Access Control Models
Part I

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Introduction

Two main categories:

- Discretionary Access Control Models (DAC)
  - Definition: 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: 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_{s_1,o_1} **and**

if r_2 in M_{s_2,o_2} **and**

$\vdots$

if r_m in M_{s_m,o_m}

then $op_1,\ldots\ldots,op_n$

end

The HRU Model - Commands

- The indices $s_1,\ldots..,s_m$ and $o_1,\ldots..,o_m$ are subjects and objects that appear in the parameter list $c(x_1,\ldots..,x_k)$
- 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 <u>o</u> into $M_{s,f}$
  enter <u>r</u> into $M_{s,f}$
  enter <u>w</u> into $M_{s,f}$
end

command grant_read (s,p,f)
  if <u>o</u> in $M_{s,f}$
  then enter <u>r</u> 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 is a state-transition 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*')
- Hence the access matrix describes the state of the *protection system*
- 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 an 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 $M_{Tom,P1}$ 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
  - Monotonic protections system means deletion of access rights are not allowed once it is entered in the protection system.
  - Biconditional means there is exactly two conditions in the precondition part of the commands.
- decidable for monoconditional monotonic protection systems
  - Monoconditional means there is exactly one condition in the precondition part of the commands.

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 Theoretical Models

- The take-grant model
  (by A. Jones, R. Lipton, and L. Snyder)
- The schematic protection model
  (by R. Sandhu)
- The typed access matrix model
  (by R. Sandhu)

Other Models

- DAC models have been widely investigated in the area of DBMS
- The first DAC model for relational databases has been developed by Griffiths and Wide
- Several extensions to such model have been developed

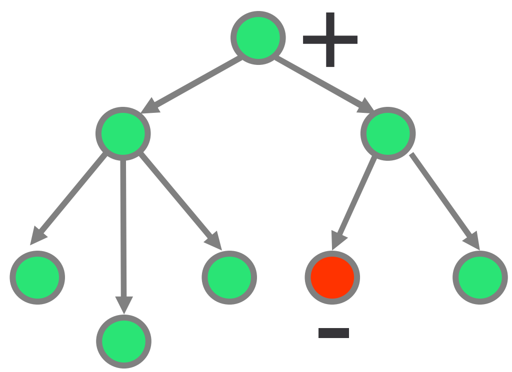
DAC – additional features and recent trends

- Flexibility is enhanced by supporting different kinds of permissions
  - Positive vs. negative
  - Strong vs. weak
  - Implicit vs. explicit
  - Content-based

Positive and Negative Permissions

- Positive permissions → Give access
- Negative permissions → Deny access
- Useful to specify exceptions to a given policy and to enforce stricter control on particular crucial data items

Positive and Negative Permissions



Main Issue: Conflicts

Authorization Conflicts

- Main solutions:
  - No conflicts
  - Negative permissions take precedence
  - Positive permissions take precedence
  - Nothing take precedence
  - Most specific permissions take precedence

Weak and Strong Permissions

- Strong permissions cannot be overwritten
- Weak permissions can be overwritten by strong and weak permissions

Implicit and Explicit Permissions

- Some models support implicit permissions
- Implicit permissions can be derived:
  - by a set of *propagation rules* exploiting the subject, object, and privilege hierarchies
  - by a set of user-defined *derivation rules*

Derivation Rules: Example

- Ann can read file F1 from a table if Bob has an explicit denial for this access
- Tom has on file F2 all the permissions that Bob has
- Derivation rules are a way to concisely express a set of security requirements

Derivation Rules

- Derivation rules are often expressed according to logic programming
- Several research efforts have been carried out to compare the expressive power of such languages
- We need languages based on SQL and/or XML

Content-based Permissions

- Content-based access control conditions the access to a given object based on its content
- This type of permissions are mainly relevant for database systems
- As an example, in a RDBMS supporting content-based access control it is possible to authorize a subject to access information only of those employees whose salary is not greater than 30K

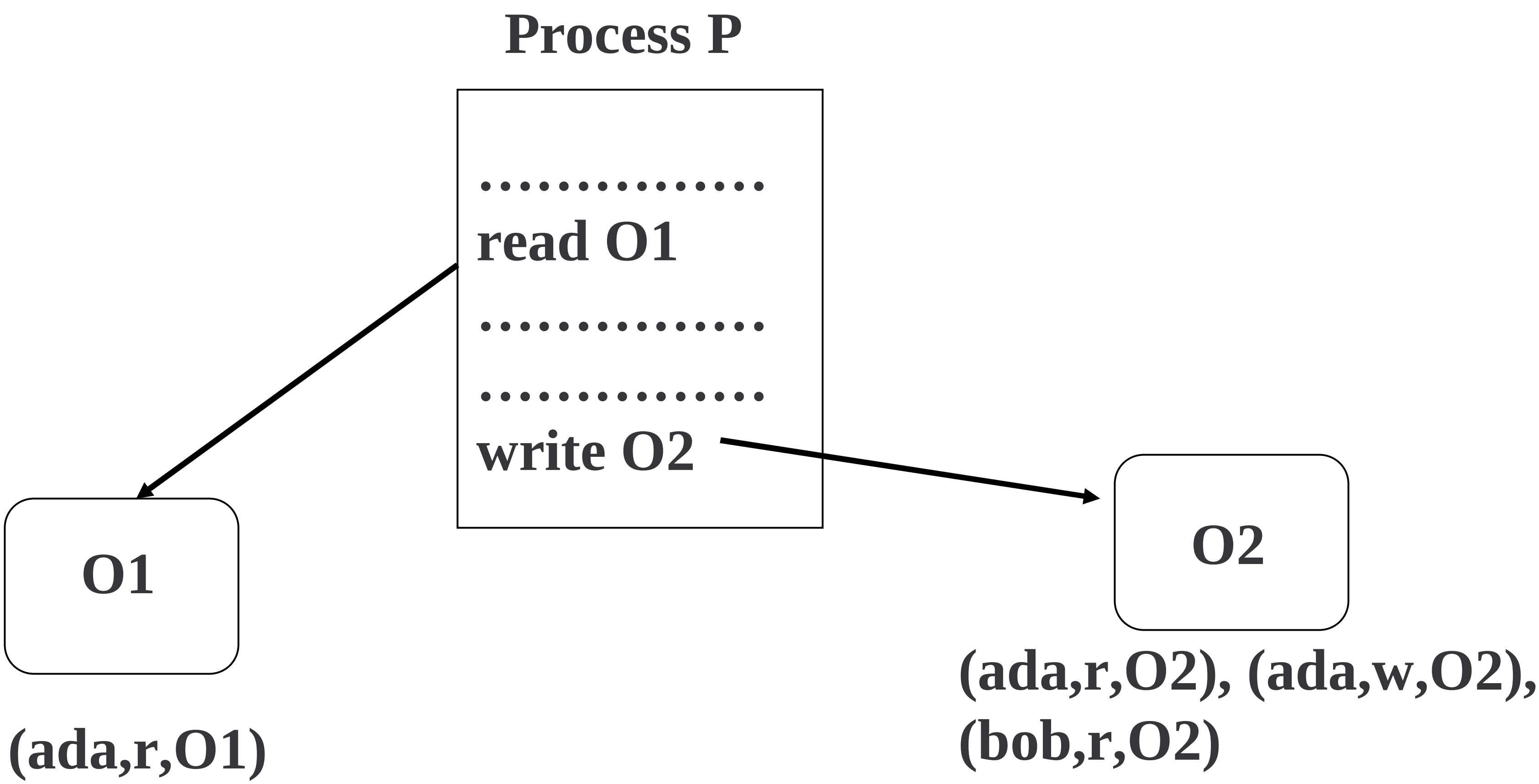
Content-based Permissions

- Two are the most common approaches to enforce content-based access control in a DBMS:
  - by associating a predicate (or a Boolean combination of predicates) with the permission
  - by defining a *view* which selects the objects whose content satisfies a given condition, and then granting the permission on the view instead of on the basic objects

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

- 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}

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 $SC_i \subset SC_k$, 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 = write

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

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

An Example of Application
The DG/Unix B2 System

- B2 is an evaluation class for secure systems defined as part of the Trusted Computer System Evaluation Criteria (TCSEC), known also as the Orange Book
- DG/Unix Provides mandatory access controls
  - MAC label identifies security level
  - Default labels, but can define others
- Initially
  - Processes (users) assigned MAC label of parent
    - Initial label assigned to user, kept in Authorization and Authentication database
  - Object assigned label at creation
    - Explicit labels stored as part of attributes
    - Implicit labels determined from parent directory

Directory Problem

- Process *p* at access class MAC_A tries to create file */tmp/x*
- */tmp/x* exists but has access class MAC_B
  - Assume MAC_B $\geq$ MAC_A (MAC_B dominates MAC_A)
- Create fails
  - Now *p* knows a file named *x* with a higher label exists
- Fix: only programs with same MAC label as directory can create files in the directory
  - This solution is too restrictive

Multilevel Directory

- Directory with a set of subdirectories, one per label
  - Not normally visible to user
  - *p* creating */tmp/x* actually creates */tmp/d/x* where *d* is directory corresponding to MAC_A
  - All *p*'s references to */tmp* go to */tmp/d*
- The directory problem illustrates an important point:

  Sometimes it is not sufficient to hide the contents of objects. Also their existence must be hidden.

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 (see the textbook for more discussions on this)