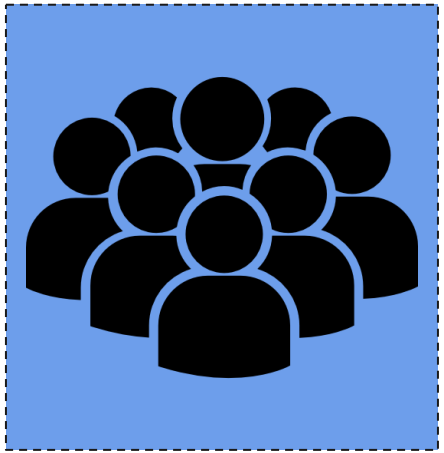
Ryoan: A Distributed Sandbox for Untrusted Computation on Secret Data

Threat Model — 3 Perspectives



Users (Data Subjects)

- Doesn't trust service providers
- Doesn't trust platforms (e.g. OS)

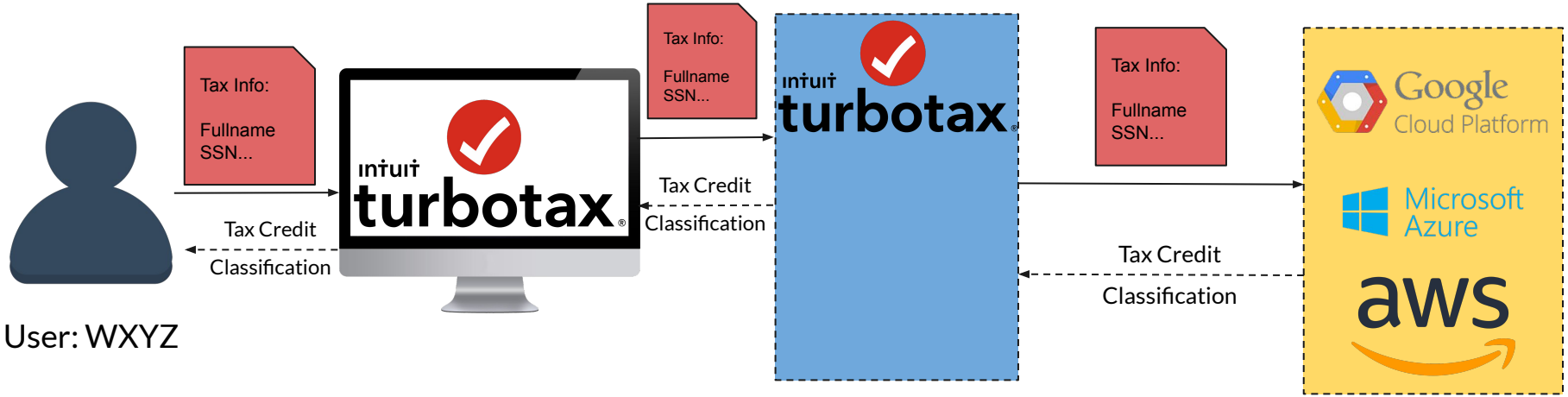
Service Providers

- Doesn't trust other service providers
- Trust their own module not to leak its own secrets

Everyone

- Trusts Intel SGX
- Trusts Ryoan

I Have Trust Issues - TurboTax Example



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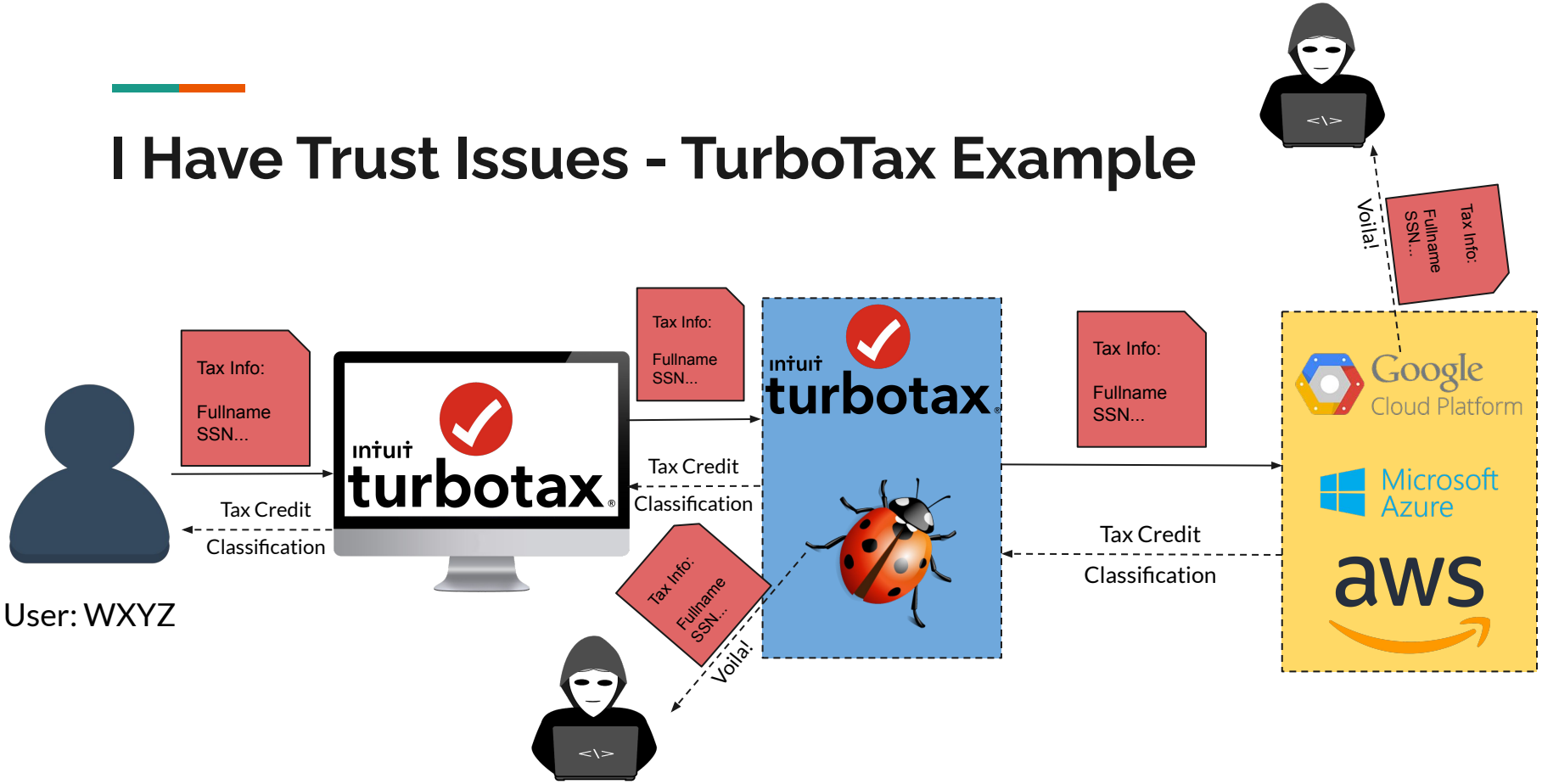
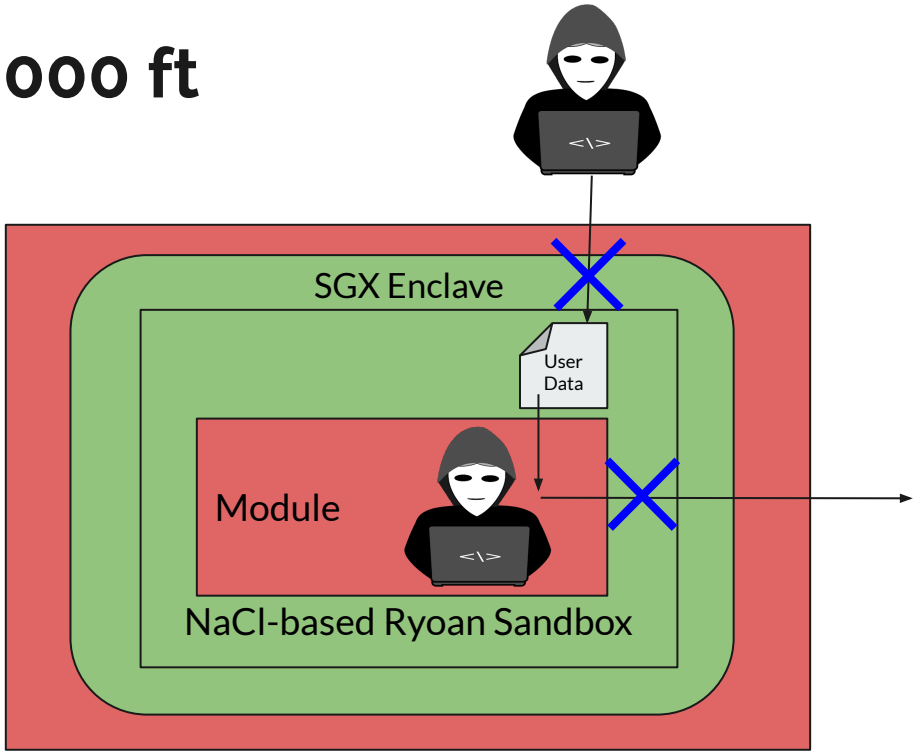


Ryoan at 10000 ft



Background Information

Intel Software Guard eXtensions (SGX)

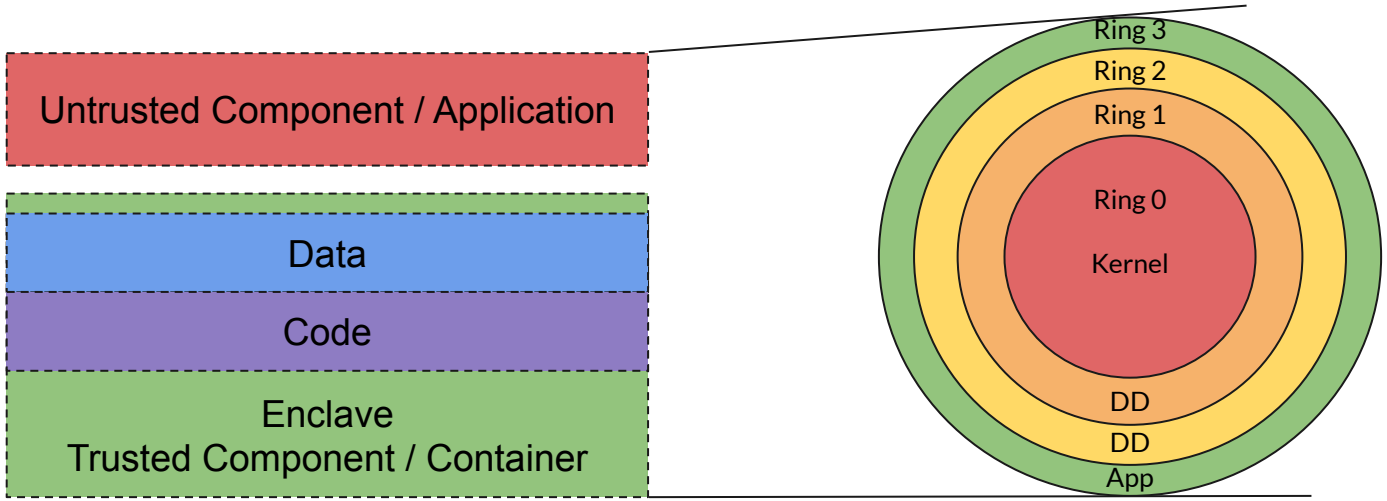
What's SGX?

Intel Software Guard Extensions (SGX) offers hardware-based memory encryption that isolates specific application code and data in memory.

SGX allows user-level code to allocate private regions of memory, called **enclaves**, which are designed to be protected from processes running at higher privilege levels.

*Even when Operating System (OS) is compromised, application can still keep secrets

SGX-based Application Partitioning

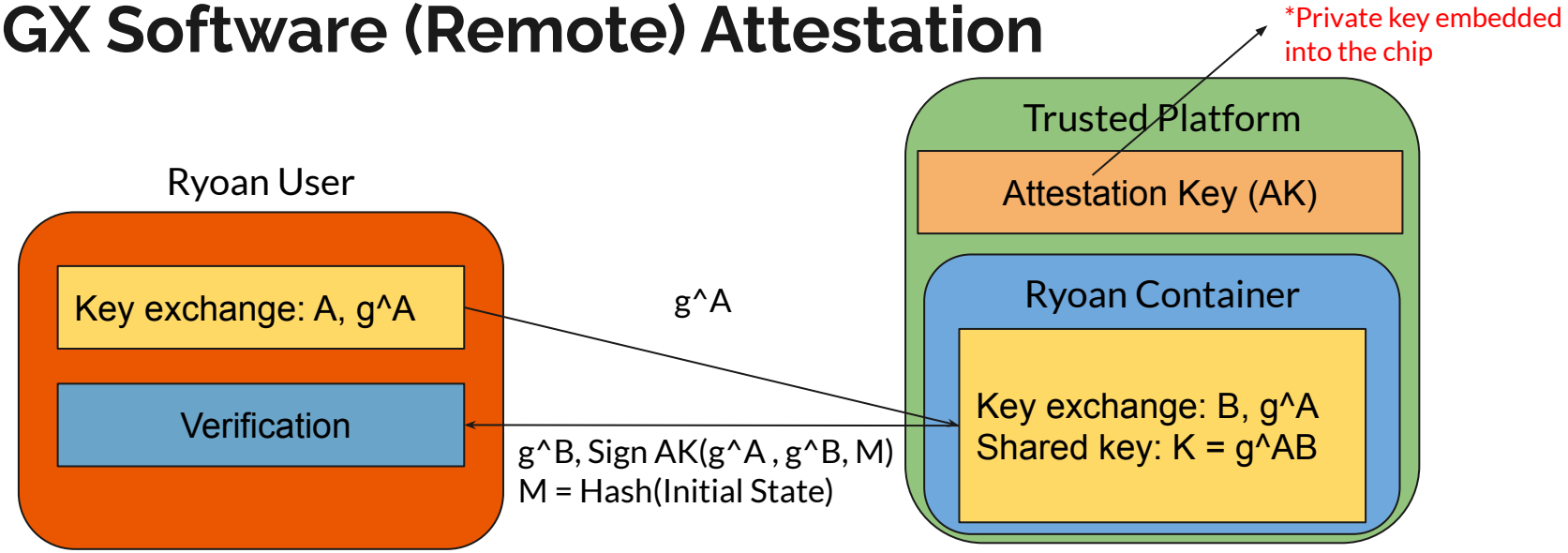


Legend:

DD : Device Driver
App: User Application

An enclave is a secure container that only contains the private data in a computation and the code that operates on it, which is isolated from the outside environment including privileged software including OS and hypervisor.

SGX Software (Remote) Attestation



Ryoan Identification: All enclaves must have the same initial state

SGX software (remote) attestation proves to the Ryoan user that she is using the service in a secure container hosted by trusted hardware before passing sensitive data

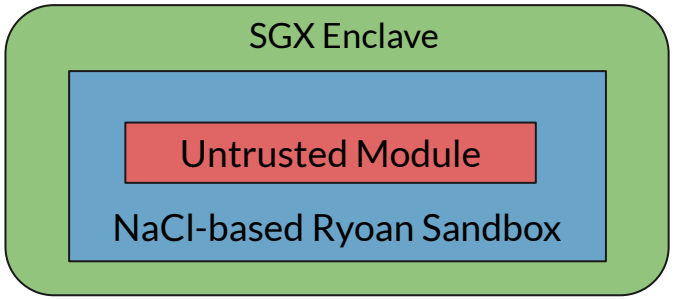
*User use Intel's public key to check signature

Google's Native Client (NaCl)

What's Native Client?

"Native Client is a sandbox for running compiled C and C++ code in the browser efficiently and securely, independent of the user's operating system"

Google's Native Client (NaCl) (1)



Each SGX enclave contains a NaCl sandbox instance that loads and executes untrusted modules

Google's Native Client (NaCl) (2)

"Why is NaCl important?"

NaCl can impose restrictions on untrusted modules:

- Can only address module memory
- Limits (intercepts & replace) syscalls
- Cannot modify SGX state

Entities in Ryoan

Modules

NaCl x86 binaries with application logic from service providers
Potentially malicious

Platforms

Host Computation
Potentially malicious

Sandboxes

Trusted code
Confine modules
Executed within enclaves

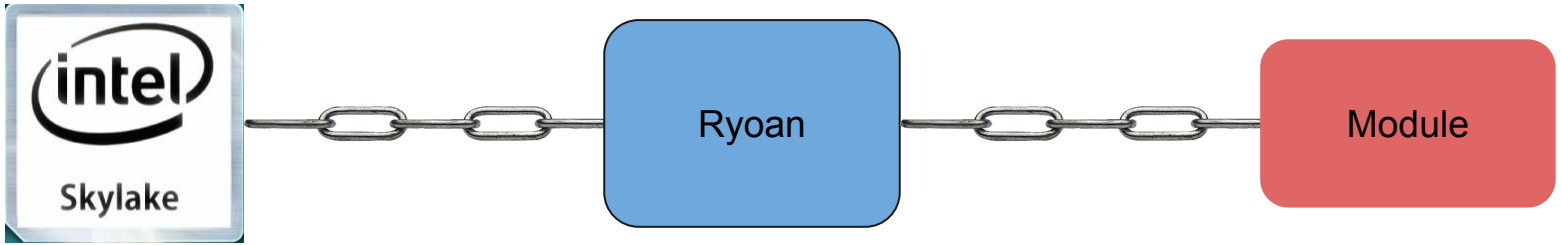
Trust no one but Ryoan & Intel SGX

Ryoan's Goals

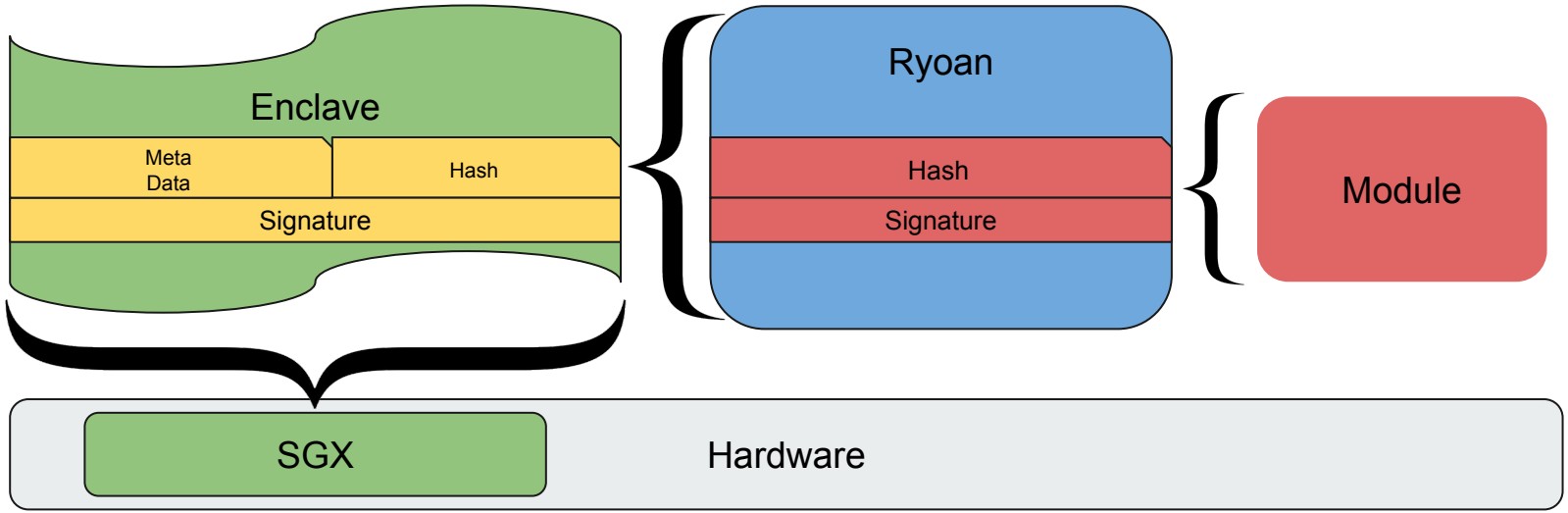
- Keep user data secret (protect data subject's data -> confidentiality)
  - Without trusting software stack and or infrastructure in-placed

- Ability to process user's confidential data in a distributed application through confined communication between different service providers
  - Prevent covert channels
  - Stop an untrusted application from intentionally and covertly using users' data to modulate events like system call arguments or I/O traffic statistics

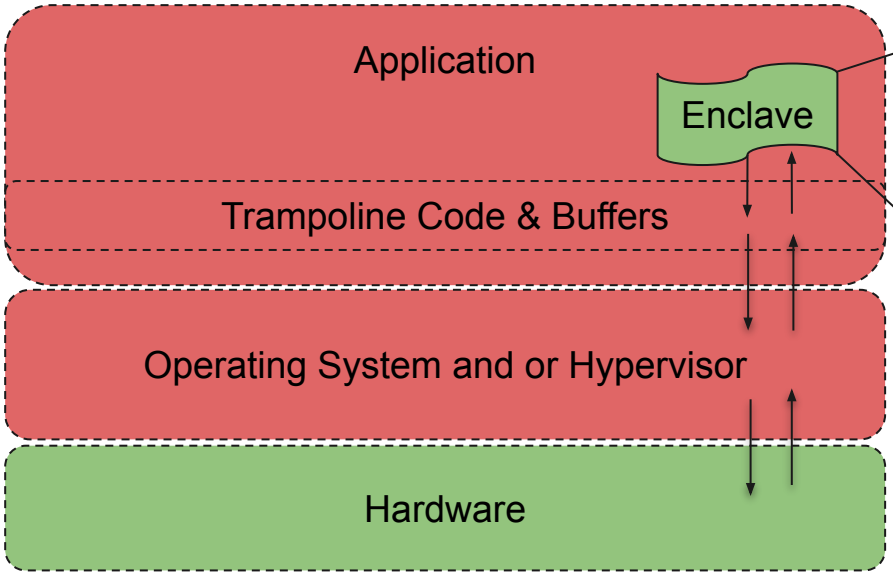
Chain of Trust



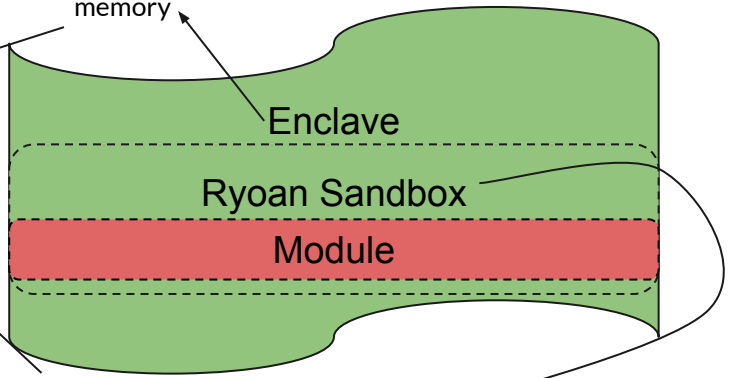
Chain of Trust (1)



Ryoan's Distributed Sandbox

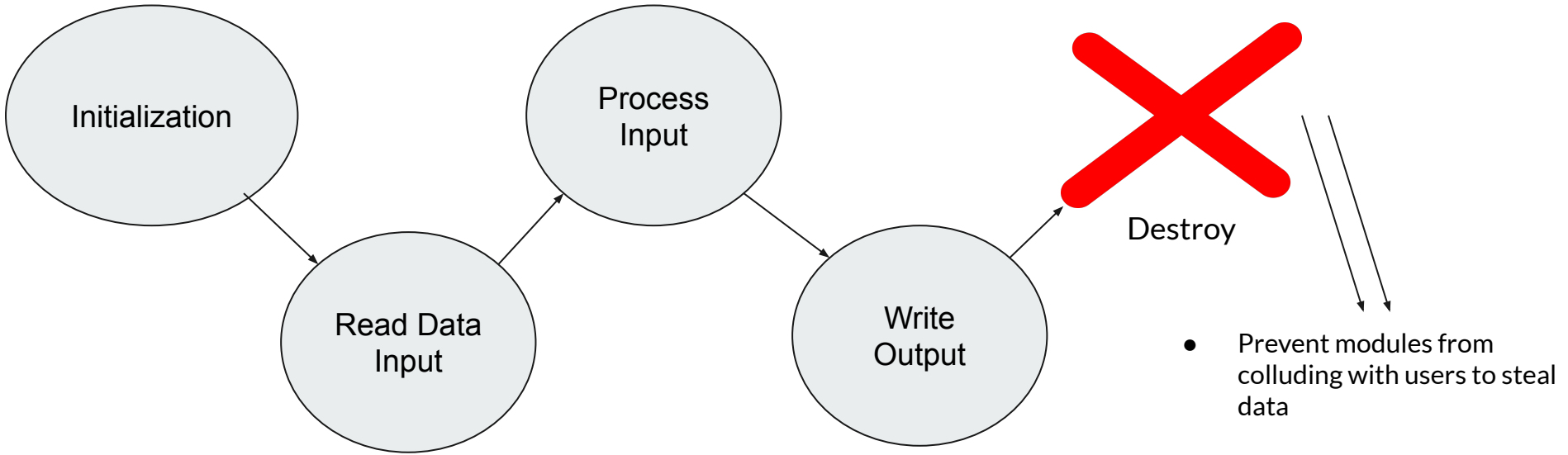


- Prevent platform (OS) from reading secrets out of memory



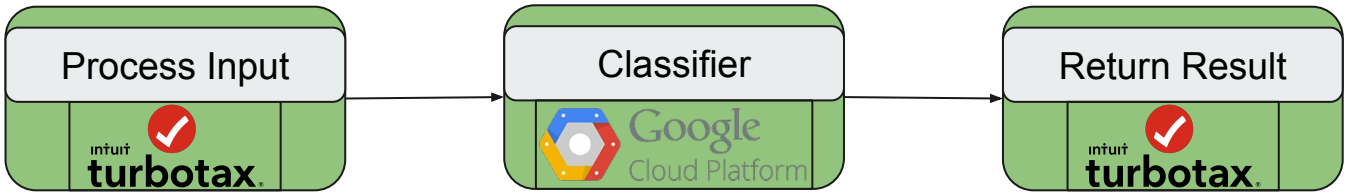
- Restricts accessible memory
  - Prevents module from copying secrets to other parts of memory
- Enforces encryption and any system calls are emulated in enclave's memory
  - Prevents module from exploiting system calls to write out secrets

Stateless Module Enforcement Between Reqs



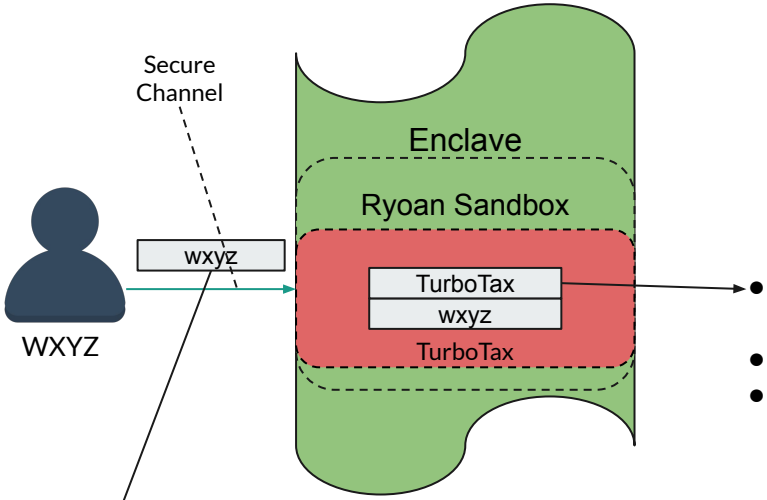
- Prevent modules from colluding with users to steal data

How Does Ryoan Work? DAG (TurboTax Example)



- User data sent to TurboTax Process Input module
- TurboTax Process Input module sends user data to GCP Classifier Module
- GCP Classifier sends output to TurboTax Return Result Module

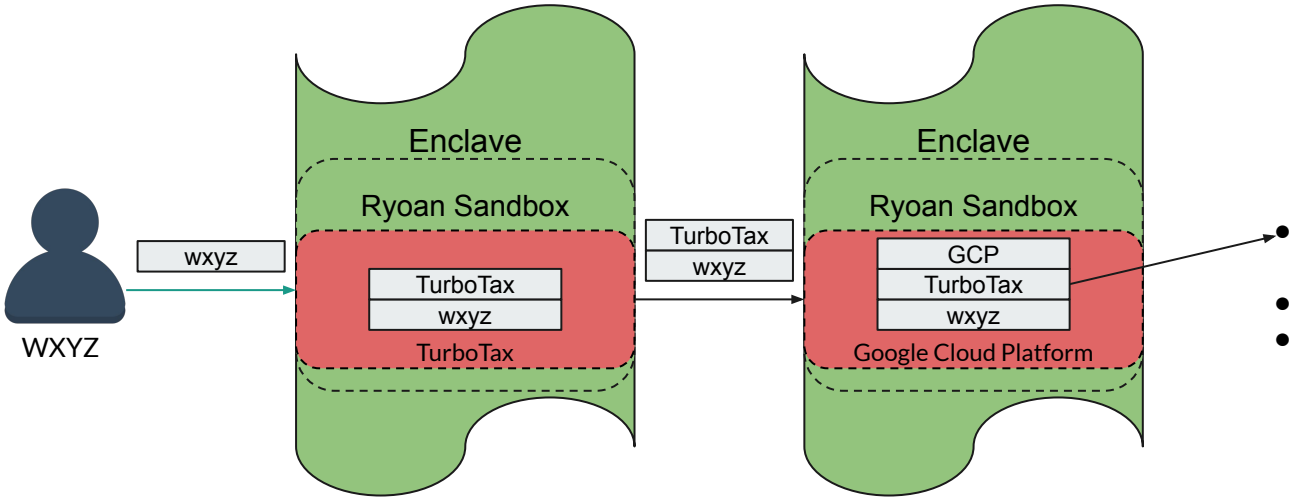
How Does Ryoan Work? TurboTax Back Again!



- TurboTax adds its tag to prevent the secrets from flowing back to user
- Secret data are encrypted
- Secret data are flushed after processing

- User wxyz's tag is added to secret data sent to TurboTax

How Does Ryoan Work? TurboTax Back Again!



- GCP adds its tag to prevent the secrets from flowing back to TurboTax
- Secret data are encrypted
- Secret data are flushed after processing

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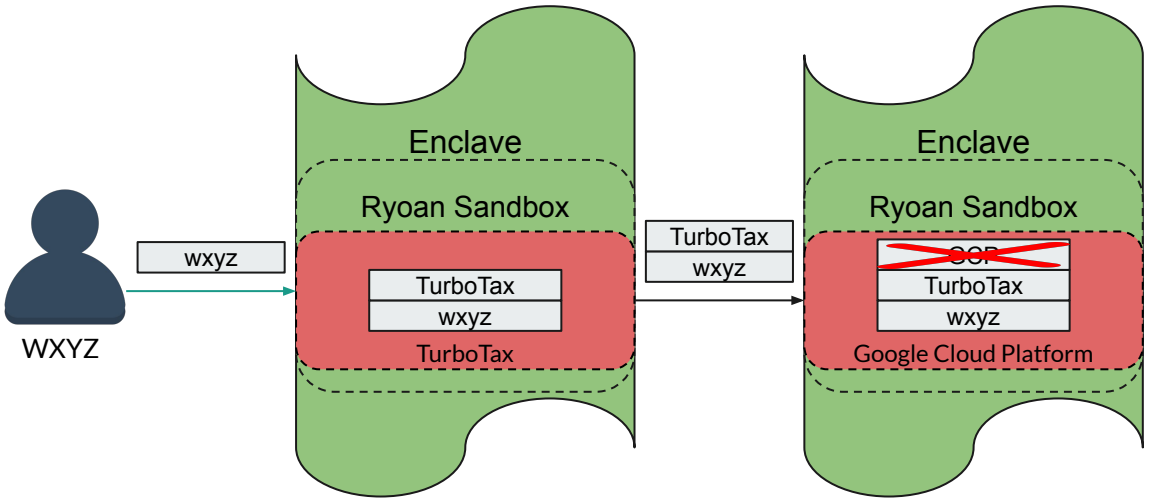

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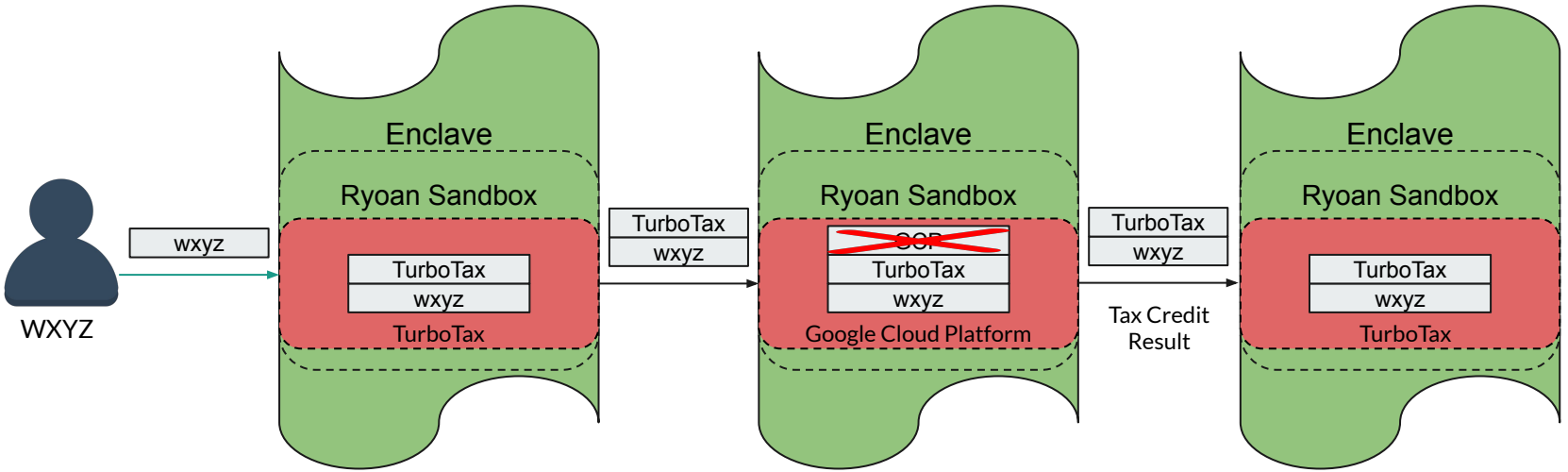

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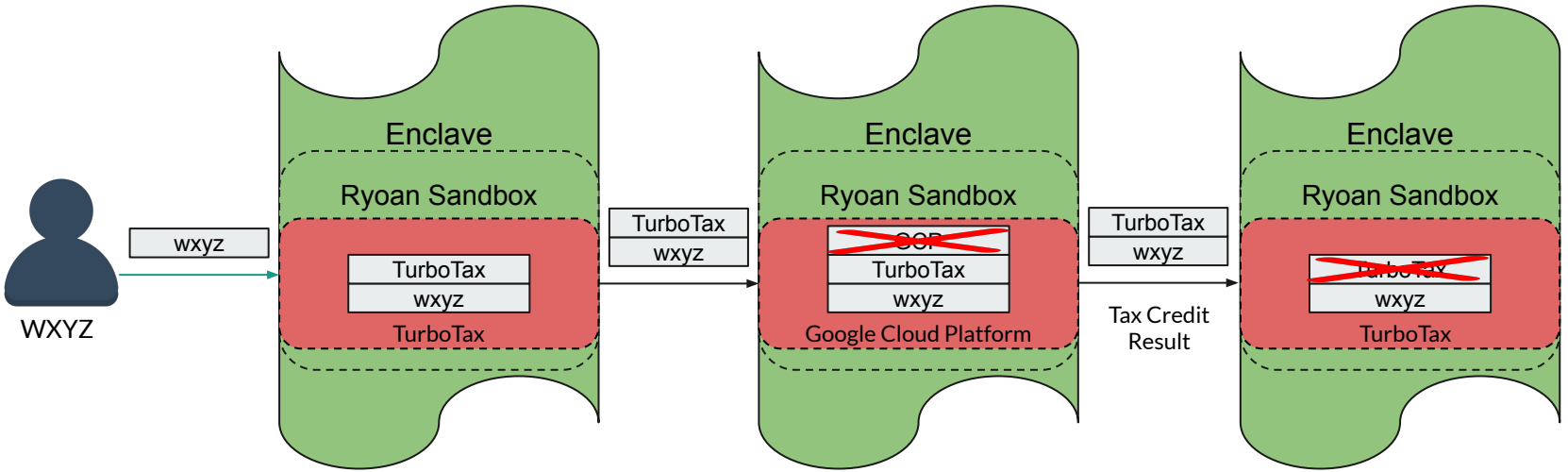

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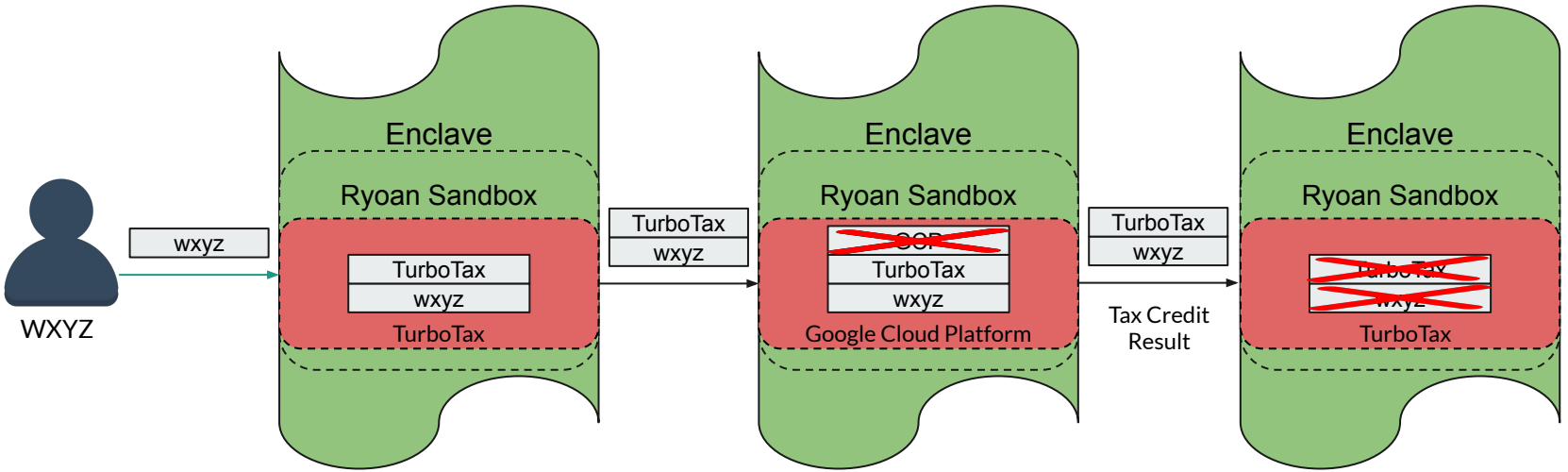

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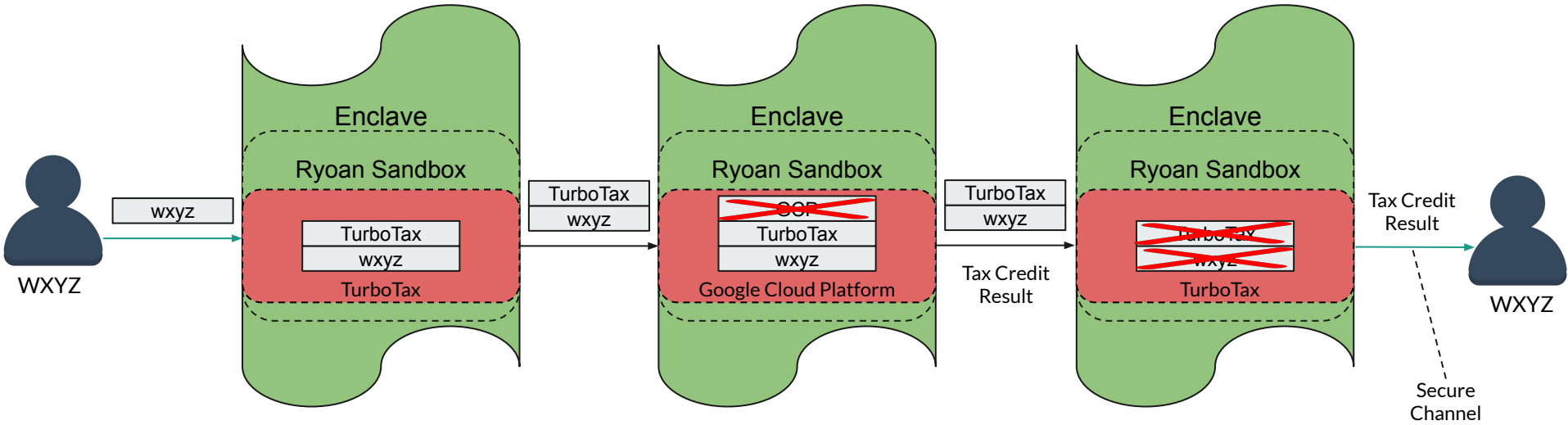

Question 1

"If Intel's SGX is not used in Ryoan, what guarantees does Ryoan provide?"

Answer 1

1. Without SGX, privileged software (OS, hypervisor, etc.) will have access to module memory
    a. Secret data could be leaked / unauthorized access

2. No code / data verification between the service user and the remote container
    a. Identities of containers will no longer exist
    b. User have no idea whether the module have been tampered or modified

Question 2

“If Google’s NaCl is not used in Ryoan, what guarantees does Ryoan provide?”

Answer 2

Without NaCl, Ryoan will lose three security properties enforced by NaCl!

1. Untrusted modules can address not only module memory but also memory that doesn't belong to themselves

2. Ryoan will not be able to intercept syscalls from these modules which may be malicious

3. The restriction that this module cannot modify SGX state will also be lifted

Limitations

- Slow performance
  - Each module running within Ryoan can only process 1 user data at any point in time
- Fixed execution - Services that are called are defined ahead of time -> **DAG**
- Applications might require custom libraries, however these libraries does not exist in Ryoan's libc
- Memory limitations
  - Module(s) which requires large memory usage cannot be loaded in as a single module
- Intel processors hardware limitations - compromises Ryoan's security goals
  - SGX page faults, cache timing, address bus monitoring, processor monitoring

Thank you for the kind attention!

Reference

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Intel introduces three Skylake "R" class processors - NotebookCheck.net News

Native Client

Conference Slides