Data management: be used to capture, store, retrieve, analyze, present and interpret (large amount of) data

Database: an organized collection of related data, usually stored on disk

- Important data
- Secured
- redundancy)
- Shared
- Well-designed (minimal
- Variable size

Database Management System (DBMS): a software system designed to store and manage databases

Usages:

- Maintain integrity (integrity constraints)
- Create, modify, and query a database
- Control redundancy
- Provide support for decision making
- Control access

  Different user groups may have different access privileges (create/ alter, update, and retrieve), which are controlled through DBMS security sub-system, through the use of accounts & passwords

  · Casual users – may not have access to confidential data

  · Parametric users – may be given update access, but are generally not allowed to change the structure of data

  · Database administrators (DBAs) – generally have highest privileges, create user accounts and enforce restrictions
- Permit concurrent/simultaneous access (multiusers)
- Provide loading, backup, and recovery

【NOT the function of DBMS: design the database to be used】

Entity-relationship (ER) diagram: a graphical data modeling technique that represents the main entities and their corresponding relationships within a system or an enterprise

Basic constructs:

- **Entity**: real-word object distinguishable from other objects (an entity is described using a set of attributes)
  - Each attribute has a domain (e.g. float, integer, string, date)
  - Each entity set has a key

  Entity set: the collection of all entities of a particular entity type in the database at any point in time
- **Attributes**
- **Relationship**: association among 2 or more entities

  Relationship degree: the number of participating entity types

  e.g. Binary relationship – 2 entities, Ternary relationship – 3 entities, N-ary relationship – n entities

  Relationship constraints: constraints on the relationship type limit the possible combination of entities that may participate in the corresponding relationship set

  Kinds of constraints (2):
  - Cardinality constraint: for a relationship set specifies the number of relationships in the set that an entity can participate in: one-to-one, one-to-many, many-to-many
  - Participation constraints: indicates if all entities participate in relationship: total OR partial participation
- **Weak entities**: can be identified uniquely only by considering the primary key of another (owner) entity
  - Owner entity set and weak entity set must participate in a 1-to-many relationship set (one owner, many weak entities)
  - Weak entity set must have total participation in this identifying relationship set
- **Specialization & generalization** [Extended ER (EER)]

  【Subclasses are specializations of superclass & Superclass is generalization of subclasses】
  - Attributes of a superclass are inherited by the subclasses
  - Subclass can have its own specific attributes/ relationships

Data abstraction: an abstract view of data that excludes many details that are either too complex or not of interest to the users

Data model: a collection of concepts that can be used to describe the structure of a database to achieve data abstraction

- **Schemas**: the metadata or data describing data – static
- **Instance**: the data in the database at a particular time – dynamic

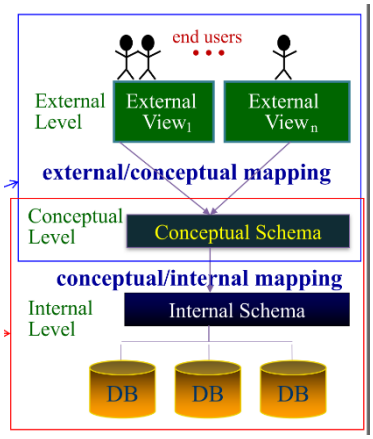
Relational model

- Main concepts (4):
  - Relations (R): the main construct for representing data in the relational model
    A set of records (similar to a table with columns and rows BUT if it has something merge or combine columns or rows together is a table not a relation)
  - Domains (D): a set of atomic values (each domain has a data type or format)
    Popular domain types: integers, real numbers, fixed or variable length character strings, date, time stamp, currency, sub-range from a data type, enumerated data type
  - Attributes (A): the name of a role played by some domain in the relation (degree of R: the number of attributes in a relation)
  - Tuples (T): an ordered list of n values (relations are sets of tuples)

$$t = <v_1, v_2, \dots, v_n>$$

where each value v_i $(1 \le i \le n)$ is an element of the corresponding domain of attribute A_i or a special value called "null"

Three-schema architecture



- External level – provides access to particular parts of the database to users
- Conceptual level – the structure of the whole database for a community of users
- Internal level – the physical storage structure of the database

Data independence: ability to change the schema at one level of a database system without having to change the schema at the next higher level

- Logical data independence: ability to change the conceptual schema without changing applications
- Physical data independence: ability to modify physical schema without changing logical/conceptual schema

Implementation of constraints:

Integrity constraints (ICs): conditions that must be true for any instance of the database
(IC is a statement about all possible instances)

- ICs are specified when schema is defined
- ICs are checked when relations are modified

A legal instance of a relation is one that satisfies all specified ICs

- DBMS should not allow illegal instances
- Avoids data entry errors

Types of ICs: [sequence to check violation of ICs: primary key (Entity, Key), Domain, Referential]

- **Domain constraints**: each attribute in a relation must belong to some domain (right stuff is in the right spot)
- **Key constraints (uniqueness constraint)**
  Superkey (SK): subset of attributes that is uniqueness of a relation schema (can have redundant attributes)
  (every relation has at least one Superkey – the set of all its attributes: $t_i[SK] \neq t_j[SK]$)
  Key (K): a minimal Superkey (minimal: removing any attribute means the proposed key is no longer a Superkey)
  When have more than one key: Candidate key & Primary key (PK) – only one is selected as PK

$$\text{(Candiate key + Primary key)} = \text{Key (minimal superkey)} \subseteq \text{Superkey}$$

- **Entity constraints**: no primary key (PK) can be null
- **Referential integrity constraints** (data exists in the 'parent' before the 'child')
  Specified between 2 relations and are based on the notion of foreign keys
  Special situation: self referencing relations

Foreign keys: relate 2 different schemas – a set of attributes FK in relation R_1 is a foreign key if: $t_1[FK] = t_2[PK]$ or $t_1[FK]$ is null (the attributes of FK have the same domain as the PK attributes of another schema R_2)

Deletion: child table → can just delete & parent table → need to check referential integrity

Modify: opposite of deletion

- **User-defined constraints**: general user defined constraints that cannot be enforced by the other constraints

  Implemented by using: checks, assertions and triggers

Mapping ER diagrams to relational models

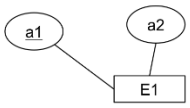
Conceptual perspective:

- Conceptual design – the Entity Relationship (ER)
- Logical design (mapping) – the relational model

Mapping (ER diagram → relational model) steps (8):

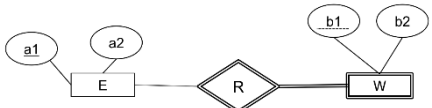
【remember to add foreign key/ reference】

1. Entity – include all simple attributes of a strong entity & Choose one key attribute as primary key (PK)



E1 [a1, a2]

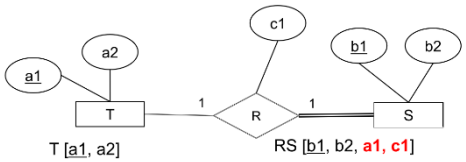
2. Weak entity – includes all simple attributes of weak entity & Primary key is the combination of the primary key of the owner/parent and the primary key of weak entity (if any)



E [a1, a2]

RW [a1, b1, b2]

3. Binary 1:1 relationship – choose the side with total/fully participation, add the PK of another side as foreign key

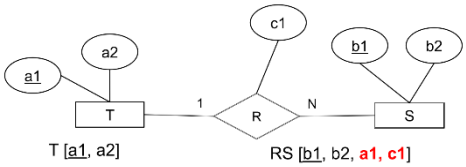


T [a1, a2]

RS [b1, b2, a1, c1]

4. Binary 1:N relationship (only 2 don't need to create a new relations/ table)

   Choose N-side, add the PK of another side as foreign key



T [a1, a2]

RS [b1, b2, a1, c1]

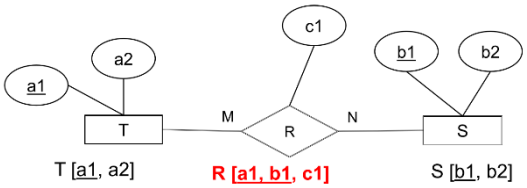
5. Binary M:N relationship

   Include any simple attributes of relationship

   Include the primary keys of both side as foreign keys

   The primary key (PK) of R is the combination of foreign keys

[Notice: 1:1, 1:N can map in the same way as M:N → advantage: reduces the number of 'null' that appear as foreign key values]



T [a1, a2]

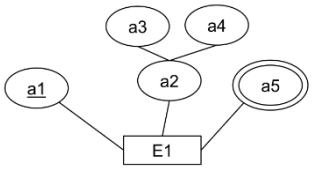
R [a1, b1, c1]

S [b1, b2]

6. Multi-valued attribute

   Includes that multi-value attribute and primary key (PK) of the entity as primary key (PK) → don't have non-key attribute (ways to distinguish with weak entity: weak entity have other non-key attribute)

   If the multi-valued attribute is composite, include its simple components



E2 [a1, a5]

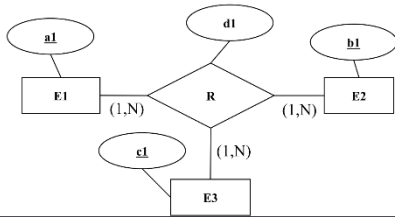
E1 [a1, a3, a4]

7. N-ary relationship

   Include the primary key of all sides as foreign key

   The combination of foreign keys (with many side relationship) is primary key (PK)

   Include any simple attributes of n-ary relationship



E1 [a1, ...]

E2 [b1, ...]

E3 [c1, ...]

R [a1, b1, c1, d1]

8. Super & subclasses (mapping of EER) – can be at anywhere

   Create a relational table for the superclass

   Create a relational table for each subclass

   The primary key (PK) of each subclass is the primary key of the superclass (it also is the foreign key)

Reverse engineering (from schema/ relational model to ER diagram):

1. Identify strong entities – the primary key (PK) has no foreign keys referencing

2. Weak entities – if primary key (PK) is combining an existing primary key (via foreign key link) & it has additional non-key attributes
3. 1:1 or 1:N relationships – have foreign key reference that is non-key attribute → 1:1 (1 side) or 1:N (n side) relationship
4. M:N relationships – the primary key (PK) is a combination of existing primary key (via foreign key links)
5. Multi-valued attributes – the primary key combines an existing primary key (via foreign key link) & adds new attributes to the key & have NO additional non-key attributes
6. N-ary relationships – the primary key (PK) is combination of existing of more than 2 primary keys
7. Super and subclasses – A relation/ table has the same primary key (PK) as an entity (via foreign key link)

Informal design guidelines

- Semantics of the attributes
  - Design each relation so that it's easy to explain its meaning
  - Do not combine attributes from multiple entity types and relationship types into a single relation
- Reducing the redundant values in tuples (minimize the storage space) & reducing the null values in tuples
- Disallowing spurious (fake/ false) tuples – when join and decomposition

Modification anomaly: data inconsistency that results from data redundancy

Deletion anomaly: loss of certain attributes because of the deletion of other attributes

Insertion anomaly: lack of ability to insert some attributes without the presence of other attributes (key cannot be null – entity constraint)

Incorrect grouping may cause update anomalies which may result in inconsistent data or even loss of data

Decomposing a relation (one table to many tables) – replace the relation R by 2 or more relations such that:

Each new relation contains a subset of the attributes of R (and no attributes not appearing in R)

Every attribute of R appears in at least one new relation

Join: $R_1 \bowtie R_2$ is the (natural) join of the 2 relations – each tuple of R_1 is concatenated (link together in a chain or series) with every tuple in R_2 having the same values on the common attributes

Lossless-join decompositions: decomposition of R into R_1 and R_2 is a lossless-join with respect of a set of functional dependences F if, for every instance r that satisfies F: $R = R_1 \bowtie R_2$ (If we break a relation R, into bits, when we put the bits back together, we can get the exactly R back again)

Lossy-join decomposition (loss – loss of information OR addition of spurious information)

Functional dependencies (FD) – one attribute determines another attribute: $x \rightarrow y$ holds if for every legal instance, for all tuples t_1, t_2: if $t_1.x = t_2.x \rightarrow t_1.y = t_2.y$

(means that given 2 tuples in r, if the x values agree, then y values must also agree)

Key: a minimal set of attributes that functionally determines all the attributes

Superkey: a relation uniquely identifies the relation, but does not have to be minimal

Closure of F: the set of all FDs implied by F (closure for a set of attributes X is denoted by $X^+ = \{X, \dots\}$)

Left	Both	Right
In every key	Might be in some keys	Not in key

Inference rules:

Armstrong's Axioms (X, Y, Z are sets of attributes):

- Reflexivity: $\text{if } Y \subseteq X, \text{then } X \rightarrow Y$
- Augmentation: $\text{if } X \rightarrow Y, \text{then } XZ \rightarrow YZ \text{ for any } Z$
- Transitivity: $\text{if } X \rightarrow Y \text{ and } Y \rightarrow Z, \text{then } X \rightarrow Z$

Additional rules:

- Union: $\text{if } X \rightarrow Y \text{ and } X \rightarrow Z, \text{then } X \rightarrow YZ$
- Decomposition: $\text{if } X \rightarrow YZ, \text{then } X \rightarrow Y \text{ and } X \rightarrow Z$

Role of FDs in detecting redundancy (suppose 3 attributes, A, B, C):

- No FDs hold: there is no redundancy here
- Given A → B: several tuples could have the same A value, and if so, they'll all have the same B value

Normalization: the process of removing redundancy from data