UNIT 9

DATA STANDARDS

Structure

9.1 INTRODUCTION

The data standards and topological modelling are important aspects to be known before creating a GIS database. GIS is capable of spatial analysis and it is possible only when the data are as per standards. Data standards are required for any GIS users since the process of standardisation helps to integrate with other GIS, data sources and hardware. Similarly, spatial analysis is possible only when there is topological data or there are topological relations among various spatial features in a data. It is indeed a mathematical application used to express the spatial relationships. If topological data structure is lacking in a vector GIS, it is difficult to perform manipulation and analysis of data.

In the previous unit you have read about the methods of data input, existing data and its conversion, creation of data, input devices, reference frameworks, georeferencing and map digitisation. In this unit, we will discuss the data standards and interoperability. We will also discuss topological models, connectivity, area definition, contiguity, topological relationship and topological rules in GIS.

Expected Learning Outcomes

After studying this unit, you should be able to:

- ❖ describe data standards and interoperability;
- ❖ illustrate topological models;
- ❖ explain connectivity, area definition and contiguity; and
- ❖ know topological relations and topology rules.

9.2 GIS DATA STANDARDS

Spatial data standards are a set of guidelines that must be followed to create, share, and use data in a way that ensures complete data compatibility throughout integration and usage. GIS combines diverse datasets to provide a complete picture of any scenario or location so that users may make better decisions based on spatial links, linkages, and patterns. This is made feasible by using data sets that are of the same quality. Other aspects of spatial data standards that are generally accepted by all data producers and users include data source, format, coordinates and projection systems, scale, themes, attributes, methodology/technology, quality control, deliverables or final output, data exchange/sharing formats, metadata, documentation, and certifications which are commonly agreed by all data creators and users.

9.2.1 Definition and Concepts

GIS data standards as defined by the International Organisation for Standardisation as "documented agreements containing technical specifications or other precise criteria to be used consistently as rules, guidelines, or definitions of characteristics, to ensure that materials, products, processes and services are fit for their purpose" (ISO/IEC Guide 2, 1996). The standards have also been developed and defined for various aspects of Geographical Information System through ISO/TC 211 GEOGRAPHIC INFORMATION/ GEOMATICS which says that "the foremost aim of international standardisation is to facilitate the exchange of goods and services through the elimination of technical barriers to trade" (www.isotc211.org). Some of the standards recorded in GIS literature (Bolstad, 2008; Lo and Yeung, 2009) are discussed below:

- **Data Creation** are the file formats like shapefile, E00, dwg, dlg, dgn, etc.
- **Data Quality** include the spatial, logical, attribute, etc.
- **Spatial Reference** are projection and coordination system and accuracy standards comprise positional, thematic and attribute accuracy.
- **Analysis** defines the methodology for data analysis and data transfer formats are like Spatial Data Transfer Standards (SDTS), DXF™ and GML
- **Documentation** captures the whole process ranging from beginning to end like project details, data source, methodologies, quality check and certification procedures, and delivery formats, etc.

For data usage in planning and administration, respective departments typically need to access the databases of various departments. For example, several departments' operations depend heavily on data related to land records and

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land use/land cover. Even the banks are given access to them for loans and agricultural credits. Similarly, the disaster management department would need databases from many organisations to deal with both man-made and natural calamities. The largest issue with data sharing is the incompatibility of various databases created by various agencies. These maps or data are created at various scales, dates, and projections. Same way, different GIS programmes used to build databases for varied purposes which cause conversion issues. These examples make it obvious that different data formats and standards (scale and time) make GIS very difficult to integrate databases for analysis and end goal. Hence, until and unless all databases are created in uniform standard, they cannot be used seamlessly by various departments for different purposes. To overcome the problem of data integration and interoperability, international and national level data standards had been defined to make data seamless such as Global Spatial Data Infrastructure (GSDI), Spatial Data Infrastructure (SDI) and National Spatial Data Infrastructure (NSDI). The geospatial community has its own International Organisation for Standardisation (acronym as ISO) Committee to set guidelines for geospatial data publishers. The Open Geospatial Consortium (OGC) and the ISO Committee collaborate to develop data standards. The OGC and ISO had collaborated to create at least 90 current standards for geospatial data publishing. For high accuracy and seamless data sharing, today the most widely used reference system is UTM - WGS 84 / GCC-WGS 84. It is important for GIS data to be shared among various users and to be interoperable. Hence, one must define the open standards for high interoperability across different platforms, databases, development languages and applications. Recent major programs in India, for example, PMGSY National GIS, MGNREGA, Smart City Yojana, etc., are being created with high standards.

Let us discuss some examples of standards for GIS data formats and GIS services.

GIS standards for data formats

- **KML** (Keyhole Markup Language) express geographic data, labels, and symbology in 2D and 3D for web map and globes.
- **GPKG** (GeoPackage) is defined by the Open Geospatial Consortium. It is an open, non-proprietary, platform-independent and standards-based data format for geographic information systems.
- **AIXM** (Aeronautical Information Exchange Model) is a global standard for digital aeronautical data.
- **IHO S-57/ENC** (Electronic Nautical Charts) is a global standard for electronic navigational charts and marine environments defined by the International Hydrographic Organisation.

GIS standards for web services

GIS service standards are used to transfer spatial data smoothly via the web or remote access to store on a web server. They enable users to interact with data, generally through web clients, on a live and real-time basis. This contains viewing maps, accessing, and querying data, analysing, and downloading GIS data (GIS standards, 2018).

Example of web services:

- **WMS** (Web Map Service) for sharing maps across the web.
- **WFS** (Web Feature Service) for sharing feature data across the web for direct access to geospatial data.
- **WMTS** (Web Map Tile Service) for sharing pre-cached map files across the web for use as base maps.
- **WPS** (Web Processing Service) for sharing geoprocessing services across the web for performing dynamic geospatial analytics.
- **WCS** (Web Coverage Service) for sharing geospatial data stored and managed as coverage across the web.
- **CSW** (Catalog Service) for the Web for sharing geospatial information, typically metadata, stored in XML across the web.

9.2.2 Interoperability

Interoperability refers to the flexible movement of a GIS database/data in terms of its utilisation, allowing any GIS professional to open and analyse it using any software. GIS applications and services should be able to read and write a variety of common data formats. Geospatial data should be stored in GIS applications using data format and standards to ensure consistency. Data should be transferable between systems. Tools for data validation, transfer, and distribution may require transformation and loading. Interoperability enables GIS databases to be opened, modified, and analysed in any GIS software. In initial phase of GIS development, GIS database used to be proprietary, where none other than creators were able to use the data. Gradually, a non-profit organisation was constituted in 1994 known as Open GIS Consortium (now Open Geospatial Consortium (OGC)) to develop a common GIS standard for database creators, software providers and others involved in the use of GIS. Hence, data created anywhere by anyone in any open standard software may be used by others. For example, Government of India (GOI) published geospatial data sharing policy (Open Data License) which includes interoperability of data. Details are available at website: **https://data.gov.in/government-open-data-license-india**. Further, the guidelines for acquiring and producing geospatial data and geospatial data services including maps, is available through website: **https://dst.gov.in/sites/default/files/Final Approved Guidelines on Geospatial Data_0.pdf**.

SAQ I

a) Define GIS data standards.

b) Name any two major programmes initiated by Government of India that are being operational with high GIS data standards.

c) What does KML stand for?

d) What is the main role played by the Open Geospatial Consortium (OGC)?

9.3 TOPOLOGICAL CONCEPTS

You have read about definition and concepts of GIS data standards and interoperability in the previous section. Now let us discuss about the topological concepts.

Topology is a concept involving mathematical formula and procedures which establishes spatial relations like connectivity, adjacency and coincidence among geographical features. In other words, topology is the spatial relation among geographical features, e.g., point, line and polygon in GIS. It determines the relationship between connecting or adjacent features. These are complex elements with coordinates. It contains the information on how points, lines and polygons are spatially arranged in terms of location, distance and direction. It also defines the common boundaries of different areas or polygons. Spatial queries based on adjacency with left and right locations and connectivity like distance between two points or locations, buffering, intersecting, union, etc., are possible only with topological data as these data are spatially related to each other.

Topological concepts are used to create a system that provides the following (e.g., Kainz 2004; Hoel et al., 2003; Ramage and Woodsford, 2002; Egenhofer et. al. 1989):

- Spatial data editing and clean up
- Improved data consistency
- Reduction or elimination of redundancy of spatial data
- Enhanced spatial data analysis
- Rapid spatial data retrieval
- Definition and enforcement of data integrity rules
- Management of shared geometry
- More efficient storage of spatial data
- Easier implementation of certain spatial business rules in the database
- Improved management of hierarchical geographic relationships
- A more straightforward way to address coordinate precision and tolerance issues that sometimes lead to gaps or slivers
- Every edge must be bounded by two nodes (start and end nodes)
- Every edge has a left and right face
- Every face has a closed boundary consisting of an alternating sequence of nodes and edges
- There is an alternating closed sequence of edges and faces around every node
- Edges do not intersect each other, except at nodes

9.3.1 Topological models

You have read the topological concepts. Let us discuss various topological models used in GIS.

Spaghetti Data Model

You have been introduced to spaghetti data model in Unit 6 of this course. Now let us know about this model in detail. Spaghetti data model also known as 'Basic topological model' is the most basic vector data structure. Each point, line, and/or polygon feature in the spaghetti model is represented as an unstructured string of X, Y coordinate pairs (or as a single X, Y coordinate pair in the case of a vector image with a single point) (Fig. 9.1). One may imagine that each line in this model is a single spaghetti strand that is added in successive layers to create complicated shapes. It is noteworthy that in this paradigm, any adjacent polygons must be composed of their own lines, or strands of spaghetti. Every polygon has to be individually defined by its own set of rules.

The spaghetti model does not explicitly encode spatial relationships; rather, they are revealed by the locations of the lines or strands of spaghetti, notwithstanding the location labels attached to each one. Since there is a lack of topological data as a result, it is difficult for the user to perform measurements or analyses. Therefore, if any sophisticated analytical methods are applied to vector files constructed in this way, the processing needs are very high. The spaghetti data model is a straightforward structure, however, enables effective map and graphic reproduction because plotting and printing do not require this topological information.

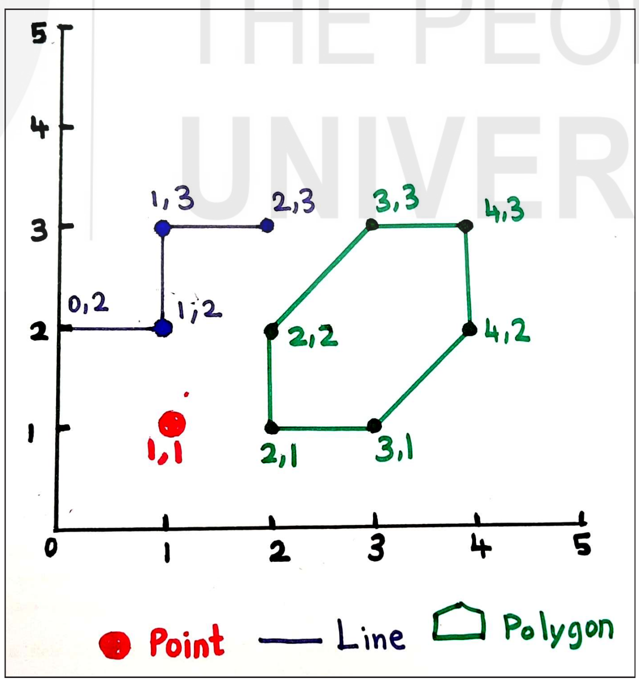

Fig 9.1: Spaghetti data model showing point, line and polygon represented in X, Y coordinates.

According to Wu Bo (2011), the spaghetti model has the advantages and limitations as listed below:

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Advantages

- Suitable for computer-assisted cartography where topological relationships are not required.

Disadvantages

- Spatial relationships are not rearranged.
- The shared boundary between two nearby polygons is twice stored
- Not efficient for most types of spatial analysis

TIGER Model

Topologically Integrated Geographic Encoding and Referencing (TIGER) model was developed by the US Bureau of Census. It is an upgrading of the Geographic Base File/Dual Independent Map Encoding (GBF/DIME) data structure and standardisation. It is an early example of topology's use in the preparation of geospatial data. The US Bureau of the Census utilised this data structure or format for the census in 2000. Data from TIGER GIS is interlocked into a single physical file. It combines the properties of spatial features with their underlying geometry. Data links to points and lines link to points. Additionally, polygons are connected by lines.

The TIGER file encompasses the fundamental theory of 0, 1 and 2-cells, but as a particular implementation of the theory. The TIGER file design includes certain rules and conventions that are added to the theory. The model is specifically derived from combinatorial topology, a branch of mathematics where the terms 0-cell, 1-cell, and 2-cell are used in place of point, line, and polygon. A combinatorial topology defines the set of global and local relationships that exist between these units. The ability to infer relationships between cells means the ability to infer relationships between features represented by cells accordingly.

For example, a 1-cell separates two different 2-cells, such a 1-cell is called boundary 1-cell (Fig. 9.2). A 1-cell that is inside of a 2-cell is called an internal 1-cell and bounded on both its left and right sides by the same 2-cell. The user can quickly recognise an address on the right or left side which is the main benefit of this data structure (Fig. 9.3).

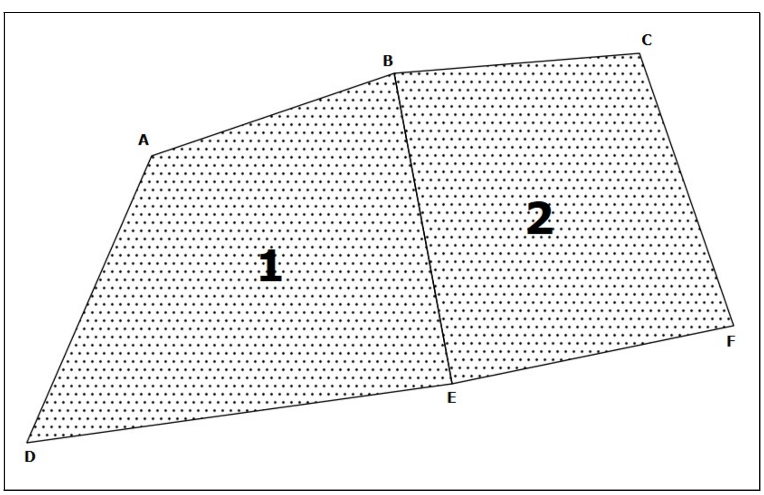
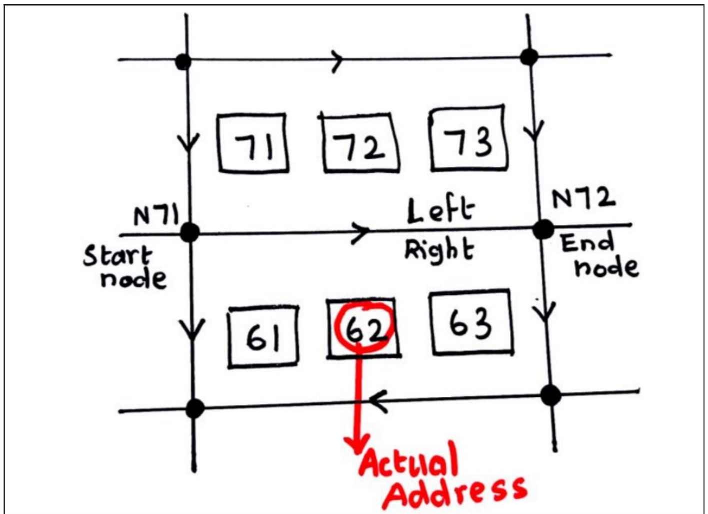


Fig. 9.2: Topology in TIGER database.



ID	Start Node	End Node	Address Range	
			Left	Right
1	N71	N72	71 to 73	61 to 63
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.

Fig. 9.3: Topology in TIGER database.

According to Wu Bo (2011), the TIGER model has the advantages and limitations listed below:

Advantages

- Automatically checks for missing segments and other errors.
- Location information (lane address) can be derived directly from this model.

Disadvantages

- Lines are not saved in any order.
- Comprehensive search to get a specific line segment and a full search for the entire file is required.

POLYVRT Model

POLYVRT (POLYgon conVeRTer) was presented by Peucker and Chrisman in 1975. POLYVRT model is more efficient for the storage of vector data. It supports arc-node topological relationships. Vector entities are stored explicitly and separately in a hierarchical data structure. When the features are digitised, each arc is digitised between nodes in a predictable direction, with a start node and a unique identification number. Arcs may be referred to as edges and sometimes as chains (Fig 9.4).

Advantages

- More efficient in retrieving than simpler topologic structures.
- Selective retrieval of only specific classes in the data model at a time.
- The queries concerning the adjacency of polygons need only to deal with the polygons of interest. Only individual chains which bound the polygons of interest are retrieved.

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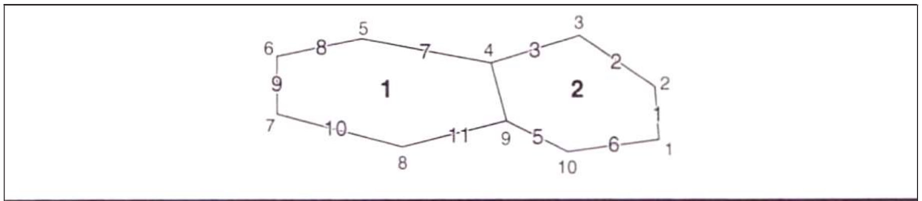

Polygons		Chain list	Chains						
Polygon name	Polygon pointer	Chain list	Chain name	Chain points (X,Y strings)	Chain length	From node	To node	Left polygon	Right polygon
1	.	4	4	x,y, x,y ...	.	4	9	2	1
2	.	5	5	.	.	.	.	.	.
.	.	6	6	.	.	.	.	.	.

Fig. 9.4: POLYVRT model representation. (Source: modified after Demers, 2005)

Disadvantages

- The physical separation of files causes the need for a link or pointer structure.
- Incorrect pointers can be extremely difficult to detect or correct.
- Initial generation of this structure can be cumbersome and time consuming.

9.3.2 Connectivity

You have read about the topological models in GIS. Now let us discuss the importance of connectivity in topological modelling.

Connectivity is a topological relationship that enables arcs to connect to each other through nodes. It has arc-node topology, where vertices define the shape of the arc and nodes define the start and end point of an arc or intersections of the arc (Fig. 9.5). Connectivity is primarily used to find out the shortest path or best route (route optimisation) in terms of distance, time taken, traffic volumes, impedance, etc. Apart from transport analysis and fleet management, it is also applied to all linear features like hydrological features (rivers and streams), telephone network, power line network, sewerage network, etc. for planning, monitoring and management.

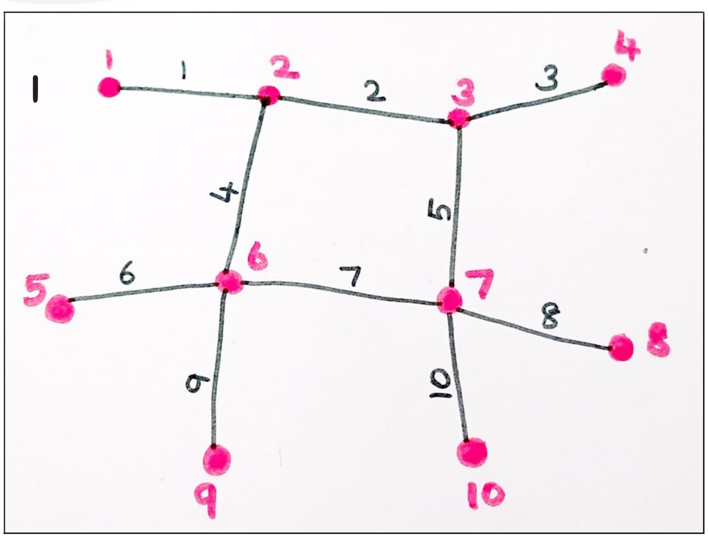

Fig. 9.5: Arc-node topology.

9.3.3 Area Definition

Area definition is the concept defined by topology. An area definition is performed by separating a specific area that differs from the surrounding space. It is defined by a closed polygon. The area is a contiguous homogeneous space where the homogeneity is found in terms of physical, political and/or socio-economic factors. In GIS, various geographical features are delineated separately based on some homogeneity criteria or some uniqueness. For example, based on physical features like land use (built-up area, agricultural fields, forest area and water bodies), land parcels, or administrative boundaries, etc. In GIS, an area is represented by the vector model in which a polygon enclosed by one or more boundary lines (arcs) using polygon-arc topology as shown in Fig. 9.6.

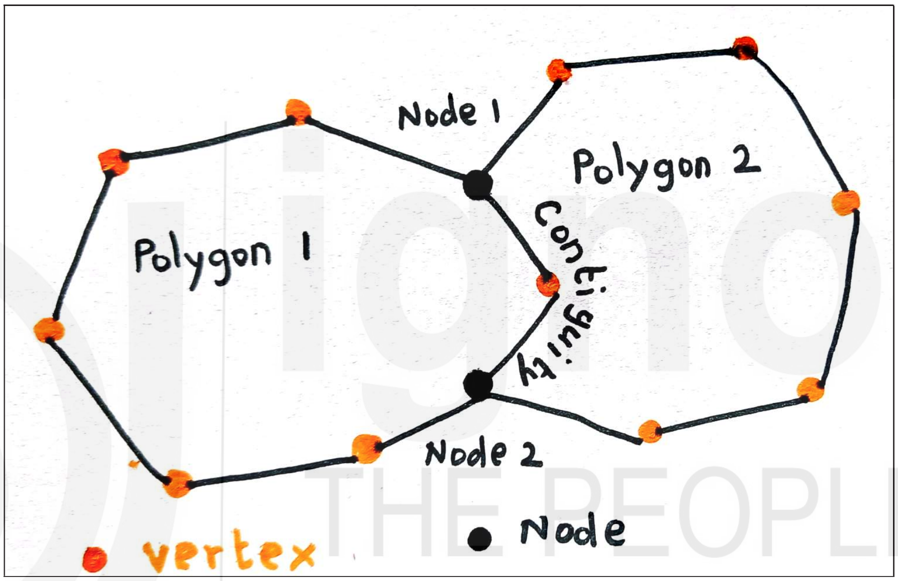

Fig. 9.6: Polygon-arc topology showing an area with polygon 1 and 2.

9.3.4 Contiguity

Contiguity is the concepts defined by topology. The contiguity is defined as the continuity of space without any gap sharing a common boundary as obvious component. Contiguity is the geographical concept where areal features are continuous. In GIS and topological sense, contiguity is the spatially continuous areas without any gap or disjoint. It basically defines the adjacency in topological data model. Contiguous areas must be connected to each other spatially. For example, two areas are contiguous if they have or share the common boundary. This concept of adjacency or contiguity enables many neighbourhood and overlay operations in GIS. Based on this concept, contiguous areas are dissolved on certain common properties. For example, the continuous areas with common soil type may be dissolved into one area based on the contiguity. If arcs and polygons are taken together, the adjacent areas are separated by a common boundary (arc), which is topologically defined as left and right polygons of the common boundary arc. In contiguity, every arc has a direction, the spatial information maintains the polygons on the left and right side of each arc and this way the spatial relations are established. The direction of arc defines the left and right place of a polygon that has already been illustrated in the Figure 9.6.

9.3.5 Topological Relationships

A distinct advantage of using topology derives from the relationships that are maintained between the “topological primitives”, i.e., nodes, edges, and faces. These relationships speed queries concerned with adjacency, connectivity, and containment of features or topological primitives. For example, from a connecting node, it is straightforward to retrieve all the edges that connect to it, through a simple database query. Similarly, it is a simple query to retrieve the faces on either side of an edge as well as to retrieve all the edges belonging to a face. More complex queries are also straightforward, such as retrieving all the faces that share a given node or all the faces adjacent to a given face. Similar operations are available to determine adjacency, connectivity, and containment of features. Again, these are available as direct database queries, without having to resort to expensive spatial data searches.

Egenhofer et al (1989) enumerated all the possible topological relationships that can occur between two spatial entities by examining the combinations of the intersections of the boundaries and interiors of the two objects. The best examples of possible relationships for objects of same dimension are shown in Figure 9.7 to 9.13.

- Equal - determine spatial equality of two geometries (Fig. 9.7).
- Intersects - assess whether the interiors of the geometries intersect (Fig. 9.8).
- Disjoint - If two geometries are disjoint, they do not intersect, and vice-versa (Fig. 9.9).
- Overlap – any two objects overlap (Fig. 9.10).
- Touch – examine whether two geometries touch at their boundaries, but do not intersect in their interiors (Fig. 9.11).
- Within/Contains – test whether one geometry is fully within the other (Fig. 9.12).

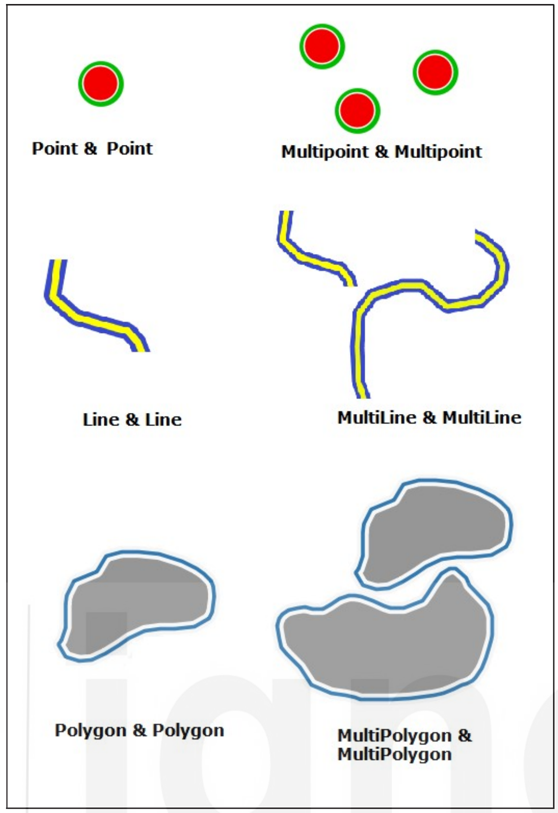

Fig. 9.7: Equal topology relationship. (Source: modified after Galdi 2005)

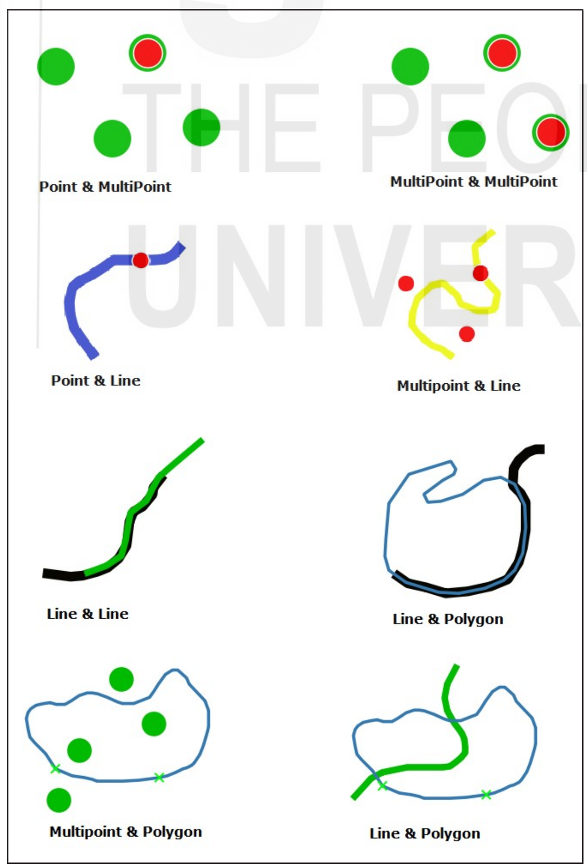

Fig. 9.8: Intersects topology relationship. (Source: modified after Galdi 2005)

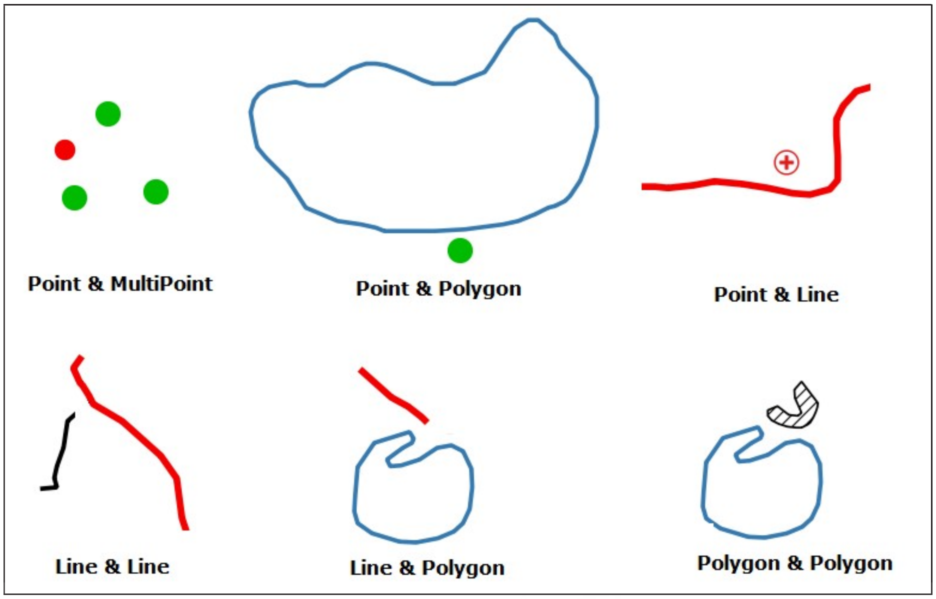

Fig. 9.9: Disjoint topology relationship. (Source: modified after Galdi 2005)

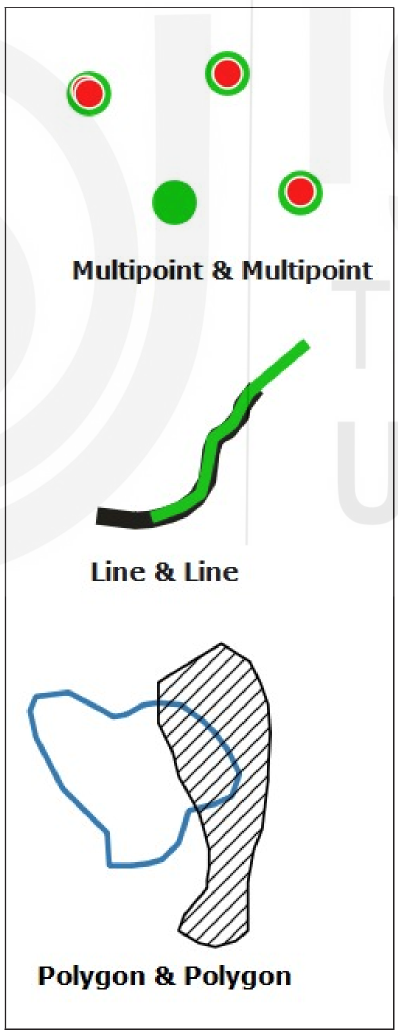

Fig. 9.10: Overlap topology relationship. (Source: modified after Galdi 2005)

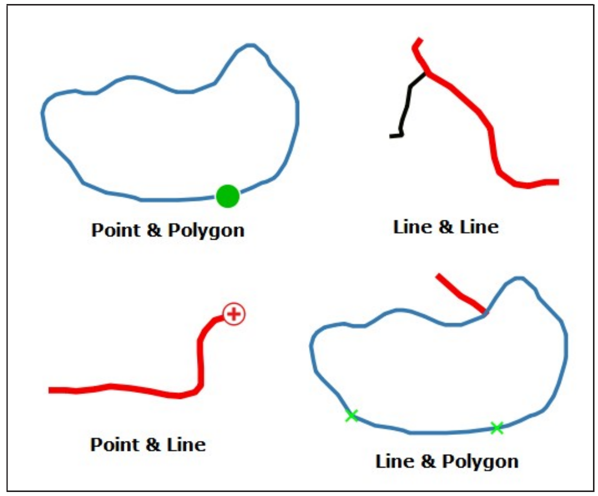

Fig. 9.11: Touch topology relationship. (Source: modified after Galdi 2005)

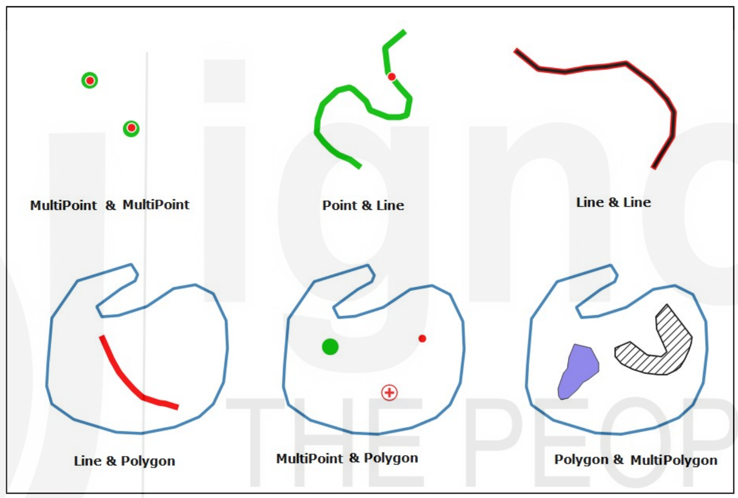

Fig. 9.12: Within/Contains topology relationship. (Source: modified after Galdi 2005)

- Cross topology relationship determines for the spatial data, if the intersection results in a geometry whose dimension is one less than the maximum dimension of the two source geometries and the intersection set is interior to both source geometries (Fig. 9.13).

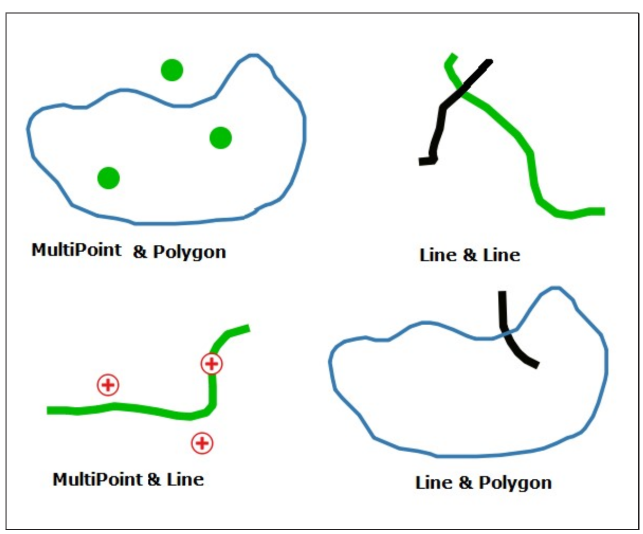

Fig. 9.13: Cross Topology relationship. (Source: modified after Galdi 2005)

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Calculation of these relationships and other functionality is possible in a database that does not utilise topology and stores a complete set of coordinates explicitly to represent each feature. However, calculations in such a database require spatial searches and comparisons rather than more efficient database queries. With the refined use of spatial indices, such as R-trees, spatial searches are getting more efficient, but they still are significantly more time-consuming than other types of data access. In addition to faster retrieval and more efficient data storage, topology also provides for more efficient and effective data cleansing, error detection, and data integrity. If the topology is stored persistently, storage of redundant data is greatly reduced or eliminated, which simplifies enforcement of data consistency. Topology allows for easy detection of gaps and overshoots, and helps prevent inadvertent overlap of areal features. It also facilitates implementation of a snapping and tolerance system to avoid slivers, arbitrarily close nodes, very small polygons, and so for.

9.3.6 Topology Rules

Topology is a set of rules that describes the relationships between neighbouring points, lines, and polygons and is used to model the connections between various geometrical objects (e.g., SPMUR, 2020). Topological consistency is described via way of means of a few rules (Fig. 9.14). Let us discuss these rules in detail.

- Rule-1: Every arc must be enclosed by two nodes, specifically its beginning and ending nodes
- Rule-2: Each arc is bordering two polygons, i.e., left and right polygons
- Rule-3: Each polygon has a closed boundary that is made series of nodes and arcs
- Rule-4: A sequence of arcs and polygons alternates (and cycles) around each node
- Rule-5: Arcs intersect only at their (boundary) nodes

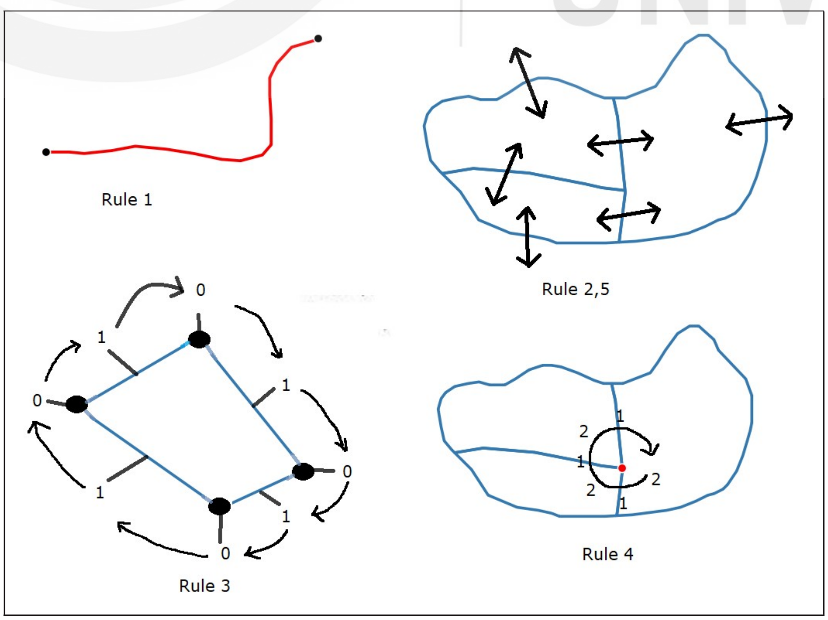

Fig.9.14: Topological consistency.

Spatial relationships specify the rules for sharing the coincident geometry of features and their spatial representation behavior. Some common spatial rules and relationships include the following (e.g., SPMUR, 2020):

- Parcel must not overlap and adjacent parcels share a common boundary
- Streamlines must not overlap and must connect at their endpoints
- Adjacent counties share borders and counties must have complete state coverage and nesting
- Adjacent census blocks have common edges and census blocks must not overlap
- Blocks must completely cover and nest block groups within block groups
- Road centerlines must be connected at their endpoints
- Road centerlines and census blocks have corresponding geometry (edges and nodes)
- Each of these situations defines a potential case for maintaining data integrity using topology rules

The following list shows few examples of where topology rules can be defined for real world features in a vector map:

- A municipality map's area borders must not cross
- A municipality map cannot include gaps at the area edges
- Property boundary polygons must be sealed
- It is not permitted to cross the border lines in any direction
- Contour lines must not cross each other

SAQ II

a) Topology in GIS is the _________among geographical features like point, line and polygon.

b) Spaghetti model is represented as an unstructured string of _____________.

c) _____________is an upgrading of the Geographic Base File/Dual Independent Map Encoding (GBF/DIME) data structure and standardisation.

d) POLYVRT model is more efficient for the storage of _______________.

e) Contiguity is the spatially continuous areas without any ___________.

9.4 SUMMARY

Let us sum up what you have studied in this unit:

- Spatial data standards are a set of guidelines that are followed to create, share, and use data and to ensures complete data compatibility throughout integration and usage. GIS service standards are used to transfer spatial data smoothly through web or remote access to store on a web server.

- Interoperability signifies the flexible movement of a GIS data in terms of its utilisation, permitting it to open and analyse using any software.
- Topology is the spatial relation among geographical features such as point, line and polygon in GIS. These are complex elements with coordinates and determine the relationship between connecting or adjacent features.
- Spaghetti data model also known as basic topological model is the most basic vector data structure. Each point, line, and polygon feature in the spaghetti model is represented as an unstructured string of X, Y coordinate pairs.
- TIGER model is derived from combinatorial topology, a branch of mathematics, where the terms 0-cell, 1-cell, and 2-cell are used in place of point, line, and polygon, respectively.
- POLYVRT model is more efficient for the storage of vector data. It supports arc-node topological relationships. Vector entities are stored explicitly and separately in a hierarchical data structure.
- Connectivity is a topological relationship that enables arcs to connect to each other through nodes. It is primarily used to find out the shortest path or best route (route optimisation) in terms of distance, time taken, traffic volumes, impedance, etc.
- Area definition is the concept defined by topology and it is performed by separating a specific area that differs from the surrounding space. Contiguity is defined as the continuity of space without any gap sharing a common boundary as obvious component.
- The main advantage of using topology is the relationships that are maintained between the topological primitives such as nodes, edges, and faces. These relationships help to speed queries that are concerned with adjacency, connectivity, and containment of features.
- Topology is a set of rules that describes the relationships between neighbouring points, lines, and polygons and is used to model the connections between various geometrical objects.

9.5 ACTIVITY

- Using GIS software, export the data in various formats and import/connect various freely available web services like open-source map, google maps, Bhuvan-ISRO satellite and thematic services, etc.

9.6 TERMINAL QUESTIONS

1. What are spatial data standards? Discuss the GIS standards for web services with examples.
2. Discuss the Spaghetti data model with a neat diagram and write its advantages and disadvantages.
3. Differentiate connectivity and area definition and discuss their significance with neat diagrams.

4. Discuss the topological rules with neat diagrams and list few examples where topology rules can be defined.

9.7 REFERENCES

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9.8 FURTHER/SUGGESTED READINGS

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9.9 ANSWERS

SAQ I

a) GIS data standards is defined as documented agreements containing technical specifications or other precise criteria to be used consistently as rules, guidelines, or definitions of characteristics, to ensure that materials, products, processes and services are fit for their purpose.

b) MGNREGA and Smart City Yojana.

c) Keyhole Markup Language.

d) The main role played by the Open Geospatial Consortium (OGC) is to develop a common GIS standard for database creators, software providers and for other GIS users.

SAQ II

a) spatial relation

b) X, Y coordinate pairs

c) TIGER model

d) vector data

e) gap or disjoint

Terminal Questions

1. Please refer to section 9.2.
2. Please refer to subsection 9.3.1.
3. Please refer to subsection 9.3.2 and 9.3.3.
4. Please refer to subsection 9.3.6.