Chapter 6: Integrity and Security

- Domain Constraints
- Referential Integrity
- Assertions
- Triggers
- Security
- Authorization
- Authorization in SQL

Domain Constraints

- Integrity constraints guard against accidental damage to the database, by ensuring that authorized changes to the database do not result in a loss of data consistency.
- Domain constraints are the most elementary form of integrity constraint.
- They test values inserted in the database, and test queries to ensure that the comparisons make sense.
- New domains can be created from existing data types
  - E.g. **create domain** *Dollars* **numeric**(12, 2)
    create domain *Pounds* **numeric**(12,2)
- We cannot assign or compare a value of type Dollars to a value of type Pounds.
  - However, we can convert type as below
    (**cast** *r.A* **as** *Pounds*)
    (Should also multiply by the dollar-to-pound conversion-rate)

Domain Constraints (Cont.)

- The **check** clause in SQL-92 permits domains to be restricted:
  - Use **check** clause to ensure that an hourly-wage domain allows only values greater than a specified value.
    create domain *hourly-wage* **numeric(5,2)**
    constraint *value-test* **check**(*value* > = 4.00)
  - The domain has a constraint that ensures that the hourly-wage is greater than 4.00
  - The clause **constraint** *value-test* is optional; useful to indicate which constraint an update violated.
- Can have complex conditions in domain check
  - **create domain** *AccountType* **char**(10)
    constraint *account-type-test*
    check (**value in** ('Checking', 'Saving'))
  - **check** (*branch-name* **in** (**select** *branch-name* **from** *branch*))

Referential Integrity

- Ensures that a value that appears in one relation for a given set of attributes also appears for a certain set of attributes in another relation.
  - Example: If "Perryridge" is a branch name appearing in one of the tuples in the *account* relation, then there exists a tuple in the *branch* relation for branch "Perryridge".
- Formal Definition
  - Let $r_1(R_1)$ and $r_2(R_2)$ be relations with primary keys K_1 and K_2 respectively.
  - The subset α of R_2 is a ***foreign key*** referencing K_1 in relation r_1, if for every t_2 in r_2 there must be a tuple t_1 in r_1 such that $t_1[K_1] = t_2[\alpha]$.
  - Referential integrity constraint also called subset dependency since its can be written as
    $\Pi_\alpha (r_2) \subseteq \Pi_{K1} (r_1)$

Referential Integrity in the E-R Model

- Consider relationship set R between entity sets E_1 and E_2. The relational schema for R includes the primary keys K_1 of E_1 and K_2 of E_2.
  Then K_1 and K_2 form foreign keys on the relational schemas for E_1 and E_2 respectively.

- Weak entity sets are also a source of referential integrity constraints.
  - For the relation schema for a weak entity set must include the primary key attributes of the entity set on which it depends

Checking Referential Integrity on Database Modification

- The following tests must be made in order to preserve the following referential integrity constraint:

$$\Pi_\alpha (r_2) \subseteq \Pi_K (r_1)$$

- **Insert.** If a tuple t_2 is inserted into r_2, the system must ensure that there is a tuple t_1 in r_1 such that $t_1[K] = t_2[\alpha]$. That is

$$t_2 [\alpha] \in \Pi_K (r_1)$$

- **Delete.** If a tuple, t_1 is deleted from r_1, the system must compute the set of tuples in r_2 that reference t_1:

$$\sigma_{\alpha = t1[K]} (r_2)$$

  If this set is not empty
  - either the delete command is rejected as an error, or
  - the tuples that reference t_1 must themselves be deleted (cascading deletions are possible).

Database Modification (Cont.)

- **Update.** There are two cases:
  - If a tuple t_2 is updated in relation r_2 and the update modifies values for foreign key α, then a test similar to the insert case is made:
    - Let t_2' denote the new value of tuple t_2. The system must ensure that

      $t_2'[\alpha] \in \Pi_K(r_1)$
  - If a tuple t_1 is updated in r_1, and the update modifies values for the primary key (K), then a test similar to the delete case is made:
    1. The system must compute
       $\sigma_{\alpha = t1[K]} (r_2)$
       using the old value of t_1 (the value before the update is applied).
    2. If this set is not empty
       1. the update may be rejected as an error, or
       2. the update may be cascaded to the tuples in the set, or
       3. the tuples in the set may be deleted.

Referential Integrity in SQL

- Primary and candidate keys and foreign keys can be specified as part of the SQL **create table** statement:
  - The **primary key** clause lists attributes that comprise the primary key.
  - The **unique key** clause lists attributes that comprise a candidate key.
  - The **foreign key** clause lists the attributes that comprise the foreign key and the name of the relation referenced by the foreign key.
- By default, a foreign key references the primary key attributes of the referenced table
  foreign key (*account-number*) **references** *account*
- Short form for specifying a single column as foreign key
  account-number **char** (10) **references** *account*
- Reference columns in the referenced table can be explicitly specified
  - but must be declared as primary/candidate keys
    foreign key (*account-number*) **references** *account*(*account-number*)

Referential Integrity in SQL – Example

create table *customer*
(*customer-name* char(20),
customer-street char(30),
customer-city char(30),
primary key (*customer-name*))

create table *branch*
(branch-name char(15),
branch-city char(30),
assets integer,
primary key (*branch-name*))

Referential Integrity in SQL – Example (Cont.)

create table *account*
(*account-number* char(10),
branch-name char(15),
balance integer,
primary key (*account-number*),
foreign key (*branch-name*) **references** *branch*)

create table *depositor*
(*customer-name* char(20),
account-number char(10),
primary key (*customer-name, account-number*),
foreign key (*account-number*) **references** *account*,
foreign key (*customer-name*) **references** *customer*)

Cascading Actions in SQL

create table *account*
. . .
foreign key(*branch-name*) **references** *branch*
on delete cascade
on update cascade
. . .)

- Due to the **on delete cascade** clauses, if a delete of a tuple in *branch* results in referential-integrity constraint violation, the delete "cascades" to the *account* relation, deleting the tuple that refers to the branch that was deleted.
- Cascading updates are similar.

Cascading Actions in SQL (Cont.)

- If there is a chain of foreign-key dependencies across multiple relations, with **on delete cascade** specified for each dependency, a deletion or update at one end of the chain can propagate across the entire chain.
- If a cascading update to delete causes a constraint violation that cannot be handled by a further cascading operation, the system aborts the transaction.
  - As a result, all the changes caused by the transaction and its cascading actions are undone.
- Referential integrity is only checked at the end of a transaction
  - Intermediate steps are allowed to violate referential integrity provided later steps remove the violation
  - Otherwise it would be impossible to create some database states, e.g. insert two tuples whose foreign keys point to each other
    - E.g. *spouse* attribute of relation *marriedperson(name, address, spouse)*

Referential Integrity in SQL (Cont.)

- Alternative to cascading:
  - **on delete set null**
  - **on delete set default**
- Null values in foreign key attributes complicate SQL referential integrity semantics, and are best prevented using **not null**
  - if any attribute of a foreign key is null, the tuple is defined to satisfy the foreign key constraint!

Assertions

- An *assertion* is a predicate expressing a condition that we wish the database always to satisfy.
- An assertion in SQL takes the form

  create assertion <assertion-name> **check** <predicate>
- When an assertion is made, the system tests it for validity, and tests it again on every update that may violate the assertion
  - This testing may introduce a significant amount of overhead; hence assertions should be used with great care.
- Asserting
  for all X, P(X)
  is achieved in a round-about fashion using
  not exists X such that not P(X)

Assertion Example

- The sum of all loan amounts for each branch must be less than the sum of all account balances at the branch.

create assertion *sum-constraint* **check**
(**not exists** (**select** * **from** *branch*
where (**select sum**(*amount*) **from** *loan*
where *loan.branch-name* =
branch.branch-name)
>= (**select sum**(*amount*) **from** *account*
where *loan.branch-name* =
branch.branch-name)))

Assertion Example

- Every loan has at least one borrower who maintains an account with a minimum balance or $1000.00

create assertion *balance-constraint* **check**
(**not exists** (
select * **from** *loan*
where not exists (
select *
from *borrower, depositor, account*
where *loan.loan-number* = *borrower.loan-number*
and *borrower.customer-name* = *depositor.customer-name*
and *depositor.account-number* = *account.account-number*
and *account.balance* >= 1000)))

Triggers

- A **trigger** is a statement that is executed automatically by the system as a side effect of a modification to the database.
- To design a trigger mechanism, we must:
  - Specify the conditions under which the trigger is to be executed.
  - Specify the actions to be taken when the trigger executes.
- Triggers introduced to SQL standard in SQL:1999, but supported even earlier using non-standard syntax by most databases.

Trigger Example

- Suppose that instead of allowing negative account balances, the bank deals with overdrafts by
  - setting the account balance to zero
  - creating a loan in the amount of the overdraft
  - giving this loan a loan number identical to the account number of the overdrawn account
- The condition for executing the trigger is an update to the *account* relation that results in a negative *balance* value.

Trigger Example in SQL:1999

```
create trigger overdraft-trigger after update on account
referencing new row as nrow
for each row
when nrow.balance < 0
begin atomic
      insert into borrower
         (select customer-name, account-number
          from depositor
          where nrow.account-number =
                   depositor.account-number);
      insert into loan values
         (n.row.account-number, nrow.branch-name,
                                    – nrow.balance);
      update account set balance = 0
      where account.account-number = nrow.account-number
end
```


Triggering Events and Actions in SQL

- Triggering event can be **insert**, **delete** or **update**
- Triggers on update can be restricted to specific attributes
  - **E.g. create trigger** *overdraft-trigger* **after update of** *balance* **on** *account*
- Values of attributes before and after an update can be referenced
  - **referencing old row as** : for deletes and updates
  - **referencing new row as** : for inserts and updates
- Triggers can be activated before an event, which can serve as extra constraints. E.g. convert blanks to null.

```
create trigger setnull-trigger before update on r
referencing new row as nrow
for each row
   when nrow.phone-number = ' '
   set nrow.phone-number = null
```


Statement Level Triggers

- Instead of executing a separate action for each affected row, a single action can be executed for all rows affected by a transaction
  - Use **for each statement** instead of **for each row**
  - Use **referencing old table** or **referencing new table** to refer to temporary tables (called ***transition tables***) containing the affected rows
  - Can be more efficient when dealing with SQL statements that update a large number of rows

External World Actions

- We sometimes require external world actions to be triggered on a database update
  - E.g. re-ordering an item whose quantity in a warehouse has become small, or turning on an alarm light,
- Triggers cannot be used to directly implement external-world actions, BUT
  - Triggers can be used to record actions-to-be-taken in a separate table
  - Have an external process that repeatedly scans the table, carries out external-world actions and deletes action from table
- E.g. Suppose a warehouse has the following tables
  - *inventory(item, level)*: How much of each item is in the warehouse
  - *minlevel(item, level)* : What is the minimum desired level of each item
  - *reorder(item, amount)*: What quantity should we re-order at a time
  - *orders(item, amount)* : Orders to be placed (read by external process)

External World Actions (Cont.)

```
create trigger reorder-trigger after update of amount on inventory
referencing old row as orow, new row as nrow
for each row
    when nrow.level < = (select level
                         from minlevel
                         where minlevel.item = orow.item)
        and orow.level > (select level
                          from minlevel
                          where minlevel.item = orow.item)
  begin
      insert into orders
         (select item, amount
          from reorder
          where reorder.item = orow.item)
  end
```


Triggers in MS-SQLServer Syntax

```
create trigger overdraft-trigger on account
for update
as
if inserted.balance < 0
begin
   insert into borrower
      (select customer-name,account-number
       from depositor, inserted
       where inserted.account-number =
                depositor.account-number)
   insert into loan values
      (inserted.account-number, inserted.branch-name,
                         – inserted.balance)
   update account set balance = 0
    from account, inserted
    where account.account-number = inserted.account-number
end
```

When Not To Use Triggers

- Triggers were used earlier for tasks such as
  - maintaining summary data (e.g. total salary of each department)
  - Replicating databases by recording changes to special relations (called **change** or **delta** relations) and having a separate process that applies the changes over to a replica
- There are better ways of doing these now:
  - Databases today provide built in materialized view facilities to maintain summary data
  - Databases provide built-in support for replication
- Encapsulation facilities can be used instead of triggers in many cases
  - Define methods to update fields
  - Carry out actions as part of the update methods instead of through a trigger

Security

- **Security** - protection from malicious attempts to steal or modify data.
  - Database system level
    - Authentication and authorization mechanisms to allow specific users access only to required data
    - We concentrate on authorization in the rest of this chapter
  - Operating system level
    - Operating system super-users can do anything they want to the database! Good operating system level security is required.
  - Network level: must use encryption to prevent
    - Eavesdropping (unauthorized reading of messages)
    - Masquerading (pretending to be an authorized user or sending messages supposedly from authorized users)

Security (Cont.)

- Physical level
  - Physical access to computers allows destruction of data by intruders; traditional lock-and-key security is needed
  - Computers must also be protected from floods, fire, etc.
    - More in Chapter 17 (Recovery)
- Human level
  - Users must be screened to ensure that an authorized users do not give access to intruders
  - Users should be trained on password selection and secrecy

Authorization

Forms of authorization on parts of the database:

- **Read authorization** - allows reading, but not modification of data.
- **Insert authorization** - allows insertion of new data, but not modification of existing data.
- **Update authorization** - allows modification, but not deletion of data.
- **Delete authorization** - allows deletion of data

Authorization (Cont.)

Forms of authorization to modify the database schema:

- **Index authorization** - allows creation and deletion of indices.
- **Resources authorization** - allows creation of new relations.
- **Alteration authorization** - allows addition or deletion of attributes in a relation.
- **Drop authorization** - allows deletion of relations.

Authorization and Views

- Users can be given authorization on views, without being given any authorization on the relations used in the view definition
- Ability of views to hide data serves both to simplify usage of the system and to enhance security by allowing users access only to data they need for their job
- A combination or relational-level security and view-level security can be used to limit a user's access to precisely the data that user needs.

View Example

- Suppose a bank clerk needs to know the names of the customers of each branch, but is not authorized to see specific loan information.
  - Approach: Deny direct access to the *loan* relation, but grant access to the view *cust-loan*, which consists only of the names of customers and the branches at which they have a loan.
  - The *cust-loan* view is defined in SQL as follows:

    create view *cust-loan* **as**
    select *branchname*, *customer-name*
    from *borrower, loan*
    where *borrower.loan-number* = *loan.loan-number*

View Example (Cont.)

- The clerk is authorized to see the result of the query:

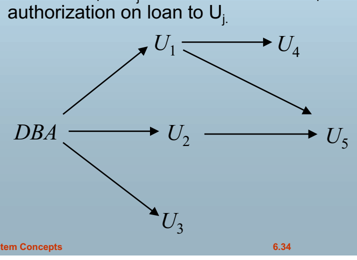
  select *
  from *cust-loan*
- When the query processor translates the result into a query on the actual relations in the database, we obtain a query on *borrower* and *loan*.
- Authorization must be checked on the clerk's query before query processing replaces a view by the definition of the view.

Authorization on Views

- Creation of view does not require **resources** authorization since no real relation is being created
- The creator of a view gets only those privileges that provide no additional authorization beyond that he already had.
- E.g. if creator of view *cust-loan* had only **read** authorization on *borrower* and *loan*, he gets only **read** authorization on *cust-loan*

Granting of Privileges

- The passage of authorization from one user to another may be represented by an authorization graph.
- The nodes of this graph are the users.
- The root of the graph is the database administrator.
- Consider graph for update authorization on loan.
- An edge $U_i \rightarrow U_j$ indicates that user U_i has granted update authorization on loan to U_j.



Authorization Grant Graph

- *Requirement*: All edges in an authorization graph must be part of some path originating with the database administrator
- If DBA revokes grant from U_1:
  - Grant must be revoked from U_4 since U_1 no longer has authorization
  - Grant must not be revoked from U_5 since U_5 has another authorization path from DBA through U_2
- Must prevent cycles of grants with no path from the root:
  - DBA grants authorization to U_7
  - U7 grants authorization to U_8
  - U8 grants authorization to U_7
  - DBA revokes authorization from U_7
- Must revoke grant U_7 to U_8 and from U_8 to U_7 since there is no path from DBA to U_7 or to U_8 anymore.

Security Specification in SQL

- The grant statement is used to confer authorization

  grant <privilege list>

  on <relation name or view name> to <user list>
- <user list> is:
  - a user-id
  - *public*, which allows all valid users the privilege granted
  - A role (more on this later)
- Granting a privilege on a view does not imply granting any privileges on the underlying relations.
- The grantor of the privilege must already hold the privilege on the specified item (or be the database administrator).

Privileges in SQL

- **select:** allows read access to relation,or the ability to query using the view
  - Example: grant users U_1, U_2, and U_3 **select** authorization on the *branch* relation:

    grant select on *branch* **to** U_1, U_2, U_3
- **insert**: the ability to insert tuples
- **update**: the ability to update using the SQL update statement
- **delete**: the ability to delete tuples.
- **references**: ability to declare foreign keys when creating relations.
- **usage**: In SQL-92; authorizes a user to use a specified domain
- **all privileges**: used as a short form for all the allowable privileges

Privilege To Grant Privileges

- **with grant option**: allows a user who is granted a privilege to pass the privilege on to other users.
  - Example:

    grant select on *branch* **to** U_1 **with grant option**

    gives U_1 the **select** privileges on branch and allows U_1 to grant this privilege to others

Roles

- Roles permit common privileges for a class of users can be specified just once by creating a corresponding "role"
- Privileges can be granted to or revoked from roles, just like user
- Roles can be assigned to users, and even to other roles
- SQL:1999 supports roles

  create role *teller*
  create role *manager*

  grant select on *branch* **to** *teller*
  grant update (*balance*) **on** *account* **to** *teller*
  grant all privileges on *account* **to** *manager*

  grant *teller* **to** *manager*

  grant *teller* **to** *alice, bob*
  grant *manager* **to** *avi*

Revoking Authorization in SQL

- The **revoke** statement is used to revoke authorization.

  revoke<privilege list>

  on <relation name or view name> **from** <user list> [**restrict**|**cascade**]
- Example:

  revoke select on *branch* **from** U_1, U_2, U_3 **cascade**
- Revocation of a privilege from a user may cause other users also to lose that privilege; referred to as cascading of the **revoke**.
- We can prevent cascading by specifying **restrict**:

  revoke select on *branch* **from** U_1, U_2, U_3 **restrict**

  With **restrict**, the **revoke** command fails if cascading revokes are required.

Revoking Authorization in SQL (Cont.)

- <privilege-list> may be **all to** revoke all privileges the revokee may hold.
- If <revokee-list> includes **public** all users lose the privilege except those granted it explicitly.
- If the same privilege was granted twice to the same user by different grantees, the user may retain the privilege after the revocation.
- All privileges that depend on the privilege being revoked are also revoked.

Limitations of SQL Authorization

- SQL does not support authorization at a tuple level
  - E.g. we cannot restrict students to see only (the tuples storing) their own grades
- With the growth in Web access to databases, database accesses come primarily from application servers.
  - End users don't have database user ids, they are all mapped to the same database user id
- All end-users of an application (such as a web application) may be mapped to a single database user
- The task of authorization in above cases falls on the application program, with no support from SQL
  - Benefit: fine grained authorizations, such as to individual tuples, can be implemented by the application.
  - Drawback: Authorization must be done in application code, and may be dispersed all over an application
  - Checking for absence of authorization loopholes becomes very difficult since it requires reading large amounts of application code

Audit Trails

- An audit trail is a log of all changes (inserts/deletes/updates) to the database along with information such as which user performed the change, and when the change was performed.
- Used to track erroneous/fraudulent updates.
- Can be implemented using triggers, but many database systems provide direct support.

Encryption

- Data may be *encrypted* when database authorization provisions do not offer sufficient protection.
- Properties of good encryption technique:
  - Relatively simple for authorized users to encrypt and decrypt data.
  - Encryption scheme depends not on the secrecy of the algorithm but on the secrecy of a parameter of the algorithm called the encryption key.
  - Extremely difficult for an intruder to determine the encryption key.

Encryption (Cont.)

- *Data Encryption Standard* (DES) substitutes characters and rearranges their order on the basis of an encryption key which is provided to authorized users via a secure mechanism. Scheme is no more secure than the key transmission mechanism since the key has to be shared.
- Advanced Encryption Standard (AES) is a new standard replacing DES, and is based on the Rijndael algorithm, but is also dependent on shared secret keys
- *Public-key encryption* is based on each user having two keys:
  - *public key* – publicly published key used to encrypt data, but cannot be used to decrypt data
  - *private key* -- key known only to individual user, and used to decrypt data. Need not be transmitted to the site doing encryption.

  Encryption scheme is such that it is impossible or extremely hard to decrypt data given only the public key.
- The RSA public-key encryption scheme is based on the hardness of factoring a very large number (100's of digits) into its prime components.

Authentication

- Password based authentication is widely used, but is susceptible to sniffing on a network
- **Challenge-response** systems avoid transmission of passwords
  - DB sends a (randomly generated) challenge string to user
  - User encrypts string and returns result.
  - DB verifies identity by decrypting result
  - Can use public-key encryption system by DB sending a message encrypted using user's public key, and user decrypting and sending the message back
- **Digital signatures** are used to verify authenticity of data
  - E.g. use private key (in reverse) to encrypt data, and anyone can verify authenticity by using public key (in reverse) to decrypt data. Only holder of private key could have created the encrypted data.
  - Digital signatures also help ensure **nonrepudiation:** sender cannot later claim to have not created the data

Digital Certificates

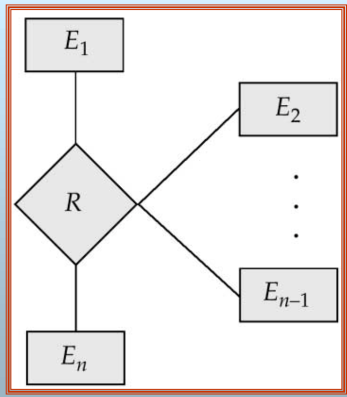
- **Digital certificates** are used to verify authenticity of public keys.
- Problem: when you communicate with a web site, how do you know if you are talking with the genuine web site or an imposter?
  - Solution: use the public key of the web site
  - Problem: how to verify if the public key itself is genuine?
- Solution:
  - Every client (e.g. browser) has public keys of a few root-level **certification authorities**
  - A site can get its name/URL and public key signed by a certification authority: signed document is called a **certificate**
  - Client can use public key of certification authority to verify certificate
  - Multiple levels of certification authorities can exist. Each certification authority
    - presents its own public-key certificate signed by a higher level authority, and
    - Uses its private key to sign the certificate of other web sites/authorities

End of Chapter

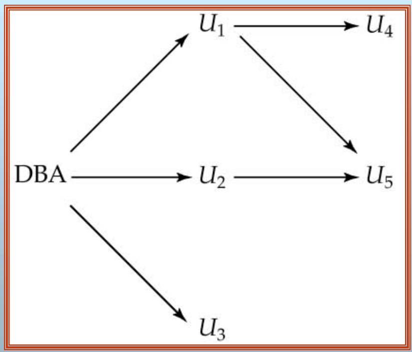
Statistical Databases

- Problem: how to ensure privacy of individuals while allowing use of data for statistical purposes (e.g., finding median income, average bank balance etc.)
- Solutions:
  - System rejects any query that involves fewer than some predetermined number of individuals.
    - Still possible to use results of multiple overlapping queries to deduce data about an individual
  - *Data pollution* -- random falsification of data provided in response to a query.
  - Random modification of the query itself.
- There is a tradeoff between accuracy and security.

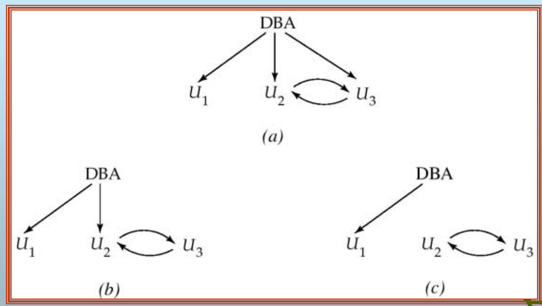
An *n*-ary Relationship Set



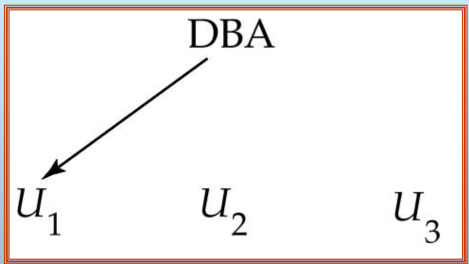
Authorization-Grant Graph



Attempt to Defeat Authorization Revocation



Authorization Graph



Physical Level Security

- Protection of equipment from floods, power failure, etc.
- Protection of disks from theft, erasure, physical damage, etc.
- Protection of network and terminal cables from wiretaps non-invasive electronic eavesdropping, physical damage, etc.

Solutions:

- Replicated hardware:
  - mirrored disks, dual busses, etc.
  - multiple access paths between every pair of devises
- Physical security: locks,police, etc.
- Software techniques to detect physical security breaches.

Human Level Security

- Protection from stolen passwords, sabotage, etc.
- Primarily a management problem:
  - Frequent change of passwords
  - Use of “non-guessable” passwords
  - Log all invalid access attempts
  - Data audits
  - Careful hiring practices

Operating System Level Security

- Protection from invalid logins
- File-level access protection (often not very helpful for database security)
- Protection from improper use of “superuser” authority.
- Protection from improper use of privileged machine intructions.

Network-Level Security

- Each site must ensure that it communicate with trusted sites (not intruders).
- Links must be protected from theft or modification of messages
- Mechanisms:
  - Identification protocol (password-based),
  - Cryptography.

Database-Level Security

- Assume security at network, operating system, human, and physical levels.
- Database specific issues:
  - each user may have authority to read only part of the data and to write only part of the data.
  - User authority may correspond to entire files or relations, but it may also correspond only to parts of files or relations.
- Local autonomy suggests site-level authorization control in a distributed database.
- Global control suggests centralized control.