Using Trusted Execution Environments for Secure Stream Processing of Medical Data

DAIS'19 - 18-20 July 2019, Copenhagen (DK) - *Use-Case Paper*

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Thursday, June 13, 2019

Outline

Motivation
Why do we need secure big data processing engines?

We want to:

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UNACCEPTABLE FOR INDUSTRIES IN THE MEDICAL DOMAIN

(and many others)

Trusted Execution Environments (TEE)
Formal definition, examples and availability

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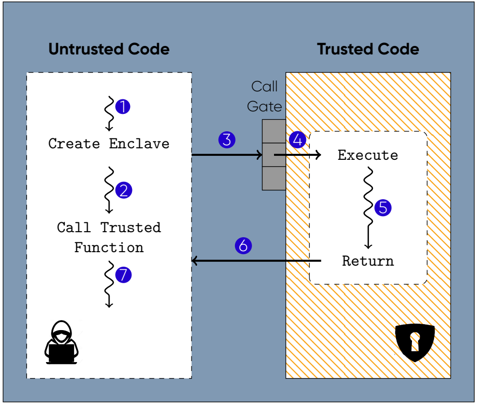
Intel SGX Available on consumer-grade CPUs starting from architecture codename *Skylake*.

Arm Trustzone Available on Cortex-A processors and v8 Cortex-M23 and Cortex-M33 (*e.g.* Raspberry Pi).

- **Intel Software Guard eXtensions (SGX)** are a set of instructions and memory access extensions that enable applications to create **hardware-protected areas** in their address space called **enclaves**.
- Security perimiter includes **only** the internals of the CPU package.
- An **attestation protocol** verifies that code is running in a **genuine enclave** and that it has not been tampered.



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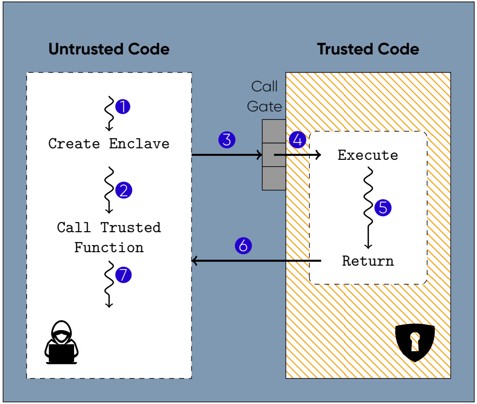

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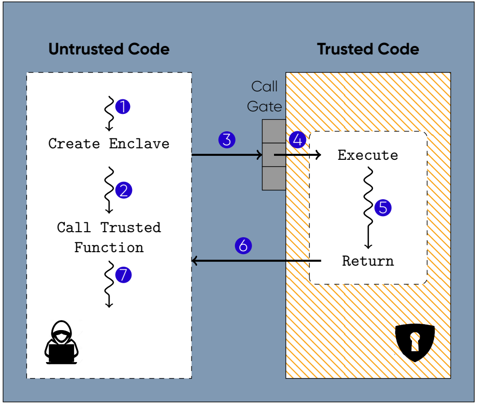

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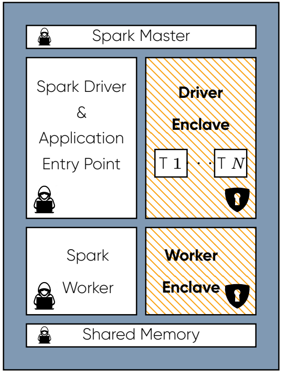

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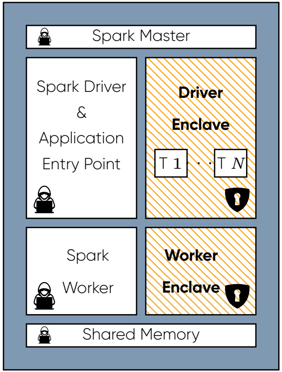

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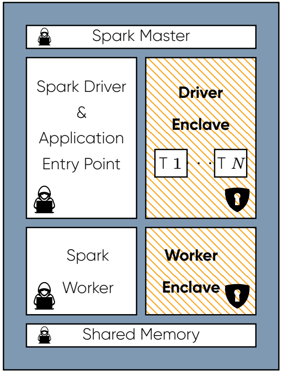

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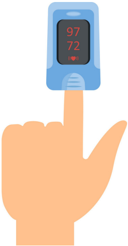
Medical Use-Case
Cardiac Monitoring, ECG, PPG, and HRV

- Our solution is **independent of the chosen data streams**, hence it could be leveraged in a variety of domains where privacy might be a concern. However,
- The data streams used for this project belong to the **medical** domain, in particular, they are obtained from human **cardiac activity monitoring**. The two most standard procedures are:

1. **ECG:** measure heart's electrical activity over time. *E.g:* chest straps.
2. **PPG:** measure blood's volume variation over time. *E.g:* smartwatches and pulse oximeters.



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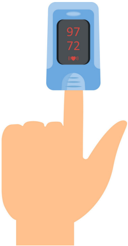

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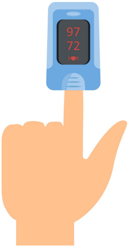

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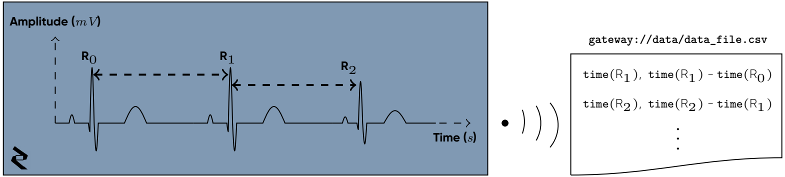
- We are interested in the **inter-beat intervals** from the generated diagram ($23 - 69$ B per second per user).
- From an **ECG** we can obtain obtain these intervals from the time between **R peaks**, abbreviated as RR intervals (Figure 3).
- With their **timestamps** we compute a live analysis of the **Heart Rate Variability (HRV)**.



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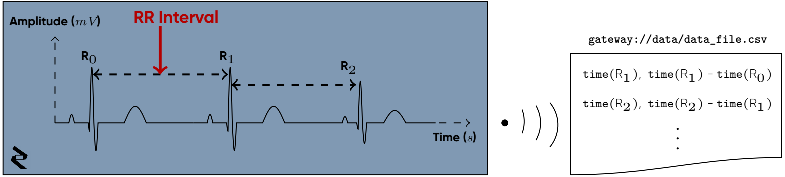

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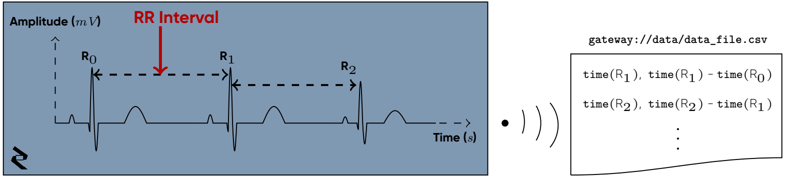

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Project Goals

- Use SGX-Spark to implement a **streaming platform** that gathers data from sensors and **securely** outsources computation.
  - Deploy in an existing medical environment.
  - Perform stress tests to assess the system's robustness and reliability.
  - Evaluate and quantify the overhead of providing strong security guarantees.

Secure Stream Processing of Medical Data
Envisioned Scenario

The **chosen scenario** involves:

1. ECG data streamed from a **sensor** to a **gateway**
2. Real-time processing with **HRV** algorithms: SDNN and HRV Bands analysis.
   - **SDNN:** rolling standard deviation of NN (RR) intervals.
   - **HRV Bands:** rolling Discrete Fourier Transform and low/high frequency component.
3. Support for **storage** and result **post-processing**

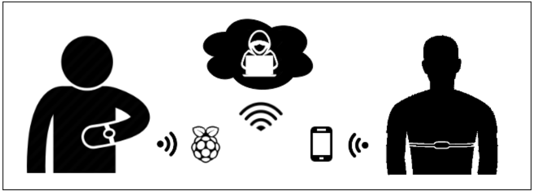


Figure 4: Wearable-enabled ecosystem of our platform.

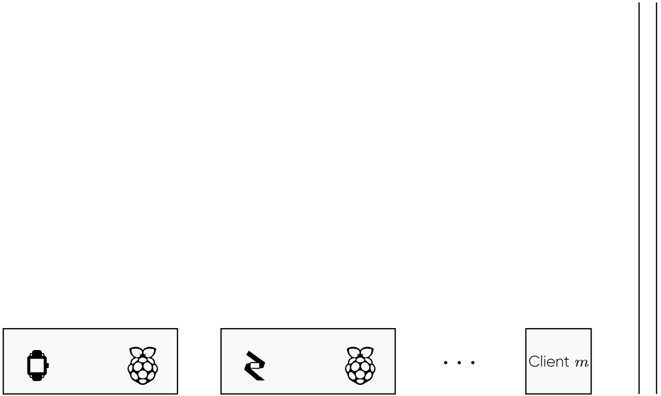
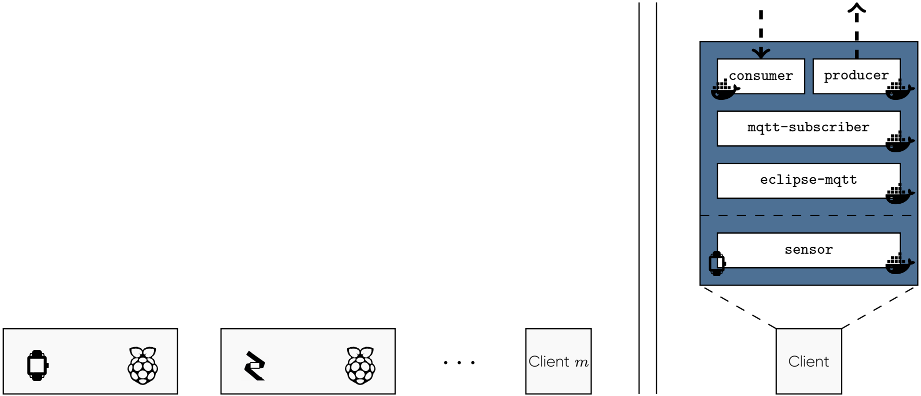


Figure 5: Client-server architecture.

System Architecture
Component Analysis and Execution Workflow



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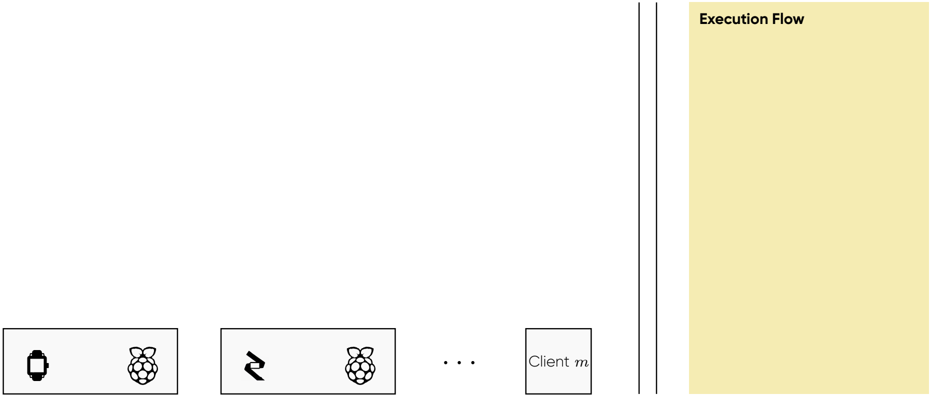

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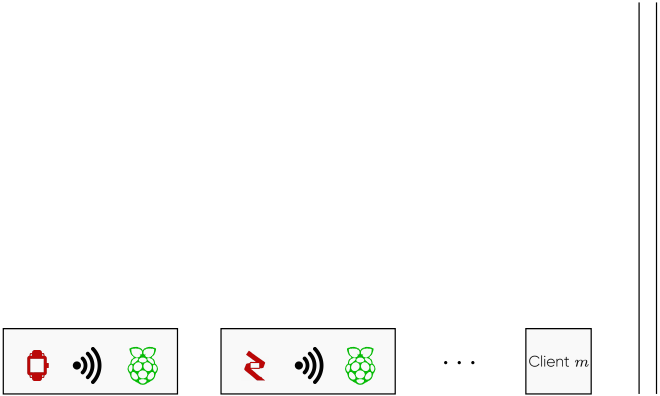

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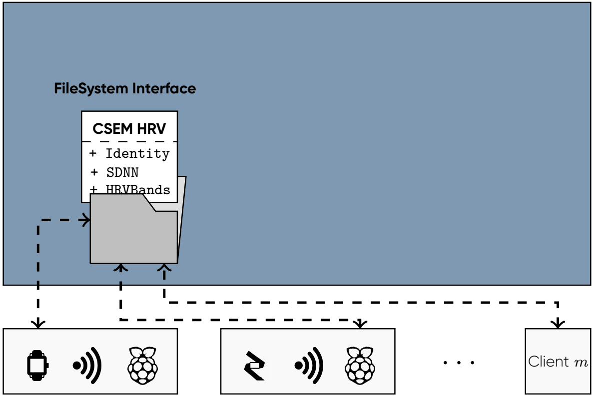

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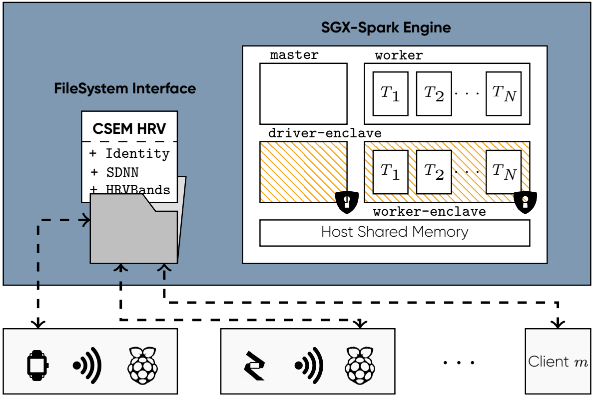

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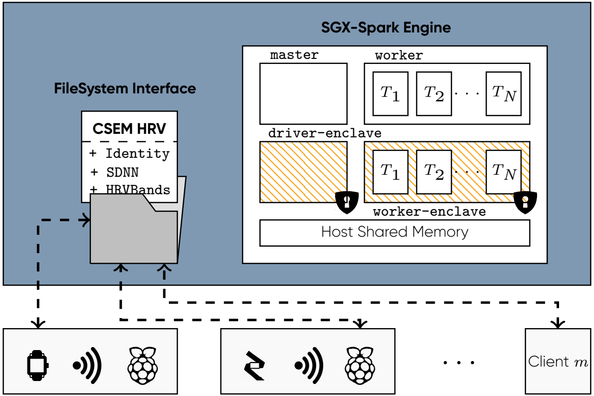

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4. Gateways fetch result files

Evaluation & Results
Experimental Setup & Metrics

Three Execution Modes:

1. Vanilla Spark
2. SGX-Spark w/o Enclaves
3. **SGX-Spark w/ Enclaves**

Two Algorithms:

1. `Identity` (Batch & Stream)
2. `SDNN` (Batch & Stream)

Two Metrics:

1. Elapsed Time
2. Avg. Batch Processing Time

Workload	`s_rate` (samples / sec)	Input Load
Batch - Small	$\{44, 89, 178, 356, 712, 1424\}$	$\{1, 2, 4, 8, 16, 32\}$ kB
Stream - Small	$\{44, 89, 178, 356, 712, 1424\}$	$\{1, 2, 4, 8, 16, 32\}$ kB / sec
Batch - Big	$\{44, 89, 178, 356, 712, 1424\} * 1024$	$\{1, 2, 4, 8, 16, 32\}$ MB
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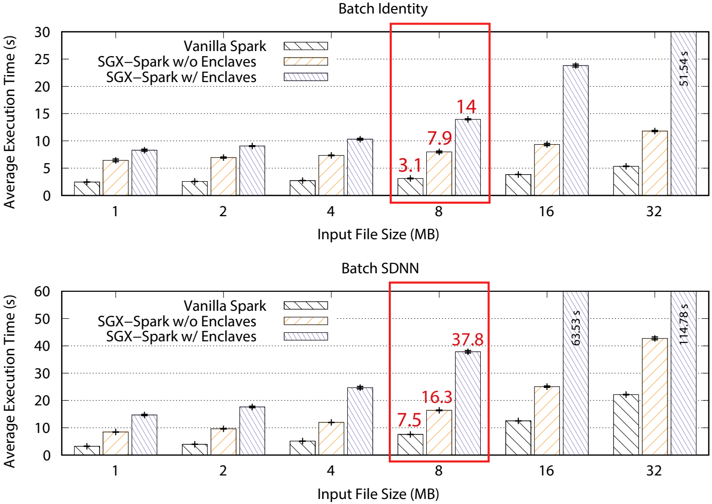
Results: Batch Execution - Big Load



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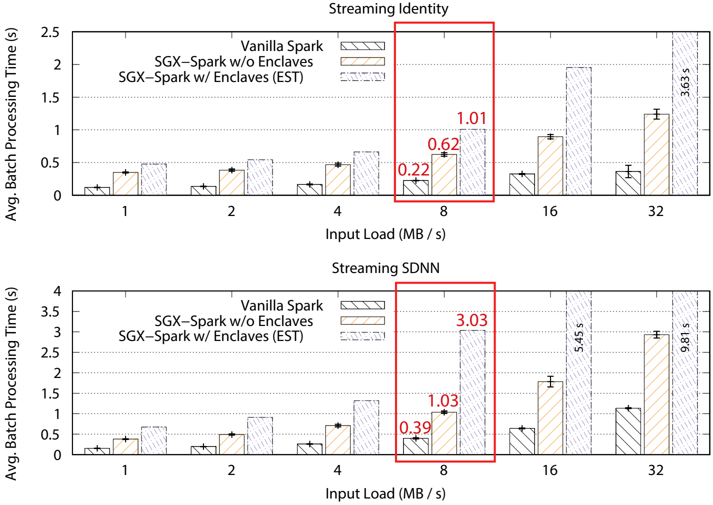

Conclusion

- Introduced a PoC of a **privacy-preserving streaming platform**.
    - Introduces $4\times - 5\times$ slowdown vs. **vanilla Spark Streaming** (load < 4 MB per second).
    - Requires **no changes** to the application source code.
- Further lines of research:
    - Perform an economical evaluation of the cost of deploying our system to the cloud: **how expensive is privacy?**
    - **Reduce the TCB** on the client side leveraging TEEs for low-power devices (*e.g.* ARM TrustZone).

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