Databases

The Database Training course is structured into five sections.

1. Data models

This is the Data models course theme. In this section we introduce concepts for modelling data and language for communicating those models.
[Complete set of notes PDF 870Kb].

1.1. Introduction

Databases are pervasive in modern society. So many of our actions and attributes are logged and stored in organised information repositories, or Databases
[Section notes PDF 227Kb].

1.1.01. Databases

- Where do we come into contact with databases?
- Supermarket inventories/EPOS
  - Supplies, shopping habits, store locations, accounts
- Films (iMDB)
  - Cast lists, shooting schedules, histories, budgets
- Department
  - Students, courses, staff, payroll

These are all examples of relatively simple databases. All of the information is textual or referential.

1.1.02. New technologies

- Not just traditional, numeric/textual
- Research 70s biased
- Digital media
  - Video servers (atom/bbc/youtube)
- Multimedia databases
  - Web site, collection of diverse data types
  - Google, AltaVista
- Stock Exchange
  - Futures, Currency markets, trends
  - Databases comprising not only data, but modelling algortihms
- Microsoft's WinFS

Databases don't have to store just text. Increasingly Database servers are storing, indexing and delivering rich-media content, explicitly images, audio and video.

Microsoft's next generation File storage system (WinFS) is a relational database. From a user perspective, searching (the process of indexing content by keyword) is already mainstream. Users are moving away from rigid directory structures (files and folders) and towards keyword-tagged content.

1.1.03. Variations

- Not only in role
- Size
    - Video server example
- Complexity
    - Ford Puma™ example
    - Ford staff organised by production line and car
    - e.g. Each staff member answers to a 'part' manager (engines, bodyshell, chassis) and a 'car' manager (Puma, Mondeo, Ka)
- Expense
- User profiles and demands

We've seen that databases are used in a variety of contexts. Those roles imply properties of each of the systems. An interlinked text-only database (such as Unix/Linux's MAN pages) will require much less storage than a video archive.

Some databases are perceptually more complex. Ford's staff management model would be represented as a matrix (in this case 2 dimensional). Computers are very good at organising multi-dimensional space.

1.1.04. Definition

- Embrace diversity
- Data and semantic
- Database: related data, implicit meaning
- Sample/subset of real world
    - real world with bounds
- Miniworld/Universe of Discourse

A single definition of a database is hard to come by. Dictionary.com defines a database as: a comprehensive collection of related data organized for convenient access, generally in a computer. The Wikipedia definition runs for several pages.

1.1.05. Abstraction

- Previous lab exercises
    - Problem: reading data from a file
- Abstraction theme
- Basis of good OOP and further good P
    - from encapsulation to software component analysis
- Layering, splitting data from design
    - Solution: grammar (language guide) and data

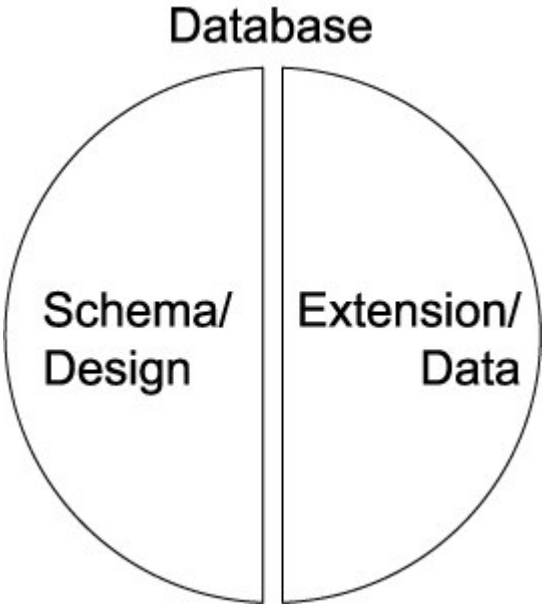
In some of your previous lab assignments, or practical experience, you may have been faced with the problem of caching information persistently in a file, later to be reloaded.

When writing the data into the file, we are storing more than just that information. We are storing implicitly a design/grammar for that data. That implicit design is evident when accessing the file with a naive interface. If you try to read the data out in a different order, it fails.

A better solution is to split the way the information is stored from the actually information stored.

1.1.06. Data-design divide

- Left-hand/right-hand divide
- LHS: Catalog
  - or Meta-data
  - or Intension
  - or Schema
  - i.e. the Design of database
  - Types of data, organisation, constraints
- RHS: Extension
  - or Snapshot
  - The data itself
  - Information stored in the database
  - Tuples



1.1.07. DBMS

- DataBase
- Management
- System
- Collection of programs that enable users to:
  - Define - patterns, boundaries, design
  - Construct - populate to go live
  - Manipulate - runtime changes
- data in a structured, organised store.

1.1.08. Database Management Systems

- Properties
- Data models and independence
    - Requirements
    - Categorisation of Database users
- DBMS components
    - Architecture

When considering the database systems as a whole, we need to look at all the components, including elements that interact with the DBMS (users, whom we categorise for simplicity).

This course will contain a discussion of the components that make up the system and the way they interact (system architecture).

1.1.09. Models

- Data models
- Relational data model (Oracle)
- Object data model (ObjectStore)
- Legacy systems
    - Hierarchical data model
    - Network data model

A data model is an invention. It is a construct that allows us to share an understanding of how the system works. As with all good constructs, it's an abstraction; a simplification; a story.

In this course we're going to look at the Relational model, where the database is organised into tables (relationals) and each row (tuple) within that relation is coded (keyed) to allow referencing between the relationals.

The Relational model, inspite of being innovated in the 1970s is still the most popular, underpining mainstream modern databases such as Oracle 10i and MySQL 5.0

As programming languages are becoming increasingly Object orientated, programmers require a means of persistently storing their Objects. Object Orientated Databases (OODBs) exist to fulfil this purpose. OODBs may ultimately replace relational databases, but it's not clear at this stage when.

1.1.10. Other properties

- Beside Data model
- Number of users
- Number of sites
- Cost
- Types of access paths
- Generality, or inversely specificity

MySQL is a highly general database system, in that it supports many different designs. My mobile phone address book is a highly specific database system and as such is not easily extensible.

1.1.11. Independence

- Based on File processing
- Data definition implicit in
    - Data
    - Application program
- Example of one specific database
- Structure embedded into access program
    - Coursework code re-use example

Earlier I made mention of this problem. Databases tie into the wider Software Engineering field. Within Software Engineering, post-development issues of code re-use, maintenance, future evolution etc. necessitate a logical flexible approach to program design. Databases are such an approach. In order to store information in a database you invest a small amount of time in explicitly structuring it, however you then get things like flexibility (data independence etc.) for free.

1.1.12. Program-data independence

- General databases
    - Separate Data definition and data
    - Catalog/meta-data & tuples
- Data format/structure stored separately
- Program-data independence (e.g. Y2K)
    - Changes in data format
        - Alter data (tuples)
        - Alter grammar (catalog/meta-data)
    - We actually split program-data independence into:
        - Logical
        - Physical
    - ...more in a second

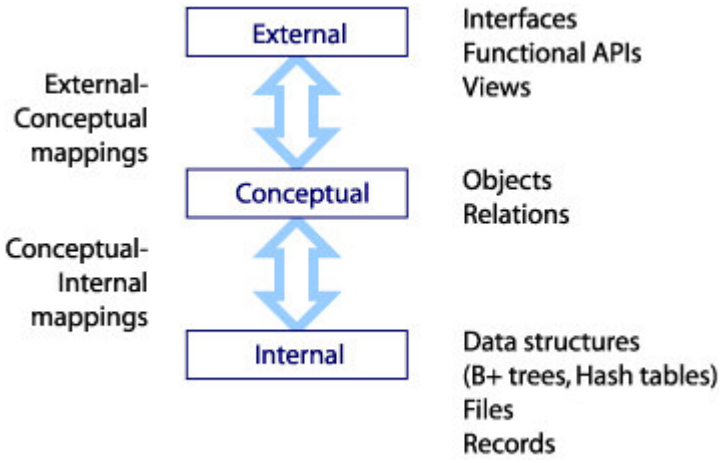
1.1.13. Program-operation independence

- In object-orientated databases
    - Objects consist of attributes and operations
    - Operation defined by
        - Header/Interface/Prototype or Signature
        - Implementation
    - Program-operation independence
        - Implementation change hidden from user
    - Collectively data abstraction

1.1.14. Logical and physical program-data independence

- Three tier data-model diagram
- Mappings, Data independence
    - Logical
        - between conceptual and external
        - changes to conceptual without changing
            - external schemas or application programs

    - Physical
        - between internal and conceptual
        - changes to internal without changing
            - conceptual or external schemas



1.1.15. DBMS Requirements

- DataBase Management System
    - Abstraction (i.e. program-data independence)
    - Conceptual representation (data models)
    - Multiple views and User Interfaces
    - Data sharing and transaction processing
    - Access restriction
    - Redundancy removal/optimisation
    - Persistent storage (Program objects) & Integrity
    - Relationship management & Inference
    - Backup and recovery

Here's a summary of what we need from a DBMS

1.1.16. Database Users

- Database as 1y resource, DBMS as 2y
- Database administrators (DBA)
- Database designers
- End users
    - Naïve - canned transactions e.g. bank/airline
    - Sophisticated - engineers, scientists, query editors
    - Stand-alone (personal databases/MS Access)

1.1.17. Results of use

- Knock-on effects of database approach
- Enforcing standards
- Reduced Development time
- Adaptive to change (design changes)

- Up-to-date information (live database)
- Economies of scale
    - centralising commonly required resources

...and this is what you get for free. These are the consequences, largely positive, of adopting a database approach to an information storage problem.

1.1.18. Design side

- Meta-data
    - Database schema, intension
    - Data Model
    - Left hand side of database divide
- Schema diagram
- Entity-relationship (ER diagrams)
- UML diagrams

GENERAL SCHEMA

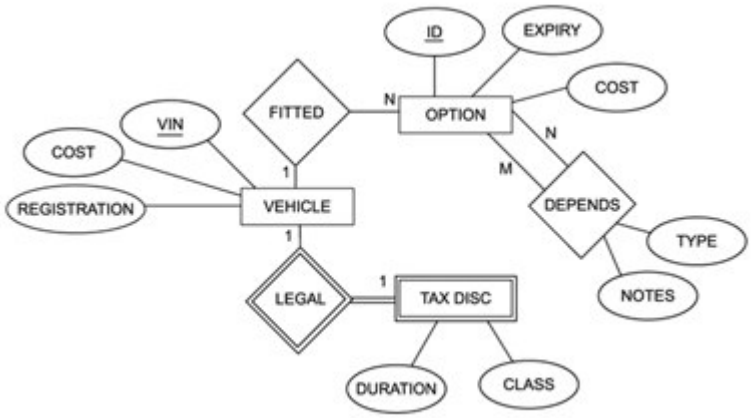
Attribute	Attribute	Attribute	Attribute	Attribute

PERSON

Name	Address	Phone	Fax	Mobile

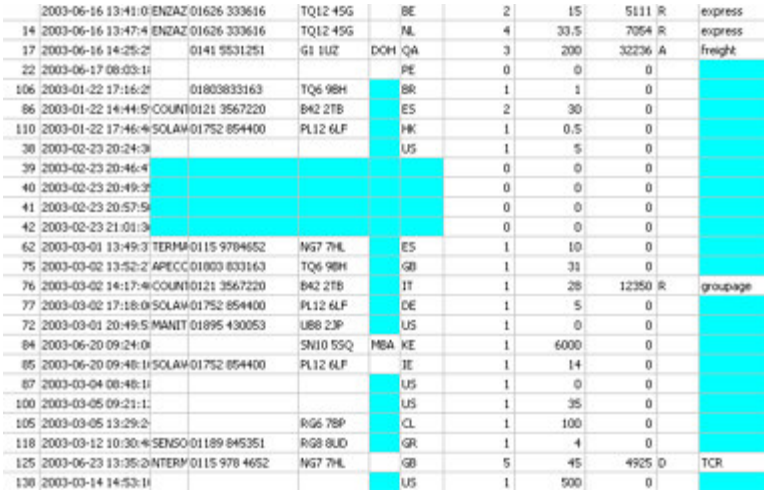
COMPANY

Name	Address	VAT ID	UKCO ID	Turnover



1.1.19. Data side

- Data, under the column heading
- Less easy to look at (volume issue)
- Fundamentally less interesting (more specific)
- Variety of tools for looking at it:
    - HeidiSQL, PhpMyAdmin, Sword
- Here's what a snapshot looks like:



	2003-06-16 13:41:0	ENZAZ	01626 333616	TQ12 4SG		BE	2	15	5111	R	express
14	2003-06-16 13:47:4	ENZAZ	01626 333616	TQ12 4SG		NL	4	33.5	7054	R	express
17	2003-06-16 14:25:2		0141 5531251	G1 1UZ	DOM	QA	3	200	32236	A	freight
22	2003-06-17 08:03:1					PE	0	0	0		
106	2003-01-22 17:16:2		01803833163	TQ6 9BH		BR	1	1	0		
86	2003-01-22 14:44:5	COUNT	0121 3567220	B42 2TB		ES	2	30	0		
110	2003-01-22 17:46:4	SOLAV	01752 854400	PL12 6LF		HK	1	0.5	0		
38	2003-02-23 20:24:3					US	1	5	0		
39	2003-02-23 20:46:4						0	0	0		
40	2003-02-23 20:49:3						0	0	0		
41	2003-02-23 20:57:5						0	0	0		
42	2003-02-23 21:01:3						0	0	0		
62	2003-03-01 13:49:3	TERMA	0115 9784652	NG7 7HL		ES	1	10	0		
75	2003-03-02 13:52:2	APECC	01803 833163	TQ6 9BH		GB	1	31	0		
76	2003-03-02 14:17:4	COUNT	0121 3567220	B42 2TB		IT	1	28	12350	R	groupage
77	2003-03-02 17:18:0	SOLAV	01752 854400	PL12 6LF		DE	1	5	0		
72	2003-03-01 20:49:5	MANIT	01895 430053	UB8 2JP		US	1	0	0		
84	2003-06-20 09:24:0			SN10 5SQ	MBA	KE	1	6000	0		
85	2003-06-20 09:48:1	SOLAV	01752 854400	PL12 6LF		IE	1	14	0		
87	2003-03-04 08:48:1					US	1	0	0		
100	2003-03-05 09:21:1					US	1	35	0		
105	2003-03-05 13:29:2			RG6 7BP		CL	1	100	0		
118	2003-03-12 10:30:4	SENSO	01189 845351	RG8 8UD		GR	1	4	0		
125	2003-06-23 13:35:2	NTERM	0115 978 4652	NG7 7HL		GB	5	45	4925	D	TCR
138	2003-03-14 14:53:1					US	1	500	0		

1.1.20. Data model

- Data model
  - Structure of the database
  - Collection of basic operations
  - Collection of behaviours/user defined operations
- Dependent on level of abstraction
- Tier diagram
  - External (user views)
  - Conceptual*
  - Internal

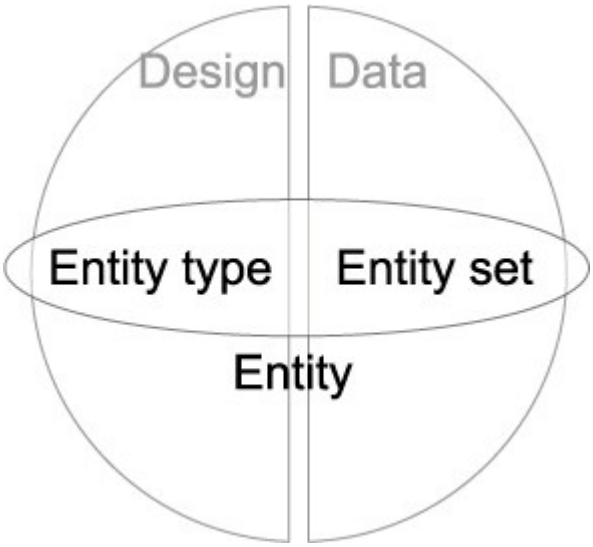
1.1.20. General data model terms

- Entity
- Relationship
- Attributes
- Keys

What follows here is an introduction to the terms which make up the language that we use to describe data models.

1.1.21. Entity

- Selected from real world
- Populate Miniworld/UoD
- Entity is an approximation
- Two elements: Entity types and sets
- Collection of attributes
  - Object similarity, classes as entity types
- Entities inter-relate



1.1.22. Attributes

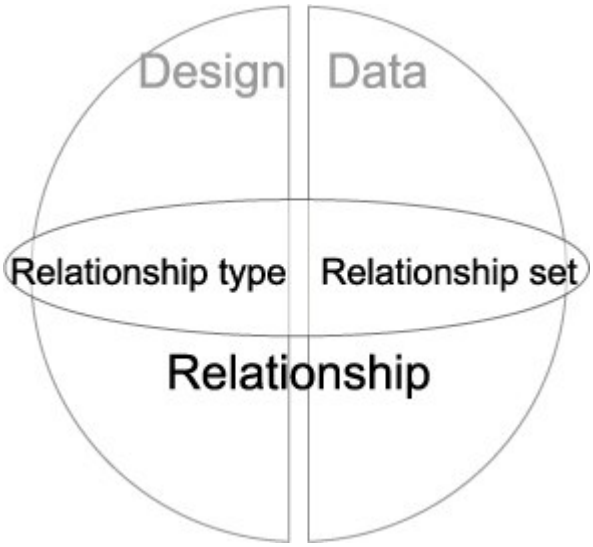
- Data type, domain
- Simple or composite
- Single or multivalued
- Stored or derived
- Null

1.1.23. Keys

- Mechanism for unique identification
- Uniqueness constraint
- Strong and weak entities
- Key attribute
- Composite keys
- Multiple keys

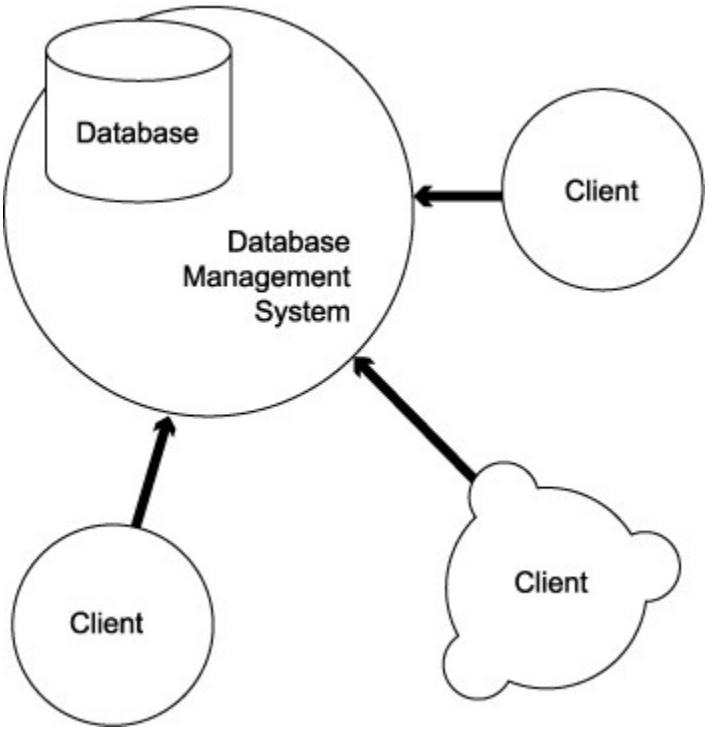
1.1.27. Relationships

- Types and Sets
- Participation by Entities
- Degree - e.g. binary
- Cardinality ratios - e.g. 1:1, 1:M
    - Determine occurrence
- Tuples example
    - Foreign keys



1.1.28. Database architecture

- Client-Server
- Distributed databases
  - Fragmentation by attribute/tuple/relation
- Language and description
  - Storage Definition Language (SDL) DESIGN
  - Data Definition Language (DDL) DESIGN
  - View Definition Language (VDL) DESIGN
  - Data Manipulation Language (DML) DATA
    - High level, can be embedded but precompiled
    - Procedural, record-at-a-time, requires high level support



1.1.29. Structured Query

- Structured Query Language (SQL or SEQUEL)
- Success of relational databases
    - Developed for SystemR at IBM
- ANSI standardised
    - SQL1 or SQL-86, ongoing extension
- SQL2 or SQL-92, current version
- SQL3 (1999), SQL2003
- DDL, DML(low-level) and VDL

1.2. Data models

A data model is a model that describes in an abstract way how data are represented in a business organization, an information system or a database management system - Wikipedia
[Section notes PDF 310Kb].

1.2.01. Introduction

- Relational model
- Abstract operations on relations
    - Set theoretic operations
    - Relational-specific operations
- Basic algebra operations
    - Union, Intersection, Difference
    - Cross product

1.2.02. Relational model

- Table as relation
- Row as tuple
    - real world entity or relationship
    - fact
- Column as attribute
    - Domain

Schema

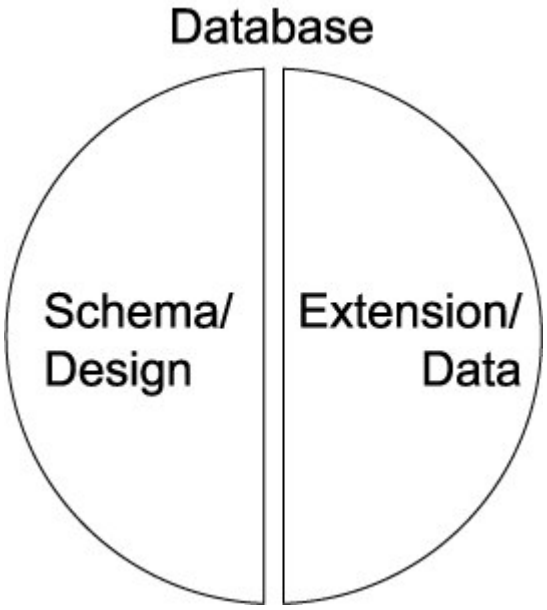
State

ID	Make	Model	Derivative
1	AC	Ace	3.5 Twin Turbo ro:
2	AC	Aceca	3.5 Twin Turbo co
3	AC	Cobra	5.0 Mk IV CRS ro
4	AC	Superblower	5.0 V8 roadster
5	AC	Superblower	5.0 V8 Spirit of Bı
6	Alfa Romeo	147	1.6 16V TS Turisr
7	Alfa Romeo	147	1.6 16V TS Lusso
8	Alfa Romeo	147	2.0 16V Selespeo
9	Alfa Romeo	147	2.0 16V Lusso 3-(
10	Alfa Romeo	147	1.6 16V TS Turisr
11	Alfa Romeo	147	1.6 16V TS Lusso
12	Alfa Romeo	147	2.0 16V Lusso 5-(
13	Alfa Romeo	147	2.0 16V Selespeo
14	Alfa Romeo	156	1.6 TS Lusso
15	Alfa Romeo	156	1.6 TS Veloce (Lı
16	Alfa Romeo	156	1.8 TS Lusso Sal
17	Alfa Romeo	156	1.8 TS Veloce (R
18	Alfa Romeo	156	1.8 TS Veloce (Lı
19	Alfa Romeo	156	2.0 TS Lusso Sal
20	Alfa Romeo	156	2.0 TS Veloce (R
21	Alfa Romeo	156	2.0 TS Veloce (Lı

The concept of a relation is abstract, therefore we have a number of different ways of visualising it.

1.2.03. Relation

- Relation schema R(A_1, A_2, A_3.. A_n)
  - Design side
  - Assertion/declaration
- Relation state
  - Data side
  - set of n-tuples
    - each one an ordered list of values
      - 1NF: each value is atomic, no composite/multivalue



1.2.04. Abstract operations

- Database lifecycle
  - design, populate, evolve
- Insert
  - tuple (a_1,a_2,a_3…a_n)
- Delete
  - tuple (a_1,a_2,a_3…a_n)
- Update (or modify)
  - tuple (a_1,a_2,a_3…a_n)
  - attribute to change, new value

ID	Make	Model	Derivative	H
1	AC	Ace	3.5 Twin Turbo roadster	3
2	AC	Aceca	3.5 Twin Turbo coupe	3
3	AC	Cobra	5.0 Mk IV CRS roadste	2
4	AC	Superblower	5.0 V8 roadster	3
5	AC	Superblower	5.0 V8 Spirit of Brookla	3
6	Alfa Romeo	147	1.6 16V TS Turismo 3-d	1
7	Alfa Romeo	147	1.6 16V TS Lusso 3-do	1
8	Alfa Romeo	147	2.0 16V Selespeed Lus	1
9	Alfa Romeo	147	2.0 16V Lusso 3-door	1
10	Alfa Romeo	147	1.6 16V TS Turismo 5-d	1
11	Alfa Romeo	147	1.6 16V TS Lusso 5-do	1
12	Alfa Romeo	147	2.0 16V Lusso 5-door	1
13	Alfa Romeo	147	2.0 16V Selespeed Lus	1
14	Alfa Romeo	156	1.6 TS Lusso	1
15	Alfa Romeo	156	1.6 TS Veloce (Leather	1
16	Alfa Romeo	156	1.8 TS Lusso Saloon	1
17	Alfa Romeo	156	1.8 TS Veloce (Recaro)	1
18	Alfa Romeo	156	1.8 TS Veloce (Leather	1
19	Alfa Romeo	156	2.0 TS Lusso Saloon	1
20	Alfa Romeo	156	2.0 TS Veloce (Recaro)	1

All the operations described in the next few sections are abstract. We're going to see how valuable they can be in processing real world data later.

1.2.05. Basic algebra

- Two categories
  - Set theoretic operations
    - Union, Intersection etc.
  - Relational specific
    - Select, project and join

  At this stage we're talking about set theoretical operators on the Relational model, not SQL instructions which confusingly have identical names and only similar behaviour.

1.2.06. Select operation

- SELECT a subset of tuples from a relation
  - Uses selection condition
    - Evaluate each tuple to true of false
    - False tuples discarded
  - Sigma (s)
  - output = $s_{(cond)}(input\_relation)$
  - Relation schema: R(output) = R(input_relation)
  - Commutative

1.2.07. Project operation

- PROJECT a subset of attributes for all tuples from a relation

    - Pi (p)
    - p<attribute list>(R)
- If sublist is only non-key attributes
    - might get duplicates
- Removes duplicates
- Attribute list:sublist example

The result set of the operation is itself a relational. That output relation will contain the same number of rows as the input, however it may contain a different number of columns; fewer if a subset of attributes is projected; more if derived or aggregated attributes are included.

1.2.07. Sequences of operations

- Select followed by projection
- Area clipping: rows then columns
- p<attr list>
  (s(select_cond)(R))
- Rename operation (r)
    - Renames attributes list2 from list1
    - r(new_attr_names)(R)

ID	Make	Model	Derivative	H
1	AC	Ace	3.5 Twin Turbo roadster	3
2	AC	Aceca	3.5 Twin Turbo coupe	3
3	AC	Cobra	5.0 Mk IV CRS roadste	2
4	AC	Superblower	5.0 V8 roadster	3
5	AC	Superblower	5.0 V8 Spirit of Brookla	3
6	Alfa Romeo	147	1.6 16V TS Turismo 3-(	1
7	Alfa Romeo	147	1.6 16V TS Lusso 3-do	1
8	Alfa Romeo	147	2.0 16V Selespeed Lus	1
9	Alfa Romeo	147	2.0 16V Lusso 3-door	1
10	Alfa Romeo	147	1.6 16V TS Turismo 5-(	1
11	Alfa Romeo	147	1.6 16V TS Lusso 5-do	1
12	Alfa Romeo	147	2.0 16V Lusso 5-door	1
13	Alfa Romeo	147	2.0 16V Selespeed Lus	1
14	Alfa Romeo	156	1.6 TS Lusso	1
15	Alfa Romeo	156	1.6 TS Veloce (Leather	1
16	Alfa Romeo	156	1.8 TS Lusso Saloon	1
17	Alfa Romeo	156	1.8 TS Veloce (Recaro)	1
18	Alfa Romeo	156	1.8 TS Veloce (Leather	1
19	Alfa Romeo	156	2.0 TS Lusso Saloon	1
20	Alfa Romeo	156	2.0 TS Veloce (Recaro)	1
21	Alfa Romeo	156	2.0 TS Veloce (Leather	1

1.2.08. Rename operation

- Attribute renaming only
    - Cannot alter domain, or add/remove attr
- Rename operation (r)
    - Renames attributes list2 from list1
    - r(new_attr_names)(R)
- Implicit renaming

- Order dictated by relational schema

1.2.08. Set Theoretic

- Binary operation: two relations
  - Sets of tuples
  - Union compatibility (same attributes)
- Union (R u S)
- Intersection (R n S)
  - Commutative (R u (S u T) = (R u S) u T)

Cars1	ID	Make	Model	Derivative
	1	BMW	3 Series	320d
	2	BMW	3 Series	318i
	3	BMW	3 Series	325i
Cars2	**ID**	**Make**	**Model**	**Derivative**
	4	Volkswage	Golf	1.6 FSI
	5	Volkswage	Golf	1.9 TDI
	6	Volkswage	Polo	1.2i
Cars3	**ID**	**Make**	**Model**	**Derivative**
	1	BMW	3 Series	320d
	2	BMW	3 Series	318i
	3	BMW	3 Series	325i
	4	Volkswage	Golf	1.6 FSI
	5	Volkswage	Golf	1.9 TDI
	6	Volkswage	Polo	1.2i

1.2.08b. Set difference

- Set difference
  - Non-commutative (R-S != S-R)

Set difference			
R	**S**	**R-S**	**S-R**
1	2	1	{empty}
2	5		
3	7	3	
4		4	
5			
6		6	
7			
8		8	
9		9	

1.2.09. Cross product

- Cartesian product of two relations
- R x S

- Also known as
  - Cross product
  - Cross join
    - Cross product diagram
  - Introduction to complexity
    - Computationally explosive

Cars1	ID	Make	Model	Derivative
	1	BMW	3 Series	320d
	2	BMW	3 Series	318i
	3	BMW	3 Series	325i

Cars2	ID	Make	Model	Derivative
	4	Volkswagen	Golf	1.6 FSI
	5	Volkswagen	Golf	1.9 TDI
	6	Volkswagen	Polo	1.2i

Cars3X	1ID	1Make	1Model	1Derivative	2ID	2Make	2Model	2Derivative
	1	BMW	3 Series	320d	4	Volkswagen	Golf	1.6 FSI
	1	BMW	3 Series	320d	5	Volkswagen	Golf	1.9 TDI
	1	BMW	3 Series	320d	6	Volkswagen	Polo	1.2i
	2	BMW	3 Series	318i	4	Volkswagen	Golf	1.6 FSI
	2	BMW	3 Series	318i	5	Volkswagen	Golf	1.9 TDI
	2	BMW	3 Series	318i	6	Volkswagen	Polo	1.2i
	3	BMW	3 Series	325i	4	Volkswagen	Golf	1.6 FSI
	3	BMW	3 Series	325i	5	Volkswagen	Golf	1.9 TDI
	3	BMW	3 Series	325i	6	Volkswagen	Polo	1.2i

1.2.10. Relational algebra/model notation

- Relational schema $R(A_1, A_2,\ldots,A_n)$
- Relation state r or r(R)
  - Set of unordered tuples
  - $r = \{t_1, t_2,\ldots,t_n\}$
- Each n-tuple is an ordered list of values
  - $t = <v_1, v_2,\ldots,v_n>$
- i^{th} value in $t = v_i$ called $t[A_i]$
- r(R) subset of $(dom(A_1) \times dom(A_2) \ldots \times dom(A_n))$

1.2.11. Constraints

- Domain constraint
  - For all v in t of r(R)
    v_i is an element of $dom(A_i)$
- Entity constraint
  - $K = SK_{min}$
  - t[K] != null
- Key constraint
  - Superkey SK as identifying subset of attributes
  - $t_1[SK] != t_2[SK]$

1.2.12. Referential integrity

- Given two relations R_1 and R_2
  - R_1 contains a foreign key (FK) that references
  - A primary key (PK) in R_2

        - R_1 referencing relation, R_2 referenced relation
    - Shared domains: dom(FK) = dom(PK)
    - Foreign exists: t_1 in r(R_1), t_2 in r(R_2)
        - t_1[FK] = t_2[PK] || NULL

1.3. Joins

In this lecture we look at...
[Section notes PDF 233Kb].

1.3.01. Introduction

- Recap: pulling data out of individual relations
    - By row, by column
    - Select and project
- Access across multiple relations
- Miniworld approximation
    - Fragmenting entities by cardinality
    - Tuples as entity fragments
    - Relationships within relations
- Joins
- Join types (condition and unmatched)

1.3.02. Access across relations

- Relational model allows multiple relations to exist within one database schema
- Relations can be accessed individually or together (joins).
- Referential integrity
    - Relations relating
- Pulling data out of single relations
    - Select and project
- Pulling related data out of
    - Multiple relations using Join

1.3.03. Miniworld approximation

- Universe of Discourse, or Miniworld
- Miniworld is an incomplete model of the real world
- The relational data model as a model for the miniworld
- Approximation
    - Separate and distinct entities
    - Single complex entities
    - Separate related entities
    - Cardinality of relationships
- Each relation made up of attributes
- Values can be used as references

1.3.04. Pointing mechanism

- Relation has a Primary key
- Tuple contains Primary key value
- Foreign keys
    - Tuples can contain a reference to another relation's Primary key
- Just numbers

Cars	ID	Make	Model	Derivative	OptionID
	1	BMW	3 Series	320d	4
	2	BMW	3 Series	318i	NULL
	3	BMW	3 Series	325i	6

Options	ID	Name	Price
	3	16" Radial alloy	800
	4	17" Star alloy	880
	5	17" Web alloy	1025
	6	Metallic paint	325

One number identifies a single tuple in one relation (local), one number identifies a single tuple in another relation (foreign).

1.3.04b. Pointing mechanism example in C

- C programming language
- Memory addresses, or pointers

```
int a=0;
int b=0;
a = &b;
```

- a points to b

	int A		int A
0xFF138	0	a = &b;	0xFF134
	int B		int B
0xFF134	0		0

In databases, typically done with unique identifiers (IDs) rather than memory addresses.

1.3.04c. Pointing mechanism with structures

- Foreign key importing

```
typedef struct car
{
  int ID;
  char[] make;
  char[] model;
  char[] derivative;
```

```
  int optionID;
} car;

typedef struct option
{
  int ID;
  char[] name;
  int price;
} option;

car c;
option o;
//...data structure populating
c.optionID = o.ID;
```

Car	ID	Make	Model	Derivative	OptionID
	1	BMW	3 Series	320d	4
Option	**ID**	**Name**		**Price**	
	4	17" Star alloy		880	

1.3.05. Relational cardinality

- 1:0 relationships
  - Single entity
  - Uniquely indentifiable
  - Candidate keys
  - Primary Key
- 1:1 relationships
  - Two entities, A and B
  - 1 A relates to 1 B and vice versa
- 1:N relationships
- M:N relationships

1.3.06. Relationships in the relational model

- Two relations, A and B
- A side, B side, 1 side, N side
- 1:1 relationships
  - Key can go on either side

Car	ID	Make	Model	Derivative	
	1	BMW	3 Series	320d	
Option	**ID**	**Name**		**Price**	**CarID**
	4	17" Star alloy		880	1

- 1:N relationships
- Key cannot go on 1 side
- Has to go on N side

Car	ID	Make	Model	Derivative	
	1	BMW	3 Series	320d	
Door	**ID**	**Name**		**Size/mm3**	**CarID**
	3	Front left		1210	1
	4	Back right		1290	2
	5	Sunroof		340	1
	6	Hatchback		325	NULL

- M:N relationships
  - Nowhere obvious for the key to go
  - Create new pairing relation

1.3.07. Joins

- Phase change, different point in lifecycle
- Join operation
  - Combines related tuples, conditionally
  - From two relations
  - Into single tuples
- Allows processing of relationships
- Among multiple relations

1.3.08. Joins, canonical algebraic form

- Conditional (on join condition)
  - Only combines tuples where true
- Cartesian product (conditionless)
  - example of conditionless join
  - all tuples combined
  - R $\bowtie_{true}$ S
- $\bowtie$, Binary operator
  e.g. R $\bowtie_{<join\_condition>}$ S

1.3.09. Join equivalence

- Equivalent to sequence
  - Cartesian product (X)
  - followed by Selection (s)
- ACTUAL_DEPENDENTS =
  $s_{SSN=ESSN}$(EMPNAMES X DEPENDENT)
- or
- ACTUAL_DEPENDENTS =
  EMPNAMES $\bowtie_{SSN=ESSN}$(DEPENDENT)

1.3.10. Join types (condition)

- Theta: A_i q B_j
  (A from R, B from S)
  - q is comparison operator
    =,<,>,!=,>=
  - A_i and B_j share the same domain
- Equi: $A_i = B_j$
  - Theta join where q is =
- Natural: A_i and B_j are the same attribute
  - in two separate relations (name and domain)
  - * denotes natural join
  - e.g. EMPNAMES * DEPENDENTS

Cars	ID	Make	Model	Derivative	OptionID
	1	BMW	3 Series	320d	4
	2	BMW	3 Series	318i	4
	3	BMW	3 Series	325i	6

Options	ID	Name	Price
	3	16" Radial alloy	800
	4	17" Star alloy	880
	5	17" Web alloy	1025
	6	Metallic paint	325

JoinRel is equijoin equivalent to s(Cars.OptionID = Options.ID)(Cars x Options)

JoinRel	ID	Make	Model	Derivative	OptionID	Name	Price
	1	BMW	3 Series	320d	4	17" Star alloy	880
	2	BMW	3 Series	318i	4	17" Star alloy	880
	3	BMW	3 Series	325i	6	Metallic paint	325

1.3.11. Join types (inner and outer)

- Inner joins
  - not the only joins
  - eliminate tuples without a matching counterpart
  - i.e. tuples with a null value for the join attribute are discarded

Cars	ID	Make	Model	Derivative	OptionID
	1	BMW	3 Series	320d	4
	2	BMW	3 Series	318i	NULL
	3	BMW	3 Series	325i	6

Options	ID	Name	Price
	3	16" Radial alloy	800
	4	17" Star alloy	880
	5	17" Web alloy	1025
	6	Metallic paint	325

Inner	ID	Make	Model	Derivative	OptionID	Name	Price
	1	BMW	3 Series	320d	4	17" Star alloy	880
	3	BMW	3 Series	325i	6	Metallic paint	325

1.3.12. Outer joins

- Outer joins control what's discarded
  - Keep unmatched tuples in either
    - Left, right, or both relations
    - Left, right of full outer join correspondingly

LeftOuter	ID	Make	Model	Derivative	OptionID	Name	Price
	1	BMW	3 Series	320d	4	17" Star alloy	880
	2	BMW	3 Series	318i	NULL	NULL	NULL
	3	BMW	3 Series	325i	6	Metallic paint	325

RightOuter	ID	Make	Model	Derivative	OptionID	Name	Price
	N	NULL	NULL	NULL	3	16" Radial alloy	800
	1	BMW	3 Series	320d	4	17" Star alloy	880
	N	NULL	NULL	NULL	5	17" Web alloy	1025
	3	BMW	3 Series	325i	6	Metallic paint	325

FullOuter	ID	Make	Model	Derivative	OptionID	Name	Price
	N	NULL	NULL	NULL	3	16" Radial alloy	800
	1	BMW	3 Series	320d	4	17" Star alloy	880
	N	NULL	NULL	NULL	5	17" Web alloy	1025
	2	BMW	3 Series	318i	NULL	NULL	NULL
	3	BMW	3 Series	325i	6	Metallic paint	325

1.4. ER diagrams

In this lecture we look at...
[Section notes PDF 75Kb].

1.4.01. ER Diagrams and Relational mapping

- Design communication techniques
  - ER diagrams
  - ER to relational mapping
- Entities to Objects
- Type Inheritance
  - EER diagrams
  - UML
- Web DB Integration

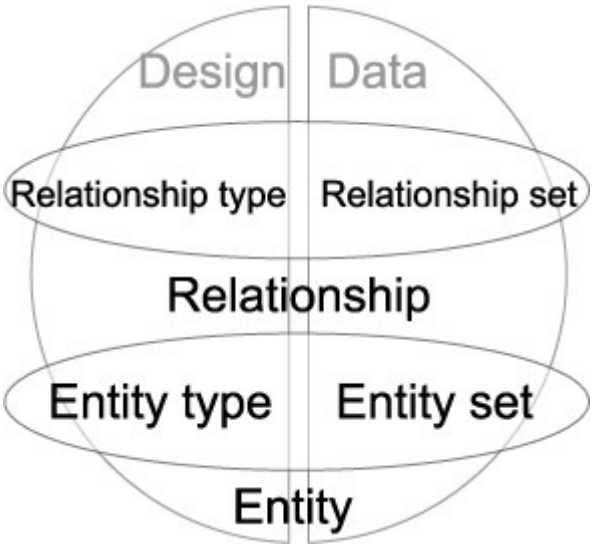
1.4.03. Design in the modern context

- Team based development
- Documentation
  - Value of design over description
- DB sketching (left hand side)
  - Concept more important than perfection
  - Design iteration
- Mini-world as approximation
  - Categorisation to create entities
  - Verb'ing to create actions/relationships

1.4.04. Database Left:right divide

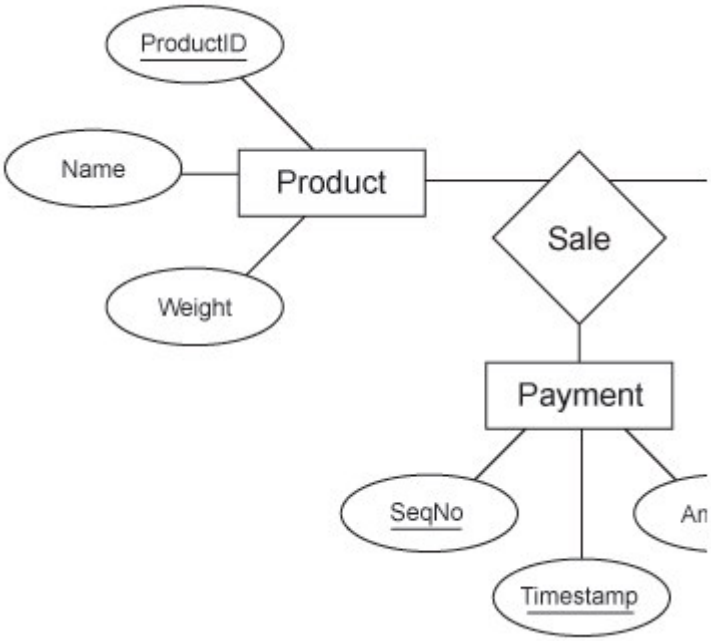
- Design
  - Catalog, Meta-data, Intension, or Database schema
  - Entity type
  - Relationship type
- State
  - Set of occurences/instances, Extension, snapshot

- Entity set
- Relationship set



1.4.05. Basic ER diagram

- Typically part of a system
- (Strong) Entities
  - Product
  - Customer
  - Payment
- Relationships
  - Sale



1.4.06. Mapping ER to Relation DB tables

- Intuitive mapping
  - Entities as tables

    - Attributes as columns
- Relationships are more difficult
- Key sharing mechanism
    - Foreign key references primary key
- Where to put the foreign key forms the intuitive guide to the rest of the mapping

1.4.07. ER to Relational mapping

- Step-by-step approach

1. Strong entities
    - Create relation including (simplified) attributes
2. Weak entities
    - Create relation inc. attr, foreign/pri key of owner
3. Binary relationship S:T, 1:1
    - Choose relation, say S (with total participation) and inc. foreign/pri key of T
    - inc. relationship attributes

1.4.08. Cardinality

- Specifies number of relationship instances a single entity can participate in
- S:T (1:1)
- An entity from table S can is related to one, and only one entity from table T
- 1:1, 1:N, N:M
    - DEPARTMENT : EMPLOYEE
    - EMPLOYEE : EMPLOYEE
    - PROJECT : EMPLOYEE

1.4.09. ER to Relational mapping

5. Binary relationship 1:N
    - Choose relation T (N-side) inc. foreign/pri key of S
6. Binary relationship M:N
    - Create relation, inc. foreign/pri keys of S&T
7. Multivalued
    - For each mv_attr, create new relation, inc. foreign/pri key of parent
8. n-ary relationship
    - Create new relation, inc. all foreign/pri keys of participating entities

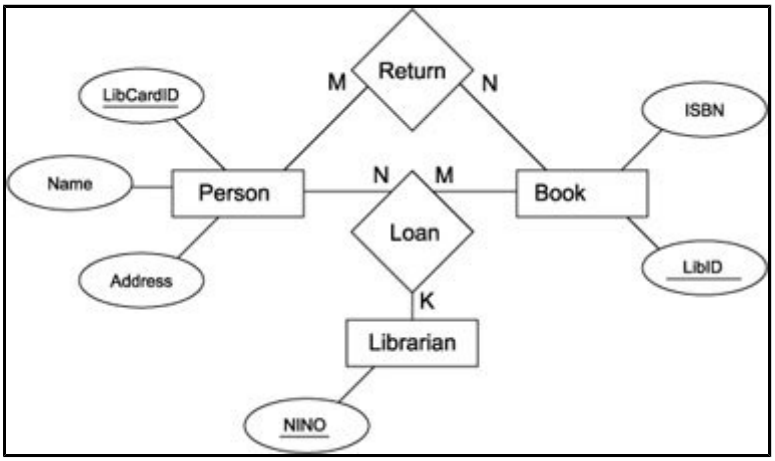
1.4.10. Participation

- Participation constraints
- Existence of an entity dependant upon
    - being related to another entity
    - via relationship type (left hand/design)

- Total (")/Existence dependency (double line)
  - Every student must be in a faculty
  - For every entity in the total set of students
- Partial ($) (single line)
  - Some students are student_representatives
  - There exists some entity(s) within the set of all…

1.4.11. Library example

- Library example
- Entities: Person, Book, Librarian
- Time-perspective implications

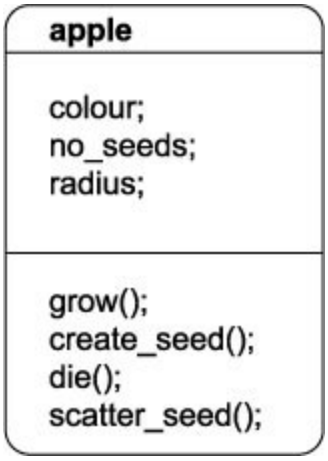


1.5. UML

In this lecture we look at...
[Section notes PDF 86Kb].

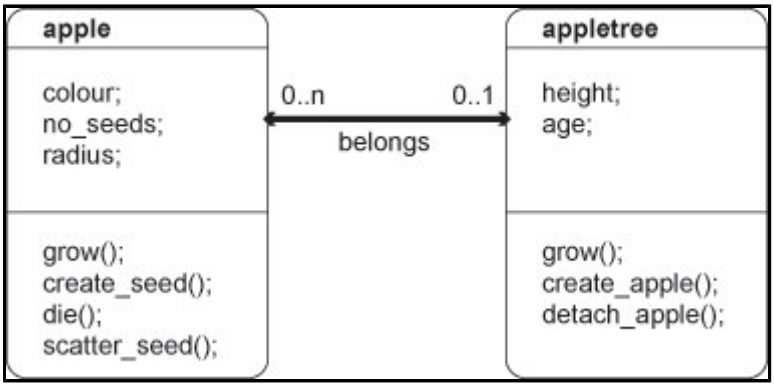
1.5.01. UML diagrams

- Not just one type of diagram
- ER Entities -> UML objects
- Adds scope to include methods



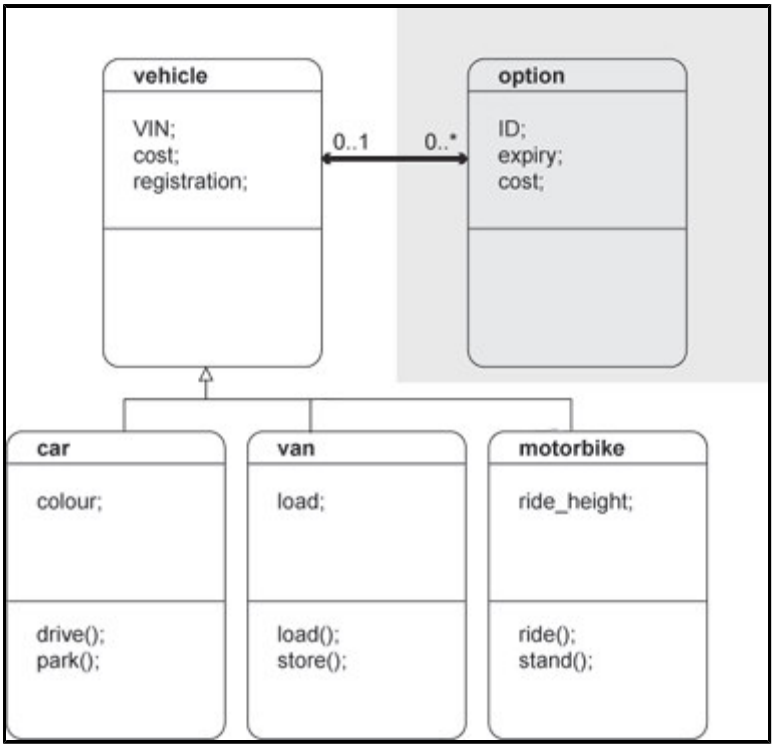
1.5.03. Simple UML relationship diagram

- Classes
  - Attributes
  - Methods
- Relationships
  - Participation
  - Cardinality
  - Roles



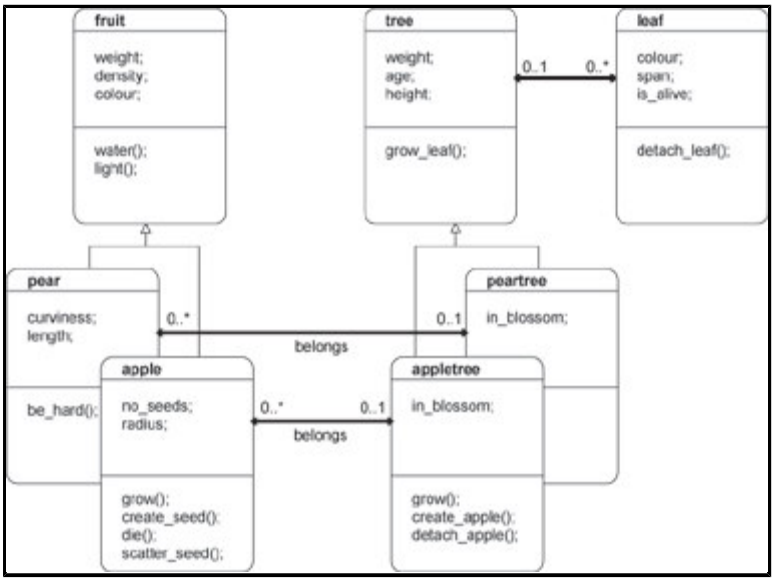
1.5.04. UML inheritance

- Notion of inheritance
  - Java parallel
  - 'is a' relationships
  - Database Student
    - is a Computer Science Student
      - is an Engineering Faculty Student
      - is a Student
        - is a Person
  - Inheritance hierarchies
- UML diagrams can be used to show inheritance



1.5.05. UML diagram

- Classes
- Relationships
- Inheritance



2. DBMS Systems

This is the DBMS Systems course theme.
[Complete set of notes PDF 482Kb]

2.1. Queries

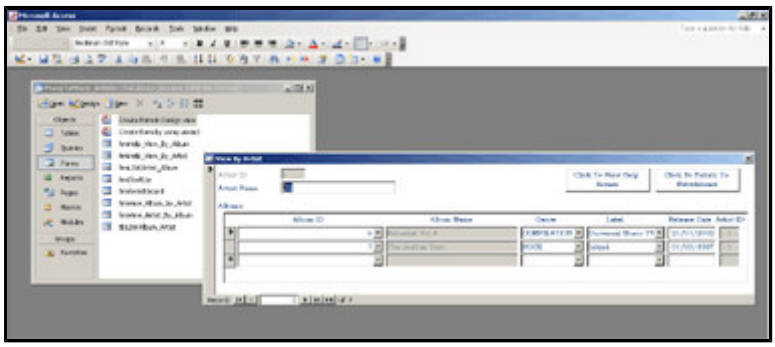
In this lecture we look at...
[Section notes PDF 319Kb]

2.1.01 Introduction

- Methods of getting data out
- The need for queries
- QBE
- SQL (design side)
    - History
    - Schemas and relations (CREATE)
    - Data types and domains
    - DROP and ALTER

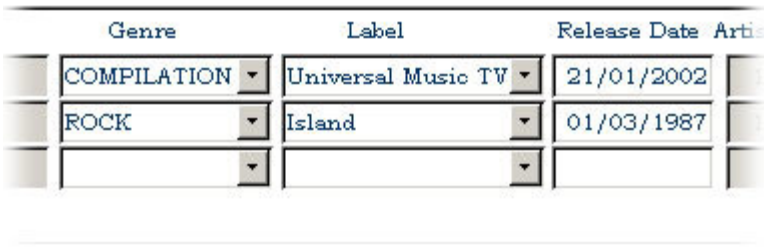
2.1.02. Querying interfaces

- High (view) level
- Query-By-Example (QBE)
    - Alternative to SQL
        - Table driven (visually similar to relations)
        - Rather than script driven, hence intuitive over learned
        - Visual or text based
    - User fills in templates
    - Microsoft Access approach



2.1.02b. QBE visual example

- Record advancing
- Query designing
    - Finite domain attributes
    - Web search parallel



Genre	Label	Release Date	Arti
COMPILATION	Universal Music TV	21/01/2002	
ROCK	Island	01/03/1987	

2.1.03. QBE text-format example

- P. print, I. insert, D. delete, U. update
- _VARNAME, copy field value into variable

Employee	Title	FirstName	Surname	NINO	Salary
	Mr	Fred	Bloggs	P.	_starting
Employee	Title	FirstName	Surname	NINO	Salary
I.	Ms	Sahika	Jones	JM12240B	_starting

2.1.05. SQL

- Structured Query Language
  - (SQL or SEQUEL)
  - Wikipedia reference
- Success of relational databases
- Developed for SystemR at IBM
- ANSI standardised
- SQL-1986 (SQL1), ongoing extension
- SQL-1992 (SQL2), current version (Oracle 9i)
- SQL-1999 (SQL3), regular expression matching, recursive queries
- SQL-2003, XML features, auto-generated columns

2.1.05b. SQL command syntax

- Where follows here is a brief summary
  - Oracle syntax
  - Similar but not identical to MySQL/MSSQL
- General familiarity
- Query writing best learnt by doing it
- Lecture live-example
- Coursework 1 will be SQL
- Oracle (9i) SQL reference
- MySQL (5.0) SQL reference

2.1.05c. SQL in application

- Keyword oriented language
- Keywords not congruous with Relational model
- Lots of different ways to write SQL
    - Analogous to C/Java formatting
    - if (b==2) { a=1; } else { a=0; }
- Recommend using case to differentiate attributes and keywords
    - SELECT colour, size, shape FROM fruit WHERE weight>22;
- Oracle user accounts on Teaching database
- Namespace references, e.g. shared.cars

2.1.06. SQL Create schema

- Data definition commands
- CREATE
    - SCHEMA <schema_name> AUTHORIZATION <a>
    - or workspace
- Beware of names
    - Name collisions produce odd behaviours
- SQL Schema embraces Tables (relations), constraints, views, domains, authorizations

2.1.07. SQL Create table

- CREATE TABLE
    - <schema_name>.<relation_name>
    - (
        - <attribute_definitions>
        - <key>
        - <constraints>
    -)
- CREATE TABLE example (Oracle)
- Tables can (and should) be indexed by user
- e.g. <username>.<tablename>
- Normal login implies username
- Non-local table access

2.1.08. Data types and domains (Oracle)

- Numeric
    - ENUM
    - NUMBER, NUMBER(i), NUMBER(i,j)
        - Formatted numbers, i precision, j scale
        - (number of digits total, after decimal point)
    - Character-string
        - CHAR(n) - n is length
        - VARCHAR2(n) - n is max
    - DESCRIBE output example
    - Multi-database comparison of Datatypes
    - Database legacy: limited storage necessitated efficient storage
    - Does it need to be efficient anymore?

You might consider all SQL types as being conceptually similar to attribute types in the relational model, although in reality the implementation of these types in a DBMS only approximates the mathematical purity of unordered domain sets etc.

2.1.08b. Data types and domains (MySQL)

- Numeric
  - TINYINT, INT, INT UNSIGNED
  - FLOAT, DOUBLE, DECIMAL
  - ENUM
  - Character-string
    - CHAR(n) - n is length
    - VARCHAR(n) - n is max
    - TINYTEXT, TEXT
    - Beware different default/maximum lengths to Oracle
  - BLOB
  - Multi-database comparison of Datatypes

2.1.09. Time-based data types

- Date and Time
  - DATE
    - Ten positions, components YYYY-MM-DD
  - TIME
    - Eight positions, components HH:MM:SS
  - TIME(i)
    - Time fractional seconds precision
    - Adds i+1 positions
  - TIMESTAMP
    - optionally WITH TIME ZONE
  - Very sensitive to syntactical ambiguities
    - day/month/year/hour/minute separators

2.1.10. DROPing

- DROP <object> <obj_name> <flags>
- DROP SCHEMA <schema_name> CASCADE
  - drops all workspace tables, domains
- DROP TABLE <relation_name> RESTRICT
  - only drops table if
  - not referenced in any constraints/views
- Notion of cascading
- Table links

2.1.11. ALTERing

- Schema evolution
- Design side

- ALTER TABLE <schema_name>.<relation_name> ADD <var_name> <var_type>;
- Example
  - ALTER TABLE uni.student ADD hall VARCHAR(32);
- Upper and lower case syntax
- Naming conventions

2.1.12. Queries

- Helper interfaces
  - HeidiSQL/phpMyAdmin/Sword/SQLplus
  - Design/perform a lot of routine queries for you
  - Important to learn SQL, reinforcement
  - Designing select queries is more difficult
  - Visual interfaces still lacking in this area
- Select queries in SQL
- Basic singlets
- Renaming
- Queries with Joins
- Nested queries

2.1.13. SQL Queries

- SELECT statement
- Similar to relational data model SELECT then PROJECT
  - SELECT <attribute list>
  - FROM <table list>
  - WHERE <condition>;

ID	Make	Model	Derivative	H
1	AC	Ace	3.5 Twin Turbo roadster	3
2	AC	Aceca	3.5 Twin Turbo coupe	3
3	AC	Cobra	5.0 Mk IV CRS roadste	2
4	AC	Superblower	5.0 V8 roadster	3
5	AC	Superblower	5.0 V8 Spirit of Brookla	3
6	Alfa Romeo	147	1.6 16V TS Turismo 3-(	1
7	Alfa Romeo	147	1.6 16V TS Lusso 3-do	1
8	Alfa Romeo	147	2.0 16V Selespeed Lus	1
9	Alfa Romeo	147	2.0 16V Lusso 3-door	1
10	Alfa Romeo	147	1.6 16V TS Turismo 5-(	1
11	Alfa Romeo	147	1.6 16V TS Lusso 5-do	1
12	Alfa Romeo	147	2.0 16V Lusso 5-door	1
13	Alfa Romeo	147	2.0 16V Selespeed Lus	1
14	Alfa Romeo	156	1.6 TS Lusso	1
15	Alfa Romeo	156	1.6 TS Veloce (Leather	1
16	Alfa Romeo	156	1.8 TS Lusso Saloon	1
17	Alfa Romeo	156	1.8 TS Veloce (Recaro)	1
18	Alfa Romeo	156	1.8 TS Veloce (Leather	1
19	Alfa Romeo	156	2.0 TS Lusso Saloon	1
20	Alfa Romeo	156	2.0 TS Veloce (Recaro)	1
21	Alfa Romeo	156	2.0 TS Veloce (Leather	1

2.1.14. SQL Queries

- SELECT <attr_list>
  - FROM R,S,T
  - WHERE DNO = 10
- equivalent to
- $p_{<attr\_list>}(s_{DNO=10}$ (R X S X T))
- True-false evaluation tuple by tuple
- WHERE clause as compound logical statement

2.1.15. SQL Queries

- Produces a relation/set of tuples
- Can be used to extract a single tuple
- e.g. SELECT bday, age
  - FROM student
  - WHERE fname='Tim' AND lname='Smith'
  - Result = (13-05-80, 20)
- Argument quoting (')
  - SQL poisoning
  - Not null
  - Not numeric values
- MySQL Attribute quoting (`)
  - Hypothetical attribute `all`, all, and ALL

SQL poisoning is a vulnerability exposed by inadequate escaping of arguments/variables used to compose SQL queries.

E.g. *Tim* in previous example, could be *Tim'; DELETE FROM student;' SELECT * FROM student WHERE 1*

2.1.16. Renaming and referencing

- AS keyword
- (Partial) Attribute renaming in projection list
  - SELECT fname AS firstName, minit, lname AS surname...
- Role names for relations
  - SELECT S.FNAME, F.FNAME, S.LNAME
    - FROM STUDENT AS S, STUDENT AS F
    - WHERE S.LNAME=F.LNAME
- (Total) Attribute renaming in FROM
  - SELECT s.firstName, s.surname
    - FROM student AS s(firstName,surname,DOB,NINO,tutor)
- Wildcards (SELECT s.* FROM...)

2.1.17. SQL Tables

- Relations are bags, not sets

    - e.g. projection of non-key attributes
- Set cannot contain duplicate item/repetition
- Duplicates exist in bags and be:
    - SELECT DISTINCT (eliminated)
    - SELECT ALL (ignored/kept)

2.1.18. Queries and Joins

- Relational database allows inter-related data
- SQL select FROM gives Cartesian product
- WHERE clause defines join condition
    - SELECT proj.pnum, mgr.ssn
    - FROM project AS proj, employee AS mgr
    - WHERE proj.mgrssn = mgr.ssn;
- Alternatively, explicitly define join (note type)
    - SELECT project.pnum, employee.ssn
    - FROM project INNER JOIN employee
    - ON project.mgrssn = employee.ssn;

2.1.18b. Outer joins

- Outer joins are crucial in the real-world
- Databases often contain NULLs (3VL)
- Analysis of where the crucial data is across a relationship
- Previous example, only get project data for managed projects
    - SELECT project.*, employee.*
    - FROM project INNER JOIN employee
    - ON project.mgrssn = employee.ssn;

Project	ID	Name	mgrssn		
	1	Marketing	1		
	2	Development	NULL		
	3	Website	4		
Employee	**SSN**	**Firstname**	**Surname**		
	1	Alex	Jones		
	2	Jamal	Al Hak		
	3	Nissan	Imdana		
	4	Johan	Fredriksson		
InnerJoin	**ID**	**Name**	**SSN**	**First**	**Surname**
	1	Marketing	1	Alex	Jones
	3	Website	4	Johan	Fredriksson

2.1.18c. Outer joins (cont)

Scale of loss isn't always instantly obvious
NULLs often used unpredicably
May want project information, even if no employee attached as manager

- SELECT project.*, employee.*
- FROM project LEFT OUTER JOIN employee
- ON project.mgrssn = employee.ssn;

Project	ID	Name	mgrssn		
	1	Marketing	1		
	2	Development	NULL		
	3	Website	4		
Employee	**SSN**	**Firstname**	**Surname**		
	1	Alex	Jones		
	2	Jamal	Al Hak		
	3	Nissan	Imdana		
	4	Johan	Fredriksson		
LeftOuter	**ID**	**Name**	**SSN**	**First**	**Surname**
	1	Marketing	1	Alex	Jones
	2	Development	NULL	NULL	NULL
	3	Website	4	Johan	Fredriksson
FullOuter	**ID**	**Name**	**SSN**	**First**	**Surname**
	1	Marketing	1	Alex	Jones
	2	Development	NULL	NULL	NULL
	3	Website	4	Johan	Fredriksson
	NULL	NULL	2	Jamal	Al Hak
	NULL	NULL	3	Nissan	Imdana

2.1.19. 2y and 3y joins

- Queries can encapsulate any number of relations
  - Even one relation many times (in different roles)
- Relationship chain
- Across many relations
  - Tuples as Entities OR Relationships
- e.g. Employee -> Works_on -> Project -> Department -> Manager

2.1.20. Recursive closure

- Can’t be done in SQL2
- Recursive relationships
- Unknown number of steps
- SQL2 can’t generalise in single query

2.1.21. Nested queries

- Essential one or more (inner) queries within an (outer) query
- Inner and outer query
- Not to be confused with inner and outer joins
- Inner query can go in three places
  - SELECT clause (projection list)
    - Must return a single value, then aliased as attribute in outer result
  - FROM clause

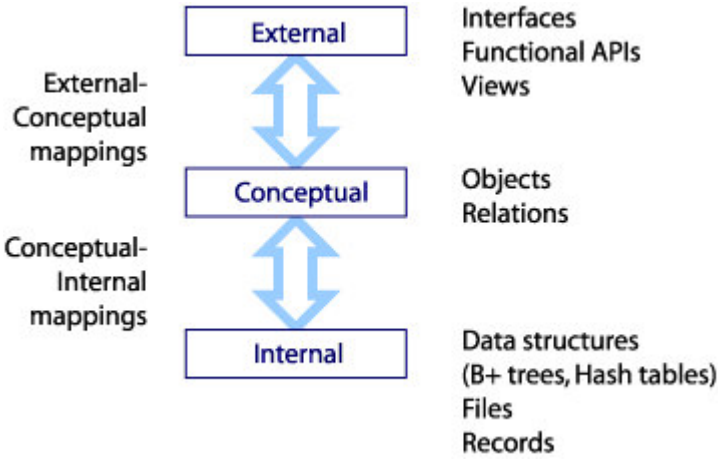
        - Inner query result used as standard table in FROM cross product
    - WHERE clause

2.1.21b. Nested query example

- Use of query result as comparator for other (outer) query
    - SELECT DISTINCT course
    - FROM dept WHERE course IN (
        - SELECT d.course
        - FROM dept AS d, faculty AS f, student AS s
        - WHERE d.ownfac=f.id AND s.owndept=d.id
        - AND f.name='Eng' AND s.year='3'
    -) OR course IN (
        - SELECT course
        - FROM dept
        - WHERE code LIKE 'COMS3%');

2.1.22. Bridging SQL across 3 tiers

- Three tier database design
- Changing role of DBMS
- Indices
- Aggregate functions (conceptual)
    - Over bags and sub-bags
- Creating and updating views (ext)
- SQL embedding



In this subsection we look at the different roles SQL play across the three tiers of database design. We discuss the areas in which SQL is lacking and how those difficiencies can be complemented by embedding SQL in other languages.

2.1.25. Indices

- Low/Internal level
- Index by one attribute
- For queries selecting by that attribute:

    - Faster tuple access (ordered tuples)
    - Reduces database memory load
        - Small cross product relation, only crosses requisites
    - Accelerates query resolution time
- CREATE INDEX Index_Name ON RELATION(Attribute);

2.1.26. Aggregate functions

- Run over groups of tuples
- Takes a projected attribute list as an argument
- Produce relation with single tuple
- SUM, MAX, MIN, AVG, COUNT
- e.g. AggFunc over all tuples
    - SELECT SUM(SALARY), MAX(SALARY), MIN(SALARY)
    - FROM EMPLOYEE;
- Single attribute lists (distinct values)
- Multi-attribute lists (granularity of distinct values by pairing)

2.1.27. Aggregates over sub-bags

- Can run over subsets of tuples
- GROUP BY keyword
- Specifies the grouping attributes
- Need to also appear in projected attr_list
- Show result along side value for group attr
- e.g. AggFunc over subgroups
    - SELECT dno, COUNT(*)
    - FROM employee
    - GROUP BY dno

Quick SQL check, do all attributes in the SELECT projection list appear in the GROUP BY projection list.

2.1.28. Creating views

- Views are partial projections
- Virtual relations, or views of live relations
- Update synchronised
    - CREATE VIEW <virtual_relname>
    - AS <real_relation>
- Real relation could be a query result
- Clever bit is the change propagation
- UPDATEs made to the view dataset are flooded back to relations
    - INSERT and DELETE behaviour needs to be defined
    - Non-trivial as INSERT into view (virtual relation) may leave holes in real relation

2.1.29. Embedding SQL

- SQL (alone) can do lots of clever things in one expression
- But can only execute a single expression
- Can structure SQL commands into proper programming languages
- Java Database Connection (JDBC)
    - javac, then java VM
- COBOL, C or PASCAL
    - precompiled with PRO*COBOL or PRO*C
- Procedure Language (PL/SQL)
    - Oracle/MySQL procedural language
    - *Stored* procedures can take parameters

2.2. Internals

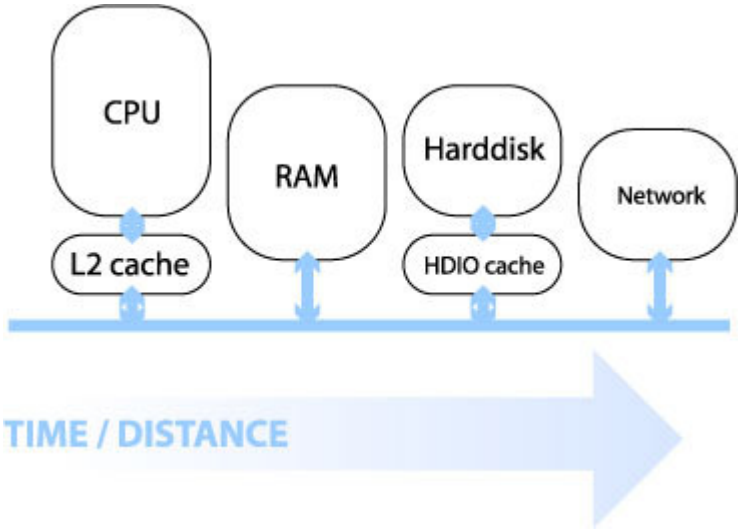
In this lecture we look at...
[Section notes PDF 180Kb]

2.2.01. Introduction

- Database internals (base tier)
- RAID technology
    - Reliability and performance improvement
- Record and field basics
- Headers to hashing
- Index structures

2.2.01b. Machine architecture (by distance)

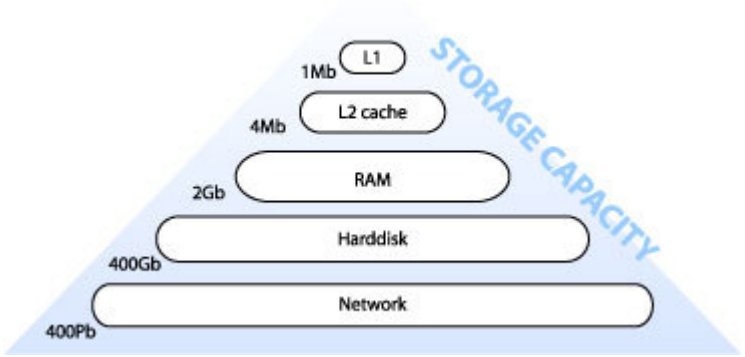
- Distance from chip determines minimum latency
- Speed of light is a constant
- Impact of bus frequencies
    - IDE (66,100,133 Hz)
    - PCI, PCI-X (66,100,133 Hz)
    - PCI Express (1Ghz to 12Ghz)
- Impact of bus bandwidths
    - PCI (32/64 bit/cycle, 133MB/s)
    - PCI Express (x16 8.0GB/s)



Here's a link from Intel showing a machine architecture with signal bandwidths: Intel diagram

2.2.01c. Machine architecture (by capacity)

- Capacity increased with distance
- Staged architecture as compromise
- Speed, time/distance
- Also cost, heat, usage scale



2.2.02. Database internals

- Stored as files of records (of data values)
  - Auxiliary data structures/indices
- 1y and 2y storage
  - memory hierarchy (pyramid diagram)
  - volatility
- Online and offline devices
- Primary file organisation, records on disk
  - Heap - unordered
  - Sorted - ordered, sequential by sort key
  - Hashed - ordered by hash key
  - B-trees - more complex

2.2.03. Disk fundamentals

- DBMS task
  - linked to backup
- 1y, 2y and 3y
  - e.g. DLT tape
- Changing face of current technology
  - Impact of inexpensive harddisks
  - Flash memory devices (CF, USB)
- Random versus sequential access
- Latency (rotational delay) and
- Bandwidth (data transfer rate)

2.2.04. RAID technology

- Redundant Array of Independent Disks
- Data striping
  - Blocks (512 bytes), bits and transparency
- Reliability (1/n)
  - Mirroring/shadowing
  - Error correction codes/parity
- Performance (n)
  - Mirroring (2x read access)
  - Multiple parallel access

2.2.05. RAID levels

- 0 No redundant data
- 1 Disk mirrors (performance gain)
- 2 Hamming codes (also detect)
- 3 Single parity disk
- 4 Block level striping
- 5 and parity/data distribution
- 6 Reed-Soloman codes

2.2.06. Records and fields

- DBMS specific, generally
- Records (tuples) comprise fields (attributes)
- File is a sequence of records
- Variable length records
  - Variable length fields
  - Multi-valued attributes/repeating fields
  - Optional fields
  - Mixed file of different record types

2.2.07. Fields

- records -> files -> disks
- Fixed length for efficient access
- Networking issues
- Delimit variable length fields (max)
- Explicit record/field lengths
- Separators (,;,:,$,?,%)
- Record headers and footers
- Spanning
    - block boundaries and redundancy

2.2.08. Primary organisation

- Bias data manipulation to 1y memory
    - Load record to 1y, write back
    - Cache theorem
- Data storage investment, rapidity of access
    - optimisations based on frequent algorithmic use
- Ordering, ordering field/key field
- Hashing

2.2.09. Indexes/indices

- Auxiliary structures/secondary access path
- Single level indexes (Key, Pointer)
- File of records
- Ordering key field
- Primary, Secondard and Clustering

2.2.09b. Primary index example

- Primary index on simple table
- Ordering key field (primary key) is Integer
- Pointers as addresses
- Sparse, not dense

Primary Index (sparse)			*File*	
OKF	**Address**		**Address**	**Surname**
Daniels	0x1F00		0x1F00	Daniels
McBane	0x2200		0x2000	Jameson
Simpson	0x2500		0x2100	Jones
			0x2200	McBane
			0x2300	O'Rourke
			0x2400	Riddesh
			0x2500	Simpson
			0x2600	Smith

2.2.10. Primary Index file (as pairs list)

- Two fields <K(i),P(i)>
- Ordering key field and pointer to block
- Second example, indexing candidate key *Surname*
    - K(1)="Barnes",P(1) -> block 1
        - Barnes record is first/anchor entry in block 1
    - K(2)="Smith",P(2) -> block 6
    - K(3)="Zeta",P(3) -> block 8
- Dense (K(i) for every record), or Sparse
- Enforce key constraint

2.2.10b. Clustering index example

- Clustering index
- Ordering key field (OKF) is non-key
- Each entry points to multiple records

Clustering Index				*File*	
OKF	**Address**		**Address**	**Surname**	**Firstname**
Sanderson	0x1F00		0x1F00	Sanderson	James
Smith	0x2000		0x2000	Smith	Abdul
Sopley	0x2300		0x2100	Smith	Jill
Stanhope	0x2400		0x2200	Smith	Rajir
Szechl	0x2500		0x2300	Sopley	John
			0x2400	Stanhope	Alex
			0x2500	Szechl	Ikir
			0x2600	Szechl	Ptolemy

2.2.11. Clustering Index (as pairs list)

- Two fields <K(i),P(i)>
- Ordering non-key field and pointer to block
    - Internal structure e.g. linked list of records
- Each block may contain multiple records
    - K(1)="Barnes",P(1) -> block 1
    - K(2)="Bates",P(2) -> block 2
    - K(3)="Zeta",P(3) -> block 3
- K(i) not required to have
    - a distinct value for each record
    - non-dense, sparse

2.2.11b. Secondary Index example

- Independent of primary ordering
- Can't use block anchors
- Needs to be dense

Secondary Index			*File*	
OKF	**Address**	**Address**	**Surname**	**Firstname**
Abdul	0x2000	0x1F00	Sanderson	James
Alex	0x2400	0x2000	Smith	Abdul
Ikir	0x2500	0x2100	Smith	Jill
James	0x1F00	0x2200	Smith	Rajir
Jill	0x2100	0x2300	Sopley	John
John	0x2300	0x2400	Stanhope	Alex
Ptolemy	0x2600	0x2500	Szechl	Ikir
Rajir	0x2200	0x2600	Szechl	Ptolemy

2.2.12. More indices

- Single level index
  - ordered index file
  - limited by binary search
- Multi level indices
  - based on tree data structures (B+/B-trees)
    - faster reduction of search space ($\log_{fo} b_i$)

2.2.13. Indices

- Database architecture
  - Intension/extension
- Indexes separated from data file
  - Created/disgraded dynamically
  - Typically 2y to avoid reordering records on disk

2.2.14. Query optimisation

- Faster query resolution
  - improved performance
  - lower load
  - hardware cost:performance ratio
- Moore's law
- Query process chain
- Query optimisation

2.2.15. Query processing

- Compile-track familiarity
  - Scanner/tokeniser - break into tokens
  - Parser - semantic understanding, grammar
  - Validated - check attribute names
    - Query tree
    - Execution strategy, heuristic
  - Query optimisation
    - In (extended relational) canonical algebra form

2.2.16. Query optimisation

- SQL query
  - SELECT lname, fname
  - FROM employee
  - WHERE salary > (
    - SELECT MAX(salary)
    - FROM employee
    - WHERE dno=5
  -);
- Worst-case
  - Process inner for each outer
- Best-base
- Canonical algrebraic form

2.2.16b. Query optimisation implementation

- Indexing accelerates query resolution
- Closed comparison (intra-tuple)
  - all variables/attributes within single tuple
  - e.g. x < 100
- Open comparison (inter-tuple)
  - variables span multiple tuples
- Essentially a sorting problem
- Internal sorting covered (pre-requisites)
- Need external sort for non-cached lists

2.2.17. Query optimisation

- External sorting
  - Stems from large disk (2y), small memory (1y)
  - Sort-merge strategy
    - Sort runs (small sets of total data file)
    - Then merge runs back together
  - Used in
    - SELECT, to accelerate selection (by index)
    - PROJECT, to eliminate duplicates
    - JOIN, UNION and INTERSECTION

3. Database Design

This is the Database Design course theme.
[Complete set of notes PDF 295Kb].

3.1. Functional Dependency

In this lecture we look at...

[Section notes PDF 64Kb]

3.1.01. Introduction

- What is relational design?
  - Notion of attribute distribution
  - Conceptual-level optimisation
- How do we asses the quality of a design?

3.1.02. Value in design

- Allocated arbitrarily by DBD under ER/EER
- Goodness at
  - Internal/storage level (base relations only)
    - Reducing nulls - obvious storage benefits /frequent
    - Reducing redundancy - for efficient storage/anomalies
  - Conceptual level
    - Semantics of the attributes /single entity:relation
    - No spurious tuple generation /no match Attr,-PK/FK

3.1.03. Initial state

- Database design
- Universal relation
  - $R = \{A_1, A_2, \ldots, A_n\}$
  - Set of functional dependencies F
- Decompose R using F to
  - $D = \{R_1, R_2, \ldots, R_n\}$
  - D is a decomposition of R under F

3.1.05. Aims

- Attribute preservation
  - Union of all decomposed relations = original
- Lossless/non-additive join
  - For every extension, total join of $r(R_i)$ yeilds r(R)
  - no spurious/erroneous tuples

3.1.06. Aims (also)

- Dependency preservation
  - Constraints on the database
  - X ® Y in F of R, appears directly in R_i
- Attributes X È Y all contained in R_i

- Each relation R_i in 3NF

But what's a dependency?

3.1.07. Functional dependency

- Constraint between two sets of attributes
  - Formal method for grouping attributes
- DB as one single universal relation/-literal
  - R = {A_1,A_2,…,A_n}
  - Two sets of attributes, X Í R,Y Í R
- Functional dependency (FD or f.d.) X ® face=Arial> Y
  - If $t_1[X] = t_2[X]$, then $t_1[Y] = t_2[Y]$
    - Values of the Y attribute depend on value of X
    - X functionally determines Y, not reverse necessarily

3.1.08. Dependency derivation

- Rules of inference
- reflexive: if X Ê Y then X face=Symbol>® Y
- augment: {X ® Y} XZ face=Symbol>® YZ
- transitive: {X ® Y,Y face=Symbol>® Z} X ® face=Arial> Z

- Armstrong demonstrated complete
- for closures

3.1.09. Functional dependency

- If X is a key (primary and/or candidate)
  - All tuples t_i have a unique value for X
  - No two tuples (t_1,t_2) share a value of X
- Therefore X ® Y
  - For any subset of attributes Y
- Examples
  - SSN ® {Fname, Minit, Lname}
  - {Country of issue, Driving license no} ® face=Arial> SSN
  - Mobile area code ® Mobile network (not anymore)

3.1.10. Process

- Typically start with set of f.d., F
  - determined from semantics of attributes
- Then use IR1,2,3 to infer additional f.d.s
- Determine left hand sides (Xs)
  - Then determine all attributes dependent on X
- For each set of attributes X,
  - determine X+ :the set of attributes f.d'ed by X on F

3.1.11. Algorithm

- Compute the closure of X under F: X+
  - xplus = x;
  - do
    - oldxplus = xplus;
    - for (each f.d. Y ® Z in F)
      - if (xplus Ê Y) then xplus = xplus È Z;
    - while (xplus = = oldxplus);

3.1.12. Function dependency

- Consider a relation schema R(A,B,C,D) and a set F of functional dependencies
  - Aim to find all keys (minimal superkeys),
  - by determining closures of all possible X subsets of R's attributes, e.g.
    - A+, B+, C+, D+,
    - AB+, AC+, AD+, BC+, BD+, CD+
    - ABC+, ABD+, BCD+
    - ABCD+

3.1.13. Worked example

- Let R be a relational schema R(A, B, C, D)
- Simple set of f.d.s
- AB ® C, C face=Symbol>® D, D ® face=Arial> A
- Calculate singletons
  - A+, B+, C+, D+,
- Pairs

    - AB+, AC+,…
- Triples
    - and so on

3.1.14. Worked example

- Compute sets of closures
    - AB ® C, C
      face=Symbol>® D, D ®
      face=Arial> A

- 1. Singletons
    - A+ ® A
    - B+ ® B
    - C+ ® CDA
    - D+ ® AD

- Question: are any singletons superkeys?

3.1.15. F.d. closure example

- 2. Pairs (note commutative)
    - AB+ ® ABCD
    - AC+ ® ACD
    - AD+ ® AD
    - BC+ ® ABCD
    - BD+ ® ABCD
    - CD+ ® ACD
- Superkeys?

3.1.16. F.d. closure example

- 3. Triples
    - ABC+ ® ABCD
    - ABD+ ® ABCD
    - BCD+ ® ABCD
- Keys?

- 4. Quadruples

- ABCD+ ® ABCD

3.1.17. F.d. closure summary

- Superkeys:
  - AB, BC, BD, ABC, ABD, BCD, ABCD
- Minimal superkeys (keys)
  - AB, BC, BD

3.2. Normal Forms

In this lecture we look at...
[Section notes PDF 121Kb]

3.2.01. Orthogonal design

- Information Principle:
  - The entire information content of the database is represented in one and only one way, namely as explicit values in column positions in tables
- Implies that two relations cannot have the same meaning
  - unless they explicitly have the same design/attributes (including name)

3.2.02. Normalization

- Reduced redundancy
- Organised data efficiently
- Improves data consistency
  - Reduces chance of update anomalies
  - Data duplicated, then updated in only one location
- Only duplicate primary key
  - All non-key data stored only once
- Data spread across multiple tables, instead of one Universal relation R

3.2.03. Good or bad?

- Depends on Application
- OLTP (Transaction processing)
  - Lots of small transactions
  - Need to execute updates quickly
- OLAP (Analytical processing/DSS)
  - Largely Read-only
  - Redundant data copies facilitate Business Intellegence applications, e.g. star schema (later)
- 3NF considered ‘normalised’

- save special cases

3.2.04. Normal forms (1NF)

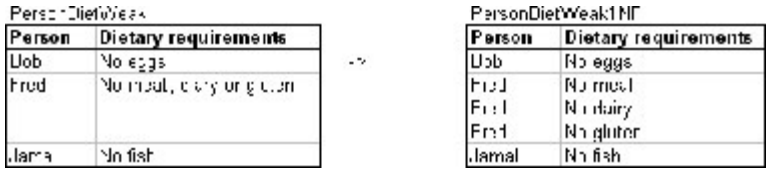
- First Normal form (1NF)
  - Disallows multivalued attributes
  - Part of the basic relational model
- Domain must include only atomic values
  - simple, indivisible
- Value of attribute-tuple in extension of schema
- $t[A_i] \hat{I} \text{dom}(A_i)$

3.2.05. Normalisation (1NF)

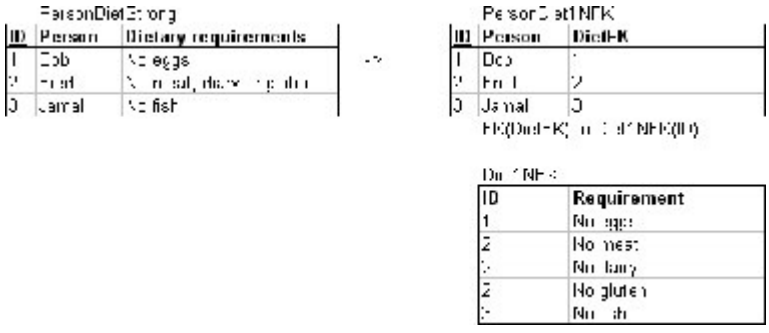
- Remove fields containing comma separated lists
- Multi-valued attribute (A_{MV}) of R_i
- Create new relation (R_{NEW})
  - with FK to R_i[PK]
  - R_{NEW}(UID, A_{MV}, FK_I)

3.2.06. Normalisation (1NF)

- On weak entity



- On strong entity



3.2.07. Normal forms (2NF)

- A relation R_i is in 2NF if:
  - Every nonprime attribute A in R_i is
  - fully functionally dependent on 1y key of R

- If all keys are singletons, guaranteed

- If R_i has composite key are
  - all non-key attributes fully functionally dependent
  - on all attributes of composite key?

3.2.08. Normal forms (2NF)

- Second normal form (2NF)
  - Full functional dependency X ®
    face=Arial> Y
    - A Î X, (X - {A}) ↛ Y

- If any attribute A is removed from X
- Then X ® Y no longer holds
  - Partial functional dependency
  - A Î X, (X - {A})
    face=Symbol>® Y

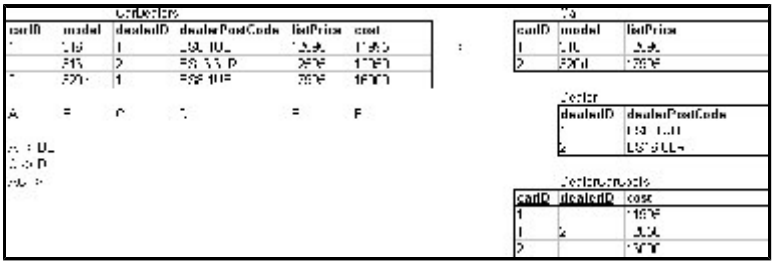
3.2.09. Normal forms (2NF)

- In context
  - Not 2NF: AB ®
    face=Arial> C, A ® C
    - AB ® C is not in 2NF,
      because B can be removed

  - Not 2NF: AB ® CDE, B
    face=Symbol>® DE
    - because attributes D&E are dependent on part of the composite key
      (B of AB), not all of it

3.2.10. Normalisation (2NF)

- Split attributes not depended on all of the primary key into separate relations



3.2.11. Normal forms (BCNF)

- Boyce-Codd Normal form (BCNF)
  - Simpler, stricter 3NF
    - BCNF ® 3NF
    - 3NF does not imply BCNF
  - nontrivial functional dependency X ®
    face=Arial> Y
  - Then X must be a superkey

3.2.12. Normal forms (3NF)

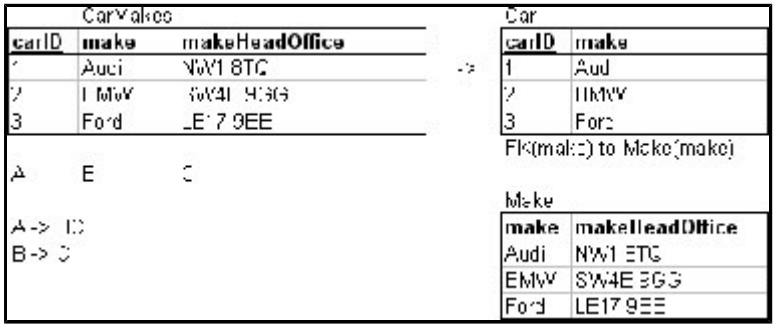
- Third Normal form (3NF)
- Derived/based on transitive dependency
- For all nontrivial functional dependencies
- X ®
  face=Arial> A
- Either X must be a superkey
- Or A is a prime attribute
- (member of a key)

3.2.13. Normal forms in context

- AB ® C, C
  face=Symbol>® D, D ®
  face=Arial> A
- In context
  - 3NF? Yes
    - Because AB is a superkey and
    - D and A are prime attributes
  - BCNF? No
    - Because C and D are not superkeys
    - (even though AB is)

3.2.14. Normalisation (3NF)

- CarMakes not in 3NF because:
  - singleton key A
  - non-trivial fd B ® C
    - B not superkey, C not prime attribute



3.3. OODB

In this lecture we look at...
[Section notes PDF 34Kb]

3.3.01. Introduction

- Database architectures, beyond
- Why OODBMS?
- ObjectStore
- CORBA object distribution standard

3.3.02. Large DBMS

- Complex entity fragmentation
  - across many relations
- Breaks the miniworld-realworld dichotomy
- Requires conceptual abstracting layer
- Difficult to retrieve all information for x
- Compounded by version control

3.3.03. Object orientation

- Object components (icv triples)
  - Object Identity (OID), I
    - replaces primary key
  - Type constructor, c
    - how the object state is constructed from sub-comp
    - e.g. atom, tuple (struct), set, list, bag, array
  - Object state, v
  - Object behaviour/action

3.3.04. Desirable features

- Encapsulation
  - Abstract data types

    - Information hiding
- Object classes and behavior
    - Defined by operations (methods)
- Inheritance and hierarchies
- Strong typing (no illegal casting)
    - don't think about inheritance just yet

3.3.05. Desirable features

- Persistence
    - Objects exist after termination
    - Naming and reachability mechanism
    - Late binding in Java
- Performance
    - user-def functions executed on server, not client
- Extension into relational model
    - Domains of objects, not just values
    - Domain hierarchies etc.

3.3.06. Desirable features

- Polymorphism
    - aka. operator overloading
    - same method name/symbol
    - multiple implementations
- Easy link to Programming languages
    - popular OO language like Java/C++
    - Better than PL/SQL integration
    - Much better than PL-JDBC integration!
- Highly suitable for multimedia data

3.3.07. Undesirable features

- Object Ids
    - Artificial Real-Mini, double edged sword
    - Exposes inner workings (suspended abstraction)
- Lack of integrity constraints
- No concept of normalisation/forms
- Extreme encapsulation
    - e.g. creation of many accessor/mutator methods
- Lack of (better) standardisation

3.3.08. More undesirables

- Originally no mechanism for specifying
- relationships between objects
- In RDBMS – relationships are tuples
- In OODBMS – relationships should be properties of objects

3.3.09. ObjectStore

- Packages supporting Java or C++
- C++ package uses:
  - C++ class definition for DDL
  - insert(e), remove(e) and create collections, for DML
- Bidirectional relationship facility
- Persistency transparency
  - Identical pointers to persistent and transient objects

3.3.10. CORBA

- Common Object Request Broker Architecture
- Object communication (unifying paradigm)
  - Distributed
  - Heterogeneous
  - Network, OS and language transparency
- Java implementation org.omg.CORBA
- Also C, C++, ADA, SMALLTALK

3.4. Type Inheritance and EER diagrams

In this lecture we look at...
[Section notes PDF 117Kb]

3.4.01. Introduction

- Design/schema side (Entity types)
- Object-orientated concepts
  - Java, C++ or UML
  - Sub/superclasses and inheritance
- EER diagrams
- EER to Relational mapping

3.4.02. OO

- Inheritance concept
  - Attributes (and methods)
- Subtypes and supertypes
- Specialisation and Generalisation
- ER diagrams
  - show entities/entity sets
- EER diagrams
  - show type inheritance
  - additional 8^{th} step to ER->Relational mapping

3.4.03. Objects

- Basic guide to Java
- Object, classes as blueprints
- Object, collection of methods and attributes
- Miniworld model of real world things
- Object, entity in database terms

3.4.04. Abstract

- Similar objects
- Car Park example
- Student example
- Shared properties/attributes
- Generalisation
- Reverse, specialisation

3.4.05. Relationships

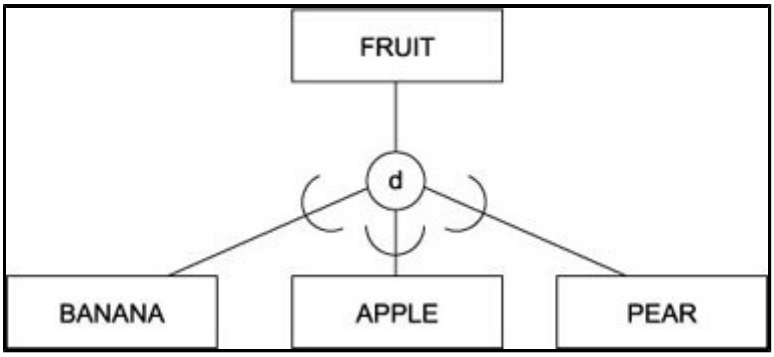
- Using English as model
- ‘Is a’ (inheritance)
- ‘Has a’ (containment)
- Nouns as objects
- Verbs as methods
- Adjectives as variables (sort of)

3.4.06. Classes

- Superclasses (Student)
- Subclasses (Engineer, Geographer, Medic)
- Inheritance
- Subclass inherits superclass attributes
    - Union of specific/local and general attributes
- Inheritance chains
    - Person -> Student -> Engineer -> Computer Scientist

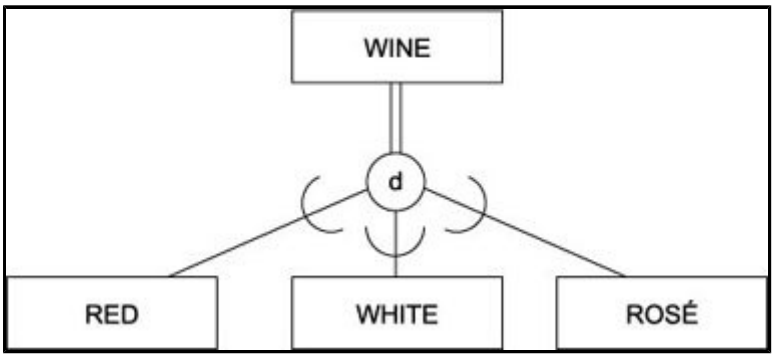
3.4.07. EER Fruit example

- Partial participation
- Disjoint subclasses
- A fruit may be either a pear or an apple or a banana, or none of them. A fruit may not be a pear and a banana, an apple and a banana, an apple and a pear....



3.4.08. EER Wine example

- Total, disjoint
- Equivalent to Java Abstract classes
- A Wine has to be either Red, White or Rosé cannot be both more



3.4.09. More extended (EER)

- Specialisation lattices
  - and Hierarchies
- Multiple inheritance
- Union of two superclasses (u in circle)
- In addition to basic ER notation

3.4.10. EER diagramatic notation

- Subset symbol to illustrate
- sub/superclass relationship
- direction of relationship
- Circle to link super to subclasses
  - Disjoint
  - Overlapping
  - Union

3.4.11. Disjointness constraint

- Disjointness (d in circle) – single honours

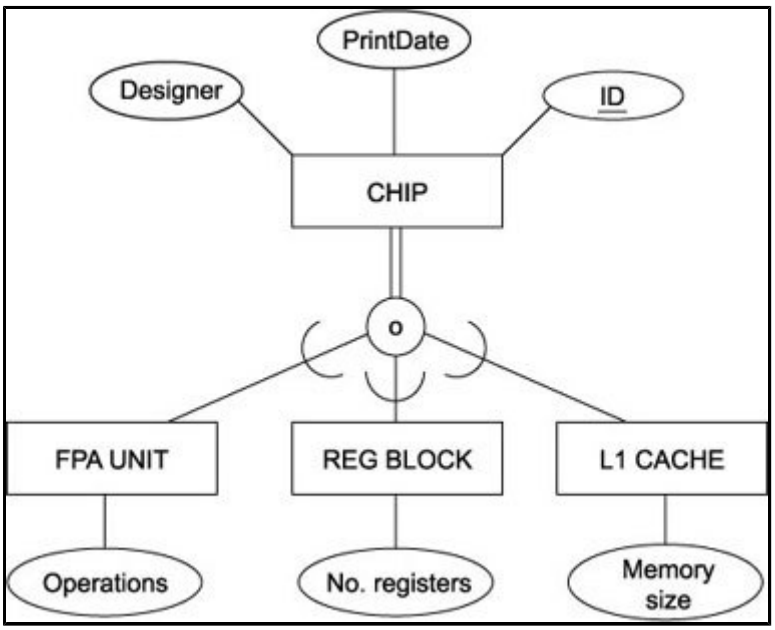
- Overlapping (o in circle) – joint honours/sports
- Membership condition on same attribute
  - attribute-defined specialisation
  - defining attribute
  - implies disjointness
- versus user-defined
  - each entity type specifically defined by user

3.4.12. Completeness constraint

- Total specialisation
  - Every entity in the superclass must be a member of atleast 1 subclass
  - Double line (as ER)
- Partial specialisation
  - Some entites may belong to atleast 1 subclass, or none at all
  - Single line
- Yields 4 possibilities
  - (Total-Dis, Total-Over, Partial-Dis, Partial-Over)

3.4.13. EER Chip example

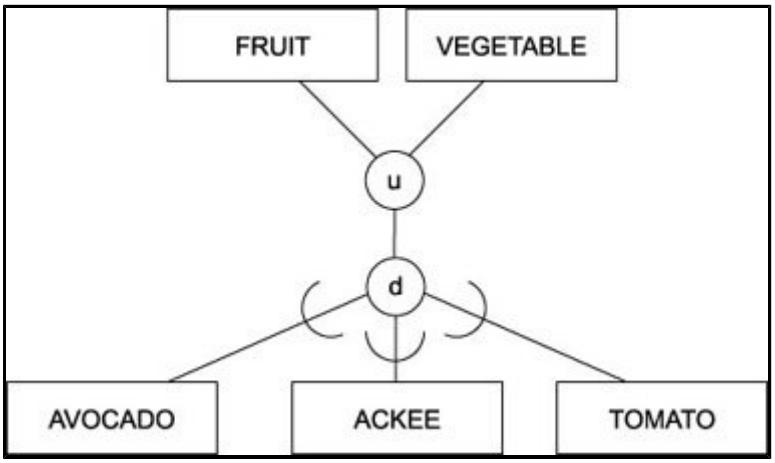
- Total, overlapping
- A Chip may has to be at least one of FPA Unit, Reg Block, L1 Cache, and may be more than one type



3.4.14. EER Multiple inheritance

- Type hierarchies
- Specialisation lattices
- *Well, sir, the Supreme Court of the United States has determined that the tomato is for legal and commercial purposes both a fruit and a vegetable. So we can legally refer to tomato juice as 'vegetable' juice.*

- Candice, General Foods



3.4.15. EER to Relational Mapping

- Initially following 7 ER stages
- Stage 8
- 4 different options
    - Optimal solution based on problem
- Let C be superclass, $S_{1...m}$ subclasses

3.4.16. Stage 8

- Create relation for C, and relations for $S_{1..m}$ each with a foreign key to C(primary key)
- Create relations for $S_{1..m}$ each including all attributes of C and its primary key

3.4.17. Stage 8

- Create a single relation including all attributes of C u $S_{1..m}$ and a type/discriminating attribute
    - only for disjoint subclasses
- Create a single relation as above, but include a boolean type flag for each subclass
    - works for overlapping, and also disjoint

3.5. System Design

In this lecture we look at...
[Section notes PDF 64Kb]

3.5.01. Databases in Application

- Where's the data?
- Programmer driven future
- OODBMS limitations
- RDBMS longevity

- System design by
    - Data store, delivery, interface
- Case study

3.5.02. Where's the data?

- Previously covered distance from User to Data (and reason for it)
- Client-Server data model creates DBMS
    - P2P alternative
- Accountability
- Distribution (BitTorrent, eDonkey)
- Caching

3.5.03. Where's the data?

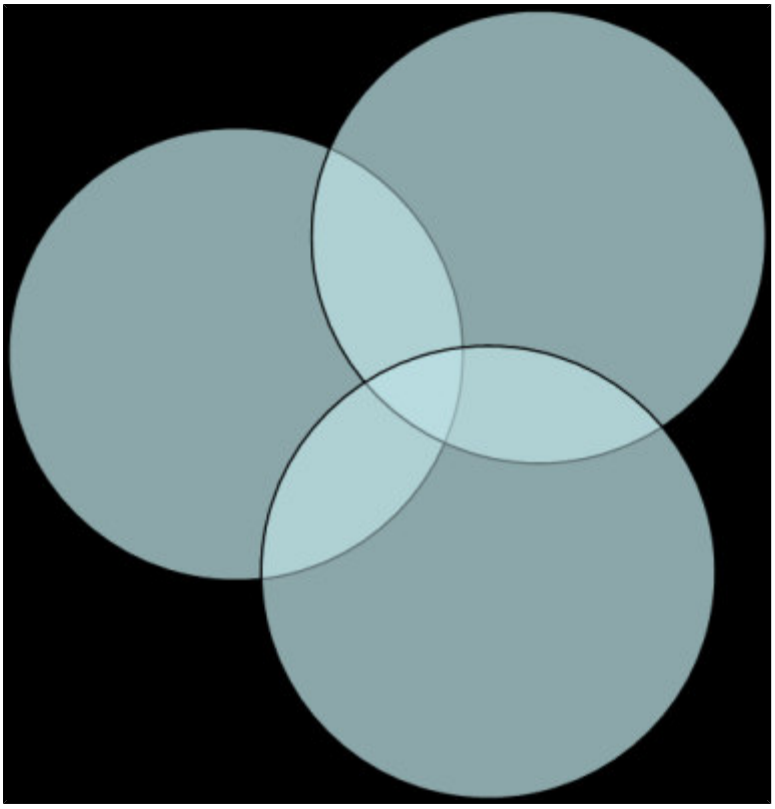
- Answer: everywhere
- But where is it meaningful?
- Answer: for whom?

Quality paradigm

- Large projects require large teams
- Team overhead (ref 2nd year)
- Code responsibilities
- Data/data model resp.
- Object responsibilities

3.5.04. Web application data support

- Web application programming
- Goal, dynamically produced XHTML
- Client side designer-programmer split
    - CSS, XHTML
- Server side programmer-programmer split
    - Old school: query design, integrator
    - New school: MVC (Model-View-Controller)
        - Controller – user input
        - Model – modelling of external world
        - View – visual feedback



3.5.05. CMS

- Content Management System
- part of other courses
- CMS is a DBMS
- Zope/Plone and ZODB
- e107, Drupal and Seagull
- Zend MVC Framework (pre-beta)

3.5.06. OODBMS limitations

- Future unknown
- RDBMS supports
    - Application data sharing
    - Physical/logical data independence/views
    - Concurrency control
    - Constraints
- at inception these requirements not known
- RDBMS mathematical basis à extensible
- Crude Type Inheritance (see EER mapping)
- OODBMS as construction kit

3.5.07. Weaknesses in RDBMS

- Data type support
- Unwieldy, created 3VL (nulls)
- Type Inheritance and Relationships
- Tuple:Entity fragmentation
    - not to be confused with ‘fragmentation’
- Entity approximation requires joins

3.5.08. System design

- Client specifications
- Variance amongst Mobile devices
- Rich-media Content delivery
- Where’s the data? (M – media database)
- Where’s it going? (C – mobile browser)
- How’s it going to get there? (query design)
- What’s it going to look like? (V – XHTML)

3.5.09. Muddy boots

- The real world of databases
- Massive Excel spreadsheets
- Access Migration
- Normalisation
- Update implications
- Visual language of the Internet limitations
- Future of browser components

4. Distributed systems

This is the Distributed systems course theme.

[Complete set of notes PDF 109Kb]

4.1. Transaction

In this lecture we look at...
[Section notes PDF 86Kb]

4.1.01. Distributed Databases

- Transactions
- Unpredictable failure
    - Commit and rollback

- Stored procedures
- Brief PL overview
    - Cursors

4.1.02. Transactions

- Real world database actions
- Rarely single step
- Flight reservation example
    - Add passenger details to roster
    - Charge passenger credit card
    - Update seats available
    - Order extra vegetarian meal

4.1.03. Transactions

- Real world database actions
- Rarely single step
- Flight reservation example
    - Add passenger details to roster
    - Charge passenger credit card
    - Update seats available
    - Order extra vegetarian meal

4.1.04. Desirable properties of transactions

- ACID test
- Atomicity
    - transaction as smallest unit of processing
    - transactions complete entirely or not at all
        - consequences of partial completion in flight example

- Consistency
    - complete execution preserves database constrained state/integrity
    - e.g. Should a transaction create an entity with a foreign key then the reference entity must exist (see 4 constraints)

4.1.05. ACID test continued

- Isolation
    - not interfered with by any other concurrent transactions

- Durable (permanency)
    - commited changes persist in the database, not vulernable to failure

4.1.06. Commit

- Notion of Commit (durability)
- Transaction failures
    - From flight reservation example
        - Add passenger details to roster
        - Charge passenger credit card
        - Update seats available: No seats remaining
        - Order extra vegetarian meal
    - Rollback

4.1.07. PL/SQL overview

- Language format
    - Declarations
    - Execution
    - Exceptions
    - Handling I/O
    - Functions
    - Cursors

4.1.08. PL/SQL

- Blocks broken into three parts
    - Declaration
        - Variables declared and initialised
    - Execution
        - Variables manipulated/actioned
    - Exception
        - Error raised and handled during exec

4.1.09. Declaration

- DECLARE
    - age NUMBER;
    - name VARCHAR(20);
    - surname employee.fname%TYPE;
    - addr student.termAddress%TYPE;

4.1.10. Execution

- BEGIN (not in order)

    - /* sql_statements */
        - UPDATE employee SET salary = salary+1;
    - /* conditionals */
        - IF (age < 0) THEN
            - age: = 0;
        - ELSE
            - age: = age + 1;
        - END IF;
    - /* transaction processing */
        - COMMIT; ROLLBACK;
    - /* loops */ /* cursors */
- [END;] (if no exception handling)

4.1.11. Exception passing

- Beginnings of PL I/O
- CREATE TABLE temp (logmessage varchar(80));
    - Can create transfer/bridge relation outside

- Within block (e.g. within exception handler)
    - WHEN invalid_age THEN
        - INSERT INTO temp VALUES(‘Cannot have negative ages’);
    - END;

    - SELECT * FROM temp;
        - To review error messages

4.1.12. Exception handling

- DECLARE
    - invalid_age exception;

- BEGIN
    - IF (age < 0) THEN
        - RAISE invalid_age
    - END IF;

EXCEPTION

- WHEN invalid_age THEN
  - INSERT INTO temp VALUES(‘Cannot have negative ages’);
- END;

4.1.13. Cursors

- Cursors
  - Tuple by tuple processing of relations
  - Three phases (two)
    - Declare
    - Use
    - Exception (as per normal raise)

4.1.14. Impact

- PL blocks coherently change database state
- No runtime I/O
- Difficult to debug
- SQL tested independently

4.1.15. PL Cursors

- DECLARE
- name_attr EMPLOYEE.NAME%TYPE;
- ssn_attr EMPLOYEE.SSN%TYPE;
- /* cursor declaration */
- CURSOR myEmployeeCursor IS
  - SELECT NAME,SSN FROM EMPLOYEE
  - WHERE DNO=1
  - FOR UPDATE;
- emp_tuple myEmployeeCursor%ROWTYPE;

4.1.16. Cursors execution

- BEGIN
- /* open cursor */
- OPEN myEmployeeCursor;
- /* can pull a tuple attributes into variables */
- FETCH myEmployeeCursor INTO name_attr,ssn_attr;
- /* or pull tuple into tuple variable */
- FETCH myEmployeeCursor INTO emp_tuple;
- CLOSE myEmployeeCursor;

- [LOOP…END LOOP example on handout]

4.1.17. Introduction

- Concurrent transactions
- Distributed databases (DDB)
- Fragmentation
- Desirable transaction properties
- Concurrency control techniques
    - Locking
    - Timestamps

4.1.18. Notation

- Language
    - PL too complex/long-winded
- Simplified database model
    - Database as collection of named items
    - Granularity, or size of data item
    - Disk block based, each block X
- Basic transaction language (BTL)
    - read_item(X);
    - write_item(X);
    - Basic algebra, X=X+N;

4.1.19. Transaction processing

- DBMS Multiuser system
    - Multiple terminals/clients
        - Single processor, client side execution
    - Single centralised database
        - Multiprocessor, server
        - Resolving many transactions simultaneously
- Concurrency issue
    - Coverage by previous courses (e.g. COMS12100)
    - PL/SQL scripts (Transactions) as processes
- Interleaved execution

4.1.20. Transactions

- Two transactions, T_1 and T_2
- Overlapping read-sets and write-sets
- Interleaved execution
- Concurrency control required
- PL/SQL example
    - Commit; and rollback;

4.1.21. Concurrency issues

- Three potential problems
  - Lost update
  - Dirty read
  - Incorrect summary

- All exemplified using BTL
  - Transaction diagrams to make clearer
  - C-like syntax for familiarity
  - Many possible examples of each problem

4.1.22. Lost update

- T_1
- read_item(X);
- X=X-N;

- write_item(X);
- read_item(Y);

- Y=Y+N;
- write_item(Y);
- T_2

- read_item(X);
- X=X+M;

- write_item(X);

4.1.23. Dirty read (or Temporary update)

- T_1
- read_item(X);
- X=X-N;
- write_item(X);

- <T_1 fails>
- <T_1 rollback>

- read_item(X);
- X=X+N;
- write_item(X);
- T_2

- read_item(X);
- X=X+M;
- write_item(X);

4.1.24. Incorrect summary

- T_1

- read_item(X);
- X=X-N;
- write_item(X);

- read_item(Y);
- Y=Y-N;
- write_item(Y);
- T_2
- sum=0;
- read_item(A)
- sum=sum+A;

- read_item(X);
- sum=sum+X;
- read_item(Y);
- sum=sum+Y;

4.1.25. Serializability

- Schedule S is a collection of transactions (T_i)
- Serial schedule S_1
  - Transactions executed one after the other
  - Performed in a serial order
  - No interleaving
  - Commit or abort of active transaction (T_i) triggers execution of the next (T_{i+1})
  - If transactions are independent
    - all serial schedules are correct

4.1.26. Serializability

- Serial schedules/histories
  - No concurrency
  - Unfair timeslicing
- Non-serial schedule S_2 of n transactions
  - Serializable if
- equivalent to some serial schedule of the same n transactions
  - correct

- n! serial schedules, more non-serial

4.1.27. Distribution

- DDB, collection of
  - multiple logically interrelated databases
  - distributed over a computer network
  - DDBMS
- Multiprocessor environments
  - Shared memory
  - Shared disk
  - Shared nothing

4.1.28. Advantages

- Distribution transparency
  - Multiple transparency levels
  - Network
  - Location/dept autonomy
  - Naming
  - Replication
  - Fragmentation
- Reliability and availability
- Performance, data localisation
- Expansion

4.1.29. Fragmentation

- Breaking the database into
  - logical units
  - for distribution (DDB design)
- Global directory to keep track/abstract
- Fragmentation schema/allocation schema
  - Relational
  - Horizontal
    - Derived (referential), complete (by union)
  - Vertical
  - Hybrid

4.1.30. Concurrency control in DDBs

- Multiple copies
- Failure of individual sites (hosts/servers)
- Failure of network/links

- Transaction processing
  - Distributed commit
  - Deadlock
- Primary/coordinator site - voting

4.1.31. Distributed commit

- Coordinator elected
- Coordinator prepares
  - writes log to disk, open sockets, sends out queries
- Process
  - Coordinator sends ‘Ready-commit’ message
  - Peers send back ‘Ready-OK’
  - Coordinator sends ‘Commit’ message
  - Peers send back ‘Commit-OK’ message

4.1.32. Query processing

- Data transfer costs of query processing
  - Local bias
  - High remote access cost
  - Vast data quantities to build intermediate relations
- Decomposition
  - Subqueries resolved locally

4.1.33. Concurrency control

- Must avoid 3+ problems
  - Lost update, dirty read, incorrect summary
  - Deadlock/livelock - dining example
- Data item granularity
- Solutions
  - Protocols, validation
  - Locking
  - Timestamps

4.1.34. Definition of terms

- Binary (two-state) locks
- locked, unlocked associated with item X
- Mutual exclusion
- Four requirements
  - Must lock before access
  - Must unlock after all access
  - No relocking of already locked
  - No unlocking of already unlocked

4.1.35. Definition

- Multiple mode locking
- Read/write locks
- aka. shared/exclusive locks
- Less restrictive (CREW)
- read_lock(X), write_lock(X), unlock(X)
    - e.g. acquire read/write_lock
    - not reading or writing the lock state

4.1.36. Rules of Multimode locks

- Must hold read/write_lock to read
- Must hold write_lock to write
- Must unlock after all access
- Cannot upgrade/downgrade locks
    - Cannot request new lock while holding one

- Upgrading permissable (read lock to write)
    - if currently holding sole read access
- Downgrading permissable (write lock to read)
    - if currently holding write lock

4.2. Concproto

In this lecture we look at...
[Section notes PDF 37Kb]

4.2.01. Introduction

- Concurrency control protocols
- Concurrency techniques
    - Locks, Protocols, Timestamps
    - Multimode locking with conversion
- Guarenteeing serializability
- Associated cost
- Timestamps and ordering

4.2.02. Guarenteeing serializability

- Two phase locking protocol (2PL)
  - Growing/expanding
    - Acquisition of all locks
    - Or upgrading of existing locks
  - Shrinking
    - Release of locks
    - Or downgrading
  - Guarentees serializability
    - equivalency without checking schedules

4.2.03. A typical transaction pair

- T_1

- read_lock(Y);
- read_item(Y);
- unlock(Y);

- write_lock(X);
- read_item(X);
- X=X+Y;
- write_item(X);
- unlock(X);

4.2.04. 2PL: Guaranteed serializable

- T_1

- read_lock(Y);
- read_item(Y);
- write_lock(X);
- unlock(Y);
- read_item(X);
- X=X+Y;
- write_item(X);
- unlock(X);

4.2.05. Guarantee cost

- T_2 ends up waiting for read access to X
- Either after T_1 finished
  - T_1 cannot release X even though it has finished using it
  - Incorrect phase (still expanding)
- Or before T_1 has used it
  - T_1 has to claim X during expansion, even if it doesn't use it until later
- Cost: limits the amount of concurrency

4.2.06. Alternatives

- Concurrency control
  - Locks limit concurrency
    - Busy waiting
  - Timestamp ordering (TO)
  - Order transaction execution
    - for a particular equivalent serial schedule
    - of transactions ordered by timestamp value
      - Note: difference to lock serial equivalent
  - No locks, no deadlock

4.2.07. Timestamps

- Unique identifier for transaction (T)
- Assigned in order of submission
  - Time
    - linear time, current date/sys clock - one per cycle
  - Counter
    - counter, finite bitspace, wrap-around issues
  - Timestamp aka. Transaction start time
  - TS(T)

4.2.08. Timestamping

- DBMS associates two TS with each item

- Read_TS(X): gets read timestamp of item X
  - timestamp of most recent successful read on X
  - = TS(T) where T is youngest read transaction

- Write_TS(X): gets write timestamp of item X
  - as for read timestamp

4.2.09. Timestamping

- Transaction T issues read_item(X)
  - TO algorithm compares TS(T) with Write_TS(X)
  - Ensures transaction order execution not violated
- If successful, Write_TS(X) <= TS(T)
  - Read_TS(X) = $MAX_{TS(T),\ current\ Read\_TS(X)}$
- If fail, Write_TS(X) > TS(T)
  - T aborted, rolled-back and resubmitted with new TS
  - Cascading rollback

4.2.10. Timestamping

- Transaction T issues write_item(X)
  - TO algorithm compares TS(T) with Read_TS(X)
    - and compares TS(T) with Write_TS(X)
- If successful, op_TS(X) <= TS(T)
  - Write_TS(X) = TS(T)
- If fail, op_TS(X) > TS(T)
  - T aborted, cascade etc.

- All operations focus on not violating the execution order defined by the timestamp ordering

4.2.11. Updates

- Insertion
  - 2PL: DBMS secures exclusive write-lock
  - TOA: op_TS(X) set to TS(creating transaction)
- Deletion
  - 2PL: as insert
  - TOA: waits to ensure later transactions don't access
- Phantom problem
  - Record being inserted matches inclusion conditions
  - of another transaction (e.g. selection by dno=5)
  - Locking doesn't guarantee inclusion

    (need index locking)

5. Real world

This is the Real world course theme.

[Complete set of notes PDF 206Kb]

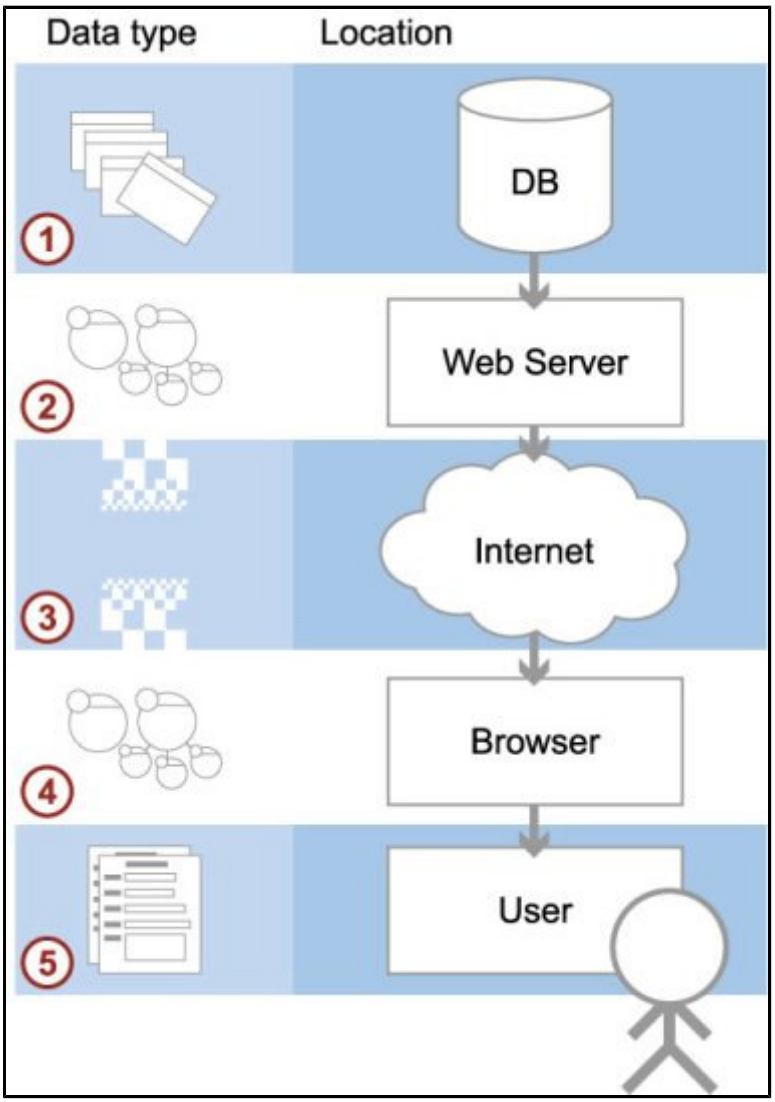
5.1. Web

In this lecture we look at...
[Section notes PDF 133Kb]

5.1.01. Databases for the Internet

- Path from DB to User
- Information flow
- Data formats (OO)
- Format transitions
- Limitations/channel

  right now
- The Future



5.1.02. OO

- Object orientated approach
  - Consistent/optimised development model
  - Good approximation of real world
  - Closer link to mini-world
- Java and PHP
- DB persistence
- UML

5.1.03. Java and PHP in context

- Java
  - JSP (server-side)
  - Javascript (client-side)
- PHP
  - Server side only
- JSON or XML
  - Object communication
- Ideal scenario
  - Java – load times

5.1.04. In a perfect world

- Homogenous data format/data model
- DB stores objects instead
- Objects transferred
  - Robust
  - Lightweight
  - Fast
  - Consistent (more later in Transactions)
  - Caching

5.1.05. In the real world

- Heterogenous data model
- Object translation/wrappers
- Different languages features at different layers
- Minimal subset of OO functionality available end-to-end
- Going to look at information flow/functionality provided

5.1.06. User

- Limitations of being human
  - short term memory
  - long term familiarity
- language of the Internet

    - hypertext linking
    - form filling
- Advantages of being human
    - impatience, no waiting
    - wants instant response

5.1.07. Browser

- Http requests
- Forms
    - Post
    - Get
- Form fields
    - By name, by ID
    - Hidden
- Javascript/DOM tree

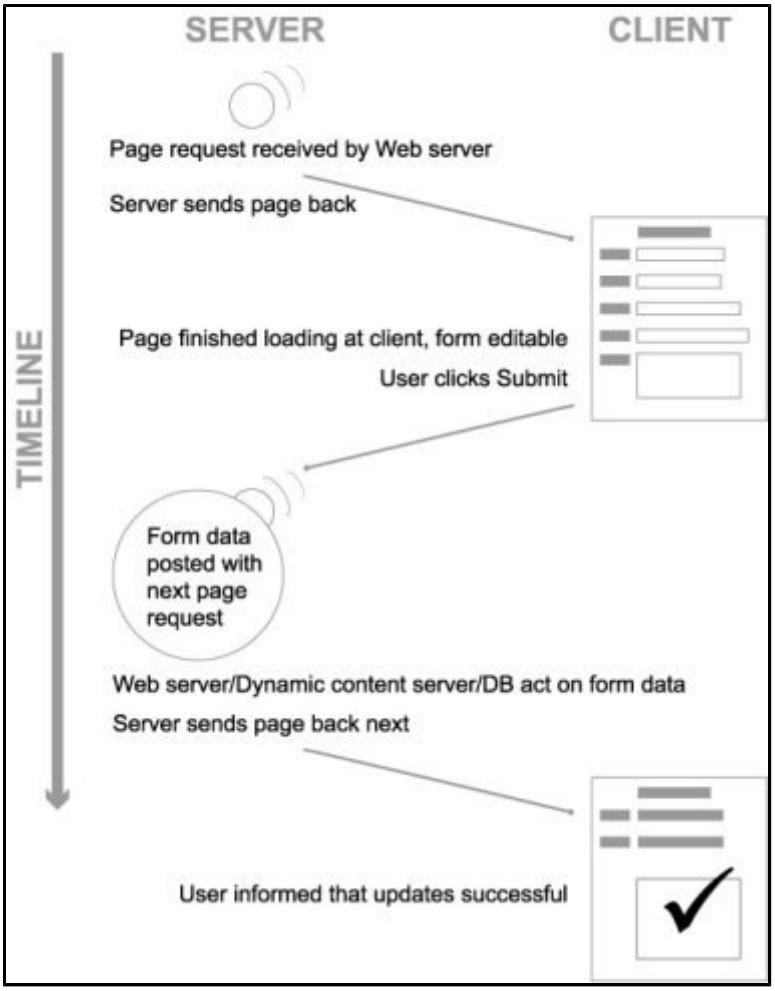
5.1.08. Internet

- Communication medium
- Good for transferring data
- Not good for transforming data
- e.g. Light in air
- e.g. Signal over CAT5e/UTP cable

5.1.09. Web server

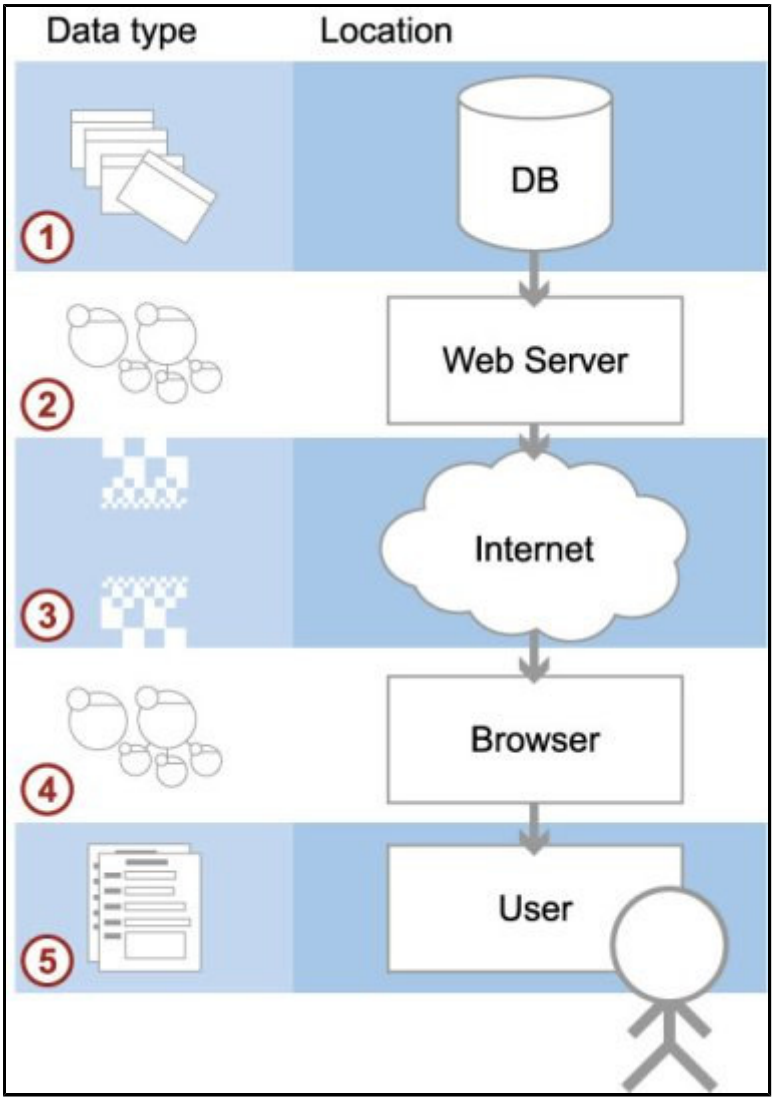
- Straight HTML pages
- Dynamic HTML pages
    - PHP example
    - JSP example
- As above with RDBMS integration
    - PHP PDO example
- As above with Objects
    - PHP DBDO example

5.1.10. load, edit, submit, act timeline



5.1.11. href click, versus form post

- Protocol stack
- Basic up-down
- Shortcuts
- Browser cache
- Web server
  - assembled page cache
  - php object cache
- DB optimised queries



5.1.12. Examples from the web

- Google Maps
  - link
- Car selector and Dealer locator
  - link

5.2. Decision Support

In this lecture we look at...
[Section notes PDF 85Kb]

5.2.01. Introduction

- Decision support systems (DSS)
- Duplicates of live systems, historical archiving
- Primarily read-only
- Load and refresh operations
- Integrity

    - Assumptions about initial data
- Large, indexed, redundancy

5.2.02. DSS Management

- Design
    - Logical
        - Temporal keys, required to distinquish historical data (since:to current & during:within interval)
    - Physical (Hash indexes, Bitmap indexes)
        - Controlled Redundancy
    - Synchronisation/update propogation
        - Synchronous (update driven)
        - Asynchronous (query driven)

5.2.03. Data Preparation

- Extract
    - pulling from live database system(s)
- Cleansing
- Transformation and Consolidation
    - migrating from live or legacy system design

      to DSS design
- Load (DSS live/query-able)
- Refresh (latest update)

5.2.04. Querying

- Boolean expression complexity
    - heavy WHERE clauses
- Join complexity
    - Normalised databases, many tables
    - Facts distributed across tables
    - Joins required to answer complex questions
- Function and Analytic complexity
    - Often require non-DBMS functions
    - Smaller queries with interleaved code

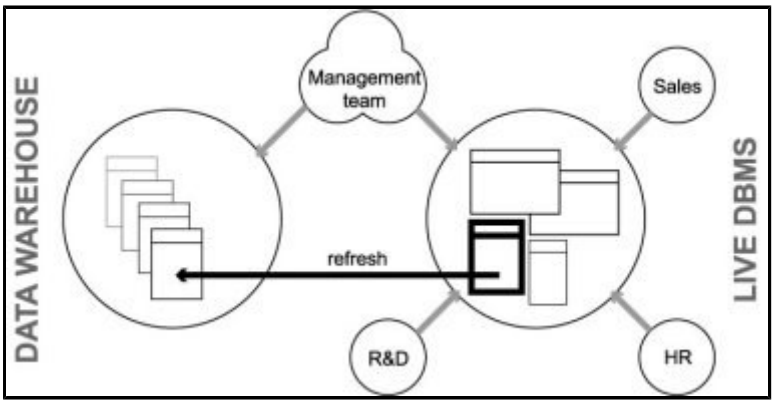
5.2.05. Data Warehouse

- Specific example of DSS
- Subject-orientated
    - e.g. customers/products
- Non-volatile
    - once inserted, items cannot be updated

- Time variant
    - Temporal keys
- Accuracy and granularity issues

5.2.06. DB Company organisation

- By example



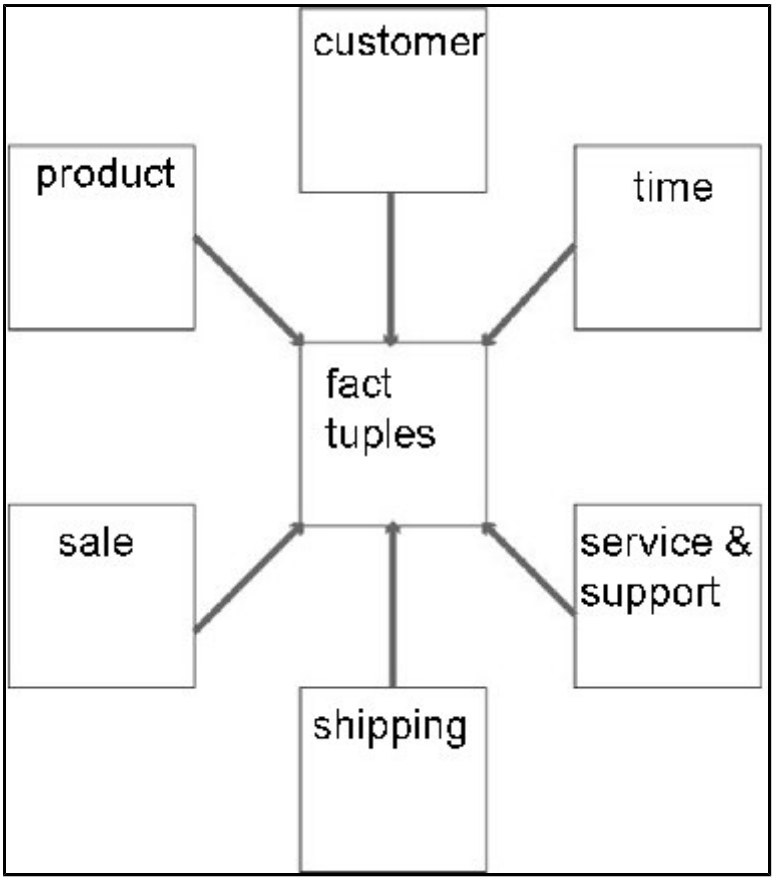
5.2.07. Dimensional Schema

- Consider product, customer, sales data
- Each sale represents a specific event
    - when a product was purchased
    - when a customer bought something
    - when a sale was recorded
- Each can be thought of as an axis

  or dimension (3D)
- Each occurred at a moment in time (4D)

5.2.08. Star schemae and Hypercubes

- Data centralised in ‘fact’ table
- Referencing creates star pattern
- Dimensions as satellite tables
- Normalising creates snowflake schema



5.2.09. Hypercubes

- Hypercube is also a multi-processor topology inspired by a 4D shape
- Used by Intel's iPSC/2
- Good at certain database operations
- e.g. Duplicate removal
- MIMD