Chapter 9:

Database Security: An Introduction

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Outline

- Introduction to Database Security Issues
  - Types of Security
  - Threats to databases
  - Database Security and DBA
  - Access Protection, User Accounts, and Database Audits
- Discretionary Access Control
  - Types of Discretionary Privileges
  - Specifying Privileges Using Views
  - Revoking Privileges
  - Propagation of Privileges Using the GRANT OPTION
  - An example
  - Weakness
- Mandatory Access Control
  - Bell-LaPudula Model
  - Comparing DAC and MAC
- RBAC (Role-Based Access Control)
- Encryption & PKI (Public Key Infrastructure)

Introduction to Database Security Issues

- Types of Security
  - Legal and ethical issues
  - Policy issues
  - System-related issues
  - The need to identify multiple security levels

Three Basic Concepts

- Authentication: a mechanism that determines whether a user is who he or she claims to be
- Authorization: the granting of a right or privilege, which enables a subject to legitimately have access to a system or a system's objects
- Access Control: a security mechanism (of a DBMS) for restricting access to a system's objects (the database) as a whole

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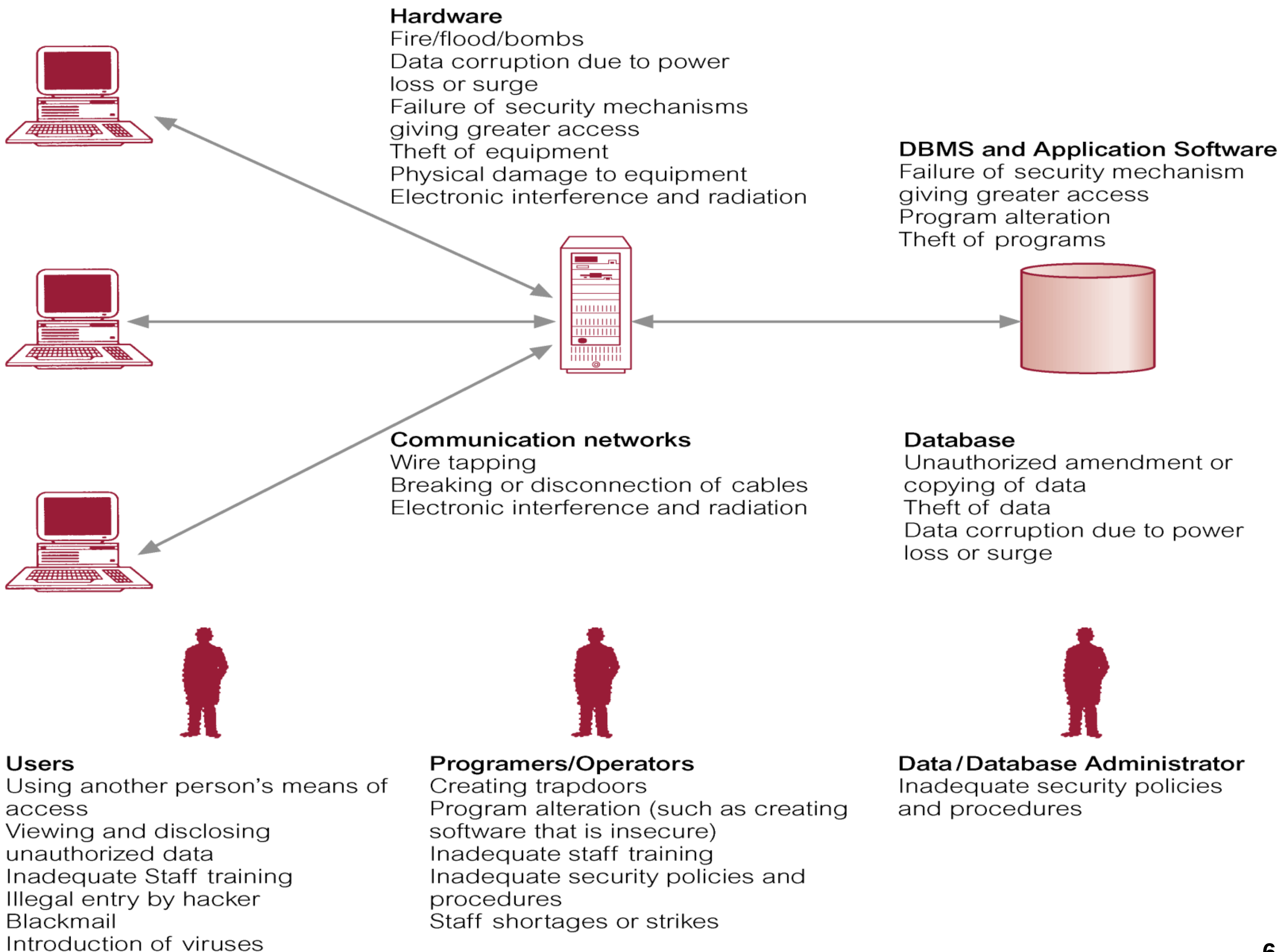
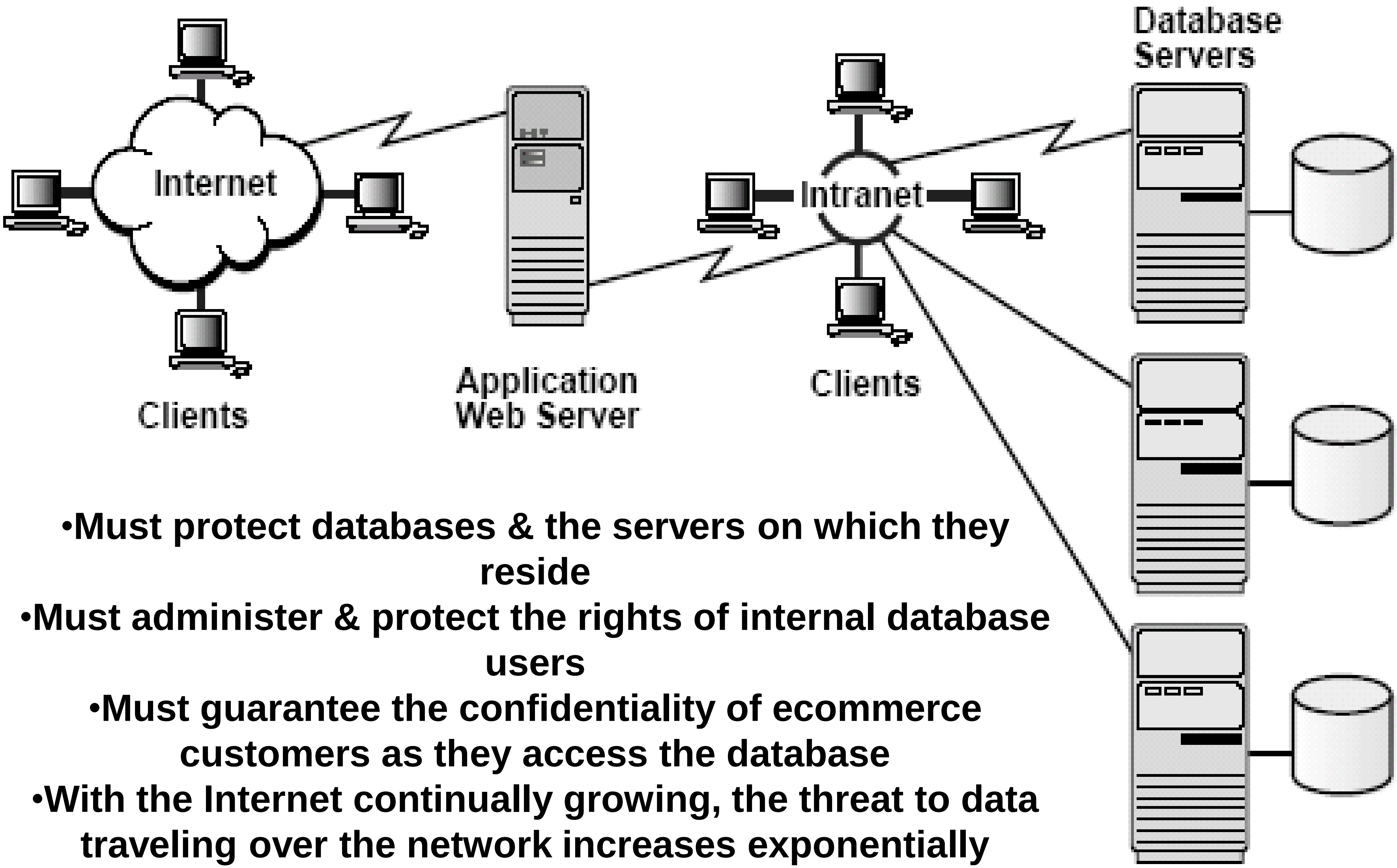
Introduction to Database Security Issue(2)

- Threats
  - Any situation or event, whether intentional or unintentional, that will adversely affect a system and consequently an organization
  - Threats to:
    - Computer systems
    - Databases

Threats to Computer Systems



Scope of Data Security Needs



- Must protect databases & the servers on which they reside
- Must administer & protect the rights of internal database users
- Must guarantee the confidentiality of ecommerce customers as they access the database
- With the Internet continually growing, the threat to data traveling over the network increases exponentially

Introduction to Database Security Issues (3)

- Threats to databases
  - Loss of **integrity**
  - Loss of **availability**
  - Loss of **confidentiality**

- To protect databases against these types of threats four kinds of countermeasures can be implemented:
  - **Access control**
  - **Inference control**
  - **Flow control**
  - **Encryption**

Introduction to Database Security Issues (4)

- A DBMS typically includes a database security and authorization subsystem that is responsible for ensuring the security portions of a database against unauthorized access.

- Two types of database security mechanisms:
  - **Discretionary** security mechanisms
  - **Mandatory** security mechanisms

Introduction to Database Security Issues 5)

- The security mechanism of a DBMS must include provisions for restricting access to the database as a whole
  - This function is called **access control** and is handled by creating user accounts and passwords to control login process by the DBMS.

Introduction to Database Security Issues (6)

- The security problem associated with databases is that of controlling the access to a **statistical database**, which is used to provide statistical information or summaries of values based on various criteria.

  - The countermeasures to **statistical database security** problem is called **inference control measures**.

Introduction to Database Security Issues (7)

- Another security is that of **flow control**, which prevents information from flowing in such a way that it reaches unauthorized users.

- Channels that are pathways for information to flow implicitly in ways that violate the security policy of an organization are called **covert channels**.

Introduction to Database Security Issues (8)

- A final security issue is **data encryption**, which is used to protect sensitive data (such as credit card numbers) that is being transmitted via some type communication network.
- The data is **encoded** using some **encoding algorithm**.
  - An unauthorized user who access encoded data will have difficulty deciphering it, but authorized users are given decoding or decrypting algorithms (or keys) to decipher data.

Database Security and the DBA

- The database administrator (**DBA**) is the central authority for managing a database system.
  - The DBA's responsibilities include
    - granting privileges to users who need to use the system
    - classifying users and data in accordance with the policy of the organization
- The DBA is responsible for the overall security of the database system.

Database Security and the DBA (2)

- The DBA has a DBA account in the DBMS
  - Sometimes these are called a system or superuser account
  - These accounts provide powerful capabilities such as:
    - 1. Account creation
    - 2. Privilege granting
    - 3. Privilege revocation
    - 4. Security level assignment
  - Action 1 is access control, whereas 2 and 3 are discretionarym and 4 is used to control mandatory authorization

Access Protection, User Accounts, and Database Audits

- Whenever a person or group of person s need to access a database system, the individual or group must first apply for a user account.
  - The DBA will then create a new **account id** and **password** for the user if he/she deems there is a legitimate need to access the database
- The user must log in to the DBMS by entering account id and password whenever database access is needed.

Access Protection, User Accounts, and Database Audits(2)

- The database system must also keep **track of all operations** on the database that are applied by a certain user throughout **each login session**.
  - To keep a record of all updates applied to the database and of the particular user who applied each update, we can modify **system log**, which includes an entry for each operation applied to the database that may be required for recovery from a transaction failure or system crash.

Access Protection, User Accounts, and Database Audits(3)

- If any tampering with the database is suspected, a **database audit** is performed
  - A database audit consists of reviewing the log to examine all accesses and operations applied to the database during a certain time period.
- A database log that is used mainly for security purposes is sometimes called an **audit trail**.

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  - Specifying Privileges Using Views
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Discretionary Access Control

- User can protect what they own.
- Owner may grant access to other.
- Owner can define the type of access (read/write/execute/…) given to others.

- The typical method of enforcing **discretionary access control** in a database system is based on the **granting** and **revoking privileges**.

Types of Discretionary Privileges

- The **account level**:
  - At this level, the DBA specifies the particular privileges that each account holds independently of the relations in the database.
- The **relation level** (or **table level**):
  - At this level, the DBA can control the privilege to access each individual relation or view in the database.

Types of Discretionary Privileges(2)

- The privileges at the **account level** apply to the capabilities provided to the account itself and can include
  - the **CREATE SCHEMA** or **CREATE TABLE** privilege, to create a schema or base relation;
  - the **CREATE VIEW** privilege;
  - the **ALTER** privilege, to apply schema changes such adding or removing attributes from relations;
  - the **DROP** privilege, to delete relations or views;
  - the **MODIFY** privilege, to insert, delete, or update tuples;
  - and the **SELECT** privilege, to retrieve information from the database by using a **SELECT** query.

Types of Discretionary Privileges(3)

- The second level of privileges applies to the **relation level**
  - This includes **base relations** and virtual (**view**) relations.
- The granting and revoking of privileges generally follow an authorization model for discretionary privileges known as the access matrix model where
  - The **rows** of a matrix M represents **subjects** (users, accounts, programs)
  - The **columns** represent **objects** (relations, records, columns, views, operations).
  - Each position **M(i,j)** in the matrix represents the types of privileges (read, write, update) that **subject i** holds on **object j**.

Types of Discretionary Privileges(4)

- To control the granting and revoking of relation privileges, for each relation R in a database:
  - The owner of a relation is given **all** privileges on that relation.
  - The owner account holder can **pass** **privileges** on any of the owned relation to other users by **granting** privileges to their accounts.
  - The owner account holder can also **take back** the **privileges** by **revoking** privileges from their accounts.

Types of Discretionary Privileges(5)

- In SQL the following types of privileges can be granted on each individual relation R:
  - **SELECT** (retrieval or read) privilege on R:
    - This gives the account retrieval privilege.
    - The **SELECT** statement is used to retrieve tuples from R.
  - **MODIFY** privileges on R:
    - This gives the account the capability to modify tuples of R.
    - In SQL this privilege is further divided into **UPDATE**, **DELETE**, and **INSERT** privileges to apply the corresponding SQL command to R.
    - In addition, both the **INSERT** and **UPDATE** privileges can specify that only certain attributes can be updated by the account.

Types of Discretionary Privileges(6)

- In SQL the following types of privileges can be granted on each individual relation R (contd.):
  - **REFERENCES** privilege on R:
    - This gives the account the capability to **reference** relation R when specifying integrity constraints.
    - The privilege can also be **restricted** to specific attributes of R.

- Notice that to create a **view**, the account must have **SELECT** privilege on all relations involved in the view definition.

Specifying Privileges Using Views

- The mechanism of **views** is an important discretionary authorization mechanism in its own right. For example,
  - If the owner A of a relation R wants another account B to be able to <u>retrieve only some fields</u> of R, then A can create a view V of R that includes <u>only those attributes</u> and then grant SELECT on V to B.
  - The same applies to limiting B to retrieving <u>only certain tuples of</u> R; a view V' can be created by defining the view by means of a query that selects only those tuples from R that A wants to allow B to access.

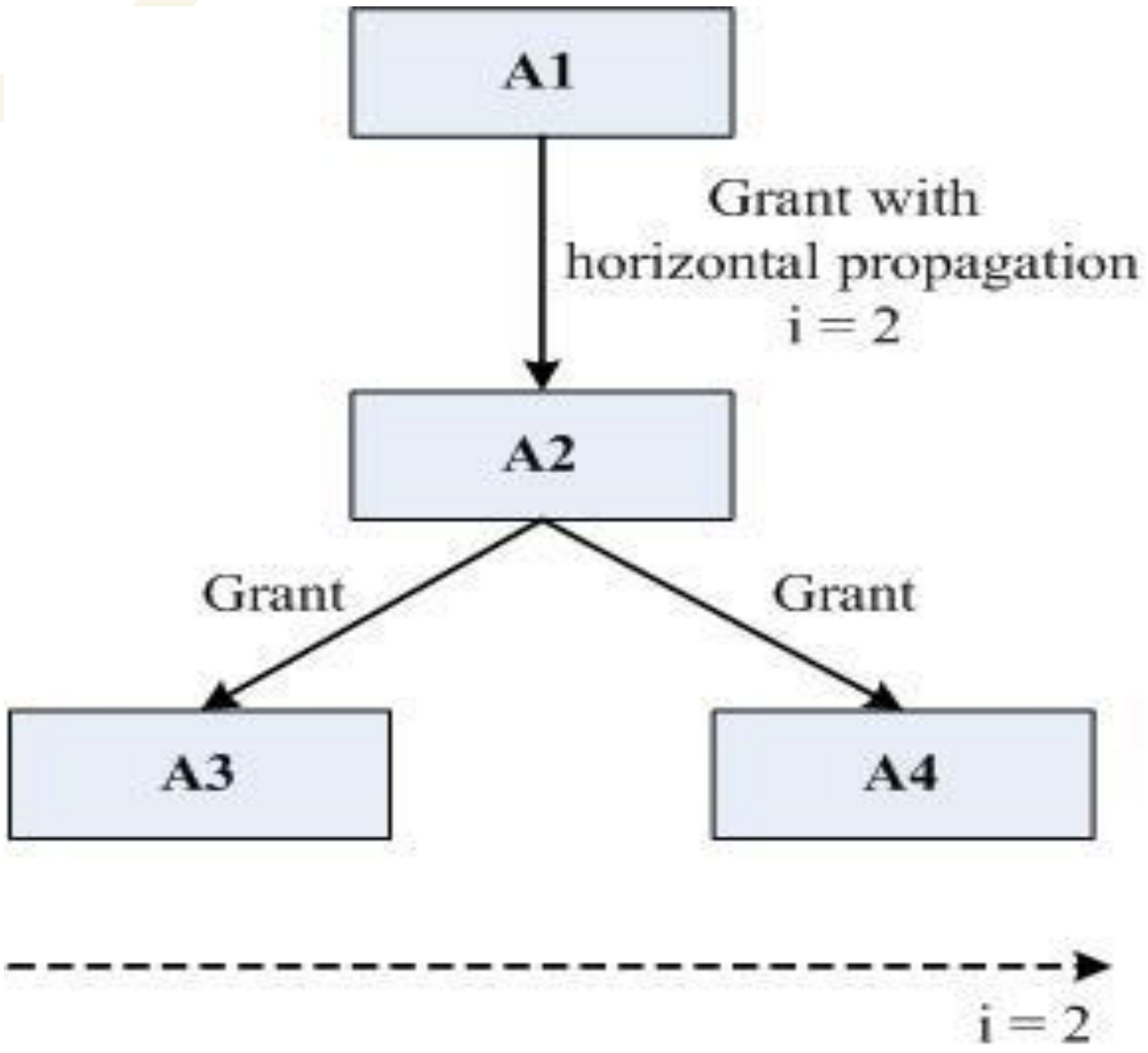
Revoking Privileges

- In some cases it is desirable to grant a privilege to a user temporarily. For example,
  - The owner of a relation may want to grant the **SELECT** privilege to a user for a specific task and then revoke that privilege once the task is completed.
  - Hence, a mechanism for **revoking** privileges is needed. In SQL, a **REVOKE** command is included for the purpose of **canceling privileges**.

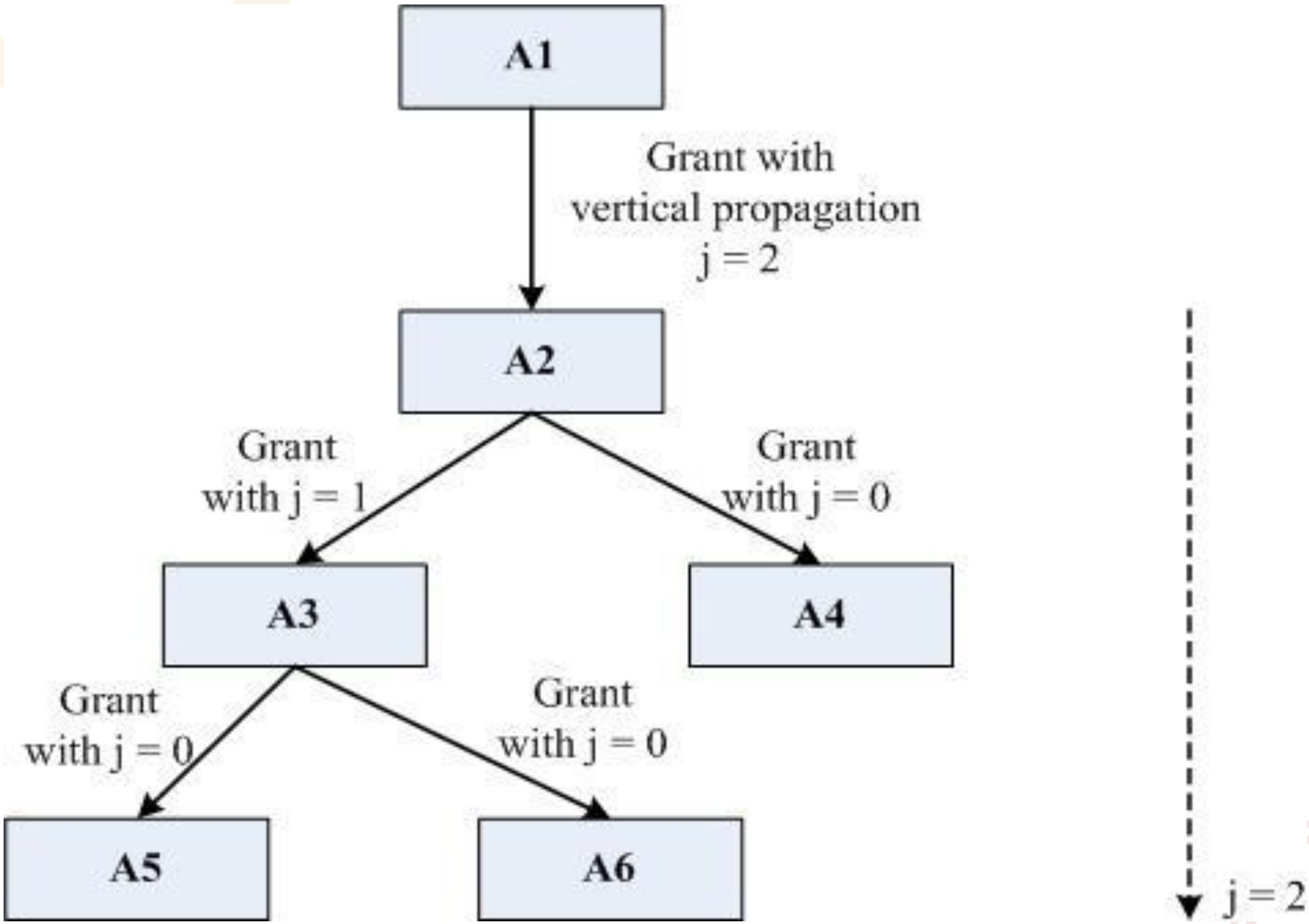
Propagation of Privileges using the GRANT OPTION

- Whenever the owner A of a relation R grants a privilege on R to another account B, privilege can be given to B with or without the **GRANT OPTION**.
- If the **GRANT OPTION** is given, this means that B can also grant that privilege on R to other accounts.
  - Suppose that B is given the **GRANT OPTION** by A and that B then grants the privilege on R to a third account C, also with **GRANT OPTION**. In this way, privileges on R can **propagate** to other accounts without the knowledge of the owner of R.
  - If the owner account A now revokes the privilege granted to B, all the privileges that B propagated based on that privilege should automatically be revoked by the system.

Limiting the horizontal propagation



Limiting the vertical propagation



An Example

- Suppose that the DBA creates four accounts
  - A1, A2, A3, A4
- and wants only A1 to be able to create base relations. Then the DBA must issue the following GRANT command in SQL

```
GRANT CREATETAB TO A1;
```

- In SQL2 the same effect can be accomplished by having the DBA issue a **CREATE SCHEMA** command as follows:

```
CREATE SCHEMA EXAMPLE AUTHORIZATION A1;
```

An Example(2)

- User account A1 can create tables under the schema called **EXAMPLE**.
- Suppose that A1 **creates** the two base relations **EMPLOYEE** and **DEPARTMENT**
  - A1 is then **owner** of these two relations and hence all the relation privileges on each of them.
- Suppose that A1 wants to grant A2 the privilege to insert and delete tuples in both of these relations, but A1 does not want A2 to be able to propagate these privileges to additional accounts:

```
GRANT INSERT, DELETE ON
    EMPLOYEE, DEPARTMENT TO A2;
```

An Example(3)

EMPLOYEE

Name	<u>Ssn</u>	Bdate	Address	Sex	Salary	Dno

DEPARTMENT

<u>Dnumber</u>	Dname	Mgr_ssn

Figure 23.1
Schemas for the two relations EMPLOYEE and DEPARTMENT.

An Example(4)

- Suppose that A1 wants to allow A3 to retrieve information from either of the two tables and also to be able to propagate the SELECT privilege to other accounts.
- A1 can issue the command:

```
GRANT SELECT ON EMPLOYEE, DEPARTMENT
    TO A3 WITH GRANT OPTION;
```

- A3 can grant the **SELECT** privilege on the **EMPLOYEE** relation to A4 by issuing:

```
GRANT SELECT ON EMPLOYEE TO A4;
```

  - Notice that A4 can’t propagate the SELECT privilege because GRANT OPTION was not given to A4

An Example(5)

- Suppose that A1 decides to revoke the SELECT privilege on the EMPLOYEE relation from A3; A1 can issue:

  ```
  REVOKE SELECT ON EMPLOYEE FROM A3;
  ```

- The DBMS must now automatically revoke the SELECT privilege on EMPLOYEE from A4, too, because A3 granted that privilege to A4 and A3 does not have the privilege any more.

An Example(6)

- Suppose that A1 wants to give back to A3 a limited capability to SELECT from the EMPLOYEE relation and wants to allow A3 to be able to propagate the privilege.
  - The limitation is to retrieve only the NAME, BDATE, and ADDRESS attributes and only for the tuples with DNO=5.
- A1 then create the view:

```
CREATE VIEW A3EMPLOYEE AS
   SELECT NAME, BDATE, ADDRESS
   FROM EMPLOYEE
   WHERE DNO = 5;
```

- After the view is created, A1 can grant **SELECT** on the view A3EMPLOYEE to A3 as follows:

```
GRANT SELECT ON A3EMPLOYEE TO A3
    WITH GRANT OPTION;
```

An Example(7)

- Finally, suppose that A1 wants to allow A4 to update only the SALARY attribute of EMPLOYEE;
- A1 can issue:

```
GRANT UPDATE ON EMPLOYEE (SALARY) TO
A4;
```

  - The **UPDATE** or **INSERT** privilege can specify particular attributes that may be updated or inserted in a relation.
  - Other privileges (**SELECT**, **DELETE**) are not attribute specific.

Inherent weakness of DAC

- Unrestricted DAC allows information from an object which can be read by a subject to be written to any other object
  - Bob is denied access to file Y, so he asks cohort Alice to copy Y to X that he can access
- Suppose our users are trusted not to do this deliberately. It is still possible for Trojan Horses to copy information from one object to another.

Trojan horse Example

r: Alice; w:Alice

User Alice

File A

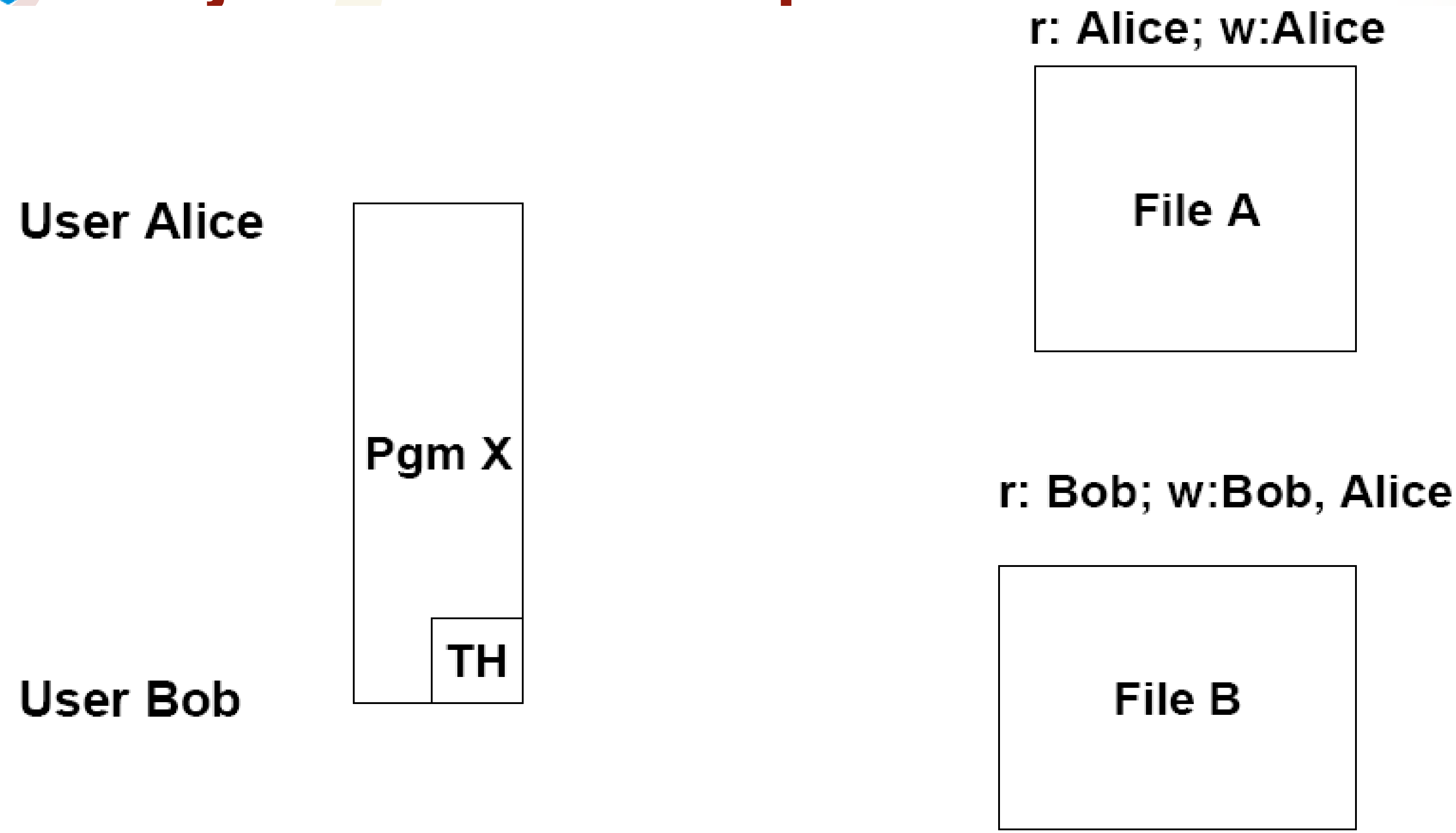
r: Bob; w:Bob

User Bob

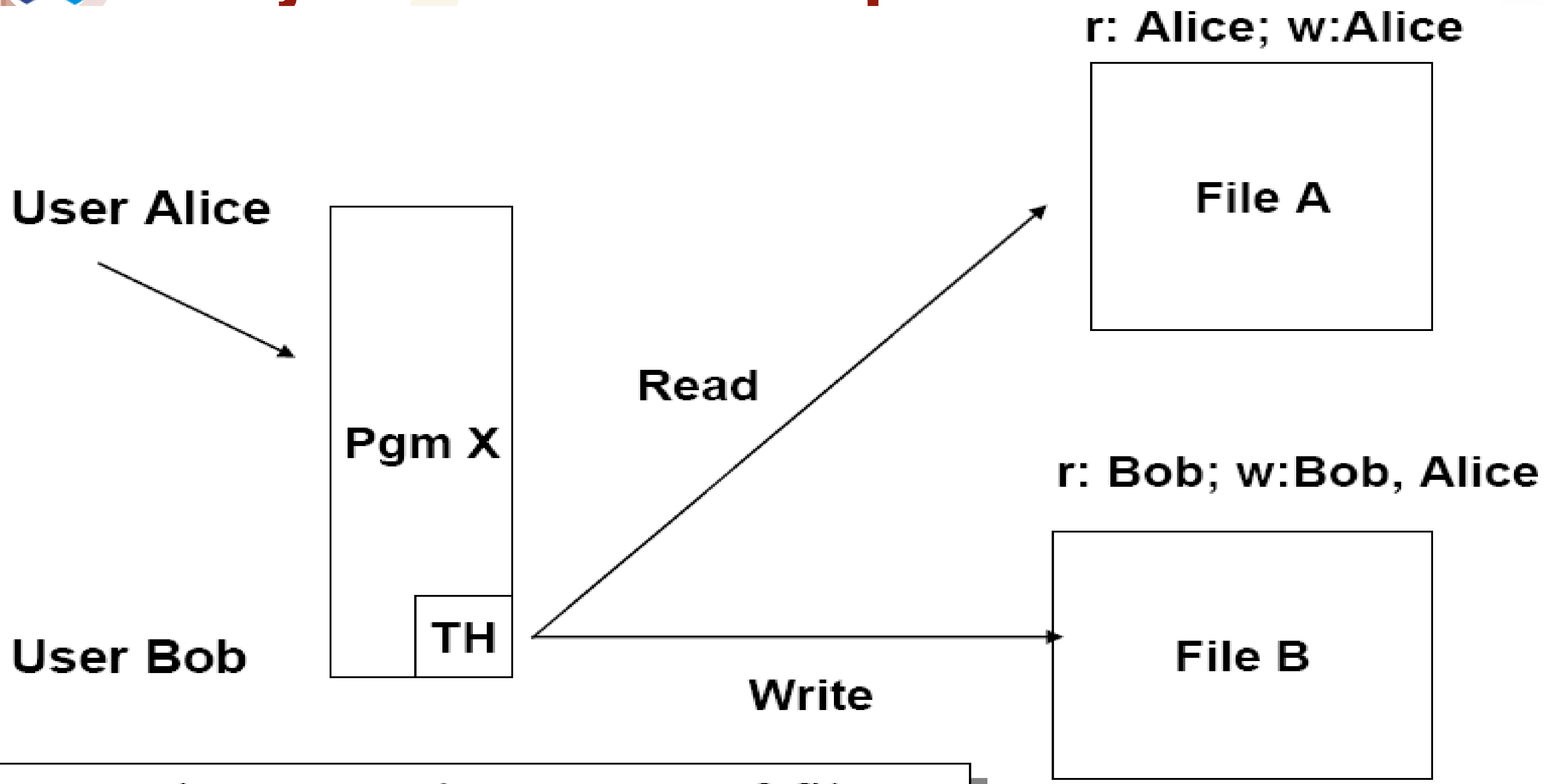
File B

User Bob cannot read the file A!

Trojan horse Example



Trojan horse Example



User Bob can read contents of file A copied to file B

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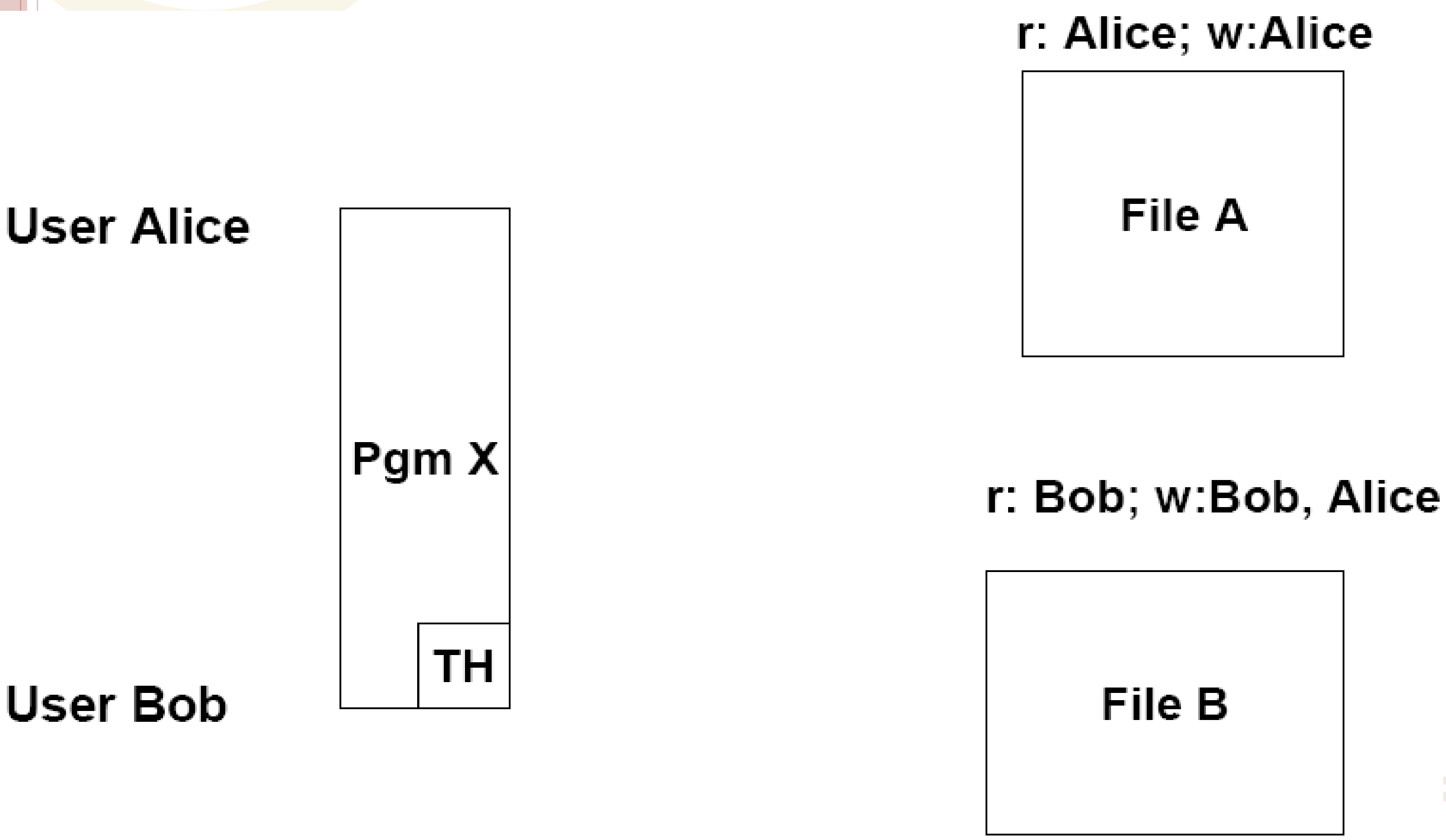
Mandatory Access Control

- Granting access to the data on the basis of users' clearance level and the sensitivity level of the data
- Bell-LaPadula's two principles: no read-up & no write-down secrecy

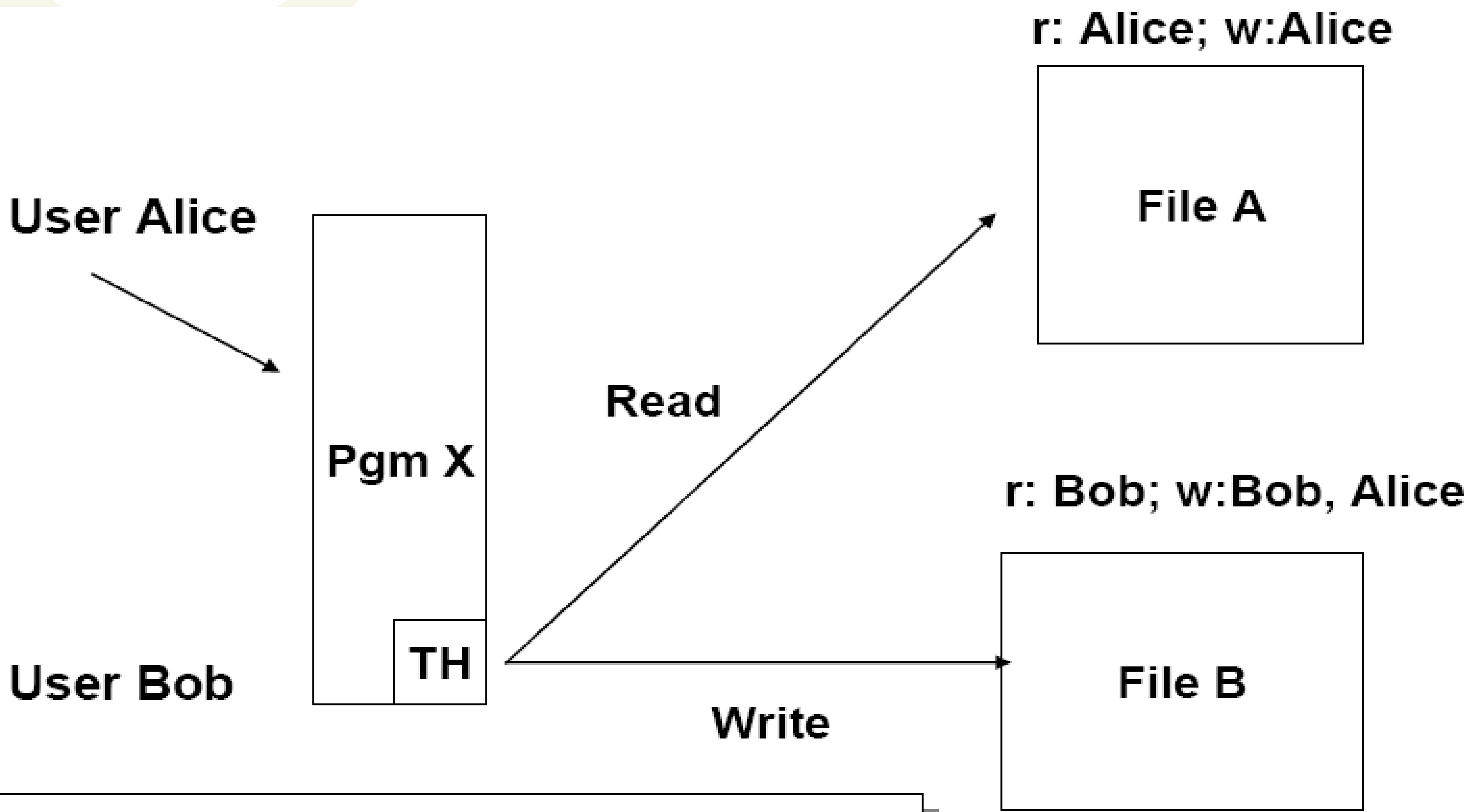
Bell-LaPudula Model

- Typical **security classes** are top secret (TS), secret (S), confidential (C), and unclassified (U), where TS is the highest level and U is the lowest one: TS > S > C > U
- Two restrictions are enforced on data access based on the subject/object classifications:
  - A subject S is not allowed read access to an object O unless class(S) ≥ class(O). This is known as the **simple security property**
  - A subject S is not allowed to write an object O unless class(S) ≤ class(O). This known as the **star property** (or * property)

Why star property?

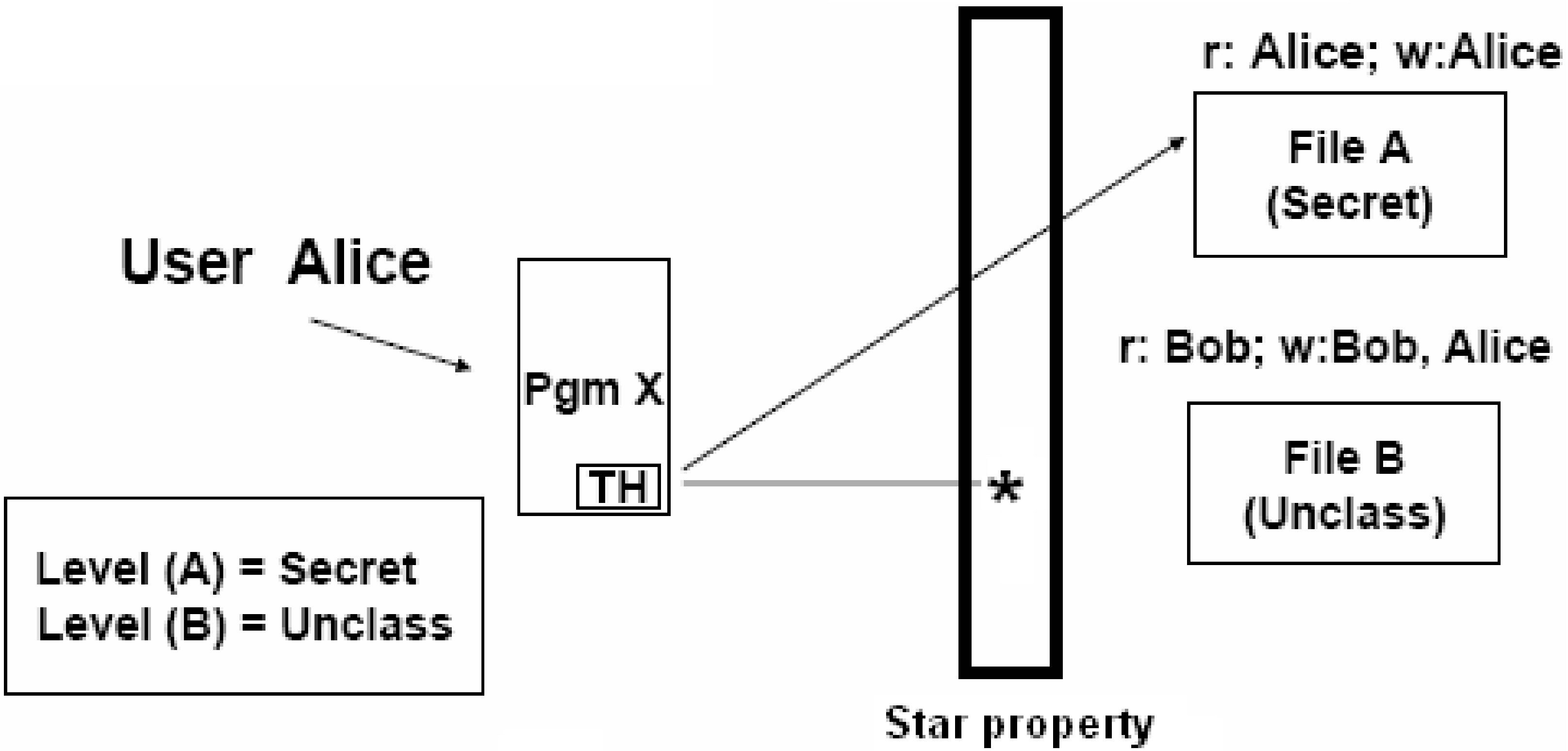


Why star property?



User Bob can read contents of file A copied to file B

Why star property?



Multilevel relation

- **Multilevel relation:** MAC + relational database model
- **Data objects:** attributes and tuples
- Each attribute A is associated with a **classification attribute C**
- A **tuple classification** attribute **TC** is to provide a classification for each tuple as a whole, the highest of all attribute classification values.

  $$R(A_1,C_1,A_2,C_2, \ldots, A_n,C_n,TC)$$

- The **apparent key** of a multilevel relation is the set of attributes that would have formed the primary key in a regular (single-level) relation.

Multilevel relation

EMPLOYEE

Name		Salary		JobPerformance		TC
Smith	U	40000	C	Fair	S	S
Brown	C	80000	S	Good	C	S

➢ **A multilevel relation will appear to contain different data to subjects (users) with different security levels**

Multilevel relation

SELECT * FROM EMPLOYEE

EMPLOYEE

Name		Salary		JobPerformance		TC
Smith	U	40000	C	Fair	S	S
Brown	C	80000	S	Good	C	S

- A user with security level S

EMPLOYEE

Name		Salary		JobPerformance		TC
Smith	U	40000	C	Fair	S	S
Brown	C	80000	S	Good	C	S

Multilevel relation

SELECT * FROM EMPLOYEE

EMPLOYEE

Name		Salary		JobPerformance		TC
Smith	U	40000	C	Fair	S	S
Brown	C	80000	S	Good	C	S

- A user with security level C

EMPLOYEE

Name		Salary		JobPerformance		TC
Smith	U	40000	C	null	C	C
Brown	C	null	C	Good	C	C

Multilevel relation

SELECT * FROM EMPLOYEE

EMPLOYEE

Name		Salary		JobPerformance		TC
Smith	U	40000	C	Fair	S	S
Brown	C	80000	S	Good	C	S

- A user with security level U

EMPLOYEE

Name		Salary		JobPerformance		TC
Smith	U	null	U	null	U	U

Multilevel relation

SELECT * FROM EMPLOYEE

EMPLOYEE

Name		Salary		JobPerformance		TC
Smith	U	40000	C	Fair	S	S
Brown	C	80000	S	Good	C	S

- **A user with security level U**

EMPLOYEE

Name		Salary		JobPerformance		TC
Smith	U	null	U	null	U	U

Mandatory Access Control(4)

(a) EMPLOYEE

Name		Salary		JobPerformance		TC
Smith	U	40000	C	Fair	S	S
Brown	C	80000	S	Good	C	S

(b) EMPLOYEE

Name		Salary		JobPerformance		TC
Smith	U	40000	C	null	C	C
Brown	C	null	C	Good	C	C

(c) EMPLOYEE

Name		Salary		JobPerformance		TC
Smith	U	null	U	null	U	U

(d) EMPLOYEE

Name		Salary		JobPerformance		TC
Smith	U	40000	C	Fair	S	S
Smith	U	40000	C	Excellent	C	C
Brown	C	80000	S	Good	C	S

Properties of Multilevel relation

Read and write operations: satisfy the No Read-Up and No Write-Down principles.

Properties of Multilevel relation

Entity integrity: all attributes that are members of the apparent key **must not be null** and must have the **same security classification** within each individual tuple.

- In addition, all other attribute values in the tuple must have a security classification greater than or equal to that of the apparent key.

→ This **constraint** ensures that a user can see the key if the user is permitted to see any part of the tuple at all.

Properties of Multilevel relation

Polyinstantiation: where several tuples can have the same apparent key value but have different attribute values for users at different classification levels.

Polyinstantiation example

EMPLOYEE

Name		Salary		JobPerformance		TC
Smith	U	40000	C	Fair	S	S
Brown	C	80000	S	Good	C	S

EMPLOYEE (security level C)

Name		Salary		JobPerformance		TC
Smith	U	40000	C	null	C	C
Brown	C	null	C	Good	C	C

- **A user with *security level C* tries to update the value of JobPerformance of Smith to 'Excellent':**

UPDATE EMPLOYEE

SET JobPerformance = 'Excellent'

WHERE Name = 'Smith';

Polyinstantiation example

EMPLOYEE

Name		Salary		JobPerformance		TC
Smith	U	40000	C	Fair	S	S
Smith	U	40000	C	Excellent	C	C
Brown	C	80000	S	Good	C	S

Comparing DAC and MAC

- **Discretionary Access Control (DAC)** policies are characterized by a high degree of flexibility, which makes them suitable for a large variety of application domains.
  - The main drawback of **DAC** models is their vulnerability to malicious attacks, such as Trojan horses embedded in application programs.

Comparing DAC and MAC (2)

- By contrast, mandatory policies ensure a high degree of protection in a way, they prevent any illegal flow of information.
- Mandatory policies have the drawback of being too rigid and they are only applicable in limited environments.
- In many practical situations, discretionary policies are preferred because they offer a better trade-off between security and applicability.

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Role-Based Access Control

- **Role-based access control (RBAC)** emerged rapidly in the 1990s as a proven technology for managing and enforcing security in large-scale enterprisewide systems.
- Its basic notion is that permissions are associated with roles, and users are assigned to appropriate roles.
- Roles can be created using the **CREATE ROLE** and **DESTROY ROLE** commands.
  - The **GRANT** and **REVOKE** commands discussed under DAC can then be used to assign and revoke privileges from roles.

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Encryption

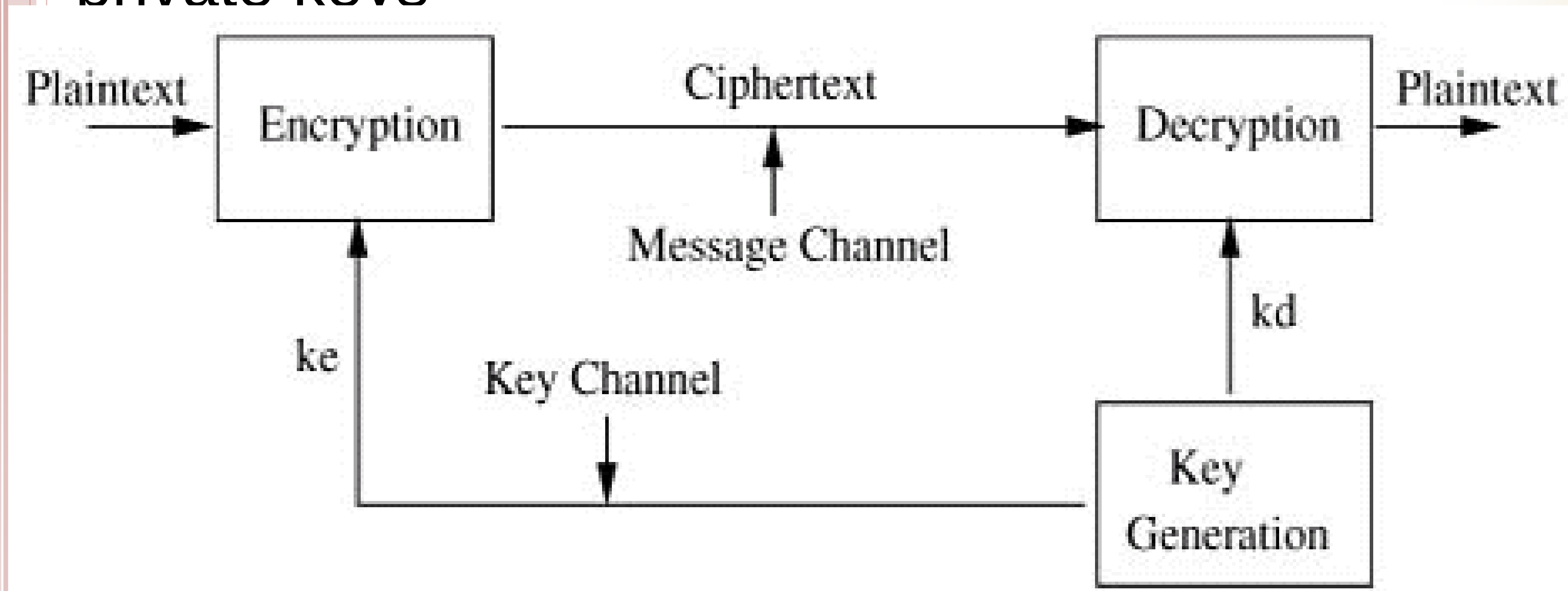
- The encoding of the data by a special algorithm that renders the data unreadable by any program without the decryption key
- Symmetric cryptography: sender and receiver use the same key
- Asymmetric cryptography: encryption & decryption keys

Encryption

- **Plaintext** is the original content which is readable as textual material. Plaintext needs protecting.
- **Ciphertext** is the result of encryption performed on plaintext using an algorithm. Ciphertext is not readable.
- **Cryptosystems** = encryption + decryption algorithms
- Encryption, decryption process needs **keys**

Encryption

- **Symmetric (shared-/secret-key) cryptosystem**: the same key for (en/de)cryption algorithms
- **Asymmetric (public-key) cryptosystem**: public & private keys



Encryption

- (Most popular) Symmetric techniques: DES, AES
  - The same key is used for both encryption and decryption
  - Faster than encryption and decryption in public-key (PK) cryptosystems
  - Less security comparing to encryption and decryption in PK cryptosystems
- Asymmetric techniques: RSA, DSA

Encryption

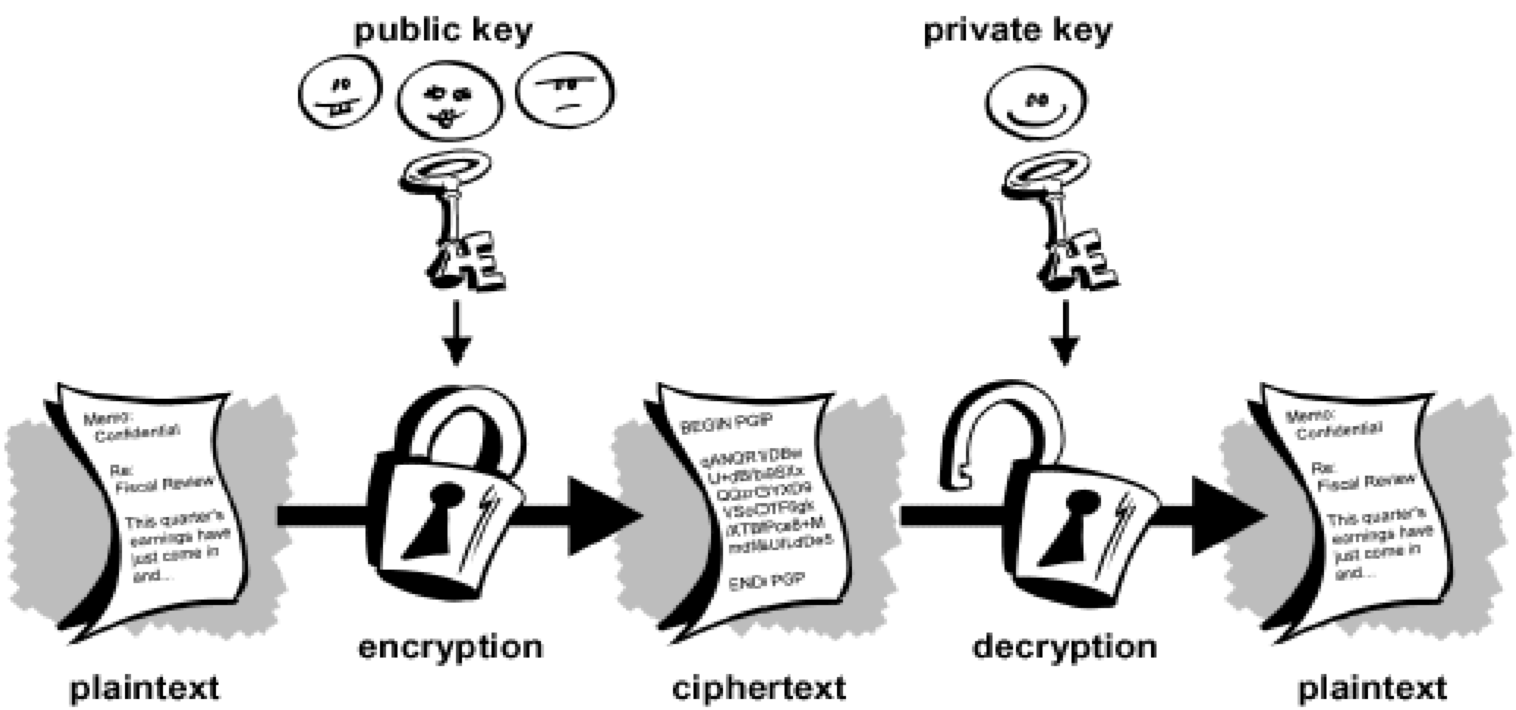
- **DES: Data Encryption Standard**
  - A message is divided into 64-bit blocks
  - Key: 56 bits
  - Brute-force or exhaustive key search attacks (now: some hours): see 7.6.3
- **Triple DES:** run the DES algorithm a multiple number of times using different keys
  - Encryption: $c \leftarrow \mathcal{E}_{k1}(\mathcal{D}_{k2}(\mathcal{E}_{k1}(m)))$
  - Decryption: $m \leftarrow \mathcal{D}_{k1}(\mathcal{E}_{k2}(\mathcal{D}_{k1}(c)))$
  - The triple DES can also use three different keys

Encryption

- **AES: Advanced Encryption Standard (Rijndael)**
  - Jan 2, 1997, NIST announced the initiation of a new symmetric-key block cipher algorithm, AES, as the new encryption standard to replace the DES
  - Oct 2, 2000: Rijndael was selected. Rijndael is designed by two Belgium cryptographers: Daemen and Rijmen
- Rijndael is a block cipher with a variable block size and variable key size
- The key size and the block size can be independently specified to 128, 192 or 256 bits

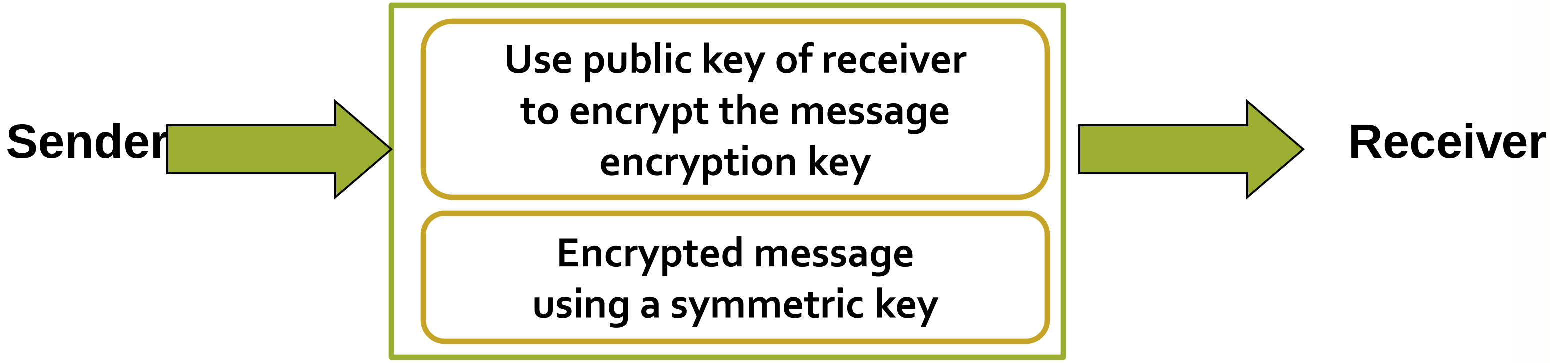
Cryptography-related concepts

- **RSA:** named after 3 inventors **R**ivest, **S**hamir và **A**dleman
  - Two keys: public key and private key
  - Public key is used for encrytion.
  - Private key is used for decrytion



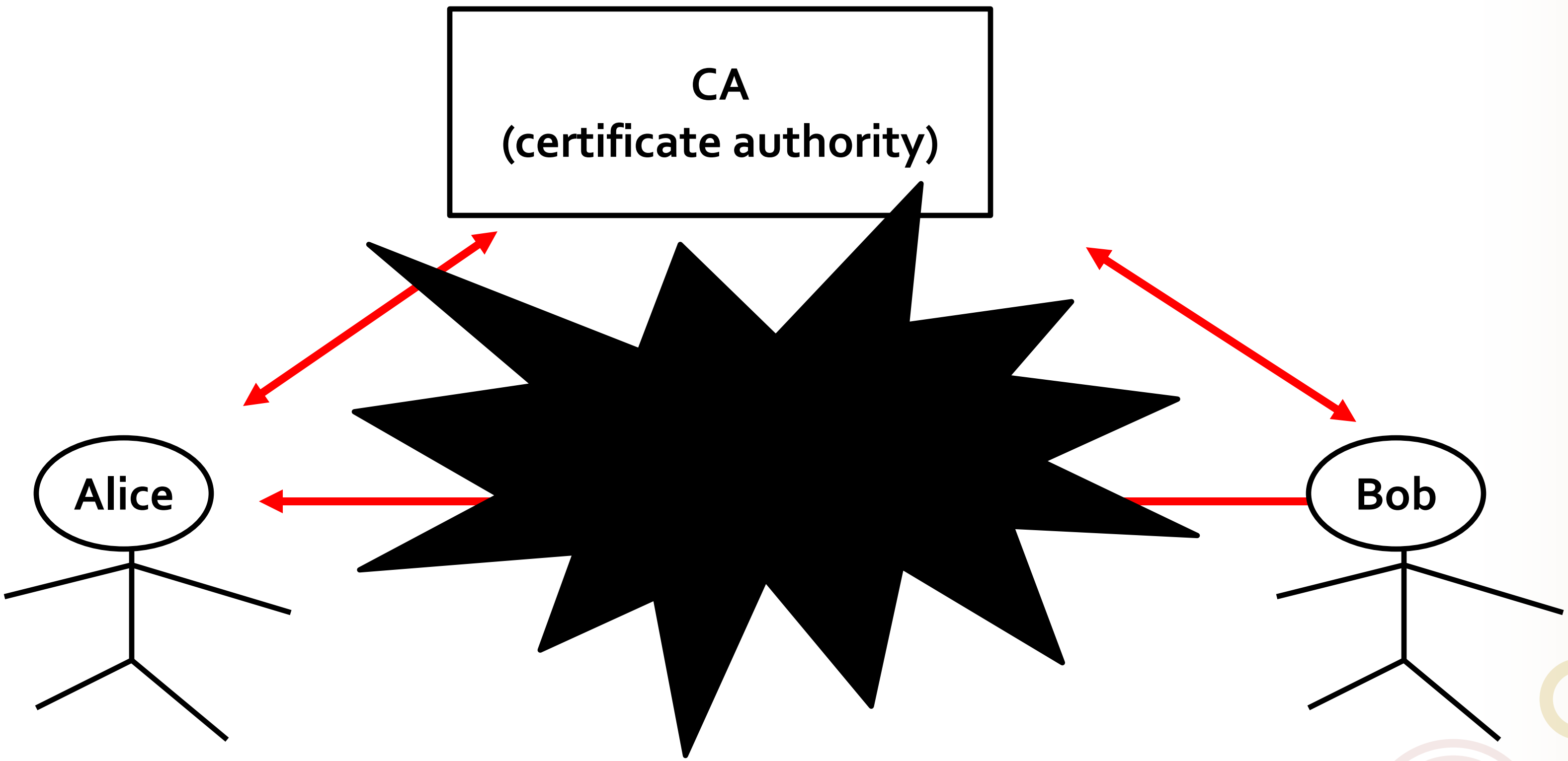
Encryption

- Encryption key: public key
- Decryption key: private key
- Asymmetric techniques: more secure but expensive in terms of computational costs



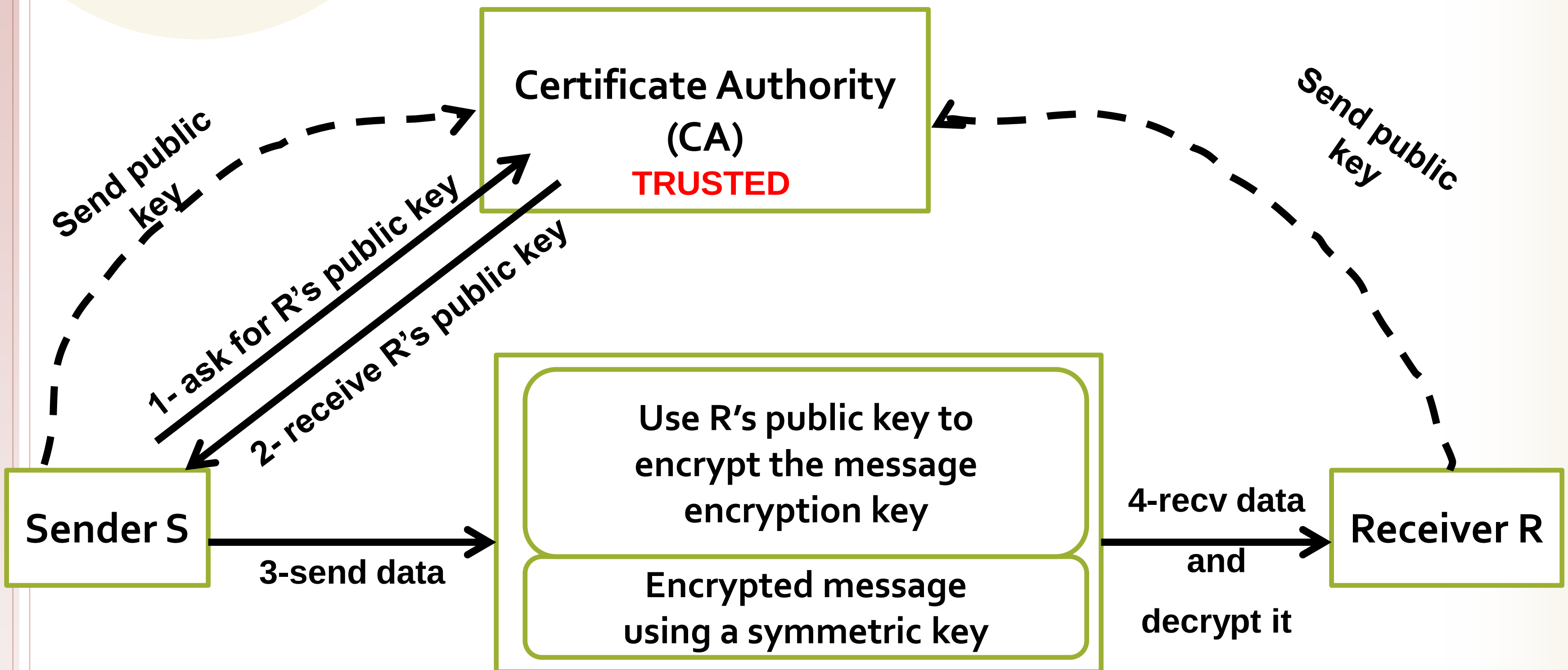
Cryptography-related concepts

- PKI (Public Key Infrastructure) and digital certificates



Encryption & PKI (Public Key Infrastructure)

- How does PKI work?



Summary

- Introduction to Database Security Issues
  - Types of Security
  - Threats to databases
  - Database Security and DBA
  - Access Protection, User Accounts, and Database Audits
- Discretionary Access Control
  - Types of Discretionary Privileges
  - Specifying Privileges Using Views
  - Revoking Privileges
  - Propagation of Privileges Using the GRANT OPTION
  - An example
  - Weakness
- Mandatory Access Control
  - Bell-LaPadula Model
  - Comparing DAC and MAC
- RBAC (Role-Based Access Control)
- Encryption & PKI (Public Key Infrastructure)


Q&A