CSE 410/565: Computer Security

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Announcements

- Midterm exam this Wednesday
  - Closed book. Random seats.
- We will contact students for HW1 misbehaviors
  - Zero points for the particular question. I will report to the Office of Academic Integrity.

Database Security

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

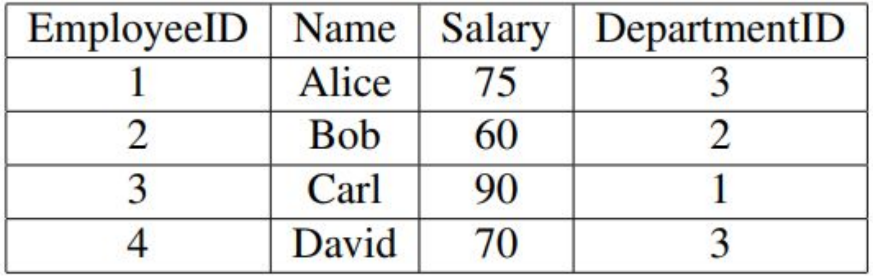
- Review of relational databases
- Database security issues
  - threats
  - access control mechanisms
- Inference in databases
- Statistical databases

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

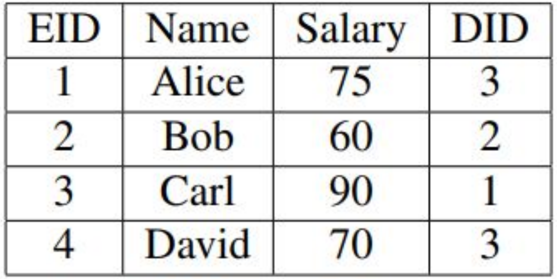


EmployeeID	Name	Salary	DepartmentID
1	Alice	75	3
2	Bob	60	2
3	Carl	90	1
4	David	70	3

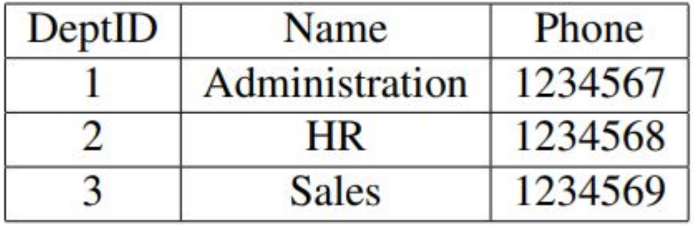
- A primary key uniquely identifies each row in a table
  - it can consist of one or more attributes
  - in the above table, Employee ID can be used as a primary key
- We create a relationship between tables by linking their attributes together
  - this is done by means of foreign keys

Relational Databases

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

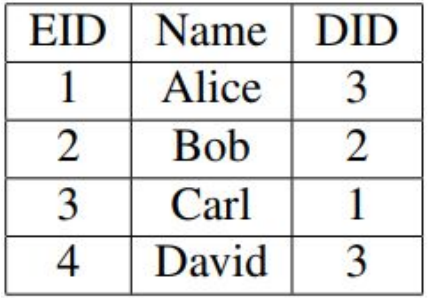


EID	Name	Salary	DID
1	Alice	75	3
2	Bob	60	2
3	Carl	90	1
4	David	70	3



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



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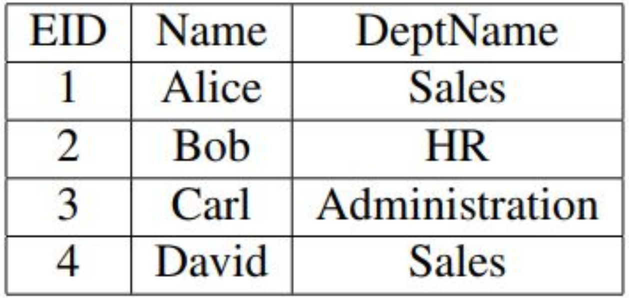


EID	Name	DeptName
1	Alice	Sales
2	Bob	HR
3	Carl	Administration
4	David	Sales

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

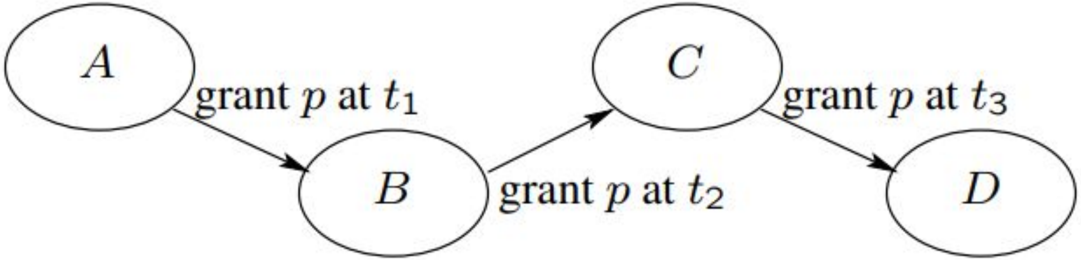
- Examples of granting and revoking privileges
    - system privileges
        - `GRANT create table TO Bob [WITH GRANT OPTION]`
        - `REVOKE create table FROM Bob`
        - users with GRANT OPTION can not only grant the privilege to others, but also revoke the privilege from any user

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 PROCEDURE statement
  - 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

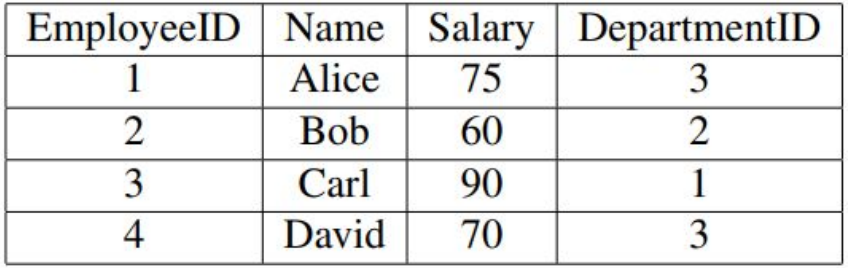
- VPD example
    - suppose Alice creates Employee table with attributes employee ID, name, and salary code
    - Alice creates a policy that an employee can access all names, but only their own salary
    - when Bob queries the table, his identity is retrieved from the session
    - if Bob queries salary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

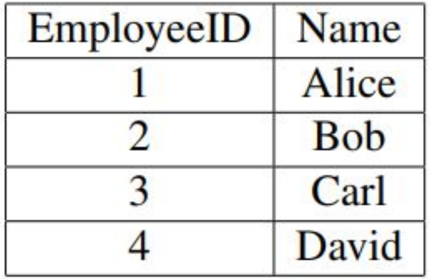
Inference in Databases

- 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
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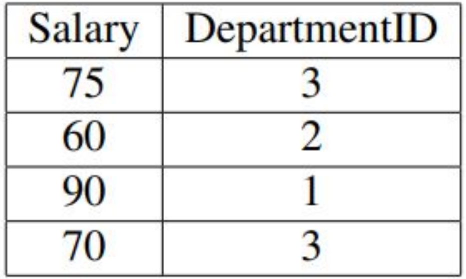

Salary	DepartmentID
75	3
60	2
90	1
70	3

Inference 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?

Inference in Databases

- Inference detection is difficult, even without assuming outside information
    - 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*(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, across databases, in statistical databases
- Newer topics include outsourcing, database encryption