signed timestamp against the data without needing to trust the SCANDALE database or its operators.

4.2 API Services and Real-time Communication

The platform's API is built on the FastAPI framework, ensuring high performance and adherence to modern web standards. It is fully compliant with the OpenAPI Specification v3.1.0, making it well-documented and easy to integrate with other tools and services.

A key feature of the API is its Pub/Sub (Publish/Subscribe) mechanism, which allows clients to receive real-time notifications about system events. The following Python code snippet demonstrates a simple client that subscribes to the scan and tst topics to receive event data as it is generated.

```python
import asyncio
import os
import sys
from fastapi_websocket_pubsub import PubSubClient

PORT = int(os.environ.get("PORT") or "8000")

async def on_events(data, topic):
    print(f"running callback for {topic}!")
    print(data)

async def main():
    # Create a client and subscribe to topics 'scan' and 'tst'.
```

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```
    client = PubSubClient(["scan", "tst"], callback=on_events)
    client.start_client(f"ws://localhost:{PORT}/pubsub")
    await client.wait_until_done()

asyncio.run(main())
```

4.3 Standardized Data Formats

To ensure seamless interoperability between components, SCANDALE employs standardized JSON formats, with validation enforced by Pydantic.

The structure for data originating from scans is designed for clarity and completeness. The meta object contains essential context like a UUID, source, and timestamp, while the payload contains the base64-encoded raw output from the scanning tool.

Data from the scans:

```
{
    "version": "1",
    "format": "scanning",
    "meta": {
        "uuid": "<UUID>",
        "source": "<source>",
        "ts": "date",
        "type": "nmap-scan"
    },
    "payload": {
        "raw": "<base64-encoded-string>"
    }
}
```

The configuration for each probe agent is also defined in a standardized format. This allows administrators to define an agent's behavior, including its execution period, target, and the command it should run. The result_parser field specifies the logic for normalizing scan output, while the up_agent field designates the destination for the processed data, typically the Aggregation Engine.

Agent configuration:

```
{
    "uuid": "",
    "period": 3600,
    "target": "",
    "command": "",
    "args": [],
    "expected_value": "",
    "result_parser": "",
    "up_agent": "",
    "jid": "",
    "passwd": ""
}
```

These technical features provide the foundation for SCANDALE's practical application in real-world scenarios requiring verifiable data.

4.4 Verifiable Data Validation

The ultimate objective of SCANDALE is not merely to collect data, but to enable independent and cryptographically verifiable validation of that data. To this end, the platform provides HTTP API endpoints that allow third parties to:

- Retrieve collected scan artifacts,
- Access the associated TimeStampTokens (TST), and
- Verify the integrity and temporal validity of data without relying on trust in the SCANDALE platform or its operators.

This trust-minimizing approach ensures that SCANDALE acts as a facilitator of evidence rather than a centralized authority.

4.4.1 Trust Model and Verification Scope

The validation workflow does not require trust in the SCANDALE database or its operators. Any third party with access to:

- the stored scan payload,
- the corresponding TimeStampToken (TST),
- and the TSA's public certificate,

can independently reproduce the verification process. This property establishes SCANDALE as a trust-minimizing system, where the platform acts as a facilitator of evidence rather than a trusted authority.

As a result, SCANDALE enables verifiable, non-repudiable proof-of-checks that remain valid even if the platform itself is decommissioned.

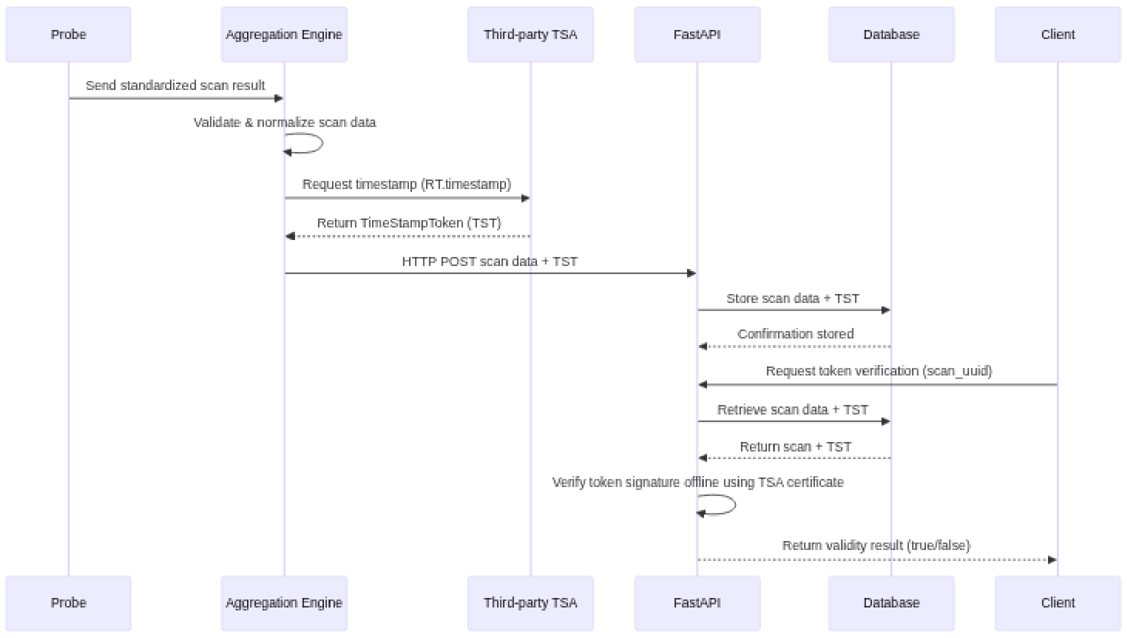
Probe
Aggregation Engine
Third-party TSA
FastAPI
Database
Client
Send standardized scan result
Validate & normalize scan data
Request timestamp (RT.timestamp)
Return TimeStampToken (TST)
HTTP POST scan data + TST
Store scan data + TST
Confirmation stored
Request token verification (scan_uuid)
Retrieve scan data + TST
Return scan + TST
Verify token signature offline using TSA certificate
Return validity result (true/false)

Figure: Sequence diagram for token validation. The SCANDALE FastAPI server performs the RFC 3161 verification and returns a validity result to the client.

Key points:

- Verification is performed entirely offline using the stored TST and TSA certificate.
- No TSA call is required during verification; the Aggregation Engine is responsible for the initial timestamp request.
- This workflow enables trust-independent, non-repudiable proof-of-checks that remain valid even if SCANDALE is decommissioned.

4.4.2 Retrieval of Timestamped Artifacts

The API provides a query interface to retrieve recently collected and timestamped items. Each item contains the original scan data as it was ingested and stored, preserving the exact payload that was used to generate the timestamp request.

Example: retrieving the most recent timestamped item:

```
$ curl -s -X 'GET' 'http://127.0.0.1:8000/items/?skip=0&limit=1'  -H
↪  'accept: application/json' | jq .
[
  {
    "scan_data": {
      "version": "1.0",
      "format": "nmap",
      "meta": {
        "uuid": "3f68c6bf-6b35-48bf-9554-b90bb5c99cf5",
        "ts": 1703064496,
        "type": "scan"
      },
      "payload": {
        "raw": "U3RhcnRpbmcgT <-SNIP-> luMuMTQgc2Vjb25kcwo="
      }
    }
  }
]
```

This endpoint allows auditors or external systems to reconstruct the exact data state that was subject to timestamping, forming the basis for subsequent verification steps.

4.4.3 Timestamp Retrieval

For a given scan UUID, the API exposes a dedicated endpoint to retrieve the corresponding timestamp metadata derived from the RFC 3161 TimeStampToken:

```
$ curl -X 'GET' \
  'http://127.0.0.1:8000/TimeStampTokens/get_timestamp/3f68c6bf-6b35-48bf-
  ↪  9554-b90bb5c99cf5' \
  -H 'accept: application/json' -s | jq .
{
  "timestamp": "2023-12-20T09:28:16"
}
```

This value represents the authoritative time asserted by the external Time-Stamping Authority (TSA), not the local system clock, thereby eliminating a common source of dispute in audit scenarios.

4.4.4 Cryptographic Validation of Timestamp Tokens

Beyond metadata inspection, SCANDALE provides an endpoint to perform a full cryptographic verification of the stored TimeStampToken against the original data payload:

```
$ curl -X 'GET' \
  'http://127.0.0.1:8000/TimeStampTokens/check/3f68c6bf-6b35-48bf-9554-
  ↪  b90bb5c99cf5' \
  -H 'accept: application/json' -s | jq .
{
  "validity": true
}
```

This verification step confirms that:

1. The timestamp token was issued by a trusted TSA.
2. The token's signature is cryptographically valid.
3. The hash embedded in the token matches the hash of the stored scan payload.
4. The data has not been altered since the timestamp was issued.

The validation process is performed using the original TSA certificate and the RFC 3161 verification workflow, as illustrated in the following implementation excerpt:

```
@app.get("/TimeStampTokens/check/{scan_uuid}")
def check_tst(scan_uuid="", db: Session = db_session):
    """Performs an offline check of a TimeStampToken."""
    db_tst = crud.get_tst(db, scan_uuid=scan_uuid)
    if db_tst is None:
        raise HTTPException(status_code=404, detail="TimeStampToken not
        ↪   found")
    db_item = crud.get_items(db, scan_uuid=scan_uuid)
    if db_item is None:
        raise HTTPException(status_code=404, detail="Item not found")

    certificate = open(config.CERTIFICATE_FILE, "rb").read()
    rt = rfc3161ng.RemoteTimestamper(config.REMOTE_TIMESTAMPER,
↪   certificate=certificate)
    result = rt.check(
        db_tst.tst,
↪   data=db_item[0].scan_data["payload"]["raw"].encode("utf-8")
    )
    return {"validity": result}
```

5 Applications, Use Cases, and Extensibility

The architectural and technical features of SCANDALE translate directly into capabilities for solving real-world trust and verification problems across various operational domains.

5.1 Core Use Cases

The platform is designed to address critical needs for accountability and certified evidence. Two primary use cases highlight its value:

- Vendor Accountability: Consider a scenario where a Small and Medium-sized Enterprise (SME) instructs its IT provider to patch a critical system. The provider claims the work was completed at a specific date but has actually failed to do so. By using the certified scan logs generated by SCANDALE, the SME can produce irrefutable, time-stamped proof of the system's vulnerable state after the claimed patch date, providing concrete grounds to break the contract and hold the provider accountable.
- Incident Timeline Certification: During a security incident, establishing a precise and verifiable timeline of events is crucial for forensic analysis, reporting, and future prevention. SCANDALE can be used to take snapshots of system states at critical moments, creating a cryptographically certified timeline. This timeline is invaluable for investigators and provides a trusted record for regulatory or legal purposes.

5.2 Extensibility and Integration

SCANDALE is not a closed system; it is designed for extensibility at both the agent and platform level. At a high level, an Ad hoc module facilitates integration with external systems, such as sharing data with MISP, a popular open-source threat intelligence platform. This allows certified logs to enrich and be enriched by broader threat intelligence ecosystems. At the component level, each agent has the capability to provide its own HTML views and discrete services, enabling custom functionality and reporting directly from the data collection points.

6 Conclusion

SCANDALE offers a robust, libre software architecture for addressing the critical need for creating immutable, time-stamped proofs of system checks. By leveraging a distributed agent network, it provides a scalable and flexible solution for data collection in complex IT environments. Its core strengths—the use of the SPADE framework for agent management, a high-performance FastAPI interface for data interaction, and the fundamental guarantee of data integrity through RFC 3161 timestamping—combine to create a powerful platform for digital verification. Ultimately, SCANDALE provides a critical capability for any organization needing to enforce accountability and maintain a verifiable audit trail of its digital operations, transforming abstract operational data into concrete, non-repudiable evidence.

7 License

The SCANDALE project is licensed under the GNU Affero General Public License version 3.

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