CIS 551 / TCOM 401

# Computer and Network Security

Spring 2007

Lecture 23

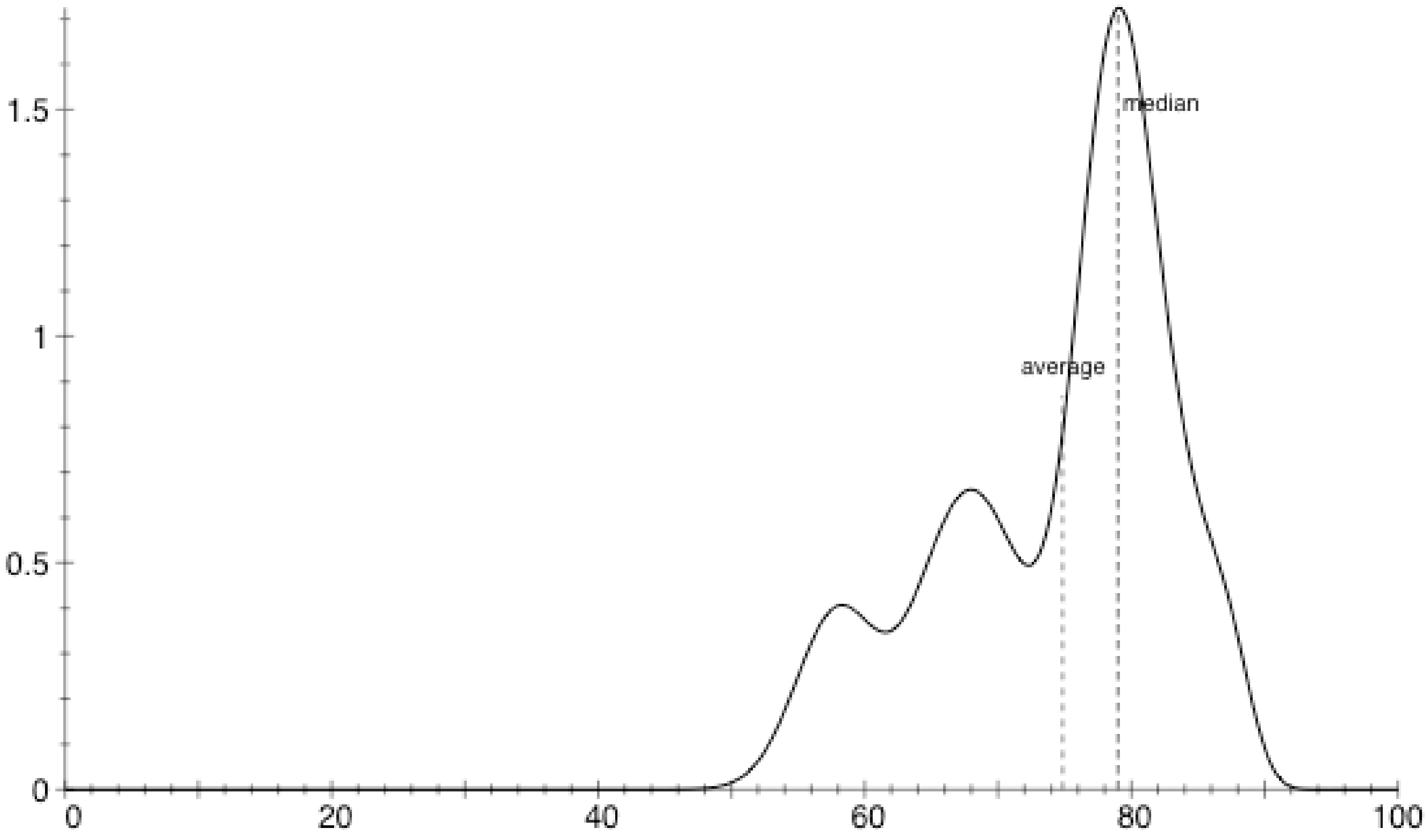
# Announcements

- Project 4 is Due Friday  April 20th  at 11:59 PM

- Today's topic:
  - Trusted Computing

- Assigned reading for next class(es):
  - "Analysis of an Electronic Voting System" by Kohno, et al.
  - http://avirubin.com/vote.pdf
  - (Links on course web pages.)

# Project 2 grade distribution



# Trusted Computing Base

- How do you know the hardware/software can be trusted?

- How can you "bootstrap" a small, trusted component into a complete trusted system?

- Important for:
  - Secure (encrypted) storage
  - Digital rights management
  - Remote "attestation"

# Trusted Computing Group

- https://www.trustedcomputinggroup.org/home
- TCG consortium. Founded in 1999 as TCPA.
  - Main players (promotors): (>200 members)

    AMD, HP, IBM, Infineon, Intel,

    Lenovo, Microsoft, Sun
- Goals:
  - **Hardware protected (encrypted) storage**:
    - Only "authorized" software can decrypt data
    - e.g.: protecting key for decrypting file system
  - **Secure boot**: method to "authorize" software
  - **Attestation**: Prove to remote server what software is running on my machine.

# TCG: changes to PC or cell phone

- Extra hardware: **TPM**
  - Trusted Platform Module (TPM) chip
    - Single 33MhZ clock.
  - TPM Chip vendors: (~7$)
    - Atmel, Infineon, National, STMicro
    - Intel D875GRH motherboard

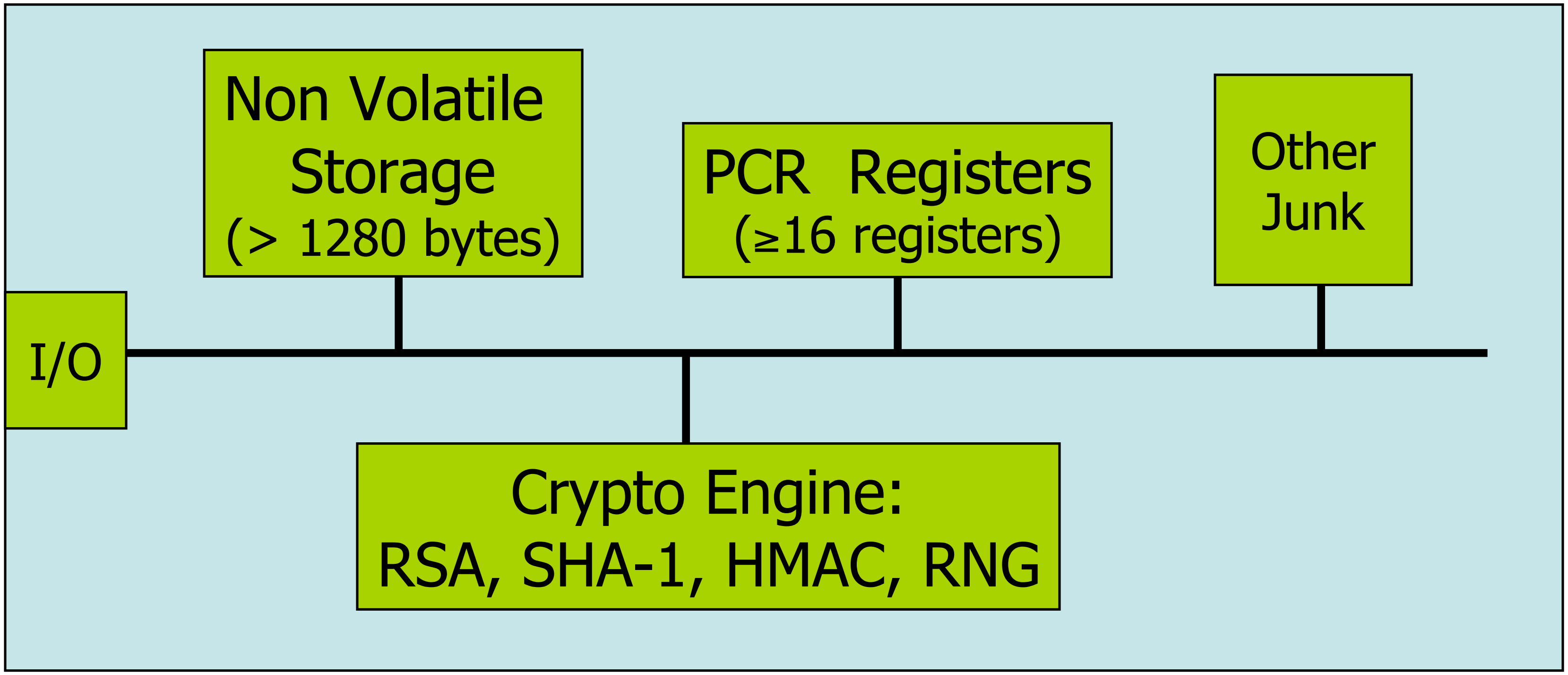
- Software changes:
  - BIOS
  - OS and Apps

# TPMs in the real world

- Systems containing TPM chips:
  - Lenovo (IBM) Thinkpads and desktops
  - Fujitsu lifebook
  - HP desktop and notebooks
  - Dell, Gateway, etc.

- Software using TPMs:
  - File/disk encryption: Vista, IBM, HP, Softex
  - Attestation for enterprise login: Cognizance, Wave
  - Client-side single sign on: IBM, Utimaco, Wave

# Components on TPM chip



| | |
|---|---|
| RSA: | 1024, 2048 bit modulus |
| SHA-1: | Outputs 20 byte digest |

# PCR: the heart of the matter

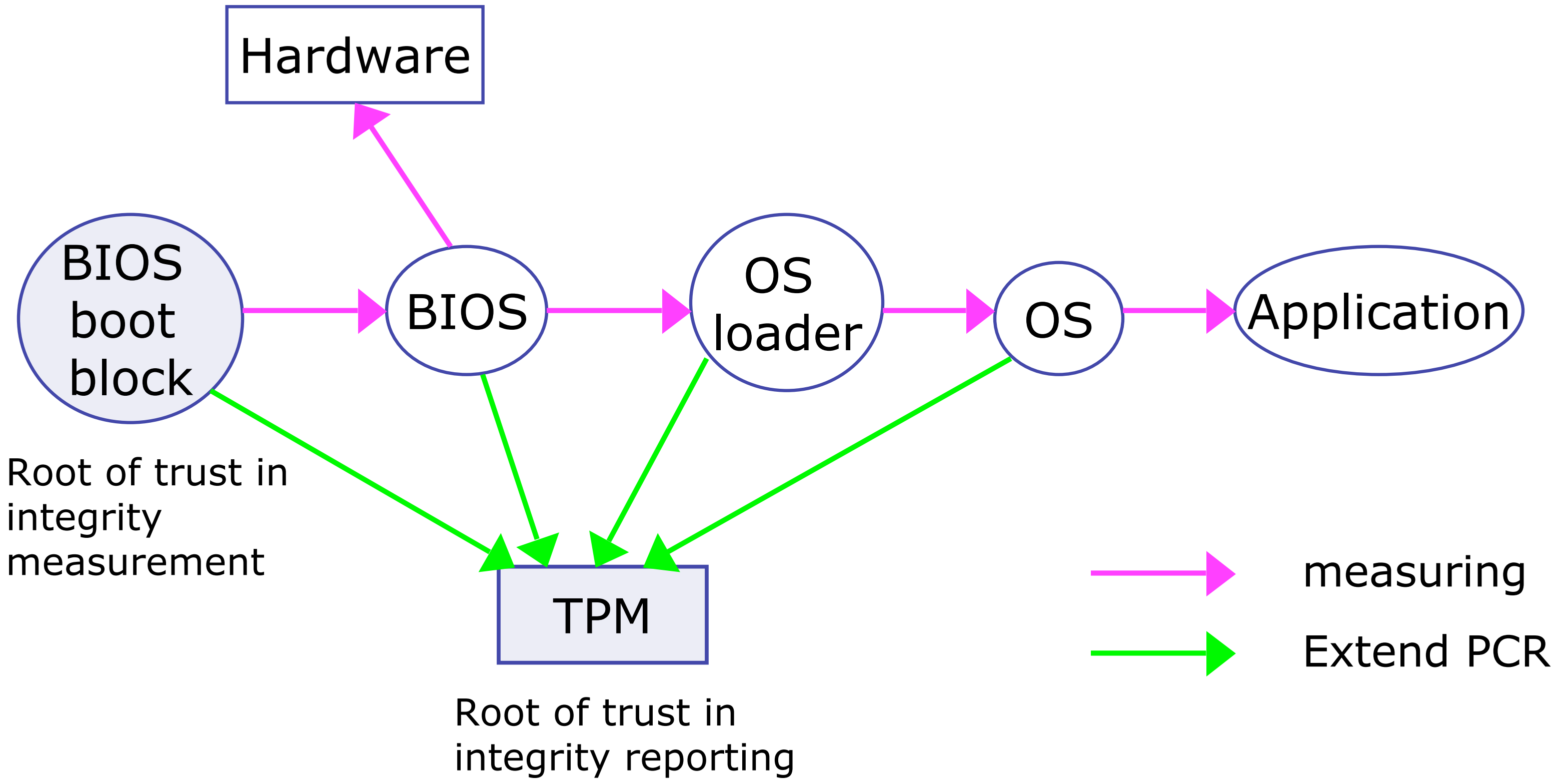
- *PCR: Platform Configuration Registers*
  - Lots of PCR registers on chip (at least 16)
  - Register contents: 20-byte SHA-1 digest (+junk)
- Updating PCR #n :
  - TPM_Extend(n,D): PCR[n] ← SHA-1 ( PCR[n] || D )
  - TPM_PcrRead(n): returns value(PCR(n))
- PCRs initialized to default value (e.g. 0) at boot time
  - TPM can be told to restore PCR values via
    TPM_SaveState and TPM_Startup(ST_STATE)

# Using PCRs: the TCG boot process

- At power-up PCR[n] initialized to 0
- BIOS boot block executes
  - Calls PCR_Extend( n, <BIOS code> )
  - Then loads and runs BIOS post boot code
- BIOS executes:
  - Calls PCR_Extend( n, <MBR code> )
  - Then runs MBR (master boot record), e.g. GRUB.
- MBR executes:
  - Calls PCR_Extend( n, <OS loader code, config> )
  - Then runs OS loader

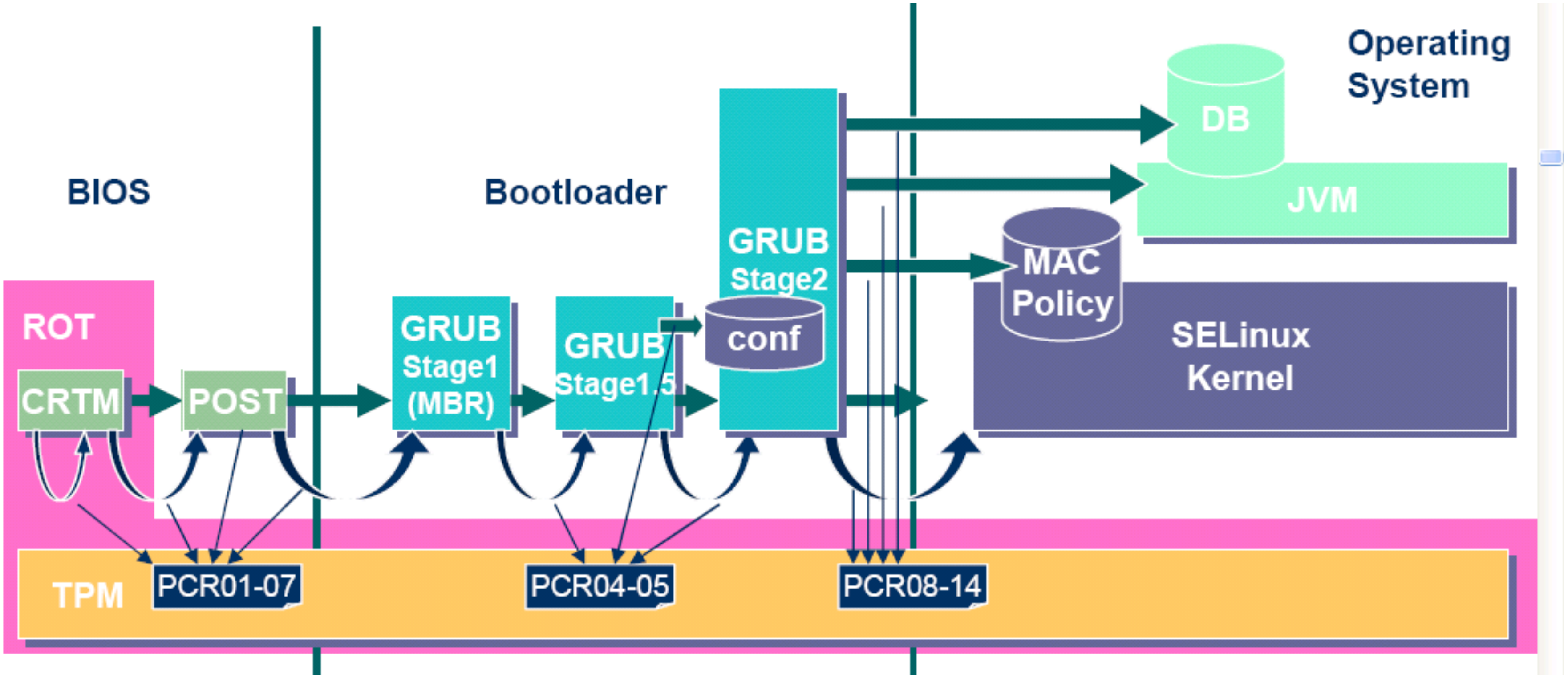
… and so on

# In a diagram


Hardware
BIOS boot block
BIOS
OS loader
OS
Application
TPM
Root of trust in integrity measurement
Root of trust in integrity reporting
measuring
Extend PCR

- After boot, PCRs contain hash chain of booted software
- Collision resistance of SHA1 (?)  ensures commitment

# Example: Trusted GRUB (IBM'05)



What PCR # to use and what to measure specified in GRUB config file

# Using PCR values after boot

- Application 1:   encrypted (a.k.a  sealed)  storage.

- Step 1: TPM_TakeOwnership( OwnerPassword,  … )
  - Creates 2048-bit RSA Storage Root Key (SRK) on TPM
  - Cannot run TPM_TakeOwnership again:
    - Ownership Enabled flag ← False
  - Done once by IT department or laptop owner.

- (optional) Step 2:   TPM_CreateWrapKey
  - Create more RSA keys on TPM certified by SRK
  - Each key identified by 32-bit keyhandle

# Protected Storage

- Main Step:   Encrypt data using RSA key on TPM
  - TPM_Seal     (some) Arguments:
    - keyhandle:   which TPM key to encrypt with
    - KeyAuth:   Password for using key `keyhandle’
    - PcrValues:   PCRs to embed in encrypted blob
    - data block:   at most 256 bytes  (2048 bits)
      - Used to encrypt symmetric key (e.g. AES)
  - Returns encrypted blob.
- **Main point**:   blob can only be decrypted with TPM_Unseal when  PCR-reg-vals =  PCR-vals  in blob.
  - TPM_Unseal will fail othrwise

# Protected Storage

- Embedding PCR values in blob ensures that only certain apps can decrypt data.
  - e.g.: Messing with MBR or OS kernel will change PCR values.

- Why can't attacker disable TPM until after boot, then extend PCRs with whatever he wants?
  - Root of trust: BIOS boot block.

- Gaping hole: roll-back attack on encrypted blobs
  - e.g. undo security patches without being noticed.
  - Can be mitigated using Data Integrity Regs (DIR)

# Sealed storage:  applications

- Lock software on machine:
  - OS and apps sealed with MBR’s PCR.
  - Any changes to MBR (to load other OS) will prevent locked software from loading.
  - Prevents reverse-engineering

- Web server:  seal server’s SSL private key
  - Goal:   only unmodified Apache can access SSL key
  - Problem:   updates to Apache, config, or content

- General problem with software patches:
  - When updating MBR, must re-seal blobs
  - Not a simple process …

# TPM Counters

- TPM must support at least four hardware counters
  - Increment rate: every 5 seconds for 7 years.

- Applications:
  - Provides time stamps on blobs.
  - Supports "music will pay for 30 days" policy.

# Non-volatile TPM memory

- Stores:
  - Storage Root Key (SRK)
  - Owner Password

  Generated when user takes ownership

  - Endorsement Key (EK)
    - Created once for the life of the TPM
    - Certificate for EK issued by TPM vendor
    - Basis of attestation
  - Persistent flags (e.g. ownership flag)

# Attestation: what it does

- **Goal**: prove to remote party what software is running on my machine.
- Good applications:
  - Bank allows money transfer only if customer’s machine runs “up-to-date” OS patches.
  - Enterprise allows laptop to connect to its network only if laptop runs “authorized” software
  - Quake players can join a Quake network only if their Quake client is unmodified.
- DRM:
  - MusicStore sells content for authorized players only.

# Attestation:  how it works

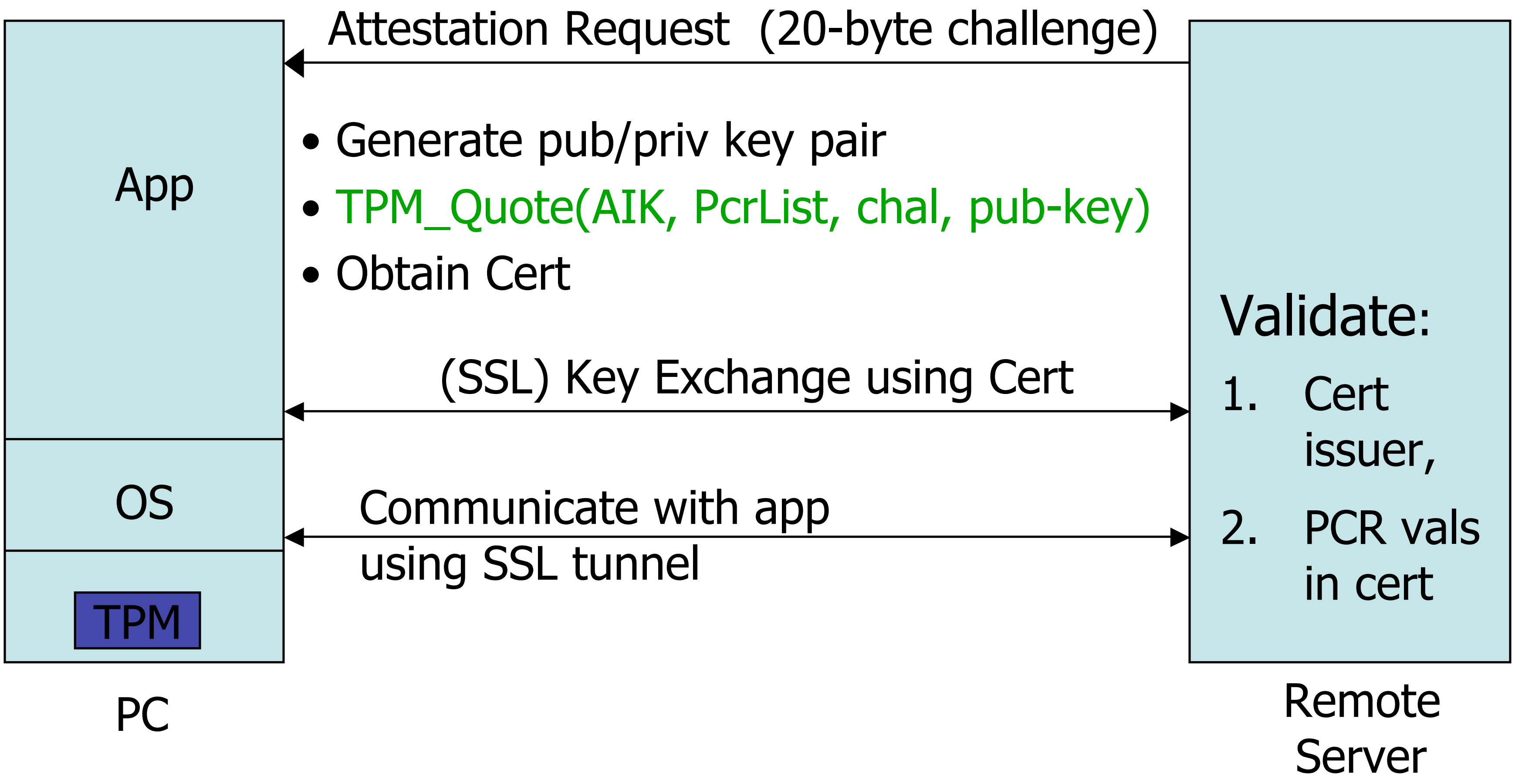
- Recall:   EK private key on TPM.
  - Cert for EK public-key issued by TPM vendor.

- Step 1:   Create Attestation Identity Key  (AIK)
  - Details not important.
  - AIK Private key known only to TPM
  - AIK public cert issued only if EK cert is valid

# Attestation:  how it works

- Step 2:    sign PCR values    (after boot)
  - Call   TPM_Quote      (some) Arguments:
    - keyhandle:   which AIK key to sign with
    - KeyAuth:   Password for using key `keyhandle’
    - PCR List:  Which PCRs to sign.
    - Challenge:   20-byte challenge from remote server
      - Prevents replay of old signatures.
    - Userdata:  additional data to include in sig.
  - Returns signed data and signature.

# Attestation: how it (should) work

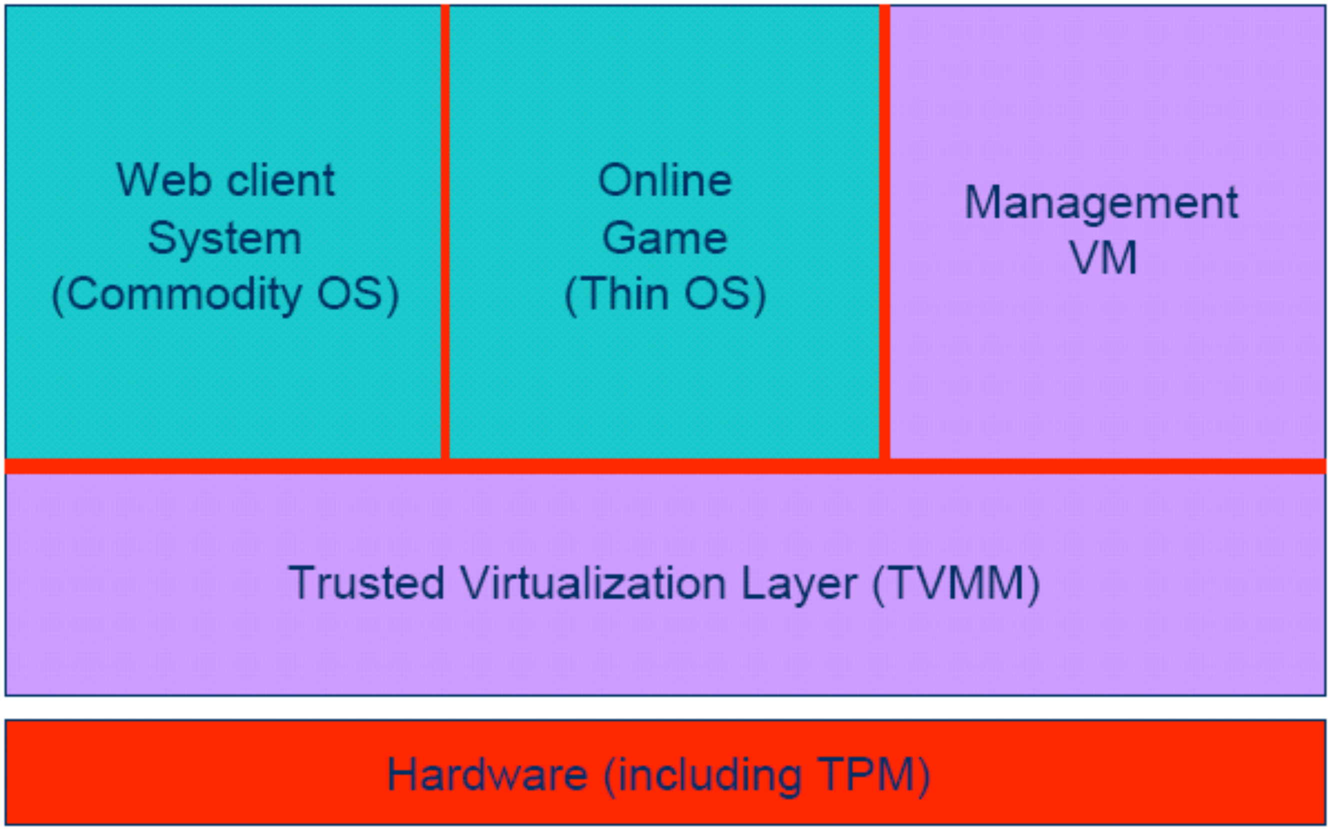


Attestation Request (20-byte challenge)
App
• Generate pub/priv key pair
• TPM_Quote(AIK, PcrList, chal, pub-key)
• Obtain Cert
Validate:
1. Cert issuer,
2. PCR vals in cert
(SSL) Key Exchange using Cert
OS
Communicate with app using SSL tunnel
TPM
PC
Remote Server

- Attestation should include key-exchange
- App must be isolated from rest of system

# Attesting to VMs:  Terra

http://suif.stanford.edu/papers/sosp03-terra.pdf



TVMM Provides isolation between attested applications

# Nexus OS [Sirer et al]

- www.cs.cornell.edu/People/egs/nexus

- Problem: attesting to hashed application/kernel code
  - Too many possible software configurations

- Better approach: attesting to properties
  - Example: "application never writes to disk"

- Supported in Nexus OS
- General attestation statements:
  - "TPM says that it booted Nexus,
    Nexus says that it ran checker with hash X,
    checker says that IPD A has property P"

# EFF: Owner Override

- EFF = Electronic Frontier Federation (www.eff.org)
- TCG attestation:
  - **The good**: enables user to prove to remote bank that machine is up-to-date
  - **The bad**: content owners can release decryption key only to machines running "authorized" software.
    - Stifles innovation in player design
- EFF: allow users to inject chosen values into PCRs.
  - Enables users to conceal changes to their computing environment.
  - Still defeats malicious changes to computing platform

# TCG Alternatives

- IBM 4758: Supports all TCG functionality and more.
  - Tamper resistant 486 100MhZ PCI co-processor.
  - Programmable.
  - … but expensive ~ $2000. TPM ~ $7.
- AEGIS System: Arbaugh, Farber, Smith '97:
  - Secure boot with BIOS changes only.
  - Cannot support sealed storage.
  - **Phoenix TrustConnector 2**
- SWATT: Seshadri et al., 2004
  - Attestation w/o extra hardware
  - Server must know precise HW configuration

# Problem 1. Attesting to Current State

- Attestation only attests to what code was loaded.
- Does not say whether running code has been compromised.
  - Problem:  what if Quake vulnerability exploited after attestation took place?
- Can we attest to the current state of a running system?
  - … or is there a better way?

# Problem 2. Encrypted viruses

- Suppose malicious music file exploits bug in Windows Media Player.
  - Music file is encrypted.
  - TCG prevents anyone from getting music file in the clear.
  - Can anti-virus companies block virus without ever seeing its code in the clear?

# Problem 3. TPM Compromise

- Suppose one TPM Endorsement Private Key is exposed
  - Destroys all attestation infrastructure:
    - Embed private EK in TPM emulator.
    - Now, can attest to anything without running it.

⇒ Certificate Revocation is critical for TCG Attestation.

# 4. Private attestation

- Attestation should not reveal platform ID.
  - Recall Intel CPU-ID fiasco.
- Private attestation:
  - Remote server can validate trustworthiness of attestation
  - … but cannot tell what machine it came from.
- TCG Solutions:
  - Privacy CA: online trusted party
  - Group sigs: privacy without trusted infrastructure