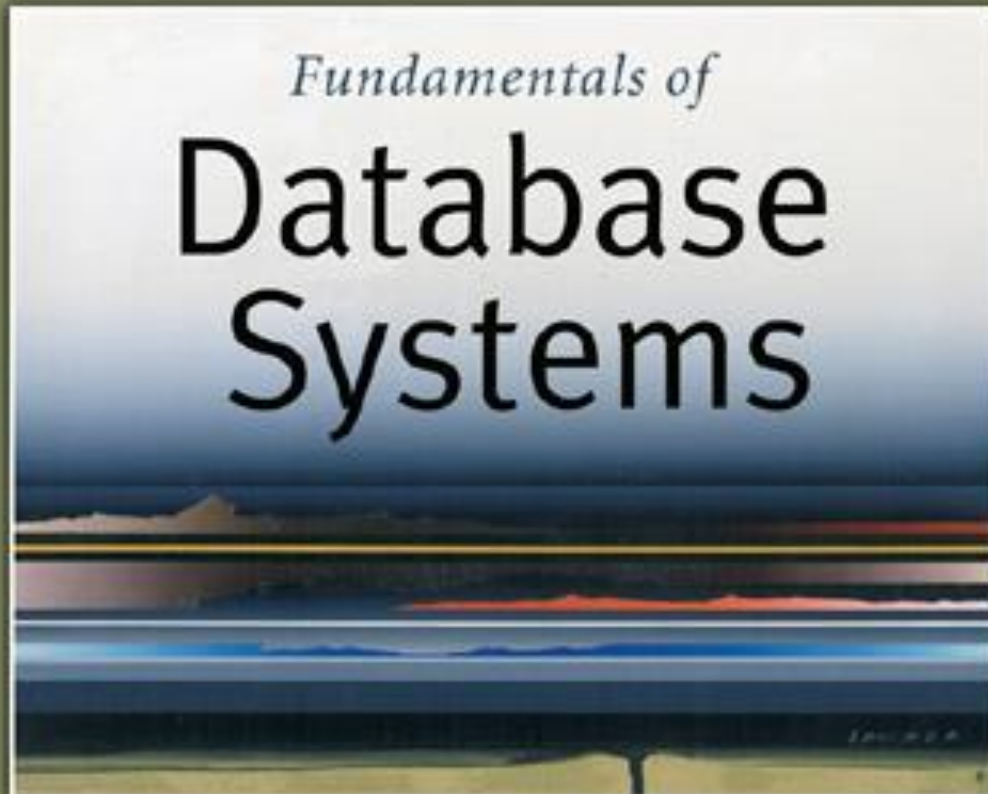
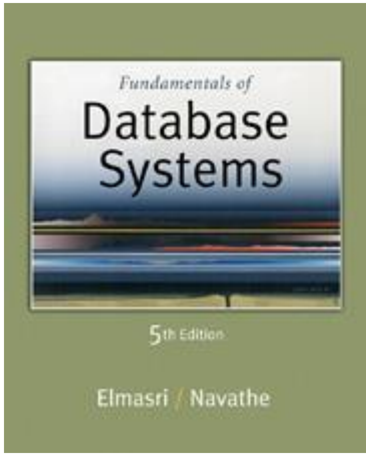


5th Edition

Elmasri / Navathe

Chapter 24

Enhanced Data Models for Advanced Applications



Outline

- Active database & triggers
- Temporal databases
- Spatial and Multimedia databases
- Deductive databases

Active Database Concepts and Triggers

Generalized Model for Active Databases and Oracle **Triggers**

- **Triggers** are executed when a specified condition occurs during insert/delete/update
  - Triggers are action that fire automatically based on these conditions

Event-Condition-Action (ECA) Model

Generalized Model (contd.)

- Triggers follow an Event-condition-action (ECA) model
  - **Event**:
    - Database modification
      - E.g., insert, delete, update),
  - **Condition**:
    - Any true/false expression
      - Optional: If no condition is specified then condition is always true
  - **Action**:
    - Sequence of SQL statements that will be automatically executed

Trigger Example

Generalized Model (contd.)

- When a new employees is added to a department, modify the Total_sal of the Department to include the new employees salary
  - Logically this means that we will CREATE a TRIGGER, let us call the trigger Total_sal1

    Condition
    - This trigger will execute AFTER INSERT ON Employee table
    - It will do the following FOR EACH ROW
      - WHEN NEW.Dno is NOT NULL
      - The trigger will UPDATE DEPARTMENT
      - By SETting the new Total_sal to be the sum of
        - old Total_sal and NEW. Salary
        - WHERE the Dno matches the NEW.Dno;

Example: Trigger Definition

Can be CREATE or ALTER

```
CREATE TRIGGER Total_sal1
   AFTER INSERT ON Employee
   FOR EACH ROW
   WHEN (NEW.Dno is NOT NULL)
      UPDATE DEPARTMENT
      SET Total_sal = Total_sal + NEW. Salary
      WHERE Dno = NEW.Dno;
```

Can be FOR, AFTER, INSTEAD OF

Can be INSERT, UPDATE, DELETE

The condition

The action

CREATE or ALTER TRIGGER

Generalized Model (contd.)

- CREATE TRIGGER <name>
  - Creates a trigger
- ALTER TRIGGER <name>
  - Alters a trigger (assuming one exists)
- CREATE OR ALTER TRIGGER <name>
  - Creates a trigger if one does not exist
  - Alters a trigger if one does exist
    - Works in both cases, whether a trigger exists or not

Conditions

Generalized Model (contd.)

- AFTER
  - Executes after the event
- BEFORE
  - Executes before the event
- INSTEAD OF
  - Executes **instead of** the event
    - Note that event does not execute in this case
      - E.g., used for modifying views

Row-Level versus Statement-level

Generalized Model (contd.)

- Triggers can be
  - **Row-level**
    - FOR EACH ROW specifies a row-level trigger
  - **Statement-level**
    - Default (when FOR EACH ROW is not specified)
- Row level triggers
  - Executed separately for each affected row
- Statement-level triggers
  - Execute once for the SQL statement,

Condition

Generalized Model (contd.)

- Any true/false condition to control whether a trigger is activated on not
  - Absence of condition means that the trigger will always execute for the even
  - Otherwise, condition is evaluated
    - before the event for BEFORE trigger
    - after the event for AFTER trigger

Action

Generalized Model (contd.)

- Action can be
  - One SQL statement
  - A sequence of SQL statements enclosed between a BEGIN and an END
- Action specifies the relevant modifications

Triggers on Views

Generalized Model (contd.)

- INSTEAD OF triggers are used to process view modifications

Active Database Concepts and Triggers

Design and Implementation Issues for Active Databases

- An active database allows users to make the following changes to triggers (rules)
  - Activate
  - Deactivate
  - Drop

Active Database Concepts and Triggers

Design and Implementation Issues for Active Databases

- An event can be considered in 3 ways
  - Immediate consideration
  - Deferred consideration
  - Detached consideration

Active Database Concepts and Triggers

Design and Implementation Issues (contd.)

- Immediate consideration
  - Part of the same transaction and can be one of the following depending on the situation
    - Before
    - After
    - Instead of
- Deferred consideration
  - Condition is evaluated at the end of the transaction
- Detached consideration
  - Condition is evaluated in a separate transaction

Active Database Concepts and Triggers

Potential Applications for Active Databases

- Notification
  - Automatic notification when certain condition occurs
  - Enforcing integrity constraints
    - Triggers are smarter and more powerful than constraints
  - Maintenance of derived data
    - Automatically update derived data and avoid anomalies due to redundancy
      - E.g., trigger to update the Total_sal in the earlier example

Active Database Concepts and Triggers

Triggers in SQL-99

- Can alias variables inside the REFERENCINFG clause

Active Database Concepts and Triggers

- Trigger examples

```
T1:  CREATE TRIGGER Total_sal1
     AFTER UPDATE OF Salary ON EMPLOYEE
     REFERENCING OLD ROW AS O, NEW ROW AS N
     FOR EACH ROW
     WHEN  ( N.Dno IS NOT NULL )
     UPDATE DEPARTMENT
     SET Total_sal = Total_sal + N.salary – O.salary
     WHERE Dno = N.Dno;

T2:  CREATE TRIGGER Total_sal2
     AFTER UPDATE OF Salary ON EMPLOYEE
     REFERENCING OLD TABLE AS O, NEW TABLE AS N
     FOR EACH STATEMENT
     WHEN  EXISTS  ( SELECT * FROM N WHERE N.Dno IS NOT NULL ) OR
           EXISTS  ( SELECT * FROM O WHERE O.Dno IS NOT NULL )
     UPDATE DEPARTMENT AS D
     SET D.Total_sal = D.Total_sal
     + ( SELECT SUM (N.Salary) FROM N WHERE D.Dno=N.Dno )
     – ( SELECT SUM (O.Salary) FROM O WHERE D.Dno=O.Dno )
     WHERE Dno IN ( ( SELECT Dno FROM N ) UNION ( SELECT Dno FROM O ) );
```

Temporal Database Concepts

Time Representation, Calendars, and Time Dimensions

- Time is considered **ordered sequence** of **points** in some **granularity**
  - Use the term **choronon** instead of point to describe minimum granularity

Temporal Database Concepts

Time Representation, … (contd.)

- A **calendar** organizes time into different time units for convenience.
  - Accommodates various calendars
    - Gregorian (western)
    - Chinese
    - Islamic
    - Hindu
    - Jewish
    - Etc.

Temporal Database Concepts

Time Representation, … (contd.)

- Point events
  - Single time point event
    - E.g., bank deposit
  - Series of point events can form a time series data
- Duration events
  - Associated with specific time period
    - Time period is represented by start time and end time

Temporal Database Concepts

Time Representation, … (contd.)

- Transaction time
  - The time when the information from a certain transaction becomes valid
- Bitemporal database
  - Databases dealing with two time dimensions

Temporal Database Concepts

Incorporating Time in Relational Databases Using Tuple Versioning

- Add to every tuple
  - Valid start time
  - Valid end time

Temporal Database Concepts

(a) **EMP_VT**

Name	Ssn	Salary	Dno	Supervisor_ssn	Vst	Vet

DEPT_VT

Dname	Dno	Total_sal	Manager_ssn	Vst	Vet

(b) **EMP_TT**

Name	Ssn	Salary	Dno	Supervisor_ssn	Tst	Tet

DEPT_TT

Dname	Dno	Total_sal	Manager_ssn	Tst	Tet

(c) **EMP_BT**

Name	Ssn	Salary	Dno	Supervisor_ssn	Vst	Vet	Tst	Tet

DEPT_BT

Dname	Dno	Total_sal	Manager_ssn	Vst	Vet	Tst	Tet

Figure 24.7
Different types of temporal relational databases. (a) Valid time database schema. (b) Transaction time database schema. (c) Bitemporal database schema.

Temporal Database Concepts

Figure 24.8
Some tuple versions in the valid time relations EMP_VT and DEPT_VT.

EMP_VT

Name	Ssn	Salary	Dno	Supervisor_ssn	Vst	Vet
Smith	123456789	25000	5	333445555	2002-06-15	2003-05-31
Smith	123456789	30000	5	333445555	2003-06-01	Now
Wong	333445555	25000	4	999887777	1999-08-20	2001-01-31
Wong	333445555	30000	5	999887777	2001-02-01	2002-03-31
Wong	333445555	40000	5	888665555	2002-04-01	Now
Brown	222447777	28000	4	999887777	2001-05-01	2002-08-10
Narayan	666884444	38000	5	333445555	2003-08-01	Now

. . .

DEPT_VT

Dname	Dno	Manager_ssn	Vst	Vet
Research	5	888665555	2001-09-20	2002-03-31
Research	5	333445555	2002-04-01	Now

Temporal Database Concepts

Incorporating Time in Object-Oriented Databases Using Attribute Versioning

- A single complex object stores all temporal changes of the object
- **Time varying attribute**
  - An attribute that changes over time
    - E.g., age
- **Non-Time varying attribute**
  - An attribute that does **not** changes over time
    - E.g., date of birth

Spatial and Multimedia Databases

- Spatial Database Concepts
- Multimedia Database Concepts

Spatial Databases

Spatial Database Concepts

- Keep track of objects in a multi-dimensional space
  - Maps
  - Geographical Information Systems (**GIS**)
  - Weather
- In general spatial databases are n-dimensional
  - This discussion is limited to 2-dimensional spatial databases

Spatial Databases

Spatial Database Concepts

- Typical Spatial Queries
  - **Range** query: Finds objects of a particular type within a particular distance from a given location
    - E.g., Taco Bells in Pleasanton, CA
  - **Nearest Neighbor** query: Finds objects of a particular type that is nearest to a given location
    - E.g., Nearest Taco Bell from an address in Pleasanton, CA
  - **Spatial joins** or overlays: Joins objects of two types based on some spatial condition (intersecting, overlapping, within certain distance, etc.)
    - E.g., All Taco Bells within 2 miles from I-680.

Spatial Databases

Spatial Database Concepts

- **R-trees**
  - Technique for typical spatial queries
  - Group objects close in spatial proximity on the same leaf nodes of a tree structured index
  - Internal nodes define areas (rectangles) that cover all areas of the rectangles in its subtree.
- **Quad trees**
  - Divide subspaces into equally sized areas

Multimedia Databases

Multimedia Database Concepts

- In the years ahead multimedia information systems are expected to dominate our daily lives.
  - Our houses will be wired for bandwidth to handle interactive multimedia applications.
  - Our high-definition TV/computer workstations will have access to a large number of databases, including digital libraries, image and video databases that will distribute vast amounts of multisource multimedia content.

Multimedia Databases

- Types of multimedia data are available in current systems
  - **Text**: May be formatted or unformatted. For ease of parsing structured documents, standards like SGML and variations such as HTML are being used.
  - **Graphics**: Examples include drawings and illustrations that are encoded using some descriptive standards (e.g. CGM, PICT, postscript).

Multimedia Databases

- Types of multimedia data are available in current systems (contd.)
  - **Images**: Includes drawings, photographs, and so forth, encoded in standard formats such as bitmap, JPEG, and MPEG. Compression is built into JPEG and MPEG.
    - These images are not subdivided into components. Hence querying them by content (e.g., find all images containing circles) is nontrivial.
  - **Animations**: Temporal sequences of image or graphic data.

Multimedia Databases

- Types of multimedia data are available in current systems (contd.)
  - **Video**: A set of temporally sequenced photographic data for presentation at specified rates– for example, 30 frames per second.
  - **Structured audio**: A sequence of audio components comprising note, tone, duration, and so forth.

Multimedia Databases

- Types of multimedia data are available in current systems (contd.)
  - **Audio**: Sample data generated from aural recordings in a string of bits in digitized form. Analog recordings are typically converted into digital form before storage.

Multimedia Databases

- Types of multimedia data are available in current systems (contd.)
  - **Composite** or mixed multimedia data: A combination of multimedia data types such as audio and video which may be physically mixed to yield a new storage format or logically mixed while retaining original types and formats. Composite data also contains additional control information describing how the information should be rendered.

Multimedia Databases

- Nature of Multimedia Applications:
  - Multimedia data may be stored, delivered, and utilized in many different ways.
  - Applications may be categorized based on their data management characteristics.

Introduction to Deductive Databases

- Overview of Deductive Databases
- Prolog/Datalog Notation
- Datalog Notation
- Clausal Form and Horn Clauses
- Interpretation of Rules
- Datalog Programs and Their Safety
- Use the Relational Operations
- Evaluation of Non-recursive Datalog Queries

Overview of Deductive Databases

- **Declarative Language**
  - Language to specify rules
- **Inference Engine** (Deduction Machine)
  - Can deduce new facts by interpreting the rules
  - Related to logic programming
    - Prolog language (Prolog => **Pro**gramming in **log**ic)
    - Uses backward chaining to evaluate
      - Top-down application of the rules

Overview of Deductive Databases

- Speciation consists of:
  - Facts
    - Similar to relation specification without the necessity of including attribute names
  - Rules
    - Similar to relational views (virtual relations that are not stored)

Prolog/Datalog Notation

- **Predicate** has
  - a name
  - a fixed number of arguments
    - Convention:
      - Constants are numeric or character strings
    - Variables start with upper case letters
  - E.g., SUPERVISE(Supervisor, Supervisee)
    - States that Supervisor SUPERVISE(s) Supervisee

Prolog/Datalog Notation

- **Rule**
  - Is of the form head :- body
    - where :- is read as if and only iff
  - E.g., SUPERIOR(X,Y) :- SUPERVISE(X,Y)
  - E.g., SUBORDINATE(Y,X) :- SUPERVISE(X,Y)

Prolog/Datalog Notation

- **Query**
  - Involves a predicate symbol followed by y some variable arguments to answer the question
    - where :- is read as if and only iff
  - E.g., SUPERIOR(james,Y)?
  - E.g., SUBORDINATE(james,X)?

Figure 24.11

- (a) Prolog notation (b) Supervisory tree

(a)

Facts

SUPERVISE(franklin, john).
SUPERVISE(franklin, ramesh).
SUPERVISE(franklin, joyce).
SUPERVISE(jennifer, alicia).
SUPERVISE(jennifer, ahmad).
SUPERVISE(james, franklin).
SUPERVISE(james, jennifer).
. . .

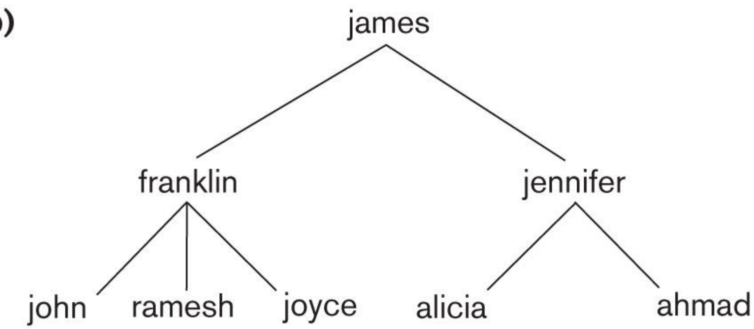
Rules

SUPERIOR(*X*, *Y*) :– SUPERVISE(*X*, *Y*).
SUPERIOR(*X*, *Y*) :– SUPERVISE(*X*, *Z*), SUPERIOR(*Z*, *Y*).
SUBORDINATE(*X*, *Y*) :– SUPERIOR(*Y*, *X*).

Queries

SUPERIOR(james, *Y*)?
SUPERIOR(james, joyce)?

(b)



Datalog Notation

- Datalog notation
  - Program is built from **atomic formulae**
    - **Literals** of the form p(a1, a2, … an) where
      - p predicate name
      - n is the number of arguments
    - Built-in predicates are included
      - E.g., <, <=, etc.
  - A **literal** is either
    - An atomic formula
    - An atomic formula preceded by not

Clausal Form and Horn Clauses

- A formula can have quantifiers
  - Universal
  - Existential

Clausal Form and Horn Clauses

- In clausal form, a formula must be transformed into another formula with the following characteristics
  - All variables are universally quantified
  - Formula is made of a number of clauses where each clause is made up of literals connected by logical ORs only
  - Clauses themselves are connected by logical ANDs only.

Clausal Form and Horn Clauses

- Any formula can be converted into a clausal form
  - A specialized case of clausal form are horn clauses that can contain no more than one positive literal
- Datalog program are made up of horn clauses

Interpretation of Rules

- There are two main alternatives for interpreting rules:
  - **Proof-theoretic**
  - **Model-theoretic**

Interpretation of Rules

- Proof-theoretic
  - Facts and rules are **axioms**
  - **Ground axioms** contain no variables
  - Rules are **deductive axioms**
  - **Deductive axioms** can be used to construct new facts from existing facts
  - This process is known as theorem proving

Proving a new fact

- Figure 24.12

1. SUPERIOR(*X*, *Y*) :– SUPERVISE(*X*, *Y*).	(rule 1)
2. SUPERIOR(*X*, *Y*) :– SUPERVISE(*X*, *Z*), SUPERIOR(*Z*, *Y*).	(rule 2)
3. SUPERVISE(jennifer, ahmad).	(ground axiom, given)
4. SUPERVISE(james, jennifer).	(ground axiom, given)
5. SUPERIOR(jennifer, ahmad).	(apply rule 1 on 3)
6. SUPERIOR(james, ahmad).	(apply rule 2 on 4 and 5)

Interpretation of Rules

- Model-theoretic
  - Given a finite or infinite domain of constant values, we assign the predicate every combination of values as arguments
  - If this is done fro every predicated, it is called **interpretation**

Interpretation of Rules

- **Model**
  - An **interpretation** for a specific set of rules
- Model-theoretic proofs
  - Whenever a particular substitution to the variables in the rules is applied, if all the predicated are true under the interpretation, the predicate at the head of the rule must also be true
- **Minimal model**
  - Cannot change any fact from true to false and still get a model for these rules

Minimal model

- Figure 24.13

Rules
SUPERIOR(*X*, *Y*) :– SUPERVISE(*X*, *Y*).
SUPERIOR(*X*, *Y*) :– SUPERVISE(*X*, *Z*), SUPERIOR(*Z*, *Y*).

Interpretation

Known Facts:
SUPERVISE(franklin, john) is **true**.
SUPERVISE(franklin, ramesh) is **true**.
SUPERVISE(franklin, joyce) is **true**.
SUPERVISE(jennifer, alicia) is **true**.
SUPERVISE(jennifer, ahmad) is **true**.
SUPERVISE(james, franklin) is **true**.
SUPERVISE(james, jennifer) is **true**.
SUPERVISE(*X*, *Y*) is **false** for all other possible (*X*, *Y*) combinations

Derived Facts:
SUPERIOR(franklin, john) is **true**.
SUPERIOR(franklin, ramesh) is **true**.
SUPERIOR(franklin, joyce) is **true**.
SUPERIOR(jennifer, alicia) is **true**.
SUPERIOR(jennifer, ahmad) is **true**.
SUPERIOR(james, franklin) is **true**.
SUPERIOR(james, jennifer) is **true**.
SUPERIOR(james, john) is **true**.
SUPERIOR(james, ramesh) is **true**.
SUPERIOR(james, joyce) is **true**.
SUPERIOR(james, alicia) is **true**.
SUPERIOR(james, ahmad) is **true**.
SUPERIOR(*X*, *Y*) is **false** for all other possible (*X*, *Y*) combinations

Datalog Programs and Their Safety

- Two main methods of defining truth values
  - Fact-defined predicates (or relations)
    - Listing all combination of values that make a predicate true
  - Rule-defined predicates (or views)
    - Head (LHS) of 1 or more Datalog rules, for example Figure 24.15

```
SUPERIOR(X, Y) :– SUPERVISE(X, Y).
SUPERIOR(X, Y) :– SUPERVISE(X, Z), SUPERIOR(Z, Y).

SUBORDINATE(X, Y) :– SUPERIOR(Y, X).

SUPERVISOR(X) :– EMPLOYEE(X), SUPERVISE(X, Y).

OVER_40K_EMP(X) :– EMPLOYEE(X), SALARY(X, Y), Y>=40000.
UNDER_40K_SUPERVISOR(X) :– SUPERVISOR(X), NOT(OVER_40_K_EMP(X)).
MAIN_PRODUCTX_EMP(X) :– EMPLOYEE(X), WORKS_ON(X, productx, Y), Y>=20.
PRESIDENT(X) :– EMPLOYEE(X), NOT(SUPERVISE(Y, X) ).
```

Datalog Programs and Their Safety

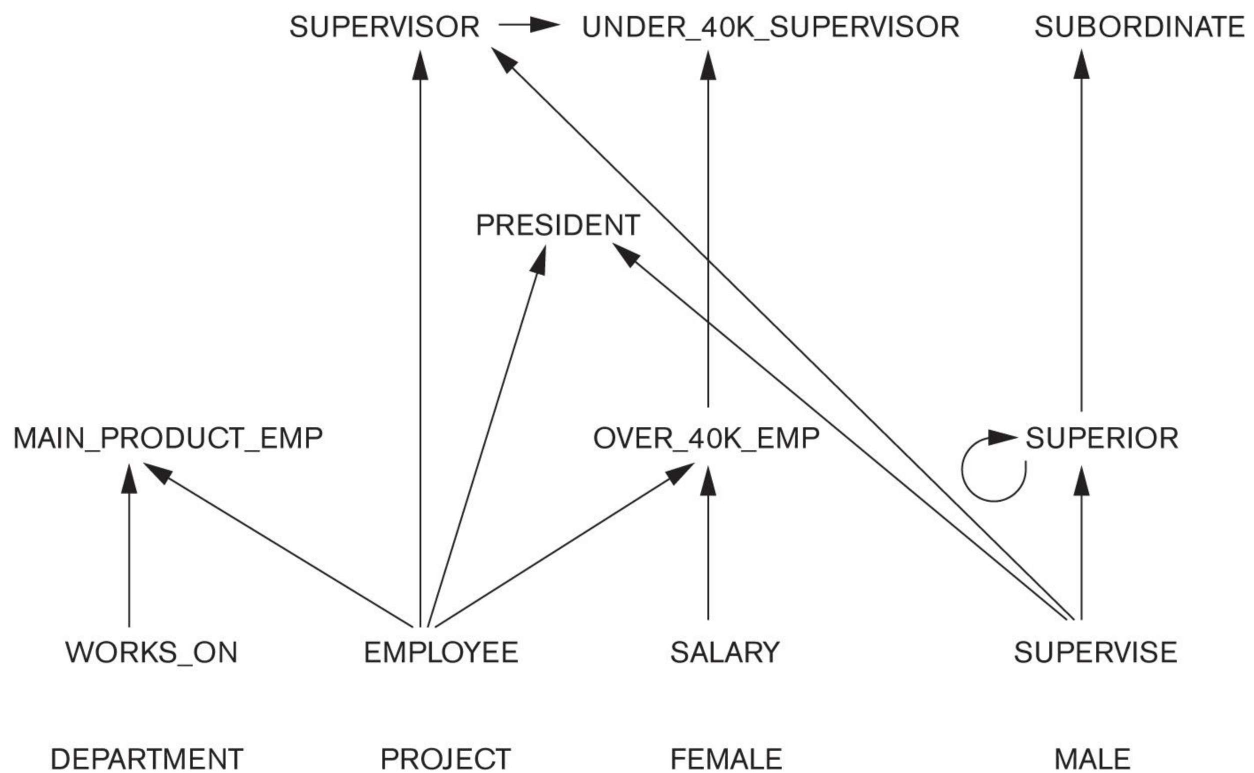
- A program is **safe** if it generates a **finite** set of facts
  - Fact-defined predicates (or relations)
    - Listing all combination of values that make a predicate true
  - Rule-defined predicates (or views)
    - Head (LHS) of 1 or more Datalog rules, for example Figure 24.15

Use the Relational Operations

- Many operations of relational algebra can be defined in the for of Datalog rules that defined the result of applying these operations on database relations (fact predicates)
  - Relational queries and views can be easily specified in Datalog

Evaluation of Non-recursive Datalog Queries

- Define an inference mechanism based on relational database query processing concepts
  - See Figure 24.17 on predicate dependencies for Figs 24.14 and 24.15



Recap

- Active database & triggers
- Temporal databases
- Spatial and Multimedia databases
- Deductive databases