Tutorial: Trusted Execution Environments and Intel SGX - a few basic notions and usages

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RESSI

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Trusted Execution Environments and Intel SGX

a few basic notions and usages

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Overview

PART I – Introduction to Trusted Execution Environments (TEE)

- Historical view of TEEs
- Promises and architecture of TEEs
- Intel Software Guard eXtensions (SGX)
- Efficient data processing with SGX
- Limitations of TEEs and attacks on TEEs (SGX)

PART II – Tutorial introducing SGX

- Federated Learning scheme using SGX

PART III – Use-case

- Secure and Extensive Personal Data Management Systems with SGX

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From Secure Elements to Trusted Execution Environments (TEEs)

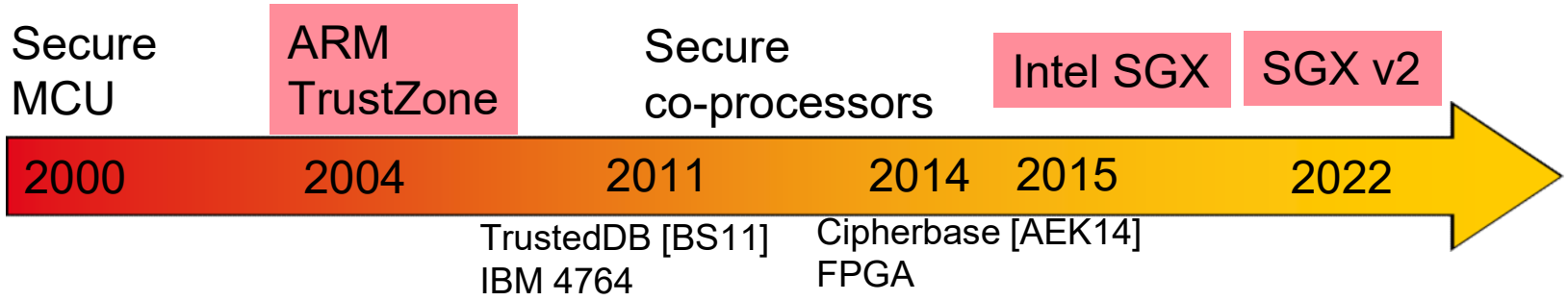
From secure elements, TPM, HSM, etc. [ANS14]

Smart cards or TPM (in smartphones, PCs, home boxes)

… to: Trusted Execution Environments (TEEs) [ABP+19]

Specialized HW: ARM TrustZone, Intel SGX, AMD platform security, etc.

Everywhere : Smartphones & PCs



Promise: HW level isolation and attestation

Isolation:

- Code executed within a TEE safe from external observation/tampering (OS, user)

Attestation:

- Ability to give a certificate that result produced by a specific piece of code running within TEE

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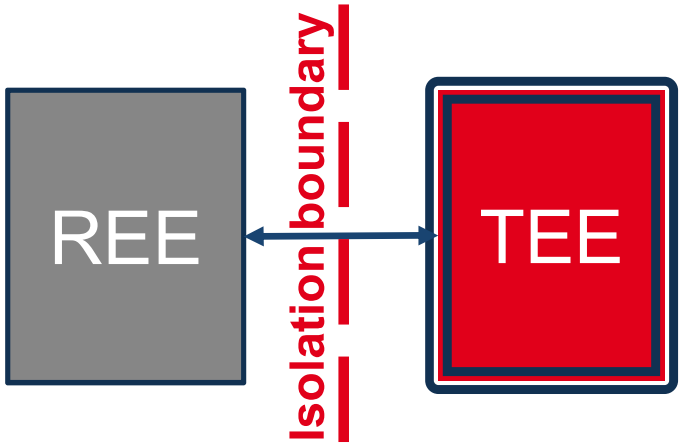
Secure data management in TEEs

Common general architecture (for existing basic TEEs, secure co-CPUs/FPGAs, recent TEEs-Intel SGX): trusted vs. untrusted memory space



What to look for in details?

- HW architecture: inherent limitations of the HW (e.g., SCPU clock, size of the secure RAM, bandwidth between secure/unsecure worlds…)
- SW architecture: which modules run inside the secure HW => Objective: minimize the Trusted Computing Base (TCB) vs. efficiency (REE/TEE context switching)
- Security guarantees: access pattern leak vs. oblivious query processing

Adversary: untrusted, curious and controls the system

- Assumption: TEE isolation cannot be bypassed by an attacker controlling the system

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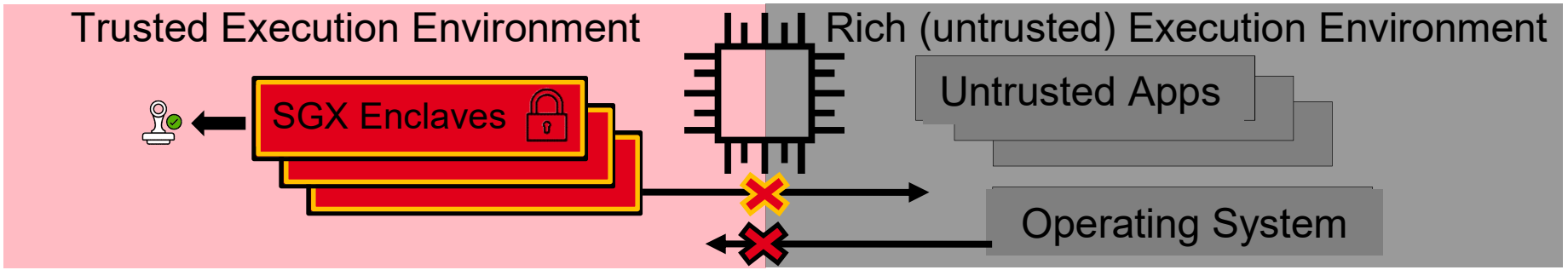
Intel Software Guard eXtensions (SGX)



- **Enclaving**
- **Attestation**
- **Confidentiality**

Insured by SGX

- + Recent works with **Sandboxing**

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Efficient data processing with TEEs

Modern HW, e.g. Intel SGX, democratize the access to trusted execution technologies

- Main CPU chip offers TEE capabilities through enclaves (special CPU mode enabled via new instructions) => ubiquitous access to TEE and strong (HW) integration between REE/TEE
- Yet, performance considerations remain critical for minimizing the enclave related overheads

Main overhead sources with SGX enclaves [WAK18] [PVC18]

- Memory encryption and integrity checking: unavoidable but low overhead
- Enclave transitions (ECALL/OCALL): high overhead
- Enclave paging (related to a limited enclave size): high overhead

It requires carefully redesigning (data-oriented) apps

Efficient data processing with TEEs – EnclaveDB [PVC18]

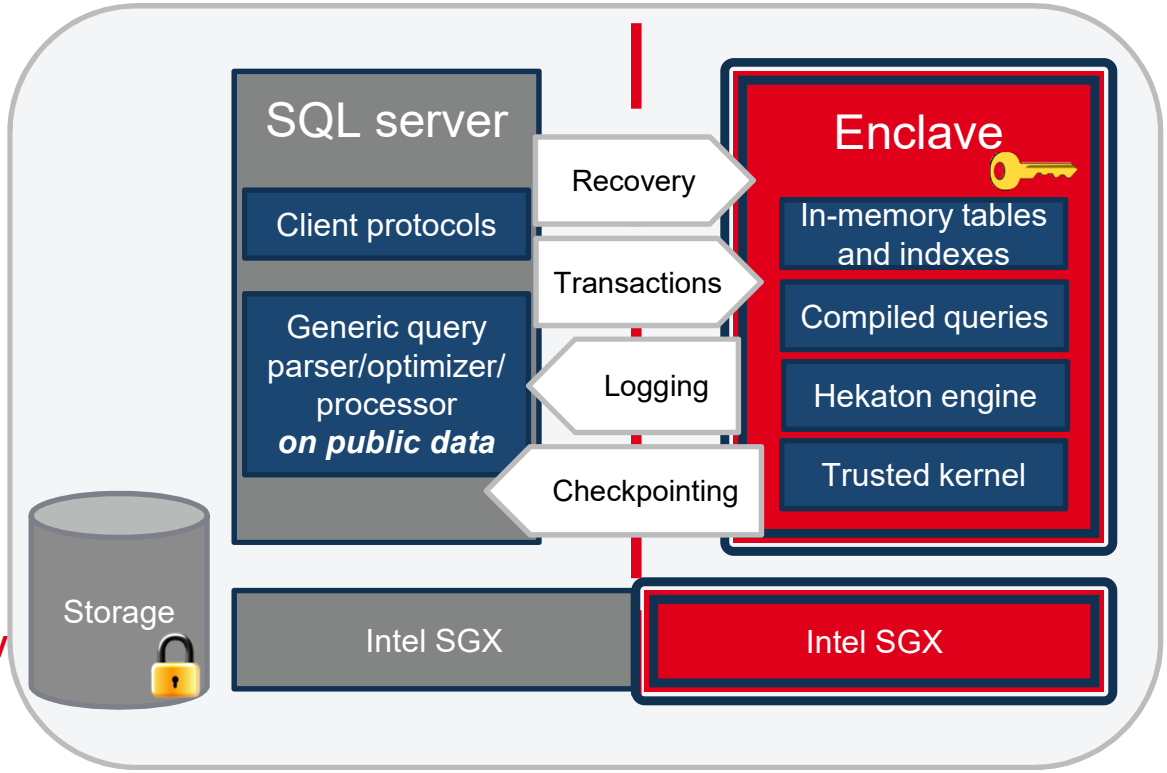
High performance DB engine…
with security using Intel SGX

Important assumption: <u>all sensitive data loaded in enclave memory</u>

- No need for expensive SW encryption/integrity checks
- In-memory enclave data minimizes the leakage of sensitive information
- Also minimizes the number of costly IN/OUT enclave transitions
- Smaller TCB (Heckaton engine) using precompiled procedures

Focus on secure and efficient DB logging and recovery

- Efficient protocol for checking integrity and freshness of the DB log
- Low overhead (~40%) compared with classical industry in-memory DBs



Efficient data processing with TEEs – Indexing/KVS

HardIDX [FBB+18]: secure and efficient B-tree indexing using SGX

- Leverage SGX enclaves to secure outsourced data searches while maintaining high query performance
- Several order of magnitude lower query processing time than with traditional compared with the best known searchable encryption schemes…
- … with similar level of confidentiality protection

eLSM [TCL+19]: authenticated KVS with TEE enclaves

- Focuses on optimizing update-oriented workloads…
- … and ensuring query authenticity: integrity, completeness and freshness
- Modifies the classical LSM-tree to cope with SGX enclave constraints

Both HardIDX and eLSM leak the access patterns

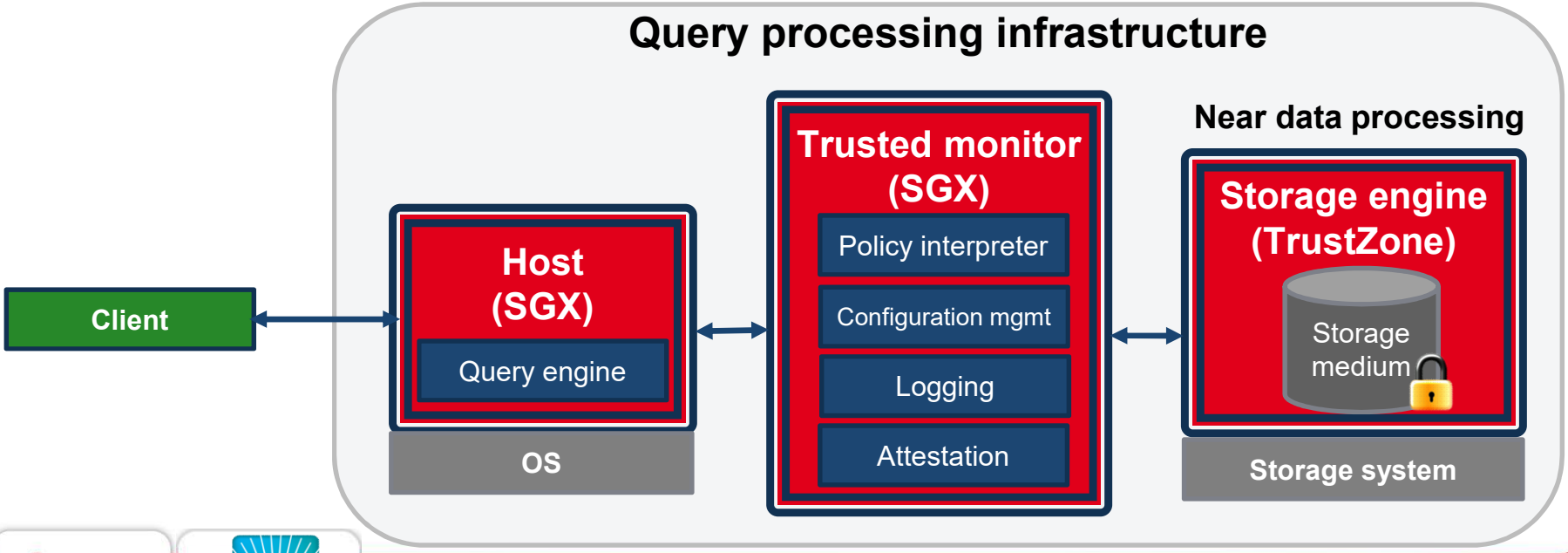
IronSafe [UCB+22]

IronSafe computing storage architecture (CSA)

- Efficient data-oriented query processing leveraging near data processing
- TEE-based policy enforcement and compliance

Heterogeneous TEEs for host (Intel SGX) and storage (ARM TrustZone)

- Combine execution across TEEs
- Offload computations closer to data (TrustZone-based storage) for performance gains
- Trusted monitor (SGX enclave) to ensure the integrity/authenticity of all components through attestation



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Security limitations of TEEs

TEEs do not protect accesses outside the secure enclave

- **Loading everything inside the enclave is not always an option**
- **Known side channel attacks with Intel SGX: OS can observe the enclave data accesses at the granularity of pages**

Access patterns in the workflow can reveal information (e.g., order, frequency distribution) for disk/memory resident data

Example:

1. Query Alice's age
2. Query average age of people who voted for X
3. If record retrieved in 1 is also retrieved in 2, Alice voted for X

Oblivious query processing

Objective: make sure memory access patterns are data independent (except for query input/output size) [AK13]

Ensures that the only leakage from a query is the size of input/output, even if the adversary observes memory

i.e., semantic security for queries

Relevant here: adversary is assumed to control all memory external to secure hardware

ORAM (Opaque [ZDB+17]), ObliDB [EZ17], Oblix [MPC18], Path ORAM[HH21]…

What if enclaved code cannot be trusted?

Problem: TEEs do not ensure that malicious code cannot voluntarily leak data

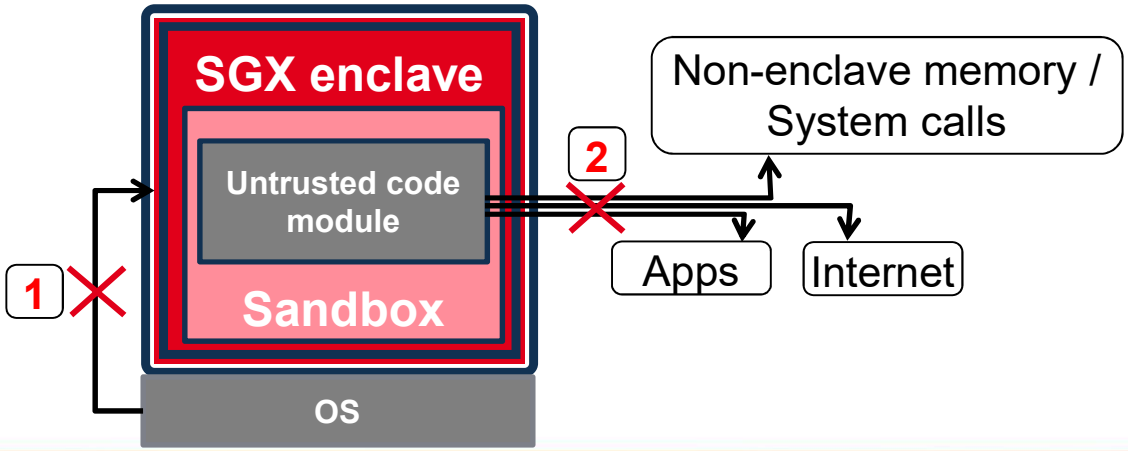
Confining untrusted code through double isolation

1. **Execute code inside of an enclave untrusted platform cannot access private enclave-memory data**
2. **Restrict accessible memory of the untrusted module execution with a sandbox module cannot copy secrets to non-enclave memory**

Ryoan [HZX18] sandboxing

Based on Google's Native Client: can only address module memory, intercepts syscalls…

Similar alternative sandboxing solutions: SGXJail [WSG19], SGX-LKL [PML+19], DBT [CSS+22]

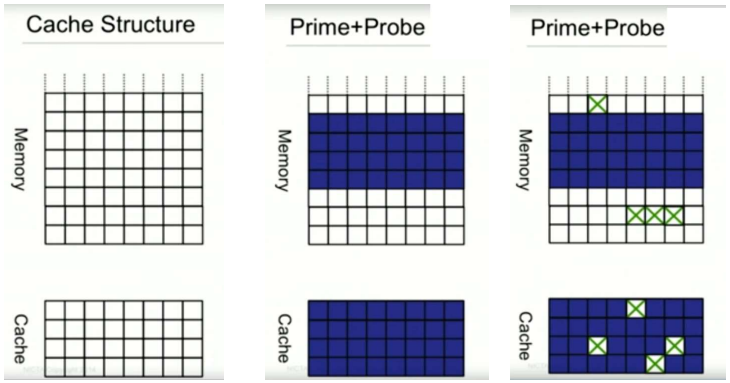


Side-channel attacks on SGX

Malware Guard Extension: abusing Intel SGX to conceal cache attacks

M Schwarz, S Weiser, D Gruss, C Maurice, S Mangard

Cybersecurity 3 (1), 2



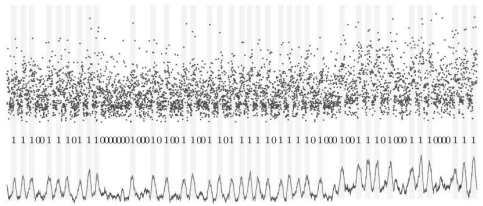


Fig. 7 On top is one trace's raw measurement over 4000000cycles. The peaks in the resampled trace on the bottom clearly indicate '1's

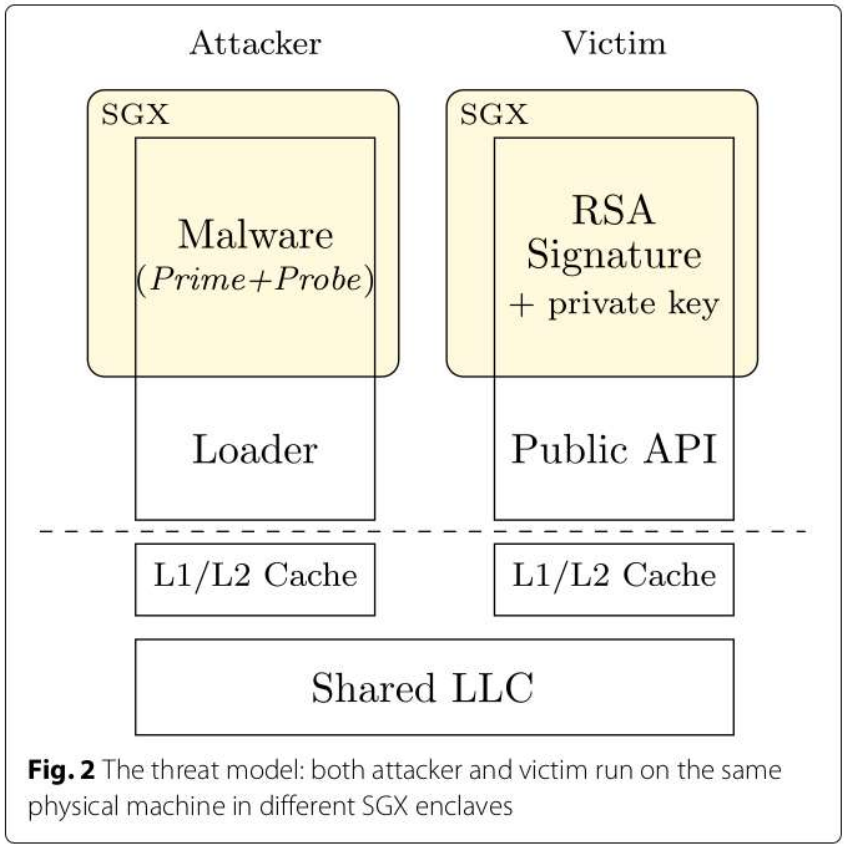


Fig. 2 The threat model: both attacker and victim run on the same physical machine in different SGX enclaves

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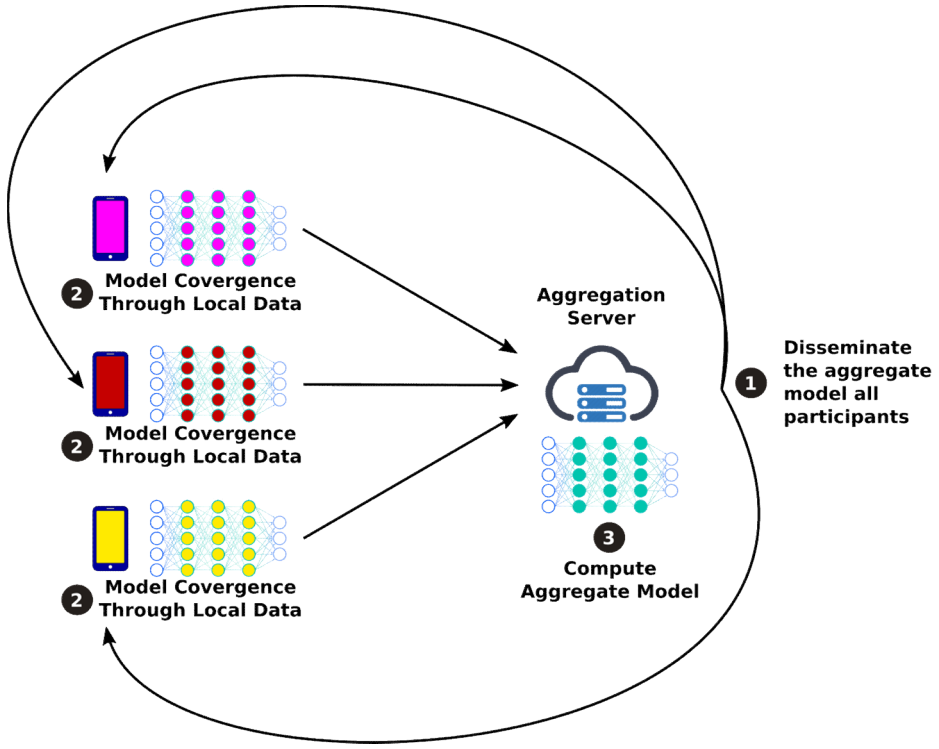
Tutorial introducing SGX

Federated Learning



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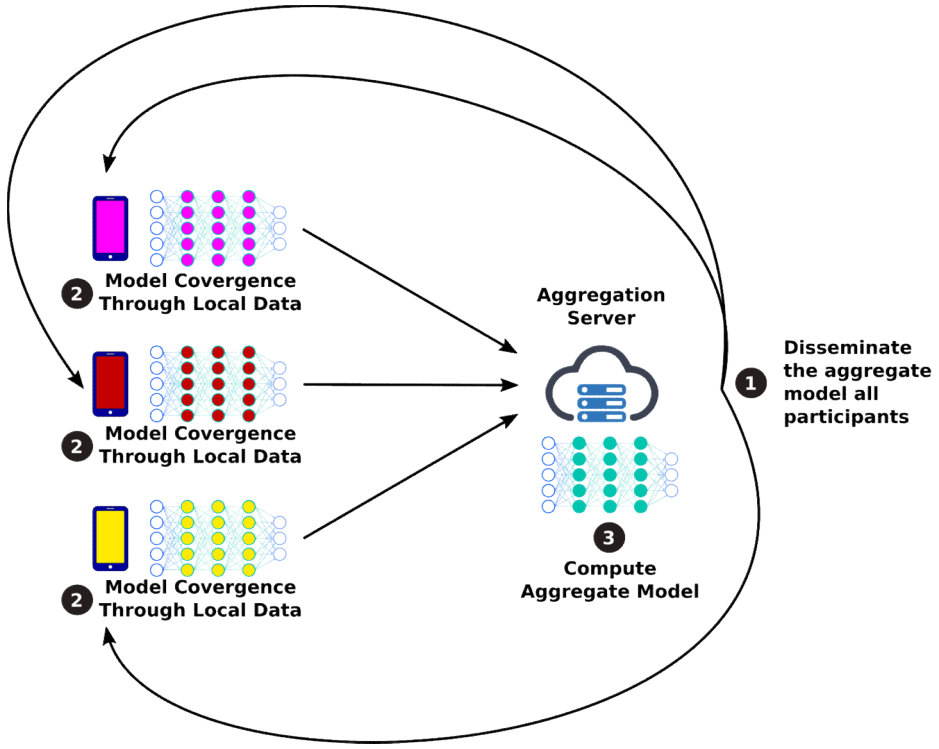
Federated Learning



- Limitations
- Countermeasures
  - Perturbation (e.g., Differential Privacy [1])

    ➔ Drastically reduces accuracy
  - Crypto (e.g., Secure Aggregation [2])

    ➔ Overhead

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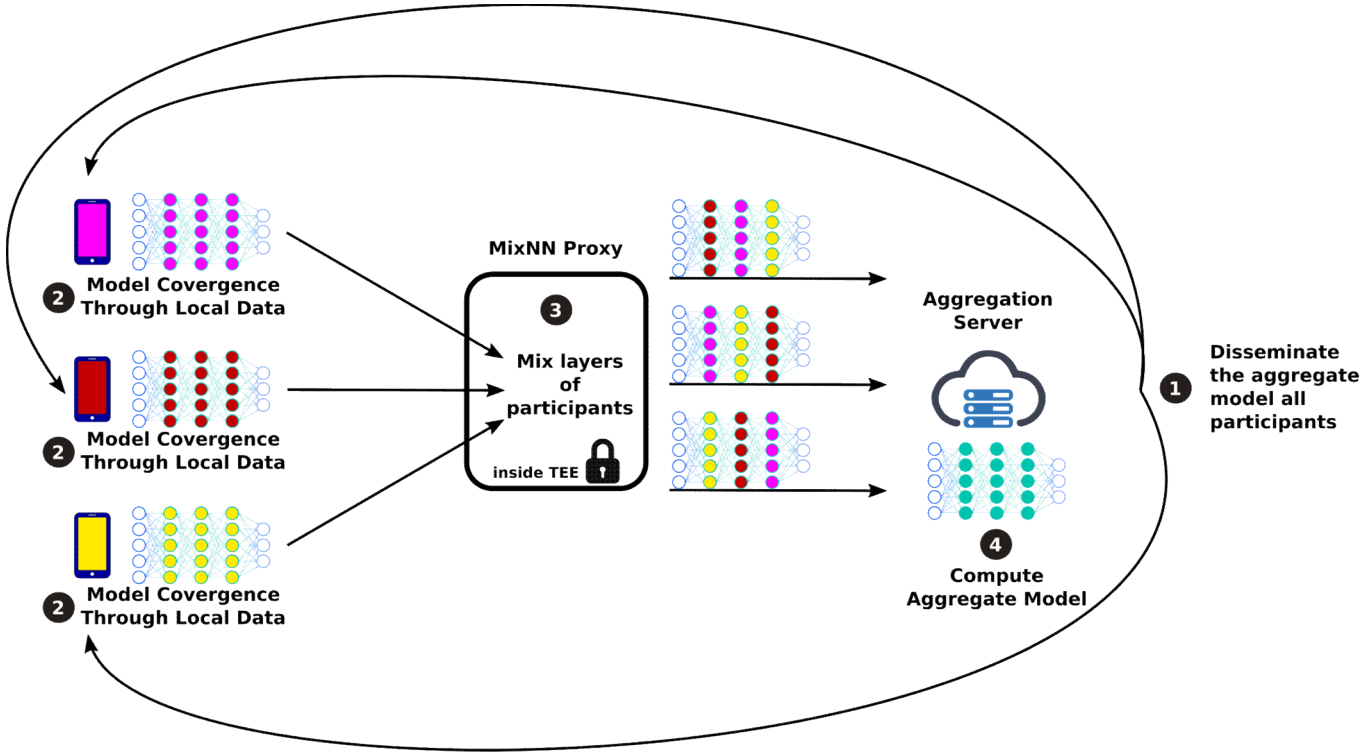
Federated Learning scheme using SGX: MixNN [1]



➔ **Improve the privacy (at low cost) without compromising the utility**

[1] MixNN : protection of federated learning against inference attacks by mixing neural network layers, T Lebrun et al., Middleware 2022

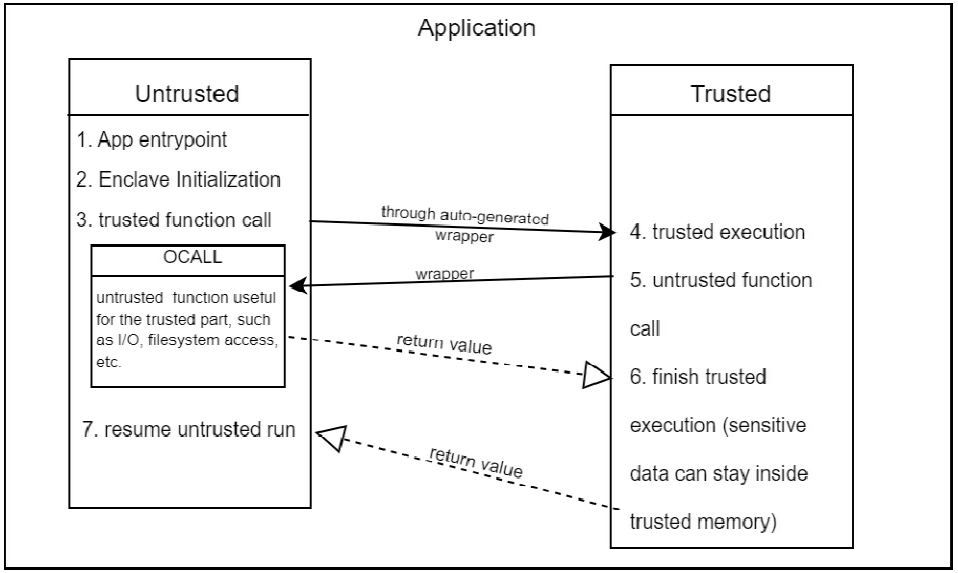
Tutorial introducing SGX

Installation

- Guide à travers l'installation des drivers & SDK SGX + OpenSSL SGX

Bases

- Architecture de base d'un projet SGX
- Initialisation d'une enclave
- Principe OCALL & ECALL : permet de faire un "context-switch" entre la partie trusté & non-trusté
- Comment faire transiter des données & stockage de données sécurisé pour l'enclave



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Crypto

- Utilisation de la librairie de crypto OpenSSL : génération d'une paire de clés RSA et l'implémentation d'un chiffrement / déchiffrement basique
- Principe de "Sealing", chiffrement d'une données qui peut être enregistrée sur disque afin d'être réutilisée entre plusieurs run d'une enclave, ici chiffrement de la clé privée

Multi Threading

- Mise en place du multi-threading à l'intérieur de l'enclave
- Synchronisation entre les différents threads

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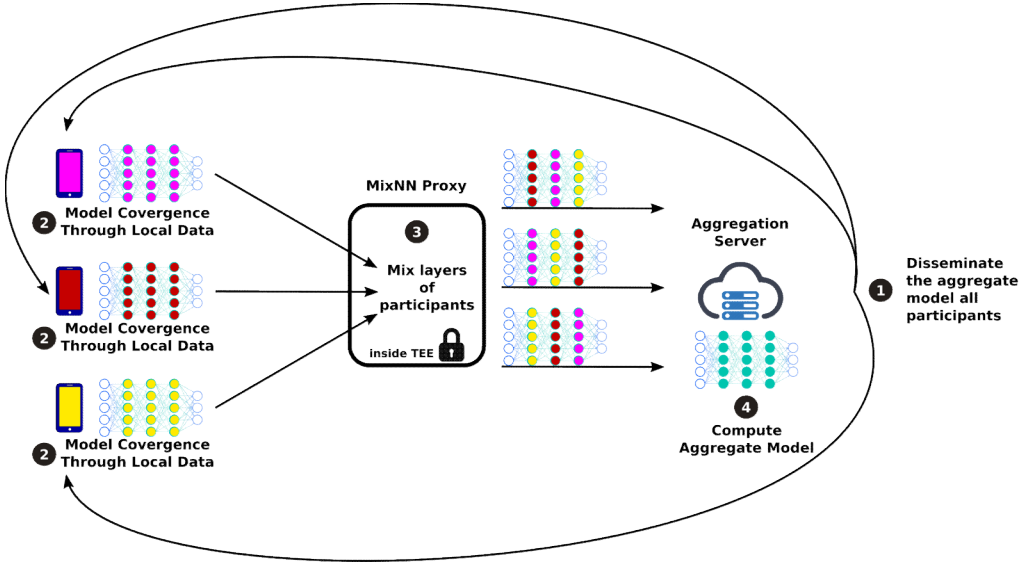
Implémentation MixNN

- Génération d'une paire de clés et partage de la clé publique
- Déchiffrent des messages en entrée et stockage de leur contenue à l'intérieur de l'enclave
- Une fois un seuil de message atteint, mixage du contenu des messages et sortie de l'enclave avec transmission des messages mixés au serveur
- Les messages sont simplement des tableaux d'entiers, ce qui simplifie le stockage dans l'enclave et les structures de données avec lesquels le mixage doit être fait



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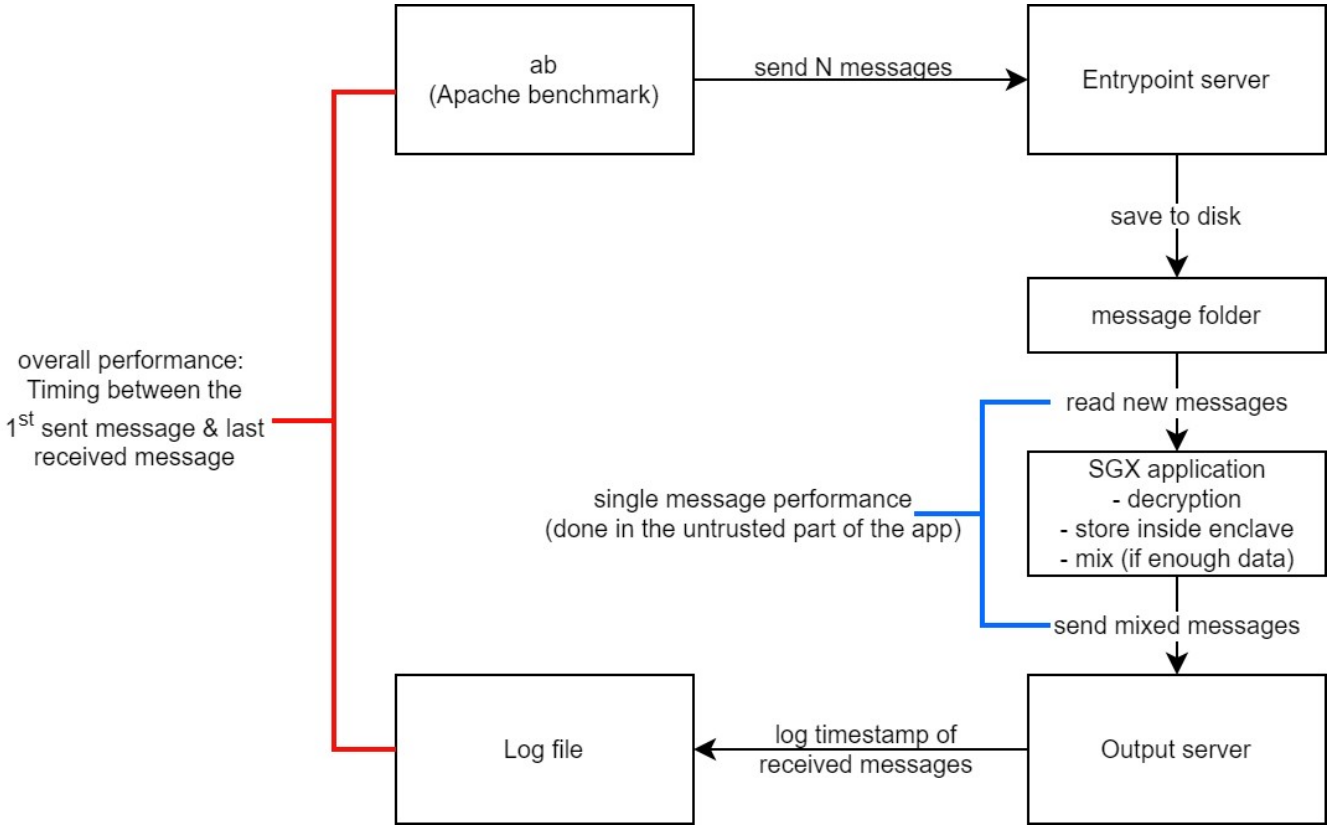
Évaluation des performances



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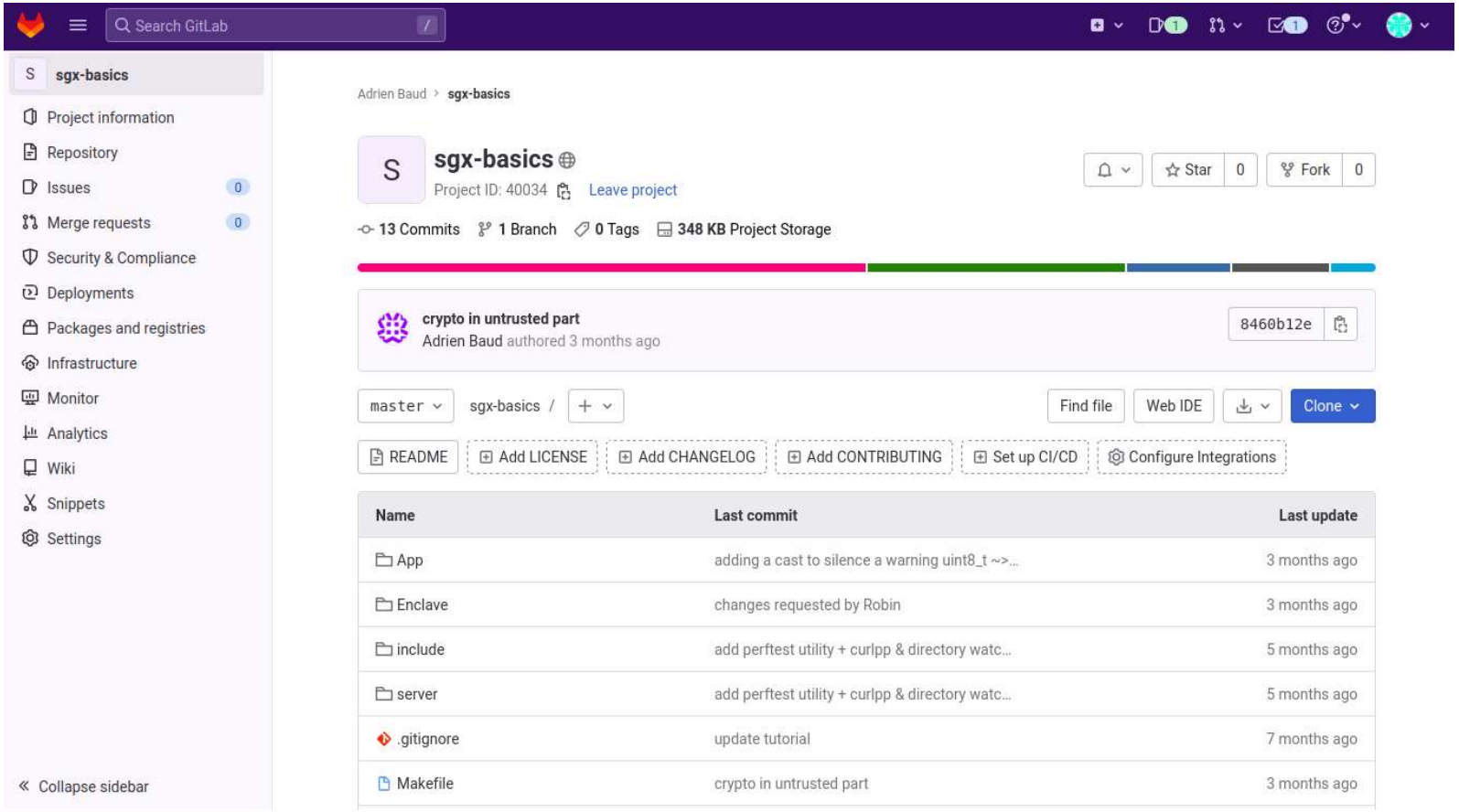
https://gitlab.inria.fr/abaud/sgx-basics



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Current trend: return personal data to the individuals to enable individual agency

Act I: the right to Data portability

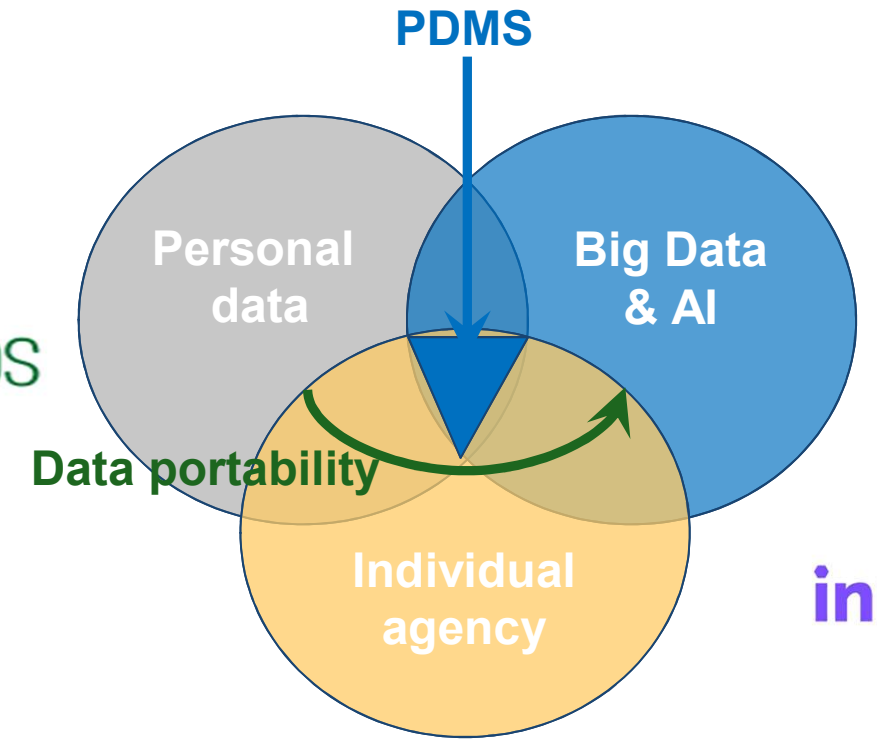
… the right to retrieve its own data

Blue Button Download My Data

Green Button Connect My Data

MesINFOS

General Data Protection Regulation



Act II: Personal Data Mg^t Systems (PDMS)

… the tool to manage its own data

cozy.io

digi.me

DATABOX

BITSABOUT.ME

inrupt Tim Berners-Lee

Personal Data Management Systems

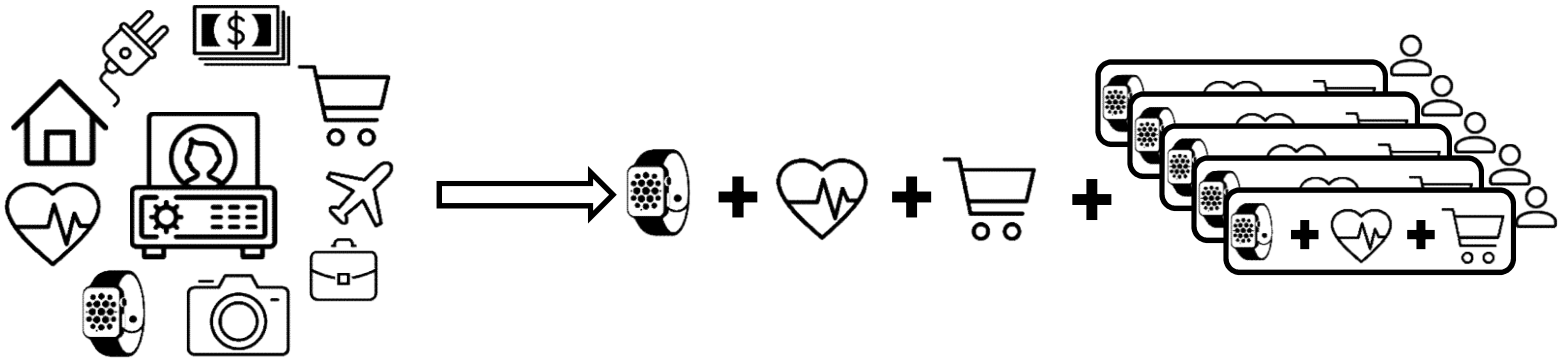
Solutions to gather the digital life of an individual

More and more solutions available (Cozy Cloud, Digi.me, Personal Infomediaries . . .)

Boosted by regulations such as Data Portability (GDPR)

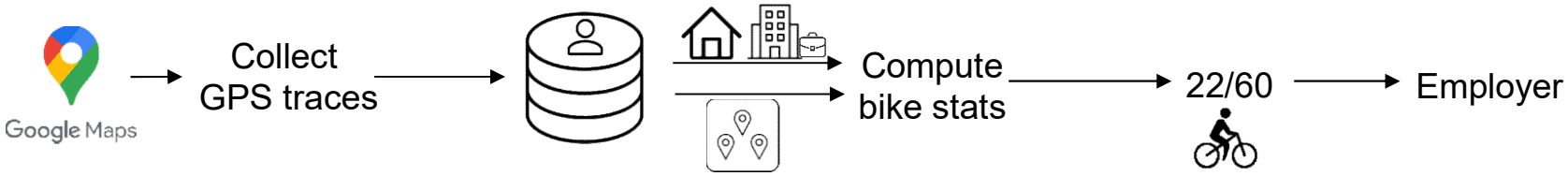
Crosses data from multiple data sources and/or multiple users

Promising paradigm : computation comes to data



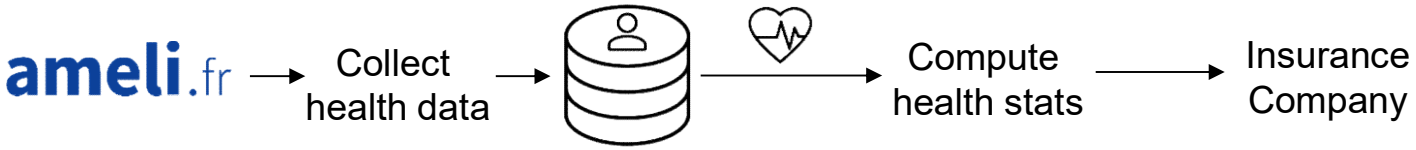
Examples of PDMS related use-cases

Companies want to reward employees commuting by bike



Green Bonus workflow

Citizens wants to get a quotation from a new health insurance company

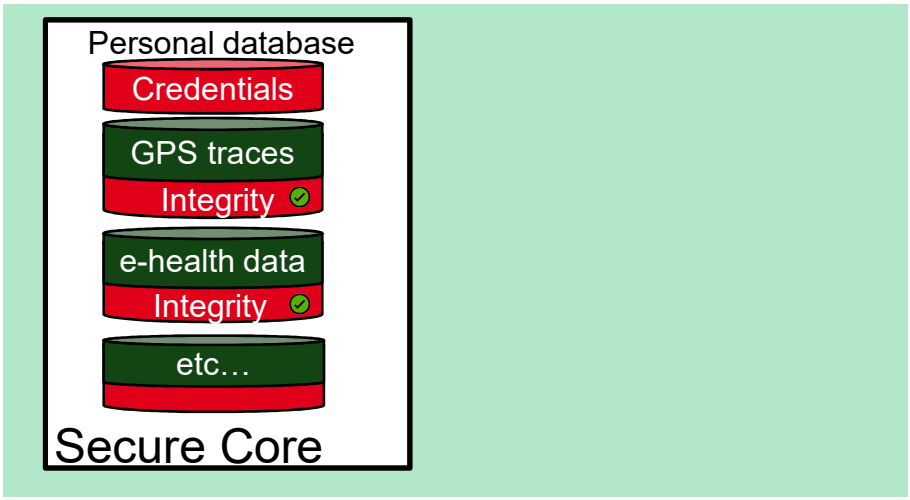


Health insurance workflow

Such use-cases require

- **Privacy**
- **Verifiability**
- **Extensibility**

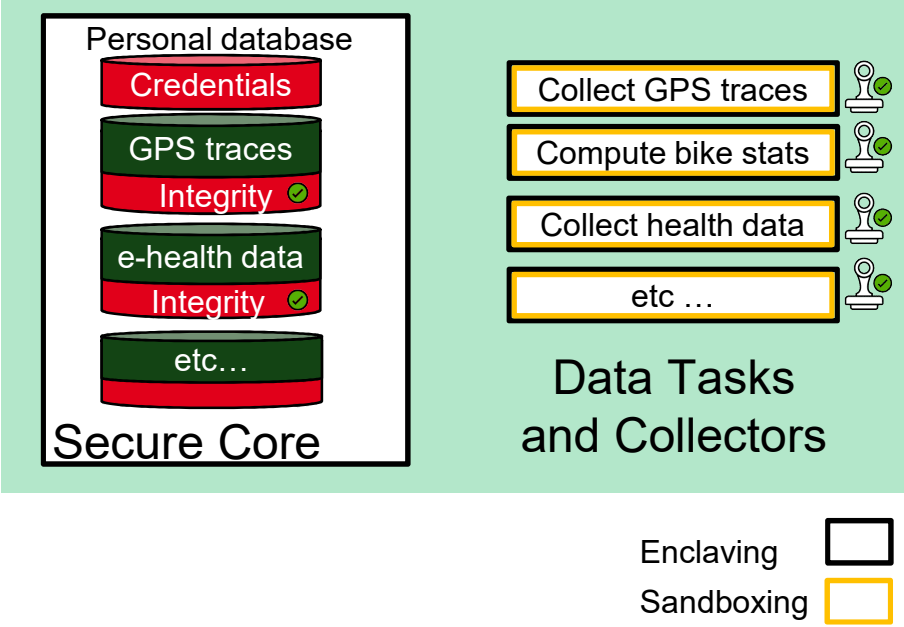
PDMS architecture leveraging SGX enclaves



Elements & Properties

- **one Secure Core**
  - Trusted Computing Base
  - Minimal and Inextensible
  - Enclaved

PDMS architecture leveraging SGX enclaves



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- **and Data Tasks/Collectors**
  - Code extensions
  - Enclaved
  - Sandboxed

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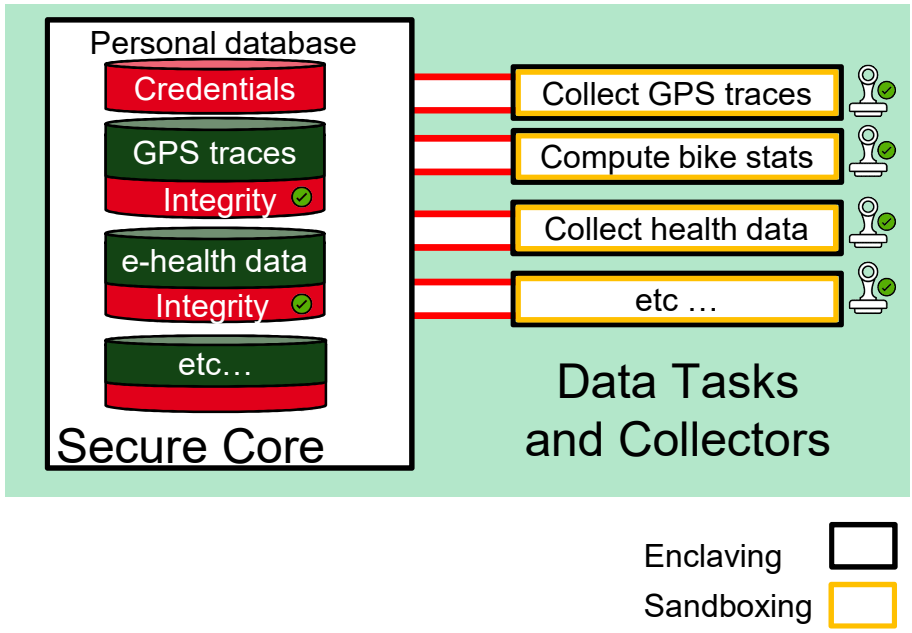

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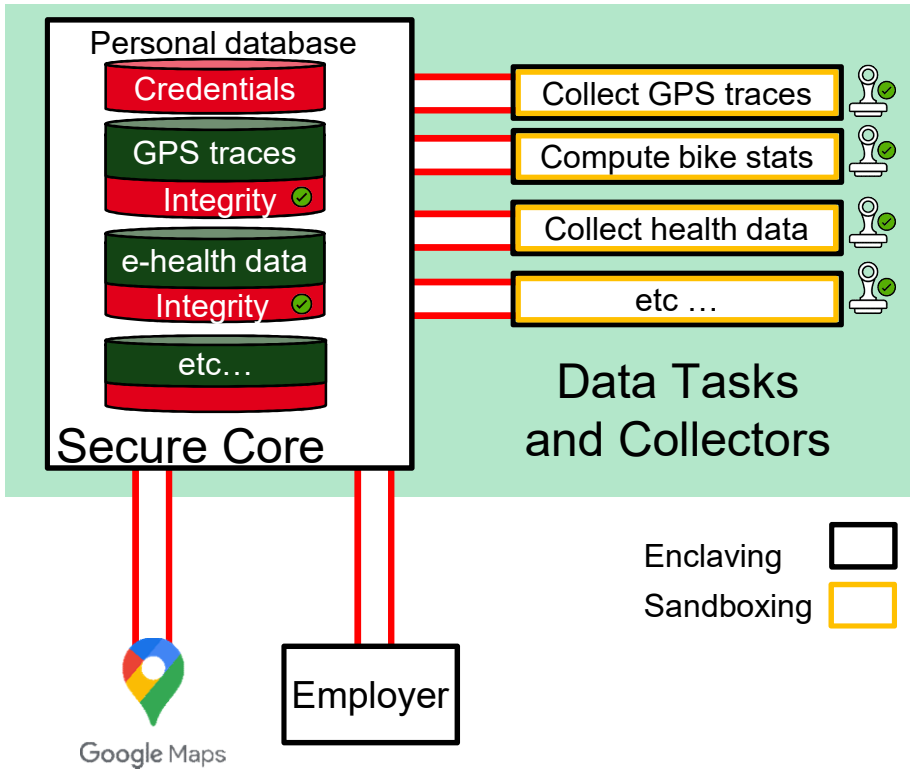

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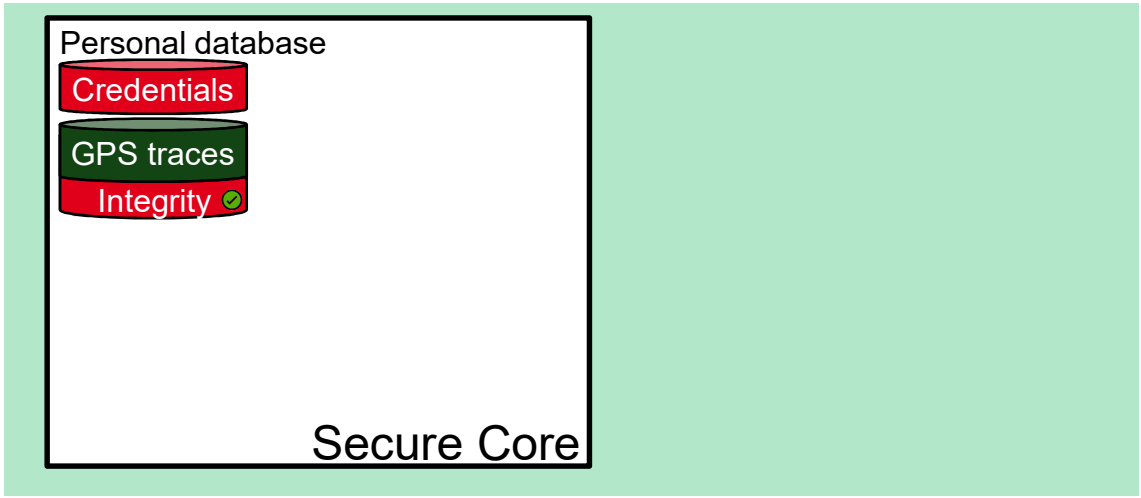
  - Sandboxed
- **Secure communications**
- **Core as proxy**

Data collection



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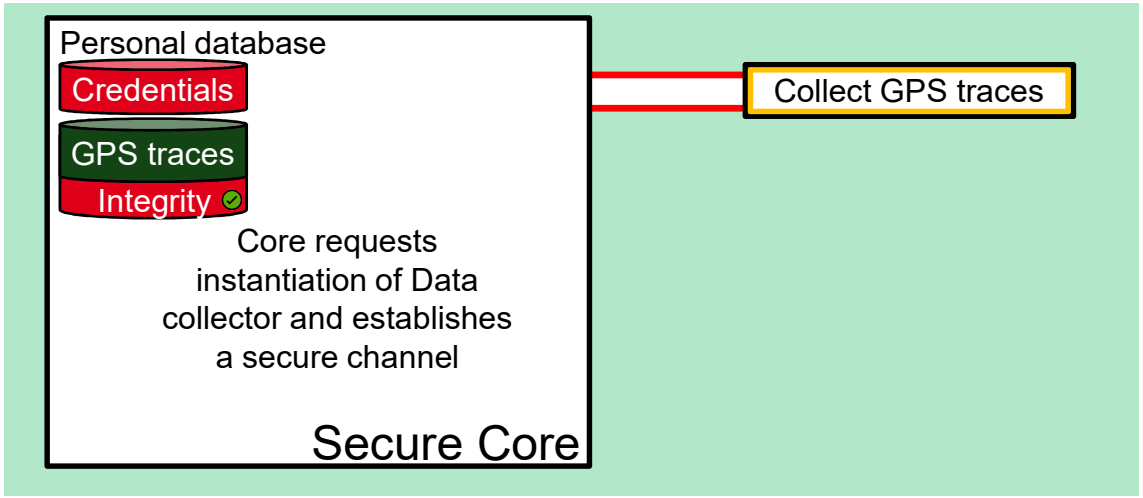

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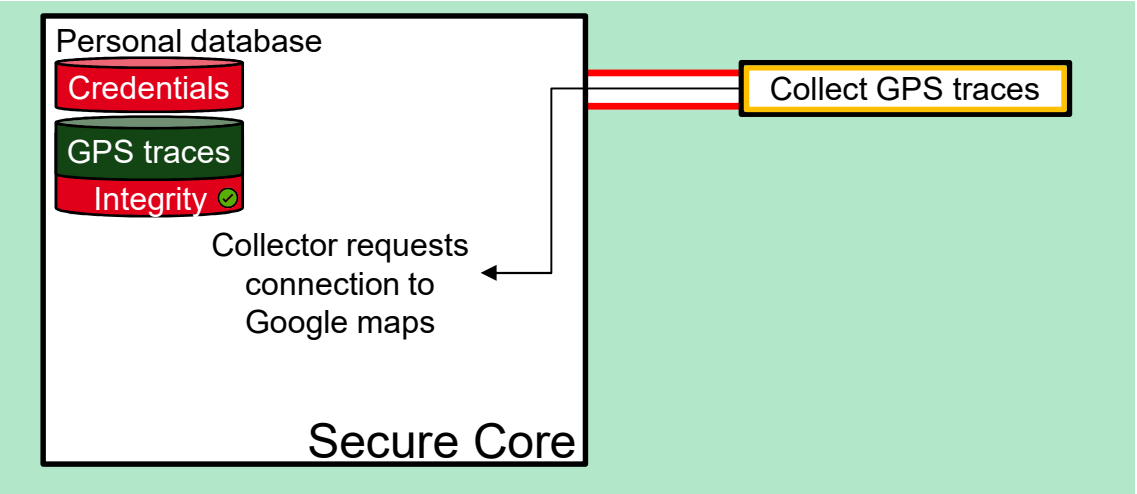

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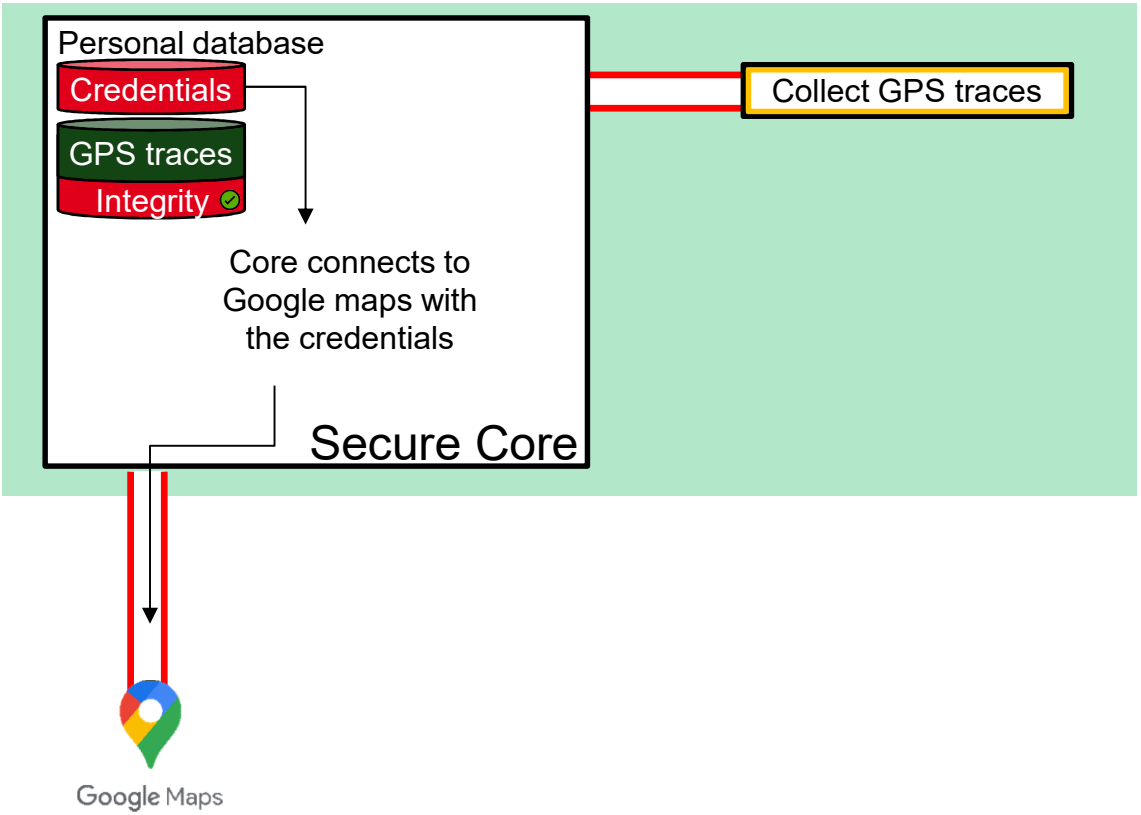

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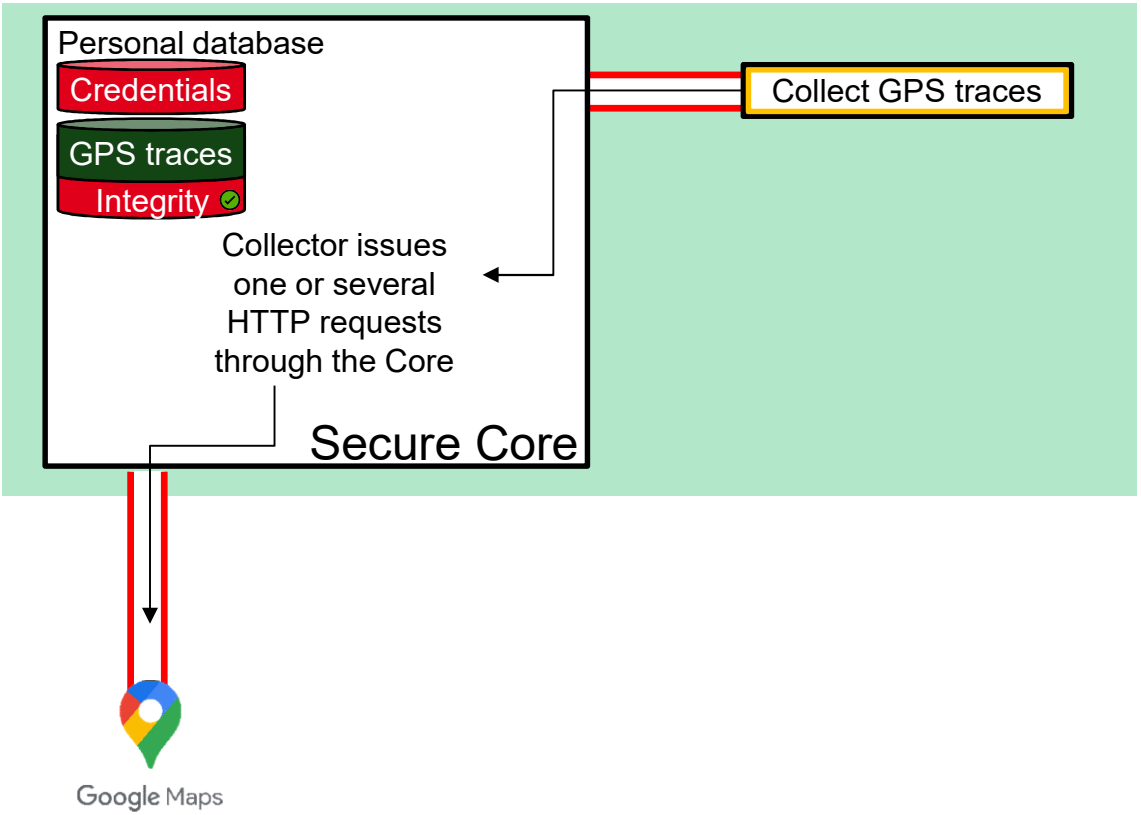

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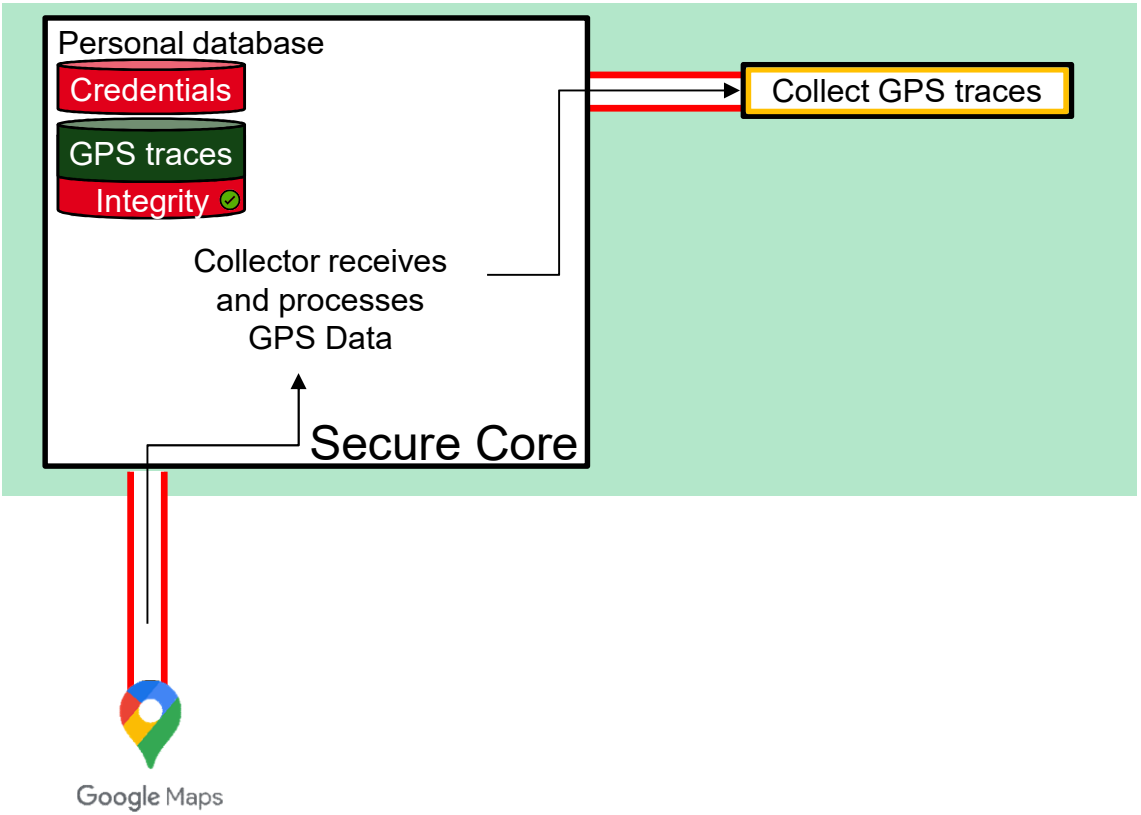

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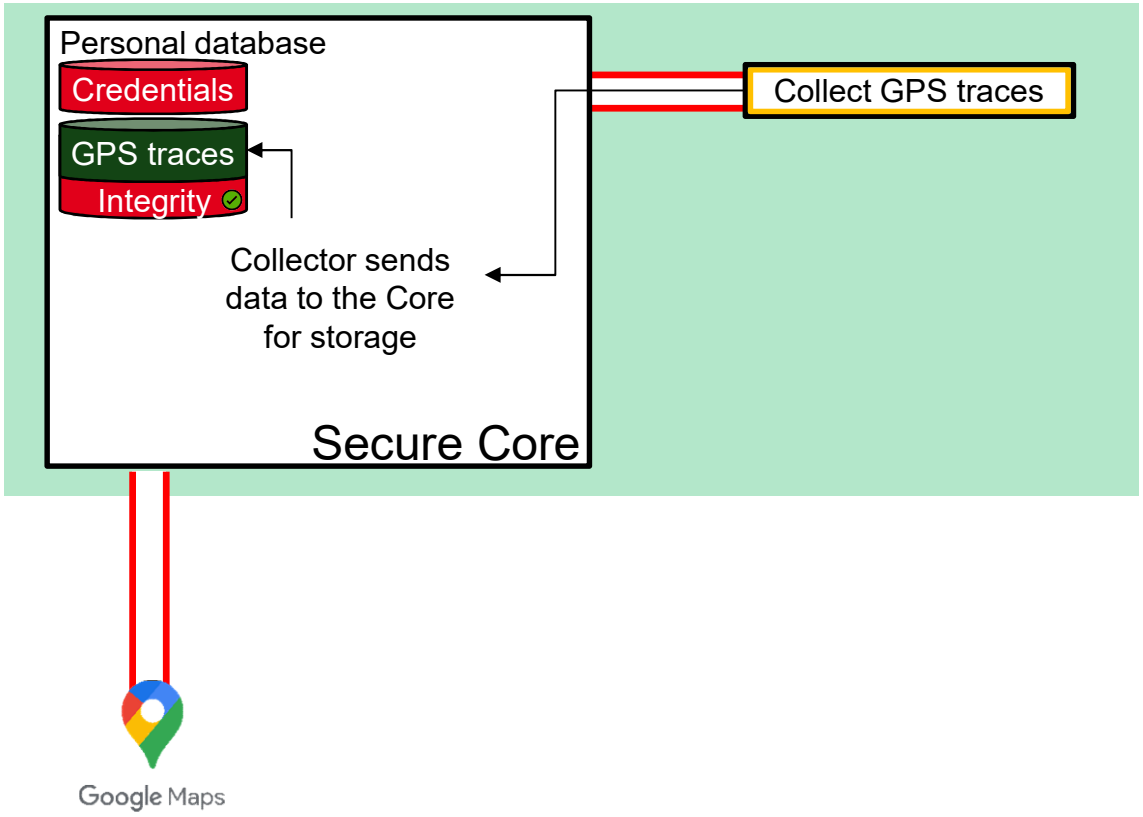
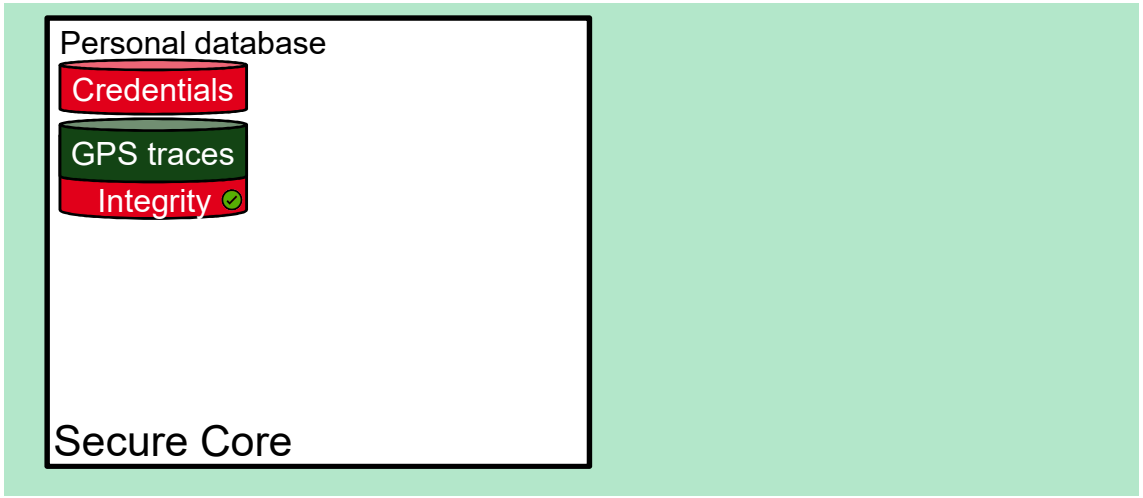


Data computation



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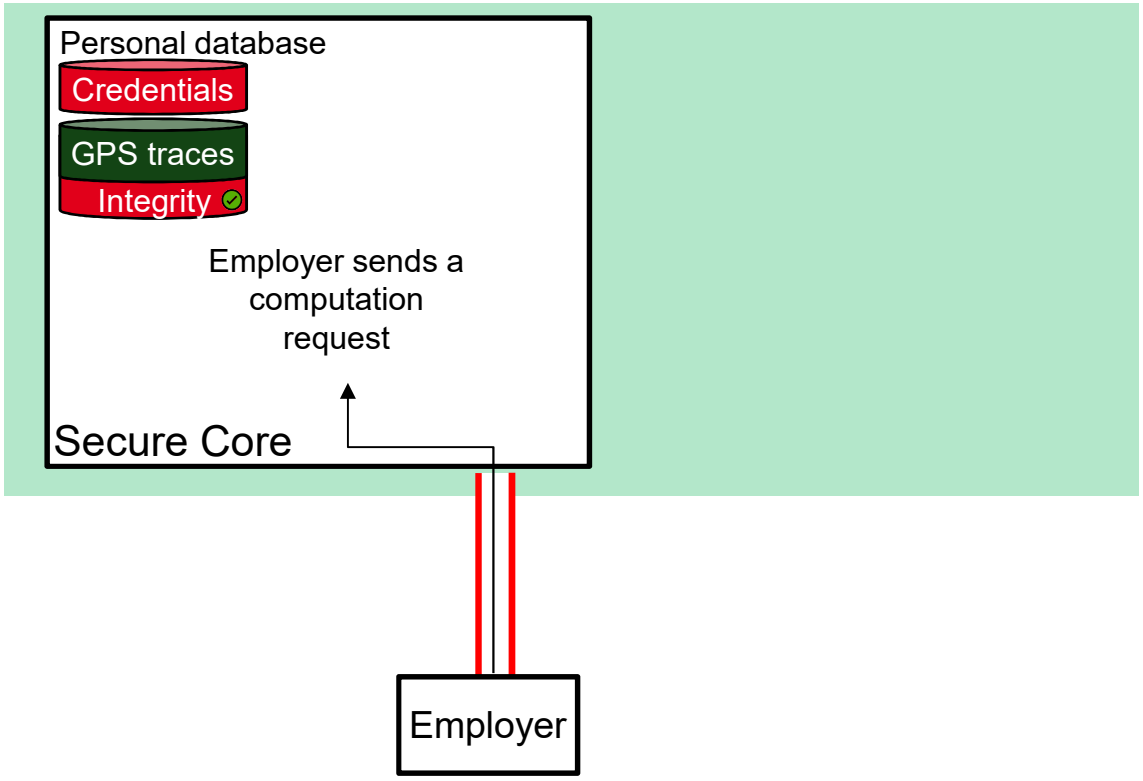

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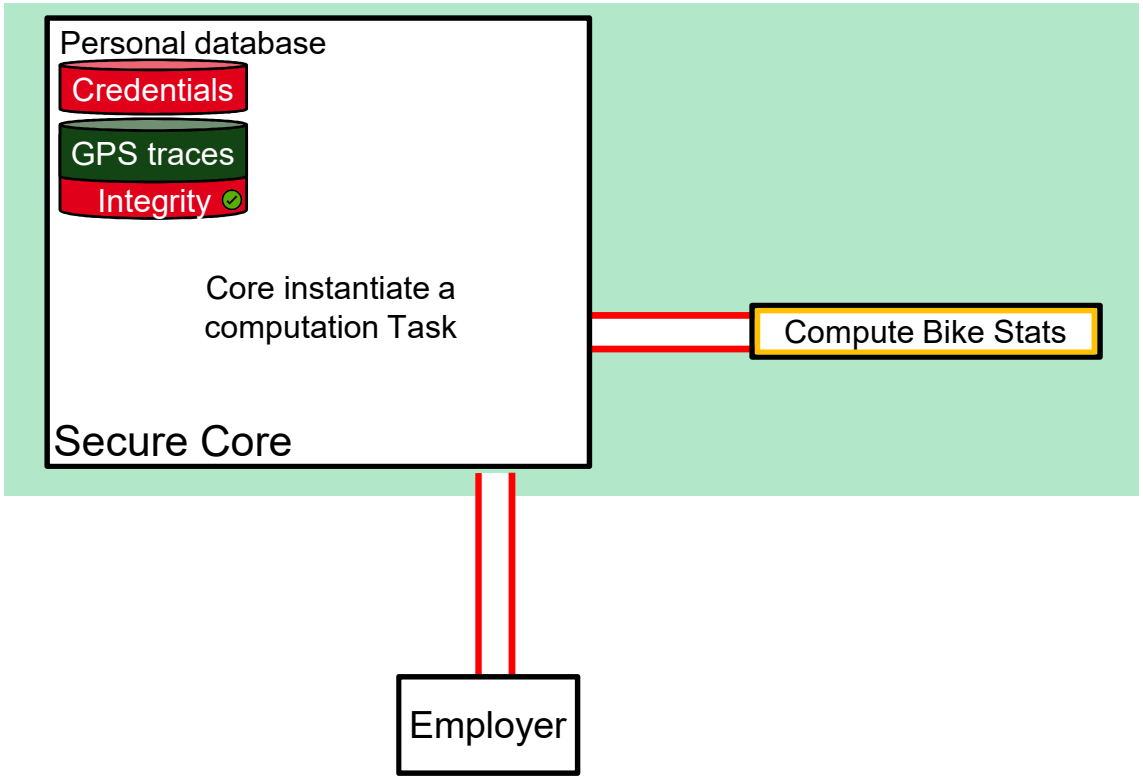

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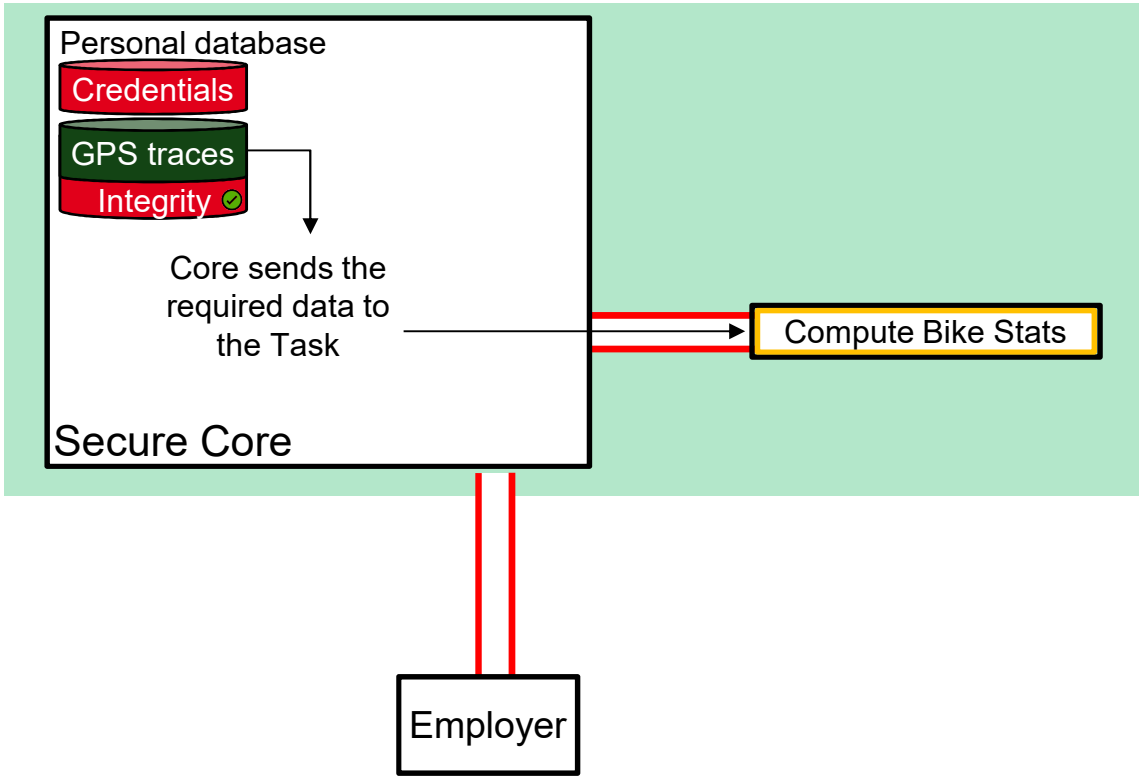

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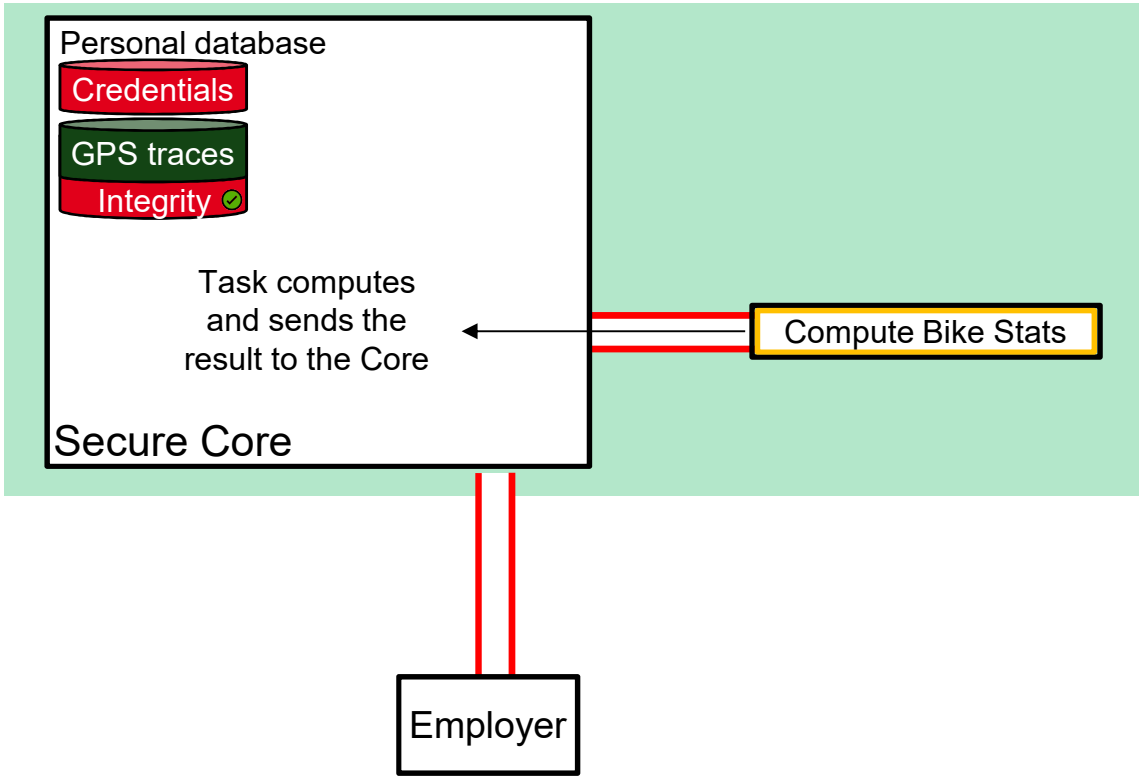

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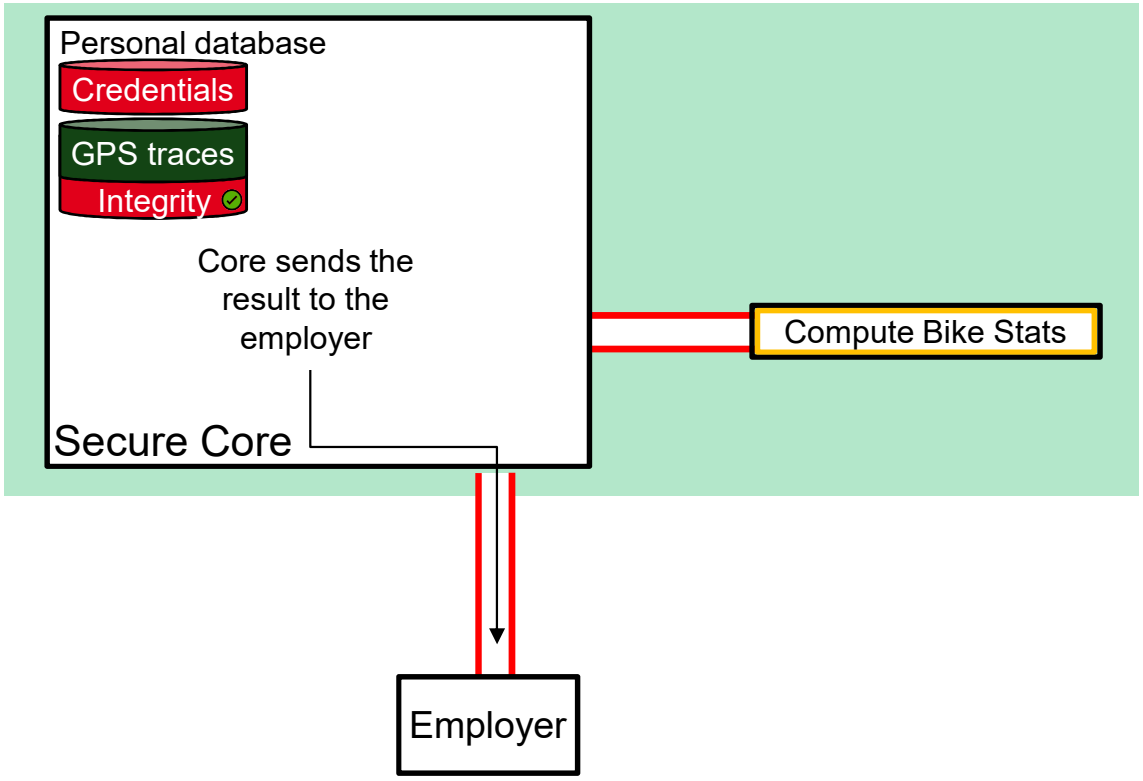

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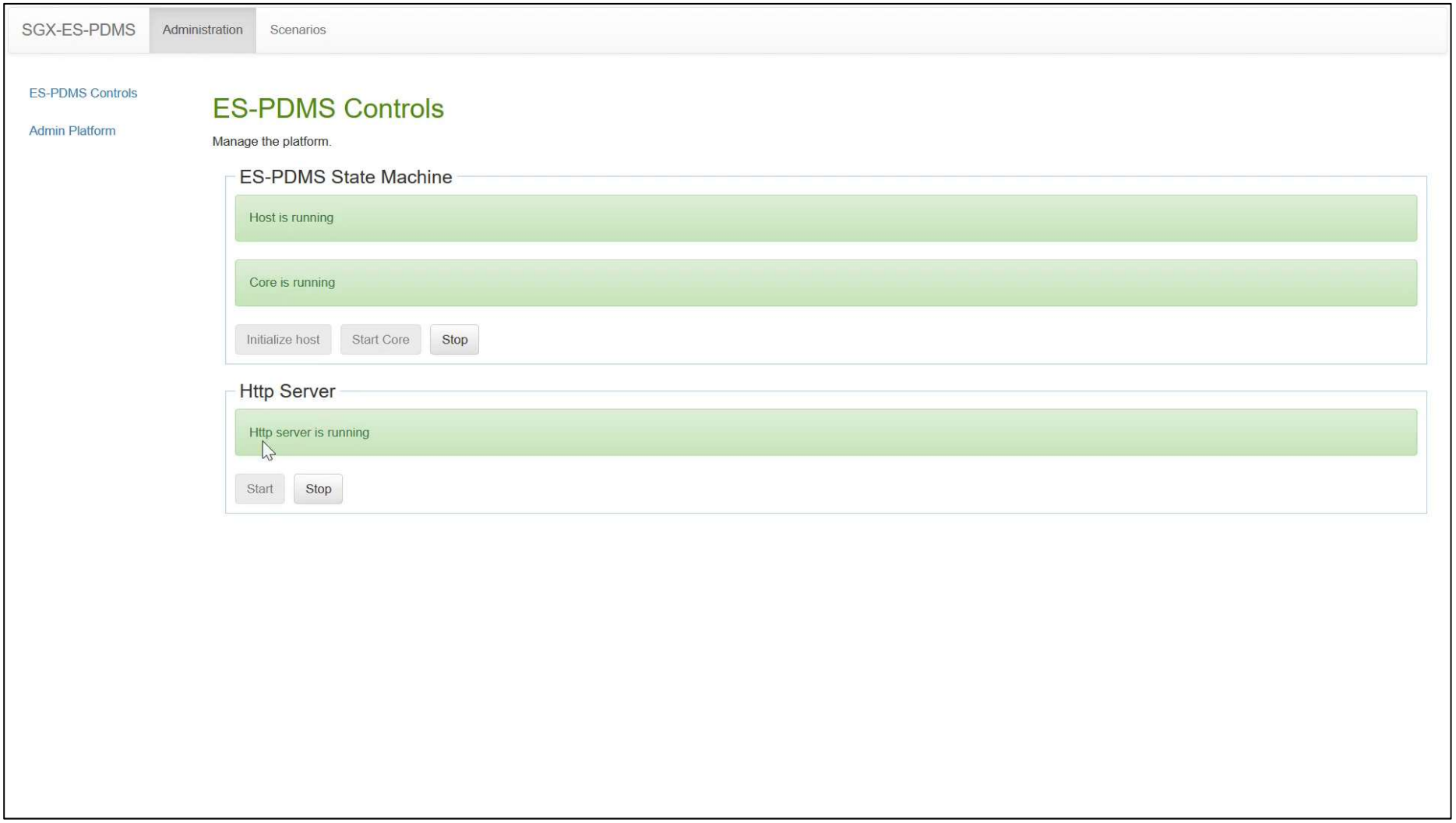

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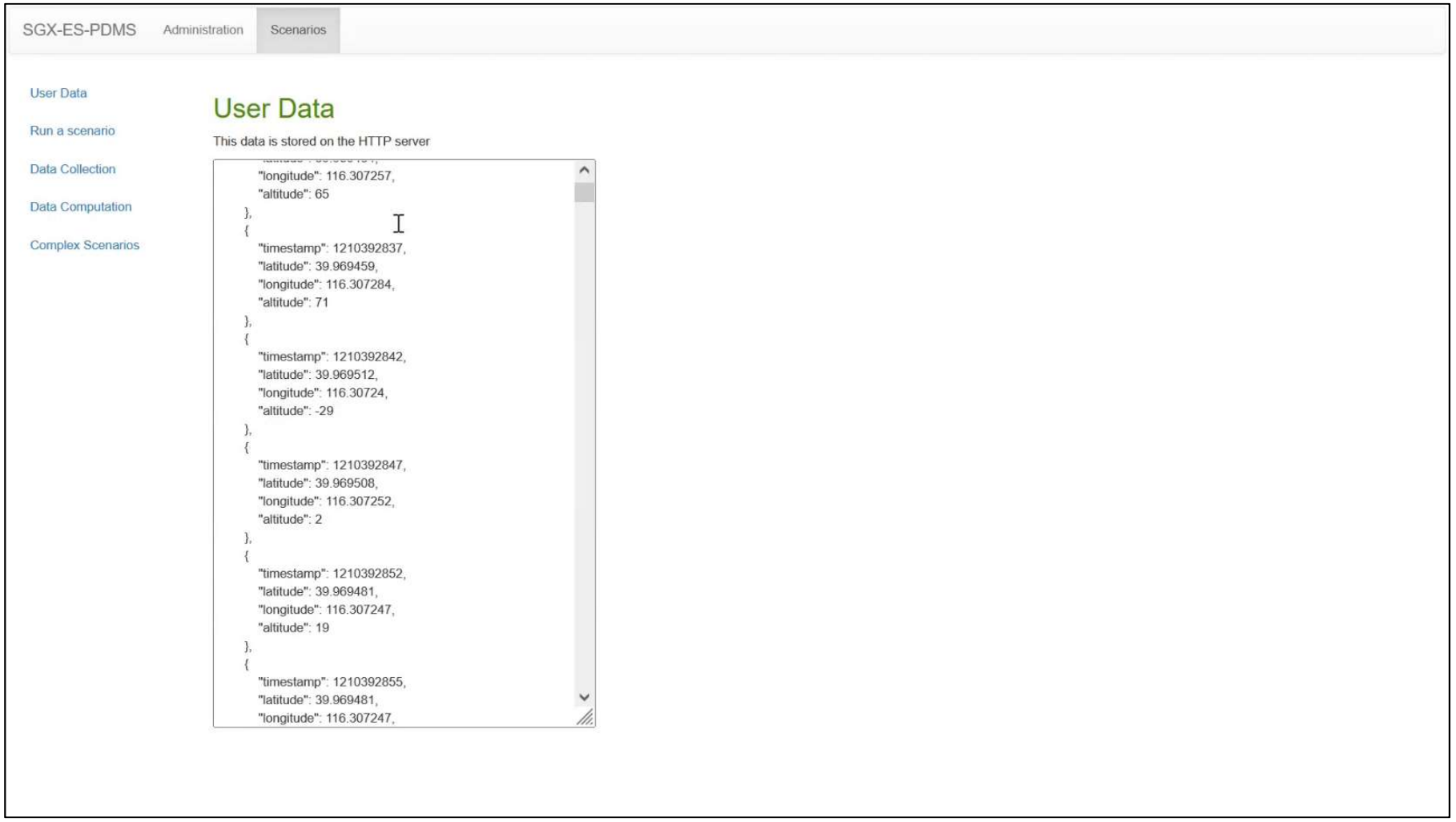

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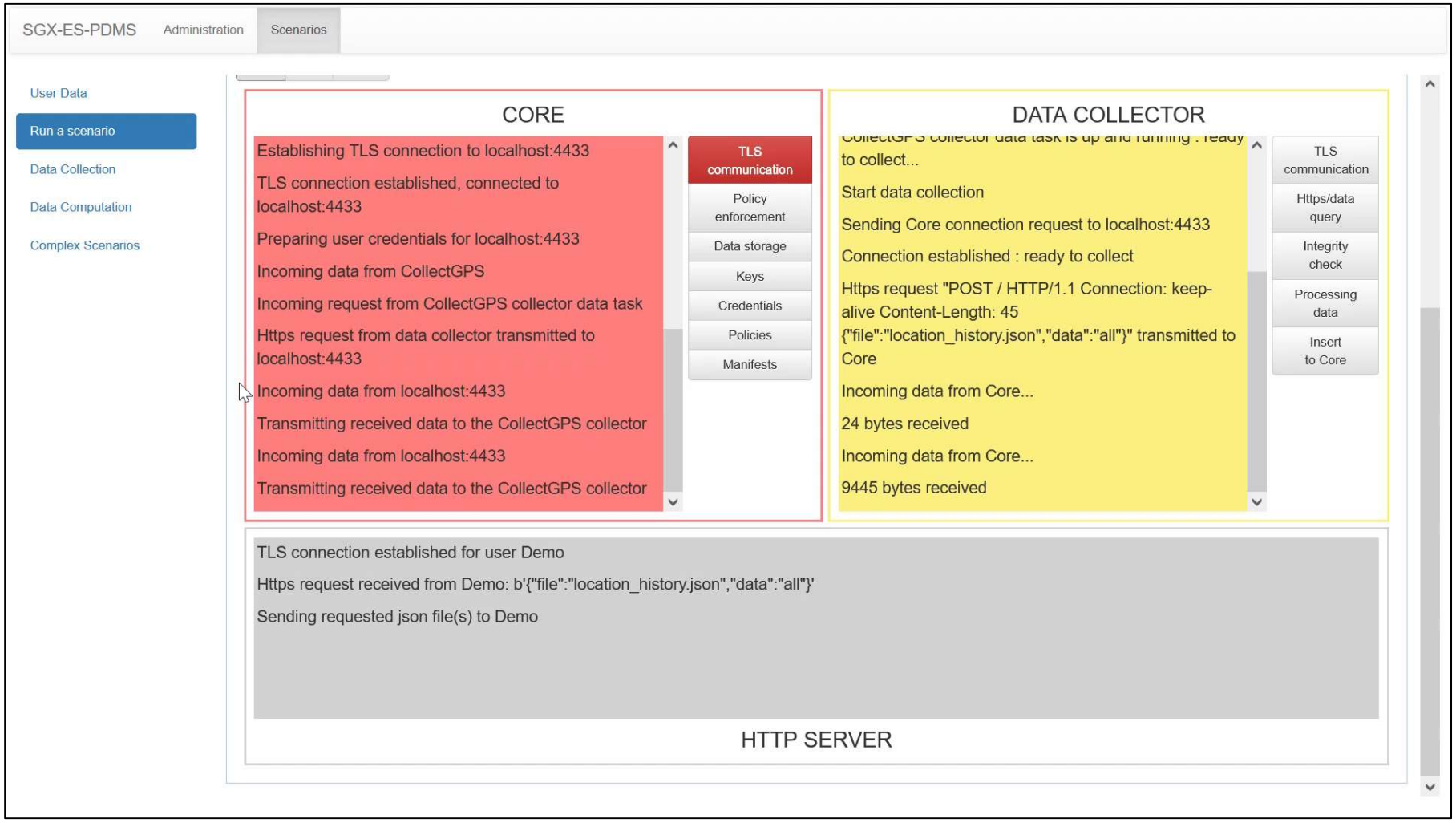

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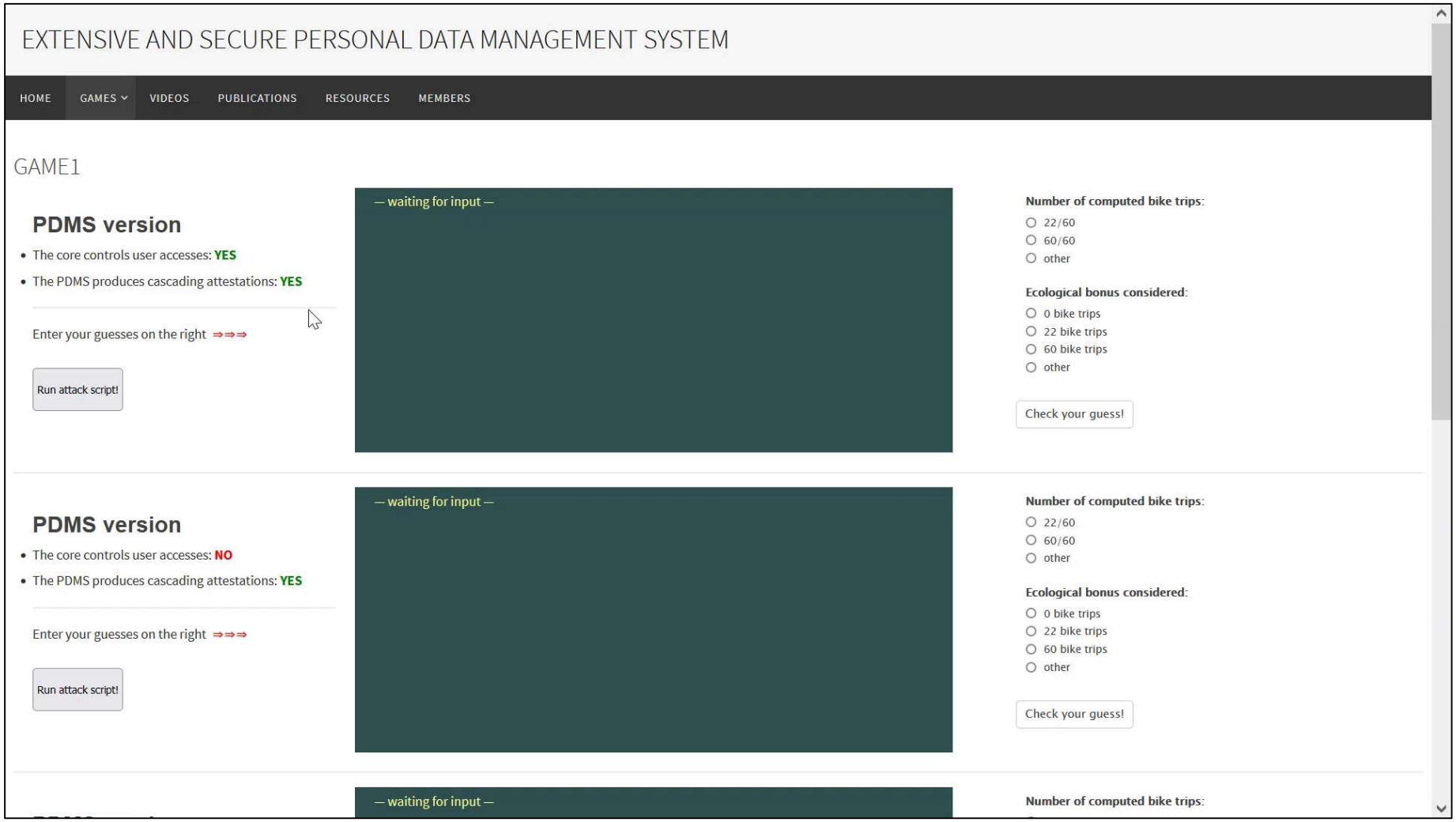

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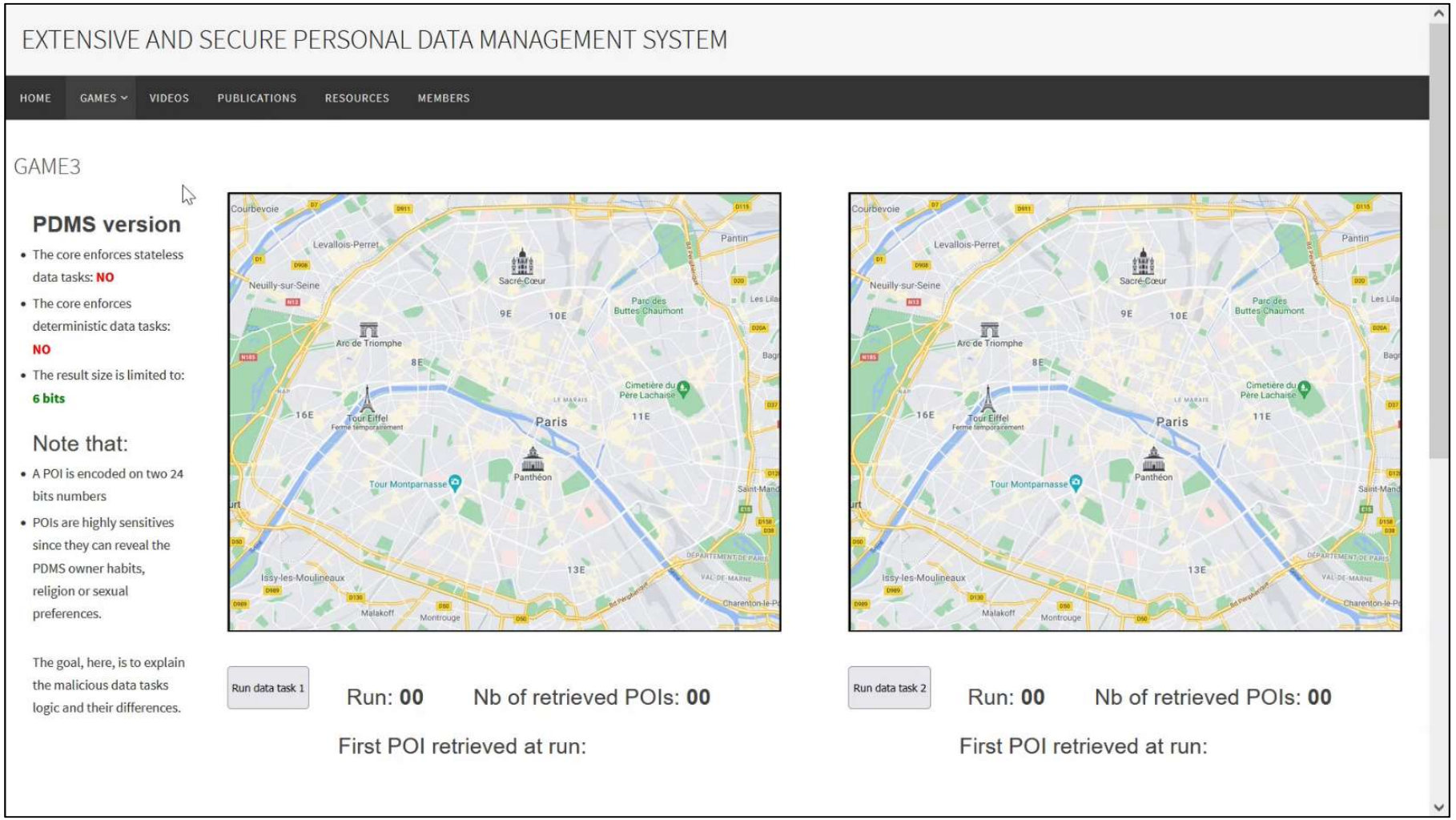

Thanks !

Questions ?

Inria

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