Spatial Query Languages

What is a query?

- What is a Query ?
  - A query is a "question" posed to a database
  - Queries are expressed in a high-level declarative manner
    - Algorithms needed to answer the query are not specified in the query
- Examples:
  - Mouse click on a map symbol (e.g. road) may mean
    - What is the name of road pointed to by mouse cursor ?
  - Typing a keyword in a search engine (e.g. google, yahoo) means
    - Which documents on web contain given keywords?
  - SELECT S.name FROM Senator S WHERE S.gender = 'F' means
    - Which senators are female?

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What is a query language?

- What is a query language?
  - A language to express interesting questions about data
  - A query language restricts the set of possible queries
- Examples:
  - Natural language, e.g. English, can express almost all queries
  - Computer programming languages, e.g. Java,
    - can express computable queries
    - however algorithms to answer the query is needed
  - Structured Query Language(SQL)
    - Can express common data intensive queries
    - Not suitable for recursive queries
  - Graphical interfaces, e.g. web-search, mouse clicks on a map
    - can express few different kinds of queries

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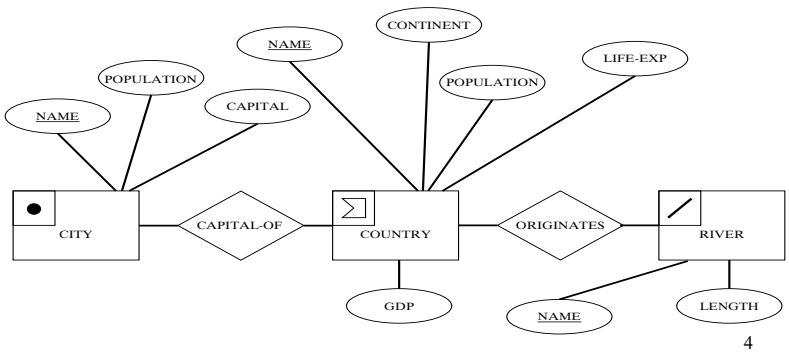
An Example World Database

- Purpose: Use an example database to learn query language SQL
- Conceptual Model
  - 3 Entities: Country, City, River
  - 2 Relationships: capital-of, originates-in
  - Attributes listed in Figure



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An Example Database - Logical Model

- 3 Relations

  Country(*Name*, *Cont*, *Pop*, *GDP*, *Life-Exp*, *Shape***)**
  City(*Name*, *Country*, *Pop*,*Capital*, *Shape***)**
  River(*Name*, *Origin*, *Length*, *Shape***)**

- Keys
  - Primary keys are Country.Name, City.Name, River.Name
  - Foreign keys are River.Origin, City.Country

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World database data tables

COUNTRY	Name	Cont	Pop (millions)	GDP (billions)	Life-Exp	Shape
	Canada	NAM	30.1	658.0	77.08	Polygonid-1
	Mexico	NAM	107.5	694.3	69.36	Polygonid-2
	Brazil	SAM	183.3	1004.0	65.60	Polygonid-3
	Cuba	NAM	11.7	16.9	75.95	Polygonid-4
	USA	NAM	270.0	8003.0	75.75	Polygonid-5
	Argentina	SAM	36.3	348.2	70.75	Polygonid-6

(a) Country

CITY	Name	Country	Pop (millions)	Capital	Shape
	Havana	Cuba	2.1	Y	Pointid-1
	Washington, D.C.	USA	3.2	Y	Pointid-2
	Monterrey	Mexico	2.0	N	Pointid-3
	Toronto	Canada	3.4	N	Pointid-4
	Brasilia	Brazil	1.5	Y	Pointid-5
	Rosario	Argentina	1.1	N	Pointid-6
	Ottawa	Canada	0.8	Y	Pointid-7
	Mexico City	Mexico	14.1	Y	Pointid-8
	Buenos Aires	Argentina	10.75	Y	Pointid-9

(b) City

RIVER	Name	Origin	Length (kilometers)	Shape
	Rio Parana	Brazil	2600	LineStringid-1
	St. Lawrence	USA	1200	LineStringid-2
	Rio Grande	USA	3000	LineStringid-3
	Mississippi	USA	6000	LineStringid-4

(c) River

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What is SQL?

- SQL - General Information
  - is a standard query language for relational databases
  - It support logical data model concepts, such as relations, keys, ...
  - Supported by major brands, e.g. IBM DB2, Oracle, MS SQL Server, Sybase, ...
  - 3 versions: SQL1 (1986), SQL2 (1992), SQL 3 (1999)
  - Can express common data intensive queries
  - SQL 1 and SQL 2 are not suitable for recursive queries
- SQL and spatial data management
  - ESRI Arc/Info included a custom relational DBMS named Info
  - Other GIS software can interact with DBMS using SQL
    - using open database connectivity (ODBC) or other protocols
  - In fact, many software use SQL to manage data in back-end DBMS
  - And a vast majority of SQL queries are generated by other software
  - Although we will be writing SQL queries manually!

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Three Components of SQL?

- Data Definition Language (DDL)
  - Creation and modification of relational schema
  - Schema objects include relations, indexes, etc.
- Data Manipulation Language (DML)
  - Insert, delete, update rows in tables
  - Query data in tables
- Data Control Language (DCL)
  - Concurrency control, transactions
  - Administrative tasks, e.g. set up database users, security permissions
- Focus for now
  - A little bit of table creation (DDL) and population (DML)
  - Primarily Querying (DML)

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Creating Tables in SQL

- Table definition
  - "CREATE TABLE" statement
  - Specifies table name, attribute names and data types
  - Create a table with no rows.
- Related statements
  - ALTER TABLE statement modifies table schema if needed
  - DROP TABLE statement removes an empty table

```
CREATE   TABLE    River(
         Name     varchar(30),
         Origin   varchar(30),
         Length   number,
         Shape    LineString   );
```

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Populating Tables in SQL

- Adding a row to an existing table
  - "INSERT INTO" statement
  - Specifies table name, attribute names and values
  - Example:

  INSERT INTO River(Name, Origin, Length) VALUES('Mississippi', 'USA', 6000)

- Related statements
  - SELECT statement with INTO clause can insert multiple rows in a table
  - Bulk load, import commands also add multiple rows
  - DELETE statement removes rows
  - UPDATE statement can change values within selected rows

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Querying populated Tables in SQL

- SELECT statement
  - Commonly used statement to query data in one or more tables
  - Returns a relation (table) as result
  - Has many clauses
  - Can refer to many operators and functions
  - Allows nested queries (which can be hard to understand)

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SELECT Statement- General Information

- Clauses
  - SELECT specifies desired columns
  - FROM specifies relevant tables
  - WHERE specifies qualifying conditions for rows
  - ORDER BY specifies sorting columns for results
  - GROUP BY, HAVING specifies aggregation and statistics
- Operators and Functions
  - arithmetic operators, e.g. +, -, …
  - comparison operators, e.g. =, <, >, BETWEEN, LIKE…
  - logical operators, e.g. AND, OR, NOT, EXISTS,
  - set operators, e.g. UNION, IN, ALL, ANY, …
  - statistical functions, e.g. SUM, COUNT, ...
  - many other operators on strings, date, currency, ...

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SELECT Example 1.

- Simplest Query has SELECT and FROM clauses
  - Query: List all the cities and the country they belong to.

```
SELECT Name, Country
FROM CITY
```

Result →

Name	Country
Havana	Cuba
Washington, D.C.	USA
Monterrey	Mexico
Toronto	Canada
Brasilia	Brazil
Rosario	Argentina
Ottawa	Canada
Mexico City	Mexico
Buenos Aires	Argentina

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SELECT Example 2.

- Commonly 3 clauses (SELECT, FROM, WHERE) are used
  - **Query:** List the names of the capital cities in the CITY table.

```
SELECT *
FROM CITY
WHERE CAPITAL='Y '
```

Result →

Name	Country	Pop(millions)	Capital	Shape
Havana	Cuba	2.1	Y	Point
Washington, D.C.	USA	3.2	Y	Point
Brasilia	Brazil	1.5	Y	Point
Ottawa	Canada	0.8	Y	Point
Mexico City	Mexico	14.1	Y	Point
Buenos Aires	Argentina	10.75	Y	Point

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Query Example…Where clause

Query: *List the attributes of countries in the Country relation where the life-expectancy is less than seventy years.*

SELECT Co.Name,Co.Life-Exp
FROM Country Co
WHERE Co.Life-Exp <70

Note: use of alias 'Co' for Table 'Country'

Result →

Name	Life-exp
Mexico	69.36
Brazil	65.60

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Multi-table Query Examples

Query: List the capital cities and populations of countries whose GDP exceeds one trillion dollars.

Note:Tables City and Country are joined by matching "City.Country = Country.Name". This simulates relational operator "join"

SELECT Ci.Name,Co.Pop
FROM City Ci,Country Co
WHERE Ci.Country =Co.Name
AND Co.GDP >1000.0
AND Ci.Capital='Y '

Ci.Name	Co.Pop
Brasilia	183.3
Washington, D.C.	270.0

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Multi-table Query Example

Query: What is the name and population of the capital city in the country where the St. Lawrence River originates?

```
SELECT Ci.Name, Ci.Pop
FROM City Ci, Country Co, River R
WHERE R.Origin =Co.Name
    AND Co.Name =Ci.Country
    AND R.Name ='St.Lawrence '
    AND Ci.Capital='Y '
```

Note: Three tables are joined together pair at a time. River.Origin is matched with Country.Name and City.Country is matched with Country.Name. The order of join is decided by query optimizer and does not affect the result.

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Query Examples…Aggregate Staistics

Query: What is the average population of the noncapital cities listed in the City table?

```
SELECT AVG(Ci.Pop)
FROM City Ci
WHERE Ci.Capital='N '
```

Query: For each continent, find the average GDP.

```
SELECT Co.Cont,Avg(Co.GDP)AS Continent-GDP
FROM Country Co
GROUP BY Co.Cont
```

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Query Example..Having clause, Nested queries

Query: For each country in which at least two rivers originate, find the length of the smallest river.

```
SELECT R.Origin, MIN(R.length) AS Min-length
FROM River
GROUP BY R.Origin
HAVING COUNT(*) > 1
```

Query: List the countries whose GDP is greater than that of Canada.

```
SELECT Co.Name
FROM Country Co
WHERE Co.GDP >ANY  (SELECT Co1.GDP
                    FROM Country Co1
                    WHERE Co1.Name ='Canada ')
```

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Extending SQL for Spatial Data

- Motivation
  - SQL has simple atomic data-types, like integer, dates and string
  - Not convenient for spatial data and queries
    - Spatial data (e.g. polygons) is complex
    - Spatial operation: Topological, Euclidean, Directional, Metric
- SQL 3 allows user defined data types and operations
  - Spatial data types and operations can be added to SQL3
- Open Geodata Interchange Standard (OGIS) / OGC Standard
  - Half a dozen spatial data types
  - Several spatial operations
  - Supported by major vendors, e.g. ESRI, Intergraph, Oracle, IBM,...

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OGIS/ OGC Spatial Data Model

- Consists of base-class Geometry and four sub-classes:
  - Point, Curve, Surface and GeometryCollection
- Operations fall into three categories:
  - Apply to all geometry types
    - SpatialReference, Envelope, Export, IsSimple, Boundary
  - Predicates for Topological relationships
    - Equal, Disjoint, Intersect, Touch, Cross, Within, Contains
  - Spatial Data Analysis
    - Distance, Buffer, Union, Intersection, ConvexHull, SymDiff

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Spatial Queries with SQL

- SQL/OGIS/OGC - General Information
  - Standards are being adopted by most vendors
  - Choice of spatial data types and operations is similar
  - Syntax differs from vendor to vendor
  - May need to alter SQL/OGIS/OGC queries given in text to make them run on specific commercial products
- Using OGIS/OGC with SQL
  - Spatial data types can be used in DML to type columns
  - Spatial operations can be used in DML

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List of Spatial Query Examples

- Simple SQL SELECT_FROM_WHERE examples
  - Spatial analysis operations
    - Unary operator: Area (Q5)
    - Binary operator: Distance (Q3)
  - Boolean Topological spatial operations - WHERE clause
    - Touch (Q1)
    - Cross (Q2)
  - Using spatial analysis and topological operations
    - Buffer, overlap (Q4)
- Complex SQL examples
  - Aggregate SQL queries
  - Nested queries

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Using spatial operation in SELECT clause

Query: List the name, population, and area of each country listed in the Country table.

```
SELECT C.Name, C.Pop, Area(C.Shape) AS "Area"
FROM Country C
```

Note: This query uses spatial operation, Area().

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Using spatial operator Distance

Query: List the GDP and the distance of a country's capital city to the equator for all countries.

```
SELECT Co.GDP, Distance(Point(0,Ci.Shape.y),Ci.Shape)
AS "Distance"
FROM Country Co,City Ci
WHERE Co.Name = Ci.Country
AND Ci.Capital ='Y '
```

Co. Name	Co. GDP	Dist-to-Eq (in Km).
Havana	16.9	2562
Washington, D.C.	8003	4324
Brasilia	1004	1756
Ottawa	658	5005
Mexico City	694.3	2161
Buenos Aires	348.2	3854

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Using Spatial Operation in WHERE clause

Query: Find the names of all countries which are neighbors of the United States (USA) in the Country table.

```
SELECT C1.Name AS "Neighbors of USA"
FROM Country C1,Country C2
WHERE Touch(C1.Shape,C2.Shape)=1
      AND C2.Name ='USA '
```

Note: Spatial operator Touch() is used in WHERE clause to join Country table with itself. This query is an example of spatial self join operation.

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Spatial Query with multiple tables

Query: For all the rivers listed in the River table, find the countries through which they pass.

```
SELECT R.Name, C.Name
FROM River R, Country C
WHERE Cross(R.Shape,C.Shape)=1
```

Note: Spatial operation “Cross” is used to join River and Country tables. This query represents a spatial join operation.

Exercise: Modify above query to report length of river in each country.

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Example Spatial Query…Buffer and Overlap

Query: The St. Lawrence River can supply water to cities that are within 300 km. List the cities that can use water from the St. Lawrence.

```
SELECT Ci.Name
FROM City Ci, River R
WHERE  Overlap(Ci.Shape, Buffer(R.Shape,300))=1
AND R.Name ='St.Lawrence '
```

Note: This query uses spatial operation of Buffer

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Recall List of Spatial Query Examples

- Simple SQL SELECT_FROM_WHERE examples
  - Spatial analysis operations
    - Unary operator: Area
    - Binary operator: Distance
  - Boolean Topological spatial operations - WHERE clause
    - Touch
    - Cross
  - Using spatial analysis and topological operations
    - Buffer, overlap
- Complex SQL examples
  - Aggregate SQL queries
  - Nested queries

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Using spatial operation in an aggregate query

Query: List all countries, ordered by number of neighboring countries.

```
SELECT Co.Name, Count(Co1.Name)
FROM Country Co, Country Co1
WHERE Touch(Co.Shape,Co1.Shape)
GROUP BY Co.Name
ORDER BY Count(Co1.Name)
```

Notes: This query can be used to differentiate querying capabilities of simple GIS software (e.g. Arc/View) and a spatial database. It is quite tedious to carry out this query using GIS tool.

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Using Spatial Operation in Nested Queries

Query: For each river, identify the closest city.

```
SELECT C1.Name, R1.Name
FROM City C1, River R1
WHERE Distance (C1.Shape,R1.Shape) <= ALL
      ( SELECT Distance(C2.Shape)
                  FROM City C2
                  WHERE C1.Name <> C2.Name
                  )
```

Note: Spatial operation Distance used in context of a nested query.

Exercise: Write a SQL expression for this query without using nested query.

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Nested Spatial Query

Query: List the countries with only one neighboring country. A country is a neighbor of another country if their land masses share a boundary. According to this definition, island countries, like Iceland, have no neighbors.

```
SELECT Co.Name
FROM   Country Co
WHERE  Co.Name IN (SELECT Co.Name
           FROM Country Co,Country Co1
           WHERE Touch(Co.Shape,Co1.Shape)
           GROUP BY Co.Name
           HAVING Count(*)=1)
```

Note: It shows a complex nested query with aggregate operations. Such queries can be written into two expression, namely a view definition, and a query on the view. The inner query becomes a view and outer query is union the view..

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Rewriting nested queries using Views

- Views are like tables
  - Represent derived data or result of a query
  - Can be used to simplify complex nested queries
  - Example:

```
CREATE VIEW Neighbor AS
SELECT Co.Name, Count(Co1.Name)AS num neighbors
FROM Country Co,Country Co1
WHERE Touch(Co.Shape,Co1.Shape)
GROUP BY Co.Name
```

```
SELECT Co.Name,num neighbors
FROM   Neighbor
WHERE  num neighbor = (SELECT Max(num neighbors)
                       FROM Neighbor)
```

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Defining Spatial Data Types in SQL3

- SQL3 User defined data type
  - CREATE TYPE statements
  - Defines a new data types
  - Attributes and methods are defined
  - Separate statements for interface and implementation
- Additional effort is needed at physical data model level

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Defining Spatial Data Types in SQL3

- Libraries, Data cartridge/blades
  - Third party libraries implementing OGIS/ OGC are available
  - Almost all user use these libraries
  - Few users need to define their own data types

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Summary

- Queries to databases are posed in high level declarative manner
- SQL is the "lingua-franca" in the commercial database world
- Standard SQL operates on relatively simple data types
- SQL3/OGIS supports several spatial data types and operations
- Additional spatial data types and operations can be defined
  - CREATE TYPE statement

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