

Models and analysis of security protocols

1st Semester 2009-2010

Acces Control

Lecture 10

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Last Time (I)

Lecture

- ▶ Tools

Outline of Today

Motivations

DAC

MAC

Side Channel

Access Control Matrix Model

RBAC

Conclusion

Outline

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Example: Security policy for university computing

- ▶ A student has full access to information that she created.
- ▶ Students have no access to other students' information unless explicitly given.
- ▶ Students may access and execute a pre-defined selection of files and/or applications. ...

Describes **access restrictions** between **subjects** and **objects**.

example: Security policy for e-banking

- ▶ A bank customer may list his account balances and recent transactions.
- ▶ He may transfer funds from his accounts provided his total overdrafts are under 10,000 Euros.
- ▶ Transfers resulting in larger overdrafts must be approved by his account manager. ...

Describes **restrictions on objects representing data and processes.**

Questions

- ▶ How do we **formalize** such **policies**?
- ▶ What **mechanisms** can we use to **enforce** them?
- ▶ Can we generalize and abstract?
 - ▶ Rather than studying **individual** policies and mechanisms, can we define and study **general classes** of them which abstract away from concrete characteristics of specific domains?
 - ▶ These classes are called **security models**.
- ▶ **Scope limitations**: We will not handle security engineering aspects like requirements analysis, policy refinement, etc.

Identity and AAA

Identification: The process of associating an identity with a subject.

Authentication: The process of verifying the validity of something claimed by a system entity (default assumption: the identity).

Authorization: An authorization is a right or a permission that is granted to a system entity to access a system resource.

Access Control: Protection of system resources against unauthorized access; a process by which use of system resources is regulated according to a security policy and is permitted by only authorized entities (users, programs, processes, or other systems) according to that policy.

Concepts independent.

Exercice

- Give examples of Authentication without Identification.
- Give examples of Authorization without Authentication.

Authorization and Access Control

- ▶ Typical access control models focus on authorization, i.e., specifying who may do what, and controlling how these permissions may change.
- ▶ Authorization specified using matrices, lattices, or other mathematical structures, which specify which rights subjects have on objects.
 - ▶ Simplest case amounts to a mathematical relation $S \times O \times R$.
 - ▶ Structure constitutes state. Changes constitute transitions between states.
 - ▶ Setup quite complex in practice. Access rights may depend on the environment and even entail obligations for the future
- ▶ Access control also is concerned with enforcement mechanisms.

Two main models: MAC & DAC

Mandatory Access Control

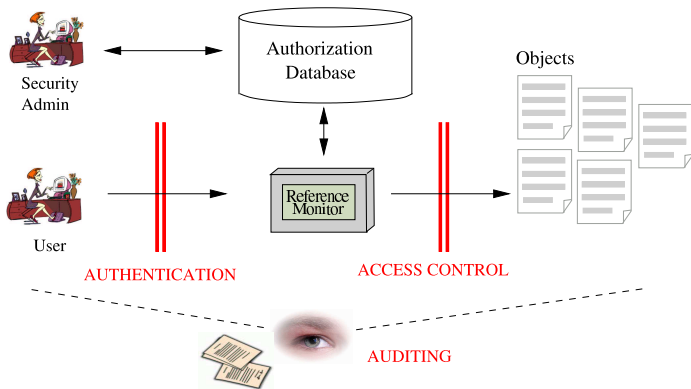
- ▶ Principle: system owner control users access to the resources.
- ▶ **Mandatory** because subjects may not transfer their access rights.
- ▶ Example: Military Top Secret information.

Discretionary Access Control

- ▶ Principle: users own resources and control their access.
- ▶ **Discretionary** because subjects may transfer their access rights.
- ▶ Example: Unix file system

MAC is more rigid than DAC, but also more secure.

Example of AAA via centralized reference monitor (Mandatory Access Control)



System designed so that access requests pass through a gatekeeper.
Other components include those for setup, auditing, and recovery.

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Discretionary Access Control

- ▶ Principle: users own resources and control their access.
 - ▶ **Owner** may change object's permissions at his **discretion**.
 - ▶ This allows direct or even transitive delegation of rights.
 - ▶ Owners may even be able to transfer ownership to other users.
- ▶ Flexible, but open to mistakes, negligence, or abuse.
 - ▶ Requires that all users understand mechanisms and understand and respect the security policy.
 - ▶ No control of information dissemination.

DAC example: Unix

- ▶ Subjects are users (plus **root**) and objects are files and directories.
- ▶ Each file has an owner and a group.
- ▶ Operations are: read (r), write (w), execute (x).
For directories, r = “list” and x = “usable in constructing paths”.
- ▶ ACLs typically limited to 9 bits: rwx for user, group, and others.

```
-rw-r--r-- 1 plafourc users 4158 2007-11-09 12:37 Intro.tex  
drwxr-xr-x 5 plafourc users 4096 2007-11-02 14:07 Tools/
```

- ▶ Discretionary AC: only file's owner (and **root**) can change its ACL.
This allows direct delegation of rights (rwx) to group or others.
- ▶ Open to abuse and source of many security holes.
- ▶ Not all policies can be directly mapped onto this mechanism.
How would we express that a patient can read but not write his medical records at a hospital?

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How would we express that a patient can read but not write his medical records at a hospital? Who owns the records?

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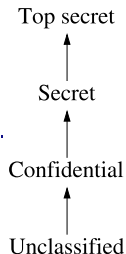
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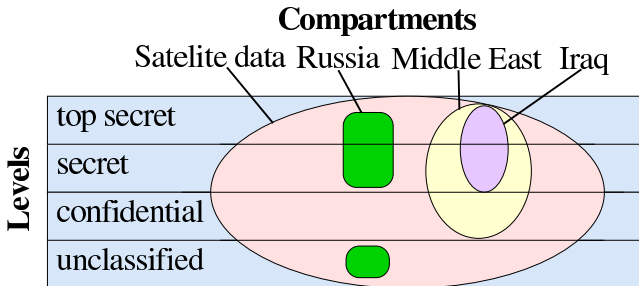
Conclusion

Mandatory Access Control

- ▶ AC decisions formalized (and controlled) by comparing security labels indicating sensitivity/criticality of **objects**, with formal authorization, i.e. security clearances, of **subjects**.
MAC policies often identified with multilevel security policies.
- ▶ Specifies system-wide access restriction to objects.
 - ▶ **Mandatory** because subjects may not transfer their access rights.
 - ▶ Shifts power from users to system owner.
- ▶ Required by US DOD for developing “trusted systems”.
- ▶ More rigid than DAC, but also more secure.

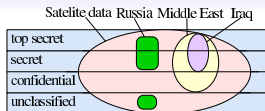


Labels



- ▶ Formalism (+ terminology) comes from US DOD “Orange Book”.
- ▶ Formalism combines
 - ▶ a **linearly ordered** ranks or sensitivity levels, and
 - ▶ a **lattice** of compartments.

Labels (cont.)



- Historically labels combine classifications on personal and data.

$$\text{Class} = \langle \text{rank}, \text{compartment} \rangle$$

- Dominance relation defined component-wise.

$$(r_1, c_1) \leq (r_2, c_2) :\Leftrightarrow r_1 \leq r_2 \wedge c_1 \subseteq c_2$$

Example: $(\text{secret}, \text{Iraq}) \leq (\text{top secret}, \text{Middle East})$

- Authorization** based on comparing labels. For example, a subject with top secret clearance for the Middle East may access (**read**) confidential data on Iraq.
- Well-suited for implementing mandatory **need-to-know** policies, where each subject is assigned a label reflecting **least privilege** required for his function.

Why lattices?

Def: a **lattice** (L, \leq) consists of a set of L and a partial ordering \leq , so that for every 2 elements $a, b \in L$ there exists a **least upper bound** $u \in L$ and a **greatest lower bound** $l \in L$, i.e.

$$\begin{array}{ll} a \leq u, b \leq u & \text{and } (a \leq v \ \& \ b \leq v) \rightarrow (u \leq v) \text{ for all } v \in L \\ l \leq a, l \leq b & \text{and } (k \leq a \ \& \ k \leq b) \rightarrow (k \leq l) \text{ for all } k \in L \end{array}$$

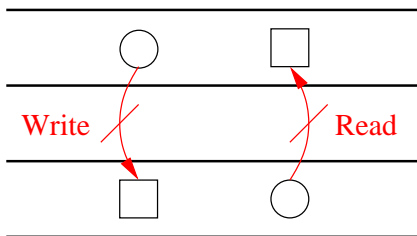
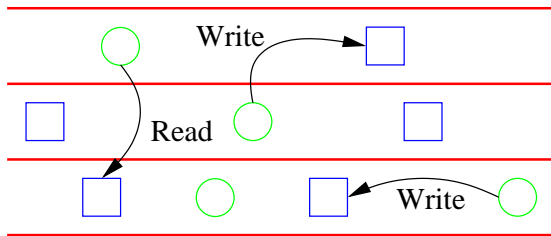
If security labels form a lattice, we can uniquely answer questions like:

- ▶ Given two objects with different labels, what is the minimal label a subject requires to be allowed to read both objects?
- ▶ Given two subjects with different labels, what is the maximal label an object can have that can still be read by both subjects?

The Bell-LaPadula (BLP) Model (1975)

- ▶ Models security policies for **confidentiality**.
Concerns authorization for subjects **reading** and **writing** objects.
 - ▶ Combines state-transition systems with partial-orders on labels.
 - ▶ Access decisions satisfy following properties:
 - No Read-Up (also called **Simple Security Property**).
A subject with label x_s can only read information in an object with label x_o if x_s dominates x_o .
 - No Write-Down (also called ***-Property**).
A subject with label x_s can only write information to an object with security label x_o if x_o dominates x_s .
- ⇒ You may only read below your classification and write above it.

BLP — (dis)allowed operations



BLP (cont.)

- ▶ MAC: labels cannot be changed. No information leakage possible!
No-read-up and no-write-down prevent untrusted subjects from simultaneously having read access to information at one level and write access to information at a lower level.
- ▶ But also prevents “legitimate” communication from high-level subjects to low-level ones. Possible solutions:

BLP (cont.)

- ▶ MAC: labels cannot be changed. No information leakage possible!
No-read-up and no-write-down prevent untrusted subjects from simultaneously having read access to information at one level and write access to information at a lower level.
- ▶ But also prevents “legitimate” communication from high-level subjects to low-level ones. Possible solutions:
 - ▶ Temporarily downgrade the subject’s security level.
 - ▶ Identify a set of **trusted subjects** that may violate the *-property.
- ▶ Mechanism support provided by some systems, e.g., BLP module for NSA’s SELinux.

Biba Integrity Model (1977)

- ▶ Dual to BLP
 - No Write-up: The writer's label must dominate the object's.
 - No Read-down: The object's label must dominate the reader's.
 - ⇒ you may only write below your classification and read above it.
- ▶ Examples:
 - ▶ A manager can overwrite subordinate's data.
 - ▶ A monk may write a prayer book read by commoners, but not by a high-priest (whose purer thoughts should not be soiled).
- ▶ But what if you want both confidentiality and integrity?
 - ▶ Use BLP for classifying some data, and Biba for others.
 - ▶ Alternatively, only read and write at same classification.

Limitations of Access Control Models

- ▶ AC models restrict operations like read and write. But information may be revealed in other ways.
- ▶ Examples of information leaks.
 - ▶ Error messages to user, e.g., “file not found”.
 - ▶ CPU usage: timing behavior, power consumption, noise, ...
 - ▶ Locking and unlocking files.
 - ▶ Sending and delaying messages.
 - ▶ Encode information in the invoice sent for services rendered.

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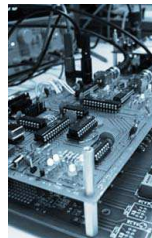
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Different Kind of Side Channel



How to determine a secret or a key by observing:

- ▶ Time : it is linked to the secret
- ▶ Power Analysis Attack: mesure the power used by the cryptosystem
- ▶ SPA (Simple), DPA (differential)
- ▶ Cache Attack: analysing the cache default can leak information
- ▶ FaultAttack: attack by injecting some faults
- ▶ Electromagnetic attack ...

First paper

Timing Attacks on Implementations of Diffie–Hellman, RSA, DSS,
and Other System... Paul Kocher - CRYPTO - 1996

Naive Example Side Channel

- ▶ Access Control with 10 digit (0..9)
- ▶ Code composed of 4 digits
- ▶ At each mistake a red light is turn on, otherwise it is the green one

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With at most 40 tries we can deduce the secret code.

Timing attack on Pin Code

For an 8 bytes pin code, we have $(2^8)^8 = 256^8$ possibilities for Brute Force attack.

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Program

```
for ( i = 0 ; i <= 7; i++)  
    if ( pinCarte[i] != pinPresente[i] ) return false;  
return true ;
```

- ▶ Present $n : 0, \dots, 256$ for the first byte $(n, 0, 0, 0, 0, 0, 0, 0)$
- ▶ Measure the execution time, the maximum give the first part of the key.
- ▶ Repeat it

We have only $8 * 256 = 2048$ possibilities.

Timing attack on Pin Code: Correction

Program

```
boolean test = true ;  
for ( i = 0 ; i <= 7; i++)  
    test = test && ( pinCarte[i] == pinPresente[i]);  
return test ;
```

Acoustic cryptanalysis I

In his book *Spycatcher*, former MI5 operative Peter Wright discusses use of an acoustic attack against Egyptian Hagelin cipher machines in 1956. The attack was codenamed "ENGULF".

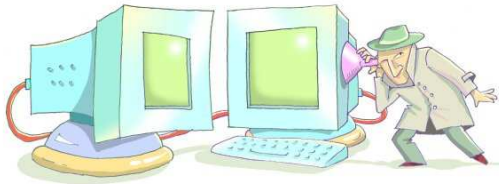


HAGELIN M-209 CIPHER MACHINE (GVG / PD)



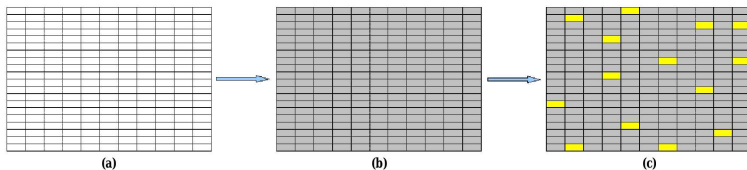
Acoustic cryptanalysis II

In 2004, Dmitri Asonov and Rakesh Agrawal of the IBM Almaden Research Center announced that computer keyboards and keypads are vulnerable to attacks based on differentiating the sound produced by different keys.



Cache Miss Attack Principle

For a text p and a key k , we will put data in the cache, encrypt p with k and look if our data are still in the cache or not.



1st round of Optimized AES

The system (E) shows us the equations of the first round :

$$(E) = \begin{cases} (x_0^{(1)}, x_1^{(1)}, x_2^{(1)}, x_3^{(1)}) \leftarrow T_0[x_0^{(0)}] \oplus T_1[x_5^{(0)}] \oplus T_2[x_{10}^{(0)}] \oplus T_3[x_{15}^{(0)}] \oplus K_0^{(1)}, \\ (x_4^{(1)}, x_5^{(1)}, x_6^{(1)}, x_7^{(1)}) \leftarrow T_0[x_4^{(0)}] \oplus T_1[x_9^{(0)}] \oplus T_2[x_{14}^{(0)}] \oplus T_3[x_3^{(0)}] \oplus K_1^{(1)}, \\ (x_8^{(1)}, x_9^{(1)}, x_{10}^{(1)}, x_{11}^{(1)}) \leftarrow T_0[x_8^{(0)}] \oplus T_1[x_{13}^{(0)}] \oplus T_2[x_2^{(0)}] \oplus T_3[x_7^{(0)}] \oplus K_2^{(1)}, \\ (x_{12}^{(1)}, x_{13}^{(1)}, x_{14}^{(1)}, x_{15}^{(1)}) \leftarrow T_0[x_{12}^{(0)}] \oplus T_1[x_1^{(0)}] \oplus T_2[x_6^{(0)}] \oplus T_3[x_{11}^{(0)}] \oplus K_3^{(1)}. \end{cases}$$

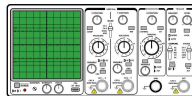
The initial intermediate state $x^{(0)}$ is calculated according to the key k and the plain text p :

$$\forall i \in [0, 15], x_i^{(0)} = p_i \oplus k_i$$

Countermeasures

- ▶ Avoiding or deactivating the cache.
- ▶ hardware implementations
- ▶ AES standard algorithm:
You can modify the encryption software to make it use the AES standard algorithm which does not look up the tables. Thus our attack does not work. However the standard algorithm is less powerful than the optimized algorithm, which we are attacking, on computers 32 bits or much.
- ▶ Playing with the look up tables:
You can play with the look up tables. For that you can put randomly the tables in memory, put each tables more than one time in memory or you can cache all the 4 tables before (or after) each encryption. By that our attack can't work any more but the encryption process is slower.

Setup for Power Analysis Attack

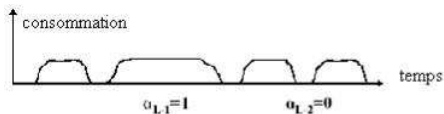
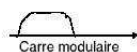
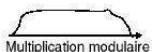


Simple Power Attack on RSA Signature

Signature si $y^a \bmod n$, where y is the message, n public and is the secret key.

Program

```
s = 1 ;
for ( i = L-1 ; i >= 0; i --) {
    s = s*s mod n ;
    if ( a [ i ] == 1)
        s = s*y mod n ;
}
```



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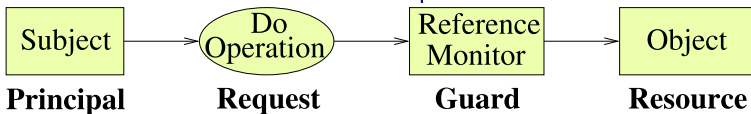
- ▶ Simple framework for describing a protection system by describing the **privileges** of **subjects** on **objects**.

Subjects: users, processes, agents, groups, ...

Objects: data, memory banks, other processes, ...

Privileges (or permissions/rights): read, write, modify, ...

- ▶ A **reference monitor** decides on requests.



- ▶ Constitutes a model and, when implemented, a mechanism.

Protection state

- ▶ A **protection state** (relative to a set of **privileges** P) is a triple (S, O, M) .
 - ▶ A set of current subjects S .
 - ▶ A set of current objects O .
 - ▶ A matrix M defining the privileges for each $(s, o) \in S \times O$, i.e., a relation $S \times O \times P$ or equivalently a function $S \times O \rightarrow \mathcal{P}(P)$.
- ▶ Example

Objects

		File 1	File 2	File 3	File 4	Account 1	Account 2
Subjects	Alice	Own R W		W X		Inquiry Credit▶ Privileges (rights)
	Bob	R	Own R W	W	R	Inquiry Debit	Inquiry Credit
	Charlie	R W	R		Own R X		Inquiry Debit

Transitions

- ▶ **State transitions** are modeled by a set of **commands**.
- ▶ **Commands** expressed in terms of 6 **primitive operations**.
 1. **enter** p **into** $M(s, o)$ (for $p \in P$)
 2. **delete** p **from** $M(s, o)$ (for $p \in P$)
 3. **create** subject s
 4. **destroy** subject s
 5. **create** object o
 6. **destroy** object o
- ▶ Operation semantics as expected, e.g., **enter** p **into** $M(s, o)$.
Precondition: $s \in S$ and $o \in O$
New state: $S' = S$, $O' = O$, $M'(s, o) = M(s, o) \cup \{p\}$,
and $M'(s_i, o_i) = M(s_i, o_i)$, for $(s'_i, o'_i) \neq (s, o)$

Examples of commands

- ▶ Consider a system where users own files and can delegate permissions directly (e.g., *ConferRead*) or transitively (e.g., *DelegateRead*) for reading and writing them.
- ▶ Privileges: ownership (**own**), read (**R**), and write (**W**).
- ▶ Commands might include:

```
command CreateFile(s, f)  
  create object f  
  enter Own into M(s, f)  
  enter R into M(s, f)  
  enter W into M(s, f)  
end
```

Transition system semantics

- Write $(S, O, M) \vdash_c (S', O', M')$ to denote a transition associated with the command c . For example:



- A starting state $st_0 = (S_0, O_0, M_0)$ and a set of commands C determines a **state-transition system**.
- So a model describes a set of system traces, namely those traces

$$st_0, st_1, st_2, st_3, \dots$$

where $st_i \vdash_{c_i} st_{i+1}$, for $c_i \in C$.

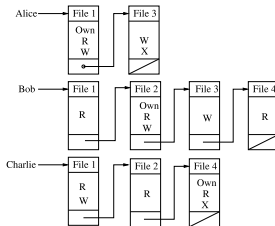
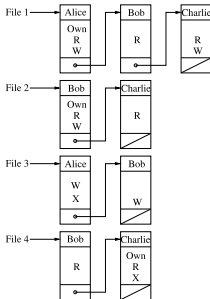
Access matrix: data structures

Matrices define access rights and provide a basis for different possible enforcement mechanism.

Access Matrix AC List (ACL)

Capabilities List

	File 1	File 2	File 3	File 4	Account 1	Account 2
Alice	Own R W		W X		Inquiry Credit	
Bob	R	Own R W	W	R	Inquiry Debit	Inquiry Credit
Charlie	R W	R		Own R X		Inquiry Debit

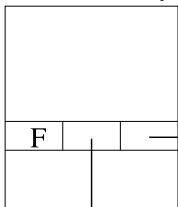


Represent as 2 dimensional objects or set of 1-dimensional objects.

Access-control (authorization) list

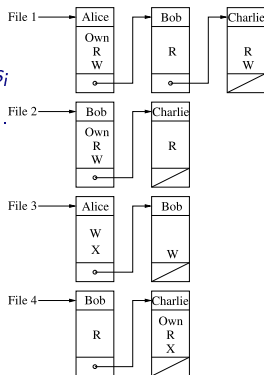
- ▶ **ACL**: use lists to express view of each object o :
 i th entry in the list gives the name of a subject s_i
 and the rights r_i in $M(s_i, o)$ of the access-matrix.
- ▶ Standard example: AC for files.

File Directory



ACL for F

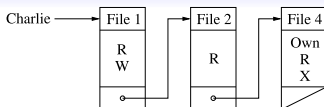
User ID	Rights
Alice	Own, RW
Bob	RW
Charlie	R
John	R



Access-control lists (cont.)

- ▶ Implementation:
 - ▶ Associate ACL with each object, typically maintained by OS, middleware, server, ...
 - ▶ Check user (group, ...) against list.
 - ▶ Relies on authentication: need to know user.
- ▶ Usually used for **discretionary access control**.
Owners have the (usually sole) authority to grant or revoke rights to the objects they own to other users.
- ▶ ACLs are found, for example in the DEC VMS operating system, Linux, and Windows NT.

Capability list



- ▶ Subject view of AC matrix.

A **capability** is essentially a pair: an object and an operation.

- ▶ Users should not be able to forge capabilities.

Centralized systems:

OS manages capabilities in protected address space.

Distributed systems:

- ▶ Pair protected using cryptography, e.g., signatures.
 - ▶ Reference monitor checks ticket.
 - ▶ Need not know identity of user or process (at least if transitive delegation is allowed).
- ▶ Capabilities not often used, but gaining popularity in distributed (e.g., mobile agent) setting.

ACLs versus capabilities

ACLs

	File 1	File 2	File 3	File 4	Account 1	Account 2
Alice	Own R W		W X		Inquiry Credit	
Bob	R	Own R W	W	R	Inquiry Debit	Inquiry Credit
Charlie	R W	R		Own R X		Inquiry Debit

- ▶ ACLs are compact and easy to review.
- ▶ Deleting an object is simple.
- ▶ Deleting a subject more difficult.
- ▶ Delegation possible in **discretionary access control** setting: Owners have the (usually sole) authority to grant or revoke rights to the objects they own to other users.

Capabilities (in particular, when distributed)

- ▶ Not so compatible with object-oriented view of the world.
- ▶ Delegation easy, revocation difficult.
- ▶ In general, difficult to know who has permissions on an object.

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Scalable security policies

- ▶ How do we formalize a policy when there are $10^3 - 10^6$ subjects and objects? An example?

Scalable security policies

- ▶ How do we formalize a policy when there are $10^3 - 10^6$ subjects and objects? An example? Your typical bank!
 - ▶ AC matrices (whether ACLs or CLs) scale poorly.
 - ▶ They are difficult (or impossible) to maintain.
- ▶ Overcome using standard tricks: abstraction and hierarchy.
 - Abstraction: Many subjects (or objects) have identical attributes, and policy is based on these attributes.
 - Hierarchy: Often functional/organizational hierarchies that determine access rights.

First, a slight reformulation to set the stage for Role-Based Access Control

- ▶ Recall AC-Matrix: M defines a relation $S \times O \times P$, where P is a privilege like “read” or “write”.
- ▶ We now recast matrix M as relation, $M \subseteq \text{Users} \times \text{Permissions}$
- ▶ A **permission** represents authorization to perform an operation on an object.
In matrix-model terminology: a pair $(\text{object}, \text{privilege}) \in O \times P$.
- ▶ **Declarative access control**: authorization specified by a relation.
A user is granted access iff he has the required permission.
$$u \in \text{Users} \text{ has } p \in \text{Permissions} : \iff (u, p) \in \text{AC}.$$

Access Control — A Simple Example

User
Alice
Bob
John

User	Permission
Alice	read file a
Alice	write file a
Alice	start application x
Alice	start application y
Bob	read file a
Bob	write file a
Bob	start application x
John	read file a
John	write file a
John	start application x

Permission
read file a
write file a
start application x
start application y

Role-Based Access Control

- ▶ **Role-Based Access Control** decouples users and permissions by introducing **roles**.
- ▶ Formalized by a set Roles and the relations $UA \subseteq \text{Users} \times \text{Roles}$ and $PA \subseteq \text{Roles} \times \text{Permissions}$, where

$$AC := PA \circ UA$$

$$AC := \{(u, p) \in \text{Users} \times \text{Permissions} \mid \exists r \in \text{Roles} : (u, r) \in UA \wedge (r, p) \in PA\} .$$

- ▶ **Example:**

User	Role
Alice	User
Alice	Superuser
Bob	User
John	User

Role
User
Superuser

Role	Permission
User	read file a
User	write file a
User	start application x
Superuser	start application y

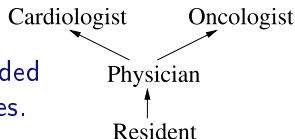
RBAC — advantages over matrix

- ▶ Roles are abstraction of jobs or functions in an organization.
 - ▶ Distinct from notion of **user groups**, which names collections of users.
 - ▶ Emphasis is on **responsibility** and associated **permissions**.
- ▶ Increases abstraction in policies. Policies become more manageable.
- ▶ Less information must usually be maintained when number of roles is small (relative to number of users and permissions).

$$|PA| + |UA| \leq |AC|$$

RBAC — Extensions

1. Factorization idea can be further extended by introducing a partial order \geq on roles.



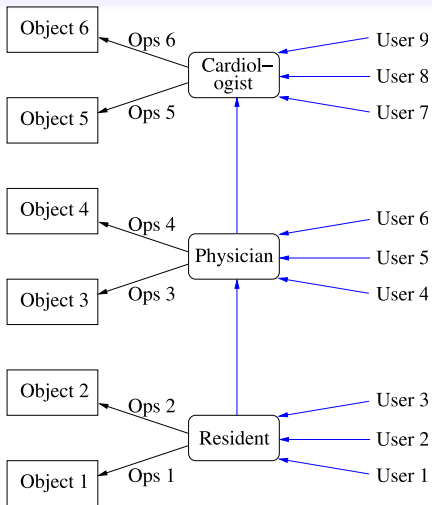
$$AC := PA \circ \geq \circ UA$$

Semantics: larger roles inherit permissions from all smaller roles.

E.g., $\text{Cardiologist} \geq \text{Physician}$, so cardiologists have physicians' rights.

2. Hierarchies on users (UA) and permissions (PA) also possible.
3. RBAC standard introduces additional extensions.
E.g., introduces notion of sessions, representing users' active roles.

An example



E.g., User 9 can carry out operation 2.

Outline

Motivations

DAC

MAC

Side Channel

Access Control Matrix Model

RBAC

Conclusion

Summary

Today

- ▶ Access Control
- ▶ Matrix Model
- ▶ MAC
- ▶ DAC
- ▶ Side Channel Attacks

Next Time

- ▶ Non Interference
- ▶ Secret Sharing
- ▶ Funny introduction to Zero Knowledge.

Thank you for your attention



Questions ?