CSE 410/565 Computer Security
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Lecture 10: Database Security

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Review of Access Control Types

- We previously studied four types of access control
  - mandatory AC
  - discretionary AC
  - RBAC
  - attribute-based AC
- Many of them can be used in databases
- There are also challenges unique to database management systems (DBMSs)

Lecture Overview

- Review of relational databases
- Database security issues
  - threats
  - access control mechanisms
- Inference in databases
- Statistical databases

Relational Databases

- A database is a structured collection of data
- A database management system (DBMS) allows one to construct, manipulate, and maintain the database
  - it provides facilities for multiple users and applications
- A query language specifies how the data can be created, queried, updated, etc.
- In relational databases, all data are stored in tables (called relations)
  - each record (called tuple) corresponds to a row of a table
  - each column lists an attribute

Relational Databases

- Example of a table

EmployeeID	Name	Salary	DepartmentID
1	Alice	75	3
2	Bob	60	2
3	Carl	90	1
4	David	70	3

- A primary key uniquely identifies each row in a table
  - it can consist of one or more attributes
  - in the above table, Employee ID can be used as a primary key
- We create a relationship between tables by linking their attributes together
  - this is done by means of foreign keys

Relational Databases

- A foreign key is one or more attributes that appear as the primary key in another table

EID	Name	Salary	DID
1	Alice	75	3
2	Bob	60	2
3	Carl	90	1
4	David	70	3

DeptID	Name	Phone
1	Administration	1234567
2	HR	1234568
3	Sales	1234569

- A view is a virtual table that displays selected attributes from one or more tables

EID	Name	DID
1	Alice	3
2	Bob	2
3	Carl	1
4	David	3

EID	Name	DeptName
1	Alice	Sales
2	Bob	HR
3	Carl	Administration
4	David	Sales

Relational Databases

- Structured Query Language (SQL) is a widely used language that allows one to manipulate databases
  - table creation

```
CREATE TABLE Employee (
EmployeeID INTEGER PRIMARY KEY,
Name CHAR (30),
Salary INTEGER,
DepartmentID INTEGER )
```

  - retrieving (querying) information

```
SELECT EmployeeID, Name
FROM Employee
WHERE Salary >= 70
```

Relational Databases

- SQL examples (cont.)
  - view creation

```
CREATE VIEW Employee2 (EID, Name, DeptName)
AS SELECT E.EmployeeID, E.Name, D.Name
FROM Employee E Department D
WHERE E.DepartmentID = D.DeptID
```

- Limited views are common as a security mechanism

Database Security

- Database security issues
  - users and authentication
    - authenticating users, assigning privileges correctly
  - secure communication between client and server
  - vulnerabilities in DBMS implementation
    - sanitizing input
    - SQL worms
    - limiting who can connect to DBMS server

SQL Injection Attacks

- SQL injection attacks are among the most prevalent and dangerous types of network-based security threats
  - they are consistently rated among most frequent and critical Web security risks by multiple reporting agencies
  - an attack consists of entering maliciously crafted input on a web form
    - this can also include maliciously modified cookies and other variables
  - the entered fields are used as inputs to an SQL query
  - a successful attack can lead to bulk extraction of customer records, corruption of data, or execution of arbitrary commands
  - we'll discuss SQL injection attacks when we talk about software security and input validation in particular

Database Access Control

- Commercial DBMSs often provide discretionary or role-based AC
  - centralized administration
  - ownership-based administration
  - decentralized administration
- Key components in DBMS access control
  - privileges
  - views
  - stored procedures
  - roles
  - row-level access control

Database Access Control

- Privileges
  - access rights: create, select, insert, update, delete, add references
  - system privilege
    - a right to perform a particular action or to perform an action on any schema object of a particular types
    - e.g., ALTER DATABASE or SELECT ANY TABLE
  - object privilege
    - a right to perform a particular action on a specific schema object such as tables, views, procedures, and types
    - e.g., SELECT, INSERT, UPDATE, DELETE

Database Access Control

- Granting and revoking privileges (or roles) with SQL
  - granting privileges has the following syntax

```
GRANT {privileges | role}
[ON table]
TO {user | role | PUBLIC}
[IDENTIFIED BY password]
[WITH GRANT OPTION]
```

  - revoking privileges

```
REVOKE {privileges | role}
[ON table]
FROM {user | role | PUBLIC}
```

Database Access Control

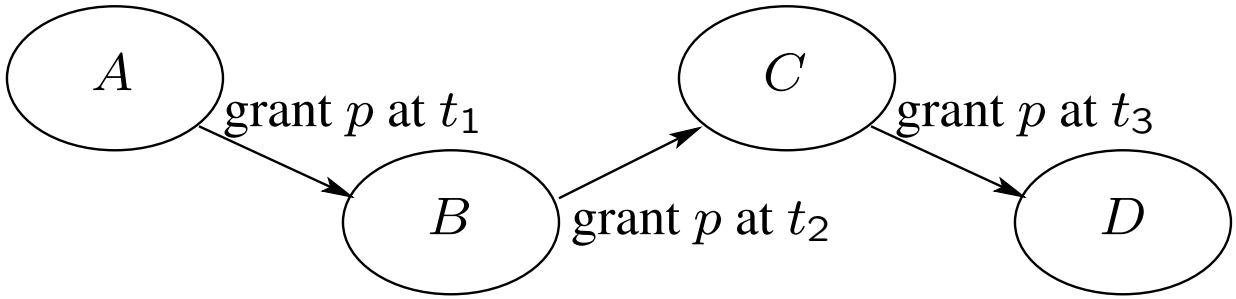
- Examples of granting and revoking privileges
  - system privileges
    - `GRANT create table TO Bob [WITH GRANT OPTION]`
    - `REVOKE create table FROM Bob`
    - users with GRANT OPTION can not only grant the privilege to others, but also revoke the privilege from any user

Database Access Control

- Examples of granting and revoking privileges
  - object privileges
    - `GRANT select ON table1 TO Bob [WITH GRANT OPTION]`
    - `REVOKE select ON table1 FROM Bob`
    - user who revokes a particular object privilege must be the direct grantor of the privilege
    - there is a cascading effect when an object privilege is revoked

Database Access Control

- Cascading effect
  - when a privilege is being revoked, all other privileges that resulted from it get revoked as well
  - for example, the privilege is being revoked from C or B



- Difficulties arise if a privilege has been granted through different paths
  - the cascading effect can either apply to all privileges or be based on timestamps

Database Access Control

- Views
  - access control is based on attributes (columns) and their contents
  - example: some users can see employees and their departments, but not salaries
    - given table `Employee(EmployeeID, Name, Salary, DepartmentID)`
    - `CREATE VIEW Employee1 AS SELECT EmployeeID, Name, DepartmentID from Employee`
    - grant select privileges on the view `Employee1`

Database Access Control

- To create a view
  - the creator must have been explicitly (not through roles) granted one of SELECT, INSERT, UPDATE, or DELETE object privileges on all base objects underlying the view or corresponding system privileges
- To grant access to the view
  - the creator must have been granted the corresponding privileges with GRANT OPTION to the base tables
- To access the view
  - the creator must have the proper privilege for the underlying base tables

Database Access Control

- Stored procedures
  - a stored procedure is a set of commands that are compiled into a single function
  - stored procedures can be invoked using the CALL statement
  - such procedures can allow for fine grained access control
    - some users may be permitted to access the database only by means of stored procedures
    - can precisely define access control privileges
  - the rights relevant to access control are
    - definer rights
    - invoker rights

Database Access Control

- Definer right procedures
  - a stored procedure is executed with the definer rights (i.e., owner of the routine)
  - a user requires only the privilege to execute the procedure and no privileges on the underlying objects
  - fewer privileges have to be granted to users
  - at runtime, owner's privileges are always checked
  - a user with CREATE procedure privilege can effectively share any privilege she has without GRANT OPTION
    - create a definer right procedure and grant execute privilege to others
    - CREATE procedure privilege is very powerful

Database Access Control

- Invoker right procedures
  - a user of an invoker right procedure needs privileges on the objects that the procedure accesses
  - invoker right procedures can prevent illegal privilege sharing
    - similar to function calls in operating systems
  - invoker right procedures can be embedded with malicious code
    - e.g., the body of a stored procedure can be

```
begin
    do something useful;
    grant some privileges to the owner;
    do something useful;
end
```

Database Access Control

- RBAC naturally fits database access control
- The use of roles allows for
  - management of privileges for a user group (user roles)
    - DB admin creates a role for a group of users with common privilege requirements
    - DB admin grants required privileges to a role and then grants the role to appropriate users
  - management of privileges for an application (application roles)
    - DB admin creates a role (or several roles) for an application and grants necessary privileges to run the application
    - DB admin grants the application role to appropriate users

Database Access Control

- User-roles assignment
  - to grant a role, one needs to have GRANT ANY ROLE system privilege or have been granted the role with GRANT OPTION
    - `GRANT ROLE clerk TO Bob`
  - to revoke a role from a user, one needs to have the GRANT ANY ROLE system privilege or have been granted the role with GRANT OPTION
    - `REVOKE ROLE clerk FROM Bob`
  - users cannot revoke a role from themselves

Database Access Control

- Role-permission assignment
  - to grant a privilege to a role, one needs to be able to grant the privilege
    - `GRANT insert ON table1 TO clerk`
  - to revoke a privilege from a role, one needs to be able to revoke the privilege
    - `REVOKE insert ON table1 FROM clerk`
- DBMS implementation can have different types of roles
  - e.g., server roles, database roles, user-defined roles

Database Access Control

- Row-based access control can be implemented using a Virtual Private Database (VPD)
  - Oracle's VPDs allow for fine-grained access control
  - e.g., customers can see only their own bank accounts
- How does it work?
  - a table (or view) can be protected by a VPD policy
  - when a user accesses such a table, the server invokes the policy function
  - the policy function returns a predicate, and server rewrites the query adding the predicate to the WHERE clause
  - the modified query is executed

Database Access Control

- VPD example
  - suppose Alice creates Employee table with attributes employee ID, name, and salary code
  - Alice creates a policy that an employee can access all names, but only their own salary
  - when Bob queries the table, his identity is retrieved from the session
  - if Bob queries salary from Employee table, '`WHERE name = Bob`' is added to the query

Inference in Databases

- Access control policy defines what information users are authorized to access
- Inference channel refers to obtaining access to unauthorized data by making inferences about authorized data
  - a combination of data may be more sensitive than individual items
- Inferences within a single database
  - certain items may be considered sensitive
  - the policy might specify that certain attributes cannot be accessed together (to remove the association between them)

Inference in Databases

- Example
  - we have Employee table for a company's branch

EmployeeID	Name	Salary	DepartmentID
1	Alice	75	3
2	Bob	60	2
3	Carl	90	1
4	David	70	3

  - the policy states that Name and Salary cannot be queried together
  - authorized views of the table

EmployeeID	Name
1	Alice
2	Bob
3	Carl
4	David

Salary	DepartmentID
75	3
60	2
90	1
70	3

Inferences in Databases

- Example (cont.)
  - can we make a connection between names and salaries?
  - it is trivial if the order of elements in the displayed queries is unchanged
  - what if the records are displayed in random order?
  - if narrower queries are allowed, a connection can still be made
- Outside information can significantly simplify making inferences
  - e.g., people might know that Bob works at HR department
- How can we eliminate inference channels?

Inferences in Databases

- Inference detection is difficult, even without assuming outside information
  - there is no general solution
  - the process is very dependent on the specifics of the database and policy
    - what data items are sensitive
    - what the security policy is
    - what functionality is desired
- Techniques that can aid in reducing the possibility of inference
  - splitting data into multiple tables
  - employing more fine-grained access control roles or procedures

Inference in Databases

- Inferences across multiple databases
  - often related information can be stored in different databases
  - designers of individual databases cannot prevent all inference channels
  - example databases
    - marriage records, voting registration, census data, etc.
  - public databases can be used for unintended purposes
    - e.g., identifying patients in anonymized medical records
  - making information easily accessible in digital form makes it prone to abuse

Statistical Databases

- A statistical database (SDB) allows users to obtain aggregate information of statistical nature
- This can be accomplished in two ways
  - the database already contains statistical data
  - the database contains information about individual data items, but answer queries of aggregate nature
- A SDB can support operations such as
  - count, sum, avg, max, min, etc.
- The goal is to prevent a user from inferring information about individual items
  - such form of inference is called a compromise

Statistical Databases

- If queries are unrestricted in a statistical database, compromising it might be easy
  - if the database size is not very big, certain queries might have $count(q_i) = 1$
  - querying $sum(q_i)$ reveals the actual value
  - e.g., $sum(\text{SELECT Salary WHERE DepartmentID} = 2) = 60$ leaks Bob's salary
- With larger databases, a combination of queries can also compromise individual entries

Statistical Databases

- Proposed solutions
  - query restriction: reject queries that lead to compromise
  - perturbation: answer all queries, but modify the data
- Types of query restrictions
  - minimum query size
    - e.g., rejects all queries covering fewer than k records
    - can also specify to reject all queries covering more than $N - k$, where N is the total number of records
    - statistics on the entire database often are still permitted
    - a compromise can still happen by querying overlapping sets

Statistical Databases

- Types of query restrictions (cont.)
  - query set overlap control
    - mandates that overlap between the current and all past queries is at most r
    - information on both a set and its subset will not be released
    - history-based access control that require logging of all previous queries
    - with enough queries, compromise is still possible
    - the method is not effective if parties can collude
  - partitioning
    - data is partitioned into groups, and only querying whole groups is allowed

Statistical Databases

- The mere fact that a query is denied can leak information!
- Types of data perturbation
  - data swapping
    - exchange attribute values between different records
    - should be applied to many records to achieve data protection
  - adding noise
    - numerical values are modified by adding a random in a range $[-t, t]$ for some fixed value t
    - individual values might be incorrect, but the distribution and aggregate statistics are preserved

Statistical Databases

- Types of data perturbation (cont.)
  - replacing the data with an estimation
    - a modified database is generated using the estimated probability distribution of the real data
    - the values are replaced with estimations
    - ordering of the elements is preserved: the smallest value is replaced with the generated smallest value
- Finding the right level of perturbation is hard
  - there is trade-off between data hiding and data accuracy
  - large amount of perturbation is often needed to achieve a reasonable level of hiding

Statistical Databases

- Common data protection models include:
  - k-anonymity
    - at least k record contain identical quasi-identifiers
    - designed for anonymized dataset release
    - protection is achieved via suppression of some attributes and generalization of others
  - differential privacy
    - the presence of a single individual in a dataset cannot be determined from the result
    - was formulated for statistical queries
    - protection is achieved via adding noise

New Trends in Database Security

- Outsourced databases or third-party publishing
  - data owner creates and maintains the database
  - service provider stores the database and answers queries on behalf of the database owner
  - users direct their queries to the service provider
- There are unique security challenges when the service provider is not completely trusted
  - users want a proof that query answers are complete (data haven't been deleted)
  - users want a proof that query answers are authentic (extra data haven't been added)

Database Encryption

- Parts of or the entire database can be encrypted
  - can be useful for protecting highly sensitive information
  - protects information in case of database outsourcing
- Working with encrypted databases is not easy
  - must properly distribute and manage different encryption keys
  - regular search doesn't work over encrypted contents
- Search over encrypted data is an active area of research
  - techniques that hide data well are not very efficient
  - simpler approaches leak significant amount of information about the stored data

Conclusions

- Database security covers several aspects
  - access control
    - discretionary, RBAC, views, stored procedures, row-level access control
  - data inference
    - within a single database, accross databases, in statistical databases
- Newer topics include outsourcing, database encryption