Chapter B: Hierarchical Model

- Basic Concepts
- Tree-Structure Diagrams
- Data-Retrieval Facility
- Update Facility
- Virtual Records
- Mapping of Hierarchies to Files
- The IMS Database System

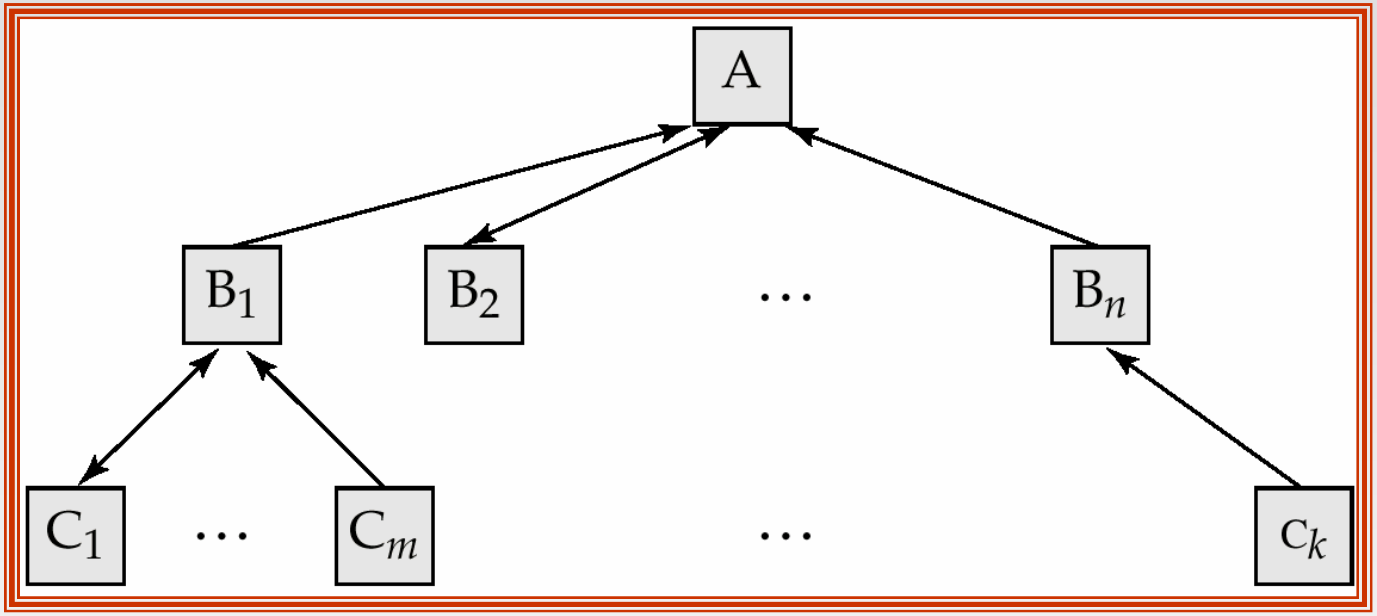
Basic Concepts

- A hierarchical database consists of a collection of *records* which are connected to one another through *links.*
- a record is a collection of fields, each of which contains only one data value.
- A link is an association between precisely two records.
- The hierarchical model differs from the network model in that the records are organized as collections of trees rather than as arbitrary graphs.

Tree-Structure Diagrams

- The schema for a hierarchical database consists of
  - *boxes,* which correspond to record types
  - *lines,* which correspond to links
- Record types are organized in the form of a *rooted tree.*
  - No cycles in the underlying graph.
  - Relationships formed in the graph must be such that only one-to-many or one-to-one relationships exist between a parent and a child.

General Structure



- A parent *may* have an arrow pointing to a child, but a child *must* have an arrow pointing to its parent.

Tree-Structure Diagrams (Cont.)

- Database schema is represented as a collection of tree-structure diagrams.
  - *single* instance of a database tree
  - The root of this tree is a dummy node
  - The children of that node are actual instances of the appropriate record type
- When transforming E-R diagrams to corresponding tree-structure diagrams, we must ensure that the resulting diagrams are in the form of rooted trees.

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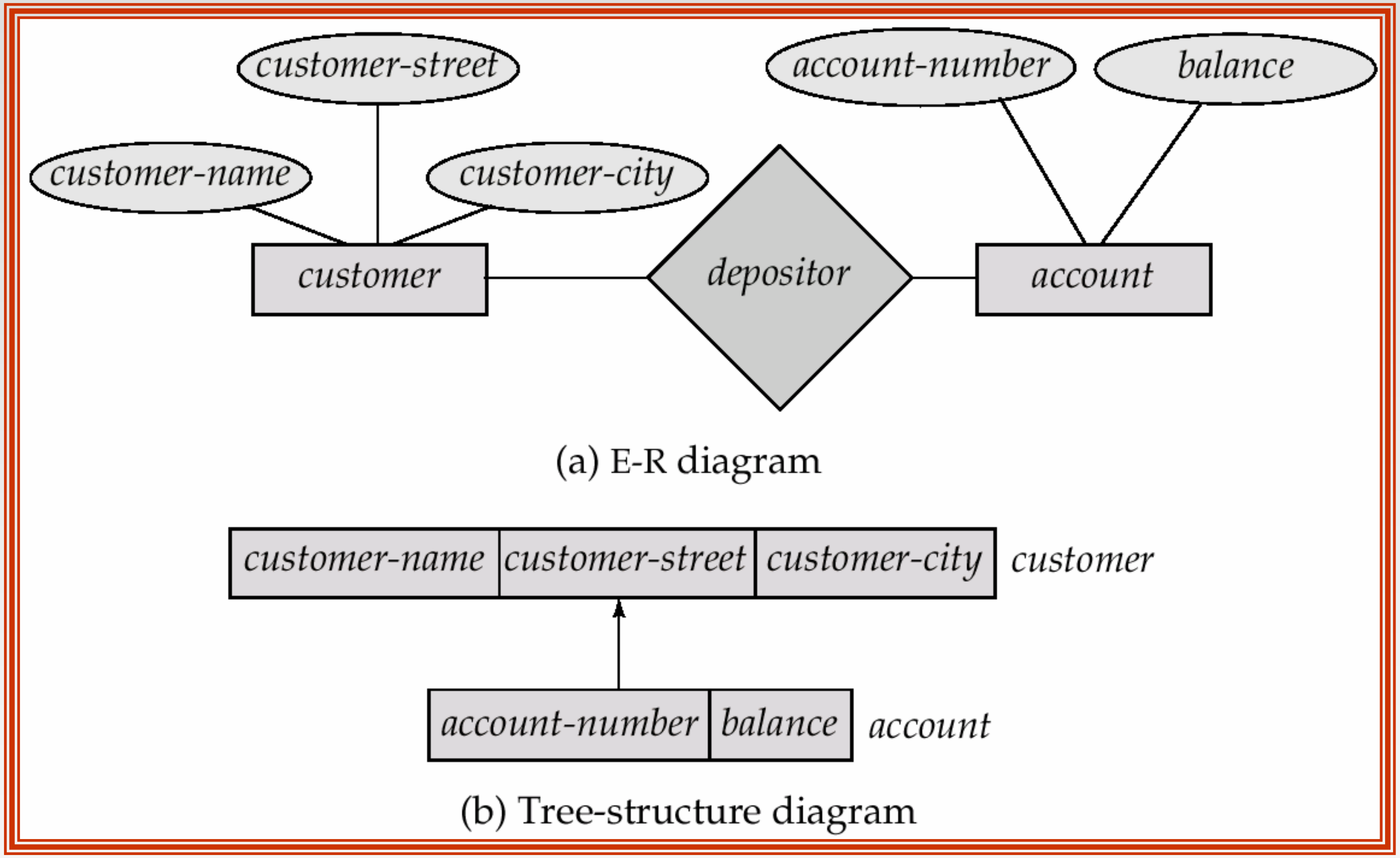
Single Relationships

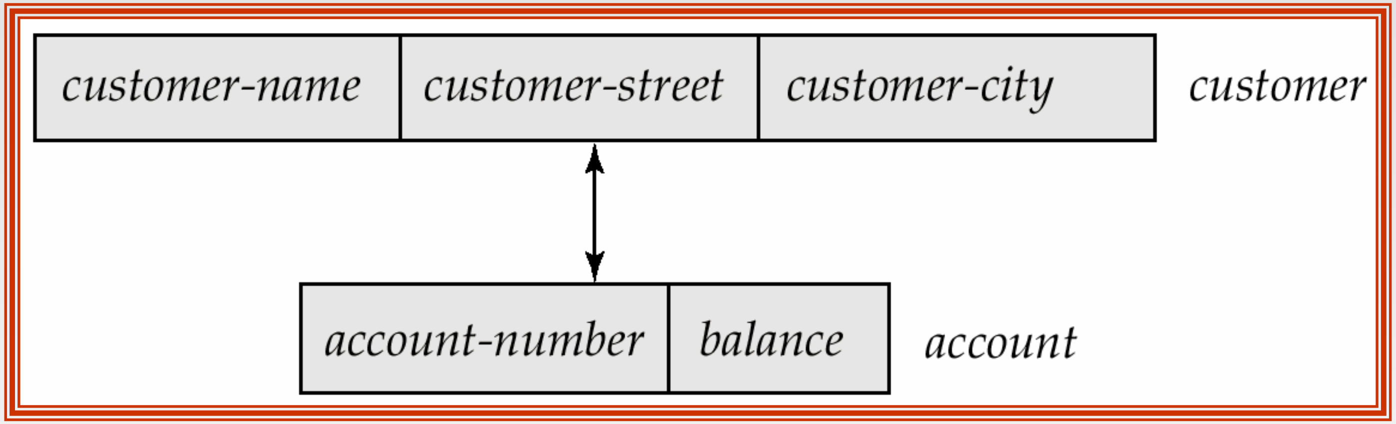


Single relationships (Cont.)

- Example E-R diagram with two entity sets, *customer* and *account,* related through a binary, one-to-many relationship *depositor.*
- Corresponding tree-structure diagram has
  - the record type *customer* with three fields: *customer-name, customer-street,* and *customer-city.*
  - the record type *account* with two fields: *account-number* and *balance*
  - the link *depositor,* with an arrow pointing to *customer*

Single Relationships (Cont.)

- If the relationship *depositor* is one to one, then the link *depositor* has two arrows.



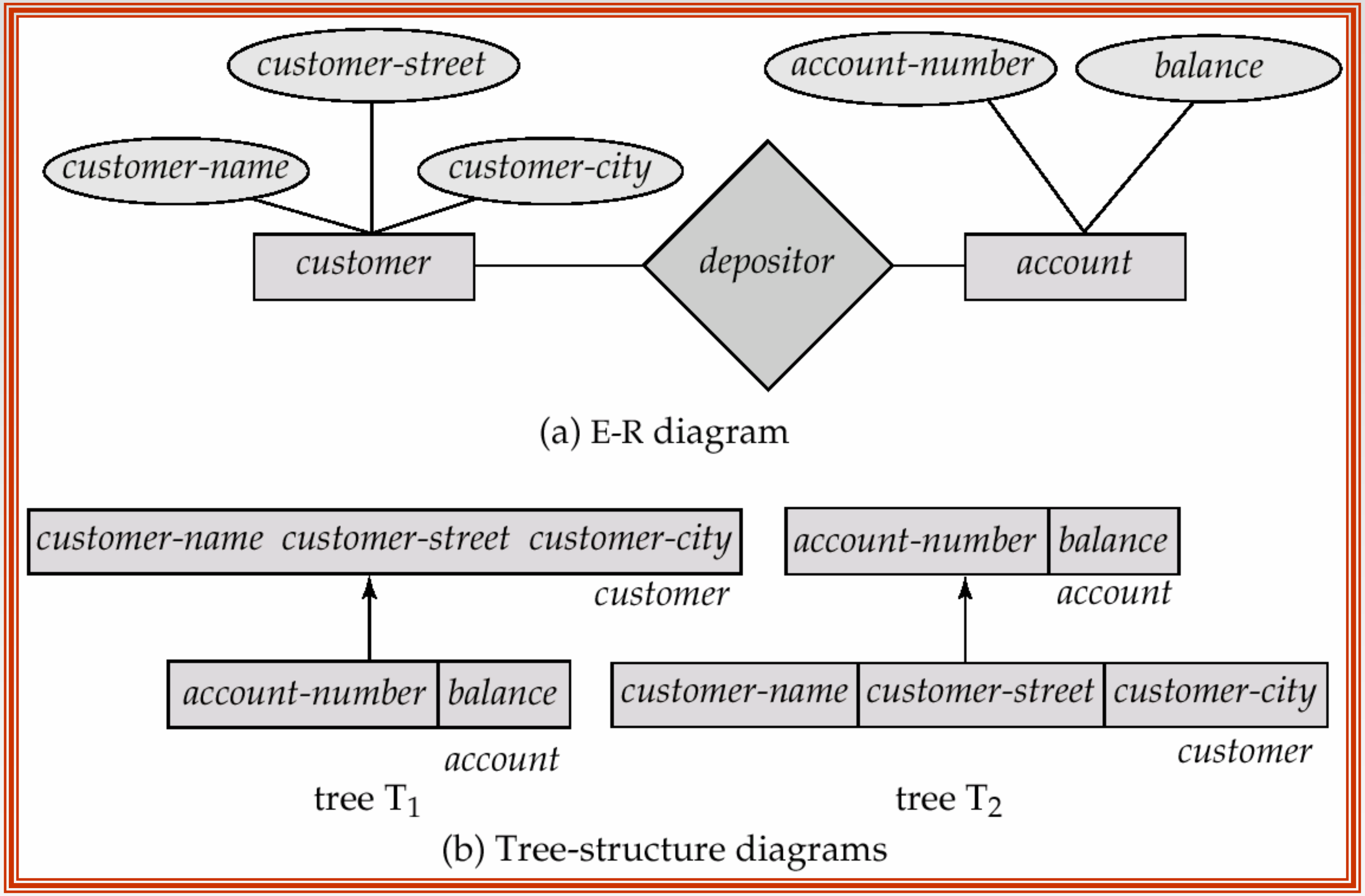
- Only one-to-many and one-to-one relationships can be directly represented in the hierarchical mode.

Transforming Many-To-Many Relationships

- Must consider the type of queries expected and the degree to which the database schema fits the given E-R diagram.

- In all versions of this transformation, the underlying database tree (or trees) will have replicated records.

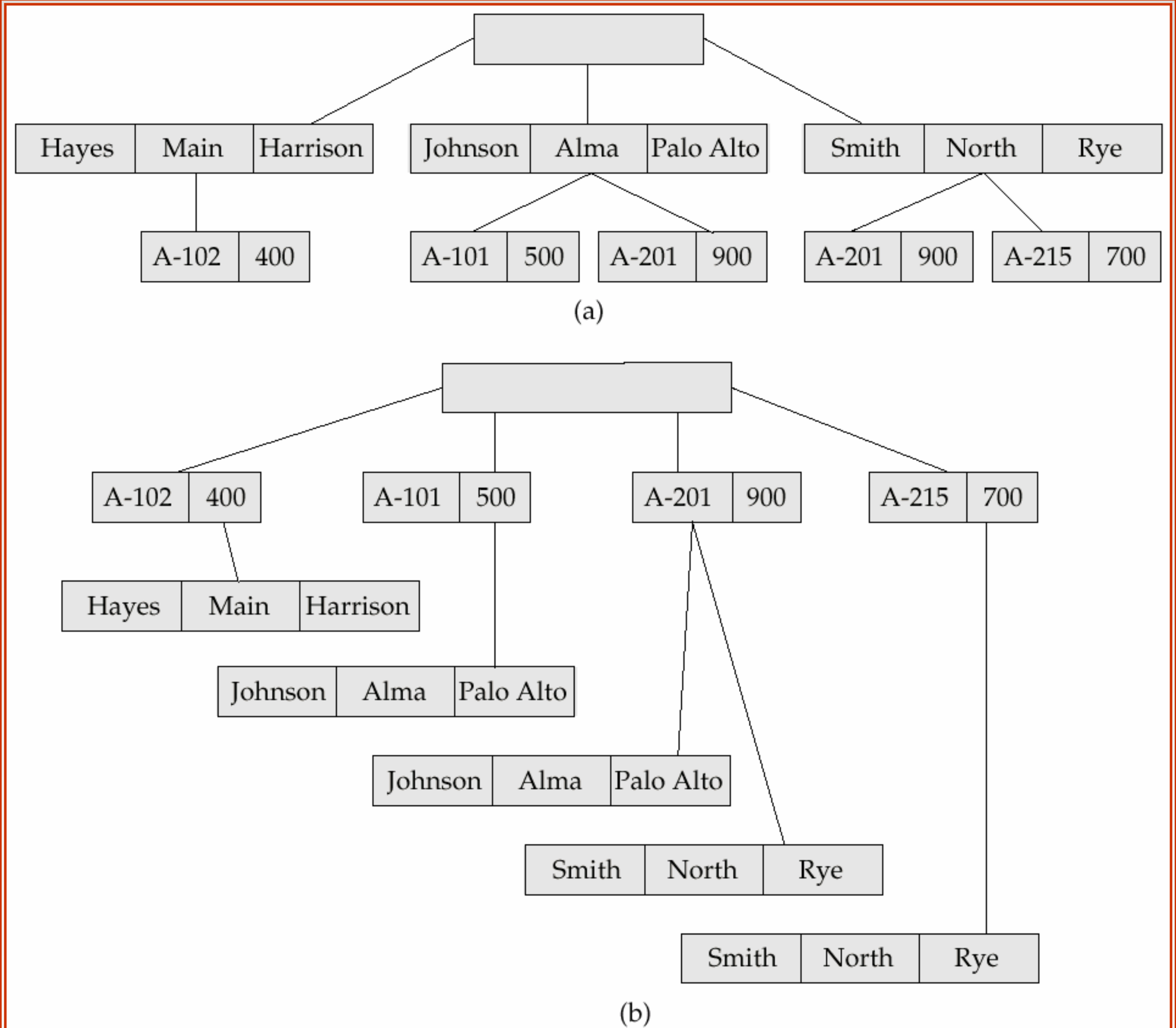
Many-To Many Relationships (Cont.)



Many-To-Many Relationships (Cont.)

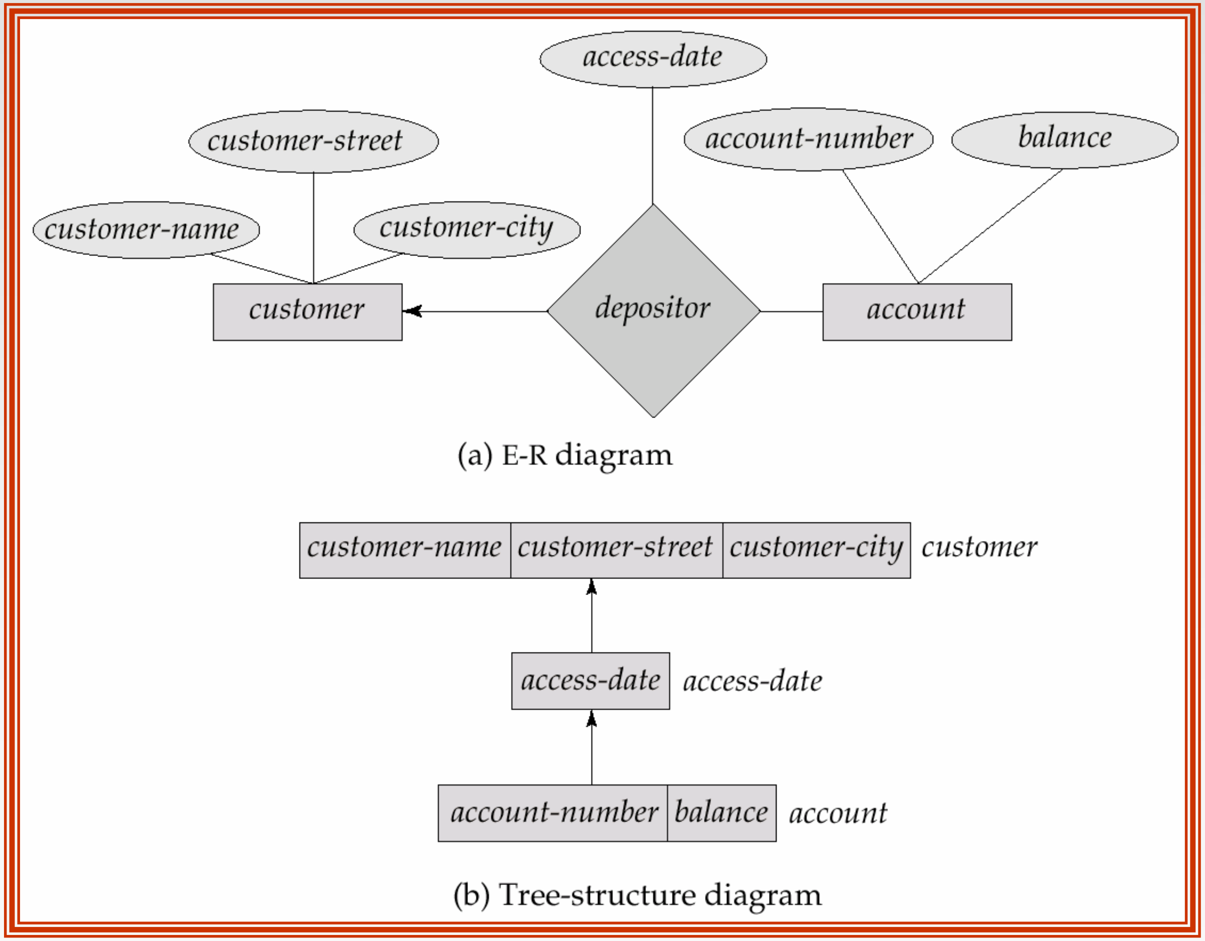
- Create two tree-structure diagrams, T_1, with the root *customer,* and T_2, with the root *account.*
- In T_1, create *depositor,* a many-to-one link from *account* to *customer.*
- In T_2, create *account-customer,* a many-to-one link from *customer* to *account.*

Sample Database

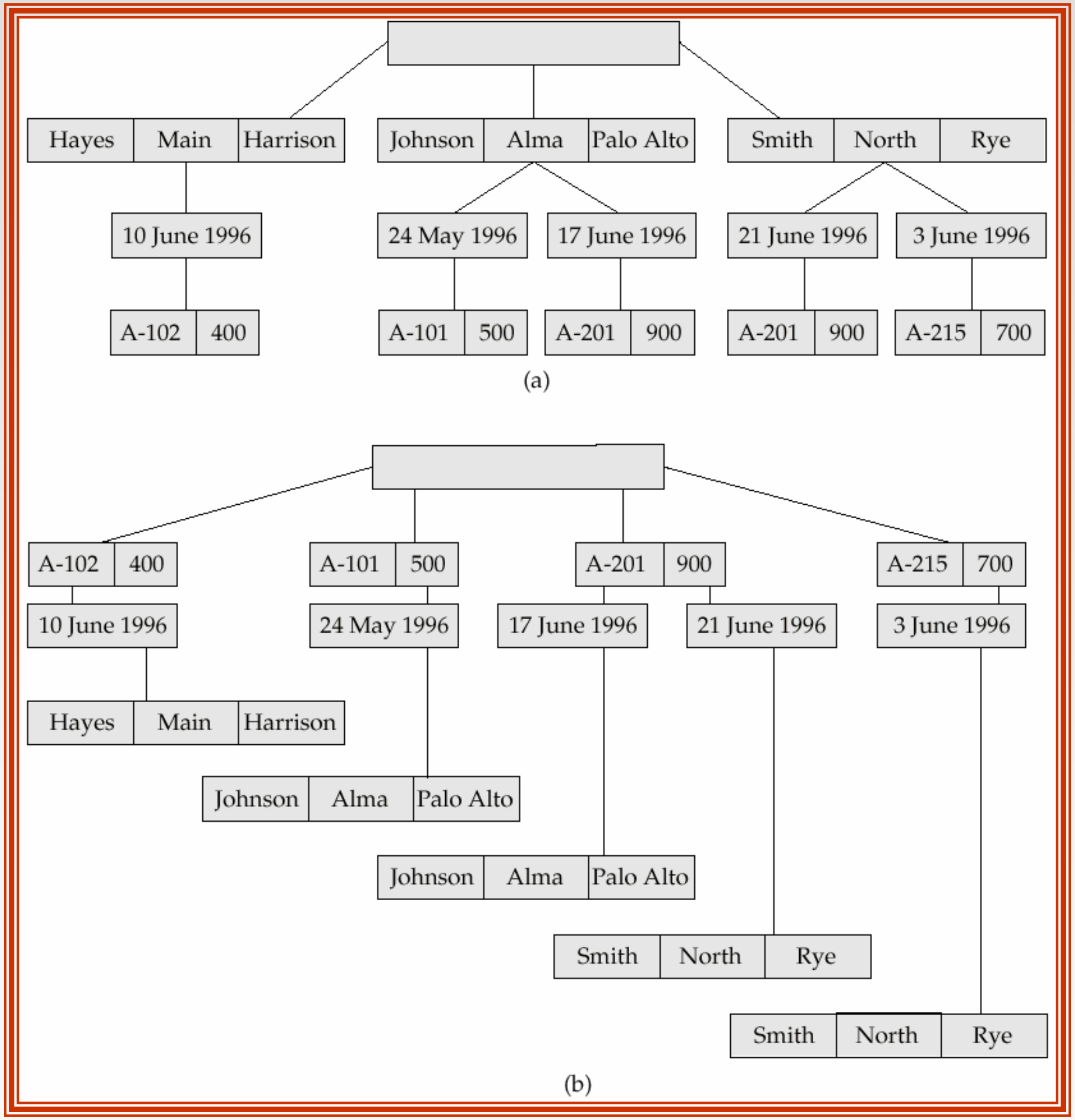


General Relationships

- Example ternary E-R diagram and corresponding tree-structure diagrams are shown on the following page.



Sample Ternary Databases. (a) T_1 (b) T_2



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Several Relationships

- To correctly transform an E-R diagram with several relationships, split the unrooted tree structure diagrams into several diagrams, each of which is a rooted tree.
- Example E-R diagram and transformation leading to diagram that is not a rooted tree:

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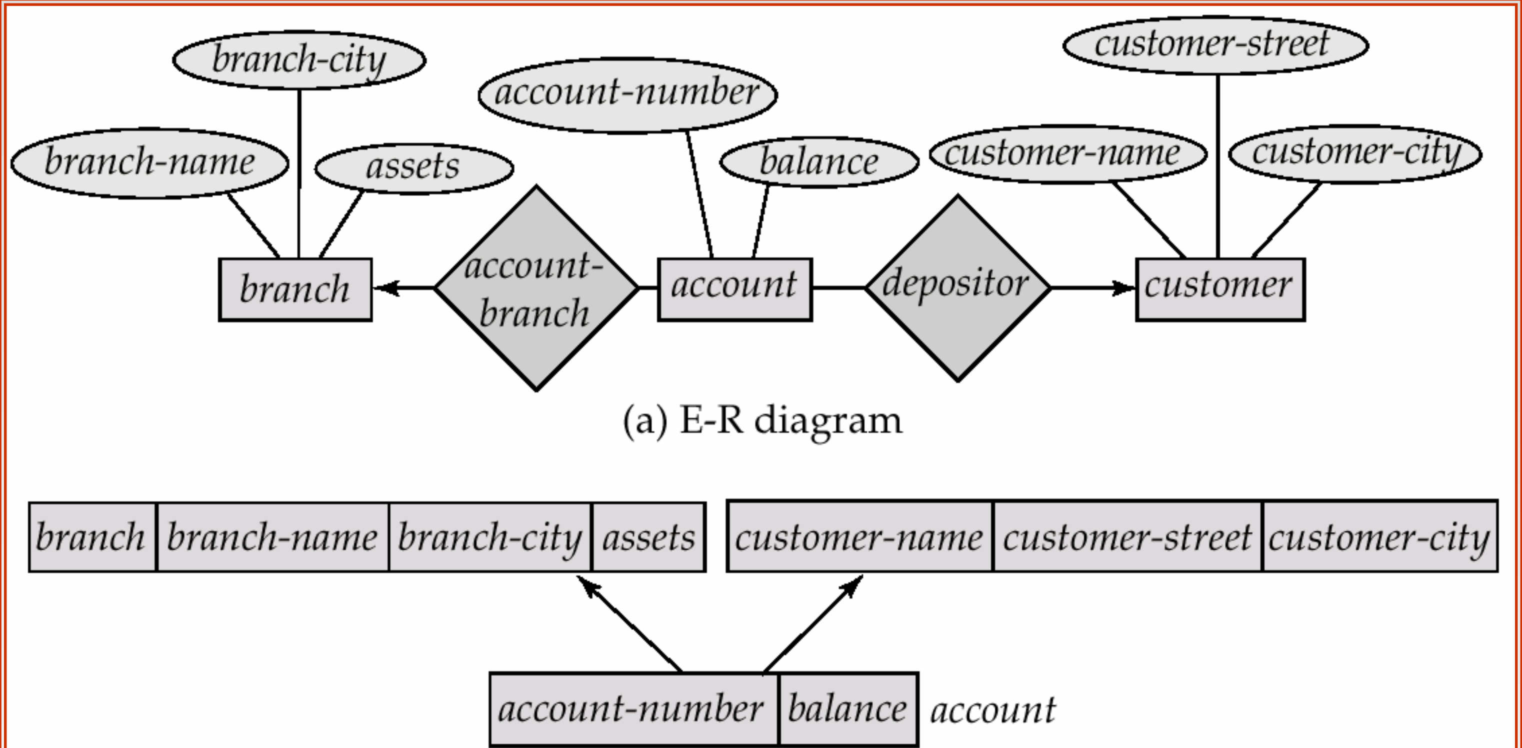
Several Relationships (Cont.)

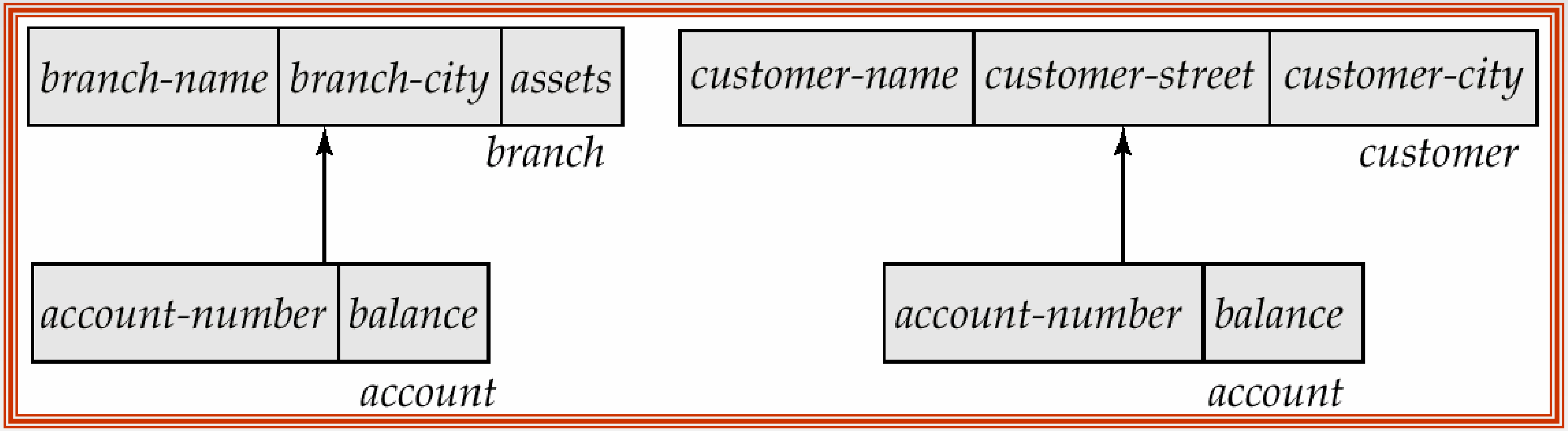


(a) E-R diagram

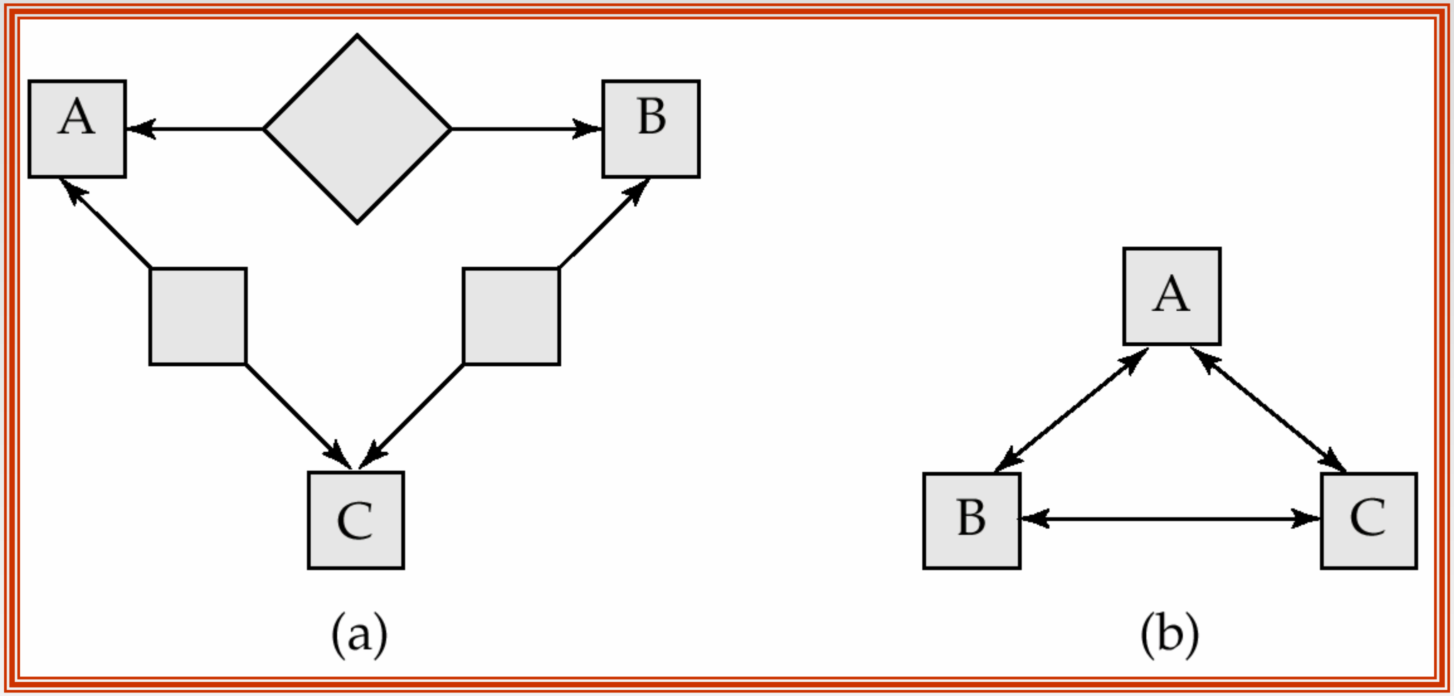
(b) transformation of E-R diagram

Several Relationships (Cont.)

- Corresponding diagrams in the form of rooted trees.



Several Relationships (2nd Example)



- Diagram (b) contains a cycle.
- Replicate all three record types, and create two separate diagrams.

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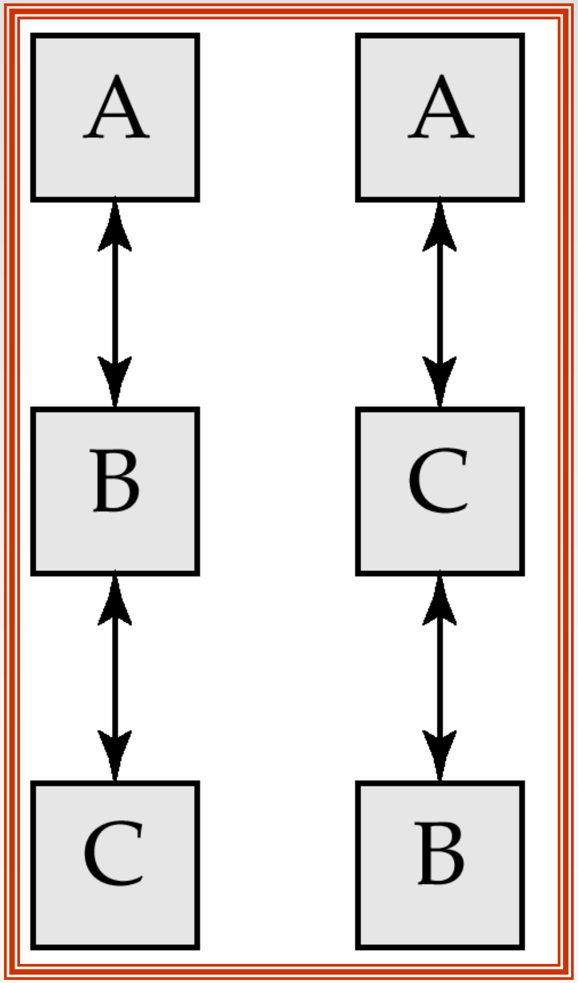
Several Relationships (2nd Example)

- Each diagram is now a rooted tree.



Data Retrieval Facility

- We present querying of hierarchical databases via a simplified version of DL/I, the data-manipulation language of IMS.
- Example schema: *customer-account-branch*
- A branch can have several customers, each of which can have several accounts.
- An account may belong to only one customer, and a customer can belong to only one branch.

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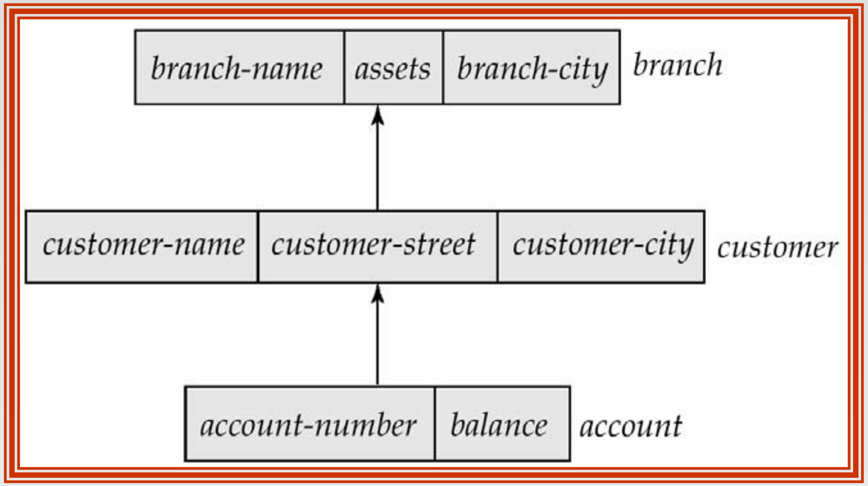
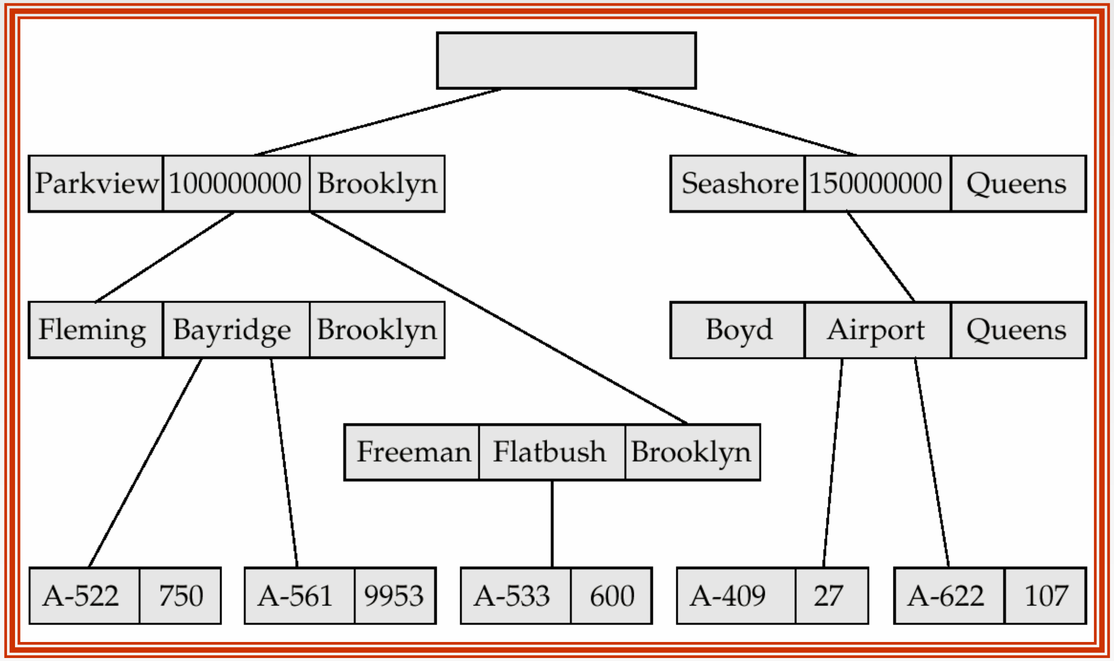
Example Schema





Program Work Area

- A buffer storage area that contains these variables
  - Record templates
  - Currency pointers
  - Status flag
- A particular program work area is associated with precisely one application program.
- Example program work area:
  - Templates for three record types: *customer, account,* and *branch.*
  - Currency pointer to the most recently accessed record of *branch, customer,* or *account* type.
  - One status variable.

The get Command

- Data items are retrieved through the **get** command
  - locates a record in the database and sets the currency pointer to point to it
  - copies that record from the database to the appropriate program work-area template
- The **get** command must specify which of the database trees is to be searched.
- State of the program work area after executing **get** command to locate the *customer* record belonging to Freeman
  - The currency pointer points now to the record of Freeman.
  - The information pertaining to Freeman is copied into the *customer* record work-area template.
  - *DB-status* is set to the value 0.

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The get Command (Cont.)

- To scan all records in a consistent manner, we must impose an ordering on the records.
- *Preorder* search starts at the root, and then searches the subtrees of the root from left to right, recursively.
  - Starts at the root, visits the leftmost child, visits its leftmost child, and so on, until a leaf (childless) node is reached.
  - Move back to the parent of the leaf and visit the leftmost unvisited child.
  - Proceed in this manner until the entire three is visited.
- Preordered listing of the records in the example database three:

  Parkview, Fleming, A-522, A-561, Freeman, A533, Seashore, Boyd, A-409, A-622

Access Within A Database Tree

- Locates the first record (in preorder), of type <record type> that satisfies the <condition> of the **where** clause.
- The **where** clause is optional <condition> is a predicate that involves either an ancestor of <record type> or the <record type> itself.
- If **where** is omitted, locate the first record of type <record-type>
  - Set currency pointer to that record
  - Copy its contents into the appropriate work-area template.
- If no such record exists in the tree, then the search fails, and *DB-status* is set to an appropriate error message.

Example Queries

- Print the address of customer Fleming:

  get first *customer*
      where *customer.customer-name* = “Fleming”;
  print (*customer.customer-address*);

- Print an account belonging to Fleming that has a balance greater than $10,000.

  get first *account*
      where *customer.customer-name* = “Fleming”;
          and *account.balance* > 10000;
  if *DB-status* = 0 **then print** (*account.account-number);*

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Access Within a Database Tree (Cont.)

get next <record type>
where <condition>

- Locates the next record (in preorder) that satisfies <condition>.
- If the **where** clause is omitted, then the next record of type <record type> is located.
- The currency pointer is used by the system to determine where to resume the search.
- As before, the currency pointer, the work-area template of type <record-type>, and *DB-status* are affected.

Example Query

- Print the account number of all the accounts that have a balance greater than $500

```
get first account
    where account.balance > 500;
while DB-status = 0 do
    begin
        print (account.account-number);
        get next account
            where account.balance > 500;
end
```

- When **while** loop returns *DB-status* $\neq$ 0, we exhausted all account records with *account.balance* > 500.

Access Within a Database Tree (Cont.)

get next within parent <record type>
where <condition>

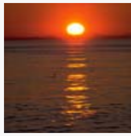
- Searches only the specific subtree whose root is the most recent record that was located with either **get first** or **get next.**
- Locates the next record (in preorder) that satisfies <condition> in the subtree whose root is the parent of current of <record type>.
- If the **where** clause is omitted, then the next record of type <record type> within the designated subtree to resume search.
- Use currency pointer to determine where to resume search.
- *DB-status* is set to a nonzero value if no such record exists in the designated subtree (rather than if none exists in the entire tree).

Example Query

- Print the total balance of all accounts belonging to Boyd:

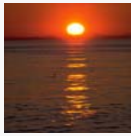
```
sum := 0;
get first customer
        where customer.customer-name = "Boyd";
get next within parent account;
while  DB-status  = 0 do
    begin
        sum = sum + account.balance;
        get next within parent account;
    end
print (sum);
```

- We exit from the **while** loop and print out the value of *sum* only when the *DB-status* is set to a value not equal to 0. This value exists after the **get next within parent** operation fails.



Update Facility

- Various mechanisms are available for updating information in the database.
- Creation and deletion of records (via the **insert** and **delete** operations).
- Modification (via the **replace** operation) of the content of existing records.



Creation of New Records

- To insert <record type> into the database, first set the appropriate values in the corresponding <record type> work-area template. Then execute

  insert <record type>
  where <condition>

- If the **where** clause is included, the system searches the database three (in preorder) for a record that satisfies the <condition> in the **where** clause.
- Once such a record — say, *X* — is found, the newly created record is inserted in the tree as the leftmost child of *X.*
- If **where** is omitted, the record is inserted in the first position (in preorder) in the tree where <record type> can be inserted in accordance with the specified schema.

Example Queries

- Add a new customer, Jackson, to the Seashore branch:

  customer.customer-name := "Jackson";
  customer.customer-street := "Old Road";
  customer.customer-city := "Queens";
  insert *customer*
      where *branch.branch-name* = "Seashore";

- Create a new account numbered A-655 that belongs to customer "Jackson";

  account.account-number := "A-655";
  account.balance := 100;
  insert *account*
      where *customer.customer-name* = "Jackson";

Modification of an Existing Record

- To modify an existing record of type <record type>, we must get that record into the work-area template for <record type>, and change the desired fields in that template.
- Reflect the changes in the database by executing

  replace

- **replace** dies not have <record type> as an argument; the record that is affected is the one to which the currency pointer points.
- DL/I requires that, prior to a record being modified, the **get** command must have the additional clause **hold**, so that the system is aware that a record is to be modified.

Example Query

- Change the street address of Boyd to Northview:

  get hold first *customer*
      where *customer.customer-name* = “Boyd”;
  customer.customer-street := “Northview”;
  replace;

- If there were more than one record containing Boyd’s address, the program would have included a loop to search all Boyd records.

Deletion of a Record

- To delete a record of type <record type>, set the currency pointer to point to that record and execute **delete.**
- As a record modification, the **get** command must have the attribute **hold** attached to it. Example: Delete account A-561:

  get hold first *account*
  where *account.account-number* = "A-561";
  delete;

- A **delete** operation deletes not only the record in question, but also the entire subtree rooted by that record. Thus, to delete customer Boyd and all his accounts, we write

  get gold first *customer*
  where *customer.customer-name* = "Boyd";
  delete;

Virtual Records

- For many-to-many relationships, record replication is necessary to preserve the tree-structure organization of the database.
  - Data inconsistency may result when updating takes place
  - Waste of space is unavoidable
- *Virtual record* — contains no data value, only a logical pointer to a particular physical record.
- When a record is to be replicated in several database trees, a single copy of that record is kept in one of the trees and all other records are replaced with a virtual record.
- Let R be a record type that is replicated in T_1, T_2, . . ., T_n. Create a new virtual record type *virtual-R* and replace R in each of the $n – 1$ trees with a record of type *virtual-R.*

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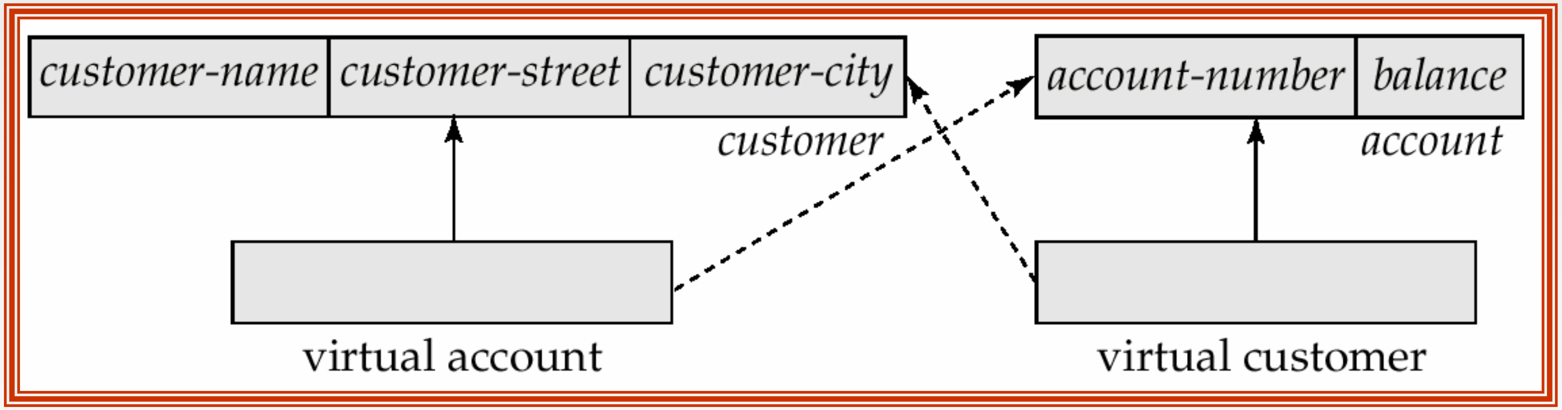
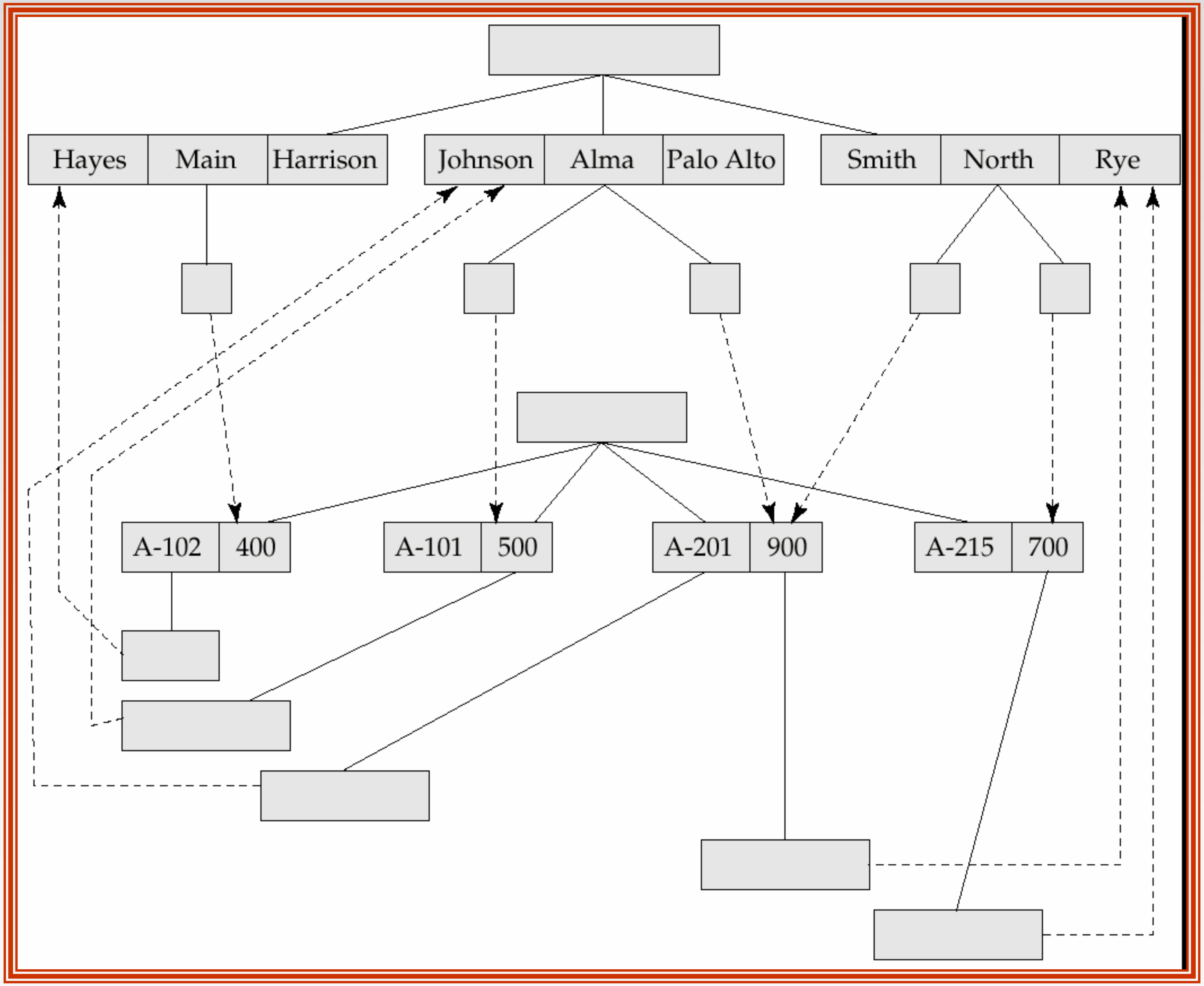
Virtual Records (Cont.)

- Eliminate data replication in the diagram shown on page B.11; create *virtual-customer* and *virtual-account.*
- Replace *account* with *virtual-account* in the first tree, and replace *customer* with *virtual-customer* in the second tree.
- Add a dashed line from *virtual-customer* to *customer*, and from *virtual-account* to *account,* to specify the association between a virtual record and its corresponding physical record.



Sample Database

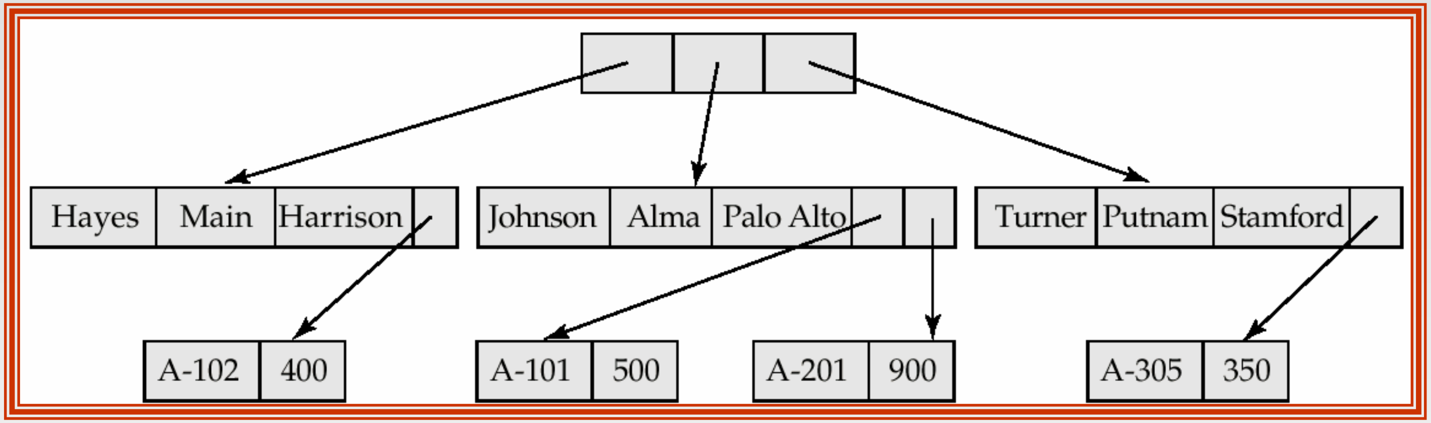


Mapping Hierarchies to Files

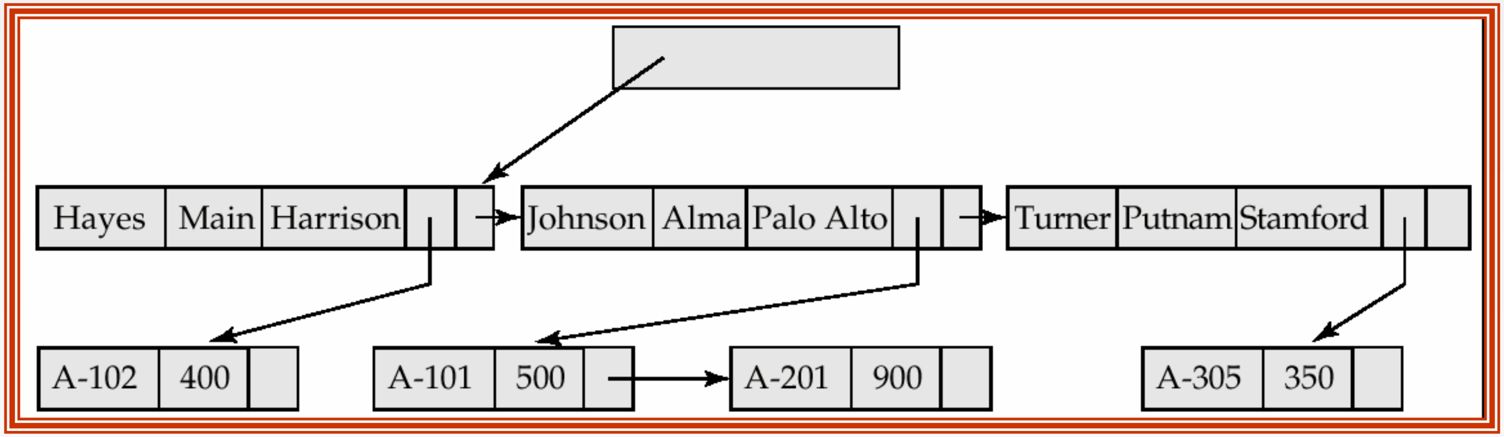
- Implementations of hierarchical databases do not use parent-to-child pointers, since these would require the use of variable-length records.
- Can use *leftmost-child* and *next-sibling* pointers which allow each record to contain exactly two pointers.
  - The leftmost-child pointer points to one child.
  - The next-sibling pointer points to another child of the same parent.

Mapping Hierarchies to Files (Cont.)

- Implementation with parent-child pointers.

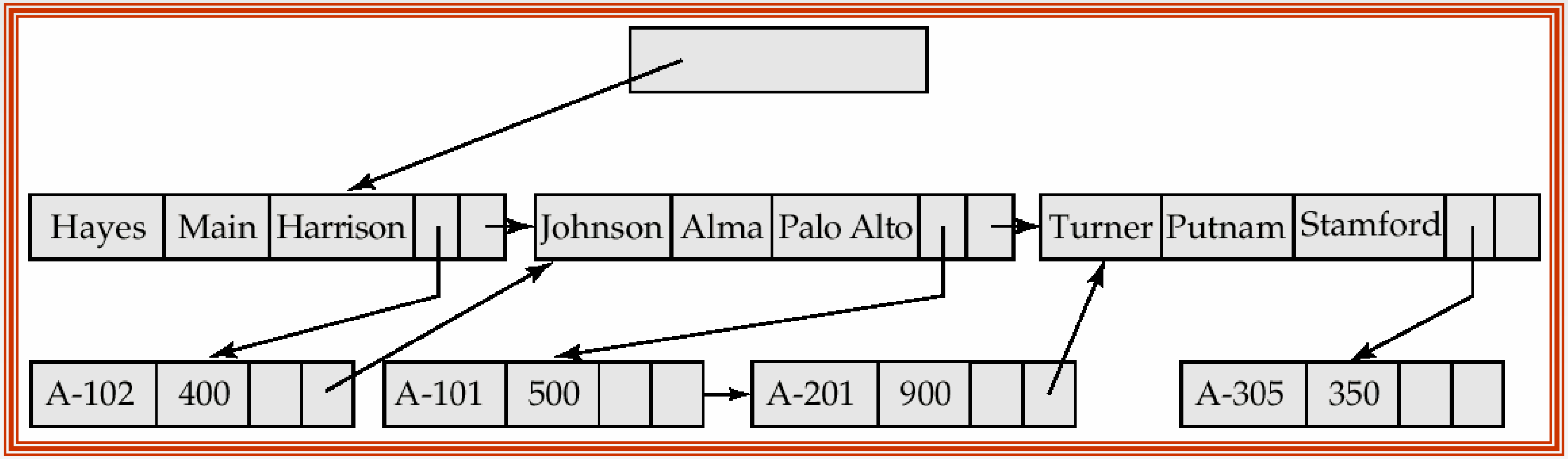


- Implementation with leftmost child and next-sibling pointers.



Mapping Hierarchies to Files (Cont.)

- In general, the final child of a parent has no next sibling; rather than setting the next-sibling filed to null, place a pointer (or *preorder thread*) that points to the next record in preorder.
- Using preorder threads allows us to process a tree instance in preorder simply by following pointers.



Mapping Hierarchies to Files (Cont.)

- May add a third child-to-parent pointer which facilitates the processing of queries that give a value for a child record and request a value from the corresponding parent record.
- the parent-child relationship within a hierarchy is analogous to the owner-member relationship within a DBTG set.
  - A one-to-many relationship is being represented.
  - Store together the members and the owners of a set occurrence.
  - Store physically close on disk the child records and their parent.
  - Such storage allows a sequence of **get first, get next,** and **get next within parent** statements to e executed with a minimal number of block accesses.

The IMS Database System

- IBM Information Management System — first developed in the late 1960s; historically among the largest databases.
- Issue queries through embedded calls which are part of the IMS database language DL/I.
- Allows the database designer a broad number of options in the data-definition language.
  - Designer defines a physically hierarchy as the database schema.
  - Can define several subschemas (or view) by constructing a logical hierarchy from the record types constituting the schema.
  - Options such as block sizes, special pointer fields, and so on, allow the database administrator to tune the system.

Record Access Schemes

- Hierarchical sequential-access method (HSAM) — used for physically sequential files (such as tape files). Records are stored physically in preorder.
- Hierarchical indexed-sequential-access method (HISAM) — an index-sequential organization at the root level of the hierarchy.
- Hierarchical indexed-direct-access method (HIDAM) — index organization at the root level with pointers to child records.
- Hierarchical direct-access method (HDAM) — similar to HIDAM, but with hashed access at the root level.

IMS Concurrency Control

- Early versions handled concurrency control by permitting only one update application program to run at a time. Read-only applications could run concurrent with updates.
- Later versions included a *program-isolation feature*
  - Allowed for improved concurrency control
  - Offered more sophisticated transaction-recovery techniques (such as logging); important to online transactions.
- The need for high-performance transaction processing led to the introduction of IMS *Fast Path.*

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IMS Fast Path

- Uses an alternative physical data organization that allows the most active parts of the database to reside in main memory.
- Instead of updates to disk being forced at the end of a transaction, update is deferred until a checkpoint or synchronization point.
- In the event of a crash, the recovery subsystem must redo all committed transactions whose updates were not forced to disk.
- Allows for extremely high rates of transaction throughput.
- Forerunner of *main-memory database systems.*

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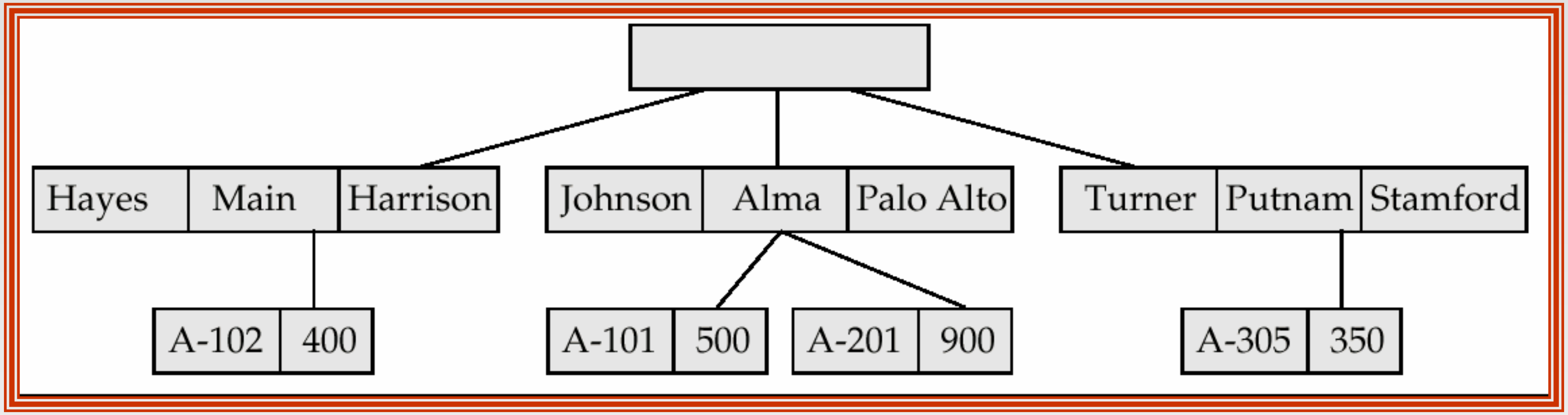
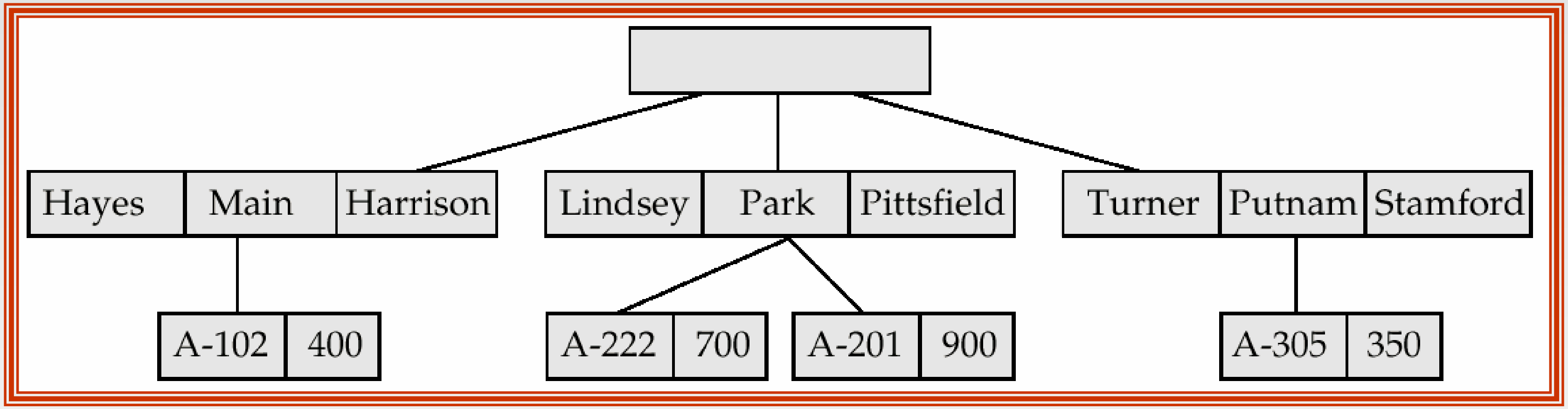
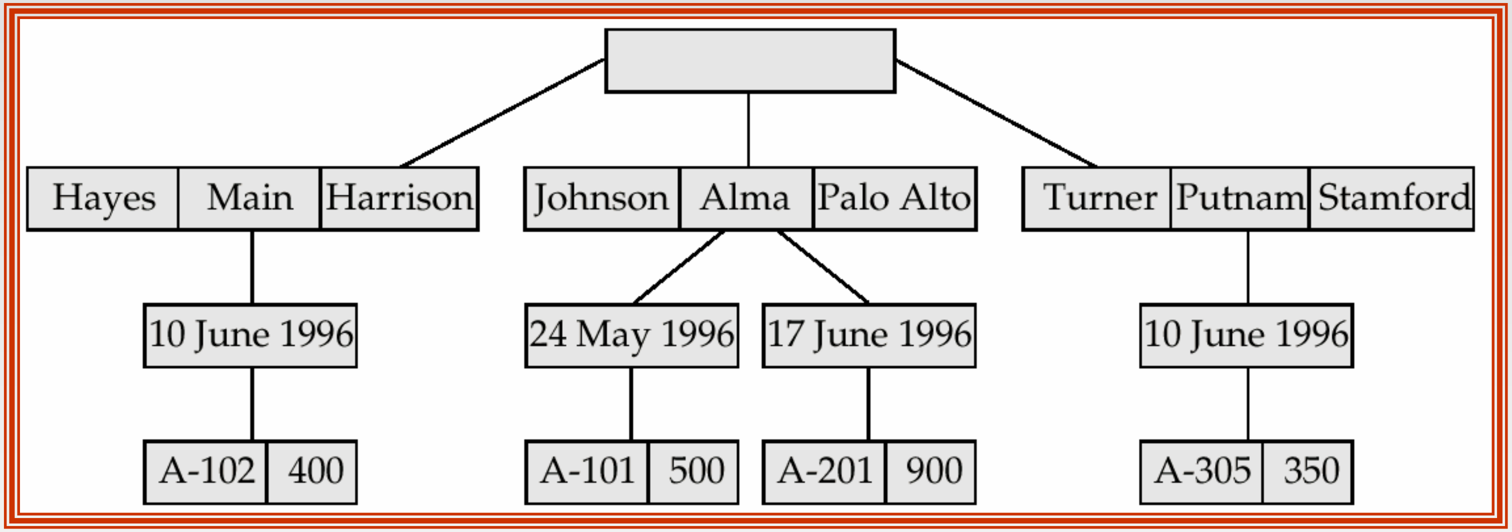
Sample Database



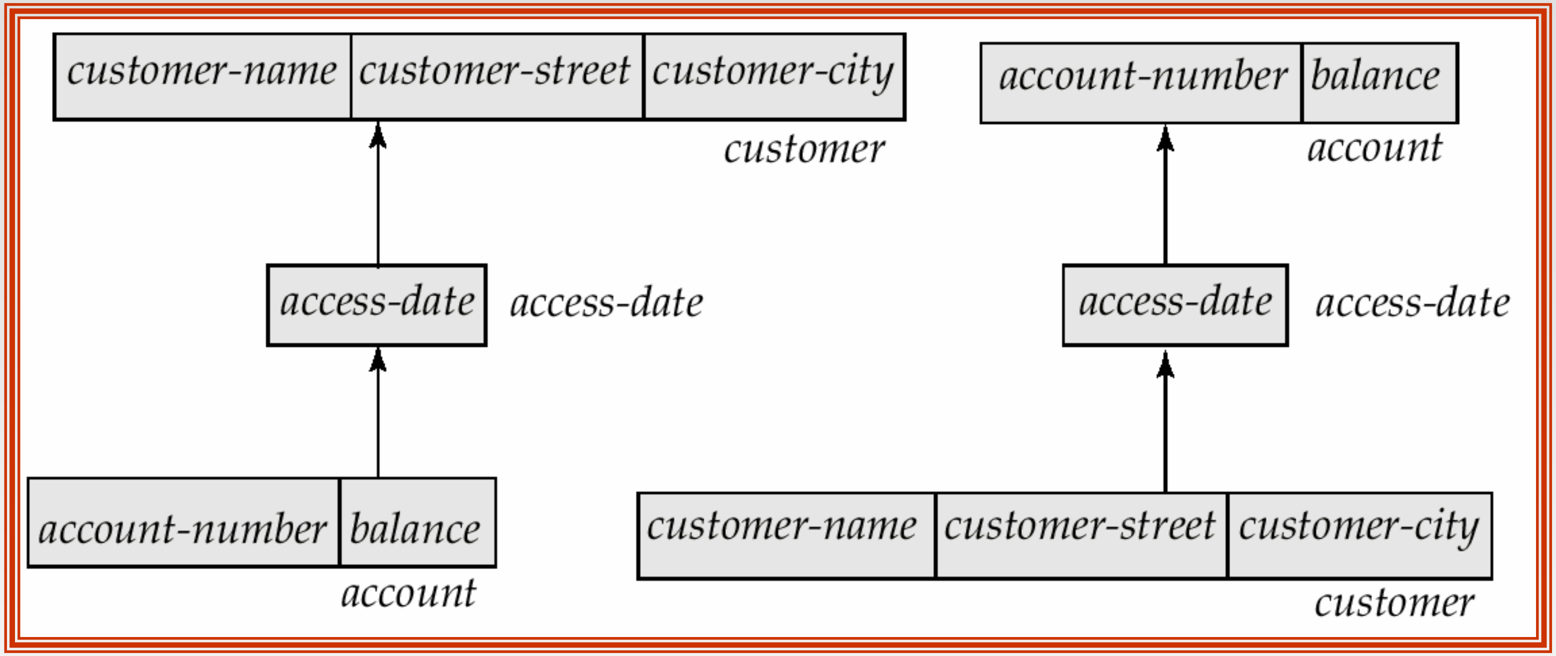
Sample Database Corresponding to Diagram of Figure B.4



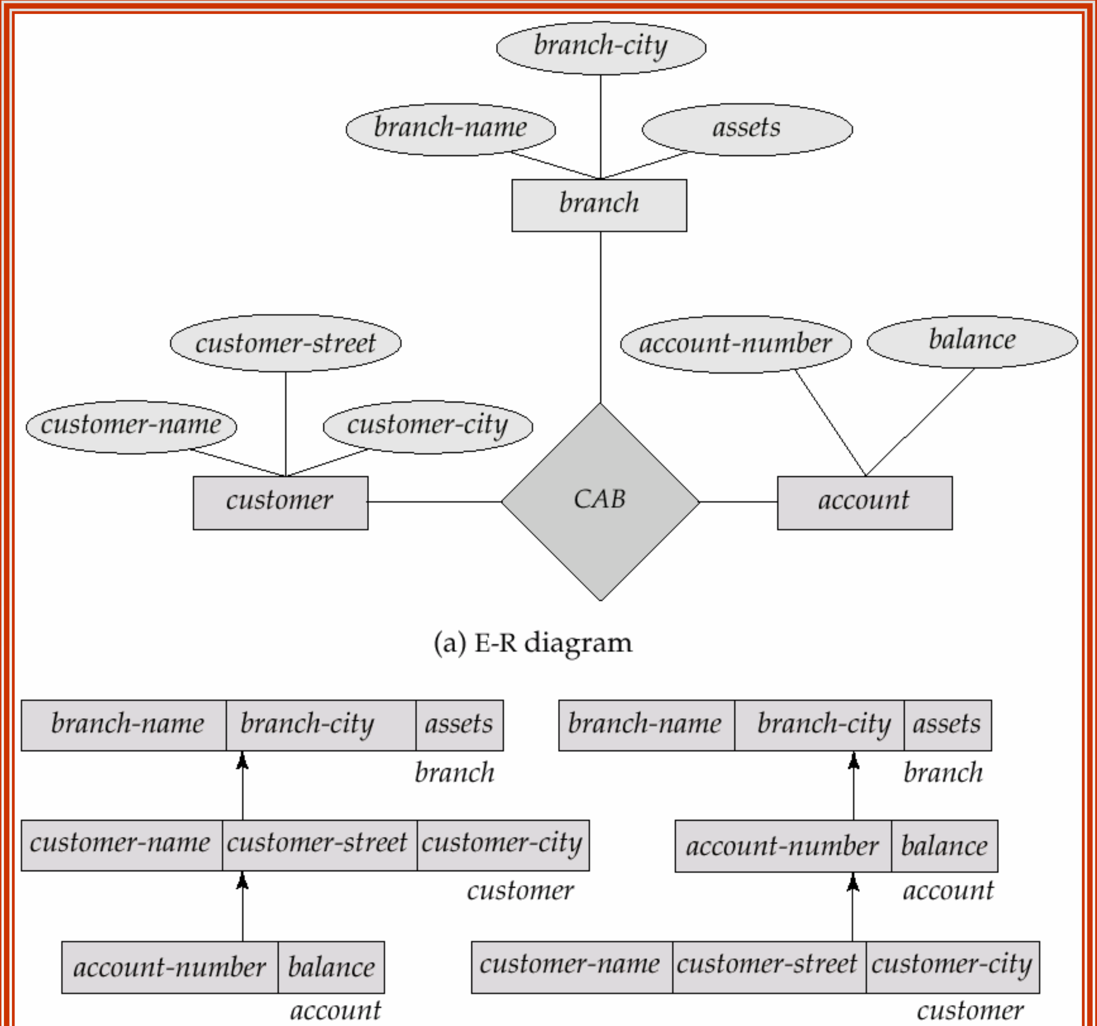
Sample Database Corresponding To Diagram of Figure B.8b



Tree-Structure Diagram With Many-To-Many Relationships



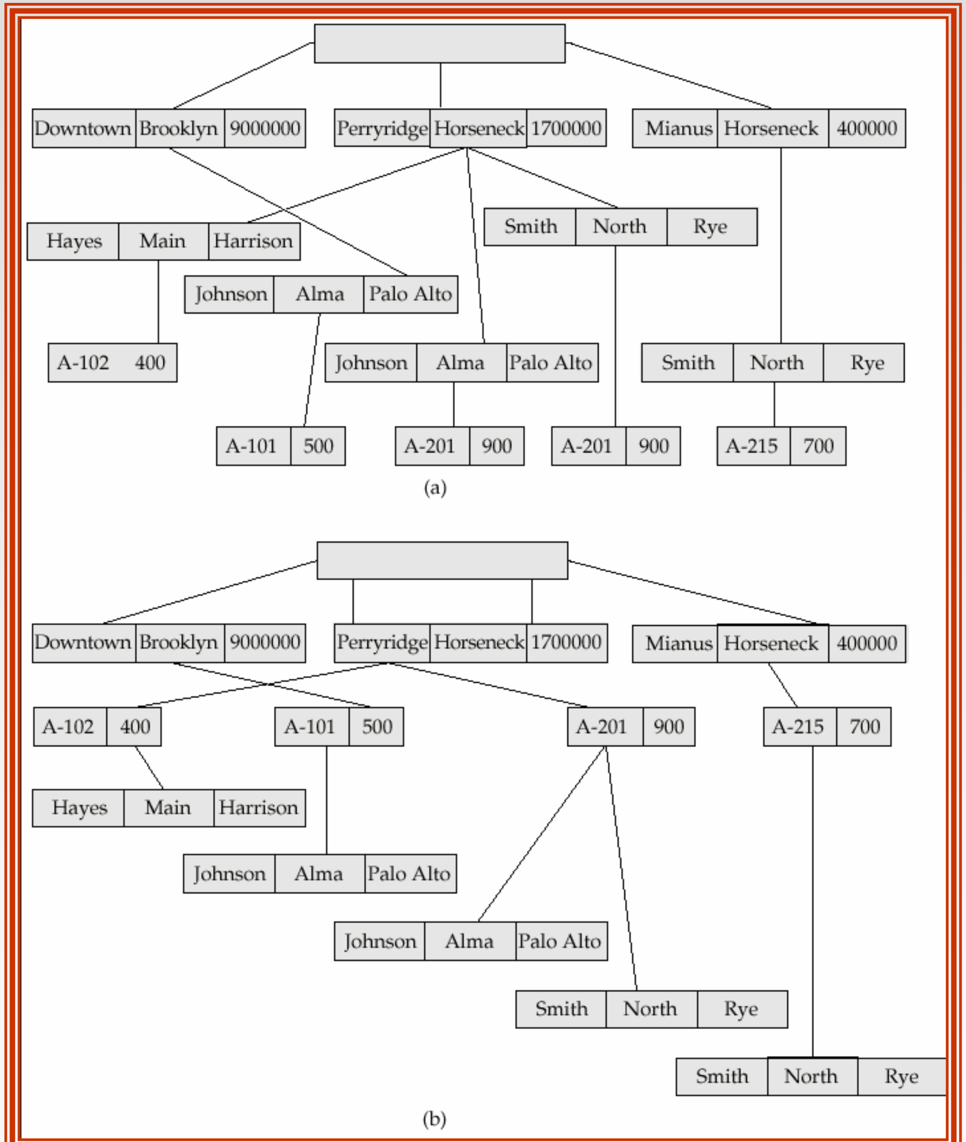
E-R Diagram and Its Corresponding Tree-Structure Diagrams



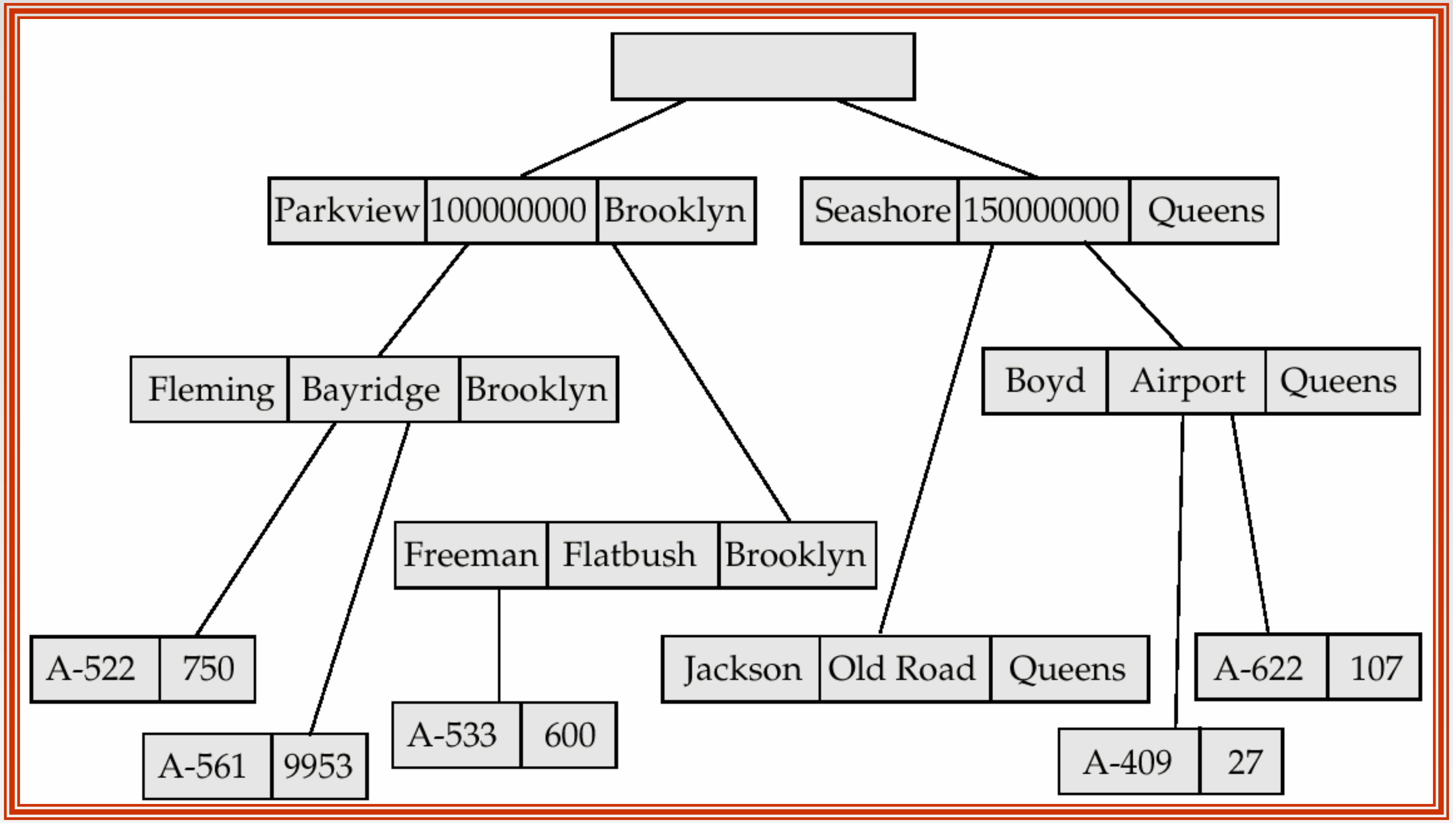
(a) E-R diagram

(b) Tree-structure diagrams

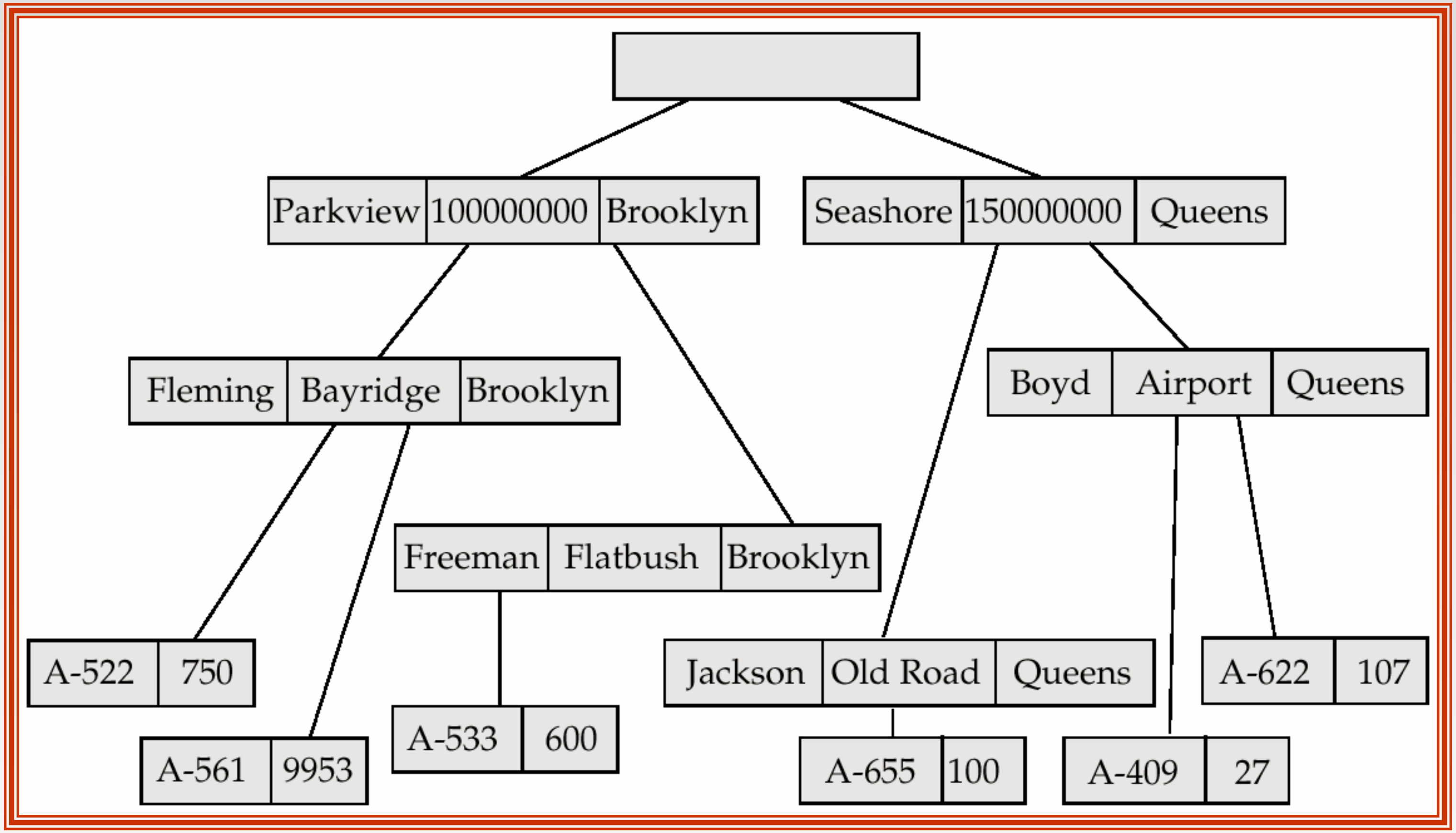
Sample Database Corresponding To Diagram of Figure B.12b



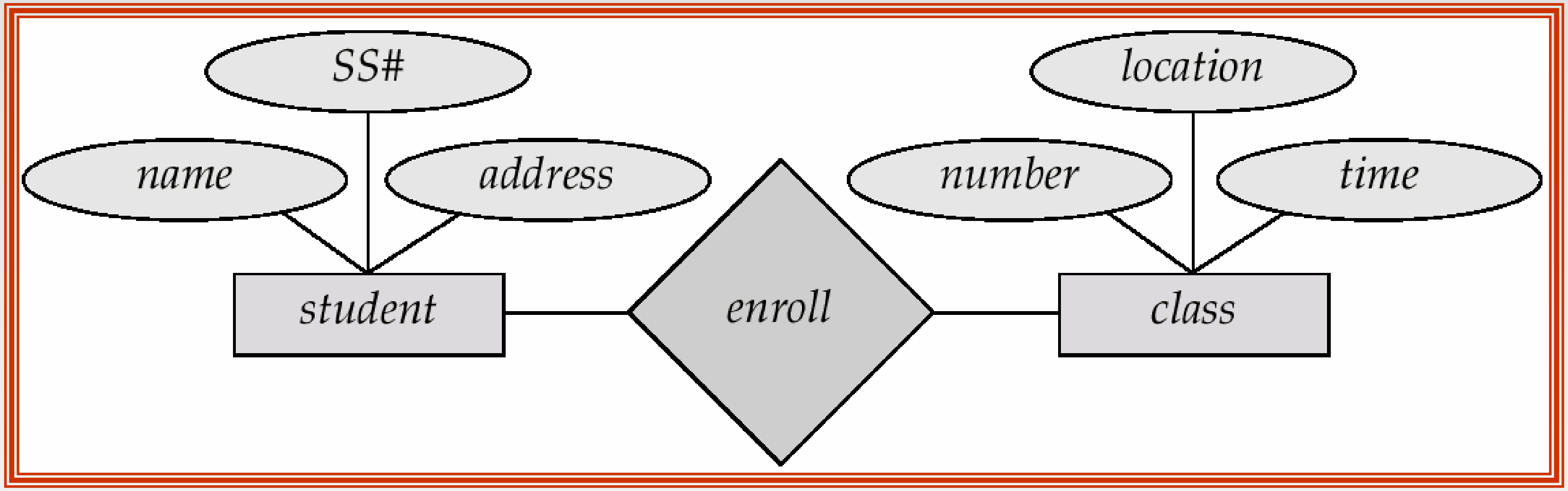
New Database Tree



New Database Tree



Class-enrollment E-R Diagram



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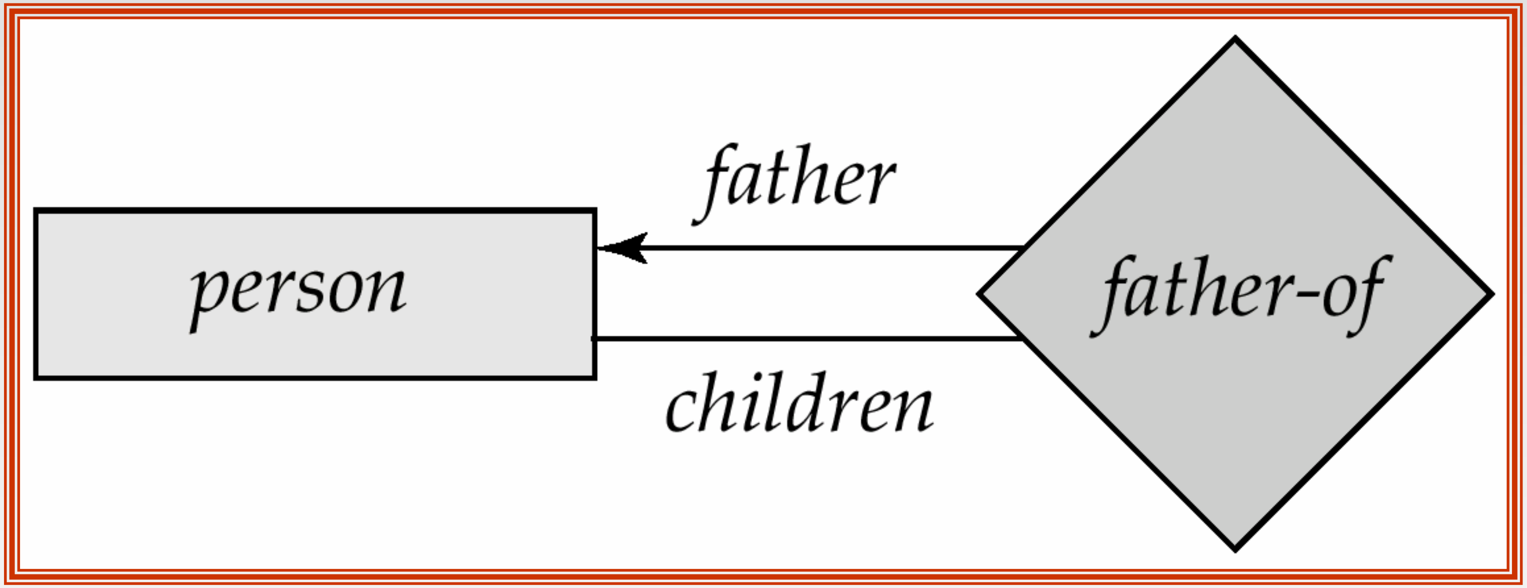
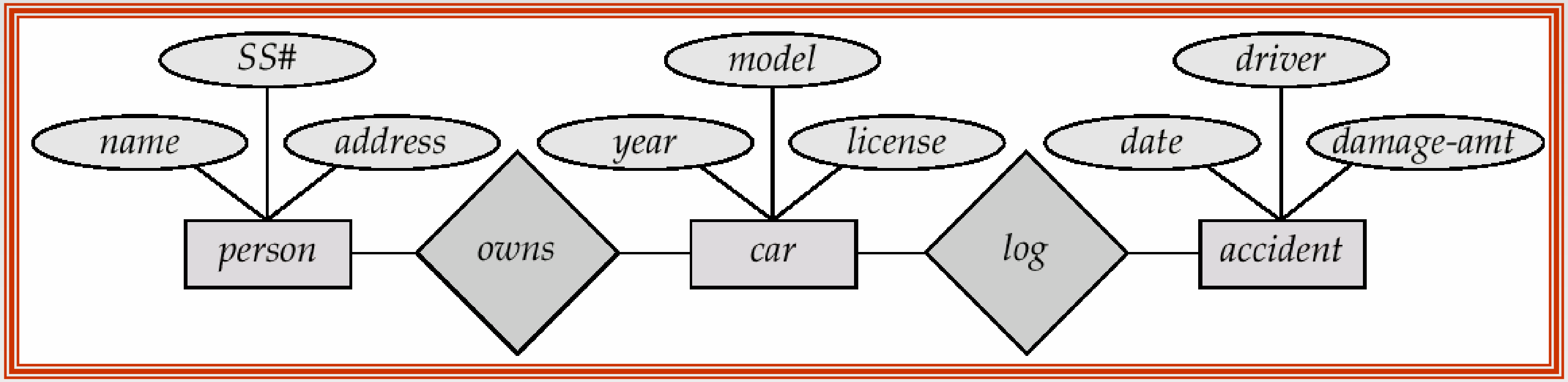
Parent–Child E-R Diagram



Car-insurance E-R Diagram



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