# Part 1:
# Background in geospatial data modeling

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# Outline

- Basic GIS concepts and terminology
- Representing geometries
- Representing topological information
- Geospatial data standards

# Basic GIS Concepts and Terminology

- **Theme:** the information corresponding to a particular domain that we want to model. A theme is a set of **geographic features.**

- **Example:** the countries of Europe

# Basic GIS Concepts (cont’d)

- **Geographic feature or geographic object:** a domain entity that can have various **attributes** that describe **spatial and non-spatial** characteristics.

- **Example:** the country Greece with attributes
  - Population
  - Flag
  - Capital
  - Geographical area
  - Coastline
  - Bordering countries

# Basic GIS Concepts (cont'd)

- Geographic features can be **atomic** or **complex.**

- **Example:** According to the Kallikratis administrative reform of 2010, Greece consists of:
    - 13 **regions** (e.g., Crete)
    - Each region consists of **regional units** (e.g., Heraklion)
    - Each regional unit consists of **municipalities** (e.g., Dimos Chersonisou)
    - …

# Basic GIS Concepts (cont'd)

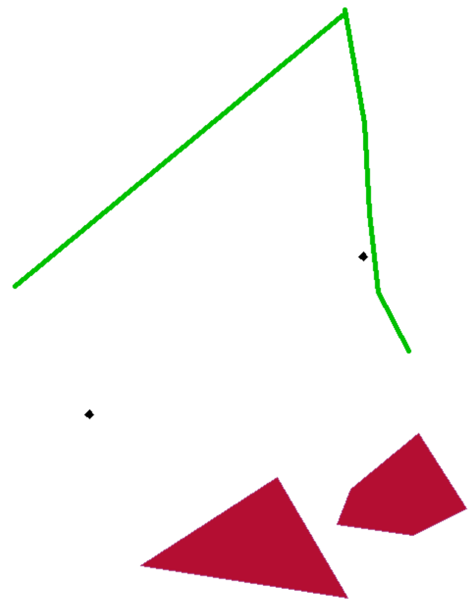
- The spatial characteristics of a feature can involve:
  - **Geometric information** (location in the underlying geographic space, shape etc.)
  - **Topological information** (containment, adjacency etc.).

**Municipalities of the regional unit of Heraklion:**

1. Dimos Irakliou
2. Dimos Archanon-Asterousion
3. Dimos Viannou
4. Dimos Gortynas
5. Dimos Maleviziou
6. Dimos Minoa Pediadas
7. Dimos Festou
8. Dimos Chersonisou

# Geometric Information

- Geometric information can be captured by using geometric primitives (**points**, **lines**, **polygons,** etc.) to approximate the spatial attributes of the real world feature that we want to model.



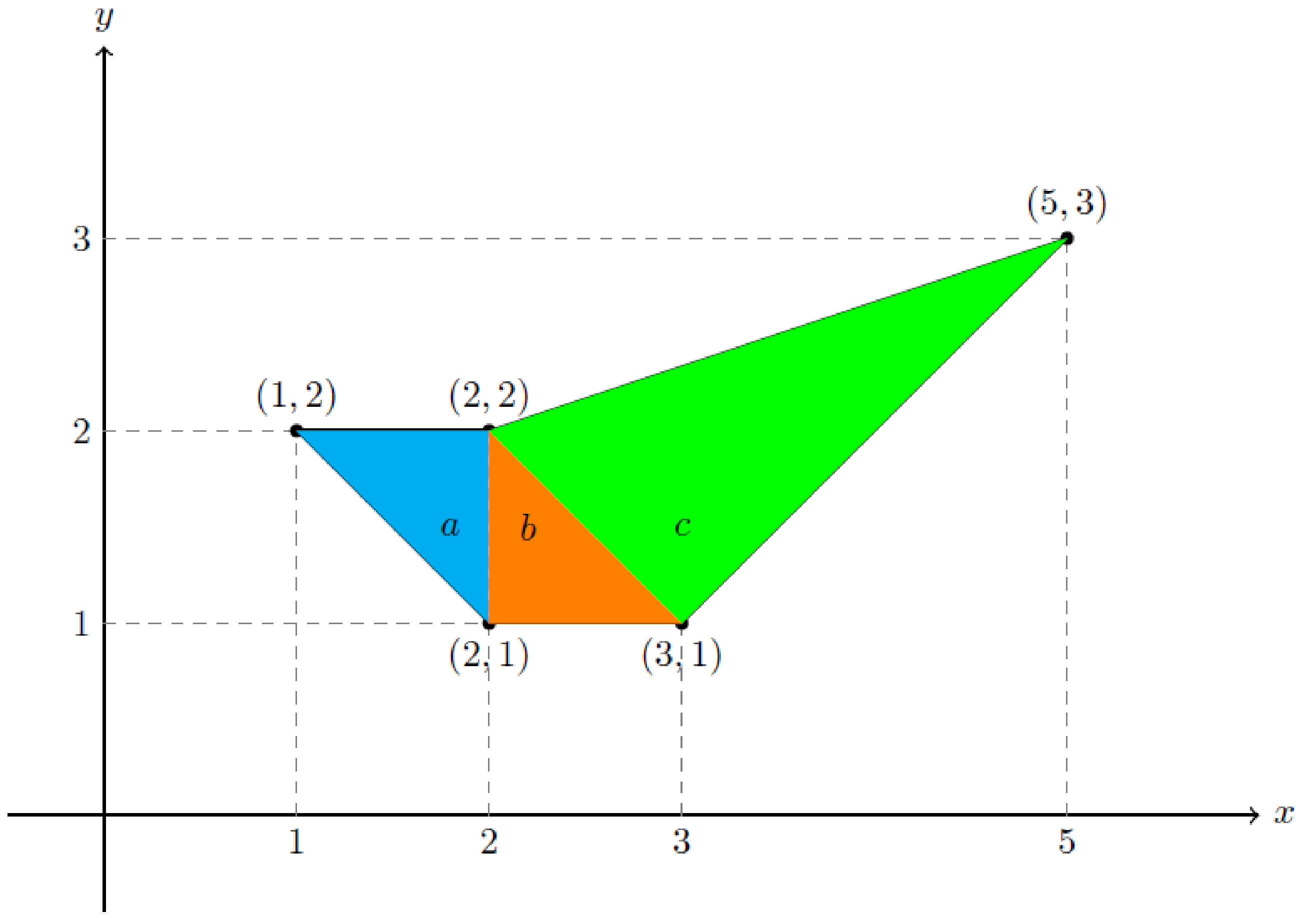
- Geometries are associated with a **coordinate reference system** which describes the coordinate space in which the geometry is defined.

# Encoding Geometries: Vector Representation

- In this encoding objects in space are represented using **points** as primitives as follows:
  - A **point** is represented by a tuple of coordinates.
  - A **line segment** is represented by a pair with its beginning and ending point.
  - **More complex objects** such as  arbitrary lines, curves, surfaces etc. are built recursively by the basic primitives using constructs such as lists, sets etc.

- This is the approach **used in all GIS and other popular systems today. It has also been standardized** by various international bodies.

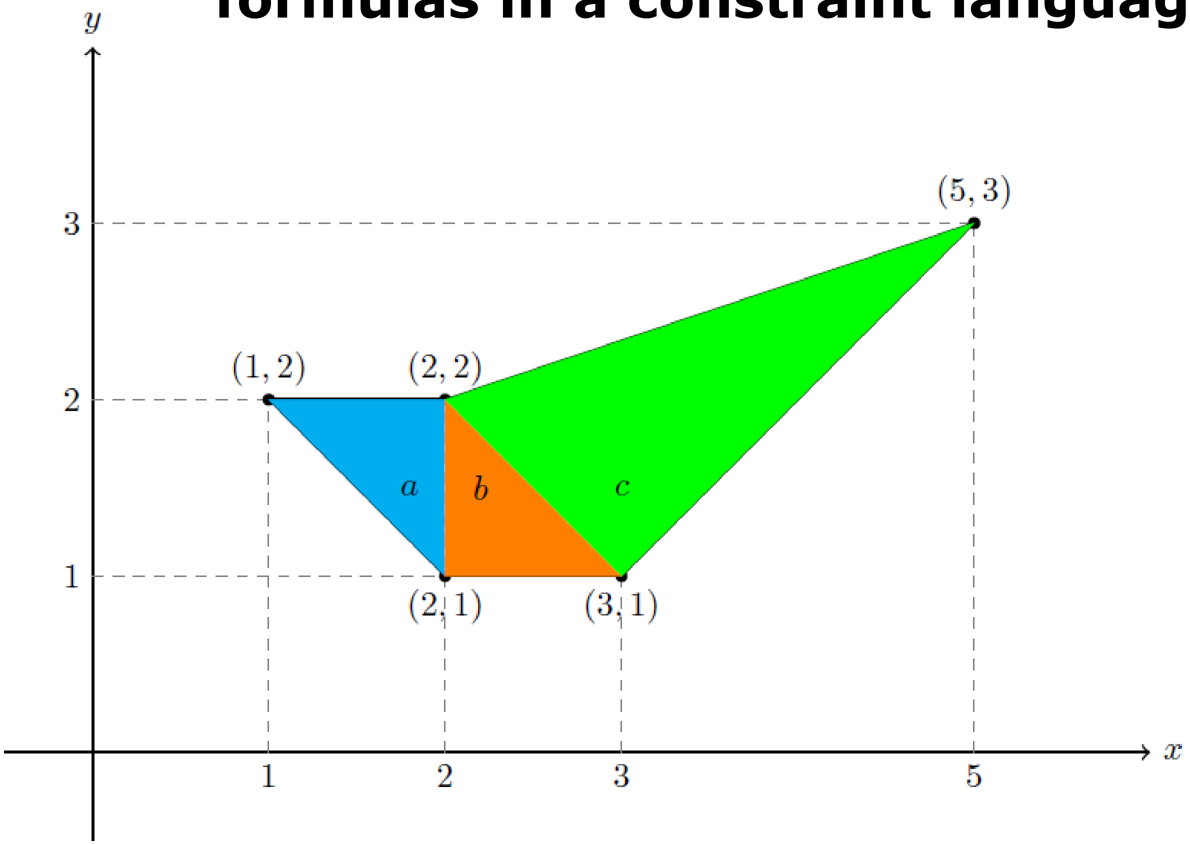
# Example




[(1,2) (2,2) (5,3) (3,1) (2,1) (1,2)]

# Encoding Geometries: Constraint Representation

- In this case objects in space are represented by **quantifier free formulas in a constraint language** (e.g., linear constraints).




$$(y+x \geq 3 \wedge x \leq 2 \wedge y \leq 2) \vee (y+x \leq 4 \wedge x \geq 2 \wedge y \geq 1) \vee (y \geq 3 \wedge x \leq 5 \wedge y - \frac{x}{3} \leq \frac{4}{3})$$

# Constraint Databases

- The constraint representation of spatial data was the focus of much work in **databases, logic programming and AI** after the paper by Kanellakis, Kuper and Revesz (PODS, 1991).

- The approach was very fruitful theoretically but was not adopted in practice.

# Topological Information

- Topological information is **inherently qualitative** and it is expressed in terms of **topological relations** (e.g., containment, adjacency, overlap etc.).

- Topological information can be **derived from geometric information** or it might be captured by **asserting explicitly the topological relations** between features.

# Topological Relations

- The study of topological relations has produced a lot of interesting results by researchers in:
  - GIS
  - Spatial databases
  - Artificial Intelligence (qualitative reasoning and knowledge representation)

# DE-9IM

- The **dimensionally extended 9-intersection model (DE-9IM)** of Clementini and Felice.

- It is based on the **point-set topology** of $R^2$.
- It deals with **simple, closed and connected geometries (areas, lines, points).**

- It is an extension of earlier approaches: the **4-intersection (4IM)** and **9-intersection (9IM)** models by Egenhofer and colleagues.

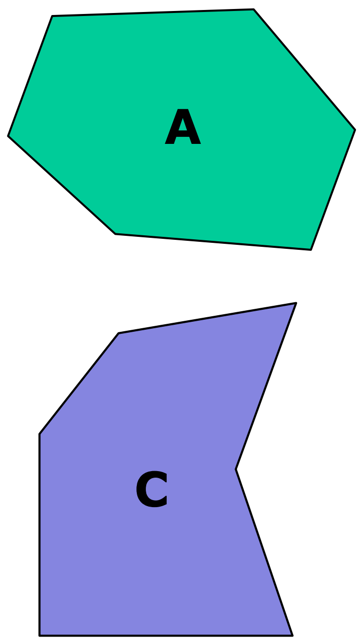
# Topological Relations in DE-9IM

- It captures **topological relationships** between two geometries *a* and *b* in $R^2$ by considering the **dimensions of the intersections of the boundaries, interiors and exteriors** of the two geometries:

$$\mathrm{DE\text{-}9IM}(a,b) = \begin{bmatrix} \dim(I(a)\cap I(b)) & \dim(I(a)\cap B(b)) & \dim(I(a)\cap E(b)) \\ \dim(B(a)\cap I(b)) & \dim(B(a)\cap B(b)) & \dim(B(a)\cap E(b)) \\ \dim(E(a)\cap I(b)) & \dim(E(a)\cap B(b)) & \dim(E(a)\cap E(b)) \end{bmatrix}.$$

- The dimension can be **2, 1, 0** and **-1** (dimension of the empty set).

# Example




| | **I**(C) | **B**(C) | **E**(C) |
|---|---|---|---|
| **I**(A) | -1 | -1 | 2 |
| **B**(A) | -1 | -1 | 1 |
| **E**(A) | 2 | 1 | 2 |

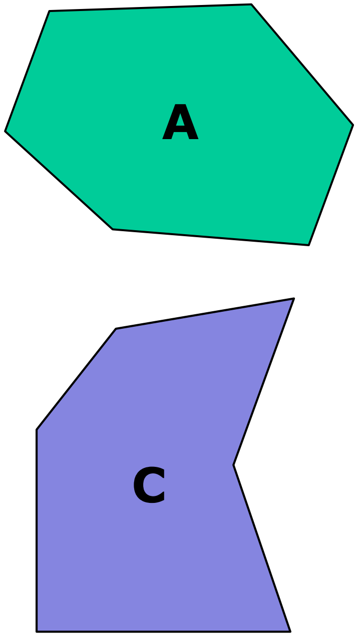
# Topological Relations in DE-9IM

- The following five **named relationships** between two different geometries can be distinguished: **disjoint, touches, crosses, within** and **overlaps**.

- The named relationships have a **reasonably intuitive meaning** for users. They are **jointly exclusive and pairwise disjoint (JEPD).**

- The model can also be defined using an appropriate **calculus of geometries** that uses these 5 binary relations and boundary operators.

# Example: A disjoint C

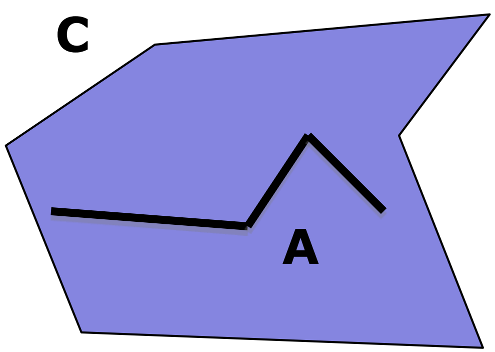



| | **I**(C) | **B**(C) | **E**(C) |
|---|---|---|---|
| **I**(A) | F | F | * |
| **B**(A) | F | F | * |
| **E**(A) | * | * | * |

**Notation:**

- T = { 0, 1, 2 }
- F = -1
- * = don't care = { -1, 0, 1, 2 }

# Example: A within C

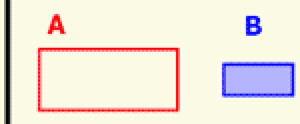
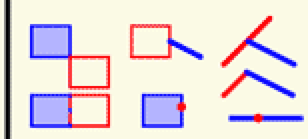
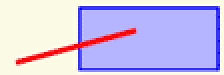
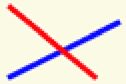
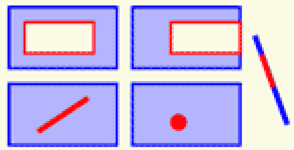
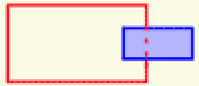
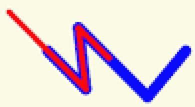



| | **I**(C) | **B**(C) | **E**(C) |
|---|---|---|---|
| **I**(A) | T | * | F |
| **B**(A) | * | * | F |
| **E**(A) | * | * | * |

**Notation equivalent to 3x3 matrix:**

- String of 9 characters representing the above matrix in row major order.
- In this case: T*F**F***

# DE-9IM Relation Definitions

| Beziehung | Definition | Beispiele |
|---|---|---|
| A disjoint B | $\begin{bmatrix} F & F & * \\ F & F & * \\ * & * & * \end{bmatrix}$ |   |
| A touches B<br>( d(A) > 0 ∨<br>d(B) > 0 ) | $\begin{bmatrix} F & T & * \\ * & * & * \\ * & * & * \end{bmatrix} \vee \begin{bmatrix} F & * & * \\ T & * & * \\ * & * & * \end{bmatrix} \vee \begin{bmatrix} F & * & * \\ * & T & * \\ * & * & * \end{bmatrix}$ |  |
| A crosses B<br>( d(A) < d(B) ) | $\begin{bmatrix} T & * & T \\ * & * & * \\ * & * & * \end{bmatrix}$ |  |
| A crosses B<br>( d(A) = d(B) = 1 ) | $\begin{bmatrix} 0 & * & * \\ * & * & * \\ * & * & * \end{bmatrix}$ |  |
| A within B | $\begin{bmatrix} T & * & F \\ * & * & F \\ * & * & * \end{bmatrix}$ |  |
| A overlaps B<br>( d(A) = d(B),<br>d(A) ≠ 1,<br>d(B) ≠ 1) | $\begin{bmatrix} T & * & T \\ * & * & * \\ T & * & * \end{bmatrix}$ |  |
| A overlaps B<br>( d(A) = d(B) = 1) | $\begin{bmatrix} 1 & * & T \\ * & * & * \\ T & * & * \end{bmatrix}$ |  |

# The Region Connection Calculus (RCC)

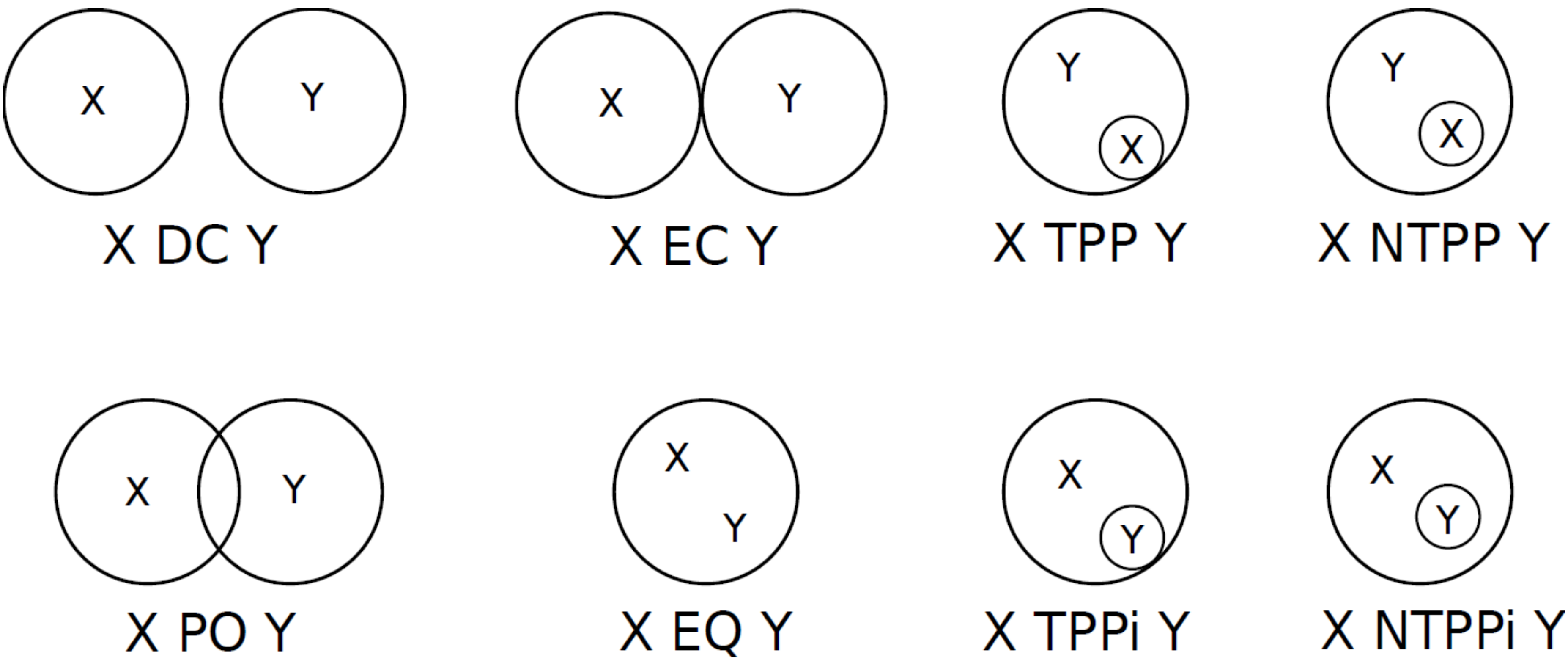
- The primitives of the calculus are **spatial regions**. These are **non-empty, regular closed** subsets of a topological space.

- The calculus is based on a single binary predicate *C* that formalizes the "**connectedness**" relation.
  - ***C(a,b)*** **is true** when the closure of *a* is connected to the closure of *b* i.e., they have at least one point in common.

- It is axiomatized using first order logic.

# RCC-8

- This is a set of **eight JEPD binary relations** that can be defined in terms of predicate *C*.



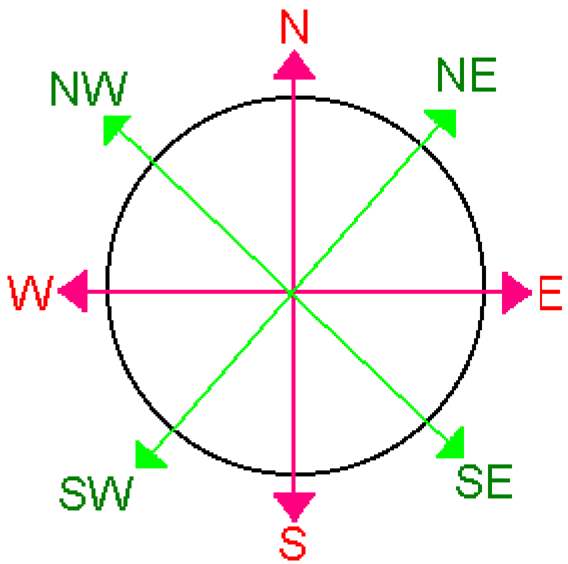
# RCC-5

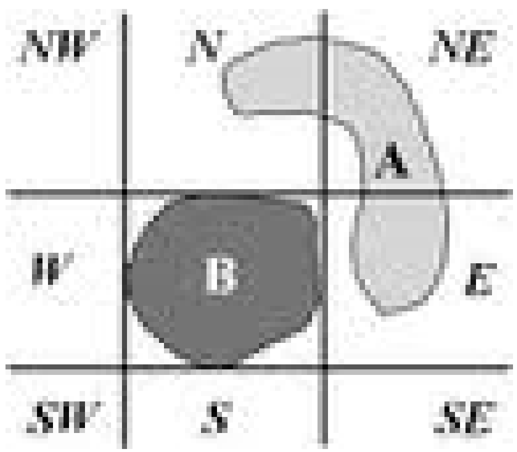
- The **RCC-5 subset** has also been studied. The granularity here is coarser. The boundary of a region is not taken into consideration:
  - No distinction among DC and EC, called just DR.
  - No distinction among TPP and NTPP, called just PP.

- RCC-8 and RCC-5 relations **can also be defined using point-set topology**, and there are very close connections to the models of Egenhofer and others.

# More Qualitative Spatial Relations

- **Orientation/Cardinal directions** (left of, right of, north of, south of, northeast of etc.)



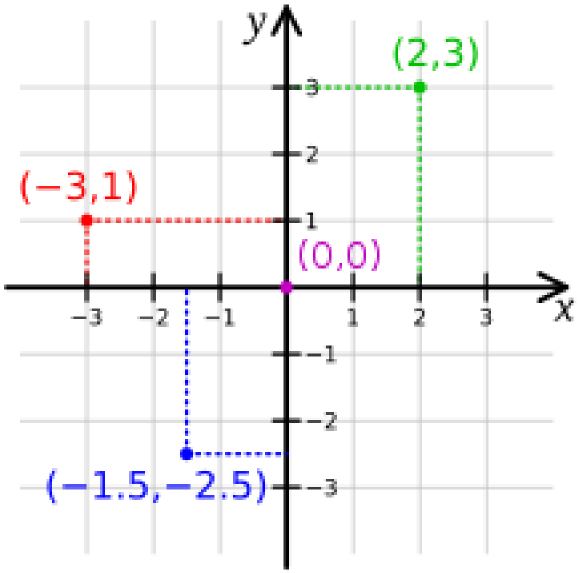




- **Distance** (close to, far from etc.). This information can also be **quantitative**.

# Coordinate Systems

- **Coordinate:** one of *n* scalar values that determines the position of a point in an *n*-dimensional space.
- **Coordinate system:** a set of mathematical rules for specifying how coordinates are to be assigned to points.

- **Example**: the Cartesian coordinate system



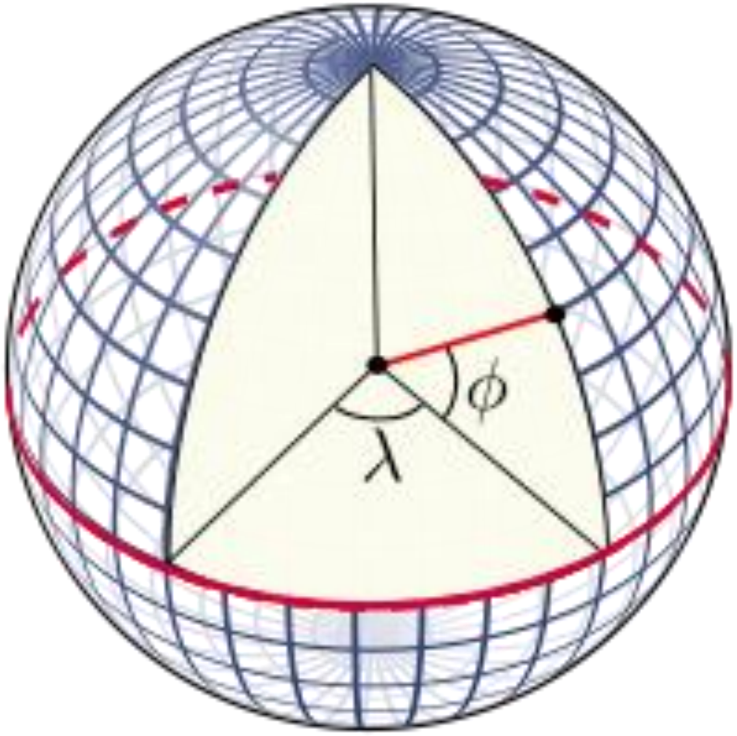
# Coordinate Reference Systems

- **Coordinate reference system**: a coordinate system that is related to an **object** (e.g., the Earth, a planar projection of the Earth, a three dimensional mathematical space such as $R^3$) through a **datum** which specifies its origin, scale, and orientation.

- The term **spatial reference system** is also used.

# Geographic Coordinate Reference Systems

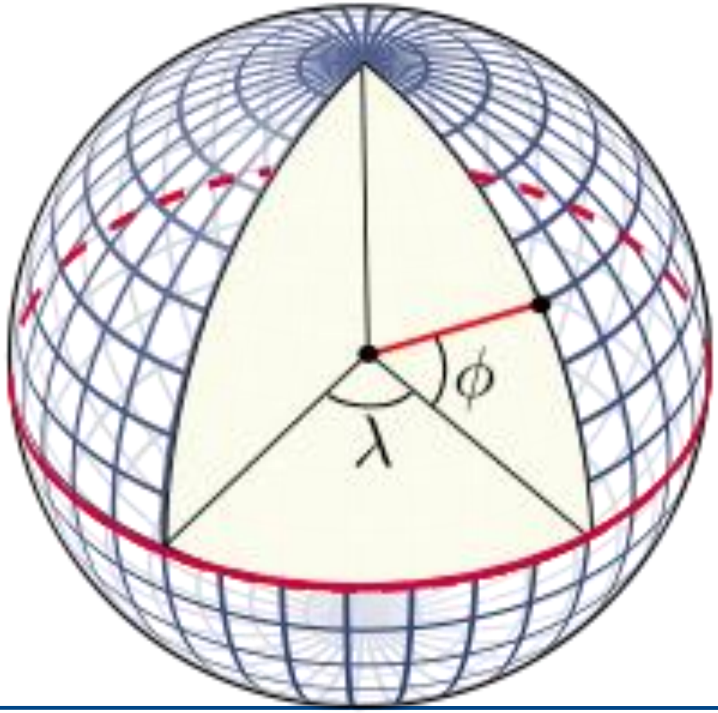
- These are 3-dimensional coordinate systems that utilize **latitude (φ)**, **longitude (λ)** , and optionally **geodetic height (i.e., elevation)**, to capture geographic locations on Earth.



# The World Geodetic System

- The **World Geodetic System (WGS)** is the most well-known geographic coordinate reference system and its latest revision is **WGS84.**

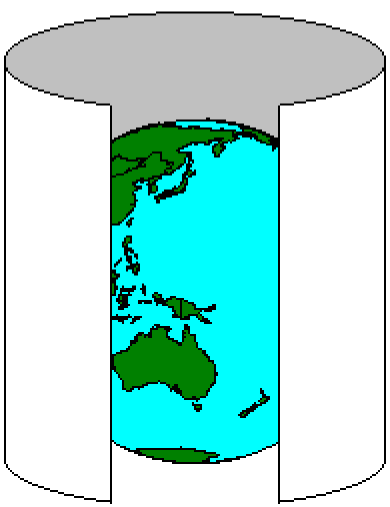
- **Applications:** cartography, geodesy, navigation (GPS), etc.



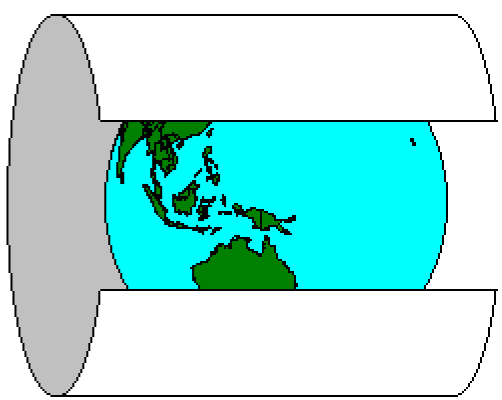
# Projected Coordinate Reference Systems

- **Projected coordinate reference systems:** they transform the 3-dimensional approximation of the Earth into a 2-dimensional surface (distortions!)

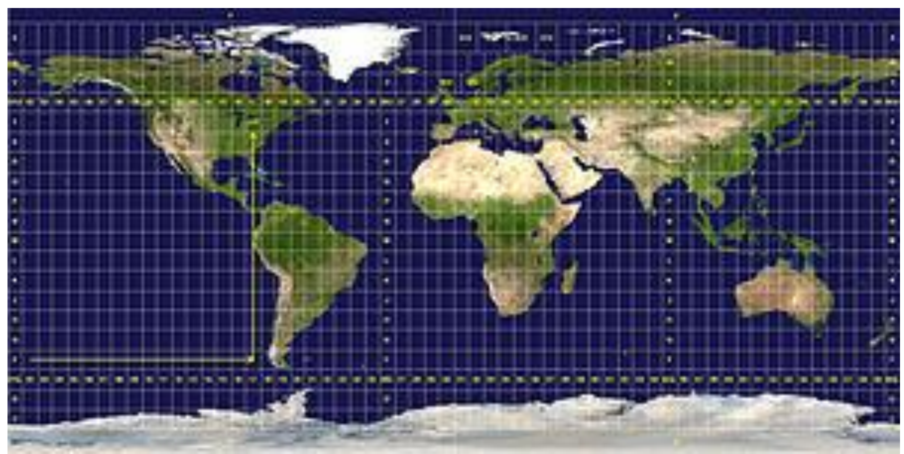
- **Example:** the **Universal Transverse Mercator (UTM)** system



Mercator projection



Transverse Mercator projection



# Coordinate Reference Systems (cont'd)

- There are well-known ways to **translate** between co-ordinate reference systems.

- See the list of coordinate reference systems of the **European Petroleum Survey Group**: http://www.epsg-registry.org/

# Geospatial Data Standards

- The **Open Geospatial Consortium (OGC)** and the **International Organization for Standardization (ISO)** have developed many geospatial data standards that are in wide use today. In this tutorial we will cover:
  - **Well-Known Text**
  - **Geography Markup Language**
  - **OpenGIS Simple Features Access**

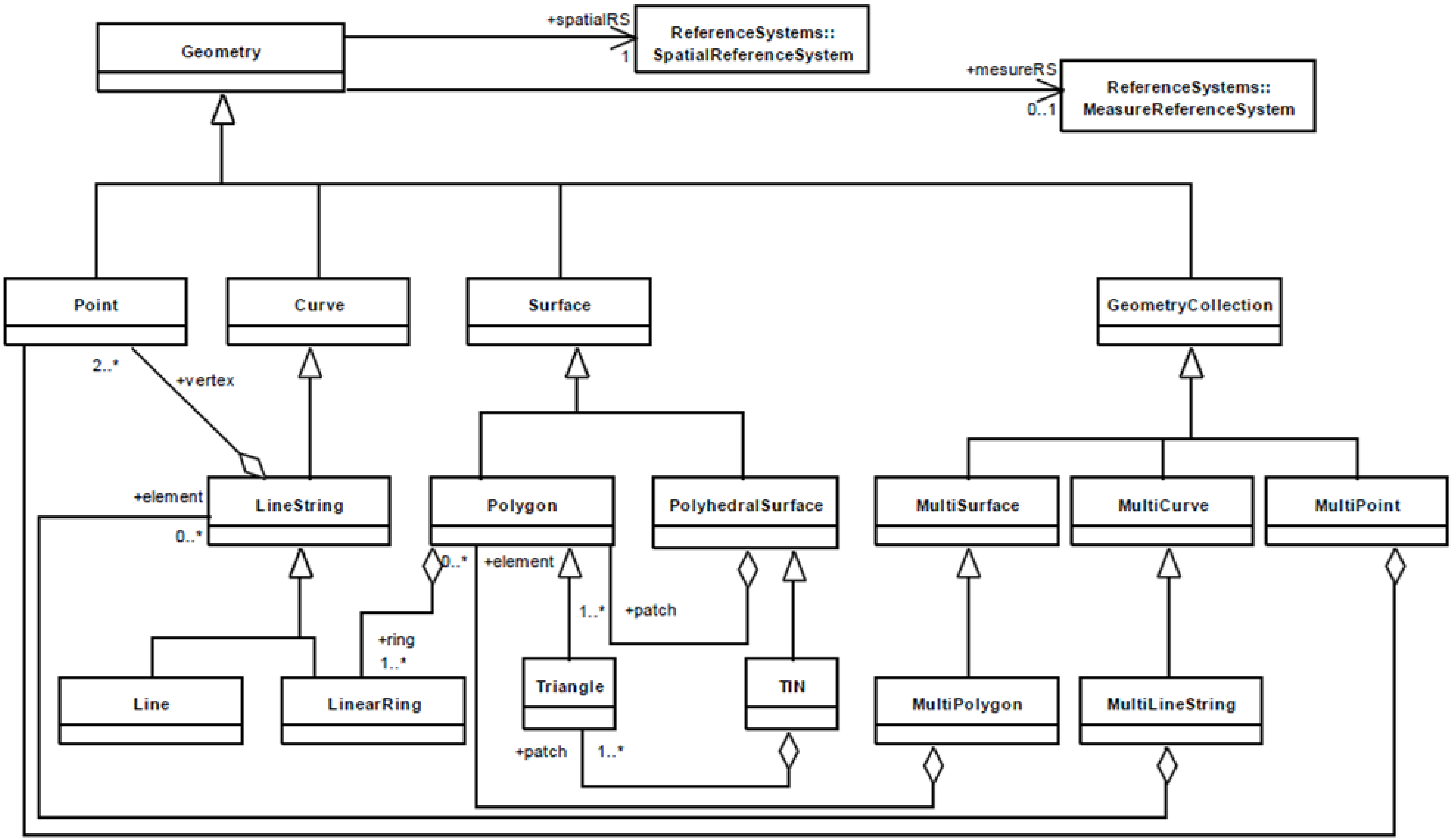
# Well-Known Text (WKT)

- WKT is an OGC and ISO standard for representing **geometries**, **coordinate reference systems**, and **transformations** between coordinate reference systems.

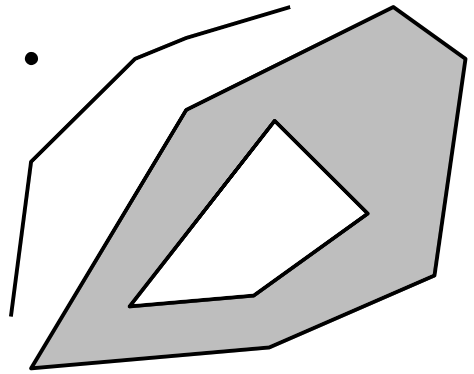
- WKT is specified in **OpenGIS Simple Feature Access - Part 1: Common Architecture** standard which is the same as the **ISO 19125-1** standard. Download from http://portal.opengeospatial.org/files/?artifact_id=25355 .

- This standard concentrates on **simple features:** features with all spatial attributes described piecewise by a straight line or a planar interpolation between sets of points.

# WKT Class Hierarchy



# Example



WKT representation:

```
GeometryCollection(
    Point(5 35),
    LineString(3 10,5 25,15 35,20 37,30 40),
    Polygon((5 5,28 7,44 14,47 35,40 40,20 30,5 5),
            (28 29,14.5 11,26.5 12,37.5 20,28 29))
    )
```

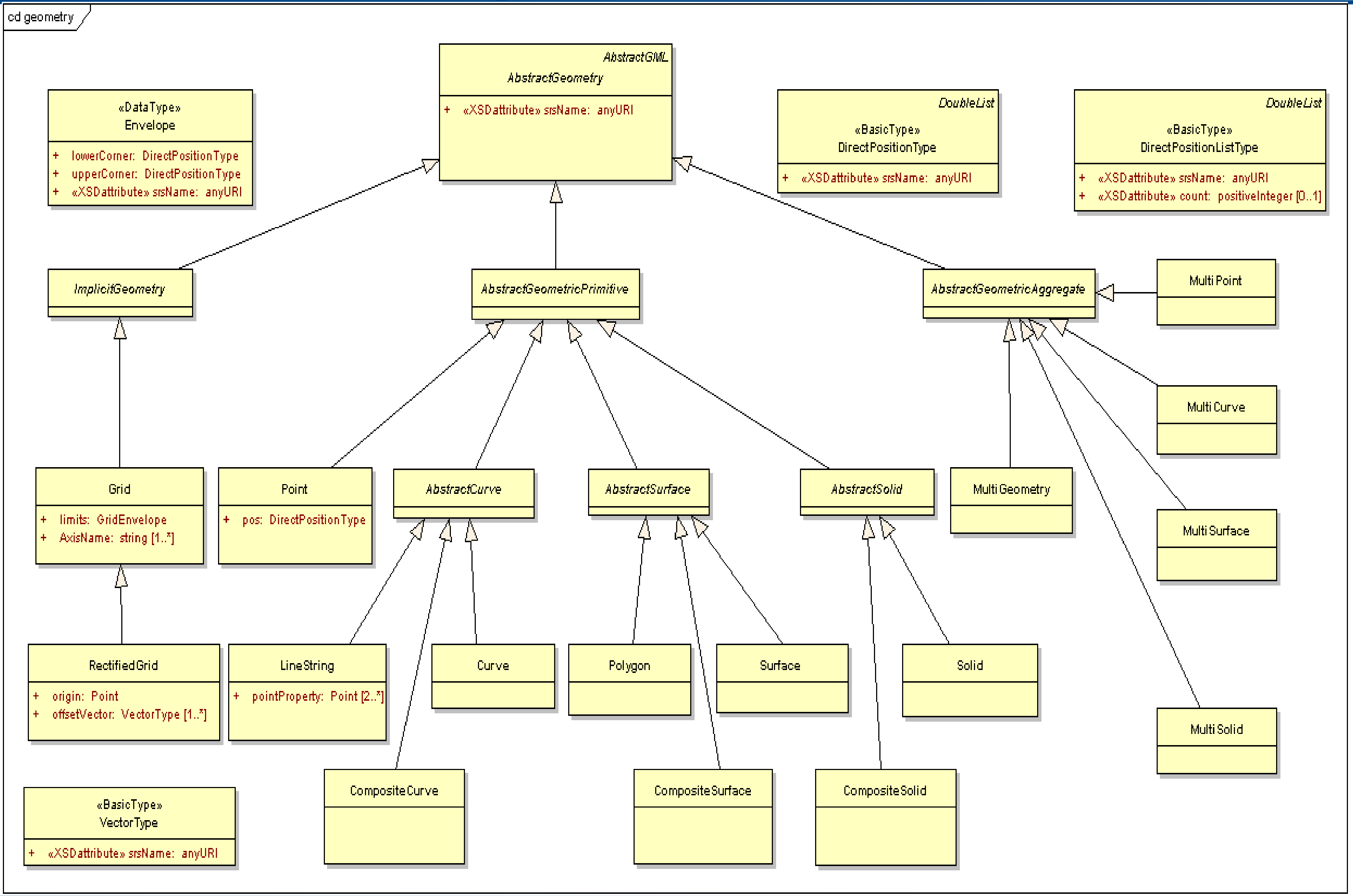
# Geography Markup Language (GML)

- **GML** is an **XML-based encoding standard** for the representation of geospatial data.

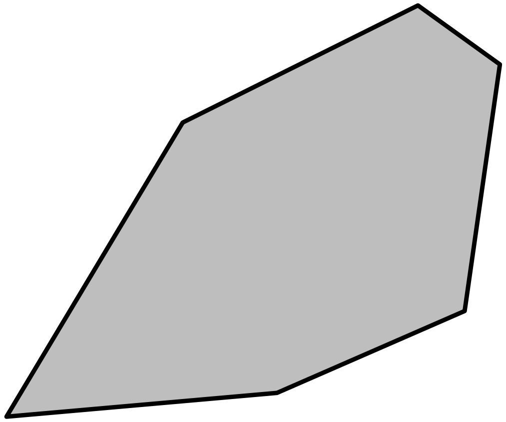
- GML provides XML schemas for defining a variety of concepts: **geographic features, geometry, coordinate reference systems, topology, time** and **units of measurement**.

- **GML profiles** are subsets of GML that target particular applications.
  - **Examples**: Point Profile, GML Simple Features Profile etc.

# GML Simple Features: Class Hierarchy



# Example



GML representation:

```
<gml:Polygon gml:id="p3" srsName="urn:ogc:def:crs:EPSG:6.6:4326”>
    <gml:exterior>
        <gml:LinearRing>
            <gml:coordinates>
                5,5 28,7 44,14 47,35 40,40 20,30 5,5
            </gml:coordinates>
        </gml:LinearRing>
    </gml:exterior>
</gml:Polygon>
```

# OpenGIS Simple Features Access

- OGC has also specified a standard for the **storage, retrieval, query and update of sets of simple features using relational DBMS and SQL.**

- This standard is **“OpenGIS Simple Feature Access - Part 2: SQL Option”** and it is the same as the **ISO 19125-2** standard. Download from http://portal.opengeospatial.org/files/?artifact_id=25354.

- **Related standard**: ISO 13249 SQL/MM - Part 3.

# OpenGIS Simple Features Access (cont’d)

- The standard covers two implementations options: (i) using **only the SQL predefined data types** and (ii) using **SQL with geometry types**.

- **SQL with geometry types:**
  - We use the WKT geometry class hierarchy presented earlier to define **new geometric data types for SQL**
  - We define new **SQL functions on those types**.

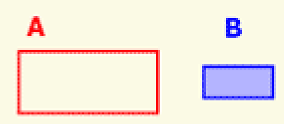
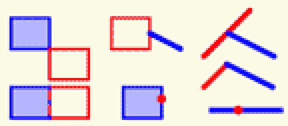
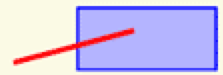
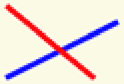
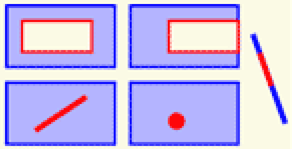
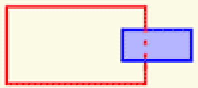
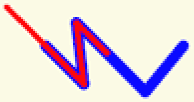
# SQL with Geometry Types - Functions

- Functions that **request or check properties** of a geometry:
  - `ST_Dimension(A:Geometry):Integer`
  - `ST_GeometryType(A:Geometry):Character Varying`
  - `ST_AsText(A:Geometry): Character Large Object`
  - `ST_AsBinary(A:Geometry): Binary Large Object`
  - `ST_SRID(A:Geometry): Integer`
  - `ST_IsEmpty(A:Geometry): Boolean`
  - `ST_IsSimple(A:Geometry): Boolean`

# SQL with Geometry Types – Functions (cont'd)

- Functions that test **topological relations** between two geometries using the **DE-9IM**:
  - `ST_Equals(A:Geometry, B:Geometry):Boolean`
  - `ST_Disjoint(A:Geometry, B:Geometry):Boolean`
  - `ST_Intersects(A:Geometry, B:Geometry):Boolean`
  - `ST_Touches(A:Geometry, B:Geometry):Boolean`
  - `ST_Crosses(A:Geometry, B:Geometry):Boolean`
  - `ST_Within(A:Geometry, B:Geometry):Boolean`
  - `ST_Contains(A:Geometry, B:Geometry):Boolean`
  - `ST_Overlaps(A:Geometry, B:Geometry):Boolean`
  - `ST_Relate(A:Geometry, B:Geometry, Matrix: Char(9)):Boolean`

# DE-9IM Relation Definitions

| Beziehung | Definition | Beispiele |
|---|---|---|
| A disjoint B | $\begin{bmatrix} F & F & * \\ F & F & * \\ * & * & * \end{bmatrix}$ |   |
| A touches B ( d(A) > 0 ∨ d(B) > 0 ) | $\begin{bmatrix} F & T & * \\ * & * & * \\ * & * & * \end{bmatrix} \vee \begin{bmatrix} F & * & * \\ T & * & * \\ * & * & * \end{bmatrix} \vee \begin{bmatrix} F & * & * \\ * & T & * \\ * & * & * \end{bmatrix}$ |  |
| A crosses B ( d(A) < d(B) ) | $\begin{bmatrix} T & * & T \\ * & * & * \\ * & * & * \end{bmatrix}$ |  |
| A crosses B ( d(A) = d(B) = 1 ) | $\begin{bmatrix} 0 & * & * \\ * & * & * \\ * & * & * \end{bmatrix}$ |  |
| A within B | $\begin{bmatrix} T & * & F \\ * & * & F \\ * & * & * \end{bmatrix}$ |  |
| A overlaps B ( d(A) = d(B), d(A) ≠ 1, d(B) ≠ 1) | $\begin{bmatrix} T & * & T \\ * & * & * \\ T & * & * \end{bmatrix}$ |  |
| A overlaps B ( d(A) = d(B) = 1) | $\begin{bmatrix} 1 & * & T \\ * & * & * \\ T & * & * \end{bmatrix}$ |  |

- **A equals B** can also be defined by the pattern TFFFTFFFT.
- **A intersects B** is the negation of **A disjoint B**
- **A contains B** is equivalent to **B within A**

# SQL with Geometry Types – Functions (cont'd)

- Functions for **constructing new geometries** out of existing ones:
  - `ST_Boundary(A:Geometry):Geometry`
  - `ST_Envelope(A:Geometry):Geometry`
  - `ST_Intersection(A:Geometry, B:Geometry):Geometry`
  - `ST_Union(A:Geometry, B:Geometry):Geometry`
  - `ST_Difference(A:Geometry, B:Geometry):Geometry`
  - `ST_SymDifference(A:Geometry, B:Geometry):Geometry`
  - `ST_Buffer(A:Geometry, distance:Double):Geometry`

# Geospatial Relational DBMS

- The OpenGIS Simple Features Access Standard is today been used in all **relational DBMS with a geospatial extension.**

  - The **abstract data type mechanism** of the DBMS allows the representation of all kinds of geospatial data types supported by the standard.
  - The query language (SQL) offers the **functions** of the standard for querying data of these types.

# Readings

- The book ***Geographic Information Systems and Science*** is a nice introduction to GIS. See: http://eu.wiley.com/WileyCDA/WileyTitle/productCd-EHEP001475.html

- The following papers present the DE-9IM model:

  Eliseo Clementini, Paolino Di Felice and Peter van Oosterom.

  A Small Set of Formal Topological Relationships Suitable for End-User Interaction. SSD 1993: 277-295

  http://link.springer.com/chapter/10.1007%2F3-540-56869-7_16

  E. Clementini and P. Felice. A Comparison of Methods for Representing Topological Relationships. Information Sciences 80 (1994), pp. 1-34. http://www.sciencedirect.com/science/article/pii/106901159400033X The paper

- The paper below surveys a lot of interesting results on the RCC calculus:
  J. Renz, B. Nebel, Qualitative Spatial Reasoning using Constraint

  Calculi, in: M. Aiello, I. Pratt-Hartmann and J. van Benthem (eds.),

  Handbook of Spatial Logics, pp. 161–215, 2007, Springer.
  http://users.cecs.anu.edu.au/~jrenz/papers/renz-nebel-los.pdf

- The two OGC standards mentioned in the slides.