INF3510 Information Security

Lecture 6: Computer Security

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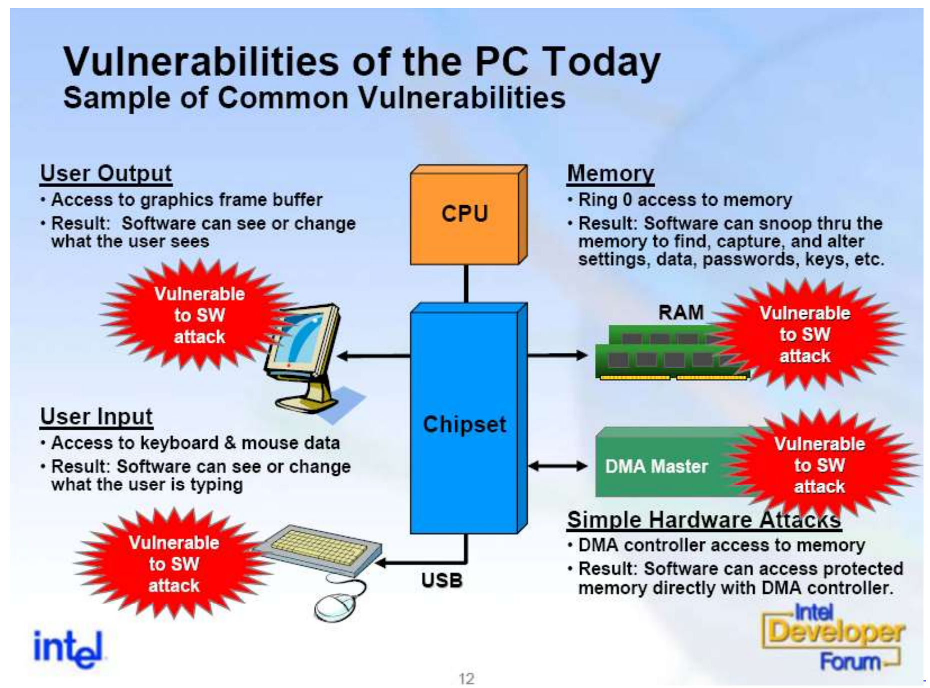
Lecture Overview

- Secure computer architectures
- Virtualisation architectures
- Trusted computing
- Security Evaluation

System & Communication Security

- "Using encryption on the Internet is the equivalent of arranging an armored car to deliver credit card information from someone living in a cardboard box to someone living on a park bench.“
  (Gene Spafford)



Source: "LaGrande Architecture" presentation by David Grawrock, delivered at Intel Developer Forum, September 2003. http://www.intel.com/idf/us/fall2003/presentations/F03USSCMS18_OS.pdf

Approaches to strengthening platform security

- Harden the operating system
  - SE (Security Enhanced) Linux, Trusted Solaris, Windows 7/8/10
- Add security features to the CPU
  - Protection Layers, NoExecute, ASLR
- Virtualisation technology
  - Separates processes by separating virtual systems
- Trusted Computing
  - Add secure hardware to the commodity platform
  - E.g. TPM (Trusted Platform Module)
- Rely on secure hardware external to commodity platform
  - Smart cards
  - Hardware tokens

TCB – Trusted Computing Base

- The trusted computing base (TCB) of a computer system is the set of all hardware, firmware, and/or software components that are critical to its security, in the sense that bugs or vulnerabilities occurring inside the TCB might jeopardize the security properties of the entire system.
- By contrast, parts of a computer system outside the TCB must not be able to breach the security policy and may not get any more privileges than are granted to them in accordance to the security policy

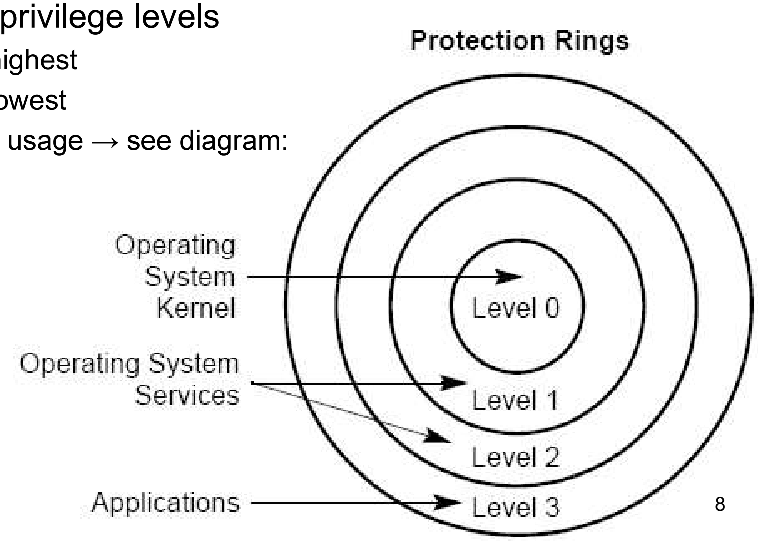
(TCSEC – Trusted Computer Evaluation Criteria, 1985).

Reference Monitor

- Reference monitor is the security model for enforcing an access control policy over subjects' (e.g., processes and users) ability to perform operations (e.g., read and write) on objects (e.g., files and sockets) on a system.
  - The reference monitor must always be invoked (complete mediation).
  - The reference monitor must be tamperproof (tamperproof).
  - The reference monitor must be small enough to be subject to analysis and tests, the completeness of which can be assured (verifiable).
- The security kernel of an OS is a low-level (close to the hardware) implememtation of a reference monitor.

OS security kernel as reference monitor

- Hierarchic security levels were introduced in X86 CPU architecture in 1985 (Intel 80386)
- 4 ordered privilege levels
  - Ring 0: highest
  - Ring 3: lowest
  - Intended usage → see diagram:



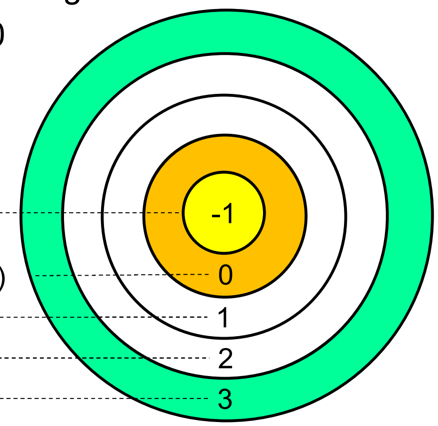
What happened to rings 1 & 2 ?

... it eventually became clear that the hierarchical protection that rings provided did not closely match the requirements of the system programmer and gave little or no improvement on the simple system of having two modes only. Rings of protection lent themselves to efficient implementation in hardware, but there was little else to be said for them. [...]. This again proved a blind alley...

Maurice Wilkes (1994)

CPU Protection Ring structure from 2006

- New Ring -1 introduced for virtualization.
- Necessary for protecting hypervisor from VMs (Virtual Machines) running in Ring 0.
- Hypervisor controls VMs in Ring 0
- Ring 0 is aka.: Supervisor Mode



Ring -1: Hypervisor Mode

Ring 0: Kernel Mode (Unix root, Win. Adm.)

Ring 1: Not used

Ring 2: Not used

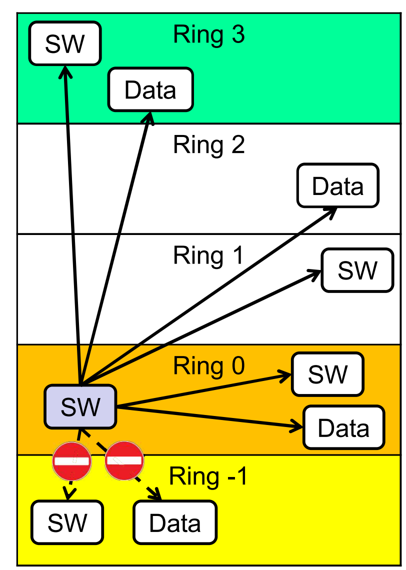
Ring 3: User Mode

Privileged Instructions

- Some of the system instructions (called "privileged instructions") are protected from use by application programs.
- The privileged instructions control system functions (such as the loading of system registers). They can be executed only when the Privilege Level is 0 or -1 (most privileged).
- If one of these instructions is attempted when the Privilege Level is not 0 or -1, then a general-protection exception (#GP) is generated, and the program crashes.

Principle of protection ring model

- A process can access and modify any data and software at the same or less privileged level as itself.
- A process that runs in kernel mode (Ring 0) can access data and SW in Rings 0, 1, 2 and 3
  - but not in Ring -1
- The goal of attackers is to get access to kernel or hypervisor mode.
  - through exploits
  - by tricking users to install software

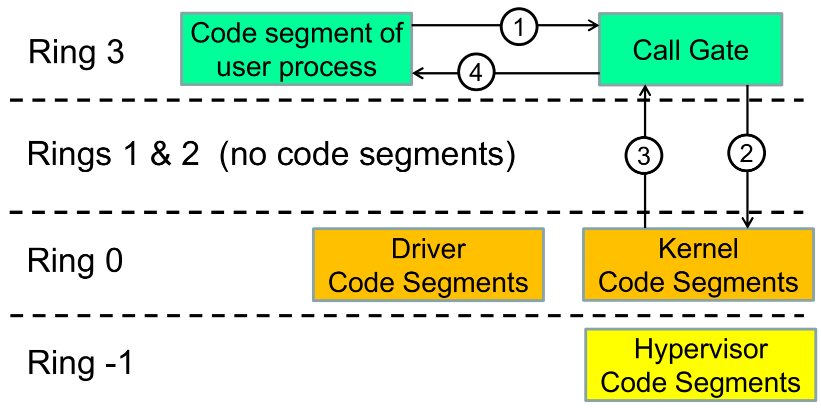


User processes access to system resources

- User processes need to access system resources (memory and drivers)
- User application processes should not access system memory directly, because they could corrupt memory.
- The CPU must restrict direct access to memory segments and other resources depending on the privilege level.

- Question 1: How can a user process execute instructions that require kernel mode, e.g. for writing to memory ?
  - Answer: The CPU must switch between privilege levels
- Question 2: How should privilege levels be switched?
  - Answer: Through Controlled invocation of code segments

Controlled Invocation of code segments



Controlled Invocation

- The user process executes code in specific code segments.
- Each code segment has an associated mode which dictates the privilege level the code executes under.
- Simply setting the mode of user process code to Kernel would give kernel-privilege to user process without any control of what the process actually does. Bad idea!
- Instead, the CPU allows the user process to call kernel code segments that only execute a predefined set of instructions in kernel mode, and then returns control back to the user-process code segment in user mode.
- We refer to this mechanism as controlled invocation.

Platform Virtualization

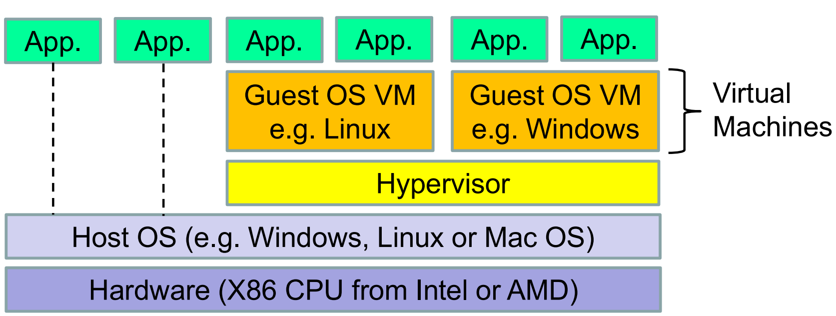
Virtual machines (VM)

- A software implementation of a machine (OS) that executes programs like a real machine (traditional OS)
- Example:
- Java Virtual Machine (JVM)
  - JVM accepts a form of computer intermediate language commonly referred to as Jave bytecode.
    - "compile once, run anywhere“
  - The JVM translates the bytecode to executable code on the fly
- Platform Virtualization
  - Simultaneous execution of multiple OSs on a single computer hardware, so each OS becomes a virtual computing platform

Platform Virtualization

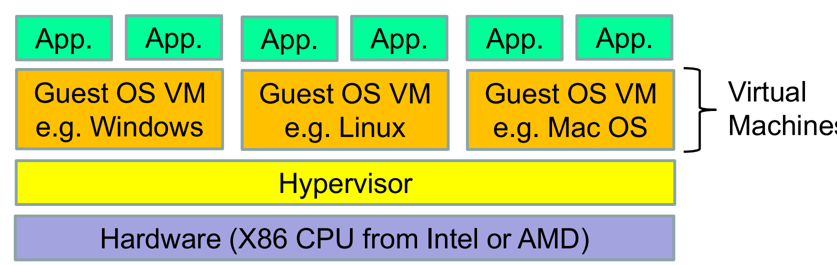
- Hypervisor (aka. VMM - Virtual Machine Monitor) is needed to manage multiple guest OSs (virtual machines) in the same hardware platform.
- Many types of hypervisors available
  - VMWare is most known Commercial product (Type 1&2)
    - Free version comes with a limitations
  - VirtualBox is a hypervisor for x86 virtualization
    - It is freely availably under GPL, Type 2
    - Runs on Windows, Linux, OS X and Solaris hosts
  - Hyper-V is Microsoft’s hypervisor technology (Type 1)
    - Requires Windows Server
  - Xen, powerful open source hypervisor, (Type 1)

Type 2 VM Architecture (simple virtualization)



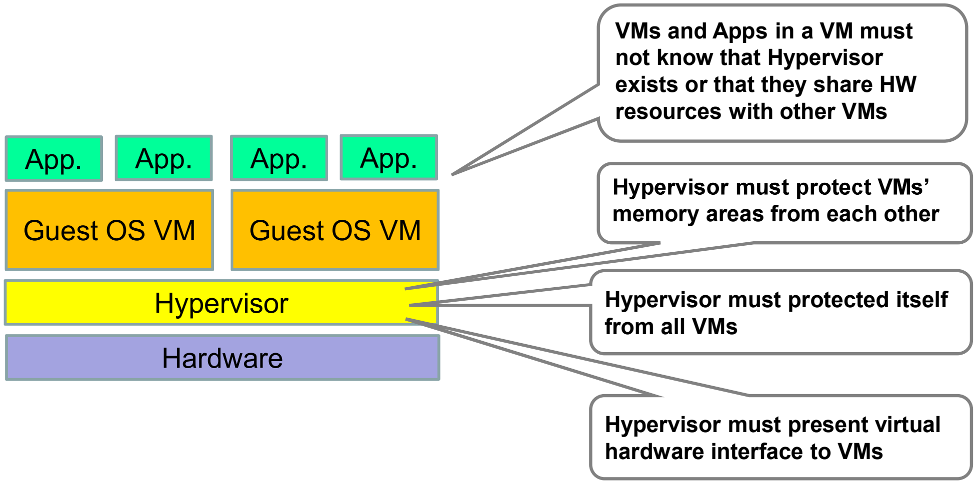
- Hypervisor runs on top of host OS
- Performance penalty, because hardware access goes through 2 OSs
- Traditionally good GUI
- Traditionally good HW support, because host OS drivers available

Type 1 VM Architecture (full virtualization)

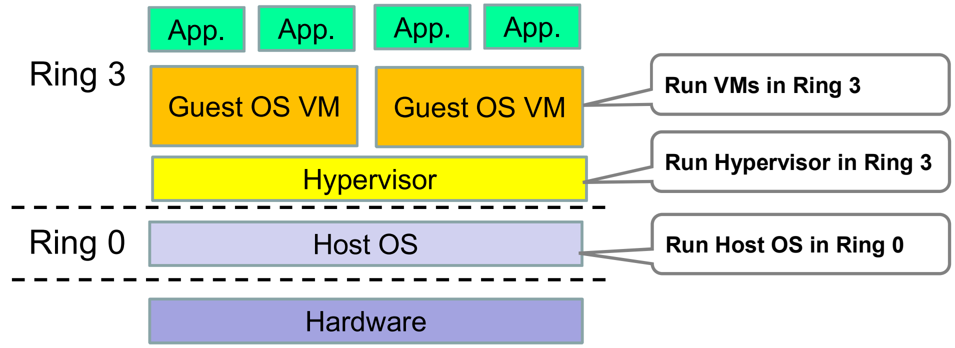


- No host OS
- Hypervisor runs directly on hardware
- High performance
- Traditionally limited GUI, but is improved in modern versions
- HW support can be an issue

Challenges of Running VMs

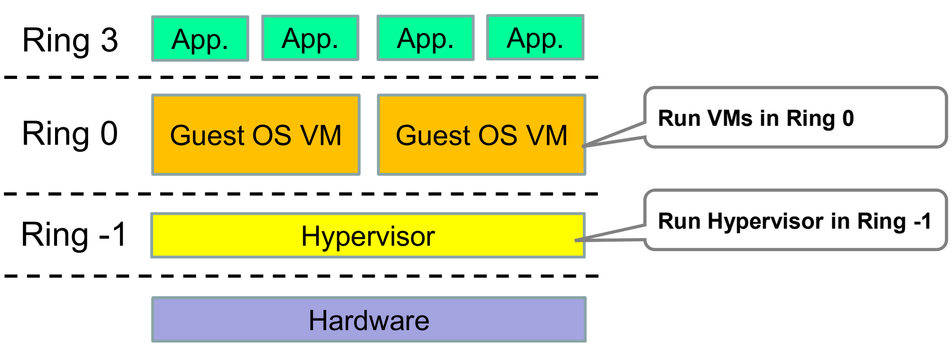


Type 2 VM Architecture Ring Allocation



- Guest OS VMs run in Ring 3.
- Guest OS VMs call privileged instructions that are forbidden in Ring 3.
- Forbidden instructions cause exceptions that are handled by interrupt/exception handler to be executed.
- Slow performance !

Type 1 VM Architecture Ring Allocation

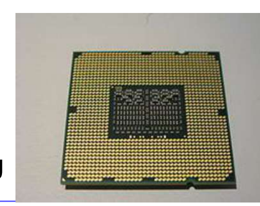


- Guest OS VMs are less privileged than the hypervisor.
- Hypervisor is well protected from the VMs.
- Good performance and good security !

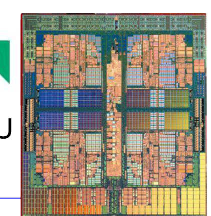
Hardware support for virtualization

- Modern Intel and AMD X86 CPUs support virtualization
  - Intel-VT (Intel Virtualization Technology)
  - AMD-V (AMD Virtualization)
- Must be enabled in BIOS
  - Can be enabled and disabled
  - Computers with single OS typically have virtualization disabled
- Access to data- and code segments for hypervisor can be restricted to processes running in hypervisor mode
- Some instructions are reserved for hypervisor mode

Intel Core i7 CPU



AMD Phenom CPU



Why use platform virtualization

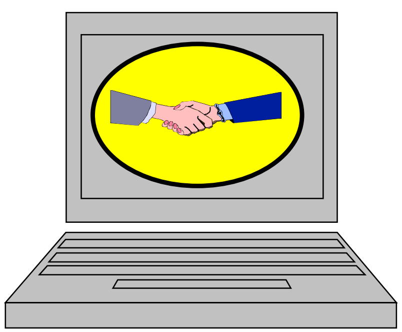
- Efficient use of hardware and resources
  - Improved management and resource utilization
  - Saves energy
- Improved security
  - Malware can only infect the VM
  - Safe testing and analysis of malware
  - Isolates VMs from each other
- Distributed applications bundled with OS
  - Allows optimal combination of OS and application
  - Ideal for cloud services
- Powerful debugging
  - Snapshot of the current state of the OS
  - Step through program and OS execution
  - Reset system state

Hypervisor examples of use

Google data center

- Cloud providers run large server parks
  - Each customer gets its own VM
  - Many customers share the same hardware
  - Migrated VMs between servers to increase/reduce capacity
- Testing and software analysis
  - Potentially damaging experiments can be executed in isolated environment
  - Take a snapshot of the current state of the OS
  - Use this later on to reset the system to that state
  - Malware Analysis

Trusted Computing



Trusted Computing Motivation

- Software alone can not be trusted.
- Malware infection in OS kernel remains undetected by anti-malware tools.
- Physical access to computers opens up for attacks that can circumvent traditional TCBs (Trusted Computing Base), e.g. secure operating systems.
- Remote parties do not know the status of systems they are communicating with.
- Remote parties do not know the physical identity of hosts they are communicating with.

Basic idea of Trusted Computing

- Use specialised **security hardware** as part of TCB in a computer system
  - Can not be compromised by malware
  - Can verify the integrity of OS kernel
  - Can make physical tampering difficult
  - Can report status of system to remote parties
  - Can report identity of system to remote parties
- Gives increased level of trust that the system will perform as expected/specified

What is "trust" in the sense of TC?

- To have confidence in assumptions about security
- Trust is to believe that security assertions will hold

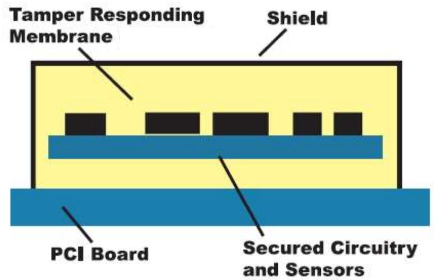
  "*A trusted component, operation, or process is one whose behaviour is assumed to be correct under any operating condition, and which is assumed to resist subversion by malicious software, viruses, and manipulations*"
- A trusted component enforces the security policy as long as these assumptions hold
- A trusted component violates the security policy if it breaks
- Q1: How do you know that a component is 'trustworthy', i.e. that it will not break ? A1: Through 'assurance'
- Q2: Trusted by whom to do what ?
  - Trusted by **user**, by **vendor**, or by **3rd party (NSA)**
  - What if they have conflicting interests ?

Characteristics of Trusted Hardware

- Physically secure hardware component
  - Assumed not to break because it's hardware
- Environmental monitoring (temperature, power supply, structural integrity)
- Tamper responsive
- Implementations
  - CPU
  - ROM for OS and application code
  - Specialized hardware for cryptography and for storing secrets

Trusted Hardware – Example

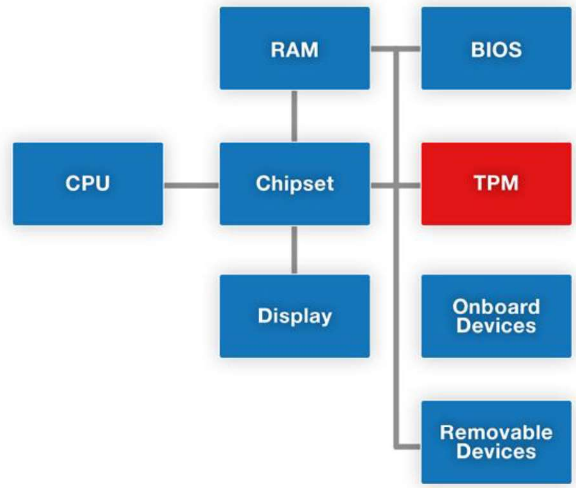
- IBM 4765 Secure Coprocessor



Trusted Computing Group
TCG History & Evolution

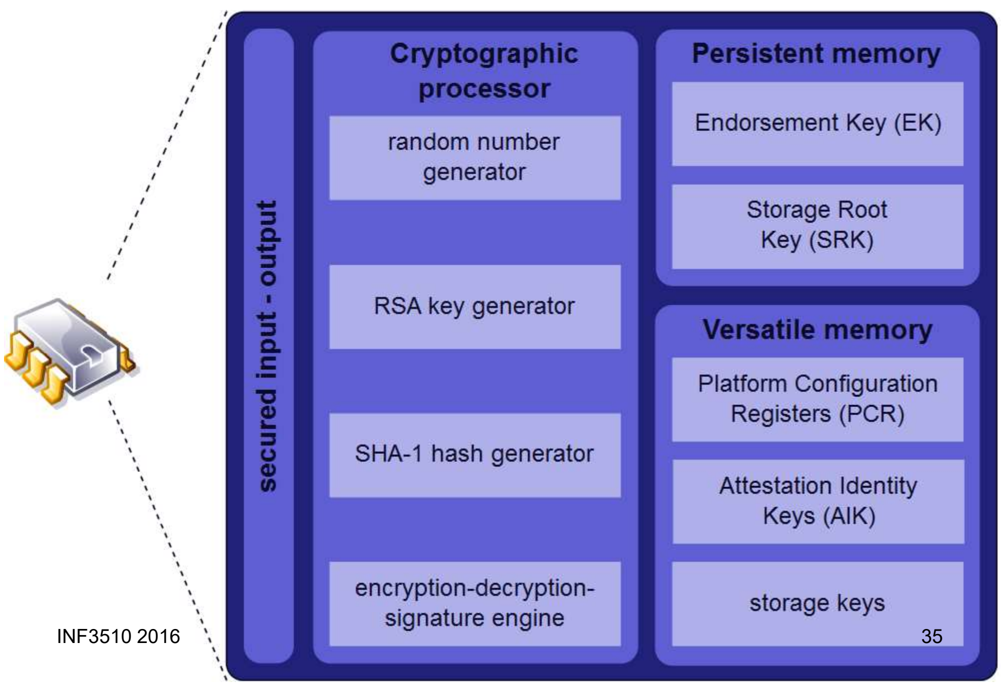
- October 1999: TCPA formed
  - Trusted Computing Platform Alliance
  - Founders: IBM, HP, Compaq, Intel and Microsoft
- 2001: 1st TPM specification released
  - Trusted Platform Module
- 2002: TCPA changes its name to TCG
  - Trusted Computing Group
  - Industry standards organization
- 2003: TCPA TPM spec. adopted by TCG as TPM 1.2
- 2011: Latest TPM spec. 1.2 Ver.116
- 2012: Draft TPM Specification 2.0 published
  - TPM 2.0 spec. not compatible with TPM 1.2 spec.
- 2015: Official TPM specification 2.0

Pervasiveness of the TPM



- The TPM chip sits on the motherboard
- Installed in 2 billion devices per 2015
- Relatively obscure

TPM 1.2 Functionality

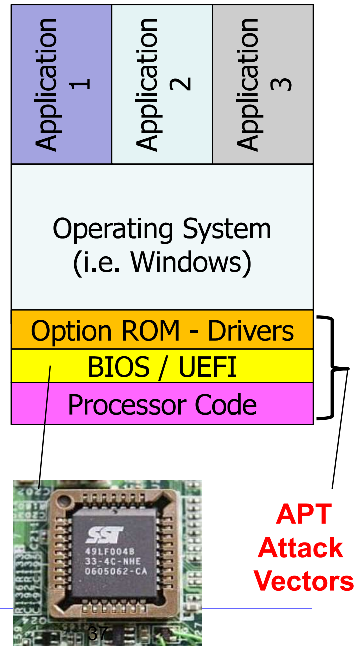


TPM usage

- TPM is both the name of a standard and a chip
- TPM chip at the heart of hardware / software approach to trusted computing
- Current TPM chips implement TPM spec. 2.0
  - Latest version of TPM spec. 2.0 is from 2015
- TPM chip mounted on motherboard,
- TPM equipped computing platforms
  - Laptops, servers, pads, mobile phones
- Used by software platforms
  - Windows Vista / 7 / 8 / 10, Linux, and MAC OS
- Supports 3 basic services:
  - Authenticated/measured boot,
  - Sealed Storage / Encryption
  - Remote attestation,

Boot protection

- BIOS /UEFI
  - First code run by a PC when powered on
  - BIOS/UEFI initializes and identifies system devices such as display and keyboard
  - BIOS/UEFI then loads software (OS) held on a peripheral device such as a hard disk
  - BIOS/UEFI firmware is stored in ROM
- Boot protection
  - Persistent OS infection is the goal of APT
  - Boot protection focuses on verifying the integrity of the OS during boot.
  - Does not protect against infection during runtime



Two modes of boot protection

- Secure boot with UEFI (not with TPM, see UEFI later)
  - The platform owner can define expected (trusted) measurements (hash values) of OS software modules.
  - Hash values stored in memory signed by private PK (Platform Key).
  - Public PK stored in secure firmware on platform
  - Measured has values can be compared with stored values.
  - Matching measurement values guarantee the integrity of the corresponding software modules.
  - Boot process terminates if a measurement does not match the stored value for that stage of the boot process.
- Authenticated/Measured boot with TPM
  - Records measured values in PCRs and reports to remote party
  - Does not terminate boot if measured values are wrong

Sealed Storage / Encryption

- Encrypts data so it can be decrypted
  - by a certain machine in given configuration
- Depends on
  - Storage Root Key (SRK) unique to machine
  - Decryption only possible on unique machine
- Can also extend this scheme upward
  - create application key for desired application version running on desired system version
- Supports disk encryption

Remote Attestation

- TPM can certify configuration to others
  - with a digital signature in configuration info
  - giving another user confidence in it
  - Based on Attestation Key (AK)
- Remote parties can validate signature based on a PKI
- Provides hierarchical certification approach
  - trust TPM, then trust the OS, then trust applications

UEFI
Unified Extensible Firmware Interface

– What is UEFI?
  - Replaces traditional BIOS
  - Like BIOS it hands control of the pre-boot environment to an OS
– Key Security Benefits:
  - Secure Boot

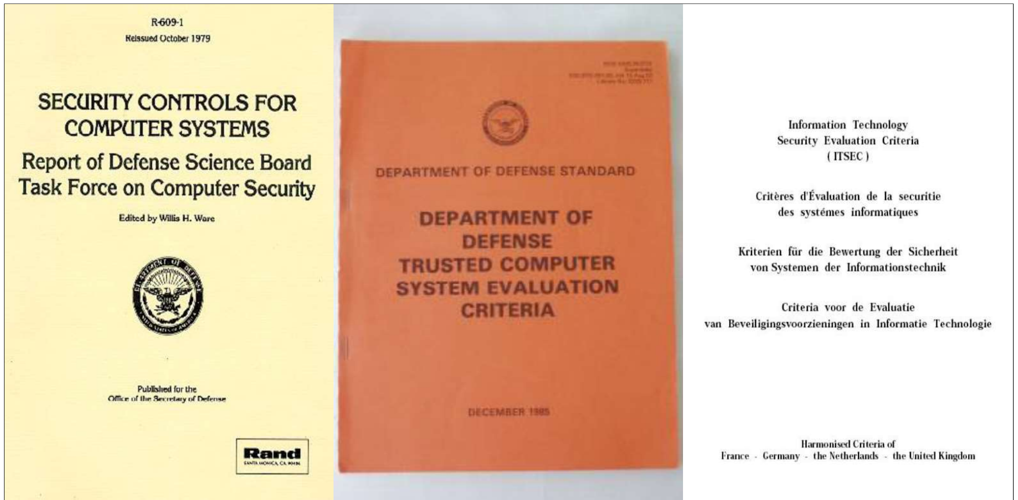
UEFI Secure Boot

- Prevents loading unsigned drivers or OS loaders
- When secure boot is enabled, it is initially placed in "setup" mode, which writes public key known as the "Platform key" (PK) to firmware.
- Once the key is written, secure boot enters "User" mode, where only drivers and loaders signed with the platform key can be loaded by the firmware.
- "Key Exchange Keys" (KEK), signed by private PK, can be added to a database stored in memory to allow other signatures by other than PK.
- Secure boot supported by Win 8, Win Server 2012, Fedora, OpenSuse, and Ubuntu
- Does not require TPM

Security Evaluation

Security Evaluation

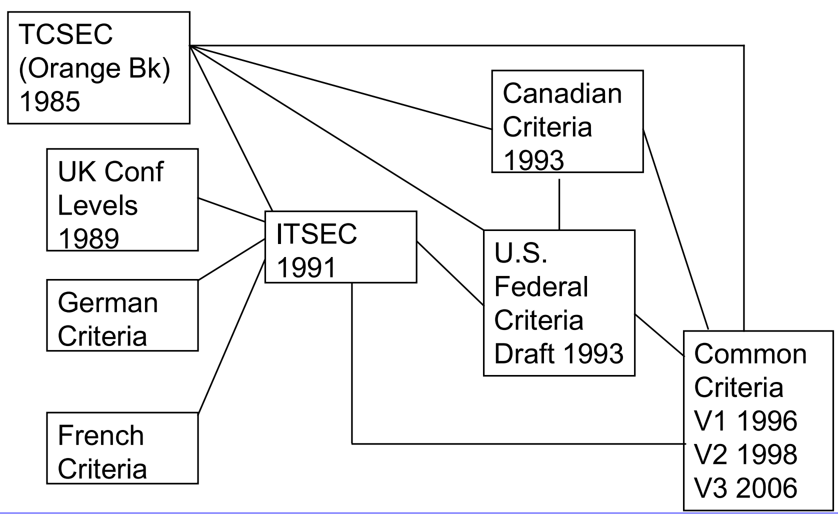
- How do you get assurance that your computer systems are adequately secure?
- You could trust your software providers.
- You could check the software yourself, but you would have to be a real expert, and it would take long.
- You could rely on an impartial security evaluation by an independent body.
- Security evaluation schemes have evolved since the 1980s; currently the Common Criteria are used internationally.



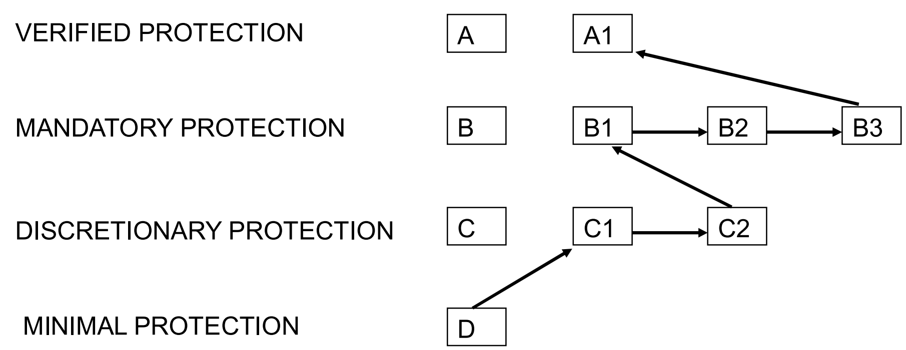
Security Evaluation – History

- TCSEC (Orange Book), 1985: criteria for the US defense sector, predefined evaluation classes linking functionality and assurance
- ITSEC, 1990: European criteria separating functionality and assurance so that very specific targets of evaluation can be specified and commercial needs can better addressed
- Common Criteria (CC): http://www.commoncriteria.org/, http://niap.nist.gov/cc-scheme (1996)
- TCSEC and ITSEC no longer in practical use, but are commonly referred to in the literature.

Security Evaluation Evolution



TCSEC 1985: Evaluation Hierarchy



The Common Criteria – IS15408: 2006

- Common Criteria for Information Technology Security Evaluation
- Represents the outcome of a series of efforts to develop criteria for evaluation of IT security that are broadly useful within the international community.
- V1 published in 1996, V3 published 2006
- Used globally

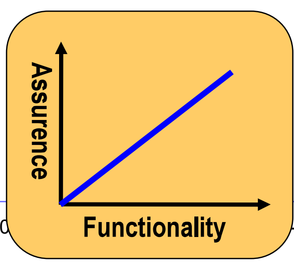
Target & Purpose

- Target of evaluation
  - Product: "off-the-shelf" software component to be used in a variety of applications; has to meet generic security requirements
  - System: collection of products assembled to meet the specific requirements of a given application
- Purpose of evaluation
  - Evaluation: assesses whether a product has the security properties claimed for it
  - Certification: assesses suitability of a product (system) for a given application
  - Accreditation: decide to use a certain system

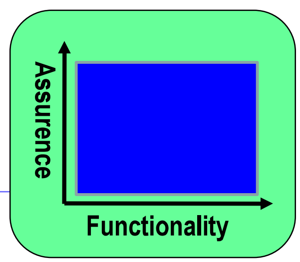
Functionality/Assurance Structure

- Two dimentions of evaluation
  1. Functionality: the security features
  2. Assurance: the robustness of the security features
- Orange Book: assurance levels for a given set of typical DoD requirements, considers both aspects simultaneously.
- CC: flexible evaluation framework that can deal with arbitrary feature sets at any assurance level; the two aspects are addressed independently.

Orange Book



Common Criteria



Common Criteria

- Criteria for the security evaluation of products or systems, called the Target of Evaluation (TOE).
- Protection Profile (PP): a (re-usable) set of security requirements, including an EAL; should be developed by user communities to capture typical protection requirements.
- Security Target (ST): expresses security requirements for a specific TOE, e.g. by reference to a PP; basis for any evaluation.
- Evaluation Assurance Level (EAL): define the specific evaluation requirements that must be satisfied in an evaluation; there are seven hierarchically ordered EALs.

The CC Standard

- Part 1 -Overview
- Part 2 – SFRs Security Functional Requirements
  - Security Functional Requirements (SFRs) are "what does the product does." Taken together, the SFRs a product claims describe the product's capabilities. A product's security features, for example, might be how it identifies and authenticates users.
- Part 3 – SARs: Security Assurance Requirements
  - Security Assurance Requirements (SARs) define the development environment in all its phases: specification, development tools and practices, for example, the use of automated tools to prevent unauthorized modifications to the product, the completeness of test coverage.

CC Assurance Levels

- EAL1 - functionally tested
- EAL2 - structurally tested
- EAL3 - methodically tested and checked
- EAL4 - methodically designed, tested, and reviewed
- EAL5 - semiformally designed and tested
- EAL6 - semiformally verified design and tested
- EAL7 - formally verified design and tested

Using the Common Criteria

- CC is useful for:
  - Specifying security features in product or system
  - Assisting in the building of security features into products or systems
  - Evaluating the security features of products or systems
  - Supporting the procurement of products or systems with security features
  - Supporting marketing of evaluated products
- But
  - Evaluation is expensive and slow
  - New versions of a product must be re-evaluated, but can be done more quickly than the original evaluation.

End of lecture