CS 4910: Intro to Computer Security

Database Security II

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Updates

- Assignment 2 is due on 3/05

So far …

- Review of relational databases
  - Primary key, foreigner key
- Database security issues
  - Threats: SQLi attack via user input
  - Access control mechanisms
    - Discretionary or role-based AC
  - Key components in DBMS access control
    - Privileges, views, stored procedures, roles, row-level access control

Today

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

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

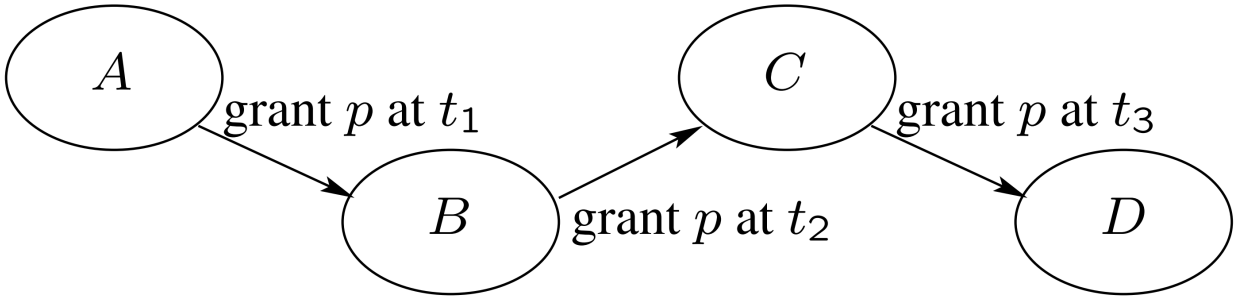
- Examples of granting and revoking privileges
  - system privileges
    - `GRANT create table TO Bob [WITH GRANT OPTION]`
    - `REVOKE create table FROM Bob`
    - users with GRANT OPTION can not only grant the privilege to others, but also revoke the privilege from any user

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

Next

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

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

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
  - 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(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

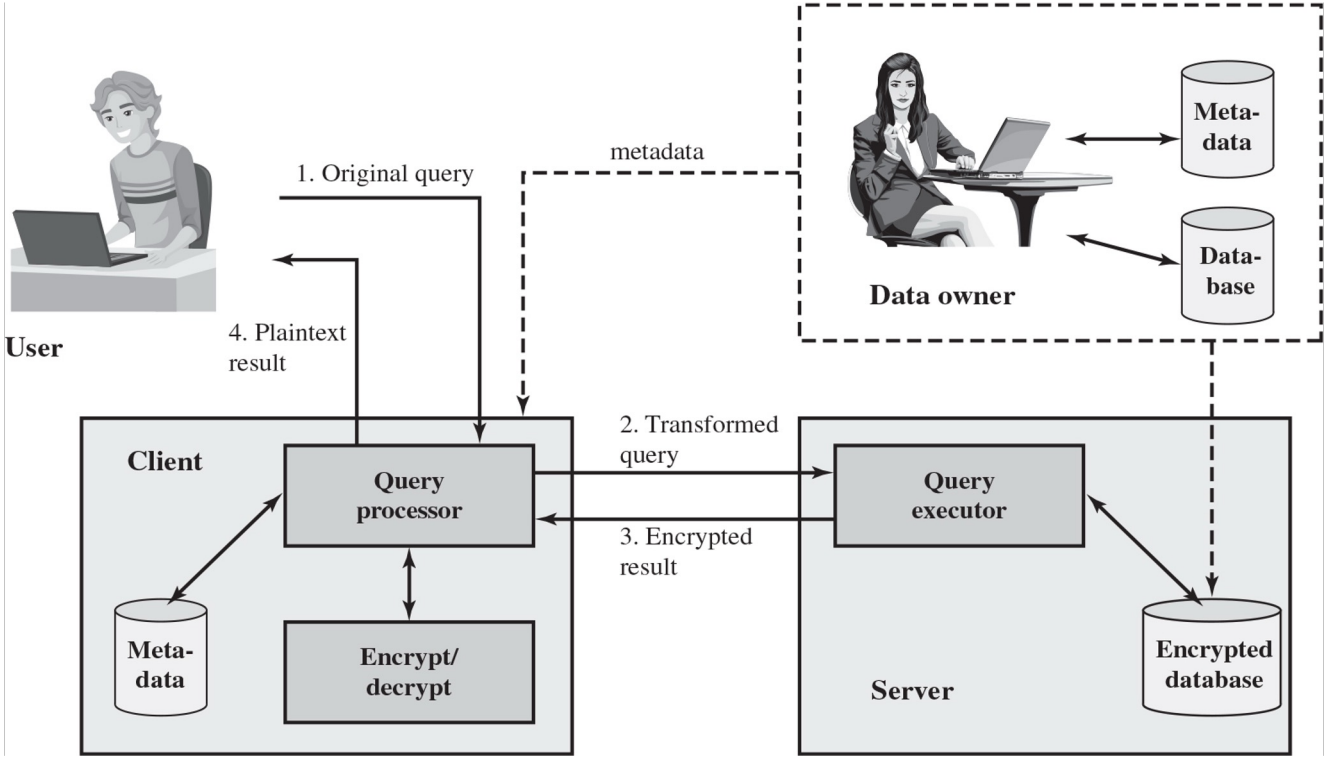
New Trends in Database Security

- 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

A Database Encryption Scheme



Encrypted Database Example

(a) Employee Table

eid	ename	salary	addr	did
23	Tom	70K	Maple	45
860	Mary	60K	Main	83
320	John	50K	River	50
875	Jerry	55K	Hopewell	92

(b) Encrypted Employee Table with Indexes (ranges?)

E(k, B)	I(eid)	I(ename)	I(salary)	I(addr)	I(did)
1100110011001011 . . .	1	10	3	7	4
0111000111001010 . . .	5	7	2	7	8
1100010010001101 . . .	2	5	1	9	5
0011010011111101 . . .	5	5	2	4	9

~~Data Center Security~~

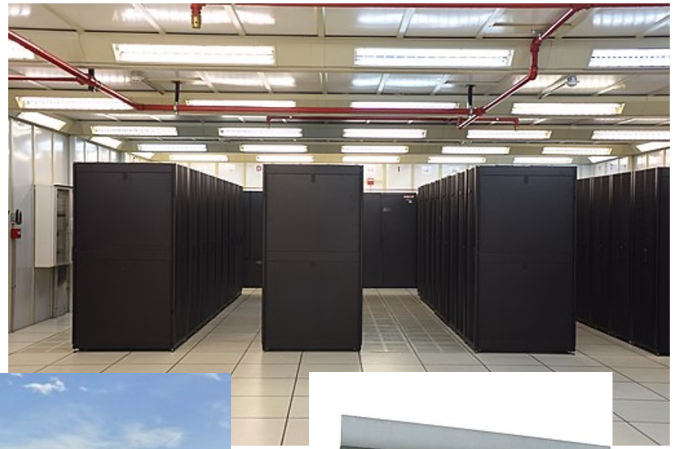
Data Center Security

- Data center:
  - Facility that houses a large number of servers, storage devices, and network switches and equipment
  - Can have tens of thousands of servers/storage devices in one facility
  - Can occupy one room of a building, one or more floors, or an entire building
  - Many are co-located
- Examples
  - Amazon, Google, MasterCard, etc.

Data Center

(13)

(2)



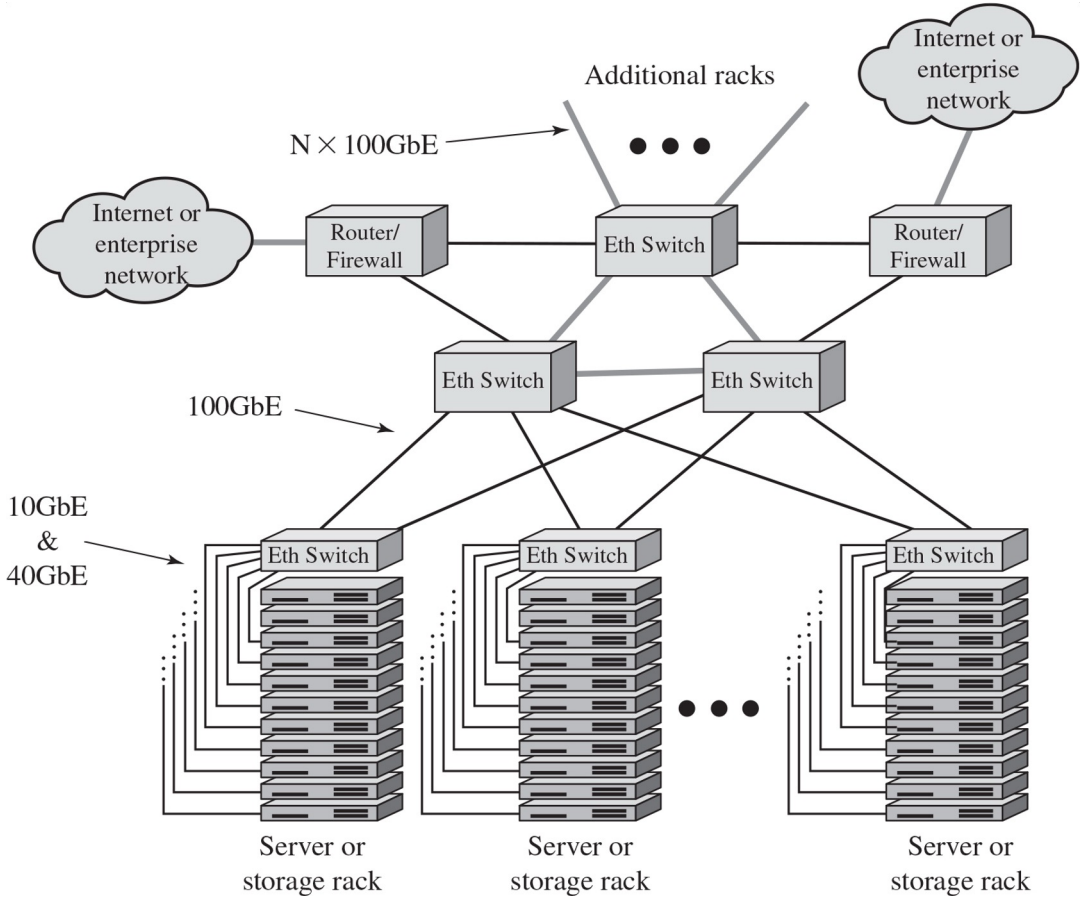
(1)

(12)

Large data centers are industrial scale operations using as much electricity as a small town.

A data center can occupy one room of a building, one or more floors, or an entire building.

Key Data Center Elements



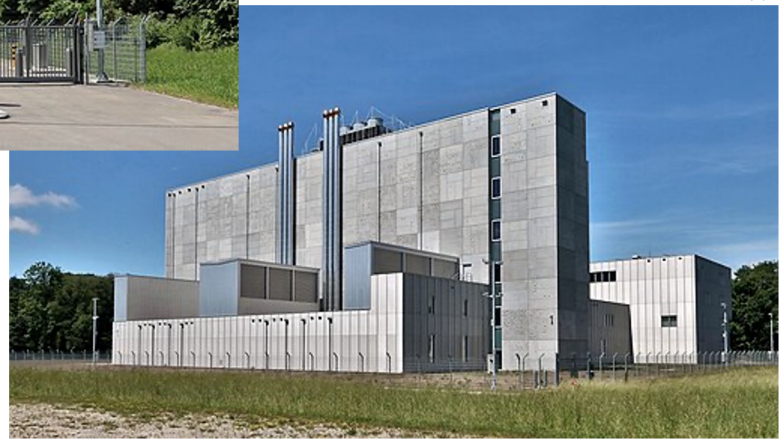
A Google Data Center, Taiwan

(5)

CAMPUS (Military) Data Center

(3)

(4)



Environment Controls

- Heating/Cooling
  - Raised Flooring
- Smoke detectors / Fire Suppression
- Moisture Detection
- Humidity Control (~30%)
  - Too Low: Static Discharge
  - Too High: Condensation
- Lightning (Surge) Protection
  - Lightening Rods / In-ground Grounding Mesh

(15)

(14)

Fire Suppression

(6)

(7)

(8)

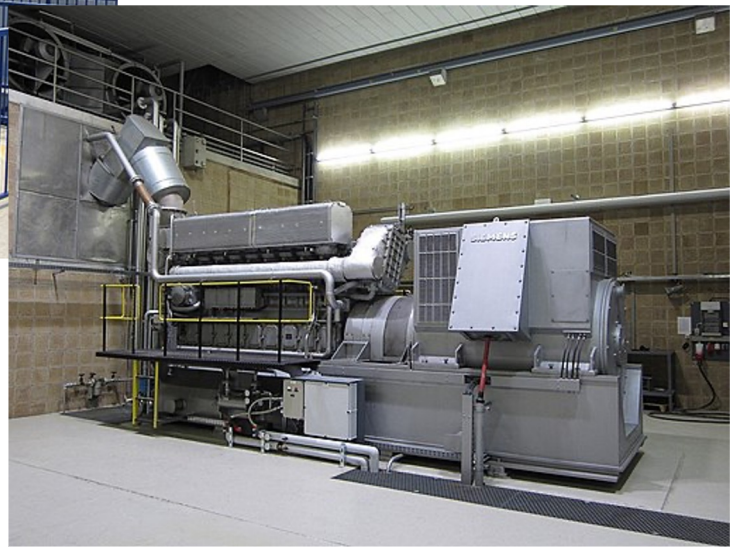
Redundancies

- Network/Communications
  - Multiple ISPs
- Electrical
  - Uninterruptible Power Supply (UPS)
  - Backup Generator
  - Long Term Fuel Supply Contracts
- Chemical Attack Resistance
  - Filtered Air
  - On-site Supplies for Personnel
- What if the data center is destroyed?
  - Backup Data Centers
  - Hot/Cold site
  - Minimum Capacity

Backup Generators

(11)

(10)



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Summary

- 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
- ~~Data center security~~