Lesson 8: Introduction to Databases
E-R Data Modeling

Contents

Database Management System (DBMS)

- DBMS contains information about a particular enterprise
  - Collection of interrelated data
  - Set of programs to access the data
  - An environment that is both *convenient* and *efficient* to use
- Database Applications:
  - Banking: all transactions
  - Airlines: reservations, schedules
  - Universities: registration, grades
  - Sales: customers, products, purchases
  - Online retailers: order tracking, customized recommendations
  - Manufacturing: production, inventory, orders, supply chain
  - Human resources: employee records, salaries, tax deductions
- Databases touch all aspects of our lives

Purpose of Database Systems

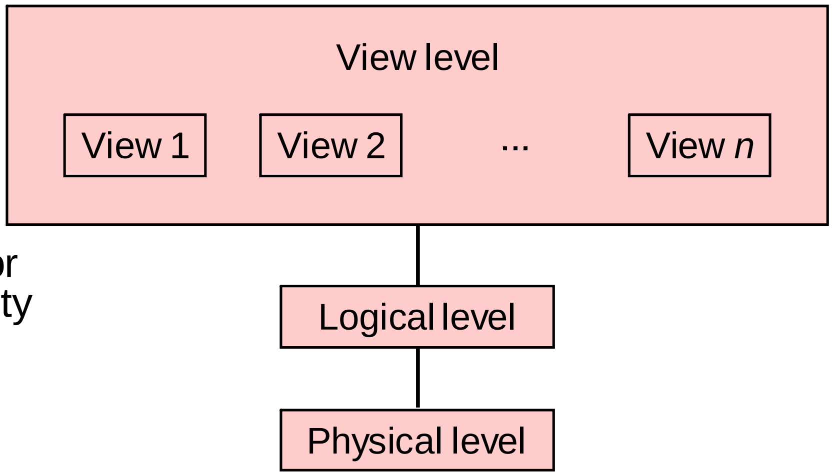
- In the early days, database applications were built directly on top of file systems
- Drawbacks of using file systems to store data:
  - Data redundancy and inconsistency
    - Multiple file formats, duplication of information in different files
  - Difficulty in accessing data
    - Need to write a new program to carry out each new task
  - Data isolation — multiple files and formats
  - Integrity problems
    - Integrity constraints (e.g. account balance > 0) become “buried” in program code rather than being stated explicitly
    - Hard to add new constraints or change existing ones
  - Atomicity of updates
    - Failures may leave database in an inconsistent state with partial updates carried out
    - Example: Transfer of funds from one account to another should either complete or not happen at all
  - Concurrent access by multiple users
    - Concurrent accessed needed for performance
    - Uncontrolled concurrent accesses can lead to inconsistencies
- Database systems offer solutions to these problems

Levels of Abstraction

- **Physical level:** describes how a record (e.g., customer) is stored.
- **Logical level:** describes data stored in database, and the relationships among the data.

```
type customer = record
        customer_id : string;
        customer_name : string;
        customer_street : string;
        customer_zip : integer;
end;
```

- **View level:** application programs hide details of data types. Views can also hide information (such as an employee's salary) for security and confidentiality purposes.



Instances and Schemas

- **Schema** – the logical structure of the database
  - Example: The database consists of information about a set of customers and accounts and the relationship between them
  - Analogous to ***type*** information of a variable in a program
  - **Physical schema**: database design at the physical level
  - **Logical schema**: database design at the logical level
- **Instance** – the actual content of the database at a particular point in time
  - Analogous to the value of a variable
- **Physical Data Independence** – the ability to modify the physical schema without changing the logical schema
  - Applications depend on the logical schema
  - In general, the interfaces between the various levels and components should be well defined so that changes in some parts do not seriously influence others.

Data Models

- A collection of tools for describing
  - Data
  - Data relationships
  - Data semantics
  - Data constraints
- Relational model
- Entity-Relationship data model
  - mainly for database design
  - designing the database schema
- Object-based data models
  - Object-oriented and Object-relational databases
- Semistructured data model (XML)
- Other older models:
  - Network model
  - Hierarchical model

Data Oriented Languages

- Data Manipulation Languages (DML)
  - Language for accessing and manipulating the data organized by the appropriate data model (also known as *query language*)
  - Two classes of languages
    - **Procedural** – user specifies what data is required and how to get those data
    - **Declarative (nonprocedural)** – user specifies what data is required without specifying how to get those data
  - SQL is the most widely used query language
- Data Definition Language (DDL)
  - Specification of the database schema definition

    Example:

    create table *account* (*account_number*: **char**(10), *balance*: **integer**)
  - DDL compiler generates a set of tables stored in a ***data dictionary***
  - Data dictionary contains metadata (i.e., data about data)
    - Database schema
    - Data *storage and definition* of data
      - Specifies the storage structure and access methods used
    - Integrity constraints
      - Domain constraints
      - Referential integrity (**references** constraint in SQL)
      - Assertions
    - Authorization

Relational Model

- Example of tabular data in the relational model
  - Columns are called attributes

customer_id	customer_name	customer_street	customer_city	account_id	balance
12-345	Johnson	12 Alma St.	Palo Alto	A-101	500
12-345	Johnson	12 Alma St.	Palo Alto	A-201	700
12-346	Hayes	22 Main St.	Bromfield	A-102	450
12-358	Smith	45 Park Ave.	Berkeley	A-118	800
25-836	Brown	33 High St.	Auckland	A-249	550
35-795	Jones	26 Almond St.	Oakwood	A-357	635
45-678	Turner	123 Putnam St.	Stanford	A-201	700

  - Bad design

- A Sample Relational Database

customer_id	customer_name	customer_street	customer_city
12-345	Johnson	12 Alma St.	Palo Alto
12-346	Hayes	22 Main St.	Bromfield
12-358	Smith	45 Park Ave.	Berkeley
25-836	Brown	33 High St.	Auckland
35-795	Jones	26 Almond St.	Oakwood
45-678	Turner	123 Putnam St.	Stanford

The *customer* table

account_id	balance
A-101	500
A-201	700
A-102	450
A-118	800
A-249	550
A-357	635

The *account* table

customer_id	account_id
12-345	A-101
12-345	A-201
12-346	A-102
12-358	A-118
25-836	A-249
35-795	A-357
45-678	A-201

The *depositor* table

SQL

- **SQL**: widely used non-procedural language
  - Example: Find the name of the customer with customer-id 192-83-7465

    select *customer.customer_name*
    from *customer*
    where *customer.customer_id* = '192-83-7465'
  - Example: Find the balances of all accounts held by the customer with customer-id 192-83-7465

    select *account.balance*
    from *depositor*, *account*
    where *depositor.customer_id* = '192-83-7465' **and**
    depositor.account_number=account.account_number
- Application programs generally access databases through one of
  - Language extensions to allow embedded SQL
  - Application program interface (e.g., ODBC/JDBC) which allow SQL queries to be sent to a database

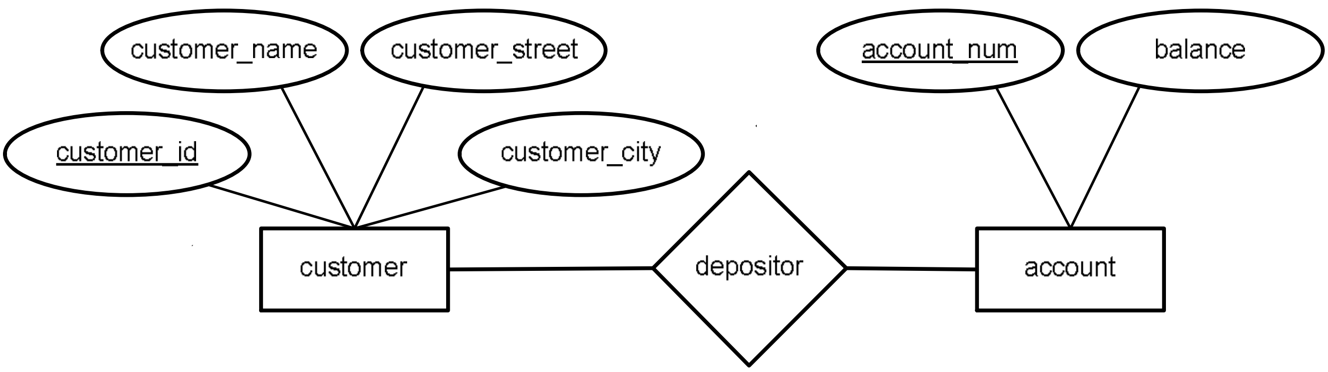
Database Design

The process of designing the general structure of the database:

- Logical Design – Deciding on the database schema. Database design requires that we find a "good" collection of relation schemas.
  - Business decision – What attributes should we record in the database?
  - Computer Science decision – What relation schemas should we have and how should the attributes be distributed among the various relation schemas?
- Physical Design – Deciding on the physical layout of the database

The Entity-Relationship Model

- Models an enterprise as a collection of *entities* and *relationships*
  - Entity: a "thing" or "object" in the enterprise that is distinguishable from other objects
    - Described by a set of *attributes*
  - Relationship: an association among several entities
- Represented diagrammatically by an *entity-relationship diagram:*



Object-Relational Data Models

- Extend the relational data model by including object orientation and constructs to deal with added data types.
- Allow attributes of tuples to have complex types, including non-atomic values such as nested relations.
- Preserve relational foundations, in particular the declarative access to data, while extending modeling power.
- Provide upward compatibility with existing relational languages.

XML: Extensible Markup Language

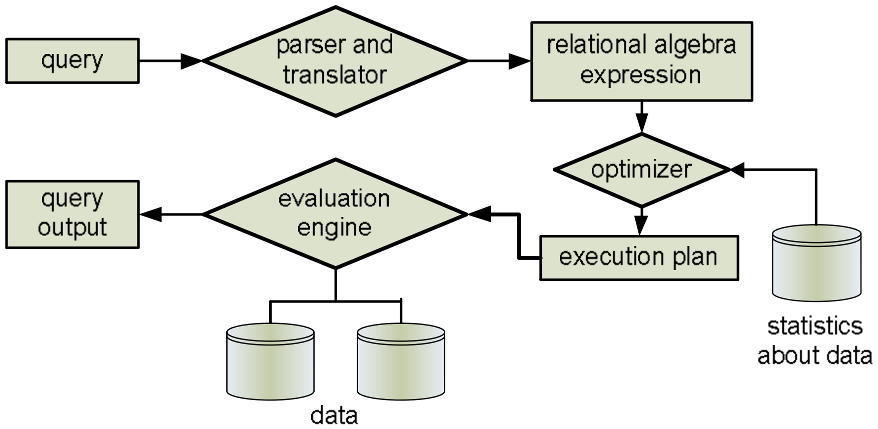
- Defined by the WWW Consortium (W3C)
- Originally intended as a document markup language not a database language
- The ability to specify new tags, and to create nested tag structures made XML a great way to exchange **data**, not just documents
- XML has become the basis for all new generation data interchange formats.
- A wide variety of tools is available for parsing, browsing and querying XML documents/data

Storage Management

- **Storage manager** is a program module that provides the interface between the low-level data stored in the database and the application programs and queries submitted to the system.
- The storage manager is responsible to the following tasks:
  - Interaction with the file manager
  - Efficient storing, retrieving and updating of data
- Issues:
  - Storage access
  - File organization
  - Indexing and hashing

Query Processing

1. Parsing and translation
2. Optimization
3. Evaluation



- Alternative ways of evaluating a given query
  - Equivalent expressions
  - Different algorithms for each operation
- Cost difference between a good and a bad way of evaluating a query can be enormous
- Need to estimate the cost of operations
  - Depends critically on statistical information about relations which the database must maintain
  - Need to estimate statistics for intermediate results to compute cost of complex expressions

Transaction Management

- A **transaction** is a collection of operations that performs a single logical function in a database application
  - E.g., transfer a given amount from one account to another
- **Transaction-management component** ensures that the database remains in a consistent (correct) state despite system failures (e.g., power failures and operating system crashes) and transaction failures
  - E.g., tries to plan (schedule) transactions to keep consistency
- **Concurrency-control manager** controls the interaction among the concurrent transactions, to ensure the consistency of the database
  - E.g., has to resolve deadlock states

Database Users

Users are differentiated by the way they are expected to interact with the system

- **Application programmers** – interact with system through DML calls
- **Sophisticated users** – form requests in a database query language
- **Specialized users** – write specialized database applications that do not fit into the traditional data processing framework
- **Naive users** – invoke one of the permanent application programs that have been written previously by an application programmer
  - Examples: E-shopping, Internet banking, University clerical staff accessing student database

Database Administrator

- Coordinates all the activities of the database system
  - the database administrator has a good understanding of the enterprise's information resources and needs.
- Database administrator's duties include:
  - Schema definition
  - Storage structure and access method definition
  - Schema and physical organization modification
  - Granting user authority to access the database
  - Specifying integrity constraints
  - Acting as liaison with users
  - Monitoring performance and responding to changes in requirements

E-R Data Modeling: Entities

- A *database* can be modeled as:
  - a collection of ***entities***,
  - ***relationships*** among entities.
- Technique called Entity-Relationship Modeling (**E-R model)**
- An **entity** is an object that exists and is distinguishable from other objects.
  - Example: specific person, company, event, plant
  - Entities are usually expressed by **nouns**
- Entities have properties denotes as *attributes*
  - Example: people have *names* and *addresses*
- An **entity set** is a set of entities of the same type that share the same properties.
  - Example: set of persons, companies, trees, loans

customer_id	customer_name	customer_street	customer_city
12-345	Johnson	12 Alma St.	Palo Alto
12-346	Hayes	22 Main St.	Bromfield
12-358	Smith	45 Park Ave.	Berkeley
25-836	Brown	33 High St.	Auckland
35-795	Jones	26 Almond St.	Oakwood
45-678	Turner	123 Putnam St.	Stanford

customer

loan_id	amount
L-101-A	1500
L-201-A	2700
L-102-C	1450
L-118-D	3800
L-249-B	2550
L-157-A	6350

loan

Attributes

- An entity is represented by a set of attributes, that is descriptive properties possessed by all members of an entity set.

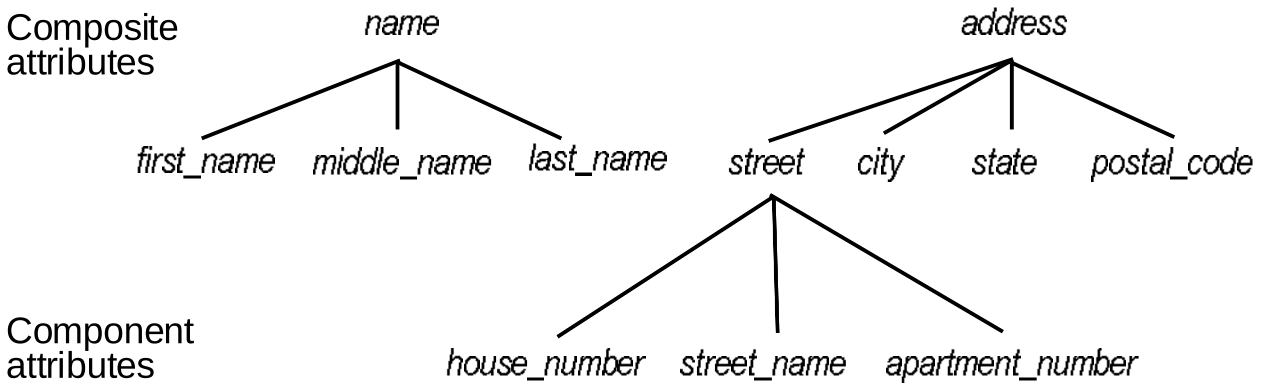
  Example:

  customer = (*customer_id*, *customer_name*, *customer_street*, *customer_city*)

  loan = (*loan_number*, *amount*)

- **Domain** – the set of permitted values for each attribute
- Attribute types:
  - *Simple* and *composite* attributes
  - *Single-valued* and *multi-valued* attributes
    - Example: multivalued attribute: *phone_numbers*
  - *Derived* attributes
    - Can be computed from other attributes
    - Example: age, given date_of_birth

Composite Attributes



Data Modeling: Relationships

- A **relationship** creates an association among several entities

  Example:

<u>Hayes</u>	<u>*deposits to*</u>	<u>A-102</u>
customer entity	relationship	*account* entity

  - Relationships are often expressed by **verb phrases**

- A **relationship set** is a set of associations between two (or more) entity sets
  - mathematical relation among $n \geq 2$ entities, each taken from an entity set

    $$\{(e_1, e_2, \ldots e_n) \mid e_1 \in E_1, e_2 \in E_2, \ldots, e_n \in E_n\}$$

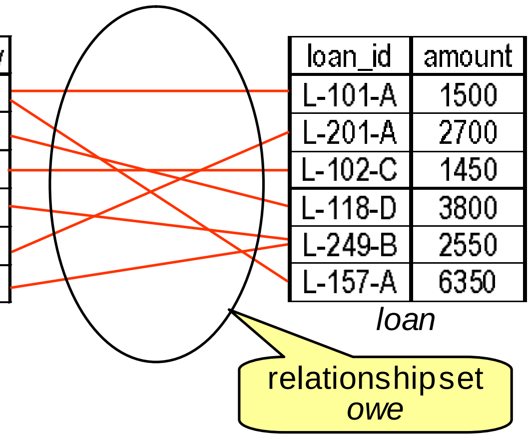
    where $(e_1, e_2, \ldots, e_n)$ is a relationship
  - Example:

    (Hayes, A-102) $\in$ *deposits_to*

Relationship Set *owe*

customer_id	customer_name	customer_street	customer_city
12-345	Johnson	12 Alma St.	Palo Alto
12-346	Hayes	22 Main St.	Bromfield
12-358	Smith	45 Park Ave.	Berkeley
25-836	Brown	33 High St.	Auckland
35-795	Jones	26 Almond St.	Oakwood
45-678	Turner	123 Putnam St.	Stanford

customer



loan_id	amount
L-101-A	1500
L-201-A	2700
L-102-C	1450
L-118-D	3800
L-249-B	2550
L-157-A	6350

loan

- Relationship sets are expressed by tables
- Relationship sets can have attributes
  - Example: Date of last access

customer_id	loan_id	access_date
12-345	L-101-A	Mar-01,2010
12-345	L-157-A	Feb-25,2010
12-346	L-118-D	Apr-06,2009
12-358	L-102-C	Dec-15,2009
25-836	L-249-B	Sep-06,2009
35-795	L-201-A	Apr-06,2010
45-678	L-249-B	Nov-16,2009

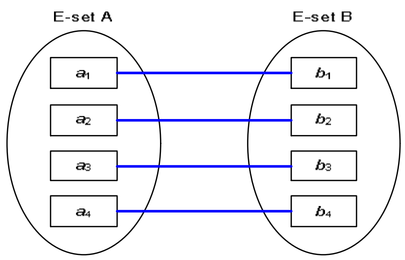
owe

Degree of a Relationship Set

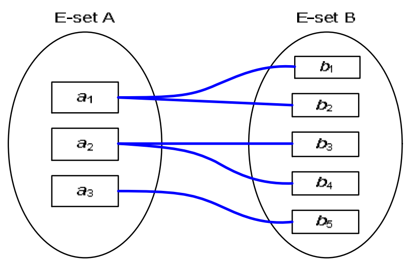
- Refers to number of entity sets that participate in a relationship
- Relationship sets that involve two entity sets are **binary** (or degree two).
  - Most relationship sets in a database system are binary.
- Relationship sets may involve more than two entity sets
  - Example: Suppose employees of a bank may have jobs (responsibilities) at multiple branches, with different jobs at different branches. Then there is a ternary relationship set between entity sets *employee, job,* and *branch*
- Relationships between more than two entity sets are rare. Most relationships are binary
  - We will mostly speak about binary relationships

Relationship Mapping Cardinality

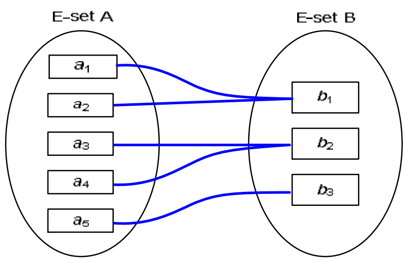
- Cardinality expresses the number of entities to which another entity can be associated via a relationship set
  - Most useful in describing binary relationship sets
  - For a binary relationship set the mapping cardinality must be one of the following types:



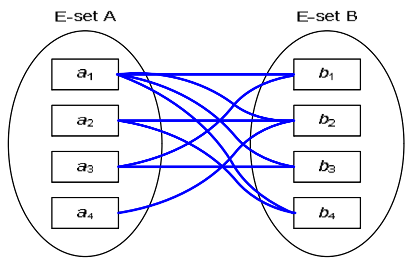
one to one



one to many



many to one



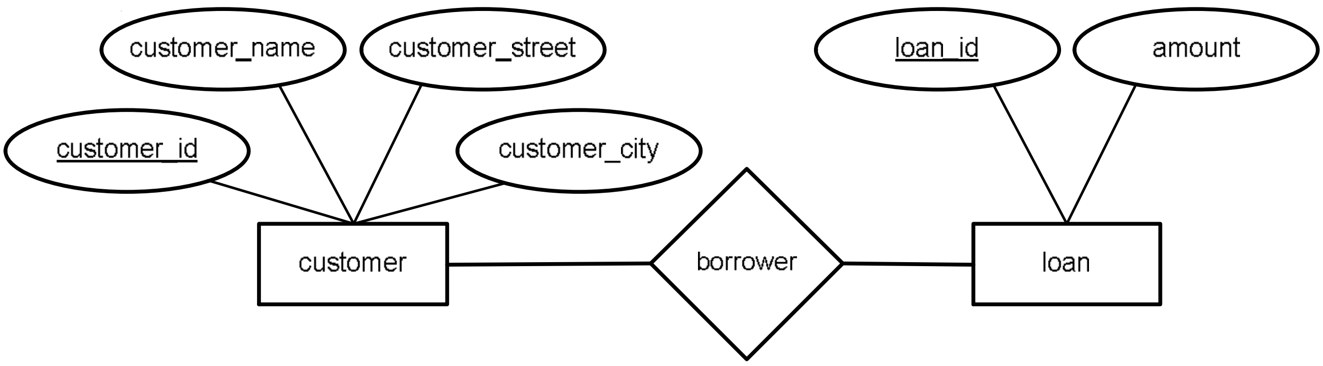
many to many

Note: Some elements in *A* and *B* may not be mapped to any elements in the other set

Keys

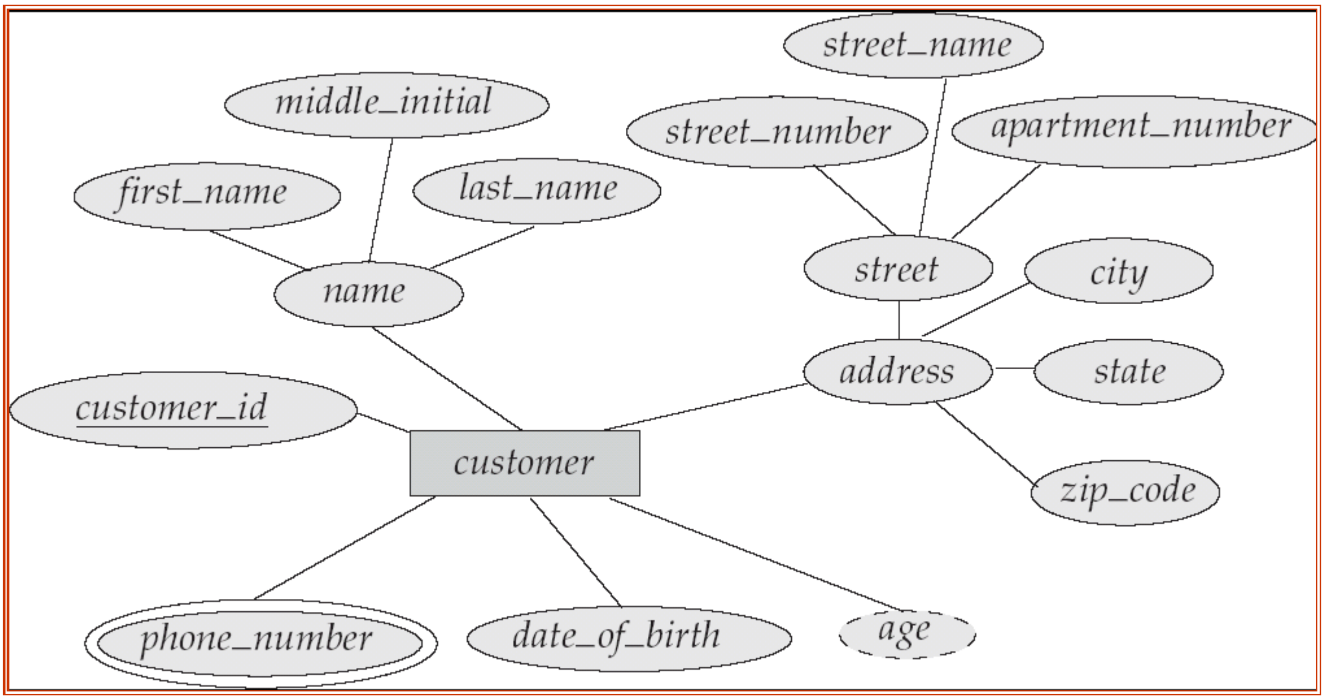
- A **super key** of an entity set is a set of one or more attributes whose values uniquely determine each entity.
- A **candidate key** of an entity set is a minimal super key
  - *Customer_id* is candidate key of *customer*
  - *account_number* is candidate key of *account*
- Although several candidate keys may exist, one of the candidate keys is selected to be the **primary key**
- The combination of primary keys of the participating entity sets forms a super key of a relationship set
  - (*customer_id, account_number*) is the super key of *depositor*
  - *NOTE: this means a pair of entity sets can have at most one relationship in a particular relationship set.*
    - Example: if we wish to track all access_dates to each account by each customer, we cannot assume a relationship for each access. We can use a multivalued attribute though
- Must consider the mapping cardinality of the relationship set when deciding what are the candidate keys
- Need to consider semantics of relationship set in selecting the *primary key* in case of more than one candidate key

E-R Diagrams

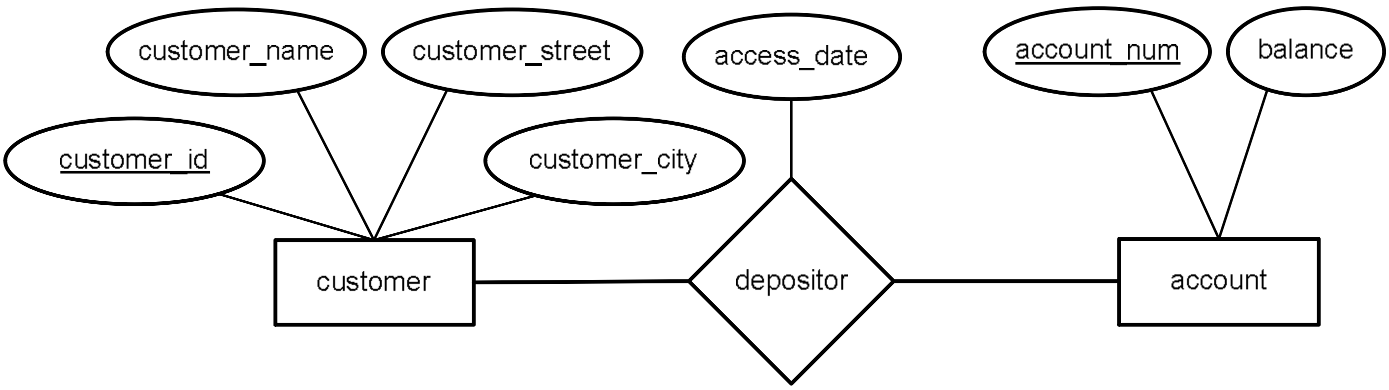


- Rectangles represent entity sets.
- Diamonds represent relationship sets.
- Lines link attributes to entity sets and entity sets to relationship sets.
- Ellipses represent attributes
  - Double ellipses represent multivalued attributes.
  - Dashed ellipses denote derived attributes.
- Underline indicates primary key attributes

E-R Diagram With Composite, Multivalued, and Derived Attributes

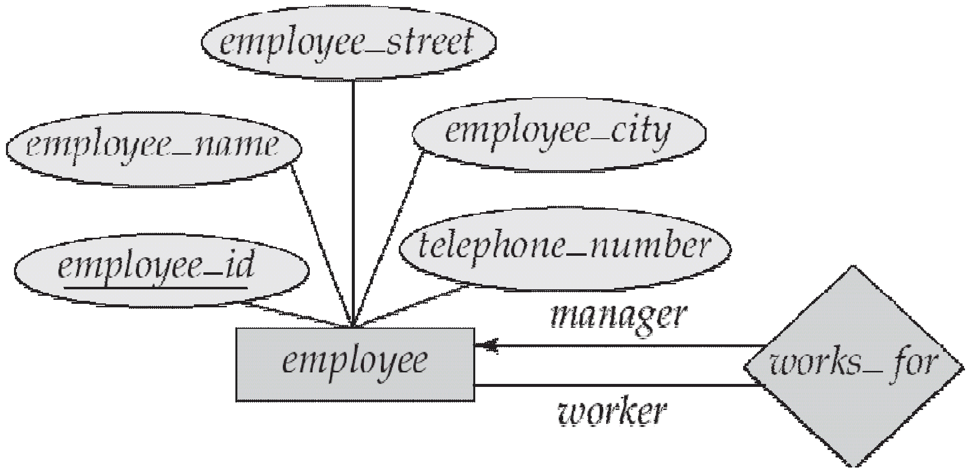


Relationship Sets with Attributes



Roles

- Entity sets of a relationship need not be distinct
- The labels “manager” and “worker” are called **roles**
  - they specify how employee entities interact via the works_for relationship set.
- Roles are indicated in E-R diagrams by labeling the lines that connect diamonds to rectangles.
- Role labels are optional, and are used to clarify semantics of the relationship

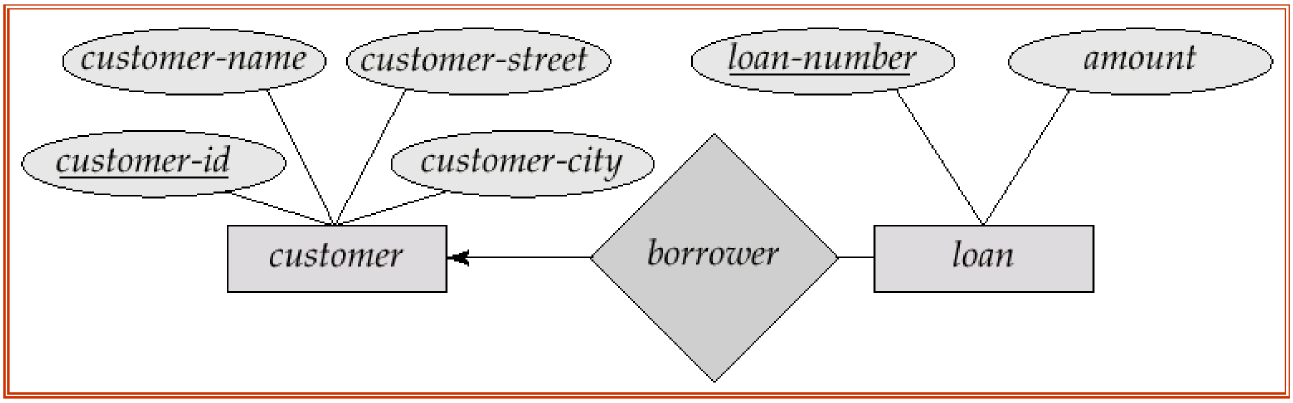


Cardinality Constraints

- We express cardinality constraints by drawing either a directed line (→), signifying “one,” or an undirected line (—), signifying “many,” between the relationship set and the entity set.
- One-to-one relationship:
  - A customer is associated with at most one loan via the relationship *borrower*
  - A loan is associated with at most one customer via *borrower*

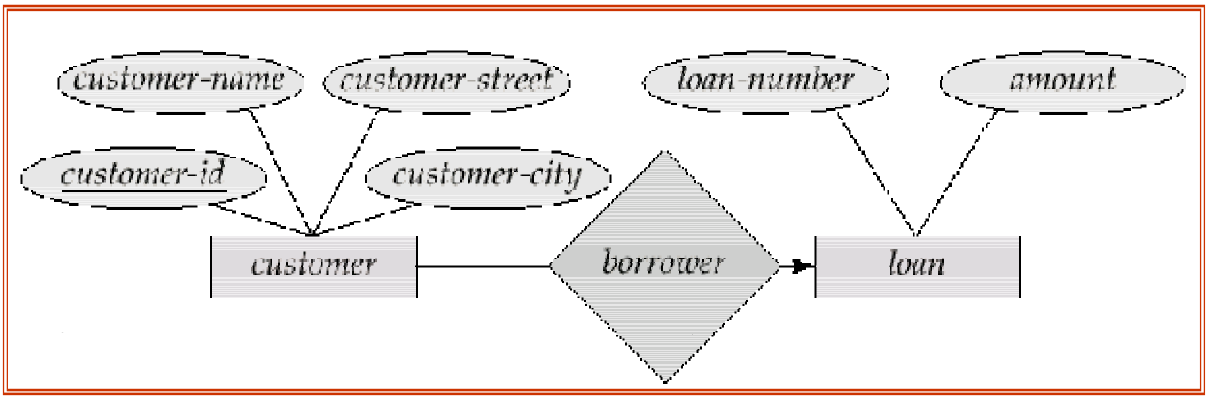
One-To-Many Relationship

- In the one-to-many relationship a loan is associated with at most one customer via *borrower*, a customer is associated with several (including 0) loans via *borrower*



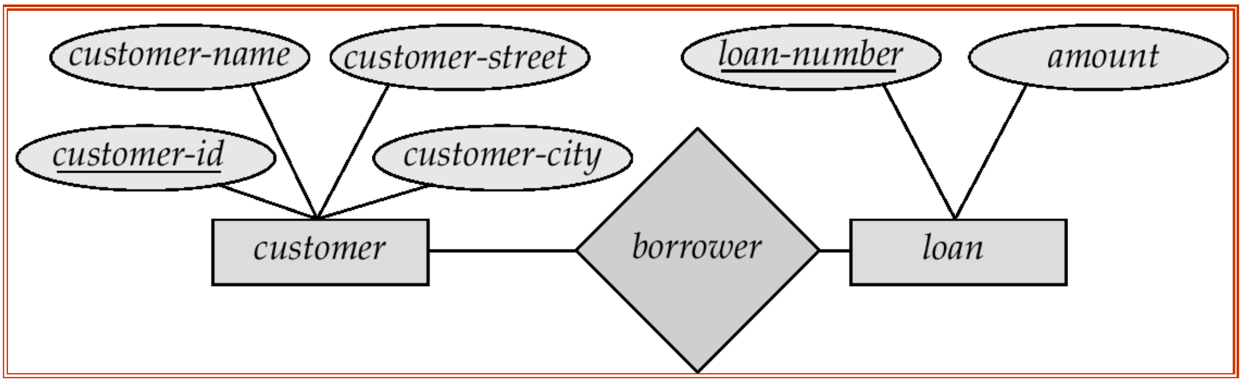
Many-To-One Relationships

- In a many-to-one relationship a loan is associated with several (including 0) customers via *borrower*, a customer is associated with at most one loan via *borrower*



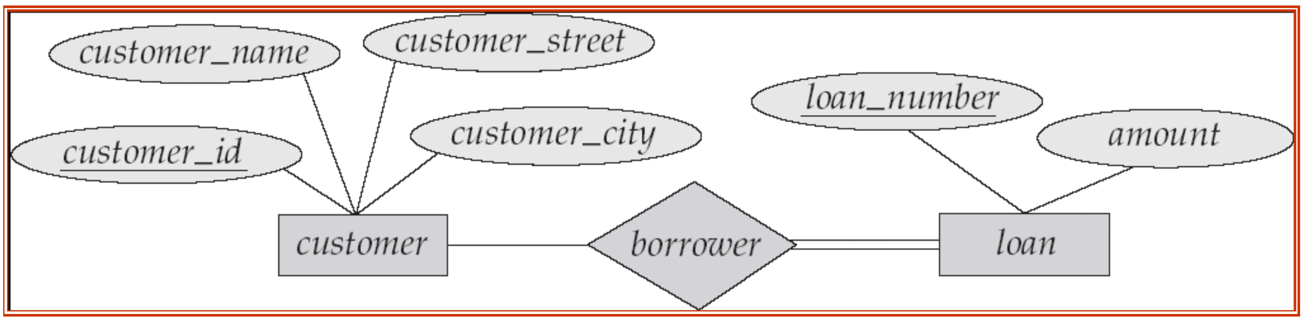
Many-To-Many Relationship

- A customer is associated with several (possibly 0) loans via borrower
- A loan is associated with several (possibly 0) customers via borrower



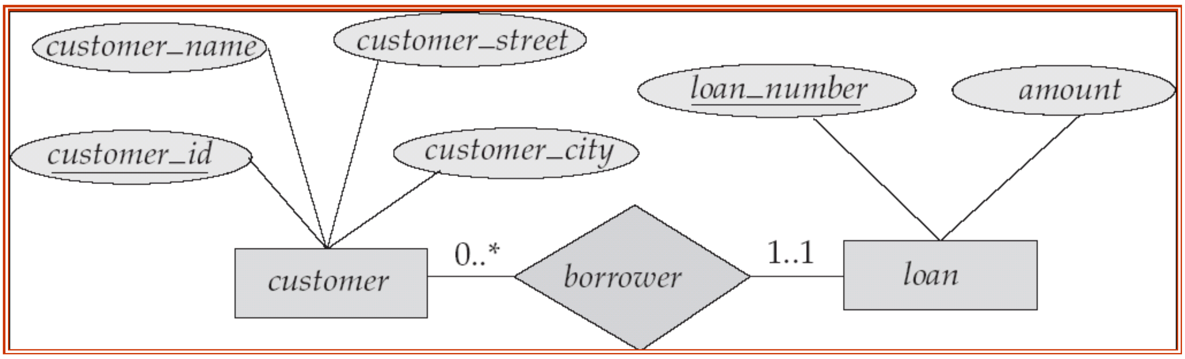
Participation of an Entity Set in a Relationship Set

- Total participation (indicated by double line): every entity in the entity set participates in at least one relationship in the relationship set
  - E.g. participation of loan in borrower is total
    - every loan must have a customer associated to it via borrower
- Partial participation: some entities may not participate in any relationship in the relationship set
  - Example: participation of customer in borrower is partial



Alternative Notation for Cardinality Limits

- Cardinality limits can also express participation constraints



Design Issues

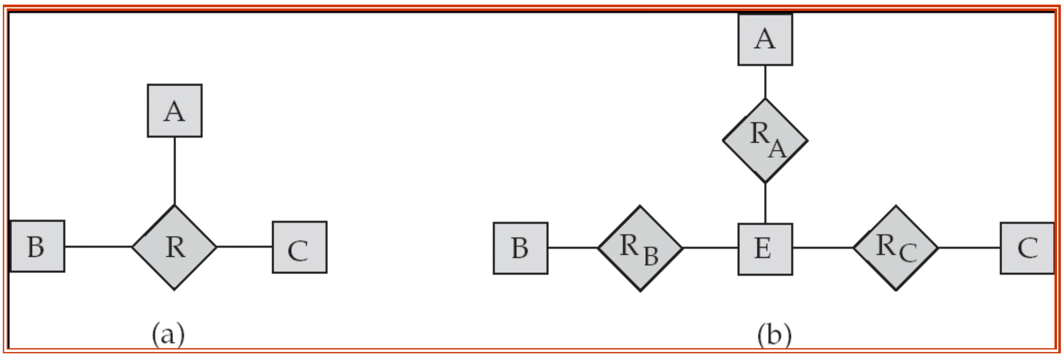
- **Use of entity sets vs. attributes**
  - Choice mainly depends on the structure of the enterprise being modeled, and on the semantics associated with the attribute in question.
- **Use of entity sets vs. relationship sets**
  - Possible guideline is to designate a relationship set to describe an action that occurs between entities
- **Binary versus n-ary relationship sets**
  - Although it is possible to replace any non-binary (n-ary, for $n > 2$) relationship set by a number of distinct binary relationship sets, a n-ary relationship set shows more clearly that several entities participate in a single relationship.
- **Placement of relationship attributes**
  - Is it reasonable to add the intended attribute to the relationship set?

Binary Vs. Non-Binary Relationships

- Some relationships that appear to be non-binary may be better represented using binary relationships
  - E.g. A ternary relationship *parents*, relating a child to his/her father and mother, is best replaced by two binary relationships, *father* and *mother*
    - Using two binary relationships allows partial information (e.g. only mother being know)
  - But there are some relationships that are naturally non-binary
    - Example: *works_on*

Converting Non-Binary Relationships to Binary

- In general, any non-binary relationship can be represented using binary relationships by creating an artificial entity set.
  - Replace *R* between entity sets A, B and C by an entity set *E*, and three relationship sets:
    1. R_A, relating *E* and *A*
    2. R_B, relating *E* and *B*
    3. R_C, relating *E* and *C*
  - Create a special identifying attribute for *E*
  - Add any attributes of *R* to *E*
  - For each relationship (a_i , b_i , c_i) in *R,* create
    1. a new entity e_i in the entity set *E*
    2. add (e_i , a_i) to R_A
    3. add (e_i , b_i) to R_B
    4. add (e_i , c_i) to R_C

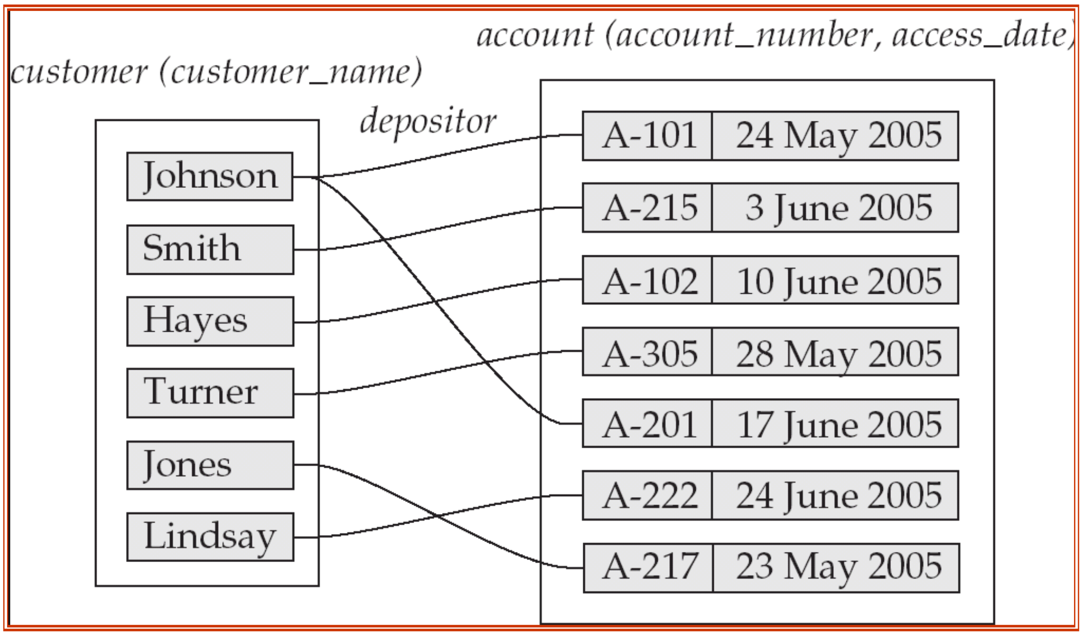


Converting Non-Binary Relationships (Cont.)

- Also need to translate constraints
  - Translating all constraints may not be possible
  - There may be instances in the translated schema that cannot correspond to any instance of *R*
    - Exercise: *add constraints to the relationships* R_A, R_B *and* R_C to ensure that a newly created entity corresponds to exactly one entity in each of entity sets *A*, *B* and *C*
  - We can avoid creating an identifying attribute by making E a weak entity set (described shortly) identified by the three relationship sets

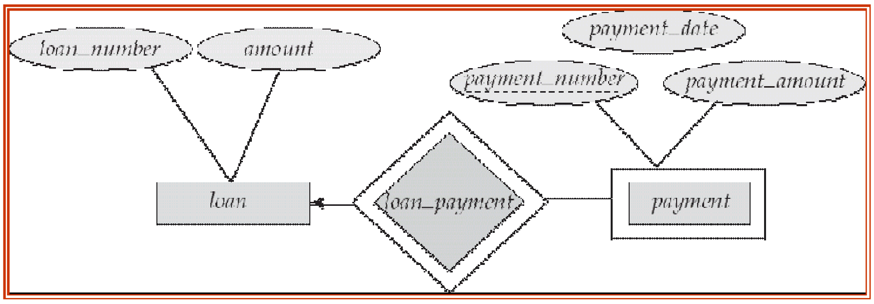
Mapping Cardinalities affect ER Design

- Can make access-date an attribute of account, instead of a relationship attribute, if each account can have only one customer
  - That is, the relationship from account to customer is many to one, or equivalently, customer to account is one to many



Weak Entity Sets

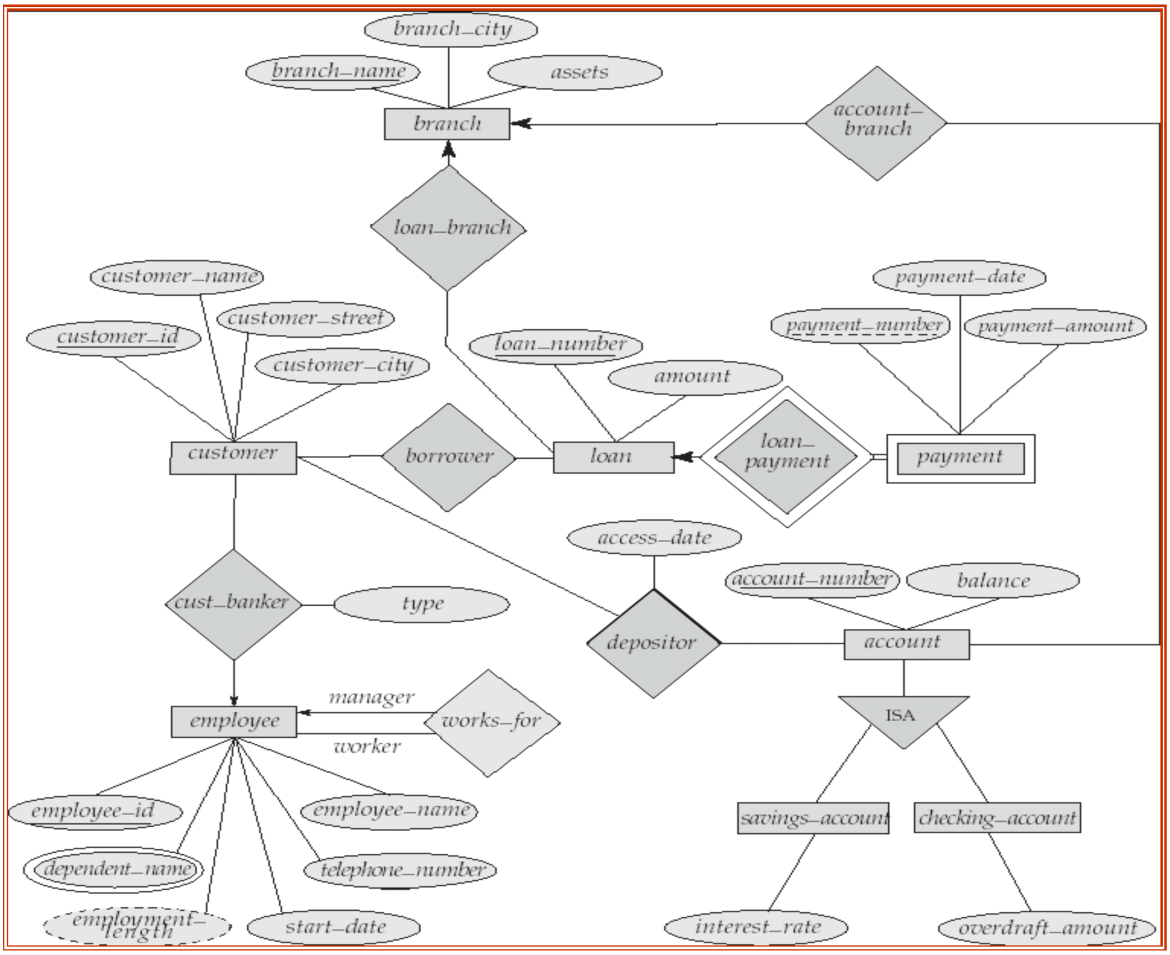
- An entity set that does not have a primary key is referred to as a **weak entity set**.
  - The existence of a weak entity set depends on the existence of an **identifying entity set**
    - It must relate to the identifying entity set via a total, one-to-many relationship set from the identifying to the weak entity set
    - Identifying relationship depicted using a double diamond
  - The **discriminator** (*or partial key)* of a weak entity set is the set of attributes that distinguishes among all the entities of a weak entity set.
  - The primary key of a weak entity set is formed by the primary key of the strong entity set on which the weak entity set is existence dependent, plus the weak entity set's discriminator.
    - We depict a weak entity set by double rectangles.
  - We underline the discriminator of a weak entity set with a dashed line.
    - *payment_number* – discriminator of the *payment* entity set
    - Primary key for *payment* – (*loan_number, payment_number*)



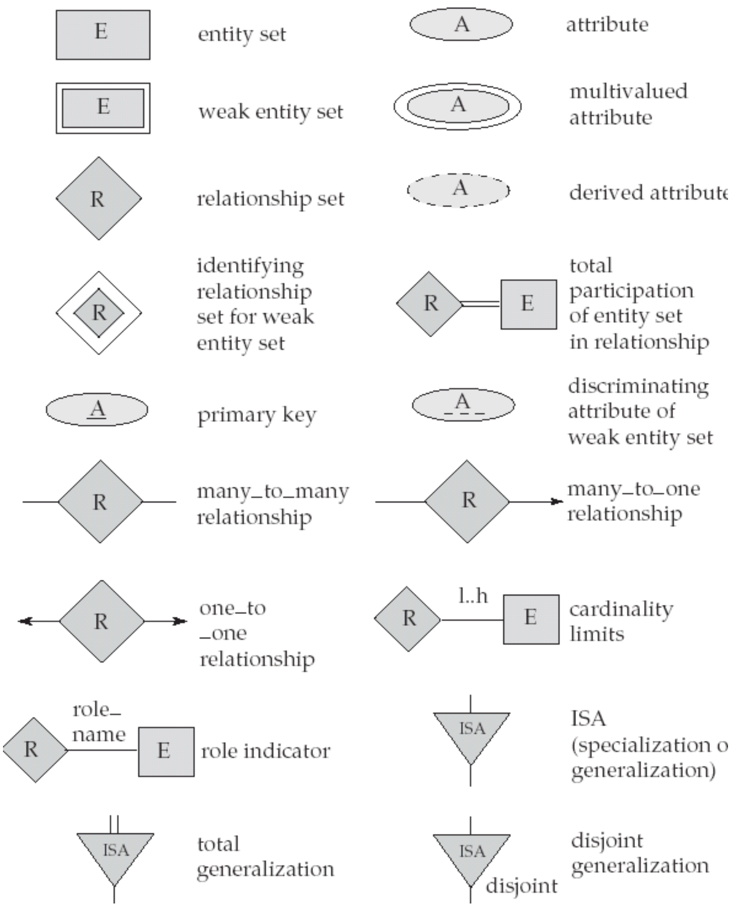
E-R Design Decisions

- The use of an attribute or entity set to represent an object.
- Whether a real-world concept is best expressed by an entity set or a relationship set.
- The use of a ternary relationship versus a pair of binary relationships.
- The use of a strong or weak entity set.
- The use of specialization/generalization – contributes to modularity in the design.
- The use of aggregation – can treat the aggregate entity set as a single unit without concern for the details of its internal structure.

E-R Diagram for a Banking Enterprise



Summary of Symbols Used in E-R Notation



Reduction to Relation Schemas

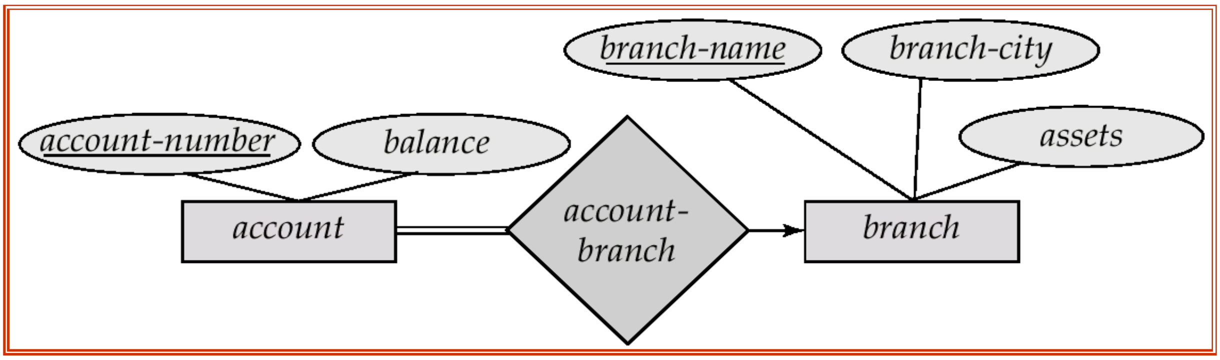
- Primary keys allow entity sets and relationship sets to be expressed uniformly as *relation schemas* that represent the contents of the database.
  - A database which conforms to an E-R diagram can be represented by a collection of schemas.
  - For each entity set and relationship set there is a unique schema that is assigned the name of the corresponding entity set or relationship set.
  - Each schema has a number of columns (generally corresponding to attributes), which have unique names
- A strong entity set reduces to a schema with the same attributes.
- A weak entity set becomes a table that includes a column for the primary key of the identifying strong entity set

  payment = (*loan_number*, *payment_number*, *payment_date*, *payment_amount*)
- A many-to-many relationship set is represented as a schema with attributes for the primary keys of the two participating entity sets
  - and perhaps any descriptive attributes of the relationship set.
  - Example: schema for relationship set borrower

    borrower = (*customer_id*, *loan_number*)

Redundancy of Schemas

- Many-to-one and one-to-many relationship sets that are total on the many-side can be represented by adding an extra attribute to the "many" side, containing the primary key of the "one" side
  - Example: Instead of creating a schema for relationship set *account_branch*, add an attribute *branch_name* to the schema arising from entity set *account*



- For one-to-one relationship sets, either side can be chosen to act as the "many" side
  - That is, extra attribute can be added to either of the tables corresponding to the two entity sets

Composite and Multivalued Attributes

- Composite attributes are flattened out by creating a separate attribute for each component attribute
  - Example: given entity set *customer* with composite attribute *name* with component attributes *first_name* and *last_name* the schema corresponding to the entity set has two attributes
    name.first_name and *name.last_name*
- A multivalued attribute *M* of an entity *E* is represented by a separate schema *EM*
  - Schema *EM* has attributes corresponding to the primary key of *E* and an attribute corresponding to multivalued attribute *M*
  - Example: Multivalued attribute *dependent_names* of *employee* is represented by a schema:
    employee_dependent_names = (<u>*employee_id*</u>, *dname*)
  - Each value of the multivalued attribute maps to a separate tuple of the relation on schema *EM*
    - For example, an employee entity with primary key 123-45-6789 and dependents Jack and Jane maps to two tuples:
      (123-45-6789 , Jack) and (123-45-6789 , Jane)

End of Lesson 8

Questions?