Background in geospatial data modeling

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Outline

- Basic GIS concepts and terminology
- Abstract geographic space modeling paradigms
- Concrete representations for the abstract modeling paradigms
- 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 **perfectures** (e.g., Heraklion)
  - Each perfecture consists of **municipalities** (e.g., Dimos Chersonisou)

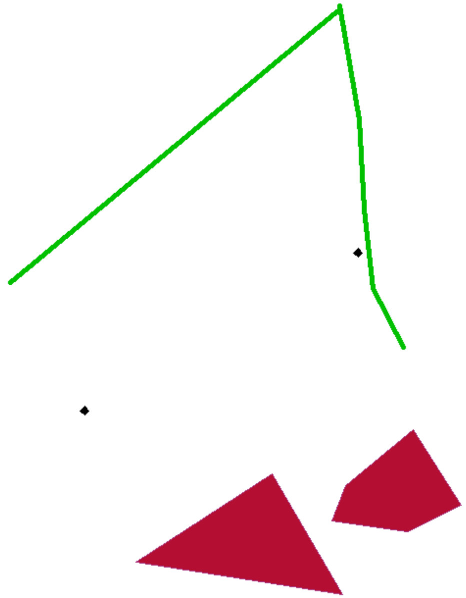
Basic GIS Concepts (cont'd)

- 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 perfecture 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** (or **spatial reference system**) which describes the coordinate space in which the geometry is defined.

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)

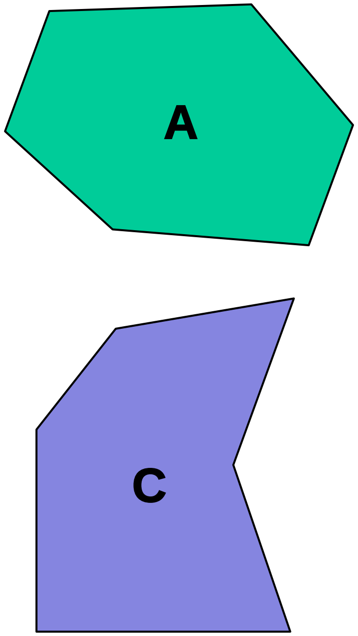
DE-9IM

- The **dimensionally extended 9-intersection model** has been defined by Clementini, Di Felice and van Oosterom in 1993 based on previous work by these authors, Egenhofer, Franzosa and others.

- It captures topological relationships between geometries in $\mathbb{R}^2$ by considering the **dimension of the intersections involving the interior, boundary and exterior of the two geometries:**

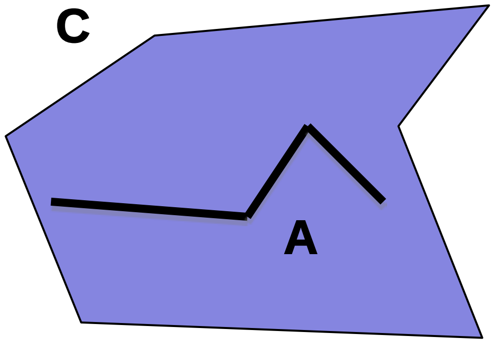
$$\text{DE-9IM}(a,b) = \begin{bmatrix} \dim(I(a) \cap I(b)) & \dim(I(a) \cap B(b)) & \dim(I(a) \cap E(b)) \\ \dim(B(a) \cap I(b)) & \dim(B(a) \cap B(b)) & \dim(B(a) \cap E(b)) \\ \dim(E(a) \cap I(b)) & \dim(E(a) \cap B(b)) & \dim(E(a) \cap E(b)) \end{bmatrix}.$$

Example: A DISJOINT C



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

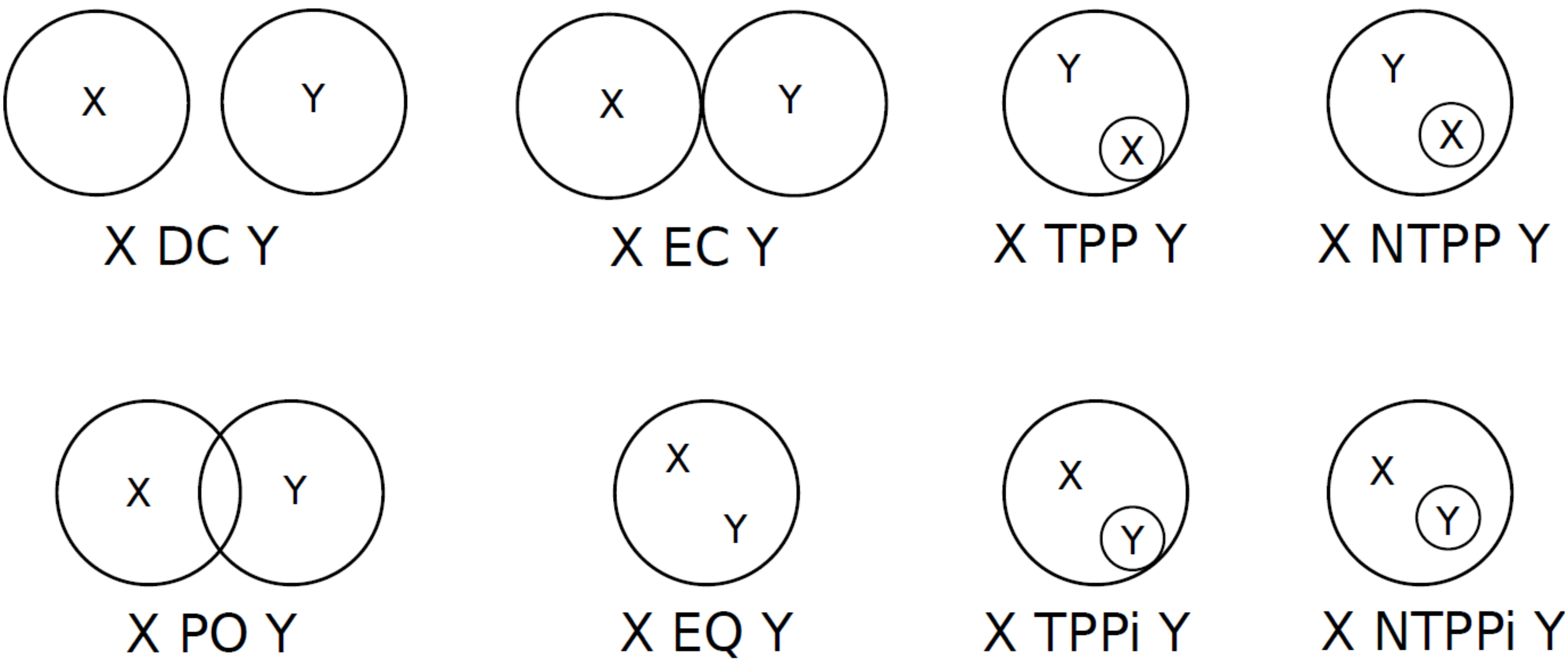
Example: A WITHIN C



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

The RCC-8 Calculus (Randell et al., 1991)

- **Eight JEPD binary relations** that can be all defined in terms of a single primitive (**connection** of two regions).



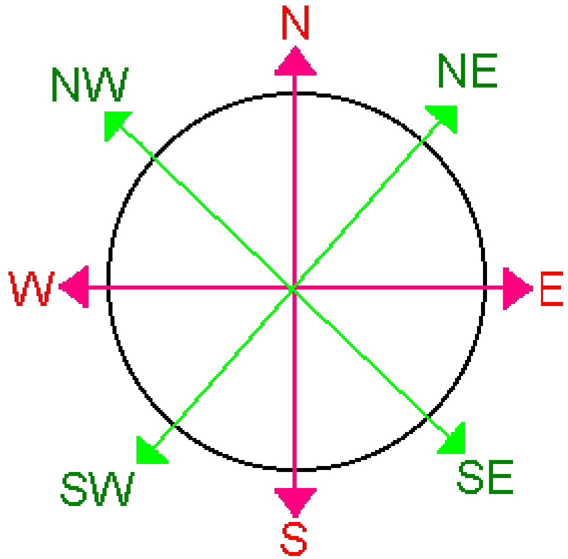
RCC-8 (cont’d)

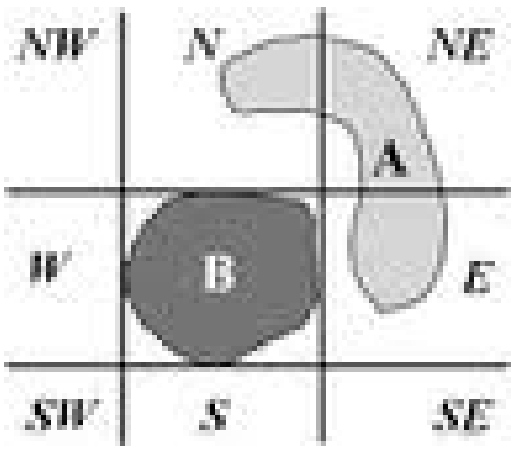
- Variations exist depending on:
  - **What kind of regions of a topological space** are considered (non-empty, regular, closed, connected, holes allowed, dimensionality).
  - How is **contact** of two regions defined (the regions have a point in common or their closures have a point in common).

- The **RCC-5 subset** has also been studied (no distinction among TPP and NTPP, called just PP).

More Qualitative Spatial Relations

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

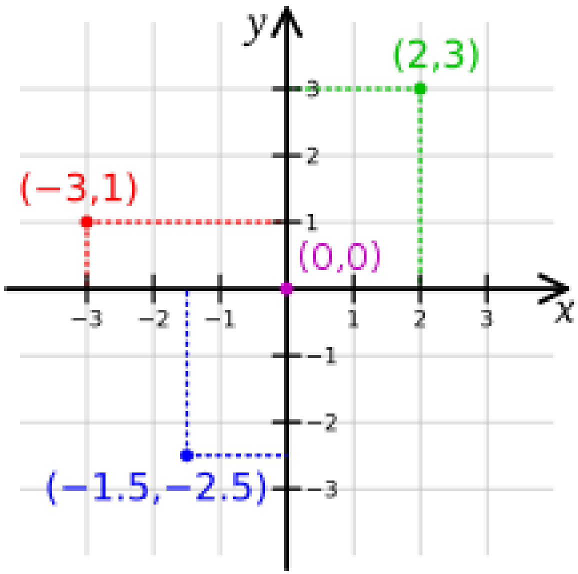




- **Distance** (close to, far from etc.). This information can also be **quantitative**.

Coordinate Systems

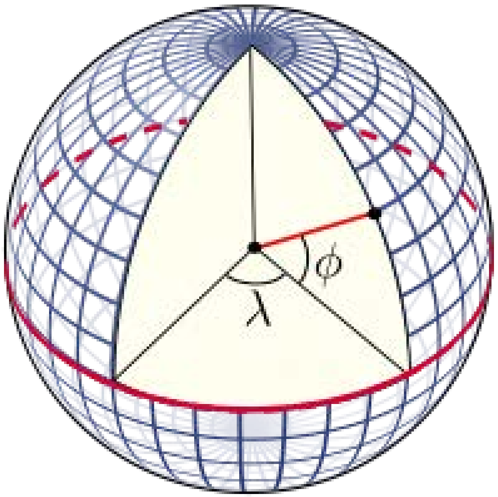
- **Coordinate:** one of *n* scalar values that determines the position of a point in an *n*-dimensional space.
- **Coordinate system:** a set of mathematical rules for specifying how coordinates are to be assigned to points.
- **Example**: the Cartesian coordinate system



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 species its origin, scale, and orientation.

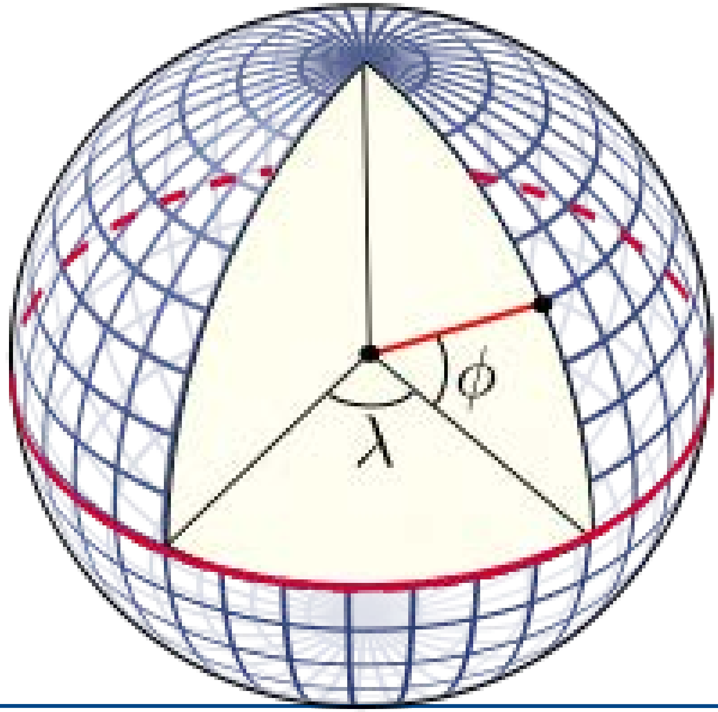
- **Geographic coordinate reference system**: a 3-dimensional coordinate system that utilizes **latitude (φ)**, **longitude (λ)** , and optionally **geodetic height (i.e., elevation)**, to capture geographic locations on Earth.



The World Geodetic System

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

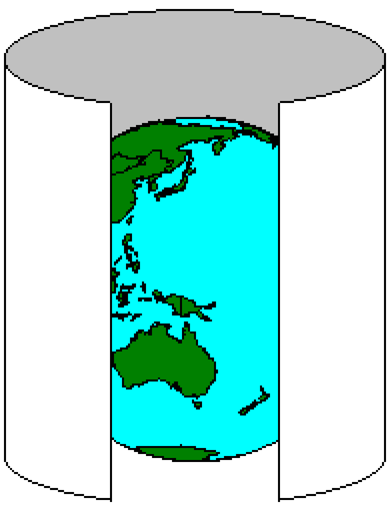
- **Applications:** cartography, geodesy, navigation (GPS), etc.



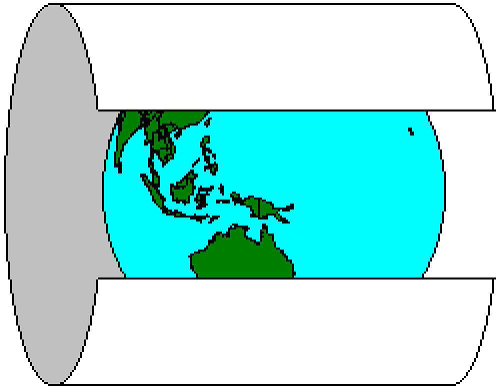
Projected Coordinate Reference Systems

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

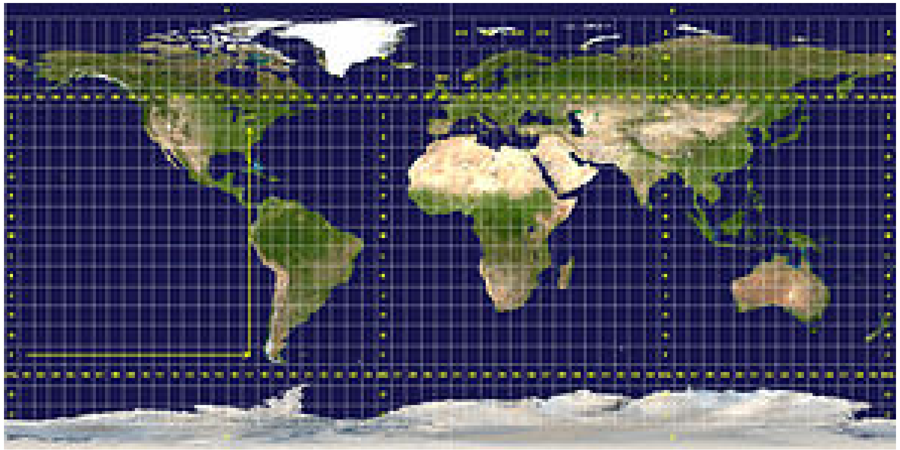
- **Example:** the **Universal Transverse Mercator (UTM)** system



Mercator projection



Transverse Mercator projection



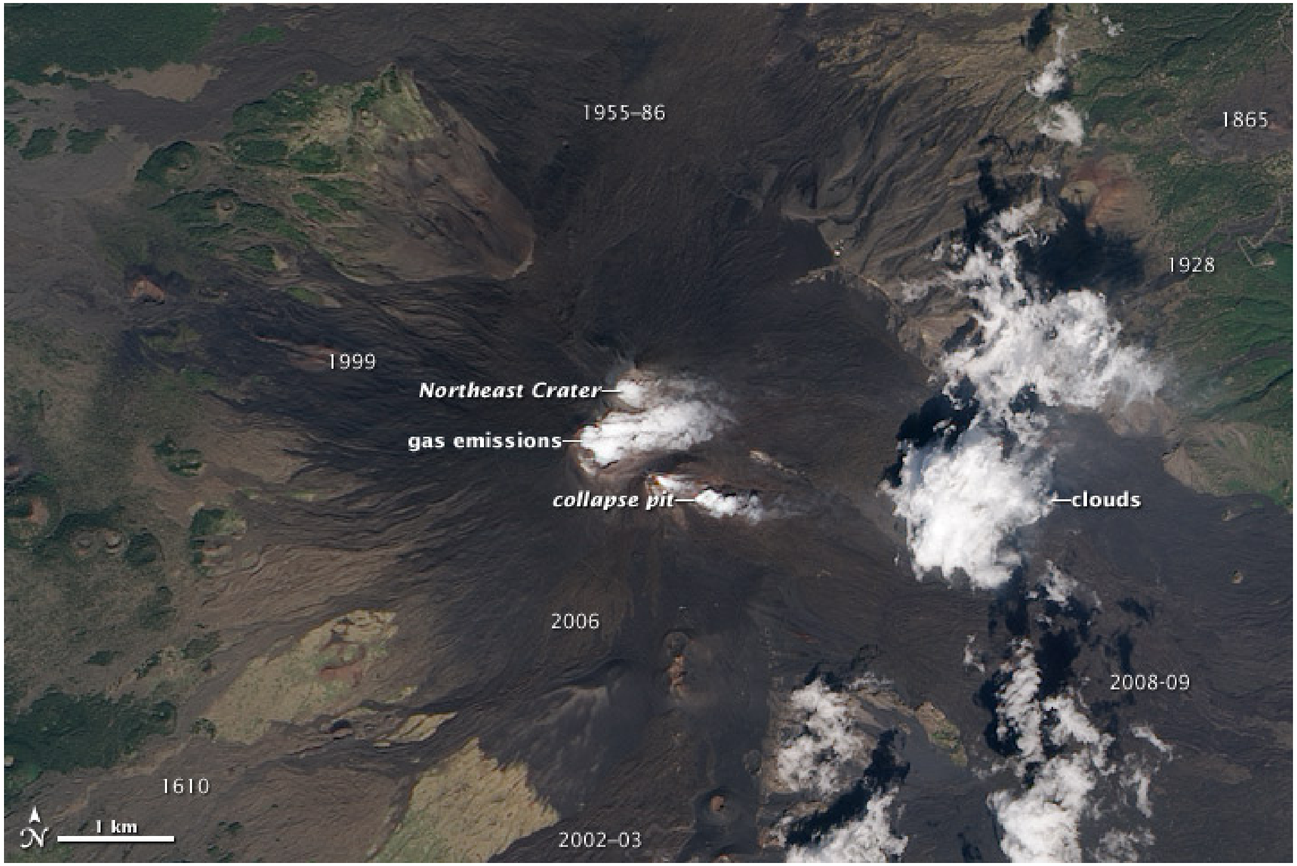
Coordinate Reference Systems (cont'd)

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

- Various authorities maintain lists of coordinate reference systems. See for example:
  - **OGC** http://www.opengis.net/def/crs/
  - **European Petroleum Survey Group** http://www.epsg-registry.org/

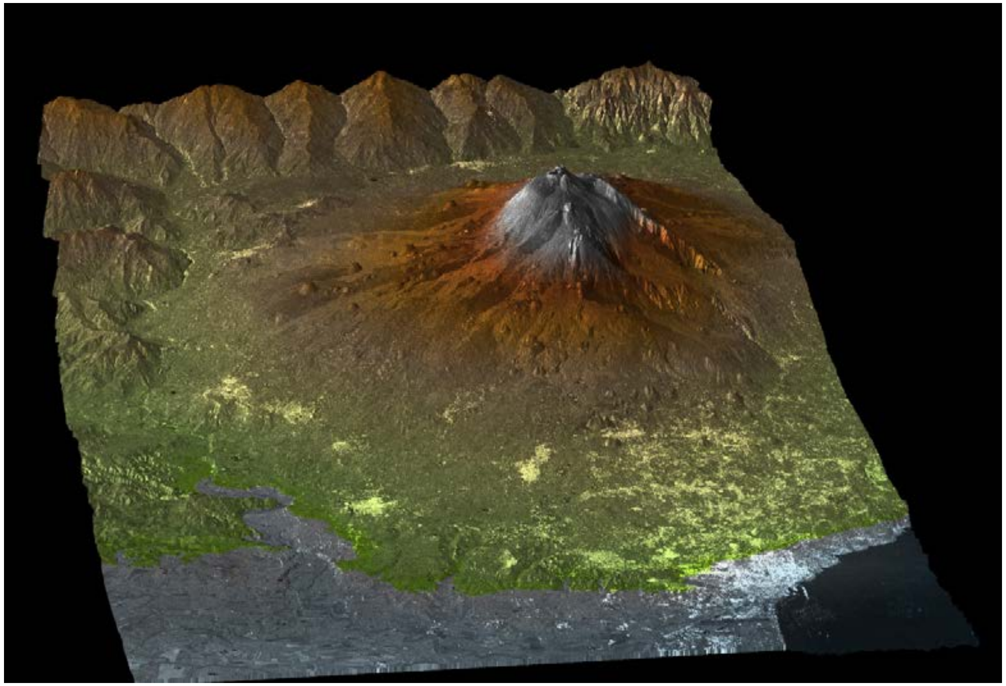
Abstract Modeling Paradigms: Feature-based

- **Feature-based** (or **entity-based** or **object-based**). This kind of modeling is based on the concepts we presented already.



Abstract Modeling Paradigms: Field-based

- Each point *(x,y)* in geographic space is associated with one or several attribute values defined as **continuous functions** in *x* and *y*.
- **Examples:** elevation, precipitation, humidity, temperature for each point *(x,y)* in the Euclidean plane.



From Abstract Modeling to Concrete Representations

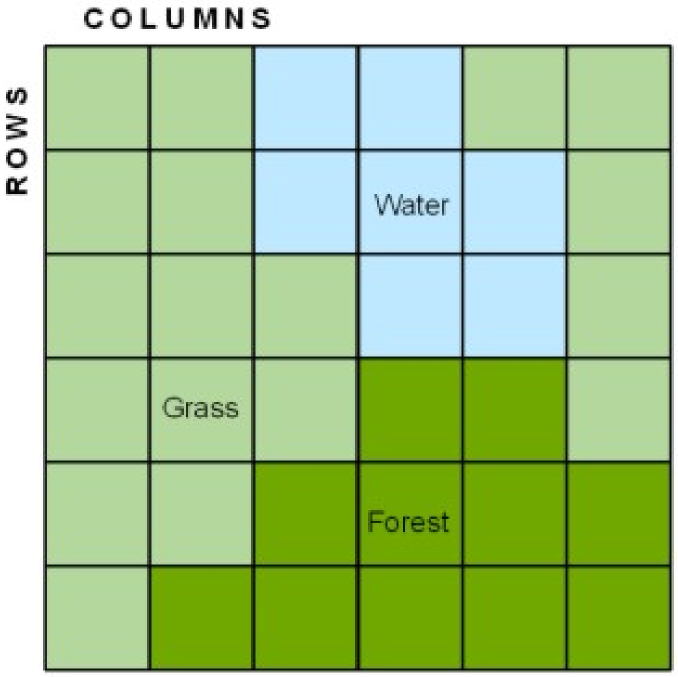
- **Question**: How do we represent the **infinite objects** of the abstract representations (points, lines, fields etc.) **by finite means** (in a computer)?

- **Answers**:
  - **Approximate** the continuous space (e.g., $\mathbb{R}^2$) by a discrete one ($\mathbb{Z}^2$).
  - Use **special encodings**

Concrete Representations - Tessellation

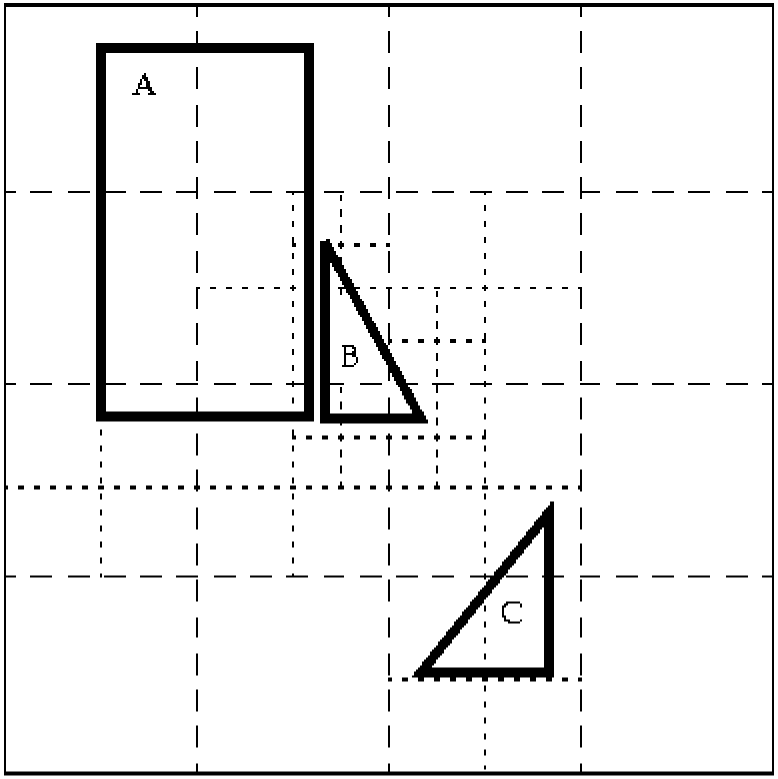
- In this case a **cellular decomposition of the plane** (usually, a grid) serves as a basis for representing the geometry.

- **Example:** raster representation



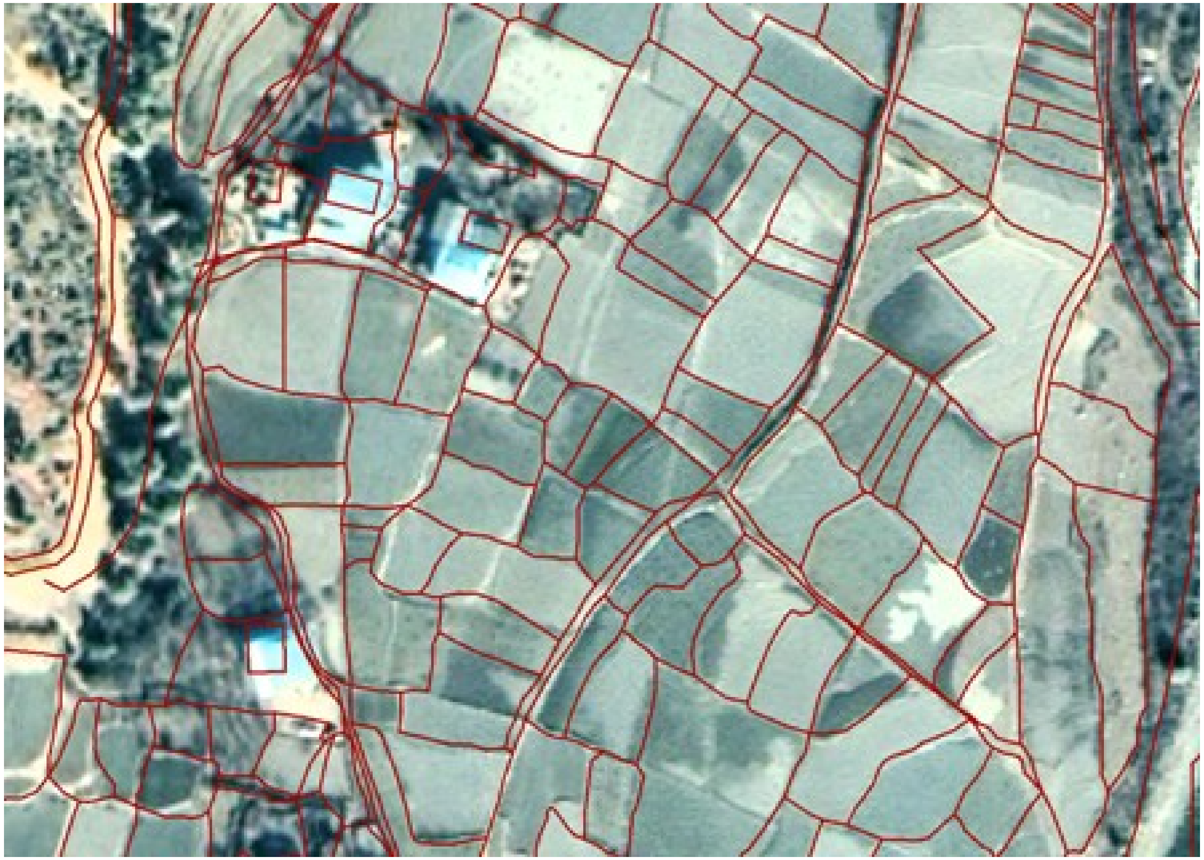
Tessellation (cont'd)

- Tiling (variable sized)



Tessellation (cont'd)

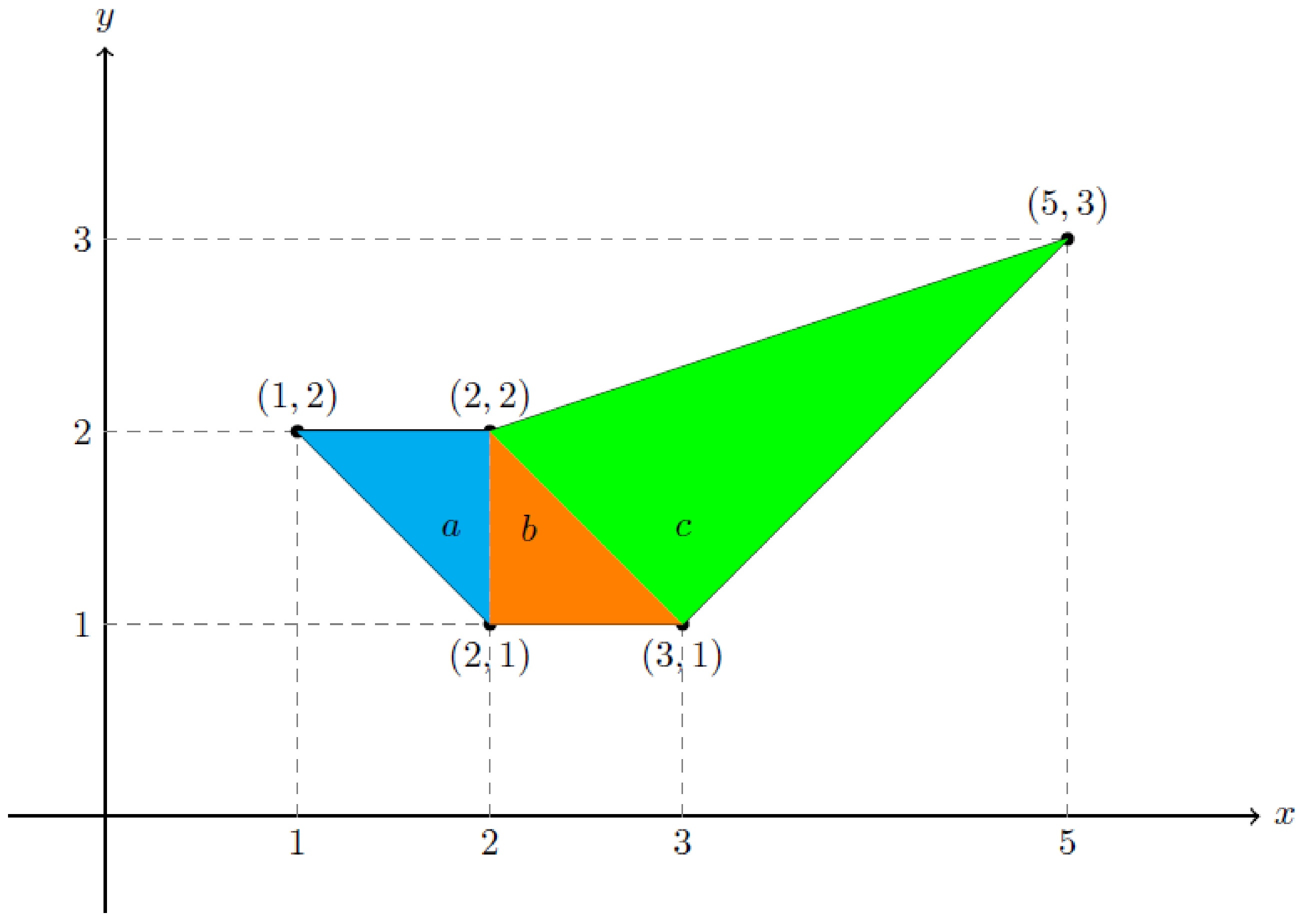
- **Cadastral map (irregular tessellation)** overlayed on a satellite image.



Concrete Representations: Vectors

- In this case objects are constructed from **points** and **line segments** 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.

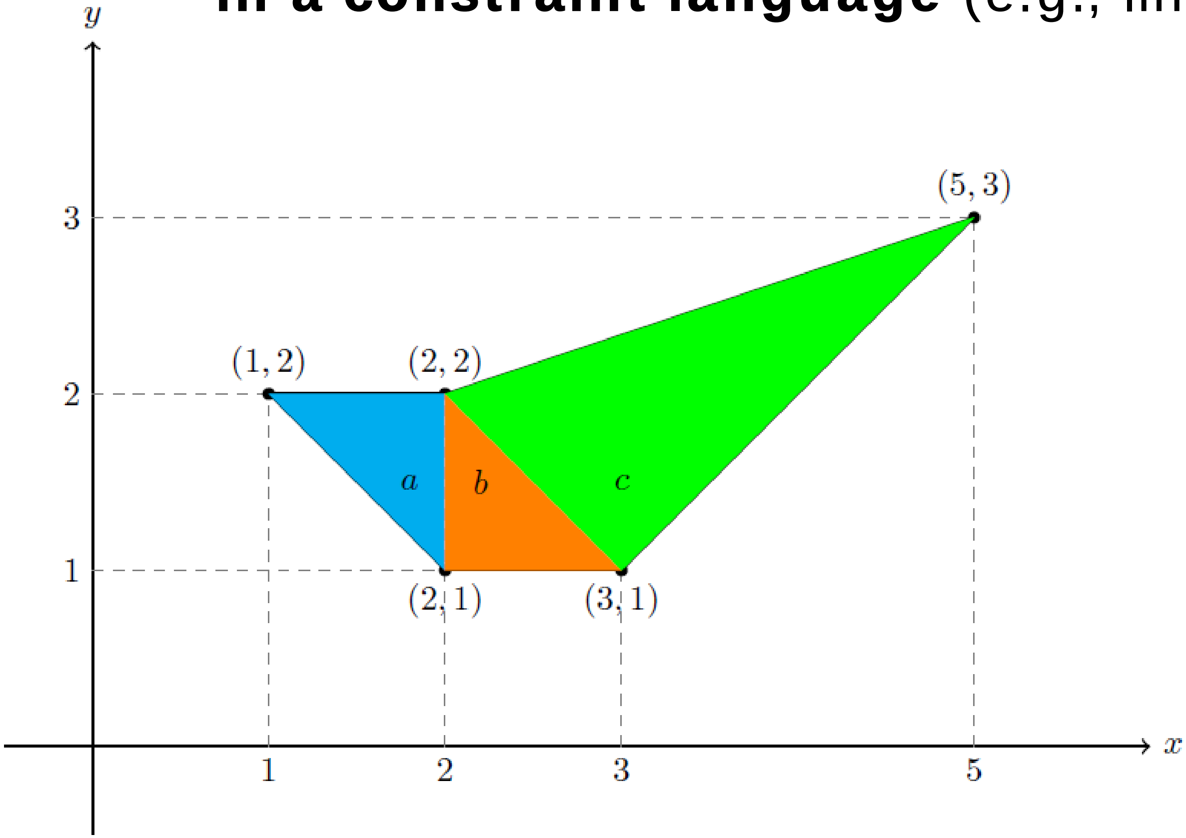
Concrete Representations: Vectors



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

Concrete Representations: Constraints

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



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

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 Feature Access**

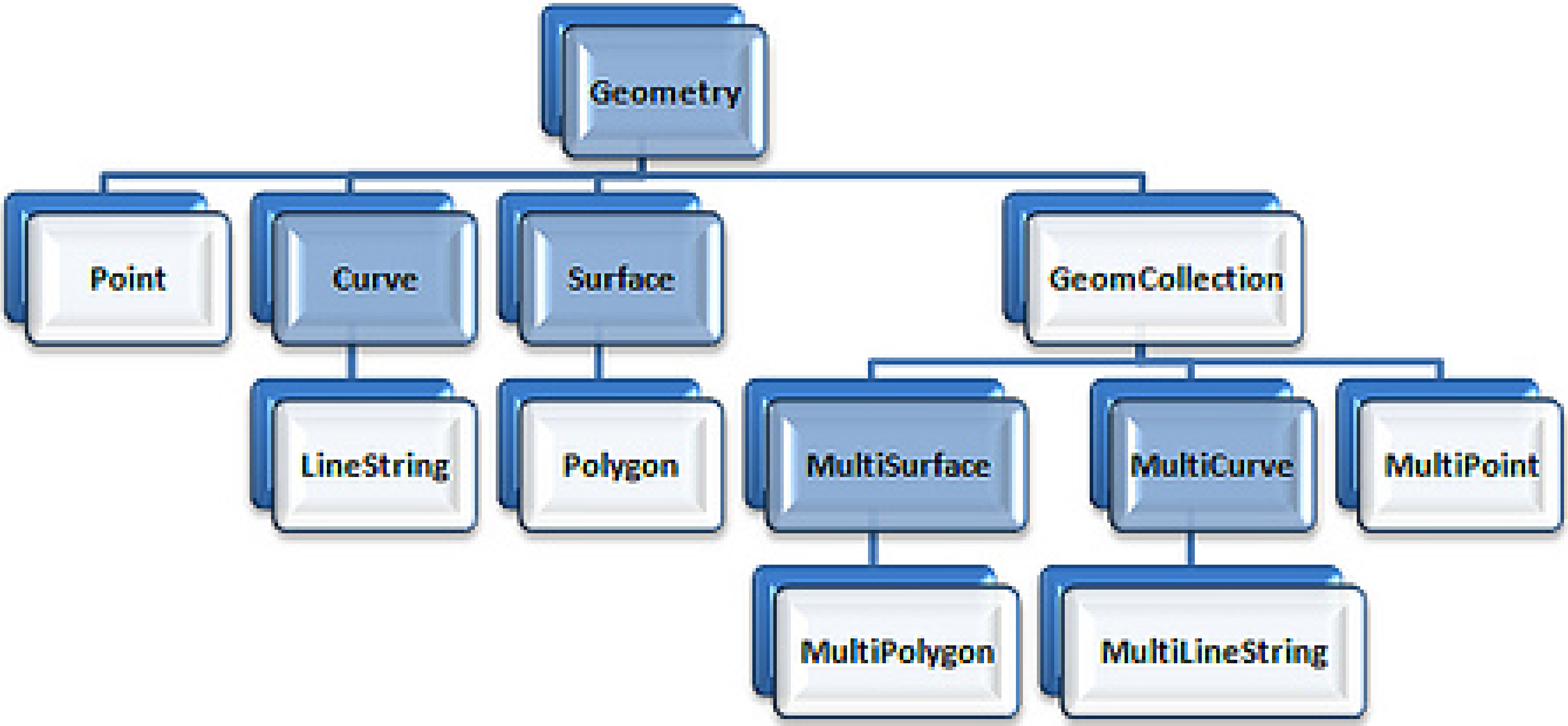
Well-Known Text (WKT)

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

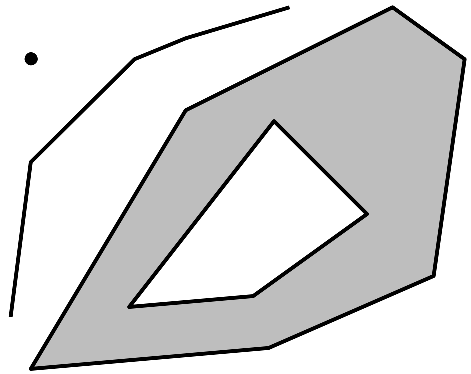
- WKT is specified in **OpenGIS Simple Feature Access - Part 1: Common Architecture** standard which is the same as the **ISO 19125-1** standard. Download from http://portal.opengeospatial.org/files/?artifact_id=25355 .

- 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))
  )
```

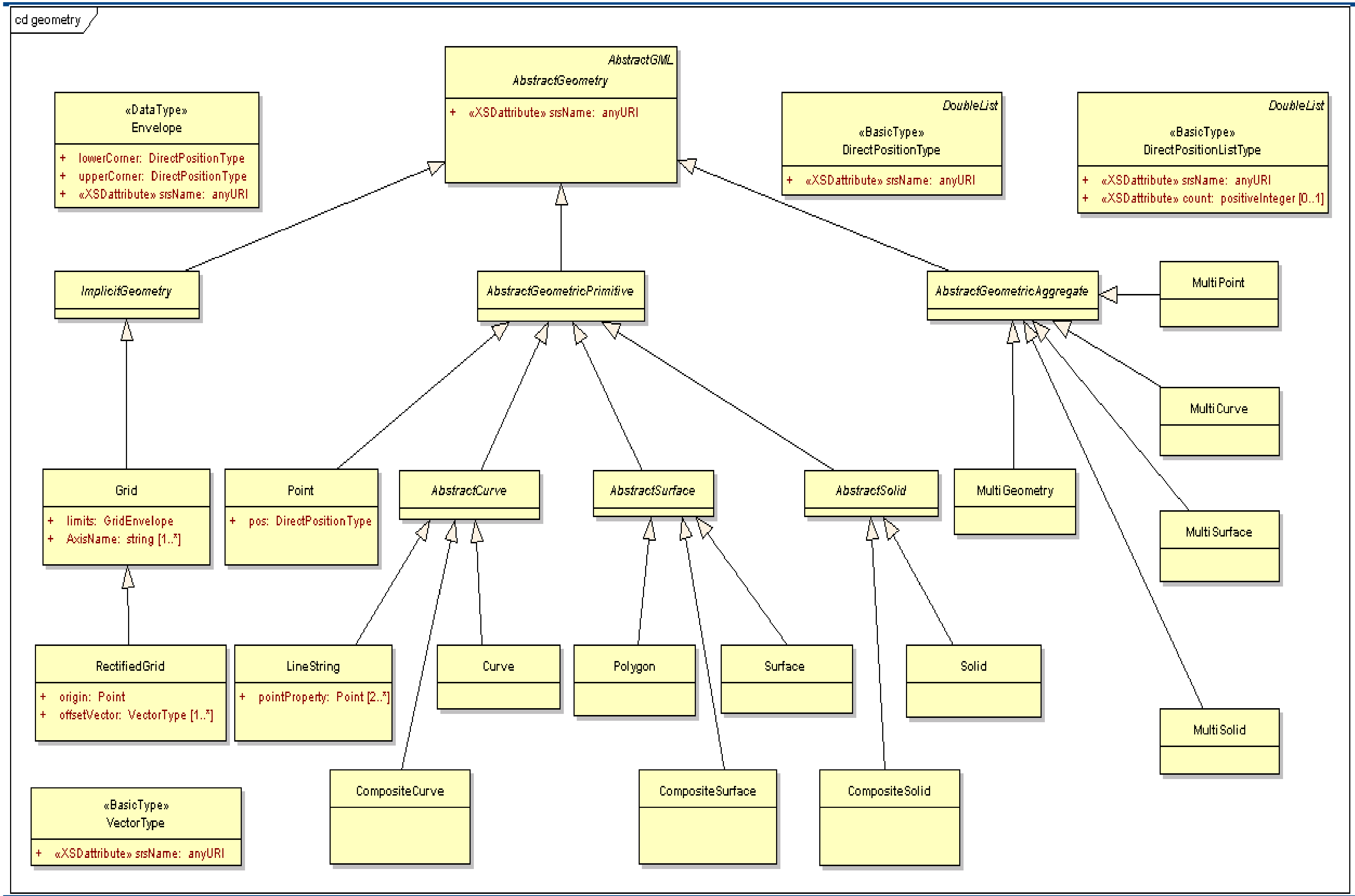
Geography Markup Language (GML)

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

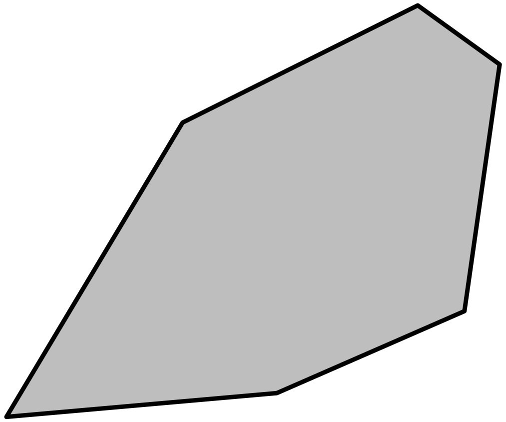
- GML provides XML schemas for defining a variety of concepts: **geographic features, geometry, coordinate reference systems, topology, time** and **units of measurement**.

- **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 (cont'd)

- 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**.

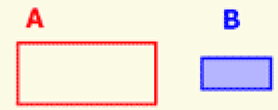
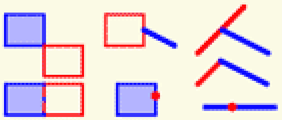
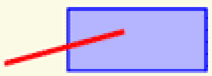
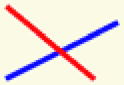
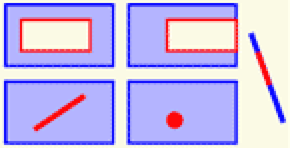
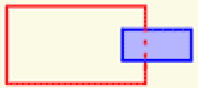
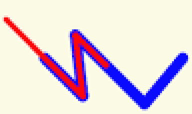
SQL with Geometry Types - Functions

- Functions that **request or check properties** of a geometry:
  - `ST Dimension(A:Geometry, B: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 spatial relationships** 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)	$\begin{bmatrix} 1 & * & T \\ * & * & * \\ T & * & * \end{bmatrix}$	

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.

Conclusions

- **Background in geospatial data modeling**:
  - Why geographical information?
  - Geographical Information Science and Systems
  - Geospatial data on the Web and linked geospatial data
  - Abstract geographic space modeling paradigms: discrete objects vs. continuous fields
  - Concrete representations: tessellation vs. vectors vs. constraints
  - Geospatial data standards

- **Next topic:** Geospatial data in the Semantic Web