



Appendix E: Hierarchical Model

Database System Concepts, 6th Ed.

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Appendix E: 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.

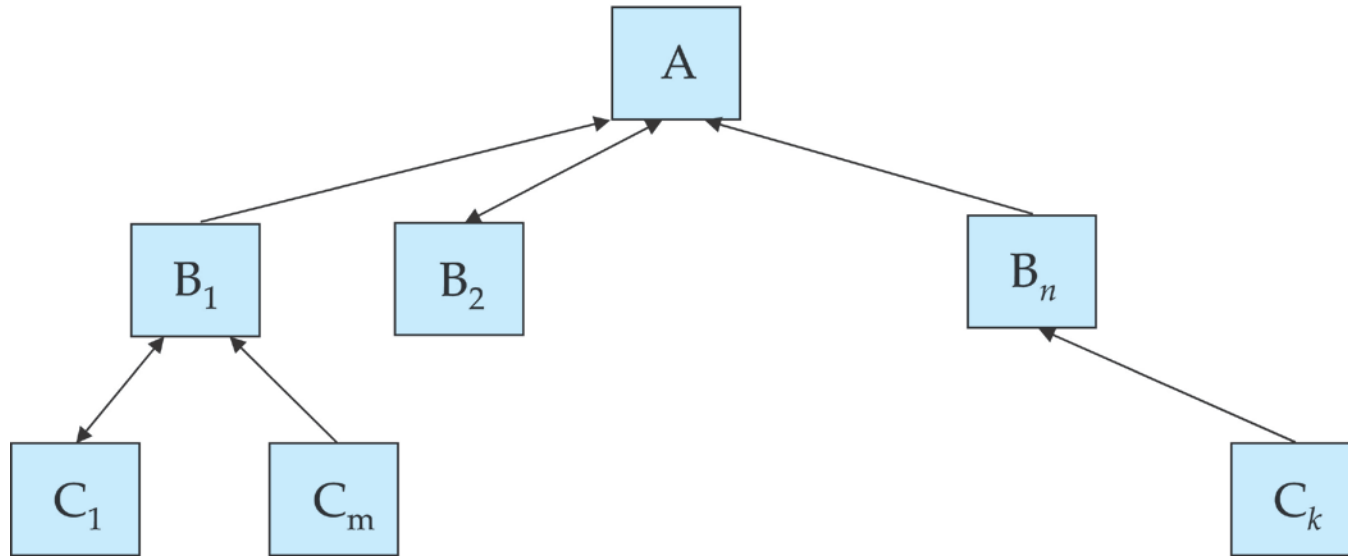


Tree-Structure Diagrams

- 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.

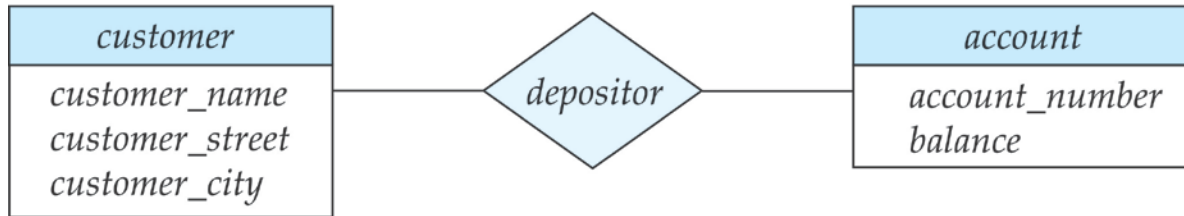


Tree-Structure Diagrams (Cont.)

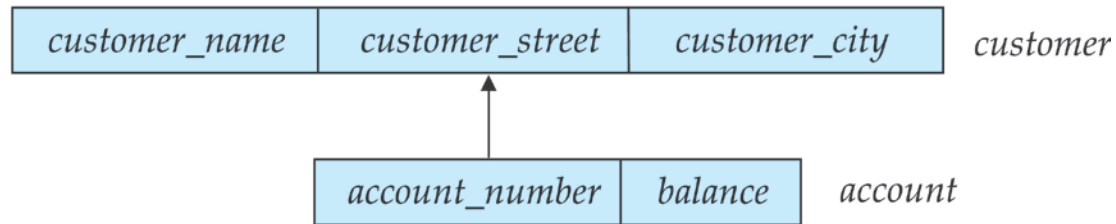
- Database schema is represented as a collection of tree-structure diagrams.
 - *single* instance of a database tree
 - The root of this tree is a dummy node
 - The children of that node are actual instances of the appropriate record type
- When transforming E-R diagrams to corresponding tree-structure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



Single Relationships



(a) E-R diagram



(b) Tree structure diagram



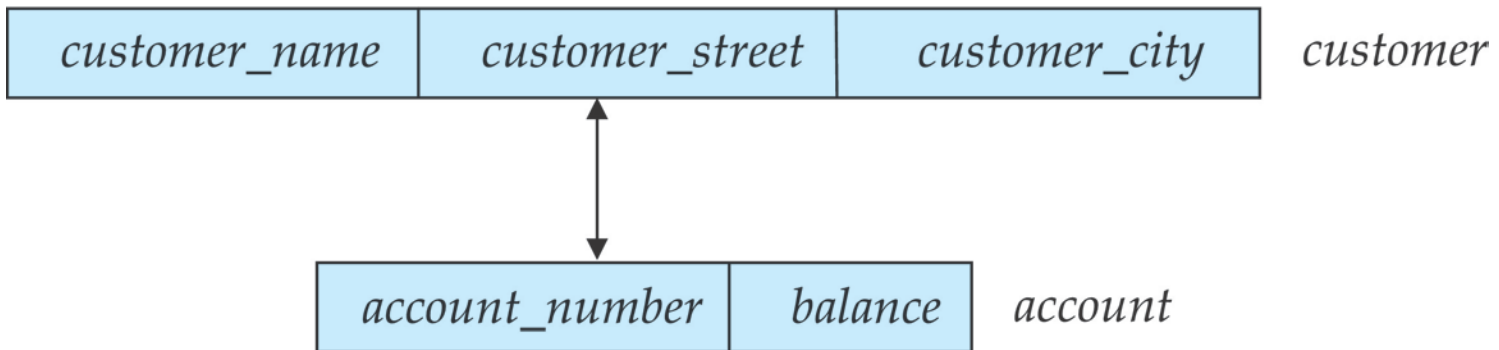
Single relationships (Cont.)

- 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

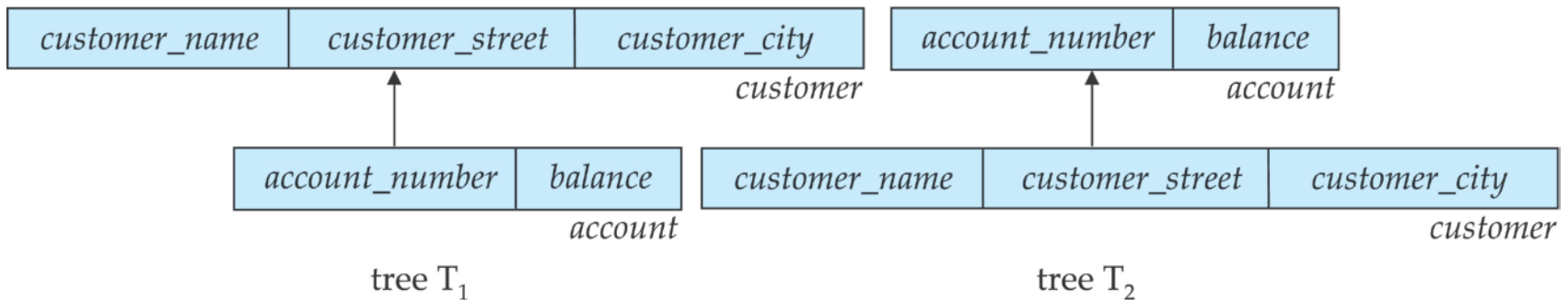
- Must consider the type of queries expected and the degree to which the database schema fits the given E-R diagram.
- In all versions of this transformation, the underlying database tree (or trees) will have replicated records.



Many-To Many Relationships (Cont.)



(a) E-R diagram



(b) Tree structure diagram

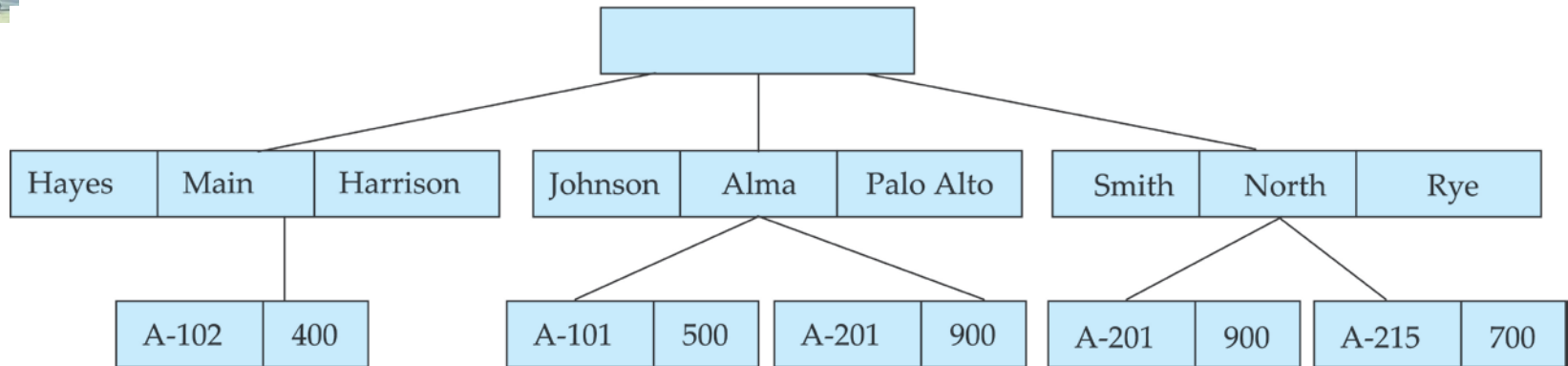


Many-To-Many Relationships (Cont.)

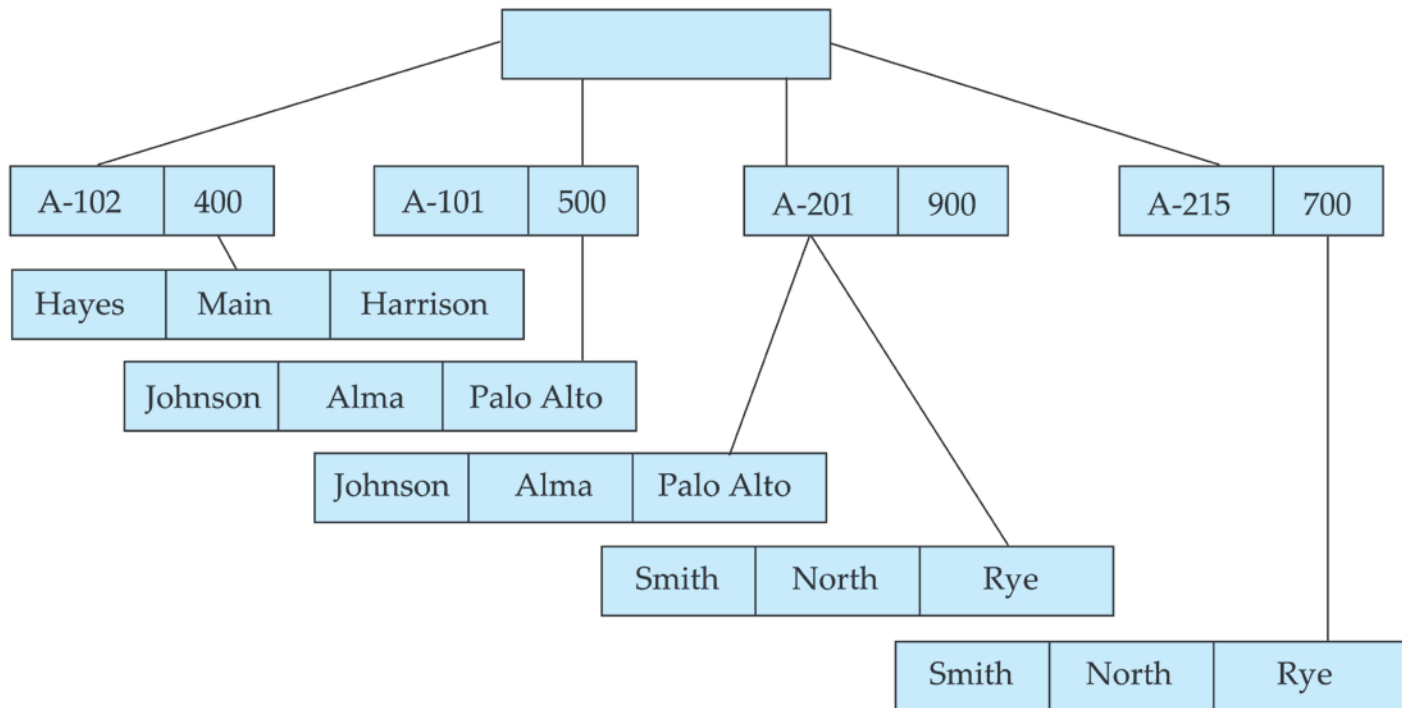
- Create two tree-structure diagrams, T_1 , with the root *customer*, and T_2 , with the root *account*.
- In T_1 , create *depositor*, a many-to-one link from *account* to *customer*.
- In T_2 , create *account-customer*, a many-to-one link from *customer* to *account*.



Sample Database



(a)

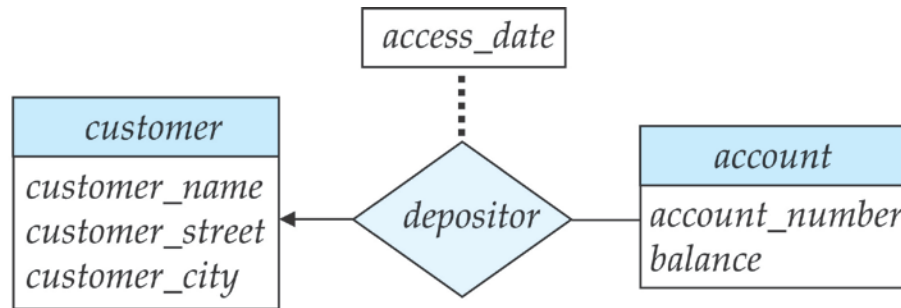


(b)

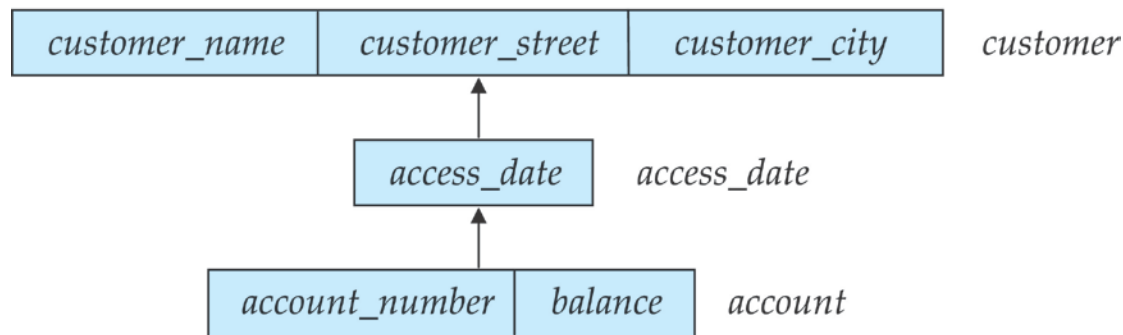


General Relationships

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



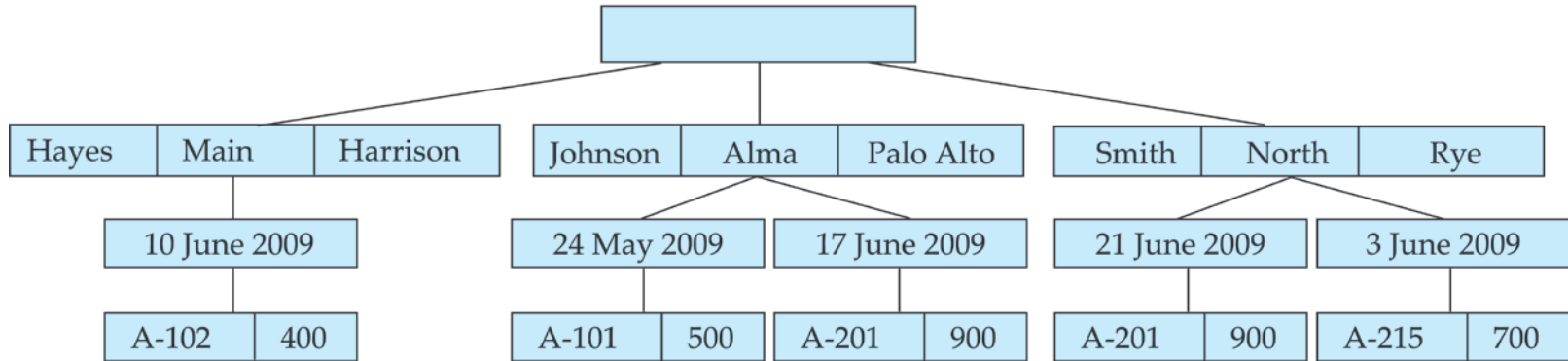
(a) E-R diagram



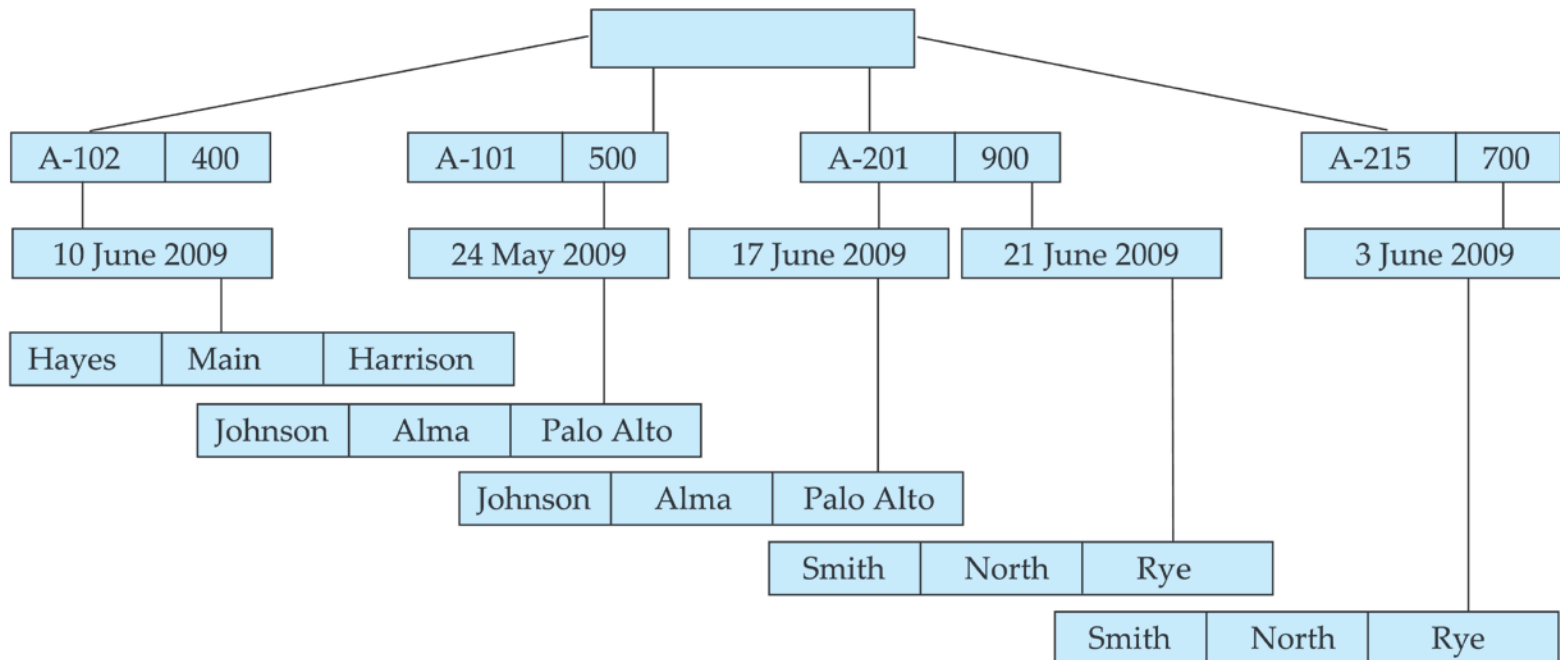
(b) Tree structure diagram



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



(a)



(b)

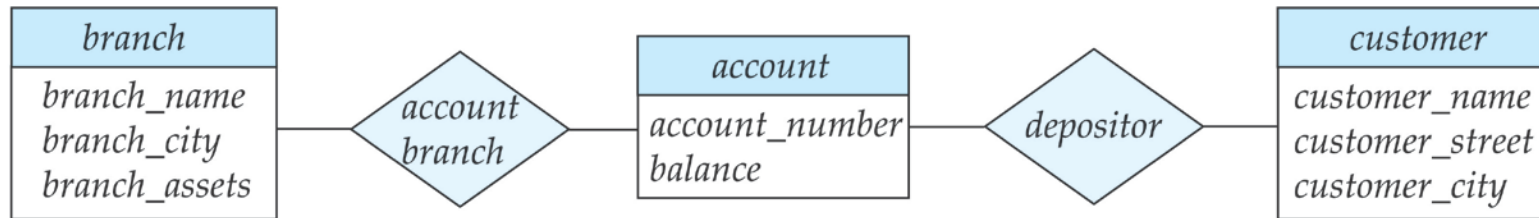


Several Relationships

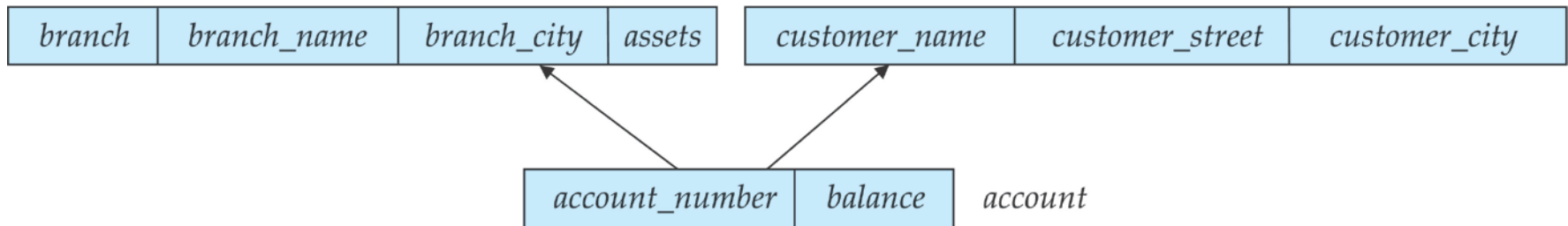
- To correctly transform an E-R diagram with several relationships, split the unrooted tree structure diagrams into several diagrams, each of which is a rooted tree.
- Example E-R diagram and transformation leading to diagram that is not a rooted tree:



Several Relationships (Cont.)



(a) E-R diagram

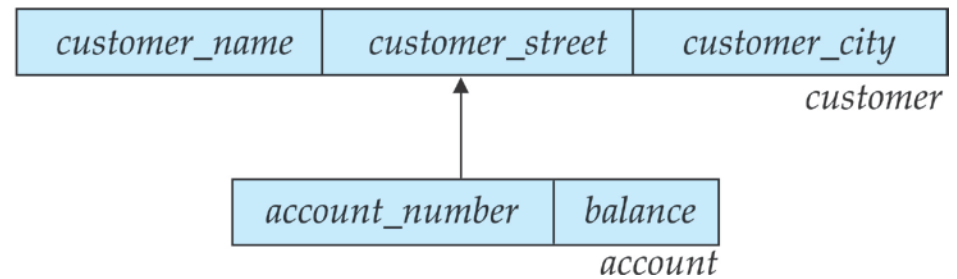
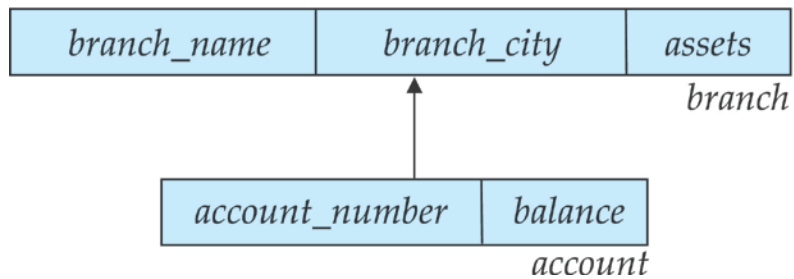


(b) Transformation of E-R diagram



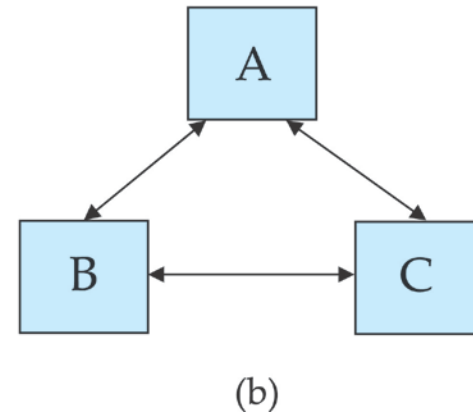
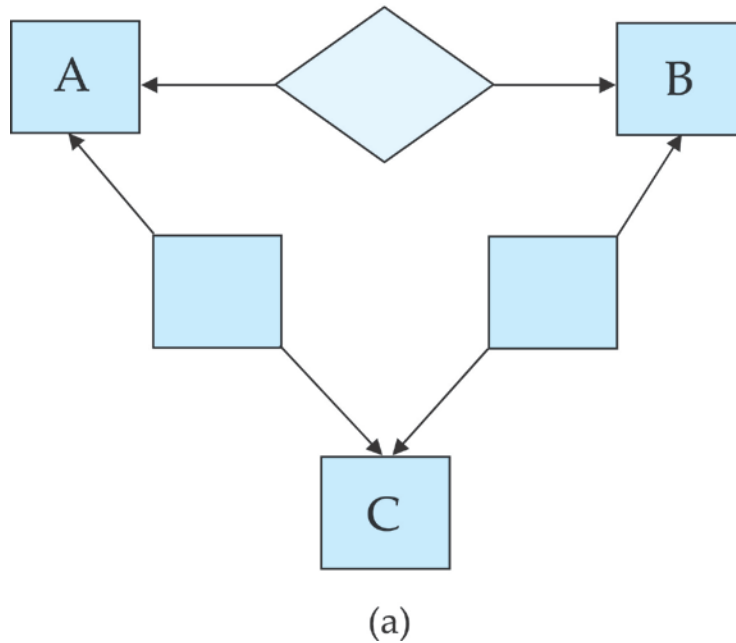
Several Relationships (Cont.)

- Corresponding diagrams in the form of rooted trees.





Several Relationships (2nd Example)

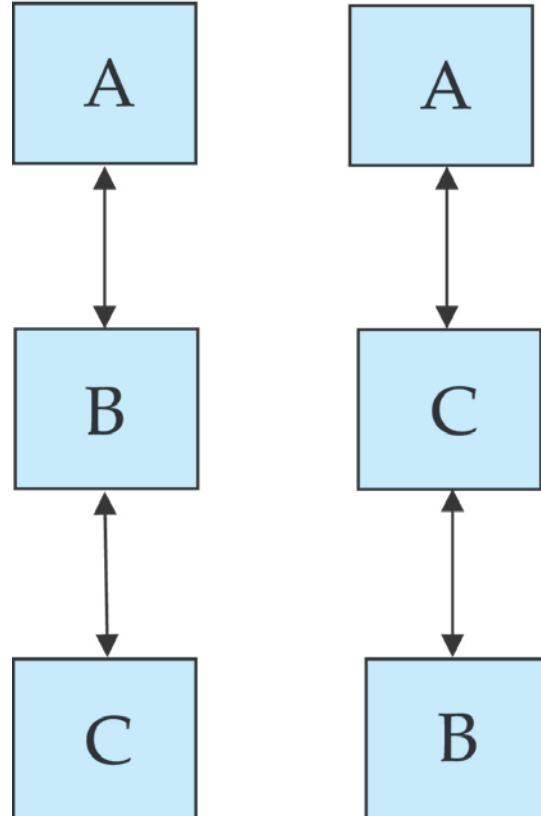


- Diagram (b) contains a cycle.
- Replicate all three record types, and create two separate diagrams.



Several Relationships (2nd Example)

- Each diagram is now a rooted tree.



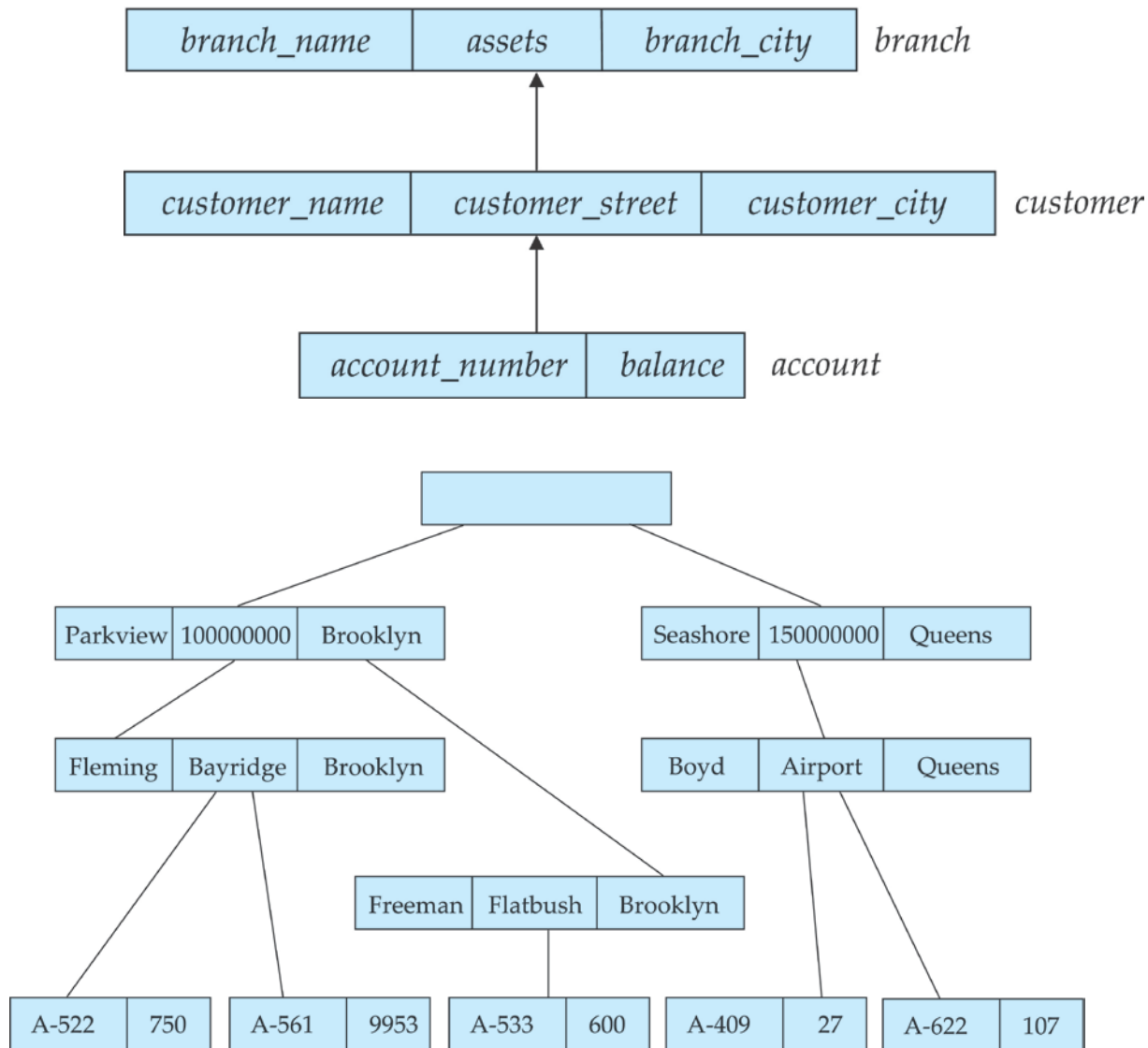


Data Retrieval Facility

- 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.



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.



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 tree is visited.
- Preordered listing of the records in the example database tree:
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);
```



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 tree (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** does 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;
```



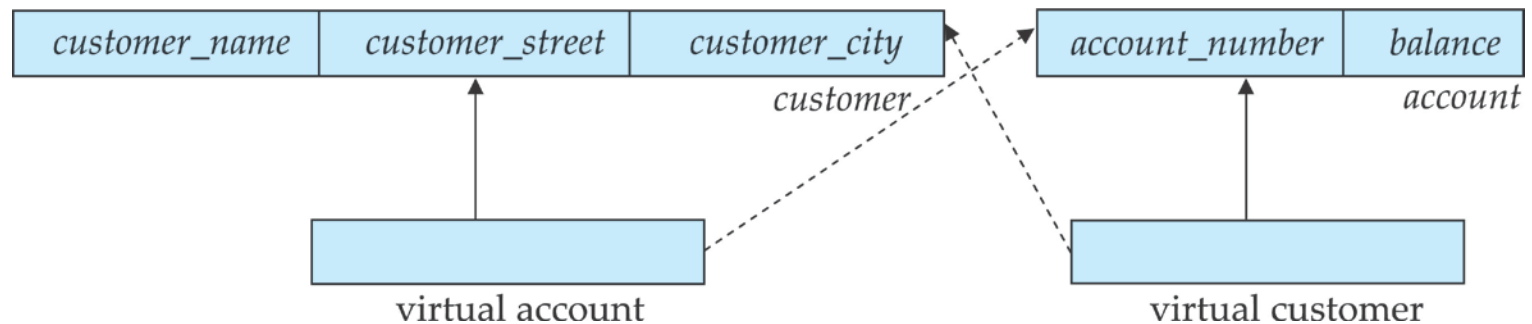
Virtual Records

- 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, \dots, 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* .



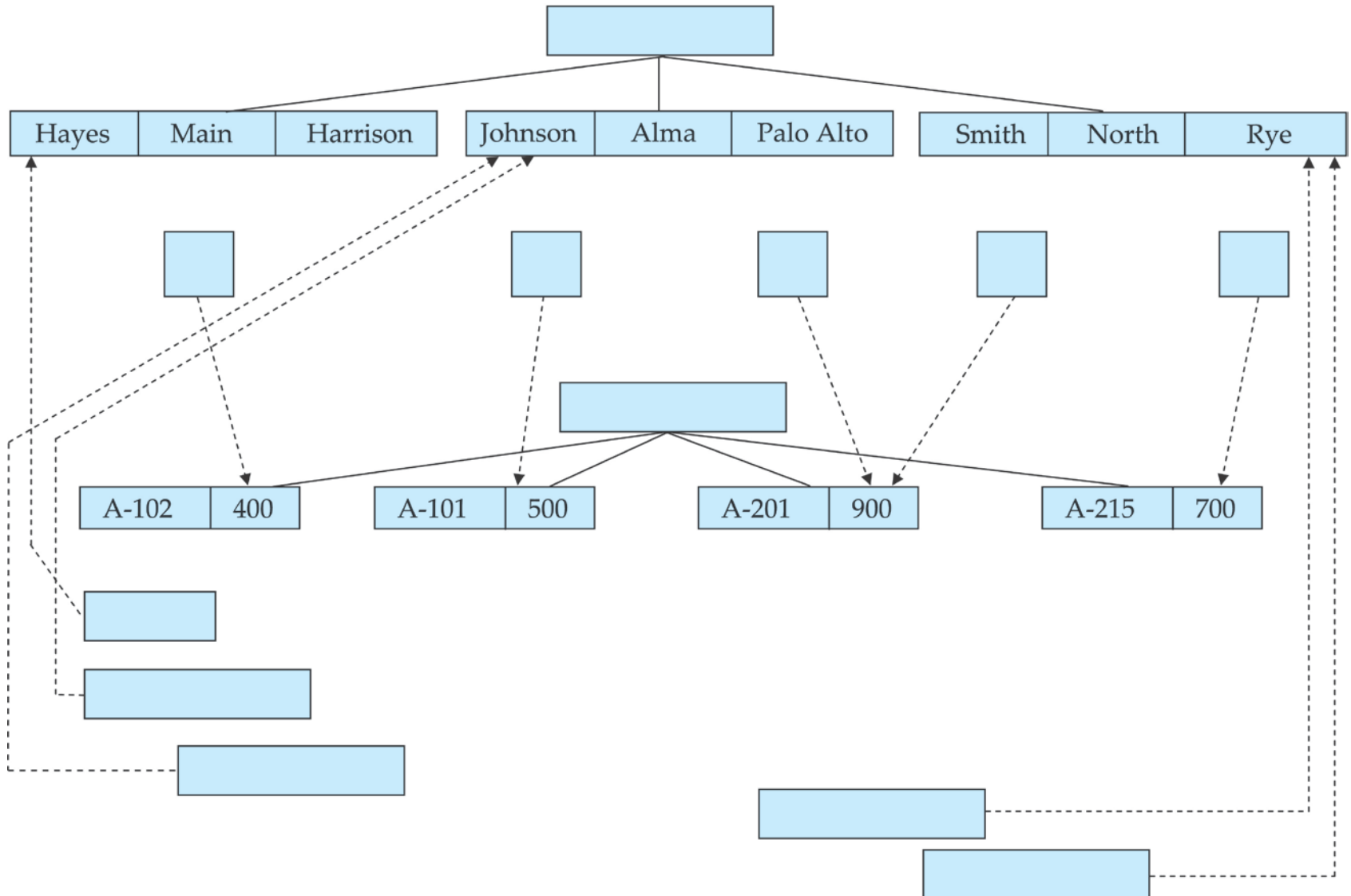
Virtual Records (Cont.)

- 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





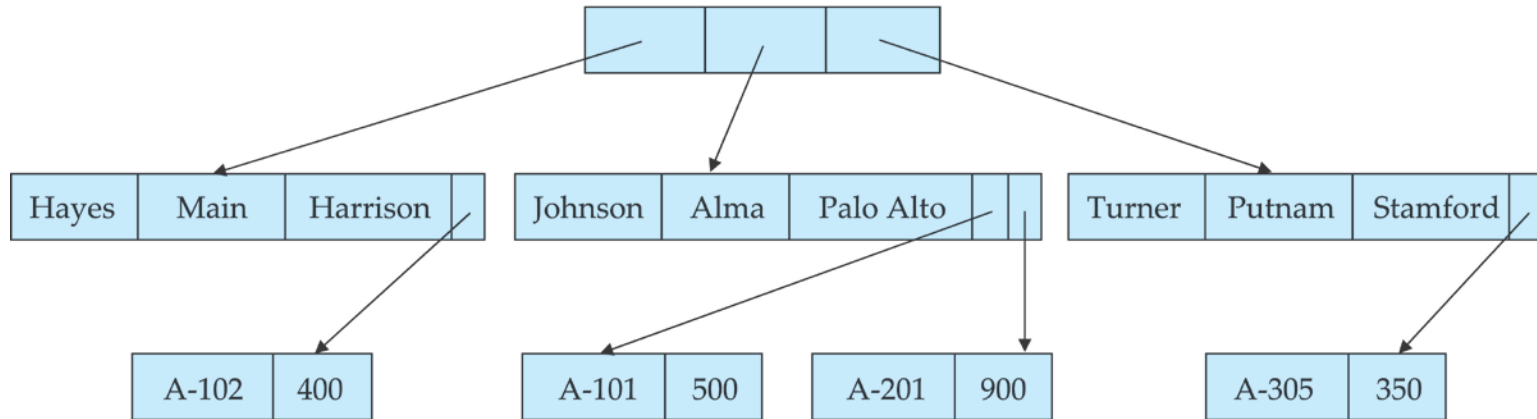
Mapping Hierarchies to Files

- 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.

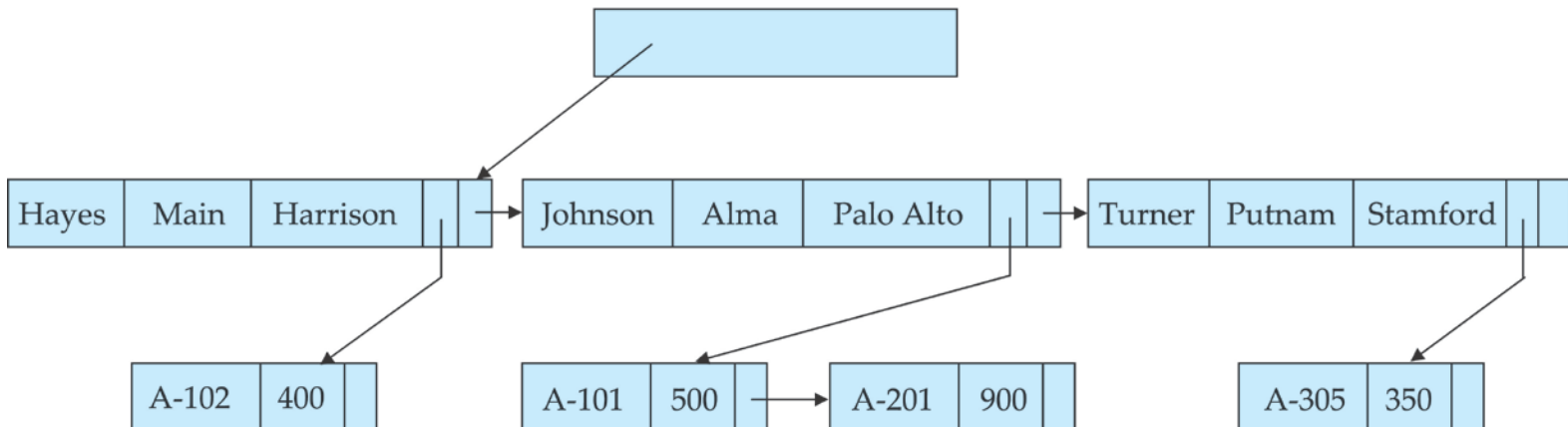


Mapping Hierarchies to Files (Cont.)

- Implementation with parent-child pointers.



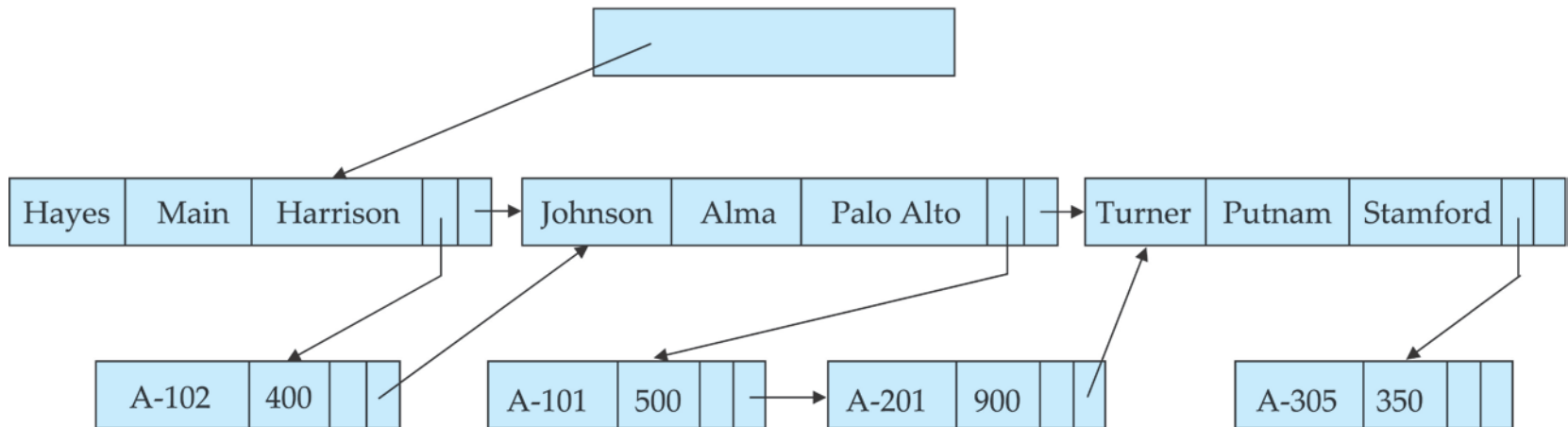
- Implementation with leftmost child and next-sibling pointers.





Mapping Hierarchies to Files (Cont.)

- In general, the final child of a parent has no next sibling; rather than setting the next-sibling field 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 be 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*.

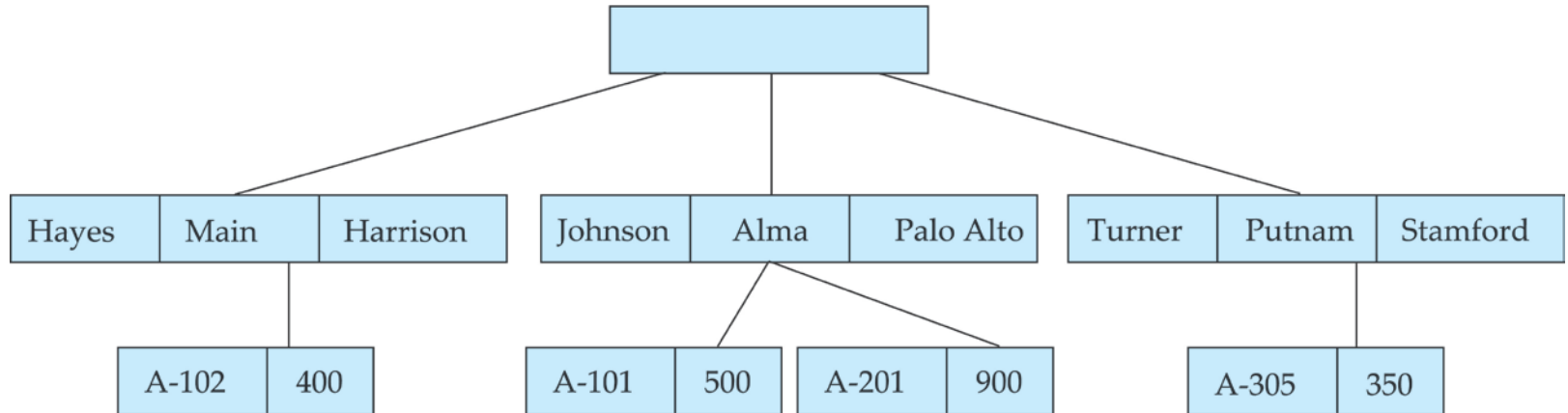


IMS Fast Path

- 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*.

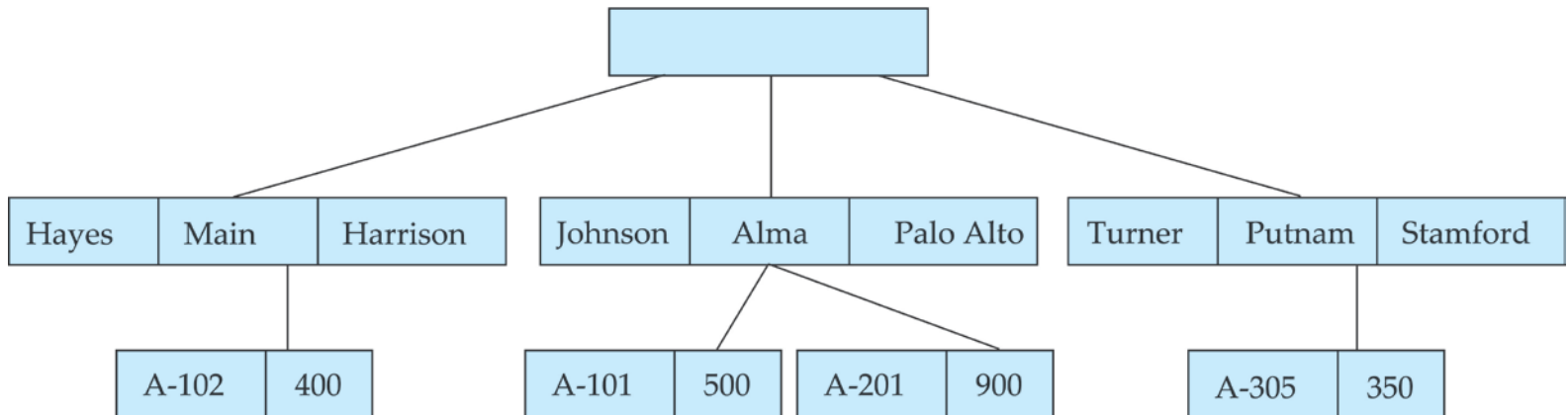


Sample Database



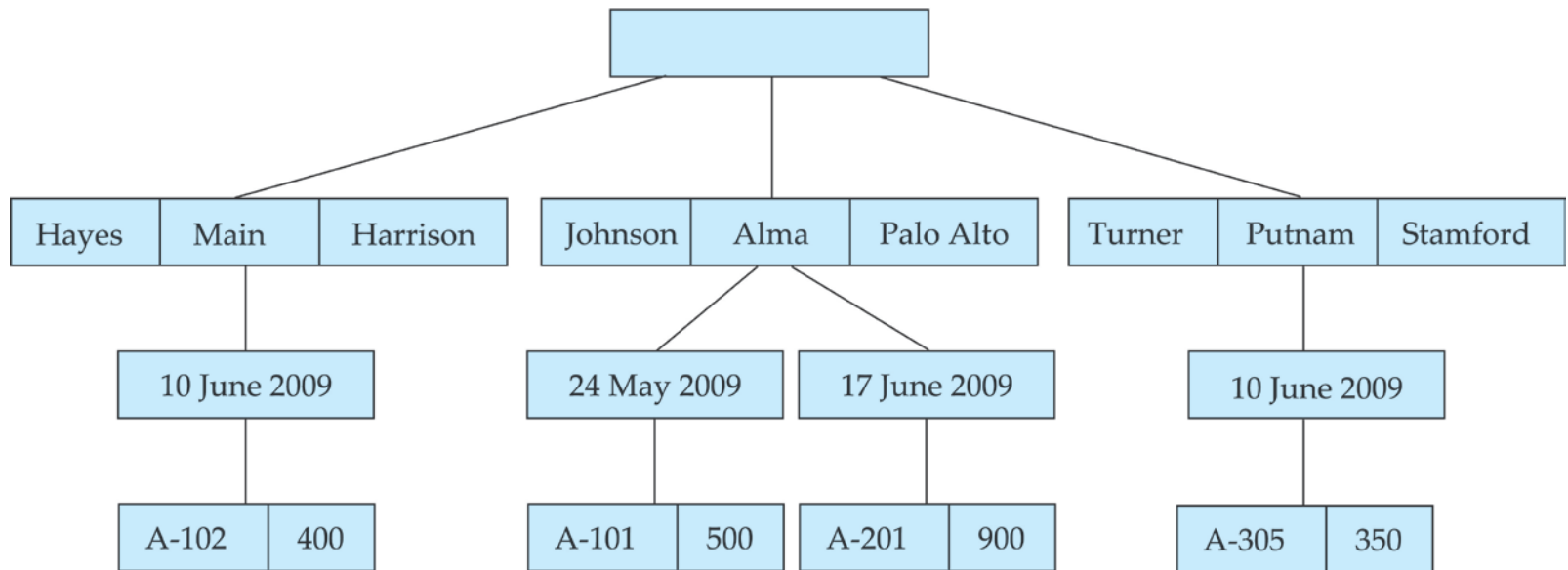


Sample Database Corresponding to Diagram of Figure B.4



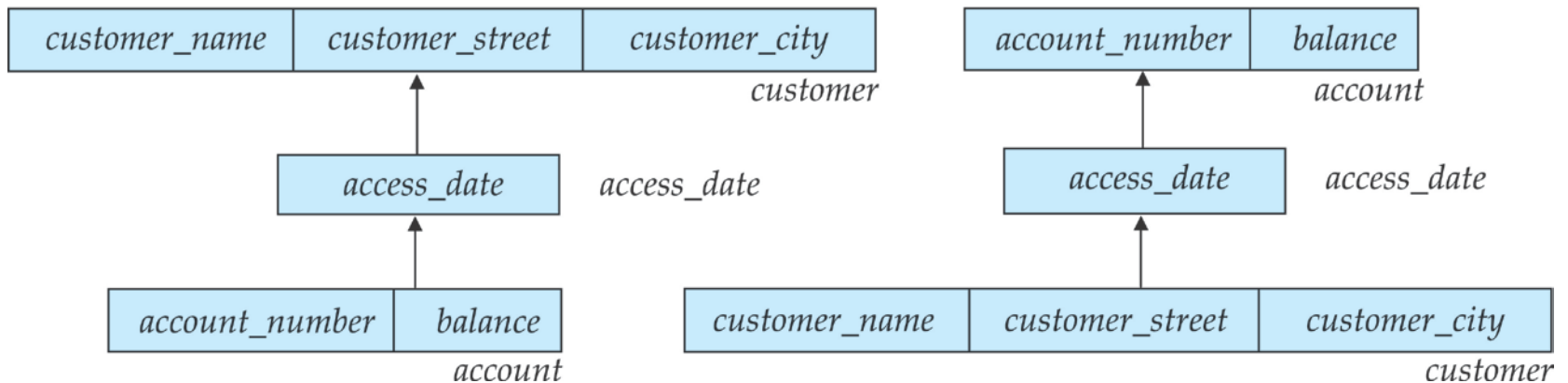


Sample Database Corresponding To Diagram of Figure B.8b



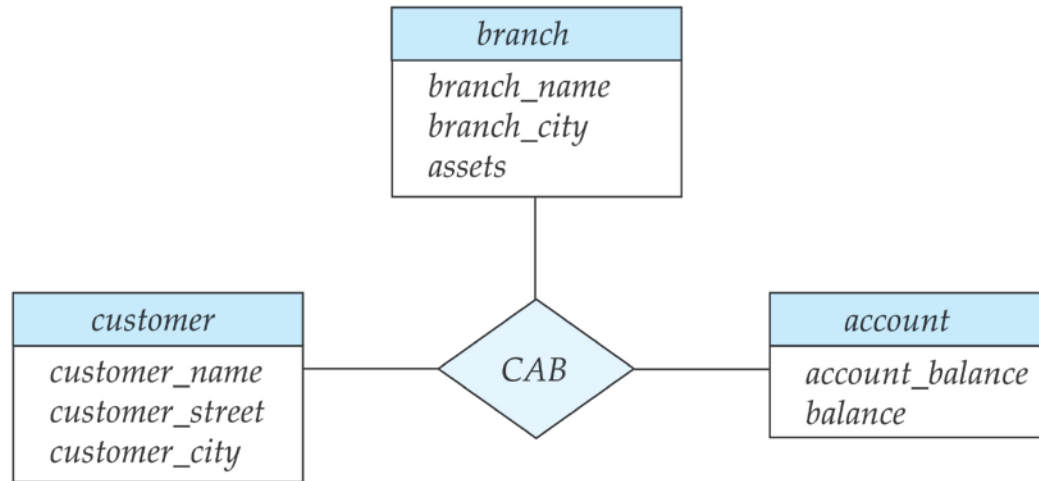


Tree-Structure Diagram With Many-To-Many Relationships

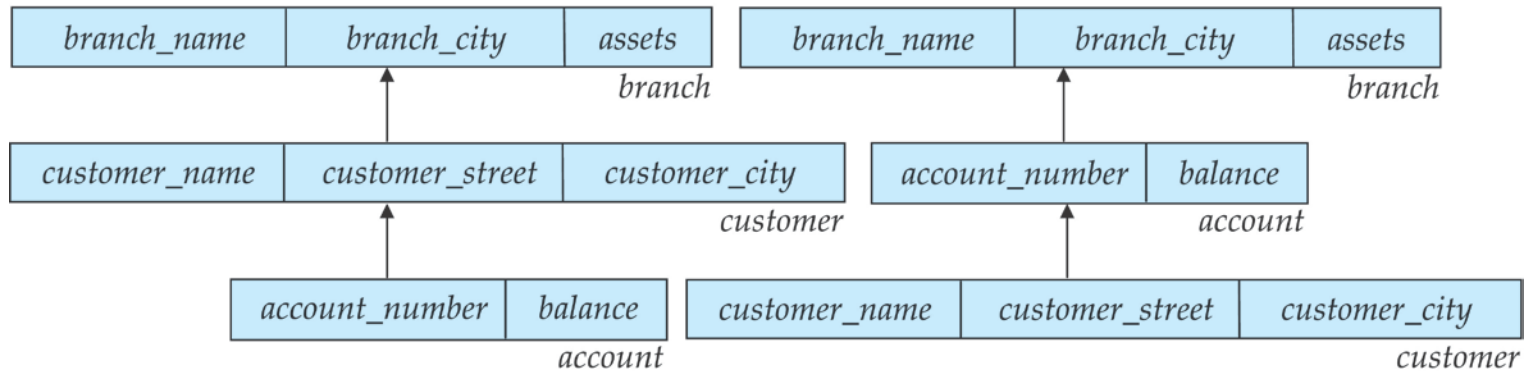




E-R Diagram and Its Corresponding Tree-Structure Diagrams



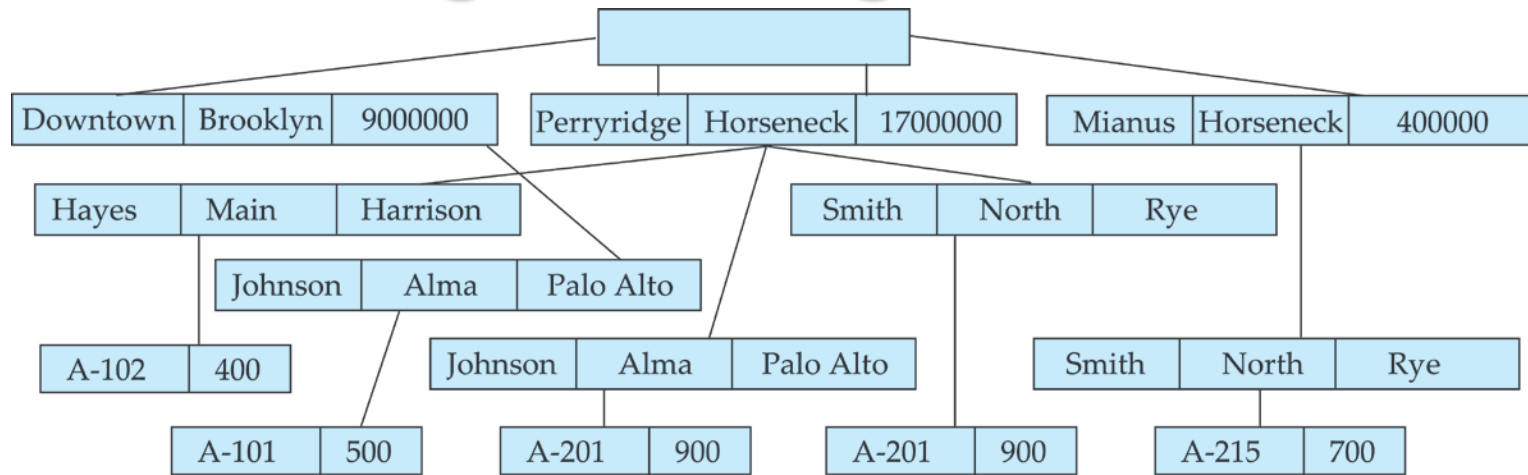
(a) E-R diagram



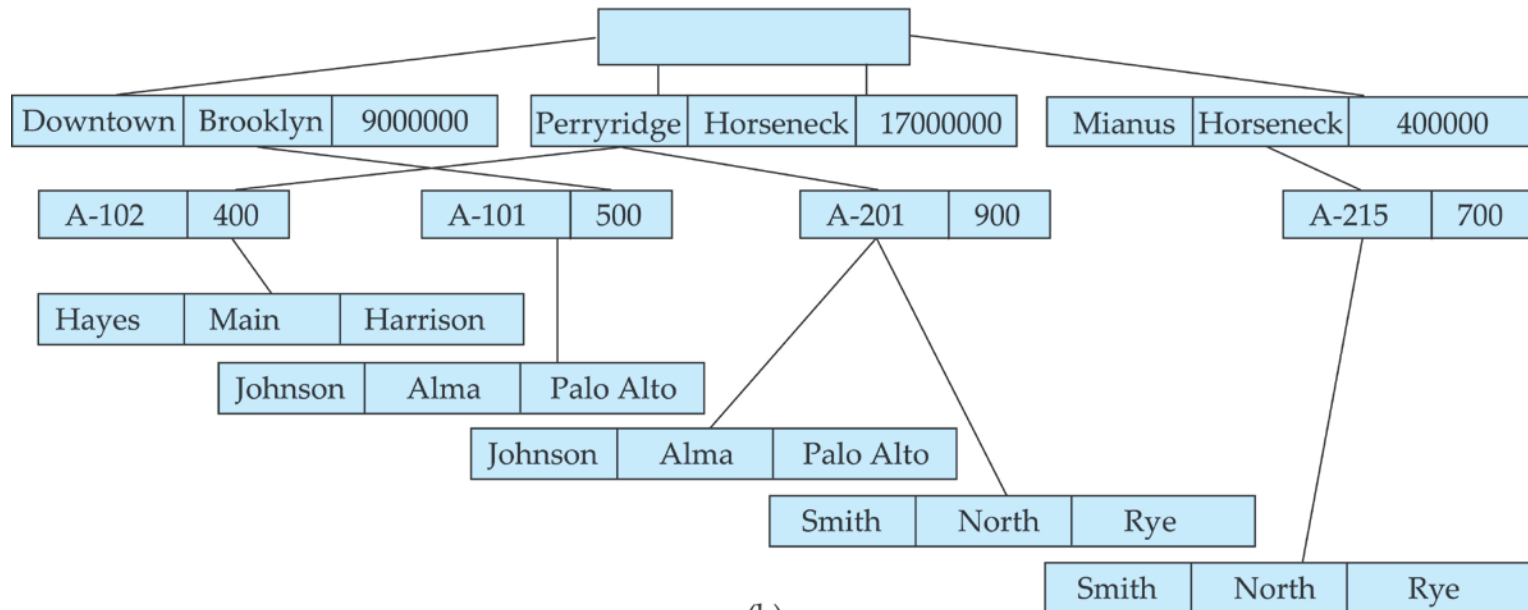
(b) Tree structure diagrams



Sample Database Corresponding To Diagram of Figure B.12b



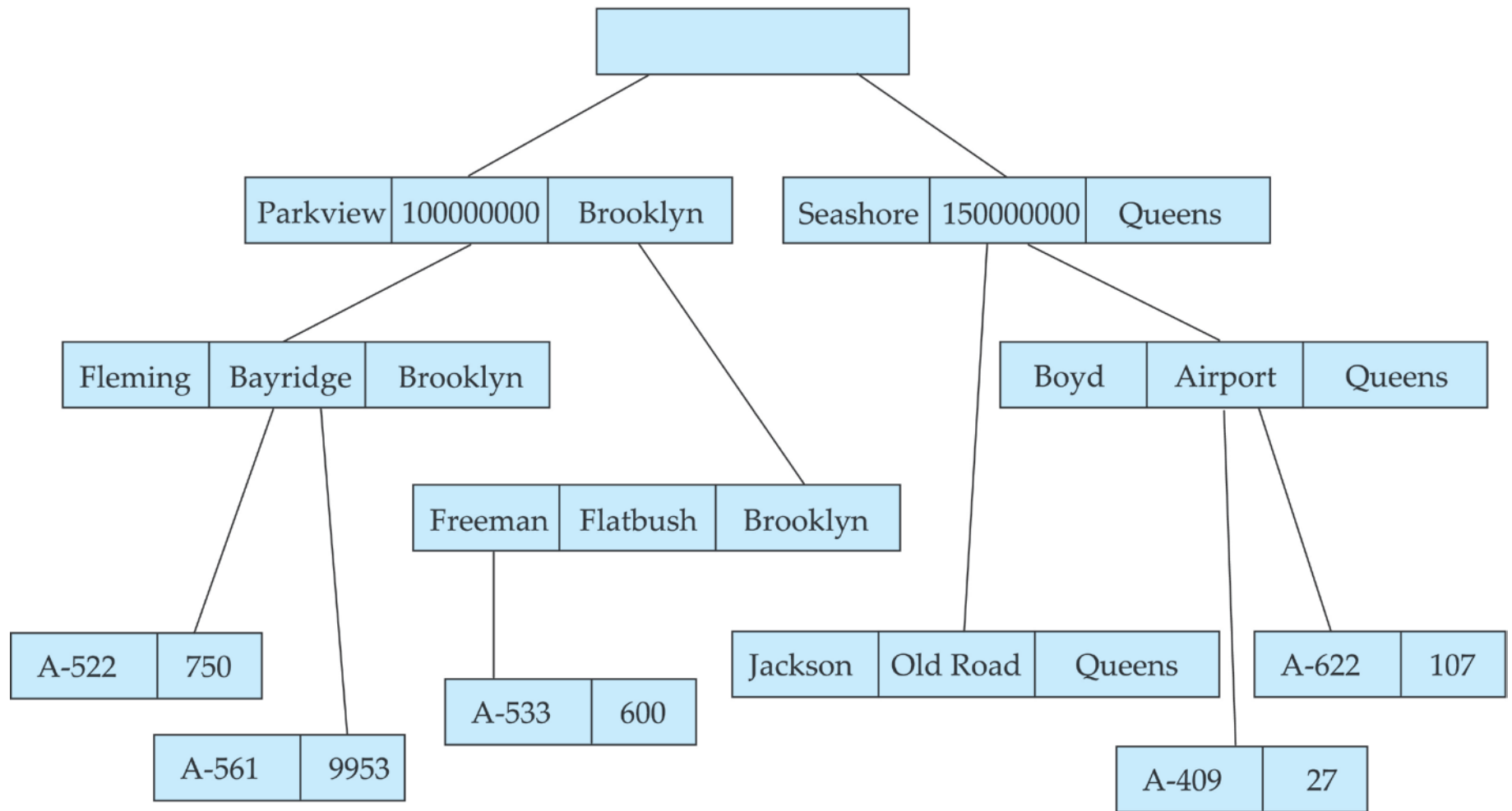
(a)



(b)

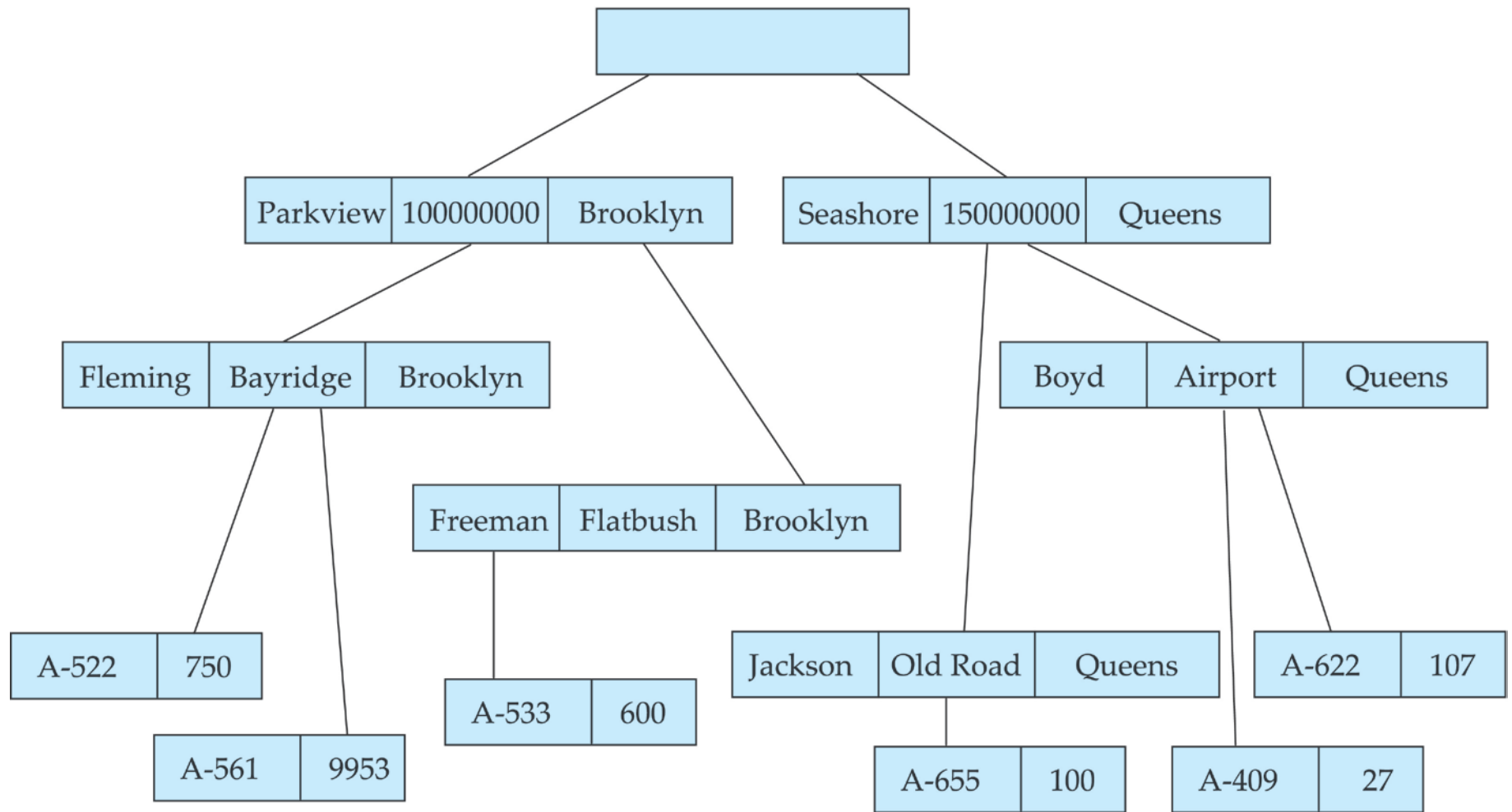


New Database Tree



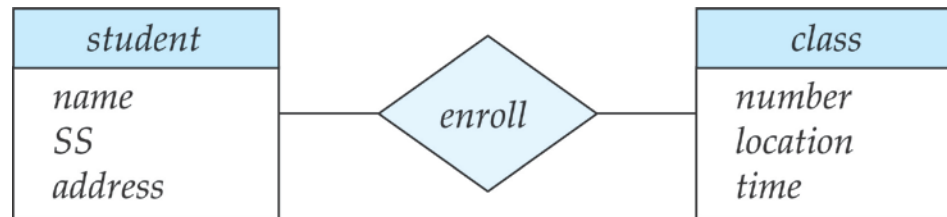


New Database Tree



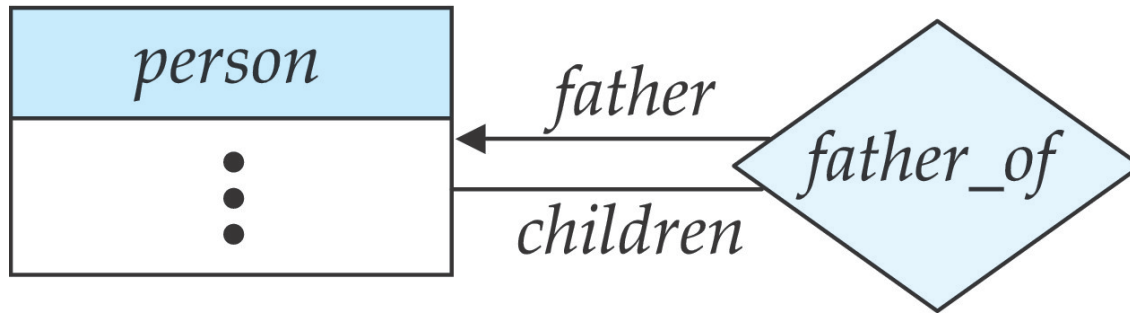


Class-enrollment E-R Diagram



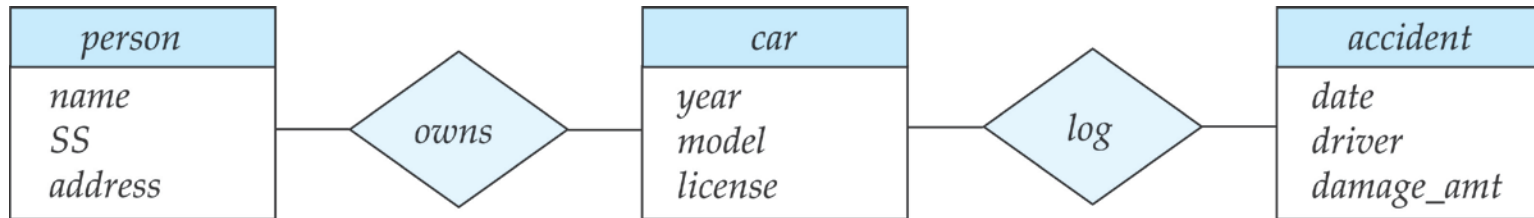


Parent–Child E-R Diagram





Car-insurance E-R Diagram





End of Appendix E

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