Database

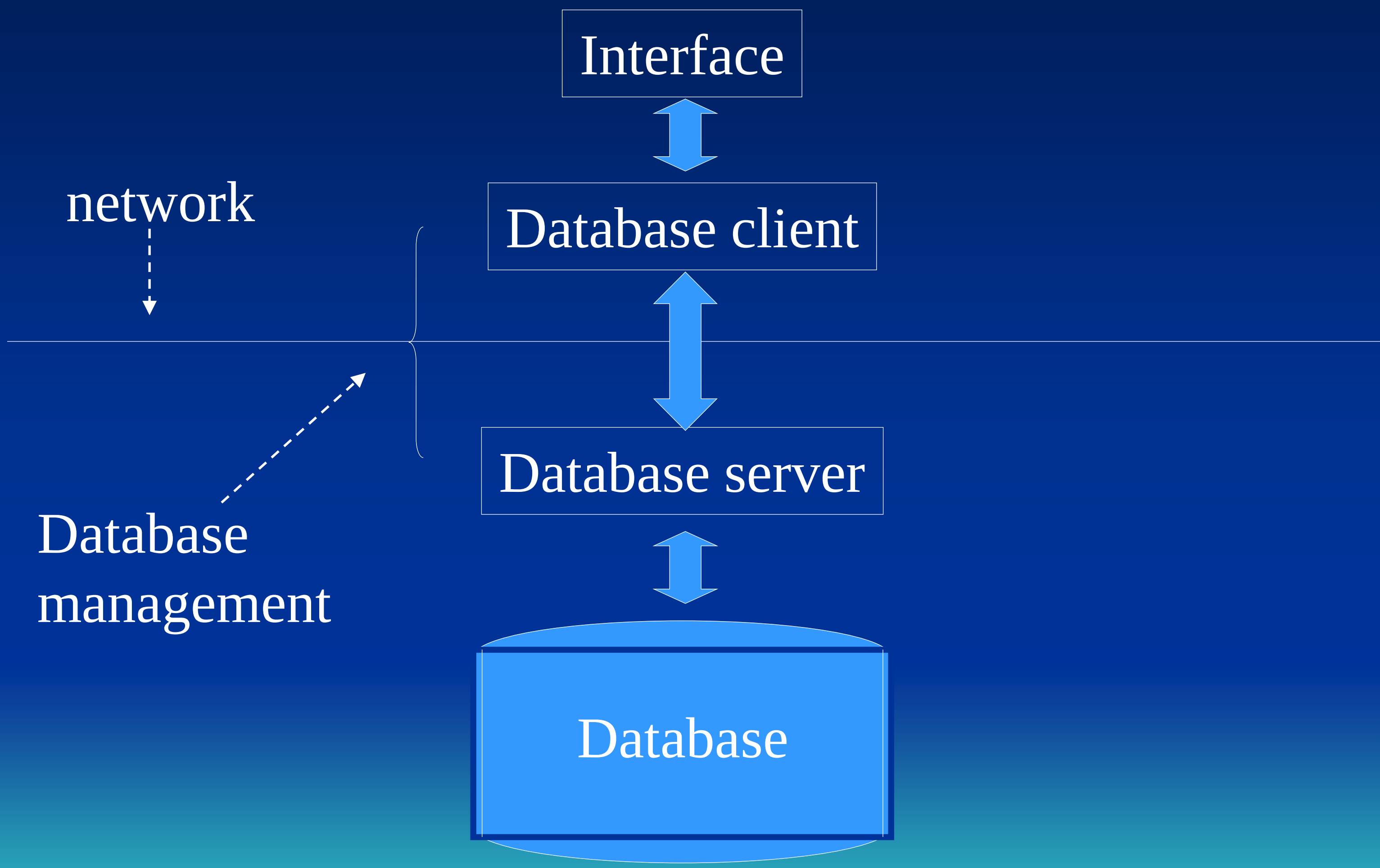
- Database Basics
- SQL Language and JDBC
- Static Hashing and Dynamic Hashing
- Index Techniques
- WEB Databases
- Semi-Structured Data Model
- Programming Language for XML
- Search engine in web browser

Not covered

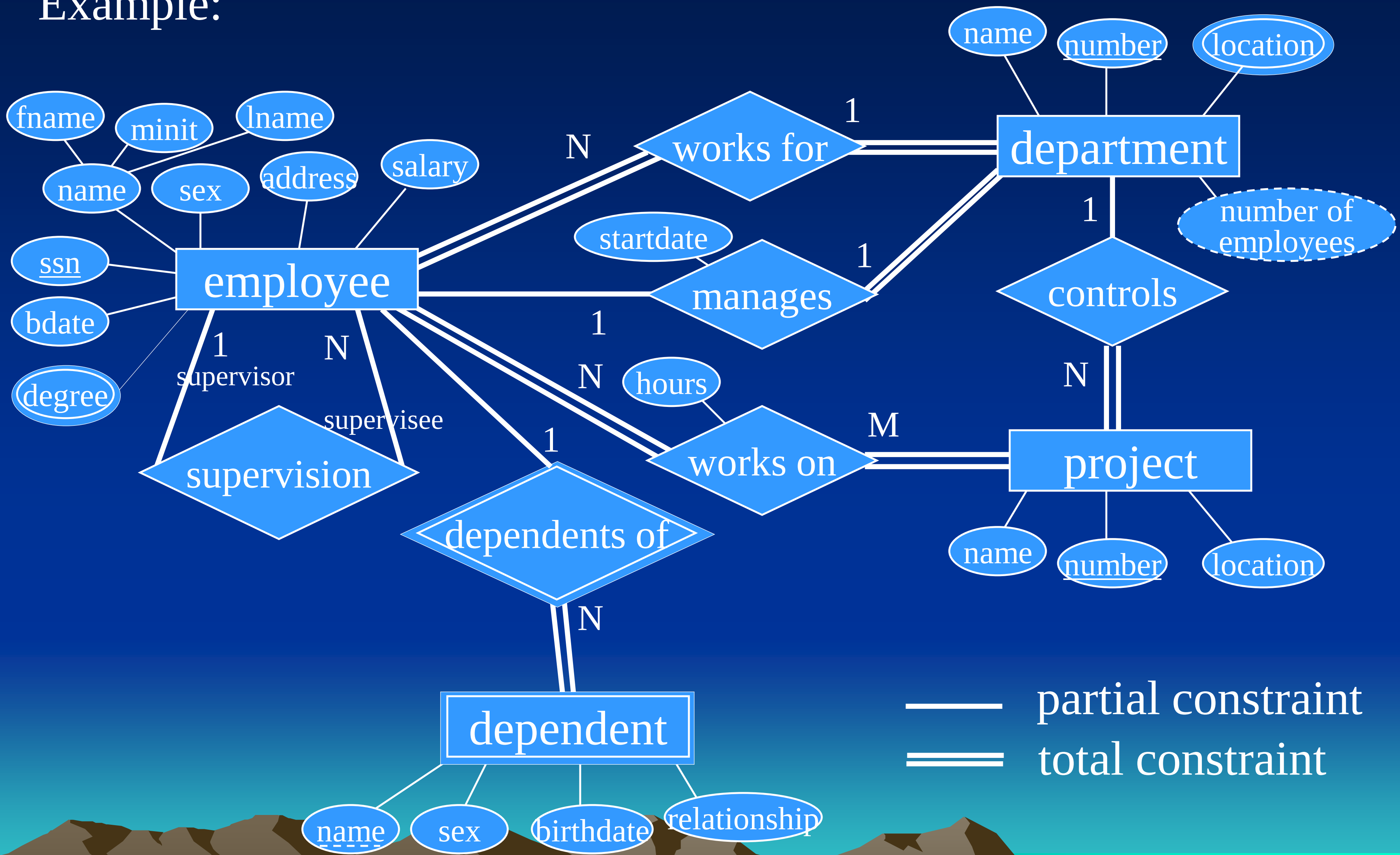
Database Basics

- Client-Server Database Architecture
- Entity-Relationship Data Modeling
- ER-to-Relation-Mapping

- Client-server database system Architecture



Example:



fname
minit
lname
name
sex
address
salary
ssn
bdate
degree
employee
1
supervisor
N
supervisee
supervision
N
works for
1
startdate
manages
1
1
N
hours
works on
M
1
dependents of
N
dependent
name
sex
birthdate
relationship
name
number
location
department
1
number of employees
controls
N
project
name
number
location
partial constraint
total constraint

- **ER-to-Relational mapping**

1. Create a relation for each strong entity type
   - For each atomic attribute associated with the entity type, an attribute in the relation will be created.
   - Composite attributes are not included. However the atomic attributes comprising the composite attribute must appear in the pertinent relation.

2. Create a relation for each weak entity type
   - include primary key of owner (an FK - foreign key)
   - owner’s PK + partial key becomes PK

3. For each binary *1:1* relationship choose an entity and include the other’s PK in it as an FK. Include any attributes of the relationship

4. For each binary *1:n* relationship, choose the *n*-side entity and include an FK with respect to the other entity. Include any attributes of the relationship

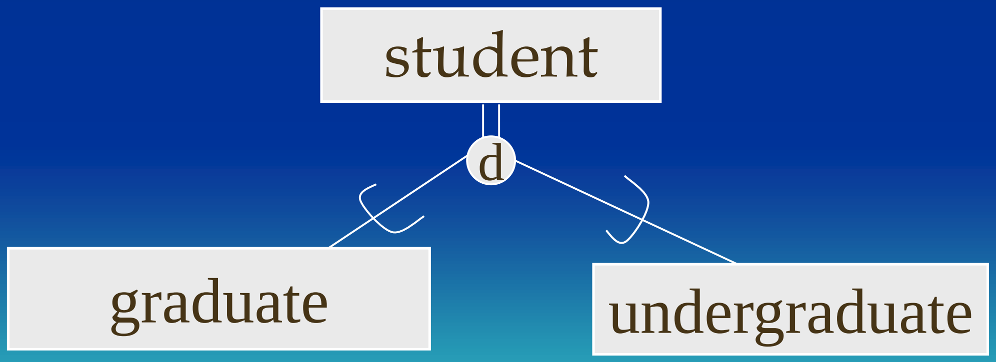
5. For each binary *M:N* relationship, create a relation for the relationship
   - include PKs of both participating entities and any attributes of the relationship
   - PK is the concatenation of the participating entity PKs

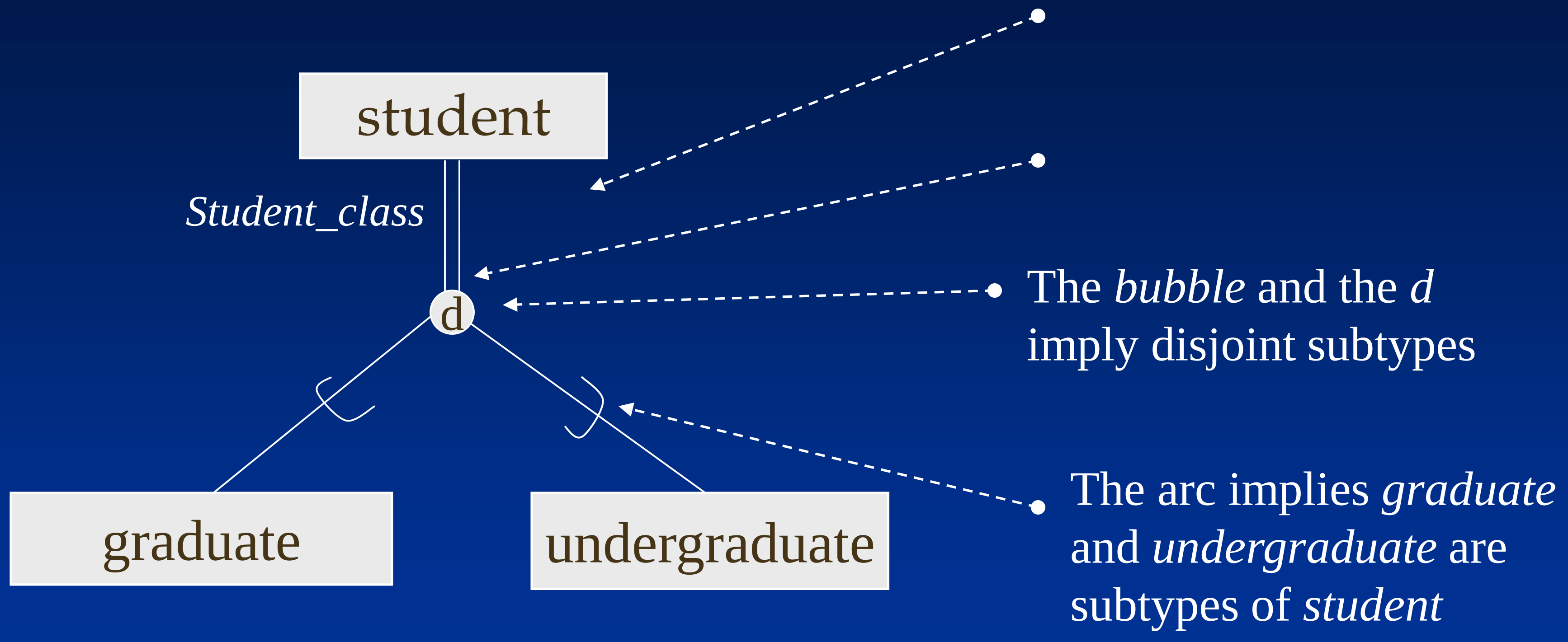
6. For each multivalued attribute create a new relation
   - include the PK attributes of the entity type
   - PK is the PK of the entity type and the multivalued attribute

7. For each *n*-ary relationship, create a relation for the relationship
   - include PKs of all participating entities and any attributes of the relationship
   - PK is the concatenation of the participating entity PKs

- **Specialization and Generalization**

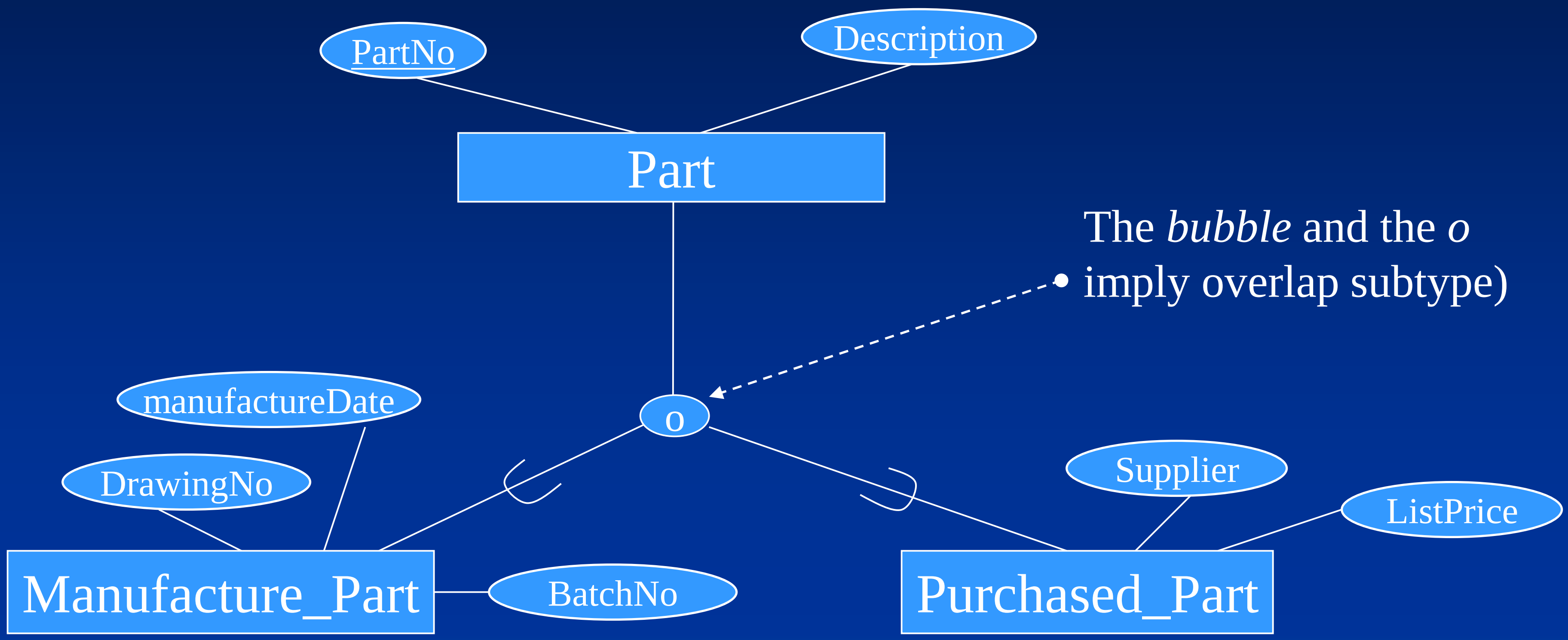
- Specialization is the process of defining a set of sub-entities of some entity type. Generalization is the opposite approach/process of determining a supertype based on certain entities having common characteristics.
  - e.g. employees may be paid by the hour or a salary (part vs full-time)
  - e.g. students may be part-time or full-time; graduate or undergraduate
- these are similar to 1:1 relationships, but they always involve entities of one (super)type
- these are *'is-a'* relationships





- Participation of supertype may be mandatory or optional
- Subtypes may be disjoint or overlapping
- a predicate (on an attribute) determines the subtype: e.g. attribute Student_class

  Student_class = ‘graduate’; Student_class = ‘undergraduate’



The *bubble* and the *o* imply overlap subtype)

- **Mapping to a relational database**

  4 choices:

  1. Create separate relations for the supertype and each of the subtypes.

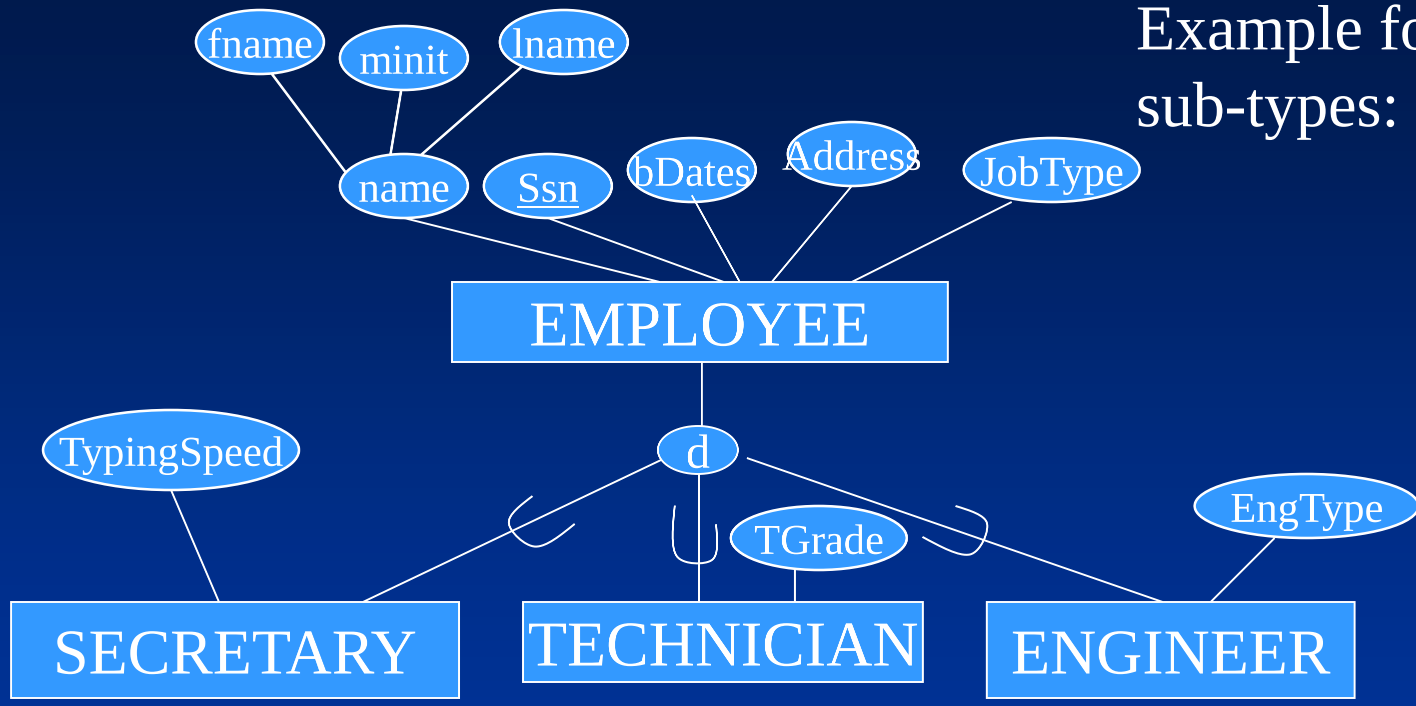
  2. Create relations for the subtypes only - each contains attributes from the supertype.

  3. (**disjoint** subtypes) Create only one relation - includes all of the attributes for the supertype and all for the subtypes, and one discriminator attribute.

  4. (**overlapping** subtypes) Create only one relation - includes all of the attributes for the supertype and all for the subtypes, and one logical discriminator attribute per subtype.

  PK is always the same - determined from the supertype

Example for super- & sub-types: choice 1



EMPLOYEE

fname, minit, lname, ssn, bdate, address, JobType

SECRETARY

Essn, TypingSpeed

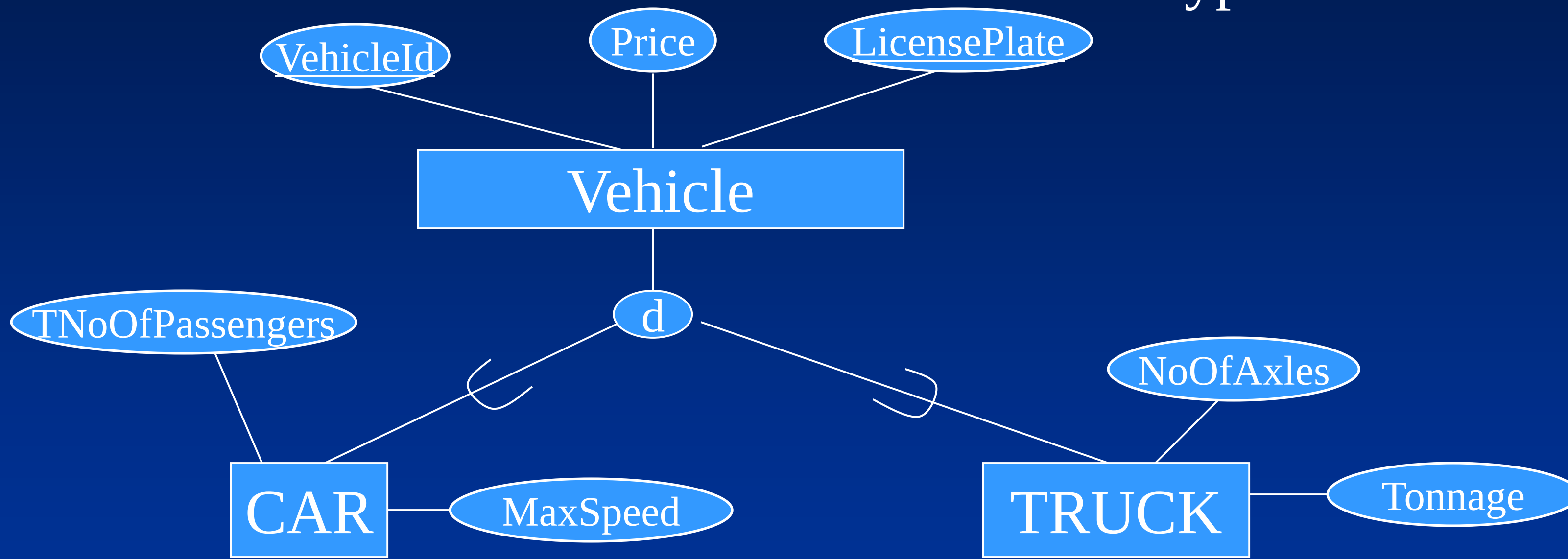
TECHNICIAN

Essn, TGrade

ENGINEER

Essn, EngType

Example for super- & sub-types: choice 2



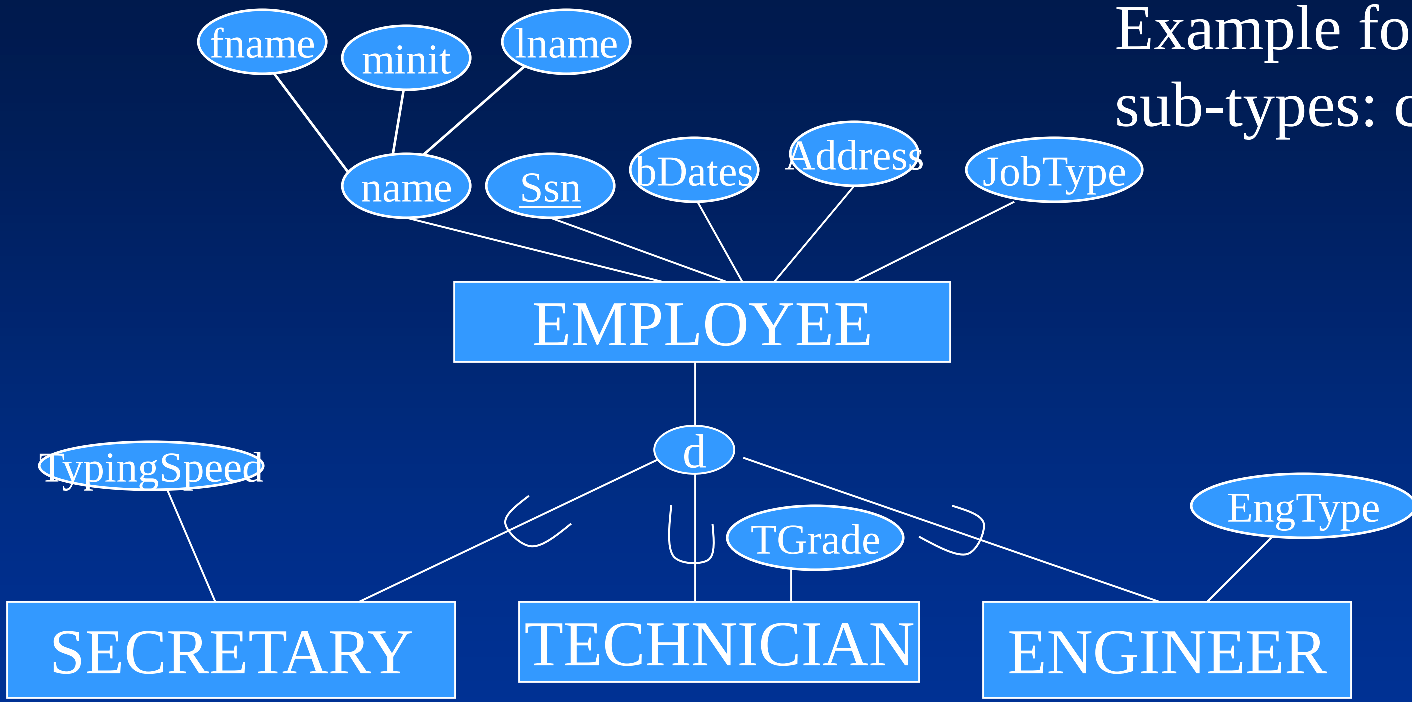
CAR

VehicleId, LicensePlate, Price, MaxSpeed, NoOfPassenger

TRUCK

VehicleId, LicensePlate, Price, NoOfAxles, Tonnage

Example for super- & sub-types: choice 3

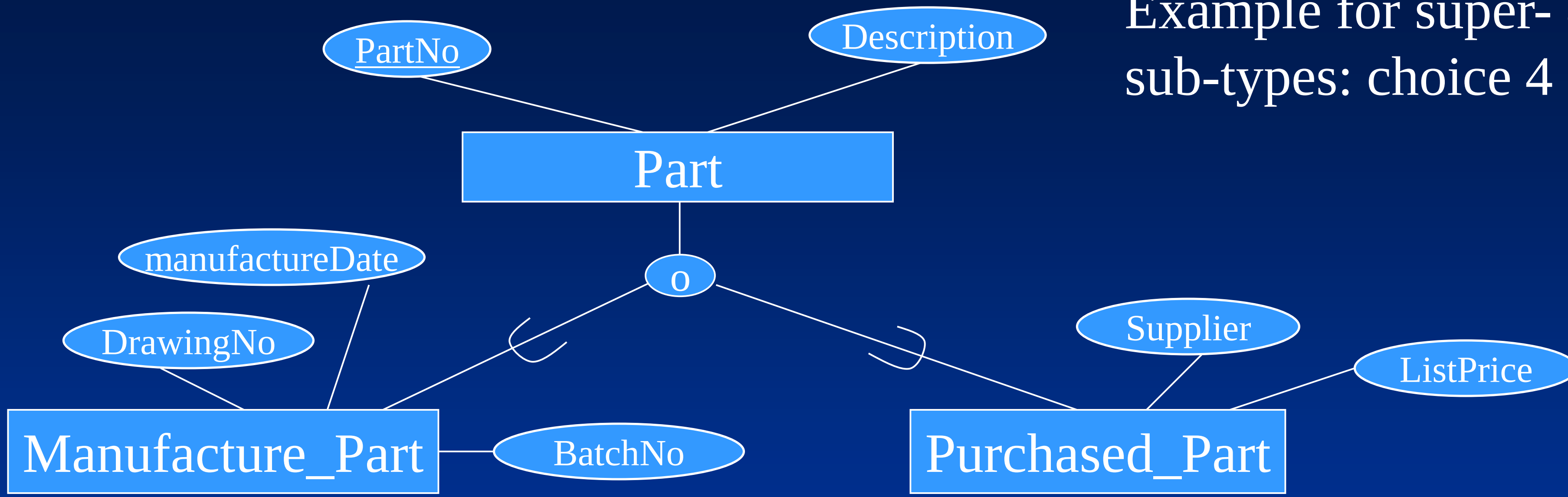


EMPLOYEE

fname, minit, lname, <u>ssn</u>, bdate, address, JobType, TypingSpeed, Tgrade, EngType

12345	…	…	1	…	…		
56463	…	…	2	…	…		
55554	…		3	…	…		

Example for super- & sub-types: choice 4

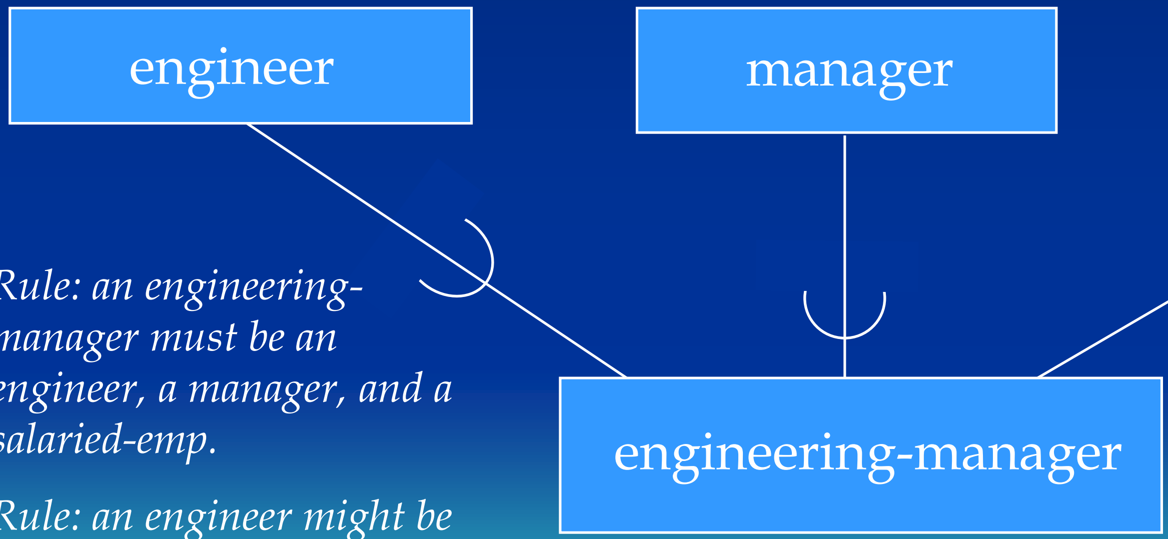


Part

PartNo, Desription, MFlag, Drawing, ManufactureDate, BatchNo, Pflag, Supplier, ListPrice

1	screw	1	…	…		…	...
2	Bolt				1	…	…
3	Axes	1			1		

- Shared SubClass
  - a subclass with more than one superclass
  - leads to the concept of multiple inheritance: engineering manager inherits attributes of engineer, manager, and salaried employee

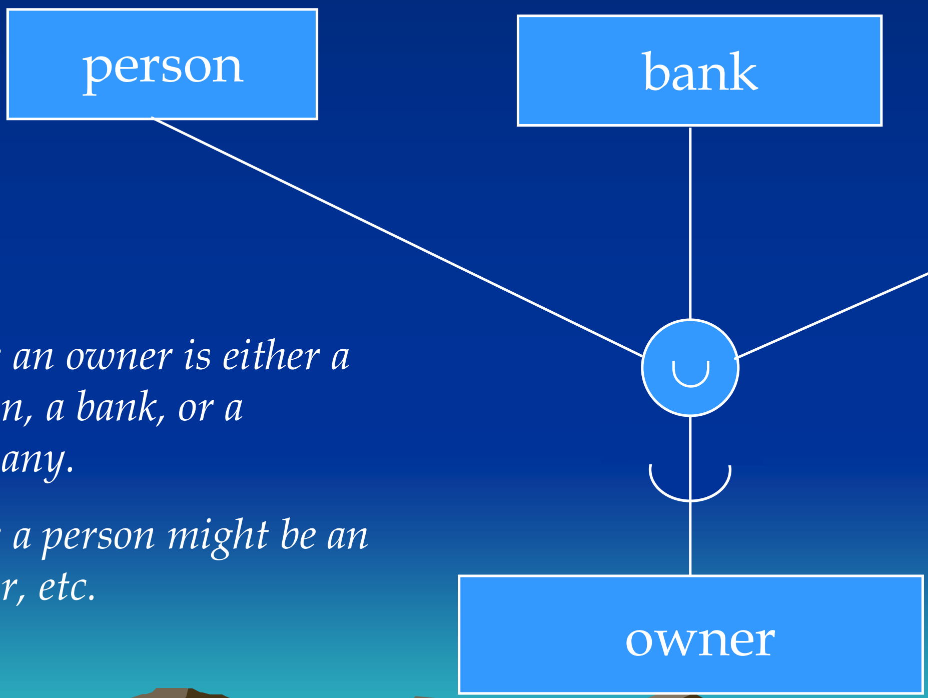


Rule: an engineering-manager must be an engineer, a manager, and a salaried-emp.

Rule: an engineer might be an engineering manager, etc.

Categories

- Models a single class/subclass with more than one super class of <u>different</u> entity types



Rule: an owner is either a person, a bank, or a company.

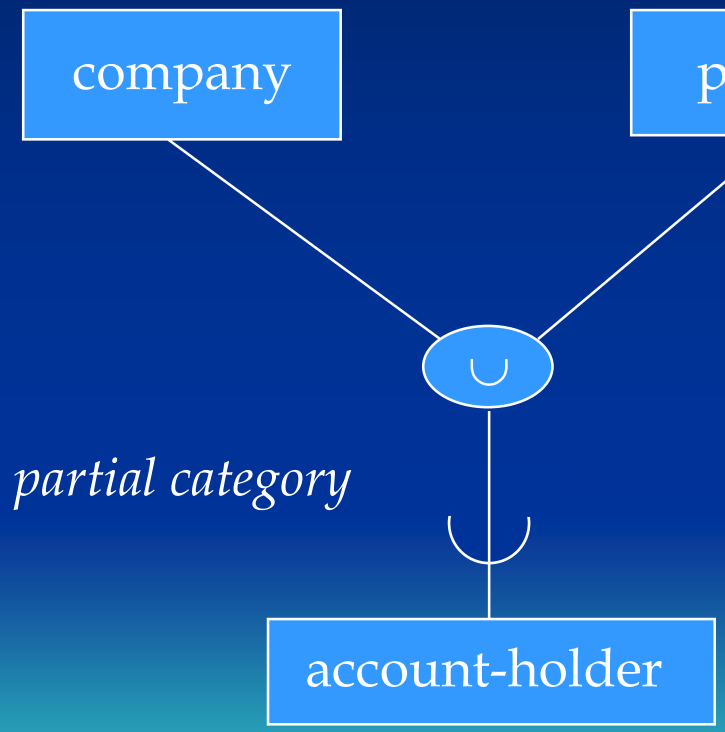
Rule: a person might be an owner, etc.

Note: set union symbol

Note: owner is a category

Categories

- A category can be either total or partial



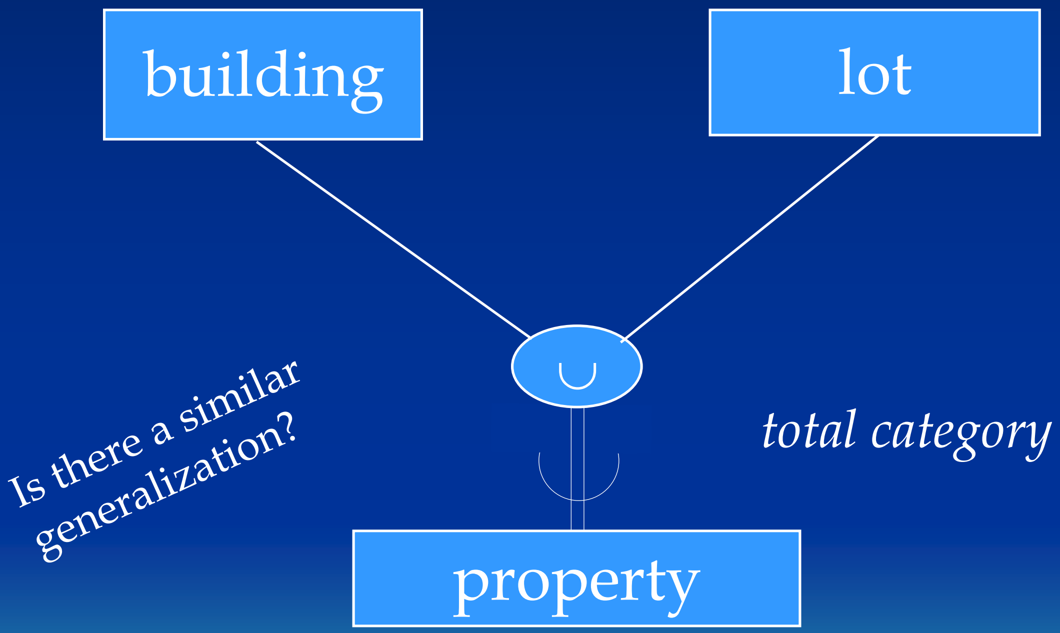
Rule: an account holder is either a person or a company.

Rule: a person may, or may not, be an account owner

Rule: a company may, or may not, be an account holder

Categories

- A category can be either total or partial



Rule: a property is either a building or a lot

Rule: a building <u>is</u> a property

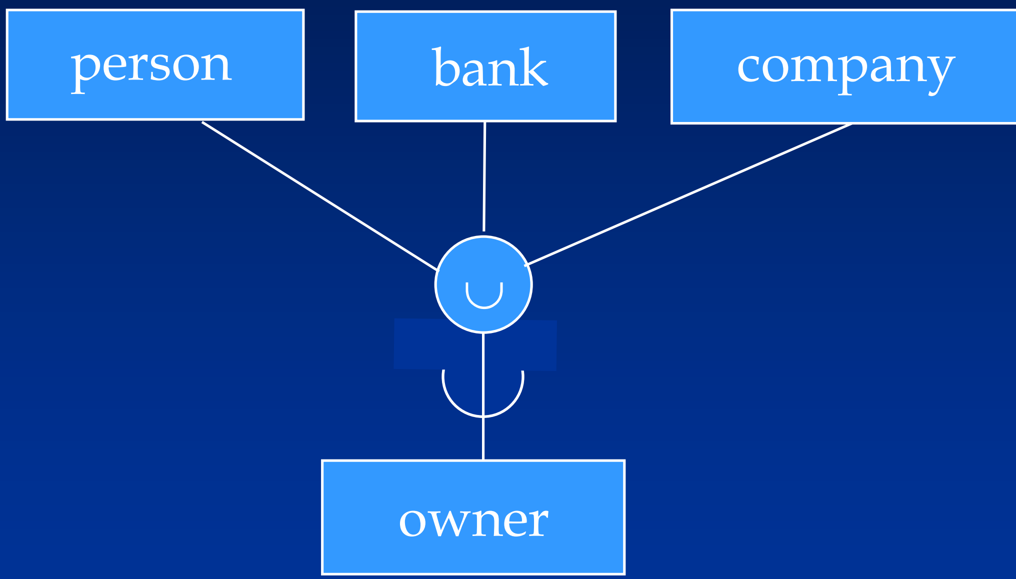
Rule: a lot <u>is</u> a property

Mapping of Categories

- Generate a table for each entity type involved
- Superclasses with different key
- Specify a new key called surrogate key for the category, which will also be included in the tables for the superclasses as foreign keys
- Superclasses with the same keys

  No need of a surrogate key

- Categories - Superclasses with different keys



Person (SSN, DrLicNo, Name, Address, *Ownerid*)

Bank (Bname, BAddress, *Ownerid*)

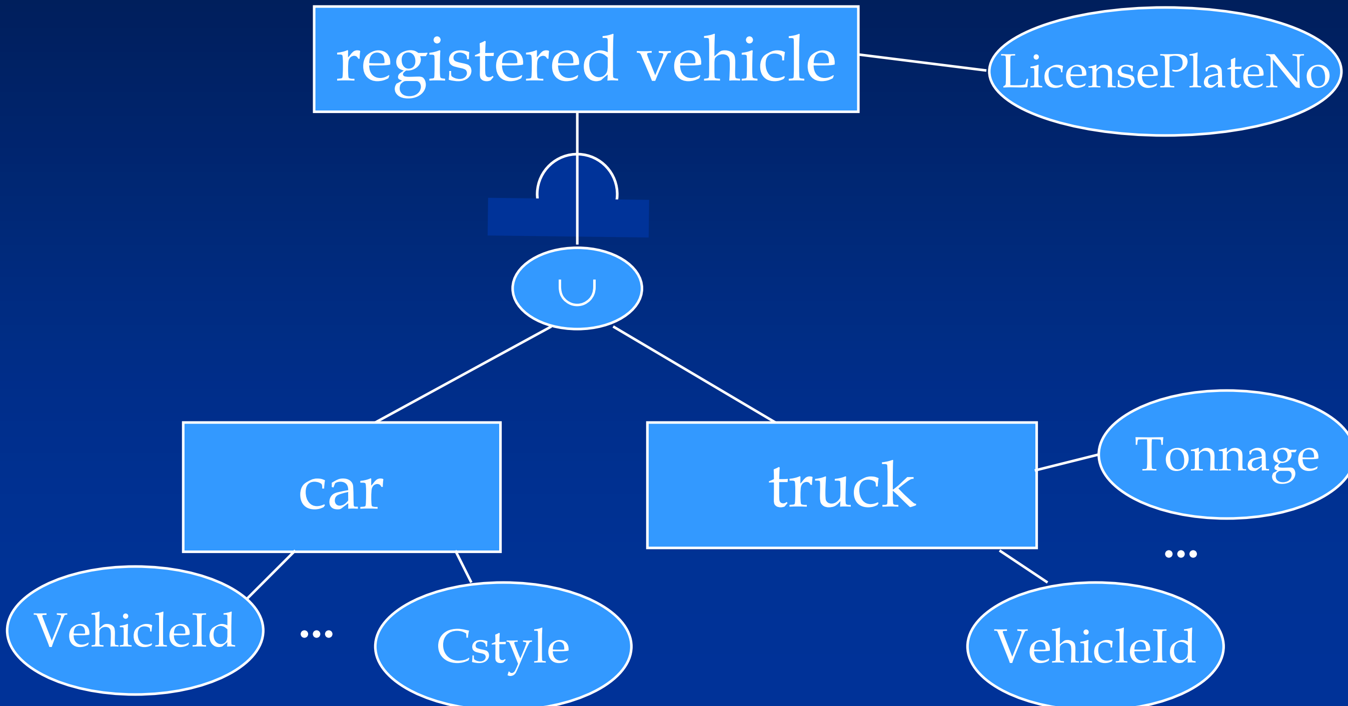
Company (CName, CAddress, *Ownerid*)

Owner (*Ownerid*)

Note the Foreign Keys

Surrogate key

- Categories - Superclasses with the same keys



Registered Vehicle (*VehicleID*, LicensePlateNo)

Car (*VehicleID* , Cstyle, CMake, CModel,CYear)

Truck (*VehicleID* , TMake, TModel,TYear, Tonnage)

Note there are no Foreign Keys

Outline: SQL and JDBC

- DDL
  - creating schemas
  - modifying schemas
- DML
  - select-from-where clause
  - group by, having, order by
  - update
  - view
- JDBC – Java Database Connectivity

DDL - creating schemas

- **Create schema** *schemaname* **authorization** *user*;
- **Create table** *tablename* …
    - attributes, data types
    - constraints:
        - primary keys
        - foreign keys
            - on delete set null|cascade|set default
            - on update set null|cascade|set default
            - on insert set null|cascade|set default
        - uniqueness for secondary keys
- **Create domain** *domainname* …

DDL - Examples:

- **Create schema:**

  Create schema COMPANY **authorization** JSMITH;

- **Create table:**

  Create table EMPLOYEE

```
(FNAME      VARCHAR(15)     NOT NULL,
 MINIT      CHAR,
 LNAME      VARCHAR(15)     NOT NULL,
 SSN        CHAR(9)         NOT NULL,
 BDATE      DATE,
 ADDRESS    VARCHAR(30),
 SEX        CHAR,
 SALARY     DECIMAL(10, 2),
 SUPERSSN   CHAR(9),
 DNO        INT             NOT NULL,
PRIMARY KEY(SSN),
FOREIGN KEY(SUPERSSN) REFERENCES EMPLOYEE(SSN),
FOREIGN KEY(DNO) REFERENCES DEPARTMENT(DNUMBER));
```

DDL - Examples:

- **Specifying constraints:**

```
Create table EMPLOYEE
(…,
DNO      INT              NOT NULL        DEFAULT 1,
CONSTRAINT EMPPK
    PRIMARY KEY(SSN),
CONSTRAINT EMPSUPERFK
FOREIGN KEY(SUPERSSN) REFERENCES EMPLOYEE(SSN)
    ON DELETE SET NULL  ON UPDATE CASCADE,
CONSTRAINT EMPDEPTFK
FOREIGN KEY(DNO) REFERENCES DEPARTMENT(DNUMBER)
     ON DELETE SET DEFAULT  ON UPDATE CASCADE);
```

- **Create domain:**

```
CREATE DOMAIN SSN_TYPE AS CHAR(9);
```

Strategies to maintain data consistency: set null or cascade

Employee

ssn	… …	supervisor
123456789		234589710
… …		
234589710		null

delete

Employee

ssn	… …	supervisor
123456789		234589710
… …		
234589710		null

not reasonable

delete

cascade

delete

Strategies to maintain data consistency: set null or cascade

Employee

ssn	… …	supervisor
123456789		234589710
… …		
234589710		null

delete

Employee

ssn	… …	supervisor
123456789		null
… …		
234589710		null

reasonable

set null

delete

Strategy to maintain data consistency: set default

Department

DNUMBER	… …	… …
1		… …
… …		
4		… …

delete

Employee

ssn	… …	DNO
123456789		4
… …		
234589710		… …

change this value to the default value 1.

Strategy to enforce referential integrity: cascade

Employee

<u>ssn</u>	…	
123456789		
…		

delete

Works_On

<u>ssn</u>	<u>pno</u>	hours
123456789	…	20
…		

Works_On

<u>ssn</u>	<u>pno</u>	hours
…		

Delete cascading.

DML - Queries (the Select statement)

select *attribute list*

from *table list*

where *condition*

group by *expression*

having *expression*

order by *expression ;*

Select *fname, salary* **from** *employee* ***where*** *salary > 30000* ⇒

$$\pi_{\text{fname, salary}}(\sigma_{\text{salary}>30000}(\text{Employee}))$$

Select *salary* **from** *employee*;

See Fig. 7.6 for the relation employee.

Salary
30000
40000
25000
43000
38000
25000
25000
55000

Duplicates are possible!

Select *fname*, *salary* **from** *employee* ***where*** *salary > 30000*;

Fname	***Salary***
Franklin	40000
Jennifer	43000
Ramesh	38000
James	55000

Correlated Subquery example:

Suppose we want to find out who is working on a project that is not located where their department is located.

- Note that the Project table has the location for the project
- Note that the Works_on relates employees to projects
- Note that the Employee table has the department number for an employee, and that Dept_locations has the locations for the department

We'll do this in two parts:

- a join that relates employees and projects (via works_on)
- a subquery that obtains the department locations for a given employee

EMPLOYEE

fname, minit, lname, ssn, bdate, address, sex, salary, superssn, dno

Dnumber, dlocation

DEPT _LOCATIONS

PROJECT

Pname, pnumber, plocation, dnum

WORKS_ON

Essn, pno, hours

EMPLOYEE

fname, minit, lname, ssn, bdate, address, sex, salary, superssn, dno

DEPARTMENT

Dname, dnumber, mgrssn, mgrstartdate

Dnumber, dlocation

DEPT _LOCATIONS

PROJECT

Pname, pnumber, plocation, dnum

Essn, pno, hours

WORKS_ON

DEPENDENT

Essn, dependentname, sex, bdate, relationship

Figure 7-7: reference integrity

Correlated Subqueries:

A 3-way join to bring related employee and project data together:

```
SELECT employee.ssn, employee.fname, employee.lname,
       project.pnumber, project.plocation
FROM employee, project, works_on
WHERE
employee.ssn = works_on.essn and
project.pnumber = works_on.pno
```

A 3-way join

We'll see this join again where Inner Joins are discussed

Correlated Subqueries:

Now we incorporate a correlated subquery to restrict the result to those employees working on a project that is not where their department is located:

```
SELECT employee.ssn, employee.fname, employee.lname,
        project.pnumber, project.plocation
FROM employee, project, works_on
WHERE
employee.ssn = works_on.essn and
project.pnumber = works_on.pno and
plocation NOT IN
        (SELECT dlocation FROM dept_locations WHERE
        dnumber=employee.dno);
```

Correlated Subqueries:

Now we incorporate a correlated subquery to restrict the result to those employees working on a project that is not where their department is located:

```
SELECT employee.ssn, employee.fname, employee.lname,
        project.pnumber, project.plocation
FROM employee x, project, works_on
WHERE
employee.ssn = works_on.essn and
project.pnumber = works_on.pno and
plocation NOT IN
        (SELECT dlocation FROM dept_locations y WHERE
        y.dnumber = x.dno);
```

Subqueries with Exists and Not Exists:

Who is working on every project?

This is not a simple query!

```
SELECT e.ssn, e.fname, e.lname
FROM employee AS e
WHERE
NOT EXISTS
    (SELECT * FROM project AS p WHERE
    NOT EXISTS
        (SELECT * FROM works_on AS w WHERE w.essn=e.ssn
        AND w.pno=p.pno));
```

There is no project that the employee does not work on.

Example:

EMPLOYEE

ssn	fname	lname
1	… …	… …
2	… …	… …
3	… …	… …

WORK_ON

essn	PNo	hours
1	1	...
1	2	...
2	3	...
3	1	...
3	2	...
3	3	...

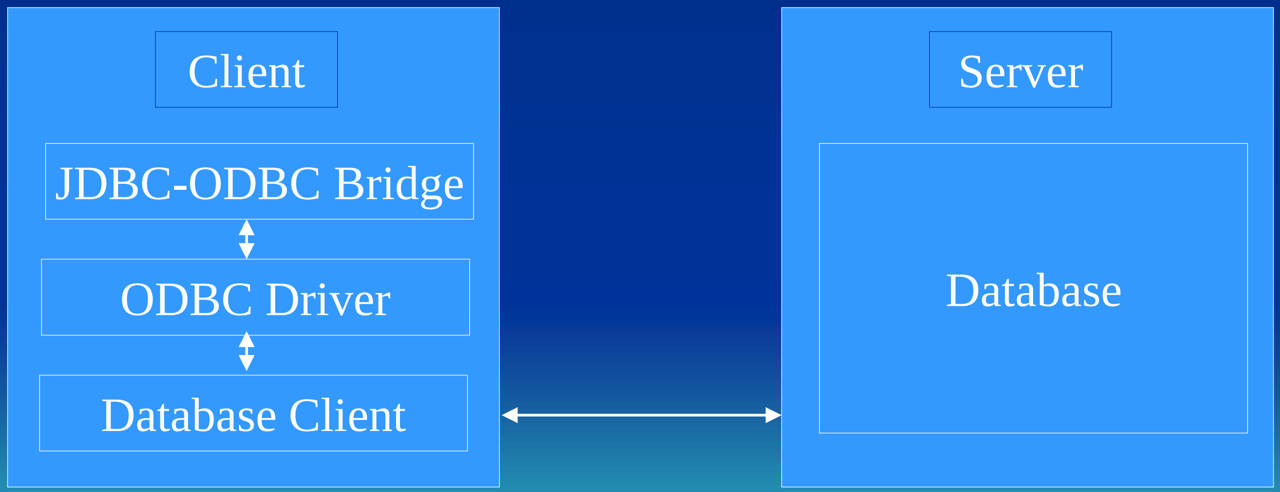
PROJECT

PNo	Pname	…
1	… …	…
2	… …	…
3	… …	…

To develop a database application, **JDBC** or **ODBC** should be used.

JDBC – JAVA Database Connectivity

ODBC – Open Database Connectivity



Connection to a database:

1. Loading driver class

```
Class.forName(“sun.jdbc.odbc.JdbcOdbcDriver”);
```

2. Connection to a database

```
String url = “jdbc:odbc:<databaseName>”;
Connction con =
DriverManager.getConnection(url, <userName>,
<password>)
```

3. Sending SQL statements

```
Statement stmt = con.createStatement();

ResultSet rs = stmt.executeQuery("SELECT *
FROM Information WHERE Balance >= 5000");
```

a table name

4. Getting results

```
while (rs.next())
    { …
    }
```

```
import java.sql.*;

public class DataSourceDemo1
{ public static void main(String[] args)
  { Connection con = null;
    try
    {//load driver class
     Class.forName{“sun.jdbs.odbs.JdbcOdbcDriver”);

     //data source
     String url = “jdbs:odbc:Customers”;

     //get connection
     con = DriverManager.getConnection(url,
     “sa”, “ “)
```

```
//create SQL statement
Statement stmt = con.createStatement();

//execute query
Result rs = stmt.executeQuery("SELECT *
FROM Information WHERE Balance >= 5000");

String firstName, lastName;
Date birthDate;
float balance;
int accountLevel;
```

```
        while(rs.next())
        {firstName = rs.getString("FirstName");
         lastName = rs.getString("lastName");
         balance = rs.getFloat("Balance");

         System.out.println(firstName + " " +
         lastName + ", balance = " + balance);
        }
      }
      catch(Exception e)
      {e.printStackTrace();}
      finally
      {try{con.close();}
       catch(Exception e){ }
      }
    }
  }
```

Programming in a dynamical environment:

Disadvantage of *DataSourceDemo1*:

If the JDBC-ODBC driver, database, user names, or password are changed, the program has to be modified.

Solution:

file name: datasource.config

Configuration file:

config.driver=sun.jdbc.odbc.JdbcOdbcDriver
config.protocol=jdbc
config.subprotocol=odbc
config.dsname=Customers
config.username=sa
config.password=… …

<property> = <property value>

config – datasource name

```
import java.sql.*;
import java.io.*;
import java.util.Properties;

public class DatabaseAccess
{ private String configDir;
  //directory for configuration file
  private String dsDriver = null;
  private String dsProtocol = null;
  private String dsSubprotocol = null;
  private String dsName = null;
  private String dsUsername = null;
  private String dsPassword = null;
```

```
public DatabaseAccess(String configDir)
{ this.configDir = configDir; }

public DatabaseAccess()
{ this(“.”); }

//source: data source name
//configFile: source configuration file

public Connection getConnection(String source,
String configFile) throws SQLException, Exception
{ Connection con = null;

  try
  {Properties prop = loadConfig(ConfigDir, ConfigFile);
```

getConnection("config",
"datasource.config");

```
if (prop != null)
{dsDriver = prop.getProperty(source + “.driver”);
 dsProtocol = prop.getPropert(source + “.protocol”);
 dsSubprotocol = prop.getPropert(source +
 “.subprotocol”);
 if (dsName == null)
   dsName = prop.getProperty(source +
   “.dsName”);
 if (dsUsername == null)
dsUsername = prop.getProperty(source +
“.username”);
 if (dsPassword == null)
   dsPassword = prop.getProperty(source +
“.password”);
```

```
    //load driver class
    Class.forName(dsDriver);

    //connect to data source
    String url = dsProtocol + ":" + dsSubprotocol + ":"
    + dsName;
    con = DriverManager.getConnection(url, dsUsername,
    dsPassword)
  }
  else
    throw new Exception("* Cannot find property file +
    configFile);

  return con;
}
catch (ClassNotFoundException e)
{ throw new Exception("* Cannot find driver class " +
  dsDriver + "!"); }
}
```

```
//dir: directory of configuration file
//filename: file name
public Properties loadConfig(String dir, String filename)
throws Exception
{ File inFile = null;
  Properties prop = null;

  try
  { inFile = new File(dir, filename);
    if (inFile.exists()
    {  prop = new Properties();
       prop.load(new FileInputStream(inFile));
    }
    else throw new Exception("* Error in finding " +
                 inFile.toString());
  }
  finally {return prop;}
  }
}
```

Using class DatabaseAccess, DataSourceDemo1 should be modified a little bit:

```
DatabaseAccess db = new databaseAccess();

con = db.getConnection("config",
"datasource.config");
```

Database updating:

```
import java.sql.*;

public class UpdateDemo1
{ public static void main(String[] args)
  { Connection con = null;
    try
    {
     //get connection
     Databaseaccess db = new DatabaseAccess();
     con = db.getConnection("config",
     "datasource.config");
```

```
    //execute update
    Statement stmt = con.CreateStatement();
    int account = stmt.executeUpdate("UPDATE
    Information SET Accountlevl = 2 WHERE
    Balance >= 50000");
    System.out.println(account + " record has been
updated");

    //execute insert
    account = stmt.executeUpdate("INSERT INTO
    Information VALUE ('David', 'Feng', '05/05/1975',
    2000, 1)");
    System.out.println(account + " record has been
    inserted");
  }
  catch (Exception e) {e.printStackTrace(); }
  finally {try{con.close(); catch(Exception e){ }}
 }
}
```

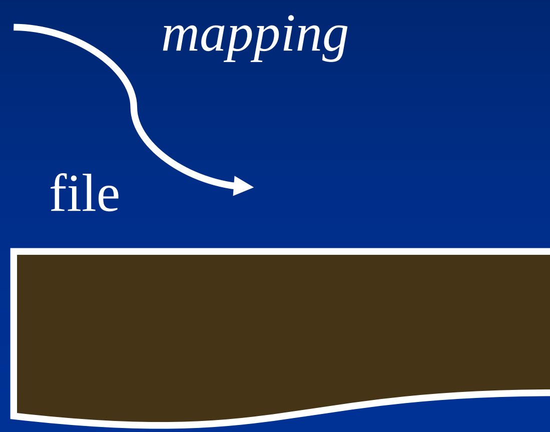
Outline: Hashing (5.9, 5.10, 3rd. ed.; 13.8, 4th, 5th ed.; 17.8, 6th ed.)

- external hashing
- static hashing & dynamic hashing
- hash function
  - mathematical function that maps a key to a bucket address
  - collisions
    - collision resolution scheme
      - open addressing
      - chaining
      - multiple hashing
- linear hashing

Mapping a table into a file

Employee

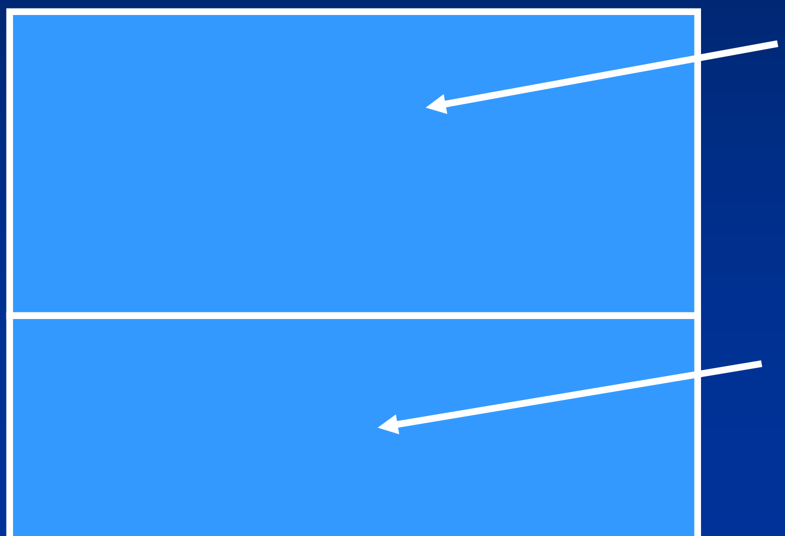
ssn	name	bdate	sex	address	salary
	… …				



- Block (or page)
  - access unit of operating system
  - block size: range from 512 to 4096 bytes
- Bucket
  - access unit of database system
  - A bucket contains one or more blocks.
- A file can be considered as a collection of buckets. Each bucket has an address.

External Hashing

- Consider a file comprising a primary area and an overflow area



Records hash to one of many primary buckets

Records not fitting into the primary area are relegated to overflow

- Common implementations are *static* - the number of primary buckets is fixed - and we expect to need to reorganize this type of files on a regular basis.

External Hashing

- Consider a static hash file comprising M primary buckets
- We need a hash function that maps the key onto {0, 1, … M-1}
- If M is prime and Key is numeric then

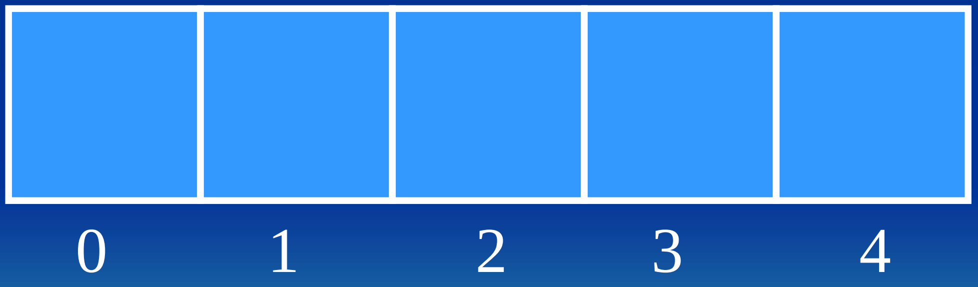
$$Hash(Key) = Key \bmod M$$

can work well

- A collision may occur when more than one records hash to the same address
- We need a collision resolution scheme for overflow handling because the number of collisions for one primary bucket can exceed the bucket capacity
  - open addressing
  - chaining

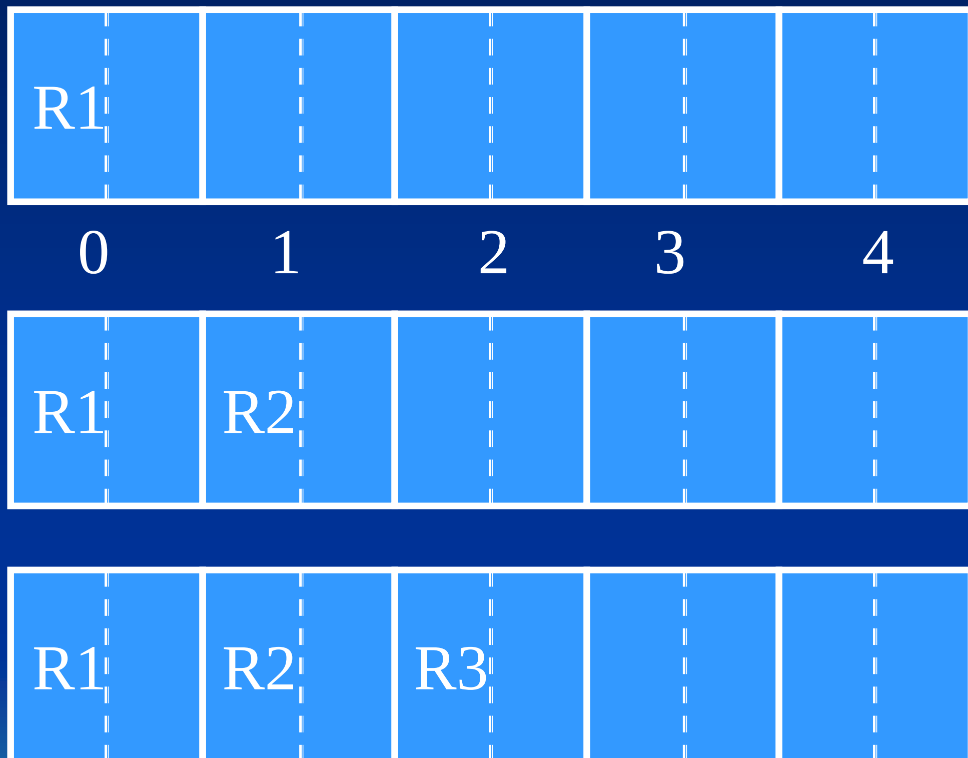
Overflow handling

- Open addressing
  - subsequent buckets are examined until an open record position is found
  - no need for an overflow area
  - consider records being inserted R1, R2, R3, R4, R5, R6, R7 with bucket capacity of 2 and hash values 0, 1, 2, 1, 1, 0, 3



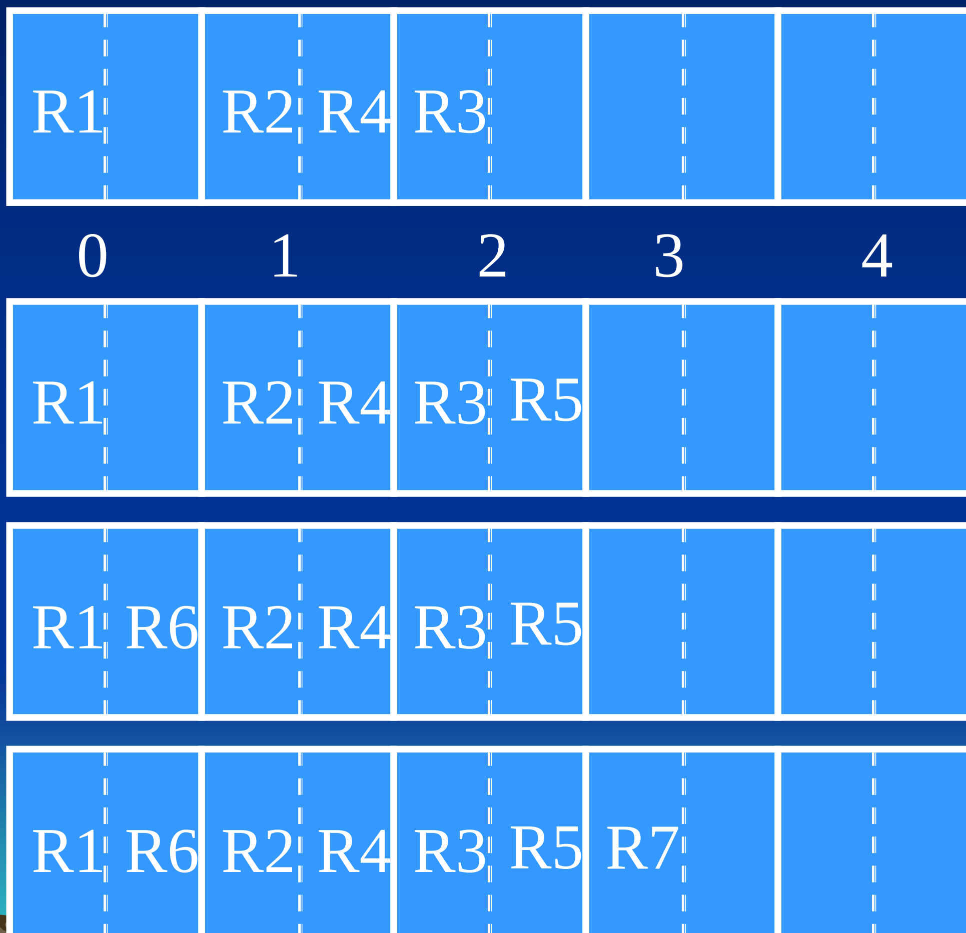
How do we handle retrieval, deletion?

- consider records being inserted R1, R2, R3, R4, R5, R6, R7 with bucket capacity of 2 and hash values 0, 1, 2, 1, 1, 0, 3



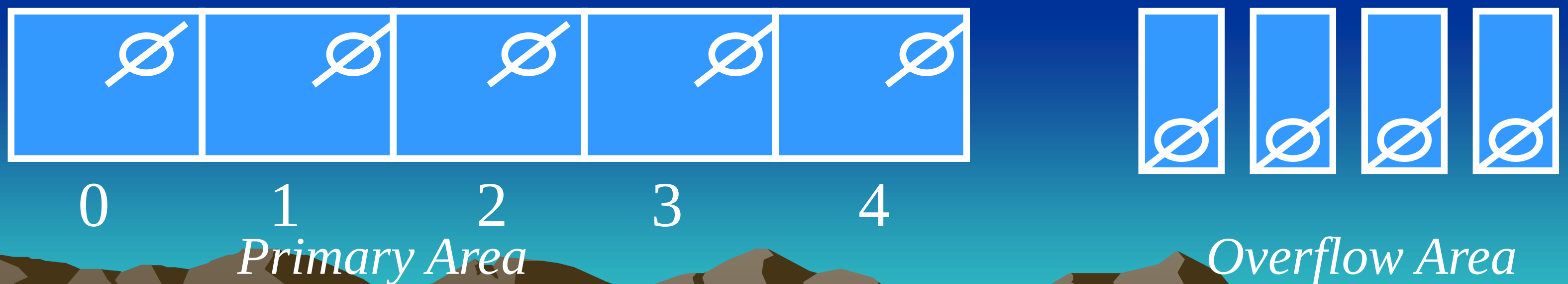
R1, R2, R3, R4, R5, R6, R7

hash values: 0, 1, 2, 1, 1, 0, 3



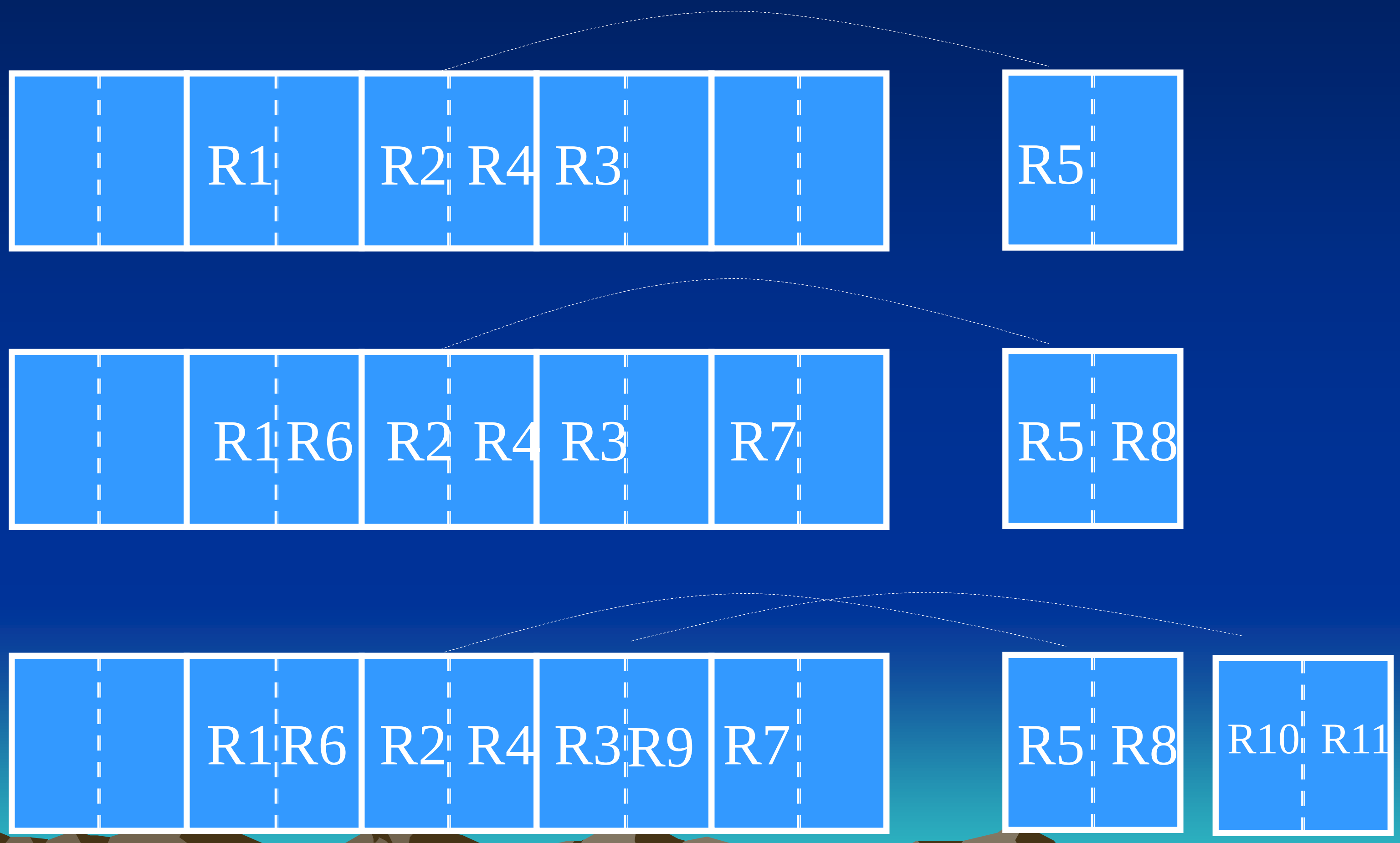
Overflow handling

- Chaining
  - a pointer in the primary bucket points to the first overflow record
  - overflow records for one primary bucket are chained together
  - consider records being inserted R1, R2, R3, R4, R5, R6, R7, R8, R9, R10, R11.
  - with bucket capacity of 2 and hash values 1, 2, 3, 2, 2, 1, 4, 2, 3, 3, 3.
  - deletions?



R1, R2, R3, R4, R5, R6, R7, R8, R9, R10, R11

1, 2, 3, 2, 2, 1, 4, 2, 3, 3, 3



Overflow handling

- Multiple Hashing
  - when collision occurs a next hash function is tried to find an unfilled bucket
  - eventually we would resort to chaining
  - note that open addressing can suffer from poor performance due to islands of full buckets occurring and having a tendency to get even longer - using a second hash function helps avoid that problem

Linear Hashing

- A dynamic hash file:

  grows and shrinks gracefully

- initially the hash file comprises M primary buckets numbered 0, 1, … M-1
- the hashing process is divided into several phases (phase 0, phase 1, phase 2, …). In phase j, records are hashed according to hash functions $h_j(key)$ and $h_{j+1}(key)$
- $h_j(key) = key \bmod (2^j * M)$

phase 0: $h_0(key) = key \bmod (2^0*M)$, $h_1(key) = key \bmod (2^1*M)$
phase 1: $h_1(key) = key \bmod (2^1*M)$, $h_2(key) = key \bmod (2^2*M)$
phase 2: $h_2(key) = key \bmod (2^2*M)$, $h_3(key) = key \bmod (2^3*M)$

… …

Linear Hashing

- h_j(key) is used first; to split, use h_{j+1}(key)
- splitting a bucket means to redistribute the records into two buckets: the original one and a new one. In phase j, to determine which ones go into the original while the others go into the new one, we use $h_{j+1}(key) = key \bmod 2^{j+1} * M$ to calculate their address.
- splitting buckets

  splitting occurs according to a specific rule such as

  - an overflow occurring, or
  - the load factor reaching a certain value, etc.
- a split pointer keeps track of which bucket to split next
- split pointer goes from 0 to $2^j*M - 1$ during the j^{th} phase, j= 0, 1, 2, … …

Linear Hashing

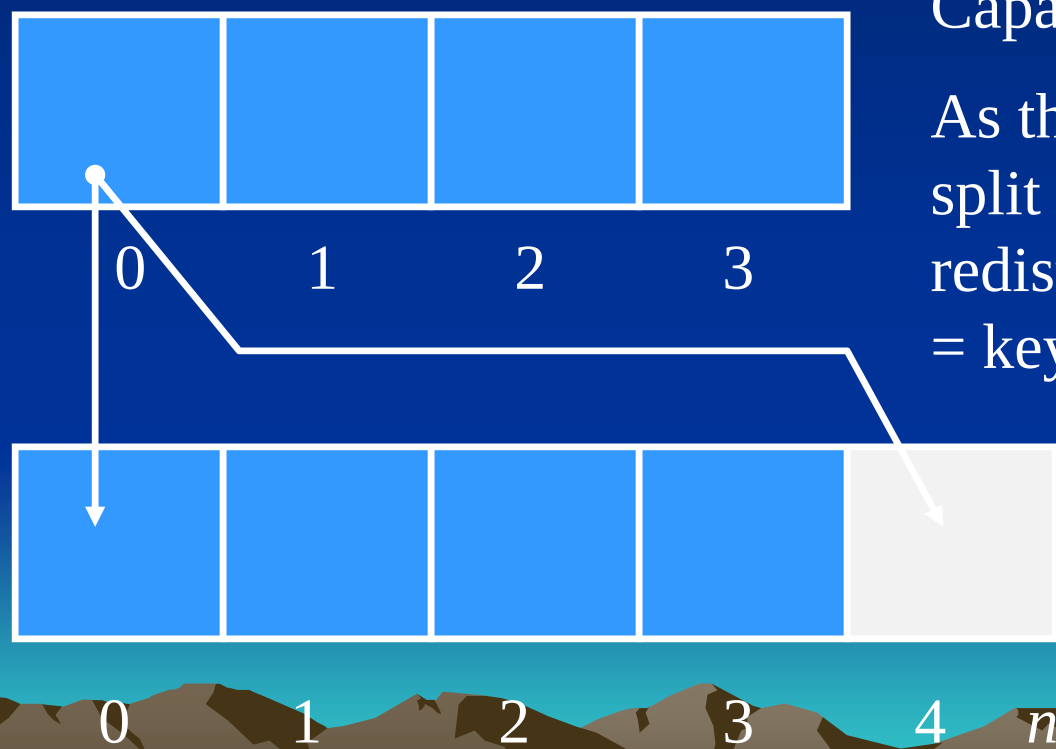
1. What is a phase?
2. When to split a bucket?
3. How to split a bucket?
4. What bucket will be chosen to split next?
5. How do we find a record inserted into a linear hashing file?

Linear Hashing, example

- initially suppose M=4
- h_0(key) = key mod M; i.e. key mod 4 (rightmost 2 bits)
- h_1(key) = key mod 2*M

Capacity of a bucket is 2.

As the file grows, buckets split and records are redistributed using h_1(key) = key mode 2*M.



n=0

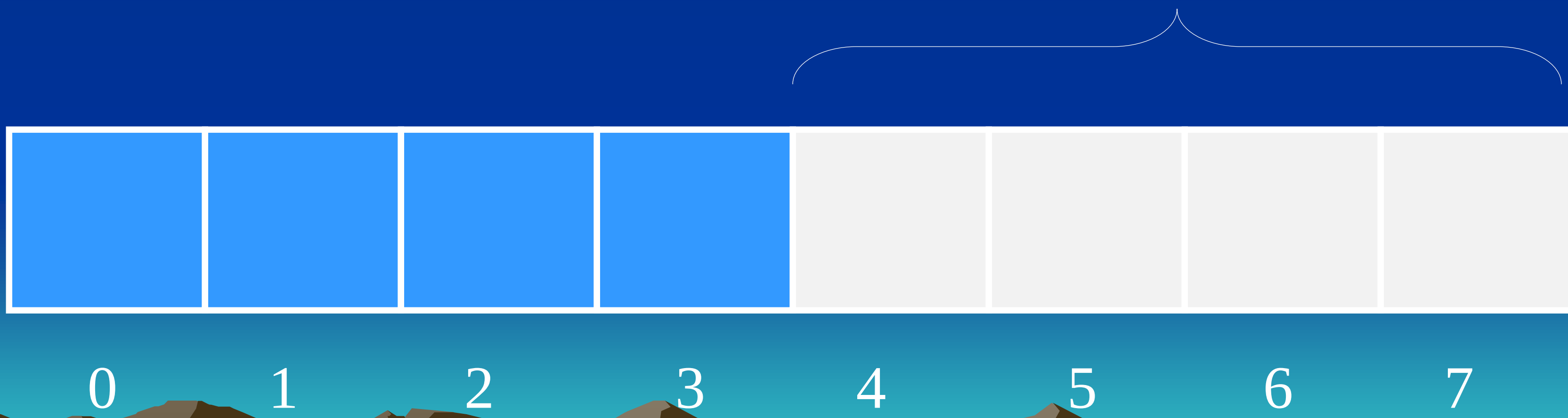
n=1 *after the split*

Linear Hashing, example

- collision resolution strategy: chaining
- split rule: if load factor > 0.70
- insert the records with key values:

0011, 0010, 0100, 0001, 1000, 1110, 0101, 1010, 0111, 1100

Buckets to be added during the expansion



Linear Hashing, example

- when inserting the sixth record (using h_0 = Key mod M) we would have

0100 1000	0001	0010 1110	0011
0	1	2	3

n=0 before the split

(n is the split point, i.e., the point to the bucket to be split.)

0011, 0010, 0100, 0001, 1000, 1110, 0101, 1010, 0111, 1100

Linear Hashing, example

- when inserting the sixth record (using h_0 = Key mod M) we would have

n=0 before the split

(n is the point to the bucket to be split.)

0	1	2	3
0100 1000	0001	0010 1110	0011

- but the load factor 6/8= 0.75 > 0.70 and so bucket 0 must be split (using h_1 = Key mod 2M):

1000	0001	0010 1110	0011	0100

n=1 after the split

load factor: 6/10=0.6

no split

Linear Hashing, example

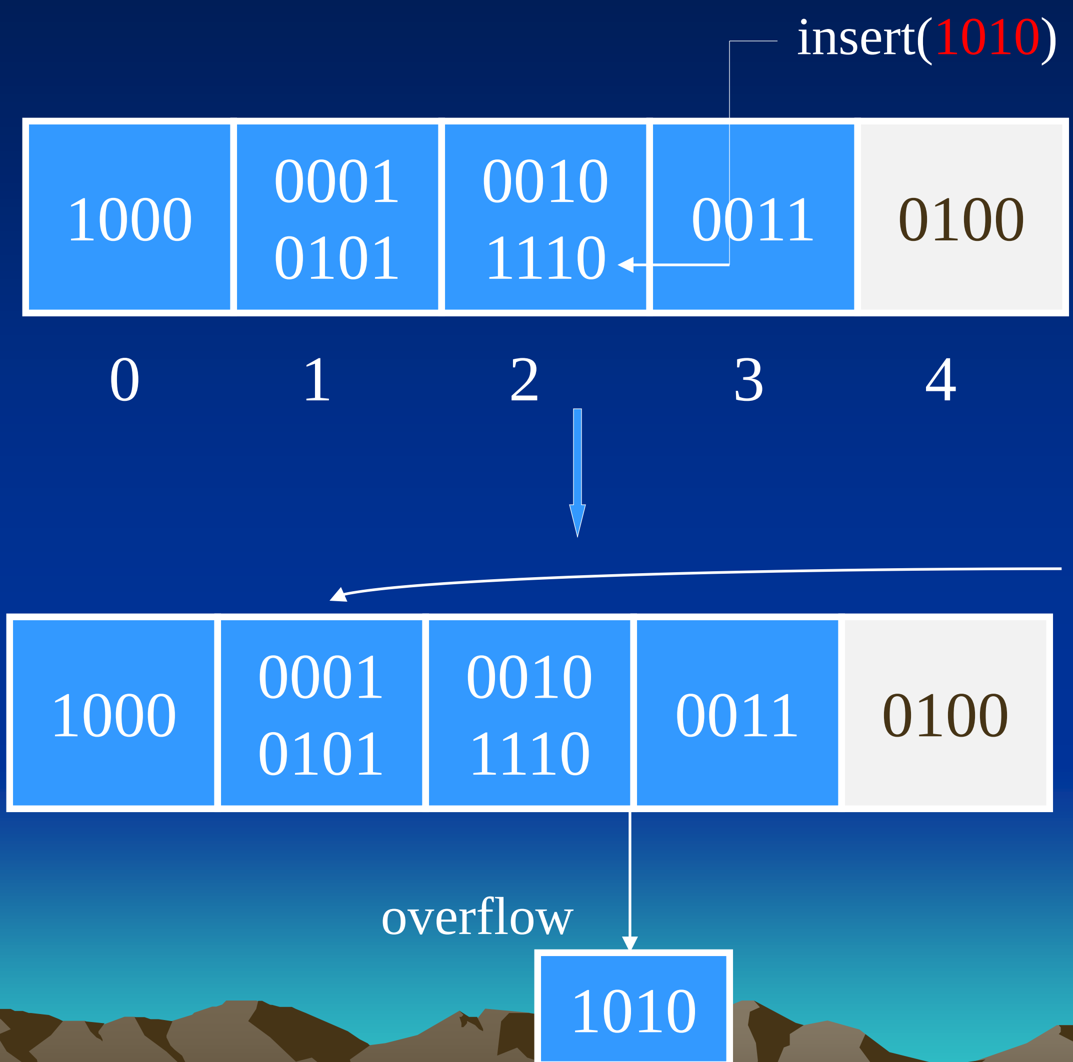
insert(0101)

0	1	2	3	4
1000	0001	0010 1110	0011	0100

0	1	2	3	4
1000	0001 0101	0010 1110	0011	0100

n=1
load factor: 7/10=0.7
no split

Linear Hashing, example

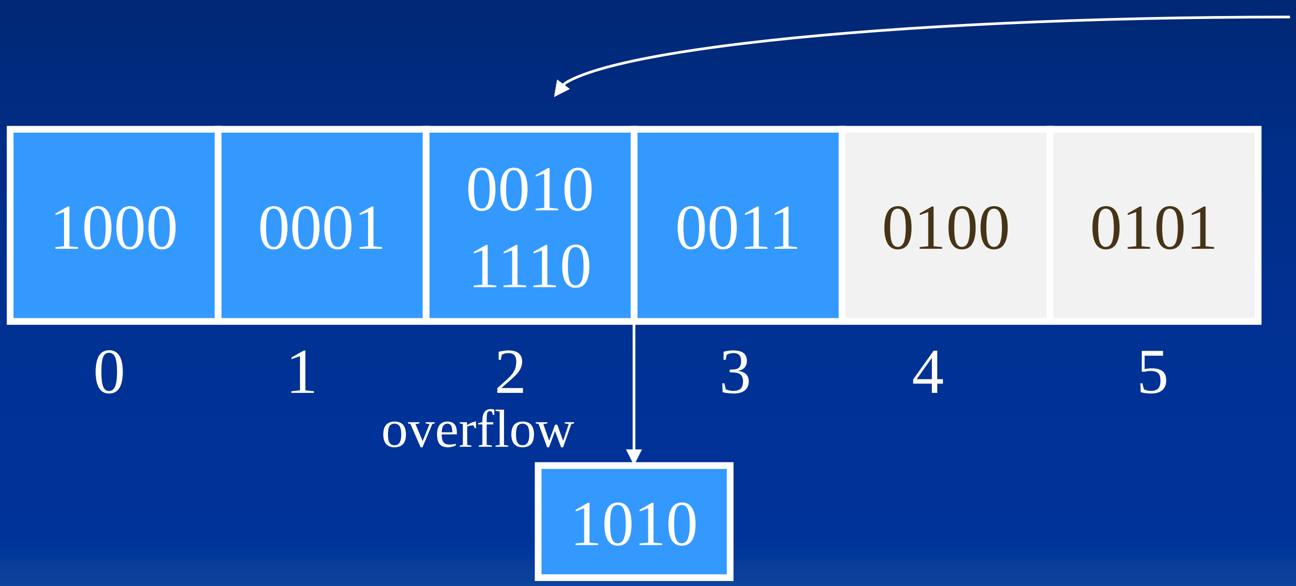


n=1

load factor: 8/10=0.8

split using h_1.

Linear Hashing, example



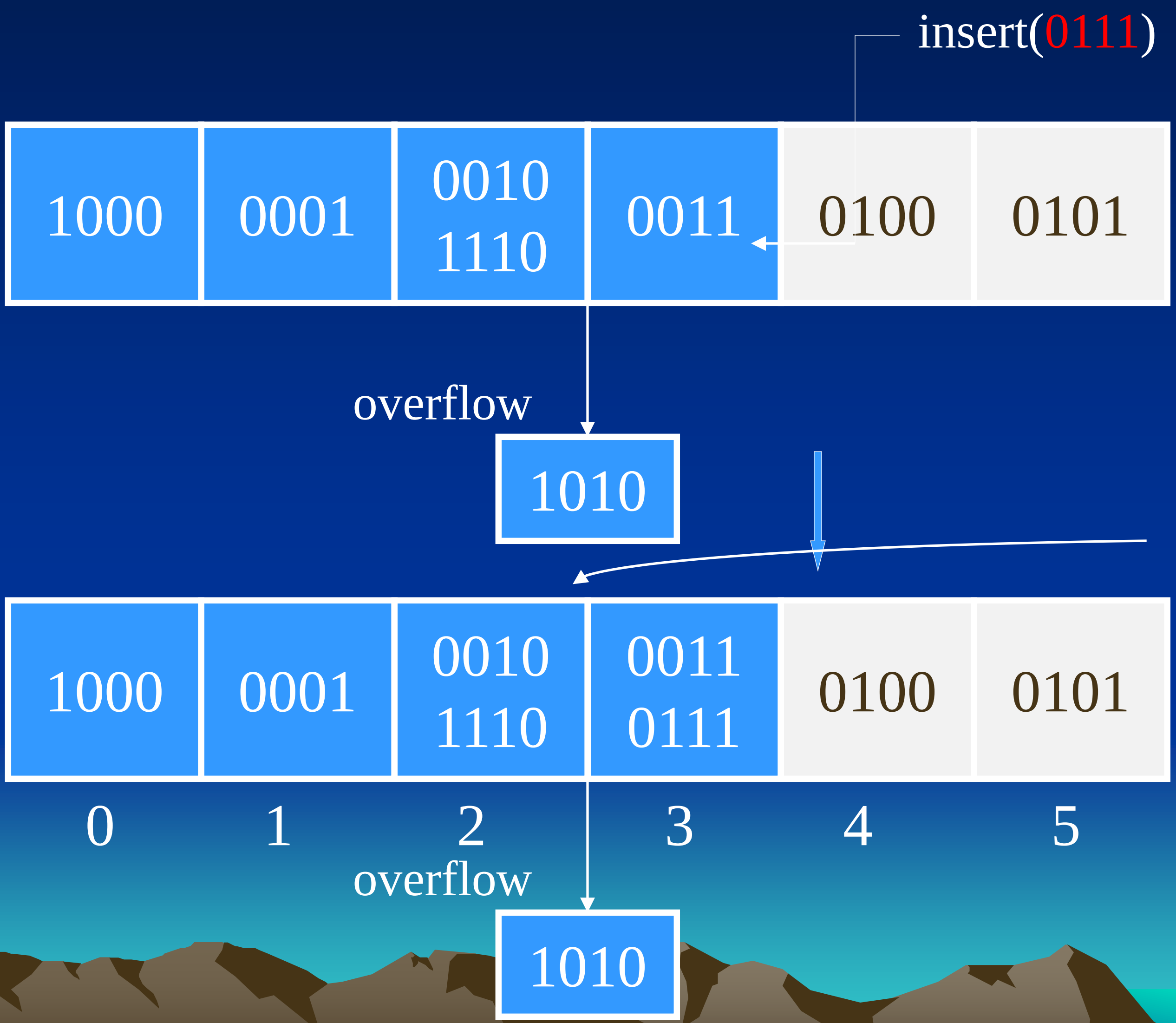
n=2

load factor:

8/12=0.66

no split

Linear Hashing, example



n=2

load factor:
9/12=0.75

split using h_1.

Linear Hashing, example

1000	0001	0010 1010	0011 0111	0100	0101	1110

n=3

load factor: 9/14=0.642

no split.

insert(1100)

1000	0001	0010 1010	0011 0111	0100	0101	1110

Linear Hashing, example

1000 1100	0001	0010 1010	0011 0111	0100	0101	1110

n=3

load factor: 10/14=0.71

split using h_1.

1000 1100	0001	0010 1010	0011	0100	0101	1110	0111

Linear Hashing, example

1000 1100	0001	0010 1010	0011	0100	0101	1110	0111

n=4

load factor: 10/16=0.625

no split.

- At this point, all the 4 (M) buckets are split. The size of the primary area becomes 2M. n should be set to 0. It begins a second phase.
- In the second phase, we will use h_1 to insert records and h_2 to split a bucket.
  - note that $h_1(K) = K \bmod 2M$ and $h_2(K) = K \bmod 4M$.

How to find a KEY in a linear hash file?

M – the size of the initial primary area
j – the last phase
n – the next bucket to be split

Algorithm find(KEY, M, j, n)

if $j = 0$ **then** return h_0(KEY) = KEY mod M;
else

BUCKET_LOC := h_{j-1}(KEY) = KEY mod 2^{j-1}M;
if BUCKET_LOC < n **then** return h_j(KEY)
else return BUCKET_LOC;

Database Index Techniques

- B^+ - tree
- Multiple-key indexes
- kd – tree
- Quad - tree
- R – tree
- Bitmap
- Inverted files

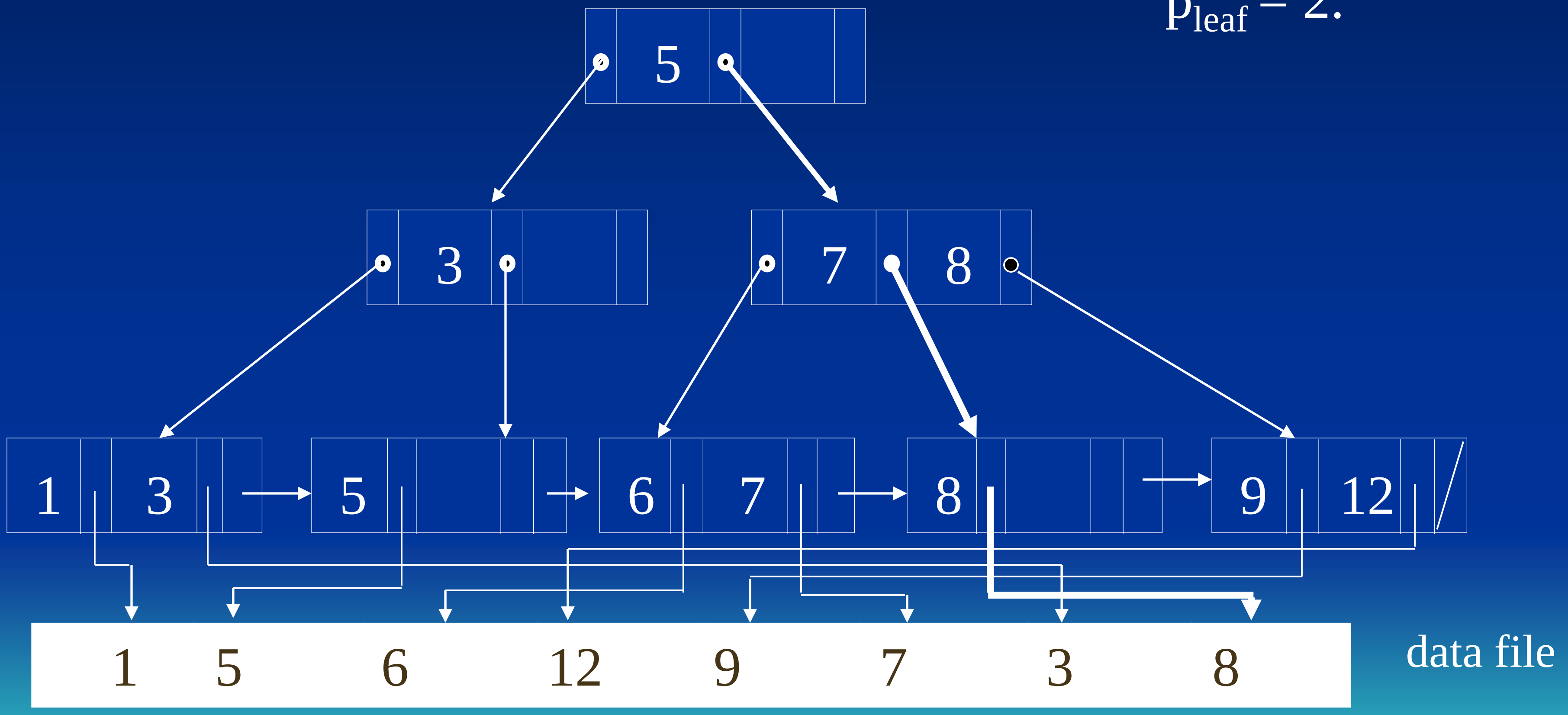
B^+-tree Structure

non-leaf node (internal node or a root)

- $< P_1, K_1, P_2, K_2, \ldots, P_{q-1}, K_{q-1}, P_q >$ $(q \le p_{internal})$
- $K_1 < K_2 < \ldots < K_{q-1}$ (i.e. it's an ordered set)
- For any key value, X, in the subtree pointed to by P_i
  - $K_{i-1} < X \le K_i$ for $1 < i < q$
  - $X \le K_1$ for $i = 1$
  - $K_{q-1} < X$ for $i = q$
- Each internal node has at most $p_{internal}$ pointers.
- Each node except root must have at least $\lceil p_{internal}/2 \rceil$ pointers.
- The root, if it has some children, must have at least 2 pointers.

A B$^+$-tree

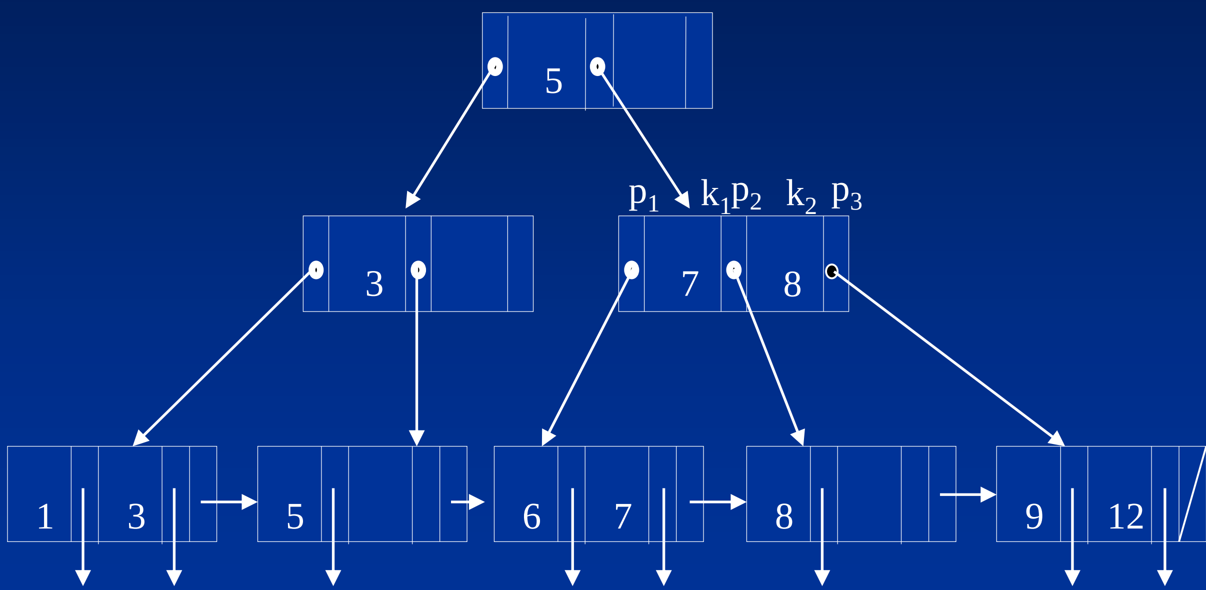
$p_{internal} = 3,$
$p_{leaf} = 2.$



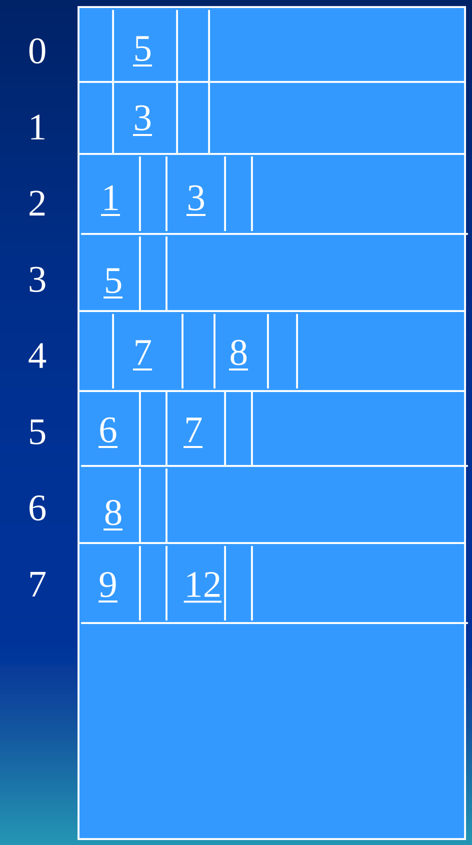
B^+-tree Structure

leaf node (terminal node)

- $< (K_1, Pr_1), (K_2, Pr_2), \ldots, (K_{q-1}, Pr_{q-1}), P_{next} >$
- $K_1 < K_2 < \ldots < K_{q-1}$
- Pr_i points to a record with key value K_i, or Pr_i points to a page containing a record with key value K_i.
- Maximum of p_{leaf} key/pointer pairs.
- Each leaf has at least $\lceil p_{leaf}/2 \rceil$ keys.
- All leaves are at the same level (balanced).
- P_{next} points to the next leaf node for key sequencing.



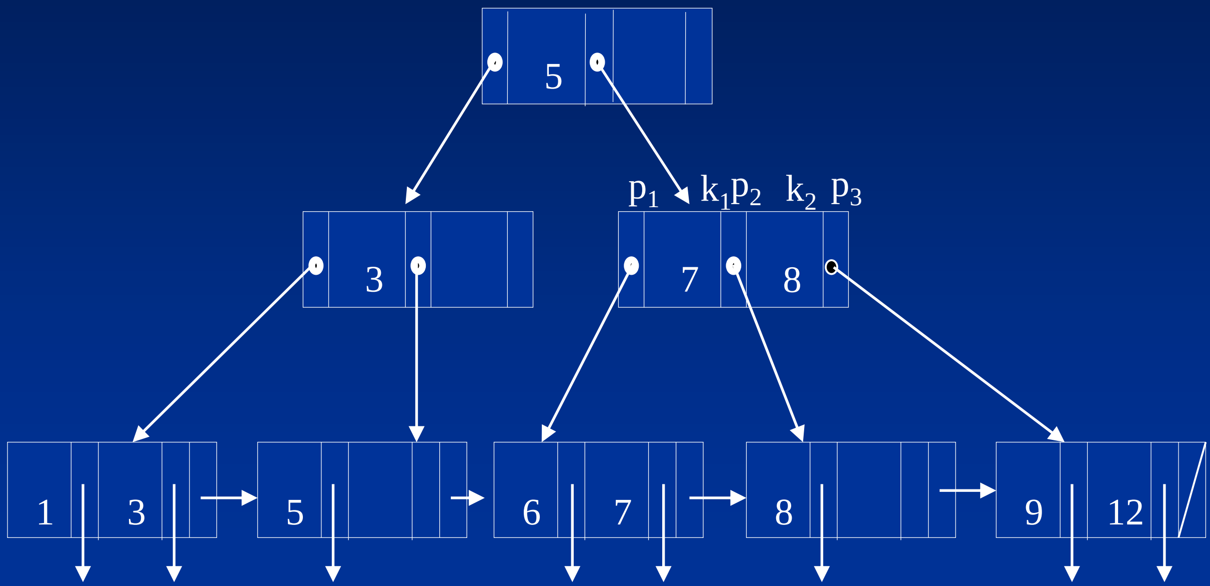
B+-tree stored in a file:



Data file:

1	5	6	12	9	7	3	8	

0 1 2 3



B+-tree stored in a file:

0	1	**5**	4		
1	2	**3**	3		
2	**1**	0	**3**	3	
3	**5**	0			
4	5	**7**	6	**8**	7
5	**6**	1	**7**	2	
6	**8**	3			
7	**9**	2	**12**	1	

Data file:

0		1		2		3	
1	5	6	12	9	7	3	8

Store a B+-tree on hard disk

Algorithm:

push(root, -1, -1);
while (*S* is not empty) do
{ x := pop( );
store x.data in file *F*;
assume that the address of x in *F* is ad;
if x.address-of-parent $\neq$ -1 then {
y := x.address-of-parent;
z := x.position;
write ad in page y at position z in *F*;
}
let x_1, …, x_k be the children of x;
for (i = k to 1) {push(x_i, ad, i)};
}

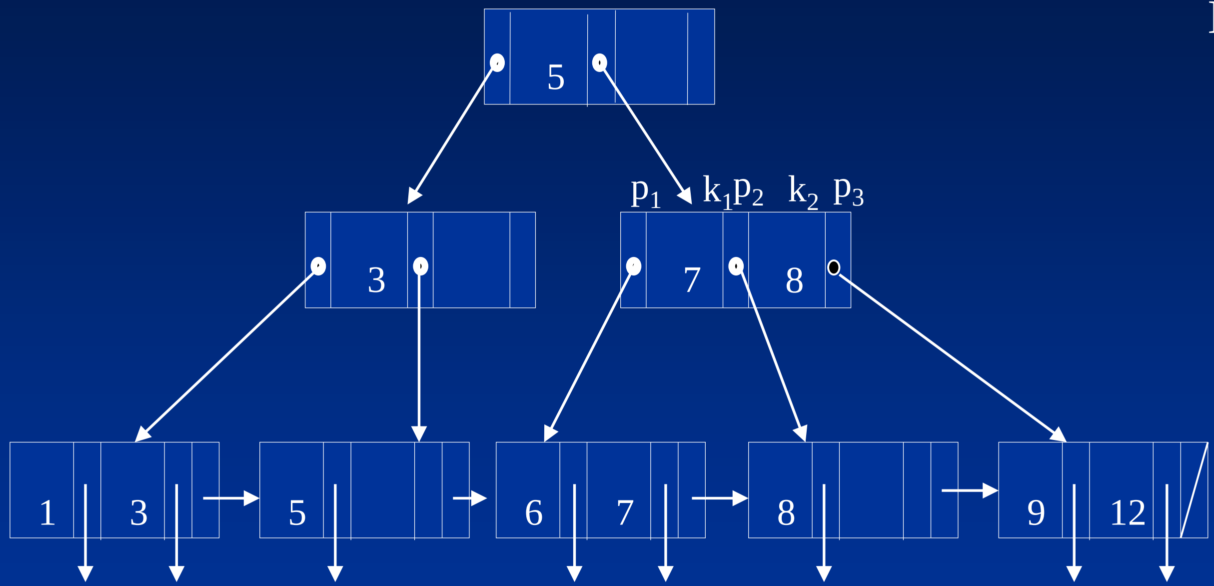
data	address-of-parent	position

stack: *S*

data: all the key values in a node

address-of-parent: a page number in the file *F*, where the parent of the node is stored.

position: a number indicating what is the ranking of a child. That is, whether it is the first, second, …, child of its parent.



B+-tree stored in a file:

Data file:

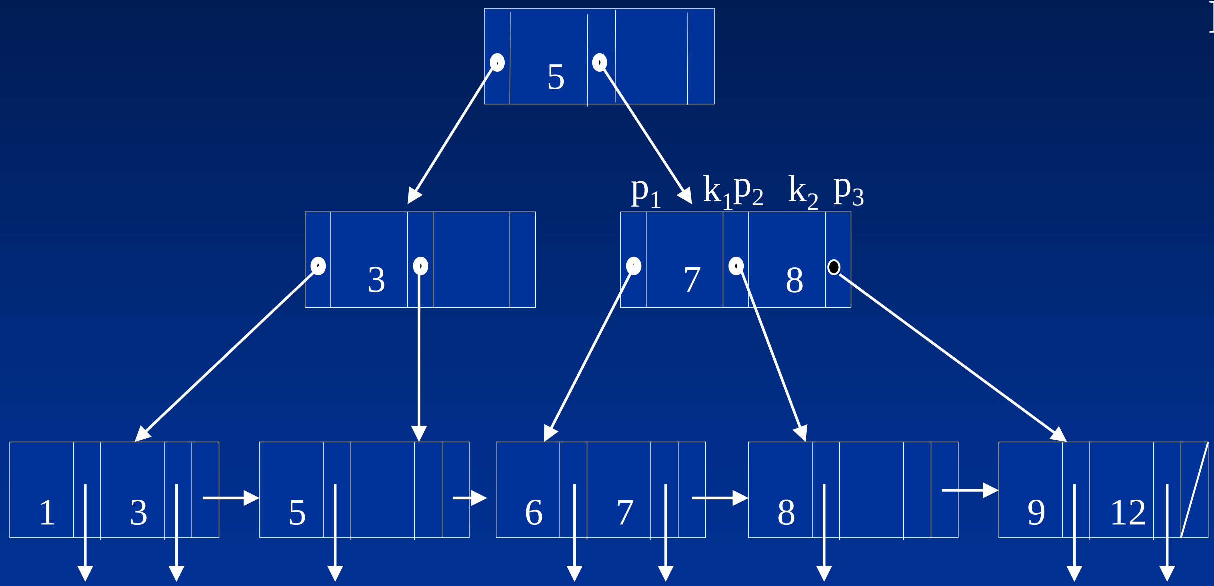
1	5	6	12	9	7	3	8	

0 1 2 3

Stack:

5	-1	-1

3	0	1
7, 8	0	2



B+-tree stored in a file:

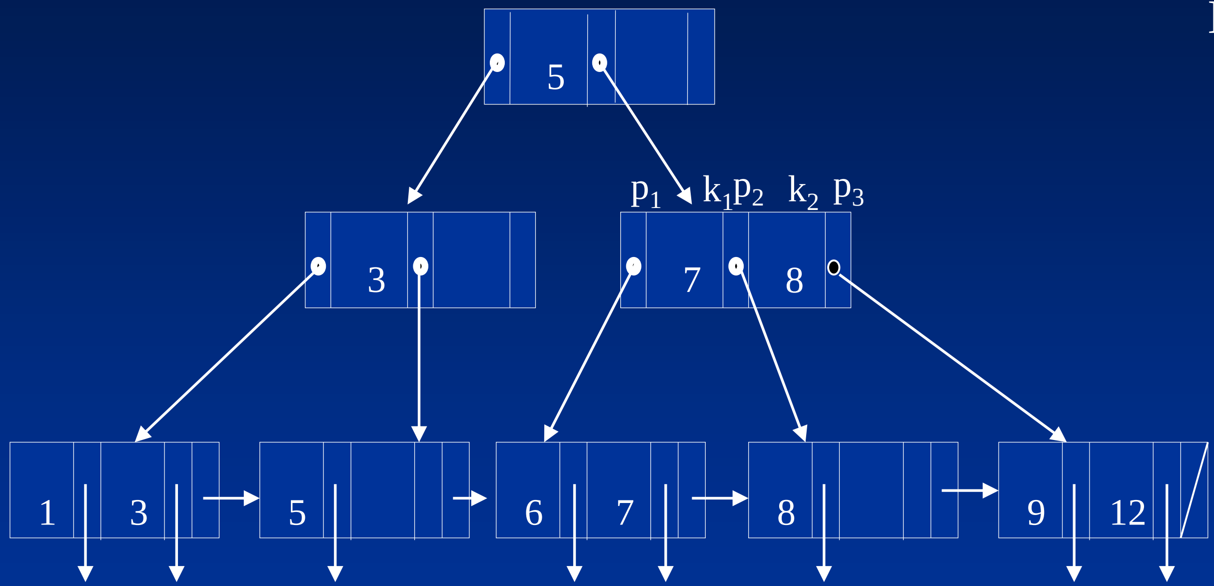
0	1	<u>**5**</u>		
1		<u>**3**</u>		
2				
3				
4				
5				
6				
7				

Data file:

1 5	6 12	9 7	3 8	
0	1	2	3	

3	0	1
7, 8	0	2

1, 3	1	1
5	1	2
7, 8	0	2



B+-tree stored in a file:

0	1	<u>5</u>		
1	2	<u>3</u>		
2	<u>1</u>	0	<u>3</u>	3
3				
4				
5				
6				
7				

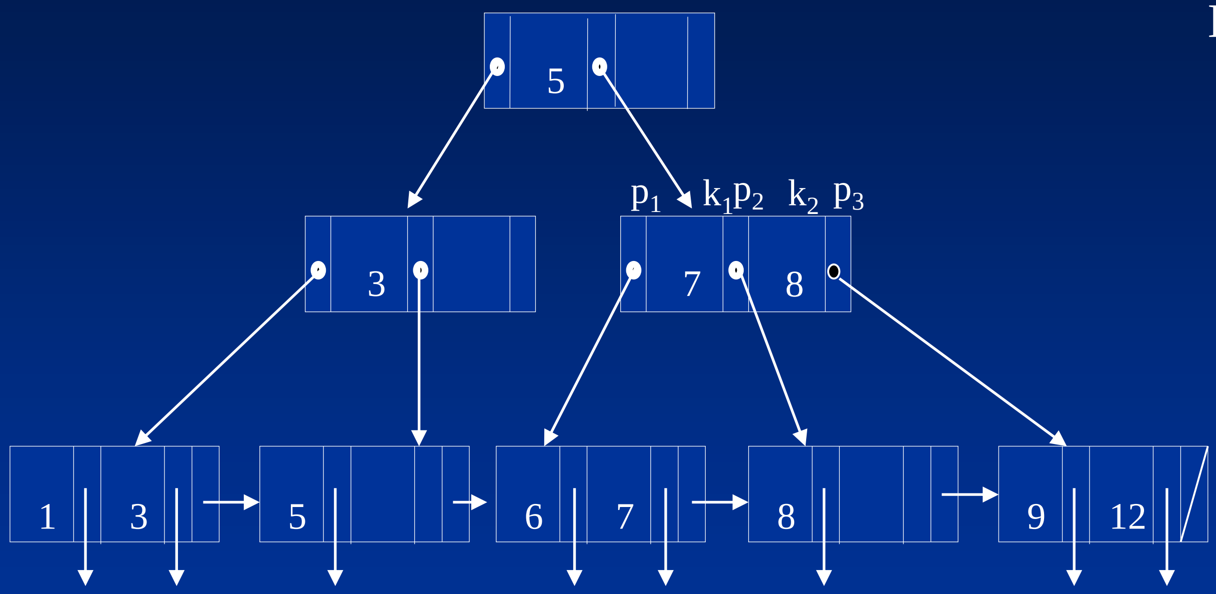
Data file:

1	5	6	12	9	7	3	8	

0	1	2	3

1, 3	1	1
5	1	2
7, 8	0	2

5	1	2
7, 8	0	2



B+-tree stored in a file:

0	1	5		
1	2	3	3	
2	1	0	3	3
3	5	0		
4				
5				
6				
7				

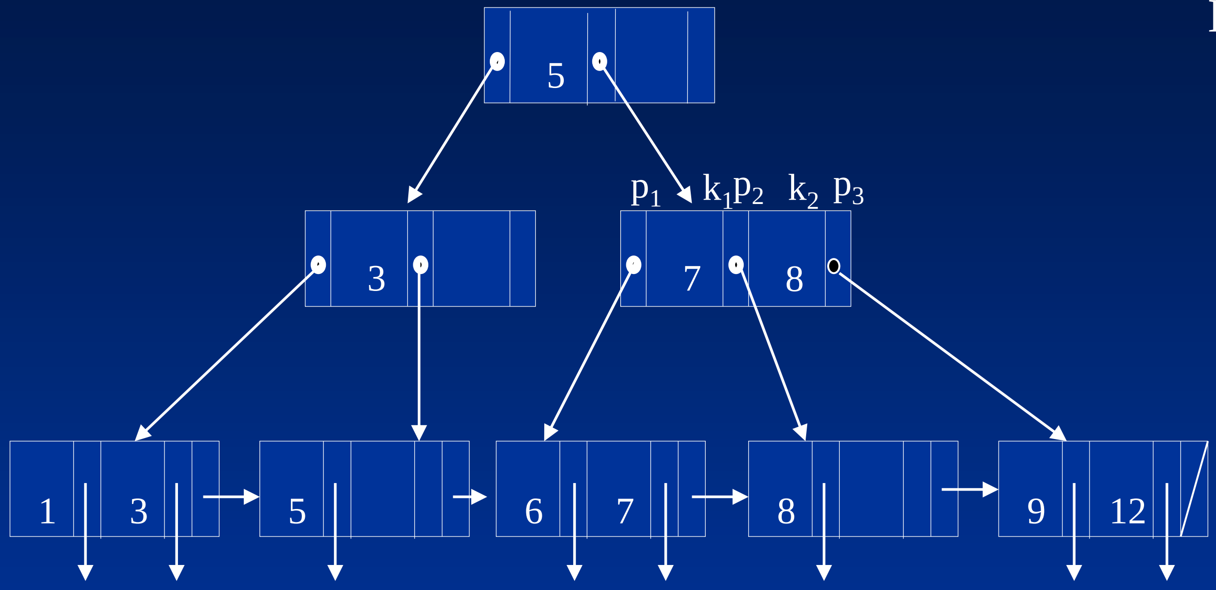
Data file:

0	1	2	3	
1 ¦ 5	6 ¦ 12	9 ¦ 7	3 ¦ 8	

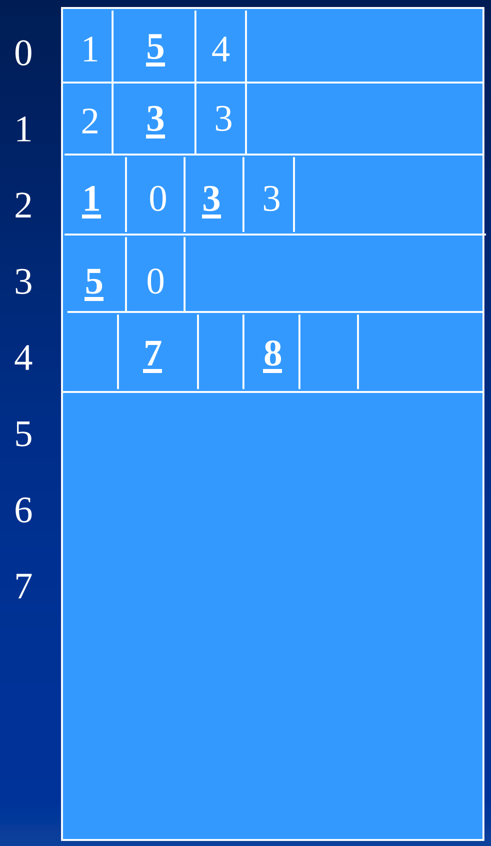
5	1	2
7, 8	0	2

⇒

7, 8	0	2



B+-tree stored in a file:



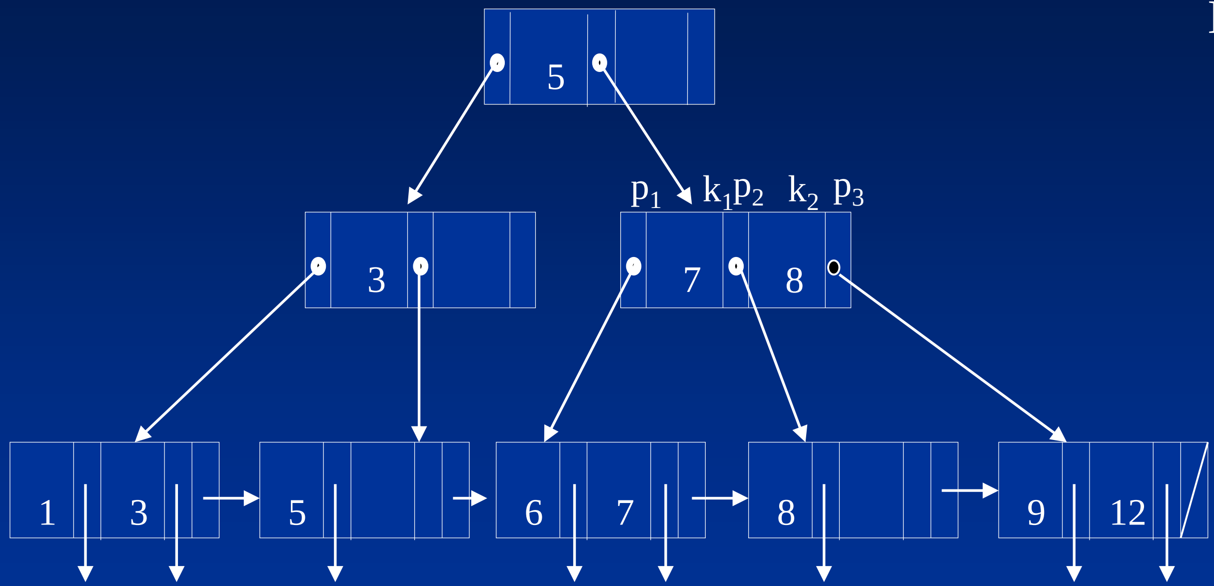
Data file:

1	5	6	12	9	7	3	8	

0 1 2 3

7, 8	0	2

6, 7	4	1
8	4	2
9,12	4	3



B+-tree stored in a file:

0	1	**5**	4			
1	2	**3**	3			
2	**1**	0	**3**	3		
3	**5**	0				
4	5	**7**		**8**		
5	**6**	1	**7**	2		
6						
7						

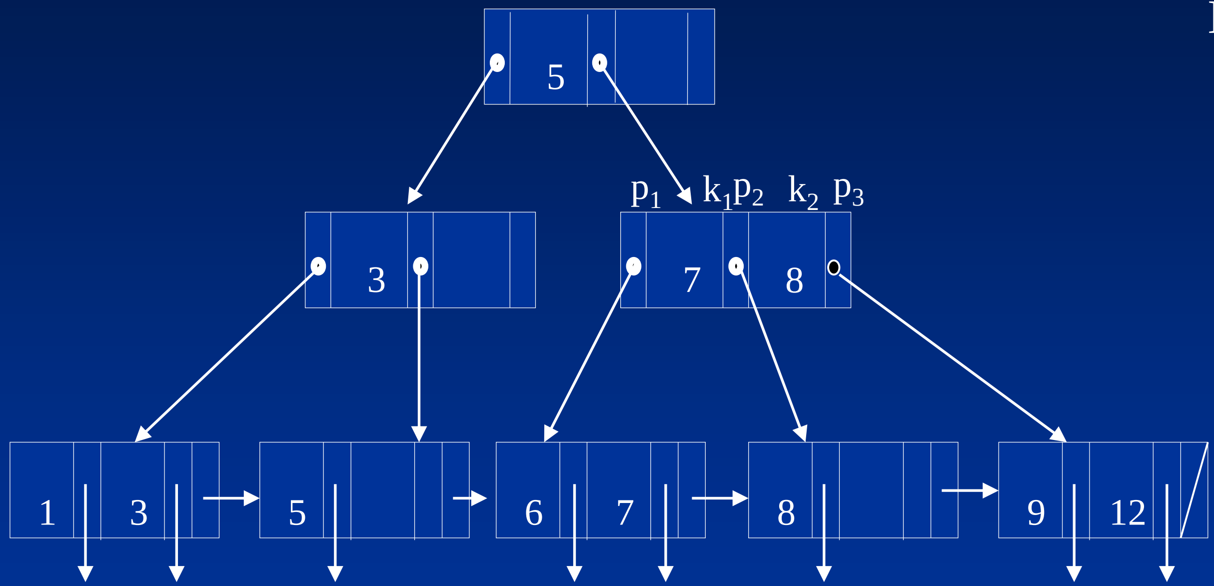
Data file:

0		1		2		3		
1	5	6	12	9	7	3	8	

6, 7	4	1
8	4	2
9,12	4	3

⇒

8	4	2
9,12	4	3



B+-tree stored in a file:

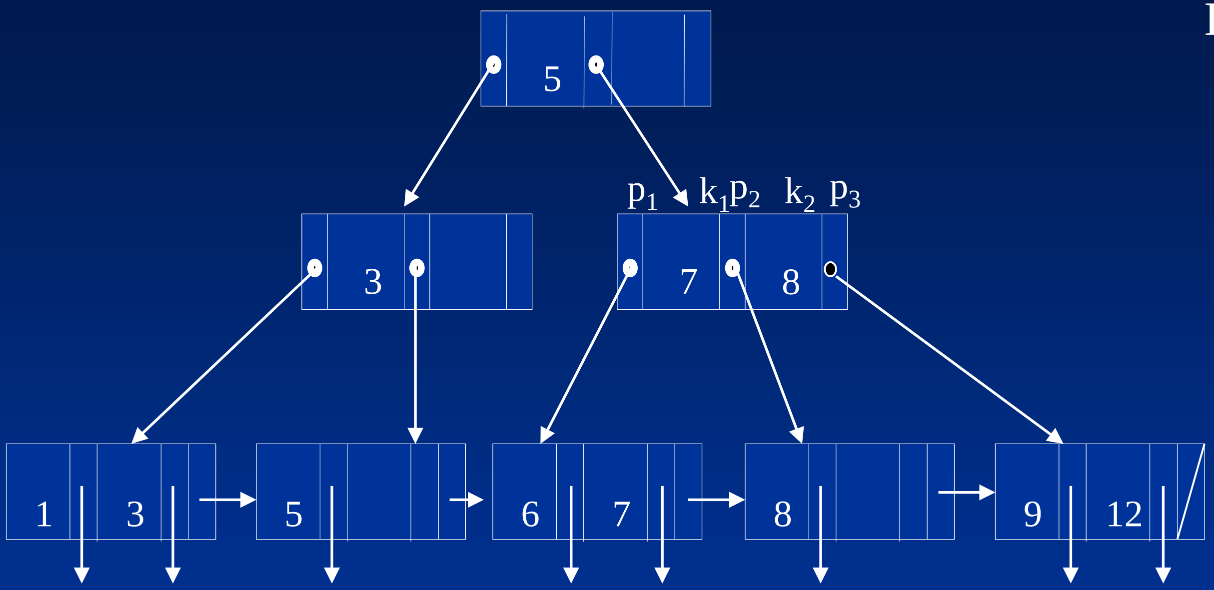
0	1	**5**	4	
1	2	**3**	3	
2	**1**	0	**3**	3
3	**5**	0		
4	5	**7**	6	**8**
5	**6**	1	**7**	2
6	**8**	3		
7				

Data file:

0		1		2		3		
1	5	6	12	9	7	3	8	

8	4	2
9,12	4	3

9,12	4	3



B+-tree stored in a file:

0	1	**5**	4			
1	2	**3**	3			
2	**1**	0	**3**	3		
3	**5**	0				
4	5	**7**	6	**8**	7	
5	**6**	1	**7**	2		
6	**8**	3				
7	**9**	2	**12**	1		

Data file:

0		1		2		3		
1	5	6	12	9	7	3	8	

9,12	4	3

empty stack

Index Structures for Multidimensional Data

- Multiple-key indexes
- *kd*-trees
- Quad trees
- R-trees
- Bit map

Indexes over texts

- Inverted files

Multiple-key indexes

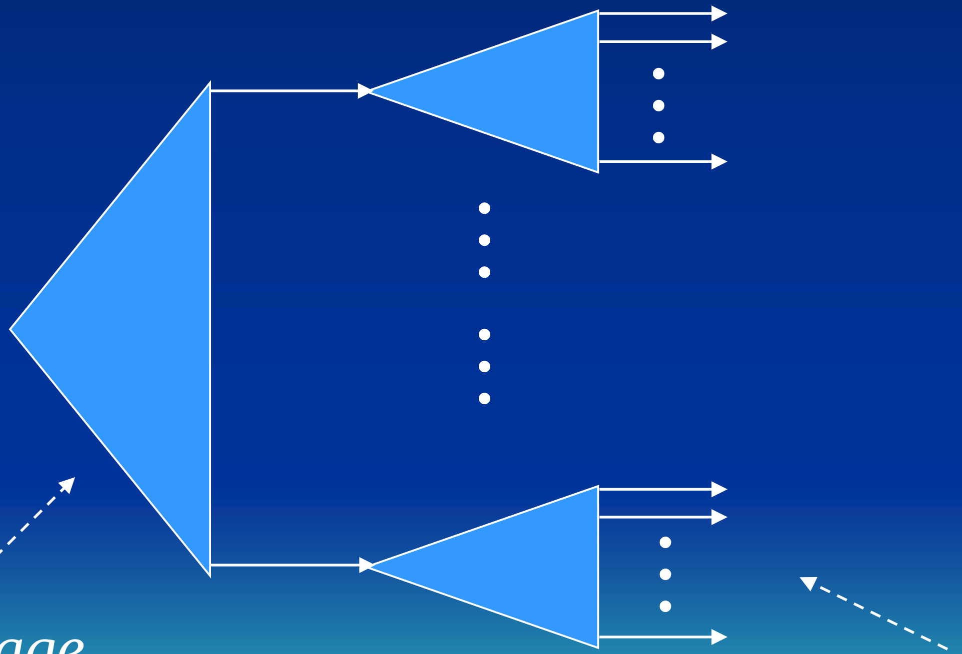
(Indexes over more than one attributes)

Employee

ename	ssn	age	salary	dnumber
Aaron, Ed				
Abbott, Diane				
Adams, John				
Adams, Robin				

Multiple-key indexes

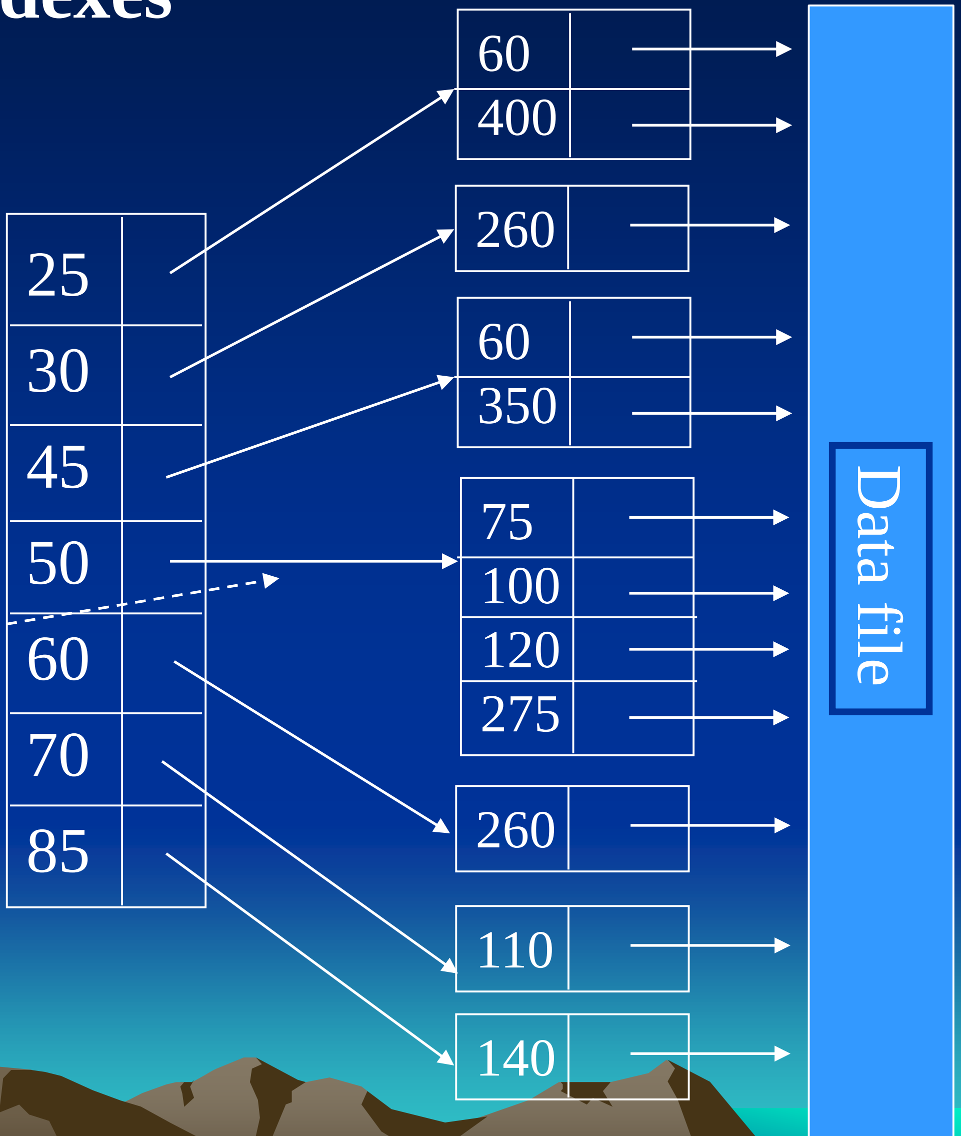
(Indexes over more than one attributes)



Index on *age*

Index on *salary*

Multiple-key indexes



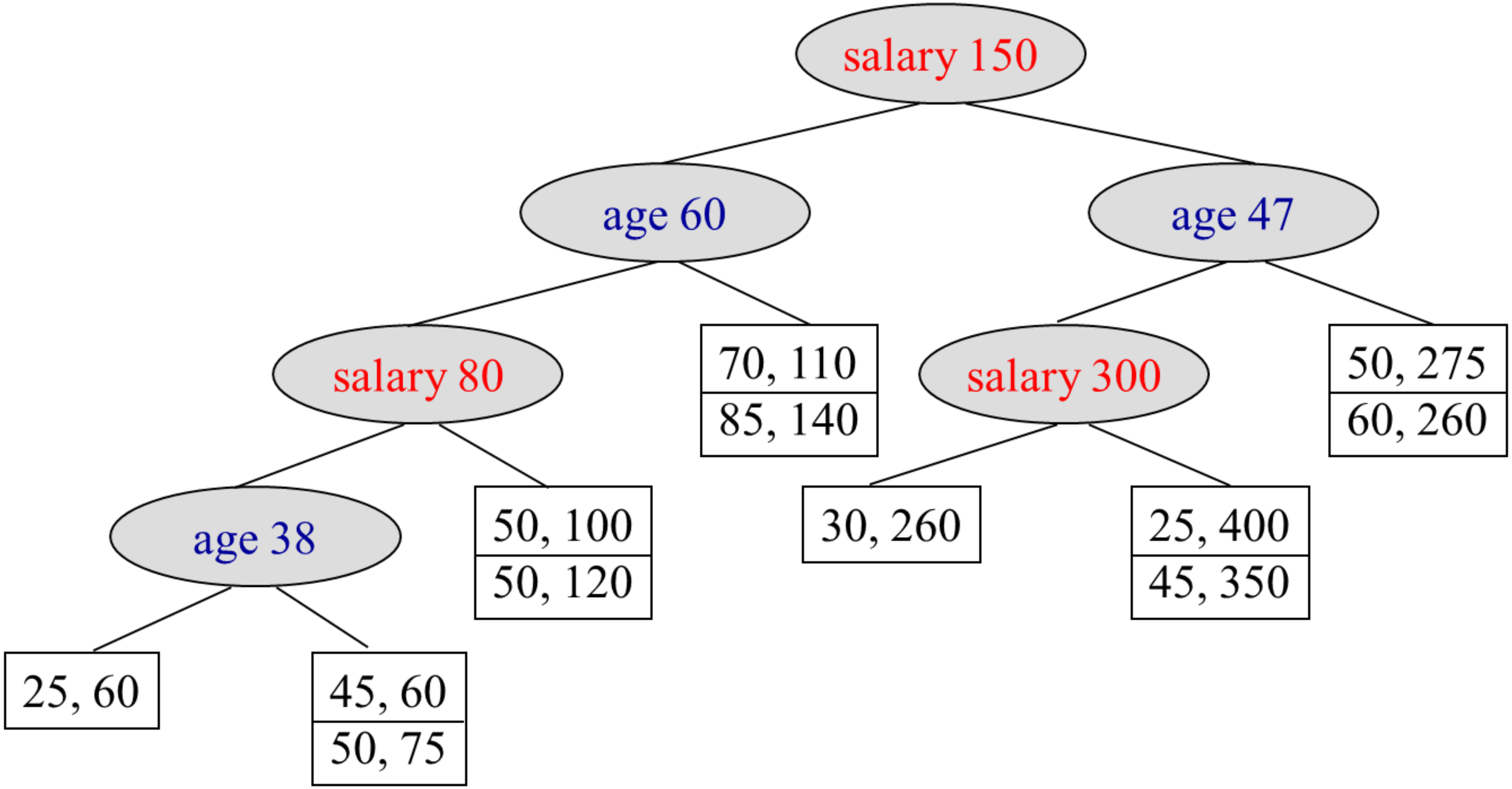
pointer to an index over a set of salaries of all those employees of age between 50 and 60

kd-Trees

(A generalization of binary search trees)

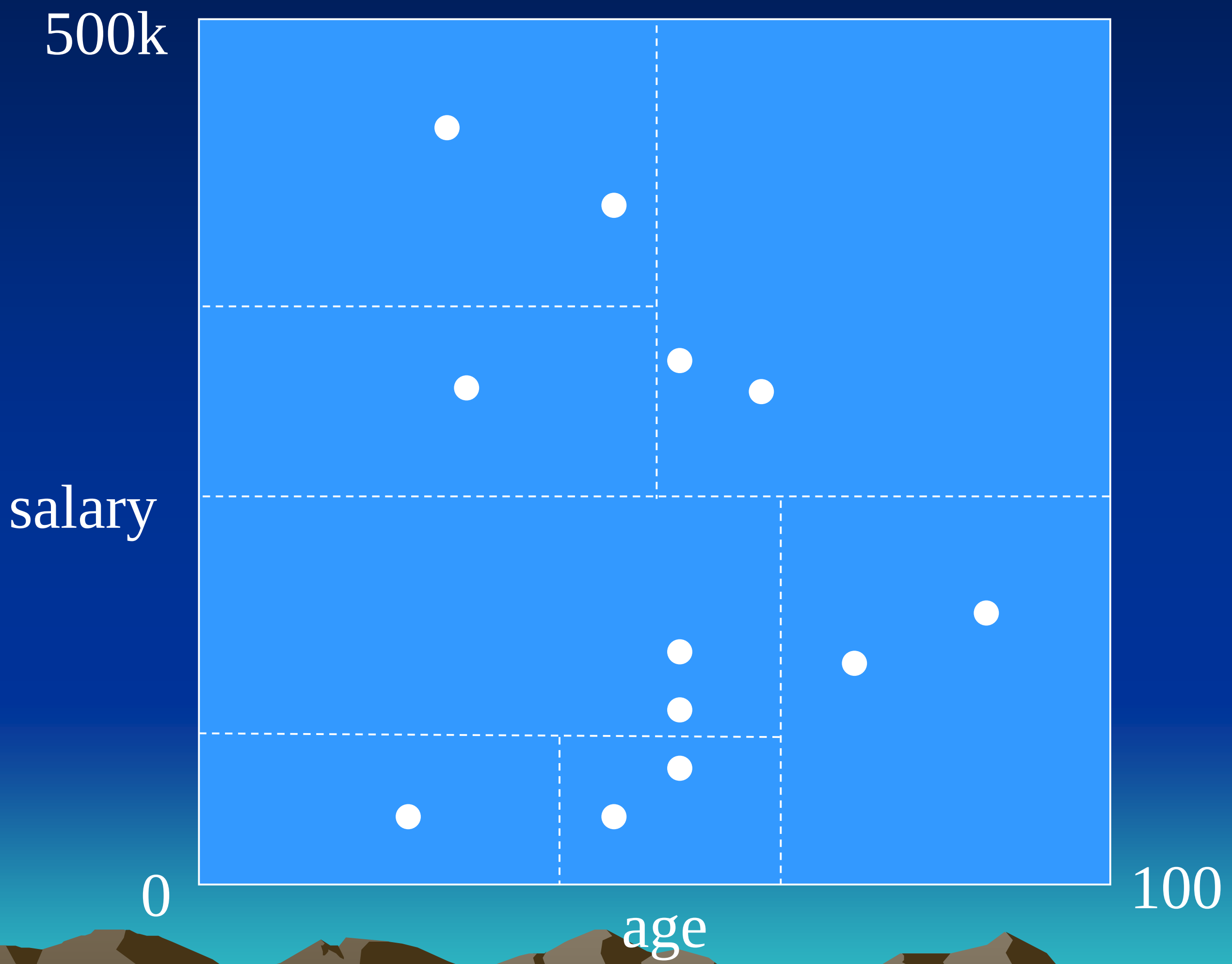
A *kd*-tree is a binary tree in which interior nodes have an associated attribute *a* and a value *v* that splits the data points into two parts: those with *a*-value less than *v* and those with *a*-value equal to or larger than *v*.

kd-Trees

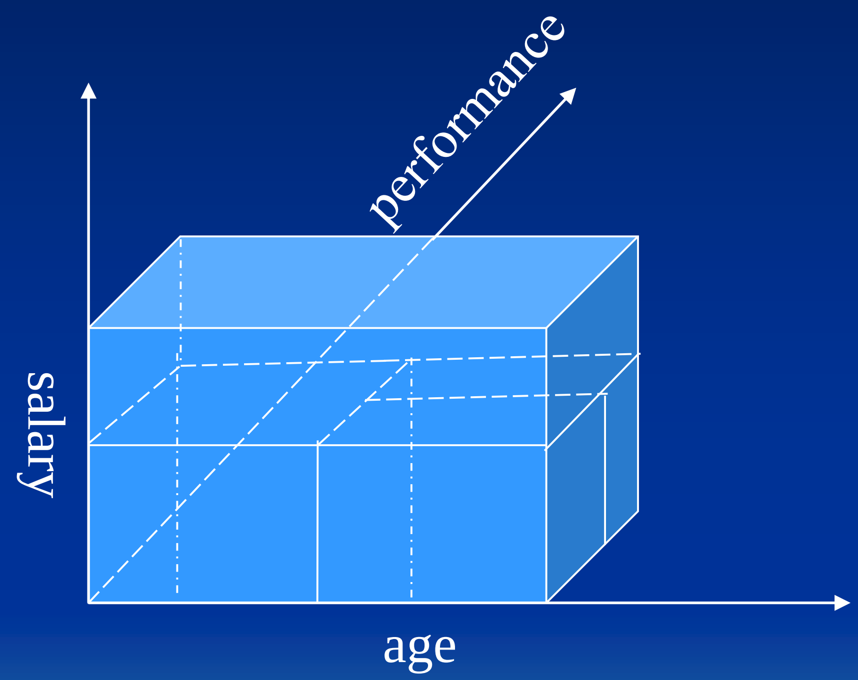


salary 150
age 60
age 47
salary 80
70, 110
85, 140
salary 300
50, 275
60, 260
age 38
50, 100
50, 120
30, 260
25, 400
45, 350
25, 60
45, 60
50, 75

kd-trees

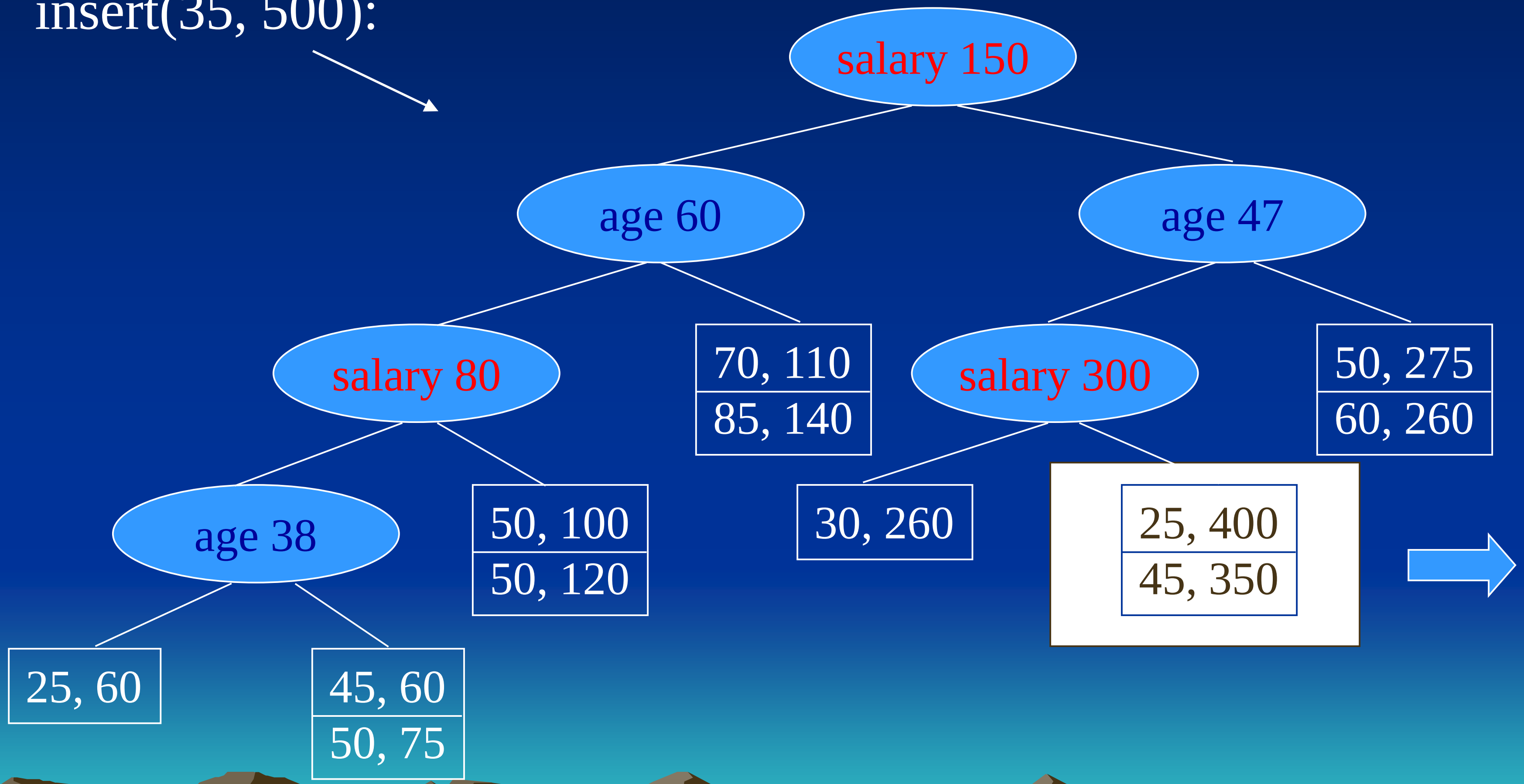


3-dimensional data division

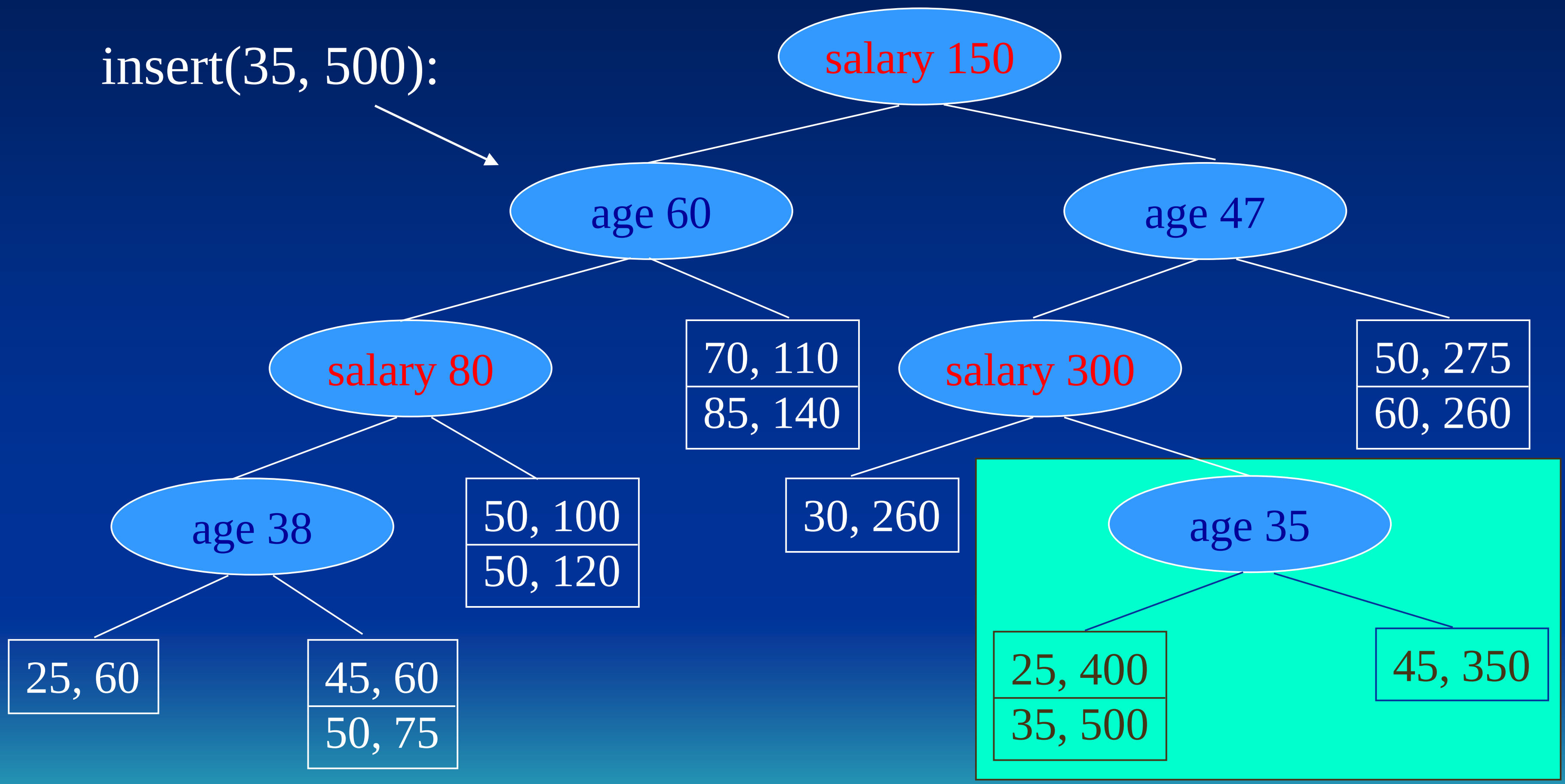


Insert a new entry into a *kd*-tree:

insert(35, 500):



Insert a new entry into a *kd*-tree:



Quad-trees

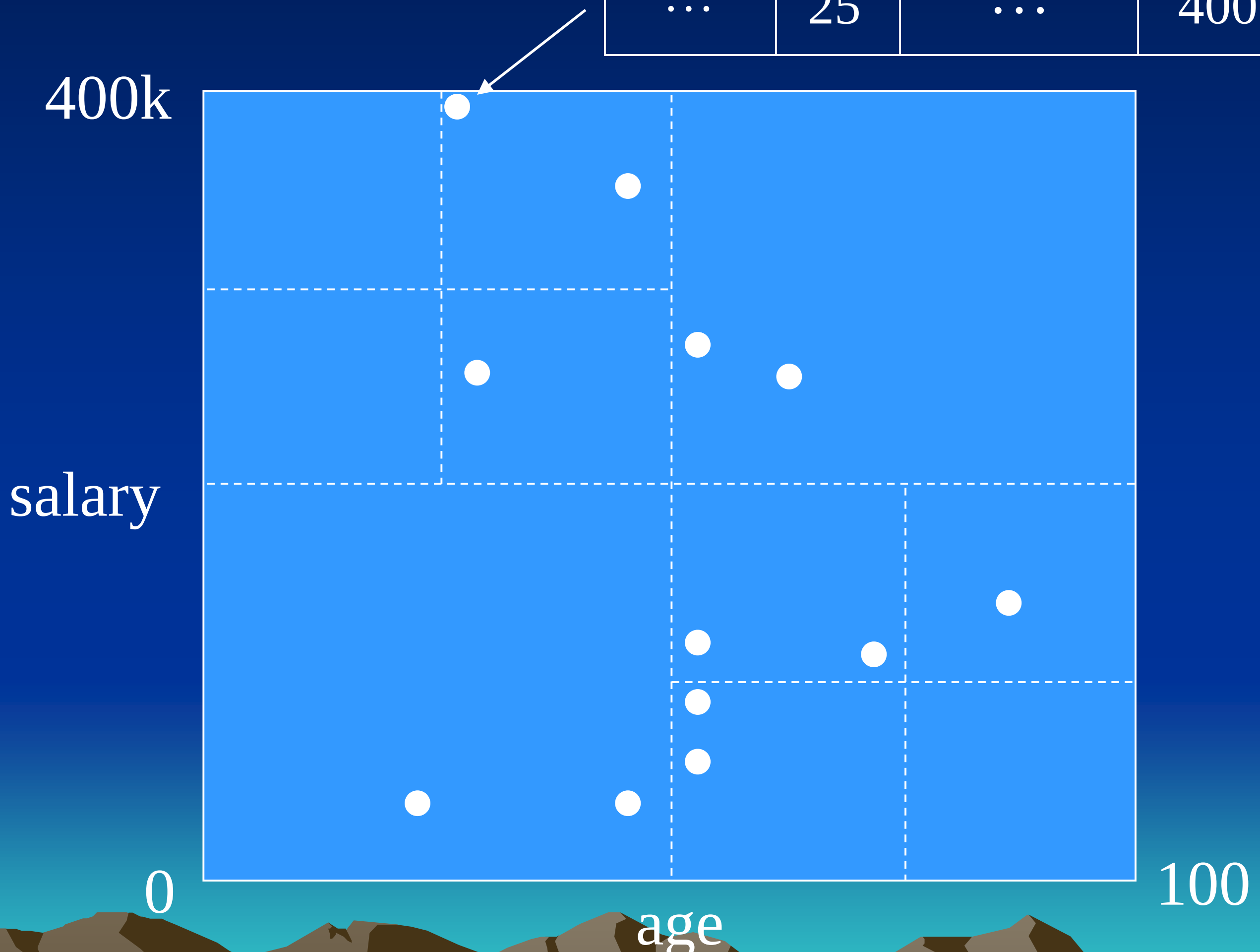
In a Quad-tree, each node corresponds to a square region in two dimensions, or to a *k*-dimensional cube in *k* dimensions.

- If the number of data entries in a square is not larger than what will fit in a block, then we can think of this square as a leaf node.

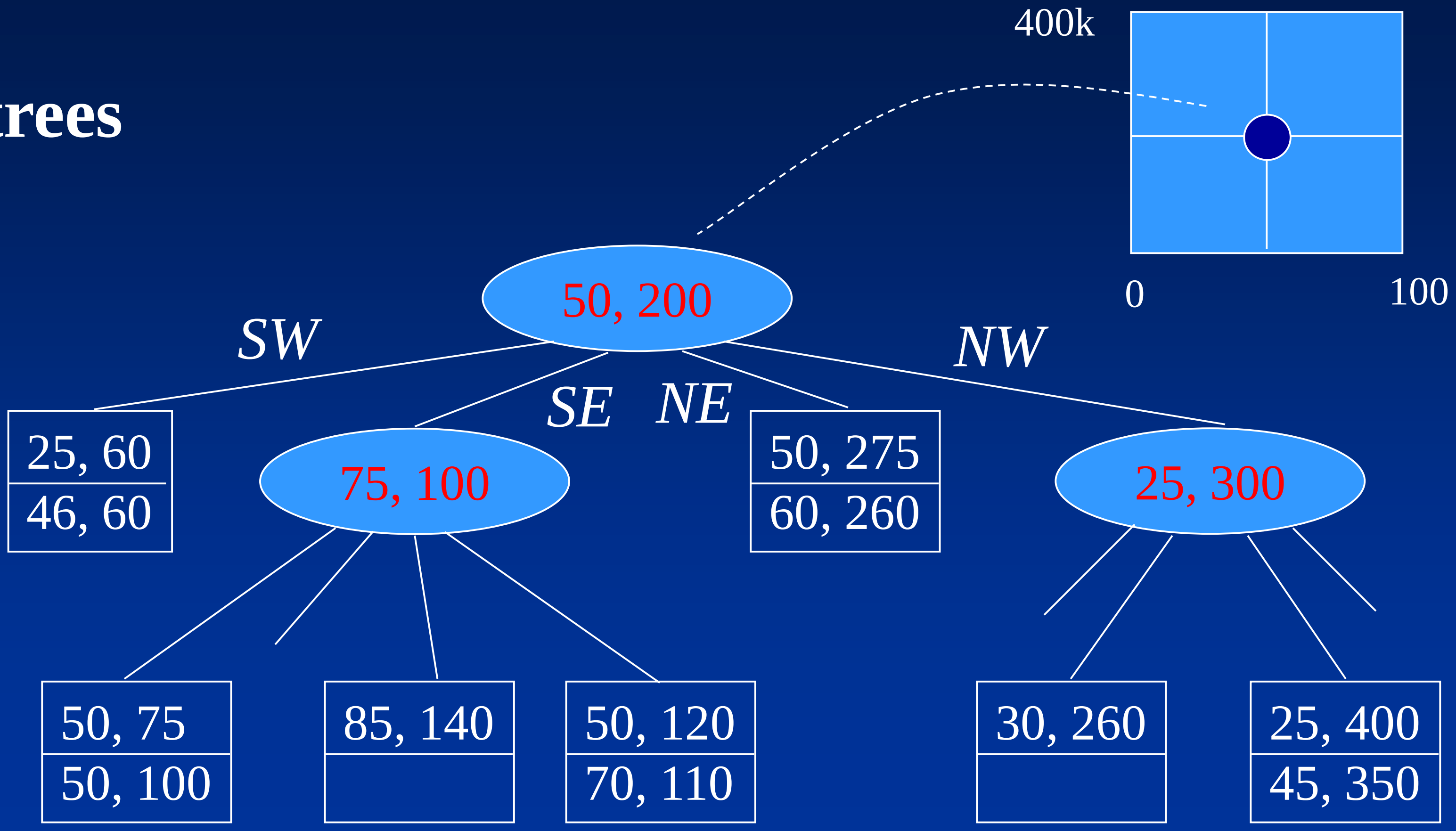
- If there are too many data entries to fit in one block, then we treat the square as an interior node, whose children correspond to its four quadrants.

Quad-trees

name	age	…	salary	…
…	25	…	400	…



Quad-trees



NW – north-west
NE – north-east

SW – south-west
SE – south-east

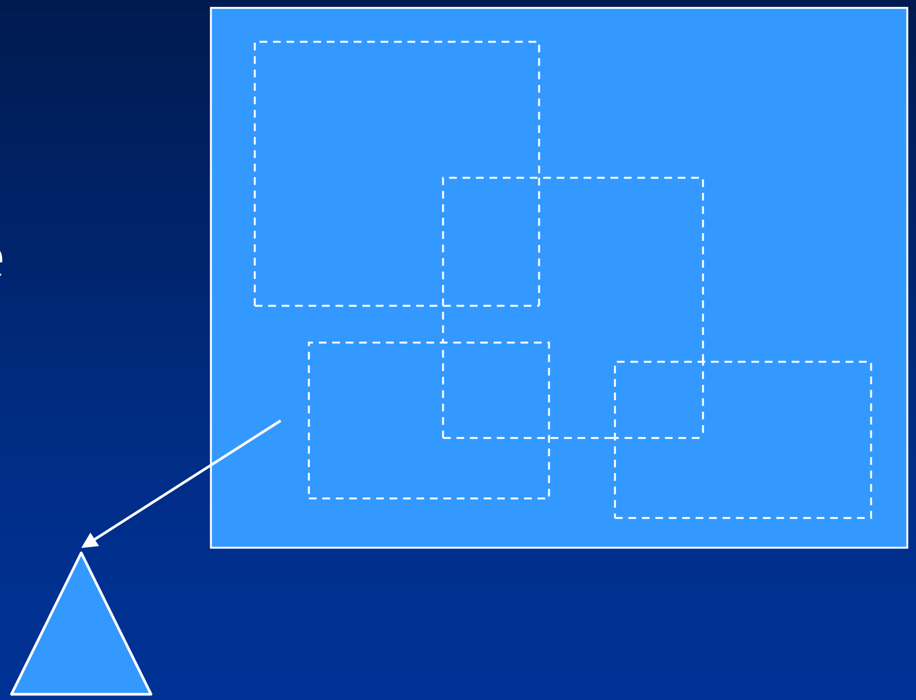
R-trees

An R-tree is an extension of B-trees for multidimensional data.

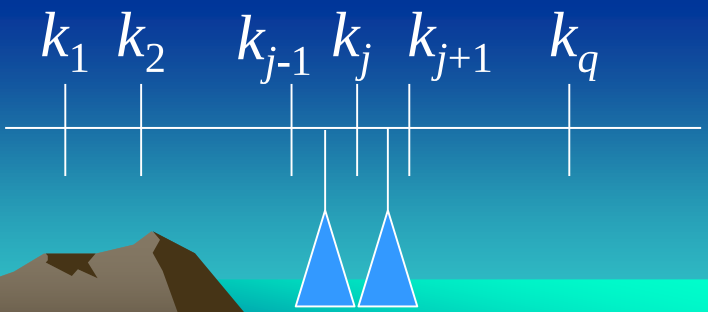
- An R-tree corresponds to a whole area (a rectangle for two-dimensional data.)
- In an R-tree, any interior node corresponds to some interior regions, or just regions, which are usually a rectangle
- Each region *x* in an interior node *n* is associated with a link to a child of *n*, which corresponds to all the subregions within *x*.

R-trees

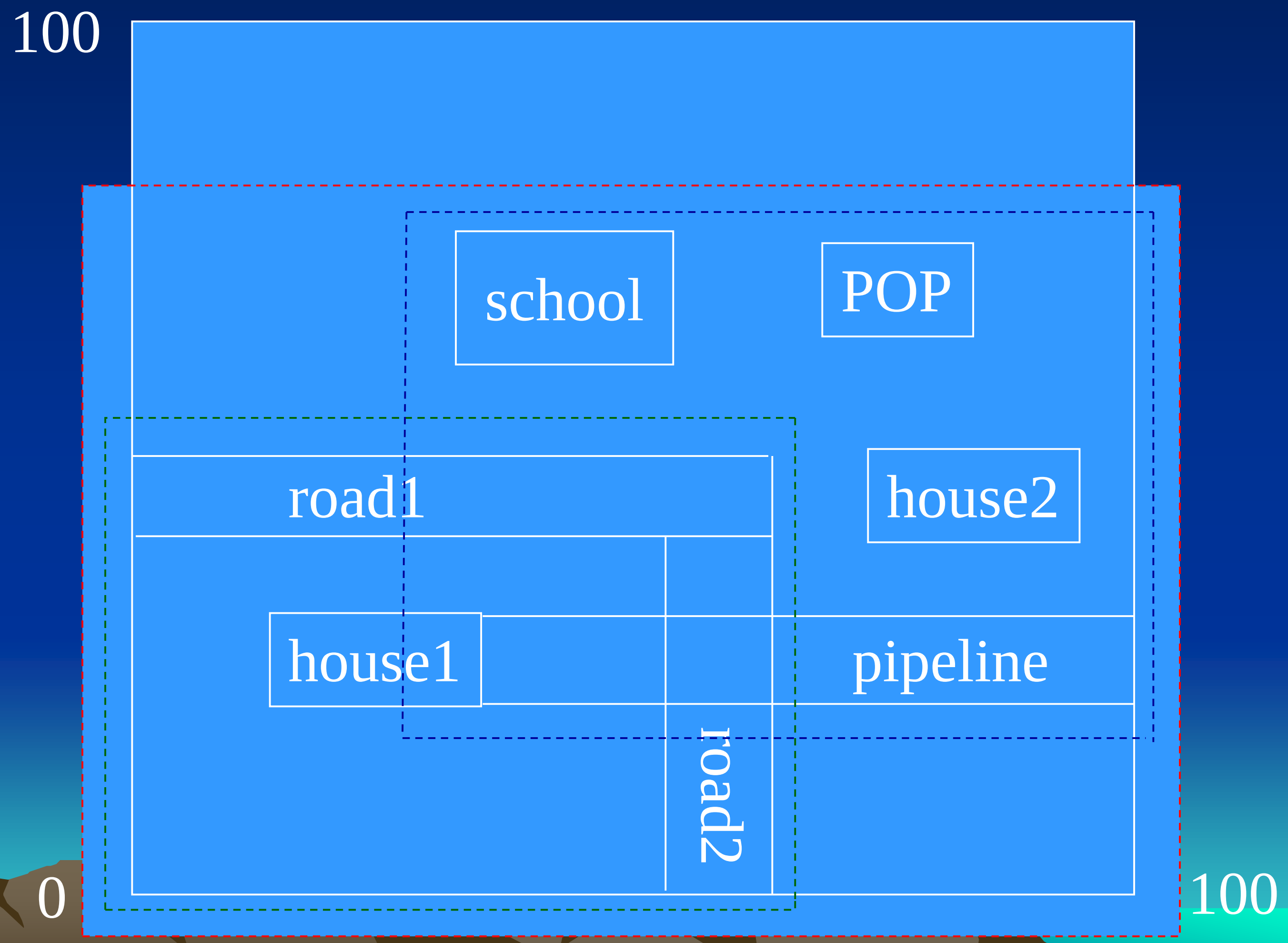
In an R-tree, each interior node contains several subregions.



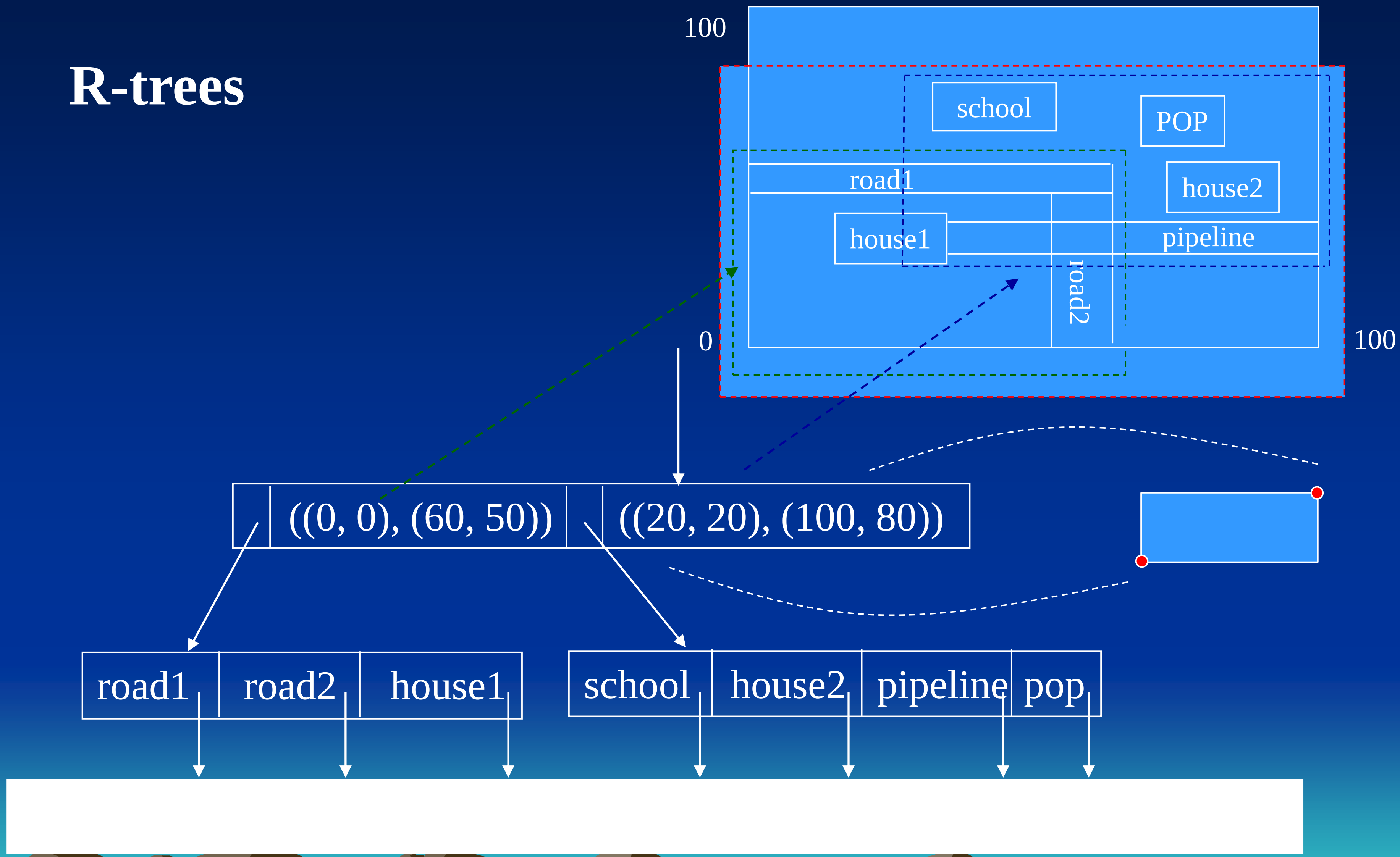
In a B+-tree, each interior node contains a set of keys that divides a line into segments.



Suppose that the local cellular phone company adds a POP (point of presence, or base station) at the position shown below.

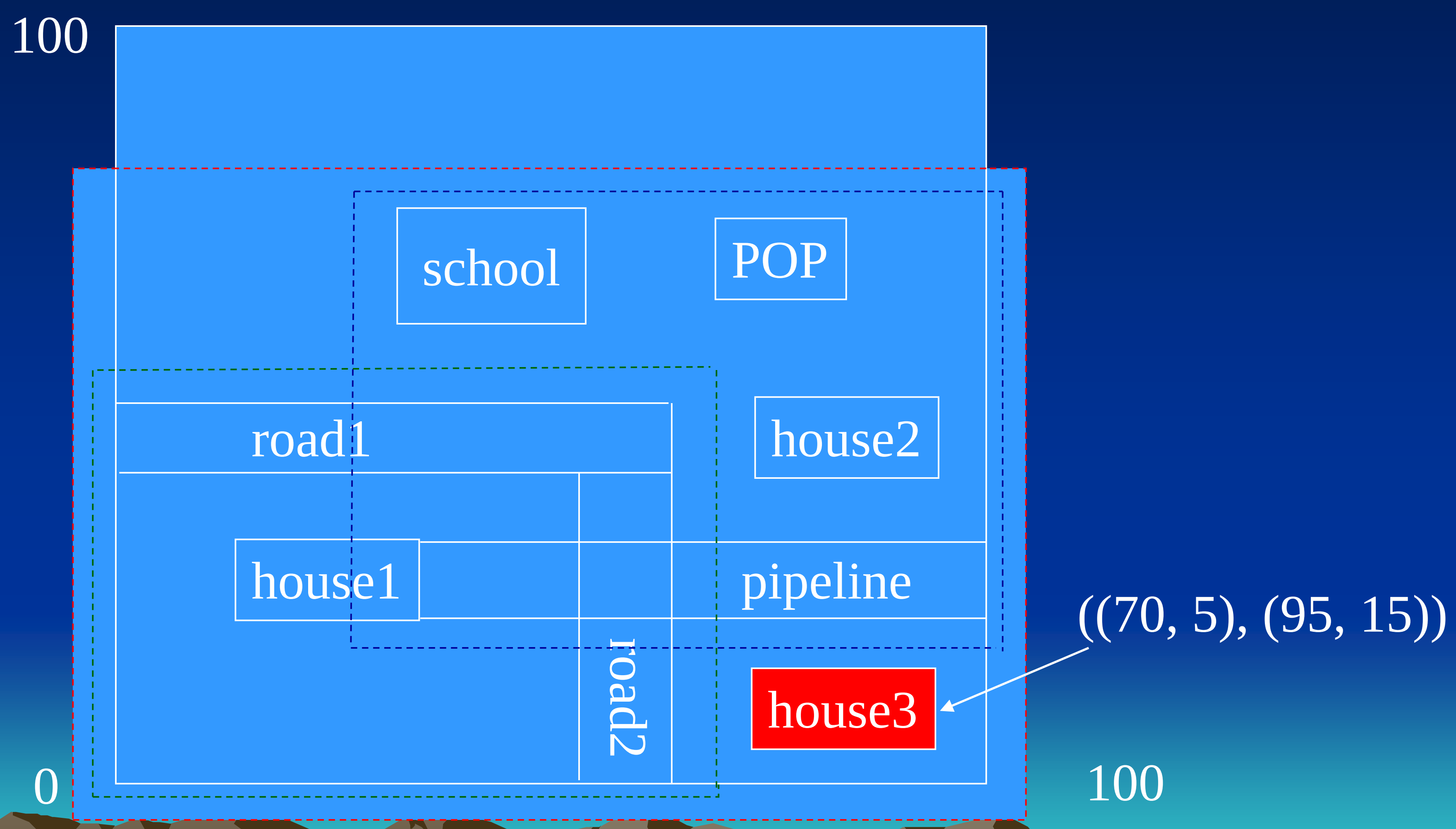


R-trees



100
0
100
school
POP
road1
house2
house1
pipeline
road2
((0, 0), (60, 50))
((20, 20), (100, 80))
road1
road2
house1
school
house2
pipeline
pop

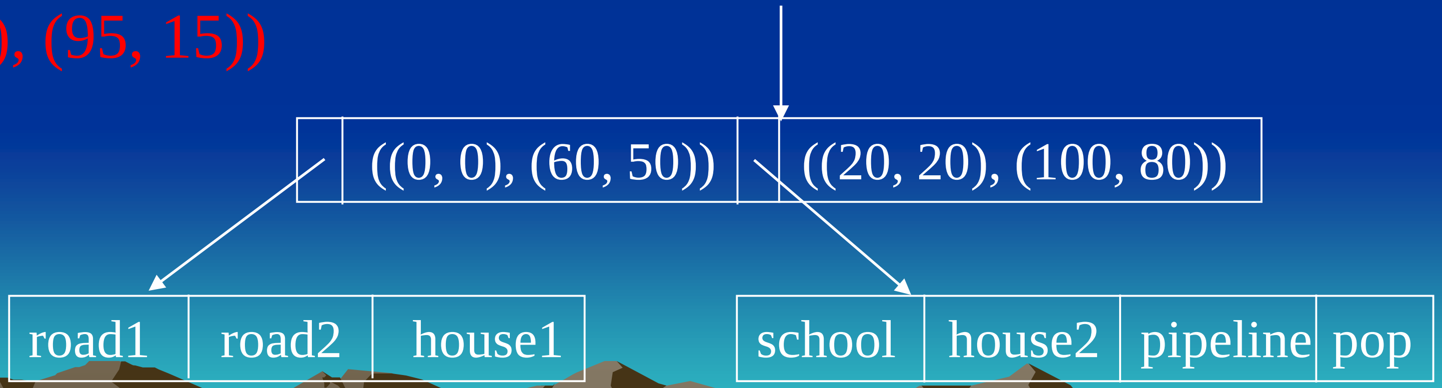
Insert a new region *r* into an R-tree.



Insert a new region *r* into an R-tree.

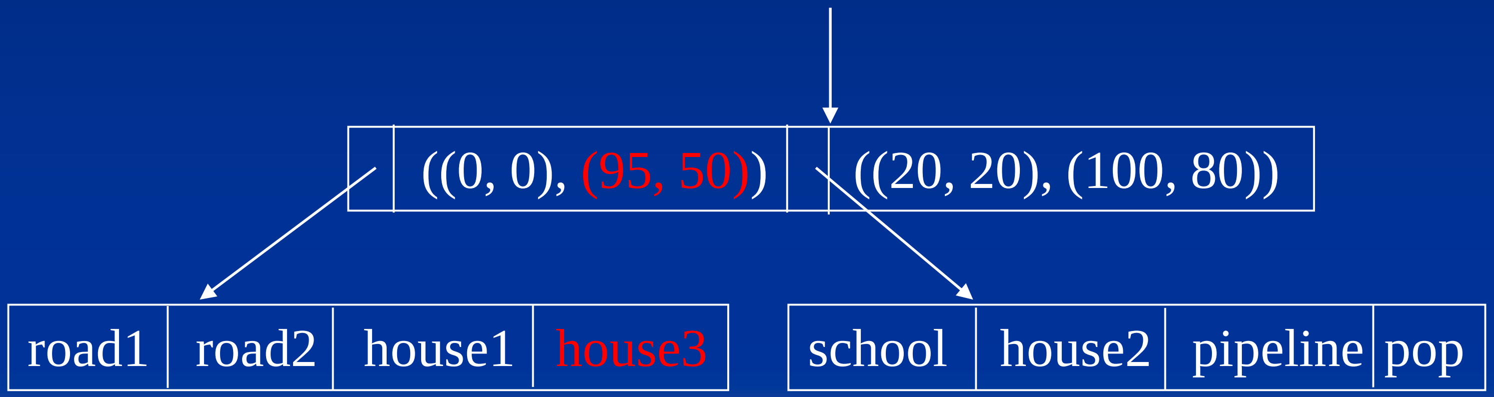
1. Search the *R*-tree, starting at the root.
2. If the encountered node is internal, find a subregion into which *r* fits.
    - If there is more than one such region, pick one and go to its corresponding child.
    - If there is no subregion that contains *r*, choose any subregion such that it needs to be expanded as little as possible to contain *r*.

((70, 5), (95, 15))

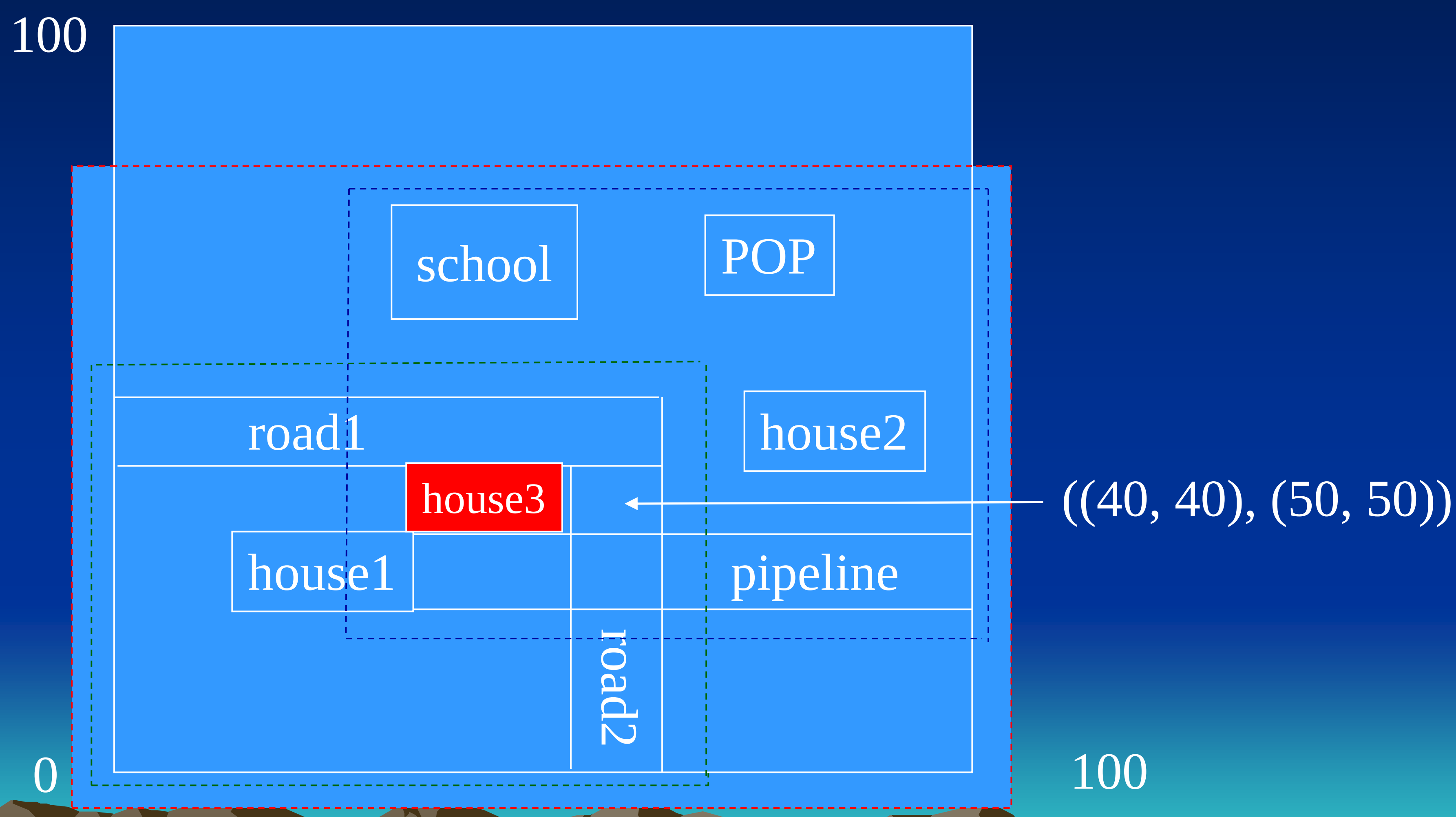


Two choices:

- If we expand the lower subregion, corresponding to the first leaf, then we add 1050 square units to the region.
- If we extend the other subregion by lowering its bottom by 15 units, then we add 1200 square units.



Insert a new region *r* into an R-tree.

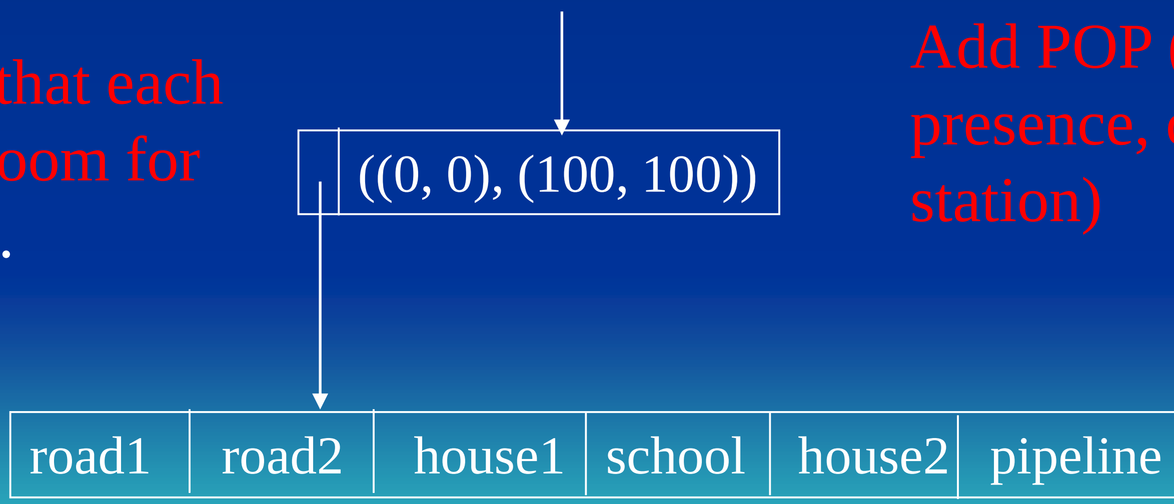


Insert a new region *r* into an R-tree.

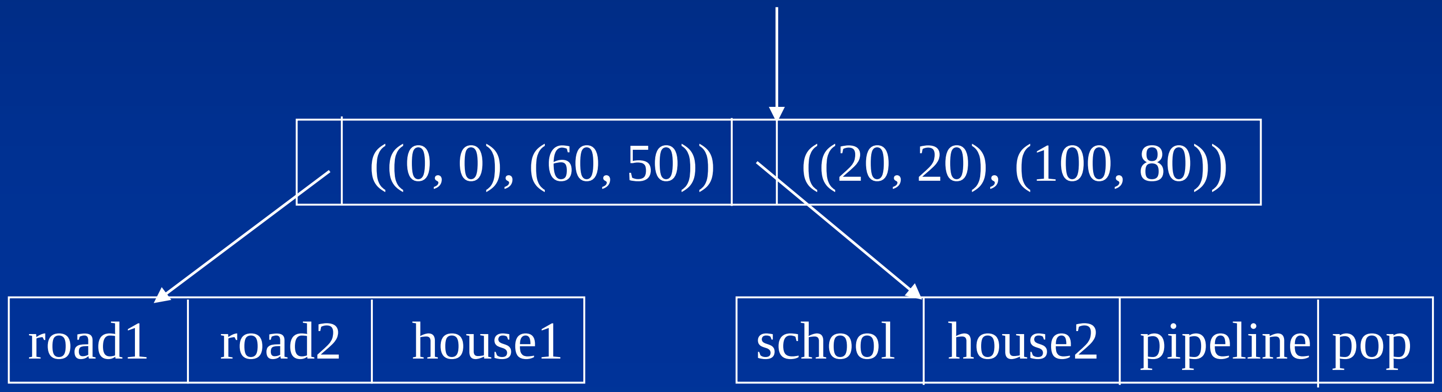
3. If the encountered node *v* is a leaf, insert *r* into it. If there is no room for *r*, split the leaf into two and distribute all subregions in them as evenly as possible. Calculate the ‘parent’ regions for the new leaf nodes and insert them into *v*’s parent. If there is the room at *v*’s parent, we are done. Otherwise, we recursively split nodes going up the tree.

Suppose that each leaf has room for 6 regions.

Add POP (point of presence, or base station)



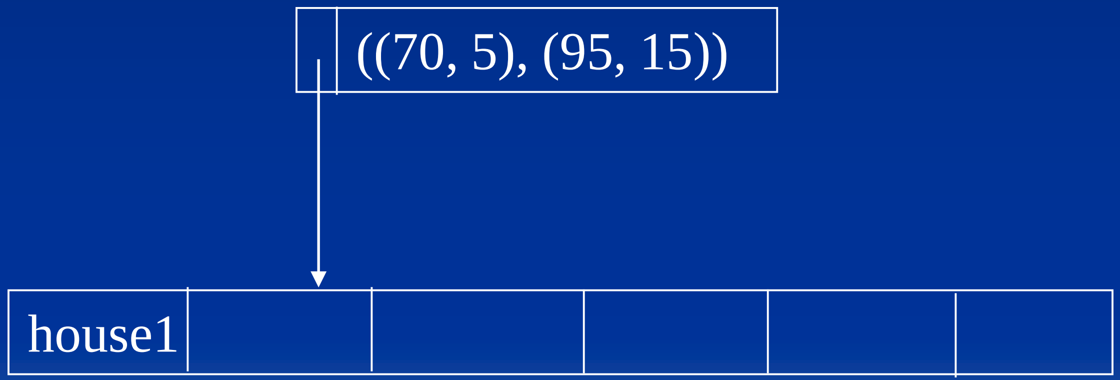
- Split the leaf into two and distribute all the regions evenly.
- Calculate two new regions each covering a leaf.



Insert the first object into an R-tree:

house1
((70, 5), (95, 15))

→ $R = \varnothing$



Bit map

1. Imagine that the records of a file are numbered 1, …, *n*.
2. A bitmap for a data field *F* is a collection of bit-vectors of length *n*, one for each possible value that may appear in the field *F*.
3. The vector for a specific value *v* has 1 in position *i* if the *i*th record has *v* in the field *F*, and it has 0 there if not.

Example

Employee

ename	<u>ssn</u>	age	salary	dnumber
Aaron, Ed		30	60	
Abbott, Diane		30	60	
Adams, John		40	75	
Adams, Robin		50	75	
Brian, Robin		55	78	
Brian, Mary		55	80	
Widom, Jones		60	100	

Bit maps for *age*:

30: 1100000
40: 0010000
50: 0001000
55: 0000110
60: 0000001

Bit maps for *salary*:

60: 1100000
75: 0011000
78: 0000100
80: 0000010
100: 0000001

Example

Employee

ename	<u>ssn</u>	age	salary	dnumber
Aaron, Ed		30	60	
Abbott, Diane		30	60	
Adams, John		40	75	
Adams, Robin		50	75	
Brian, Robin		55	78	
Brian, Mary		55	80	
Widom, Jones		60	100	

Bit maps for *age*:

30: 1100000
40: 0010000
50: 0001000
55: 0000110
60: 0000001

Bit maps for *salary*:

60: 1100000
75: 0011000
78: 0000100
80: 0000010
100: 0000001

Range query evaluation

```
Select ename
From Employee
Where 40 ≤ age ≤ 50 and 50 ≤ salary ≤ 78
```

We first find the bit-vectors for the age values in (30, 50); there are only two: 0010000 and 0001000 for 40 and 50, respectively.

Take their bitwise OR: $0010000 \vee 0001000 = 0011000$.

Next find the bit-vectors for the salary values in (50, 78) and take their bitwise OR: $1100000 \vee 0011000 \vee 0000100 = 1111100$.

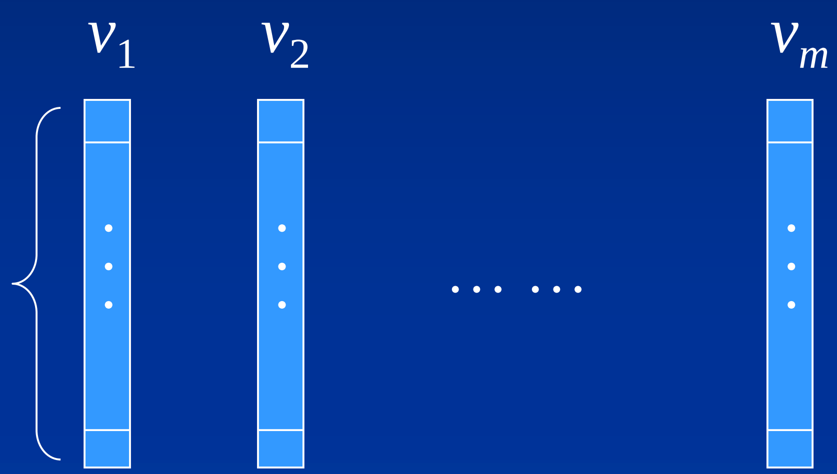
$$\begin{array}{r} 0011000 \\ \wedge \quad 1111100 \\ \hline 0011000 \end{array}$$

The 3rd and 4th tuples are the answer.

Compression of bitmaps

Suppose we have a bitmap index on field *F* of a file with *n* records, and there are *m* different values for field *F* that appear in the file.

n bits



O(*mn*) space

Compression of bitmaps

Run-length encoding:

Run in a bit vector: a sequence of i 0's followed by a 1.

$$\underbrace{00000001}\underbrace{0001} \longleftarrow$$ This bit vector contains two runs.

Run compression: a run r is represented as another bit string r' composed of two parts.

part 1: i expressed as a binary number, denoted as $b_1(i)$.
part 2: Assume that $b_1(i)$ is j bits long. Then, part 2 is a sequence of $(j - 1)$ 1's followed by a 0, denoted as $b_2(i)$.

$r' = b_2(i)b_1(i)$.

Compression of bitmaps

Run-length encoding:

Run in a bit vector *s*: a sequence of *i* 0's followed by a 1.

$$\underbrace{00000001}\underbrace{0001}$$ ← This bit vector contains two runs.

$r' = b_2(i)b_1(i).$

$r_1 = 00000001$

$b_{11} = 7 = 111,\ b_{12} = 110$ ⇒ $r_1' = 110111$

$r_2 = 0001$

$b_{11} = 3 = 11,\ b_{12} = 10$ ⇒ $r_2' = 1011$

000000010001

$r_1'r_2' = 1101111011$

Starting at the beginning, find the first 0 at the 3rd bit, so j = 3. The next 3 bits are 111, so we determine that the first integer is 7. In the same way, we can decode1011.

Decoding a compressed sequence s:

1. Scan s from the beginning to find the first 0.
2. Let the first 0 appears at position j. Check the next j bits. The corresponding value is a run.
3. Remove all these bits from s. Go to (1).

Uncompression:

$r_1'r_2' = 1101111011$

$\Downarrow$ $r_1 = 00000001$

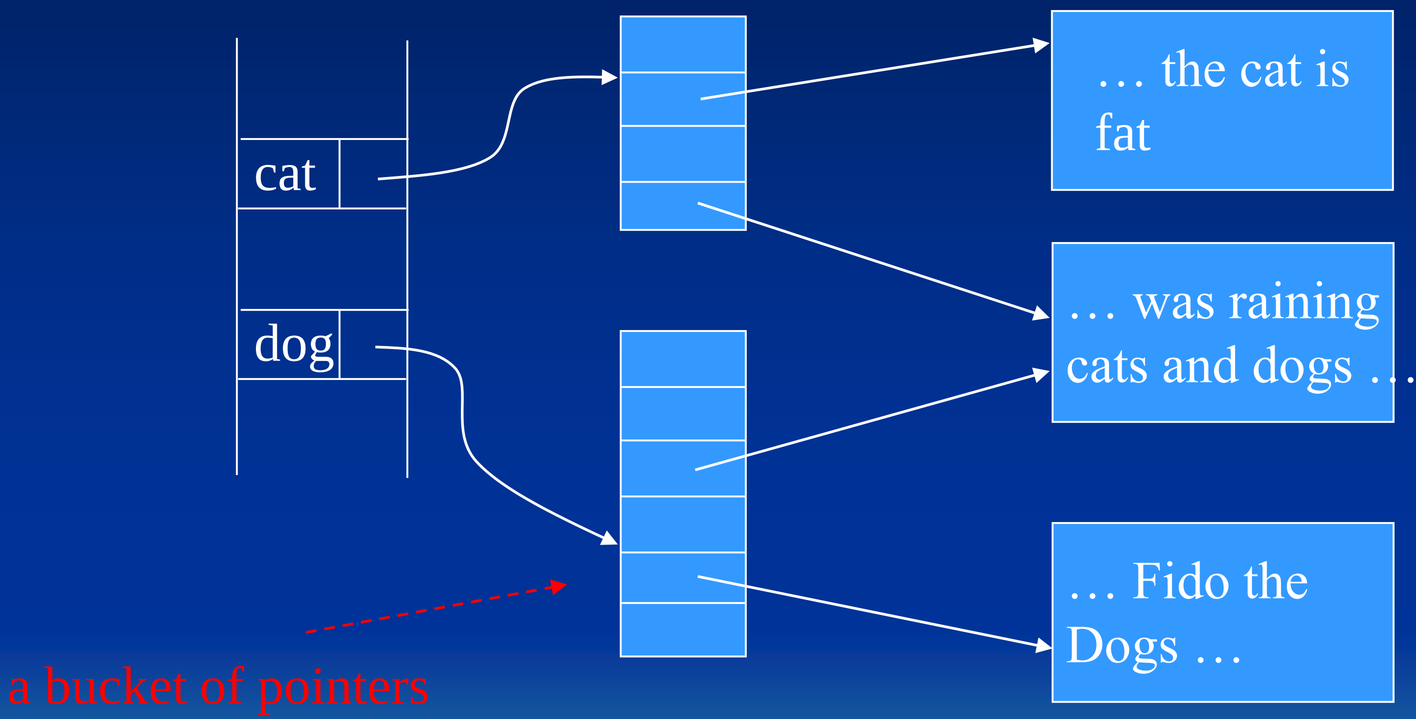
$r_2' = 1011$ $\Rightarrow$ $r_1r_2 = 000000010001$

$\Downarrow$ $r_2 = 0001$

$\square$

Inverted files

An inverted file - A list of pairs of the form: <key word, pointer>

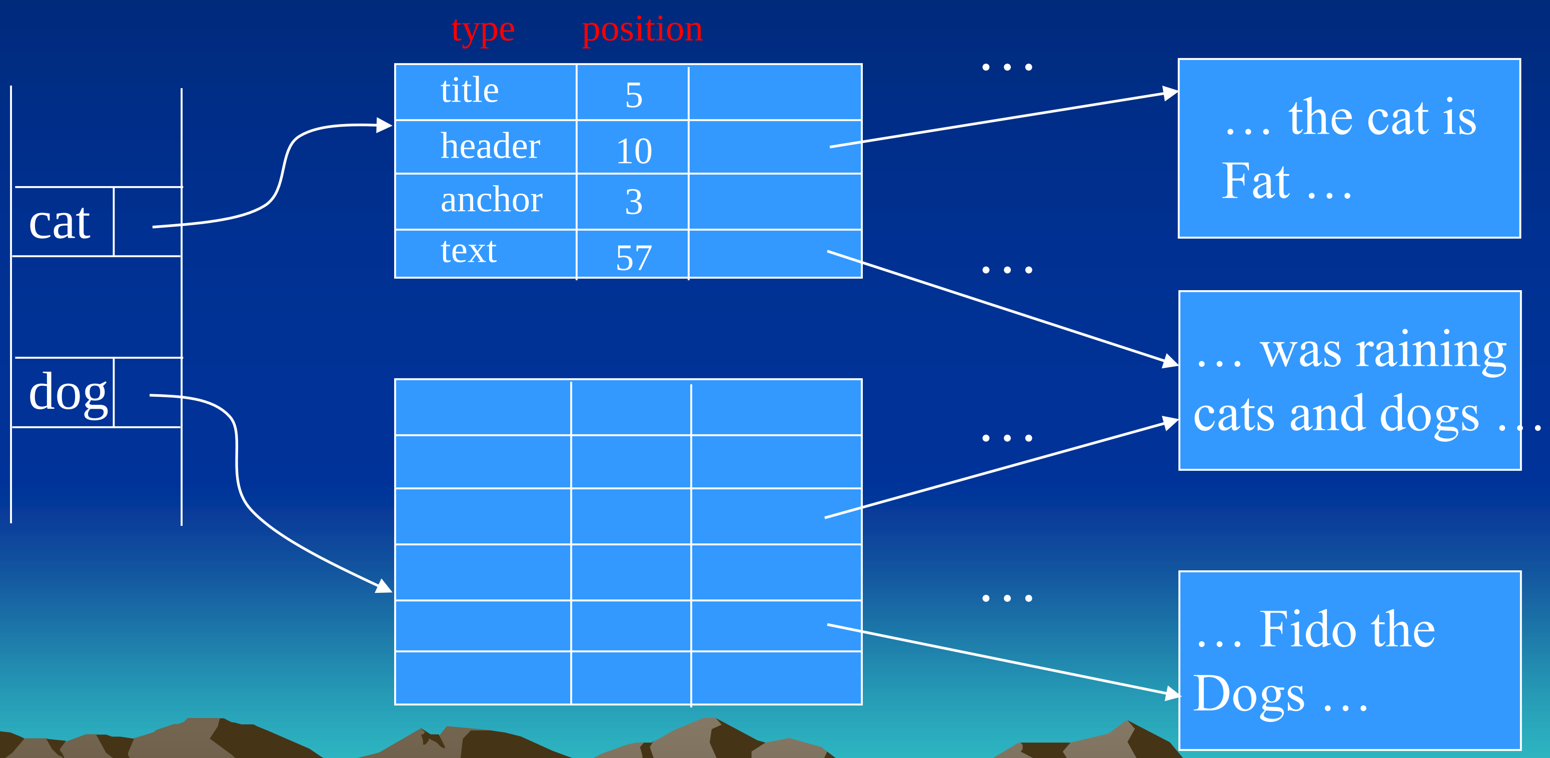


$L(\text{cat}) = \{1, 3, 5\}$ $L(\text{dog}) = \{3, 5, 8, 9\}$

$L(\text{cat} \wedge \text{dog}) = \{1, 3, 5\} \cap \{3, 5, 8, 9\} = \{3, 5\}$

Inverted files

When we use "buckets" of pointers to occurrences of each word, we may extend the idea to include in the bucket array some information about each occurrence.



Web Databases

Not included in the mid-term

- Web database
- System architecture
- Web programming language:
  - PHP
  - Node.js

- What is a web database?
  - A database accessed from the Internet
  - E-commence and other Internet applications are designed to interact with the user through *web interfaces*
  - An online flight ticket booking system

    web interface:

    input - customer information: time, location, airport, destination

    output – departure time, arrival time, flight number, price

    database access:

    query evaluation

- Three-tier architecture:

Client	Gui Web interface	Presentation layer
Application server or Web server	Application Programs Web pages (HTML)	Business logic layer
Database server	DB management system	DB service layer

• **Web server language (script language): PHP**

- PHP – a script language, used to generate *dynamic HTML pages*.

  PHP programs are executed on Web server computers. (This is in contrast to some scripting languages, such as JavaScript, which are executed on client computers.)

- The official PHP website has installation instructions for PHP: http://PHP.org.net

- PHP 5 and later versions can work with a MySQL database using:
  - MySQLi extension (the 'i' stands for improved)
  - PDO (PHP Data Objects)

- **A simple PHP example**
  - The program prompts a user to enter the first and last name and then prints a welcome message to that user.

```
<?PHP
    //Printing a welcome message if the user submitted his/her name
    //through the PHP form
    if ($_post[‘user_name’]) {
            print(“Welcome, “);
            print($_post[‘user_name’]); }
    else { print <<<_HTML_
            <FORM method=“post” action=“$_SERVER[‘PHP_SELF’]”>
            Enter your name: <input type=“text” name=“user_name”>
            <BR/>
            <INPUT type=“submit” value=“SUBMIT NAME”></FORM>
             _HTML_;
            }
?>
```

Enter your name:

SUBMIT NAME

Enter your name John Smith

SUBMIT NAME

Welcome, John Smith

- A PHP script is enclosed with a pair of tags:

  start tag: <?php

  end tag: ?>

  Stored in a file, named, for example,

  greeting.php,

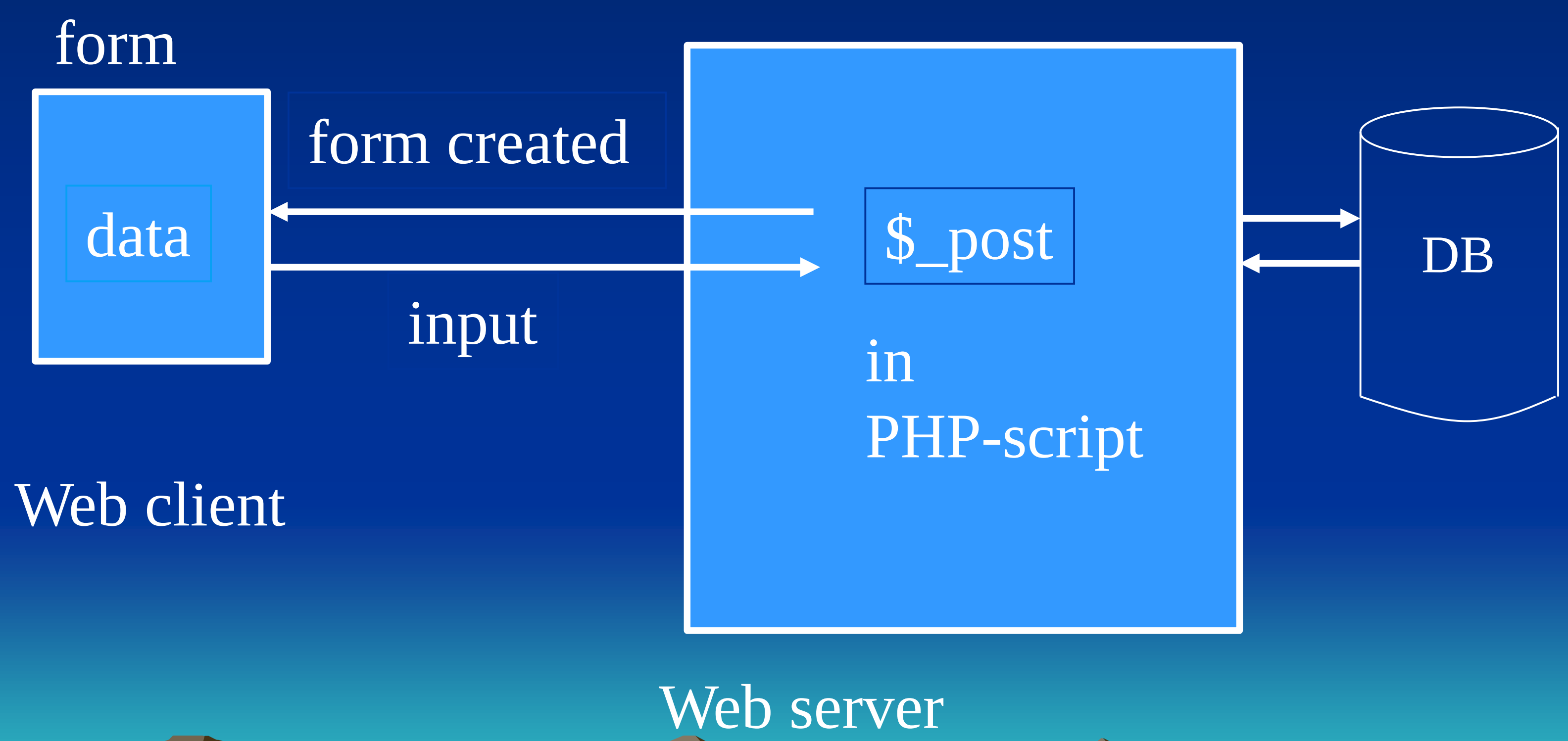
  and located in an address, for example,

  http://www.myserver.com/examples/greeting.php.

- You can also put it is a HTML file.

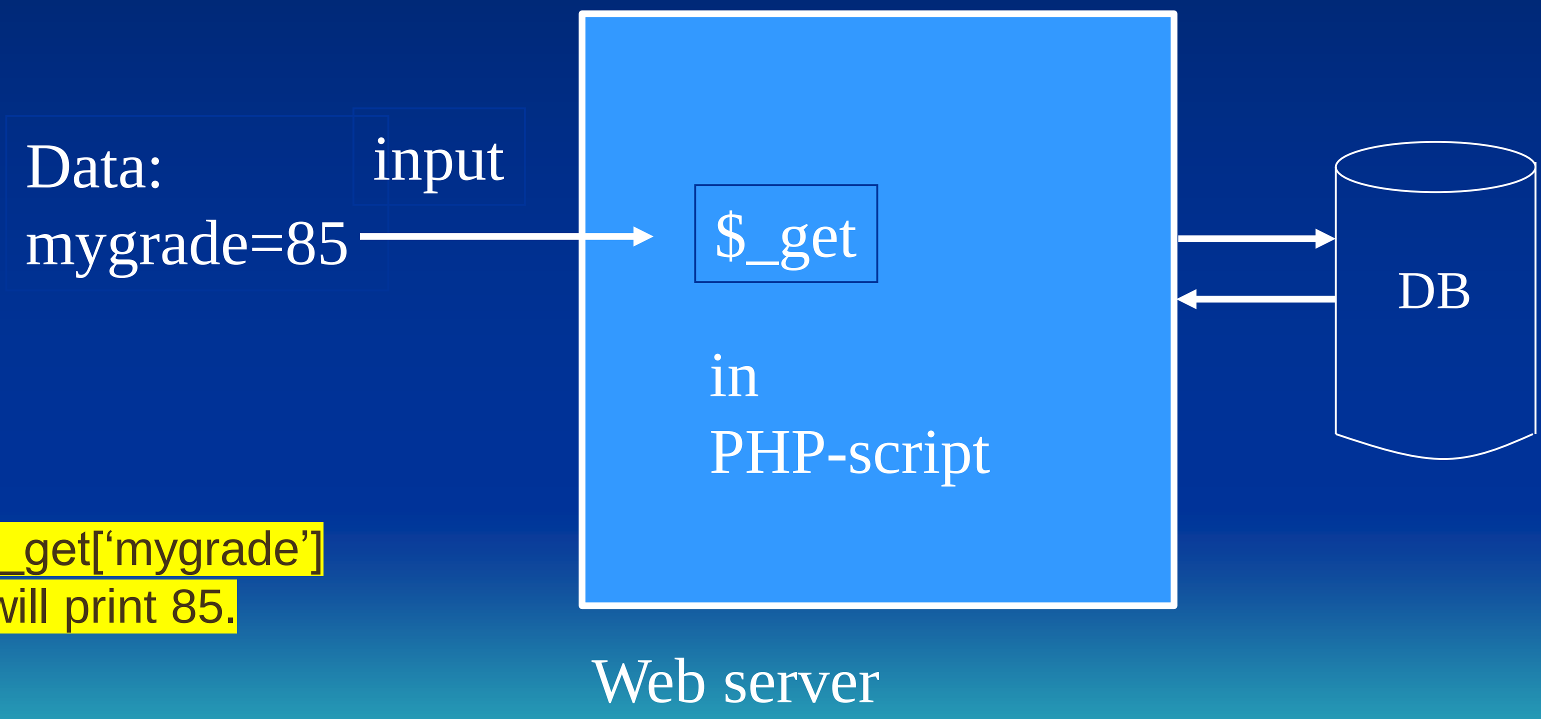
post: (data transfer through post array)

http://www.myserver.com/examples/greeting.php



get: (data transfer through get array)

http://www.myserver.com/examples/another.php?mygrade=85




```
echo $_get['mygrade']
//This will print 85.
```

- **Connecting to a database**

```
require 'DB.php'
$d = DB::connect{'mysqli://acct1:pass12@www.host.com/db1'};
if (DB:isError($d)){die("cannot connect …", $d->getMessage());}
    …
$q = $d->query("CREATE TABLE EMPLOYEE
    (       Emp_id INT,
            Name VARCHAR(15),
            Job VARCHAR(10),
            Dno INT)"   );
if (DB:isError($q)) {die("table creation not successful …", $d->getMessage());
    …
$d ->setErrorHandling( );
    …          <-----------------------
$eid = $d->nextID('EMPLOYEE');
$q = $d->query("INSERT INTO EMPLOYEE VALUES
    ($eid,$_post['emp_name'], $_post['emp_job'], $_post['emp_dno'])");
```

A form should be displayed here to receive input data.

What is Node.js?

- Node.js is a script language
- Node.js is an open source server environment
- Node.js runs on various platforms (Windows, Linux, Unix, Mac OS X, etc.)
- Node.js uses JavaScript on the serve

myfirst.js

```
var http = require('http');
http.createServer(function (req, res) {
  res.writeHead(200, {'Content-Type': 'text/html'});
  res.end('Hello World!'); //write a response and then
                           //end the response
}).listen(8080);
```

Save the file on your computer:

C:\Users*Your Name*\myfirst.js

The code tells the computer to write "Hello World!" if anyone (e.g. a web browser) tries to access your computer on port 8080.

- **Command Line Interface**

  -Node.js files must be initiated in the "Command Line Interface" program of your computer.

  -Navigate to the folder that contains the file "myfirst.js", the command line interface window should look something like this:

  C:\Users*Your Name*>_

  C:\Users*Your Name*>node myfirst.js

- **Execution of myfirst.js**

  -Now, your computer works as a server!
  -If anyone tries to access your computer on port 8080, they will get a "Hello World!" message in return!
  -Start your internet browser, and type in address:

  http://localhost:8080

- MySQL databases in a web server
  - You can download a free MySQL database at http://www.mysql.com/downloads/
  - Install MySQL Driver
- Once you have MySQL up and running on your computer, you can access it by using Node.js.
- To access a MySQL database with Node.js, you need a MySQL driver.
- Install MySQL from nmp.

- To download and install the "mysql" module, open the Command Terminal and execute the following:

C:\Users*Your Name*>npm install mysql

npm - a package manager for installing Node.js packages.

- Create Connection

demo_db_connection.js

```
var mysql = require('mysql');
var con = mysql.createConnection({
  host: "localhost",
  user: "yourusername",
  password: "yourpassword"
});
con.connect(function(err) {
  if (err) throw err;
  console.log("Connected!");
});
```

C:\Users*Your Name*>node demo_db_connection.js

- Creating a Database
  - Create a database named "mydb”

```
var mysql = require('mysql');
var con = mysql.createConnection({
  host: "localhost",
  user: "yourusername",
  password: "yourpassword"
});
con.connect(function(err) {
  if (err) throw err;
  console.log("Connected!");
  con.query("CREATE DATABASE mydb", function (err,
result) {if (err) throw err;
    console.log("Database created"); }); });
```

Save the code above in a file called "demo_create_db.js“
C:\Users*Your Name*>node demo_create_db.js

- Creating a table
  - Create a table named “customers”

```
var mysql = require('mysql');
var con = mysql.createConnection({
  host: "localhost", user: "yourusername“,
  password: "yourpassword", database: "mydb"});
con.connect(function(err) {
  if (err) throw err;
  console.log("Connected!");
  var sql = "CREATE TABLE customers (name
  VARCHAR(255), address VARCHAR(255))";
  con.query(sql, function (err, result) {
    if (err) throw err;
    console.log("Table created");});
```

```
var mysql = require('mysql');
var con = mysql.createConnection({
  host: "localhost",
  user: "yourusername",
  password: "yourpassword",
  database: "mydb"
});
con.connect(function(err) {
  if (err) throw err;
  console.log("Connected!");
  var sql = "INSERT INTO customers (name, address)
             VALUES ('Company Inc', 'Highway 37')";
  con.query(sql, function (err, result) {
    if (err) throw err;
    console.log("1 record inserted");
  });
}).listen(8080);
```

- Query a Database
  - Use SQL statements to read from (or write to) a MySQL database

```
… …
con.connect(function(err) {
  if (err) throw err;
  console.log("Connected!");
 database: “mydb”
 var sql = “select * from customers where  name = 'David'";
  con.query(sql, function (err, result) {
    if (err) throw err;
    console.log("Result: " + result);
  });
});
```

Semistructured-Data Model

- Semistructured data
- XML
- DTD (Document type definitions)
- XML schema

Semistructured Data

The semistructured-data model plays a special role in database systems:

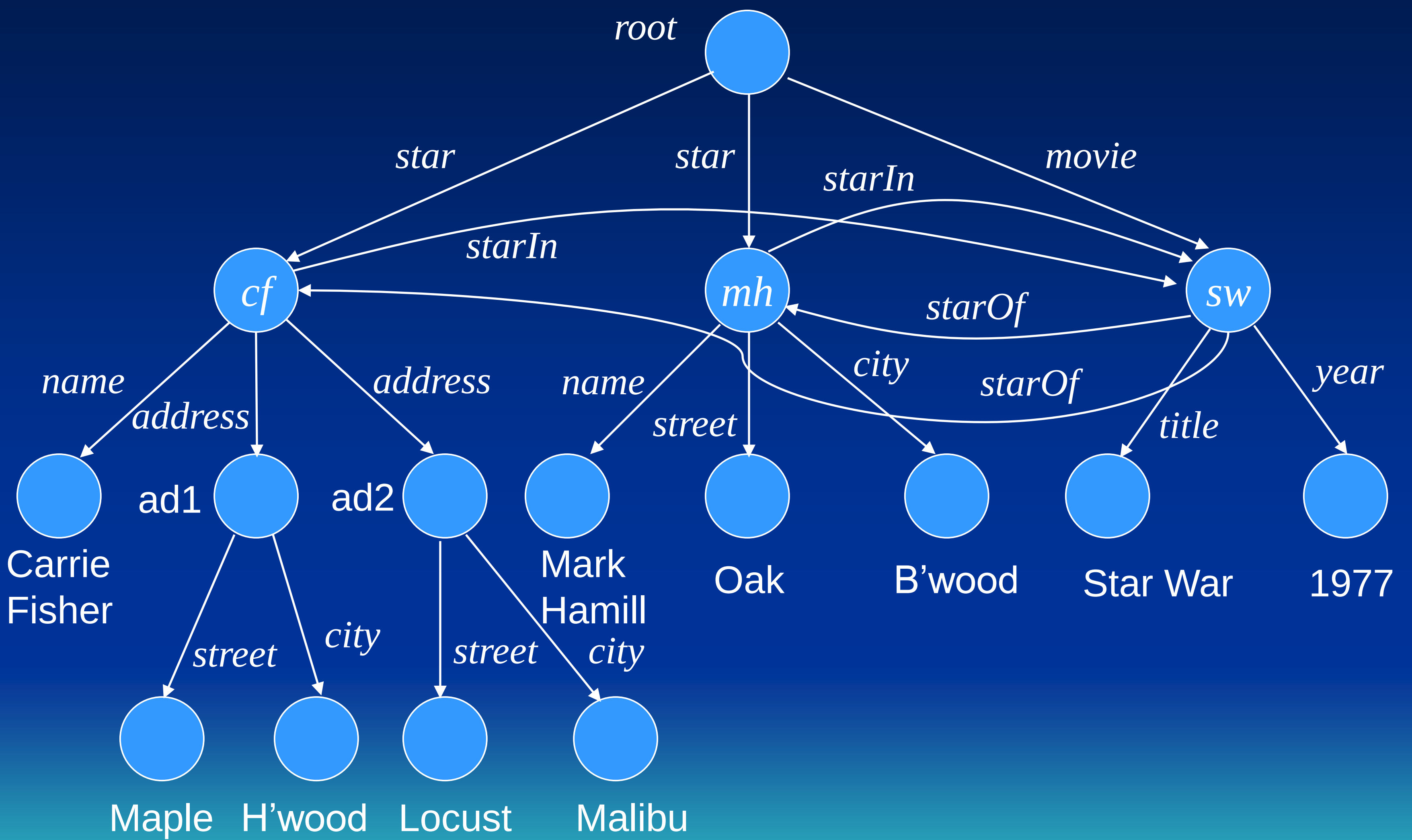
1. It serves as a model suitable for integration of databases, i.e., for describing the data contained in two or more databases that contain similar data with different schemas.
2. It serves as the underlying model for notations such as XML that are being used to share information on the web.

The semistructured data model can represent information more flexibly than the other models – E-R, UML, relational model, ODL (Object Definition Language).

Semistructured Data representation

A database of semistructured data is a collection of nodes.

- Each node is either a leaf or interior
- Leaf nodes have associated data; the type of this data can be any atomic type, such as numbers and strings.
- Interior nodes have one or more arcs out. Each arc has a label, which indicates how the node at the head of the arc relates to the node at the tail.
- One interior node, called the root, has no arcs entering and represents the entire database.


root
star
star
movie
starIn
starIn
cf
mh
sw
starOf
starOf
name
address
address
name
street
city
title
year
ad1
ad2
Carrie
Fisher
Mark
Hamill
Oak
B'wood
Star War
1977
street
city
street
city
Maple
H'wood
Locust
Malibu

Semistructured Data representation

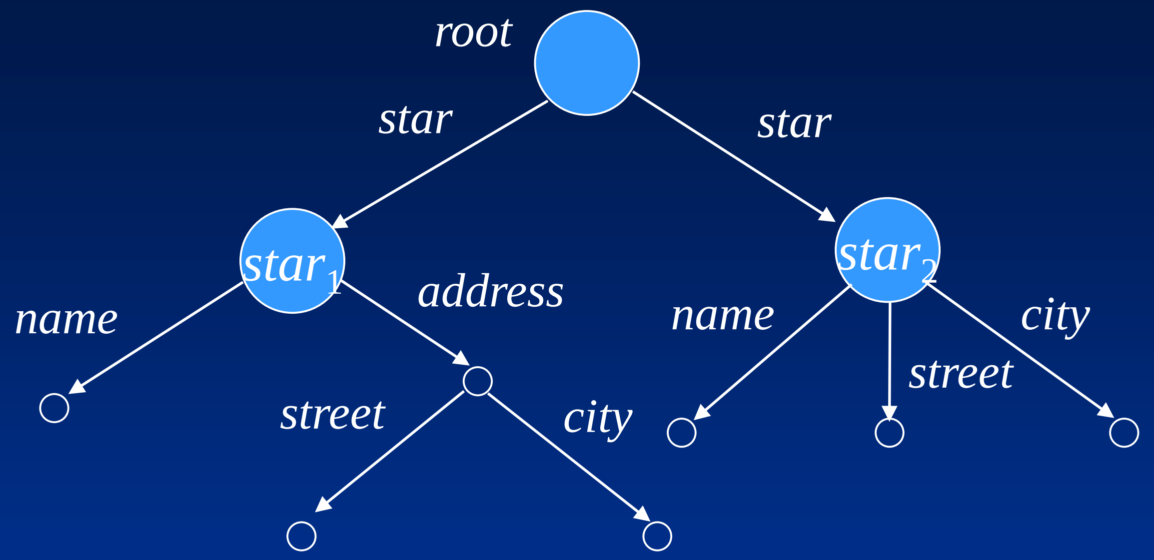
A label *L* on the arc from node *N* to node *M* can play one of two roles.

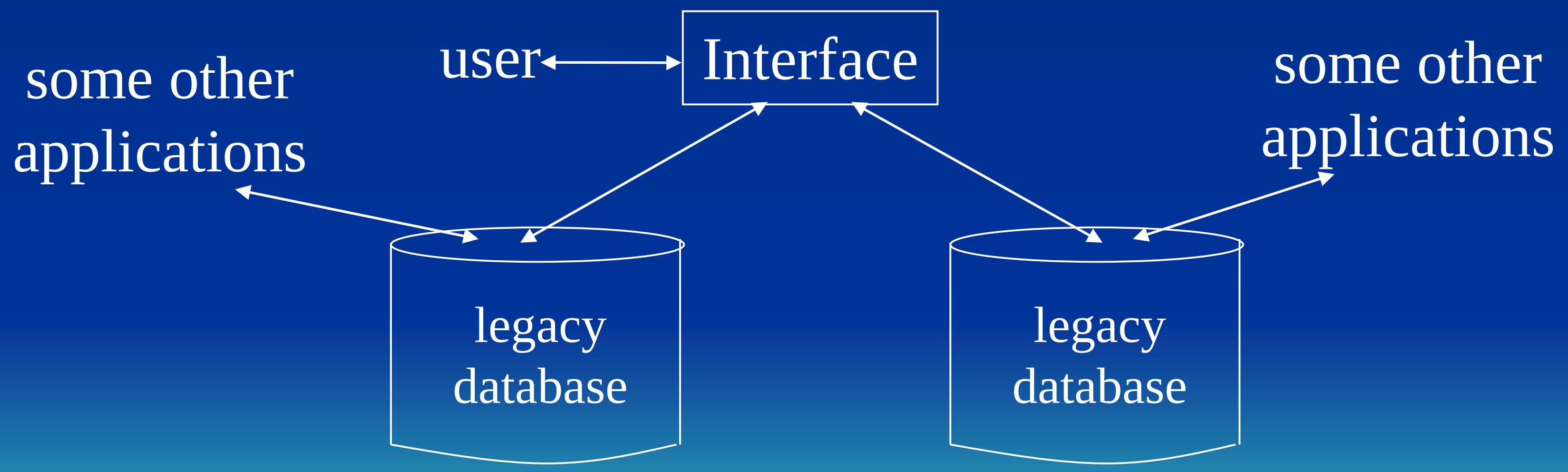
1. It may be possible to think of *N* as representing an object or entity, while *M* represents one of its attributes. Then, *L* represents the name of the attribute.
2. We may be able to think of *N* and *M* as objects or entities and *L* as the name of a relationship from *N* to *M*.

Semistructured Data model can be used to integrate information

Legacy-database problem: Databases tend over time to be used in so many different applications that it is impossible to turn them off and copy or translate their data into another database, even if we could figure out an efficient way to transform the data from one schema to another.

In this case, we will define a semistructured data model over all the legacy databases, working as an interface for users. Then, any query submitted against the interface will be translated according to local schemas.

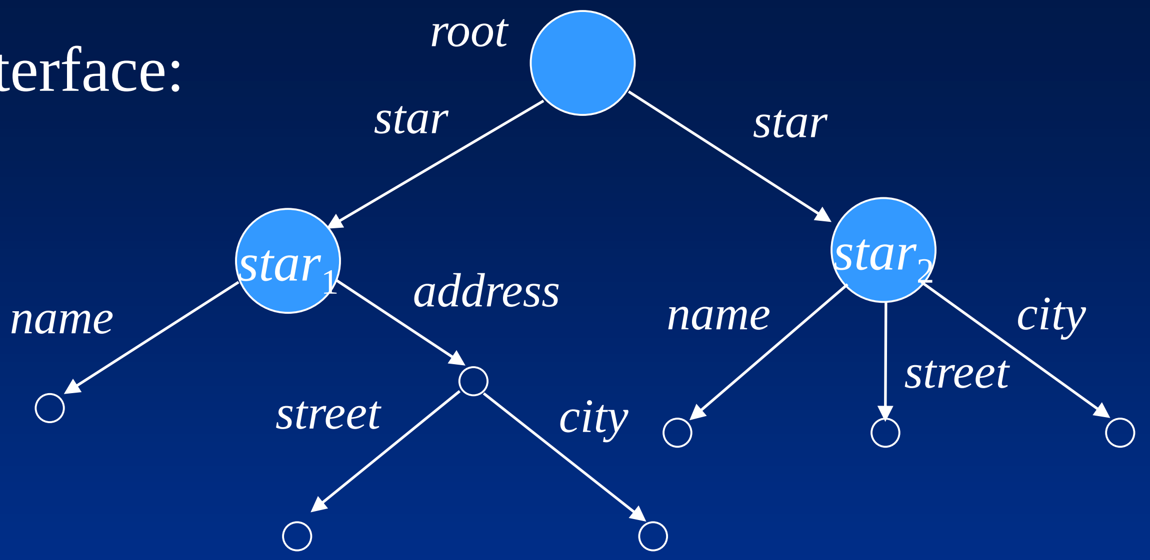




Stars(name, address(street, city))

Stars(name, street, city)

Integrated interface:



for $m in root/star
where $m//city = ‘Malibu’
return <star>{$m/name}</star>

X-Query

decomposing

select name
from Stars
where address.city = ‘Malibu’

select name
from Stars
where address.city = ‘Malibu’

XML (*Extensible Markup Language*)

XML is a tag-based notation designed originally for *marking* documents, much like HTML. While HTML's tags talk about the presentation of the information contained in documents – for instance, which portion is to be displayed in italics or what the entries of a list are – XML tags intended to talk about the meanings of pieces of the document.

Tags:

opening tag - < …. >, e.g., <Foo>
closing tag - </ … >, e.g., </Foo>

A pair of matching tags and everything that comes between them is called an *element*.

XML with and without a schema

XML is designed to be used in two somewhat different modes:

1. *Well-formed* XML allows you to invent your own tags, much like the arc-labels in semistructured data. But there is no predefined schema. However, the nesting rule for tags must be obeyed, or the document is not well-formed.
2. *Valid* XML involves a DTD (Document Type Definition) that specifies the allowed tags and gives a grammar for how they may be nested. This form of XML is intermediate between the strict-schema such as the relational model, and the completely schemaless world of semistructured data.

```
<? Xml version = “1.0” encoding = “utf-8” standalone = “yes” ?>  ←------  prologue
<StarMovieData>
    <Star>
        <Name>Carrie Fishes</Name>
        <Address>
            <Street>123 Maple St.</Street><City>Hollywood</City>
        </Address>
        <Address>
            <Street>5 Locust Ln.</Street><City>Malibu</City>
        <Address>
    </Star>
    <Star>
        <Name>Mark Hamill</Name><Street>456 Oak Rd.</Street>
        <City>Brentwood</City>
    </Star>
    <Movie>
        <Title>Star Wars</title><Year>1977</Year>
    </Movie>
</StarMovieData>
```

Attributes

As in HTML, an XML element can have attributes (name-value pairs) with its opening tag. An attribute is an alternative way to represent a leaf node of semistructured data. Attributes, like tags, can represent labeled arcs in a semisructured-data graph.

<Movie title = “Star War” year = 1977>
</Movie>

<Movie year = 1977>
<Title>“Star Wars”</title>
</Movie>

<Movie>
<Title>“Star Wars”</title>
<Year>1977</Year>
</Movie>

Attributes that connect elements

An important use for attributes is to represent connections in a semistructured data graph that do not form a tree.

```
<? Xml version = “1.0” encoding = “utf-8” standalone = “yes” ?>
<StarMovieData>
    <Star starID = “cf” starredIn = “sw”>
            … …
    </Star>
    <Star starID = “mh” starredIn = “sw”>
            …  …
    </Star>
    <Movie movieID = “sw” starsOf = “cf”, “mh”>
        <Title>Star Wars</title><Year>1977</Year>
    </Movie>
</StarMovieData>
```

Namespace

There are situations in which XML data involves tags that come from two or more different sources. So we may have conflicting names. For example, we would not want to confuse an HTML tag used in a text with an XML tag that represents the meaning of that text. To distinguish among different vocabularies for tags in the same document, we can use a *namespace* for a set of tags.

To indicate that an element's tag should be interpreted as part of a certain space, we use the attribute xmlns in its opening tag:

xmlns: name = <Universal Resource Identifier>

Example:

<md : StarMoviedata xmlns : md = http://infolab.stanford.edu/movies>

XML storage

There are three approaches to storing XML to provide some efficiency:

1. Store the XML data in a parsed form, and provide a library of tools to navigate the data in that form. Two common standards are called SAX (Simple API for XML), and DOM (Document Object Model).
2. MongoDB – non-tabular databases

In Mongo DB, a document is stored as a set of property-value pairs (JSON format).

```
[    { title : "post1",
       body: "body of post 1",
       category: "news",
       time: Date( )
       }
       { title : "post2",
       body: "body of post 2",
       category: "events",
       time: Date( )
       }    ]
```

3. Represent the document and their elements as relations, and use a conventional, relational DBMS to store them.

In order to represent XML documents as relations, we should give each document and each element of a document a unique ID. For each document, the ID could be its URL or its path in a file system.

A possible relational database schema:

DocRoot(docID, rootElmentID)
ElementValue(elementID, value)
SubElement(parentID, childID, position)
ElementAttribute(elementID, name, value)

```
<? Xml version = “1.0” encoding = “utf-8” standalone = “yes” ?>
< md : StarMovieData xmlns : md = http://infolab.stanford.edu/movies >
    <Star starID = “cf” starredIn = “sw”>
        <Name>Carrie Fishes</Name>
        <Address>
            <Street>123 Maple St.</Street><City>Hollywood</City>
        </Address>
        <Address>
            <Street>5 Locust Ln.</Street><City>Malibu</City>
        <Address>
    </Star>
    <Star starID = “mh” starredIn = “sw”>
        <Name>Mark Hamill</Name><Street>456 Oak Rd.</Street>
        <City>Brentwood</City>
    </Star>
    <Movie movieID = “sw” starsOf = “cf”, “mh”>
        <Title>Star Wars</title><Year>1977</Year>
    </Movie>
</StarMovieData>
```

DocRoot

Doc-id	rootElementID
1	1

elementValue

Doc-id	element-id	value
1	1	starMovieData
1	2	Star
1	3	Star
1	4	movie
…	…	…

subElement

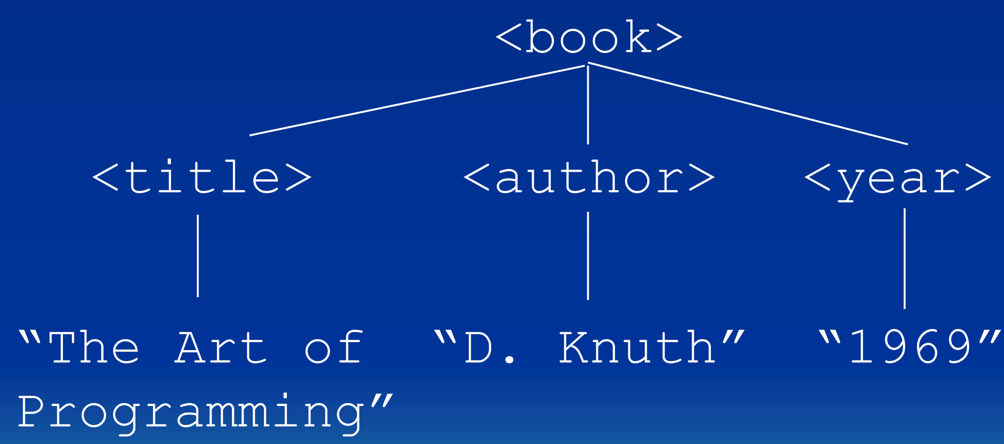
parentId	childId	position
1.1	1.2	1
1.1	1.3	2
1.1	1.4	4
… …	… …	… …

elementAttribute

elemenAttId	attName	value
1.1	xmlns : md	http://... …
1.2	starId	“mf”
1.2	starId	“mh”
1.3	starredIn	“sw”
1.3	starredIn	“sw”
1.4	movieId	“sw”
1.4	starsOf	“sf”, “mh”

Transform an XML document to a tree

```
<book>
     <title>
        "The Art of Programming"
     </title>
      <author>
         "D. Knuth"
      </author>
      <year>
         "1969"
      </year>
</book>
```



Transform an XML document to a tree

Read a file into a character array `A`:

<	b	o	o	k	>	<	t	i	t	l	e	>	"	T	h	e		A	r	t	…

stack S:

node_value	Pointer_to_node

Transform an XML document to a tree

```
Algorithm:
Scan array A; Let A[i] be the character currently
encountered;
If A[i] is '<' and A[i+1] is a character then {
      generate a node x for A[i..j],
      where A[j] is '>' directly after A[i];
      let y = S.top().pointer_to_node;
      make x be a child of y; S.push(A[i..j], x);
If A[i] is ' " ', then {
      genearte a node x for A[i..j],
      where A[j] is ' " ' directly after A[i];
      let y = S.top().pointer_to_node;
      make x be a child of y;
If A[i] is '<' and A[i+1] is '/',
then S.pop();
```

Generating a node for an opening tag.

Generating a leaf node for a string value.

Popping out the stack when meeting a closing tag.

Document Type Definition (*DTD*)

A DTD is a set of grammar-like rules to indicate how elements can be nested.

DTD general form:

```
<!DOCTYPE root-tag [
    <!ELEMENT element-name (components)>
        … …
    ]>
```

Stars.dtd

```
<!DOCTYPE Stars [
    <!ELEMENT Stars (Star*)>
    <!ELEMENT Star (Name, Address+, Movies)>
    <!ELEMENT Name (#PCDATA)>
    <!ELEMENT Address (Street, City)>
    <!ELEMENT Street (#PCDATA)>
    <!ELEMENT City (#PCDATA)>
    <!ELEMENT Movies (Movie*)>
    <!ELEMENT Movie (Title, Year)>
    <!ELEMENT Title (#PCDATA)>
    <!ELEMENT Year (#PCDATA)>
]>
```

&lt

escape symbol

```
<Stars>
    <Star>
        <Name>Carrie Fishes</Name>
        <Address>
            <Street>123 Maple St.</Street>
            <City>Hollywood</City>
        </Address>
        <Movies>
            <Movie>
                <Title>Star Wars</Title>
                <Year>1977</Year>
            </Movie>
            <Movie>
                <Title>Empire Striker</Title>
                <Year>1980</Year>
            </Movie>
            <Movie>
                <Title>Return of the Jedi</Title><Year>1983</Year>
            </Movie>
        </Movies>
    </Star>
```

```
<!DOCTYPE Stars [
    <!ELEMENT Stars (Star*)>
    <!ELEMENT Star (Name, Address+, Movies)>
    <!ELEMENT Name (#PCDATA)>
    <!ELEMENT Address (Street, City)>
    <!ELEMENT Street (#PCDATA)>
    <!ELEMENT City (#PCDATA)>
    <!ELEMENT Movies (Movie*)>
    <!ELEMENT Movie (Title, Year)>
    <!ELEMENT Title (#PCDATA)>
    <!ELEMENT Year (#PCDATA)>
]>
```

```
<Star>
    <Name>Mark Hamill</Name>
    <Address>
        <Street>456 Oak Rd.</Street>
        <City>Brentwood</City>
    </Address>
    <Movies>
        <Movie>
            <Title>Star Wars</Title>
            <Year>1977</Year>
        </Movie>
        <Movie>
            <Title>Empire Wars</Title>
            <Year>1980</Year>
        </Movie>
        <Movie>
            <Title>Return of the Jedi</Title>
            <Year>1983</Year>
        </Movie>
    </Movie>
</Star>
</Stars>
```

```
<!DOCTYPE Stars [
    <!ELEMENT Stars (Star*)>
    <!ELEMENT Star (Name, Address+, Movies)>
    <!ELEMENT Name (#PCDATA)>
    <!ELEMENT Address (Street, City)>
    <!ELEMENT Street (#PCDATA)>
    <!ELEMENT City (#PCDATA)>
    <!ELEMENT Movies (Movie*)>
    <!ELEMENT Movie (Title, Year)>
    <!ELEMENT Title (#PCDATA)>
    <!ELEMENT Year (#PCDATA)>
]>
```

```
<!DOCTYPE Stars [
    <!ELEMENT Stars (Star*)>
    <!ELEMENT Star (Name, Address+, Movies)>
    <!ELEMENT Name (#PCDATA)>
    <!ELEMENT Address (Street, City)>
    <!ELEMENT Street (#PCDATA)>
    <!ELEMENT City (#PCDATA)>
    <!ELEMENT Movies (Movie*)>
    <!ELEMENT Movie (Title, Year)>
    <!ELEMENT Title (#PCDATA)>
    <!ELEMENT Year (#PCDATA)>
]>
```

```
<? Xml version = “1.0” encoding = “utf-8” standalone = “yes” ?>
<Stars>
    <Star>
        <Name>Carrie Fishes</Name>
        <Address>
            <Street>123 Maple St.</Street>
            <City>Hollywood</City>
        </Address>
        <Address>
            <Street>5 Locust Ln.</Street>
            <City>Malibu</City>
        <Address>
    </Star>
    <Star>
        <Name>Mark Hamill</Nam>
        <Street>456 Oak Rd.</Street>
        <City>Brentwood</City>
    </Star>
    <Movie>
        <Title>Star Wars</title><Year>1977</Year>
    </Movie>
</Stars>
```

This document does not confirm to the DTD.

Attribute Lists

An element may be associated with an attribute list:

<!ATTLIST *element-name attribute-name type*>

```
<!ELEMENT Movie EMPTY>
    <!ATTLIST        Movie
        title    CDATA          #REQUIRED
        year     CDATA          #REQUIRED
        genre    (comedy | drama | sciFi | teen) #IMPLIED
    >
```

<Movie title = “Star Wars” year = “1977” genre = “sciFi”/>

Using a DTD

If a document is intended to conform to a certain DTD, we

a) Include the DTD itself as a preamble to the document, or

b) In the opening line, refer to the DTD, which must be stored separately in the file system accessible to the application that is processing the document.

<?xml version = “1.0” encoding = “utf-8” standalone = “no”?>

<!DOCTYPE Star SYSTEM “star.dtd”>

SYSTEM – keyword indicating that the DTD can be find in file star.dtd (this can also be a valid URL if the .dtd file is remote.)

```
<?xml version="1.0" ?>
 <!DOCTYPE r [
<!ELEMENT r ANY >
<!ELEMENT a ANY >
<!ELEMENT b ANY >              <------------ A DTD is included as a preamble.
<!ELEMENT c (a*)>
<!ELEMENT d (b*)>
]>
<r>
        <a>
                <b>
                        <a></a><a></a><b></b>
                </b>
                <c>
                        <a>
                                <b></b>
                        </a>
                </c>
                <a>
                        <a></a><b></b>
                </a>
        </a>
</r>
```

```xml
<?xml version = "1.0" encoding = "UTF-8" standalone = "no" ?>
<!DOCTYPE address SYSTEM "address.dtd">
<address>
        <name>Tanmay Patil</name>
        <company>TutorialsPoint</company>
        <phone>(011) 123-4567</phone>
</address>
```

```
<!DOCTYPE StarMovieData [
  <!ELEMENT StarMovieData        (Star*, Movie*)>
  <!ELEMENT Star                 (Name, Address+)>
    <!ATTLIST Star
      starId         ID        #REQUIRED
      StarredIn      IDREFS    #IMPLIED
    >
  <!ELEMENT Name                 (#PCDATA)>
  <!ELEMENT Address              (Street, City)>
  <!ELEMNT Street                (#PCDATA)>
  <!ELEMENT City                 (#PCDATA)>
  <!ELEMENT Movie                (Title, Year)>
    <!ATTLIST      Movie
      movieId        ID        #REQUIRED
      startOf        IDREFS    #REQUIRED
    >
  <!ELEMENT Title                (#PCDATA)>
  <!ELEMENT Year                 (#PCDATA)>
]>
```

Identifiers and Reference

```
<? Xml version = “1.0” encoding = “utf-8” standalone = “yes” ?>
<StarMovieData>
    <Star starID = “cf” starredIn = “sw”>
        <Name>Carrie Fishes</Name>
        <Address>
            <Street>123 Maple St.</Street><City>Hollywood</City>
        </Address>
        <Address>
            <Street>5 Locust Ln.</Street><City>Malibu</City>
        <Address>
    </Star>
    <Star starID = “mh” starredIn = “sw”>
        <Name>Mark Hamill</Name>
        <address>
            <Street>456 Oak Rd.</Street>
            <City>Brentwood</City>
        </address>
    </Star>
    <Movie movieID = “sw” starOf = “cf mh”>
        <Title>Star Wars</title><Year>1977</Yea
    </Movie>
</StarMovieData>
```

```
<!DOCTYPE StarMovieData [
    <!ELEMENT StarMovieData          (Star*, Movie*)>
        <!ELEMENT Star               (Name, Address+)>
            <!ATTLIST Star
                starId     ID        #REQUIRED
                StarredIn  INREFS    #IMPLIED
            >
    <!ELEMENT Name                   (#PCDATA)>
    <ELEMENT Address                 (Street, City)>
    <!ELEMNT Street                  (#PCDATA)>
    <!ELEMENT City                   (#PCDATA)>
    <!ELEMENT Movie                  (Title,  Year)>
        <!ATTLIST Movie
                movieIn              ID        #REQUIRED
                startOf              IDREFS    #REQUIRED
            >
    <!ELEMENT Title  (#PCDATA)>
    <!ELEMENT Year  (#PCDATA)>
]>
```

XML Schema

XML Schema is an alternative way to provide a schema for XML documents.

More powerful – give the schema designer extra capabilities.

- allow us to declare types, such as integers or float for simple elements.
- allow arbitrary restriction on the number of occurrences of subelements.
- give us the ability to declare keys and foreign keys.

The Form of an XML schema

- An XML schema description of a schema is itself an XML document. It uses the namespace at the URL

  http://www.w3.org/2001/XMLSchema

  that is provided by the World-Wide-Web Consortium.
- Each XML-schema document has the form:

```
<? xml version = '1.0" encoding = "utf-8" ?>
<xs: schema xmlns: xs = "http://www.w3.org/2001/XMLSchema">
      …   …
</xs: schema>
```

Elements

An important component in an XML schema is the element, which is similar to an element definition in a DTD.

The form of an element definition in XML schema is:

```
<xs: element name = element name type = element type>
    constraints and/or structure information
</xs: element>
```

```
<xs: element name = “Title” type = “xs: string” />
<xs: element name = “Year” type = “xs: integer” />
```

DTD

```
<!DOCTYPE root-tag [
        … …
    <!ELEMENT Title (#PCDATA)>
    <!ELEMENT Year (#PCDATA)>
        … …
    ]>
```

Complex Types

A *complex type* in XML Schema can have several forms, but the most common is a sequence of elements.

```
<xs: complexType name = type name >
     <xs: sequence>
          list of element definitions
     </xs: sequence>
</xs: complexType>
```

```
<xs: complexType name = type name >
          list of attribute definitions
     </xs: complexType>
```

DTD

```
<!DOCTYPE root-tag [
     <!ELEMENT element-name (components)>
          ... ...
     ]>
```

```
<? Xml version = “1.0” encoding = “utf-8” ?>
<xs: schema xmlns: xs = “http://www.w3.org/2001/XMLSchema”>

    <xs:complexType name = “movieType”>
        <xs: sequence>
            <xs: element name = “Title” type = “xs: string” />
            </xs: element name = “Year” type = “xs: integer” />
        </xs: sequence>
    </xs: complexType>

    <xs: element name = “Movies”>
        <xs: complexTyp>
            <xs: sequence>
                <xs: element name = “Movie” type = “movieType””
                    minOccurs = “0” maxOcurs = “unbouned” />
            </xs: sequence>
        </xs: complexTyp>
    </xs: element>
</xs: schema>
```

```
<xs: complexType name = type name >
    <xs: sequence>
        list of element definitions
    </xs: sequence>
</xs: complexType>
```

A schema for movies in XML schema. Itself is a document.

The above schema (in XML schema) is equivalent to the following DTD.

```
<!DOCTYPE Movies [
    <!ELEMENT      Movies (Movie*) >
    <!ELEMENT      Movie (Title, Year) >
    <!ELEMENT      Title (#PCDATA) >
    <!ELEMENT      Year (#PCDATA) >
]>
```

Attributes

A *complex type* can have *attributes*. That is, when we define a complex type *T*, we can include instances of element <xs: attribute>. Thus, when we use *T* as the type of an element *E* (in a document), then *E* can have (or must have) an instance of this attribute. The form of an attribute definition is:

<xs: attribute name = *attribute name* type = *type name*
other information about attribute />

<xs: attribute name = "title" type = "xs: integer" default = "0" />
<xs: attribute name = "year" type = "xs: integer" use = "required" />

```
<? Xml version = “1.0” encoding = “utf-8” ?>
<xs: schema xmlns: xs = “http://www.w3.org/2001/XMLSchema”>

    <xs: complexType name = “movieType”>
        <xs: attribute name = “title” type = “xs: string” use = “required” />
        <xs: attribute name = “year” type = “xs: integer” use = “required” />
    </xs: complexType>

    <xs: element name = “Movies”>
        <xs: complexTyp>
            <xs: sequence>
                <xs: element name = “Movie” type = “movieType”
                    minOccurs = “0” maxOcurs = “unbouned” />
            </xs: sequence>
        </xs: complexTyp>
    </xs: element>
</xs: schema>
```

```
<xs:complexType name = “movieType”>
    <xs: sequence>
        <xs: element name = “Title” type = “xs: string” />
        </xs: element name = “Year” type = “xs: integer” />
    </xs: sequence>
</xs: complexType>
```

A schema for movies in XML schema.
Itself is a document.

The above schema (in XML schema) is equivalent to the following DTD.

```
<!DOCTYPE Movies [
    <!ELEMENT      Movies (Movie*) >
    <!ELEMENT      Movie EMPTY >
        <!ATTLIST  Movie
            Title  CDATA #REQUIRED
            Year   CDATA #REQUIRED
        >
]>
```

```
<!DOCTYPE Movies [
    <!ELEMENT      Movies (Movie*) >
    <!ELEMENT      Movie (Title, Year) >
    <!ELEMENT      Title (#PCDATA) >
    <!ELEMENT      Year (#PCDATA) >
]>
```

Restricted Simple Types

It is possible to create a restricted version of a simple type such as integer or string by limiting the values the type can take. These types can then be used as the type of an attribute or element.

1. Restricting numerical values by using minInclusive to state the lower bound, maxInclusive to state the upper bound.
2. Restricting values to an numerated type.

```
<xs: simpleType name = type name >
    <xs: restriction base = base type >
        upper and/or lower bounds
    </xs: restriction>
</xs: simpleType>
```

```
<xs: enumeration value = some value />
```

```
<xs: simpleType name = "movieYearType" >
    <xs: restriction base = "xs: integer" >
        <xs:minInclusive value = "1915" />
    </xs: restriction>
</xs: simpleType>
```

```
<xs: simpleType name = "genretype" >
    <xs: restriction base = "xs: string" >
        <xs: enumeration value = "comedy" />
        <xs: enumeration value = "drama" />
        <xs: enumeration value = "sciFi" />
        <xs: enumeration value = "teen" />
    </xs: restriction>
</xs: simpleType>
```

Keys in XML Schema

An element can have a *key declaration*, which is a field or several fields to uniquely identify the element among a certain class *C* of elements).

field: an attribute or a subelement.
selector: a path to reach a certain node in a document tree.

```
<xs: key name = key name >
     <xs: selector xpath = path description >
     <xs: field xpath = path description >
          more field specification
</xs: key>
```

```
Create table EMPLOYEE
        (…,
         DNO INT NOT NULL DEFAULT 1,
  CONSTRAINT EMPPK
        PRIMARY KEY(SSN),
  CONSTRAINT EMPSUPERFK
  FOREIGN KEY(SUPERSSN)
  REFERENCES
                 EMPLOYEE(SSN)
        ON DELETE SET NULL  ON
  UPDATE
                 CASCADE,
  CONSTRAINT EMPDEPTFK
  FOREIGN KEY(DNO) REFERENCES

        DEPARTMENT(DNUMBER)
         ON DELETE SET DEFAULT
        ON UPDATE CASCADE);
```

```
<? Xml version = “1.0” encoding = “utf-8” ?>
<xs: schema xmlns: xs = “http://www.w3.org/2001/XMLSchema”>

  <xs: simpleType name = “genretype” >
    <xs: restriction base = “xs: string” >
      <xs: enumeration value = “comedy” />
      <xs: enumeration value = “drama” />
      <xs: enumeration value = “sciFi” />
      <xs: enumeration value = “teen” />
    </xs: restriction>
  </xs: simpleType>

  <xs: complexType name = “movieType”>
    <xs: attribute name = “title” type = “xs: string” />
    <xs: attribute name = “year” type = “xs: integer” />
    <xs: attribute name = “Genre” type = “genreType”
      minOccurs = “0” maxOccurs = “1” />
  </xs: complexType>
```

```
<xs: element name = “Movies”>
  <xs: complexTyp>
    <xs: sequence>
      <xs: element name = “Movie” type = “movieType”
      minOccurs = “0” maxOcurs = “unbouned” />
    </xs: sequence>
  </xs: complexTyp>
  <xs: key name = “movieKey”>
    <xs: selector xpath = “Movie” />
    <xs: field xpath = “@Title” />
    <xs: field xpath = “@Year” />
  </xs: key>
</xs: element>
</xs: schema>
```

/Movies/Movie

/Movies/Movie@Title

/Movies/Movie@Year

```
<? Xml version = “1.0” encoding = “utf-8” standalone = “yes” ?>
  <Movies>
        … …
    <Movie Title = “Star Wars” Year = 1977 Genre = “comedy” />
        … …
  </Movies>
```

Foreign Keys in XML Schema

We can declare that an element has, perhaps deeply nested within it, a field or fields that serve as a reference to the key for some other element. It is similar to what we get with ID's and IDREF's in DTD.

In DTD: untyped references
In XML schema: typed references

```
<xs: keyref name = foreign-key name
     refer = key name>
     <xs: selector xpath = path description >
     <xs: field xpath = path description >
          more field specification
</xs: keyref>
```

```
Create table EMPLOYEE
          (…,
           DNO INT NOT NULL DEFAULT 1,
   CONSTRAINT EMPPK
          PRIMARY KEY(SSN),
   CONSTRAINT EMPSUPERFK
   FOREIGN KEY(SUPERSSN)
   REFERENCES
                    EMPLOYEE(SSN)
          ON DELETE SET NULL  ON
   UPDATE
                    CASCADE,
   CONSTRAINT EMPDEPTFK
   FOREIGN KEY(DNO) REFERENCES
          DEPARTMENT(DNUMBER)
           ON DELETE SET DEFAULT
          ON UPDATE CASCADE);
```

```
<? Xml version = “1.0” encoding = “utf-8” ?>
<xs: schema xmlns: xs = “http://www.w3.org/2001/XMLSchema”>
<xs: element name = “Stars”>
   <xs: complxType>
      <xs: sequence>
         <xs: element name = “Star” minOccurs = “1” maxOccurs = “unbounded”>
            <xs: complexType>
               <xs: sequence>
                  <xs: element name = “Name” type = “xs: string” />
                  <xs: element name = “Address” type = “xs: string” />
                  <xs: element name = “StarredIn” minOccurs = “0” maxOccurs = “1”>
                     <xs: complexType>
                        <xs: attribute name = “title” type = “xs: string” />
                        <xs: attribute name = “year” type = “xs: integer” />
                     </xs: complexType>
                  </xs: element>
               </xs: sequence>
            </xs: complexType>
         </xs: element>
      </xs: sequence>
   </xs: complexType>
```

```
<xs: keyref name = "movieRef" refers = "movieKey">
    <xs: selector xpath = "Star/StarredIn" />
    <xs: field xpath = "@title" />
    <xs: field xpath = "@year" />
</xs: keyref>
</xs: element>
</xs: schema>
```

```
<? Xml version = "1.0" encoding = "utf-8" standalone = "yes" ?>
  <Stars>
    <Star>
        <Name>Mark Hamill</Name>
        <Address>456 Oak Rd. Brentwood</Address>
        <StarredIn title = "star war" year = "1977"/>
    </Star>
    … …

  </Stars>
```

About usage of XML schema

```
<?xml version="1.0"?>
<note xmlns: xsi = "http://www.w3.org/2001/XMLSchema-instance"
xsi: schemaLocation = "https://www.w3schools.com/xml note.xsd">
  <to>Tove</to>
  <from>Jani</from>
  <heading>Reminder</heading>
  <body>Don't forget me this weekend!</body>
</note>
```

The following example is an XML Schema file called "note.xsd" that defines the elements of the above XML document ("note.xml"):

```
<?xml version="1.0"?>
<xs: schema xmlns: xs = "http://www.w3.org/2001/XMLSchema">
        <xs: element name = "note">
        <xs:complexType>
                <xs:sequence>
                        <xs:element name = "to" type = "xs:string"/>
                        <xs:element name = "from" type = "xs:string"/>
                        <xs:element name = "heading" type = "xs:string"/>
                        <xs:element name = "body" type = "xs:string"/>
                        </xs:sequence>
         </xs:complexType>
        </xs:element>
</xs:schema>
```

Programming Languages for XML

- XPath
- XQuery
- Extensible StyleSheets Language (XSLT)

XPath

XPath is a simple language for describing sets of similar paths in a graph of semistrucured data.

The XPath Data Model

Sequence of items corresponds to a set of tuples in the relational algebra.

An item is either:

1. A value of primitive type: integer, real, boolean, or string.
2. A node (three kinds of nodes)

Three kinds of nodes:

(a) Documents. These are files containing an XML document, perhaps denoted by their local path name or URL.
(b) Elements. These are XML elements, including their opening tags, their matching closing tags if there is one, and everything in between (i.e., below them in the tree of semistructured data that an XML document represents).
(c) Attributes. These are found inside opening tags.

The items in a sequence needn't be all of the same type although often they will be.

A sequence of five items:

10
“ten”
10.0
<Number base = “8”>
    <Digit>1</Digit>
    <Digit>2</Digit>
</Number>
@val=“10”

Document Nodes

It is common to apply XPath to documents that are files. We can make a document node from a file by applying the function:

doc(*file name*)

The named file should be an XML document. We can name a file either by giving its local name or a URL if it is remote.

doc("*movie.xml*")
doc("*/usr/slly/data/movies.xml*")
doc("*infolab.stanford.edu/~hector/movies.xml*")

Path Expressions

An XPath expression starts at the root of a document and gives a sequence of tags and slashes (/).

doc(*file name*)/T_1/T_2/…/T_n

doc(*“movie.xml”*)/StarMoviedata/Star/Name

Evaluation of XPath expressions:

1. Start with a sequence of items consisting of one node: the document node.
2. Then, process each of T_1, T_2, …, T_n in turn.
3. To process T_i, consider the sequence of items that results from processing the previous tag, if any. Examine those items, in order, and find each of all its subelements whose tag is T_i.

```
<? Xml version = “1.0” encoding = “utf-8” standalone = “yes” ?>
<StarMovieData>
    <Star starID = “cf” starredIn = “sw”>
        <Name>Carrie Fishes</Name>
        <Address>
            <Street>123 Maple St.</Street><City>Hollywood</City>
        </Address>
        <Address>
            <Street>5 Locust Ln.</Street><City>Malibu</City>
        <Address>
    </Star>
    <Star starID = “mh” starredIn = “sw”>
        <Name>Mark Hamill</Name><Street>456 Oak Rd.</Street>
        <City>Brentwood</City>
    </Star>
    <Movie movieID = “sw” starOf = “cf mh”>
        <Title>Star Wars</title><Year>1977</Year>
    </Movie>
</StarMovieData>
```

doc(*“movie.xml”*)/StarMoviedata/Star/Name

In the following discussion, the document node is not included in an XPath for simplicity.

/StarMoviedata/Star/Name

```
<? Xml version = "1.0" …  ?>
<StarMovieData>
    <Star starID = "cf" starredIn = "sw">
        <Name>Carrie Fishes</Name>
        … …
    </Star>
    <Star starID = "mh" starredIn = "sw">
        <Name>Mark Hamill</Name>
    </Star>
    <Movie>
        … ..
    </Movie>
</StarMovieData>
```

```
<Name>Carrie Fisher</Name>
<Name>Mark Hamill</Name>
```

Relative Path Expressions

In several contexts, we shall use XPath expressions that are relative to the *current node* or sequence of nodes.

```
<xs: element name = “Movies”>          ◄--------------------     a current node
   <xs: complexTyp>                                                   ⇕
      <xs: sequence>                                          /StarMovieData/Movies
         <xs: element name = “Movie” type = “movieType”>
                  minOccurs = “0” maxOcurs = “unbouned” />
      </xs: sequence>
   </xs: complexTyp>
   <xs: key name = “movieKey”>
      <xs: selector xpath = “Movie” /> ◄-----     a relative path, equal to
      <xs: field xpath = “@Title” />              /StartMovieData/Movies/Movie
      <xs: field xpath = “@Year” />
   </xs: key>
</xs: element>                           /StartMovieData/Movies/Movie/@Title
</xs: schema>                            /StartMovieData/Movies/Movie/@Year
```

Attribute in Path Expressions

- Path expressions allow us to find all the elements within a document that are reached from the root along a particular path.

$$/T_1/T_2/\ldots/T_n$$

- We can also end a path by an attribute name preceded by an *at-sign*.

$$/T_1/T_2/\ldots/T_n/@A$$

```
/StarMovieData/Star/@starID
```

Axes

So far, we have only navigated though semistructured-data graphs in two ways: from a node to its children or to an attribute. In fact, XPath provides several axes to navigate a graph in different ways. Two of these axes are *child* (the default axis) and *attribute*, for which @ is really a shorthand.

Axes used in Xpath expressions: /axis::

Self	/self::	/next-sibling::
Parent	/parent::	/following::
descendant	/descendant::	/preceding::
Ancestor	/ancestor::	/child::
Next-sibling		/attribute::
Following		
Preceding		

/child::StarMovieData/descentend::Star/attribute::starID

self	Selects the current node
parent	Selects the parent of the current node
descendant	Selects all descendants (children, grandchildren, etc.) of the current node
ancestor	Selects all ancestors (parent, grandparent, etc.) of the current node
next-sibling	Select the next sibling
following	Selects everything in the document after the closing tag of the current node
preceding	Selects all nodes that appear before the current node in the document, except ancestors, attribute nodes and namespace nodes
child	Selects all children of the current node
attribute	Selects all attributes of the current node

- All the children of the current node are referred to as siblings.
- All those nodes visited after the current node during a DFS search are referred as the following nodes.
- All those nodes visited before the current node during a DFS search are referred as the preceding nodes.

Abbreviated axes

/ - stands for *child*
@ – stands for *attribute*

. - stands for *self*
.. – stands for *parent*
// - stands for *descendant*

/child::StarMovieData/descentend::Star/attribute::starID

/StarMovieData//Star/@starID

/descendant::City

//City

/StarMovieData//Star//City
produces the same results as //City.

Context of Expression

- By “context”, we mean an element in a document, working as a reference point (current node).
- So it makes sense to apply axes like *parent*, *ancestor*, or *next-sibling* to a current node.

- Two functions: text( ), node( )
  - /child::text( ) – select all those children of the current node, which are text nodes
  - /child::node( ) – select all the children of the current node, whatever their node type
  - /self::node( ) – select the current node

/StarMovieData//Star/self::node( )

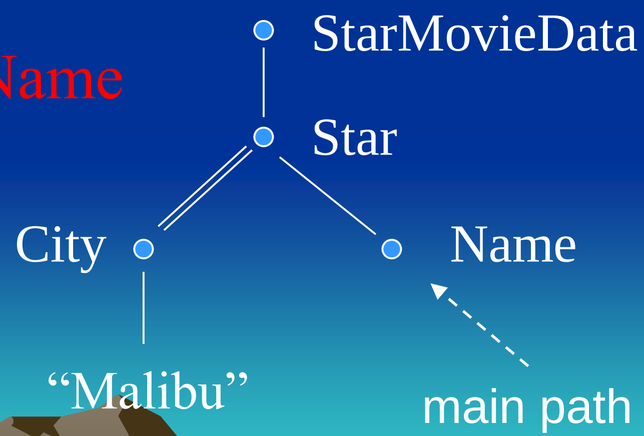
↓

/StarMovieData//Star

Conditions in Path Expressions

As we evaluate a path expression, we can restrict ourselves to follow only a subset of the paths whose tags match the tags in the expression. To do so, we follow a tag by a condition, surrounded by square brackets. Such a condition can be anything that has a boolean value. Values can be compared by comparison operators: = , >=, !=. A compound condition can be constructed by connecting comparisons with logic operations: ∨, ∧.

/StarMovieData/Star[.//City = “Malibu”]/Name



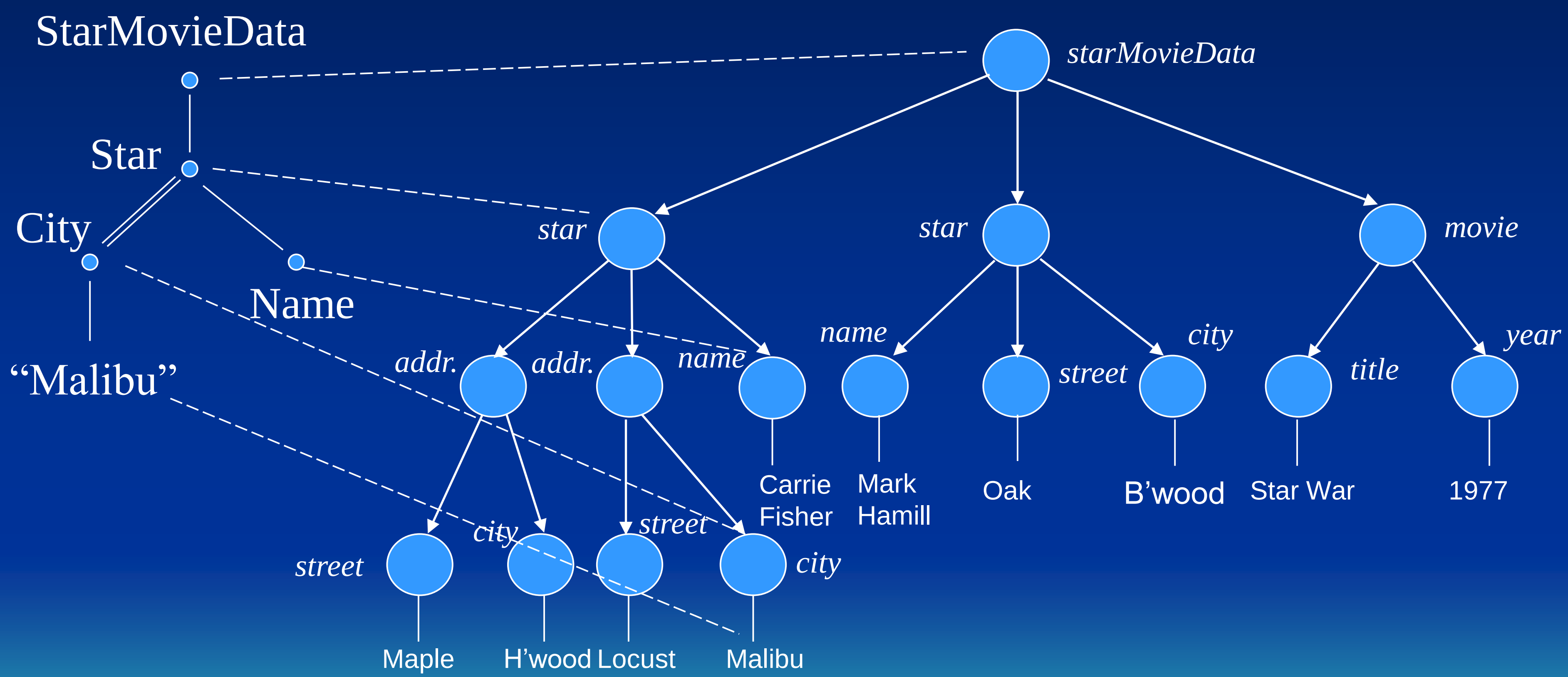
<Name>Carrie Fisher</Name>

<? Xml version = “1.0” encoding = “utf-8” standalone = “yes” ?>
<StarMovieData>
<Star starID = “cf” starredIn = “sw”>
<Name>Carrie Fishes</Name>
<Address>
<Street>123 Maple St.</Street><City>Hollywood</City>
</Address>
<Address>
<Street>5 Locust Ln.</Street><City>Malibu</City>
<Address>
</Star>
<Star starID = “mh” starredIn = “sw”>
<Name>Mark Hamill</Name><Street>456 Oak Rd.</Street>
<City>Brentwood</City>
</Star>
<Movie movieID = “sw” starOf = “cf mh”>
<Title>Star Wars</title><Year>1977</Year>
</Movie>
</StarMovieData>

<Name>Carrie Fisher</Name>

/StarMovieData/Star[.//City = “Malibu”]/Name

/StarMovieData/Star[.//City = “Malibu”]/Name

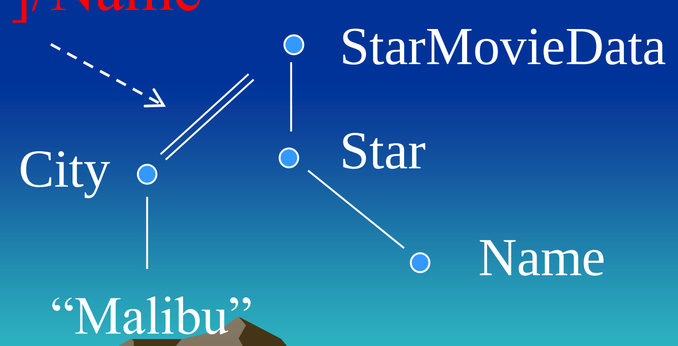


Name = “Carrie Fisher”

Conditions in Path Expressions

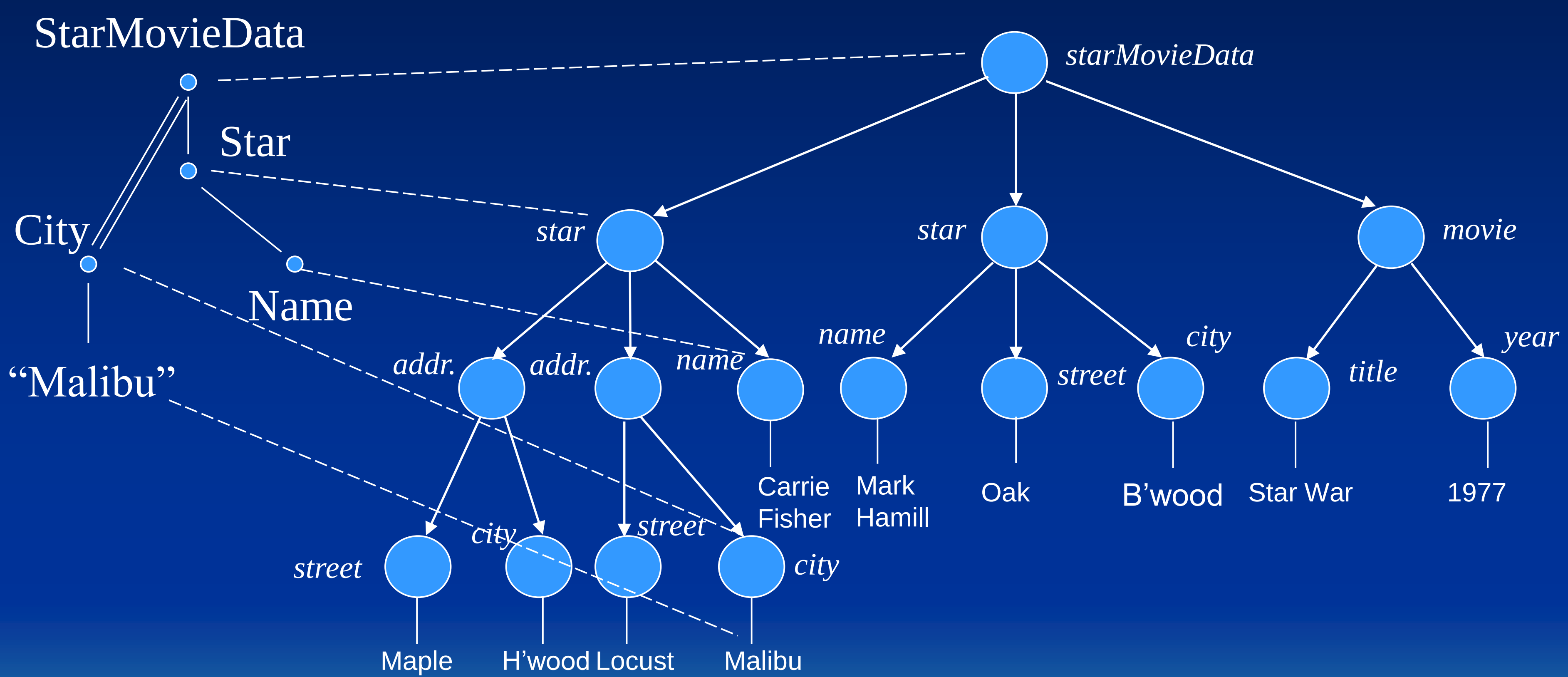
As we evaluate a path expression, we can restrict ourselves to follow only a subset of the paths whose tags match the tags in the expression. To do so, we follow a tag by a condition, surrounded by square brackets. Such a condition can be anything that has a boolean value. Values can be compared by comparison operators: = , >=, !=. A compound condition can be constructed by connecting comparisons with operations: ∨, ∧.

/StarMovieData/Star[..//City = “Malibu”]/Name



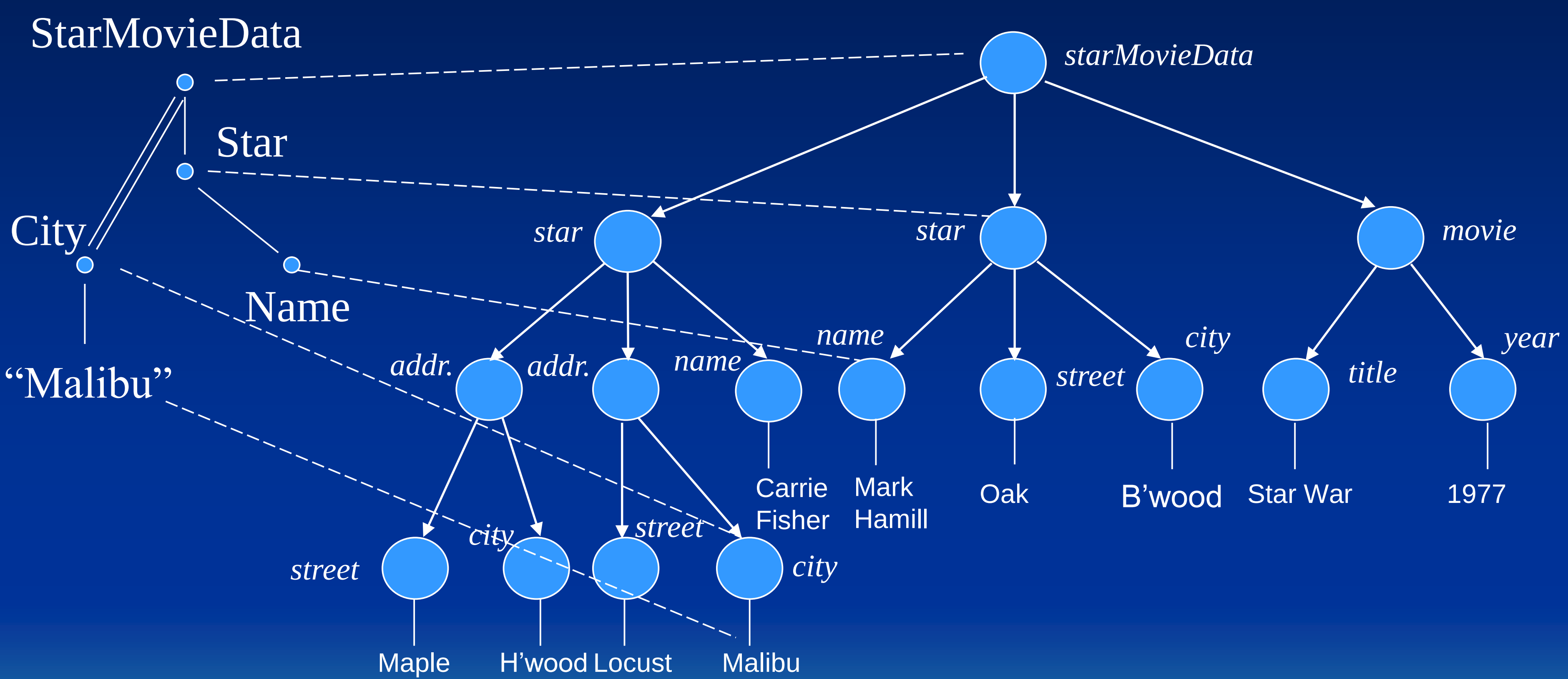
/StarMovieData/Star[.//City = “Malibu”]/Name

/StarMovieData/Star[..//City = “Malibu”]/Name



Name = “Carrie Fisher”

/StarMovieData/Star[..//City = “Malibu”]/Name



Name = “Mark Hamil”

Conditions in Path Expressions

Several other useful forms of condition are:

- An integer [*i*] by itself is true only when applied the *i*th child of its parent.

/StarMovieData/Stars/Star[2]

- A tag [*T*] by itself is true only for elements that have one or more subelements with tag *T*.

/StarMovieData/Stars/Star[Address]

- An attribute [*A*] by itself is true only for elements that have an attribute *A*.

/StarMovieData/Stars/Star[@startID]

```
<? Xml version = “1.0” encoding = “utf-8” standalone = “yes” ?>
<Movies>
    <Movie title = “King Kong” >
        <Version year = “1933”>
            <Star>Fay Wray</Star>
        </Version>
        <Version year = “1976”>
            <Star>Jeff Bridegs</Star>
            <Star>Jessica Lange</Star>
        </Version>
    </Movie>
    <Movie title = “Footloose”>
        <Version year = “1984”>
            <Star>Kevin Bacon</Star>
            <Star>John Lithgow</Star>
            <Star>Sarah Jessica Parkr</Star>
        </Version>
    </Movie>
</Movies>
```

/Movies/Movie/Version[1]/@year

/Movies/Movie/Version/Star?

/Movies/Movie/Version[Star] ?

Wildcards

In an XPath expression, we can use * to say “any tag”. Likewise, @* says “any attribute.”

```
/StarMovieData/*/@*
```

Results: “cf”, “sw”, “mh”, “sw”, “sw”, “cf mh”

```
<StarMovieData>
    <Star starID = “cf” starredIn = “sw”>
        … …
    </Star>
    <Star starID = “mh” starredIn = “sw”>
        … …
    </Star>
    <Movie movieID = “sw” starOf = “cf mh”>
        … …
    </Movie>
</StarMovieData>
```

The XPath expressions are mainly used in HTML, XQuery and XSLT languages.

Example:

```
<ul>
    {doc(starMovie.xml)/StarMovieData/*/@*}
</ul>
```

↓

- Cf
- Sw
- Mh
- Sw
- Sw
- cf mh

XQuery

- XQuery is an extension of XPath that has become a standard for high-level querying of databases containing XML data.
- XQuery is designed to take data from multiple databases, from XML files, from remote Web documents, even from CGI (common gate interface) scripts, and to produce XML results that you can process with XSLT.

XQuery Basics

All values produced by XQuery expressions are sequences of items.

Items:

primitive values

nodes: document, element, attribute nodes

XQuery is a *functional language*, which implies that any XQuery expression can be used in any place that an expression is expected.

FLWR Expressions

FLWR (pronounced “flower”) expressions are in some sense analogous to SQL select-from-where expressions.
An XQuery expression may involve clauses of four types, called for-, let-, where-, and return-clauses (FLWR).

1. The query begins with zero or more for- and let-clauses. There can be more than one of each kind, and they can be interlaced in any order, e.g., for, for, let, for, let.
2. Then comes an optional where-clause.
3. Finally, there is exactly one return-clause.

```
Return <Greeting>“Hello World”</Greeting>
```

Let Clause

let *variable* := *expression*

- The intent of this clause is that the expression is evaluated and assigned to the variable for the remainder of the FLWR expression.
- Variables in XQuery must begin with a dollar-sign.
- More generally, a comma-separated list of assignments to variables can appear.

```
let $stars := doc("stars.xml")
```

```
let   $movies := doc("movies.xml")
      $stars := doc("stars.xml")
```

for Clause

for *variable* in *expression*

```
let $movies := doc("movies.xml")
for $m in $movies/Movies/Movie
```

Stars.xml

```
<? Xml version = “1.0” encoding = “utf-8” standalone = “yes” ?>
<Stars>
    <Star>
        <Name>Carrie Fisher</Name>
        <Address>
            <Street>123 Maples St.</street>
            <City>Hollywood</City>
        </Address>
        <Address>
            <Street>5 Locust Ave.</Street>
            <City>Malibu</City>
        </Address>
    </Star>
            … more stars
</Stars>
```

Movies.xml

```
<? Xml version = “1.0” encoding = “utf-8” standalone = “yes” ?>
<Movies>
    <Movie title = “King Kong”>
        <Version year = “1993”>
            <Star>Fay Wray</Star>
        </Version>
        <Version year = “1976”>
            <Star>Jeff Brideges</Star>
            <Star>Jessica Lange</Star>
        </version>
    </Movie>
    <Movie title = “Footloose”>
        <Version year = “1984”>
            <Star>Kevin Bacon</Star>
            <Star>John Lithgow</Star>
            <Star>Sarah Jessica Parkr</Star>
        </Version>
    </Movie>
</Movies>
```

Where Clause

where *condition*

where $s/Address/Street = "123 Maple St." and $s/Address/City = "Malibu"

This clause is applied to an item, and the condition, which is an expression, evaluates to true or false.

return Clause

return *expression*

This clause returns the values obtained by evaluating *expression*.

```
let $movies := doc("movies.xml")
for $m in $movies/Movies/Movie
return $m/Version/Star
```

```
<Star>Fay Wray</Star>
<Star>Jeff Brideges</Star>
<Star>Jessica Lange</Star>
<Star>Kevin Bacon</Star>
<Star>John Lithgow</Star>
<Star>Sarah Jessica Parker</Star>
```

```
let $movies := doc(“movies.xml”)
for $m in $movies/Movies/Movie
return $m/Version/Star
```

```
<? Xml version = “1.0” encoding = “utf-8” … ?>
<Movies>
    <Movie title = “King Kong”>
        <Version year = “1993”>
            <Star>Fay Wray</Star>
        </Version>
        <Version year = “1976”>
            <Star>Jeff Brideges</Star>
            <Star>Jessica Lange</Star>
        </version>
    </Movie>
    <Movie title = “Footloose”>
        <Version year = “1984”>
            <Star>Kevin Bacon</Star>
            <Star>John Lithgow</Star>
            <Star>Sarah Jessica Parkr</Star>
        </Version>
    </Movie>
</Movies>
```

```
<Star>Fay Wray</Star>
<Star>Jeff Brideges</Star>
<Star>Jessica Lange</Star>
<Star>Kevin Bacon</Star>
<Star>John Lithgow</Star>
<Star>Sarah Jessica Parker</Star>
```

Replacement of variables by their Values

```
let $movies := doc("movies.xml")
for $m in $movies/Movies/Movie
return <Movie title = $m/@title>$m/Version/Star</Movie>
```

Not correct! The variable will not be replaced by its values.

```
<Movie title = $m/@title>$m/Version/Star</Movie>
<Movie title = $m/@title>$m/Version/Star</Movie>
<Movie title = $m/@title>$m/Version/Star</Movie>
   … …
```

```
let $movies := doc("movies.xml")
for $m in $movies/Movies/Movie
return <Movie title = {$m/@title}>{$m/Version/Star}</Movie>
```

```
<Movie title = "King Kong"><Star>Fay Wray</Star></Movie>
<Movie title = "King Kong"><Star>Jeff Brideges</Star></Movie>
<Movie title = "King Kong"><Star>Jessica Lange</Star></Movie>
<Movie title = "Footloose"><Star>Kevin Bacon</Star></Movie>
<Movie title = "Footloose"><Star>John Lithgow</Star></Movie>
<Movie title = "Footloose"><Star>Sarah Jessica Parker</Star></Movie>
        … …
```

Joins in XQuery

We can join two or more documents in XQuery in much the same way as in SQL. In each case, we need variables, each of which ranges over elements of one of the documents or tuples of one of the relations, respectively.

1. In SQL, we use a from-clause to introduce the needed tuple variables
2. In XQuery, we use a for-clause.

```
let   $movies := doc("movies.xml")
      $stars := doc("stars.xml")
for   $s1 in $movies/Movies/Movie/Version/Star
      $s2 in $Stars/Stars/Star
where data($s1) = data($s2/Name)
return $s2/Address/City
```

```
Select ssn, lname, Dname
From employees s1, departments s2
Where s1.dno = s2. Dnumber
```

```
let    $movies := doc("movies.xml")
       $stars := doc("stars.xml")
for    $s1 in $movies/Movies/Movie/Version/Star
       $s2 in $Stars/Stars/Star
where data($s1) = data($s2/Name)
return $s2/Address/City
```

```
<? Xml version = "1.0" …. … ?>
<Movies>
    <Movie title = "King Kong">
        <Version year = "1993">
            <Star>Fay Wray</Star>
        </Version>
        <Version year = "1976">
            <Star>Jeff Brideges</Star>
            <Star>Jessica Lange</Star>
        </version>
    </Movie>
    <Movie title = "Footloose">
        <Version year = "1984">
            <Star>Kevin Bacon</Star>
            <Star>John Lithgow</Star>
            <Star>Sarah Jessica Parkr</Star>
        </Version>
    </Movie>
</Movies>
```

```
<? Xml version = "1.0" encoding = "utf-8" … ?>
<Stars>
    <Star>
        <Name>Fay Wray</Name>
        <Address>
            <Street>123 Maples St.</street>
            <City>Hollywood</City>
        </Address>
        <Address>
            <Street>5 Locust Ln.</Street>
            <City>Mallibu</City>
        </Address>
    </Star>
            … more stars
</Stars>
```

XQuery Comparison Operators

A query: find all the stars that live at 123 Maple St., Malibu.

The following FLWR seems correct. But it does not work.

```
let    $stars := doc("stars.xml")
for    $s in $stars/Stars/Star
where $s/Address/Street = "123 Maple St
       and $s/Address/City = "Malibu"
return $s/Name
```

Correct query:

```
let    $stars := doc("stars.xml")
for    $s in $stars/Stars/Star,
       $s1 in $s/Address
where $s1/Street = "123 Maple St." and
       $s1//City = "Malibu"
return $s/Name
```

```
<? Xml version = "1.0" encoding = "utf-8" …
?>
<Stars>
    <Star>
        <Name>Fay Wray</Name>
        <Address>
            <Street>123 Maples St.</street>
            <City>Hollywood</City>
        </Address>
        <Address>
            <Street>5 Locust Ave.</Street>
            <City>Mallibu</City>
        </Address>
    </Star>
            … more stars
</Stars>
```

Elimination of Duplicates

XQuery allows us to eliminate duplicates in sequences of any kind, by applying the built-in distinct values.
Example. The result obtained by executing the following first query may contain duplicates. But the second not.

```
let     $starsSeq := (
        let $movies := doc("movies.xml")
        for $m in $movies/Movies/Movie
        return $m/Version/Star
)
return <Stars>{$starSeq}</Stars>
```

```
let     $starsSeq := distinct-values(
        let $movies := doc("movies.xml")
        for $m in $movies/Movies/Movie
        return $m/Version/Star
)
return <Stars>{$starSeq}</Stars>
```

Select average(distinct *salary*) **from** *employee*;

Quantification in XQuery

There are expressions that say, in effect, *for all* (∀), and *there exists* (∃):

every *variable* in *expression1* satisfies *expression2*
some *variable* in *expression1* satisfies *expression2*

```
let     $stars := doc("stars.xml")
for     $s in $stars/Stars/Star
where   every $c in $s/Address/City
            satisfies $c = "Hollywood"
return $s/Name
```

Find the stars who have houses only in Hollywood.

```
let     $stars := doc("stars.xml")
for     $s in $stars/Stars/Star
where   $c in $s/Address/City satisfies
            $c = "Hollywood"
return $s/Name
```

Find the stars with a home in Hollywood. (Key word *some* is not used.)

Select *ssn, fname, salary* **from** *employee* ***where*** *salary* > **all** *(**select** salary **from** employee **where** dno = 4);*

```
Select fname, lname
from employee
where
        exists (select *
                from dependent
                where essn = ssn);
```

Aggregation

XQuery provides built-in functions to compute the usual aggregations such as count, average, sum, min, or max. They take any sequence as argument. That is, they can be applied to the result of any XPath expression.

```
let     $movies := doc("movies.xml")
for     $m in $movies/Movies/Movie
where count($m/Version) > 1
return $m
```

Find the movies with multiple versions.

Select *s.ssn, s.lname, count(r.lname)*

from *employee s, employee r*

where *s.ssn = r.superssn*

group by *s.ssn, s.lname;*

having *count(s.name)* < 3;

Branching in XQuery Expressions

There is an *if-then* expression in Xquery of the form:

if (*expression1*) **then** (*expression2*)

```
let     $kk := doc("movies.xml")/Movies/Movie/Movie[@title = "King Kong"]
for     $v in $kk/Version
return     if ($v/@year = max($kk/Version/@year))
           then <Latest>{$v}</Latest>
           else <Old>{$v}</Old>
```

Tag the version of *King Kong*.

```
<? Xml version = "1.0" …. … ?>
<Movies>
    <Movie title = "King Kong">
        <Version year = "1993">
            <Star>Fay Wray</Star>
        </Version>
        <Version year = "1976">
            <Star>Jeff Brideges</Star>
            <Star>Jessica Lange</Star>
        </version>
    </Movie>
    <Movie title = "Footloose">
        <Version year = "1984">
            <Star>Kevin Bacon</Star>
            <Star>John Lithgow</Star>
            <Star>Sarah Jessica Parkr</Star>
        </Version>
    </Movie>
</Movies>
```

Movies.xml

```
<? Xml version = "1.0" encoding = "utf-8" standalone = "yes" ?>
<Movies>
    <Movie title = "King Kong">
        <Version year = "1993">
            <Star>Fay Wray</Star>
        </Version>
        <Version year = "1976">
            <Star>Jeff Brideges</Star>
            <Star>Jessica Lange</Star>
        </version>
    </Movie>
    <Movie title = "Footloose">
        <Version year = "1984">
            <Star>Kevin Bacon</Star>
            <Star>John Lithgow</Star>
            <Star>Sarah Jessica Parkr</Star>
        </Version>
    </Movie>
</Movies>
```

```
Let $kk :=
   doc("movies.xml")/Movies/Movie/Movie
   [@title = "King Kong"]
For $v in $kk/Version
Return if ($v/@year =
   max($kk/Version/@year))
        then <Latest>{$v}</Latest>
        else <Old>{$v}</Old>
```

⇩

```
<Latest><Version year = "1993"> … </Latest>
<Old><Version year = "1976"> … </Old>
```

Ordering the Result of a Query

It is possible to sort the result as part of a FLWR query

order *list of expressions*

```
let     $movies := doc("movies.xml")
for     $m in $movies/Movies/Movie,
        $v in $m/Version
order   $v/@year
return  <Movie title = "{$m/@title}" year = "{$v/@year}" />
```

Select *
From employees
order by ssn

Construct the sequence of *title-year* pairs, ordered by *year*.

Movies.xml

```
<? Xml version = “1.0” encoding = “utf-8” standalone = “yes” ?>
<Movies>
    <Movie title = “King Kong”>
        <Version year = “1993”>
            <Star>Fay Wray</Star>
        </Version>
        <Version year = “1976”>
            <Star>Jeff Brideges</Star>
            <Star>Jessica Lange</Star>
        </version>
    </Movie>
    <Movie title = “Footloose”>
        <Version year = “1984”>
            <Star>Kevin Bacon</Star>
            <Star>John Lithgow</Star>
            <Star>Sarah Jessica Parkr</Star>
        </Version>
    </Movie>
</Movies>
```

```
let     $movies := doc(“movies.xml”)
for     $m in $movies/Movies/Movie,
        $v in $m/Version
order   $v/@year
return <Movie title = “{$m/@title}”
year = “{$v/@year}” />
```

```
<Movie title = “King Kong” year = “1976” />
<Movie title = “Footloose” year = “1984” />
<Movie title = “King Kong” year = “1993” />
```

```
let     $movies := doc("movies.xml")
for     $m in $movies/Movies/Movie,
        $v in $m/Version
order   $m/@title, $v/@year
return  <Movie title = "{$m/@title}" year = "{$v/@year}" />
```

```
<Movie title = "Footloose" year = "1984" />
<Movie title = "King Kong" year = "1976" />
<Movie title = "King Kong" year = "1993" />
```

About usage of XQuery

An XQuery expression can be embedded in an HTML file.

```
:
<ul>
        {
          for $x in doc("books.xml")/bookstore/book/title
          order by $x
          return <li>{$x}</li>
        }
</ul>
:
```

Extensible Stylesheet Language

XSLT (Extensible Stylesheet Language for Transformation) is a standard of the World-Wide-Web Consortium.

- Its original purpose was to allow XML documents to be transformed into HTML or similar forms that allowed the document to be viewed or printed.
- In practice, XSLT is another query language for XML to extract data from documents or turn one document form into another form.

XSLT Basics

Like XML schema, XSLT specifications are XML documents, called *stylsheet*. The tag used in XSLT are found in a name-space: http://www.w3.org/1999/XSL/Transform.

At the highest level, a stylesheet looks like:

```
<? Xml version = ‘1.0” encoding = “utf-8” ?>
<xsl:stylesheet xmlns:xsl =
            http://www.w3.org/1999/XSL/Transform>
… …
</xsl:stylesheet>
```

Templates

A stylesheet will have one or more templates. To apply a stylesheet to an XML document, we go down the list of templates until we find one that matches the root.

<xsl:template match = “*XPath expression*”>

Templates

<xsl:template match = “*XPath expression*”>

XPath expression can be either rooted (beginning with a slash) or relative. It describes the elements of XML documents to which this template is applied.

Rooted expression – the template is applied to every element of the document that matches the path (absolute path).

Relative expression – part of an Xpath, evaluated relative to a reference point (the current node).

```
<? Xml version = "1.0" encoding = "utf-8" ?>
<xsl:stylesheet xmlns:xsl =
                http://www.w3.org/1999/XSL/Transform>
        <xsl:template match = "/">
             <HTML>
                 <BODY>
                     <B>This is a document</B>
                 </BODY>
             </HTML>
        </xsl:template >
</xsl:stylesheet>
```

Applying the template, an XML document is transformed to a HTML file:

```
<HTML>
    <BODY>
        <B>This is a document</B>
    </BODY>
</HTML>
```

Obtaining Values from XML Data

<xsl:value-of select = “*expression*” />

```
<? Xml version = “1.0” encoding = “utf-8” standalone = “yes” ?>
<Movies>
    <Movie title = “King Kong”>
        <Version year = “1993”>
            <Star>Fay Wray</Star>
        </Version>
        <Version year = “1976”>
            <Star>Jeff Brideges</Star>
            <Star>Jessica Lange</Star>
        <version year = “2005” />
    </Movie>
    <Movie title = “Footloose”>
        <Version year = “1984”>
            <Star>Kevin Bacon</Star>
            <Star>John Lithgow</Star>
            <Star>Sarah Jessica Parkr</Star>
        </Version>
    </Movie>
</Movies>
```

```
<? Xml version = “1.0” encoding = “utf-8” ?>
<xsl:stylesheet xmlns:xsl =
        http://www.w3.org/1999/XSL/Transform>
    <xsl:template match = “/Movies/Movie”>
        <xsl:value-of select = “@title” />
        <BR/>
    </xsl:template >
</xsl:stylesheet>
```

“King Kong”

“Footloose”

This ability makes XSTL a query language.

Recursive Use of Templates

Powerful transformations require recursive application of templates at various elements of the input.

<xsl:apply-template select = “*expression*” />

```
<? Xml version = "1.0" encoding = "utf-8" ?>
<xsl:stylesheet xmlns:xsl =
 http://www.w3.org/1999/XSL/Transform>

    <xsl:template match = "/Movies">
       <Movies>
           <xsl:apply-templates />
       </Movies>
    </xsl:template >

    <xsl:template match = "Movie">
       <Movie title = "<xsl:value-of select = "@title" />
           <xsl:apply-templates />
       </Movie>
    </xsl:template>
    <xsl:template match = "Version">
        <xsl:apply-template />
    </xsl:template>
    <xsl:template match = "Star">
        <Star name = "<xsl:value-of select = "." />"/>
    </xsl:template>
</xsl:stylesheet>
```

use this template

use this template

use this template

```
<? Xml version = "1.0" encoding = "utf-8"
    standalone = "yes" ?>
<Movies>
    <Movie title = "King Kong">
        <Version year = "1993">
            <Star>Fay Wray</Star>
        </Version>
        <Version year = "1976">
            <Star>Jeff Brideges</Star>
            <Star>Jessica Lange</Star>
        </version>
    </Movie>
    <Movie title = "Footloose">
        <Version year = "1984">
            <Star>Kevin Bacon</Star>
            <Star>John Lithgow</Star>
            <Star>Sarah Jessica Parkr
            </Star>
        </Version>
    </Movie>
</Movies>
```

```
<? Xml version = “1.0” encoding = “utf-8”
    standalone = “yes” ?>
<Movies>
    <Movie title = “King Kong”>
        <Version year = “1993”>
            <Star>Fay Wray</Star>
        </Version>
        <Version year = “1976”>
            <Star>Jeff Brideges</Star>
            <Star>Jessica Lange</Star>
        </version>
    </Movie>
    <Movie title = “Footloose”>
        <Version year = “1984”>
            <Star>Kevin Bacon</Star>
            <Star>John Lithgow</Star>
            <Star>Sarah Jessica
Parkr</Star>
        </Version>
    </Movie>
</Movies>
```

```
<? Xml version = “1.0” encoding = “utf-8”
                      standalone = “yes” ?>
<Movies>
    <Movie title = “King Kong”>
        <Star name = “Fay Wray” />
        <Star name = “Jeff Brideges” />
        <Star name = “Jessica Lange” />
    </Movie>
    <Movie title = “Footloose”>
        <Star name = “Kevin Bacon” />
        <Star name = “John Lithgow” />
        <Star name = “Sarah Jessica Parkr” />
    </Movie>
</Movies>
```

Iteration in XSLT

We can put a loop within a template that gives us freedom over the order in which we visit certain subelements of the element to which the template is being applied.

<xsl:for-each select = "*expression*" >

The expression is an XPath expression whose value is a sequence of items. Whatever is between the opening <for-each> tag and its matching closing tag is executed for each item, in turn.

```
<? Xml version = “1.0” encoding = “utf-8” standalone = “yes” ?>
<Stars>
    <Star>
        <Name>Carrie Fisher</Name>
        <Address>
            <Street>123 Maples St.</street>
            <City>Hollywood</City>
        </Address>
        <Address>
            <Street>5 Locust Ln.</Street>
            <City>Mallibu</City>
        </Address>
    </Star>
            … more stars
</Stars>
```

```
<? Xml version = “1.0” encoding = “utf-8” ?>
<xsl:stylesheet xmlns:xsl =
        http://www.w3.org/1999/XSL/Transform >
    <xsl:template match = “/”>
        <0L>
            <xsl:for-each select = “Stars/Star” >
                <LI>
                    <xsl:value-of select = “Name”>
                </LI>
            </xsl:for-each>
        </0L><P />
        <0L>
            <xsl:for-each select =
                    “Stars/Star/Address”>
                <LI>
                    <xsl:value-of select = “City”>
                </LI>
            </xsl:for-each>
        </0L>
    </xsl:template >
</xsl:stylesheet>
```

1. Carrie Fishes
2. Mark Hamill

… …

1. Hollywood
2. Malibu

… …

```
<Stars>
    <Star>
        <Name>Carrie Fisher</Name>
        <Address>
            <Street>123 Maples St.</street>
            <City>Hollywood</City>
        </Address>
        <Address>
            <Street>5 Locust Ln.</Street>
            <City>Mallibu</City>
        </Address>
    </Star>
            … more stars
</Stars>
```

```
<0L>
    <LI>
        Carrie Fisher
    </LI>
    <LI>
        Mark Hamil
    </LI>
    … more stars

</0L><P/>
<0L>
    <LI>
        Hollywood
    </LI>
    <LI>
        Malibu
    </LI>
    … more cities

</0L>
```

1. Carrie Fishes
2. Mark Hamill

… …

1. Hollywood
2. Malibu

… …

```
<? Xml version = “1.0” encoding = “utf-8” ?>
<xsl:stylesheet xmlns:xsl =
http://www.w3.org/1999/XSL/Transform>
        <xsl:template match = “/”>
            <0L>
                <xsl:for-each select =
                        “Stars/Star” >
                    <LI>
                        <xsl:value-of select =
                          “Name”>
                    </LI>
                </xsl:for-each>
            </0L><P/>
            <0L>
                <xsl:for-each select =
                        “Stars/Star/Address”>
                    <LI>
                        <xsl:value-of select =
                        “City”>
                    </LI>
                </xsl:for-each>
            </0L>
        </xsl:template >
</xsl:stylesheet>
```

Conditions in XSLT

We can introduce branching into our templates by using an if tag.

<xsl:if test = “*boolean expression*” >

Whatever appears between its tag and its matched closing tag is executed if and only if the boolean expression is *true*.

```
<? Xml version = “1.0” encoding = “utf-8” ?>
<xsl:stylesheet xmlns:xsl =
http://www.w3.org/1999/XSL/Transform>
        <xsl:template match = “/”>
          <TABLE border = “5”><TR><TH>Stars</TH><TR>
            <xsl:for-each select = “Stars/Star” >
              <xsl:if test = “Address/City = ‘Hollywood’”>
                  <TR><TD><xsl:value-of select = “Name”</TD>
                  </TR>
              </xsl:if>
            </xsl:for-each>
          </TABLE>
        </xsl:template >
</xsl:stylesheet>
```

Stars
Carrie Fishes
⋮

```
<TABLE border = "5"><TR><TH>Stars</TH><TR>
        <TR>
                <TD>
                        Carrie Fishes
                </TD>
        </TR>
        <TR>
                <TD>
                        … …
                </TD>
        </TR>
                … …
</TABLE>
```

List all those stars who have a house in Hollywood.

Stars
Carrie Fishes
⋮

```
<html>
<body>
        <table border="1">
        <tr>
        <th>Month</th>
        <th>Savings</th>
         </tr>
        <tr>
        <td>January</td>
        <td>$100</td>
        </tr>
        </table>
</body>
</html>
```

Month	**Savings**
January	$100

How to use XSTL to make document transformation?

In this example, creating the XML file that contains the information about three students and displaying the XML file using XSLT.

```
<?xml version = "1.0" encoding = "UTF-8"?>
<?xml-stylesheet type = "text/xsl "href = “transform.xsl" ?>
<Student>
 <s>
  <name> David John Agarwal</name><branch> CSE</branch>
  <age> 23</age><city> Manibu</city>
 </s>
 <s>
  <name> Mary Chen</name><branch> CSE</branch>
  <age> 17</age><city> New York</city>
 </s>
 <s>
  <name> Christ Henry</name><branch> IT</branch>
  <age> 25</age> <city> Washington</city>
 </s>
</student>
```

students.xml

transform.xsl

```
<?xml version="1.0" encoding="UTF-8"?>
<xsl:stylesheet version="1.0"  xmlns:xsl="http://www.w3.org/1999/XSL/Transform">
<xsl:template match="/">
 <html> <body>
  <h1 align="center">Students' Basic Details</h1>
   <table border="3" align="center" >
            <tr>
                        <th>Name</th>
                        <th>Branch</th>
                        <th>Age</th>
                        <th>City</th>
            </tr>
            <xsl:for-each select="student/s">
            <tr>
                        <td><xsl:value-of select="name"/></td>
                        <td><xsl:value-of select="branch"/></td>
                         <td><xsl:value-of select="age"/></td>
                        <td><xsl:value-of select="city"/></td>
            </tr>
            </xsl:for-each>
    </table> </body> </html> </xsl:template> </xsl:stylesheet>
```

Name	Branch	Age	City
David John	CSE	23	Malibu
Mary Chen	CSE	21	New York
Christ Henry	CSE	22	Washington

How to use XSTL to make document transformation?

(in Java)

```
import javax.xml.transform.Transformer;
import javax.xml.transform.TransformerFactory;
import javax.xml.transform.stream.StreamResult;
import javax.xml.transform.stream.StreamSource;

public class Main {
  public static void main(String args[]) throws Exception {

    StreamSource source = new StreamSource(args[0]);
    StreamSource stylesource = new StreamSource(args[1]);

    TransformerFactory factory = TransformerFactory.newInstance();
    Transformer transformer = factory.newTransformer(stylesource);

    StreamResult result = new StreamResult(System.out);
    transformer.transform(source, result);
  }
}
```

How to use XSTL to make document transformation?

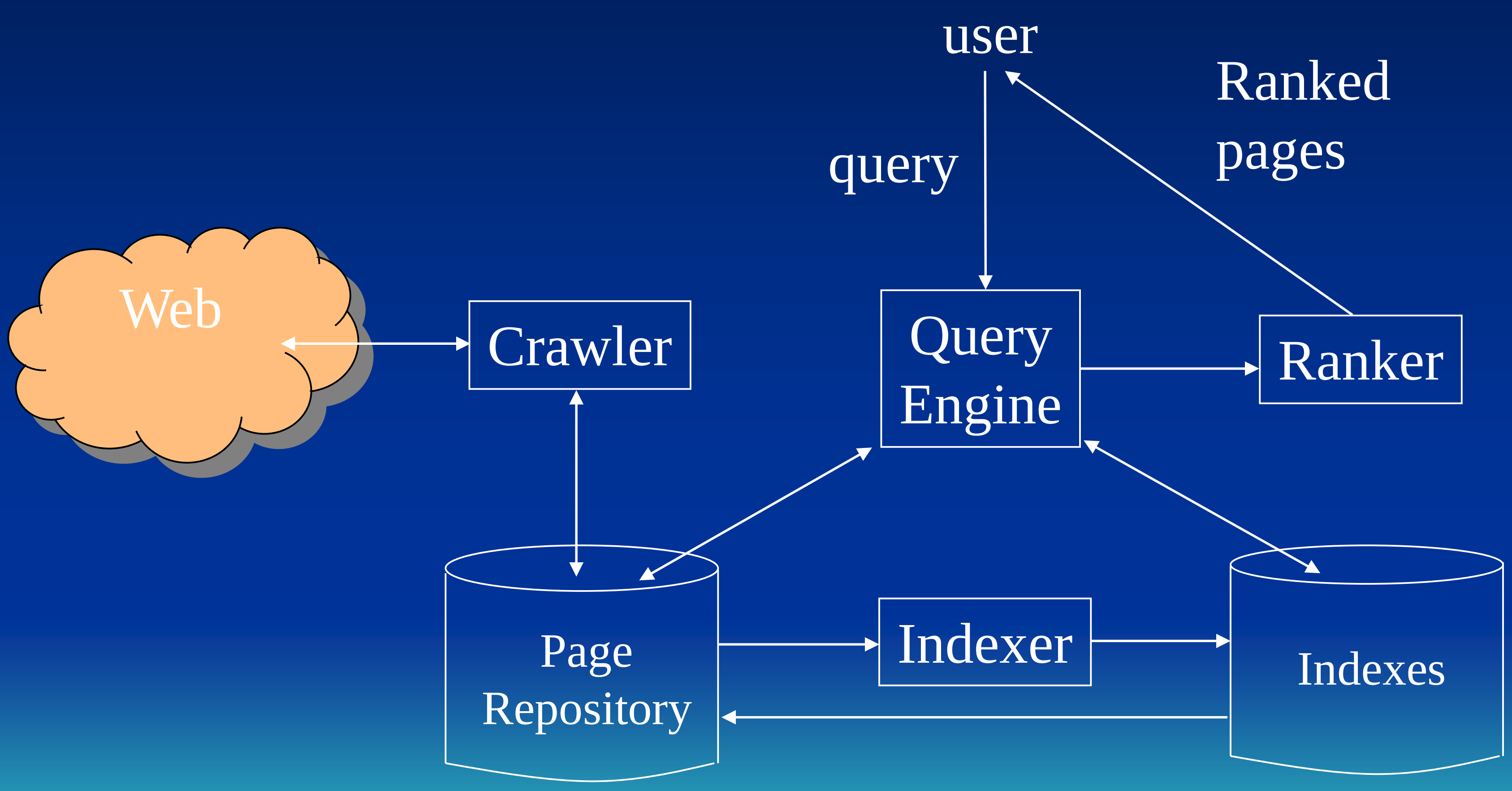
```
XslTransform xslTran = new XslTransform();
xslTran.Load("transform.xsl");
XmlTextWriter writer = new XmlTextWriter("xslt_output.html",
System.Text.Encoding.UTF8);
xslTran.Transform(students.xml, null, writer);
```

an XSTL sheet

create a file to store the output

a file containing an XML document to be transformed

The Architecture of a Search Engine



The Architecture of a Search Engine

There are two main functions that a search engine must perform.

1. The Web must be crawled. That is, copies of many of the pages on the Web must be brought to the search engine and processed.
2. Queries must be answered, based on the material gathered from the Web. Usually, a query is in the form of a word or words that the desired Web pages should contain, and the answer to a query is a ranked list of the pages that contain all those words, or at least some of them.

The Architecture of a Search Engine

Crawler – interact with the Web and find pages, which will be stored in Page Repository.

Query engine – takes one or more words and interacts with indexes, to determine which pages satisfy the query.

Indexer – inverted file: for each word, there is a list of the pages that contain the word. Additional information in the index for the word may include its locations within the page or its role, e.g., whether the word is in the header.

Ranker – order the pages according to some criteria.

Web Crawler

A crawler can be a single machine that is started with a set ***S***, containing the URL's of one or more Web pages to crawl. There is a repository ***R*** of pages, with the URL's that have already been crawled; initially *R* is empty.

Algorithm: A simple Web Crawler
Input: an initial set of URL's *S*.
Output: a repository *R* of Web pages

Web Crawler

Method: Repeatedly, the crawler does the following steps.

1. If *S* is empty, end.
2. Select a URL *r* from the set *S* to "crawl" and delete *r* from *S*.
3. Obtain a page *p*, using its URL *r*. If *p* is already in repository *R*, return to step (1) to select another URL from *S*.
4. If *p* is not already in *R*:
   (a) Add *p* to *R*.
   (b) Examine *p* for links to other pages. Insert into *S* the URL of each page *q* that *p* links to, but that is not already in *R* or *S*.
5. Go to step (1).

r: https://www.youtube.com/watch?v =EctlAlYVWwU → *p*: r1 r2 ⋮

Web Crawler

The algorithm raises several questions.

a) How to terminate the search if we do not want to search the entire Web?
b) How to check efficiently whether a page is already in repository *R*?
c) How to select a URL *r* from *S* to search next?
d) How to speed up the search, e.g., by exploiting parallelism?

Terminating Search

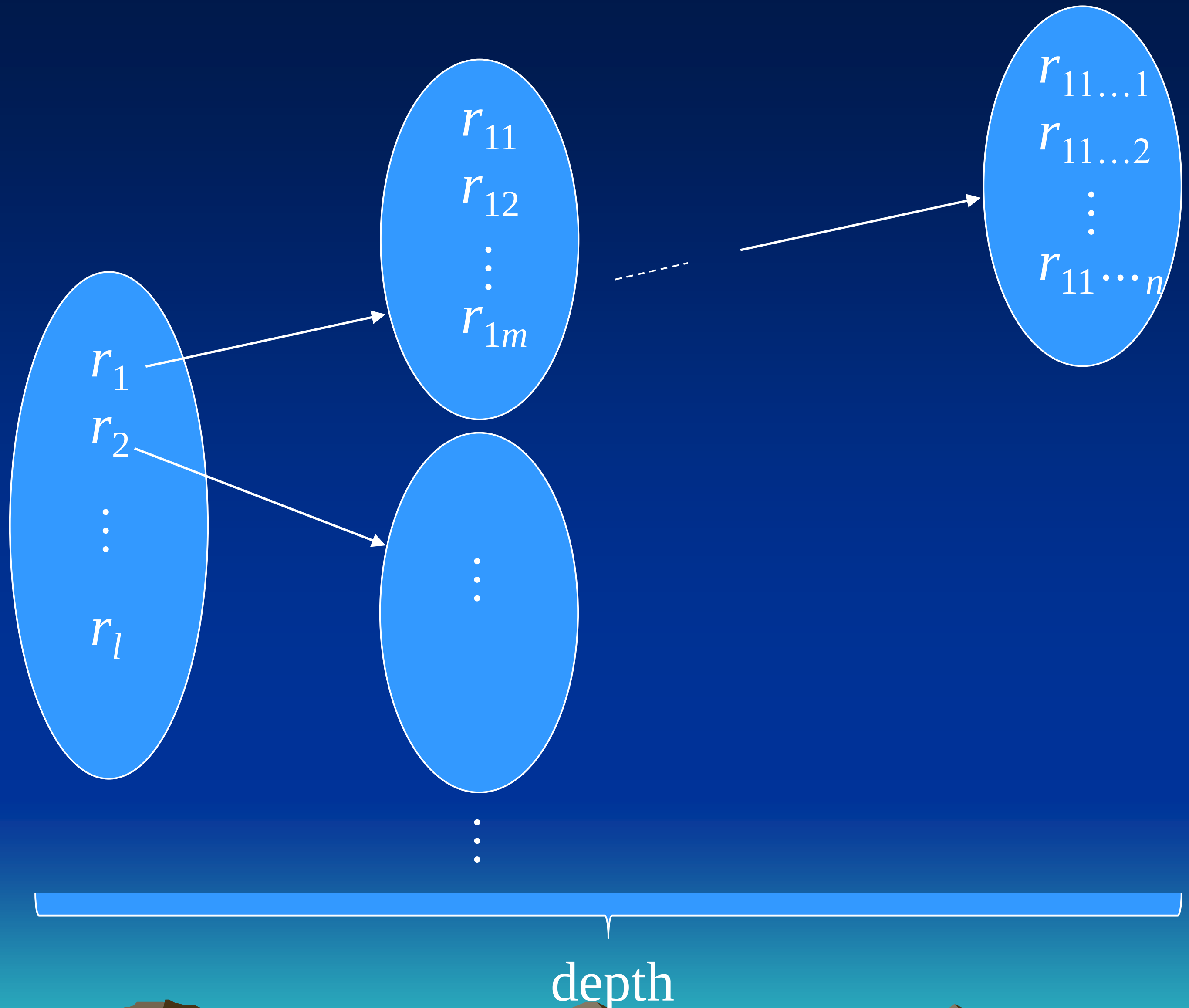
The search could go on forever due to dynamically constructed pages.

Set limitation:

- Set a limit on the number of pages to crawl.

  The limit could be either on each site or on the total number of pages.

- Set a limit on the depth of the crawl.
  Initially, the pages in set *S* have depth 1. If the page *p* selected for crawling at step (2) of the algorithm has depth *i*, then any page *q* we add to *S* at step 4-(b) is given depth *i* + 1. Moreover, if *p* has depth equal to the limit, then do not examine links out of *p* at all. Rather we simply add *p* to *R* if it is not already there.


r_1
r_2
r_l
r_{11}
r_{12}
r_{1m}
$r_{11\ldots1}$
$r_{11\ldots2}$
$r_{11\cdots n}$
depth

Managing the Repository

- When we add a new URL for a page *p* to the set *S*, we should check that it is not already there.

- When we decide to add a new page *p* to *R* at step 4-(a) of the algorithm, we should be sure the page is not already there.

Page signatures:

- Hash each Web page to a signature of, say, 64 bits.
- The signatures themselves are stored in a hash table *T*, i.e., they are further hashed into a smaller number of buckets, say one million buckets.

Page signatures:

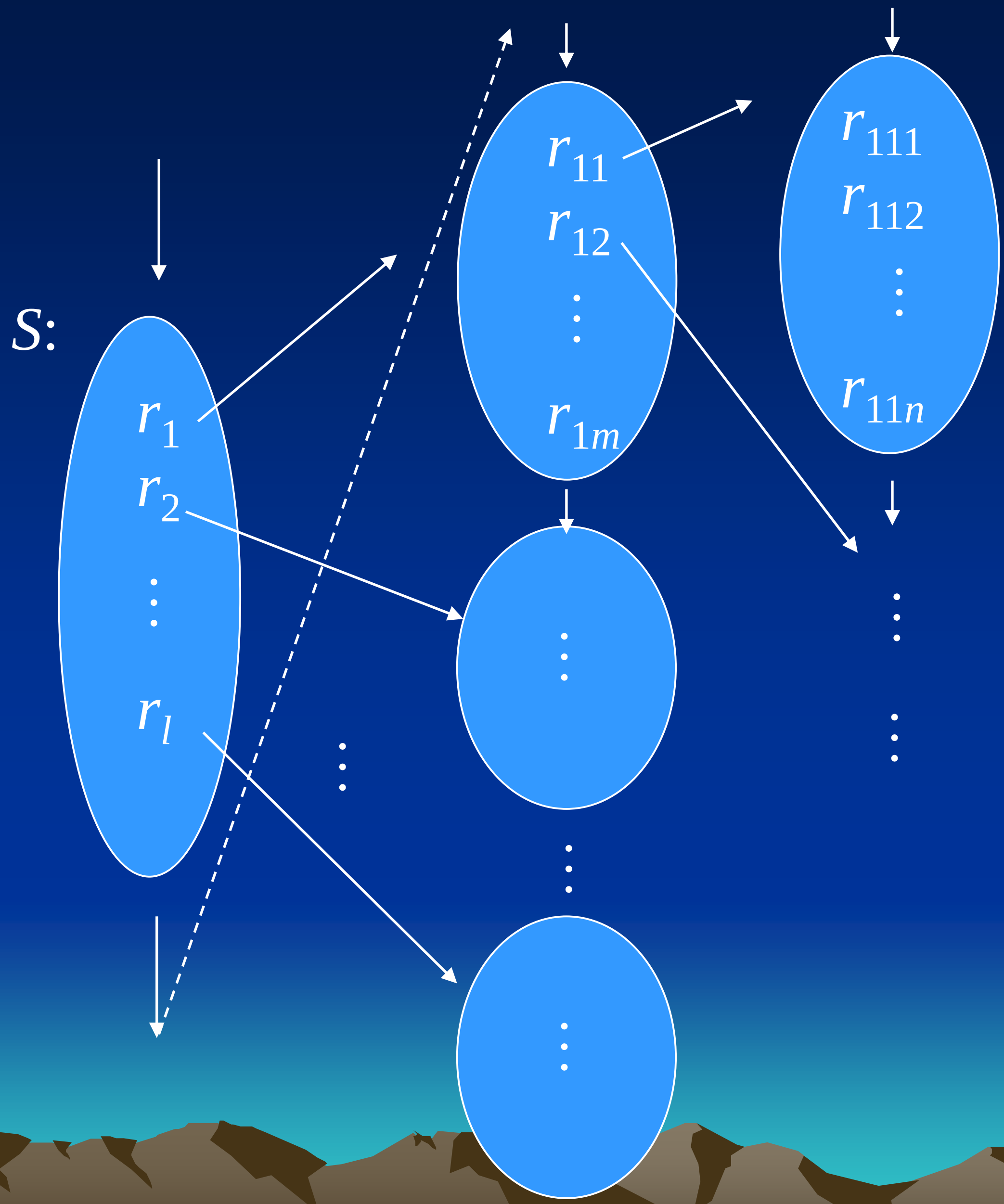
- Hash each Web page to a signature of, say, 64 bits.
- The signatures themselves are stored in a hash table *T*, i.e., they are further hashed into a smaller number of buckets, say one million buckets.
- When inserting *p* into *R*, compute the 64-bit signature *h*(*p*), and see whether *h*(*p*) is already in the hash table *T*. If so, do not store *p*; otherwise, store *p* in *T*.

Selecting the next URL from *S*

- Completely random choice of next page.

- Maintain *S* as a queue. Thus, do a breadth-first search of the Web from the starting point or points with which we initialized *S*. Since we presumably start the search from places in the Web that have "important" pages, we are assured of visiting preferentially those portions of the Web.

- Estimate the importance of page links in *S*, and to favor those pages we estimate to be the most important.
  - PageRank
  - Priority queue



S:
r_1
r_2
r_l
r_{11}
r_{12}
r_{1m}
r_{111}
r_{112}
r_{11n}

Speeding up the Crawl

- More than one crawling machine
- More crawling processes in a machine
- Concurrent access to *S*

Query Processing in Search Engine

- Search engine queries are word-oriented: a boolean combination of words
- Answer: all pages that contain such words
- Method:

  - The first step is to use the inverted index to determine those pages that contain the words in the query.
  - The second step is to evaluate the boolean expression:

  The AND of bit vectors (a bit vector represents an inverted list) gives the pages containing both words.
  The OR of bit vectors gives the pages containing one or both.

$$(\text{word1} \wedge \text{word2}) \vee (\text{word3} \wedge \text{word4})$$

word1 appears in document *i*

word1: 10 … 001 … 00 ← Inverted list

$\wedge$ word2: 10 … 101 … 10

---

10 … 001 … 00 ← Show all the documents which contain word1 and word2

word3: 10 … 001 … 01

$\wedge$ Word4: 10 … 101 … 11

---

10 … 001 … 01

(word1 $\wedge$ word2) $\vee$ (word3 $\wedge$ word4):

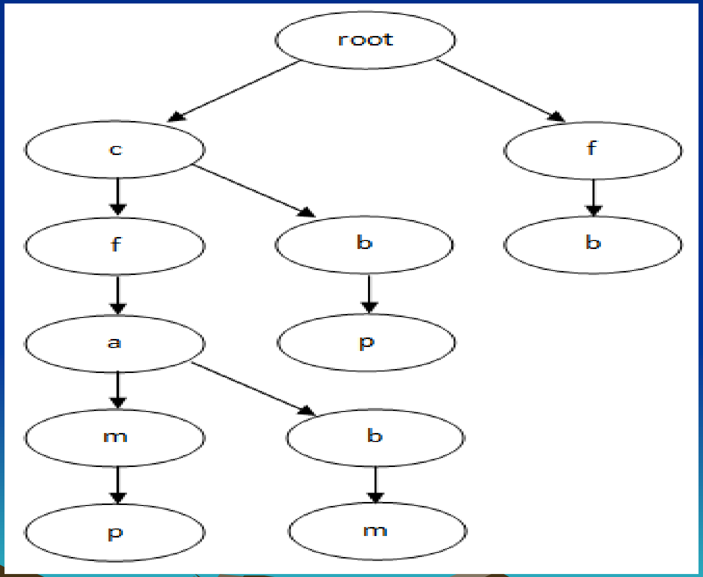
10 … 001 … 00

$\vee$ 10 … 001 … 01

Trie-based Method for Query Processing

- A trie is a multiway tree, in which each path corresponds to a string, and common prefixes in strings to common prefix paths.
- Leaf nodes include either the documents themselves, or links to the documents containing the string that corresponds to the path.

Example:



A trie constructed for The following strings:

s1: cfamp
s2: cbp
s3: cfabm
s4: fb

Trie-based Method for Query Processing

- Item sequences sorted (decreasingly) by appearance frequency (*af*) in documents.

DocID	Items	Sorted item sequence
1	*f, a, c, m, p*	*c, f, a, m, p*
2	*a, b, c, f*	*c, f, a, b*
3	*b, f*	*f, b*
4	*b, c, p*	*c, b, p*
5	*a, f, c, m, p, e*	*c, f, a, m, p, e*

$$af(w) = \frac{\text{No. of doc. Containing } w}{\text{No. of doc.}}$$

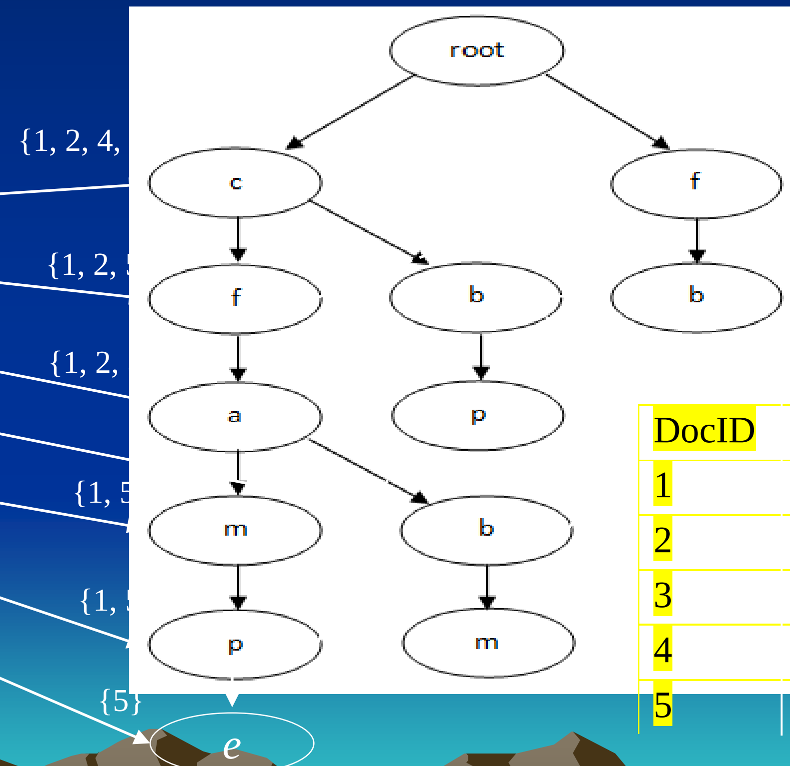
- View each sorted item sequence as a string
- Construct a trie over them, in which each node is associated with a set of document IDs each containing the substring represented by the corresponding prefix.

Trie-based Method for Query Processing

- View each sorted item sequence as a string and construct a trie over them.

Header table:

items	links
c	
f	
a	
b	
m	
p	
e	



DocID	Sorted item sequence
1	*c, f, a, m, p*
2	*c, f, a, b, m*
3	*f, b*
4	*c, b, p*
5	*c, f, a, m, p, e*

Trie-based Method for Query Processing

- Evaluation of queries

- Let Q = word$_1$ $\wedge$ word$_2$ … $\wedge$ word$_k$ be a query
- Sort increasingly the words in Q according to the appearance frequency:

$$\text{word}_{i_1} \wedge \text{word}_{i_2} \wedge \ldots \wedge \text{word}_{i_k}$$

- Find a node in the trie, which is labeled with word$_{i_1}$

- If the path from the root to word$_{i_1}$ contains all word$_i$ (i = 1, …, k), return the document identifiers associated with word$_{i_1}$

- The check can be done by searching the path bottom-up, starting from word$_{i_1}$. In this process, we will first try to find word$_{i_2}$, and then word$_{i_3}$, and so on.

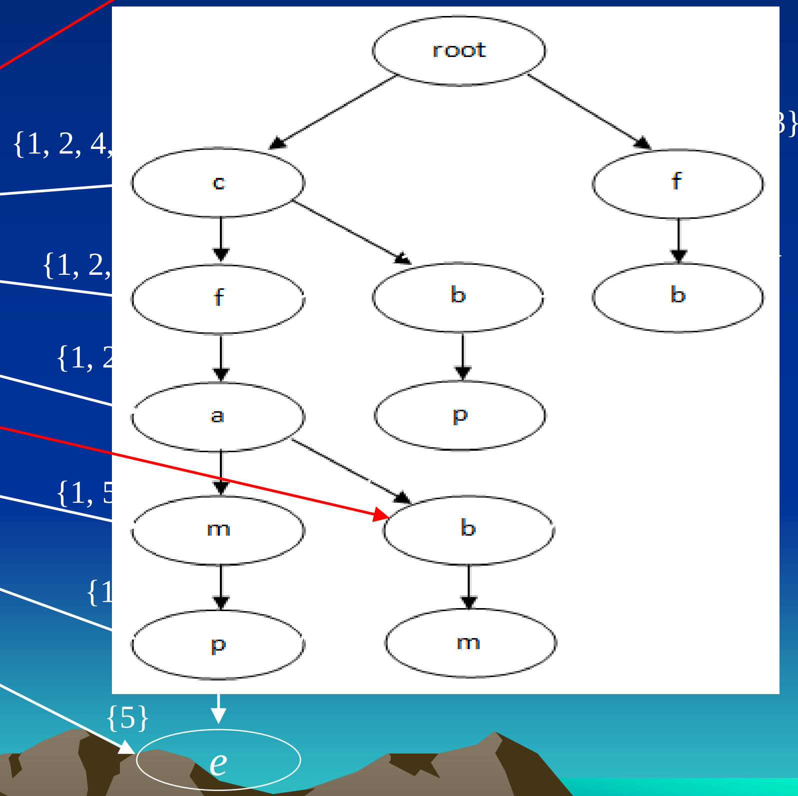
Trie-based Method for Query Processing

- Example

query: c ∧ b ∧ f $\xrightarrow{\text{sorting}}$ b ∧ f ∧ c

Header table:

items	links
c	
f	
a	
b	
m	
P	
e	



Ranker: ranking pages

Once the set of pages that match the query is determined, these pages are ranked, and only the highest-ranked pages are shown to the user.

Measuring PageRank:

- The presence of all the query words
- The presence of query words in important positions in the page
- Presence of several query words near each other would be a more favorable indication than if the words appeared in the page, but widely separated.
- Presence of the query words in or near the anchor text in links leading to the page in question.

PageRank for Identifying Important Pages

One of the key technological advances in search is the PageRank algorithm for identifying the "importance" of Web pages.

The Intuition behind PageRank

When you create a page, you tend to link that page to others that you think are important or valuable

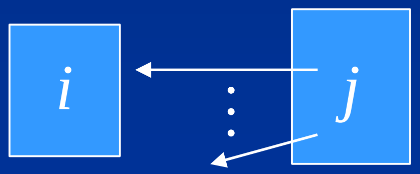
A Web page is important if many important pages link to it.

Recursive Formulation of PageRank

The Web navigation can be modeled as random walker move. So we will maintain a *transition matrix* to represent links.

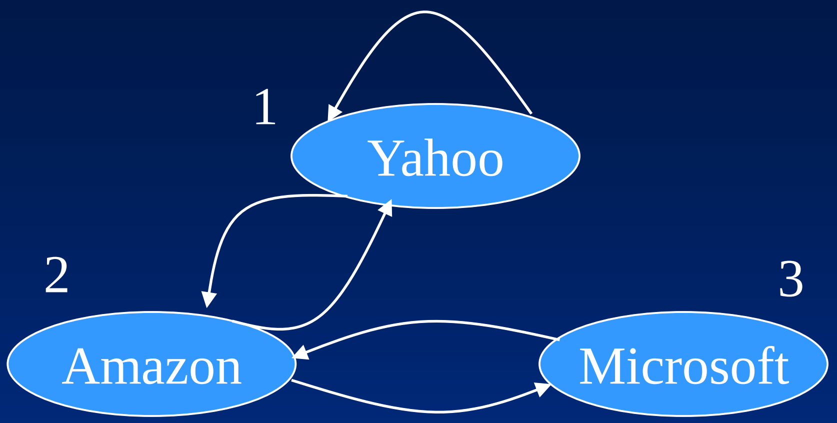
- Number the pages 1, 2, …, n.
- The transition matrix **M** has entries m_{ij} in row i and column j, where:

    1. $m_{ij} = 1/r$ if page j has a link to page i, and there are a total $r \geq 1$ pages that j links to.
    2. $m_{ij} = 0$ otherwise.



- If every page has at least one link out, then **M** is *stochastic* – elements are nonnegative, and its columns each sum to exactly 1.
- If there are pages with no links out, then the column for that page will be all 0's. **M** is said to be *substochastic* if there are columns sum to less than 1.

$$\mathbf{M} = \begin{array}{c} \begin{array}{ccc} p1 & p2 & p3 \end{array} \\ \begin{pmatrix} ½ & ½ & 0 \\ ½ & 0 & 1 \\ 0 & ½ & 0 \end{pmatrix} \end{array}$$



Let *y*, *a*, *m* represent the fractions of the time the random walker spends at the three pages, respectively. We have

$$\begin{pmatrix} y \\ a \\ m \end{pmatrix} = \begin{pmatrix} ½ & ½ & 0 \\ ½ & 0 & 1 \\ 0 & ½ & 0 \end{pmatrix} \begin{pmatrix} y \\ a \\ m \end{pmatrix}$$

It is because after a large number of moves, the walker's distribution of possible locations is the same at each step.
The time that the random walker spends at a page is used as the measurement of "importance".

$$\begin{pmatrix} y \\ a \\ m \end{pmatrix} = \begin{pmatrix} ½ & ½ & 0 \\ ½ & 0 & 1 \\ 0 & ½ & 0 \end{pmatrix} \begin{pmatrix} y \\ a \\ m \end{pmatrix}$$

$$y = ½ \cdot y + ½ \cdot a + 0 \cdot m$$

$$a = ½ \cdot y + 0 \cdot a + 1 \cdot m$$

$$m = 0 \cdot y + ½ \cdot a + 0 \cdot m$$

$$y = ½ \cdot y + ½ \cdot a + 0 \cdot m \qquad P(y) = ½ \cdot P(y) + ½ \cdot P(a) + 0 \cdot P(m)$$

$$a = ½ \cdot y + 0 \cdot a + 1 \cdot m \qquad P(a) = ½ \cdot P(y) + 0 \cdot a\, P(a) + 1 \cdot P(y)$$

$$m = 0 \cdot y + ½ \cdot a + 0 \cdot m \qquad P(m) = 0 \cdot P(y) + ½ \cdot P(a) + 0 \cdot P(m)$$

$$P(y) = P(y \mid y) \cdot P(y) + P(y \mid a) \cdot P(a) + P(y \mid m) \cdot P(m)$$

$$P(a) = P(a \mid y) \cdot P(y) + P(a \mid a) \cdot P(a) + P(a \mid m) \cdot P(m)$$

$$P(m) = P(m \mid y) \cdot P(y) + P(m \mid a) \cdot P(a) + P(m \mid m) \cdot P(m)$$

Conditional probability

Solutions to the equation:

$$\begin{pmatrix} y \\ a \\ m \end{pmatrix} = \begin{pmatrix} ½ & ½ & 0 \\ ½ & 0 & 1 \\ 0 & ½ & 0 \end{pmatrix} \begin{pmatrix} y \\ a \\ m \end{pmatrix}$$

- If (y_0, a_0, m_0) is a solution to the equation, then (cy_0, ca_0, cm_0) is also a solution for any constant c.
- $y_0 + a_0 + m_0 = 1$.

Gaussian elimination method – $O(n^3)$. If n is large, the method cannot be used. (Consider billions pages!)

Approximation by the method of *relaxation*:

- Start with some estimate of the solution and repeatedly multiply the estimate by **M.**
- As long as the columns of **M** each add up to 1, then the sum of the values of the variables will not change, and eventually they converge to the distribution of the walker's location.
- In practice, 50 to 100 iterations of this process suffice to get very close to the exact solution.

Suppose we start with (y, a, m) = (1/3, 1/3, 1/3). We have

$$\begin{pmatrix} 2/6 \\ 3/6 \\ 1/6 \end{pmatrix} = \begin{pmatrix} ½ & ½ & 0 \\ ½ & 0 & 1 \\ 0 & ½ & 0 \end{pmatrix} \begin{pmatrix} 1/3 \\ 1/3 \\ 1/3 \end{pmatrix}$$

At the next iteration, we multiply the new estimate (2/6, 3/6, 1/6) by **M**, as:

$$\begin{pmatrix} 5/12 \\ 4/12 \\ 3/12 \end{pmatrix} = \begin{pmatrix} \frac{1}{2} & \frac{1}{2} & 0 \\ \frac{1}{2} & 0 & 1 \\ 0 & \frac{1}{2} & 0 \end{pmatrix} \begin{pmatrix} 2/6 \\ 3/6 \\ 1/6 \end{pmatrix}$$

If we repeat this process, we get the following sequence of vectors:

$$\begin{pmatrix} 9/24 \\ 11/24 \\ 4/24 \end{pmatrix}, \begin{pmatrix} 20/48 \\ 17/48 \\ 11/48 \end{pmatrix}, \ldots, \begin{pmatrix} 2/5 \\ 2/5 \\ 1/5 \end{pmatrix}$$

Spider Traps and Dead Ends

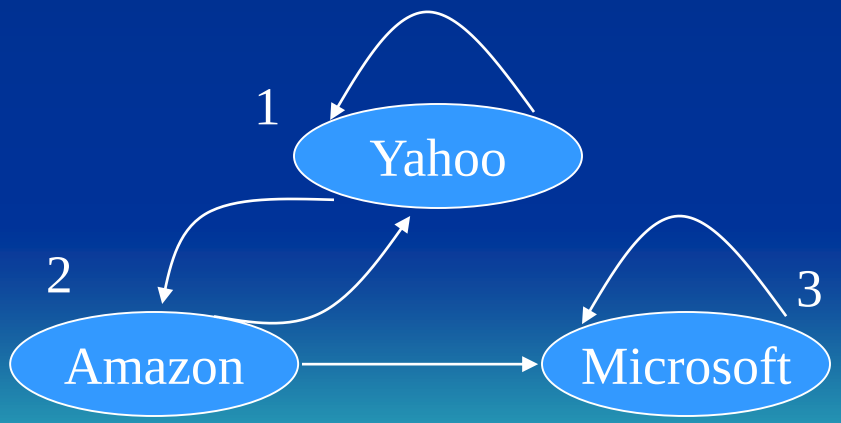
- Spider traps. There are sets of Web pages with the property that if you enter that set of pages, you can never leave because there are no links from any page in the set to any page outside the set.
- Dead ends. Some Web pages have no out-links. If the random walker arrives at such a page, there is no place to go next, and the walk ends.
  - Any dead end is, by itself, a spider trap. Any page that links only to itself is a spider trap.
  - If a spider trap can be reached from outside, then the random walker may wind up there eventually and never leave.

Spider Traps and Dead Ends

Problem:

Applying relaxation to the matrix of the Web with spider traps can result in a limiting distribution where all probabilities outside a spider trap are 0.

Example.



$$\mathbf{M} = \begin{array}{c} \begin{array}{ccc} p1 & p2 & p3 \end{array} \\ \begin{pmatrix} ½ & ½ & 0 \\ ½ & 0 & 0 \\ 0 & ½ & 1 \end{pmatrix} \end{array}$$

Solutions to the equation:

$$\begin{pmatrix} y \\ a \\ m \end{pmatrix} = \begin{pmatrix} ½ & ½ & 0 \\ ½ & 0 & 1 \\ 0 & ½ & 0 \end{pmatrix} \begin{pmatrix} y \\ a \\ m \end{pmatrix}$$

Initially, $\begin{pmatrix} y \\ a \\ m \end{pmatrix} = \begin{pmatrix} 1/3 \\ 1/3 \\ 1/3 \end{pmatrix}$

$$\begin{pmatrix} 1/3 \\ 1/3 \\ 1/3 \end{pmatrix} \quad \begin{pmatrix} 2/6 \\ 1/6 \\ 3/6 \end{pmatrix} \quad \begin{pmatrix} 3/12 \\ 2/12 \\ 7/12 \end{pmatrix} \quad \begin{pmatrix} 5/24 \\ 3/24 \\ 16/24 \end{pmatrix} \quad \begin{pmatrix} 8/48 \\ 5/48 \\ 35/48 \end{pmatrix} \quad \ldots \ldots \quad \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$$

This shows that with probability 1, the walker will eventually wind up at the Microsoft page (page 3) and stay there.

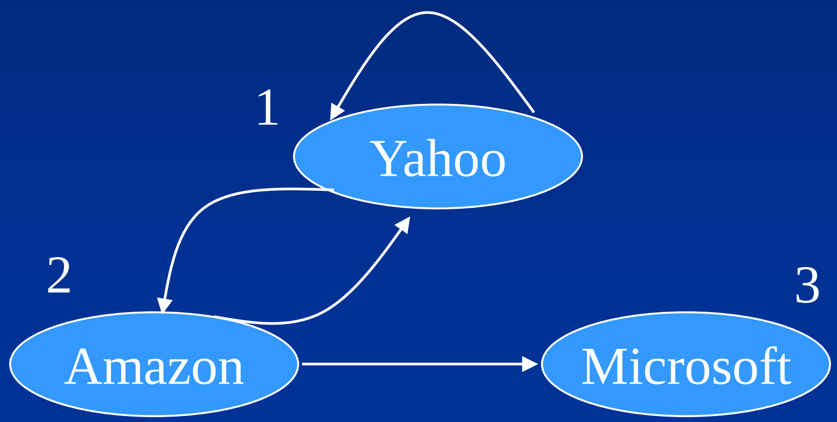
Problem Caused by Spider Traps

- If we interpret these PageRank probabilities as "importance" of pages, then the Microsoft page has gathered all importance to itself simply by choosing not to link outside.
- The situation intuitively violates the principle that other pages, not you yourself, should determine the importance of your page.

Problem Caused by Dead Ends

- The dead end also cause the PageRank not to reflect importance of pages.

Example.



$$\mathbf{M} = \begin{array}{c} \begin{array}{ccc} p1 & p2 & p3 \end{array} \\ \begin{pmatrix} \frac{1}{2} & \frac{1}{2} & 0 \\ \frac{1}{2} & 0 & 0 \\ 0 & \frac{1}{2} & 0 \end{pmatrix} \end{array}$$

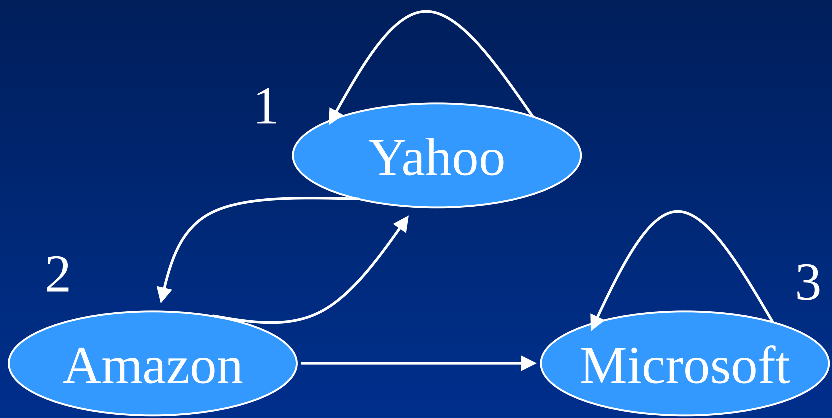
$$\begin{pmatrix} 1/3 \\ 1/3 \\ 1/3 \end{pmatrix} \quad \begin{pmatrix} 2/6 \\ 1/6 \\ 1/6 \end{pmatrix} \quad \begin{pmatrix} 3/12 \\ 2/12 \\ 1/12 \end{pmatrix} \quad \begin{pmatrix} 5/24 \\ 3/24 \\ 2/24 \end{pmatrix} \quad \begin{pmatrix} 8/48 \\ 5/48 \\ 3/48 \end{pmatrix} \quad \ldots \ldots \quad \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}$$

PageRank Accounting for Spider Traps and Dead Ends

We simulate the web navigation by a random walk. Each time a walker goes to a page, we let the walker follow a random out-link, if there is one, with probability β (normally, $0.8 \leq \beta \leq 0.9$). With probability $1 - \beta$ (called the taxation rate), we remove that walker and deposit a new walker at a randomly chosen Web page.

- If the walker gets stuck in a spider trap, it doesn't matter because after a few time steps, that walker will disappear and be replaced by a new walker.
- If the walker reaches a dead end and disappears, a new walker will take over shortly.

Example.



$$\mathbf{M} = \begin{array}{c} \begin{array}{ccc} p1 & p2 & p3 \end{array} \\ \begin{pmatrix} ½ & ½ & 0 \\ ½ & 0 & 0 \\ 0 & ½ & 1 \end{pmatrix} \end{array}$$

Let $\mathbf{P}_{new}$ and $\mathbf{P}_{old}$ be the new and old distributions of the location of the walker after one iteration, the relationship between these two can be expressed as:

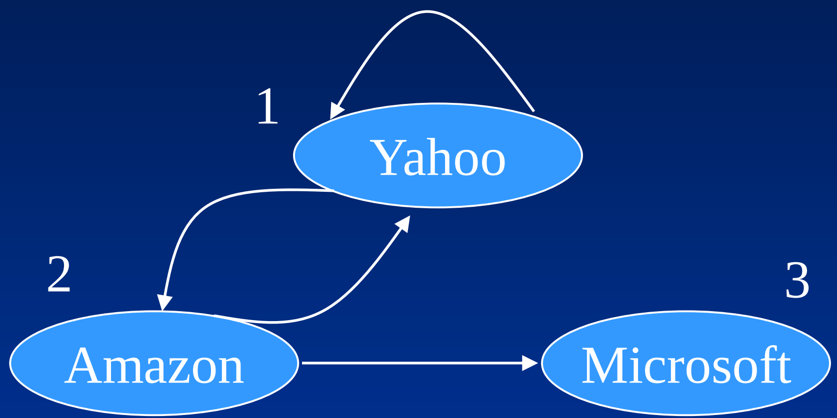
$$\mathbf{P}_{new} = \underbrace{0.8}_{\beta} \begin{pmatrix} ½ & ½ & 0 \\ ½ & 0 & 0 \\ 0 & ½ & 1 \end{pmatrix} \mathbf{P}_{old} + \underbrace{0.2}_{1 - \beta} \begin{pmatrix} 1/3 \\ 1/3 \\ 1/3 \end{pmatrix}$$

The meaning of the above equation is:
With probability 0.8, we multiply $\mathbf{P}_{old}$ by the matrix of the Web to get the new location of the walker, and with probability 0.2 we start with a new walker at a random place.

If we start with $\mathbf{P}_{old} = (1/3, 1/3, 1/3)$ and repeatedly compute $\mathbf{P}_{new}$ and then replace $\mathbf{P}_{old}$ by $\mathbf{P}_{new}$, we get the following sequence of approximation to the asymptotic distribution of the walker:

$$\begin{pmatrix} .333 \\ .333 \\ .333 \end{pmatrix} \quad \begin{pmatrix} .333 \\ .200 \\ .467 \end{pmatrix} \quad \begin{pmatrix} .280 \\ .300 \\ .520 \end{pmatrix} \quad \begin{pmatrix} .259 \\ .179 \\ .563 \end{pmatrix} \quad \ldots \ldots \quad \begin{pmatrix} 7/33 \\ 5/33 \\ 21/33 \end{pmatrix}$$

Example.



$$\mathbf{M} = \begin{array}{c} \begin{array}{ccc} p1 & p2 & p3 \end{array} \\ \begin{pmatrix} \frac{1}{2} & \frac{1}{2} & 0 \\ \frac{1}{2} & 0 & 0 \\ 0 & \frac{1}{2} & 0 \end{pmatrix} \end{array}$$

$$\mathbf{P}_{new} = \underset{\beta}{0.8} \begin{pmatrix} \frac{1}{2} & \frac{1}{2} & 0 \\ \frac{1}{2} & 0 & 0 \\ 0 & \frac{1}{2} & 0 \end{pmatrix} \mathbf{P}_{old} + \underset{1 - \beta}{0.2} \begin{pmatrix} 1/3 \\ 1/3 \\ 1/3 \end{pmatrix}$$

If we start with $\mathbf{P}_{old}$ = (1/3, 1/3, 1/3) and repeatedly compute $\mathbf{P}_{new}$ and then replace $\mathbf{P}_{old}$ by $\mathbf{P}_{new}$, we get the following sequence of approximation to the asymptotic distribution of the walker:

$$\begin{pmatrix} .333 \\ .333 \\ .333 \end{pmatrix} \begin{pmatrix} .333 \\ .200 \\ .200 \end{pmatrix} \begin{pmatrix} .280 \\ .200 \\ .147 \end{pmatrix} \begin{pmatrix} .259 \\ .179 \\ .147 \end{pmatrix}, \ldots, \begin{pmatrix} 35/165 \\ 25/165 \\ 21/165 \end{pmatrix}$$

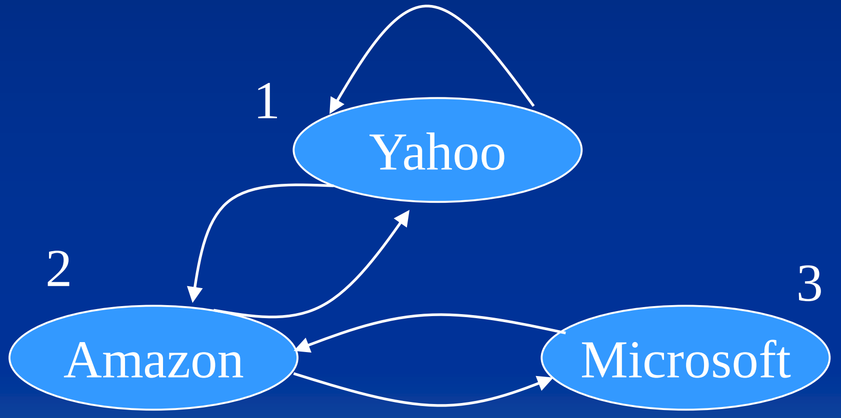
Notice that these probabilities do not sum to one, and there is slightly more than 50% probability that the walker is "lost" at any given time. However, the ratio of the importance of Yahoo!, and Amazon are the same as in the above example. That makes sense because in both the cases there are no links from the Microsoft page to influence the importance of Yahoo! or Amazon.

Topic-Specific PageRank

The calculation o PageRank should be biased to favor certain pages.

Teleport Sets

Choose a set of pages about a certain topic (e.g., sport) as a teleport set.



Assume that we are interested only in retail sales, so we choose a teleport set that consists of Amazon alone.

$$\begin{pmatrix} y \\ a \\ m \end{pmatrix} = \begin{pmatrix} \frac{1}{2} & \frac{1}{2} & 0 \\ \frac{1}{2} & 0 & 1 \\ 0 & \frac{1}{2} & 0 \end{pmatrix} \begin{pmatrix} y \\ a \\ m \end{pmatrix}$$

$$\Downarrow$$

$$\begin{pmatrix} y \\ a \\ m \end{pmatrix} = 0.8 \begin{pmatrix} \frac{1}{2} & \frac{1}{2} & 0 \\ \frac{1}{2} & 0 & 1 \\ 0 & \frac{1}{2} & 0 \end{pmatrix} \begin{pmatrix} y \\ a \\ m \end{pmatrix} + 0.2 \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix}$$

The entry for Amazon is set to 1.

Topic-Specific PageRank

The *general rule* for setting up the equations in a topic-specific PageRank problem is as follows.

Suppose there are k pages in the teleport set. Let **T** be a column-vector that has $1/k$ in the positions corresponding to members of the teleport set and 0 elsewhere. Let **M** be the transition matrix of the Web. Then, we must solve by relaxation the following iterative rule:

$$\mathbf{P}_{new} = \beta \mathbf{M} \mathbf{P}_{old} + (1 - \beta)\mathbf{T}$$

$$\mathbf{T} = \begin{pmatrix} 0 \\ 1/k \\ 0 \\ \vdots \\ 1/k \\ \vdots \end{pmatrix}$$