Access Control Models
Part I

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Introduction

Two main categories:

- Discretionary Access Control Models (DAC)
  - Definition [Bishop p.53] If an individual user can set an access control mechanism to allow or deny access to an object, that mechanism is a *discretionary access control (DAC*), also called an *identity-based access control* (*IBAC*).
- Mandatory Access Control Models (MAC)
  - Definition [Bishop p.53] When a system mechanism controls access to an object and an individual user cannot alter that access, the control is a *mandatory access control* (MAC) [occasionally called a *rule-based access control*.]

Introduction

- Other models:
  - The Chinese Wall Model – it combines elements of DAC and MAC
  - RBAC Model – it is a DAC model; however, it is sometimes considered a policy-neutral model
  - The Biba Model – relevant for integrity
  - The Information-Flow model – generalizes the ideas underlying MAC

DAC

- DAC policies govern the access of subjects to objects on the basis of subjects' identity, objects' identity and permissions
- When an access request is submitted to the system, the access control mechanism verifies whether there is a permission authorizing the access
- Such mechanisms are discretionary in that they allow subjects to grant other subjects authorization to access their objects at their discretion

DAC

- Advantages:
  - Flexibility in terms of policy specification
  - Supported by all OS and DBMS
- Drawbacks:
  - No information flow control (Trojan Horses attacks)

DAC – The HRU Model

- The Harrison-Ruzzo-Ullman (HRU) has introduced some important concepts:
  - The notion of *authorization systems*
    - This is way we include it among the DAC models, even though the distinction between DAC and MAC was introduced much later
  - The notion of *safety*

[HRU76] M.Harrison, W. Ruzzo, J. Ullman. Protection in Operating Systems. *Comm. of ACM* 19(8), August 1976.

The HRU Model

To describe the HRU model we need:

- S be a set of subjects
- O be a set of objects
- R be a set of access rights
- an access matrix $M = (M_{so})_{s \in S,\, o \in O}$
- the entry M_{so} is the subset R specifying the rights subject s has on object o

The HRU Model – Primitive Operations

The model includes six *primitive operations* for manipulating the set of subjects, the set of objects, and the access matrix:

- **enter** r into M_{so}
- **delete** r from M_{so}
- **create subject** s
- **delete subject** s
- **create object** o
- **delete object** o

The HRU Model - Commands

Commands in the HRU model have the format

command $c(x_1, \ldots\ldots, x_k)$

if r_1 in $M_{s1,o1}$ **and**

if r_2 in $M_{s2,o2}$ **and**

$\vdots$

if r_m in $M_{sm,om}$

then $op_1, \ldots\ldots, op_n$

end

The HRU Model - Commands

- The indices $s_1,\ldots\ldots,s_m$ and $o_1,\ldots\ldots,o_m$ are subjects and objects that appear in the parameter list $c(x_1,\ldots\ldots,x_k)$
- The condition part of the command checks whether particular access rights are present; the list of conditions can be empty
- If all conditions hold, then the sequence of basic operations is executed
- Each command contains at least one operation
- Commands containing exactly one operation are said *mono-operational* commands

The HRU Model – Command examples

command create_file (s,f)
  create f
  enter o into $M_{s,f}$
  enter r into $M_{s,f}$
  enter w into $M_{s,f}$
end

command grant_read (s,p,f)
  if o in $M_{s,f}$
  then enter r into $M_{p,f}$
end

The HRU Model – Protection Systems

- A protection system is defined as
  - A finite set of rights
  - A finite set of commands
- A protection system evolves over time (as a consequence of executing commands)
- The access matrix describes the state of the *protection system*

The HRU Model - States

- The effects of a command are recorded as a change to the access matrix (usually the modified access control matrix is denoted by *M*')
- What do we mean by the state of the protection system?
  - The *state* of a system is the collection of the current values of all memory locations, all secondary storage, and all registers and other components of the system
  - The *state of the protection system* is the subset of such a collection that deals with allocation of access permissions; it is thus presented by the access control matrix

The HRU Model – States

Definition. A state, i.e. an access matrix M, is said to ***leak*** the right r if there exists a command c that adds the right r into an entry in the access matrix that previously did not contain r. More formally, there exist s and o such that $r \notin M_{so}$ and, after the execution of c, $r \in M'_{so}$.

Note: The fact that a right is leaked is not necessarily bad; many systems allow subjects to give other subjects access rights

The HRU Model – Safety of States

What do we mean by saying that a state is "safe"?

Definition 1: "access to resources without the concurrence of the owner is impossible" [HRU76]

Definition 2: "the user should be able to tell whether what he is about to do (give away a right, presumably) can lead to the further leakage of that right to truly unauthorized subjects" [HRU76]

The HRU Model – Safety

The problem motivating the introduction of safety can be described as follows:

"*Suppose a subject s plans to give subjects s' right r to object o. The natural question is whether the current access matrix, with r entered into (s',o), is such that right r could subsequently be entered somewhere new.*"

The HRU Model – An example of "unsafe" protection system

Assume to have a protection system with the following two commands:

command grant_execute (s,p,f)
  if <u>o</u> in $M_{s,f}$
  then enter <u>x</u> into $M_{p,f}$
end

command modify_own_right (s,f)
  if <u>x</u> in $M_{s,f}$
  then enter <u>w</u> into $M_{s,f}$
end

The HRU Model – An example of "unsafe" protection system

- Suppose user Bob has developed an application program; he wants this program to be run by other users but not modified by them
- The previous protection system is not safe with respect to this policy; consider the following sequence of commands:

  - Bob: grant_execute (Bob, Tom, P1)
  - Tom: modify_own_right (Tom, P1)

  it results in access matrix where the entry $M_{\mathrm{Tom,P1}}$ contains the <u>w</u> access right

The HRU Model - Safety

Definition. Given a protection system and a right r, we say that the initial configuration Q_0 is unsafe for r (or leaks r) if there is a configuration Q and a command α such that

- Q is reachable from Q_0
- α leaks r from Q

We say Q_0 is safe for r if Q_0 is not unsafe for r.

Alternative (more intuitive) definition. A state of a protection system, that is, its matrix M, is said to be safe with respect to the right r if no sequence of commands can transform M into a state that leaks r.

Theorem. Given an access matrix M and a right r, verifying the safety of M with respect to r is an ***undecidable*** problem.

The HRU Model – Safety
Other relevant results

The safety question is

- decidable for mono-operational protection systems
- undecidable for biconditional monotonic protection systems
- decidable for monoconditional monotonic protection systems

The HRU Model
Concluding Remarks

The results on the decidability of the safety problem illustrate an important security principle, the *principle of economy of mechanisms*

- if one designs complex systems that can only be described by complex models, it becomes difficult to find proofs of security
- in the worst case (undecidability), there does not exist a universal algorithm that verifies security for all problem instances

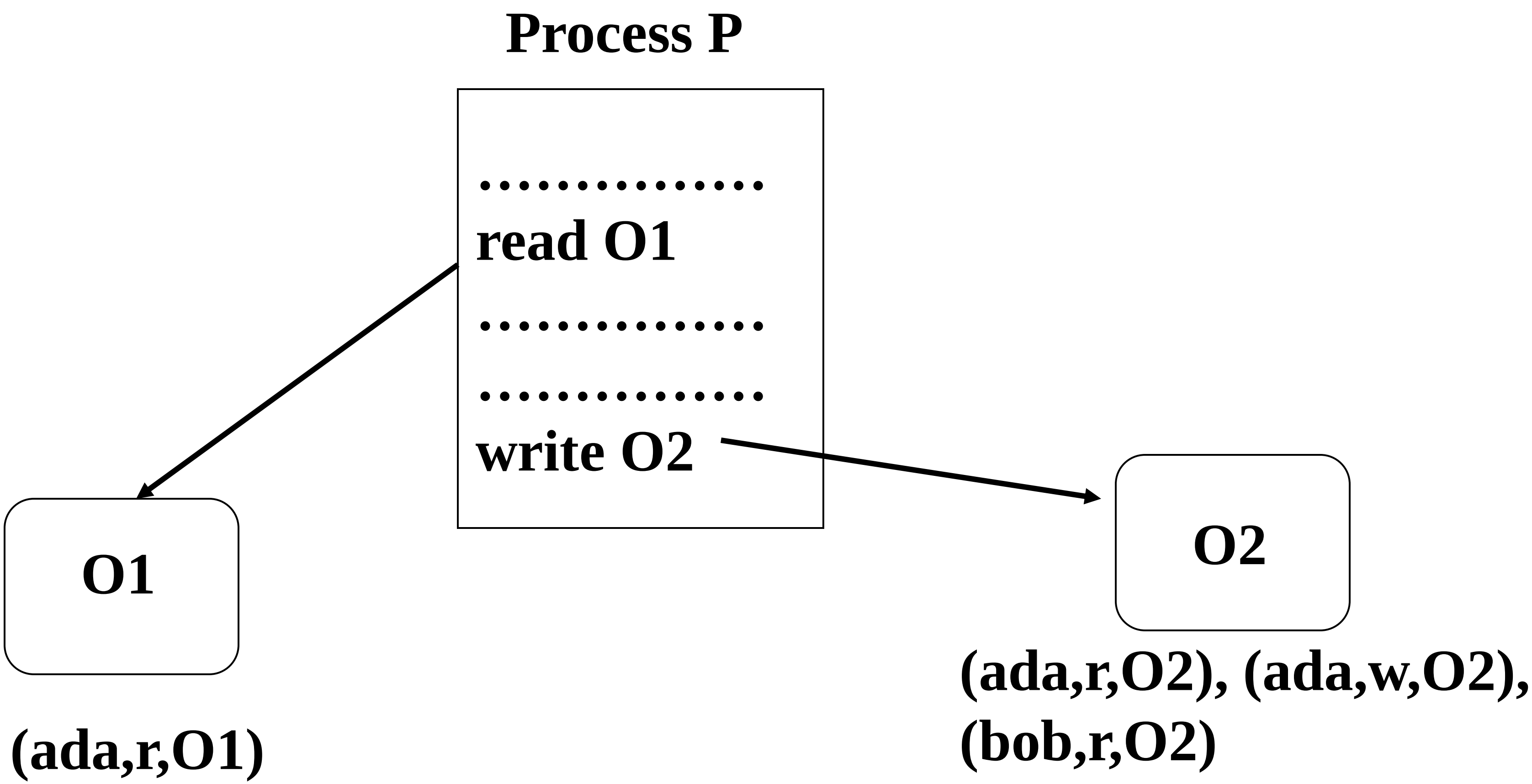
Other Models

- DAC models have been widely investigates in the area of DBMS
- Several extensions have been developed that support different kinds of permissions
  - Positive vs. negative
  - Strong vs. weak
  - Implicit vs. explicit
  - Content-based

DAC models - DBMS vs OS

- Increased number of objects to be protected
- Different granularity levels (relations, tuples, single attributes)
- Protection of logical structures (relations, views) instead of real resources (files)
- Different architectural levels with different protection requirements
- Relevance not only of data physical representation, but also of their semantics

The Trojan Horse



The Trojan Horse

- DAC models **are unable to protect data against Trojan Horses** embedded in application programs
- MAC models were developed to prevent this type of illegal access

MAC

- MAC specifies the access that subjects have to objects based on subjects and objects classification
- This type of security has also been referred to as *multilevel security*
- Database systems that satisfy multilevel security properties are called multilevel secure database management systems (MLS/DBMSs)
- Many of the MLS/DBMSs have been designed based on the Bell and LaPadula (BLP) model

Bell and LaPadula Model

Elements of the model:

- *objects* - passive entities containing information to be protected
- *subjects*: active entities requiring accesses to objects (*users*, *processes*)
- *access modes*: types of operations performed by subjects on objects
  - read: reading operation
  - append: modification operation
  - write: both reading and modification

Bell and LaPadula Model

http://en.wikipedia.org/wiki/Bell-La_Padula_model

- Subjects are assigned clearance levels and they can operate at a level up to and including their clearance levels
- Objects are assigned sensitivity levels
- The clearance levels as well as the sensitivity levels are called access classes

BLP Model - access classes

- An access class consists of two components

  a security level　　　　　a category set

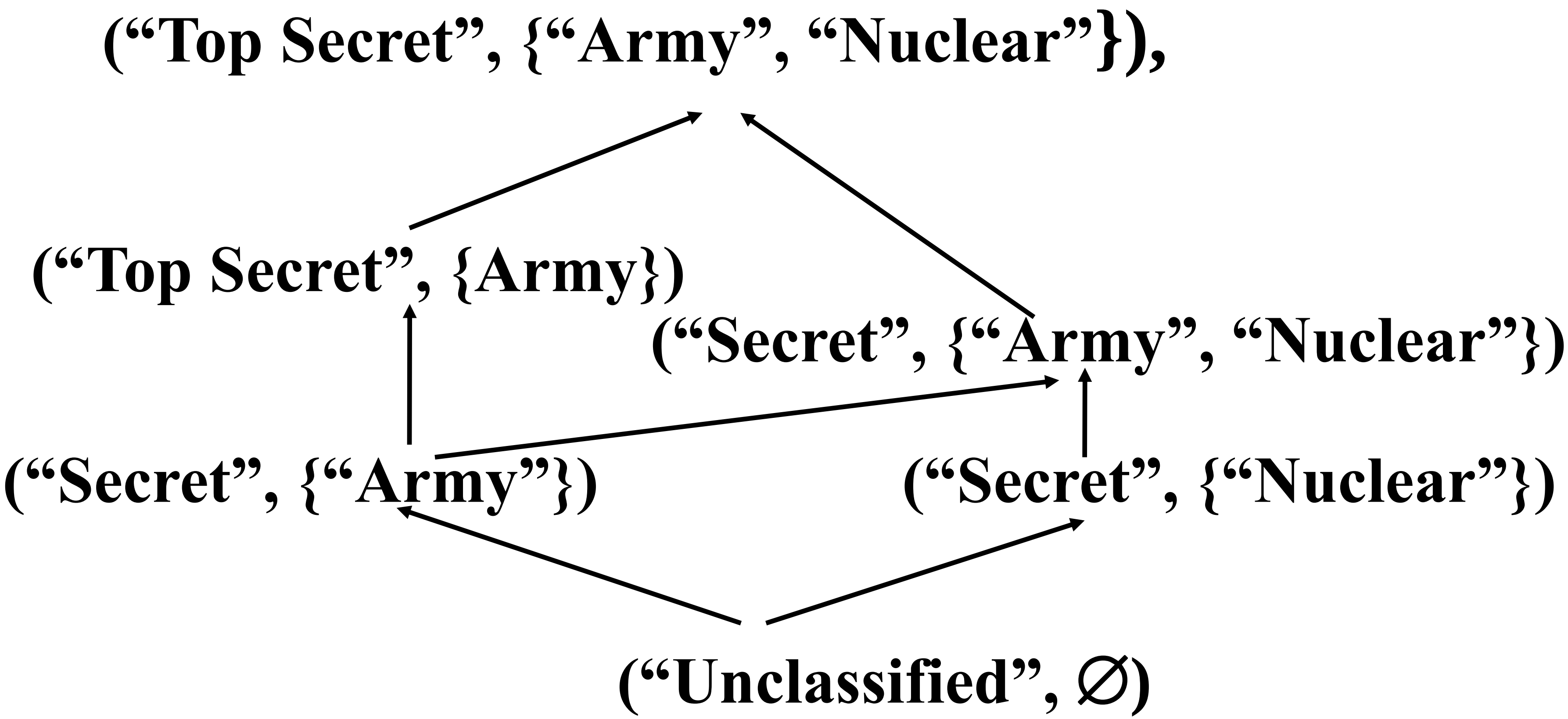
- The security level is an element from a totally ordered set - example

  {Top Secret (TS), Secret (S), Confidential (C), Unclassified (U)}
  where TS > S > C >U

- The category set is a set of elements, dependent from the application area in which data are to be used - example

  {Army, Navy, Air Force, Nuclear}

Example Lattice



Formalising the Policy

- Bell-LaPadula :
  - *simple security policy*: no read up
  - *-*policy*: no write down
- With these, one can prove that a system which starts in a secure state will remain in one
- Ideal: minimise the Trusted Computing Base (set of hardware, software and procedures that can break the security policy) so it's verifiable
- 1970s idea: use a reference monitor

BLP Model - Access classes

Access class $c_i = (L_i, SC_i)$ dominates access class $c_k = (L_k, SC_k)$, denoted as $c_i \geq c_k$, if both the following conditions hold:

- $L_i \geq L_k$ The security level of c_i is greater or equal to the security level of c_k
- $SC_i \supseteq SC_k$ The category set of c_i includes the category set of c_k

BLP Model - Access classes

- If $L_i > L_k$ and $SC_i \supset SC_k$, we say that
  c_i strictly dominates c_k

- c_i and c_k are said to be incomparable (denoted as $c_i <> c_k$) if
  neither $c_i \geq c_k$ nor $c_k \geq c_i$ holds

BLP Model - Examples

Access classes

$c_1 = (TS, \{Nuclear, Army\})$

$c_2 = (TS, \{Nuclear\})$

$c_3 = (C, \{Army\})$

- $c_1 \geq c_2$
- $c_1 > c_3$ (TS > C and $\{Army\} \subset \{Nuclear, Army\}$)
- $c_2 <> c_3$

BLP Model - Axioms

- The state of the system is described by the pair ($\mathcal{A}$, $\mathcal{L}$), where:
  - $\mathcal{A}$ is the *set of current accesses*: triples of the form (s,o,m) denoting that subject s is exercising access m on object o - example (Bob, o_1, read)
  - $\mathcal{L}$ is the *level function*: it associates with each element in the system its access class

  Let O be the set of objects, S the set of subjects, and C the set of access classes

  $$\mathcal{L} : O \cup S \rightarrow C$$

BLP Model - Axioms

- Simple security property (*no-read-up*)

  a given state ($\mathcal{A}$, $\mathcal{L}$) satisfies the simple security property if for each element a= (s,o,m) $\in \mathcal{A}$ one of the following condition holds

  1. m = append

  2. m = read or m = write and $\mathcal{L}(s) \geq \mathcal{L}(o)$

- Example: a subject with access class (C, {Army}) is <u>not allowed</u> to read objects with access classes

  (C, {Navy, Air Force}) or (U, {Air Force})

BLP Model - Axioms

- The simple security property prevents subjects from reading data with access classes dominating or incomparable with respect with the subject access class
- It therefore ensures that subjects have access only to information for which they have the necessary access class

BLP Model - Axioms

- Star (*) property (*no-write-down*)

  a given state ($\mathcal{A}$, $\mathcal{L}$) satisfies the *-property if for each element a= (s,o,m) $\in \mathcal{A}$ one of the following condition holds

  1. m = read
  2. m = append and $\mathcal{L}(o) \geq \mathcal{L}(s)$
  3. m = write and $\mathcal{L}(o) = \mathcal{L}(s)$

- Example: a subject with access class (C,{Army,Nuclear}) is <u>not allowed</u> to append data into objects with access class (U, {Army,Nuclear})

BLP Model - Axioms

- The *-property has been defined to prevent information flow into objects with lower-level access classes or incomparable classes
- For a system to be secure both properties must be verified by any system state

Bell and LaPadula Model

- Summary of access rules:
  - **Simple security property**: A subject has read access to an object if its access class dominates the access class of the object;
  - ***-Property**: A subject has append access to an object if the subject's access class is dominated by that of the object

Problem

- Colonel has (Secret, {Nuclear, Army}) clearance
- Major has (Secret, {Army}) clearance
- The Colonel needs to send a message to the Major. The Colonel cannot write a document that has access class (Secret, {Army}) because such a document would violate the *-property
- To address this problem the model provides a mechanism; each subject has a *maximum access class* and a *current access class*
- A subject may change its access class; the current access class must however be dominated by the maximum access class

Problem

- Colonel has (Secret, {NUC, EUR}) clearance
- Major has (Secret, {EUR}) clearance
  - Major can talk to colonel (“write up” or “read down”)
  - Colonel cannot talk to major (“read up” or “write down”)
- Clearly absurd!

Solution

- Define maximum, current levels for subjects
  - *maxlevel*(*s*) *dom curlevel*(*s*)
- Example
  - Treat Major as an object (Colonel is writing to him/her)
  - Colonel has *maxlevel* (Secret,{NUCLEAR, ARMY})
  - Colonel sets *curlevel* to (Secret, { ARMY})
  - Now *L*(Major) *dom curlevel*(Colonel)
    - Colonel can write to Major without violating "no writes down"
  - Does *L*(*s*) mean *curlevel*(*s*) or *maxlevel*(*s*)?
    - Formally, we need a more precise notation

Bell and LaPadula Model

- It is a significant model and it has been used in both OS and DBMS
- Some criticisms:
  - Only dealing with confidentiality, not with integrity
  - Containing covert channels

Covert Channels

- A covert channel allows a transfer of information that violates the MLS policy
- It is an information flow which is not controlled by a security mechanism
- Covert channels can be classified into two broad categories: timing and storage channels
- The difference between the two is that in timing channels the information in conveyed by the timing of events or processes, whereas storage channels do not require any temporal synchronization is that information is conveyed by accessing system information

Covert Channels - example

- A well-known covert channel is based on the exploitation of the 2PL concurreny control
- Consider two transactions T_l and T_h of access class low and high respectively; consider a data item d_1 classified at class low; assume that those all the only transactions running
- Suppose that T_h requires a read lock on d_l; the lock is granted because no other transaction is running

Covert Channels - example

- Suppose now that transaction T_l wishes to write the same data item; it thus requires a write lock on d_1
- Since transaction T_h holds a read lock on d_1, transaction T_l is forced to wait until T_h releases the lock on d_1
- By selectively issuing requests to read low data, transaction T_h can modulate the delay experienced by transaction T_l

Covert Channels - example

- Since has full access to high data, this delay can be used by T_h to transfer high information to transaction T_l
- Thus a timing channel is established between the two transactions

Covert Channels

- The BLP access control mechanism does not protect against attacks through covert channels
- MLS need to be engineered in order to close all covert channels

Covert Channels - 2PL

- The problem of designing concurrency control algorithms free of timing channels has been extensively investigated
- For example Trusted Oracle adopts a synchronization based on 2PL combined with multiversion techniques
- It has been proved, however, that such algorithm does not generate serializable histories