Napier University
Edinburgh

Database Systems
Student Notes

CO22001/CO72010
Version 2.0

School Of Computing

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This Document

This document is for use with a variety of Napier University modules, and forms a good introduction to the basics of database systems for university students. The modules at Napier which use this module include:

- CO22001 – Database Systems. This is a 2nd year module for computing students.
- CS22010 – Database Systems 2. This is the old name for CO22001.
- CO72010 – Database Systems. This is a postgraduate module taught on some of our postgraduate conversion courses.

The notes are for use with both locally taught modules and those affiliated to Napier University. If you wish to use these notes for other purposes please let me know. Suggestions and corrections welcomed.

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Acknowledgments:

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Unit 1.1 - Introduction

Unit 1.1 - Introduction

Relational database systems have became increasingly popular single the late 1970's. They offer a powerful method for storing data in an application-independent manner. This means for many enterprises the database is at the core of the I.T. strategy. Developments can progress around a relatively stable database structure which is secure, reliable, efficient, and transparent.

In early systems, each suite of application programs had its own independent master file. The duplication of data over master files could lead to inconsistent data.

Efforts to use a common master file for a number of application programs resulted in problems of integrity and security. The production of new application programs could require amendments to existing application programs - `unproductive maintenance'.

Data structuring techniques, developed to exploit random access storage devices, increased the complexity of the insert, delete and update operations on data. As a first step towards a DBMS, packages of subroutines were introduced to reduce programmer effort in maintaining these data structures. However, the use of these packages still requires knowledge of the physical organization of the data.

Database System

A database system is a computer-based system to record and maintain information. The information concerned can be anything of significance to the organisation for whose use it is intended. A database system involves four major components: data, hardware, software and users.

Data

A database is a repository for data which, in general, is both integrated and shared. Integration means that the database may be thought of as a unification of several otherwise distinct files, with any redundancy among those files partially or wholly eliminated. The sharing of a database refers to the sharing of data by different users, in the sense that each of those users may have access to the same piece of data and may use it for different purposes. Any given user will normally be concerned with only a subset of the whole database.

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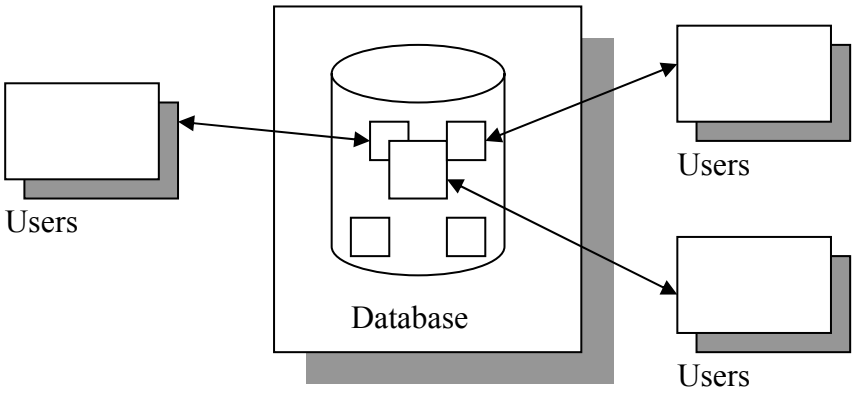
Simplified view of a Database System



Hardware

The hardware involved consists of secondary storage devices (disks) on which the data resides, together with a processor, control units, channels and so forth. The database is assumed to be too large to be held in its entirety in the computer's primary storage, therefore there is a need for software to manage that data.

Software

The software that allows one or many persons to use and/or modify data stored in this database is a database management system (DBMS). A DBMS allows the user to deal with the data in abstract terms (logical data structure).

Users

There are three broad classes of user:

1. the application programmer, responsible for writing programs in some high-level language such as COBOL, C++, etc.
2. the end-user, who accesses the database via a query language
3. the database administrator (DBA), who controls all operations on the database

Database Architecture

DBMSs do not all confirm to the same architecture.

- The three-level architecture forms the basis of modern database architectures.
    - this is in agreement with the ANSI/SPARC study group on Database Management

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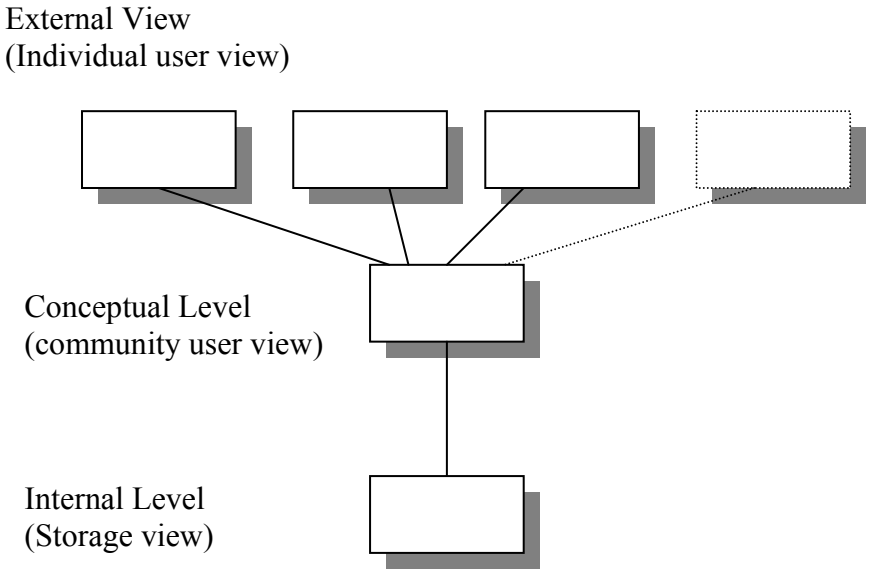
Systems.

- ANSI/SPARC is the American National Standards Institute/Standard Planning and Requirement Committee).

- The architecture for DBMSs is divided into three general levels:

1. external
2. conceptual
3. internal

Three level database architecture



1. the external level : concerned with the way individual users see the data
2. the conceptual level : can be regarded as a community user view - a formal description of data of interest to the organisation, independent of any storage considerations.
3. the internal level : concerned with the way in which the data is actually stored

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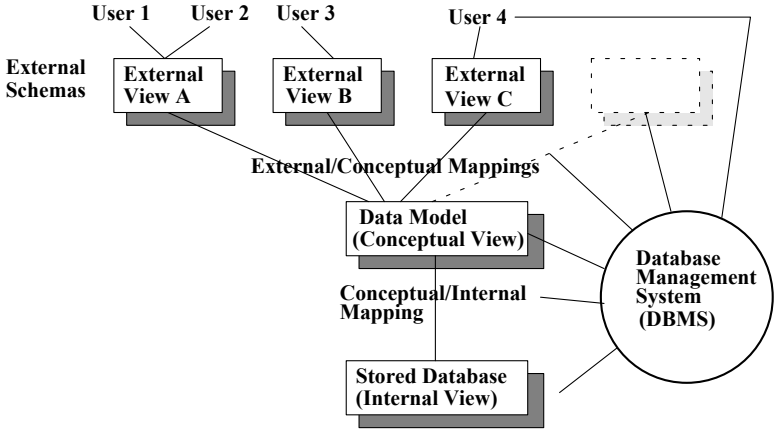

External View

- A user is anyone who needs to access some portion of the data. They may range from application programmers to casual users with ad-hoc queries. Each user has a language at his/her disposal.
    - The application programmer may use a high level language (e.g. COBOL) while the casual user will probably use a query language.
    - Regardless of the language used, it will include a data sub-language DSL which is that subset of the language which is concerned with storage and retrieval of information in the database and may or may not be apparent to the user.
- A DSL is a combination of two languages:
    1. a data definition language (DDL) - provides for the definition or description of database objects
    2. a data manipulation language (DML) - supports the manipulation or processing of database objects.
- Each user sees the data in terms of an external view:
    - Defined by an external schema, consisting basically of descriptions of each of the various types of external record in that external view, and also a definition of the mapping between the external schema and the underlying conceptual schema.

Conceptual View

- An abstract representation of the entire information content of the database.
- It is in general a view of the data as it actually is, that is, it is a `model' of the `real-world'.
- It consists of multiple occurrences of multiple types of conceptual record, defined in the conceptual schema.
- To achieve data independence, the definitions of conceptual records must involve information content only.

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    - storage structure is ignored
    - access strategy is ignored
- The conceptual schema, as well as definitions, contains authorisation and validation procedures.

Internal View

- The internal view is a very low-level representation of the entire database consisting of multiple occurrences of multiple types of internal (stored) records.
- It is however at one remove from the physical level since it does not deal in terms of physical records or blocks nor with any device specific constraints such as cylinder or track sizes. Details of mapping to physical storage is highly implementation specific and are not expressed in the three-level architecture.
- The internal view described by the internal schema:
    - defines the various types of stored record
    - what indices exist
    - how stored fields are represented
    - what physical sequence the stored records are in
- In effect the internal schema is the storage definition structure.

Mappings

- The conceptual/internal mapping:
    - defines conceptual and internal view correspondence
    - specifies mapping from conceptual records to their stored counterparts
- An external/conceptual mapping:
    - defines a particular external and conceptual view correspondence
- A change to the storage structure definition means that the conceptual/internal mapping must be changed accordingly, so that the conceptual schema may remain invariant, achieving physical data independence.
- A change to the conceptual definition means that the conceptual/external mapping must be changed accordingly, so that the external schema may remain invariant, achieving logical data independence.

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DBMS

The database management system (DBMS) is the software that:

- handles all access to the database
- is responsible for applying the authorisation checks and validation procedures

Conceptually what happens is:

1. A user issues an access request, using some particular DML.
2. The DBMS intercepts the request and interprets it.
3. The DBMS inspects in turn the external schema, the external/conceptual mapping, the conceptual schema, the conceptual internal mapping, and the storage structure definition.
4. The DBMS performs the necessary operations on the stored database.

Database Administrator

The database administrator (DBA) is the person (or group of people) responsible for overall control of the database system. The DBA's responsibilities include the following:

- deciding the information content of the database, i.e. identifying the entities of interest to the enterprise and the information to be recorded about those entities. This is defined by writing the conceptual schema using the DDL
- deciding the storage structure and access strategy, i.e. how the data is to be represented by writing the storage structure definition. The associated internal/conceptual schema must also be specified using the DDL
- liaising with users, i.e. to ensure that the data they require is available and to write the necessary external schemas and conceptual/external mapping (again using DDL)
- defining authorisation checks and validation procedures. Authorisation checks and validation procedures are extensions to the conceptual schema and can be specified using the DDL
- defining a strategy for backup and recovery. For example periodic dumping of the database to a backup tape and procedures for reloading the database for backup. Use of a log file where each log record contains the values for database items before and after a change and can be used for recovery purposes
- monitoring performance and responding to changes in requirements, i.e. changing details of storage and access thereby organising the system so as to get the performance that is `best for the enterprise'

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DBA Tools

To facilitate these tasks the DBA has a number of tools at his/her disposal, e.g.

- loading routines
- reorganisation routines
- journaling routines (log files)
- recovery routines
- statistical analysis routines

One of the most important tools of the DBA is the data dictionary. The data dictionary is simply a database that contains data about data, i.e. descriptions of other objects in the system.

Facilities and Limitations

The facilities offered by DBMS vary a great deal, depending on their level of sophistication. In general, however, a good DBMS should provide the following advantages over a conventional system:

- Independence of data and program - This is a prime advantage of a database. Both the database and the user program can be altered independently of each other thus saving time and money which would be required to retain consistency.
- Data shareability and non-redundance of data - The ideal situation is to enable applications to share an integrated database containing all the data needed by the applications and thus eliminate as much as possible the need to store data redundantly.
- Integrity - With many different users sharing various portions of the database, it is impossible for each user to be responsible for the consistency of the values in the database and for maintaining the relationships of the user data items to all other data item, some of which may be unknown or even prohibited for the user to access.
- Centralised control - With central control of the database, the DBA can ensure that standards are followed in the representation of data.
- Security - Having control over the database the DBA can ensure that access to the database is through proper channels and can define the access rights of any user to any data items or defined subset of the database. The security system must prevent corruption of the existing data either accidently or maliciously.
- Performance and Efficiency - In view of the size of databases and of demanding database accessing requirements, good performance and efficiency are major requirements. Knowing the overall requirements of the organisation, as opposed to the requirements of any individual user, the DBA can structure the database system to provide an overall service that is `best for the enterprise'.

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Data Independence

- This is a prime advantage of a database. Both the database and the user program can be altered independently of each other.
- In a conventional system applications are data-dependent. This means that the way in which the data is organised in secondary storage and the way in which it is accessed are both dictated by the requirements of the application, and, moreover, that knowledge of the data organisation and access technique is built into the application logic.
- For example, if a file is stored in indexed sequential form then an application must know
    - that the index exists
    - the file sequence (as defined by the index)

  The internal structure of the application will be built around this knowledge. If, for example, the file was to be replaced by a hash-addressed file major modifications would have to be made to the application.
- Such an application is data-dependent - it is impossible to change the storage structure (how the data is physically recorded) or the access strategy (how it is accessed) without affecting the application, probably drastically. The portions of the application requiring alteration are those that communicate with the file handling software - the difficulties involved are quite irrelevant to the problem the application was written to solve.
- it is undesirable to allow applications to be data-dependent - different applications will need different views of the same data.
- the DBA must have the freedom to change storage structure or access strategy in response to changing requirements without having to modify existing applications.
- Data independence can be defines as
  `The immunity of applications to change in storage structure and access strategy'.

Data Redundancy

- In non-database systems each application has its own private files
    - This can often lead to redundancy in stored data, with resultant waste in storage space.
- in a database the data is integrated
    - the database may be thought of as a unification of several otherwise distinct data files, with any redundancy among those files partially or wholly eliminated.
- Data integration is generally regarded as an important characteristic of a database
    - The avoidance of redundancy should be an aim, however, the vigour with which

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this aim should be pursued is open to question.

Redundancy is

- direct if a value is a copy of another
- indirect if the value can be derived from other values:
    - simplifies retrieval but complicates update
    - conversely integration makes retrieval slow and updates easier
- Data redundancy can lead to inconsistency in the database unless controlled.
    - the system should be aware of any data duplication - the system is responsible for ensuring updates are carried out correctly.
    - a DB with uncontrolled redundancy can be in an inconsistent state - it can supply incorrect or conflicting information
    - a given fact represented by a single entry cannot result in inconsistency - few systems are capable of propagating updates i.e. most systems do not support controlled redundancy.

Data Integrity

This describes the problem of ensuring that the data in the database is accurate...

- inconsistencies between two entries representing the same `fact' give an example of lack of integrity (caused by redundancy in the database).
- integrity constraints can be viewed as a set of assertions to be obeyed when updating a DB to preserve an error-free state.
- even if redundancy is eliminated, the DB may still contain incorrect data.
- integrity checks which are important are checks on data items and record types.

Integrity checks on data items can be divided into 4 groups:

1. type checks
    - e.g. ensuring a numeric field is numeric and not a character - this check should be performed automatically by the DBMS.
2. redundancy checks
    - direct or indirect (see data redundancy) - this check is not automatic in most cases.
3. range checks

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- e.g. to ensure a data item value falls within a specified range of values, such as checking dates so that say (age > 0 AND age < 110).

4. comparison checks

    - in this check a function of a set of data item values is compared against a function of another set of data item values.

    - e.g. the max salary for a given set of employees must be less than the min salary for the set of employees on a higher salary scale.

- A record type may have constraints on the total number of occurrences, or on the insertions and deletions of records.

    - for example in a patient database there may be a limit on the number of x-ray results for each patient

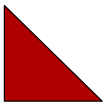
    - or the details of a patients visit to hospital must be kept for a minimum of 5 years before it can be deleted

- Centralized control of the database helps maintain integrity

    - permits the DBA to define validation procedures to be carried out whenever any update operation is attempted (update covers modification, creation and deletion).

- Integrity is important in a database system

    - an application run without validation procedures can produce erroneous data which can then affect other applications using that data.



Unit 1.2 - SQL 1

Unit 1.2 - SQL

This unit is focused on teaching how to access the data within a DBMS. This module concentrates of a particular class of DBMS, that of the `relational database'. Each DBMS can have a variety of methods to access the data contained therein, but rather than each vendor inventing a new approach, standards do exist to express access languages. These languages are often called Data Sub-Languages (DSL), and are really a combination of two languages; a data definition language (DDL) which provides for the definition or description of database objects and a data manipulation language (DML) which supports the manipulation or processing of such objects. This unit uses SQL as the DSL to access a database. However, before SQL is presented, a number of terms must first be discussed.

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Database Models

A data model comprises

- a data structure
- a set of integrity constraints
- operations associated with the data structure

Examples of data models include:

- hierarchic
- network
- relational

Relational Databases

The relational data model comprises:

- relational data structure
- relational integrity constraints
- relational algebra or equivalent (SQL)
    - SQL is an ISO language based on relational algebra
    - relational algebra is a mathematical formulation

Relational Data Structure

A relational data structure is a collection of tables or relations.

- A relation is a collection of rows or tuples
- A tuple is a collection of columns or attributes
- A domain is a pool of values from which the actual attribute values are taken.

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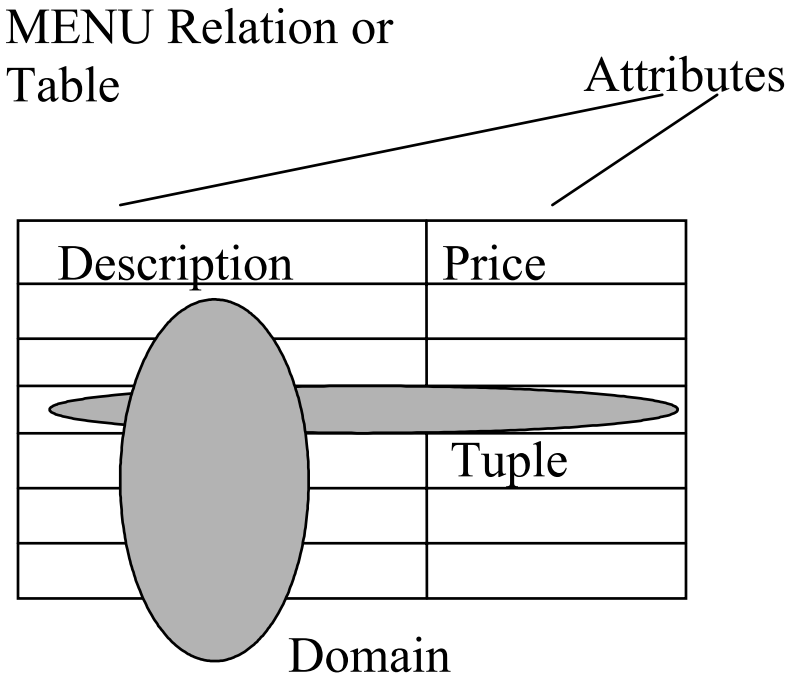

Domain and Integrity Constraints

- Domain Constraints
  - limit the range of domain values of an attribute
  - specify uniqueness and `nullness' of an attribute
  - specify a default value for an attribute when no value is provided.
- Entity Integrity
  - every tuple is uniquely identified by a unique non-null attribute, the primary key.
- Referential Integrity
  - rows in different tables are correctly related by valid key values (`foreign' keys refer to primary keys).

Menu Example

Description	Price
Large Cola	£0.99
Cheeseburger	£1.99
Burger Royalé	£3.49

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External vs Logical

The way a menu is to be shown to a customer may not be the way in which the data is held in a logical model.

The menu model could hold tables about ingredients, individual ingredient costs, overheads, and tax.

The menu provided to a customer is derived from these other tables. It provides a customer-oriented view of the base data.

Columns or Attributes

Each column is given a name which is unique within a table

Each column holds data of one specified type. E.g.

```
integer                decimal
character text         data
 -- the range of values can be further constrained
```

If – a column of a row contains no data, we say it is NULL. For example, an unmarked assessment has no mark. A NULL value may also indicate that the value is unavailable or inappropriate. For example, a lost mark, or a mark more than 100%.

Rows or Tuples

All the rows of a table are different. One row records a transaction in the bank case

Columns in a specified row may contain no value

- a transaction cannot have credit and debit values simultaneously.

Some columns must contain values for all rows

- date and source, which make the row unique, in the bank account case.

Primary Keys

A table requires a key which uniquely identifies each row in the table. This is entity integrity.

The key could have one column, or it could use all the columns. It should not use more columns than necessary. A key with more than one column is called a *composite* key.

A table may have several possible keys, the candidate keys, from which one is chosen as the primary key.

No part of a primary key may be NULL.

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i If the rows of the data are not unique, it is necessary to generate an artificial primary key.

Employee Table - Columns

empno	fornames	surname	depno	telno	dob
001	Hillary	Bobbit	01	4677	1/1/1968
002	Pat	Pettit	01	4678	2/1/1968
003	Pete	Pettit	02	4655	2/1/1968

- What is a suitable primary key?
- An artificial key (empno) must be generated since it is possible for two distinct employees to have all other attributes the same.

Jobhistory Table - Columns

empno	startdate	salary	position	enddate
001	1/1/2000	10000	Tea Maker	1/5/2000
001	2/5/2000	90000	Boss	NULL
002	7/5/1989	12000	WageSlave	NULL
003	7/5/1989	12000	Jobworth	NULL

- The primary key empno + startdate uniquely identifies each row. No employee starts two different jobs on the same day.
- empno relates a Jobhistory row to the corresponding Employee row - it is the primary key in the Employee table and a foreign key in the Jobhistory table.

Foreign Keys

A foreign key is a column in one table that refers to the primary key of a another table by holding the same value.

A foreign key maintains a relationship between the tables. You can't change a primary key value to without changing the foreign key values that refer to it.

The column empno (foreign key) in the Jobhistory table must have the same value as one of the empno (primary key) values in the Employee table. This is an example of referential integrity.

SQL

An international Standard Language for manipulating relational databases. It is based on an IBM product called the Structured Query Language.

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SQL creates and manipulates tables of data (relations) - it is a data handling language, not a programming language.

A table is a collection of rows (tuples or records).

A row is a collection of columns (attributes).

SQL Basics

Basic SQL Statements include:

- CREATE - a data structure
- SELECT - read one or more rows from a table
- INSERT - one or more rows into a table
- DELETE - one or more rows from a table
- UPDATE - change the column values in a row
- DROP - a data structure

CREATE table employee

```
CREATE TABLE employee (
  empno       INTEGER      PRIMARY KEY,
  surname     VARCHAR(15),
  forenames   VARCHAR(30),
  dob         date,
  address     VARCHAR(50),
  telno       VARCHAR(50),
  depno       INTEGER REFERENCES department(depno),
    CHECK(dob IS NULL OR
           (dob > '1-jan-1950' AND dob < '31-dec-1980')
         )
);
```

CREATE Table Jobhistory

```
CREATE TABLE jobhistory (
  empno       INTEGER REFERENCES employee(empno)
  position    VARCHAR(30),
  startdate   date,
  enddate     date,
  salary      DECIMAL(8,2),
    PRIMARY KEY(empno,position)
);
```

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SQL SELECT

```
SELECT  column-list          -- the simplest SQL SELECT
FROM    table_list;

SELECT  *                    -- list ALL employee data
FROM    employee             -- for each employee
;

SELECT depno,forenames,surname  -- list SOME employee
FROM   employee                 -- data for each employee
;
```

Comparison

```
SELECT  column-list          --
FROM    table_list
[WHERE   condition];         -- Comparison Operators:
                             =,!=,<>,<,<=,>,>=
SELECT  empno,surname
FROM    employee
WHERE   depno = 3;

SELECT  forenames,surname
FROM    employee
WHERE   dob > '2-jan-1958';

SELECT  empno                -- who is or have been
FROM    jobhistory           -- a programmer?
WHERE   position = 'Programmer';

SELECT  empno,position       -- what are employee's
FROM    jobhistory           -- current positions?
WHERE   enddate IS NULL;
```

Note that NULL indicates a value which is missing, not known, inappropriate, etc. NULL is not a blank or zero. NULL cannot be tested for equality with other NULL values.

SELECT with BETWEEN

```
SELECT  empno,surname,forenames,dob
FROM    employee
WHERE   dob BETWEEN '30-jun-1954' AND '1-jan-1959';
```

Note that the BETWEEN predicate is inclusive. The above condition is equivalent to :

```
WHERE   dob >= '30-jun-1954' AND <='1-jan-1959';
```

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Pattern Matching

Simple pattern matching is carried out using LIKE:
LIKE 'pattern-to-match'
Where the pattern can include special wildcard characters:

```
%  0 or more arbitrary characters
_  any one character

SELECT  forenames, surname, address
FROM    employee
WHERE   address LIKE '%Edinburgh%';
```

ORDER and DISTINCT

```
SELECT [DISTINCT] column_list
FROM              table_list
[WHERE            condition]
[ORDER BY         attribute[ DESC/ASC]
                  [,attribute [DESC,ASC]]...];
```

Note that ASCending order is the default

```
SELECT DISTINCT empno
FROM jobhistory
WHERE startdate < '1-jan-1980'
ORDER BY empno DESC;
```

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Unit 1.3 - SQL 2

Unit 1.3 - Logical Operators

- NOT, AND, OR (decreasing precedence),
  the usual operators on boolean values.

Fine those who are neither accountants nor analysts who are currently paid £16,000 to £30,000:

```
SELECT  empno
FROM    jobhistory
WHERE   salary BETWEEN 16000 AND 30000
  AND   enddate IS NULL
  AND   NOT ( position LIKE '%Accountant%' OR
              position LIKE '%Analyst%' );
```

IN

- IN (list of values) determines whether a specified value is in a set of one or more listed values.

List the names of employees in departments 3 or 4 born before 1950:

```
SELECT  forenames,surname
FROM    employee
WHERE   depno IN (3,4)
      AND    dob < '1-jan-1950';
```

Other SELECT capabilities

- SET or AGGREGATE functions
  - COUNT counts the rows in a table or group
  - SUM, AVERAGE, MIN, MAX - undertake the indicated operation on numeric columns of a table or group.
- GROUP BY - forms the result of a query into groups. Set functions can then be applied to these groups.
- HAVING - applies conditions to choose GROUPS of interest.

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Simple COUNT examples

- How many employees are there?

```
SELECT  COUNT(*)
FROM    employee;
```

- What is the total salary bill?

```
SELECT  SUM(salary) totalsalary
FROM    jobhistory
WHERE   enddate IS NULL;
```

NOTE - the column title, `totalsalary', to be printed with the result.

Grouped COUNTs

- How many employees are there in each department?

```
SELECT    depno, COUNT(depno)
FROM      employee
GROUP BY  depno;
```

- How many employees are there in each department with more than 6 people?

```
SELECT    depno, COUNT(depno)
FROM      employee
GROUP BY  depno
HAVING    COUNT(depno) > 6;
```

The select lists above can include only set functions and the column(s) specified in the GROUP BY clause.

Joining Tables

- The information required to answer a query may be spread over two or more tables
- Two tables in a FROM clause are joined so that every row in one table is combined with every row in the other table. The combined table is called the Cartesian Product.
- A table with M rows combined with a table of N rows will produce a Cartesian Product of M × N rows;
- The tables in a query are usually related by foreign keys. Rows of the Cartesian Product where foreign keys do not match the primary keys they refer to are meaningless.
- *Join conditions* in the WHERE clause equating foreign keys to primary keys eliminate invalid row combinations from the Cartesian Product.
- Join using the equality comparison operator are called *Equi-joins*.
- If there are N tables to be joined, then (N-1) join conditions will be required (If there is a

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compound primary key has say two attributes its join condition will require two conditional statements).

- Further conditions may be included to obtain just those rows required to satisfy the query.

List the numbers, names and current positions of employees in departments 3 or 4 who were born before 1950:

```
SELECT  employee.empno, forenames,surname,position
FROM    employee,jobhistory
WHERE   employee.empno = jobhistory.empno -- Equi-join
  AND   depno IN (3,4)
  AND   dob < '1-jan-1950'
  AND   enddate IS NULL;
```

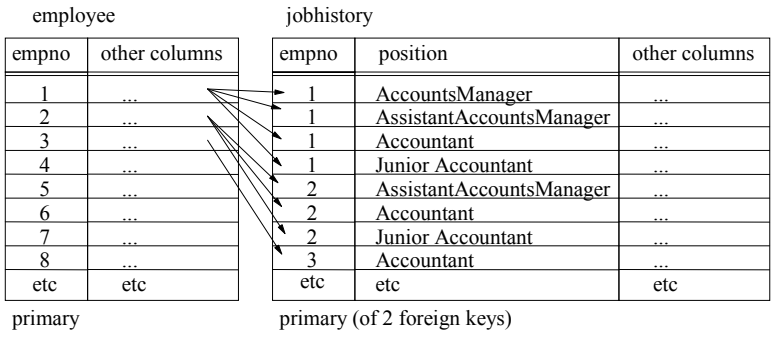
NOTE – that the order of the WHERE predicates is not significant, and the need to always qualify empno with the table name.

SELECT - Order of Evaluation

```
 SELECT  [DISTINCT] column_name   6,5 eliminate unwanted data
 FROM    label_list               1   Cartesian Product
[WHERE   condition ]               2   eliminate unwanted rows
[GROUP BY column_list              3   group rows
  [HAVING condition ]]             4   eliminate unwanted groups
[ORDER BY column_list[DESC]]       7   sort rows
```

The last four components are optional.

One-to-Many Relationships



Many-to-Many Relationships.

```
create table course ( courseno integer primary key,
                      cname    varchar(20),
                      cdate    date );
```

- Given the above course table, relationships between employees and courses can be represented by a table, commonly called a linker table, which implements many-to-many relationships

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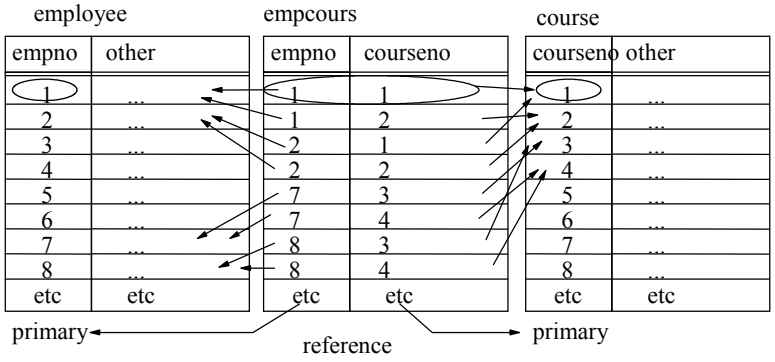
- empno - foreign key references employer
- course - foreign key references course

The `linker table' that implements the many-to-many relationship:

```
create table empcourse
(
  empno     integer references employee (empno),
  courseno  integer references (courseno),
    primary key (empno,courseno)
);
```

The **primary key** of empcourse is the **combination** (empno,course) and must be unique.

A linker table would commonly also hold information about the relationship. For the example above, the assessment of the employer on a particular course might usefully be included.



Aliases

- Temporary labels, aliases can be defined for table names in the FROM clause and can then be used wherever the table name might appear.
- Aliases may simply be a shorthand.

List employee numbers with surname and current job title:

```
SELECT  emp.empno, emp.surname, jh.position
FROM    employee emp, jobhistory jh
WHERE   emp.empno = jh.empno
  AND   jh.enddate IS NULL;
```

Aliases with Self Joins

- aliases become essential if a table appears more than once in an enquiry, as when it is joined to itself (Self Join).

Name employees younger than Liza Brunell:

```
SELECT  young.surname, young.forenames
FROM    employee young, employee liza
```

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```
WHERE   liza.forenames = 'Liza'
  AND   liza.surname  = 'Brunell'
  AND   young.dob  liza.dob;
```

Note

`liza` is the `employee` table searched for Liza Brunell.

`young` is the `employee` table searched for employees younger than Liza Brunell.

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Unit 1.4 - SQL 3

Unit 1.4 - Subqueries

- One SELECT query can be used within another. It appear in the WHERE condition and is then known as a subquery
- A subquery can return only one attribute having zero or more values
- A subquery may provide a simpler query format than a self-join

Simple Example

Name employees younger than Liza Brunell:

```
SELECT surname,forenames
FROM   employee
WHERE  dob <
  ( SELECT dob FROM employee   -- subquery
    WHERE  forenames = 'Liza'
      AND  surname  = 'Brunell');
```

Note - there is no need to use aliases for the employee table since the main query does not see the table used by the subquery and the subquery does not use the table employed by the main query.

Subqueries with ANY, ALL

- ANY or ALL can be used to qualify tests carried out on the values in the set returned by a subquery.

List employees currently earning less than anyone now in programming:

```
SELECT empno FROM jobhistory
WHERE  salary < ALL (
        SELECT salary FROM jobhistory -- subquery
        WHERE position LIKE '%Programmer%'
        AND enddate IS NULL)
  AND   enddate IS NULL;
```

Subqueries with IN, NOT IN

- IN and NOT IN can be used to test if a value is or is not present in the set of values returned by a subquery

List the names and employee numbers of all those who have never been on a training course:

```
SELECT  empno,forenames,surname
```

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```
FROM    employee
WHERE   empno NOT IN
        (SELECT DISTINCT empno
         FROM empcourse);
```

Subqueries with EXISTS

- EXISTS tests if a set returned by a subquery is empty

List the employee number and job title of all those doing a unique job:

```
SELECT empno
FROM jobhistory mainjh
WHERE enddate IS NULL
  AND NOT EXISTS (
       SELECT empno
       FROM jobhistory subjh
       WHERE enddate IS NULL
       AND mainjh.position = subjh.position
       AND mainjh.empno != subjh.empno );
```

Note that aliases are needed to enable references from subquery to main query

UNION of Subqueries

- A query included two or more subqueries connected by a set operation such as UNION (MINUS or INTERSECT).
- UNION returns all the distinct rows returned by two subqueries

List the number of each employee in departments 2 or 4, plus employees who know about administration:

```
(SELECT empno FROM employee
 WHERE depno IN (2,4))
UNION
(SELECT empno FROM course,empcourse
 WHERE course.courseno = empcourse.courseno
 AND cname LIKE '%Administration%');
```

Views

- A view is a named query.

```
CREATE VIEW view_name [(column_list)]
  AS query;
```

Attributes can be renamed in column_list if required.

- Suppose a user needs to regularly manipulate details about employee, name, and current position. It might be simpler to create a view limited to this information only, rather than always extracting it from two tables:

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```
CREATE VIEW empjob AS
  SELECT employee.empno,surname,forenames,position
  FROM   employee,jobhistory
  WHERE  employee.empno = jobhistory.empno
    AND  enddate IS NULL;
```

- A view can be accessed like any other table

List those currently in Programming type jobs:

```
SELECT  empno,surname,forenames
FROM    empjob
WHERE   position LIKE '%Program%';
```

- A view can (should) be dropped when no longer required:

```
DROP VIEW view_name
```

- The use of a view may provide a simpler query format than using self-joins or subqueries

Name employees younger than Liza Brunell:

```
CREATE VIEW liza AS
  SELECT dob FROM employee
  WHERE forenames = 'Liza'
    AND surname  = 'Brunell';
SELECT surname,forenames
FROM   employee,liza
WHERE  employee.dob > liza.dob;
DROP VIEW liza;
```

View Manipulation

When is a view `materialised' or populated with rows of data?

- When it is defined or
- when it is accessed

If it is the former then subsequent inserts, deletes and updates would not be visible. If the latter then changes will be seen.

Some systems allow you to chose when views are materialised, most do not and views are materialised whenever they are accessed thus all changes can be seen.

VIEW update, insert and delete

Can we change views?

- Yes, provided the primary key of all the base tables which make up the view are present in the view.

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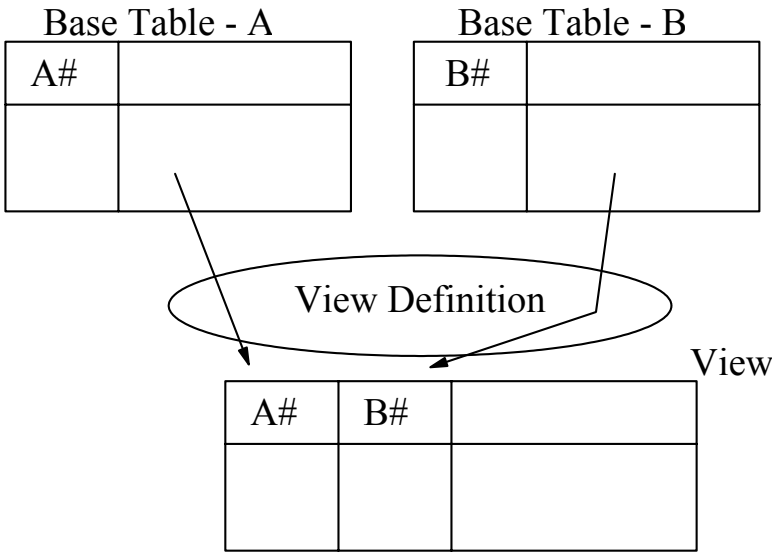
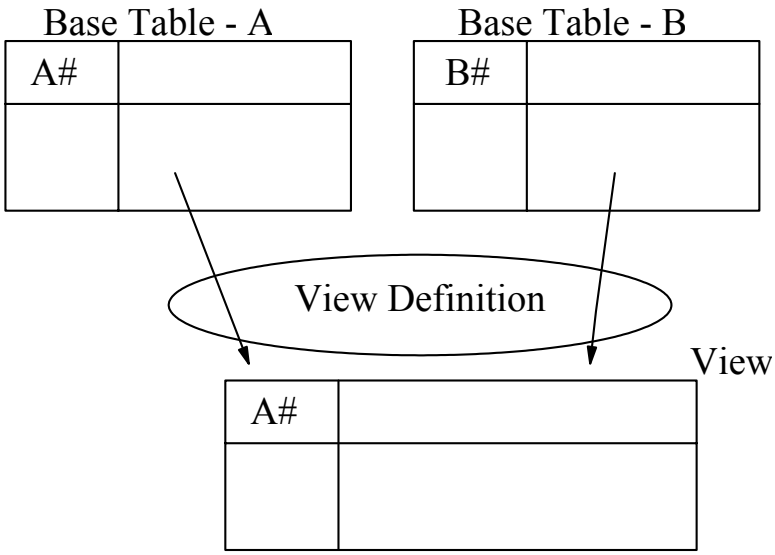


- This view cannot be changed because we have no means of knowing which row of B to modify



Other SQL Statements

- So far we have just looked at SELECT but we need to be able to do other operations as follows:
    - INSERT - which writes new rows into a database
    - DELETE - which deletes rows from a database
    - UPDATE - which changes values in existing rows
- We also need to be able to control access to out tables by other users (see the later SECURITY lecture).

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- We may need to provide special views of tables to make queries easier to write. These views can also be made available to other users so that they can easily see our data but not change it in any way.

INSERT

```
INSERT INTO table_name
  [(column_list)] VALUES (value_list)
```

The column_list lists columns to be assigned values. It can be omitted if every column is to be assigned a value. The value_list is a set of literal values giving the value for each column in column_list or CREATE TABLE order.

```
  insert into course
     values (11,'Advanced Accounting',10-jan-2000);
  insert into course (courseno,cname)
     values(13,'Advanced Administration');
```

DELETE

```
  DELETE FROM table_name [WHERE condition];
```

the rows of table_name which satify the condition are deleted.

- Delete Examples:

```
DELETE FROM jobhistory -- remote current posts from jobhistory
WHERE enddate IS NULL;

DELETE FROM jobhistory -- Remove all posts from jobhistory,
;                      -- leaving an empty table

DROP jobhistory;       -- Remove jobhistory table completely
```

UPDATE

```
UPDATE table_name
  SET column_name = expression,{column_name=expression}
  [WHERE condition]
```

The expression can be

- NULL
- a literal value
- an expression based upon the current column value

Give a salary rise of 10% to all accountants:

```
UPDATE jobhistory
  SET salary = salary * 1.10
  WHERE position LIKE '%Accountant%'
```

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```
    AND enddate IS NULL;
```

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Unit 2.1 - Data Analysis

Unit 2.1: Database Analysis

This unit it concerned with the process of taking a database specification from a customer and implementing the underlying database structure necessary to support that specification.

Entity Relationship Modelling

Data analysis is concerned with the NATURE and USE of data. It involves the identification of the data elements which are needed to support the data processing system of the organization, the placing of these elements into logical groups and the definition of the relationships between the resulting groups.

Other approaches, e.g. D.F.Ds and Flowcharts, have been concerned with the flow of data - dataflow methodologies. Data analysis is one of several data structure based methodologies - Jackson SP/D is another.

Systems analysts often, in practice, go directly from fact finding to implementation dependent data analysis. Their assumptions about the usage of properties of and relationships between data elements are embodied directly in record and file designs and computer procedure specifications. The introduction of Database Management Systems (DBMS) has encouraged a higher level of analysis, where the data elements are defined by a logical model or `schema' (conceptual schema). When discussing the schema in the context of a DBMS, the effects of alternative designs on the efficiency or ease of implementation is considered, i.e. the analysis is still somewhat implementation dependent. If we consider the data relationships, usages and properties that are important to the business without regard to their representation in a particular computerised system using particular software, we have what we are concerned with, implementation-independent data analysis.

It is fair to ask why data analysis should be done if it is possible, in practice to go straight to a computerised system design. Data analysis is time consuming; it throws up a lot of questions. Implementation may be slowed down while the answers are sought. It is more expedient to have an experienced analyst `get on with the job' and come up with a design straight away. The main difference is that data analysis is more likely to result in a design which meets both present and future requirements, being more easily adapted to changes in the business or in the computing equipment. It can also be argued that it tends to ensure that policy questions concerning the organisations' data are answered by the managers of the organisation, not by the systems analysts. Data analysis may be thought of as the `slow and careful' approach, whereas omitting this step is `quick and dirty'.

From another viewpoint, data analysis provides useful insights for general design principals which will benefit the trainee analyst even if he finally settles for a `quick and dirty' solution.

The development of techniques of data analysis have helped to understand the structure and

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meaning of data in organisations. Data analysis techniques can be used as the first step of extrapolating the complexities of the real world into a model that can be held on a computer and be accessed by many users. The data can be gathered by conventional methods such as interviewing people in the organisation and studying documents. The facts can be represented as objects of interest. There are a number of documentation tools available for data analysis, such as entity-relationship diagrams. These are useful aids to communication, help to ensure that the work is carried out in a thorough manner, and ease the mapping processes that follow data analysis. Some of the documents can be used as source documents for the data dictionary.

In data analysis we analyse the data and build a systems representation in the form of a data model (conceptual). A conceptual data model specifies the structure of the data and the processes which use that data.

Data Analysis = establishing the nature of data.

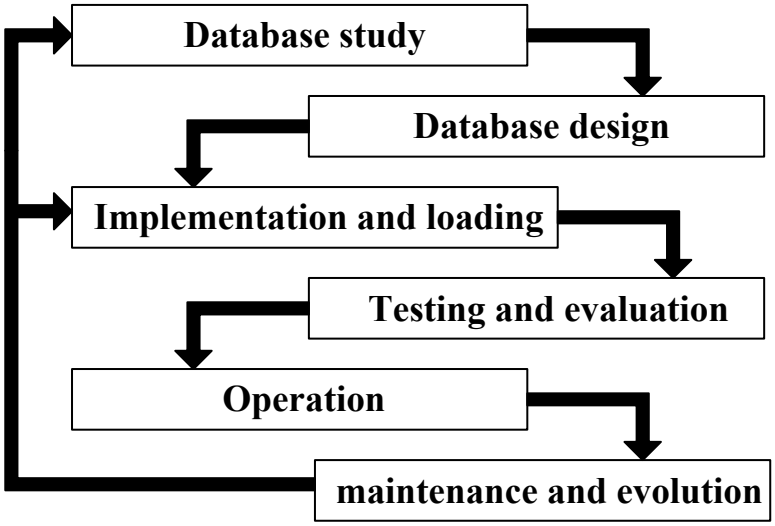
Functional Analysis = establishing the use of data.

However, since Data and Functional Analysis are so intermixed, we shall use the term Data Analysis to cover both.

Building a model of an organisation is not easy. The whole organisation is too large as there will be too many things to be modelled. It takes too long and does not achieve anything concrete like an information system, and managers want tangible results fairly quickly. It is therefore the task of the data analyst to model a particular view of the organisation, one which proves reasonable and accurate for most applications and uses. Data has an intrinsic structure of its own, independent of processing, reports formats etc. The data model seeks to make explicit that structure

Data analysis was described as establishing the nature and use of data.

Database Analysis Life Cycle



When a database designer is approaching the problem of constructing a database system, the logical steps followed is that of the database analysis life cycle:

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- Database study - here the designer creates a written specification in words for the database system to be built. This involves
    - analysing the company situation - is it an expanding company, dynamic in its requirements, mature in nature, solid background in employee training for new internal products, etc. These have an impact on how the specification is to be viewed.
    - define problems and constraints - what is the situation currently? How does the company deal with the task which the new database is to perform. Any issues around the current method? What are the limits of the new system?
    - define objectives - what is the new database system going to have to do, and in what way must it be done. What information does the company want to store specifically, and what does it want to calculate. How will the data evolve.
    - define scope and boundaries - what is stored on this new database system, and what it stored elsewhere. Will it interface to another database?
- Database Design - conceptual, logical, and physical design steps in taking specifications to physical implementable designs. This is looked at more closely in a moment.
- Implementation and loading - it is quite possible that the database is to run on a machine which as yet does not have a database management system running on it at the moment. If this is the case one must be installed on that machine. Once a DBMS has been installed, the database itself must be created within the DBMS. Finally, not all databases start completely empty, and thus must be loaded with the initial data set (such as the current inventory, current staff names, current customer details, etc).
- Testing and evaluation - the database, once implemented, must be tested against the specification supplied by the client. It is also useful to test the database with the client using mock data, as clients do not always have a full understanding of what they thing they have specified and how it differs from what they have actually asked for! In addition, this step in the life cycle offers the chance to the designer to fine-tune the system for best performance. Finally, it is a good idea to evaluate the database in-situ, along with any linked applications.
- Operation - this step is where the system is actually in real usage by the company.
- Maintenance and evolution - designers rarely get everything perfect first time, and it may be the case that the company requests changes to fix problems with the system or to recommend enhancements or new requirements.
- Commonly development takes place without change to the database structure. In elderly systems the DB structure becomes fossilised.

Three-level Database Model

Often referred to as the three-level model, this is where the design moves from a written specification taken from the real-world requirements to a physically-implementable design for a

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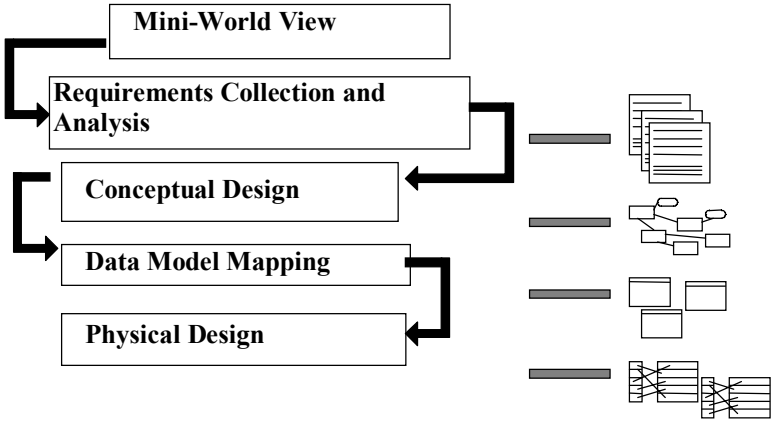
specific DBMS. The three levels commonly referred to are `Conceptual Design', `Data Model Mapping', and `Physical Design'.



The specification is usually in the form of a written document containing customer requirements, mock reports, screen drawings and the like, written by the client to indicate the requirements which the final system is to have. Often such data has to be collected together from a variety of internal sources to the company and then analysed to see if the requirements are necessary, correct, and efficient.

Once the Database requirements have been collated, the Conceptual Design phase takes the requirements and produces a high-level data model of the database structure. In this module, we use ER modelling to represent high-level data models, but there are other techniques. This model is independent of the final DBMS which the database will be installed in.

Next, the Conceptual Design phase takes the high-level data model it taken and converted into a conceptual schema, which is specific to a particular DBMS class (e.g. relational). For a relational system, such as Oracle, an appropriate conceptual schema would be relations.

Finally, in the Physical Design phase the conceptual schema is converted into database internal structures. This is specific to a particular DBMS product.

Entity Relationship Modelling

Entity Relationship (ER) modelling

- is a design tool
- is a graphical representation of the database system
- provides a high-level conceptual data model
- supports the user's perception of the data
- is DBMS and hardware independent
- had many variants
- is composed of entities, attributes, and relationships

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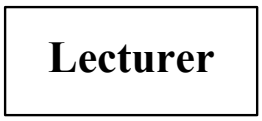
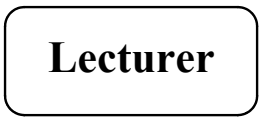
Entities

- An entity is any object in the system that we want to model and store information about
    - Individual objects are called entities
    - Groups of the same type of objects are called entity types or entity sets
    - Entities are represented by rectangles (either with round or square corners)



Chen's notation



other notations

    - There are two types of entities; weak and strong entity types.

Attribute

- All the data relating to an entity is held in its attributes.
- An attribute is a property of an entity.
- Each attribute can have any value from its domain.
- Each entity within an entity type:
    - May have any number of attributes.
    - Can have different attribute values than that in any other entity.
    - Have the same number of attributes.
- Attributes can be
    - simple or composite
    - single-valued or multi-valued
- Attributes can be shown on ER models
    - They appear inside ovals and are attached to their entity.
    - Note that entity types can have a large number of attributes... If all are shown then the diagrams would be confusing. Only show an attribute if it adds information to the ER diagram, or clarifies a point.

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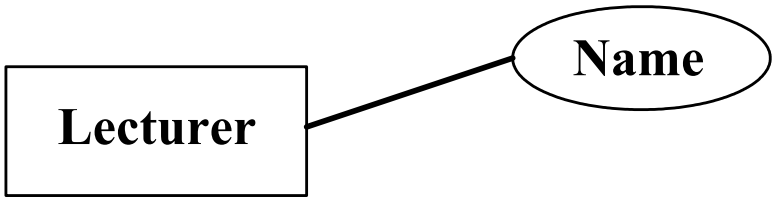


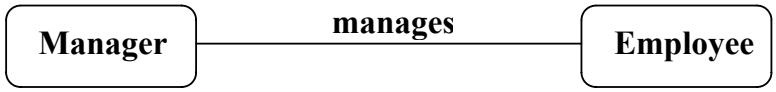
Keys

- A key is a data item that allows us to uniquely identify individual occurrences or an entity type.
- A candidate key is an attribute or set of attributes that uniquely identifies individual occurrences or an entity type.
- An entity type may have one or more possible candidate keys, the one which is selected is known as the primary key.
- A composite key is a candidate key that consists of two or more attributes
- The name of each primary key attribute is underlined.

Relationships

- A *relationship type* is a meaningful association between entity types
- A *relationship* is an association of entities where the association includes one entity from each participating entity type.
- Relationship types are represented on the ER diagram by a series of lines.
- As always, there are many notations in use today...
- In the original Chen notation, the relationship is placed inside a diamond, e.g. managers manage employees:

- For this module, we will use an alternative notation, where the relationship is a label on the line. The meaning is identical



Degree of a Relationship

- The number of participating entities in a relationship is known as the degree of the relationship.

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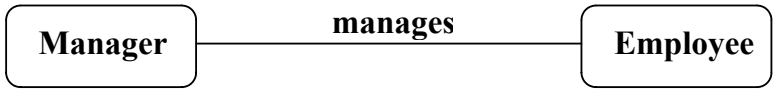
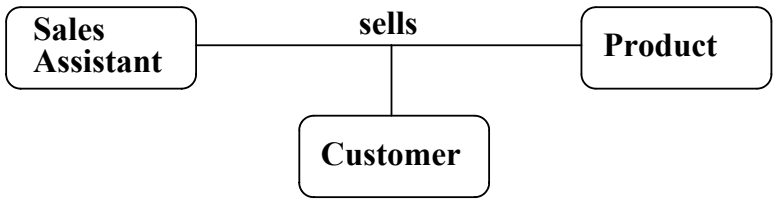
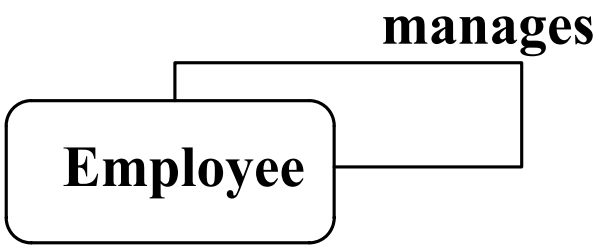
- If there are two entity types involved it is a *binary* relationship type



- If there are three entity types involved it is a *ternary* relationship type



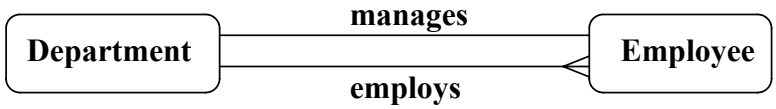
- It is possible to have a n-ary relationship (e.g. quaternary or unary).
- Unary relationships are also known as a *recursive* relationship.



- It is a relationship where the same entity participates more than once in different roles.
- In the example above we are saying that employees are managed by employees.
- If we wanted more information about who manages whom, we could introduce a second entity type called manager.

Degree of a Relationship

- It is also possible to have entities associated through two or more distinct relationships.



- In the representation we use it is not possible to have attributes as part of a relationship. To support this other entity types need to be developed.

Replacing ternary relationships

When ternary relationships occurs in an ER model they should always be removed before finishing the model. Sometimes the relationships can be replaced by a series of binary relationships that link pairs of the original ternary relationship.

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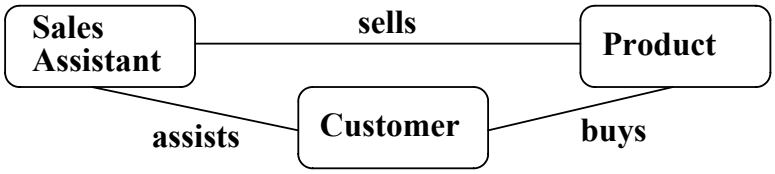
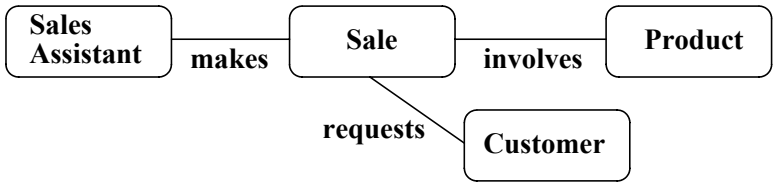


- This can result in the loss of some information - It is no longer clear which sales assistant sold a customer a particular product.
- Try replacing the ternary relationship with an entity type and a set of binary relationships.

Relationships are usually verbs, so name the new entity type by the relationship verb rewritten as a noun.

- The relationship *sells* can become the entity type *sale*.



- So a sales assistant can be linked to a specific customer and both of them to the sale of a particular product.
- This process also works for higher order relationships.

Cardinality

- Relationships are rarely one-to-one
    - For example, a manager usually manages more than one employee
- This is described by the *cardinality* of the relationship, for which there are four possible categories.
    - One to one (1:1) relationship
    - One to many (1:m) relationship
    - Many to one (m:1) relationship
    - Many to many (m:n) relationship
- On an ER diagram, if the end of a relationship is straight, it represents 1, while a "crow's foot" end represents many.
- A one to one relationship - a man can only marry one woman, and a woman can only marry one man, so it is a one to one (1:1) relationship

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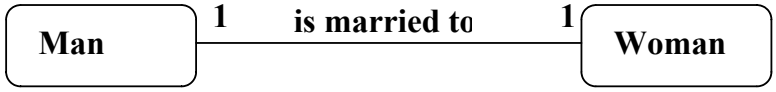
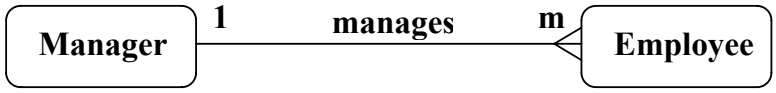
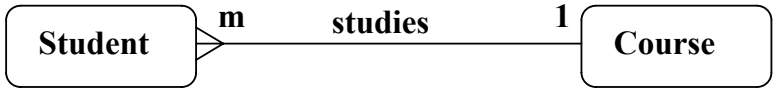


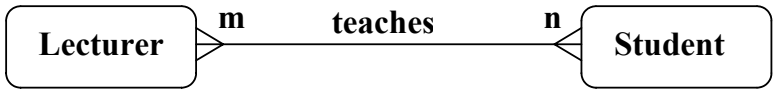
- A one to may relationship - one manager manages many employees, but each employee only has one manager, so it is a one to many (1:n) relationship



- A many to one relationship - many students study one course. They do not study more than one course, so it is a many to one (m:1) relationship



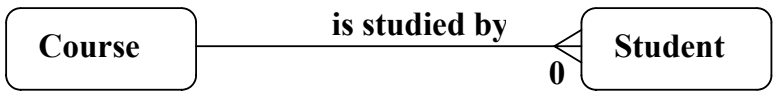
- A many to many relationship - One lecturer teaches many students and a student is taught by many lecturers, so it is a many to many (m:n) relationship



Optionality

A relationship can be option or mandatory.

- If the relationship is mandatory
    - an entity at one end of the relationship must be related to an entity at the other end.
- The optionality can be different at each end of the relationship
    - For example, a student must be on a course. This is mandatory. To the relationship `student studies course' is mandatory.
    - But a course can exist before any students have enrolled. Thus the relationship `course is_studied_by student' is optional.
- To show optionality, put a circle or `0' at the `optional end' of the relationship.
- As the optional relationship is `course is_studied_by student', and the optional part of this is the student, then the `O' goes at the student end of the relationship connection.



- It is important to know the optionality because you must ensure that whenever you create a new entity it has the required mandatory links.

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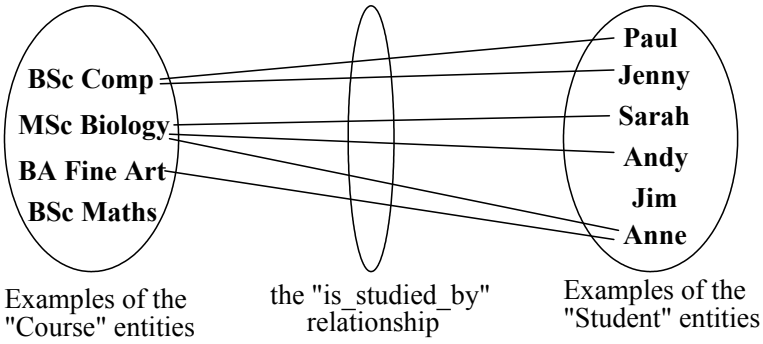
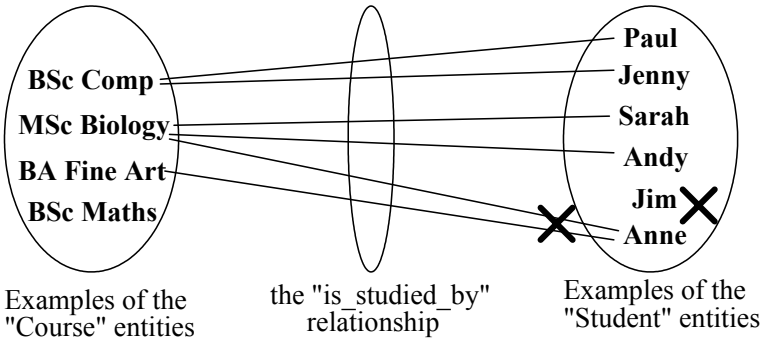
Entity Sets

Sometimes it is useful to try out various examples of entities from an ER model. One reason for this is to confirm the correct cardinality and optionality of a relationship. We use an `entity set diagram' to show entity examples graphically. Consider the example of `course is_studied_by student'.



Confirming Correctness



- Use the diagram to show all possible relationship scenarios.
    - Go back to the requirements specification and check to see if they are allowed.
    - If not, then put a cross through the forbidden relationships
- This allows you to show the cardinality and optionality of the relationship

Deriving the relationship parameters

To check we have the correct parameters (sometimes also known as the degree) of a relationship, ask two questions:

One course is studied by how many students? Answer = `zero or more'.

- This gives us the degree at the `student' end.
- The answer `zero or more' needs to be split into two parts.
    - The `more' part means that the cardinality is `many'.

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    - The `zero' part means that the relationship is `optional'.
- If the answer was `one or more', then the relationship would be `mandatory'.

2. One student studies how many courses? Answer = `One'
    - This gives us the degree at the `course' end of the relationship.
        - The answer `one' means that the cardinality of this relationship is 1, and is `mandatory'
    - If the answer had been `zero or one', then the cardinality of the relationship would have been 1, and be `optional'.

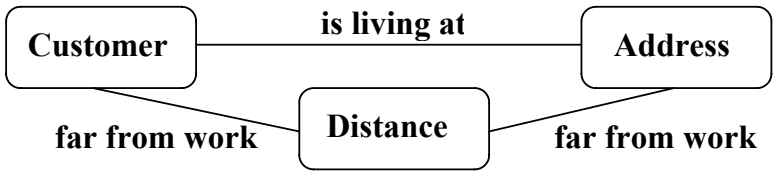
Redundant relationships

Some ER diagrams end up with a relationship loop.

- check to see if it is possible to break the loop without losing info
- Given three entities A, B, C, where there are relations A-B, B-C, and C-A, check if it is possible to navigate between A and C via B. If it is possible, then A-C was a redundant relationship.
- Always check carefully for ways to simplify your ER diagram. It makes it easier to read the remaining information.

Redundant relationships example

- Consider entities `customer' (customer details), `address' (the address of a customer) and `distance' (distance from the company to the customer address).



Splitting n:m Relationships

A many to many relationship in an ER model is not necessarily incorrect. They can be replaced using an intermediate entity. This should only be done where:

- the m:n relationship hides an entity
- the resulting ER diagram is easier to understand.

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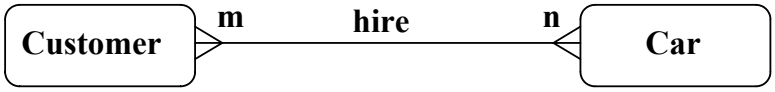
Splitting n:m Relationships - Example

Consider the case of a car hire company. Customers hire cars, one customer hires many card and a car is hired by many customers.



The many to many relationship can be broken down to reveal a `hire' entity, which contains an attribute `date of hire'.

Constructing an ER model - Entities

Before beginning to draw the ER model, read the requirements specification carefully. Document any assumptions you need to make.

1. Identify entities - list all potential entity types. These are the object of interest in the system. It is better to put too many entities in at this stage and them discard them later if necessary.
2. Remove duplicate entities - Ensure that they really separate entity types or just two names for the same thing.
    - Also do not include the system as an entity type
    - e.g. if modelling a library, the entity types might be books, borrowers, etc.
    - The library is the system, thus should not be an entity type.

Constructing an ER model - Attributes

3. List the attributes of each entity (all properties to describe the entity which are relevant to the application).
    - Ensure that the entity types are really needed.
        - are any of them just attributes of another entity type?
        - if so keep them as attributes and cross them off the entity list.
    - Do not have attributes of one entity as attributes of another entity!
4. Mark the primary keys.
    - Which attributes uniquely identify instances of that entity type?
    - This may not be possible for some weak entities.

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Constructing an ER model - Relationships

5. Define the relationships
    - Examine each entity type to see its relationship to the others.
6. Describe the cardinality and optionality of the relationships
    - Examine the constraints between participating entities.
7. Remove redundant relationships
    - Examine the ER model for redundant relationships.

ER modelling is an iterative process, so draw several versions, refining each one until you are happy with it. Note that there is no one right answer to the problem, but some solutions are better than others!

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Unit 2.2 - ER Modelling 2

Unit 2.2 - Entity Relationship Modelling - 2

Overview

- construct an ER model
- understand the problems associated with ER models
- understand the modelling concepts of Enhanced ER modelling

Country Bus Company

A Country Bus Company owns a number of busses. Each bus is allocated to a particular route, although some routes may have several busses. Each route passes through a number of towns. One or more drivers are allocated to each stage of a route, which corresponds to a journey through some or all of the towns on a route. Some of the towns have a garage where busses are kept and each of the busses are identified by the registration number and can carry different numbers of passengers, since the vehicles vary in size and can be single or double-decked. Each route is identified by a route number and information is available on the average number of passengers carried per day for each route. Drivers have an employee number, name, address, and sometimes a telephone number.

Entities

- Bus - Company owns busses and will hold information about them.
- Route - Buses travel on routes and will need described.
- Town - Buses pass through towns and need to know about them
- Driver - Company employs drivers, personnel will hold their data.
- Stage - Routes are made up of stages
- Garage - Garage houses buses, and need to know where they are.

Relationships

- A bus is allocated to a route and a route may have several buses.
    - Bus-route (m:1) is serviced by
- A route comprises of one or more stages.

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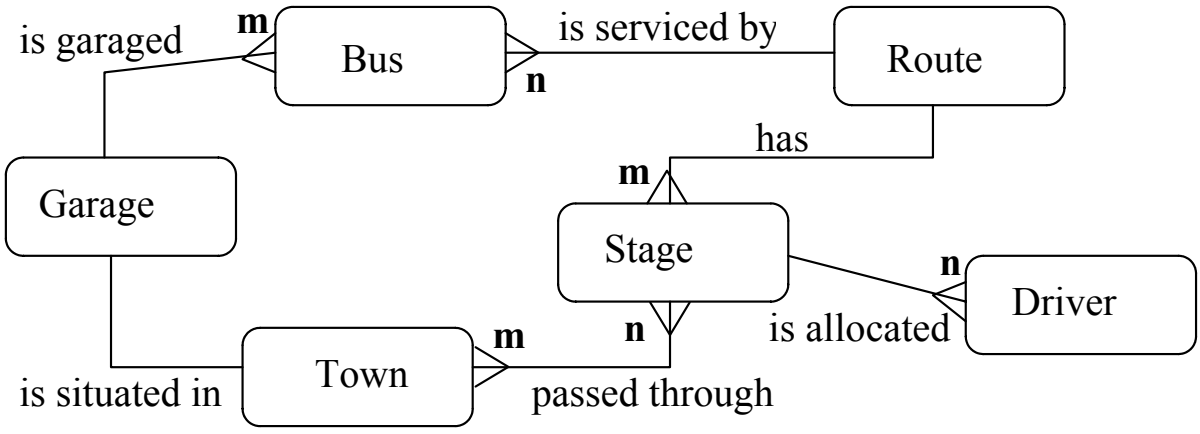
    - route-stage (1:m) comprises
- One or more drivers are allocated to each stage.
    - driver-stage (m:1) is allocated
- A stage passes through some or all of the towns on a route.
    - stage-town (m:n) passes-through
- A route passes through some or all of the towns
    - route-town (m:n) passes-through
- Some of the towns have a garage
    - garage-town (1:1) is situated
- A garage keeps buses and each bus has one `home' garage
    - garage-bus (m:1) is garaged

Draw E-R Diagram



Attributes

- Bus (reg-no,make,size,deck,no-pass)
- Route (route-no,avg-pass)
- Driver (emp-no,name,address,tel-no)
- Town (name)

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- Stage (stage-no)
- Garage (name,address)

Problems with ER Models

There are several problems that may arise when designing a conceptual data model. These are known as connection traps.

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There are two main types of connection traps:

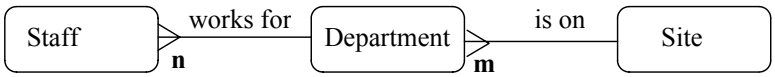
1. fan traps
2. chasm traps

Fan traps

A fan trap occurs when a model represents a relationship between entity types, but the pathway between certain entity occurrences is ambiguous. It occurs when 1:m relationships fan out from a single entity.

A single site contains many departments and employs many staff. However, which staff work in a particular department?

The fan trap is resolved by restructuring the original ER model to represent the correct association.



Chasm traps

A chasm trap occurs when a model suggests the existence of a relationship between entity types, but the pathway does not exist between certain entity occurrences.

It occurs where there is a relationship with partial participation, which forms part of the pathway between entities that are related.

- A single branch is allocated many staff who oversee the management of properties for rent. Not all staff oversee property and not all property is managed by a member of staff.
- What properties are available at a branch?
- The partial participation of Staff and Property in the oversees relation means that some properties cannot be associated with a branch office through a member of staff.
- We need to add the missing relationship which is called `has' between the Branch and the Property entities.
- You need to therefore be careful when you remove relationships which you consider to be redundant.

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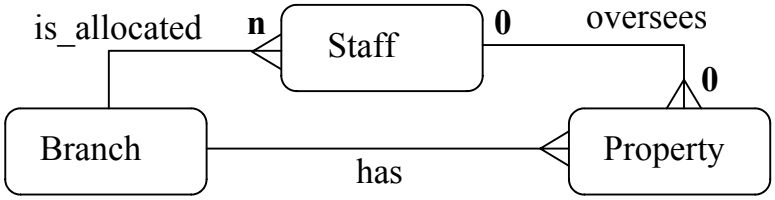


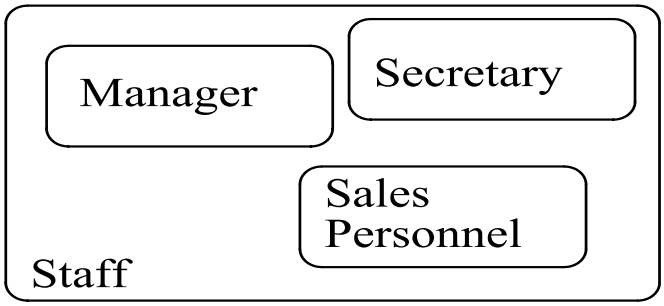
Enhanced ER Models (EER)

The basic concepts of ER modelling is not powerful enough for some complex applications... We require some additional semantic modelling concepts:

- Specialisation
- Generalisation
- Categorisation
- Aggregation

First we need some new entity constructs.

- Superclass - an entity type that includes distinct subclasses that require to be represented in a data model.
- Subclass - an entity type that has a distinct role and is also a member of a superclass.



Subclasses need not be mutually exclusive; a member of staff may be a manager and a sales person.

The purpose of introducing superclasses and subclasses is to avoid describing types of staff with possibly different attributes within a single entity. This could waste space and you might want to make some attributes mandatory for some types of staff but other staff would not need these attributes at all.

Specialisation

This is the process of maximising the differences between members of an entity by identifying their distinguishing characteristics.

- Staff(staff_no,name,address,dob)

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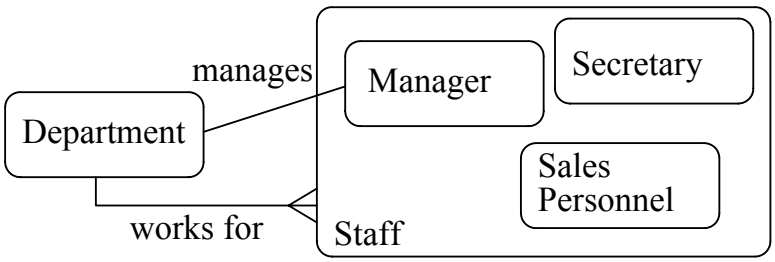
- Manager(bonus)
- Secretary(wp_skills)
- Sales_personnel(sales_area, car_allowance)



- Here we have shown that the manages relationship is only applicable to the Manager subclass, whereas the works_for relationship is applicable to all staff.
- It is possible to have subclasses of subclasses.

Generalisation

Generalisation is the process of minimising the differences between entities by identifying common features.

This is the identification of a generalised superclass from the original subclasses. This is the process of identifying the common attributes and relationships.

Unit 2.3 - Mapping ER Models into Relations

Unit 2.3 - Mapping ER Models into Relations

Overview

- map 1:1 relationships into relations
- map 1:m relationships into relations
- map m:n relationships into relations
- differences between mapping optional and mandatory relationships.

What is a relation?

A relation is a table that holds the data we are interested in. It is two-dimensional and has rows and columns.

Each entity type in the ER model is mapped into a relation.

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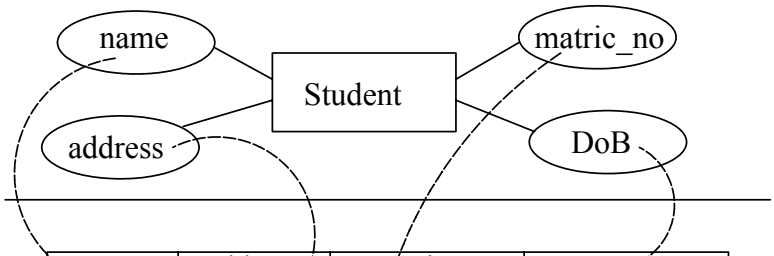
- The attributes become the columns.
- The individual entities become the rows.



name	address	matric_no	DoB
John Smith	Scotland	0987654	12/12/99
Paul James	Japan	1234567	1/2/33

Relations can be represented textually as:

```
tablename(primary key, attribute 1, attribute 2, ... , foreign key)
```

If matric_no was the primary key, and there were no foreign keys, then the table above could be represented as:

```
student(matric no, name, address, date_of_birth)
```

When referring to relations or tables, cardinality is considered to the the number of rows in the relation or table, and arity is the number of columns in a table or attributes in a relation.

Foreign keys

A foreign key is an attribute (or group of attributes) that is the primary key to another relation.

- Roughly, each foreign key represents a relationship between two entity types.
- They are added to relations as we go through the mapping process.
- They allow the relations to be linked together.
- A relation can have several foreign keys.
- It will generally have a foreign key from each table that it is related to.
- Foreign keys are usually shown in italics or with a wiggly underline.

Preparing to map the ER model

Before we start the actual mapping process we need to be certain that we have simplified the ER model as much as possible.

This is the ideal time to check the model, as it is really the last chance to make changes to the ER model without causing major complications.

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Mapping 1:1 relationships

Before tackling a 1:1 relationship, we need to know its optionality.

There are three possibilities the relationship can be:

1. mandatory at both ends
2. mandatory at one end and optional at the other
3. optional at both ends

Mandatory at both ends

If the relationship is mandatory at both ends it is often possible to subsume one entity type into the other.

- The choice of which entity type subsumes the other depends on which is the most important entity type (more attributes, better key, semantic nature of them).
- The result of this amalgamation is that all the attributes of the `swallowed up' entity become attributes of the more important entity.
- The key of the subsumed entity type becomes a normal attribute.
- If there are any attributes in common, the duplicates are removed.
- The primary key of the new combined entity is usually the same as that of the original more important entity type.

When not to combine

There are a few reason why you might not combine a 1:1 mandatory relationship.

- the two entity types represent different entities in the `real world'.
- the entities participate in very different relationships with other entities.
- efficiency considerations when fast responses are required or different patterns of updating occur to the two different entity types.

If not combined...

If the two entity types are kept separate then the association between them must be represented by a foreign key.

- The primary key of one entity type comes the foreign key in the other.
- It does not matter which way around it id done but you should not have a foreign key in each entity.

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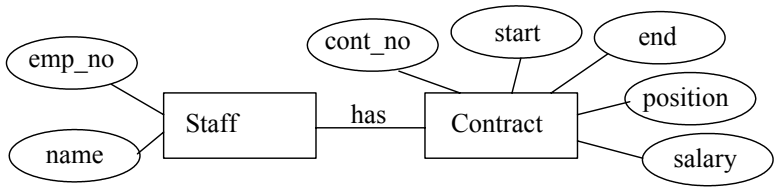
Example

- Two entity types; staff and contract.
    - Each member of staff must have one contract and each contract must have one member of staff associated with it.
    - It is therefore a mandatory relations at both ends.



- These to entity types could be amalgamated into one.

```
Staff(emp_no, name, cont_no, start, end, position, salary)
```

- or kept apart and a foreign key used

```
Staff(emp_no, name, contract_no)
Contract(cont_no, start, end, position, salary)
```

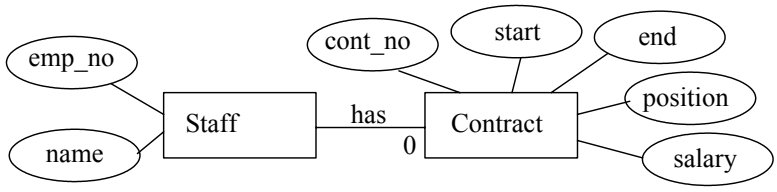
- or

```
Staff(emp_no, name)
Contract(cont_no, start, end, position, salary, emp_no)
```

Mandatory Optional

The entity type of the optional end may be subsumed into the mandatory end as in the previous example.

It is better NOT to subsume the mandatory end into the optional end as this will create null entries.



If we add to the specification that each staff member may have at most one contract (thus making the relation optional at one end).

- Map the foreign key into Staff - the key is null for staff without a contract.

```
Staff(emp_no, name, contract_no)
Contract(cont_no, start, end, position, salary)
```

- Map the foreign key into Contract - emp_no is mandatory thus never null.

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```
Staff(emp_no, name)
Contract(cont_no, start, end, position, salary, emp_no)
```

Example

Consider this example:

- Staff "Gordon", empno 10, contract no 11.
- Staff "Andrew", empno 11, no contract.
- Contract 11, from 1st Jan 2001 to 10th Jan 2001, lecturer, on £2.00 a year.

Foreign key in Staff:

Contract Table:

Cont_no	Start	End	Position	Salary
11	1st Jan 2001	10th Jan 2001	Lecturer	£2.00

Staff Table:

Empno	Name	Contract No
10	Gordon	11
11	Andrew	**NULL**

However, Foreign key in Contract:

Contract Table:

Cont_no	Start	End	Position	Salary	Empno
11	1st Jan 2001	10th Jan 2001	Lecturer	£2.00	10

Staff Table:

Empno	Name
10	Gordon
11	Andrew

As you can see, both ways store the same information, but the second way has no NULLs.

Mandatory Optional - Subsume?

The reasons for not subsuming are the same as before with the following additional reason.

- very few of the entities from the mandatory end are involved in the relationship. This could cause a lot of wasted space with many blank or null entries.

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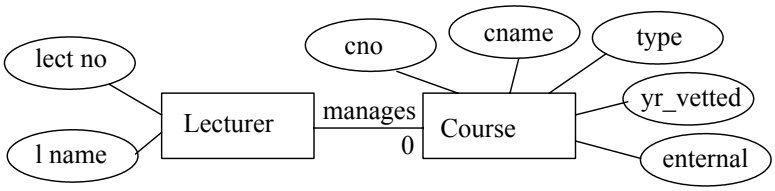


- If only a few lecturers manage courses and Course is subsumed into Lecturer then there would be many null entries in the table.

```
Lecturer(lect_no, l_name, cno, c_name, type, yr_vetted, external)
```

- It would be better to keep them separate.

```
Lecturer(lect_no, l_name)
Course(cno, c_name, type, yr_vetted, external,lect_no)
```

Summary...

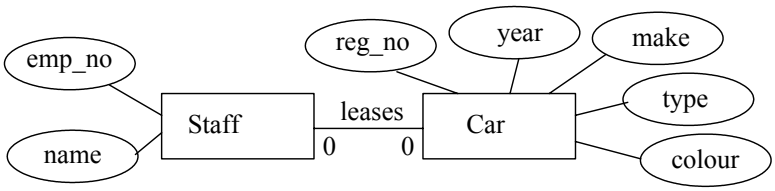
So for 1:1 optional relationships, take the primary key from the `mandatory end' and add it to the `optional end' as a foreign key.

So, given entity types A and B, where A B is a relationship where the A end it optional, the result would be:

```
A (primary key,attribute,...,foreign key to B)
B (primary key,attribute,...)
```

Optional at both ends...

Such examples cannot be amalgamated as you could not select a primary key. Instead, one foreign key is used as before.



- Each staff member may lease up to one car
- Each car may be leased by at most one member of staff
- If these were combined together...

```
Staff_car(emp_no, name, reg_no, year, make, type, colour)
```

what would be the primary key?

- If emp_no is used then all the cars which are not being leased will not have a key.
- Similarly, if the reg_no is used, all the staff not leasing a car will not have a key.

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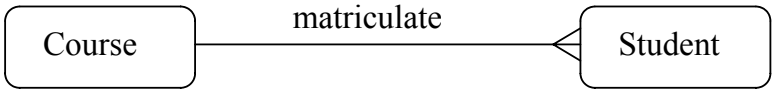
- A compound key will not work either.

Mapping 1:m relationships

To map 1:m relationships, the primary key on the `one side' of the relationship is added to the `many side' as a foreign key.

For example, the 1:m relationship `course-student':



- Assuming that the entity types have the following attributes:

```
Course(course_no, c_name)
Student(matric_no, st_name, dob)
```

- Then after mapping, the following relations are produced:

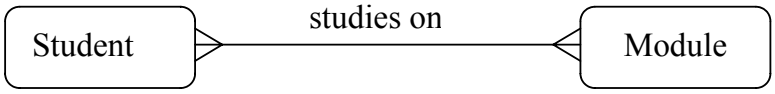
```
Course(course_no, c_name)
Student(matric_no, st_name, dob, course_no)
```

- If an entity type participates in several 1:m relationships, then you apply the rule to each relationship, and add foreign keys as appropriate.

Mapping n:m relationships

If you have some m:n relationships in your ER model then these are mapped in the following manner.

- A new relation is produced which contains the primary keys from both sides of the relationship
- These primary keys form a composite primary key.



- Thus

```
Student(matric_no, st_name, dob)
Module(module_no, m_name, level, credits)
```

- becomes

```
Student(matric_no, st_name, dob)
Module(module_no, m_name, level, credits)
Studies(matric_no,module_no)
```

This is equivalent to:

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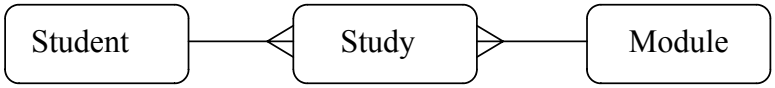



```
Student(matric_no,st_name,dob)
Module(module_no,m_name,level,credits)
Study()
```

Summary

- 1-1 relationships
  Depending on the optionality of the relationship, the entities are either combined or the primary key of one entity type is placed as a foreign key in the other relation.
- 1-m relationships
  The primary key from the `one side' is placed as a foreign key in the `many side'.
- m-n relationships
  A new relation is created with the primary keys from each entity forming a composite key.

Unit 2.4 - Advanced ER Mapping

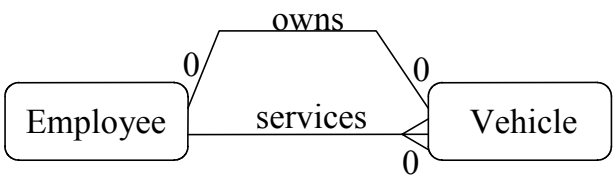
Unit 2.4 - Advanced ER Mapping

Overview

- map parallel relationships into relations
- map unary relationships into relations
- map superclasses and subclasses into relations

Mapping parallel relationships

Parallel relationships occur when there are two or more relationships between two entity types (e.g. employees own and service cars).



- In order to distinguish between the two roles we can give the foreign keys different names.
- Each relationship is mapped according to the rules, and we end up with two foreign keys

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added to the Vehicle table.

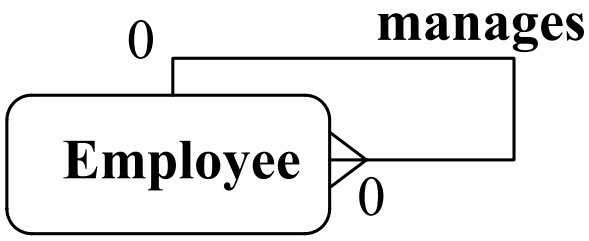
- So we add the *employee_no* as the *owner_no* in order to represent the `owns' relationship.
- We then add the *employee_no* as the *serviced_by* attribute in order to represent the `services' relationship.
- Before mapping

```
Employee(employee_no,...)
Vehicle(registration_no,...)
```

- After mapping

```
Employee(employee_no,...)
Vehicle(registration_no,owner_no,serviced_by,...)
```

Mapping 1:m in unary relationships



- Employees manage employees
- Each employee has an employee_no with is the primary key
- We represent the manages relationship by adding a *manager_no* as a foreign key.
- This is in fact the employee_no of the manager.
- It is given a different name to clearly convey what it represents, and to ensure that all the entity type's attributes have unique names, as to do otherwise would be invalid.
- After mapping

```
Employee(employee_no,manager_no, name,...)
```

- So in general, for unary 1:n relationships, the foreign key is the primary key of the same table, but is given a different name.
- Note that the relationship is optional in both directions because not all staff can be managers, and the top manager is not managed by anybody else.

Mapping superclasses and subclasses

There are three ways of implementing superclasses and subclasses and it depends on the application which will be the most suitable.

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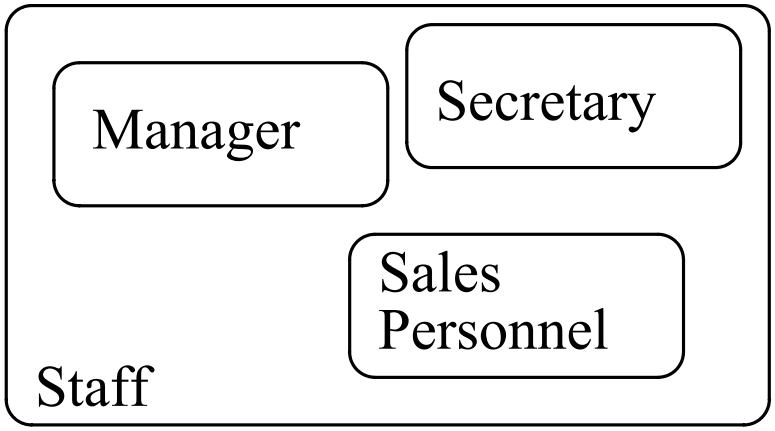
Only the first method is a true reflection of the superclasses and subclasses and if either of the other methods is preferential then the model should not have subclasses.

1. One relation for the superclass and one relation for each subclass.
2. One relation for each subclass.
3. One relation for the superclass.

Example




```
Staff(staff_no,name,address,dob)
Manager(bonus)
Secretary(wp_skills)
Sales_personnel(sales_area, car_allowance)
```

One relation for the superclass and one relation for each subclass:

```
Staff(staff_no,name,address,dob)
Manager(staff_no,bonus)
Secretary(staff_no,wp_skills)
Sales_personnel(staff_no,sales_area, car_allowance)
```

The primary key of the superclass is mapped into each subclass and becomes the subclasses primary key. This represents most closely the EER model. However is can cause efficiency problems as there needs to be a lot of joins if the additional information is often needed for all staff.

One relation for each subclass:

```
Manager(staff_no,name,address,dob,bonus)
Secretary(staff_no,name,address,dob,wp_skills)
Sales_personnel(staff_no,name,address,dob,sales_area, car_allowance)
```

All attributes are mapped into each subclass. It is equivalent to having three separate entity types and no superclass.

It is useful if there are no overlapping and there are no relationships between the superclass and other entity types. It is poor if the subclasses are not disjoint as there is data duplication in each relation which can cause problems with consistency.

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One relation for the superclass:

```
  Staff(staff_no,name,address,dob, bonus, wp_skills, sales_area,
car_allowance)
```

This represents a single entity type with no subclasses.

This is no good if the subclasses are not disjoint or if there are relationships between the subclasses and the other entities.

In addition, there will be many null fields if the subclasses do not overlap a lot. However, it avoids any joins to get additional information about each member of staff.

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Unit 3.1 - Normalisation 1

Unit 3.1 - Normalisation

What is normalisation?

Normalisation is the process of taking data from a problem and reducing it to a set of relations while ensuring data integrity and eliminating data redundancy

- Data integrity - all of the data in the database are consistent, and satisfies all integrity constraints.
- Data redundancy – if data in the database can be found in two different locations (direct redundancy) or if data can be calculated from other data items (indirect redundancy) then the data is said to contain redundancy.

Data should only be stored once and avoid storing data that can be calculated from other data already held in the database. During the process or normalisation redundancy must be removed, but not at the expense of breaking data integrity rules.

If redundancy exists in the database then problems can arise when the database is in normal operation:

- When data is inserted the data must be duplicated correctly in all places where there is redundancy. For instance, if two tables exist for in a database, and both tables contain the employee name, then creating a new employee entry requires that both tables be updated with the employee name.
- When data is modified in the database, if the data being changed has redundancy, then all versions of the redundant data must be updated simultaneously. So in the employee example a change to the employee name must happen in both tables simultaneously.

The removal of redundancy helps to prevent insertion and update errors, since the data is only available in one attribute of one table in the database.

The data in the database can be considered to be in one of a number of `normal forms'. Basically the normal form of the data indicates how much redundancy is in that data. The normal forms have a strict ordering:

1. 1st Normal Form
2. 2nd Normal Form
3. 3rd Normal Form
4. BCNF

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5. 4th Normal Form
6. 5th Normal Form

   To be in a particular form requires that the data meets the criteria to also be in all normal forms before that form. Thus to be in 2nd normal form the data must meet the criteria for both 2nd normal form and 1st normal form. The higher the form the more redundancy has been eliminated.

Integrity Constraints

An integrity constraint is a rule that restricts the values that may be present in the database The relational data model includes constraints that are used to verify the validity of the data as well as adding meaningful structure to it:

- entity integrity :

  The rows (or tuples) in a relation represent entities, and each one must be uniquely identified. Hence we have the primary key that must have a unique non-null value for each row.

- referential integrity :

  This constraint involves the foreign keys. Foreign keys tie the relations together, so it is vitally important that the links are correct. Every foreign key must either be null or its value must be the actual value of a key in another relation.

Understanding Data

Sometimes the starting point for understanding data is given in the form of relations and functional dependancies. This would be the case where the starting point in the process was a detailed specification of the problem. We already know what relations are. Functional dependancies are rules stating that given a certain set of attributes (the determinant) determines a second set of attributes. Consider this example:

R(matric_no, firstname, surname, tutor_number, tutor_name)

tutor_number -> tutor_name

Here there is a relation R, and a functional dependency that indicates that:

- instances of tutor_number are unique in the data
- from the data, given a tutor_number, it is always possible to work out the tutor_name.

There is actually a second functional dependency for this relation, which can be worked out from the relation itself. As the relation has a primary key, then given this attribute you can determine all the other attributes in R. This is an implied functional dependency and is not normally listed

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in the list of functional dependents.

Extracting understanding

It is possible that the relations and the determinants have not yet been defined for a problem, and therefore must be calculated from examples of the data. Consider the following Student table.

Student - an unnormalised table with repeating groups

matric_no	Name	date_of_birth	subject	grade
960100	Smith, J	14/11/1977	Databases Soft_Dev ISDE	C A D
960105	White, A	10/05/1975	Soft_Dev ISDE	B B
960120	Moore, T	11/03/1970	Databases Soft_Dev Workshop	A B C
960145	Smith, J	09/01/1972	Databases	B
960150	Black, D	21/08/1973	Databases Soft_Dev ISDE Workshop	B D C D

The subject/grade pair is repeated for each student. 960145 has 1 pair while 960150 has four. Repeating groups are placed inside another set of parenthesizes. From the table the following relation is generated:

Student(matric_no, name, date_of_birth, (subject, grade))

The repeating group needs a key in order that the relation can be correctly defined. Looking at the data one can see that grade repeats within matric_no (for instance, for 960150, the student has 2 D grades). However, subject never seems to repeat for a single matric_no, and therefore is a candidate key in the repeating group.

Whenever keys or dependencies are extracted from example data, the information extracted is only as good as the data sample examined. It could be that another data sample disproves some of the key selections made or dependencies extracted. What is important however is that the information extracted during these exercises is correct for the data being examined.

Looking at the data itself, we can see that the same name appears more than once in the name column. The name in conjunction with the date_of_birth seems to be unique, suggesting a functional dependency of:

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name, date_of_birth -> matric_no

This implies that not only is the matric_no sufficient to uniquely identify a student, the student's name combined with the date of birth is also sufficient to uniquely identify a student. It is therefore possible to have the relation Student written as:

Student(matric_no, name, date_of_birth, (subject, grade))

As guidance in cases where a variety of keys could be selected one should try to select the relation with the least number of attributes defined as primary keys.

Flattened Tables

Note that the student table shown above explicitly identifies the repeating group. It is also possible that the table presented will be what is called a flat table, where the repeating group is not explicitly shown:

Student #2 - Flattened Table

matric_no	name	date_of_birth	Subject	grade
960100	Smith, J	14/11/1977	Databases	C
960100	Smith, J	14/11/1977	Soft_Dev	A
960100	Smith, J	14/11/1977	ISDE	D
960105	White, A	10/05/1975	Soft_Dev	B
960105	White, A	10/05/1975	ISDE	B
960120	Moore, T	11/03/1970	Databases	A
960120	Moore, T	11/03/1970	Soft_Dev	B
960120	Moore, T	11/03/1970	Workshop	C
960145	Smith, J	09/01/1972	Databases	B
960150	Black, D	21/08/1973	Databases	B
960150	Black, D	21/08/1973	Soft_Dev	D
960150	Black, D	21/08/1973	ISDE	C
960150	Black, D	21/08/1973	Workshop	B

The table still shows the same data as the previous example, but the format is different. We have

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removed the repeating group (which is good) but we have introduced redundancy (which is bad).

Sometimes you will miss spotting the repeating group, so you may produce something like the following relation for the Student data.

Student(matric_no, name, date_of_birth, subject, grade)

matric_no -> name, date_of_birth
name, date_of_birth -> matric_no

This data does not explicitly identify the repeating group, but as you will see the result of the normalisation process on this relation produces exactly the same relations as the normalisation of the version that explicitly does have a repeating group.

First Normal Form

- First normal form (1NF) deals with the `shape' of the record type
- A relation is in 1NF if, and only if, it contains no repeating attributes or groups of attributes.
- Example:
    - The Student table with the repeating group is not in 1NF
    - It has repeating groups, and it is called an `unnormalised table'.

Relational databases require that each row only has a single value per attribute, and so a repeating group in a row is not allowed.

To remove the repeating group, one of two things can be done:

- either flatten the table and extend the key, or
- decompose the relation- leading to First Normal Form

Flatten table and Extend Primary Key

The Student table with the repeating group can be written as:

Student(matric_no, name, date_of_birth, (subject, grade))

If the repeating group was flattened, as in the Student #2 data table, it would look something like:

Student(matric_no, name, date_of_birth, subject, grade)

Although this is an improvement, we still have a problem. matric_no can no longer be the primary key - it does not have an unique value for each row. So we have to find a new primary key - in this case it has to be a compound key since no single attribute can uniquely identify a row. The new primary key is a compound key (matrix_no + subject).

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We have now solved the repeating groups problem, but we have created other complications. Every repetition of the matric_no, name, and data_of_birth is redundant and liable to produce errors.

With the relation in its flattened form, strange anomalies appear in the system. Redundant data is the main cause of insertion, deletion, and updating anomalies.

- Insertion anomaly:

  With the primary key including subject, we cannot enter a new student until they have at least one subject to study. We are not allowed NULLs in the primary key so we must have an entry in both matric_no and subject before we can create a new record.

  - This is known as the insertion anomaly. It is difficult to insert new records into the database.
  - On a practical level, it also means that it is difficult to keep the data up to date.

- Update anomaly
  - If the name of a student were changed
    - for example Smith, J. was changed to Green, J.
  - this would require not one change but many
    - one for every subject that Smith, J. studied.

- Deletion anomaly

  If all of the records for the `Databases' subject were deleted from the table,we would inadvertently lose all of the information on the student with matric_no 960145.

  - This would be the same for any student who was studying only one subject and the subject was deleted.
  - Again this problem arises from the need to have a compound primary key.

Decomposing the relation

- The alternative approach is to split the table into two parts, one for the repeating groups and one of the non-repeating groups.
- the primary key for the original relation is included in both of the new relations

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Record

matric_no	subject	grade
960100	Databases	C
960100	Soft_Dev	A
960100	ISDE	D
960105	Soft_Dev	B
960105	ISDE	B
...	...	...
960150	Workshop	B

Student

matric_no	name	date_of_birth
960100	Smith,J	14/11/1977
960105	White,A	10/05/1975
960120	Moore,T	11/03/1970
960145	Smith,J	09/01/1972
960150	Black,D	21/08/1973

- We now have two relations, Student and Record.
    - Student contains the original non-repeating groups
    - Record has the original repeating groups and the matric_no

Student(matric_no, name, date_of_birth)
Record(matric_no, subject, grade)

Matric_no remains the key to the Student relation. It cannot be the complete key to the new Record relation - we end up with a compound primary key consisting of matric_no and subject. The matric_no is the link between the two tables - it will allow us to find out which subjects a student is studying . So in the Record relation, matric_no is the foreign key.

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This method has eliminated some of the anomalies. It does not always do so, it depends on the example chosen

- In this case we no longer have the insertion anomaly
    - It is now possible to enter new students without knowing the subjects that they will be studying
    - They will exist only in the Student table, and will not be entered in the Record table until they are studying at least one subject.
- We have also removed the deletion anomaly
    - If all of the `databases' subject records are removed, student 960145 still exists in the Student table.
- We have also removed the update anomaly

Student and Record are now in First Normal Form.

Second Normal Form

Second normal form (or 2NF) is a more stringent normal form defined as:

> A relation is in 2NF if, and only if, it is in 1NF and every non-key attribute is fully functionally dependent on the whole key.
>
> Thus the relation is in 1NF with no repeating groups, and all non-key attributes must depend on the whole key, not just some part of it. Another way of saying this is that there must be no partial key dependencies (PKDs).

The problems arise when there is a compound key, e.g. the key to the Record relation - matric_no, subject. In this case it is possible for non-key attributes to depend on only part of the key - i.e. on only one of the two key attributes. This is what 2NF tries to prevent.

Consider again the Student relation from the flattened Student #2 table:

```
Student(matric_no, name, date_of_birth,  subject, grade  )
```

- There are no repeating groups
- The relation is already in 1NF
- However, we have a compound primary key - so we must check all of the non-key attributes against each part of the key to ensure they are functionally dependent on it.
- matric_no determines name and date_of_birth, but not grade.
- subject together with matric_no determines grade, but not name or date_of_birth.
    - So there is a problem with potential redundancies

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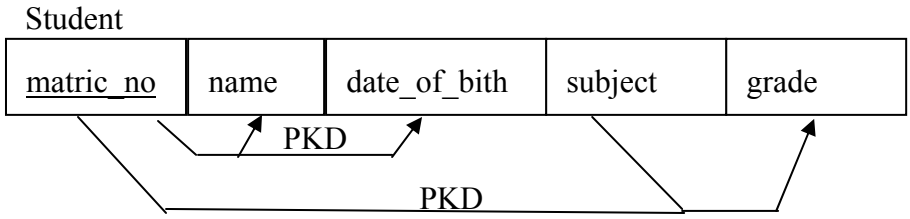
A dependency diagram is used to show how non-key attributes relate to each part or combination of parts in the primary key.



- This relation is not in 2NF
    - It appears to be two tables squashed into one.
    - the solutions is to split the relation up into its component parts.
- separate out all the attributes that are solely dependent on matric_no
    - put them in a new Student_details relation, with matric_no as the primary key
- separate out all the attributes that are solely dependent on subject.
    - in this case no attributes are solely dependent on subject.
- separate out all the attributes that are solely dependent on matric_no + subject
    - put them into a separate Student relation, keyed on matric_no + subject

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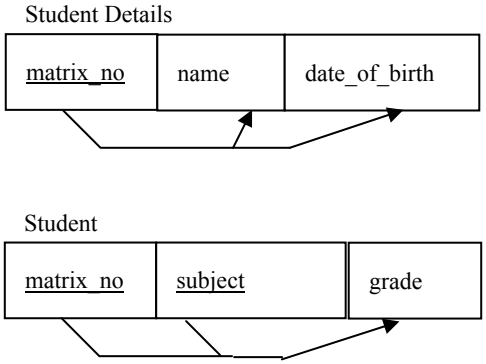

All attributes in each relation are fully functionally dependent upon its primary key

These relations are now in 2NF

Interestingly this is the same set of relations as when we recognized that there were repeating terms in the table and directly removed the repeating terms. It should not really matter what process you followed when normalizing, as the end result should be similar relations.

Third Normal Form

3NF is an even stricter normal form and removes virtually all the redundant data :

- A relation is in 3NF if, and only if, it is in 2NF and there are no transitive functional dependencies
- Transitive functional dependencies arise:
    - when one non-key attribute is functionally dependent on another non-key attribute:
        - FD: non-key attribute -> non-key attribute
    - and when there is redundancy in the database

By definition transitive functional dependency can only occur if there is more than one non-key field, so we can say that a relation in 2NF with zero or one non-key field must automatically be in 3NF.

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project_no	manager	address
p1	Black,B	32 High Street
p2	Smith,J	11 New Street
p3	Black,B	32 High Street
p4	Black,B	32 High Street

Project has more than one non-key field so we must check for transitive dependency:

- address depends on the value in the manager column
- every time B Black is listed in the manager column, the address column has the value `32 High Street'. From this the relation and functional dependency can be implied as:

  Project(project_no, manager, address)

  manager -> address
- in this case address is transitively dependent on manager. Manager is the determinant - it determines the value of address. It is transitive functional dependency only if all attributes on the left of the "->" are not in the key but are all in the relation, and all attributes to the right of the "->" are not in the key with at least one actually being in the relation.
- Data redundancy arises from this
  - we duplicate address if a manager is in charge of more than one project
  - causes problems if we had to change the address- have to change several entries, and this could lead to errors.
- Eliminate transitive functional dependency by splitting the table
  - create two relations - one with the transitive dependency in it, and another for all of the remaining attributes.
  - split Project into Project and Manager.
- the determinant attribute becomes the primary key in the new relation
  - manager becomes the primary key to the Manager relation
- the original key is the primary key to the remaining non-transitive attributes
  - in this case, project_no remains the key to the new Projects table.

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Project

project_no	manager
p1	Black,B
p2	Smith,J
p3	Black,B
p4	Black,B

Manager

manager	address
Black,B	32 High Street
Smith,J	11 New Street

- Now we need to store the address only once
- If we need to know a manager's address we can look it up in the Manager relation
- The manager attribute is the link between the two tables, and in the Projects table it is now a foreign key.
- These relations are now in third normal form.

Summary: 1NF

- A relation is in 1NF if it contains no repeating groups
- To convert an unnormalised relation to 1NF either:
    - Flatten the table and change the primary key, or
    - Decompose the relation into smaller relations, one for the repeating groups and one for the non-repeating groups.
        - Remember to put the primary key from the original relation into both new relations.
        - This option is liable to give the best results.

Summary: 2NF

- A relation is in 2NF if it contains no repeating groups and no partial key functional dependencies

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- Rule: A relation in 1NF with a single key field must be in 2NF
- To convert a relation with partial functional dependencies to 2NF. create a set of new relations:
    - One relation for the attributes that are fully dependent upon the key.
    - One relation for each part of the key that has partially dependent attributes

Summary: 3NF

- A relation is in 3NF if it contains no repeating groups, no partial functional dependencies, and no transitive functional dependencies
    - To convert a relation with transitive functional dependencies to 3NF, remove the attributes involved in the transitive dependency and put them in a new relation
    - Rule: A relation in 2NF with only one non-key attribute must be in 3NF
    - In a normalised relation a non-key field must provide a fact about the key, the whole key and nothing but the key.
- Relations in 3NF are sufficient for most practical database design problems. However, 3NF does not guarantee that all anomalies have been removed.

Unit 3.2 - Normalisation 2

Unit 3.2 - Normalisation Continued

Overview

- normalise a relation to Boyce Codd Normal Form (BCNF)
- normalise a relation to forth normal form (4NF)
- normalise a relation to fifth normal form (5NF)

Boyce-Codd Normal Form (BCNF)

- When a relation has more than one candidate key, anomalies may result even though the relation is in 3NF.
- 3NF does not deal satisfactorily with the case of a relation with overlapping candidate keys
    - i.e. composite candidate keys with at least one attribute in common.

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- BCNF is based on the concept of a *determinant*.
    - A determinant is any attribute (simple or composite) on which some other attribute is fully functionally dependent.
- A relation is in BCNF is, and only if, every determinant is a candidate key.

Consider the following relation and determinants.

R(a,b,c,d)
a,c -> b,d
a,d -> b

Here, the first determinant suggests that the primary key of R could be changed from a,b to a,c. If this change was done all of the non-key attributes present in R could still be determined, and therefore this change is legal. However, the second determinant indicates that a,d determines b, but a,d could not be the key of R as a,d does not determine all of the non key attributes of R (it does not determine c). We would say that the first determinate is a candidate key, but the second determinant is not a candidate key, and thus this relation is not in BCNF (but is in 3rd normal form).

Normalisation to BCNF - Example 1

Patient No	Patient Name	Appointment Id	Time	Doctor
1	John	0	09:00	Zorro
2	Kerr	0	09:00	Killer
3	Adam	1	10:00	Zorro
4	Robert	0	13:00	Killer
5	Zane	1	14:00	Zorro

Lets consider the database extract shown above. This depicts a special dieting clinic where the each patient has 4 appointments. On the first they are weighed, the second they are exercised, the third their fat is removed by surgery, and on the fourth their mouth is stitched closed… Not all patients need all four appointments! If the Patient Name begins with a letter before "P" they get a morning appointment, otherwise they get an afternoon appointment. Appointment 1 is either 09:00 or 13:00, appointment 2 10:00 or 14:00, and so on. From this (hopefully) make-believe scenario we can extract the following determinants:

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DB(Patno,PatName,appNo,time,doctor)

Patno -> PatName
Patno,appNo -> Time,doctor
Time -> appNo

Now we have to decide what the primary key of DB is going to be. From the information we have, we could chose:

DB(Patno,PatName,appNo,time,doctor) (example 1a)

or

DB(Patno,PatName,appNo,time,doctor) (example 1b)

Example 1a - DB(Patno,PatName,appNo,time,doctor)

- 1NF Eliminate repeating groups.

  None:

  DB(Patno,PatName,appNo,time,doctor)

- 2NF Eliminate partial key dependencies

```
DB(Patno,appNo,time,doctor)
R1(Patno,PatName)
```

- 3NF Eliminate transitive dependencies

```
None: so just as 2NF
```

- BCNF Every determinant is a candidate key

  DB(Patno,appNo,time,doctor)
  R1(Patno,PatName)

  - Go through all determinates where ALL of the left hand attributes are present in a relation and at least ONE of the right hand attributes are also present in the relation.

    - Patno -> PatName
      Patno is present in DB, but not PatName, so not relevant.

    - Patno,appNo -> Time,doctor
      All LHS present, and time and doctor also present, so relevant. Is this a candidate key? Patno,appNo IS the key, so this is a candidate key. Thus this is OK for BCNF compliance.

    - Time -> appNo
      Time is present, and so is appNo, so relevant. Is this a candidate key. If it was then we could rewrite DB as:
      DB(Patno,appNo,time,doctor)
      This will not work, as you need both time and Patno together to form a

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unique key. Thus this determinate is not a candidate key, and therefore DB is not in BCNF. We need to fix this.

- BCNF: rewrite to
  DB(Patno,time,doctor)
  R1(Patno,PatName)
  R2(time,appNo)

  time is enough to work out the appointment number of a patient. Now BCNF is satisfied, and the final relations shown are in BCNF.

Example 1b - DB(Patno,PatName,appNo,time,doctor)

- 1NF Eliminate repeating groups.

  None:

  DB(Patno,PatName,appNo,time,doctor)

- 2NF Eliminate partial key dependencies

```
DB(Patno,time,doctor)
R1(Patno,PatName)
R2(time,appNo)
```

- 3NF Eliminate transitive dependencies

```
None: so just as 2NF
```

- BCNF Every determinant is a candidate key
  DB(Patno,appNo,time,doctor)
  R1(Patno,PatName)

  - Go through all determinates where ALL of the left hand attributes are present in a relation and at least ONE of the right hand attributes are also present in the relation.

    - Patno -> PatName
      Patno is present in DB, but not PatName, so not relevant.

    - Patno,appNo -> Time,doctor
      Not all LHS present, so not relevant.

    - Time -> appNo
      Time is present, and so is appNo, so relevant. Is this a candidate key. However, is the key and determinant for R2, so it is OK for BCNF.

  - BCNF: as 3NF
    DB(Patno,time,doctor)
    R1(Patno,PatName)
    R2(time,appNo)

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Summary - Example 1

This example has demonstrated three things:

1. BCNF is stronger than 3NF, relations that are in 3NF are not necessarily in BCNF
2. BCNF is needed in certain situations to obtain full understanding of the data model
3. there are several routes to take to arrive at the same set of relations in BCNF.
    - Unfortunately there are no rules as to which route will be the easiest one to take.

Example 2

```
Grade_report(StudNo,StudName,(Major,Adviser,
  (Course,Ctitle,InstrucName,InstructLocn,Grade)))
```

- Functional dependencies

```
StudNo -> StudName
CourseNo -> Ctitle,InstrucName
InstrucName -> InstrucLocn
StudNo,CourseNo,Major -> Grade
StudNo,Major -> Advisor
Advisor -> Major
```

- Unnormalised

```
Grade_report(StudNo,StudName,(Major,Adviser,
  (Course,Ctitle,InstrucName,InstructLocn,Grade)))
```

- 1NF Remove repeating groups

```
Student(StudNo,StudName)
StudMajor(StudNo,Major,Adviser)
StudCourse(StudNo,Major,Course,
   Ctitle,InstrucName,InstructLocn,Grade)
```

- 2NF Remove partial key dependencies

```
Student(StudNo,StudName)
StudMajor(StudNo,Major,Adviser)
StudCourse(StudNo,Major,Course,Grade)
Course(Course,Ctitle,InstrucName,InstructLocn)
```

- 3NF Remove transitive dependencies

```
Student(StudNo,StudName)
StudMajor(StudNo,Major,Adviser)
StudCourse(StudNo,Major,Course,Grade)
Course(Course,Ctitle,InstrucName)
Instructor(InstructName,InstructLocn)
```

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- BCNF Every determinant is a candidate key
    - Student : only determinant is StudNo
    - StudCourse: only determinant is StudNo,Major
    - Course: only determinant is Course
    - Instructor: only determinant is InstrucName
    - StudMajor: the determinants are
        - StudNo,Major, or
        - Adviser

      Only StudNo,Major is a candidate key.
- BCNF

```
Student(StudNo,StudName)
StudCourse(StudNo,Major,Course,Grade)
Course(Course,Ctitle,InstrucName)
Instructor(InstructName,InstructLocn)
StudMajor(StudNo,Adviser)
Adviser(Adviser,Major)
```

Problems BCNF overcomes

STUDENT	MAJOR	ADVISOR
123	PHYSICS	EINSTEIN
123	MUSIC	MOZART
456	BIOLOGY	DARWIN
789	PHYSICS	BOHR
999	PHYSICS	EINSTEIN

- If the record for student 456 is deleted we lose not only information on student 456 but also the fact that DARWIN advises in BIOLOGY
- we cannot record the fact that WATSON can advise on COMPUTING until we have a student majoring in COMPUTING to whom we can assign WATSON as an advisor.

In BCNF we have two tables:

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STUDENT	ADVISOR
123	EINSTEIN
123	MOZART
456	DARWIN
789	BOHR
999	EINSTEIN

ADVISOR	MAJOR
EINSTEIN	PHYSICS
MOZART	MUSIC
DARWIN	BIOLOGY
BOHR	PHYSICS

Fourth Normal Form

Under 4NF, a record type should not contain two or more independent multi-valued facts about an entity. Note that 4NF and 5NF are not examinable, and are shown here for completeness. They should never occur using the approaches you have been taught in this module, but can occur if you were taking over a database project where poor design techniques were involved or where redundancy was deliberately introduced for some reason.

- A relation is in 4NF if it is in BCNF and it contains no multi-valued dependencies.
- A multi-valued fact may correspond to a many-many relationship or to a many-one relationship.
- A multi-valued dependency exists when there are three attributes (e.g. A,B, and C) in a relation, and for each value of A there is a well-defined set of valued B and a well defined set of values C. However, the set of values of B is independent of set C and vice-versa.

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Example

- Consider information stored about movie stars. It includes details of their various addresses and the movies they starred in:
    - Name - Address
    - Name - Movie

Name	Street	City	Title	Year
C. Fisher	123 Maple St.	Hollywood	Star Wars	1977
C. Fisher	5 Locust Ln.	Malibu	Star Wars	1977
C. Fisher	123 Maple St.	Hollywood	Empire Strikes Back	1980
C. Fisher	5 Locust Ln.	Malibu	Empire Strikes Back	1980
C. Fisher	123 Maple St.	Hollywood	Return of the Jedi	1983
C. Fisher	5 Locust Ln.	Malibu	Return of the Jedi	1983

- Carrie Fisher has two addresses and has been in three movies
- The only way to express the fact that addresses and movies are independent is to have each address appear with each movie
    - but this has introduced redundancy
- There is no BCNF violation
    - But the relation is not in 4NF
    - We need to break it up into 2 tables

Name	Street	City
C. Fisher	123 Maple St.	Hollywood
C. Fisher	5 Locust Ln.	Malibu

Name	Title	Year
C.Fisher	Star Wars	1977

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C.Fisher	Empire Strikes Back	1980
C.Fisher	Return of the Jedi	1983

Fifth Normal Form

5NF is designed to cope with a type of dependency called join dependency

- A relation that has a join dependency cannot be decomposed by a projection into other relations without spurious results
- a relation is in 5NF when its information content cannot be reconstructed from several smaller relations
    - i.e. from relations having fewer attributes than the original relation

Join Dependency Decomposition

Name	Language	Hobby
C. Fisher	French	Cooks
C. Fisher	Spanish	Cooks
C. Fisher	English	Writes
M. Brown	Spanish	Read
M. Brown	Italian	Cook
K. Clark	Italian	Cook
K. Clark	Japanese	Decorating

Name	Language
C. Fisher	French
C. Fisher	Spanish
C. Fisher	English
M. Brown	Spanish
M. Brown	Italian
K. Clark	Italian
K. Clark	Japanese

Name	Hobby
C. Fisher	Cooks
C. Fisher	Writes
M. Brown	Read
M. Brown	Cook
K. Clark	Cook
K. Clark	Decorating

Spurious results

Name	Language	Hobby
C. Fisher	French	Cooks
C. Fisher	French	Writes
C. Fisher	Spanish	Cooks
C. Fisher	Spanish	Writes
C. Fisher	English	Cooks
C. Fisher	English	Writes

Name	Language	Hobby
M. Brown	Spanish	Cook
M. Brown	Italian	Read
M. Brown	Italian	Cook
K. Clark	Italian	Cook
K. Clark	Italian	Decorating
K. Clark	Japanese	Cook

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M. Brown	Spanish	Read

K. Clark	Japanese	Decorating

Returning to the ER Model

- Now that we have reached the end of the normalisation process, you must go back and compare the resulting relations with the original ER model
    - You may need to alter it to take account of the changes that have occurred during the normalisation process Your ER diagram should always be a prefect reflection of the model you are going to implement in the database, so keep it up to date!
    - The changes required depends on how good the ER model was at first!

Unit 3.3 - Relational Algebra 1

Unit 3.3 - Relational Algebra

In order to implement a DBMS, there must exist a set of rules which state how the database system will behave. For instance, somewhere in the DBMS must be a set of statements which indicate than when someone inserts data into a row of a relation, it has the effect which the user expects. One way to specify this is to use words to write an `essay' as to how the DBMS will operate, but words tend to be imprecise and open to interpretation. Instead, relational databases are more usually defined using Relational Algebra.

Relational Algebra is :

- the formal description of how a relational database operates
- an interface to the data stored in the database itself
- the mathematics which underpin SQL operations

Operators in relational algebra are not necessarily the same as SQL operators, even if they have the same name. For example, the SELECT statement exists in SQL, and also exists in relational algebra. These two uses of SELECT are not the same. The DBMS must take whatever SQL statements the user types in and translate them into relational algebra operations before applying them to the database.

Terminology

- Relation - a set of tuples.

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- Tuple - a collection of attributes which describe some real world entity.
- Attribute - a real world role played by a named domain.
- Domain - a set of atomic values.
- Set - a mathematical definition for a collection of objects which contains no duplicates.

Operators - Write

- INSERT - provides a list of attribute values for a new tuple in a relation. This operator is the same as SQL.
- DELETE - provides a condition on the attributes of a relation to determine which tuple(s) to remove from the relation. This operator is the same as SQL.
- MODIFY - changes the values of one or more attributes in one or more tuples of a relation, as identified by a condition operating on the attributes of the relation. This is equivalent to SQL UPDATE.

Operators - Retrieval

There are two groups of operations:

- Mathematical set theory based relations:
  UNION, INTERSECTION, DIFFERENCE, and CARTESIAN PRODUCT.
- Special database operations:
  SELECT (not the same as SQL SELECT), PROJECT, and JOIN.

Relational SELECT

SELECT is used to obtain a subset of the tuples of a relation that satisfy a *select condition*.

For example, find all employees born after 1st Jan 1950:

$$SELECT_{dob\ '01/JAN/1950'}(employee)$$

Relational PROJECT

The PROJECT operation is used to select a subset of the attributes of a relation by specifying the names of the required attributes.

For example, to get a list of all employees surnames and employee numbers:

$$PROJECT_{surname,empno}(employee)$$

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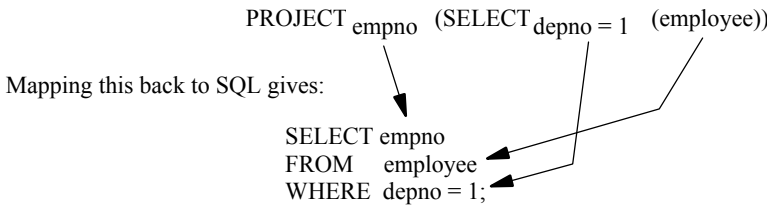
SELECT and PROJECT

SELECT and PROJECT can be combined together. For example, to get a list of employee numbers for employees in department number 1:



Set Operations - semantics

Consider two relations R and S.

- UNION of R and S
  the union of two relations is a relation that includes all the tuples that are either in R or in S or in both R and S. Duplicate tuples are eliminated.
- INTERSECTION of R and S
  the intersection of R and S is a relation that includes all tuples that are both in R and S.
- DIFFERENCE of R and S
  the difference of R and S is the relation that contains all the tuples that are in R but that are not in S.

SET Operations - requirements

For set operations to function correctly the relations R and S must be union compatible. Two relations are union compatible if

- they have the same number of attributes
- the domain of each attribute in column order is the same in both R and S.

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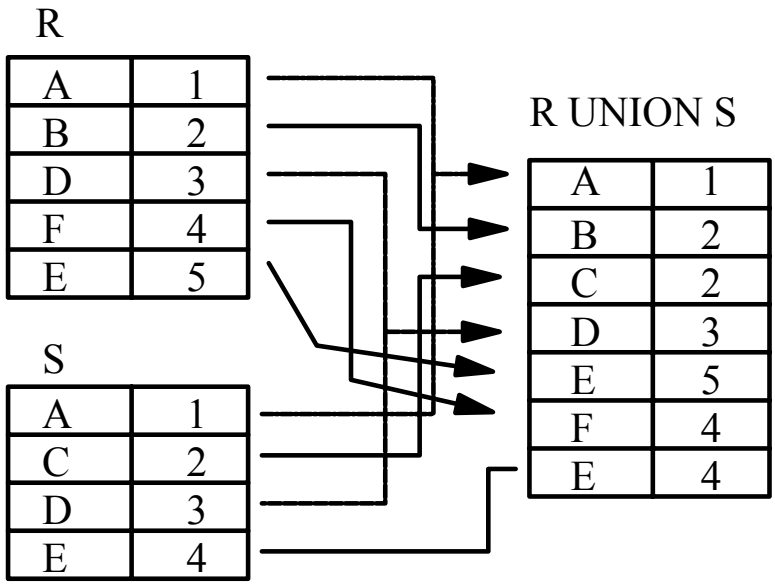
UNION Example



INTERSECTION Example

R

A	1
B	2
D	3
F	4
E	5

S

A	1
C	2
D	3
E	4

R |NTERSECTION S

A	1
D	3

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DIFFERENCE Example

R

A	1
B	2
D	3
F	4
E	5

S

A	1
C	2
D	3
E	4

R DIFFERENCE S

B	2
F	4
E	5

S DIFFERENCE R

C	2
E	4

CARTESIAN PRODUCT

The Cartesian Product is also an operator which works on two sets. It is sometimes called the CROSS PRODUCT or CROSS JOIN.

It combines the tuples of one relation with all the tuples of the other relation.

CARTESIAN PRODUCT example

R

A	1
B	2
D	3
F	4
E	5

S

A	1
C	2
D	3
E	4

R CROSS S

A	1	A	1
A	1	C	2
A	1	D	3
A	1	E	4
B	2	A	1
B	2	C	2
B	2	D	3
B	2	E	4
D	3	A	1
D	3	C	2
D	3	D	3
D	3	E	4

F	4	A	1
F	4	C	2
F	4	D	3
F	4	E	4
E	5	A	1
E	5	C	2
E	5	D	3
E	5	E	4

JOIN Operator

JOIN is used to combine related tuples from two relations:

- In its simplest form the JOIN operator is just the cross product of the two relations.
- As the join becomes more complex, tuples are removed within the cross product to make the result of the join more meaningful.
- JOIN allows you to evaluate a join condition between the attributes of the relations on which the join is undertaken.

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The notation used is

```
R JOIN(join condition) S
```

JOIN Example

R

ColA	*ColB*
A	1
B	2
D	3
F	4
E	5

S

SColA	*SColB*
A	1
C	2
D	3
E	4

R JOIN$_{R.ColA = S.SColA}$ S

A	1	A	1
D	3	D	3
E	5	E	4

R JOIN$_{R.ColB = S.SColB}$ S

A	1	A	1
B	2	C	2
D	3	D	3
F	4	E	4

Natural Join

Invariably the JOIN involves an equality test, and thus is often described as an equi-join. Such joins result in two attributes in the resulting relation having exactly the same value. A `natural join' will remove the duplicate attribute(s).

- In most systems a natural join will require that the attributes have the same name to identify the attribute(s) to be used in the join. This may require a renaming mechanism.
- If you do use natural joins make sure that the relations do not have two attributes with the same name by accident.

OUTER JOINs

Notice that much of the data is lost when applying a join to two relations. In some cases this lost data might hold useful information. An outer join retains the information that would have been lost from the tables, replacing missing data with nulls.

There are three forms of the outer join, depending on which data is to be kept.

- LEFT OUTER JOIN - keep data from the left-hand table
- RIGHT OUTER JOIN - keep data from the right-hand table
- FULL OUTER JOIN - keep data from both tables

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OUTER JOIN example 1

R

ColA	*ColB*
A	1
B	2
D	3
F	4
E	5

S

SColA	*SColB*
A	1
C	2
D	3
E	4

R LEFT OUTER JOIN $_{\text{R.ColA = S.SColA}}$ S

A	1	A	1
D	3	D	3
E	5	E	4
B	2	-	-
F	4	-	-

R RIGHT OUTER JOIN $_{\text{R.ColA = S.SColA}}$ S

A	1	A	1
D	3	D	3
E	5	E	4
-	-	C	2

OUTER JOIN example 2

R

ColA	*ColB*
A	1
B	2
D	3
F	4
E	5

S

SColA	*SColB*
A	1
C	2
D	3
E	4

R FULL OUTER JOIN $_{\text{R.ColA = S.SColA}}$ S

A	1	A	1
D	3	D	3
E	5	E	4
B	2	-	-
F	4	-	-
-	-	C	2

Unit 3.4 - Relational Algebra 2

Unit 3.4 - Relational Algebra - Example

Consider the following SQL to find which departments have had employees on the `Further Accounting' course.

```
SELECT DISTINCT dname
FROM   department, course, empcourse, employee
WHERE  cname = `Further Accounting'
  AND  course.courseno = empcourse.courseno
  AND  empcourse.empno = employee.empno
  AND  employee.depno  = department.depno;
```

The equivalent relational algebra is

$$\text{PROJECT}_{\text{dname}}\ (\text{department JOIN}_{\text{depno = depno}}\ (\text{PROJECT}_{\text{depno}}\ (\text{employee JOIN}_{\text{empno = empno}}\ ($$

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```
   PROJECT empno (empcourse JOIN courseno = courseno (
    PROJECT courseno (SELECT cname = `Further Accounting' course)
   ))
  ))
 ))
```

Symbolic Notation

From the example, one can see that for complicated cases a large amount of the answer is formed from operator names, such as PROJECT and JOIN. It is therefore commonplace to use symbolic notation to represent the operators.

- SELECT ->σ (sigma)
- PROJECT -> π(pi)
- PRODUCT -> ×(times)
- JOIN -> |x| (bow-tie)
- UNION -> ∪(cup)
- INTERSECTION -> ∩(cap)
- DIFFERENCE -> - (minus)
- RENAME ->ρ (rho)

Usage

The symbolic operators are used as with the verbal ones. So, to find all employees in department 1:

```
SELECT depno = 1 (employee)
becomes σ depno = 1 (employee)
```

Conditions can be combined together using ^ (AND) and v (OR). For example, all employees in department 1 called `Smith':

```
SELECT depno = 1 ^ surname = `Smith' (employee)
becomes σ depno = 1 ^ surname = `Smith' (employee)
```

The use of the symbolic notation can lend itself to brevity. Even better, when the JOIN is a natural join, the JOIN condition may be omitted from |x|. The earlier example resulted in:

```
PROJECT dname (department JOIN depno = depno (
 PROJECT depno (employee JOIN empno = empno (
  PROJECT empno (empcourse JOIN courseno = courseno (
   PROJECT courseno (SELECT cname = `Further Accounting' course)))))))
```

becomes

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```
πdname (department |x| (
  πdepno (employee |x| (
    πempno (empcourse |x| (
      πcourseno (σcname = `Further Accounting' course) ))))))
```

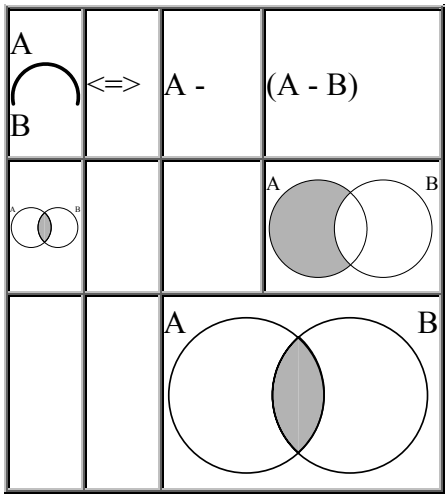
Rename Operator

The rename operator returns an existing relation under a new name. $\sigma_A(B)$ is the relation B with its name changed to A. For example, find the employees in the same Department as employee 3.

```
πemp2.surname,emp2.forenames (
 σemployee.empno = 3 ^ employee.depno = emp2.depno (
    employee × (ρemp2employee)
 )
)
```

Derivable Operators

- Fundamental operators:σ, π, ×, ∪, -, ρ
- Derivable operators: |x|,∩



Equivalence

$A|x|_cB \iff \pi_{a1,a2,...aN}(\sigma_c(A \times B))$

- where c is the join condition (eg A.a1 = B.a1),
- and a1,a2,...aN are all the attributes of A and B without repetition.

c is called the join-condition, and is usually the comparison of primary and foreign key. Where there are N tables, there are usually N-1 join-conditions. In the case of a natural join, the conditions can be missed out, but otherwise missing out conditions results in a cartesian product (a common mistake to make).

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Equivalences

The same relational algebraic expression can be written in many different ways. The order in which tuples appear in relations is never significant.

- $A \times B \Leftrightarrow B \times A$
- $A \cap B \Leftrightarrow B \cap A$
- $A \cup B \Leftrightarrow B \cup A$
- (A - B) is not the same as (B - A)
- $\sigma_{c1}(\sigma_{c2}(A)) \Leftrightarrow \sigma_{c2}(\sigma_{c1}(A)) \Leftrightarrow \sigma_{c1 \wedge c2}(A)$
- $\pi_{a1}(A) \Leftrightarrow \pi_{a1}(\pi_{a1,etc}(A))$
  where etc represents any other attributes of A.
- many other equivalences exist.

While equivalent expressions always give the same result, some may be much easier to evaluate that others.

When any query is submitted to the DBMS, its query optimiser tries to find the most efficient equivalent expression before evaluating it.

Comparing RA and SQL

- Relational algebra:
  - is closed (the result of every expression is a relation)
  - has a rigorous foundation
  - has simple semantics
  - is used for reasoning, query optimisation, etc.
- SQL:
  - is a superset of relational algebra
  - has convenient formatting features, etc.
  - provides aggregate functions
  - has complicated semantics
  - is an end-user language.

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Comparing RA and SQL

Any relational language as powerful as relational algebra is called relationally complete.

A relationally complete language can perform all basic, meaningful operations on relations.

Since SQL is a superset of relational algebra, it is also relationally complete.

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Unit 4.1 - Transactions

Unit 4.1 - Concurrency using Transactions

The goal in a `concurrent' DBMS is to allow multiple users to access the database simultaneously without interfering with each other.

A problem with multiple users using the DBMS is that it may be possible for two users to try and change data in the database simultaneously. If this type of action is not carefully controlled, inconsistencies are possible.

To control data access, we first need a concept to allow us to encapsulate database accesses. Such encapsulation is called a `Transaction'.

Transactions

- Transaction (ACID)
  - unit of logical work and recovery
  - atomicity (for integrity)
  - consistency preservation
  - isolation
  - durability
- Available in SQL
- Some applications require nested or long transactions

After work is performed in a transaction, two outcomes are possible:

- Commit - Any changes made during the transaction by this transaction are committed to the database.
- Abort - All the changes made during the transaction by this transaction are not made to the database. The result of this is as if the transaction was never started.

Transaction Schedules

A transaction schedule is a tabular representation of how a set of transactions were executed over time. This is useful when examining problem scenarios. Within the diagrams various nomenclatures are used:

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- READ(*a*) - This is a read action on an attribute or data item called `a'.
- WRITE(*a*) - This is a write action on an attribute or data item called `a'.
- WRITE(*a*[*x*]) - This is a write action on an attribute or data item called `a', where the value `x' is written into `a'.
- tn (e.g. t1,t2,t10) - This indicates the time at which something occurred. The units are not important, but t*n* always occurs before t*n+1*.

Consider transaction A, which loads in a bank account balance X (initially 20) and adds 10 pounds to it. Such a schedule would look like this:

Time	Transaction A
t1	TOTAL:=READ(X)
t2	TOTAL:=TOTAL+10
t3	WRITE(X[30])

Now consider that, at the same time as transaction A runs, transaction B runs. Transaction B gives all accounts a 10% increase. Will X be 32 or 33?

Time	Transaction A	Transaction B
t1		TOTAL:=READ(X)
t2	TOTAL:=READ(X)	
t3	TOTAL:=TOTAL+10	
t4	WRITE(X[30])	
t5		TOTAL:=TOTAL*110%
t6		WRITE(X[22])

Whoops... X is 22! Depending on the interleaving, X can also be 32, 33, or 30. Lets classify erroneous scenarios.

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Lost Update scenario.

Time	Transaction A	Transaction B
t1	READ(R)	
t2		READ(R)
t3	WRITE(R)	
t4		WRITE(R)

Transaction A's update is lost at t4, because Transaction B overwrites it. B missed A's update at t3 as it got the value of R at t2.

Uncommitted Dependency

Time	Transaction A	Transaction B
t1		WRITE(R)
t2	READ(R)	
t3		ABORT

Transaction A is allowed to READ (or WRITE) item R which has been updated by another transaction but not committed (and in this case ABORTed).

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Inconsistency

Time	X	Y	Z	Transaction A		Transaction B
				Action	SUM	
t1	40	50	30	SUM:=READ(X)	40	
t2	40	50	30	SUM+=READ(Y)	90	
t3	40	50	30			READ(Z)
t4	40	50	20			WRITE(Z[20])
t5	40	50	20			READ(X)
t6	50	50	20			WRITE(X[50])
t7	50	50	20			COMMIT
t7	50	50	20	SUM+=READ(Z)	110	
				SUM should have been 120...		

Serialisability

- A `schedule' is the actual execution sequence of two or more concurrent transactions.
- A schedule of two transactions T1 and T2 is `serialisable' if and only if executing this schedule has the same effect as either T1;T2 or T2;T1.

Precedence Graph

In order to know that a particular transaction schedule can be serialized, we can draw a precedence graph. This is a graph of nodes and vertices, where the nodes are the transaction names and the vertices are attribute collisions. To draw one;

The schedule is said to be serialised if and only if there are no cycles in the resulting diagram.

Precedence Graph : Method

To draw one;

1. Draw a node for each transaction in the schedule
2. Where transaction A writes to an attribute which transaction B has read from, draw an line pointing from B to A.

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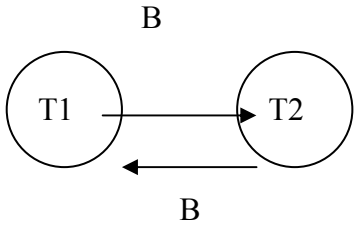
3. Where transaction A writes to an attribute which transaction B has written to, draw a line pointing from B to A.

4. Where transaction A reads from an attribute which transaction B has written to, draw a line pointing from B to A.

Example 1

Consider the following schedule:

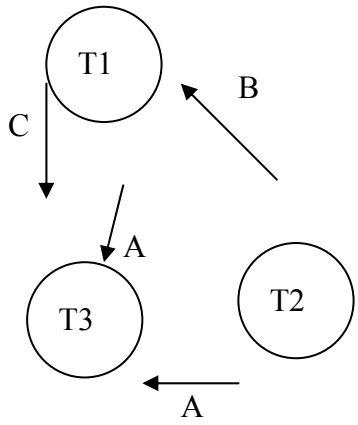
T1	time	T2
read(A)	t1	
read(B)	t2	
	t3	read(A)
	t4	read(B)
	t5	
write(B)	t6	
	t7	write(B)



Example 2

Consider the following schedule:

T1	time	T2	T3
read(A)	t1		
read(B)	t2		
	t3	read(A)	
	t4	read(B)	
write(C)	t5		
	t6		write(A)
write(B)	t7		
	t8		write(C)



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Unit 4.2 - Concurrency

Unit 4.2 - Concurrency

Locking

A solution to enforcing serialisability?

- read (shareable) lock
- write (exclusive) lock
- coarse granularity
    - easier processing
    - less concurrency
- fine granularity
    - more processing
    - higher concurrency

Many systems use locking mechanisms for concurrency control. When a transaction needs an assurance that some object will not change in some unpredictable manner, it acquires a lock on that object.

- A transaction holding a read lock is permitted to read an object but not to change it.
- More than one transaction can hold a read lock for the same object.
- Usually, only one transaction may hold a write lock on an object.
- On a transaction schedule, we use `S' to indicate a shared lock, and `X' for an exclusive write lock.

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Locking - Uncommitted Dependency

Locking solves the uncommitted dependency problem.

Time	Transaction A	Transaction B	Lock on R
t1		WRITE(R)	- = X
t2	READ R (WAIT)		X
t3	...wait...	ABORT	X = -
t4	READ R (CONT)		- = S

Deadlock

Deadlock can arise when locks are used, and causes all related transactions to WAIT forever...

time	Transaction A	Transaction B	Lock State	
			X	**Y**
t1	WRITE(X)		- = X	-
t2		WRITE(Y)	X	- = X
t3	READ(Y) (WAIT)		X	X
t3	...WAIT...	READ(X) (WAIT)	X	X
t3	...WAIT...	...WAIT...	X	X

The `lost update' senario results in deadlock with locks. So does the `inconsistency' scenario.

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time	Transaction A	Transaction B	Lock R
t1	READ(R)		- = S
t2		READ(R)	S = S
t3	WRITE(R) (WAIT)		S
t3	...wait...	WRITE(R) (WAIT)	S
t3	...wait...	...wait...	S

Deadlock Handling

- Deadlock avoidance
  - pre-claim strategy used in operating systems
  - not effective in database environments.
- Deadlock detection
  - whenever a lock requests a wait, or on some perodic basis.
  - if a transaction is blocked due to another transaction, make sure that that transaction is not blocked on the first transaction, either directly or indirectly via another transaction.

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Deadlock Resolution

If a set of transactions is considered to be deadlocked:

1. choose a victim (e.g. the shortest-lived transaction)
2. rollback `victim' transaction and restart it.
    - The rollback terminates the transaction, undoing all its updates and releasing all of its locks.
    - A message is passed to the victim and depending on the system the transaction may or may not be started again automatically.

Two-Phase Locking

The presence of locks does not guarantee serialisability. If a transaction is allowed to release locks before the transaction has completed, and is also allowed to acquire more (or even the same) locks later then the benifit or locking is lost.

If all transactions obey the `two-phase locking protocol', then all possible interleaved executions are guarenteed serialisable.

The two-phase locking protocol:

- Before operating on any item, a transaction must acquire at least a shared lock on that item. Thus no item can be accessed without first obtaining the correct lock.
- After releasing a lock, a transaction must never go on to acquire any more locks.

The technical names for the two phases of the locking protocol are the `lock-acquisition phase' and the `lock-release phase'.

Other Database Consistency Methods

Two-phase locking is not the only approach to enforcing database consistency. Another method used in some DMBS is timestamping. With timestamping, there are no locks to prevent transactions seeing uncommitted changes, and all physical updates are deferred to commit time.

- locking synchronises the interleaved execution of a set of transactions in such a way that it is equivalent to some serial execution of those transactions.
- timestamping synchronises that interleaved execution in such a way that it is equivalent to a particular serial order - the order of the timestamps.

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Timestamping rules

The following rules are checked when transaction T attempts to change a data item. If the rule indicates ABORT, then transaction T is rolled back and aborted (and perhaps restarted).

- If T attempts to read a data item which has already been written to by a younger transaction then ABORT T.
- If T attempts to write a data item which has been seen or written to by a younger transaction then ABORT T.

If transaction T aborts, then all other transactions which have seen a data item written to by T must also abort. In addition, other aborting transactions can cause further aborts on other transactions. This is a `cascading rollback'.

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Unit 4.3 - Storage Structures

Unit 4.3 – Storage Structures

The Physical Store

Storage Medium	Transfer Rate	Capacity	Seek Time
Main Memory	800 MB/s	100 MB	Instant
Hard Drive	10 MB/s	10 GB	10 ms
CD-ROM Drive	5 MB/s	0.6 GB	100 ms
Floppy Drive	2 MB/s	1.44 MB	300 ms
Tape Drive	1 MB/s	20 GB	30 s

Why not all Main Memory?

The performance of main memory is the greatest of all storage methods, but it is also the most expensive per MB.

- All the other types of storage are `persistent'. A persistent store keeps the data stored on it even when the power is switched off.
- Only main memory can be directly accessed by the programmer. Data held using other methods must be loaded into main memory before being accessed, and must be transferred back to storage from main memory in order to save the changes.
- We tend to refer to storage methods which are not main memory as `secondary storage'.

Secondary Storage - Blocks

All storage devices have a block size. Block size is the minimum amount which can be read or written to on a storage device. Main memory can have a block size of 1-8 bytes, depending on the processor being used. Secondary storage blocks are usually much bigger.

- Hard Drive disk blocks are usually 4 KBytes in size.
- For efficiency, multiple contiguous blocks can be be requested.
- On average, to access a block you first have to request it, wait the seek time, and

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then wait the transfer time of the blocks requested.

- Remember, you cannot read or write data smaller than a single block.

Hard Drives

The most common secondary storage medium for DBMS is the hard drive.

- Data on a hard-drive is often arranged into files by the Operating System.
- the DBMS holds the database within one or more files.
- The data is arranged within a file in blocks, and the position of a block within a file is controlled by the DBMS.
- Files are stored on the disk in blocks, but the placement of a file block on the disk is controlled by the O/S (although the DBMS may be allowed to `hint' to the O/S concerning disk block placement strategies).
- File blocks and disk blocks are not necessarily equal in size.

DBMS Data Items

Data from the DBMS is split into records.

- a record is a logical collection of data items
- a file is a collection of records.
- one or more records may map onto a single or multiple file blocks.
- a single record may map onto multiple file blocks.

Comparing terminology...

Relational	SQL	Physical Storage
Relation	Table	File
Tuple	Row	Record
Attribute	Column	Data Item/Field
Domain	Type	Data Type

File Organisations

- Serial (or unordered, or heap) - records are written to secondary storage in the order in which they are created.

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- Sequential (or sorted, or ordered) - records are written to secondary storage in the sorted order of a key (one or more data items) from each record.
- Hash - A `hash' function is applied to each record key, which returns a number used to indicate the position of the record in the file. The hash function must be used for both reading and writing.
- Indexed - the location in secondary storage of some (partial index) or all (full index) records is noted in an index.

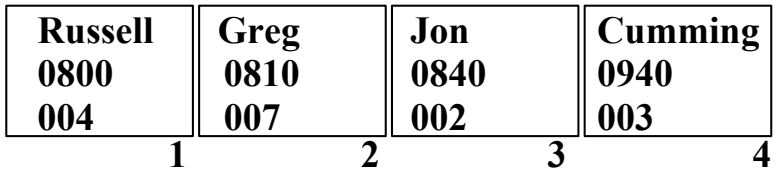
Storage Scenario

To better explain each of these file organisations we will create 4 records and place them in secondary storage. The records are created by a security guard, and records who passes his desk in the morning and at what time they pass.

The records therefore each have three data items; `name', `time', and `id number'. Only four people arrive for work:

1. name=`Russell' at time=`0800' with id_number=`004'.
2. name=`Greg' at time=`0810' with id_number=`007'.
3. name=`Jon' at time=`0840' with id_number=`002'.
4. name=`Cumming' at time=`0940' with id_number=`003'.

Serial Organisation



- Writing - the data is written at the end of the previous record.
- Reading -
  - reading records in the order they were written is a cheap operation.
  - Trying to find a particular record means you have to read each record in turn until you locate it. This is expensive.
- Deleting - Deleting data in such an structure usually means marking the data as deleted (thus not actually removing it) which is cheap but wasteful or rewriting the whole file to overwrite the deleted record (space-efficient but expensive).

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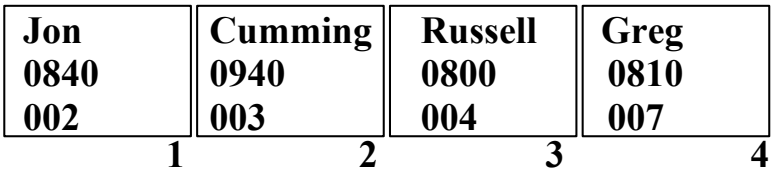
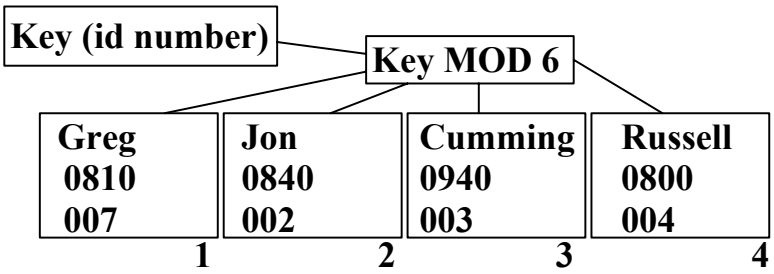
Sequential Organisation



- Writing - records are in `id number' order, thus new records may need to be inserted into the store needing a complete file copy (expensive).
- Deleting - as with serial, either leave holes or perform make file copies.
- Reading -
  - reading records in `id number' order is cheap.
  - the ability to chose sort order makes this more useful than serial.
  - `binary search' could be used. Goto middle of file - if record key greater than that wanted search the low half, else search the high half, until the record is found. (average accesses to find something is $\log_2$no_of_records.)

Hash Organisation



- Writing - Initially the file has 6 spaces (n MOD 6 can be 0-5). To write, calculate the hash and write the record in that location (cheap).
- Deleting - leave holes by marking the record deleted (wasteful of space but cheap to process).
- Reading -
  - reading records an order is expensive.
  - finding a particular record from a key is cheap and easy.
  - If two records can result in the same hash number, then a strategy must be found to solve this problem (which will incur overheads).

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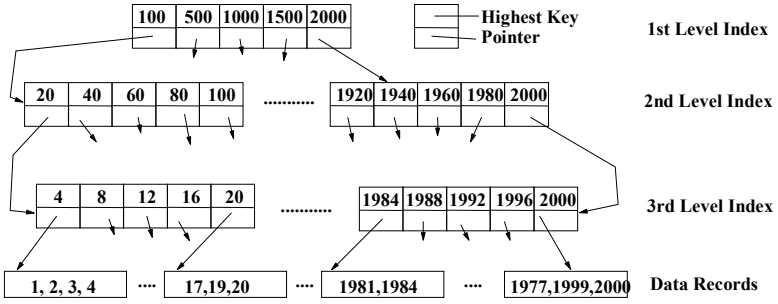
Indexed Sequential Access Method

The Indexed Sequential Access Method (ISAM) is frequently used for partial indexes.

- there may be several levels of indexes, commonly 3
- each index-entry is equal to the highest key of the records or indices it points to.
- the records of the file are effectively sorted and broken down into small groups of data records.
- the indices are built when the data is first loaded as sorted records.
- the index is static, and does not change as records are inserted and deleted
- insertion and deletion adds to one of the small groups of data records. As the number in each group changes, the performance may deteriorate.

ISAM Example



B+ Tree Index

With B+ tree, a full index is maintained, allowing the ordering of the records in the file to be independent of the index. This allows multiple B+ tree indices to be kept for the same set of data records.

- the lowest level in the index has one entry for each data record.
- the index is created dynamically as data is added to the file.
- as data is added the index is expanded such that each record requires the same number of index levels to reach it (thus the tree stays `balanced').
- the records can be accessed via an index or sequentially.

Each index node in a B+ Tree can hold a certain number of keys. The number of keys is often referred to as the `order'. Unfortunately, `Order 2' and `Order 1' are frequently confused in the database literature. For the purposes of our coursework and exam, `Order 2' means that there can be a maximum of 2 keys per index node. In this module, we only ever consider order 2 B+ trees.

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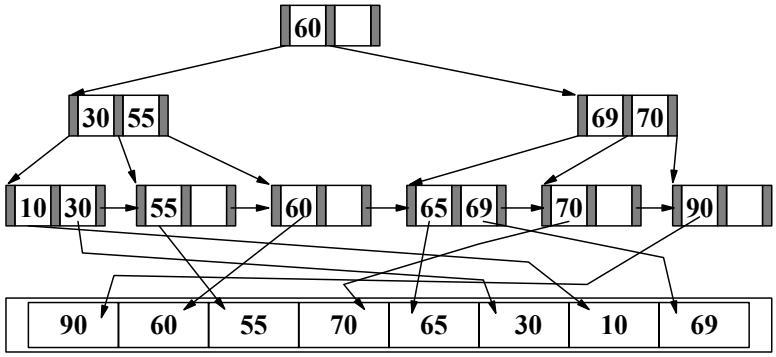
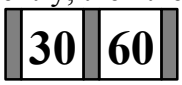
B+ Tree Example

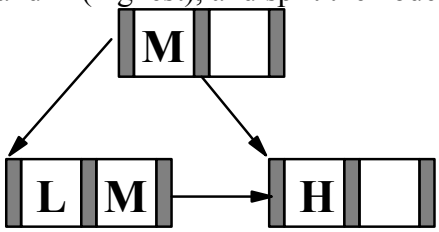


Building a B+ Tree

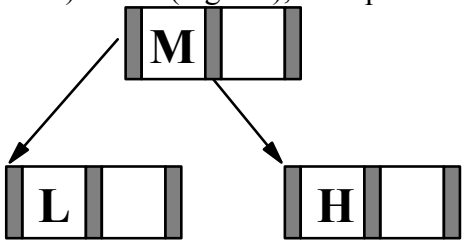
- Only nodes at the bottom of the tree point to records, and all other nodes point to other nodes. Nodes which point to records are called leaf nodes.
- If a node is empty the data is added on the left. 

- If a node has one entry, then the left takes the smallest valued key and the right takes the biggest. 

- If a node is full and is a leaf node, classify the keys L (lowest), M (middle value) and H (highest), and split the node.



- If a node is full and is not a leaf node, classify the keys L (lowest), M (middle value) and H (highest), and split the node.



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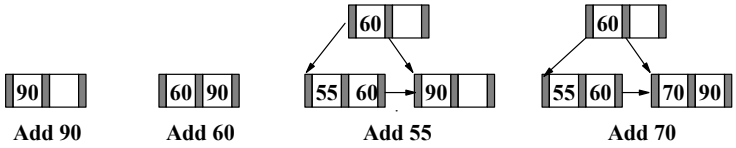
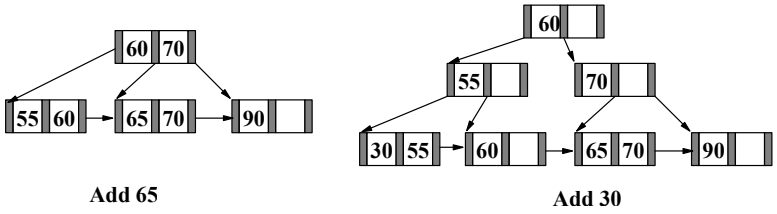
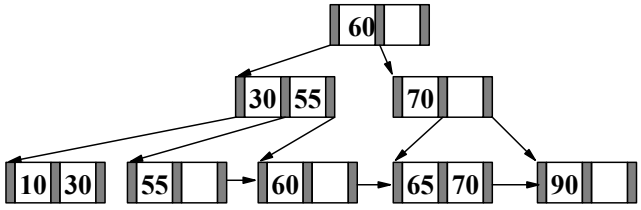
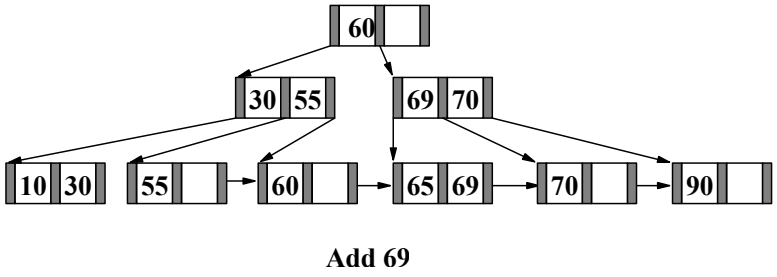
B+ Tree Build Example









Index Structure and Access

- The top level of an index is usually held in memory. It is read once from disk at the start of queries.
- Each index entry points to either another level of the index, a data record, or a block of data records.
- The top level of the index is searched to find the range within which the desired record lies.
- The appropriate part of the next level is read into memory from disc and searched.
- This continues until the required data is found.
- The use of indices reduce the amount of file which has to be searched.

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Costing Index and File Access

- The major cost of accessing an index is associated with reading in each of the intermediate levels of the index from a disk (milliseconds).
- Searching the index once it is in memory is comparatively inexpensive (microseconds).
- The major cost of accessing data records involves waiting for the media to recover the required blocks (milliseconds).
- Some indexes mix the index blocks with the data blocks, which means that disk accesses can be saved because the final level of the index is read into memory with the associated data records.

Use of Indexes

- A DBMS may use different file organisations for its own purposes.
- A DBMS user is generally given little choice of file type.
- A B+ Tree is likely to be used wherever an index is needed.
- Indexes are generated:
    - (Probably) for fields specified with `PRIMARY KEY' or `UNIQUE' constraints in a CREATE TABLE statement.
    - For fields specified in SQL statements such as CREATE [UNIQUE] INDEX indexname ON tablename (col [,col]...);
- Primary Indexes have unique keys.
- Secondary Indexes may have duplicates.
- An index on a column which is used in an SQL `WHERE' predicate is likely to speed up an enquiry.
    - this is particularly so when `=' is involved (equijoin)
    - no improvement will occur with `IS [NOT] NULL' statements
    - an index is best used on a column which widely varying data.
    - indexing and column of Y/N values might slow down enquiries.
    - an index on telephone numbers might be very good but an index on area code might be a poor performer.
- Multicolumn index can be used, and the column which has the biggest range of values or is the most frequently accessed should be listed first.

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- Avoid indexing small relations, frequently updated columns, or those with long strings.
- There may be several indexes on each table. Note that partial indexing normally supports only one index per table.
- Reading or updating a particular record should be fast.
- Inserting records should be reasonably fast. However, each index has to be updated too, so increasing the indexes makes this slower.
- Deletion may be slow.
    - particularly when indexes have to be updated.
    - deletion may be fast if records are simply flagged as `deleted'.

Unit 4.4 - Recovery

Unit 4.4 - Recovery

A database might be left in an inconsistent state when:

- deadlock has occurred.
- a transaction aborts after updating the database.
- software or hardware errors.
- incorrect updates have been applied to the database.

If the database is in an inconsistent state, it is necessary to recover to a consistent state. The basis of recovery is to have backups of the data in the database.

Recovery: the dump

The simplest backup technique is `the Dump'.

- entire contents of the database is backed up to an auxiliary store.
- must be performed when the state of the database is consistent - therefore no transactions which modify the database can be running
- dumping can take a long time to perform
- you need to store the data in the database twice.
- as dumping is expensive, it probably cannot be performed as often as one would

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like.

- a cut-down version can be used to take `snapshots' of the most volatile areas.

Recovery: the transaction log

A technique often used to perform recovery is the transaction log or journal.

- records information about the progress of transactions in a log since the last consistent state.
- the database therefore knows the state of the database before and after each transaction.
- every so often database is returned to a consistent state and the log may be truncated to remove committed transactions.
- when the database is returned to a consistent state the process is often referred to as `checkpointing'.

Deferred Update

Deferred update, or NO-UNDO/REDO, is an algorithm to support ABORT and machine failure scenarios.

- While a transaction runs, no changes made by that transaction are recorded in the database.
- On a commit:
    1. The new data is recorded in a log file and flushed to disk
    2. The new data is then recorded in the database itself.
- On an abort, do nothing (the database has not been changed).
- On a system restart after a failure, REDO the log.

Example

Consider the following transaction T1

Transaction T1

read(A)

write(B[10])

write(C[20])

Commit

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Using deferred update, the process is:

Transaction	Action	Data
T1	START	-
T2	read(A)	-
T3	write(B)	B = 10
T4	write(C)	C = 20
T5	COMMIT	-

Disk

Before		
		B=6
A=5	C=2	

After		
		B=10
A=5	C=20	

If the DMBS fails and is restarted:

1. The disks are physically or logically damaged then recovery from the log is impossible and instead a restore from a dump is needed.
2. If the disks are OK then the database consistency must be maintained. Writes to the disk which was in progress at the time of the failure may have only been partially done.
3. Parse the log file, and where a transaction has been ended with `COMMIT' apply the data part of the log to the database.
4. If a log entry for a transaction ends with anything other than COMMIT, do nothing for that transaction.
5. flush the data to the disk, and then truncate the log to zero.
6. the process or reapplying transaction from the log is sometimes referred to as `rollforward'.

Immediate Update

Immediate update, or UNDO/REDO, is another algorithm to support ABORT and machine failure scenarios.

- While a transaction runs, changes made by that transaction can be written to the database at any time. However, the original and the new data being written must both be stored in the log BEFORE storing it on the database disk.

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- On a commit:
    1. All the updates which has not yet been recorded on the disk is first stored in the log file and then flushed to disk.
    2. The new data is then recorded in the database itself.
- On an abort, REDO all the changes which that transaction has made to the database disk using the log entries.
- On a system restart after a failure, REDO committed changes from log.

Example

Using immediate update, and the transaction T1 again, the process is:

Transaction	Action	Old Data	New Data
T1	START	-	-
T2	read(A)	-	-
T3	write(B)	B == 6	B = 10
T4	write(C)	C == 2	C = 20
T5	COMMIT	-	-

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Disk

Before		
		B=6
A=5	C=2	

During		
		B=10
A=5	C=2	

After		
		B=10
A=5	C=20	

If the DMBS fails and is restarted:

1. The disks are physically or logically damaged then recovery from the log is impossible and instead a restore from a dump is needed.
2. If the disks are OK then the database consistency must be maintained. Writes to the disk which was in progress at the time of the failure may have only been partially done.
3. Parse the log file, and where a transaction has been ended with `COMMIT' apply the `new data' part of the log to the database.
4. If a log entry for a transaction ends with anything other than COMMIT, apply the `old data' part of the log to the database.
5. flush the data to the disk, and then truncate the log to zero.

Rollback

The process of undoing changes done to the disk under immediate update is frequently referred to as rollback.

- Where the DBMS does not prevent one transaction from reading uncommitted modifications (a `dirty read') of another transaction (i.e. the uncommitted dependency problem) then aborting the first transaction also means aborting all the transactions which have performed these dirty reads.
- as a transaction is aborted, it can therefore cause aborts in other dirty reader transactions, which in turn can cause other aborts in other dirty reader transaction. This is referred to as `cascade rollback'.

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Unit 5.1 - Embedded SQL

Unit 5.1 - Embedded SQL

Interactive SQL

So far in the module we have considered only the SQL queries which you can type in at the SQL prompt. We refer to this as `interactive' SQL. This is a good way to learn SQL. Interactive SQL also allows the database designer to set up the database structure (tables and so forth), making small queries or one-off queries, and for testing out ways to extract data from the database.

SQL itself is a `non-procedural' language. There are no good ways to build up complex queries, and reuse of queries is complicated. It is good at specifying WHAT is required of the database, but its control of how the data is manipulated to solve real-world problem specifications is weak.

Interactive SQL it is not good for more sophisticated applications for which a programming language with links to SQL might be better. To this end the idea of EMBEDDED SQL was produced.

Embedded SQL

SQL can be embedded within procedural programming languages. These language (sometimes referred to as 3GLs) include C/C++, Cobol, Fortran, and Ada. Thus the embedded SQL provides the 3GL with a way to manipulate a database, supporting:

- highly customized applications
- background applications running without user intervention
- database manipulation which exceeds the abilities of simple SQL
- applications linking to Oracle packages, e.g. forms and reports
- applications which need customized window interfaces

SQL Precompiler

A precompiler is used to translate SQL statements embedded in a host language into DBMS library calls which can be implemented in the host language.

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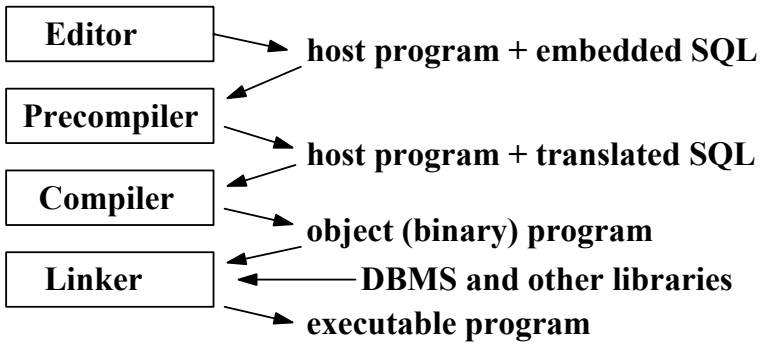

Sharing Variables

Variables to be shared between the embedded SQL code and the 3GL have to be specified in the program.

```
EXEC SQL begin declare section;
  varchar userid[10],password[10],cname[15];
  int cno;
EXEC SQL end declare section;
```

We also should declare a link to the DBMS so that database status information can be accessed.

```
EXEC SQL include sqlca;
```

This allows access to a structure sqlca, of which the most common element sqlca.sqlcode has the value 0 (operation OK), >0 (no data found), and <0 (an error).

Connecting to the DBMS

Before operations can be performed on the database, a valid connection has to be established.

```
EXEC SQL connect :userid identified by :password;
```

- In all SQL statements, variables with the `:' prefix refer to shared host variables, as opposed to database variables (e.g. row or column identifiers).
- This assumes that userid and password have been properly declared and initialised.

When the program is finished using the DBMS, it should disconnect using:

```
EXEC SQL commit release;
```

Queries producing a single row

A single piece of data (or row) can be queried from the database so that the result is accessible from the host program.

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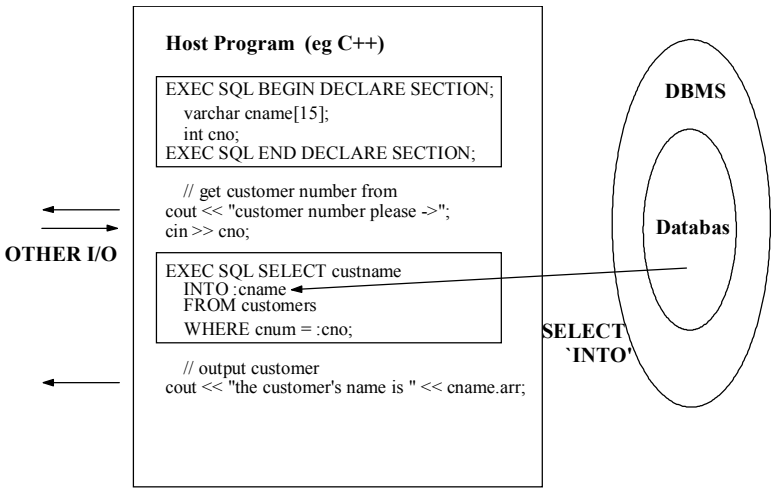
```
EXEC SQL   SELECT     custname
           INTO       :cname
           FROM       customers
           WHERE      cno = :cno;
```

Thus the custname with the unique identifier :cno is stored in :cname.

However, a selection query may generate many rows, and a way is needed for the host program to access results one row at a time.

SELECT with a single result



Cursors - SELECT many rows

- A cursor provides a pointer to a single row in the result of a selection query (which may return may rows)
- Cursors are declared by statements similar to view definitions
- One row at a time is accessed through the cursor, which is moved to the next row before each data transfer
- The columns of that one row are `fetched' into the program variables which can then be manipulated in the normal way by the host program.
- A cursor can also be used to update values in tables.

Fetching values

```
EXEC SQL fetch <cursor-name> into <target-list>
```

- this moves the cursor to the next row of the select query result and transfers the values from the result row into the program variables specified in target-list.
- a special value is returned when an attempt is made to fetch a non-existent row after the last row available to the cursor, (sqlca.sqlcode > 0)

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Declaring and Opening a Cursor

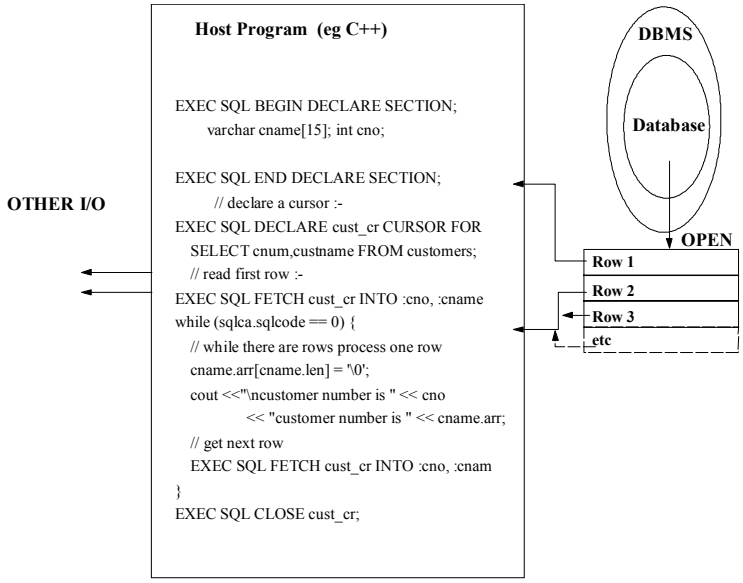
```
EXEC SQL declare <cursor name> cursor for
  <select statement>
  [for update [<of column-list>]]
```

- the last element of the definition is required only if the cursor is to be used for updates or deletes on the parts of the table involved in the cursor select statement.
- the column-list part is omitted if the rows are to be deleted.

```
EXEC SQL open <cursor name>
```

- the view described in the cursor declaration is created
- the cursor is positioned before the first row of the select query result.

Program Example



Summary

- Cursors provide a means of integrating traditional 3GL procedural languages and databases by enabling row-at-a-time access.
- Languages such as Visual Basic and Visual C++ also have build-in statements that enable this type of processing with a dedicated database, like that provided by MS-Access.
- Java has a well-defined interface to enable easy access to databases through a Database Connectivity library - JDBC.
- Unfortunately, there are many `standards'.

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Unit 5.2a - Database Administrator

Unit 5.2a - Database Administrator

The database administrator (DBA) should be positioned in middle-top management in an Organisation. DBAs are highly paid, due to the nature of their responsibilities and technical know-how.

The importance of their role varies according to the complexity and number of databases in the organisation.

A DBA is involved in a large number of tasks:

- design and organisation
    - Data Definition - what is to go into the database
    - Physical Structure - how the data is to be held in the database
    - Data Dictionary/Directory - documentation on the database implementation
- user interface
    - Provision of documentation - users need to understand the database
    - Liason with users/Education - users have needs which must be met, and need educating on how to achieve their goals with respect to accessing and manipulating the database.
    - GUI - often the users will required a graphical user interface for the database. This will have to be written to match their needs and requirements.
- security
    - Normal Operations - day to day maintainance, adding users, etc.
    - Failure Conditions - disk failures, machine failures, and database flaws.
    - Compatibility with non-DBMS - some users will need to read database entries out of the database and into other products, such as spreadsheets and word processors. This must be achieved without violating security and the organisation's policy.
    - Test Databases - new databases (and modified old ones) must be tested.

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- system performance
    - Timing - it is important to detect where the DBMS spends its time, and what effect this is going to have in the future. Future predictions can be made using the organisation's short and long-term plan.
    - Performance tuning - if the DBMS is slow for some tasks, then perhaps by manipulating the database the tasks can be speeded up.

DBA Tools

To assist the DBA in his or her duties, a number of tools are available:

- Loading routines
- Reorganising routines
- Journaling routines
- Recovery routines
- Statistical Analysis routines
- Data Dictionary

DBMS Product Evaluation

Another task performed by the DBA is the evaluation and comparison of DBMS's, so that the correct product can be selected to meet the database and customer specification. This cannot be done in isolation from the context in which the product will operate, and should be done before database implementation. Consider:

- Price
- Documentation
- Support Agreements
- Data Structurer supported
- Performance
- Tools

Data Structures Supported

The DBA must select which data model to use. In this module on relation data models have really been considered. There are also object-oriented, hierarchical, and network models. Some data sets will fall naturally into one model. For instance, a hierarchical model can be specified as a network, but network has more overheads. The DBA must

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weigh up all the pros and cons of each model.

Note that the selection of DBMS should not occur until after proper business analysis, data analysis, and logical design. Thus model used should not be affected by the DBMS selected.

Performance

Response depends on a variety of factors

- Quality of software-implementation and engineering
- Hardware support
- CPU power
- Main memory
- Disks
- Dedicated DB machine
- Volume of data
- Series of benchmarks available.

Tools

- Faculties offered in addition to DBMS, eg
    - Report writer
    - Forms generator
    - 4GL
    - Query Language
    - Data Dictionary
- How user-friendly are the tools?
    - Query language - adhere to any standard? (eg SQL for a relational DBMS)
    - If the DBMS selected is relational, one can check how it measures up against Codd's rules.

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Unit 5.2b - Security

Unit 5.2b - Security

Security of the database involves the protection of the database against:

- unauthorised disclosures
- alteration
- destruction

The protection which security gives is usually directed against two classes of user

- Stop people without database access from having any form of access.
- Stop people with database access from performing actions on the database which are not required to perform their duties.

There are many aspects to security

- Legal, social and ethical aspects

  Legally there is the Data Protection Act, which places restrictions on databases which contain information on living people. This was created to protect the public from data contained on a computer, about themselves, to which the public had previously no legal right of access. Information on computers can be wrong, and decisions made on wrong information concerns the public and additionally is of no benefit to the company holding the data. The act supports the idea of the public querying data, and indicating errors in that data.

  However, just because a database is legal does not make it socially or ethically acceptable. Collating medical records on computer for a hospital is acceptable, but not having enough security to prevent insurance companies accessing the database and using that as a basis for rejecting life assurance applications could be considered questionable. Frequently is it best to place the tightest restrictions on who can access data, and where necessary security deliberately relaxed to allow only legitimate queries to take place.

- Physical controls

  Security often begins with physical controls. If a person cannot enter the building where the database runs and is accessed, then that person cannot access the database. Usually the construction of security is a layered approach, where a person bent on accessing the database must penetrate multiple levels of security. The simple precaution of having all the database access points behind locked doors can only add to the security of the system.

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- Policy questions

  Security of a database is often the enforcement in the database of the company policy. All companies should have a policy statement, listing what is acceptable and what is not. Companies with weak policy statements will often have the weakest security. At a minimum, it should be policy that data stored in the database should not be made available to outside agents without written consent from a Managing Director. Without a policy statement, it is hard to argue that an employee has actually done anything wrong...

- Operational problems

  If only a single person has access to a database, security is certainly higher than if many people have access. However, if all the people in the UK had to phone the same one person to find out what their bank balance was the whole system would quickly become unworkable. Security considerations often have to be balanced against operational issues.

- Hardware controls

  No matter how secure the database actually is, if a person can simply steal the hard drive on which the database is stored, then that person can access the database at leisure. This case is obvious, but less obvious security failures, such as taking a copy of a backup tape of the database, can be harder to safeguard against.

- Operating system security

  Most DBMS's run on top of an operating system (OS). Examples of OS's include Window 95, Windows NT, and Unix. The database may be secure from within the DBMS, but if the database can also be accessed from the OS using simple file handling programs, then a clear weakness in the security model exists.

- Database system security

  Within the DBMS itself, if anyone can access anything then having any other sort of security seems pointless. The use of user accounts and password protection of user identities is a good starting point to improve security. User identities is also an aid to accountability. Protection of certain elements of the database with respect to certain users (or user groups) should always be considered where potentially confidential data is being stored. It is DBMS security which is the focus of this discussion.

Granularity of DBMS Security

The unit of data used in specifying security in the database can be, for example;

- the entire database
- a set of relations

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- individual relation
- a set of tuples in a relation
- individual tuple
- a set of attributes of all tuples
- an attribute of an individual tuple.

DBMS-level Protection

- Data encryption:

  Often it is hard to prevent people from copying the database and then hacking into the copy at another location. It is easier to simply make copying the data a useless activity by encrypting the data. This means that the data itself is unreadable unless you know a secret code. The encrypted data in combination with the secret key is needed to use the DBMS.

- Audit Trails:

  If someone does penetrate the DBMS, it is useful to find out how they did it and what was accessed or altered. Audit Trails can be set up selectively to minimise disk usage, identify system weaknesses, and finger naughty users.

User-level Security for SQL

- Each user has certain access rights on certain objects.
- Different users may have different access rights on the same object.

In order to control the granularity of access rights, users can

- Have rights of access (authorisations) on a table
- Have rights of access on a view. Using views, access rights can be controlled horizontal and vertical subsets on a table, and on dynamically generated data from other tables.

Naming Hierarchy

In a DBMS, there is a two layer approach to naming relations.

- The DBMS is made up of a number of `databases'. The Database Administrator (DBA) has permission to create and delete databases, and to grant users access to databases.
- Each database is a flat name space. Users with the necessary permission can create tables and views in a database. Because it is a flat name space, all table

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names must be unique within a database. The DBMS helps users in this regard:

- table and view names are prepended with the name of the user who created it.
- the database login name is often taken as the username.

By way of an example, consider a table `hello' created by a user jbloggs.

- The table will have the name jbloggs.hello
- The user jbloggs can access the table using the name `hello'
- Other users must use the table's full name to access the table

The user jbloggs can control who has access to the table using the GRANT command.

If the DBA creates a table, and makes it available to PUBLIC, then no user needs to specify the full table name in order to access it.

The GRANT command

GRANT is used to grant privileges to users

```
GRANT privileges ON tablename
  TO { grantee ... }
  [ WITH GRANT OPTION ]
```

Possible privileges are:

- SELECT - user can retrieve data
- UPDATE - user can modify existing data
- DELETE - user can remove data
- INSERT - user can insert new data
- REFERENCES - user can make references to the table

The WITH GRANT OPTION permits the specified user can grant privileges which that user possesses on that table to other users. This is a good way to permit other users to look after permissions for certain tables, such as allowing a manager to control access to a table for his or her subordinates.

grantee need not be a username or a set of usernames. It is permitted to specify PUBLIC, which means that the privileges are granted to everyone.

```
GRANT SELECT ON userlist TO PUBLIC;
```

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Unit 5.3 - Data Dictionary

Unit 5.3 - Data Dictionary

A Data Dictionary System (DDS) is a software tool for recording and processing data about the data (metadata) that an organisation uses and processes. Originally DDS were designed as documentation tools, ensuring standard terminology for data items (and sometimes programs) and providing a cross reference capability. They have now evolved as an essential feature of the systems environment and as a tool for the DBA to keep track of data on the database and control its use. This helps to minimise maintenance and development costs.

A DDS is a central catalogue of the definitions and usage of the data within an organization. It can be used as a stand alone tool or integrated with a DBMS. Most DDS are used chiefly as a documentation aid and as a control point for referencing data. They may also play an active role in systems design, programming and in running systems. It could be used to provide the data structures to the program at compile time or validate data at execution time. It can be used as a storage base of programming code (sub-programs) and these sub-programs may be used in a number of programs.

Benefits of a DDS

Benefits of a DDS are mainly due to the fact that it is a central store of information about the database.

Benefits include -

- improved documentation and control
- consistency in data use
- easier data analysis
- reduced data redundancy
- simpler programming
- the enforcement of standards
- better means of estimating the effect of change.

DDS Facilities

A DDS should provide two sets of facilities:

- To record and analyse data requirements independently of how they are going to

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be met - conceptual data models.

- To record and design decisions in terms of database or file structures implemented and the programs which access them - internal schema.

The conceptual view shows a model of the organisation, that is, the entities, their attributes, and the relationship between these entities. This model is a result of the data analysis process and is therefore independent of any data processing implications. The conceptual view can also include details of the events and operations that occur in the organisation. It represents the conceptual schema.

The implementation view gives information about the data processing applications in computing terms. The processes are therefore described as systems, programs and sub-programs. The data is described in terms of files, records and fields.

One of the main functions of a DDS is to show the relationship between the conceptual and implementation views. The mapping should be consistent - inconsistencies are an error and can be detected here.

DD Information

- The names associated with that element (aliases)
- A description of the data element in natural language.
- Details of ownership.
- Details of users that refer to the element.
- Details of the systems and programs which refer to or update the element.
- Details on any privacy constraints that should be associated with the item.
- Details about the data element in data processing systems, such as the length of the data item in characters, whether it is numeric alphabetic or another data type, and what logical files include the data item.
- The security level attached to the element in order to control access.
- The total storage requirement.
- The validation rules for each element (e.g. acceptable values).
- Details of the relationship of the data items to others.

DD Management

- With so much detail held on the DDS, it is essential that an indexing and cross-referencing facility is provided by the DDS.
- The DDS can produce reports for use by the data administration staff (to

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investigate the efficiency of use and storage of data), systems analysts, programmers, and users.

- DDS can provide a pre-printed form to aid data input into the database and DD.
- A query language is provided for ad-hoc queries. If the DD is tied to the DBMS, then the query language will be that of the DBMS itself.

Management Objectives

From an management point of view, the DDS should

- provide facilities for documenting information collected during all stages of a computer project.
- provide details of applications usage and their data usage once a system has been implemented, so that analysis and redesign may be facilitated as the environment changes.
- make access to the DD information easier than a paper-based approach by providing cross-referencing and indexing facilities.
- make extension of the DD information easier.
- encourage systems analysts to follow structured methodologies.

Advanced Facilities

Extra facilities which may be supported by DDS are:-

- Automatic input from source code of data definitions (at compile time).
- The recognition that several versions of the same programs or data structures may exist at the same time.
    - live and test states of the programs or data.
    - programs and data structures which may be used at different sites.
    - data set up under different software or validation routine.
- The provision of an interface with a DBMS.
- Security features such as password protection, to restrict DDS access.
- Generation of update application programs and programs to produce reports and validation routines.

Management Advantages

A number of possible benefits may come from using a DDS:-

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- A DDS can improve the ability of management to control and know about the data resource of the enterprise.

  It can also show all the program files and reports that may be affected by any change to the definition or usage of data elements and possibly to generate code which reflects that change. This allows accurate assessment of cost and time scale to effect any change.

- A DDS reduces the clerical load of database administration. It gives the DBA more control over the design and use of the data base.

  Accurate data definitions can be provided directly to program. Sensitive data can be made available only to particular users. Files and programs can be checked to ensure that standards are being followed.

- A DDS can aid the recording, processing, storage and destruction of data and associated documents flowing through an organisation.

- A DDS can help systems development by generating test files and providing documentation.

- A DDS provides application programs with data definitions and subroutines and therefore enforces some standards on programming, making programs more readable and consistent.

- A DDS aids application program maintenance because changes to the data and the data structures can be made where appropriate to all programs using the data.

- A DDS aids the operations side of computing by holding details of storage and recovery procedures, and archiving information.

- A DDS can provide effective security features such as passwords to assist in the protection of the data resource.

Management Disadvantages

A DDS is a useful management tool, but at a price.

- The DDS 'project' may itself take two or three years.

- It needs careful planning, defining the exact requirements designing its contents, testing, implementation and evaluation.

- The cost of a DDS includes not only the initial price of its installation and any hardware requirements, but also the cost of collecting the information entering it into the DDS, keeping it up-to-date and enforcing standards.

- The use of a DDS requires management commitment, which is not easy to achieve, particularly where the benefits are intangible and long term.

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Tutorial - ER Modelling 1

Tutorial - ER Diagram Examples 1-2

Example 1

A publishing company produces scientific books on various subjects. The books are written by authors who specialize in one particular subject. The company employs editors who, not necessarily being specialists in a particular area, each take sole responsibility for editing one or more publications. A publication covers essentially one of the specialist subjects and is normally written by a single author. When writing a particular book, each author works with on editor, but may submit another work for publication to be supervised by other editors. To improve their competitiveness, the company tries to employ a variety of authors, more than one author being a specialist in a particular subject.

Example 2

A General Hospital consists of a number of specialized wards (such as Maternity, Paediatry, Oncology, etc). Each ward hosts a number of patients, who were admitted on the recommendation of their own GP and confirmed by a consultant employed by the Hospital. On admission, the personal details of every patient are recorded. A separate register is to be held to store the information of the tests undertaken and the results of a prescribed treatment. A number of tests may be conducted for each patient. Each patient is assigned to one leading consultant but may be examined by another doctor, if required. Doctors are specialists in some branch of medicine and may be leading consultants for a number of patients, not necessarily from the same ward.

Tutorial - ER Modelling 2

Tutorial - ER Diagram Examples 3-5

Example 3

A database is to be designed for a Car Rental Co. (CRC). The information required includes a description of cars, subcontractors (i.e. garages), company expenditures, company revenues and customers. Cars are to be described by such data as: make, model, year of production, engine size, fuel type, number of passengers, registration number, purchase price, purchase date, rent price and insurance details. It is the company policy not to keep any car for a period exceeding one year. All major repairs and maintenance

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are done by subcontractors (i.e. franchised garages), with whom CRC has long-term agreements. Therefore the data about garages to be kept in the database includes garage names, addressees, range of services and the like. Some garages require payments immediately after a repair has been made; with others CRC has made arrangements for credit facilities. Company expenditures are to be registered for all outgoings connected with purchases, repairs, maintenance, insurance etc. Similarly the cash inflow coming from all sources - car hire, car sales, insurance claims - must be kept of file.CRC maintains a reasonably stable client base. For this privileged category of customers special credit card facilities are provided. These customers may also book in advance a particular car. These reservations can be made for any period of time up to one month. Casual customers must pay a deposit for an estimated time of rental, unless they wish to pay by credit card. All major credit cards care accepted. Personal details (such as name, address, telephone number, driving licence, number) about each customer are kept in the database.

Example 4

A database is to be designed for a college to monitor students' progress throughout their course of study. The students are reading for a degree (such as BA, BA(Hons) MSc, etc) within the framework of the modular system. The college provides a number of module, each being characterised by its code , title, credit value, module leader, teaching staff and the department they come from. A module is co-ordinated by a module leader who shares teaching duties with one or more lecturers. A lecturer may teach (and be a module leader for) more than one module. Students are free to choose any module they wish but the following rules must be observed: some modules require pre-requisites modules and some degree programmes have compulsory modules. The database is also to contain some information about students including their numbers, names, addresses, degrees they read for, and their past performance (i.e. modules taken and examination results).

Example 5

A relational database is to be designed for a medium sized Company dealing with industrial applications of computers. The Company delivers various products to its customers ranging from a single application program through to complete installation of hardware with customized software. The Company employs various experts, consultants and supporting staff. All personnel are employed on long-term basis, i.e. there are no short-term or temporary staff. Although the Company is somehow structured for administrative purposes (that is, it is divided into departments headed by department managers) all projects are carried out in an inter-disciplinary way. For each project a project team is selected, grouping employees from different departments, and a Project Manager (also an employee of the Company) is appointed who is entirely and exclusively responsible for the control of the project, quite independently of the Company's hierarchy. The following is a brief statement of some facts and policies adopted by the Company.

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Multiple Choice Tutorial

Multiple Choice - HOWTO

The first diet exam for databases is often a Multiple Choice exam paper. The second diet (the resit paper) is more usually a written paper. However, be prepared for either multiple choice or a written paper. It should not affect your study method, and if it does you are doing something wrong.

Here are a couple of useful guides to a successful multiple-choice exam.

1. Look at each question in turn.
2. Score out answers on the question sheet which are obviously wrong.
3. Do not be afraid of going onto the next question if no single correct answer can be selected immediately.
4. Read each question CAREFULLY. Are you selecting a TRUE answer or a FALSE answer from the options?
5. Try not to revisit answers before attempting all the other questions.

The Answer Sheet

There are a few different answer sheets in use for this exam. It is ALWAYS best to read the instructions given with the exam, and any comments which the invigilator gives you. In some cases the exam may be automatically scanned and marked by computer, which may require you to use a very specific way of entering the answers.

The answer sheet shown here is the one first used in this module, and is still used where electronic support for automatic marking is not available. In all exams there may be a box for your full name. Napier currently uses an anonymous marking system, so do not enter your name unless you are uncertain if you have entered your Matrix No correctly. Every year there are still a few students who seem unable to write in their Matrix No properly and legibly.

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Matrix No:

Full Name: _____

QABCDE Q ABCDE

1 6

2 7

3 8

4 9

5 10

Entering an answer

Entering A for Q1.

QABCDE

1 |

Changing A to C in Q1.

QABCDE

1 ✝ |

Changing C back to A in Q1.

QABCD E

1 ✝ ✝ A

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Reason/Assertion

In past exams a number of REASON/ASSERTION question were used. For example

```
Assertion : Fire is hot to the touch
Reason    : Fire needs Oxygen to burn
```

Option	Assertion	Reason	Assertion BECAUSE reason
A	True	True	REASON IS a valid reason...
B	True	True	REASON IS NOT a valid reason...
C	True	False	
D	False	True	
E	False	False	

The Assertion is TRUE, and the Reason is TRUE, but the Assertion is not true because of the Reason, so the answer is B.

Reason/Assertion questions are NO LONGER USED in current exams.

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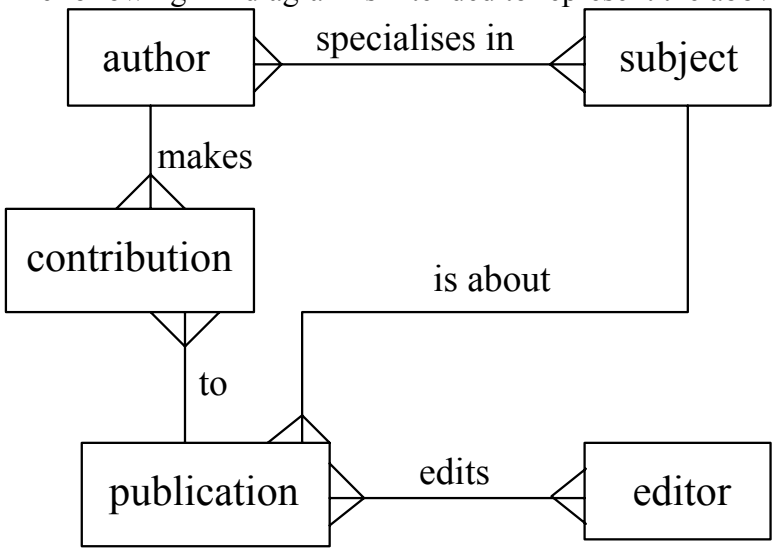
Example

Now give the written Multiple Choice tutorial a try. Give yourself 30 minutes for the test. It is not assessed, and it does not count towards your final mark.

In a subsequent session, I will go over the assessment with you. Good luck!

1. A publishing company produces academic books on various subjects. Books are written by authors who specialise in one or more particular subject. The company employs a number of editors who do not have particular specialisations but who take sole responsibilty for for editing one or more publications. A publication covers a single subject area but may be written by one or more author - the contribution of each author is recorded as a percentage for the purposes of calculating royalties.

   The following ER diagram is intended to represent the above specification:



   Indicate the relation which has an incorrect cardinality shown:

   A. specialises in

   B. makes

   C. is about

   D. to

   E. None of the above

2. The specification is to be changed so that an author can develop a publication covering more than one subject area and that the schema must be able to store the

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percentage of the compents concerned with each of the subjects. Select an appropriate change to the ER diagram:

A. publication-subject becomes many to many

B. author-subject becomes many to many

C. author-publication becomes many to many

D. more than one of the above

E. none of the above

---

3. Consider the relational schema R(A,B,C,D,E) with non-key functional dependencies C,D - E and B - C.

   Select the strongest statement that can be made about the schema R

   A. R is in first normal form

   B. R is in second normal form

   C. R is in third normal form

   D. R is in BCNF normal form

   E. None of the above

---

4. Locking was introduced into databases so that

   A. Keys can be provided to maintain security.

   B. Reading and writing is possible.

   C. All simultaneous transactions are prevented.

   D. Passwords can be provided to maintain security

   E. Consistency can be enforced.

---

5. When accessing a disk block, the seek time

   A. is insignificant in comparison to transfer times

   B. is about the same as transfer times

   C. greatly exceeds transfer times

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D. is the time taken to search for data in a sorted list of database rows

E. is measured in nanoseconds

---

6. Hash-table insertions

   A. avoid hash-collisions by manipulating the foreign keys

   B. might use hash-chains to allow hash-collisions

   C. use balanced binary trees to allow hash-collisions

   D. use primary keys to avoid hash-collisions

   E. become unusable if there are any hash-collisions

---

7. When a transaction aborts

   A. all users must be notified

   B. all changes it has made are immediately available to other transactions

   C. the modifications of all transactions currently running are also aborted

   D. it can abort transactions which have already committed

   E. it releases all of its locks

---

8. Films Database

   Consider the following database:
   MOVIE(id,title,yr)
   ACTOR(id,name)
   CASTING(movieid,actorid)

Assertion	Reason
The films database is NOT in BCNF	The table CASTING has a composite key

Option	Assertion	Reason	Assertion BECAUSE reason
A	True	True	REASON IS a valid reason...
B	True	True	REASON IS NOT a valid reason...
C	True	False	

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D	False	True
E	False	False

9. Using the same Films Database, identify the SQL command which will return the titles of all 1959 Marilyn Monroe films.

   A. The following SQL...

```
SELECT title FROM movie,casting,actor
  WHERE    movieid = movie.id
  AND      name    = 'Marilyn Monroe'
;
```

   B. The following SQL...

```
SELECT title FROM movie,actor
  WHERE    name    = 'Marilyn Monroe'
  AND      yr = 1959
;
```

   C. The following SQL...

```
SELECT title FROM movie,casting,actor
  WHERE    movieid  = movie.id
  AND      actor.id = actorid
  AND      name     = 'Marilyn Monroe'
  AND      yr = 1959
;
```

   D. The following SQL...

```
SELECT title FROM movie,casting,actor
  WHERE    movieid  = movie.id
  AND      actor.id = actorid
  AND      movie.yr = casting.yr
  AND      name     = 'Marilyn Monroe'
  AND      yr = 1959
;
```

   E. None of the above

---

10. Consider the relational schema R(A,B,C,D,E) with non-key functional dependencies C,D - E and B - C.

Assertion	Reason
In the relation R (above) the functional dependency C,D-E is transitive	C and D do NOT contribute to the primary key

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Option	Assertion	Reason	Assertion BECAUSE reason
A	True	True	REASON IS a valid reason...
B	True	True	REASON IS NOT a valid reason...
C	True	False	
D	False	True	
E	False	False	

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