Flicker: Minimal TCB Code Execution

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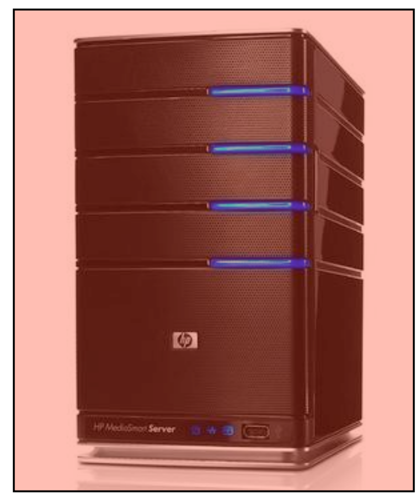
Password Reuse

- People often use 1 password for 2+ websites
- Banking, social networking, file sharing, …

Password Exposure

- Password provided to compromised web server



www.myhobby.com is compromised!

Password Verification

- What if…
  - A compromised OS cannot learn the password
  - Only essential code can access password
    - Decrypt SSL traffic
    - Salt and hash password
    - Compare with stored hash
    - Output MATCH or FAILURE
  - Can remotely verify this is so
- Requires strong system security
- What about zero knowledge protocols?
  - A viable alternative for passwords
  - Our techniques are more general
    - Password verification is just an example

Outline

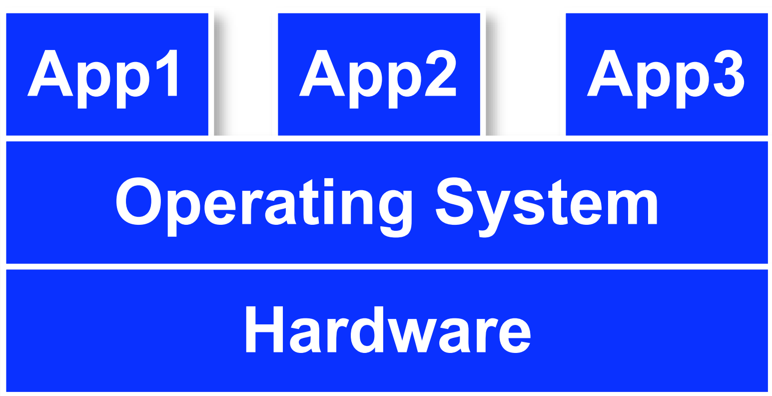
1. **Existing approaches to system security**
2. Remote attestation and verification
3. Static root of trust for measurement
4. Dynamic root of trust for measurement
5. Flicker: Minimal TCB Code Execution

- Optional
  - Example: IBM Integrity Measurement Arch.
  - Specifics of AMD SVM / Intel TXT

Some Current Approaches

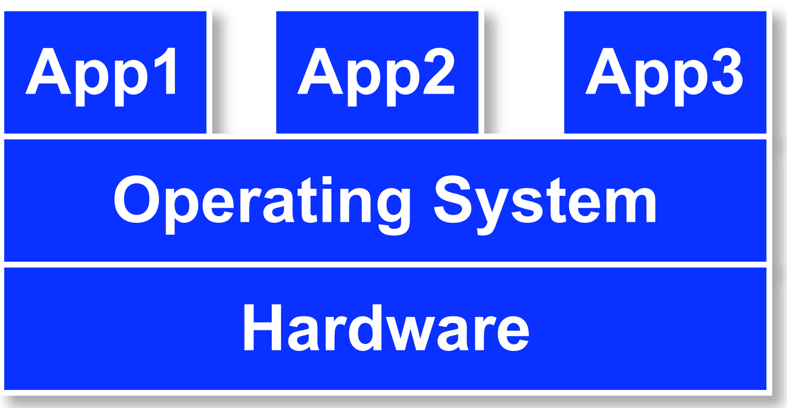
- Program code in ROM
- Secure boot
- Virtual-machine-based isolation

- Evaluation metric: size of Trusted Computing Base (TCB)



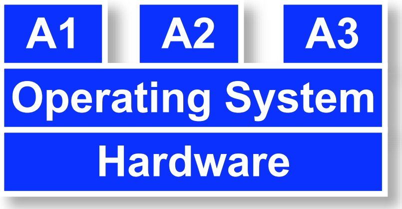
Security Properties to Consider

- How can we trust operations that our devices perform?
- How can we trust App1?
- What if App2 has a security vulnerability?
- What if Operating System has a security vulnerability?



Program Code in ROM

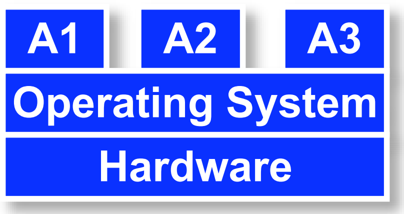
- Advantages
  - Simplicity
  - Adversary cannot inject any additional software
- Disadvantages
  - Cannot update software (without exchanging ROM)
  - Adversary can still use control-flow attack
  - Entire system is in TCB, no isolation



- Verdict
  - Impractical for current systems
  - Code updates are critical
    - Bug fixes
    - New features

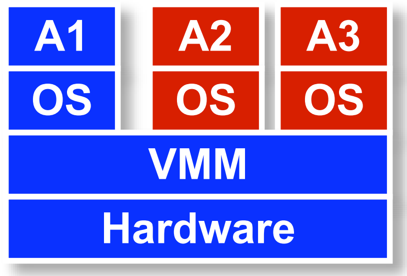
Secure Boot

- Boot process uses signature chain
  - BIOS verifies signature on boot loader
  - Boot loader verifies signature on OS, ...
- Advantages
  - Only approved software can be loaded
    - Assuming no vulnerabilities
- Disadvantages
  - Adversary only needs to compromise singe component
  - Entire system is in TCB, no isolation
  - Not all software is commercial
- Verdict
  - Entire system is still part of TCB
  - Relatively weak security guarantee



Virtual-machine-based Isolation

- Approach: Isolate applications by executing them inside different Virtual Machines
- Advantages
  - Smaller TCB
  - Isolation between applications
- Disadvantages
  - VMM is still large and part of TCB
  - Relatively complex, not suitable for average user
- Verdict: Smaller TCB, step in right direction



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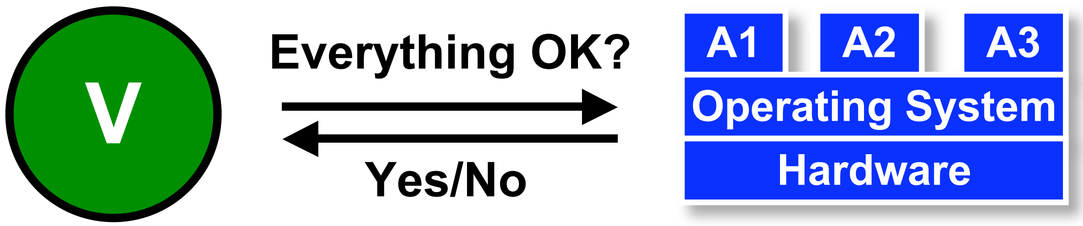
Remote Verification?

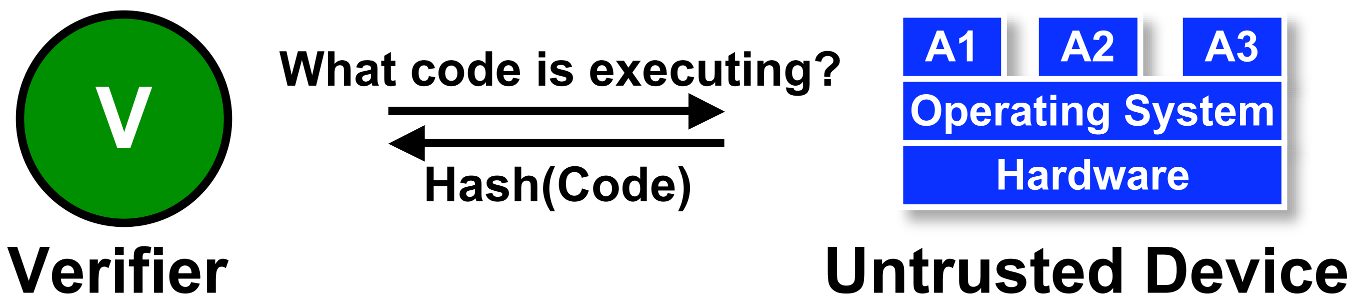
- Desirable property: Remotely verify trustworthy device operation



- Presented approaches not verifiable
  - Higher resilience to attacks
  - Remote verifier obtains no additional assurance

Remote Attestation

- Attestation enables verifier to establish trust in untrusted device
  - Attestation tells verifier what code is executing on device
  - If intended code is executing on untrusted device, verifier can trust its operation



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Hardware-based Attestation

- Leverages hardware support for attestation
- Trusted Platform Module (TPM) chip
  - Already included in many platforms
  - Cost per chip less than $10

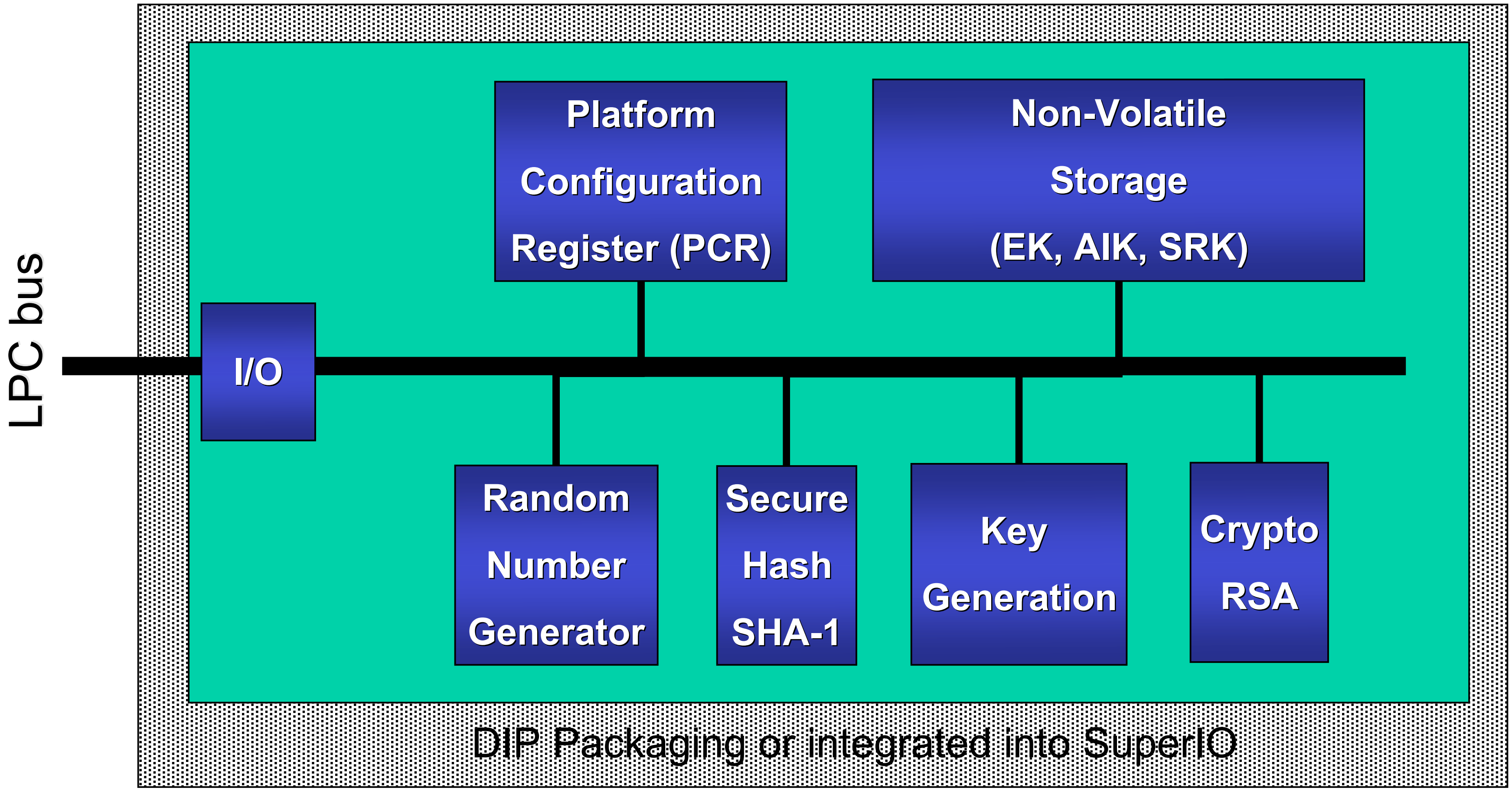
- Modern microprocessors provide special instructions that interact with TPM chip
  - AMD SVM: SKINIT instruction
  - Intel TXT/LT: GETSEC[SENTER] instruction

Trusted Computing Group (TCG)

- Open organization to “develop, define, and promote open standards for hardware-enabled trusted computing and security technologies.”

- These secure platform primitives include
  - Platform integrity measurements
  - Measurement attestation
  - Sealed storage
- Can enable
  - Trusted boot (not secure boot)
  - Attestation
- Goals:
  - Ensure absence of malware
  - Detect spyware, viruses, worms, …

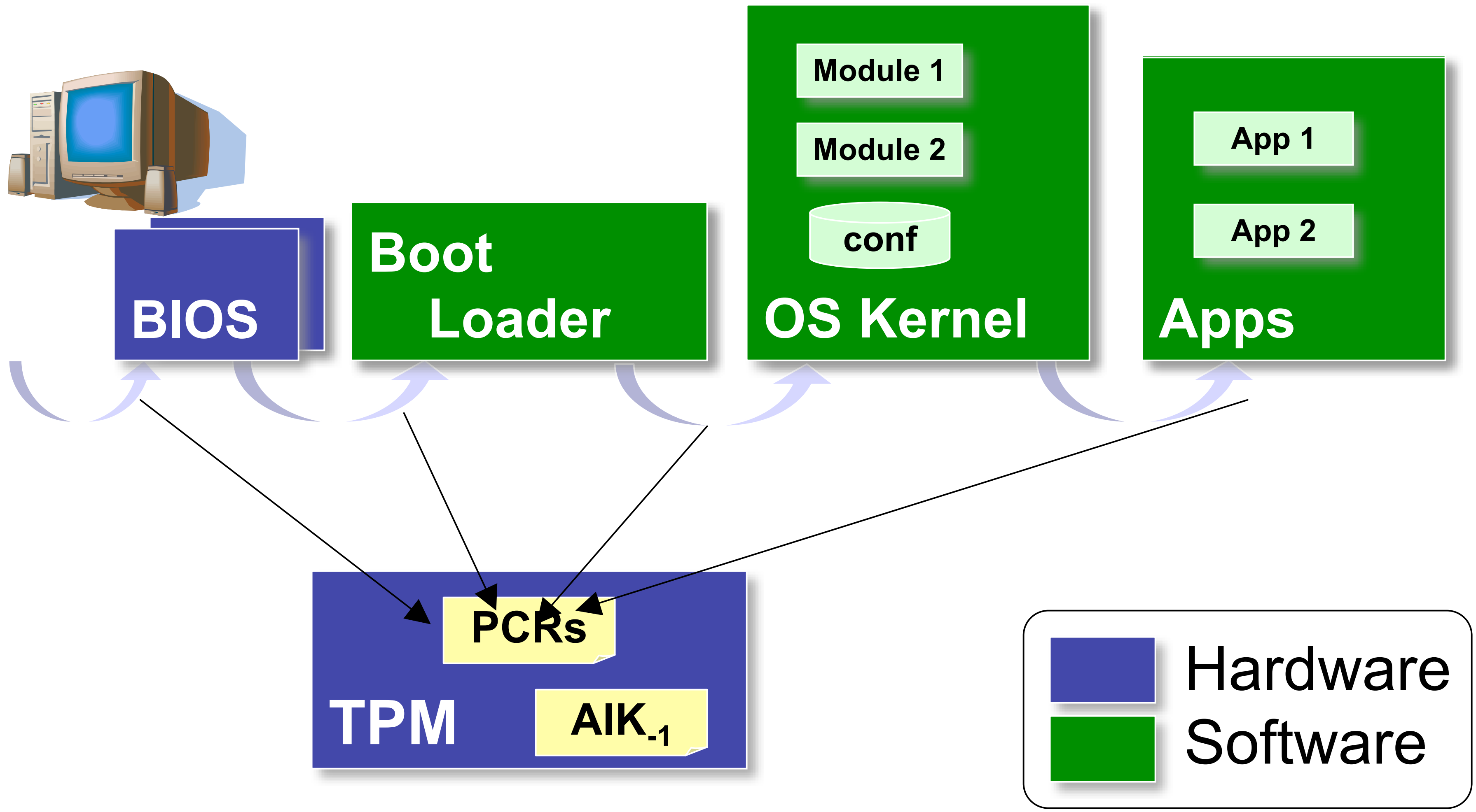
TCG Trusted Platform Module (TPM)



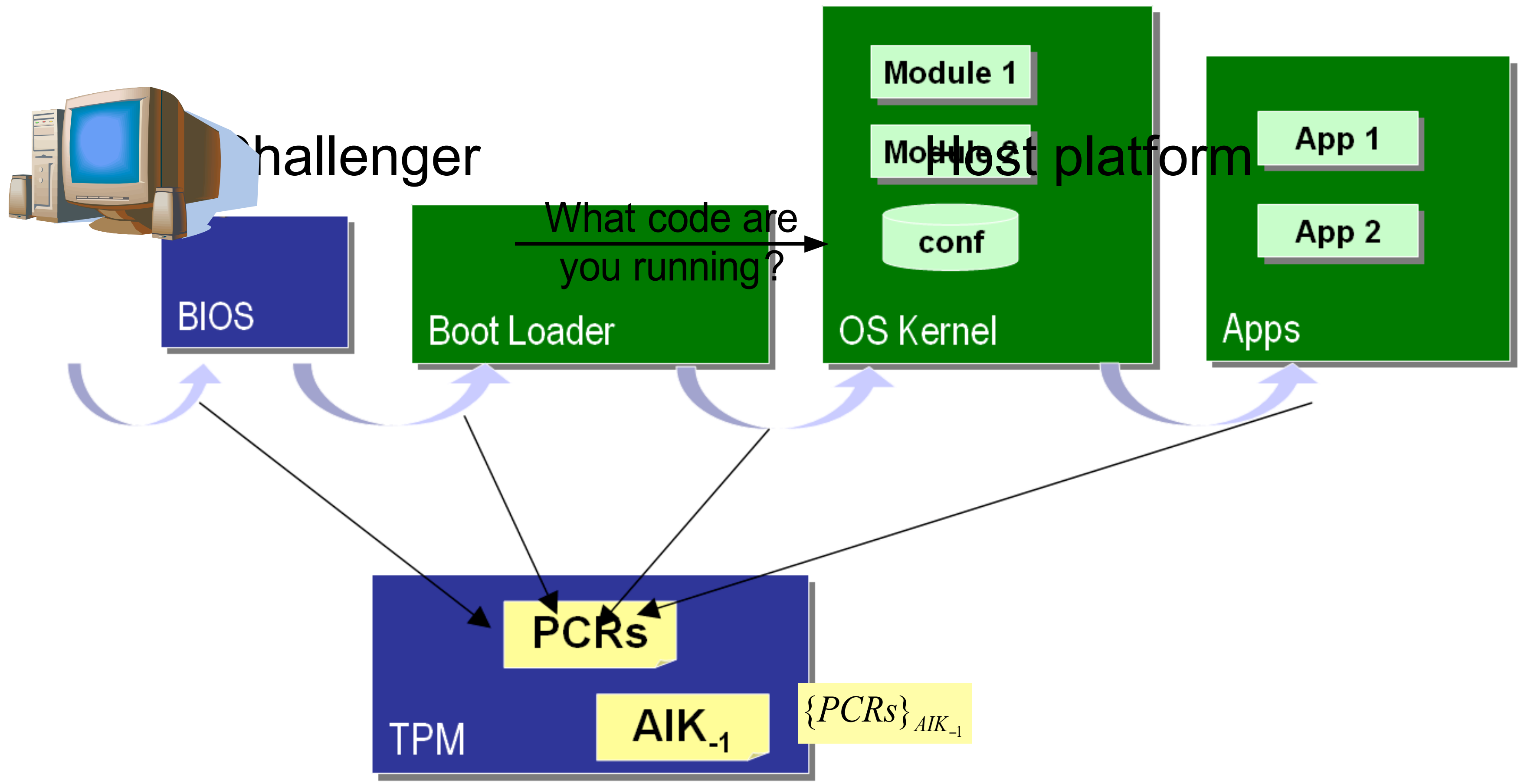
Basic TPM Functions

- PCRs store integrity measurement chain
  - PCR_{new} = SHA-1(PCR_{old}||measurement)
- Remote attestation (PCRs + AIK)
  - Attestation Identity Keys (AIKs) for signing PCRs
  - Attest to value of integrity measurements to remote party
- Sealed storage (PCRs + SRK)
  - Protected storage + unlock state under a particular integrity measurement (data portability concern)

TCG-Style Attestation



TCG-Style Attestation

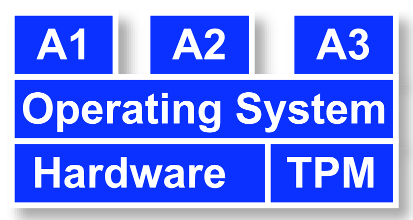


Optional

- IBM's Integrity Measurement Architecture
- Works for Linux

Shortcomings of TCG-style Attestation

- **Static** root of trust for measurement (**reboot**)
- Coarse-grained, measures entire system
  - Requires hundreds of integrity measurements just to boot
  - Every host is different
    - firmware versions, drivers, patches, apps, spyware, …
  - What does a PCR mean in this context?
  - TCB includes entire system!
- Integrity measurements are done at load-time not at run-time
  - Time-of-check-time-of-use (TOCTOU) problem
  - Cannot detect any dynamic attacks!
  - No guarantee of execution



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Dynamic Root of Trust for Measurement aka: Late Launch

- Involves both CPU and TPM v1.2
- Security properties similar to reboot
  - Without a reboot!
  - Removes many things from TCB
    - BIOS, boot loader, DMA-enabled devices, …
    - Long-running OS and Apps if done right
- When combined with virtualization
  - VMM can be measured (MVMM)
    - Uptimes measured in *years*
  - Integrity of loaded code can be attested
  - Untrusted legacy OS can coexist with trusted software
- Allows introduction of new, higher-assurance software without breaking existing systems

AMD/Intel Late Launch Extensions

- AMD: Secure Virtual Machine (SVM)
- Intel: Trusted eXecution Technology (TXT)
  - Formerly LaGrande Technology (LT)
- Similarities:
  - Late launch of a measured block of code
  - Hardware support for virtualization
- Differences:
  - AMD provides measured environment only
  - Intel adds authenticated code capabilities
    - The system's chipset contains a public key to verify signed code

AMD Secure Virtual Machine

- Virtualization support
  - DMA protection for memory
  - Intercept selected guest instructions / events
  - Much more…

- Late launch with support for attestation
  - New instruction: SKINIT (Secure Kernel Init)
  - Requires appropriate platform support (e.g., TPM 1.2)
  - Allows verifiable startup of trusted software
    - Such as a VMM
    - Based on hash comparison

SKINIT (Secure Kernel Init)

- Accepts address of Secure Loader Block (SLB)
  - Memory region up to 64 KB

- SKINIT executes atomically
  - Sets CPU state similar to INIT (soft reset)
  - Disables interrupts
  - Enables DMA protection for entire 64 KB SLB
  - Causes TPM to *reset dynamic PCRs* to 0
  - Sends SLB contents to TPM
  - TPM hashes SLB contents and extends PCR 17
  - Begins executing SLB

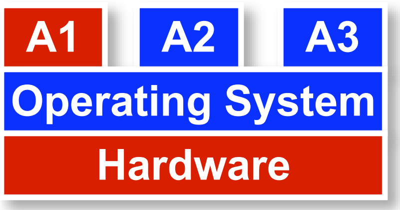
SKINIT Security Properties

- Verifier receives attestation after SKINIT
  - Knows SKINIT was used
  - Knows software TCB includes only the SLB
  - Knows exactly what SLB was executed

- SLB can be written to provide add’l props.
  - Knows any inputs to SLB
  - Knows any outputs from SLB
  - Knows exactly when SLB finished executing

AMD SVM Security Discussion

- Property: Verifiable untampered code execution
- SKINIT + TCG 1.2 provide very strong security properties
- Minimal TCB: Only hardware and application need to be trusted



Optional

- Detail on specific AMD/Intel Extensions
  - AMD Secure Virtual Machine (SVM)
  - Intel Trusted eXecution Technology (TXT)

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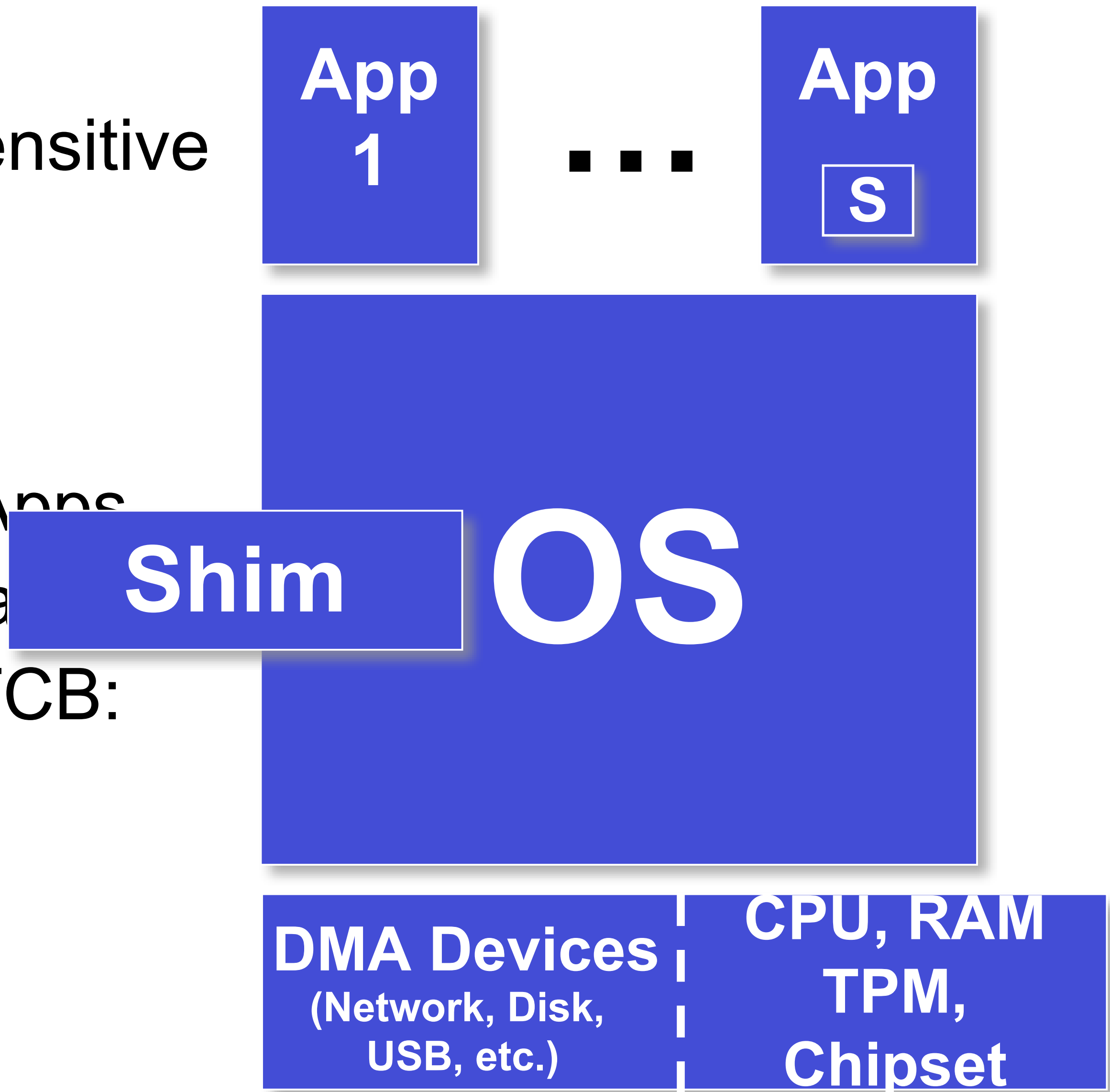
TCB Reduction with Flicker

Today, TCB for sensitive code S:

- Includes App
- Includes OS
- Includes other Apps
- Includes hardwa

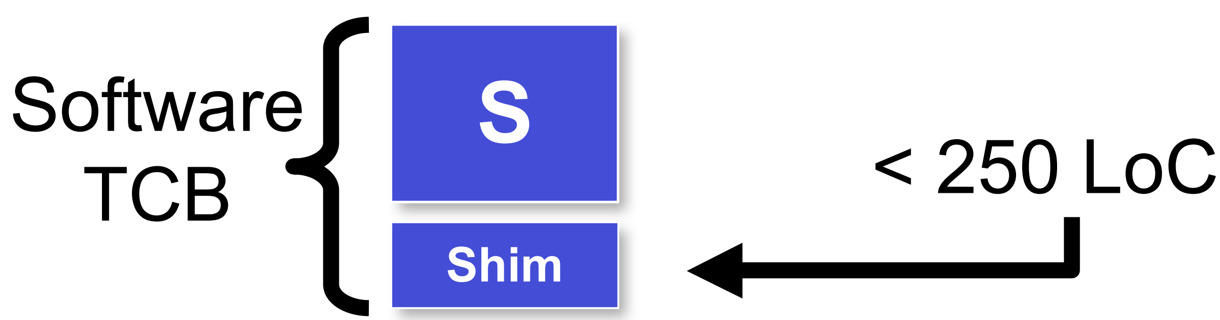
With Flicker, S's TCB:

- Includes Shim
- Includes some hardware

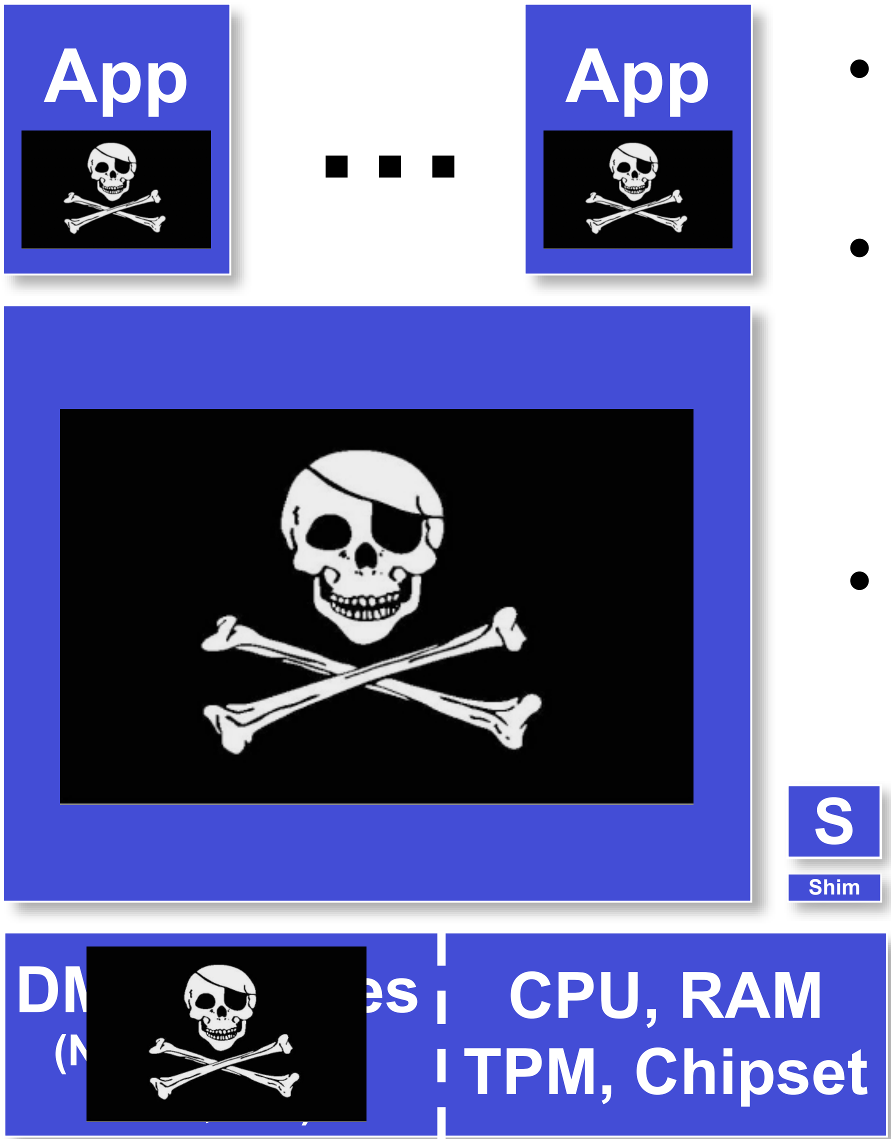


Contributions

- Isolate security-sensitive code execution from all other code and devices
- Attest to security-sensitive code and its arguments and nothing else
- Convince a remote party that security-sensitive code was protected
- Add < 250 LoC to the software TCB



Adversary Capabilities

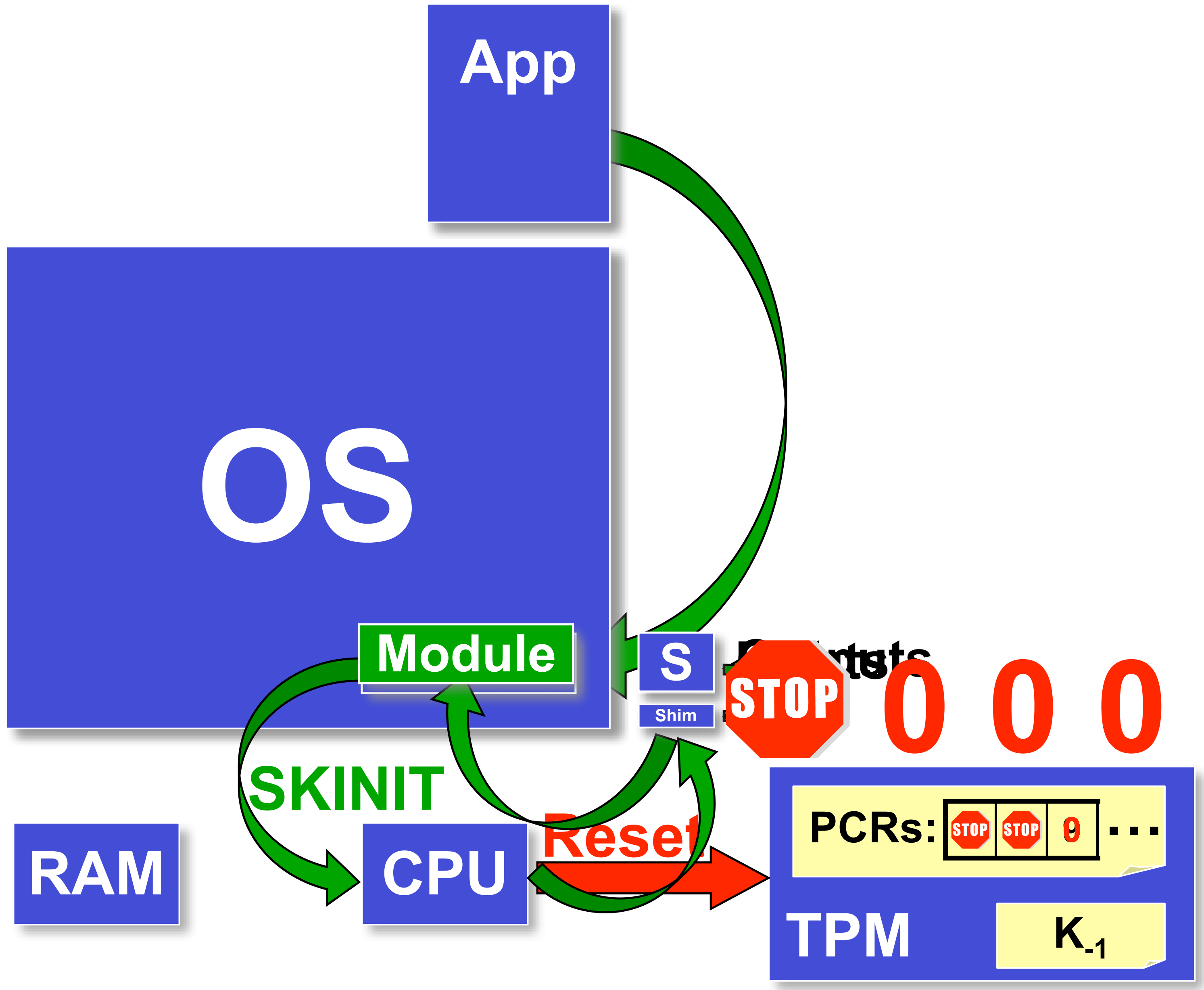


- Run arbitrary code with maximum privileges
- Subvert any DMA-enabled device
  - E.g., network cards, USB devices, hard drives
- Perform limited hardware attacks
  - E.g., power cycle the machine
  - Excludes physically monitoring/modifying CPU-to-RAM communication

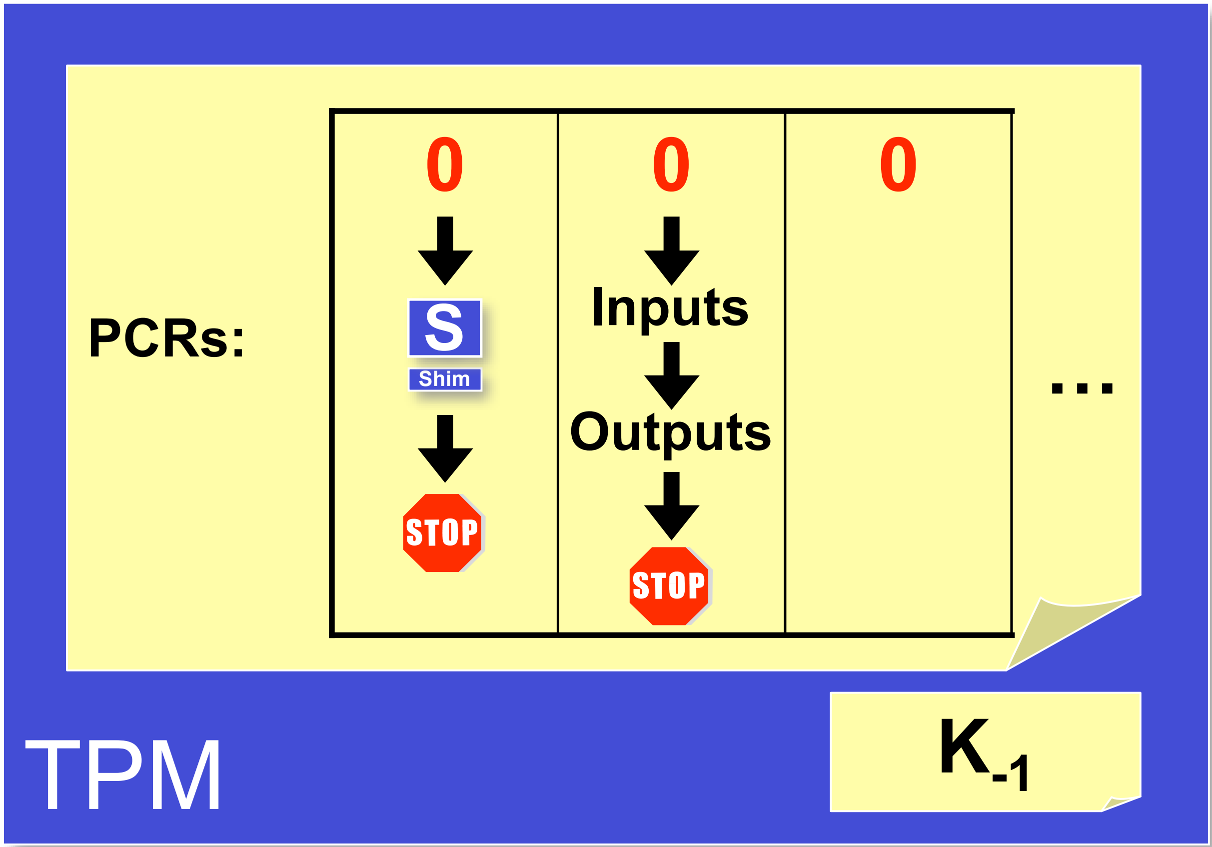
Architecture Overview

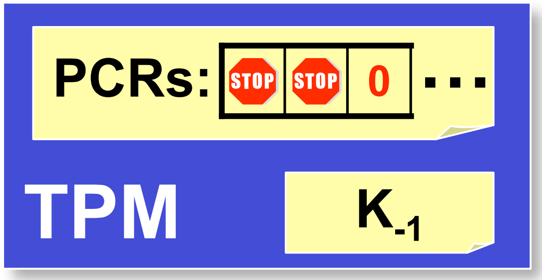
- Core technique
  - Pause current execution environment
  - Execute security-sensitive code with hardware-enforced isolation
  - Resume previous execution
- Extensions
  - Preserve state securely across invocations
  - Attest **only** to code execution and protection
  - Establish secure communication with remote parties

Execution Flow

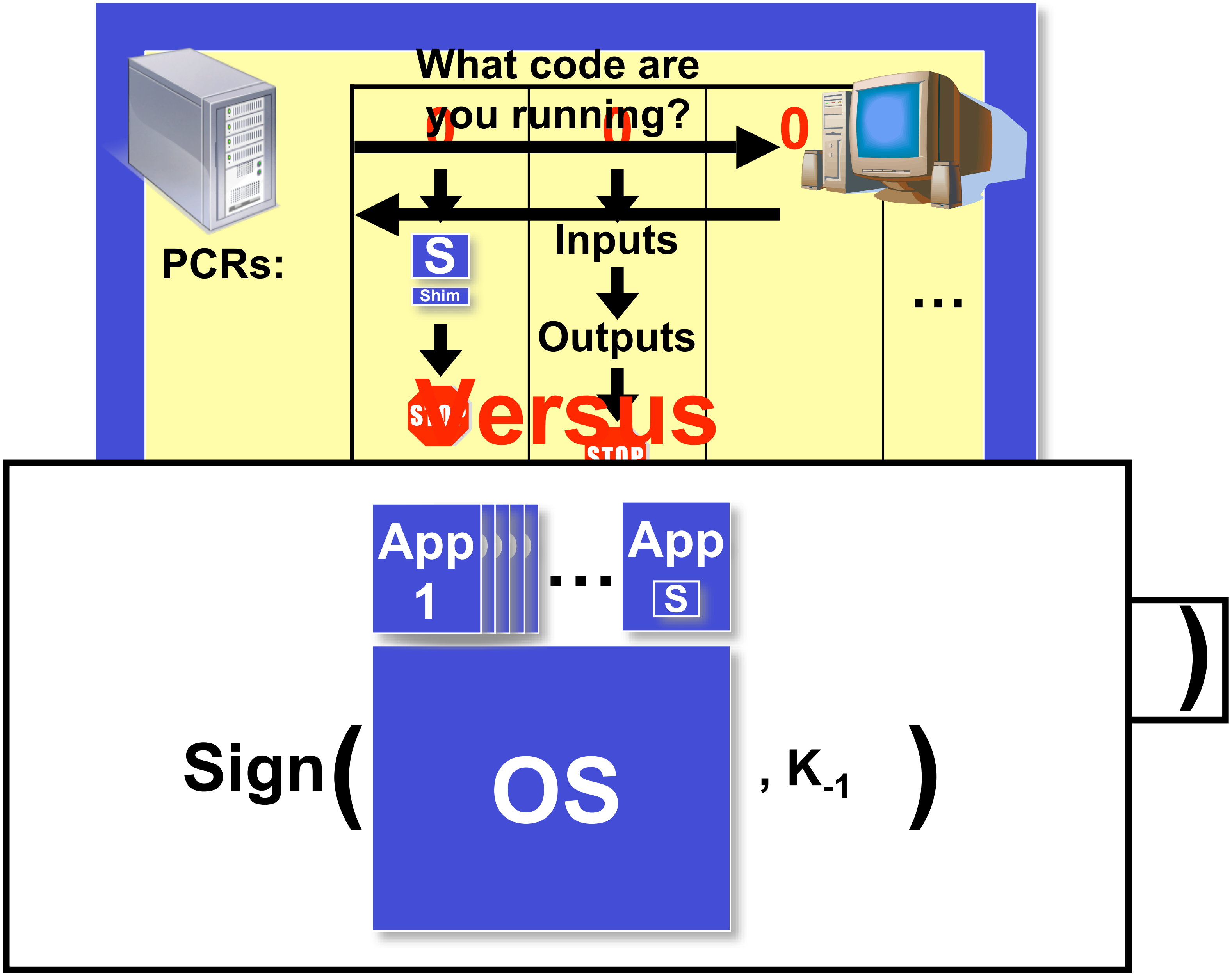


Attestation



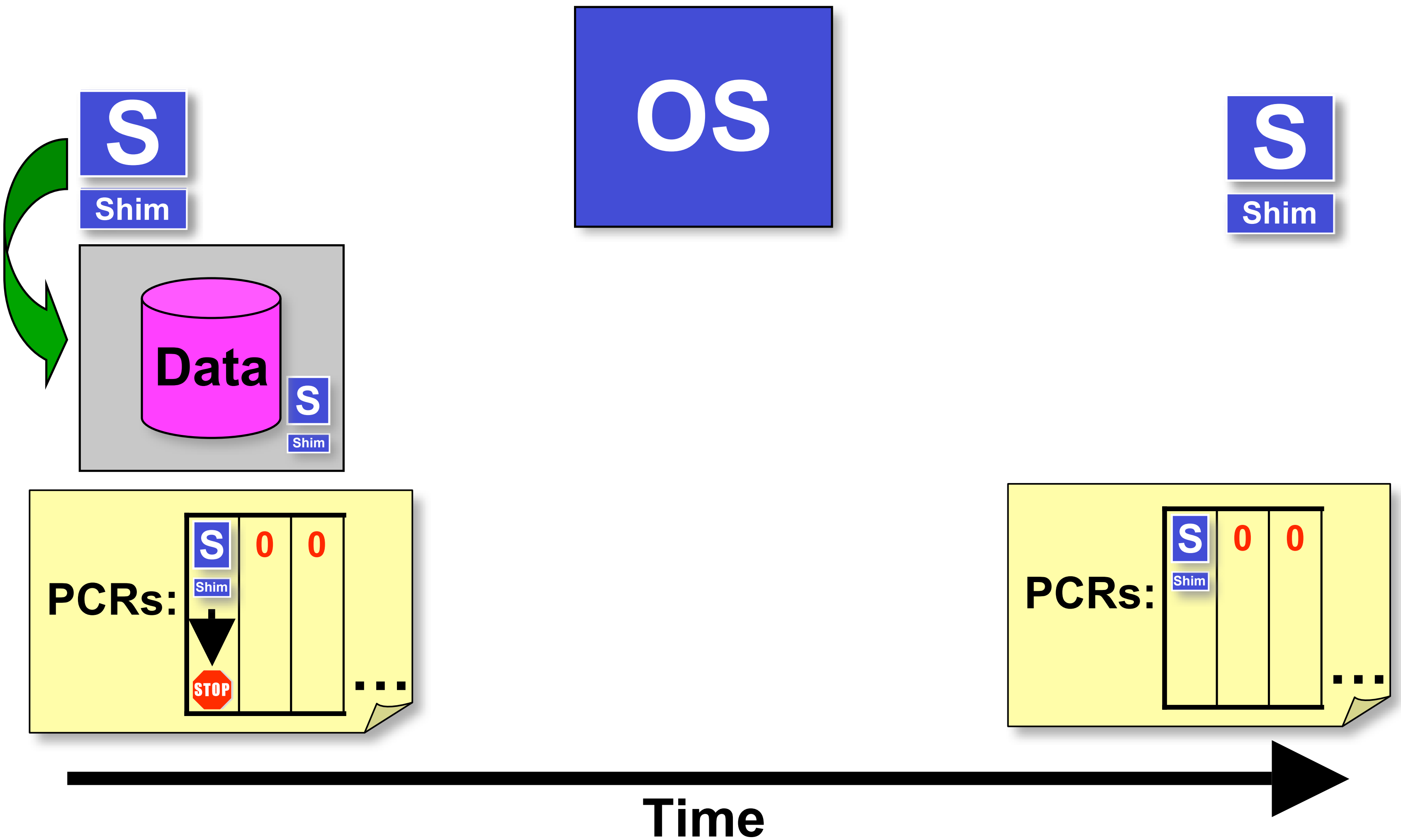


Attestation



Context Switch with Sealed Storage

- **Seal** data under combination of code, inputs, outputs
- Data unavailable to other code

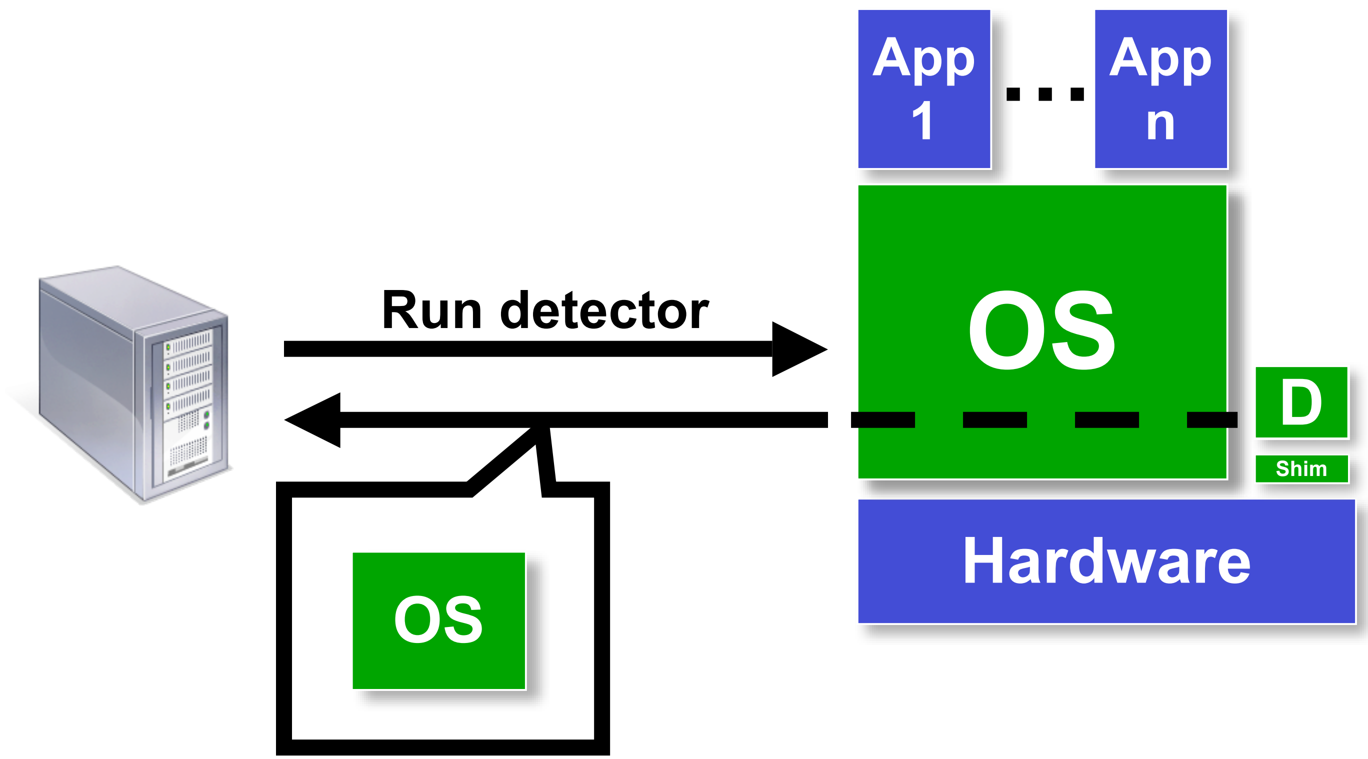


Functionality

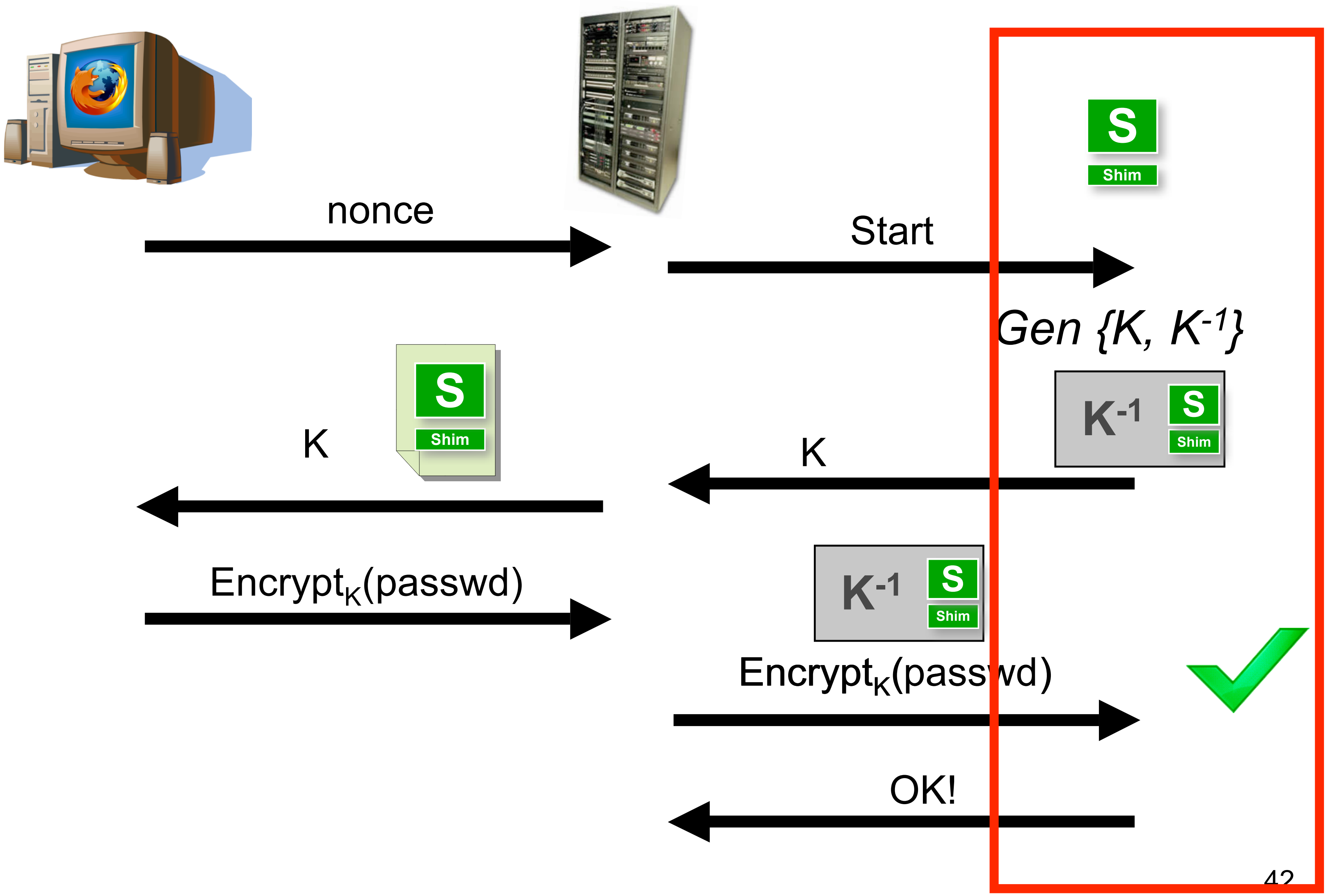
- Shim can execute arbitrary x86 code but provides very limited functionality
- Fortunately, many security-sensitive functions do not require much
  - E.g., key generation, encryption/decryption, FFT
- Functionality can be added to support a particular security-sensitive operation
- We have partially automated the extraction of support code for security-sensitive code

Application: Rootkit Detector

- Administrator can check the integrity of remote hosts
  - E.g., only allow uncompromised laptops to connect to the corporate VPN



Application: SSH Passwords

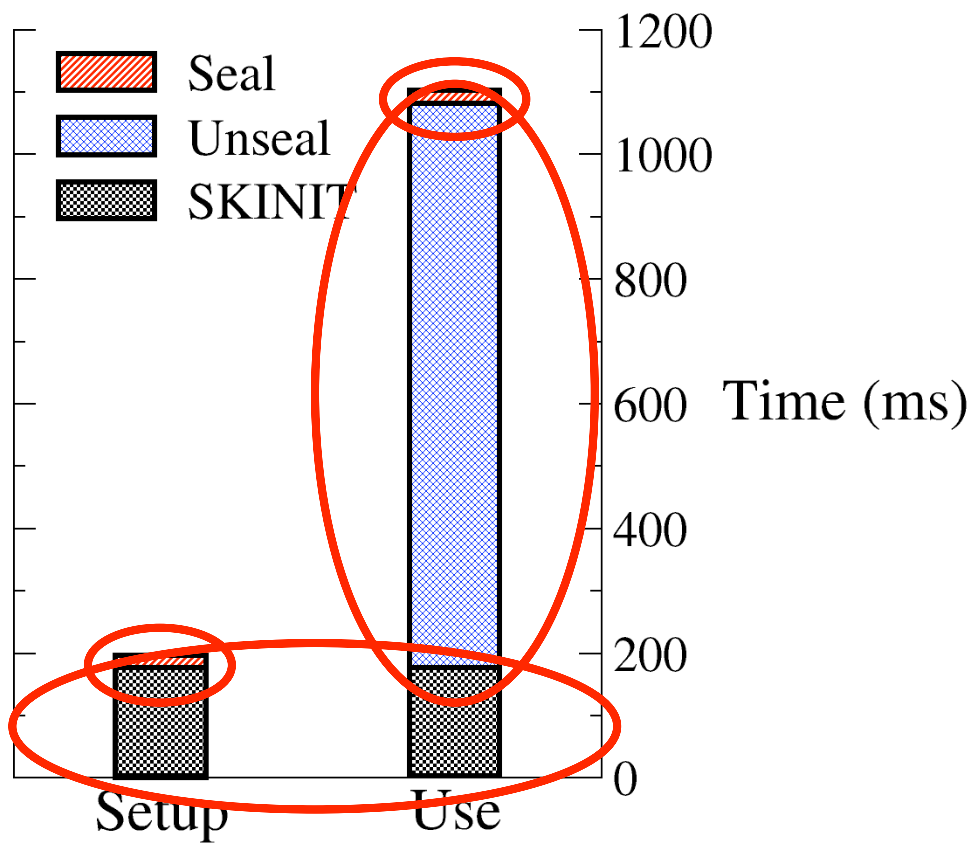


Other Applications Implemented

- Enhanced Certificate Authority (CA)
  - Private signing key isolated from entire system
- Verifiable distributed computing
  - Verifiably perform a computational task on a remote computer
  - Ex: SETI@Home, Folding@Home, distcc

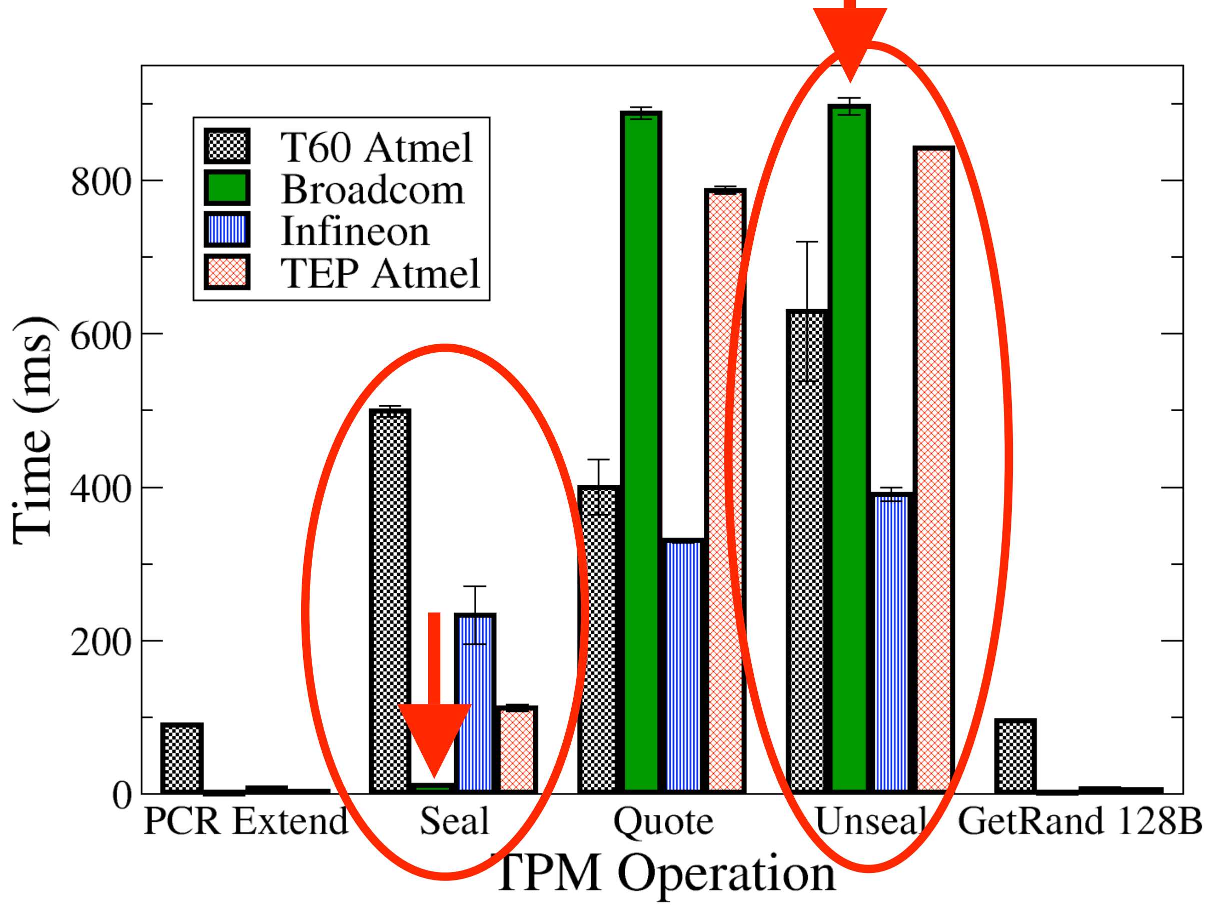
TPM-related Performance

- During every Flicker context switch
  - Application state protection while OS runs



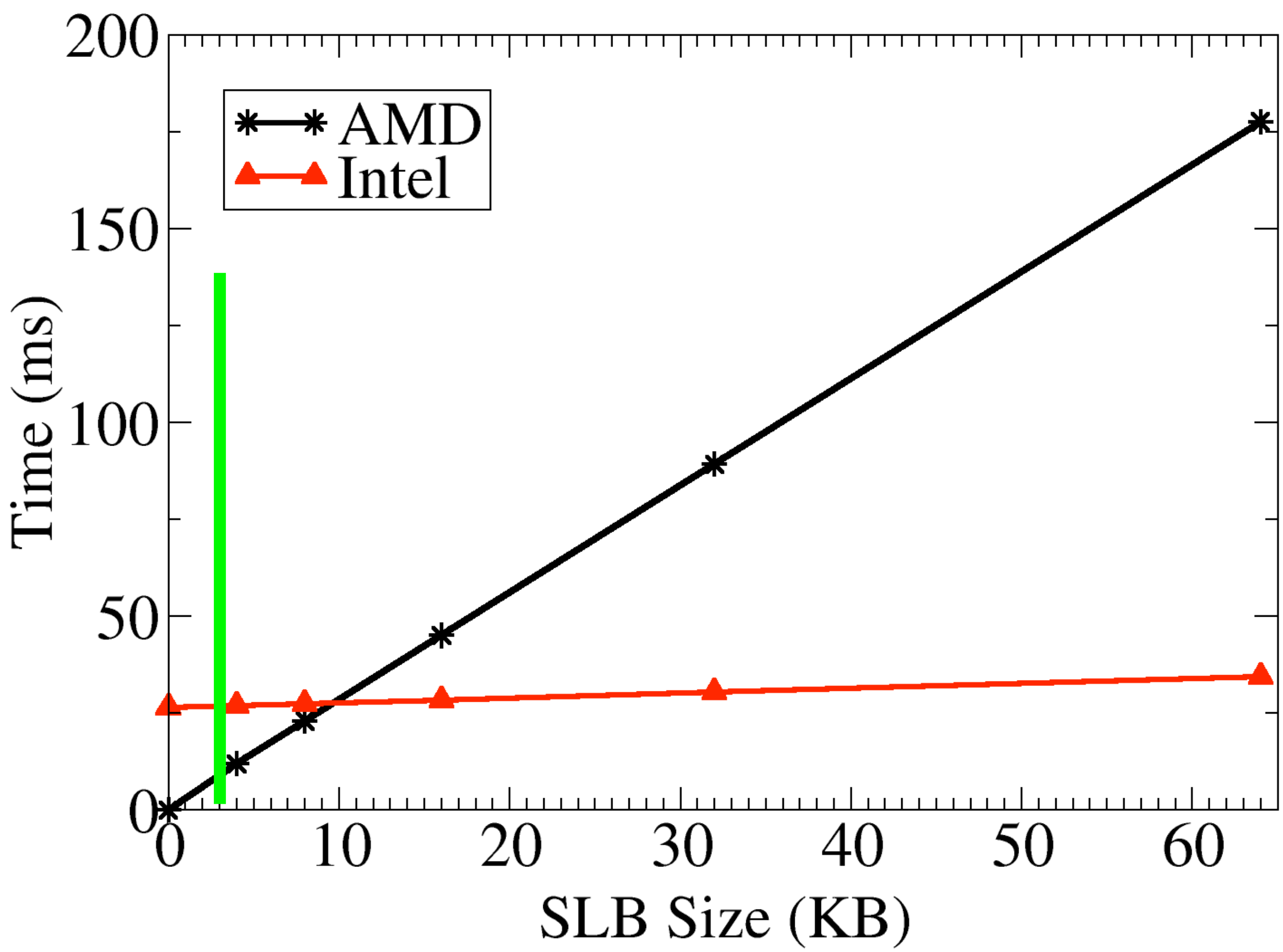
TPM Microbenchmarks

- Significant variation by TPM model



Breakdown of Late Launch Overhead

- After ~4KB, code can measure itself



Ongoing Work

- Containing malicious or malfunctioning security-sensitive code
- Creating a trusted path to the user
- Porting implementation to Intel
- Improving automatic privilege separation

Conclusions

- Explore how far an application's TCB can be minimized
- Isolate security-sensitive code execution
- Provide fine-grained attestations
- Allow application writers to focus on the security of their own code

Thank you!

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