TDDE49
Databases and Information Security for Bioinformatics

Topic: Database Security

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Threads and Control Measures

What are the threads?

- Loss of confidentiality: unauthorized disclosure of data
  - e.g., student learns other students' grades
- Loss of integrity: improper modification of data
  - e.g., students changing their grades
- Loss of availability: unavailability of database objects to authorized programs and people
  - e.g., students are denied seeing their own grades
  - “denial of service attack”

Control Measures to Provide DB Security

- Access control
  - Restricting the access to the database (or parts thereof)
  - Requires authentication (e.g., through login and password)
  - Usually with auditing (i.e., logging DB operations by each user)
- Inference control
  - Preventing deductions about database content
  - Summary data without possibility to determine individuals' data
- Flow control
  - Preventing information from reaching unauthorized users
- Data encryption
  - Protecting sensitive data (e.g., when transmitted over network)
  - Making information unintelligible unless authorized
  - Making changes traceable to source

Access Control

Access Control in a Database System

- Security policy specifies who is authorized to do what in the system
- DBMS provides access control mechanisms to help implement a security policy
- Two complementary types of such mechanisms:
  - Discretionary access control
  - Mandatory access control

Access Control

Discretionary Access Control

Idea and Related Concepts

- Idea: achieve access control based on
  1. privileges (specific rights for tables, columns, etc.), and
  2. a mechanism for granting and revoking such privileges
- Authorization administration policy specifies how granting and revoking is organized
  - i.e., who may grant / revoke
  - *Centralized administration*: only some privileged users
  - *Ownership-based administration*: creator of the object
- Administration delegation: if authorized to do so, a user may assign others the right to grant / revoke

Discretionary Access Control in SQL

- Simple examples:
  - to allow user Alice to query the table called Student

    GRANT SELECT **ON** Student **TO** Alice

  - to allow Alice to delete from the Student table

    GRANT DELETE **ON** Student **TO** Alice

  - revoke the previous privilege

    REVOKE DELETE **ON** Student **FROM** Alice

  - to allow Alice to modify any value in Employee

    GRANT UPDATE **ON** Employee **TO** Alice

  - to allow Bob to modify Salary values in Employee

    GRANT UPDATE **ON** Employee(Salary) **TO** Bob

Discretionary Access Control in SQL (cont'd)

GRANT *privileges* **ON** *objects* **TO** *users*

REVOKE *privileges* **ON** *objects* **FROM** *users*

- Possible privileges:
  - SELECT
  - INSERT (may be restricted to specific attributes)
  - UPDATE (may be restricted to specific attributes)
  - DELETE
  - REFERENCES (may be restricted to specific attributes)
- Possible objects:
  - Tables
  - Views
  - Specific attributes (for INSERT, UPDATE, REFERENCES)

Revisiting the Related Concepts

- Idea: achieve access control based on
  1. privileges (specific rights for tables, columns, etc.), and
  2. a mechanism for granting and revoking such privileges

- Authorization administration policy specifies how granting and revoking is organized
  - i.e., who may grant / revoke
  - *Centralized administration*: only some privileged users
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- Administration delegation: if authorized to do so, a user may assign others the right to grant / revoke

Discretionary Access Control in SQL (cont'd)

GRANT *privileges* **ON** *objects* **TO** *users* **[WITH GRANT OPTION]**

REVOKE [GRANT OPTION FOR] *privileges* **ON** *objects* **FROM** *users*

- WITH GRANT OPTION allows users to pass on a privilege (with or without passing on the grant option)
  - When a privilege is revoked from user *X*, it is also revoked from all users who were granted this privilege *solely* from *X*

Example

- Assume we do

GRANT UPDATE **ON** Emp **TO** Alice

GRANT UPDATE **ON** Emp **TO** Bob **WITH GRANT OPTION**

- Next, Bob does

GRANT UPDATE **ON** Emp **TO** Alice, Eve

- Now, Bob, Alice, and Eve have the privilege
- Assume we now do

REVOKE UPDATE **ON** Emp **FROM** Alice

- Alice still has the privilege (thanks to Bob)
- Let's do

REVOKE UPDATE **ON** Emp **FROM** Bob

- Now, neither of them has the privilege anymore

What are Views?

- A **virtual** table **derived** from other (possibly virtual) tables
- Defined by means of a query; view is the up-to-date result of the query (up to date regarding current data in base tables)

```
CREATE VIEW dept_view AS
  SELECT DeptNo, COUNT(*) AS C, AVG(Salary) AS S
  FROM    EMPLOYEE
  GROUP BY DeptNo;
```

- Example of usage in queries:

```
SELECT DeptNo  FROM dept_view  WHERE S > 25000 ;
```

- Why?
  - Simplify query commands; enhance programming productivity
  - Means to implement data security policies with access control

Example: Views in Access Control

```
CREATE VIEW research_colleagues_view AS
  SELECT Fname, Lname, Email
   FROM    EMPLOYEE
   WHERE Dept = 'Research';
```

```
GRANT SELECT ON research_colleagues_view ON Bob;
```

```
SELECT Fname FROM research_colleagues_view;
```

~~SELECT Fname, Salary FROM EMPLOYEE;~~

Granularity of Privileges in SQL

- Seen so far, object-level privileges
  - Objects: tables, views, attributes
  - SQL does not support tuple-specific privileges

- System-level privileges
  - CREATE / ALTER / DROP tables or views
  - Not supported by standard SQL but by DBMS-specific extensions of SQL
  - Creator of an object gets all (object-level) privileges on that object

Trojan Horse Attack

- Assume **discretionary access control**
- Suppose user *Bob* has privileges to read a secret table *T*
- User *Mallory* wants to see the data in *T*
  (but does not have the privileges to do so)
- *Mallory* creates a table *T'* and gives INSERT privileges to *Bob*
- *Mallory* tricks *Bob* into copying data from *T* to *T'* (e.g., by extending the “functionality” of a program used by *Bob*)
- *Mallory* can then see the data that comes from *T*

Access Control

Mandatory Access Control

Idea

- Achieve access control based on system-wide policies that cannot be changed by individual users
- Basis: partially ordered set of security classes
  - e.g., TopSecrect > Secret > Confidential > Unclassified
- Each database object (e.g., tables, columns, rows) is assigned such a class
- Each subject (users, programs) are assigned a clearance for such a class
- Subject's clearance must match class of object

Bell-LaPadula Model

- Rule 1 (no read-up): subject *S* can read object *O* only if clearance(*S*) ≥ class(*O*)
  - e.g., reading *secret* data requires at least *secret* clearance
  - Goal: protect classified data

- Rule 2 (no write-down): subject *S* can write object *O* only if clearance(*S*) ≤ class(*O*)
  - e.g., person with *confidential* clearance cannot write *unclassified* object
  - Goal: flow control (information never flows from a higher to a lower class)

Trojan Horse Attack revisited

- Let's try to use **mandatory access control** instead
- Suppose user *Bob* has privileges to read a secret table *T*

  clearance(*Bob*) = *secret*
- User *Mallory* wants to see the data in *T*
(but does not have the privileges to do so)

  clearance(*Mallory*) < *secret*
- *Mallory* creates a table *T'* and gives INSERT privileges to *Bob*

  class(*T'*) := clearance(*Mallory*), i.e., class(*T'*) < *secret*
- *Mallory* tricks *Bob* into copying data from *T* to *T'* (e.g., by extending the "functionality" of a program used by *Bob*)

  → Writing to T' fails because clearance(*Bob*) $\not\leq$ class(*T'*)
- ~~*Mallory* can then see the data that comes from *T*~~

Multilevel Relations

- Incorporate multilevel security into the relational data model
- Attributes (columns) of a multilevel relation are associated with a corresponding *classification attribute* to denote the security class of the attribute value
- Additionally, a *tuple classification attribute* is added
  - Value of this attribute in a tuple is the highest of the classification attribute values in that tuple
- Example of a multilevel relation:

EMPLOYEE

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

Example from "Fundamentals of Database Systems" by Elmasri and Navathe, Addison Wesley.

Multilevel Relations (cont'd)

- Appearance of such a relation depends on clearance of user
- Example:
  - For a user with *Confidential* clearance:

EMPLOYEE

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

EMPLOYEE

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

Example from "Fundamentals of Database Systems" by Elmasri and Navathe, Addison Wesley.

Database Encryption

Limitations of Access Control

… as a means to achieve the objectives of DB security (in particular, confidentiality and integrity)

- Authorizations enforced by DBMS may be bypassed
  - Intruder can try to mine the database footprint on disk
  - DB administrator has enough privileges to tamper the access control definitions and gain access
- Management of databases outsourced
  - "Database as a service" / cloud services
  - No other choice than trusting the service provider

Purpose of Database Encryption

- Complement and reinforce access control by resorting to cryptographic techniques
- Ensure confidentiality of DBs by keeping data hidden from unauthorized persons

Relevant Factors for Database Encryption

- Where should the encryption be performed?

  …in the storage layer? …in the DBMS?

  …in the application that produces the data?

- How much data should be encrypted and exactly which?

- What encryption algorithm and mode of operation?

- Who should have access to the encryption keys?

- How to minimize the impact on performance?

Data Structures for Databases

A *very* brief overview before we continue ...

Database Files

- File is a sequence of records
  - Record is a set of fields that contain values
  - For instance, file = relation / table
    record = tuple / row
    field = attribute value / cell

Data File

ID#	SSN	Dept.	Salary
1	4945864	12	2000
2	7000111	13	4000
3	…		
4	…		

Database Files

- File is a sequence of records
  - Record is a set of fields that contain values
  - For instance, file = relation / table
    record = tuple / row
    field = attribute value / cell

- Files may consist of multiple blocks
  - Block is the unit of data transfer between disk and main memory
  - Each record is allocated to a block

- DBMS maintains not only data files
  - index files (to speed up the search over data files)
  - log files (to be able to recover from failures/crashes)

Data File

ID#	SSN	Dept.	Salary
1	4945864	12	2000
2	7000111	13	4000
3	…		
4	…		

Block 1

ID#	SSN	Dept.	Salary
5	6487539		
6	7299990		
7	3452626		
8	9000013		

Block 2

ID#	SSN	Dept.	Salary
9	8232333		
10	…		
11	5012128		
12	…		

Block 3

Encryption Granularity

How much data should be encrypted and exactly which?

Encryption Granularity

- Common levels of encryption granularity:
  - field
  - record
  - file
  - whole database
- Finer granularity has advantages:
  - allows for encryption of only the sensitive data
  - only relevant data need to be decrypted for query execution
  - different encryption keys may be used for different parts
- However, finer granularity is not always possible (see later)
- Note: sensitive data may not only be in the data file, but also in temporary files, log files, indexes, etc.

Encryption Layer

Where should the encryption be performed?

Storage-Level Encryption

- Use the storage subsystem to encrypt database files
  - i.e., file pages are encrypted/decrypted by the operating system when written/read from disk
- Advantages:
  - Transparent from the DB perspective, i.e., no changes to the DBMS or the applications necessary
- Disadvantages:
  - Limited to file granularity
  - Cannot be related with user privileges or data sensitivity (because storage subsystem has no knowledge of DB objects or structure)

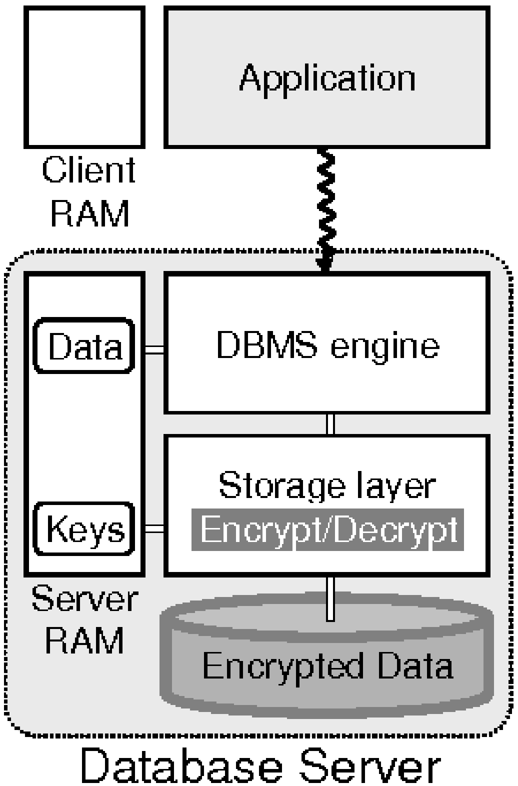


Figure from "Database Encryption" by Bouganim and Guo (2009).

Database-Level Encryption

- DBMS encrypts data when it is inserted into the database
- Advantage: Encryption strategy can be part of the database design (i.e., selective encryption possible, various granularities possible)
- Disadvantage: Performance degradation possible (e.g., encryption may make indexes useless)

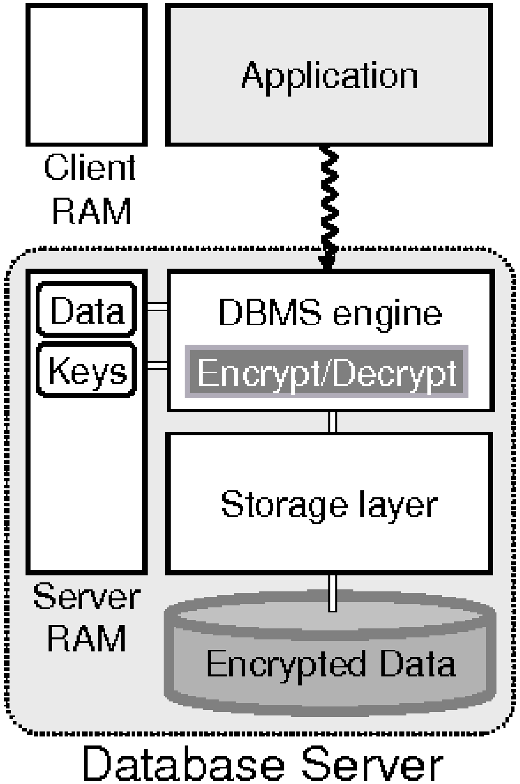


Figure from “Database Encryption” by Bouganim and Guo (2009).

Application-Level Encryption

- Application encrypts sensitive data before sending it to the DBS and decrypts data returned by the DBS
- Advantages:
  - Encryption keys separated from the encrypted data (i.e., no need to trust the DB administrator or cloud provider)
  - Highest flexibility in terms of granularity and key management
- Disadvantages:
  - Applications need to be modified
  - Performance overhead possible (e.g., prevents indexes for range queries)
  - No stored procedures and triggers

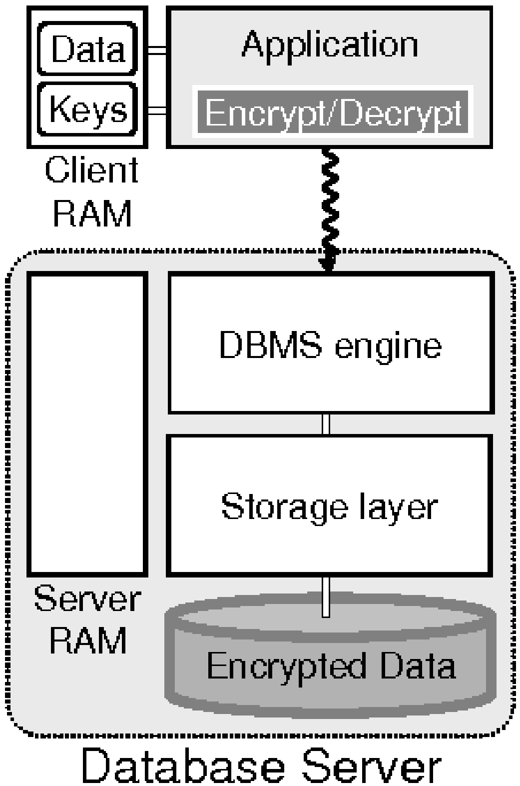


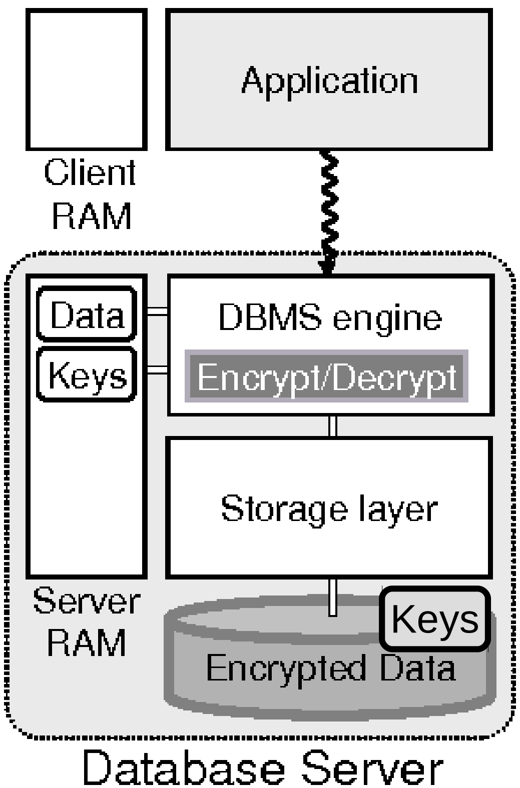
Figure from "Database Encryption" by Bouganim and Guo (2009).

Key Management

Who should have access to the encryption keys?

Naive Solution (for DB-Level Encryption)

- Store keys in a restricted database table or file
- Potentially encrypt this table/file with a master key
  - Master key must also be stored on the database server

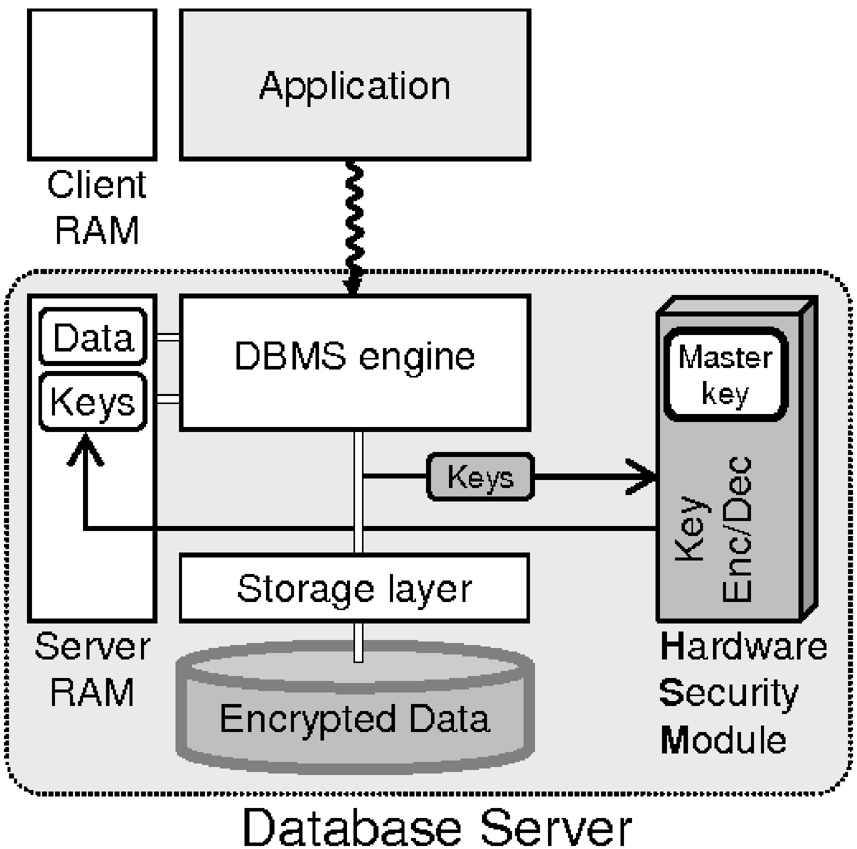


- Disadvantage:
  - Administrators with privileged access may use the keys to see and/or modify the data without being detected

Figure from "Database Encryption" by Bouganim and Guo (2009).

HSM Approach

- Use a hardware security module (HSM)
  - Specialized, tamper-resistant cryptographic chipsets

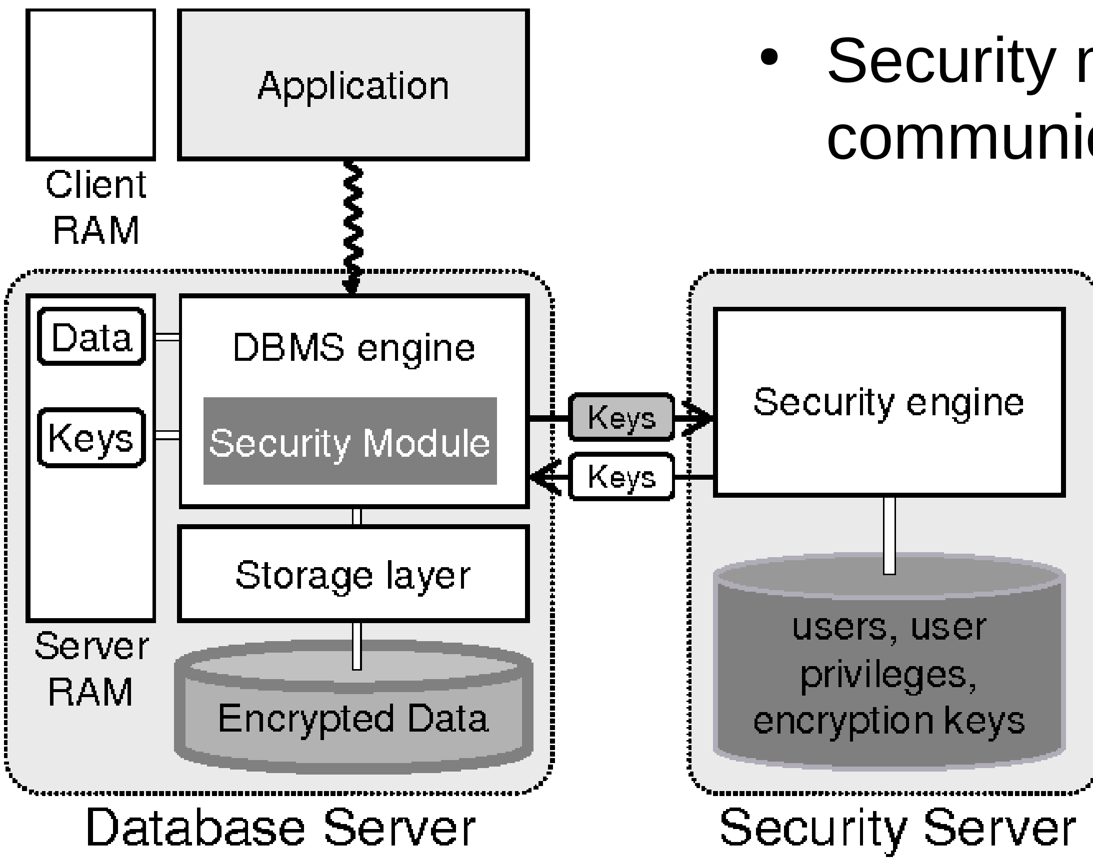


- Keys are stored encrypted in a restricted database table
- To encrypt/decrypt data the needed keys are decrypted by the HSM using the master key
- Decrypted keys are removed from main memory as soon as encryption/decryption of data has been performed

Figure from “Database Encryption” by Bouganim and Guo (2009).

Security Server Approach

- Move security-related tasks to distinct software on a distinct server that manages users, roles, privileges, encryption policies, and keys (potentially using an HSM)



- Security module within the DBMS communicates with the security server
- Clear distinction between DB administrator and security administrator

Figure from "Database Encryption" by Bouganim and Guo (2009).

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