Australian National University

Week 9 Workshop - Database Security

Qing Wang

Zoom drop-in session: Friday 1pm-2pm (Week 9 to Week 12)
Board Room 4.15, Building 145

Research areas: Data management and analytics
Data mining
Graph machine learning
Graph algorithms

Australian National University

Graph Research Lab

(*https://graphlabanu.github.io/website/*)

Graph Research Lab @ ANU Home Team Research Projects Activities Tools&Dataset Vacancies Contact

Welcome to Graph Research Lab

We are a research team at the School of Computing, Australian National University. Our overarching research goal is to explore and understand graph-structured data. In today's real-world applications, graphs are ubiquitously used for representing complex objects and their relationships such as cities in a road network, atoms in a molecule, friendships in social networks, connections in computer networks, and links among web pages. We focus on the following research areas:

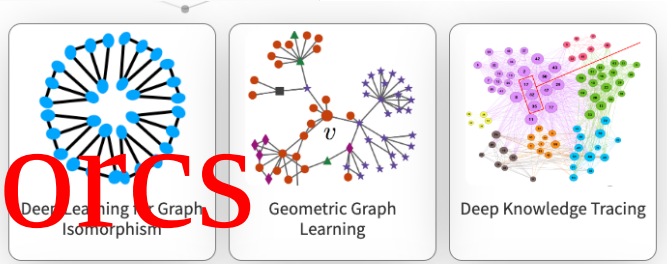
- Graph theory and algorithms
- Machine learning on graphs
- Bridging between graph theory and machine learning

Check out our recent research highlights and research opportunities.

News

10 Sep 2021
Ghodai's paper "Deep Graph Memory Networks for Forgetting-Robust Knowledge Tracing" is accepted for publication at TKDE.

20 June 2022
Buddhi will be joining us soon! Welcome!



House Keeping

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- All the labs on Oct 3 (Monday) this week will be moved to the same venues on Oct 10 (Monday) in Week 10.
- Lab 8 is optional and runs from Oct 11 to Oct 14 (Tuesday to Friday) next week. There is a separate sign-up page on the Wattle course site.

"Hardware is easy to protect: lock it in a room, chain it to a desk, or buy a spare. Information poses more of a problem. It can exist in more than one place; be transported halfway across the planet in seconds; and be stolen without your knowledge."

— Bruce Schneier

Data Breaches

- In 80% of cases, attackers are able to compromise an organization within minutes. However, in almost 60% of cases, it takes years to learn that they have been breached.[1]

Time-to-discovery within Public breaches (n=66)

[1] Verizon 2016&2017 Data Breach Investigation Reports

Data Breaches

Anna was ready to buy her first home - but then her details were leaked in the Optus data breach and everything changed

By Widia Jalal

Posted 16h ago, updated 10h ago

Optus customers affected by the data hack have been left to mitigate cyber security risks on their own. *(Unsplash: Elisa Ventur)*

Top Stories

Putin signs Russia's annexation of four Ukrainian regions into law

'Treated with disdain': Affected families query Hawthorn review's independence

McLachlan says AFL 'doing what we were asked' in naming panel to conduct Hawthorn review

Brittany Higgins told police she took pregnancy test after alleged rape

After tax U-turn, UK PM Liz Truss pledges to steer Britain through 'stormy days'

Nobel Prize goes to three chemists who made molecules 'click'

Alleged killers of Danielle Easey admitted their role in her death to friends, court told

Which banks are passing on the interest rates to borrowers? What

Data Breaches

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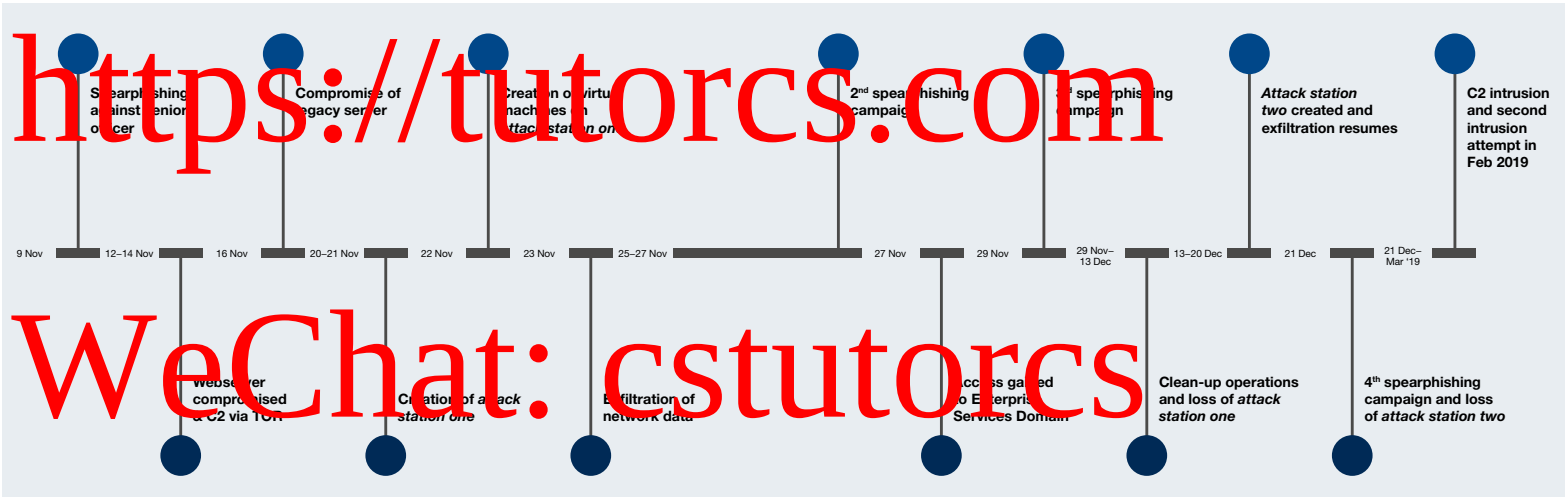
"It's shocking in its sophistication"



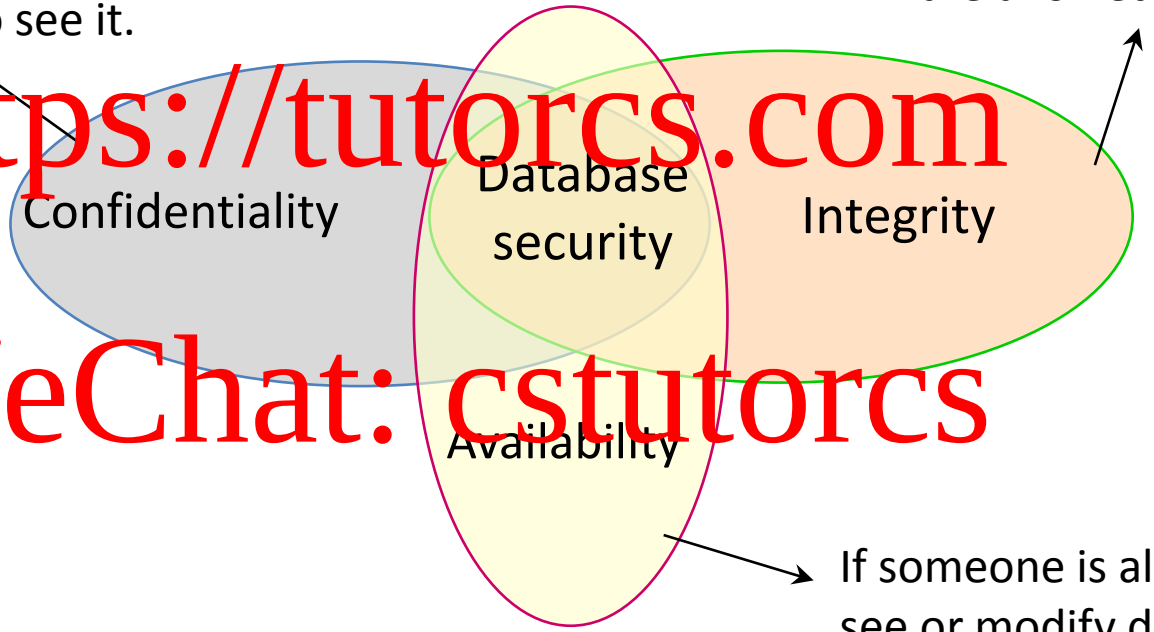
"While we cannot confirm exactly what data was taken, we know it was much less than the 19 years' worth we originally reported"

from VC's message - Release of the data breach incident report, 2nd October 2019

Objectives of Database Security

Data should only be shown to people who are allowed to see it.

Data should only be modified by people who are allowed to modify it.



If someone is allowed to see or modify data, they should be able to do so.

Database Security - Examples

1. *A health-care information system*

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Database Security - Core Services

- Confidentiality
- Integrity

- Availability

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  - E.g. enforced by access control mechanisms
- **Integrity**

- **Availability**

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Some further services

- **Encryption**: to protect data when being transmitted across systems and when being stored on secondary storage
- **Query authentication**: to ensure a query result is correct by using signature mechanisms and data structures
- ...

Access Control Mechanisms

Access Control Mechanisms

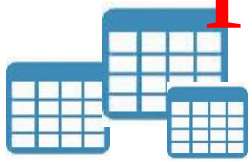
- Three types:
  1. Discretionary access control (DAC)
  2. Mandatory access control (MAC)
  3. Role-based access control (RBAC)

Database Security - DAC

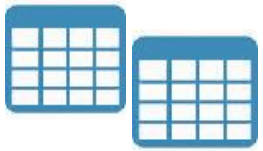
Your objects at your own discretion!

Grant privileges
Revoke privileges
Delegate privileges

Bob



Alice



Granting/Revoking/Delegating Privileges


```
GRANT privileges ON object TO users [WITH GRANT OPTION]
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- Possible privileges:
  - `SELECT`
  - `INSERT` and `INSERT` (column)
  - `UPDATE` and `UPDATE` (column)
  - `DELETE`
  - `REFERENCES` (column)
  - ...

Granting/Revoking/Delegating Privileges

- The privileges of an object can be given to a user with or without the `GRANT OPTION`


```
GRANT SELECT ON SUPPLIER TO Bob;
GRANT SELECT ON SUPPLIER TO Bob WITH GRANT OPTION;
```

Granting/Revoking/Delegating Privileges

- The privileges of an object can be given to a user with or without the `GRANT OPTION`


```
GRANT SELECT ON Supplier TO Bob;
GRANT SELECT ON Supplier TO Bob WITH GRANT OPTION;
```

- The privileges of an object can be taken away from a user. It is also possible to only revoke the `GRANT OPTION` on a privilege.


```
REVOKE SELECT ON Supplier FROM Bob;
REVOKE GRANT OPTION FOR SELECT ON Supplier FROM Bob;
```

Question

- In which situations a user can grant a privilege on an object to other users?
  (1) The user is the owner of the object.
  (2) The user has the privilege on the object without the `GRANT OPTION`.
  (3) The user is a superuser of the database.
  (4) The user has received the privilege with the `GRANT OPTION` from the owner of the object.

Example - Granting Privileges

- Alice owns table EMPLOYEE.

```
(Alice):  GRANT SELECT, INSERT ON Employee TO Bob WITH GRANT OPTION;
(Alice):  GRANT SELECT ON Employee TO Jane WITH GRANT OPTION;
(Alice):  GRANT INSERT ON Employee TO Jane;
  (Bob):  GRANT UPDATE ON Employee TO Tom WITH GRANT OPTION;
 (Jane):  GRANT SELECT, INSERT ON Employee TO Tom;
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(Jane):  GRANT SELECT, INSERT ON Employee TO Tom;
```

- Questions:
  1. What privilege(s) does Jane receive?

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```

- Questions:
  1. What privilege(s) does Jane receive?
  2. What privilege(s) does Tom receive?

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- Can these commands be executed?

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  - The first three are fully executed.

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- Can these commands be executed?
  - The first three are fully executed.
  - The fourth one is not executed, because Bob does not have the `UPDATE` privilege on the table.

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(Jane):   GRANT SELECT, INSERT ON Employee TO Tom;
```


- Can these commands be executed?

  - The first three are fully executed.
  - The fourth one is not executed, because Bob does not have the `UPDATE` privilege on the table.
  - The fifth one is partially executed because Jane has the `SELECT` and `INSERT` privileges but no `GRANT OPTION` for `INSERT`. Therefore, Tom only receives the `SELECT` privilege.

Granting/Revoking/Delegating Privileges

- A user can only revoke privileges that the user has granted earlier, with two optional keywords in the `REVOKE` command:
  - `CASCADE`: revoking the privilege from a specified user also revokes the privileges from all users who received the privilege from that user.
  - `RESTRICT`: revoking the privilege only from a specified user.

  Possible implementations:
  (1) Causing an error message in some DBMS if the revoked privilege is still delegated.
  (2) Revoking the privilege from the specified user in any case.

- If a user receives a certain privilege from multiple sources, and the user would lose the privilege only after all sources revoke this privilege.

Example - Revoking Privileges

- Again, Alice owns table EMPLOYEE:

```
(Alice):  GRANT SELECT ON Employee TO Bob WITH GRANT OPTION;
(Alice):  GRANT SELECT ON Employee TO Jane WITH GRANT OPTION;
  (Bob):  GRANT SELECT ON Employee TO Tom;
 (Jane):  GRANT SELECT ON Employee TO Tom;
  (Bob):  REVOKE SELECT ON Employee FROM Tom;
```


- Will Tom lose the SELECT privilege on EMPLOYEE?

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- Will Tom lose the SELECT privilege on EMPLOYEE?
  - Tom will still hold the SELECT privilege on EMPLOYEE, since he has independently obtained such privilege from Jane.

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```


- Will Tom lose the SELECT privilege on EMPLOYEE?
  - Tom will lose the SELECT privilege on EMPLOYEE.

Delegating Privileges - Propagation

- There are techniques to limit the propagation of privileges.
  - Limiting **horizontal propagation**: limits that a user that has been given the `GRANT OPTION` can grant the privilege to at most n other users;
  - Limiting **vertical propagation**: limits the depth of the granting privileges.
- How can we keep track of privilege propagation?

Privilege Propagation

- tuna owns

CITY(name, state, population)

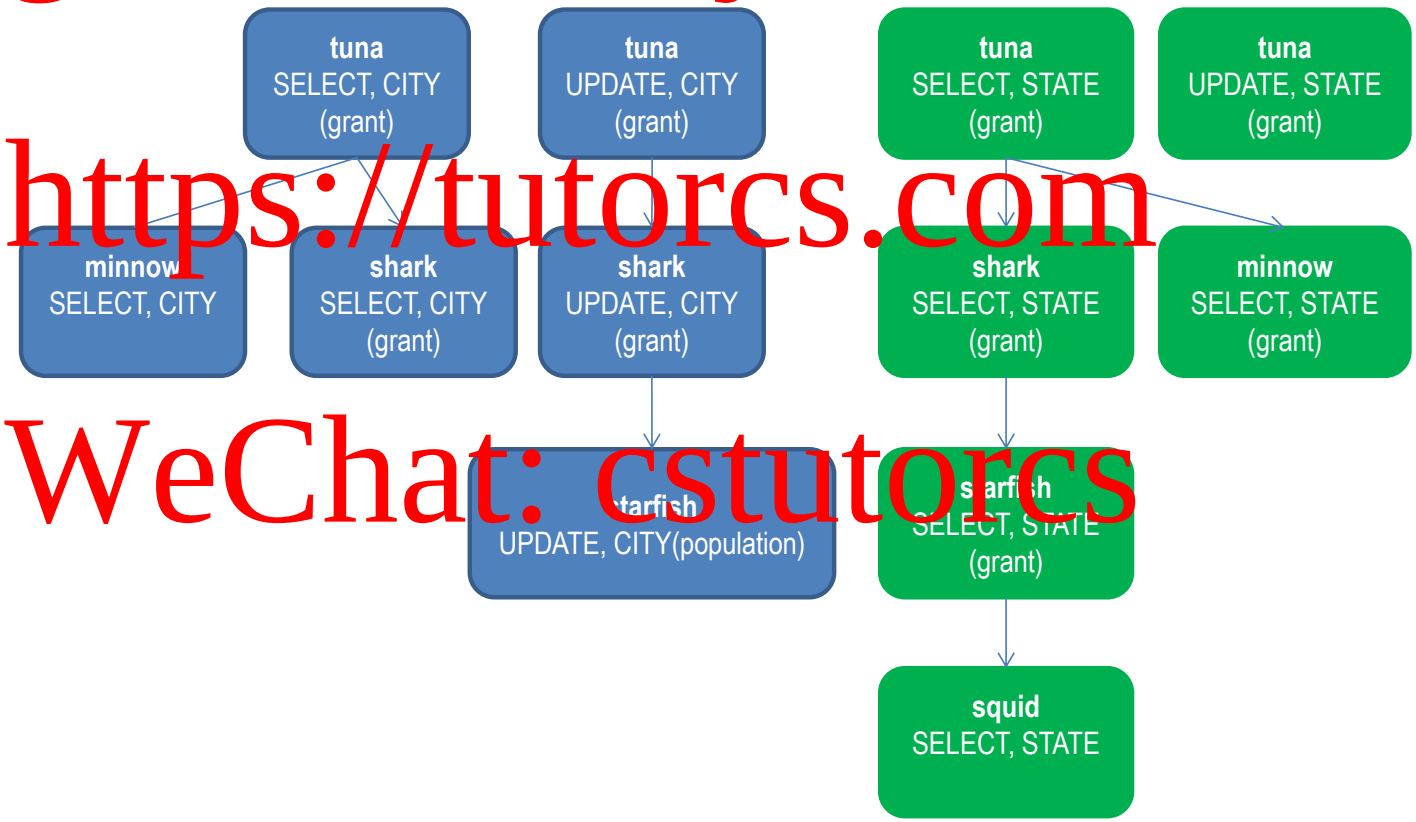
STATE(name, abbreviation, capital, area, population)

- The following commands are executed in order:

```
    (tuna):  GRANT SELECT, UPDATE ON City TO shark WITH GRANT OPTION;
    (tuna):  GRANT SELECT ON City TO minnow;
    (tuna):  GRANT SELECT ON State TO shark, minnow WITH GRANT OPTION;
   (shark):  GRANT SELECT ON State TO starfish WITH GRANT OPTION;
   (shark):  GRANT UPDATE (population) ON City TO starfish;
(starfish):  GRANT SELECT ON State TO squid;
   (shark):  ...
```

Privilege Propagation

- A grant graph can be used to keep track of privilege propagation.



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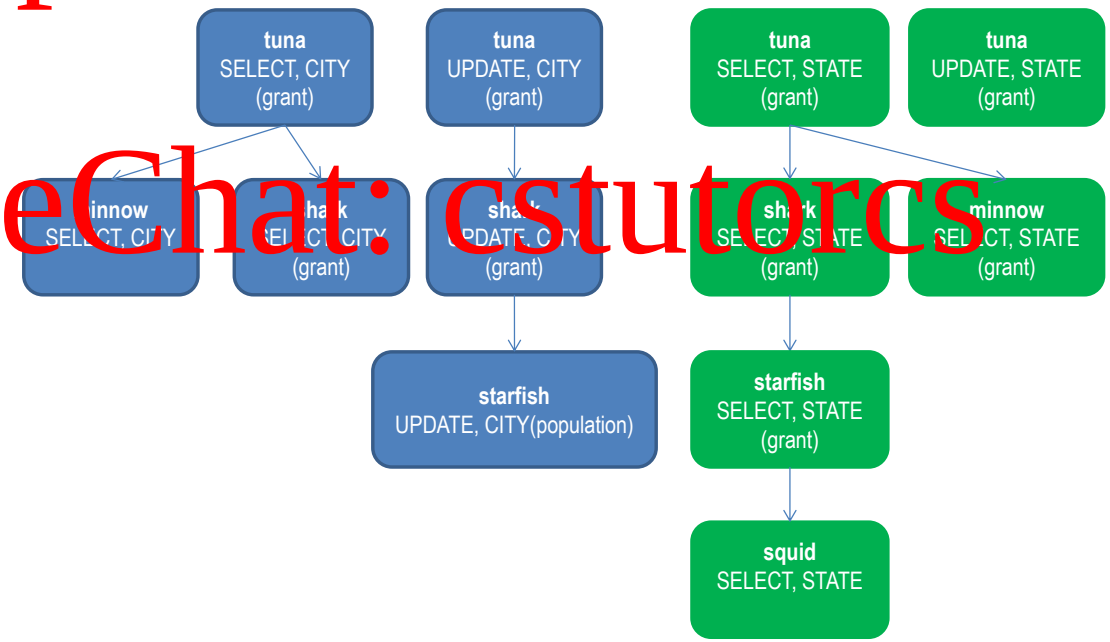
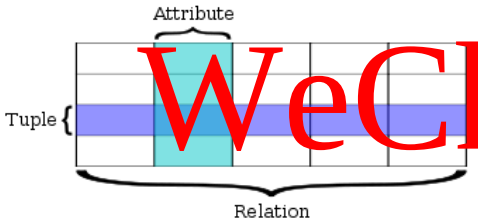


Using Views


```
CREATE VIEW view_name AS
  SELECT attribute_list
    FROM table_list
    ...
```


- Views can be used to create a "window" on a collection of data that is appropriate for some users to access.



Some examples:

1. To grant read access to some columns of a table, we can create a view that ...
2. To grant read access to some rows of a table, we can create a view that ...
3. There are more useful scenarios ...

Using Views

- EXAMS(CourseID, StudtID, Grade, Date)

(Tom): CREATE VIEW HardCourses AS
SELECT CourseID, AVG(Grade) AS Difficulty FROM EXAMS
GROUP BY CourseID
Having AVG(Grade)≤50;

(Tom): CREATE VIEW AllCourses AS
SELECT CourseID, Grade FROM EXAMS;

Database Security - DAC

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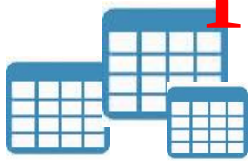

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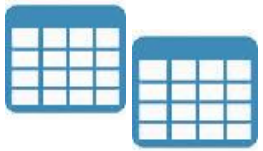

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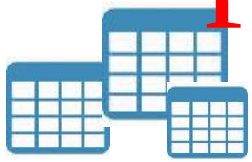

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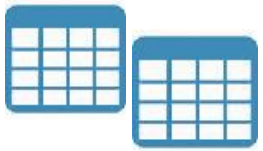

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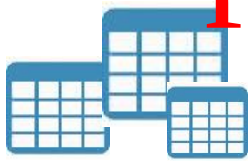

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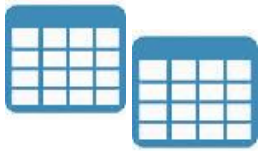

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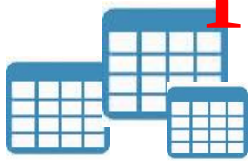

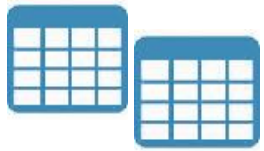

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- `GARNT SELECT ON` tableB `TO` Alice
  `WITH GRANT OPTION`;

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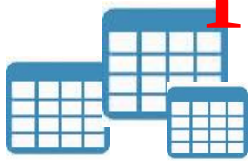

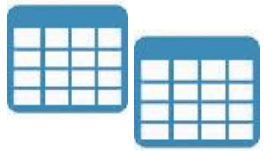

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Database Security - DAC

Your objects at your own discretion!

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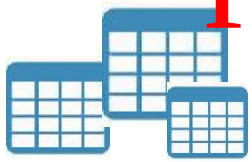

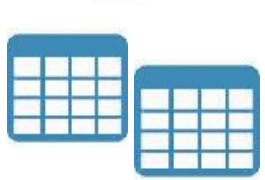

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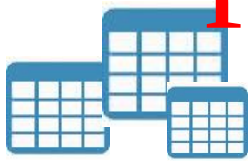

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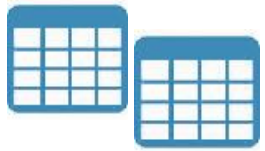

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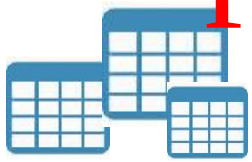

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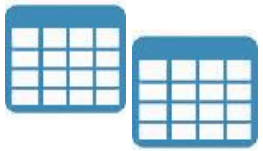

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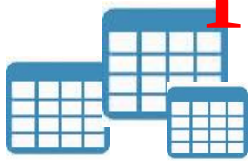

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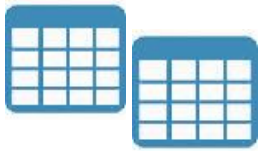

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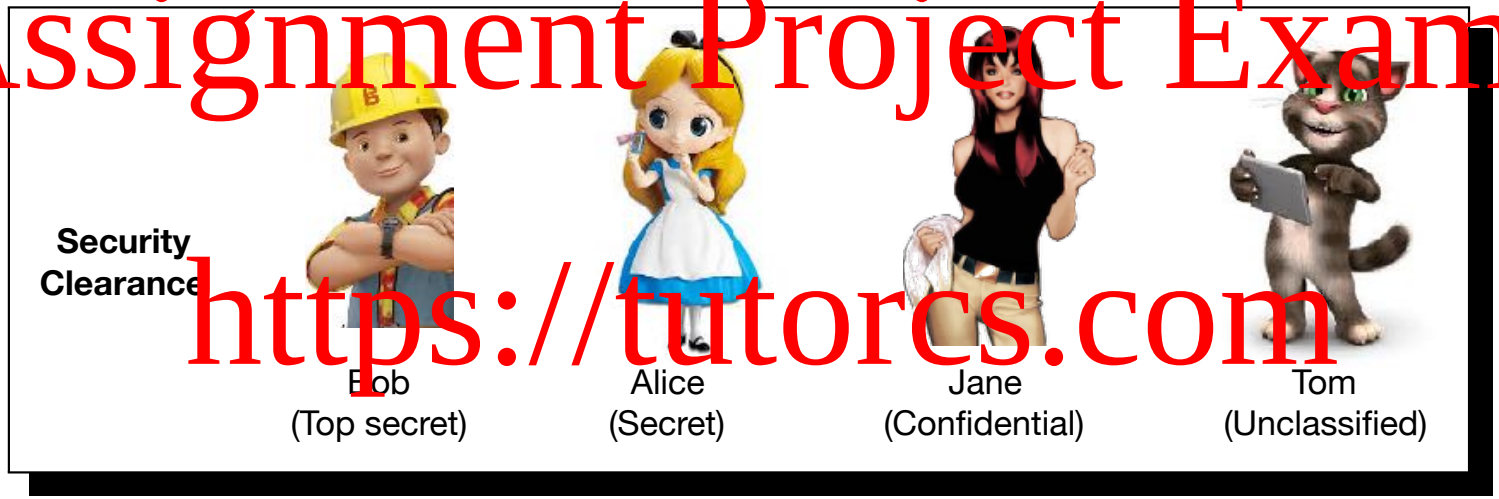
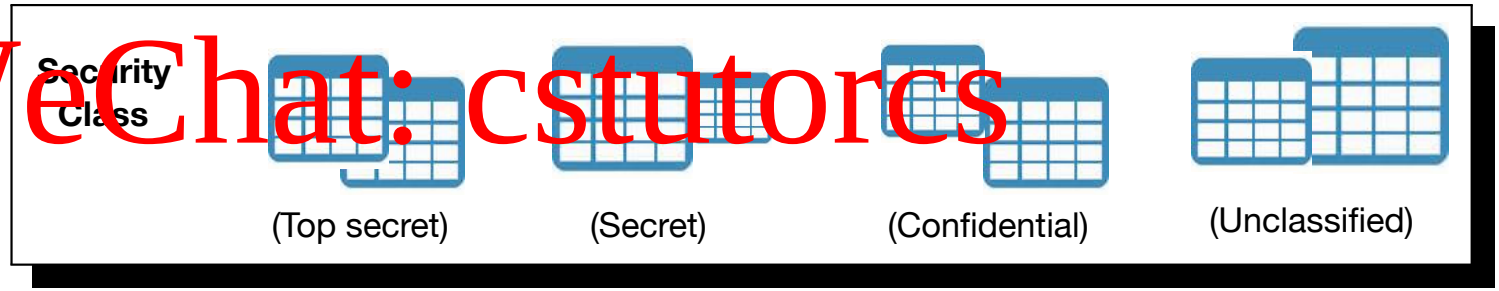
Database Security - MAC





System-wide policies govern controlled access to classified information.

Mandatory Access Control

- It is based the **Bell-LaPadula** model (originally developed for U.S. Department of Defense multilevel security policy).
  - Subjects (e.g. users) are assigned *security clearances*;
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1. Subject X can read object Y only if $clearance(X) \geq class(Y)$.
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- The key idea is "**preventing information in high level objects from flowing to low level subjects**".

Mandatory Access Control

- **Multilevel relations:** Assume that each row is assigned a security class. Then users with different security clearances see a different collection of rows when they access the same table.

city	rating	security class
Paris	4	secret (S)
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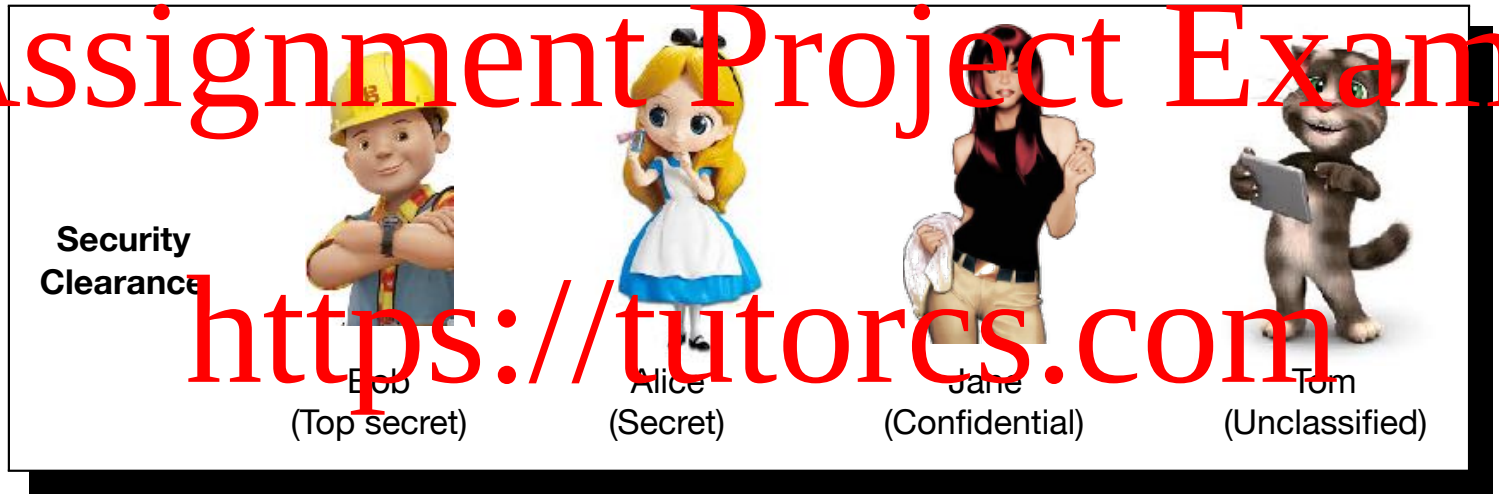
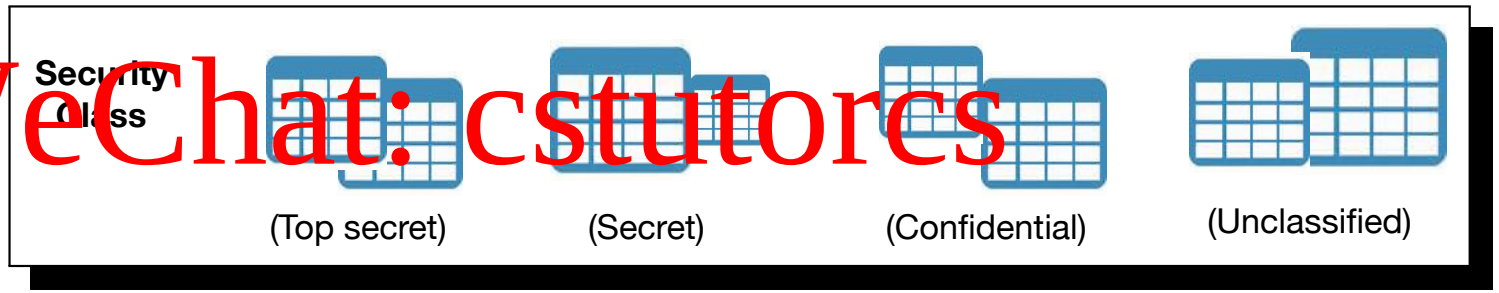
Database Security - MAC





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  - **MAC is comparatively rigid.**
    - The system decides how data is shared.
    - Each object is given a security class, and each user is given a security clearance.
    - An object can then be accessed by users with the appropriate clearance.
    - ...

DAC - Limitations

- Suppose that Alice owns a table *R*.
  - Alice gives Bob the `SELECT` privilege to read it, but not Steve. However, Steve may steal the information in *R* from Bob.
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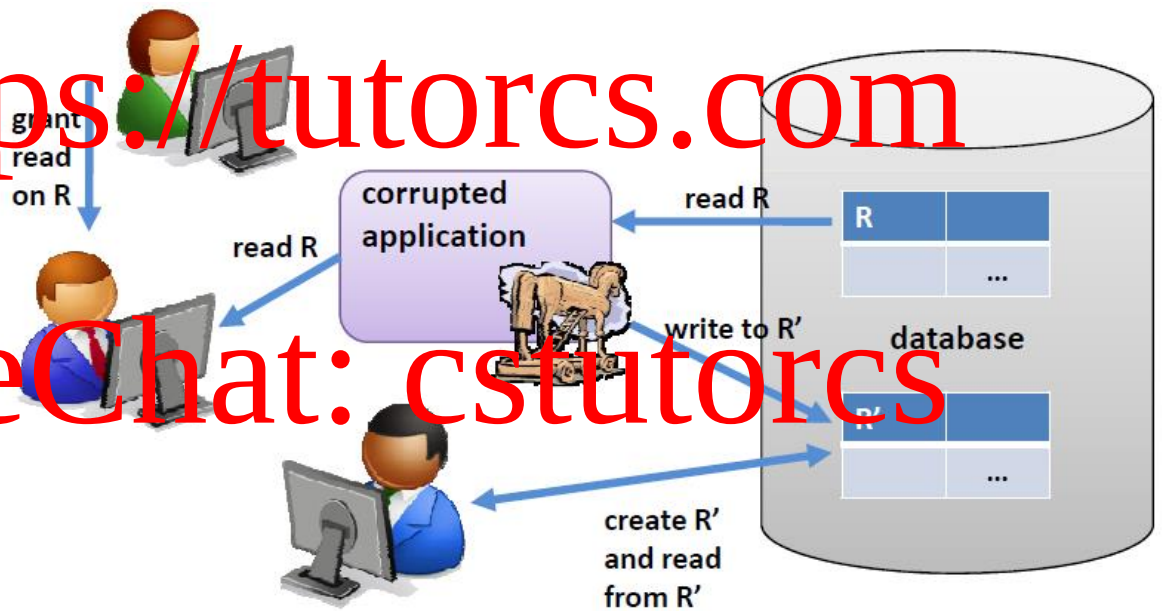
DAC - Limitations

- **Trojan Horse attacks**: If Steve tricks Bob into copying data from table *R* into table *R′*, then the access control on table *R* doesn't apply to the copy of the data in table *R′*.



- Can this problem occur in MAC?

DAC - Limitations

- DAC does not impose any restriction on the usage once data has been obtained by a user, i.e. the dissemination of data is not controlled.

- MAC prevents illegitimate flow of information by attaching security classes to objects and security clearances to subjects.

SQL Injection Attacks

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- How do web applications access a database?

1. Connect to the database;
2. Send SQL statements to the database; → **SQL Injection!**
3. Fetch the result and display data from the database;
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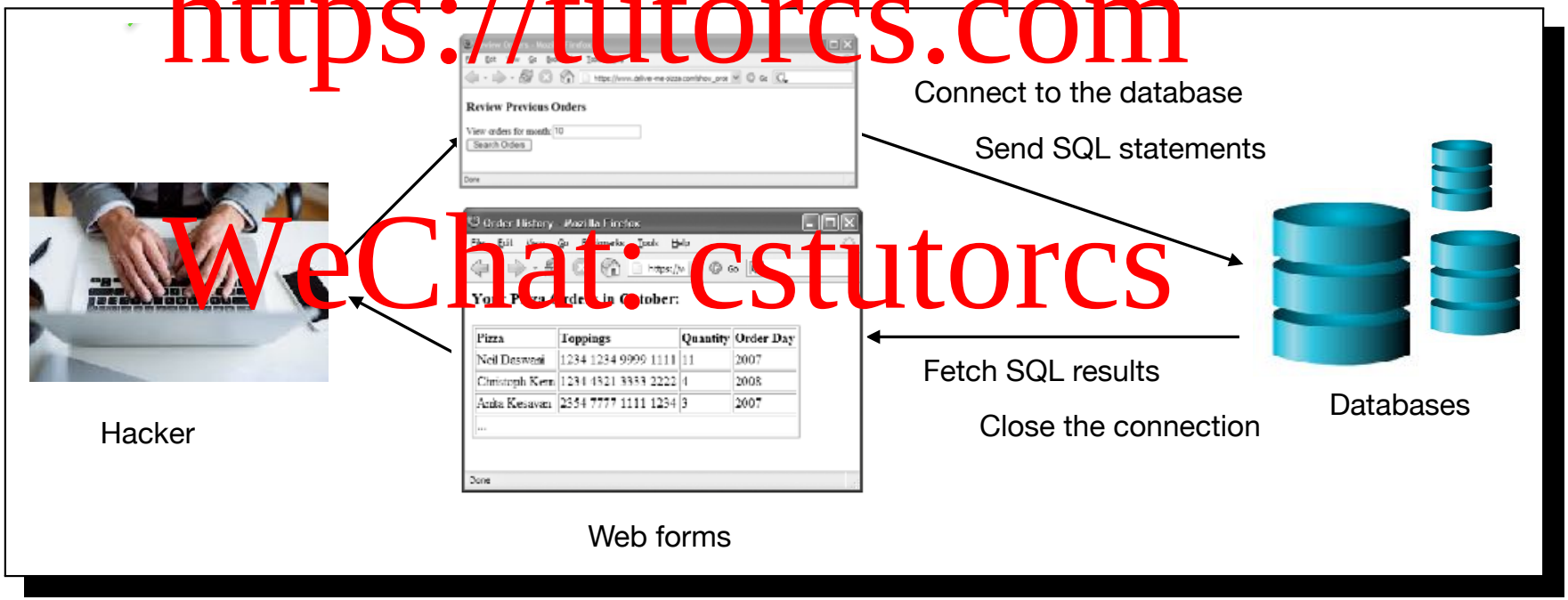
SQL Injection Attacks

- Many web applications take user input from a form.
- A user input is used in constructing a SQL query submitted to a database.
- A SQL injection attack involves manipulating queries through the user input.



SQL Injection - Example

- Consider a pizza-ordering application that allows users to review the orders they have made in a given month.

The pizza order review form

SQL Injection - Example

- When the form is submitted, it results in an HTTP request to the application:

https://www.deliver-me-pizza.com/show_orders?month=10

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- When receiving such a request, the application constructs an SQL query:

```
sql_query = "SELECT pizza, toppings, quantity, order_day "
          + "FROM orders "
          + "WHERE userid=" + session.getCurrentUserId() + " "
          + "AND order_month=" + request.getParameter("month");
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- Assuming that the current user's userid is 1234, we have:

```
SELECT pizza, toppings, quantity, order_day
  FROM orders
 WHERE userid=1234 AND order_month=10
```

SQL Injection - Example

- The application then executes the query and retrieves the result set.

Pizza order history

- How can this application be attacked?

SQL Injection - Example

- What would happen if an attacker replaces '10' with '0 OR 1=1'?

SQL Injection - Example

- What would happen if an attacker replaces '10' with '`0 OR 1=1`'?

- Alternatively, the attacker may modify the HTTP request, e.g.,

https://www.deliver-me-pizza.com/show_orders?month=0%20OR%201%3D1

Then request.getParameter("month") extracts '0%20*OR*%201%3*D*1' and returns the string '`0 OR 1=1`'.

SQL Injection - Example

- The SQL query that the application constructs and sends to the database now becomes:

```
SELECT pizza, toppings, quantity, order_day
  FROM orders
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- Since the operator precedence of the `AND` operator is higher than that of `OR`, the `WHERE` condition is equivalent to

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- What happened?

  The (malicious) user supplied a parameter that, once inserted into the SQL query string, actually altered the meaning of the query!

SQL Injection - Example

- However, the attacker might be able to do even more damage, e.g. making a request such that the request parameter month evaluates to:

```
0 AND 1=0
UNION
SELECT cardholder, number, exp_month, exp_year
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- Then, the SQL query that the application constructs and sends to the database becomes:


```
SELECT pizza, toppings, quantity, order_day
FROM orders
WHERE userid=4123 AND order_month=0 AND 1=0
UNION
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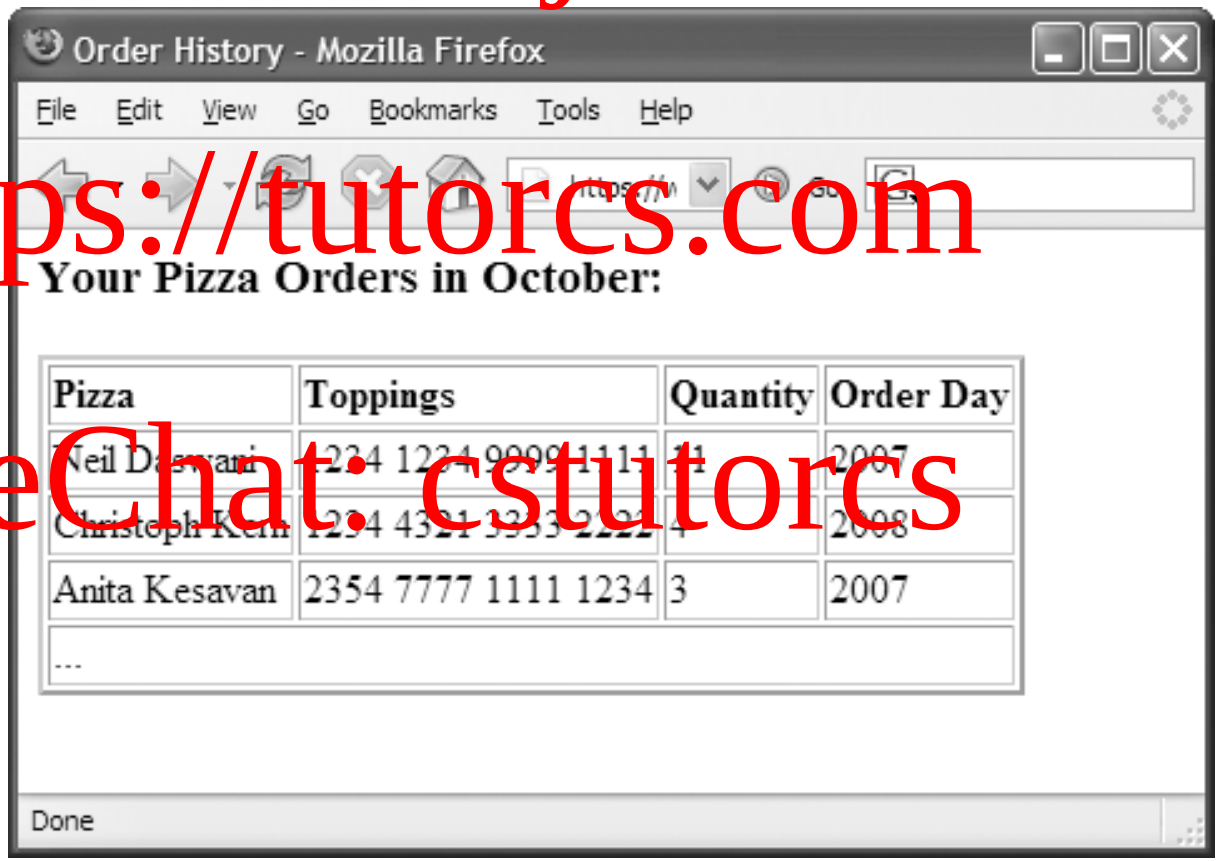
SQL Injection - Example

- As a result, the attacker receives an HTML page that contains the entire content of the creditcards table.



Pizzas ordered in October

SQL Injection Attacks

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3. **Authentication**

   i.e., the process by which a system can identify users

SQL Injection Attacks - Protection Techniques

- Several techniques of input validation:
  - **Blacklisting**?

    i.e., blacklist quotes, semicolons, etc. from the input string. However, if you forget to blacklist just one type of dangerous character, it could give rise to a successful attack.

  - **Whitelisting**?

    i.e., explicitly test whether a given input is within a well-defined set of values that are known to be safe, e.g., the parameter month is a string that represents a non-negative integer.

  - **Escaping**?

    i.e., transform dangerous input characters to turn a potentially dangerous input string into a sanitized one, e.g., escape(o‘connor)= o“connor (the double quote is the escaped version of the single quote).

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  1. The statement is prepared (parsed and compiled), in which ? is used as place-holders of the actual parameters.

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  1. The statement is prepared (parsed and compiled), in which ? is used as place-holders of the actual parameters.


```
PreparedStatement stmt=conn.prepareStatement(
    "SELECT pizza, toppings, quantity, order_day "
    + "FROM orders WHERE userid=? AND order_month=?");
```


  2. The actual parameters are passed to the prepared statement for execution.

```
stmt.setInt(1, session.getCurrentUserId());
stmt.setInt(2, Integer.parseInt(request.getParamenter("month")));

ResultSet res = ps.executeQuery();
```

Research Topics

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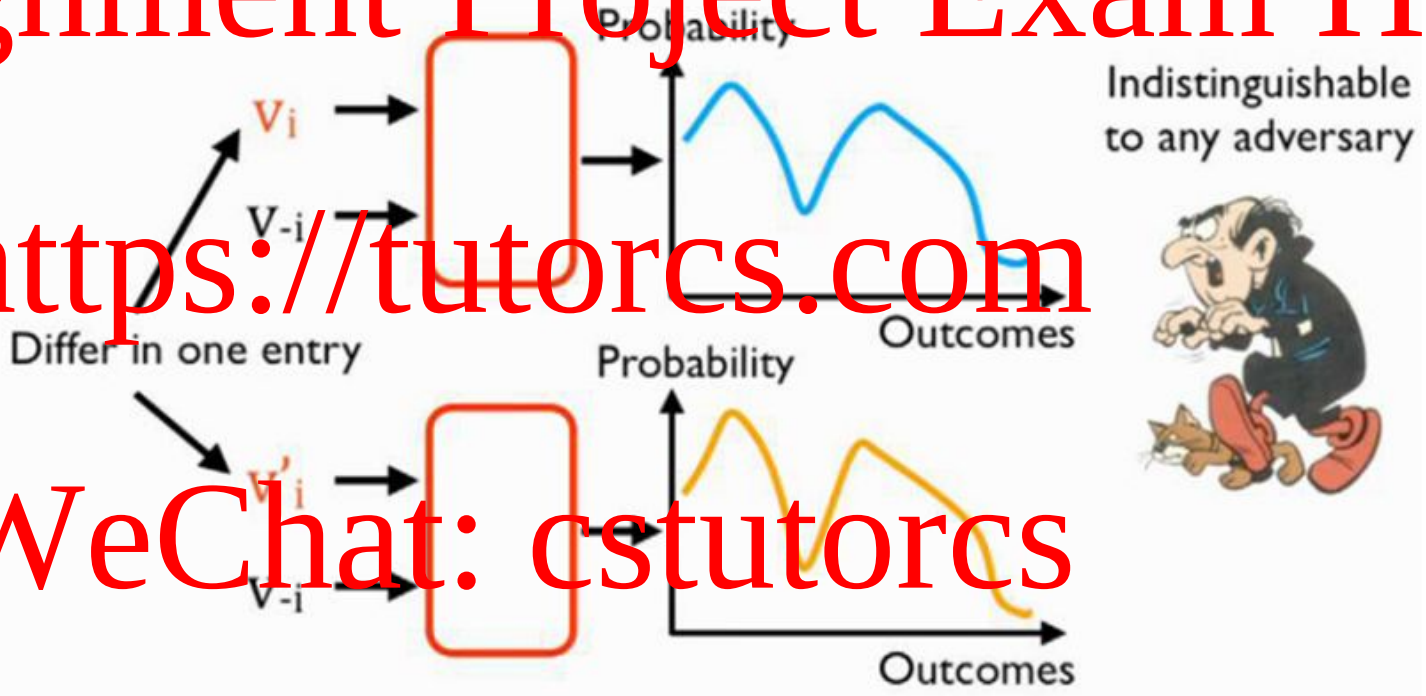
- Differential privacy



- What Apple's differential privacy means for your data and the future machine learning: *https://techcrunch.com/2016/06/14/differential-privacy/*
- Learning with privacy at scale: *https://machinelearning.apple.com/research/learning-with-privacy-at-scale*