Lecture 18: Mandatory Access Control

CS 138

Spring 2026

Review: Access control

- **Subject:** principal to which execution can be attributed
- **Object:** data or resource
- **Operation:** performed by subject on object
- **Right:** entitlement to perform operation

Review: DAC

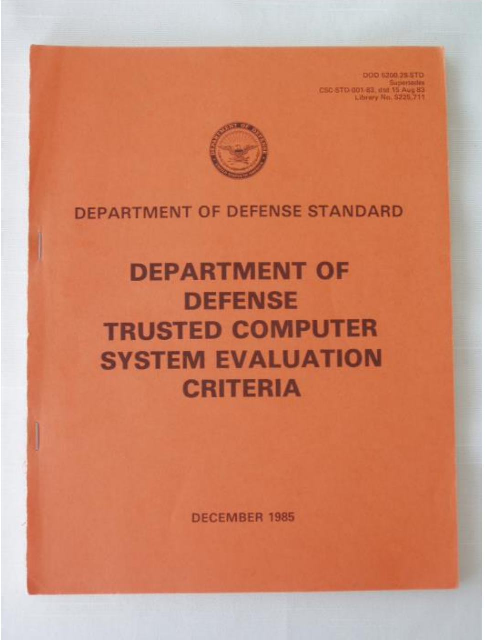
- **Discretionary access control** (DAC)
  - **Philosophy:** users have the *discretion* to specify policy themselves
  - Commonly, information belongs to the **owner** of object
  - Model: access control **relation**
    - Set of triples (subj,obj,rights)
    - Sometimes described as access control "matrix"
- Implementations:
  - **Access control lists** (ACLs): each object associated with list of (subject, rights)
  - **Capability lists:** each subject associated with list of (object, rights)

MAC

- **Mandatory access control** (MAC)
  - **philosophy:** central authority *mandates* policy
  - information belongs to the authority, not to the individual users
  - not Message Authentication Code (applied crypto), nor Media Access Control (networking)

Multi-Level Security

- A mechanism for monitoring access control in a system where both principals and objects have security labels drawn from a hierarchy of labels
- Commonly associated with military systems
- Influenced "Orange Book" (DoD Trusted Computer System Evaluation Criteria)
  - A) Verified Protection
  - B) Mandatory Protection
  - C) Discretionary Protection
  - D) Minimal Protection



Sensitivity

- Concern is **confidentiality** of information
- Documents classified according to **sensitivity**: risk associated with release of information
- In US:
  - Top Secret
  - Secret
  - Confidential
  - Unclassified

Compartments

- Documents classified according to **compartment(s):** categories of information (in fact, aka **category**)
  - cryptography
  - nuclear
  - biological
  - reconnaissance
- **Need to Know Principle:** access should be granted only when necessary to perform assigned duties (instance of Least Privilege)
  - {crypto, nuclear}: must need to know about **both** to access
  - {}: no particular compartments

Labels

- **Label:** pair of sensitivity level and set of compartments, e.g.,
  - (Top Secret, {crypto, nuclear})
  - (Unclassified, {})
- Document is labeled aka **classified**
  - Perhaps each paragraph labeled
  - Label of document is most restrictive label for any paragraph
- Users are labeled according to their **clearance**
  - Users trustworthy by virtue of vetting process for security clearance
  - Out of scope (e.g.): user who views Top Secret information and calls the *Washington Post*
- Labels are imposed by organization
- **Notation:** let L(X) be the label of entity X

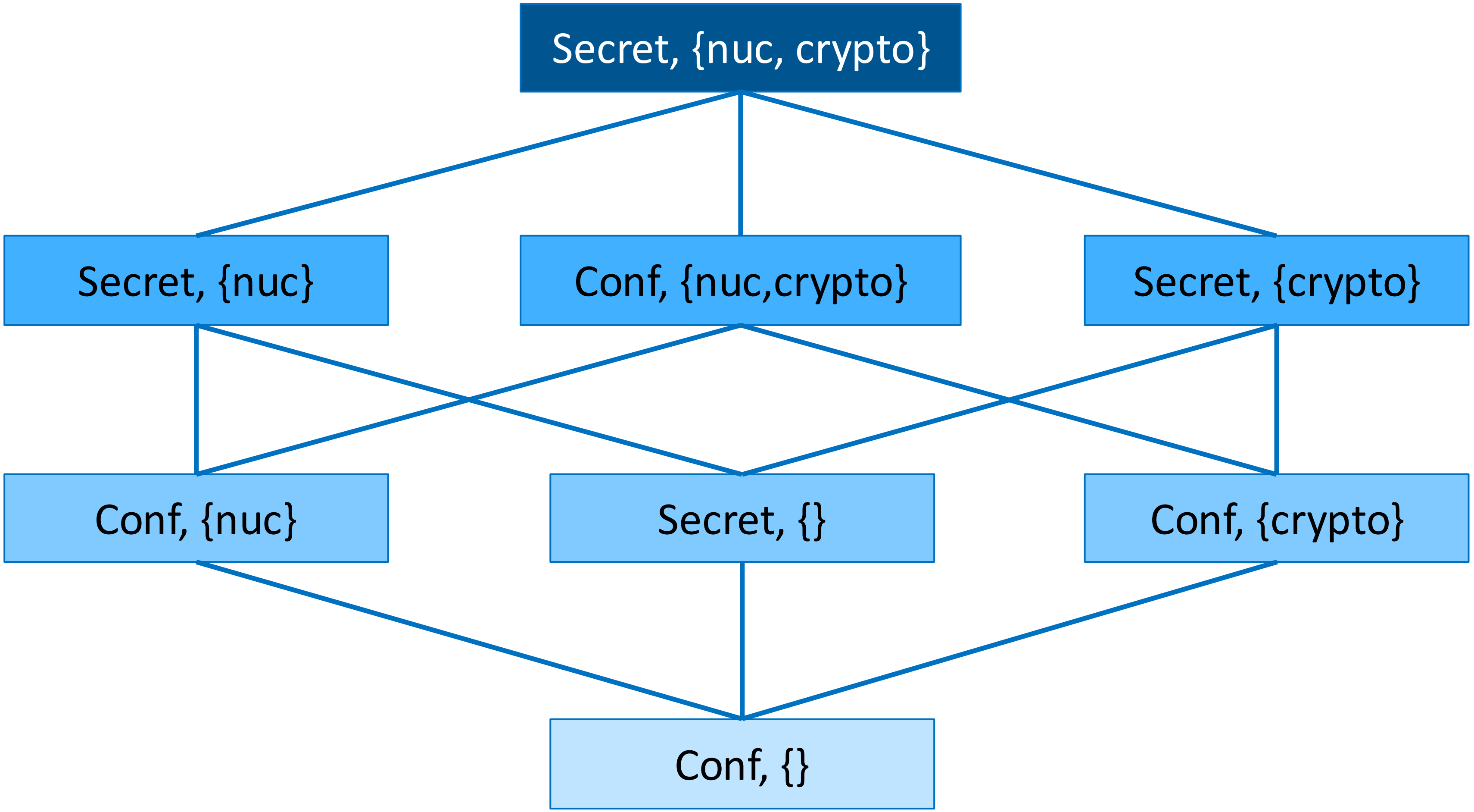
Restrictiveness of labels

Notation: L1 □ L2

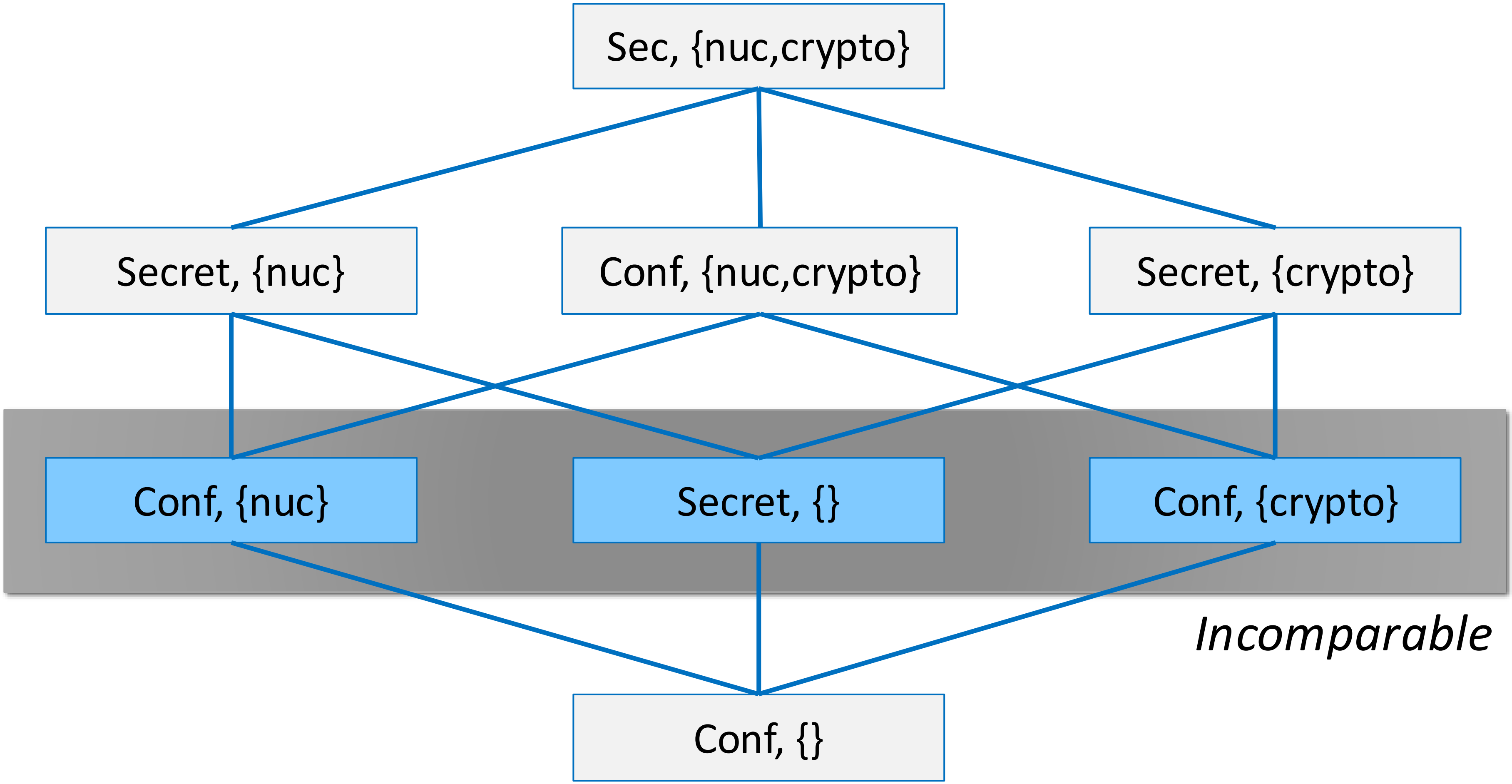
- means **L1 is less (or equally) restrictive than L2**

- **Definition:**
  - Let L1 = (S1, C1) and L2 = (S2, C2)
  - **L1 □ L2 iff S1 ≤ S2 and C1 □ C2**
  - Where ≤ is order on sensitivity:
    Unclassified ≤ Confidential ≤ Secret ≤ Top Secret
- e.g.
  - (Unclassified,{}) □ (Top Secret, {})
  - (Top Secret, {crypto}) □ (Top Secret, {crypto,nuclear})

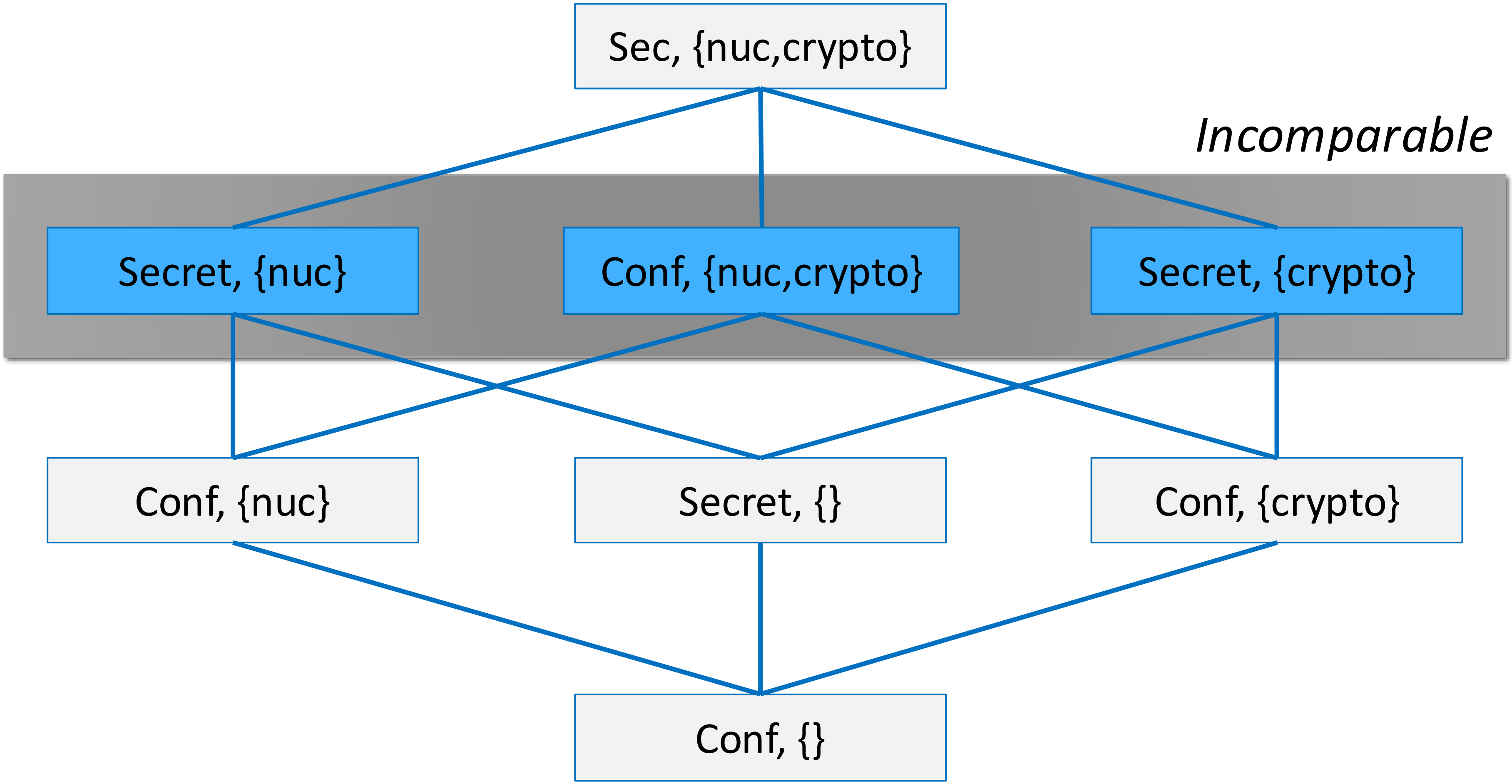
Label partial order



Label partial order



Label partial order



Exercise 1: Label Partial Order

- For each pair of labels, determine whether L1 □ L2, L2 □ L1, or neither

1. L1= (Conf, {}), L2 = (Secret, {crypto})
2. L1 = (Conf, {nuc}), L2 = (Secret, {crypto})
3. L1 = (Secret, {nuc,crypto}), L2= (Conf, {crypto}

Access control with MLS

- When may a subject read an object?
  - **Threat:** subject attempts to read information for which it is not cleared
  - e.g., subject with clearance Unclassified attempts to read Top Secret information

Access control with MLS

- When may a subject read an object?
  - **S may read O iff L(O) □ L(S)**
  - object's classification must be below (or equal to) subject's clearance
  - "no read up"

Exercise 2: Reading with MLS

- Scenario:
  - Alice has clearance (Secret, {nuclear, Europe})
  - DocA with classification (Confidential, {nuclear})
  - DocB with classification (Secret, {Europe, US})
  - DocC with classification (Top Secret, {nuclear, Europe})
- Which documents may Alice **read**?
  - Recall: S may read O iff L(O) □ L(S)

Access control with MLS

- When may a subject read an object?
  - **S may read O iff L(O) □ L(S)**
  - object's classification must be below (or equal to) subject's clearance
  - "no read up"
- When may a subject write an object?
  - **Threat:** subject attempts to *leak* information by writing into a lower-security object
  - e.g., subject with clearance Top Secret reads Top Secret information then writes it into an Unclassified file

Access control with MLS

- When may a subject read an object?
  - **S may read O iff L(O) □ L(S)**
  - object's classification must be below (or equal to) subject's clearance
  - "no read up"
- When may a subject write an object?
  - **S may write O iff L(S) □ L(O)**
  - object's classification must be above (or equal to) subject's clearance
  - "no write down"

Exercise 3: Writing with MLS

- Scenario:
  - Alice has clearance (Secret, {nuclear, Europe})
  - DocA with classification (Confidential, {nuclear})
  - DocB with classification (Secret, {Europe, US})
  - DocC with classification (Top Secret, {nuclear, Europe})
- Which documents may Alice **write**?
  - Recall: S may write O iff L(S) □ L(O)

Reading and writing with MLS

- Scenario:
  - Principal P with clearance (Secret, {nuclear, Europe})
  - DocA with classification (Confidential, {nuclear})
  - DocB with classification (Secret, {Europe, US})
  - DocC with classification (Top Secret, {nuclear, Europe})
- Summary:
  - DocA: P may read but not write
  - DocB: P may neither read nor write
  - DocC: P may write but not read

Perplexities of writing with MLS

1. **Blind write:** subject may not read higher-security object yet may write it
   - Useful for logging
   - Some implementations prohibit writing up as well as writing down

2. User who wants to write lower-security object may not
   - **Attenuation of privilege:** login at a lower security level than clearance
   - Nice (annoying?) application of Least Privilege

3. **Declassification** violates "no write down"
   - Encryption or billing procedure produces (e.g.) Unclassified output from Secret information
   - Traditional solution is trusted subjects who are not constrained by access control rules

Formalizing MLS

[Bell and LaPadula 1973]

- Formal mathematical model of MLS plus access control matrix
- Proof that information cannot leak to subjects not cleared for it
- "No read up": simple security property
- "No write down": *-property
- *"The influence of [BLP] permeates all policy modeling in computer security"* –Matt Bishop
  - Influenced Orange Book
  - Led to research field "foundations of computer security”

Exercise

A fictitious microprocessor company called Mintel, Inc., is implementing a MLS model for its computer systems. The security officer of Mintel proposes the following labels:

- Users:
  - **Alice** is the CEO of Mintel. **L(Alice) = (Top Secret, {NewCPU,HR})**
  - **Bob** is a manager in the HR office. **L(Bob) = (Secret, {HR})**
  - **Cindy** is a working on a new CPU product. **L(Cindy) = (Secret, {NewCPU})**
  - **Dave** is a receptionist in the main lobby. **L(Dave) = (Unclassified, {})**
- Objects:
  - **payroll.xlsx** Salaray spreadsheet. **L(payroll.xlsx) = (Confidential, {HR})**
  - **strategy.pptx** Briefing on new CPU. **L(strategy.pptx) = (TopSecret, {NewCPU})**
  - **index.php** Homepage of Mintel's website. **L(index.php) = (Unclassified, {})**

Assuming each user logs in with their full clearance, which files can each user read? Which files can each user write?

Integrity

- BLP is about confidentiality
- Adapted to integrity by Biba [1977]: same rules, different lattice
  - Instead of Unclassified and Secret, labels could be Untrusted and Trusted
- L1 □ L2 means "L1 may flow to L2 without breaking confidentiality"
  - BLP: low secrecy sources may flow to high secrecy sinks
    - Hence Unclassified □ Secret, but not v.v.
  - Biba: low integrity sources may not flow to high integrity sinks
    - Hence Trusted □ Untrusted, but not v.v.
  - High vs. low is "flipped" (lattices are *duals*)

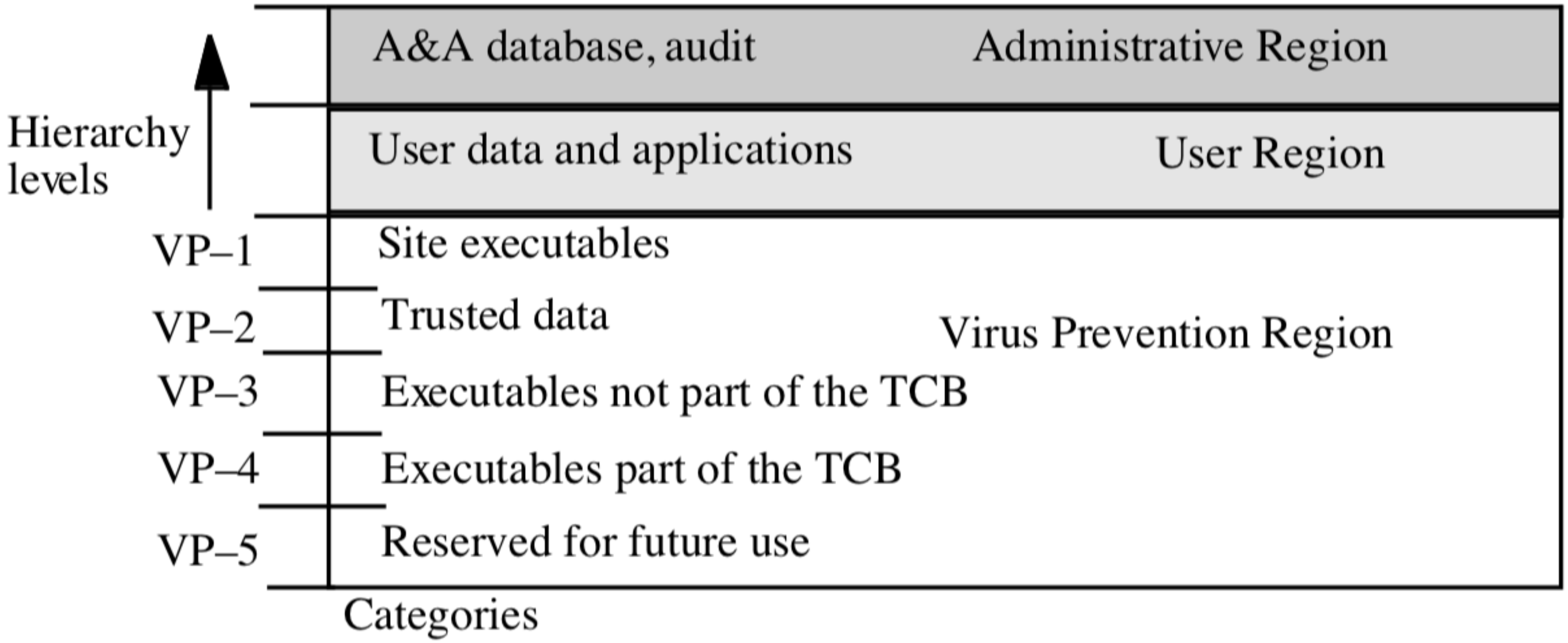
Biba model

- **S may read O iff L(O) □ L(S)**
  - E.g., Trusted subject cannot read Untrusted object
  - But Untrusted subject may read Trusted object
- **S may write O iff L(S) □ L(O)**
  - E.g., Trusted subject may write Untrusted object
  - But Untrusted subject may not write Trusted object

MLS in OSs

DG/UX

- Discontinued Unix OS, release 1985
- Three regions:
  Virus Protection User Region Administrative Region



MLS in OSs

DG/UX

- Discontinued Unix OS, release 1985
- Three regions:
  Virus Protection □ User Region □ Administrative Region
- MLS confidentiality: read down, no read up
- Extra integrity: no write down, no write up
  - for shared directories (e.g., /tmp), introduced multi-level directories with one hidden subdirectory for each level

MLS in OSs

SELinux

- Kernel security module, dates back to NSA c. 2000, merged with Linux kernel mainline in 2.6
- Goal: separate security policy from security decisions
- Supports mandatory access controls in reference policy. When MLS is enabled:
  - Each principal (user or process) is assigned a context
    (username, role, domain, (sensitivity))
  - Each object (file, port, hardware) is assigned a context
  - SELinux enforces MLS

MLS in OSs

TrustedBSD [2000]

- Similar goals to SELinux: separate policy from security mechanism, implements MLS
- ported parts of SELinux to FreeBSD
- Many components eventually folded into FreeBSD
- Most interfaces supported on Macs since OSX 10.5

Beyond Multi-level Security…

Mandatory access control comes in many different forms:

1. Multi-level security (confidentiality, military)
2. Biba model (integrity, military)
3. Role-based access control (hybrid, organization)
4. Clark-Wilson (integrity, business)
5. Brewer-Nash (hybrid, consulting firm)

Mandatory Access Control