# Security
# An Advanced Introduction

COMP9242
2008/S2 Week 6

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# What is Security?

- Example 1: DOS
  - Single-user system with no access control
  - Is it secure?
    - ... if it has no data?
    - ... if it contains the payroll database?
    - ... if it is on a machine in the foyer
    - ... if it is in a locked room?
    - ... if it is behind a firewall?

# What is Security?

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- Example 2: Banking store's weekly earnings:
  - Is it secure to
    - ... ask a random customer to do it?
    - ... ask many random customers to do it?
    - ... ask a staff member to do it?
    - ... ask several staff members to do it?
    - ... hire a security firm?
    - ... hire several security firms?
  - Depends? On what?

# Overview

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- → *Operating systems security overview*
- → Types of secure systems
- → Security policies
- → Security mechanisms
- → Trusted Computing
- → Design principles
- → OS security verification
- → OS design for security

# Secure Operating System

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- Provides for secure execution of applications
- Must provide security policies that support the users' security requirements
- Must enforce those security policies
- Must be safe from tampering etc.

# Security Policies

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- Security policy:
  - specifies *allowed* and *disallowed states* of a system
  - OS needs to ensure that no disallowed state is ever entered
  - OS *mechanisms* prevent transitions from allowed to disallowed states
- Security policy needs to identify the *assets* to be secure
  - For computer security, assets are typically *data*
- Perfect security is generally unachievable
  - need to be aware of *threats*
  - need to understand what *risks* can be tolerated

# Data Security

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Three aspects:

- **Confidentiality**: prevent *theft* of data
  - concealing data from unauthorised agents
  - *need-to-know principle*
- **Integrity**: prevent *damage* to data
  - trustworthiness of data: data *correctness*
  - trustworthiness of origin of data: *authentication*
- **Availability**: prevent *denial* of service
  - ensuring data is usable when needed

# Threats

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- A *weakness* is a potential for a security violation
- An *attack* is an attempt by an *attacker* to violate security
  - generally implies exploiting a weakness
- A *threat* is a potential for an attack
- There is never a shortage of attackers, hence in practice:
  - threat ⇒ attack
  - weakness ⇒ violation

# Threats

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- Snooping
  - disclosure of data
  - attack on *confidentiality*
- Modification/alteration
  - unauthorised change of data
  - attack on *data integrity*
- Masquerading/spoofing
  - one entity impersonating another
  - attack on *authentication integrity*
  - delegation?
- Repudiation of origin
  - false denial of being source
  - attack on *integrity*
- Denial of receipt
  - false denial of receiving
  - attack on *availability* and *integrity*
- Delay
  - temporarily inhibiting service
  - attack on *availability*
- Denial of service
  - permanently inhibiting service
  - attack on *availability*

# Security Policy

- Partitions system into allowed and disallowed states
- Ideally mathematical model
- In practice, natural-language description
  - often imprecise, ambiguous, inconsistent, unenforceable
  - Example: transactions over $10k require manager approval
    - but transferring $10k into own account is no violation

# Security Mechanisms

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- Used to enforce security policy
  - computer access control (login authentication)
  - operating system file access control system
  - controls implemented in tools
- Example:
  - Policy: only accountant can access financial system
  - Mechanism: on un-networked computer in locked room with only one key
- A *secure system* provides mechanisms that ensure that violations are
  - prevented
  - detected
  - recovered from

# Assumptions

- Security is always based on assumptions
  - eg. lock is secure, key holders are trustworthy
- Invalid assumptions *void* security!
- Problem: assumptions are often implicit and poorly understood
- Security assumptions must be:
  - clearly identified
  - evaluated for validity

# Potentially Invalid Assumptions

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- The security policy is unambiguous and consistent
- The mechanisms used to implement the policy are correctly designed
- The union of mechanisms implements the policy correctly
- The mechanisms are correctly implemented
- The mechanisms are correctly installed and administered

# Trust

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- Systems always have *trusted entities*
  - hardware, operating system, sysadmin
- Totally of trusted entities is the *trusted computing base* (TCB)
  - the part of the system that can circumvent security
- A *trusted system* can be used to process security-critical assets
  - gone through some process ("*assurance*") to establish its trustworthiness
  - should really be called *trustworthy system*
- *Trusted computing*:
  - provides mechanisms and procedures for trusted systems
  - in practice usually refers to TCG mechanisms for secure boot, encryption etc

# Trusted Computing Base

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- TCB: *The totality of protection mechanisms within a computer system — including hardware, firmware and software — the combination of which is responsible for enforcing a security policy*

  *[RFC 2828]*

  A TCB consists of one or more components that together enforce a unified security policy over a product or system

  The ability of the TCB to correctly enforce a security policy depends solely on the mechanisms within the TCB and on the correct inputs by system administrative personnel or parameters related to the security policy

# Trusted Computing

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- TCB is by definition *trusted*. That doesn't make it *trustworthy*!
- Aim of *trusted computing* (TC): establish and maintain trustworthiness
  - ... with respect to certain security requirements
  - should really be called *trustworthy computing*!
- TC ensures that system is operating in defined configuration
  - based on the assumption that certain components can be trusted
- Challenge: maintain system security during configuration changes
- Idea based on notion of *secure booting* [Arbaugh et al. 97]:
  - *root of trust* provided by hardware
  - software components are *certified* as trusted
  - TCB securely expanded by loading trusted components only
  - hardware- and software mechanisms to prevent tampering
- Establish *chain of trust* from root of trust

# Covert Channels (Side Channels)

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- Information flow that is not controlled by a security mechanism
  - Security requires *absence of covert channels*
- Two types of covert channels
  - Covert *storage* channel uses an attribute of a shared resource
    - shared resource states (eg. meta data, object accessibility)
    - global names can create covert storage channels
    - in principle subject to access control
    - a sound access-control system should be *free* of covert channels
  - Covert *timing* channel uses temporal order of accesses to shared resource
    - outside access-control system
    - difficult to reason about
    - difficult to prevent

# Covert Timing Channels

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- Created via shared resource whose behaviour can be monitored
  - network bandwidth
  - CPU load
  - response time
  - locks
- Requires access to a time source
  - real-time clock
  - anything else that allows unrelated processes to synchronise
  - preventable by perfect virtualisation?
- Critical issue is bandwidth
  - in practice, the damage is limited if the bandwidth is low
    - e.g DRM doesn't care about low-bandwidth channels
  - beware of amplification
    - e.g leaking of passwords

# Establishing Trustworthiness

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- Process to show *TCB is trustworthy*
- Two approaches
  - *assurance* (systematic evaluation and testing)
  - *formal verification* (mathematical proof)
- *Certification* confirms process was successfully concluded

# Assurance

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- Process for *bolstering* (substantiating or specifying) trustworthiness
  - Specifications
    - unambiguous description of system behaviour
    - Can be formal (mathematical model) or informal
  - Design
    - justification that it meets specification
    - mathematical translation of specification or compelling argument
  - Implementation
    - justification that it is consistent with the design
    - mathematical proof or code inspection and rigorous testing
    - by implication must also satisfy specification
  - Operation and maintenance
    - justification that system is used as per assumption in specification
- Assurance does not *guarantee* correctness or security!

# Assurance: Orange Book

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**US Department of Defence "Orange Book" [DoD 86]:**

- Officially the *Trusted Computing Systems Evaluation Criteria* (TCSEC)
- Defines security classes
  - D: minimal protection
  - C1-2: discretionary access control (DAC)
  - B1-B3: mandatory access control (MAC)
  - A1: verified design
- Designed for military use
- Systems can be certified to a certain class
  - very costly, hence only available for big companies
  - most systems only certified C2 (essentially Unix-style security)
- Superseded by *Common Criteria*
  - orange book no longer has any official standing
  - however, still an excellent reference for security terminology and rationale

# Assurance: Common Criteria

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**Common Criteria for IT Security Evaluation [ISO/IEC 15408, 99]:**

- ISO standard, developed out of Orange Book and other approaches
  - US, Canada, UK, Germany, France, Netherlands
  - for general use (not just military, not just operating systems)
- Unlike Orange Book, doesn't prescribe specific security requirements
  - evaluates quality assurance used to ensure requirements are met
- *Target of evaluation* (TOE) evaluated against *security target* (ST)
  - ST is statement of desired security properties
  - based on *protection profiles* (PPs) — generic sets of requirements
    - defined by “users” (typically governments)
- Seven *evaluation assurance levels* (EALs)
  - higher levels imply more thorough evaluation (and higher cost)
  - *not* necessarily better security
- Details later

# Formal Verification

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- → Process of mathematical proof of security properties
- → Based on a mathematical *model* of the system
- → Two Parts:
  - Proof that *model satisfies security requirements*
    - generally difficult, except for very simple models
  - Proof that *code implements model*
    - proving theorems showing correspondence
    - even harder, feasible only for few 1000 LOC
    - hardly ever done (few tiny special-purpose OS kernels only to date)
- → Note: *model checking* (static analysis) is not sufficient
  - shows presence or absence of certain properties of code
    - uninitialised variables, array-bounds, null-pointer de-ref
    - may be sound (guaranteed to detect all violations) or unsound
  - Model checking does not prove implementation correctness!

# Summary

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- Computer security is complex
  - depends on many aspects of computer system
- Policy defines security, mechanisms enforce security
- Important to consider:
  - what are the assumptions about threats and trustworthiness?
  - incorrect assumptions $\Rightarrow$ no security
- Security is never absolute
  - given enough resources, mechanisms can be defeated
  - important to understand limitations
  - inherent tradeoffs between security and usability
- Human factors are important
  - people make mistakes
  - people may not understand security impact of actions
  - people may be less trustworthy than thought

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# Secure Systems Classification

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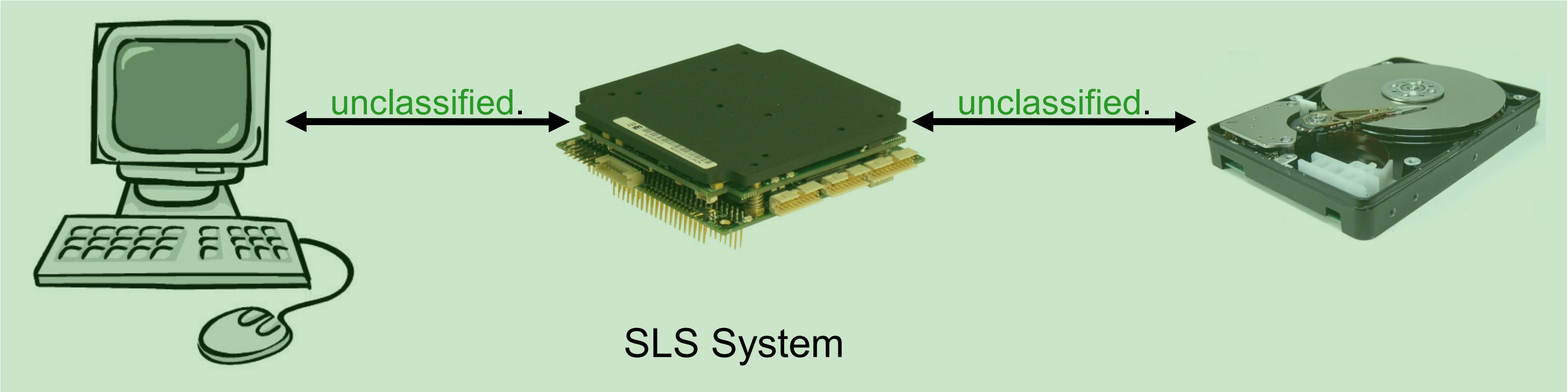
- Based on Orange Book terminology
  - assumes military-style security problem
  - data of different security classifications
  - system must ensure that classification is enforced
  - focussed on confidentiality
- Classifies systems based on the kind of data they can deal with
  - *single-level secure* (SLS) system
  - *multiple single-level secure* (MSL) system
  - *multi-level secure* (MLS) system
- Basis of *multiple-independent levels of security* (MILS) architecture

# Single-Level Secure (SLS) System

- Suitable only for processing data of one particular security level
  - generally the lowest, i.e. unclassified



# Multiple Single-Level (MSL) Secure System

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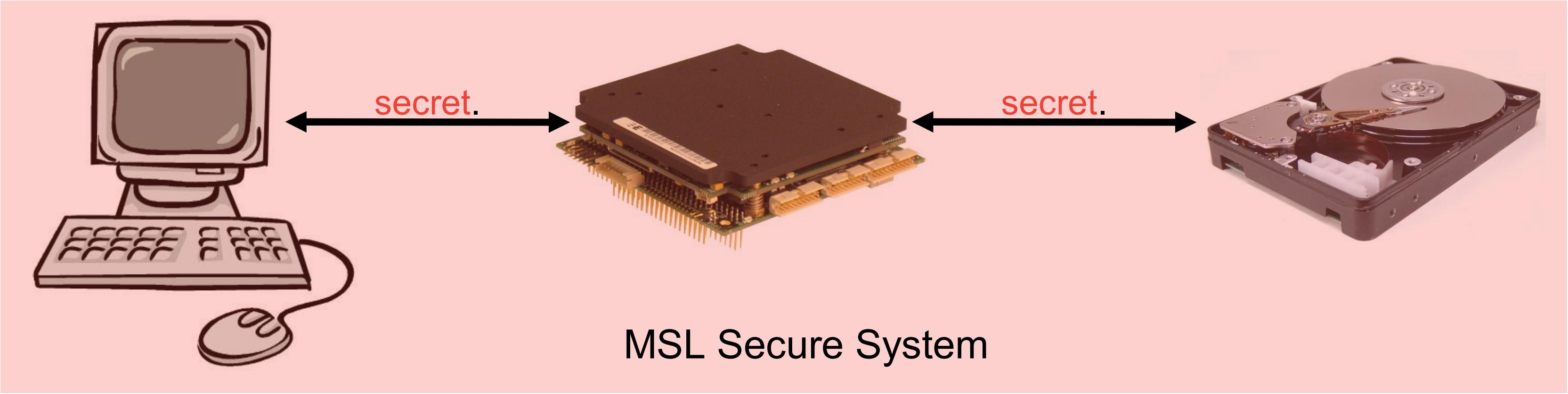
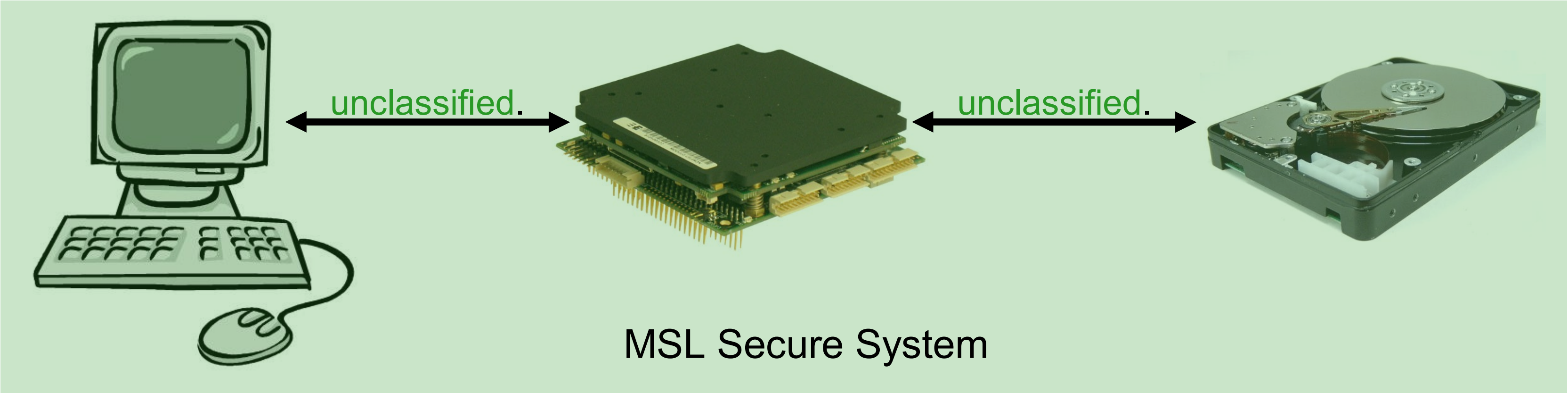
- System suitable for processing data of several security levels
  - only one security level at a time, up to some limit
- Multiple instances used, each one as a SLS system



# Multi-Level Secure (MLS) System

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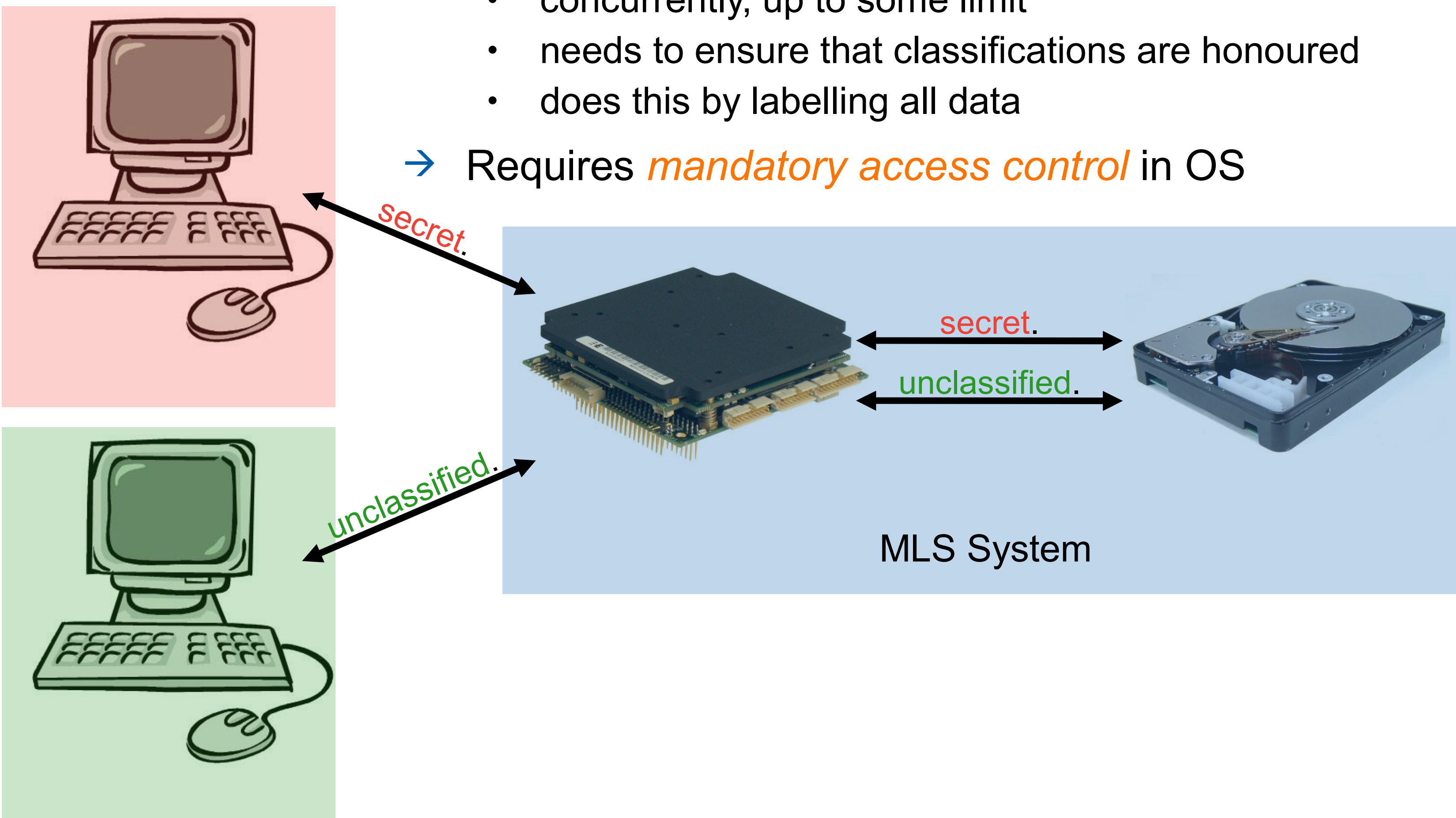
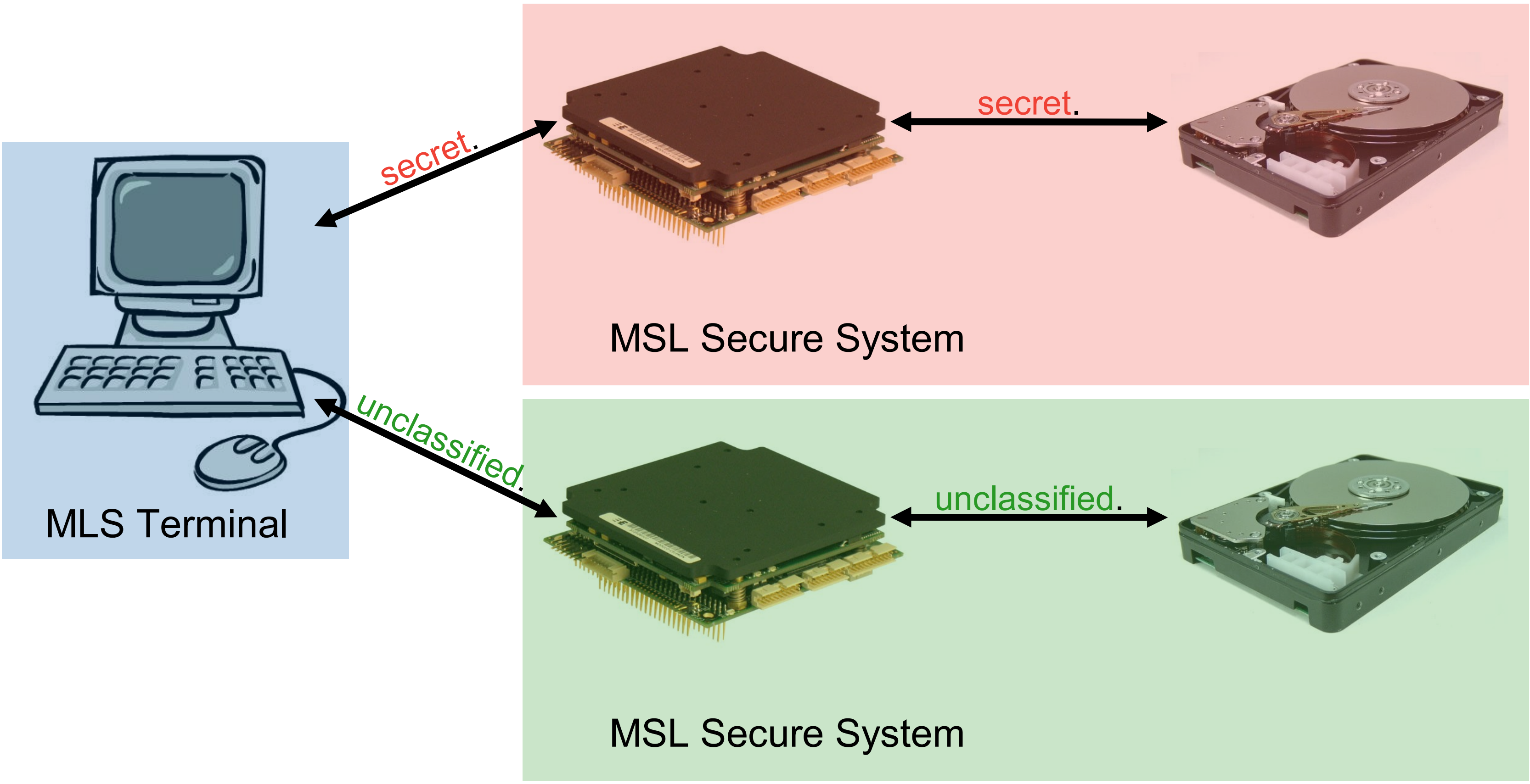
- Suitable for processing data of several security levels
  - concurrently, up to some limit
  - needs to ensure that classifications are honoured
  - does this by labelling all data
- Requires *mandatory access control* in OS



# MLS + MSL System

- MLS component handles multiple levels of data
- Only a single level of data goes to each of the MSL secure systems



# MLS System Using Virtualization

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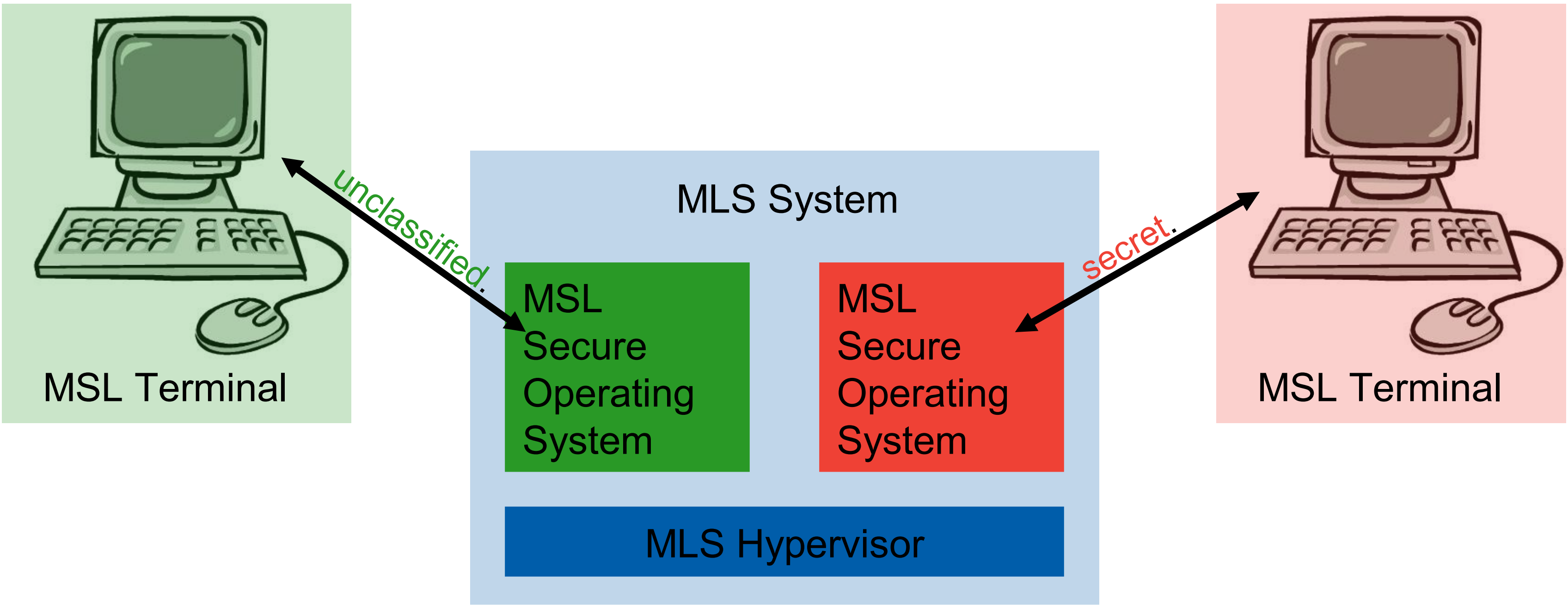
- MLS hypervisor runs several MSL secure OSes in individual virtual machines
- Result is MLS system
- An example of a *multiple independent levels of security* (MILS) architecture
  - Hypervisor here operates as a *separation kernel*
  - Separates (isolates) different *security domains*



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# Security Policies: Categories

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- *Discretionary* (user-controlled) policies (DAC)
  - e.g A can read B's objects only with A's permission
  - user decides about access (at their discretion)
  - classical example: Unix permissions
- *Mandatory* (system-controlled) policies (MAC)
  - e.g certain users cannot ever access certain objects
  - no user can change these
  - focus on restricting *information flow*
  - inherent requirement for MLS systems, MILS
- *Role-based* policies (RBAC)
  - agents can take on specific pre-defined roles
    - well-defined set of roles for each agent
    - e.g normal user, sysadmin, database admin
  - access rights depend on role

# Models for Security Policies

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- Represent a whole class of security policies
- Most system-wide policies focus on *confidentiality*
  - e.g military-style multi-level security models
  - Classical example is *Bell-LaPadula* model [Bell & LaPadula 76]
    - example of a *labelled security model*
    - most others developed from this
    - Orange Book based on this model
  - *Chinese-wall* policy focuses on conflict of interest
- Some newer models focus on *integrity*
  - *Bibra* model derived from Bell-LaPadula
  - *Clark-Wilson* model based on separation of duty
    - maps to role-based access control

# Bell-LaPadula Model

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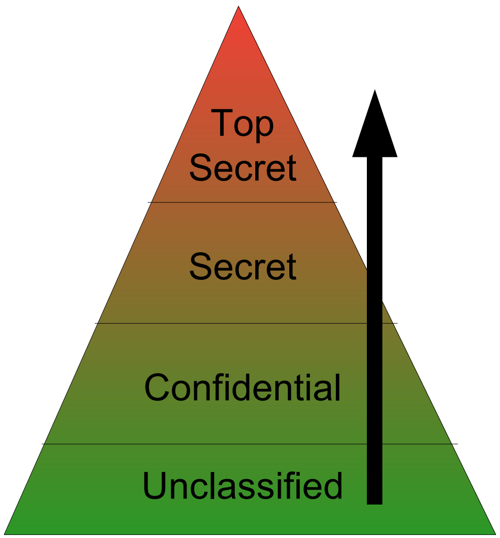
- Each object $a$ has a security *classification* $L(a)$
- Each agent $o$ has a security *clearance* $L(o)$
- Classifications
  - e.g top secret > secret > confidential > unclassified
- Rule 1 (*no read up*):
  - $a$ can *read* $o$ only if $L(a) \geq L(o)$
  - standard confidentiality
- Rule 2 (*★ Property — no write down*)
  - $a$ can *write* $o$ only if $L(a) \leq L(o)$
  - prevents *leakage* (accidental of by conspiracy)



# Bell-LaPadula Model

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- Mother of all military-style security models
- Inherently requires implementation as MAC
  - all subjects must be bound to policy
- If implemented inside a single system, requires MLS system
- Major limitation: cannot deal with *declassification*
  - needed to pass any information from high- to low-security domain
    - logging
    - command chain
    - documents where sensitive portions have been censored
    - encrypted data
- Typically dealt with by special *privileged functions*
  - outside security policy
  - outside systematic reasoning
  - part of TCB
  - likely source of security holes

# Chinese Wall Policy

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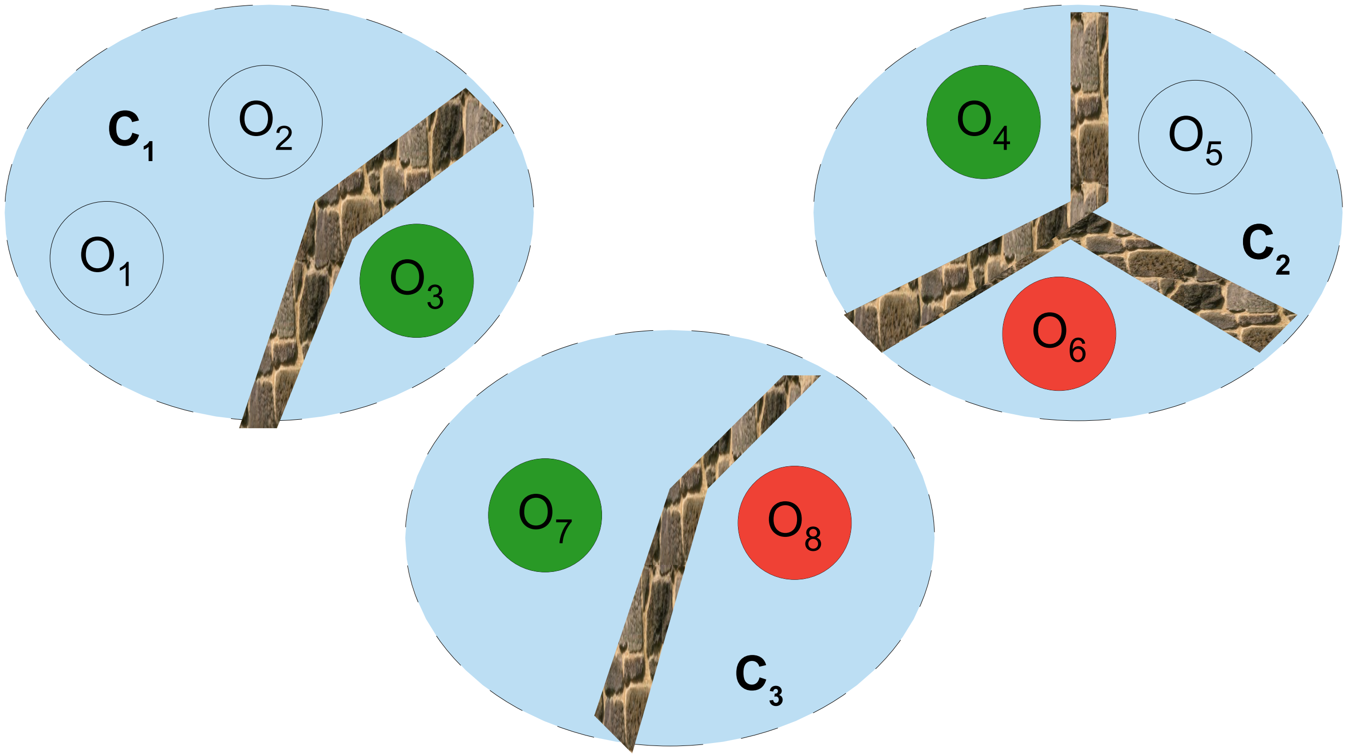
- Employed by investment banks to manage conflict of interest
- Idea: Consultant cannot talk to clients' competitors
  - single consultant can have multiple concurrent clients
- Define *conflict classes* (groups of potentially competing clients)
  - eg banks, oil companies, insurance companies, OS vendors
- Consultant dealing with client of class $A$ cannot talk to others in $A$
  - but can continue talking to members of other classes
  - some data belongs to several conflict classes
- Public information is not restricted
  - consultant can read and write public info at any time
  - but must observe ✶ property (cannot publish confidential info)
- Example of a *dynamic MAC policy*
  - allowed information flow changes over time

# Chinese Wall Policy

UNSW




→ In practice need a way to remove conflicts

- transaction completed...

# Bibra Model

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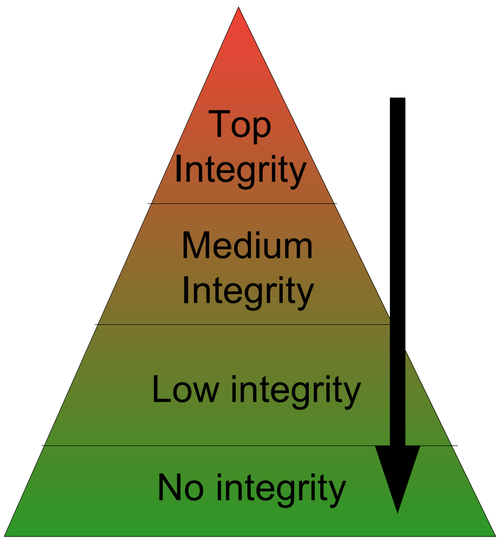
- Dual to Bell-LaPadula for integrity
- Each subject `a`, object `o` has a integrity level `L`
- Rule 1 (*no read down*):
  - `a` can *read* `o` only if $L(a) \leq L(o)$
- Rule 2 ( ✶ *Property — no write up*)
  - `a` can *write* `o` only if $L(a) \geq L(o)$
- Obviously incompatible with Bell-LaPadula
  - ... if higher security requires higher integrity
  - must choose between confidentiality and integrity
- Bibra doesn't model any practical system



# Clark-Wilson Model

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- Security *framework* for ensuring integrity based on separation of duties
  - doesn't provide specific state transformations, only constraints on them
  - helps in formalising security policies
- Distinguishes *constrained* (integrity-guaranteed) and *unconstrained* data
  - Operations on unconstrained data must be defined for all values and produce constrained data
- Specifies requirements on the system and its operations
  - protect integrity-critical data, authentication, integrity of transformations, logging
  - operations certified to operate on certain data
- Doesn't actually specify what “separation of duties” means
  - “Allowed reltations must meet the requirements of 'separation of duties'“

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- *Security mechanisms*
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# Security Mechanisms

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- Used to implement security policies
- Based on access control
  - Discretionary access control (DAC)
  - Mandatory access control (MAC)
  - Role-based access control (RBAC)
- Access rights
  - *Simple rights*
    - Read, write, execute/invoke, send, receive
  - *Meta rights* (DAC only)
    - Copy
      - Propagate own rights to another agent
    - Own
      - Change rights of an object or agent

# Access Control Matrix

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| | Objects | | | |
|---|---|---|---|---|
| Agents | $S_1$ | $S_2$ | $O_3$ | $O_4$ |
| $S_1$ | terminate | wait, signal, send | read | |
| $S_2$ | wait, signal, terminate | | | read, execute, write |
| $S_3$ | | wait, signal, receive | | |
| $S_4$ | control | | execute | write |

Defines each agent's rights on any object

Note: agents are objects too

# Properties of the Access Control Matrix

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- → Rows define agents' *protection domains (PDs)*
- → *Columns* define objects' *accessibility*
- → Dynamic data structure:
  - Frequent permanent changes (e.g. object creation, `chmod`)
  - Frequent temporary changes (e.g. `setuid`)
- → Very *sparse* with many repeated entries
- → Impractical to store explicitly

# Protection-Matrix Implementation: ACLs

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**Represent column-wise: access control list (ALC):**

- *ACL* associated with *object*
- Usually condensed via *domain classes* (UNIX, NT groups)
- Full ACLs used by Multics, Apollo Domain, Andrew FS, NTFS
- Can have *negative rights* to:
  - reduce window of vulnerability
  - simplify exclusion from groups
- Sometimes implicit (Unix process hierarchy)
- Implemented in almost all commercial systems

# Protection-Matrix Implementation: Capabilities

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**Represent row-wise: capabilities [Dennis & Van Horn 66]:**

- *Capability list* associated with agent
  - each capability confers a certain right to its holder
- Can have *negative rights* to:
  - reduce window of vulnerability
  - simplify management of groups of capabilities
- Caps have been popular in research for a long time
- Few successful commercial systems until recently:
  - main one is IBM System/38 / AS400 / i-Series
  - increasingly appearing in commercial systems (usually add-on)

# Capabilities

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- Main advantage of capabilities is the *fine-grained access control*:
  - easy to provide specific agents access to individual objects
- Capability presets *prima facie* evidence of the *right to access*
  - capability ⇒ *object identifier* (implies naming)
  - capability ⇒ (set of) *access rights*
    - any representation must contain object ID and access rights
    - any representation must protect capability from forgery
- How are caps implemented and protected?
  - *tagged* — protected by hardware
    - popular in the past, rarely today (exception: IBM i-Series)
  - *sparse* (or *user-mode*) — protected by sparsity
    - probabilistically secure, like encryption
    - propagation outside system control — hard to enforce security policies
  - *partitioned*/*segregated* — protected by software (kernel)
    - main version of caps used in modern systems

# Tagged Capabilities

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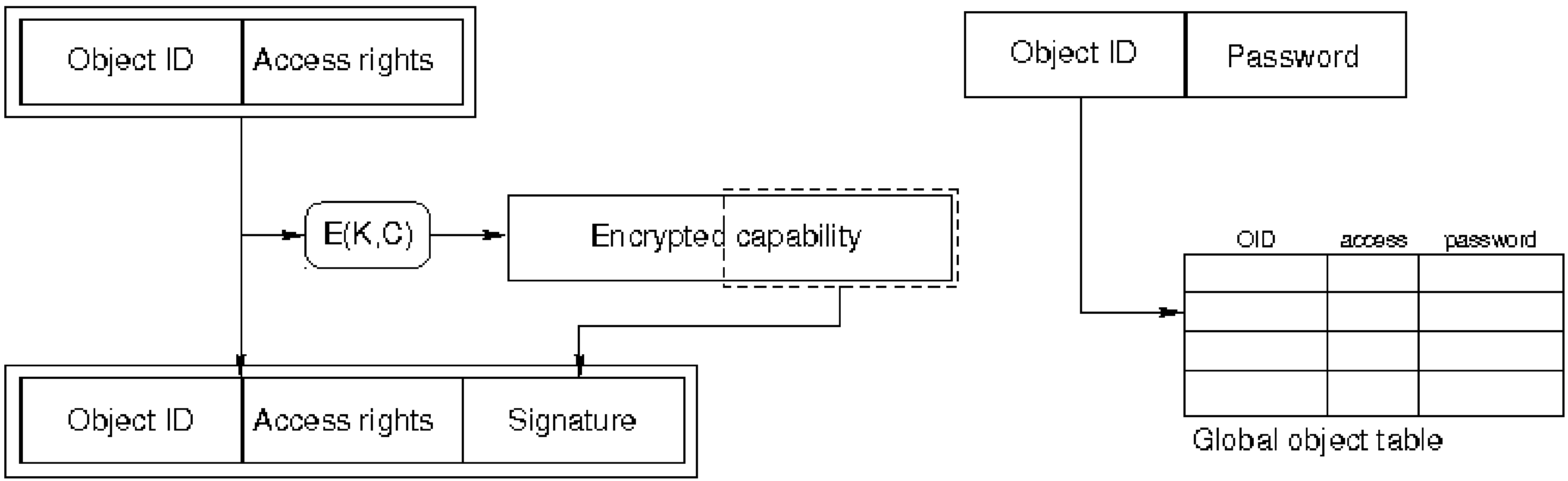
- *Tag bit(s)* with every (group of) memory word(s)
  - tag identifies capabilities
  - capabilities are used and copied like “normal” pointers
  - hardware checks permissions when deferencing capability
  - modifications turn tags off (convert to plain data)
  - only privileged instructions(kernel) can turn tags on
  - Issues:
    - ➔ capability hardware tends to be slow (too complex)
    - ➔ hard (if not impossible) to control propagation of authority
    - ➔ revocation virtually impossible (requires memory scan)
    - ➔ amplification possible (below)
- IBM System/38, AS/400, i-Series, many historical systems

# Sparse Capabilities

- Basic idea similar to encryption
  - add bit string to make valid capabilities a very small subset of cap space
  - either encrypted object info or password
  - secure by infeasibility of exhaustive search of cap space



# Sparse Capabilities

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- Sparse caps are user-level objects
  - can be passed like other data
    - similar to tagged caps, but without hardware support
    - validated at mapping time (explicit or implicit)
  - good match to user-level servers
    - no central authority, no kernel required on most ops
    - cannot reference-count objects
- Issues:
  - Full mediation requires extra work
    - but doable, see Mungi [Heiser et al. 98]
    - essentially provided user-level cap segregation
  - High amplification of leaked data
    - problem with convert channels

# Segregated (Partitioned) Capabilities

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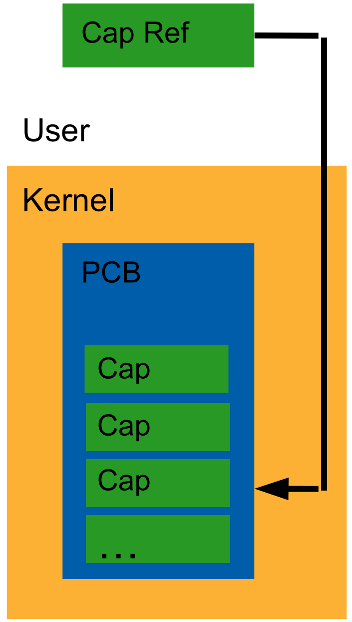
- System maintains *capability list* (Clist) with each agent (process)
  - User code uses indirect references to caps (clist index)
    - c.f Unix file descriptors
  - System validates permissions on access
    - syscall or page-fault time
- Many research systems
  - Hydra, Mach, EROS, and many others
- Increasingly commercial systems
  - KeyKOS (92), OKL4 (08)
  - add-on to Linux, Solaris



# Confinement

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- Problem 1: Executing untrusted code
  - you downloaded a game from the internet
  - how can you be sure it doesn't steal/corrupt your data?
- Problem 2: Digital rights management (DRM)
  - you own copyrighted material (e.g. entertainment media content)
  - you want to let others use it (for a fee)
  - how can you prevent them from making unauthorised copies?
- You need to *confine* the program (game, viewer) so it cannot leak
- Cannot be done with most protection schemes!
  - not with Unix or most other ACL-based schemes
  - not with most tagged or sparse capability schemes
  - multi-level security has some inherent confinement (but can't do DRM)
- Some protection models can confine in principle
  - e.g segregated caps system, can instruct system not to accept any
  - EROS has formal proof of confinement for system model [Shapiro & Weber 00]
  - similar for seL4 (machine-checked proof)
- In practice difficult to achieve due to *covert channels*

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# Trusted Computing: The TCG Approach

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- Trusted Computing Group (TCG)
  - industry consortium with many members
  - defines industry standards to enable trusted computing
  - term “trusted computing” now virtually synonymous with TCG model
  - ... although it only solves part of the problem
- Defines Trusted Computing Module (TCM)
  - hardware root of trust, aimed at PC/server platforms
  - minimal functionality to support TC
  - implemented either as separate chip or onboard processor chip
- Similarly Mobile Trusted Module (MTM) for mobile devices
  - puts more functionality into software
  - remaining hardware suitable for on-chip integration
  - but no agreement on model yet
- Also TCG Software Stack (TSS) for higher-level functionality

# TPM-Enabled Functionality

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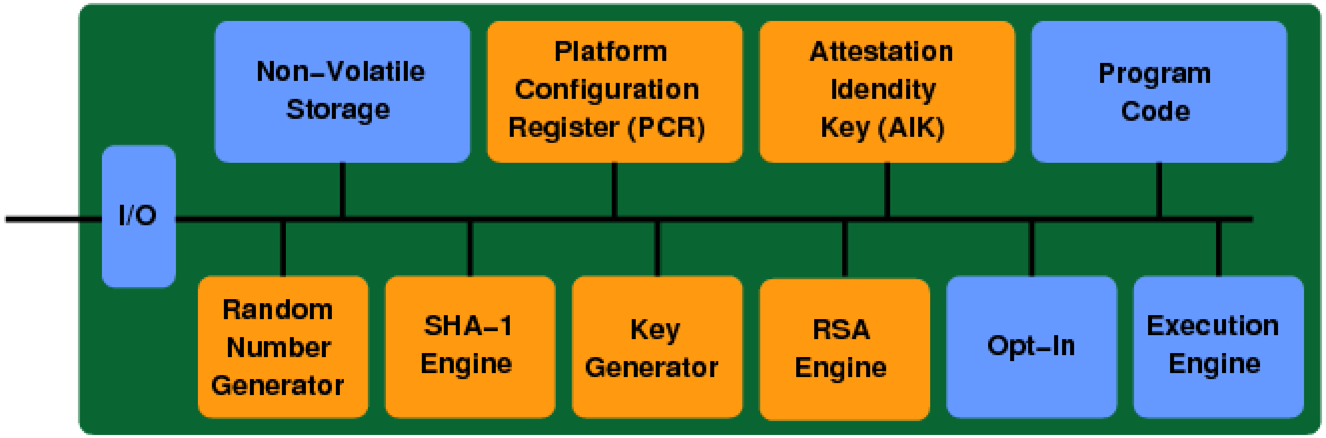
- Authenticated booting
  - bring up system in well-defined configuration
  - executing only certified binaries
- Remote attestation
  - allow remote party to confirm system configuration
- Sealed storage
  - ensure that data can only be read if system is in particular configuration

**Enabled by a set of TPM-provided mechanisms:**

- Random-number generation
- Key generation
- key storage
- public-key encryption
- configuration storage
- certificate storage

# TPM Components

- Hardware implementations of security-relevant low-level functions
  - random numbers, SHA-1 hash, public-key generation, RSA encryption
  - slow — meant for use before enough trusted software is booted
- Endorsement key (EK)
  - hard-wired private key, uniquely identifies physical device
  - public EK certified and supplied by manufacturer
- Non-volatile storage
  - small amount for EK, some symmetric keys, opt-in flags
  - storage root key (SRK), protected by SRK pass phrase
    - to encrypt keys stored outside TPM

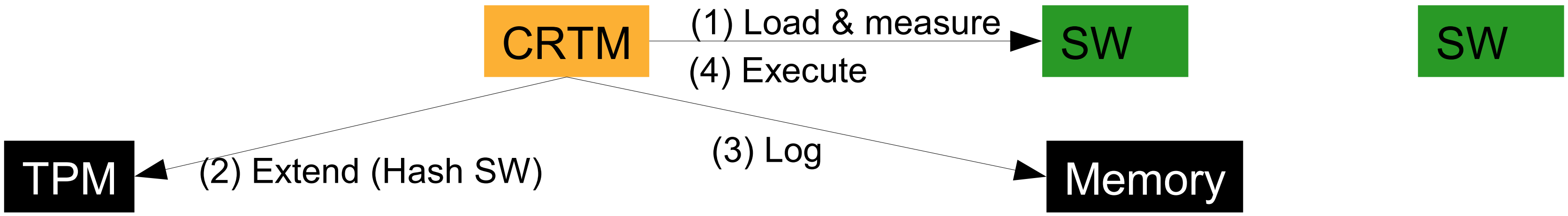


# Integrity Measurement

UNSW

- Idea: "*measure*" all components and securely store measurements
- Measurement: SHA-1 hash of component
  - computed at component-load time, before execution
  - normally computed by software (outside TPM) as TPM SHA-1 is slow
- Secure storage of measurements:
  - store log of measurements outside TPM
  - inside TPM's PCR store condensed ("extended") measurement:

    PCR ← SHA-1(PCR || SHA-1 (component))




- Suffices to verify configuration:
  - compute condensed measurement from log and compare to PCR
  - does not guarantee that software hasn't been modified after loading!
- SHA-1 engine + boot block (CRTM) is *root of trust for measurement* (RTM)

# Remote Attestation (aka Integrity Reporting)

UNSW

- Idea: Provide certified representation of machine state to challenger
  - e.g. service provider who insists on particular configuration
- Two parts reported
  - measurement log kept by software
  - PCR value (accumulated measurements) signed by endorsement key
    - alternatively can set up specific attestation identity key (AIK)
- Challenger can verify
  - recompute PCR value
  - verify signature using
    - knowledge of endorsement key, or
    - previously exchanged AIK
- Endorsement key is *root of trust for reporting* (RTR)

# Secure Storage Channel: Sealing

UNSW

- Idea: Make certain data accessible only to correct machine state
  - pass data securely from “sender” to “receiver” configuration
  - time-travel IPC ☺
- Uses secure encryption
  - generate secret key (random number)
  - use this to encrypt data with trusted (authenticated) program
  - encrypt secret key using SRK, can then be stored anywhere
- Sealing:
  - RSA engine can optionally include PCR configuration in encryption
  - when encrypting key, include
    - present (“sender”) PCR state
    - desired (“receiver”) PCR state
  - only decrypt key if present PCR state matches “receiver” state
  - return “sender” PCR state with decrypted key for confirmation
- Storage root key is *root of trust for storage* (RTS)

# Authenticated Boot

UNSW

- TPM ROM contains:
  - boot block
  - public key of OS manufacturer
- OS components signed by manufacturers key(s)
  - only load components after verifying signatures
  - *measure* components prior to executing
- Boot block loads first OS component
  - using TPM cryptography hardware to authenticate
- First OS components contains
  - SW implementation of crypto
  - potential further software vendor keys

## Secure Boot

UNSW

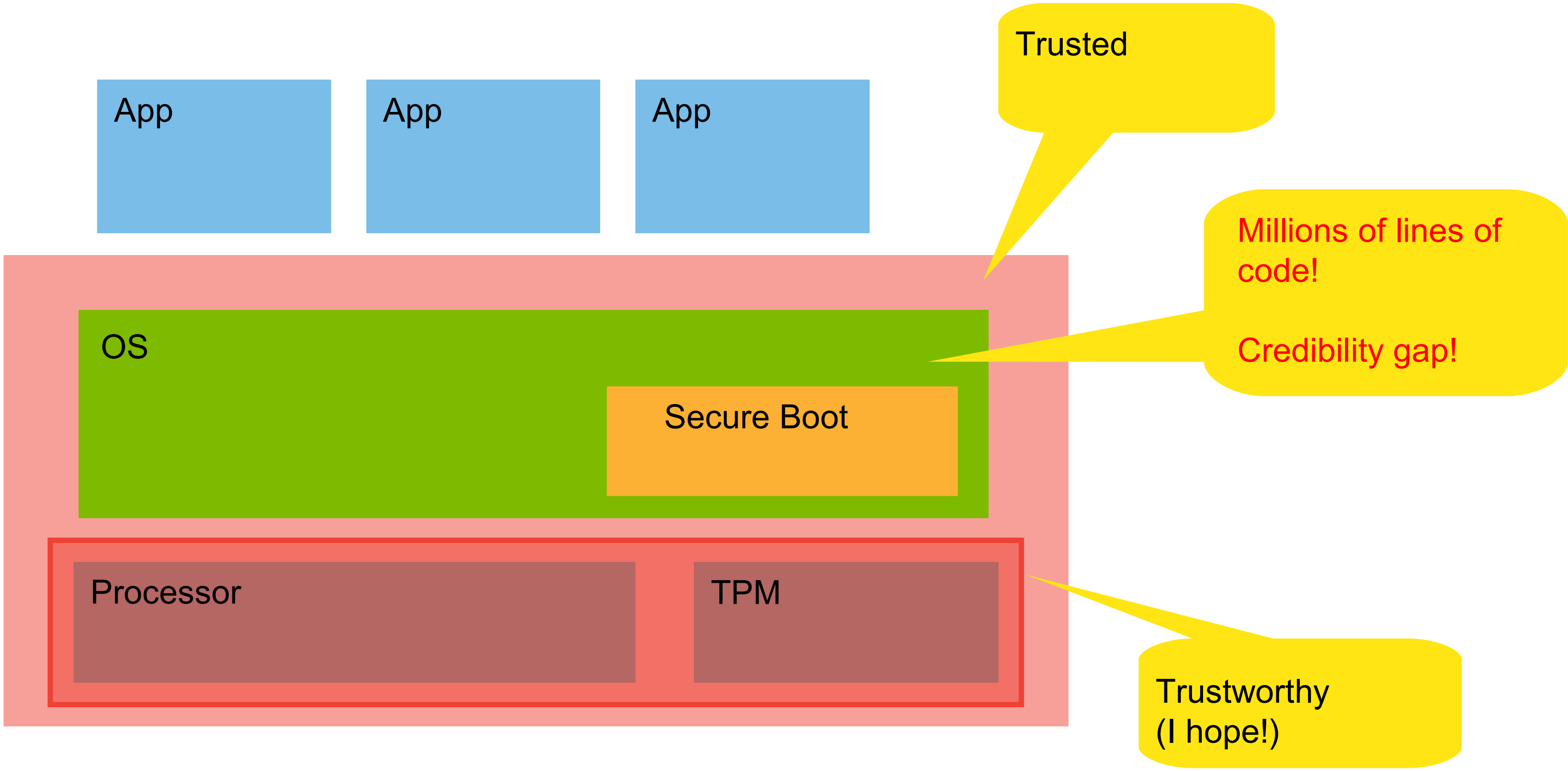
- Seal (rather than just sign) OS components
  - makes it impossible to boot other than predetermined OS version
- Rather painful
  - complete OS must be sealed separately for individual target machine
  - any software upgrade requires re-sealing
- Quite impractical for normal OS
  - but could be feasible for hypervisor or microkernel
- Based on secure bootstrap work [Arbaugh et al. 97]

# Trusted Computing vs Secure OS

UNSW

- TPM-based trusted-computing approach is based on
  - Hardware root of trust
  - Mechanisms to provide a chain of trust
- Objective is to guarantee that system boots into a well-defined configuration
  - Guarantees that a particular OS binary is running
  - What does this mean about security/trustworthiness?

# Trusted Computing vs Secure OS




- TPM-based trusted-computing approach is of limited use
  - As long as the OS isn't trustworthy

# Overview

UNSW

- Operating systems security overview
- Types of secure systems
- Security policies
- Security mechanisms
- Trusted Computing
- *Design principles*
- OS security verification
- OS design for security

# Design Principles for Secure OS

UNSW

- Least privilege (POLA)
- Economy of mechanisms
- Fail-safe defaults
- Complete mediation
- Open design
- Separation of privilege
- Least common mechanisms
- Psychological acceptability

# Least Privilege

UNSW

- Also called the *principle of least authority* (POLA)
- Agent should only be given the minimal rights needed for task
  - minimal protection domain
  - PD determined by *function*, not *identity*
    - Unix *root* is evil
    - aim of role-based access control (RBAC)
  - rights added as needed, removed when no longer needed
  - violated by all mainstream OSes
- Example: executing web applet
  - should not have all of user's privileges, only minimal access
  - hard to do with ACL-based systems
  - main motivation for using caps

# Least Privilege: Implications for OS

UNSW

- OS kernel executes in privileged mode of hardware
  - kernel has unlimited privilege!
- POLA implies keeping kernel code to an absolute minimum
  - this means a secure OS must be based on a microkernel!
- Trusted computing base can bypass security
- POLA requires that TCB is minimal
  - microkernel plus minimal security manager

# Economy of Mechanisms

UNSW

- KISS principle of engineering
  - "keep it simple, stupid!"
- Less code/features/stuff ⇒ less to get wrong
  - makes it easier to fix if something does go wrong
  - complexity is the natural enemy of security
- Also applies to interfaces, interactions, protocols, ...
- Specifically applies to TCB

# Fail-Safe Defaults

UNSW

- Default action is no-access
  - if action fails, system remains secure
  - if security administrator forgets to add rule, system remains secure
  - "better safe than sorry"

# Complete Mediation

UNSW

- *Reference monitor* checks every access
  - violated in Unix file access:
    - access rights checked at open(), then cached
    - access remains enabled until `close()`, even if attributes change
  - also implies that any rights propagation must be controlled
    - not done with tagged or sparse capability systems
- In practice conflicts with performance!
  - caching of buffers, file descriptors etc
  - without caching unacceptable performance
- Should at least limit window of opportunity
  - e.g guarantee caches are flushed after some fixed period
  - guarantee no cached access after revoking access

# Open Design

UNSW

- Security must not depend on secrecy of design or implementation
  - TCB must be open to scrutiny
  - *Security by obscurity is poor security*
    - Not all security/certification agencies seem to understand this
- Note that this doesn't rule out passwords or secret keys
  - ... but their creation requires careful *cryptoanalysis*

# Separation of Privilege

UNSW

- Require a combination of conditions for granting access
  - e.g user is in group wheel *and* knows the root password
  - Take-grant model for capability-based protection:
    - sender needs *grant* right on capability
    - receiver needs *take* right to accept capability
  - In reality, the security benefit of a separate *take* right is minimal
    - practical cap implementations only provide *grant* as a privilege
- Closely related to least privilege

# Least Common Mechanisms

UNSW

- Avoid sharing mechanisms
  - shared mechanism $\Rightarrow$ shared channel
  - potential covert channel
- Inherent conflict with other design imperatives
  - simplicity $\Rightarrow$ shared mechanisms
  - classical tradeoff...

# Psychological Acceptability

UNSW

- Security mechanisms should not add to difficulty of use
  - hide complexity introduced by security mechanisms
  - ensure ease of installation, configurations, use
  - systems are used by humans!
- Inherently problematic:
  - security inherently inhibits ease of use
  - idea is to minimise impact
- Security-usability tradeoff is to a degree unavoidable

# Overview

UNSW

- → Operating systems security overview
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- → Design principles
- → *OS security verification*
- → OS design for security

# Common-Criteria Protection Profiles for OS

UNSW

- Controlled Access Protection Profile (CAPP)
  - standard OS security, derived from Orange Book C2
  - certified up to level EAL3
- Single-level Operating System Protection Profile
  - superset of CAPP
  - certified up to EAL4+
- Labeled Security Protection Profile (LSPP)
  - mandatory access control for COTS OSes
  - similar to Orange Book B1
- Role-based Access Control Protection Profile
- Multi-level Operating System Protection Profile
  - superset of CAPP, LSPP
  - certified up to EAL4+
- Separation Kernel Protection Profile (SKPP)
  - strict partitioning
  - certifications aiming for EAL6–7

# Common Criteria Assurance Levels

UNSW

- EAL1: functionally tested
  - simple to do, can be done without help from developer
- EAL2: structurally tested
  - functional and interface spec
  - black- and white-box testing
  - vulnerability analysis
- EAL3: methodically tested and checked
  - improved test coverage
  - procedures to avoid tampering during development
  - highest assurance level achieved for Mac OS X

# Common Criteria Assurance Levels

UNSW

- EAL4: methodically designed, tested and reviewed
  - design docs used for testing, avoid tampering during delivery
  - independent vulnerability analysis
  - highest level feasible on existing product (not developed for CC certific.)
  - achieved by a  number of main-stream OSes
    - Windows 2000: EAL4 in 2003
    - SuSe Enterprise Linux: EAL4 in 2005
    - Solaris-10: EAL4+ in 2006
      - controlled access protection profile (CAPP) — *Note: EAL3 profile!*
      - role-based access control PP — *example of non-NSA PP?*
    - RedHat Linux EAL4+ in 2007
  - They still get broken!
    - certification is based on assumptions about environment, etc...
    - most use is outside those assumptions
      - certification means nothing in such a case
      - presumably there were no compromises were assumptions held

# Common Criteria Assurance Levels

UNSW

- EAL5: semi-formally designed and tested
  - formal model of TEO security policy
  - semi-formal model of functional spec & high-level design
  - semi-formal arguments about correspondence
  - covert-channel analysis
  - IBM z-Series hypervisor EAL5 in 2003 (partitioning)
  - attempted by Mandrake for Linux with French Government support
- EAL6: semiformally verified design and tested
  - semiformal low-level design
  - structured representation of implementation
  - modular and layered TOE design
  - systematic covert-channel identification
  - Green Hills Integrity microkernel presently undergoing EAL6+ certification
    - separation kernel protection profile

# Common Criteria Assurance Levels

UNSW

- → EAL7: formally verified design and tested
  - formal functional spec and high-level design
  - formal and semiformal demonstration of correspondence
    - between specification and low-level design
  - simple TOE
  - complete independent confirmation of developer tests
  - LynuxWorks claims LynxSecure separation kernel EAL7 “certifiable”
    - ... but not *certified*
  - Green Hills also aiming for EAL7

**Note:**

- → *Even EAL7 relies on testing!*
- → EAL7 requires proof of correspondence between formal descriptions
- → However, no requirement of formalising LLD, implementation
- → Hence no requirement for formal proof of implementation correctness

# Common Criteria Limitations

UNSW

- Little (if any) use in commercial space outside national security
  - This was one of the intentions — by all indications, CC failed here
- Very expensive
  - industry rule-of-thumb: EAL6+ costs $10k per LOC
  - dominated by documentation requirements
  - no “credit” for doing things better
    - eg formal methods instead of excessive documentation
- Lower EALs of limited practical use
  - Windows is EAL4+ certified!
  - marketing seems to be main driver behind EAL3–4 certification
- Over-evaluation abuses system
  - eg. CAPP (EAL3 profile) certification to EAL4
  - in reality a pointless exercise

# Formal Verification

UNSW

- Based on mathematical model of the system
- Complete verification requires two parts:
  - proof that model satisfies requirements of security policies
    - typically prove generic properties that actual policies map to
    - required by CC EAL5–7
  - proof that implementation has same properties as model
    - proof of correspondence between model and implementation
    - not required by CC even at EAL7
    - done by some kernels with very limited functionality
    - never done for any general-purpose OS!
- Model-checking (static analysis) is *incomplete* formal verification
  - shows presence or absence of certain properties
    - e.g uninitialised variables, array-bounds overflows
  - nevertheless useful for assurance

# Common Criteria and Formal Verification

UNSW

| EAL | Requirem. | Funct Spec | HLD | LLD | Implem. |
|---|---|---|---|---|---|
| EAL 1 | Informal | Informal | Informal | Informal | Informal |
| EAL 2 | Informal | Informal | Informal | Informal | Informal |
| EAL 3 | Informal | Informal | Informal | Informal | Informal |
| EAL 4 | Informal | Informal | Informal | Informal | Informal |
| EAL 5 | Formal | Semiformal | Semiformal | Informal | Informal |
| EAL 6 | Formal | Semiformal | Semiformal | Semiformal | Informal |
| EAL 7 | Formal | Formal | Formal | Semiformal | Informal |

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# OS Design for Security

UNSW

- Minimize kernel code
  - kernel = code that executes in privileged mode
  - kernel can bypass any security
  - kernel is inherently part of TCB
  - kernel can only be verified as a whole (not in components)
    - it's hard enough to verify a minimal kernel
- How?
  - generic mechanisms (economy of mechanisms)
  - no policies, only mechanisms
  - mechanisms as simple as possible
  - only code that must be privileged in order to support secure systems
  - free of covert channels:
    - no global names, absolute time
- Formally specify API

# OS Design for Security

UNSW

- Minimize mandatory TCB
  - unless formally verified, TCB must be assumed imperfect
  - the smaller, the fewer defects
  - POLA requires, economy of mechanisms leads to minimal TCB
- Ensure TCB is well defined and understood
  - make security policy explicit
  - make granting of authority explicit
- Flexibility to support various uses
  - make authority delegatable
  - ensure mechanisms allow high-performance implementation
- Design for verifiability
  - minimize implementation complexity

# Example: NICTA's seL4

- High-security version of L4 microkernel API
  - all authority granted by capabilities
    - full mediation, least privilege, separation of privilege, fail-safe defaults
  - only four system calls: read, write, create, derive
    - economy of mechanisms
  - semi-formal and formal models and design specs
    - open design (once published)
  - kernel memory explicitly managed by user-level resource manager
    - least privilege, separation of privilege
  - 7,000–10,000 lines of kernel code
    - least privilege
- Details later...