# FUNDAMENTAL CONCEPT OF TOPOLOGY

## Unit: III

**Semester: II**

**Paper Code: GIS 07**
**Name of Paper: Geographic Information System**

**PG Diploma in RS & GIS**

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## FUNDAMENTAL CONCEPT OF TOPOLOGY

Topology deals with spatial properties that do not change under specific transformations:

- ✓ The neighbourhood relationships between the areas remain, and the boundary lines have the same start and end nodes.
- ✓ The areas are still bounded by the same boundary lines, only the shapes and lengths of their perimeters have changed.

Topology is the branch of mathematics used to define spatial relationships between entities (ESRI, 1999). GIS conveys information by graphic symbolization (points, lines, and polygons), and retains spatial relationships mathematically through the concept of topology. For example, when you stand on a hill and look down on a landscape, you can easily identify intersecting streets and adjacent properties. The mathematical logic, a computer uses to identify these relationships, is topology. Topology can be ―stored‖ as topological data model (geometric correction of the data) but you can also use topology for analysis on non-topological data. Creating and storing topological relationships have a number of advantages:

- ✓ Data is stored efficiently, so large datasets can be processed quickly.
- ✓ Allows the computer to rapidly determine and analyze the spatial relationships of all features.
- ✓ Ensuring geometric correctness of the data
- ✓ Improved data quality - detecting and correcting digitizing errors and validates data to make
- ✓ them accurate and error-free at all times.
- ✓ Carrying out some types of spatial analysis (selections, network analysis)
    - ▪ Find all light poles that are inside pasture
    - ▪ Find all the plots adjacent to a river
    - ▪ Network analysis
- ✓ GIS queries that can be optimized by pre-computing and storing information about topological relationships. Some common examples include:
    - a. Network tracing (e.g., find all connected water pipes and fittings).
    - b. Polygon adjacency (e.g., who owns the parcels adjoining those owned by a specific owner?).
    - c. Containment (e.g., which manholes lie within the pavement area of a given street?).
    - d. Intersection (e.g., which census tracts intersect with a set of health areas?).

## 1. Topological/ spatial relationships

Topology explicitly defines spatial relationships between connecting or adjacent features in geographic data. The geometric relationship between spatial entities and the corresponding attributes are crucial for spatial analysis and integration in GIS (M. Anji Reddy, 2008). The inclusion of topology into the data model allows a single line to represent the shared boundary to denote which side of the line belongs with which polygon. The spatial relationships are expressed as lists (for example, a polygon is defined by the list of arcs comprising its border).

Topological relationships are built from simple elements into more complex elements:

- ✓ Nodes define line segments
- ✓ Line segments connect to define lines
- ✓ Lines define polygons

Figure No 1. shows eight spatial relationships: disjoint, meets, equals, inside, covered by, contains, covers, and overlaps. How can spatial relationships be used? These relationships can be used, for instance, in queries on a spatial database.

- ✓ Find all light poles that are inside pasture
- ✓ Find all the plots adjacent to a river

Topological relationships can also be used to ensure topological consistency of space. The rules presented and illustrated in Figure No 6 are satisfied for all features in 2D space, then the features define a topologically consistent configuration in 2D space.

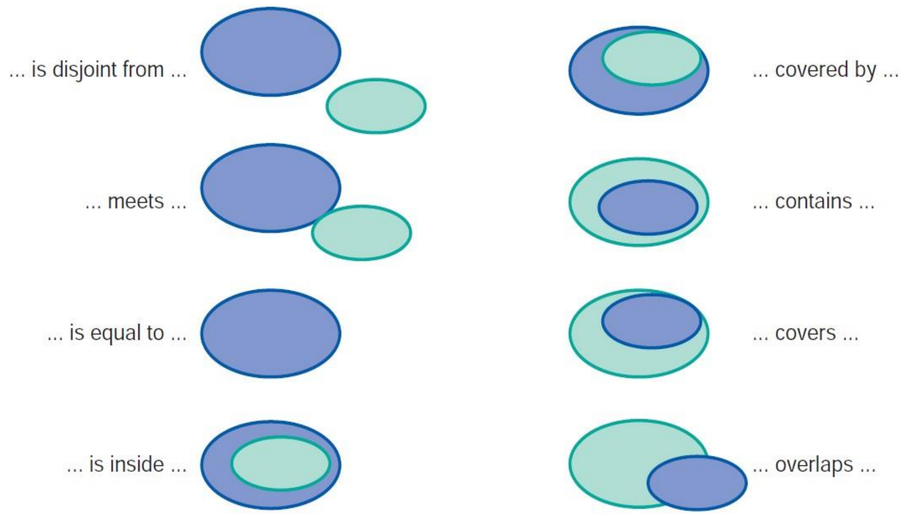



Figure No:1. Spatial relationships between two regions derived from the topological invariants of intersections of boundary and interior

Topology, as it relates to spatial data, consists of three elements: adjacency, containment and connectivity. Adjacency and containment describe the geometric relationships that exist between area features. Containment is an extension of adjacency that describes area features which may be wholly contained within another area feature. These three topological relationships will ensure that:

- ✓ No node or line segment is duplicated;
- ✓ Line segments and nodes can be referenced to more than one polygon;
- ✓ All polygons have unique identifiers; and
- ✓ Island and hole polygons can be adequately represented

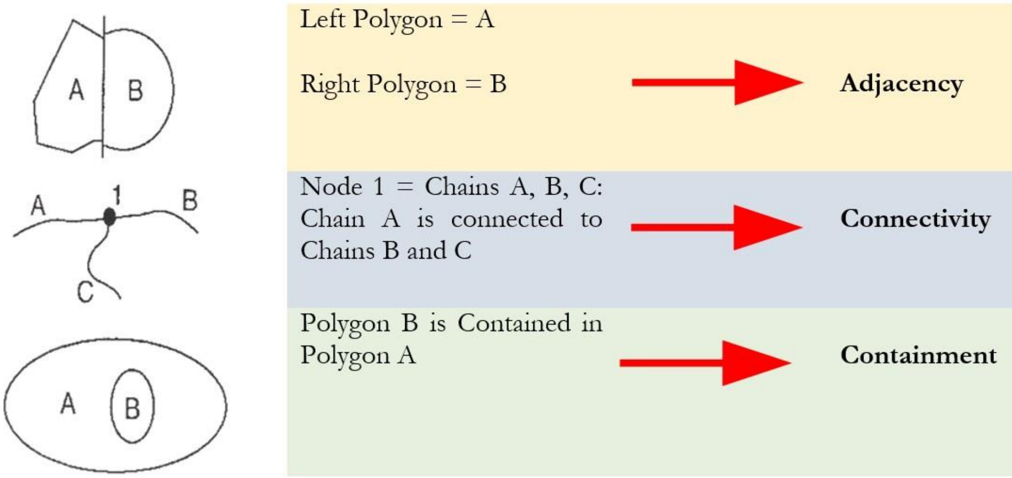



Figure No:2. Topological spatial relationships

## 1.1. Connectivity

Connectivity is a geometric property used to describe the linkages between line features, like road network. Connectivity allows you to identify a route to the airport, connect streams to rivers, or follow a path from the water treatment plant to a house. This is the basis for many network tracing and path finding operations. In the arc-node data structure, arcs connect to each other at nodes and have both a from-node (i.e., starting node) indicating where the arc begins and a to-node (i.e., ending node) indicating where the arc ends. This is called arc-node topology. Arc-node topology is supported through an arc-node list. The list identifies the from- and to-nodes for each arc. Connected arcs are determined by searching through the list for common node numbers. In Figure No 3, arcs 1, 2, and 3 all intersect because they share node 11. It is possible to travel along arc 1 and turn onto arc 3 because they share a common node

(11), but it is not possible to turn directly from arc 1 onto arc 5 because they do not share a common node. Connectivity answers which line segments are connected?" for network analysis.

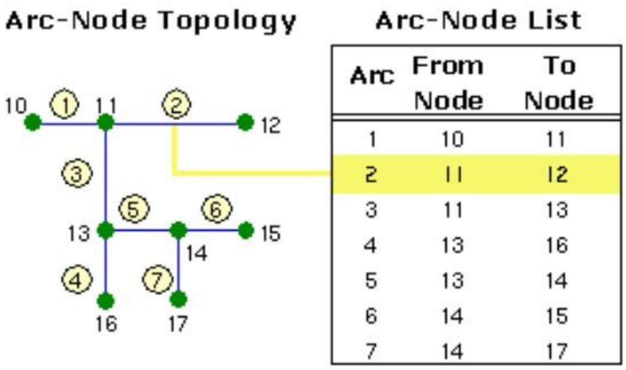
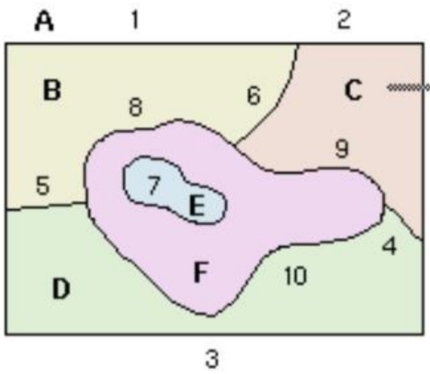



Figure No 3: Arc-Node Topology example

## 1.2. Area definition/ containment

Containment is an extension of the adjacency that describes area features which may be wholly contained within another area feature. For instance, an island defines an inner boundary (or hole) of a polygon. The lake actually has two boundaries: one that defines its outer edge and the island that defines its inner edge. In the terminology of the vector model, an island defines an inner boundary (or hole) of a polygon. The arc-node structure represents polygons as an ordered list of arcs rather than a closed loop of x, y coordinates. The arc-node structure represents polygons as an ordered list of arcs rather than a closed loop of (x, y) coordinates – known as polygon-arc topology.

In Figure No 4, polygon F is made up of arcs 8, 9, 10, and 7 (the 0 before the 7 indicates that this arc creates an island in the polygon). Each arc appears in two polygons (in the illustration below, arc 6 appears in the list for polygons B and C). Since the polygon is simply the list of arcs defining its boundary, arc coordinates are stored only once, thereby reducing the amount of data and ensuring that the boundaries of adjacent polygons do not overlap. Containment answers, "Which spatial features are contained within which?" and used for selection or geocoding



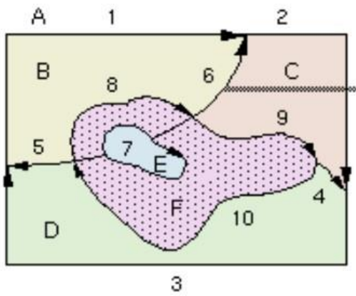

**Polygon-Arc Topology**

| Polygon | Arc List |
|---|---|
| B | 1, 6, 8, 5 |
| C | 2, 4, 9, 6 |
| D | 3, 5, 10, 4 |
| E | 7 |
| F | 8, 9, 10, 0, 7 |

Figure No: 4. Polygon-Arc Topology example

### 1.3. Contiguity or adjacency:

Contiguity is the topological concept that allows the vector data model to determine adjacency of features share a boundary. This is the basis for many neighbor and overlay operations. Areas can be described as being adjacent when they share a common boundary. The from-node and the to-node define an arc. Arcs have direction and left and right sides so the polygons on its left and right sides can be determined. In Figure No 5, polygon B is on the left of arc 6, and polygon C is on the right. Thus, polygons B and C are adjacent. Notice that the label for polygon A is outside the boundary of the area. This polygon is called the external, or universe, polygon and represents the world outside the study area. The universe polygon ensures that each arc always has a left and right side. Adjacency answers "Which polygons are adjacent to which?" and used in spatial analysis of areal data.




**Left-Right Topology**

| Arc | Left Polygon | Right Polygon |
|---|---|---|
| 1 | A | B |
| 2 | A | C |
| 3 | A | D |
| 4 | C | D |
| 5 | D | B |
| 6 | B | C |
| 7 | F | E |
| 8 | B | F |
| 9 | C | F |
| 10 | D | F |

Figure No:5. Topology contiguity example

## 2. Rules of topological consistency:

Topology is a set of rules that models the relationships between neighbouring points, lines, and polygons to determine how they share geometry. There are five rules of topological consistency:

- ✓ Rule 1: Every arc must be bounded by two _nodes ', namely it begins and end node
- ✓ Rule 2: Every arc border two _polygons ', namely its _left 'and _right 'polygons
- ✓ Rule 3: Every polygon has a closed boundary consisting of an alternating (and cyclic) sequence of nodes and arcs.
- ✓ Rule 4: Around every node exists an alternating (and cyclic) sequence of arcs and polygons.
- ✓ Rule 5: -Arcs only intersect at their (bounding) nodes.

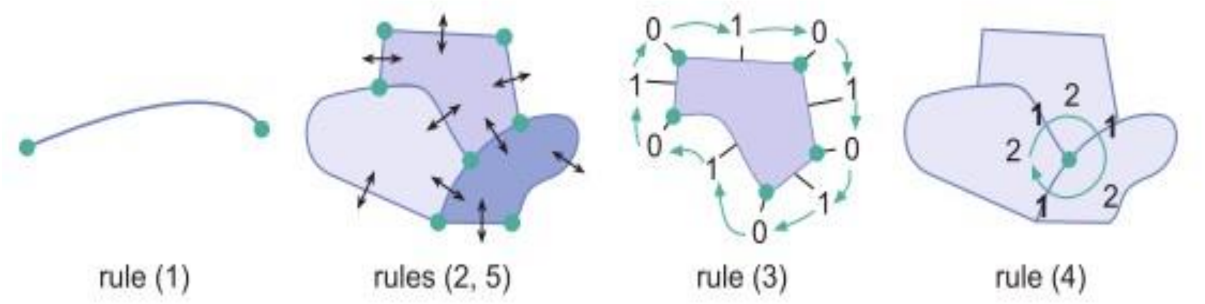



Figure No:6. The five rules of topological consistency in two-dimensional space

## 3.Common topological errors in GIS and detection

Topological information permits an automatic verification of data consistency and detects such errors as incomplete closing polygons during the encoding process. In the case of polygon features, open or unclosed polygons, which occur when an arc does not completely loop back upon itself; and unlabelled polygons, which occur when an area does not contain any attribute information, violate polygon-arc topology rules. Another topological error is sliver polygons, which are small, long and narrow polygons resulting from the overlay operation of polygons with a common but separately digitized boundary. The shared boundary of the two polygons does not meet exactly. In the case of line features, the common error types are undershot and overshoot of lines (see Figure No.7).

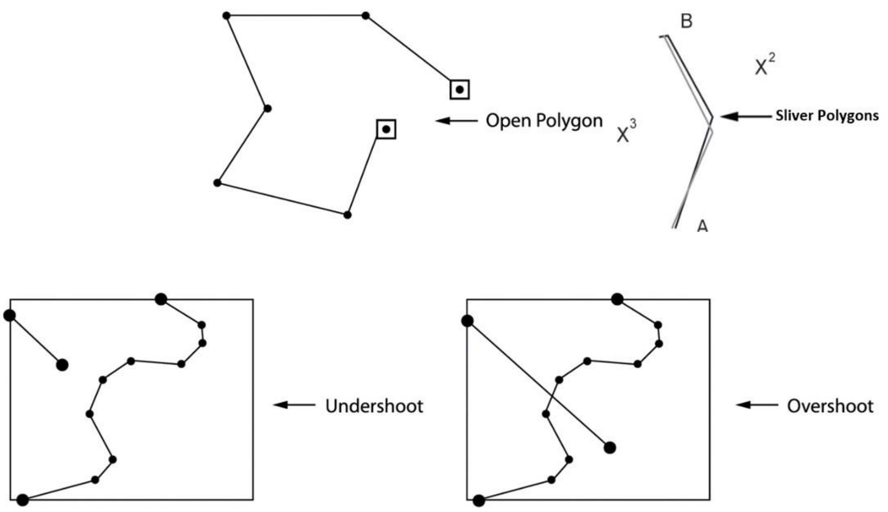



Figure No:7 Common topological errors

## 4. Topology in a geodatabase:

The vector data model in ARC/INFO supports the topological concepts of connectivity, area definition and contiguity. Every topology in the geodatabase is associated with a set of topology rules. Topology rules can be defined for the features within a feature class or alternatively for features between two feature classes. When a topology is validated, the rules are tested. ArcGIS topology begins with the definition of parameters to be included through a wizard in ArcCatalog. ArcGIS topologies have the following characteristics:

They exist within feature datasets

- ✓ All participating feature classes have the same spatial reference.
- ✓ There can be multiple topologies within a data set.
- ✓ Feature classes can only participate in one topology.
- ✓ Feature classes cannot participate in both a topology and a geometric network.
- ✓ A topology can contain multiple point, line, and polygon feature classes.

The ArcGIS Geodatabase topology can be employed to:

1. Mange shared geometry, for example adjacent polygons share edges
2. Define and enforce data integrity rules (no gaps in between polygons)
3. Support topological relationships queries
4. Support sophisticated editing tools
5. Construct features from unstructured geometries

Spatial relationships express specifically how features share coincident geometry along with the rules for the behavior of their spatial representations. For example, some common spatial relationships and rules include the following:

- ✓ Parcels cannot overlap. Adjacent parcels have shared boundaries.
- ✓ Stream lines cannot overlap and must connect to one another at their endpoints.
- ✓ Adjacent counties have shared edges. Counties must completely cover and nest within states.
- ✓ Adjacent Census Blocks have shared edges. Census Blocks must not overlap, and Census Blocks must completely cover and nest within Block Groups.
- ✓ Road centrelines must connect at their endpoints.
- ✓ Road centrelines and Census Blocks share coincident geometry (edges and nodes).

Each of these situations defines a potential case for using topology rules to maintain data integrity.