Databases

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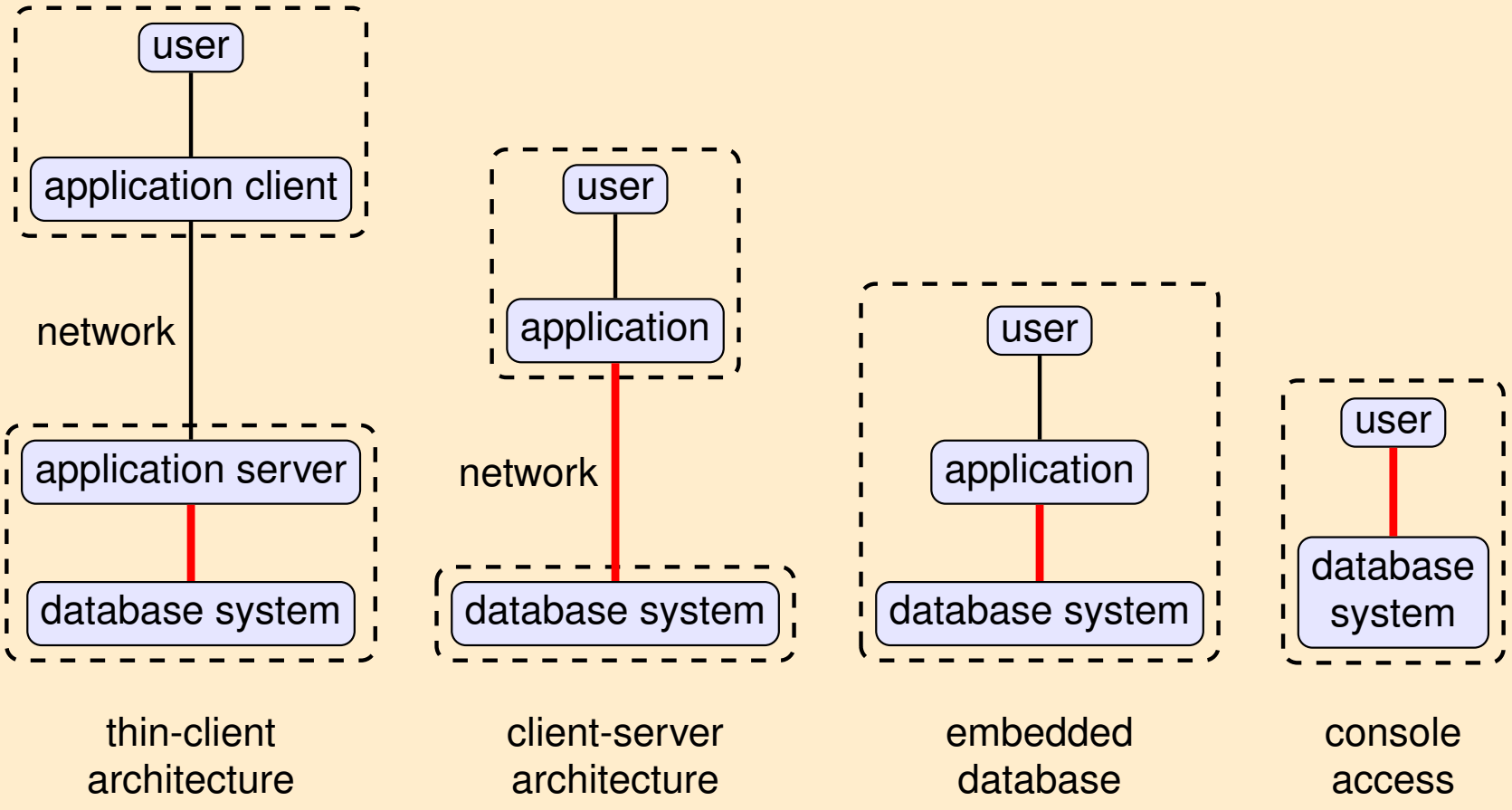
Application Architectures

Various ways of using database technology



How do these applications talk to the database?

How to Talk to a Database?

Database application programming:
how to access a database from an application?

- **Static** embedded queries
  - preprocessor-based, static SQL
  - e.g. SQLJ, Embedded SQL (C/C++)
- **Dynamic**
  - SQL queries constructed at runtime
  - e.g. JDBC, Python DB-API, ODBC, OLE-DB,. . .
- **Object Relational Mappings (ORM)**, and beyond
  - hide navigational access behind objects
  - e.g. JPA/Hibernate, RubyOnRails, ADO.NET/LinQ

Dynamic: JDBC

```
import java.sql.* ;

public class ShowStudents {
  public static void main(String args[]) throws Exception {
    String url = "jdbc:mysql://localhost/db" ;
    System.setProperty("jdbc.drivers",
                       "org.gjt.mm.mysql.Driver");
    Connection conn = DriverManager.getConnection(url);

    Statement stat = conn.createStatement() ;
    ResultSet rs = stat.executeQuery(
                     "SELECT sid, name FROM students");

    while (rs.next()) {
      int sid = rs.getInt("sid");
      String name = rs.getString("name");
      System.out.println(sid + ": " + name);
    }
    conn.close();
```

fetch results row by row

getInt(...), getString(...) fetch column values by name

Checking whether a field is NULL is done in JDBC by explicitly calling rs.wasNull(column).

Type (mis)Match

Mapping SQL types to Java Types

SQL type	Java Type
CHAR, VARCHAR	String
NUMERICAL, DECIMAL	java.math.BigDecimal
BIT	boolean
TINYINT	byte
SMALLINT	short
INTEGER	int
BIGINT	long
REAL	float
FLOAT, DOUBLE	double
BINARY, VARBINARY	byte[]
DATE	java.sql.Date
TIME	java.sql.Time
TIMESTAMP	java.sql.Timestamp

The match is not precise! E.g. `VARCHAR(20)` versus String.

JDBC: Optimising Applications

For improving the performance of JDBC applications:

- **Connection pooling**:
  - keep DB connection open, reduces latency
- **Prepared statements**:
  - SQL calls that are repeated often
  - allows driver to optimise queries (precompiled by DBMS)
  - created with **Connection.prepareStatement()**
  - allows parameters: `SELECT * FROM products WHERE id = ?`
- **Stored procedures** to reduce #query roundtrips
  - written in DB-specific language, not portable 
  - accessed with **Connection.prepareCall()**
- Use a **driver** that is **bulk**-transfer optimised
  - when retrieving large result sets
  - driver can send several tuples in a single network packet

SQL Injection

Website with Login Screen

Name: Maria

Password: 12345

Server Side SQL

```
String userName = // name that the user has entered
String userPassword = // password that the user has entered

ResultSet rs = stat.executeQuery(
                    "SELECT balance FROM accounts " +
                    "WHERE name = '" + userName + "'" +
                    "  AND passwd = '" + userPassword + "'"
                  );
```

The Resulting SQL Query

```
SELECT balance FROM accounts
WHERE name = 'Maria' AND passwd = '12345'
```

SQL Injection

Website with Login Screen

Name: Joe' --

Password: who cares

Server Side SQL

```
String userName = // name that the user has entered
String userPassword = // password that the user has entered

ResultSet rs = stat.executeQuery(
                    "SELECT balance FROM accounts " +
                    "WHERE name = '" + userName + "'" +
                    "  AND passwd = '" + userPassword + "'"
                  );
```

The Resulting SQL Query

```
SELECT balance FROM accounts
WHERE name = 'Maria' AND passwd = '12345'
```

SQL Injection

Website with Login Screen

Name: Joe' --

Password: who cares

Server Side SQL

```
String userName = // name that the user has entered
String userPassword = // password that the user has entered

ResultSet rs = stat.executeQuery(
                    "SELECT balance FROM accounts " +
                    "WHERE name = '" + userName + "'" +
                    "  AND passwd = '" + userPassword + "'"
                  );
```

The Resulting SQL Query

```
SELECT balance FROM accounts
WHERE name = 'Joe' -- ' AND passwd = 'who cares'
```

SQL injection is a very common mistake! Very dangerous!

SQL Injection: How to Prevent It?

To Prevent SQL Injection

- **Never build SQL queries with user input using string concatenation!**
- Use the API to fill in the query parameters.

Preventing SQL Injection

```
String userName = // name that the user has entered
String userPassword = // password that the user has entered

PreparedStatement stat = conn.prepareStatement(
                         "SELECT balance FROM accounts " +
                         "WHERE name = ?" +
                         "  AND passwd = ?");

 // use JDBC to fill the name and password
stat.setString(1, userName);
stat.setString(2, userPassword);

ResultSet rs = stat.executeQuery();
```

The Impedance Mismatch

The **Impedance Mismatch**: database query language does not match the application programming language.

- Static API (SQLJ):
  - mismatch between SQL and Java types (isNull)
  - SQL checked for correctness at development time
  - inflexible (preprocessor needed)
- Dynamic API (JDBC):
  - mismatch between SQL and Java types (isNull)
  - powerful, flexible, but error-prone
  - SQL query given as strings may be incorrect
    - no error checking at development time
    - column names and types unknown at compile time
  - risk of SQL injection

Can we do better?. . .

Object Relational Mapping

Logical database schemas are not always ideal

- New applications on top of existing schemas
- Not the same set of constructs and abstractions
  - objects, relations, inheritance

In applications we would like to work with

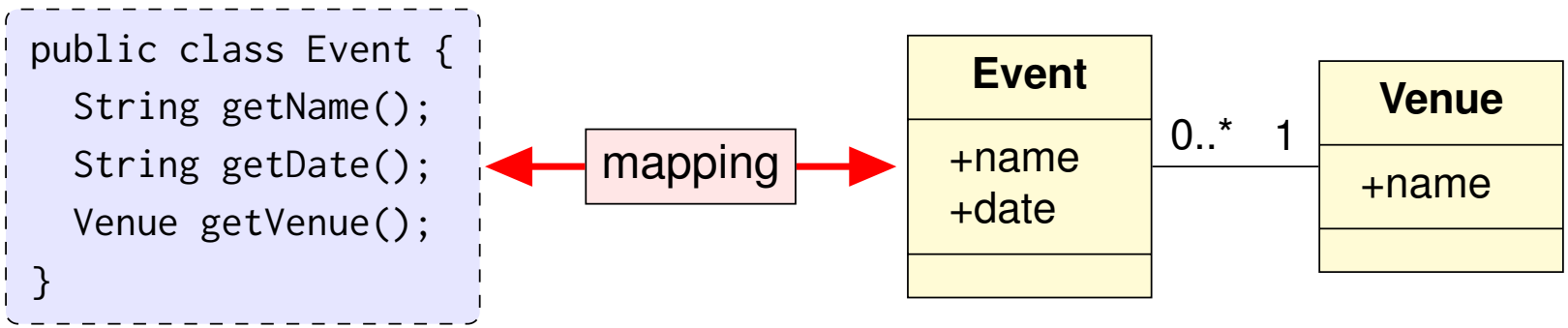
- objects / entities
- inheritance
- relations

Object Relational Mapping

Object Relational Mapping

Maps rows in tables to objects:

- Table ≈ Class
- Row ≈ Object
- Foreign key navigation ≈ pointers / references

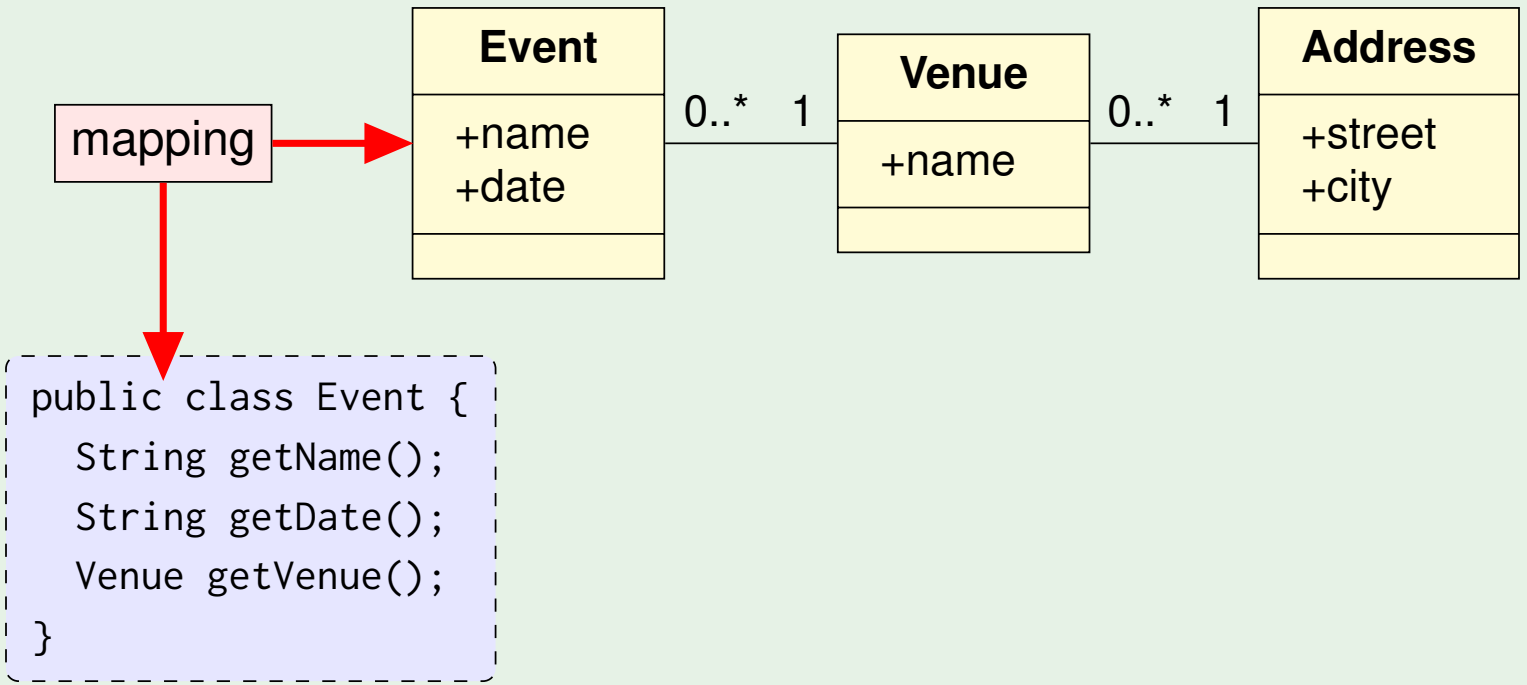


Ingredients

- mapping from objects to database (automatic or designed)
- run-time library handles interaction with the database

Many ORM toolkits: Hybernate, RubyOnRails, ADO.NET,. . .

Object Relational Mapping: JPA/Hibernate



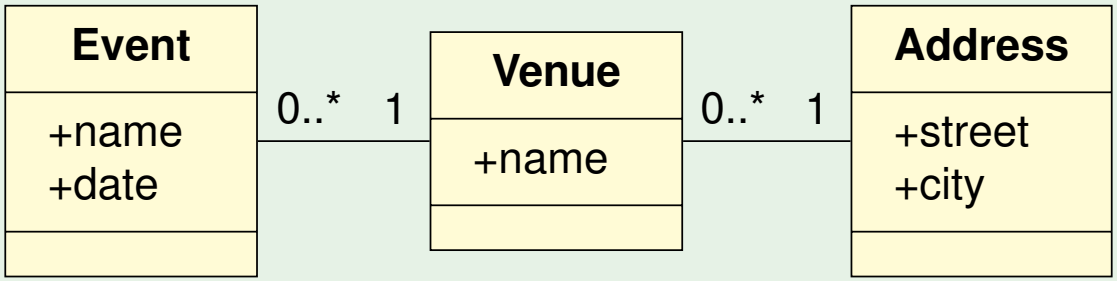
Example:

- `event.getVenue().getAddress().getStreet();`

Under the hood:

- `venue = SELECT * FROM Venues WHERE VenueId = event.venueID`
- `addr = SELECT * FROM Addresses WHERE AddressId = venue.addressID`
- `return addr.getStreet()`

Object Relational Mapping: Dangers



We want all events in Amsterdam:

```
List<Event> eventList = // get all events
for (Event event : eventList) {
  Address address = event.getVenue().getAddress();
  if ("Amsterdam".equals(address.getCity())) {
    System.out.println(event.getName());
  }
}
```

Inefficient!

Instead of loading just the events with city "Amsterdam":

- loads all events, and then iterates through all of them
- also each call to getVenue() will result in an SQL query

JPA/Hibernate: HQL Queries

HQL queries query the object-representation of data:

- Allows member access, e.g. employee.department.name.
- This is not calling methods on the objects!
- Query may return objects (if you are careful).

HQL Query: all events in Amsterdam

```
Query query = em.createQuery("from Events as event
                  where event.venue.address.city = 'Amsterdam'");
List<Event> eventsInAmsterdam = (List<Event>) query.list();
for(Event event : eventsInAmsterdam) {
  ... something ...
}
```

This is a more efficient way to get the events in Amsterdam.

Under the hood translated to SQL with two joins.

Many queries do not return a full object!
E.g. what is the type of "select name,date from Events"?

Important Aspects of ORM Toolkits

- Mapping specification:
  - map relational data onto objects
  - can largely be derived automatically
- Query language (e.g. HQL):
  - adds object-oriented features to SQL
  - typically queries as strings (second class citizen)
- Persistence:
  - transaction semantics
  - languages offer start of transactions, commit, abort
- Fetch strategies
  - danger of implementing queries in Java 
  - object caching

Challenges of ORMs

- ORMs introduce an additional level of complexity
  - can be difficult to debug
- Performance analysis is problematic because:
  - database queries are under the hood
  - sometimes very complex SQL queries are generated
  - difficult to understand what caused the complex queries

ADO.NET Entity Framework

- Different applications can have different views on the data.
- **Views entirely implemented on the client side**.
  - Avoid polluting DB schema with per-application views.
  - No added maintenance on the database side.

  (ANSI-SPARC model has views on server side)
- Powerfull
  - Broad set of views that are updatable.
  - Updatability can be statically verified.

ADO.NET Entity Framework

Entity Data Model (EDM)

Data representation on client side: Entity Data Model.

- **Entity type** = structured record with a key
- **Entity** = instance of an Entity Type
- Entity types can inherit from other entity types

Object-relational mapping

The EDM is then mapped to the logical database schema.

- can be queried similar to HQL
- can be queried similar to JDBC

Can we do better?

LinQ

LinQ

LinQ stands for Language INtegrated Query. Allows developers to query data structures using an SQL-like syntax.

Advantages of LinQ

- **Queries are first-class citizens** (not strings).
- **Full type-checking and error checking for queries**.
- Allows to query all collection structures.
  (lists, sets, . . . ; not restricted to databases)

Problem

LinQ is not portable! Only available for C# and Visual Basic.

Luckily. . . similar frameworks in other programming languages.

LinQ

LinQ: Querying an array

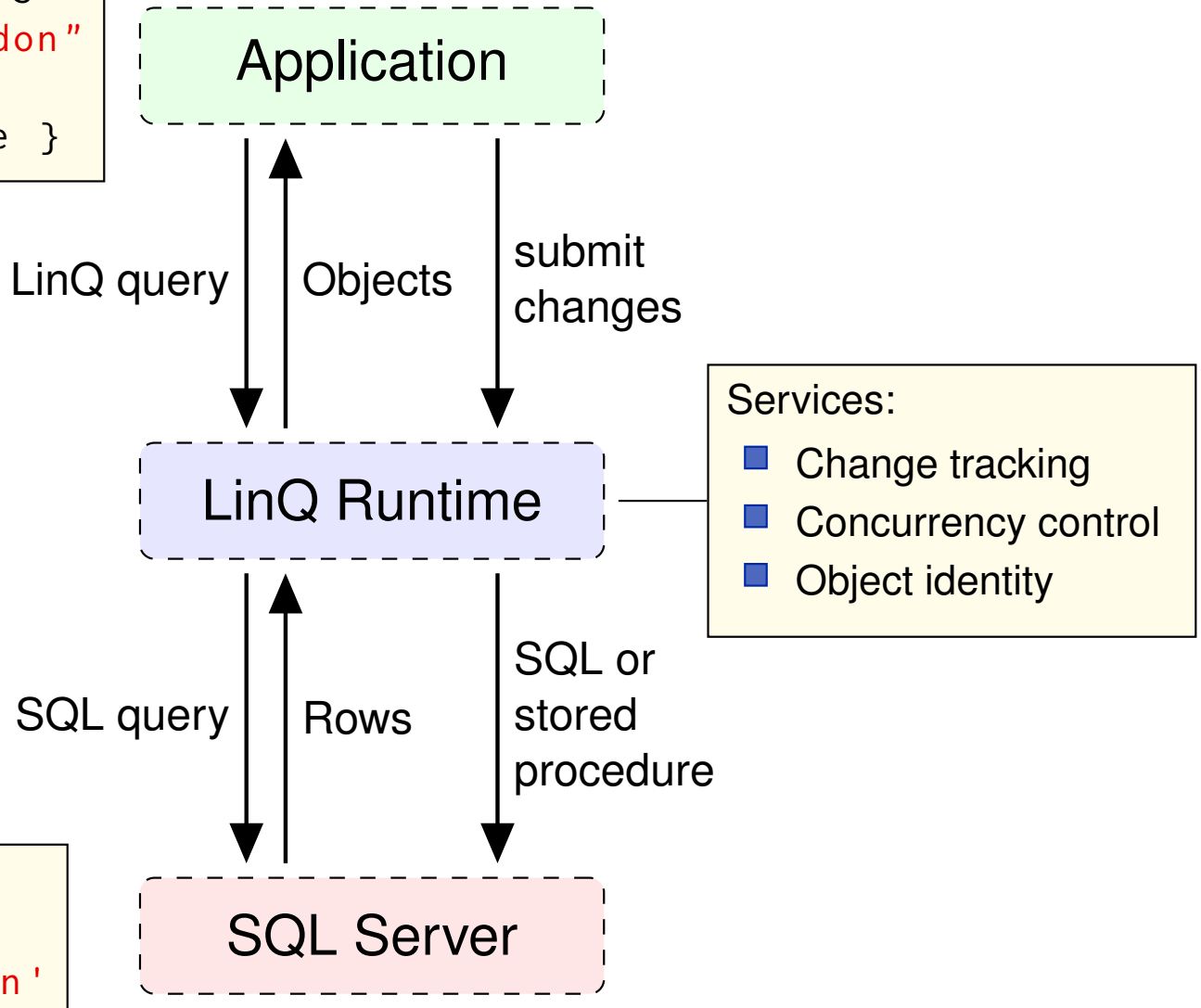
```
//Create an array of integers
int[] myarray = new int[] { 49, 28, 20, 15, 25, 23, 24, 10, 7 };

//Create a a query for odd numbers,
var oddNumbers = from i in myarray where i \% 2 == 1 select i;

//Odd numbers in descending order
var sorted = from i in oddNumbers orderby i descending select i;

//Display the results of the query
foreach (int i in oddNumbers)
  Console.WriteLine(i);
```

LinQ allows query various kinds of data sources:

- LinQ to DataSet (querying data sets like lists)
- LinQ to XML
- LinQ to SQL (interact with logical database model)
- **LinQ to Entities** (interact with conceptual/object model)

LinQ: What the Runtime Module Does

```
from c in db.Customers
where c.City == "London"
select
new { c.Name, c.Phone }
```




```
select Name, Phone
from customers
where city = 'London'
```

LinQ: Under the Hood

Syntactic sugar...

```
var contacts =
  from c in customers
  where c.State == "WA"
  select new { c.Name, c.Phone };
```

Syntactic sugar for an expression with lambda expressions:

Query operations with lambda expressions

```
var contacts =
  customers
  .Where(c => c.State == "WA")
  .Select(c => new{c.Name, c.Phone});
```

LinQ: Under the Hood

```
var contacts =
  customers
  .Where(c => c.State == "WA")
  .Select(c => new{c.Name, c.Phone});
```

Here customers is of type IEnumerable<Customer>.

IEnumerable<...> provides methods for querying:

```
public static IEnumerable<T>
         Where<T>(this IEnumerable<T> src,
                  Func<T, bool>> p);
```

`Func<T, bool>> p` converted on-the-fly in an **expression tree** (a delegate). This is then translated into an SQL expression...

Database APIs

After this lecture, you should be able to:

- Explain the problem of **impedance mismatch**.
- Be able to classify DB application interfaces:
  - static, dynamic, object-relational mapping
- Discuss advantages and disadvantages of an API in terms of object **navigation** and complex **query execution**.
- Understand object-relational mappings:
  - **Hibernate** for Java
  - **Entity Framework** for .NET

  Relate these to the ANSI SPARC 3-layer model and the concepts of logical and physical data independence
- Explain advantages of **LinQ** and how it relates to impedance mismatch.