School of Computer Science & Engineering

**COMP9242 Advanced Operating Systems**

# 2020 T2 Week 07a

# **Security Fundamentals**

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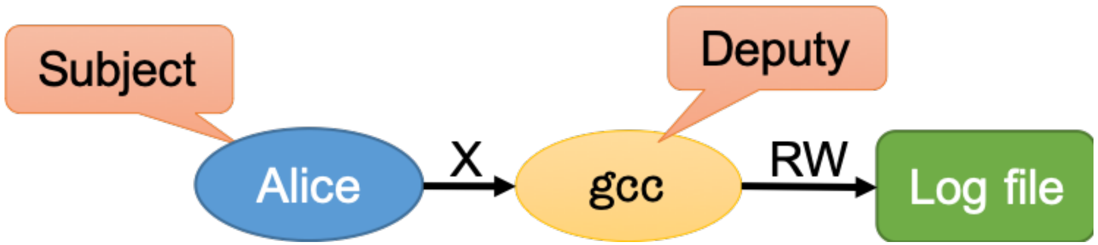
Incorporating material from Toby Murray



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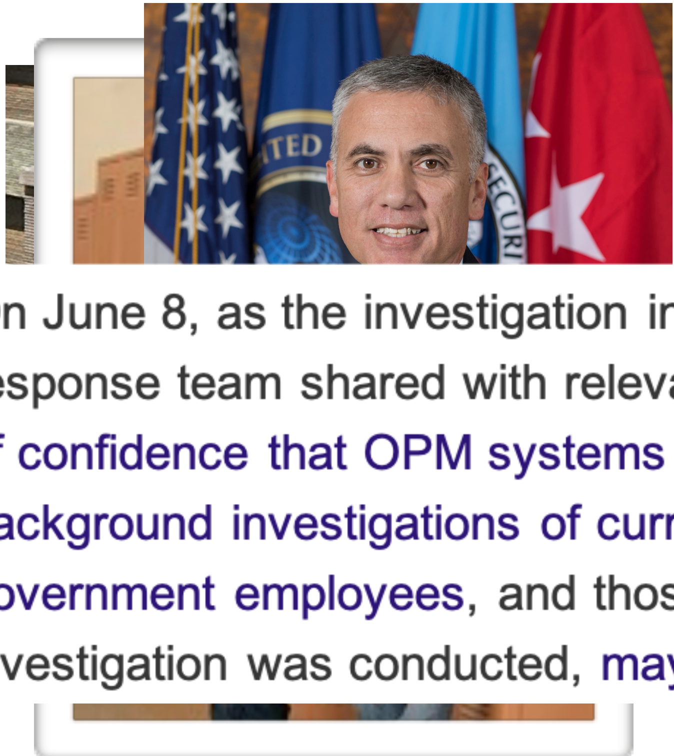
# What is Security?

Different things to different people:




On June 8, as the investigation into the initial intrusion proceeded, the response team shared with relevant agencies that there was a high degree of confidence that OPM systems containing information related to the background investigations of current, former, and prospective Federal government employees, and those for whom a Federal background investigation was conducted, may have been compromised.

# Computer Security

**Protecting *my interests* (that are under computer control) from *threats***

- Inherently subjective
  - Different people have different interests
  - Different people face different threats
- Don't expect one-size-fits-all solutions
  - Grandma doesn't need an air gap
  - Windows insufficient for protecting TOP SECRET (TS) classified data on an Internet-connected machine

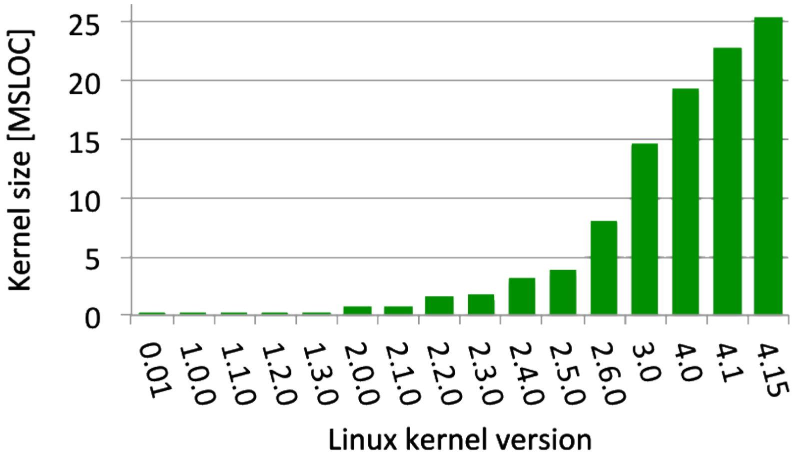
Security claims only make sense
- wrt *defined objectives*
- while *identifying threats*
- and *identifying secure states*

# State of OS Security

- Traditionally:
  - Has not kept pace with evolving user demographics
    - Focused on e.g. Defence and Enterprise
  - Has not kept pace with evolving threats
    - Much security work is reactive rather than proactive

Some things are getting better:
- more systematic hardening of OSes
- Better security models in smartphones compared to desktops

Other things are getting worse:
- OS kernel sizes keep growing
- Fast growth in attacker capabilities
- Slow growth in defensive capabilities



# OS Security

- What is the role of the OS for security?
- Minimum:
  - provide **mechanisms** to allow the construction of secure systems
  - that are capable of securely implementing the intended users'/administrators' **policies**
  - while ensuring these mechanisms cannot be subverted

# Good Security Mechanisms

- Are widely applicable
- Support general security principles
- Are easy to use correctly and securely
- Do not hinder non-security priorities (e.g. productivity, generativity)
    - Principle of “do not pay for what you don’t need”

Good mechanisms lend themselves to correct implementation and *verification*!

# Security Design Principles

Saltzer & Schroeder [SOSP ’73, CACM ’74]

- **Economy of mechanism** – KISS
- **Fail-safe defaults** – as in any good engineering
- **Complete mediation** – check everything
- **Open design** – not security by obscurity
- **Separation of privilege** – defence in depth
- **Least privilege** – aka *principle of least authority* (POLA)
- **Least common mechanism** – minimise sharing
- **Psychological acceptability** – if it’s hard to use it won’t be

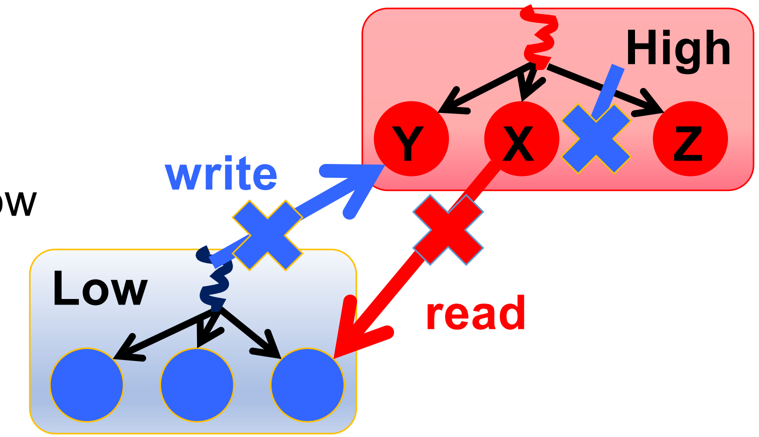
# Common OS Security Mechanisms

- Access Control Systems
  - control what each process can access
- Authentication Systems
  - confirm the identity on whose behalf a process is running
- Logging
  - for audit, detection, forensics and recovery
- Filesystem Encryption
- Credential Management
- Automatic Updates

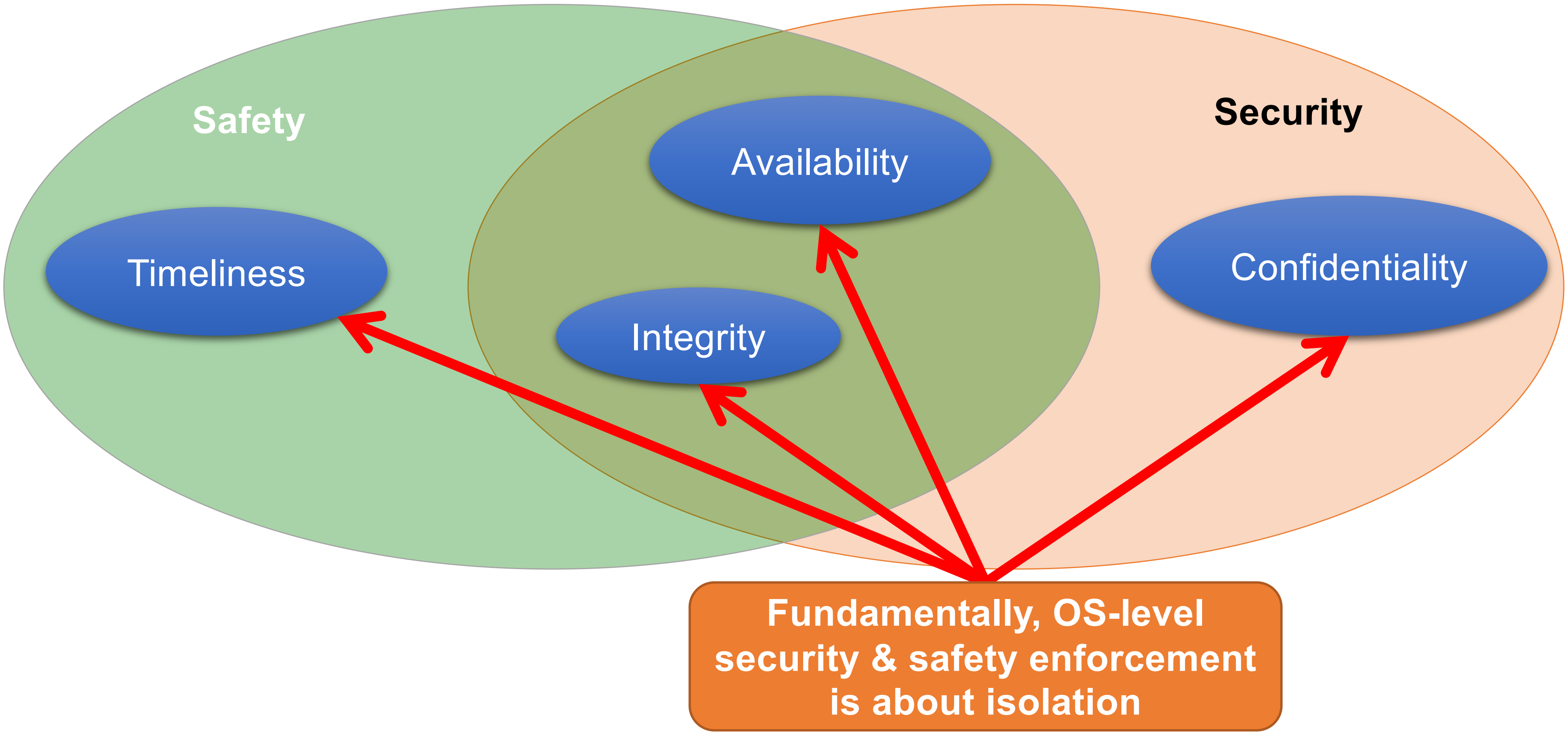
Fundamental mechanism

# Security Policies

- Define what should be protected, and from whom
- Often in terms of common security goals (*CIA properties*):
  - **Confidentiality**
    - X should not be learnt by Low
  - **Integrity**
    - Y should not be tampered with by Low
  - **Availability**
    - Z should not be made unavailable to High by Low



# Security vs Safety



# Policy vs Mechanism

- Policies accompany mechanisms:
  - **access control** policy
    - who can access what?
  - **authentication** policy
    - is password sufficient to authenticate TS access?
- Policy often restricts the applicable mechanisms
- One person’s policy is another’s mechanism

# Assumptions

- All policies and mechanisms operate under certain **assumptions**
  - **e.g.** TS-cleared users can be trusted not to write TS data into the UNCLASS window
- Problem: implicit or poorly understood assumption

Good assumptions are
- *clearly identified*
- *verifiable*!

# Risk Management

- Comes down to **risk management**
  - There is no absolute security, what risks we are willing to tolerate?
  - Cost & likelihood of violation vs. cost of prevention
  - Gain vs cost for attacker
- Actions:
  - mitigate – using security mechanisms
  - transfer – e.g. by buying insurance

Good security policy will identify appropriate action, based on risk assessment

# Trust

- Systems always have **trusted** entites
  - whose misbehaviour can cause insecurity
  - hardware, OS, sysadmin ...

Trusted computing base (TCB):
The set of all trusted entities

- Secure systems require the TCB to be **trustworthy**
  - achieved through **assurance** and **verification**
  - shows that the TCB is unlikely to misbehave
- *Minimising the TCB is key* for ensuring correct behaviour

# Assurance and Formal Verification

- **Assurance**:
  - systematic evaluation and testing
  - essentially an intensive and onerous form of quality assurance
- **Formal verification**:
  - mathematical proof
- **Certification**: independent examination
  - confirming that the assurance or verification was done right

Assurance and formal verification aim to establish correctness of
- mechanism design
- mechanism implementation

# Covert Channels

- Information flow not controlled by security mechanisms
  - Confidentiality requires absence of all such channels
- **Storage** Channel: Attribute of shared resource used as channel
  - Controllable by access control
- **Timing** Channel: Temporal order of shared resource accesses
  - Outside of access-control system
  - Much more difficult to control and analyse
- Other **physical** channels:
  - Power draw
  - Temperature (fan speed)
  - Electromagnetic emanation
  - Acoustic emanation

```
void leak(secret){
  if (secret) {
    create ("/tmp/true");
  } else {
    create ("/tmp/false");
  }
}
```

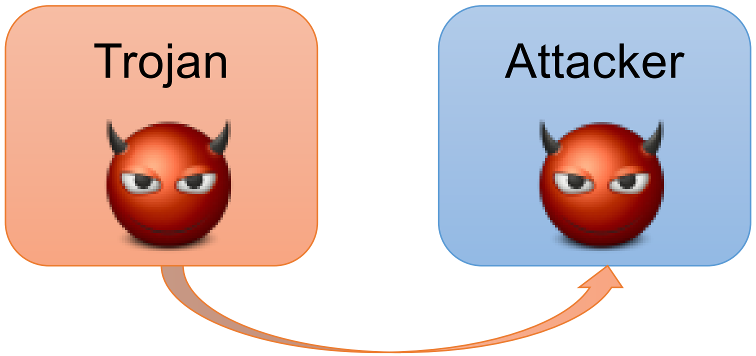
# Covert Timing Channels

- Created by shared resource whose effect on timing can be monitored
  - network bandwidth, CPU load, memory latency ...
- Requires access to a time source
  - Anything that allows processes to synchronise
  - Generally any relative occurrence of two event
- Critical issue is channel bandwidth
  - low bandwidth limits damage
    - why DRM ignores low bandwidth channels
  - beware of amplification
    - e.g. leaking passwords, encryption keys etc.

Typical timing channels:
- Measure server response times
- Measure own progress

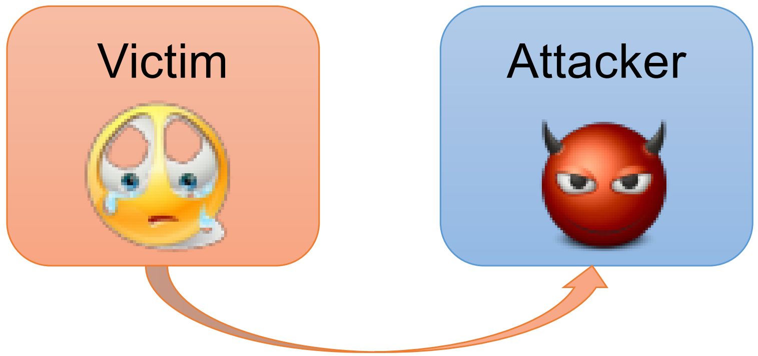
# Covert Channels vs Side Channels

**Covert Channel**




- Trojan intentionally creates signal through targeted resource use
- Worst-case bandwidth

**Side Channel**




- Attacker uses signal created by victim's innocent operations
- Much lower bandwidth

# Summary of Introduction

- Security is very subjective, needs well-defined objectives
- OS security:
  - provide good security **mechanisms**
  - that support users' **policies**
- Security depends on establishing **trustworthiness** of trusted entities
  - **TCB: set of all such entities**
    - **should be as small as possible**
  - Main approaches: assurance and verification

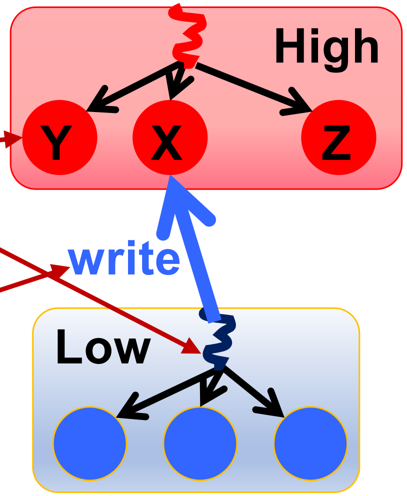
The OS is necessarily part of the TCB

# Access-Control Principles

# Access Control

**Who** can access **what** in which ways

- The “who” are called **subjects** (or **agents**)
  - e.g. users, processes etc.
- The “what” are called **objects**
  - e.g. individual files, sockets, processes etc.
  - includes all subjects
- The “ways” are called **permissions**
  - e.g. read, write, execute etc.
  - are usually specific to each kind of object
  - include those meta-permissions that allow modification of the protection state
    - e.g. own



# Access Control Mechanisms & Policies

- Access Control **Policy**
  - Specifies allowed accesses
  - And how these can change over time
- Access Control **Mechanism**
  - Used to implement the policy
- Certain mechanisms lend themselves to certain kinds of policies
- Some policies cannot be expressed using your OS's mechanisms

# Protection State: Access-Control Matrix

Defines system's protection state at a particular time instance [Lampson '71]

Subjects are also objects

| | Obj1 | Obj2 | Obj3 | Subj2 |
|---|---|---|---|---|
| **Subj1** | R | RW | | send |
| **Subj2** | | RX | | control |
| **Subj3** | RW | | RWX own | recv |

# Representing Protection State

Store by row
or by column

Storing full matrix too inefficient
- huge but sparse
- highly dynamic

| | **Obj1** | **Obj2** | **Obj3** | **Subj2** |
|---|---|---|---|---|
| **Subj1** | R | RW | | send |
| **Subj2** | | RX | | control |
| **Subj3** | RW | | RWX own | recv |

Obj1

`Subj1: R`
`Subj3: RW`

Access-control list (ACL)

Subj3

`Obj1: RW`
`Obj3: RWX, own`
`Subj2: recv`

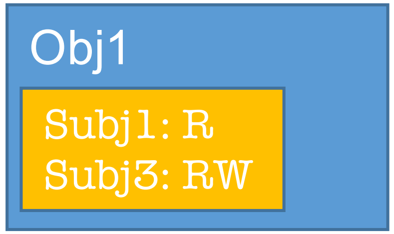
Capability

Capability list (Clist)

Defines subject's protection domain

# Access Control Lists (ACLs)

- Subjects usually aggregated into classes
  - e.g. UNIX: owner, group, everyone
  - more general lists in Windows, recent Linux
  - Can have negative rights
    eg. to overwrite group rights
- Meta-permissions (e.g. own)
  - control class membership
  - allow modifying the ACL



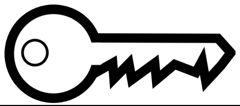

Used by all mainstream OSes

# Capability-Based Access Contol

**Capability = Access Token:**
Prima-facie evidence of privilege

Subj3

Obj1: RW
Obj3: RWX, own
Subj2: recv



Obj reference
Access rights

Object

Capabilities provide:
- Fine-grained access control
- Reasoning about information flow

Any system call is invoking a capability:

err = cap.method( args );

Used in very few commercial systems:
- IBM System/38→AS/400→i-Series
- KeyKOS [Bomberger et al, 1992]



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# Capabilities: Implementations

- Capabilities must be unforgeable
  - Traditionally protected by hardware (tagged memory), eg System-38
  - Can be copied etc like data
  - eg IBM System/38, Hydra, Cheri

| | | | | |
|---|---|---|---|---|
| tag | word | word | word | word |

- On conventional hardware, either:
  - Stored as ordinary user-level data, but unguessable due to sparseness
    - contains password or secure hash: PCS [Anderson'86], Mungi
    - **"sparse" capabilies**
  - Privileged kernel data
    - referred to by user programs by index/address
    - eg Mach [Accetta'86], EROS [Shapiro'99], seL4, Unix file descriptors
    - **"partitioned" or "segregated" capabilities**

# ACLs & Capabilities – Duals?

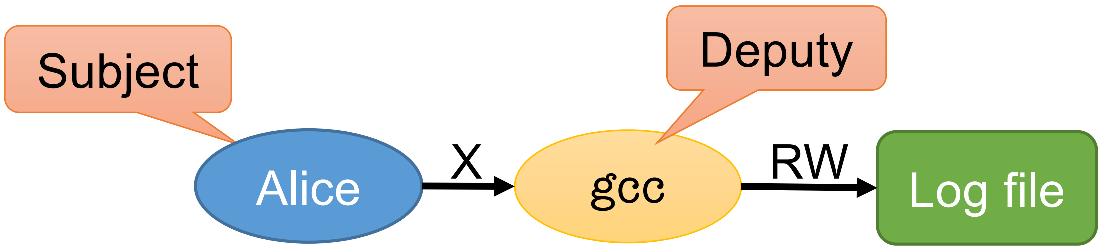
- In theory dual representations of access control matrix
- Practical differences:
  - Naming and namespaces
    - Ambient authority
    - Deputies
  - Evolution of protection state
  - Forking
  - Auditing of protection state

# Duals: Naming and Name Spaces

Cover storage channel?

- ACLs:
  - objects referenced by **name**
    - requires separate (global) name space
    - e.g. open(“/etc/passwd”,O_RDONLY)
  - require a subject (class) namespace
    - e.g. UNIX users and groups
- Capabilities:
  - objects referenced by **capability**
  - no further namespace required
  - cannot even *name* object without access

# Duals: Confused Deputy




```
alice$ gcc –o LogFile source.c
```

- ACLs separate naming and permissions
- Deputy depends on *ambient authority*
  - Uses own authority for access

Confused-deputy problem is unsolvable with ACLs!

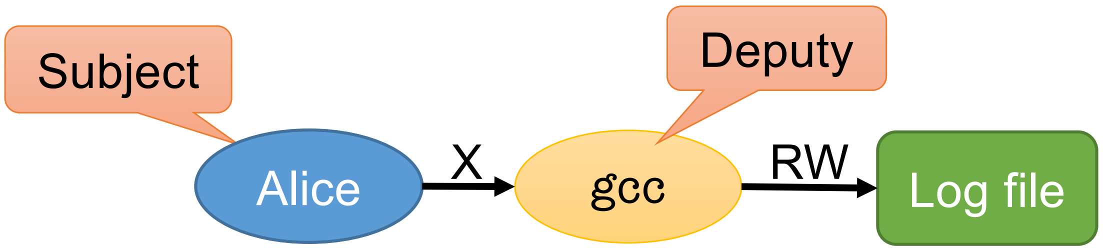
**Unix:**

- Log file is group admin
- Alice not member of admin
- gcc is set-UID admin

```
static char* log = "/var/gcc/log";
int gcc (char *src, *dest) {
   int s = open (src, RDONLY );
   int l  = open (log, APPEND);
   int d = open (dest, WRONLY);
    ...
   write (dest, ...);
}
```

Clobber log!

# Duals: Confused Deputy




```
alice$ gcc –o LogFile source.c
```

- Caps are both names and permissions
- Presentation is *explicit*, not ambient
- Can't name something if don't have access!

Capabilities avoid confused deputies

**Cap system:**

- gcc holds `w` cap for log file
- Alice holds `r` cap for source, `w` cap for destination
- Alice holds no cap for log file

```
static cap_t log = <cap>;
int gcc (cap_t src, dest) {
   fd_t s = open (src, RDONLY );
   fd_t l = open (log, APPEND);
   df_t d = open (dest, WRONLY);
   …
   write (d, …);
}
```

Open fails!

# Duals: Evolution of Protection State

**ACLs**: Protection state changes by modifying ACLs

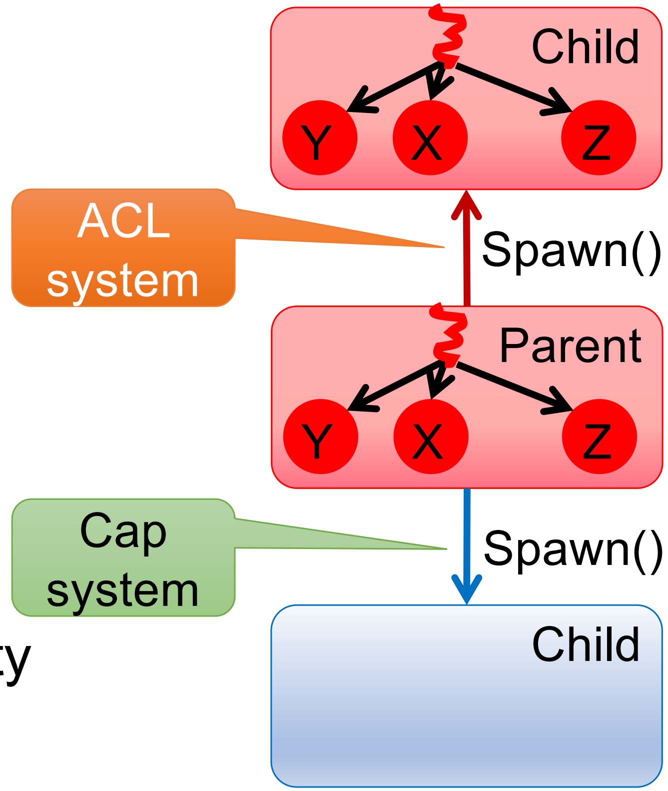
- Requires certain meta-permissions on the ACL

**Capabilities**: Protection state changes by delegating and revoking caps

- Fundamental properties enable reasoning about *information flow*:
  - A can send message to B only if A holds cap to B
  - A can obtain access to C only if it receives message with cap to C
- *Right to delegate* may also be controlled by capabilities, e.g.:
  - A can delegate to B only if A has a *delegatable* capability to B
  - A can delegate X to B only if it has *grant* authority on X

# Duals: Process Creation

- What permissions should children get?
- ACLs: depends on the child's subject
  - UNIX etc.: child inherits parent's subject
    - Inherits **all** of the parent's permissions
    - Any program you run inherits all of your authority
  - Opposite of least privilege!
- Capabilities: child has no caps by default
  - Parent gets a capability to the child upon fork
  - Used to delegate explicitly the necessary authority
  - **Defaults to least privilege**



# Duals: Auditing of Protection State

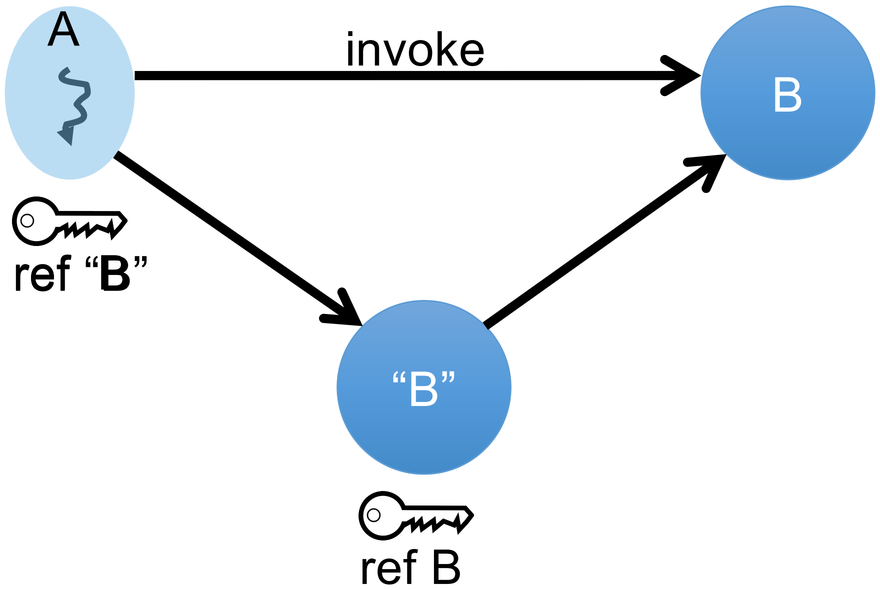
- Who has permission to access a particular object (right now)?
  - ACLs: Just look at the ACL
  - Caps: hard to determine with sparse or tagged caps, or for partitioned
- What objects can a particular subject access (right now)?
  - Capabilities: Just look at its capabilities
  - ACLs: may be impossible to determine without full scan

"Who can access my stuff?"
vs
"How much damage can C do?"

# Interposing Access

**Caps are opaque object references (pure names)**

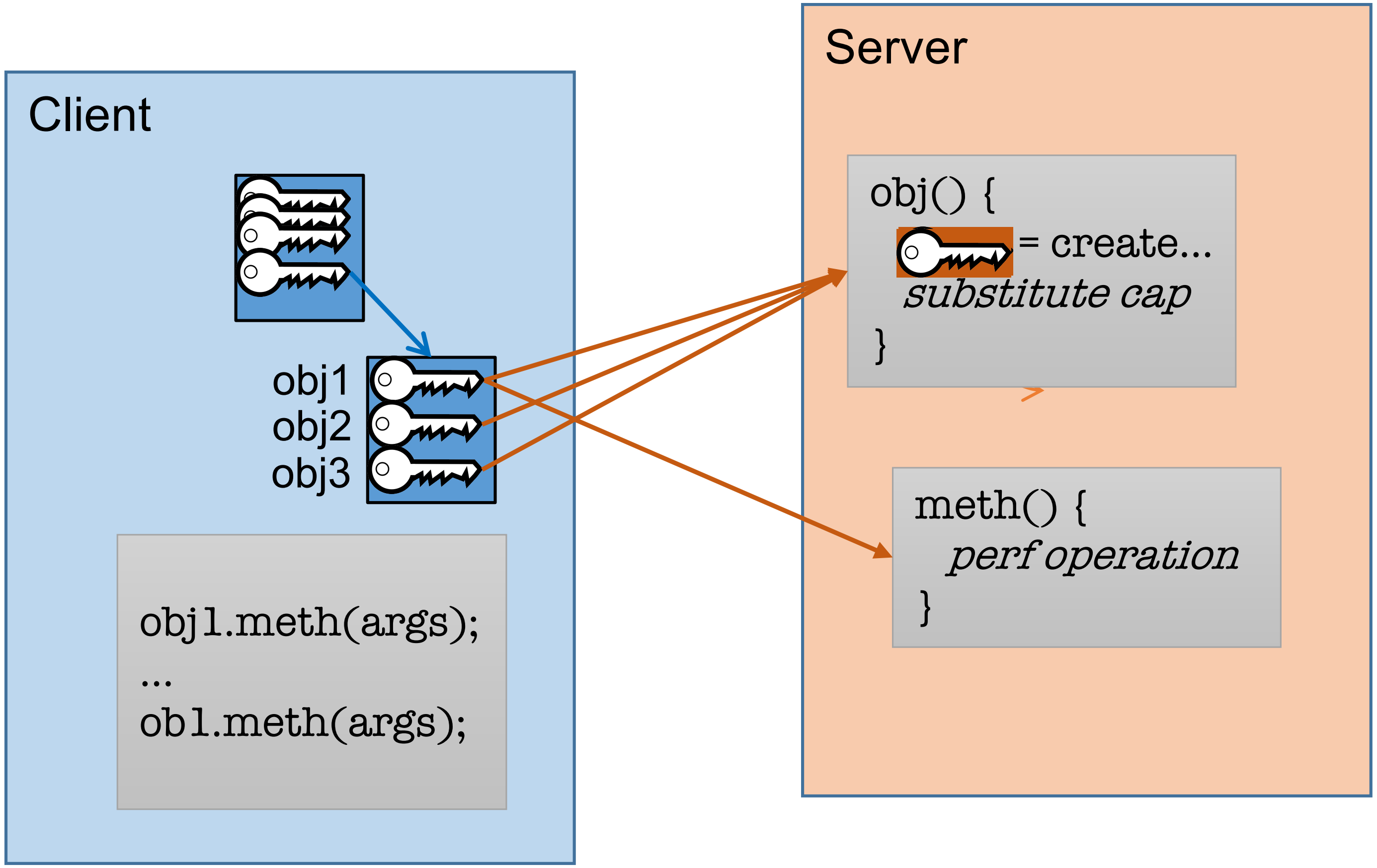
- Holder cannot tell which object a cap references nor the authority
- Supports transparent interposition (virtualisation)




**Usage:**

- API virtualisation
- Security monitor
  - Security policy enforcement
  - Info flow tracing
  - Packet filtering…
- Secure logging
- Debugging
- Lazy object creation

# Example: Lazy Object Construction



# Duals: Satzer & Schroeder Principles

| Security Principle | ACLs | Capabilities |
|---|---|---|
| Economy of Mechanism | Dubious | Yes! |
| Fail-safe defaults | Generally not | Yes! |
| Complete mediation | Yes (if properly done) | Yes (if properly done) |
| Open design | Neutral | Neutral |
| Separation of privilege | No | Doable |
| Least privilege | No | Yes |
| Least common mechanism | No | Yes, but… |
| Psychological acceptability | Neutral | Neutral |

# Mandatory vs Discretionar Access Control

**Discretionary Access Control (DAC):**

- Users can make access control decisions
  - Delegate their access to other users etc.

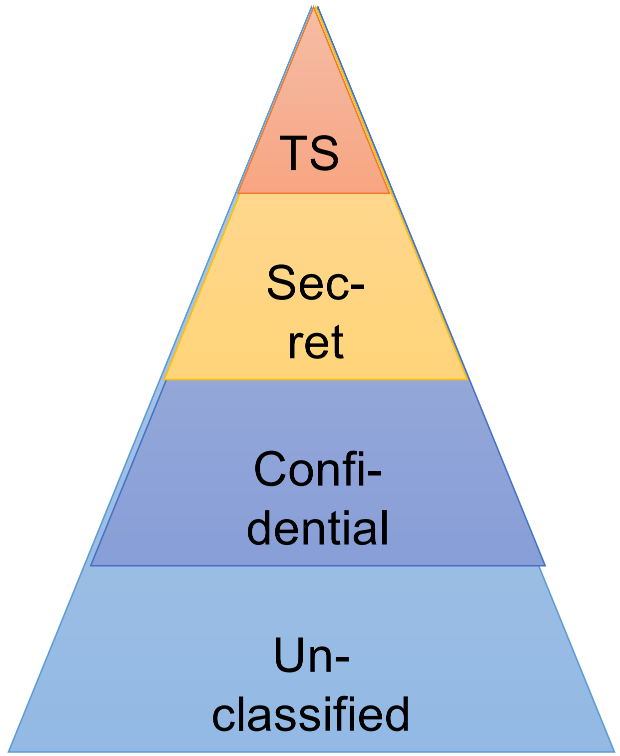
Can I stop my browser leaking secrets?

**Mandatory Access Control (MAC):**

- System enforces administrator-defined policy
- Users can only make access control decisions subject to mandatory policy
- Can prevent untrusted applications from causing damage
- Traditionally used in national security environments

# Bell & LaPadula (BLP) Model [1966]

- MAC Policy/Mechanism
  - Formalises national security classifications
- Every object assigned a **classification**
  - e.g. TS, S, C, U
  - orthogonal security **compartments**
    - Support need-to-know
- Classifications ordered in a **lattice**
  - e.g. TS > S > C > U
- Every subject assigned a **clearance**
  - Highest classification they're allowed to learn



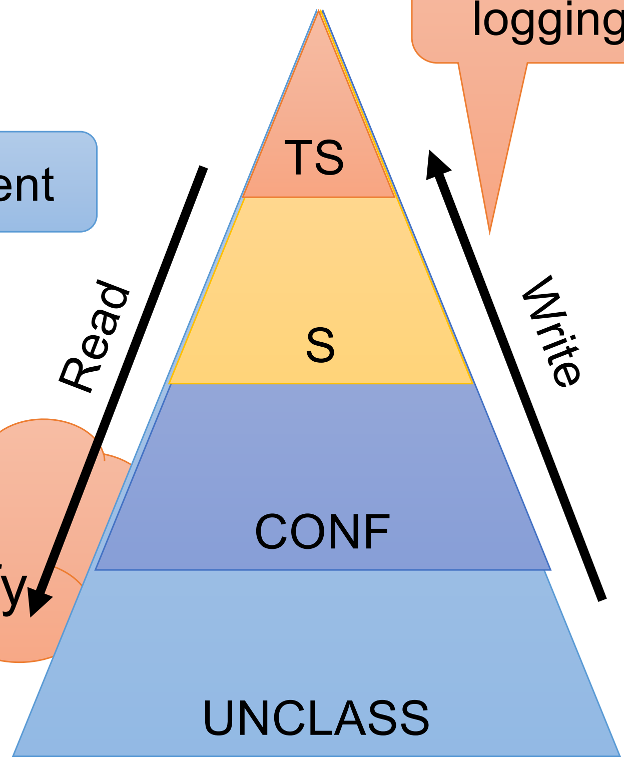
# BLP: Rules

- **Simple Security Property** ("no read up"):
  - s can read o iff clearance(s) >= class(o)
  - s-cleared subject can read U,C,S but not TS
  - standard confidentiality
- **★-Property** ("no write down"):
  - s can write o iff clearance(s) <= class(o)
  - S-cleared subject can write TS,S, but not C,U
  - to prevent accidental or malicious leakage of data to lower levels
- In practice need exceptions
  - allow trusted entity to write down
  - de-classify

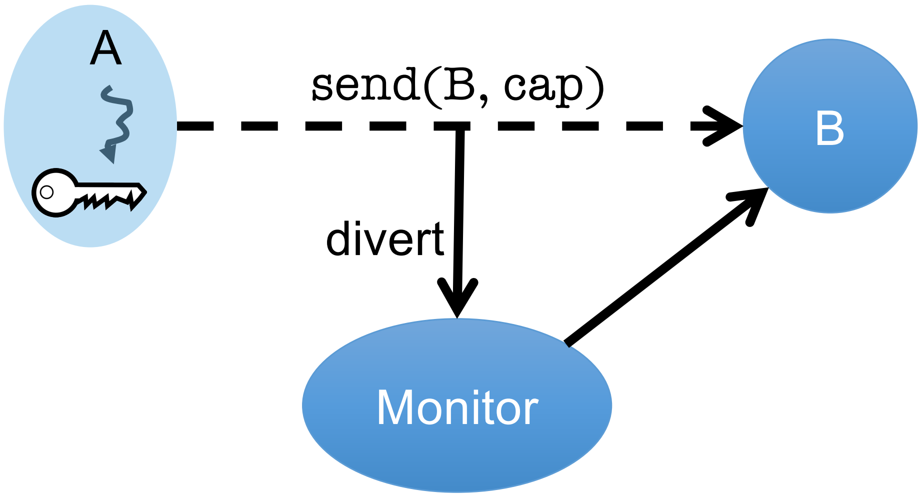
Confinement

Trend to over-classify

E.g. logging



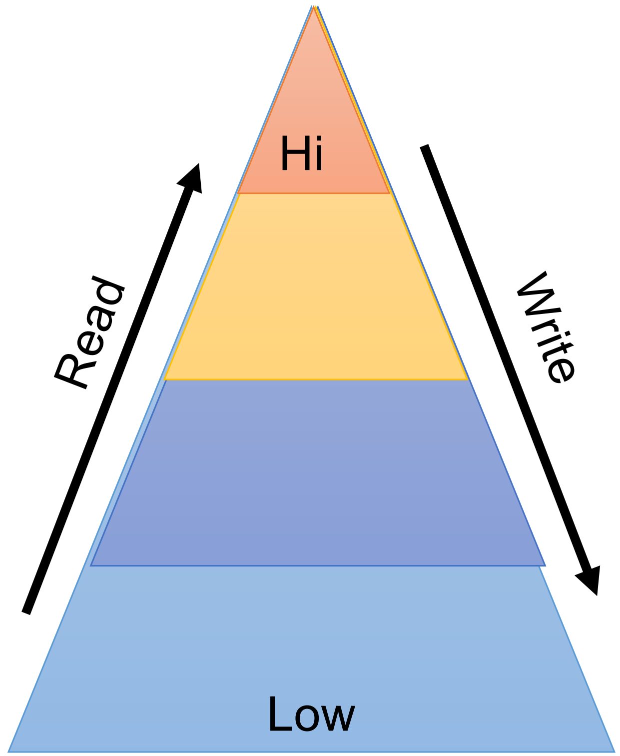
# MAC With Caps




```
interpose_transfer(cap) {
  if (A.clear > B.clear) {
    c = mint(cap, -r);
    send(B,c);
  } else if (A.clear < B.clear) {
    c = mint(cap, -w);
    send(B,c);
  } else {
    send(B,cap);
  }
}
```

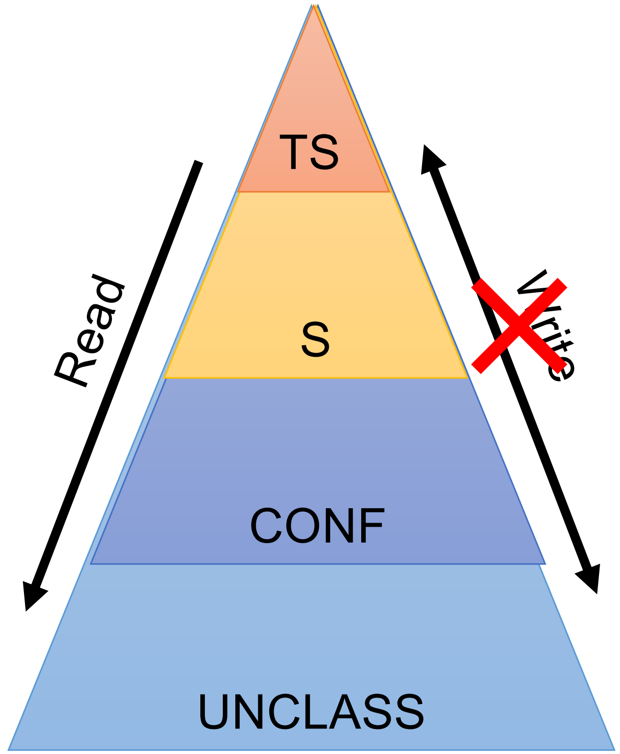
# Biba Integrity Model

- Bell-LaPadula enforces **confidentiality**
- **Biba:** Its dual, enforces **integrity**
- Objects now carry **integrity** classification
- Subjects labelled by **lowest** level of data each subject is allowed to learn
- BLP order is inverted:
  - s can read o iff clearance(s) <= class(o)
  - s can write o iff clearance(s) >= class(o)



# Confidentiality + Integrity

- BLP+Biba allows no information flow across classes
- Practicality requires weakening
  - Assume high-classified subject to treat low-integrity info responsibly
  - Allow read-down
- **Strong *-Property** ("matching writes only"):
  - s can write o iff clearance(s) = class(o)
  - Eg for logging, high reads low data and logs

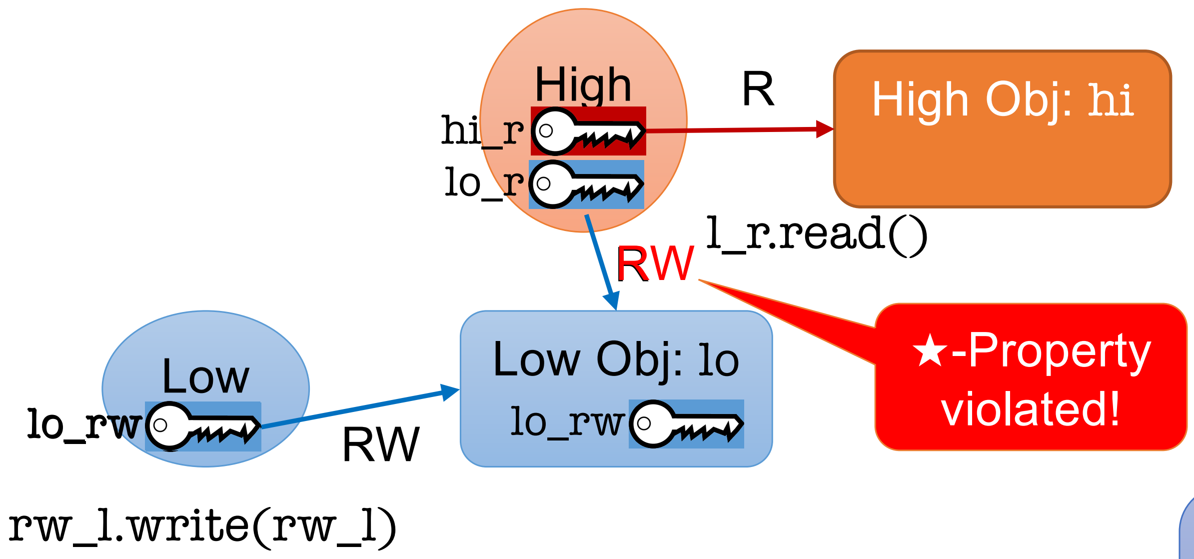


# Clark & Wilson Model

- In commercial settings integrity is more important than confidentiality
- Restrict possible operations to *well-formed transactions*
  - eg payment issued only after goods and invoice received
  - performed by trusted programs
  - easy with caps, SetUID cesspit with ACLs
- Restrict access to trusted programs to specific people
  - separation of duty: running payment program separate from goods-received role

# Boebert's Attack on Capability Machines




Takeaway: Need mechanism to limit cap propagation: *take-grant model*

"On the inability of an unmodified capability machine to enforce the ★-property" [Boebert'84]

Works where caps are indistinguishable from data (HW & sparse caps)

# Decidability

**Safety**: Given initial *safe state s*, system will never reach *unsafe state s'*

**Decidability**: AC system is decidable if safety can aways be computationally determined

Equivalent to halting problem [Harrison, Ruzzo, Ullman '75]

- Most capability systems are decidable
- Unclear for many common ACL systems

# Summary: AC Principles

- ACLs and Capabilities:
  - Capabilities tend to better support least privilege
  - But ACLs can be better for auditing
- MAC good for global security requirements
- Not all mechanisms can enforce all policies
  - e.g. ★-property with sparse or HW capabilities
- AC systems should be decidable so we can reason about security