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AccTEE: A WebAssembly-based Two-way Sandbox for Trusted Resource Accounting

MIDDLEWARE 2019, UC Davis

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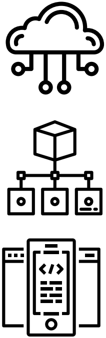
Offloading Computations

- Offloading computations to remote infrastructure
  - Cloud Computing
  - Volunteer Computing
  - Client-side Web applications
- Reasons:
  - Remotely available resources
  - Moving computations closer to customers
- Usually two entities:
  - **Workload provider**
  - **Infrastructure provider**



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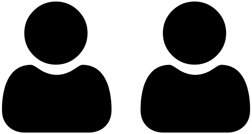

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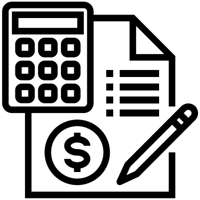
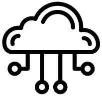


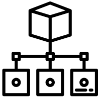
Accounting of consumed resources in some cases

Resource Accounting

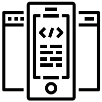
- Cloud Computing
  - CPU and memory usage, I/O operations



- Volunteer Computing
  - Logging of donated CPU time



- Client-side Web applications
  - No accounting in practice



Resource Accounting in Practice

- Accounting on different levels
  - Task level (e.g. for completed tasks)
  - Hardware level (e.g. CPU usage)
- Resources always accounted by infrastructure provider

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Current approaches of resource accounting **require trust** in the infrastructure provider

Trust Relationship

- Malicious infrastructure provider can ...
  - Spy on provided code or data
  - Fake accounting results (overbilling)

- Malicious workload provider can ...
  - Provide crafted workload to destroy execution environment
  - Trick resource accounting

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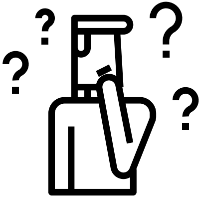

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  - Provide crafted workload to destroy execution environment
  - Trick resource accounting

Problem: Limited trust between infrastructure and workload provider

Outline

- Design of AccTEE
- Evaluation of AccTEE
- Related Work
- Conclusion

Approach of AccTEE

1. Workload provider provides workload
2. Infrastructure provider executes workload in **sandbox**
3. Sandbox produces **mutually trusted resource usage log**

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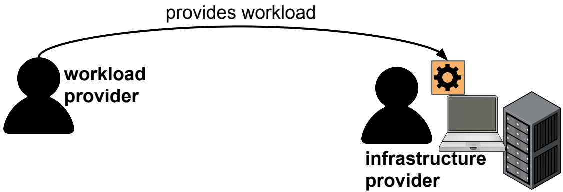

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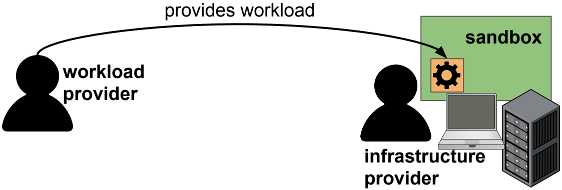

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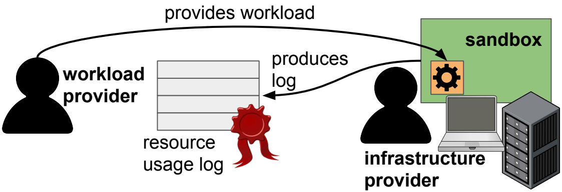

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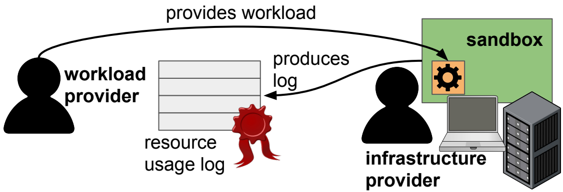

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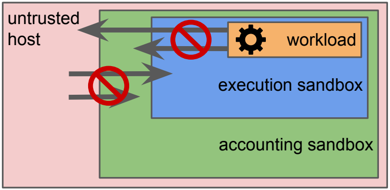
How do we get an **sandbox** with **mutually trusted resource accounting**?

AccTEE's Sandbox

- Accountable sandbox is a combination of two sandboxes

- **Execution sandbox**
  - Shields host from workload
  - Shields accounting from workload

- **Accounting sandbox**
  - Shields workload from host
  - Shields accounting from host

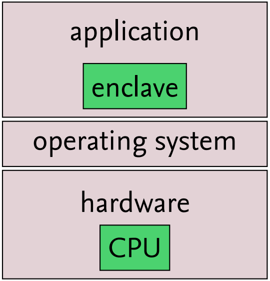


Background: WebAssembly (WASM)

- A platform independent binary instruction format
- Initially designed for computations in browsers
  - Standalone execution emerging
- **Goal:** a safe, fast and portable low-level code
- Application code is **compiled to WASM**
- WebAssembly code executed in sandboxes
  - Based on software fault isolation

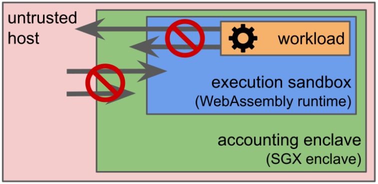
Background: Intel SGX

- x86 **instruction set extension**
- Creation of trusted execution environments (TEEs) → **enclaves**
- Execution and data inside enclaves **protected** from privileged software
- Hardware-based **memory integrity protection and encryption**
- Only CPU is trusted
- **Remote attestation** of enclaves
- Limitation: enclave page cache (EPC) size



AccTEE's Two-way Sandbox

- AccTEE combines two sandboxes
- **Execution sandbox**
  - Based on **WebAssembly**
- **Accounting sandbox**
  - Based on **Intel SGX**
  - **Code instrumentation** for resource accounting



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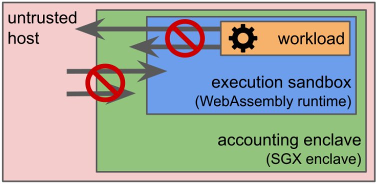

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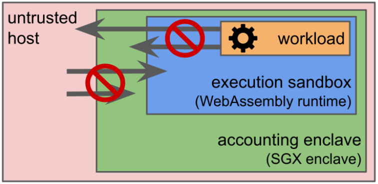

AccTEE combines SGX and WebAssembly to create a **two-way sandbox**

AccTEE **instruments WebAssembly code**
for mutually trusted resource accounting

WebAssembly Code Instrumentation

Goal: Count WebAssembly instructions

- `naive` instrumentation
  - Based on **basic blocks**
  - Counter incremented at end of block
- `flow-based` optimization
  - Increment by minimum instruction count
  - Update counter based on **control flow**
- `loop-based` optimization
  - Identify **loop iterators** with constant increments
  - Increment counter **once** after loop
- Different instruction costs
  - AccTEE uses a **weighted instruction counter**

```
get_global 12
set_local 3
i32.lt_s
if (result i32)
  get_local 0
  i32.load offset=4
else
  get_local 4
  i32.const 255
  i32.and
end
tee_local 4
get_local 1
```

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set_local 3
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<Increment counter by 3>
if (result i32)
    get_local 0
    i32.load offset=4
    <Increment counter by 2>
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end
tee_local 4
get_local 1
<Increment counter by 2>
```

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  i32.and
  <Increment counter by 1>
end
tee_local 4
get_local 1
<Increment counter by 7>
```
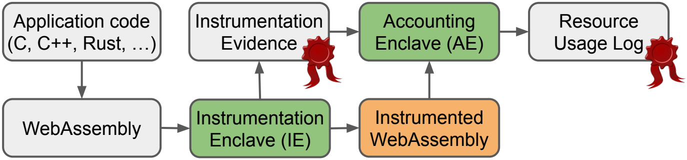
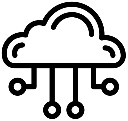

AccTEE's Workflow



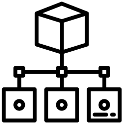
1. Workload provider compiles application to WebAssembly
2. WebAssembly is instrumented inside Instrumentation Enclave
   - Instrumentation evidence
   - Instrumented WebAssembly code
3. Accounting Enclave verifies evidence and executes WebAssembly code
4. Result: mutually trusted resource usage log

Example Use Cases

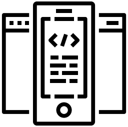
- Function-as-a-Service
  - **Trusted** resource accounting in data centers



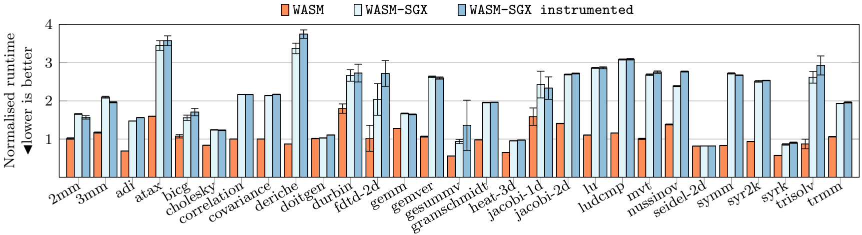
- Volunteer Computing
  - **Trusted** resource accounting at clients



- Client-side web applications
  - **Trusted** resource accounting in browsers
  - e.g. for replacing micro payments

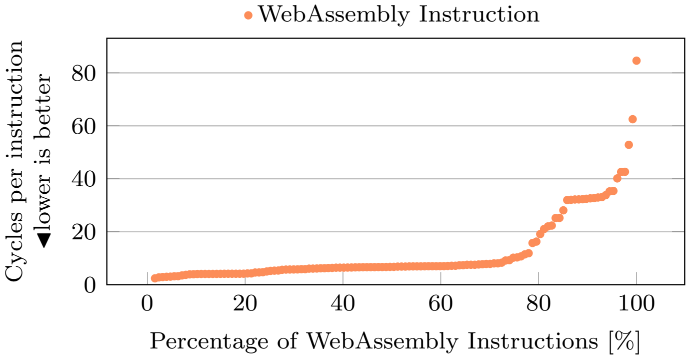


PolyBench/C Benchmark Suite



- Overhead for WASM: 10%
- Overhead for WASM-SGX: 2.1× (EPC exhaustion)
- Instrumentation overhead over WASM-SGX: 4% on average

WebAssembly Instruction Weights



- 74% of instructions need < 10 cycles
- 2% of instructions (e.g. `f32.sqrt`) > 50 cycles

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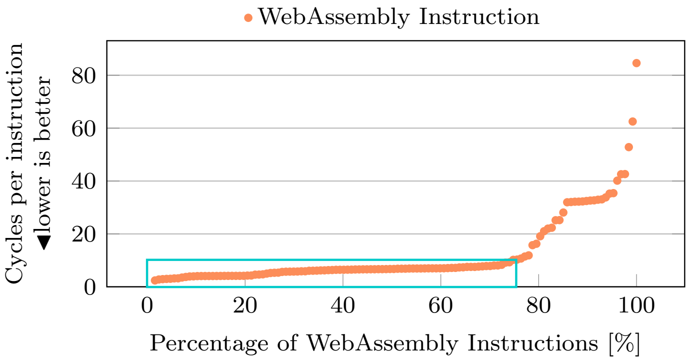

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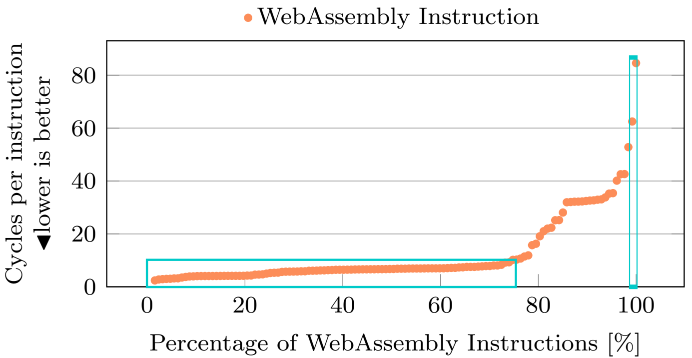

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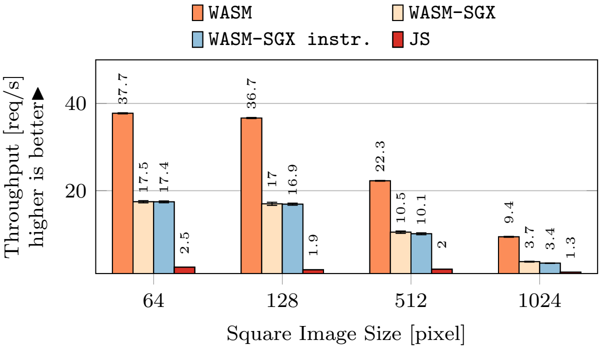
Function-as-a-Service (FaaS) Use Case



- Benchmark: Image resize FaaS function
- Accounting overhead is negligible
- Between 3 $\times$ and 9 $\times$ faster than JavaScript baseline

Related Work

- Combination of Google Native Client (NaCl) and SGX enclaves
  - **MiniBox** (ATC'14), **Ryoan** (OSDI'16)
  - No platform independence
  - No resource accounting

- **S-FaaS** (CCSW'19) Trustworthy and Accountable FaaS
  - Combines SGX and hyper-threading
  - CPU time measured by dedicated timer thread
  - Wastes an entire core to count CPU cycles

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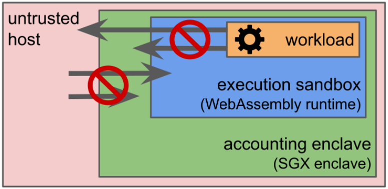
AccTEE is the **first two-way sandbox** based on SGX and WebAssembly enabling **mutually trusted resource accounting**

Conclusion

AccTEE's contributions:

- Implements **two-way sandbox**
- Mutually trusted resource accounting
  - **Instrumentation** of WebAssembly code
  - Platform independent
- More contributions in the paper
  - Volunteer Computing use case
  - Accounting of I/O and memory usage



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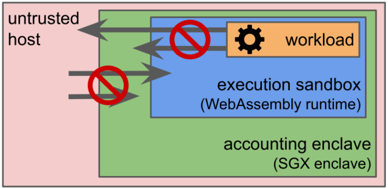

Thank you for your time! Questions?

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Side-channel Attacks against Intel SGX Enclaves

- Side-channel attacks against SGX:
  - Spectre Attacks: Exploiting Speculative Execution (S&P'19)
  - Foreshadow: Extracting the Keys to the Intel SGX Kingdom with Transient Out-of-Order Execution (USENIX Security'18)
  - ZombieLoad: Cross-Privilege-Boundary Data Sampling (2019)
- **All side-channels are not exclusive to SGX!**
- **All fixed by microcode updates at cost of transition performance**