Graphene:

Securing unmodified Linux Applications with Confidential Computing

Prof Don Porter, UNC, Chapel Hill
Mona Vij, Principal Engineer, Intel

The Confidential Computing Consortium

- Community focused on Open Source licensed projects securing DATA IN USE and accelerating the adoption of confidential computing through open collaboration
- Announced the intent to form in August at the Open Source Summit North America in San Diego, formally launched on 17 October 2019 with governance in place

Please visit https://confidentialcomputing.io

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MIT Connection Science

OASIS LABS

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Confidential Computing

Confidential Computing Definition

Confidential Computing is the ***protection of data in use*** *by performing computation in a* ***hardware-based Trusted Execution Environment***

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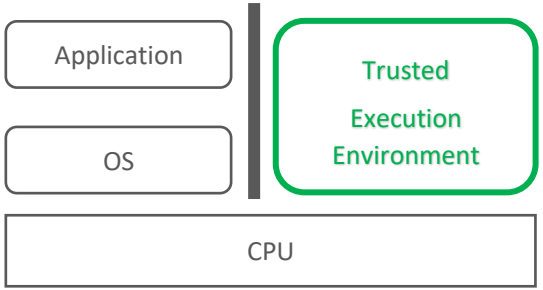
Trusted Execution Environment (TEE)

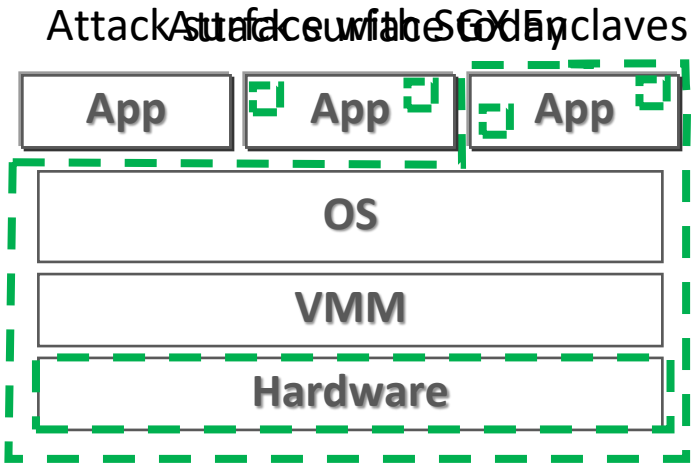
- A TEE is an environment that provides a level of assurance of three key properties
  - Data Confidentiality
  - Data Integrity
  - Code Integrity
- Hardware based TEE
  - Maps to a secure portion of memory
  - The code and data inside TEE can not be accessed from outside
  - Can prove to 3rd party its identity via attestation



- Most major hardware vendors support TEE
  - **Intel® SGX**, Intel TDX, AMD SEV, ARM TrustZone

Intel® Software Guard Extension (Intel® SGX)

- Intel® SGX provides a set of ISA extensions to build a protected enclave
- Application is split into untrusted app and trusted enclave
- Application builds trusted enclave with well-defined entry points
- Attest enclave fingerprint to 3rd parties for verification and secrets provisioning



Lift and Shift Unmodified Applications

- In un-trusted cloud and edge deployments, there is a strong desire to shield the whole application from rest of the infrastructure
- Developers want end-to-end secure solutions with “push-button” approach
- Graphene supports lift and shift paradigm for unmodified application binaries for CC with Intel SGX

Graphene Overview

Graphene Project Summary

- Technical acceptance by CCC - pending legal review for trademark/naming

- Graphene runs unmodified Linux Applications on other platforms
  - Current focus on Intel® SGX
- Community maintained Open-Source (LGPL) project hosted on Github
- Well defined testing and validation criteria with CI/CD (Jenkins)
- Project maintenance is governed via a well-defined governance criteria
- Cloud deployment with Azure Kubernetes Service
- Very actively being developed towards production readiness in Q2'21

Growing Community

AI/ML

Databases

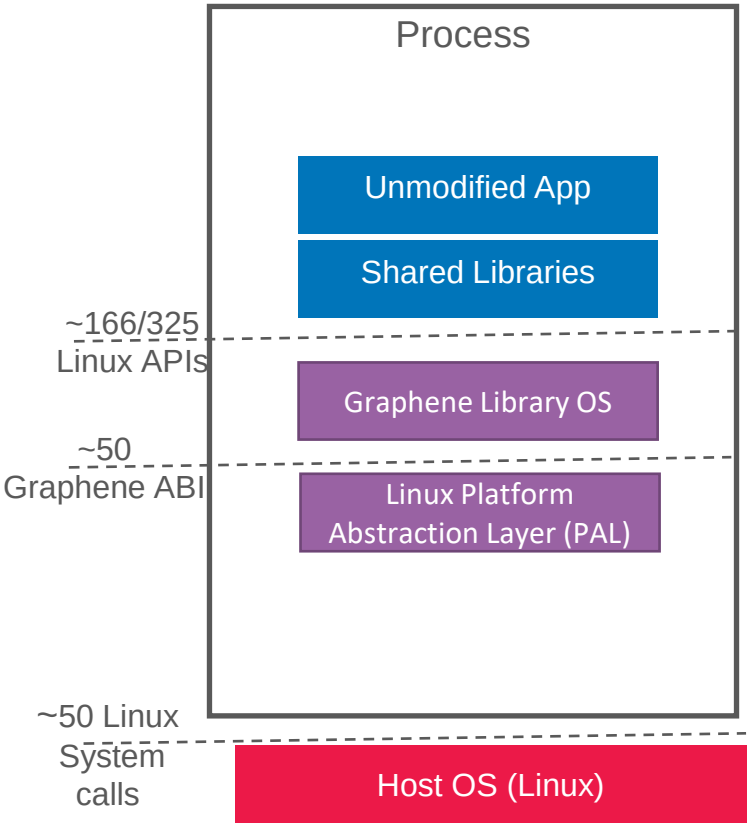
Web Servers

Languages

Misc

Graphene Architecture

Graphene Library OS



SUNY Stony Brook
Graphene [EuroSys'14]

Cooperation and Security Isolation of Library OSes for Multi-Process Applications

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Intel Labs and SUNY Stony Brook
Graphene-SGX [ATC'17]

Graphene-SGX: A Practical Library OS for Unmodified Applications on SGX

Chia-Che Tsai
Stony Brook University

Donald E. Porter
University of North Carolina at Chapel Hill and Fortanix

Mona Vij
Intel Corporation

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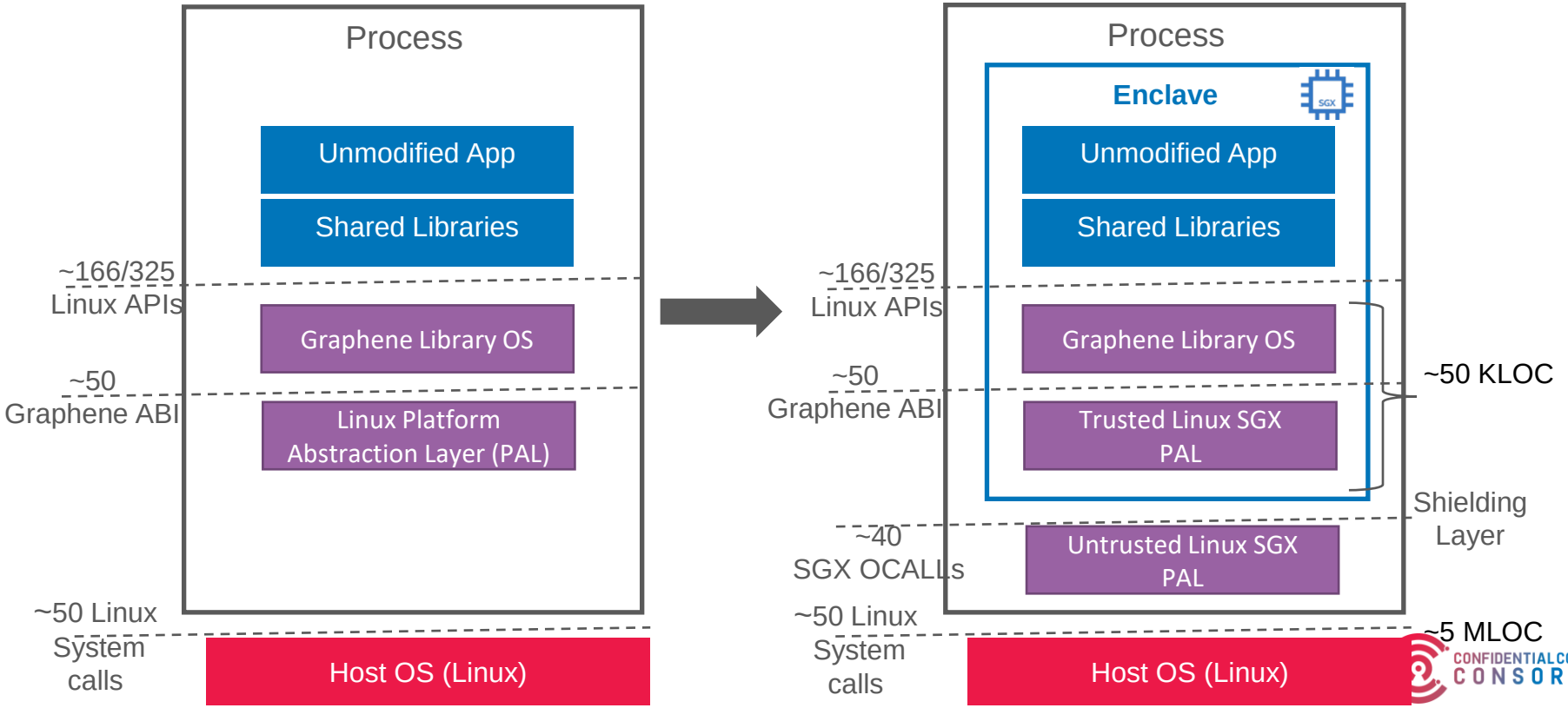
Library OS architecture is very suitable for Intel® SGX



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Graphene Shielding Layer

- All security-critical paths are hardened against eavesdropping/attacks
  - Integrity of the loadable libraries is verified via checking against valid hash values
  - Transparent File encryption is supported via protected FS for “protected” files”
  - Migration of checkpointed state from parent to the child process is transparently encrypted for secure fork
  - All Pipes, messages and signals among Graphene processes are encrypted
  - Additional checks in SGX-PAL prevent against Iago attacks
- All network communication is assumed to be SSL/TLS-protected by the app itself

Enabling app in Graphene requires a manifest file

redis.manifest (TOML format)

```
libos.entrypoint = “file:/usr/bin/redis”
loader.env.LD_LIBRARY_PATH = “/lib”

fs.mount.lib.type = “chroot”
fs.mount.lib.path = “/lib”
fs.mount.lib.uri = “file:/graphene/Runtime”

sgx.enclave_size = “1024M”
sgx.thread_num = 8

sgx.trusted_files.libc = “file:/graphene/Runtime/libc.so.6”
…
```

Executable to load into SGX enclave

Environment variables are overwritten

Restrict mount points to a small subset of host-OS directories

SGX-specific limits like the maximum enclave size and number of threads

SGX-specific trusted files (securely hashed and verified at load time)

Graphene Features for SGX Infrastructure

- SGX Attestation
  - Supports both EPID and DCAP/ECDSA SGX attestations
- Protected Files
  - Automatically encrypt/decrypt specified files in the manifest
- Asynchronous System Calls
  - Exit-less support as a performance enhancement feature
- Multi-process support
  - Fork and secure comm between parent and child process via encrypted IPC
- Docker Integration
  - Automatically convert Docker images to Graphene images

Graphene Remote Attestation

Graphene Remote Attestation

There level approach to Attestation

- Remote/Local Attestation Support:
  - Exposed via `/dev/attestation` pseudo-filesystem
  - Integrates with multiple backends under the hood including Intel DCAP
- Secure Channel Establishment
  - Constructed using RA-TLS (Remote Attestation integrated with Transport Layer Security)
- Secret Provisioning
  - Built using secret provisioning libraries

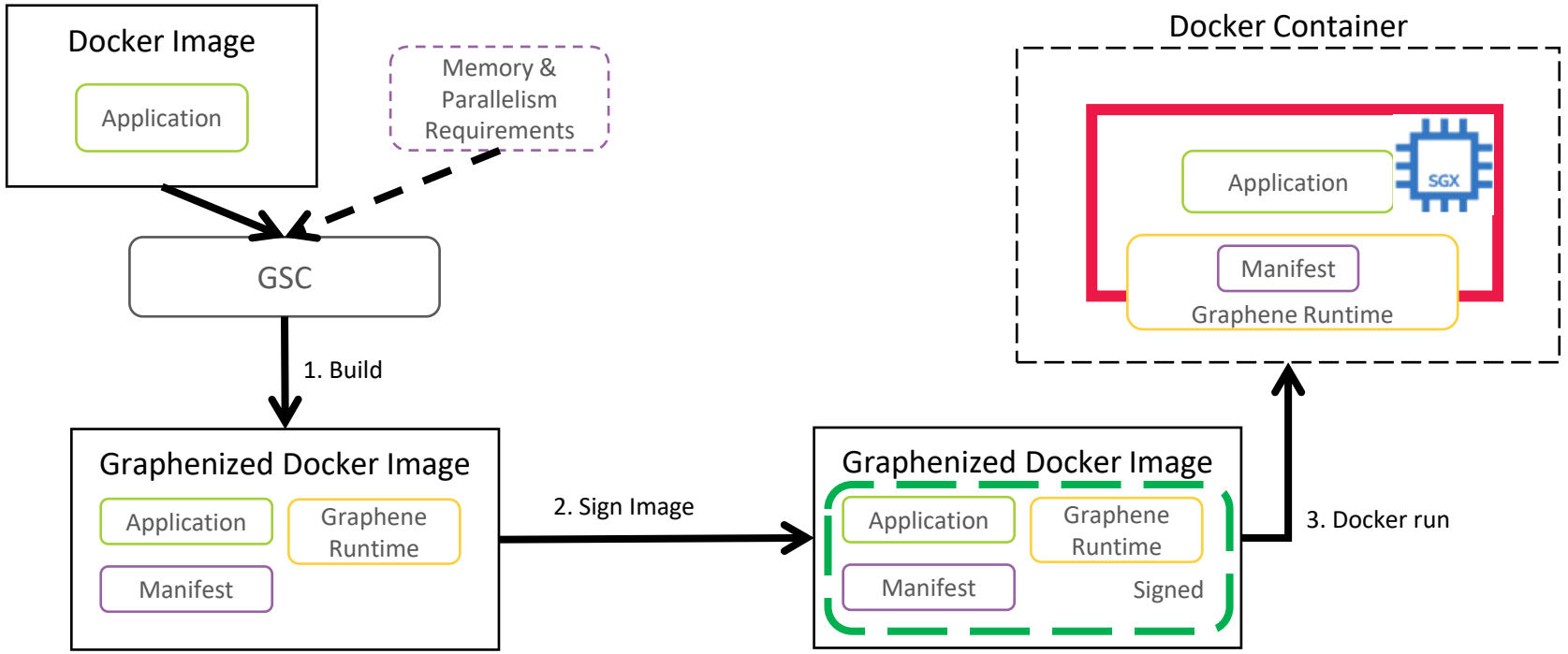
Docker Container Integration

Containers are deployment model for cloud

- Containers have become the defacto deployment model besides VMs
  - Small memory footprint
  - Fast startup

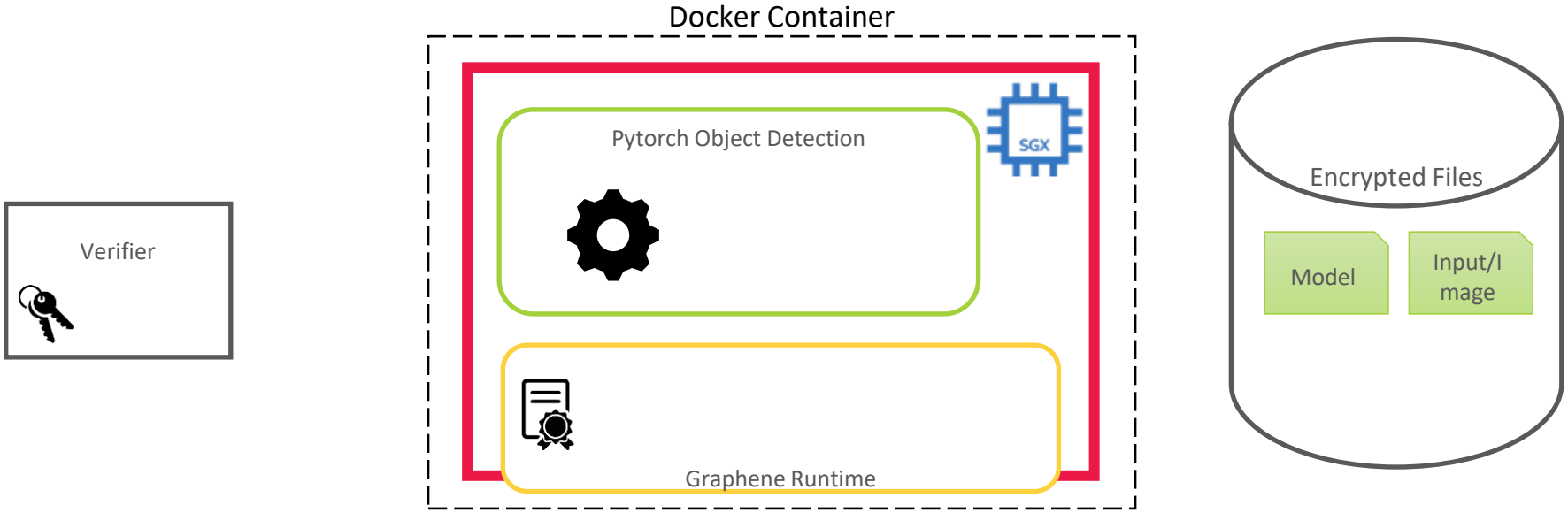
- Goals:
  - Provide an interface for automatically securing Docker container applications with SGX with Graphene
  - Minimize burden to craft application manifest

Graphene Shielded Containers (GSC) in a Nutshell

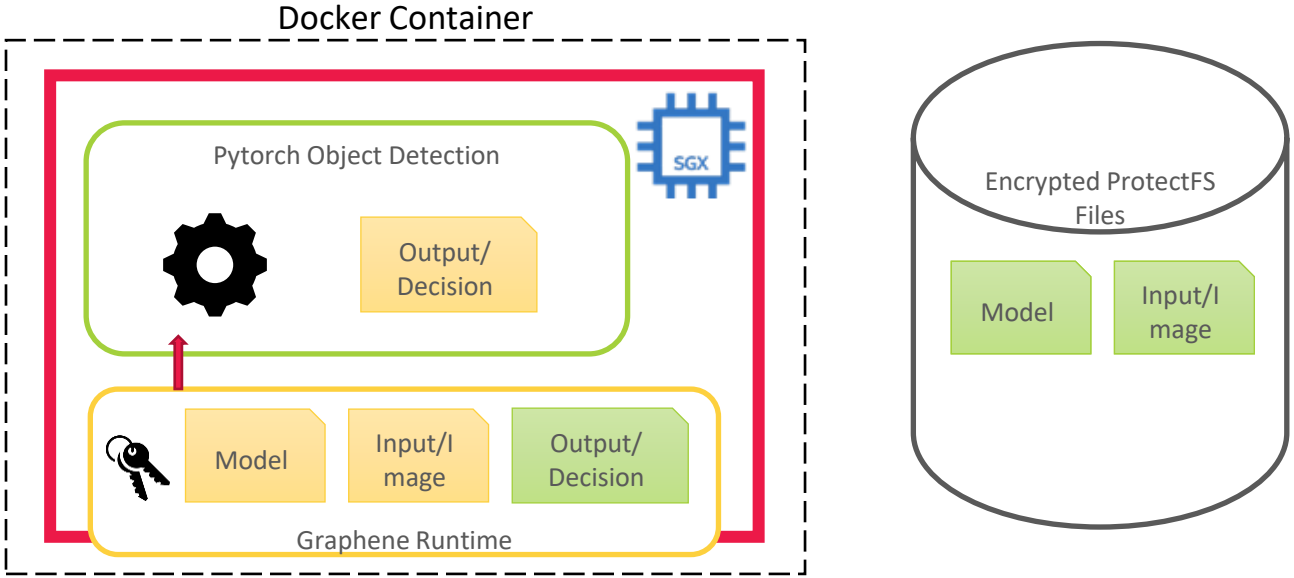


Securing an unmodified workload

End-to-End Secure Machine Learning with Pytorch



End-to-End Use Case using Pytorch



[PyTorch PPML Framework Tutorial]

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Graphene is actively evolving

- Initial SGX port released in 2017
- Open-source community established in Dec 2018
- First major release was in September 2019
- Difference between current version and that first release (~1.5 years):
    - 1,179 files changed
    - 87,890 insertions, 86,287 deletions
    - 1,143 commits from 34 authors
    - Memory management, threads, processes, signals 99% reworked

Graphene Project Future Plans

- Continue the development towards production readiness in Q2’21
- Improve tooling and documentation
- Integration with future cloud-based container deployments
- Grow supported runtimes and workloads
- Extend to secure communication with accelerators
- Explore addition of future TEE backends

Join our community!

- We welcome contributions of all type from the community!
  - Code
  - Issues
  - Documentation
  - Fruit baskets…
- Try deploying your unmodified Docker workloads with Graphene
  - In your datacenter or cloud
- We want to hear from your experience of using Graphene
  - Email or github issues welcome

Graphene project:
http://www.grapheneproject.io

GitHub repo:
https://github.com/oscarlab/graphene

Graphene Documentation:
https://graphene.readthedocs.io/en/latest/

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