# GIS$_{n}otes$

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## Contents

**Lesson Objectives**

- Introduction to ArcGIS PRO 3.0 Environment
- View, manage, and organize GIS data in ArcCatalog
- Working with the Map Window
- Saving map documents (.aprx)

A Geographic Information System (GIS) is a powerful tool used for computerized mapping and spatial analysis. For this seminar, we will use **ArcGIS PRO 3.0**.

# 1 Preparation: Data Setup

Before opening the software, you must prepare your file structure.

1. **Log in** to your computer.
2. **Copy Data:** Navigate to Sharepoint and copy the `Lesson01` data folder.
3. **Paste Data:** Paste the folder into `C:/GIS/Lesson01` on your local machine.

**Important Note**

Data in the `C:/GIS` folder is often deleted after a computer restart. Always back up your work to a portable device.

# 2 Part 1: The Catalog Window (Data Management)

The Catalog is used to browse, search, and manage GIS data before placing it on a map.

## 2.1 Initialize the Project

1. Open **ArcGIS PRO**.
2. Select **Catalog** via **Start** → **ArcGIS PRO** → **Catalog**.
3. Create a **New Project**:
   - **Name:** `MyFirstProject`
   - **Location:** `C:/GIS`
   - **Important:** Toggle **OFF** the option "Create a new folder for this project".

## 2.2 Connect to Data

Navigate to `C:/GIS` in the Catalog window. You should see three shapefiles: *Capitals, Countries, Railroads*.

If the folder is missing, right-click **Folders** → **Add Folder Connection** and select your directory.

### 2.3 Explore Data Views

The Catalog has three specific tabs for viewing data. Click on the layers and explore each tab:

- **Metadata:** View and edit details about the data (Right-click layer → **Edit Metadata**).
- **Geography:** A preview mode to see the geometry.
- **Table:** A preview of the spreadsheet data associated with the map features.

  **Technical Note:** The data used here are **Shapefiles (.shp)**. These are Vector data types, which come in three forms: **Points** (Capitals), **Polylines** (Railroads), or **Polygons** (Countries).

### 2.4 Switch to Pane View

Go to the **View** menu tab and click **Catalog Pane** to dock the catalog to the side of your screen.

## 3 Part 2: The Map Window (Visualization)

The Map Window is where you analyze, edit, and visualize data.

### 3.1 Create a Map

1. Go to the **Insert** menu tab.
2. Click **New Map**.
3. A map will appear with default background layers. Toggle them off in the **Table of Contents (TOC)** to start with a blank screen.

### 3.2 Add Data

1. Go to the **Map** menu tab and click the **Add Data** button.
2. Navigate to `data_lesson01`.
3. Select all files (Hold Ctrl to select multiple) and click **OK**.

### 3.3 Manage Layers in Table of Contents (TOC)

- **Visibility:** Use the checkboxes next to layer names to toggle them ON or OFF.
- **Order:** Drag and drop layers to change their drawing order.
  - *Rule of thumb:* Points on top, Lines in the middle, Polygons on the bottom.
- **TOC Modes:** Experiment with listing modes (icons at the top of TOC):
  - *List by Drawing Order:* For reordering layers.
  - *List by Source:* To see file paths.

### 3.4 Attributes and Properties

- **Properties:** Right-click the *Countries* layer → **Properties**. Explore options like transparency and labeling.
- **Attribute Table:** Right-click the *Countries* layer → **Attribute Table**. This opens the database view of the layer.

### 3.5 Symbology (Styling)

- **Quick Change:** Right-click the symbol icon under the layer name in the TOC to change the color.
- **Advanced Change:** Right-click the layer name → **Symbology**. This opens the Symbology pane to adjust size, shape, and advanced settings.

# 4 Part 3: Saving Your Work

It is vital to understand what you are saving. You are saving a Map Document (`.aprx`).

- This file saves the **links** to data and the **symbology**.
- It does **not** save the actual spatial data (shapefiles).

**Task:** Go to the **Project** menu → **Save As** → Save into your personal folder.

# 5 Summary of Skills Acquired

By completing this lesson, you can now:

Connect to local folders in ArcGIS Pro.

Differentiate between Metadata, Geography, and Table views in Catalog.

Add, order, and toggle layers in the Map window.

View Attribute tables and change basic Symbology.

Save a `.aprx` project file correctly.

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By completing this lesson, you can now:

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Differentiate between Metadata, Geography, and Table views in Catalog.

Add, order, and toggle layers in the Map window.

View Attribute tables and change basic Symbology.

Save a `.aprx` project file correctly.

**Lesson Objectives**

- Set or fix the data source for a missing layer.
- Add a new map and set its properties.
- Understand the difference between a layer's Coordinate System (CRS) and a map's CRS.
- Project data from one coordinate system to another using the **Project** tool.

# 11 Part 1: Source Data in a Map Document

As previously explained, the ArcGIS map document (`.aprx`) maintains **links** to the data source files, not the data itself. If the source data is moved, the link breaks, resulting in a red exclamation mark (!) next to the layer name.

## 11.1 Task: Fix Broken Data Link

1. Open ArcGIS Project File `Lesson_03.aprx` from your data folder.
2. **Fix Path to Layer:** Left-click the $\boxed{!}$ red exclamation point next to the `Cntries_WGS` layer in the Contents pane.
3. The **Change Data Source** dialog box opens. Navigate to the folder `..._IN_4326`.
4. Select the `Cntries_WGS.shp` layer and click **OK**. The layer should now appear on the map.
5. Save the map (**Project** → **Save**).

# 12 Part 2: Working with Multiple Maps (Data Frames)

In ArcGIS Pro, you can work with several **Maps** (equivalent to Data Frames in older versions) within a single project.

## 12.1 Task: Create and Manage Maps

1. **Create New Map:** Click **Insert** → **New map**. A new tab, `Map1`, appears.
2. **Rename Map:** Click the name `Map1` once to select it, then click again to rename it to **EU NUTS**.
3. **Add Data to New Map:** Add the `NUTS` layer from the `..._IN_3035` folder to the **EU NUTS** map.
4. **Copy Layer Between Maps:** Drag the `Cntries_WGS` layer from the original **Map** tab header and drop it onto the **EU NUTS** map tab header.

**Important Note**

If a **Geographic Coordinate Systems Warning** appears, it means you are mixing data with different Coordinate Reference Systems (CRS) and ArcGIS Pro is performing an "on-the-fly" transformation. Close the warning.

# 13 Part 3: Coordinate Systems

The **Coordinate System (CRS)** is one of the most critical properties of a map, as it defines the projection used to display all data layers.

## 13.1 Task: Setting a Map's Coordinate System

1. Add another map: **Insert** → **New Map**. Rename it to **CZ**.
2. Right-click the **CZ** map in the Contents pane and select **Properties...**.
3. Go to the **Coordinate Systems** tab.
4. **Set CRS:** Navigate to **Projected Coordinate Systems** / **National Grids** / **Europe**. Select **S-JTSK Krovak EastNorth**.
   - *Alternatively, use the Search field with "Krovak" or the EPSG code* ***5514****.*
5. Click **OK**.

## 13.2 Task: Checking Layer's Coordinate System

1. In the **Catalog** pane, find the `NUTS_CZ` layer (`..._IN_5514`).
2. Right-click the layer → **Properties...**.
3. Go to the **Source** tab, under **Spatial Reference**. Verify that the layer's native CRS is **S-JTSK Krovak EastNorth**.
4. Drag and drop the `NUTS_CZ` layer onto the **CZ** map.

   **CRS Rule:** When a map is empty, its CRS is set by the **first layer** added. Subsequent layers are projected "on-the-fly" to match the map's CRS.

## 13.3 Task: Comparing Coordinate Readouts

1. Activate the **EU NUTS** map. Check its properties to ensure its CRS is **ETRS 1989 LAEA**.
2. Move your mouse over the map and note the coordinate values displayed at the bottom of the map window.
3. Activate the **CZ** map. Note the coordinate values again.

The values are different because each map has its own CRS for display, even if they show the same geographic area.

# 14 Part 4: Projection (Transforming Data)

If you need to permanently change a layer's CRS to integrate it with other data, you must use the **Project** geoprocessing tool.

## 14.1 Task: Project NUTS Data

The goal is to convert `NUTS_CZ` (CRS: S-JTSK Krovak East North) to the European standard CRS: ETRS 1989 LAEA.

1. Open the **Geoprocessing** pane (**View** → **Geoprocessing**).
2. Search for the tool **Project**.
3. Click the **Project (Data Management)** tool.
4. **Input Dataset:** Choose `NUTS_CZ`.
5. **Input coordinate system:** This should be automatically detected (S-JTSK Krovak East North).
6. **Output Dataset:** Click the browse button and save the result to `..._OUT`. Name the new layer `NUTS_CZ_3035`.
7. **Output Coordinate System:** Search for or select **ETRS 1989 LAEA** (EPSG code **3035**).
8. **Geographic Transformation:** Select **S_JTSK_To_ETRS_1989_1**.
9. Click **Run**.

## 14.2 Task: Verify Transformed Data

1. Activate the **EU NUTS** map.
2. Add the newly created layer, `NUTS_CZ_3035`, to this map. It should align perfectly with the other European NUTS data.

**Lesson Objectives**

- Create new empty shapefiles for points and polylines.
- Digitize new line features using an image as a reference (vectorization).
- Utilize **Snapping** to ensure topological correctness (connected lines).
- Convert polylines (boundaries) to polygon features.
- Add new attribute fields and edit field values.
- Use the **Attributes** pane for mass editing.
- Use the **Autocomplete Polygon** tool for editing adjoining areas.
- Document data using **Metadata**.
- Convert GPS coordinates from a text file to a point shapefile.

# 15 Part 1: Creating Shapefiles

You will create a new polyline shapefile for pathways, using the **Create Feature Class** pane.

1. Copy the folder for this lesson (`.../Lesson04`) to your personal folder.
2. Open ArcGIS Pro and save the new empty project to `Lessons/Lesson04`.
3. Create a new Map and add the raster layer `Orto_Suchdol.png` and the polyline shapefile `Boundary_lines` from `.../Lesson04/data_less04` folder.
4. In the **Catalog** pane, right-click the `data_less04` folder → **New** → **Shapefile**. The **Create Feature Class** pane opens.
5. Configure the new shapefile:
   - **Feature Class Name:** `Pathways`
   - **Geometry Type: Polyline**
   - **Coordinate System:** Click **Select Coordinate System** and find **S-JTSK Krovak East-North**.
6. Click **Run**. The empty `Pathways` layer is added to the map.

# 16 Part 2: Digitizing Features (Create Lines)

You will now trace the pathways visible on the orthophoto (`Orto_Suchdol.png`).

## 16.1 Setup and Digitizing

5. On the **Map** tab, click **Bookmarks** → **Import bookmarks...** and import the `CZU - Park` bookmark. Then select the bookmark to zoom in.
6. Change the symbol for `Pathways` (e.g., Mars red, width 2pt).
7. On the **Edit** tab, in the **Features** group, click **Create**. The **Create Features** pane opens.

8. In the pane, click `Pathways` and then click the **Line** tool.
9. To digitize the first pathway: **Click once** to begin, click again for each **vertex** (change of direction), and **double-click** to finish the line.

### 16.2 Snapping for Connectivity

Snapping ensures that features, like pathways, connect perfectly at junctions, maintaining **topological correctness**.

10. On the **Edit** tab, click the **Snapping** button to enable it.
11. Click the down arrow next to **Snapping** to open settings. Ensure **Endpoint**, **Vertex**, and **Edge** snapping are turned **ON**.
12. Draw a new pathway connected to the existing one.
    - As you hover over an existing feature, a square snap indicator appears (e.g., `Pathways: Endpoint`).
    - Click to start the new line exactly on the snap point.
13. **Edit Existing Features:** Click the **Modify** button (Edit tab). Select **Edit Vertices** and click the line you want to change. Click and drag a vertex to a new location, or use the Delete key to remove the line.
14. Finish editing all the pathways in the park using snapping to ensure connectivity.

## 17 Part 3: Converting Lines to Polygons

You will add to the boundary lines and then convert the enclosed areas into polygons (`Campus_landuse`) for visualization.

### 17.1 Digitize Boundaries

16. Add missing lines to the `Boundary_lines` layer (polyline). These lines define the perimeter of buildings and paved areas.
17. In the **Create Features** pane, select the `Boundary_lines` template and **Line** tool.
18. **Tip (Perpendicular):** While drawing a building boundary, right-click anywhere on the map to open the context menu and click **Perpendicular** to constrain the next segment.

### 17.2 Conversion (Line to Polygon)

18. Open the **Geoprocessing** pane (**View** → **Geoprocessing**).
19. In the Search bar, type and search for “Feature to polygon”.
20. Click the **Feature to polygon (Data Management)** tool.
21. Configure the tool:
    - **Input Features:** `Boundary_lines`
    - **Output Feature Class:** Save to the same lesson folder as `Campus_landuse`
22. Click **Run**. The new polygon shapefile is added.
23. Switch off the `Boundary_lines` layer and explore the resulting polygon layer. Open its attribute table.
24. Save your project.

# 18 Part 4: Feature Attribute Values

You will add a field to the polygon layer and populate it with land use categories (`LU_CAT`).

## 18.1 Add Field and Categories

23. Open the `Campus_landuse` attribute table. On the toolbar, click **Add field** (+ icon).
24. In the Fields tab:
    - **Field Name:** `LU_CAT`
    - **Data Type: Text** (since it will store names like 'Buildings').
25. Close the Fields tab and save changes.
26. Open the **Symbology** pane for `Campus_landuse`. Change Primary symbology to **Unique values**.
27. Set the **Field** to `LU_CAT`.
28. In the **Classes** tab, click **Add unlisted values** → **Options** → **Add new value**.
29. Add the categories: **Buildings**, **water**, **roads**, **others**. Set appropriate colors for each.
30. Save your project.

## 18.2 Editing Attributes

29. From the **Edit** tab, click **Select** and click any building polygon.
30. Open the attribute table. In the `LU_CAT` field for the selected feature, type `Buildings` and press Enter. The polygon's color will update.
31. **Mass Editing:** From the **Edit** tab, click **Attributes** (in the Selection group). The **Attributes** pane opens.
32. Click **Select one or more features**. Hold Shift and click multiple features (e.g., all buildings).
33. In the **Attributes** pane, select all the items in the list. Change the `LU_CAT` value to `Buildings` and click **Apply**.
34. Continue filling in the land-use category for all polygons.

## 18.3 Editing Adjoining Polygons

To avoid gaps or overlaps (slivers), use the **Autocomplete Polygon** tool when drawing polygons adjacent to existing ones.

34. In the **Create Features** pane, select an appropriate template from `Campus_landuse`.
35. From Construction tools, select **Autocomplete Polygon**.
36. Draw the new polygon. The new shape must overlap or snap to the edge of the existing polygon at least twice.
37. Double-click to finish the feature. The boundary will be automatically generated, sharing the edge with the existing polygon.
38. Save edits and save the map document.

## 19 Part 5: Metadata

Metadata describes the data (purpose, attributes, creator, date, terms of use) and is critical for data sharing and long-term use.

38. In the **Catalog** pane, find the `Campus_landuse` layer.
39. Right-click the layer and choose **Edit Metadata**.
40. Add descriptive **Tags** and a detailed **Summary** (Purpose) explaining the data.
41. Click the **Save** button.

## 20 Part 6: Converting GPS Data to Shapefile (Bonus)

You will convert a CSV file containing WGS84 coordinates into a point shapefile and add it to your map.

42. Insert a new map. Add the `GPS_TREES.csv` file from the data folder to the map.
43. Open the attribute table to confirm the fields: `LON` (Longitude - X) and `LAT` (Latitude - Y).
44. In the **Catalog** pane, right-click `GPS_TREES.csv` → **Export** → **Table To Point Feature Class...** (or search for **XY Table to Point** tool).
45. Configure the tool:
    - **Output Feature Class:** `XYGPS_TREES`
    - **X Field:** `LON`
    - **Y Field:** `LAT`
    - **Coordinate System:** Select **WGS 1984** (Geographic Coordinate System).
46. Click **Run**. A new point shapefile is created.
47. Add the `XYGPS_TREES` shapefile to your `CZU` map.
48. Change the symbol for the trees and save your map.

**Lesson Objectives**

- Calculate geometric properties (area, perimeter) of features.
- Use the Field Calculator to perform mathematical operations on attributes.
- Join non-spatial tables to spatial layers based on a common key.
- Construct **SQL query expressions** to select features by attribute.
- Export selected features to a new permanent layer.
- Calculate **Summary Statistics** based on categories.
- Create a **Relate** between two tables for linked selection.
- Perform a **Spatial Join** (Bonus).

## 21 Part 1: Geometry Attributes

Geometric properties like area and perimeter are best calculated when your data is in a **Projected Coordinate System** (CRS), especially an equal-area projection.

1. Copy the data for this lesson (`...05`) to your personal folder.
2. Open the `Lesson05.aprx` map document. Rename the layer `CLC_2012` to **Land-cover**.
3. Check the layer's CRS (Right-click layer → **Properties** → **Source** → **Spatial Reference**).
4. Open the Land-cover attribute table and examine the `CODE` field.
5. **Calculate Area (Hectares):**
   - Right-click the `Area_Ha` field name → **Calculate Geometry...**.
   - **Property: Area**
   - **Area Unit: Hectares**
   - **Coordinate system:** Select the layer's projected CRS.
   - Click **OK**.
6. **Calculate Perimeter (Meters):**
   - Right-click the `Perim_m` field name → **Calculate Geometry...**.
   - **Property: Perimeter**
   - **Units: Meters**
   - Click **OK**.

## 22 Part 2: Field Calculator

You can perform mathematical operations using the **Calculate Field** tool. Here, you will calculate the **Edge Density (ED)** index, defined as Perimeter divided by Area ($ED = \text{Perimeter}/\text{Area}$).

### 22.1 Task: Add Field for ED

8. In the Land-cover attribute table, click **Add** (+ icon) to open the Fields tab.
9. Create a new field:
    - **Field Name:** `ED`
    - **Data Type: Double** (Used for numbers with decimal places/fractional numbers).
    - **Precision:** 7, **Scale:** 2.
10. Click **Save**. Close the Fields tab.

### 22.2 Task: Calculate ED

9. Right-click the new `ED` field name → **Calculate Field**.
10. Create the expression:
    - Double-click `Perim_m`.
    - Click the division button (/).
    - Double-click `Area_Ha`.
    - The final expression should be: **`!Perim_m!  / !Area_Ha!`**
11. Click **Run** (or **OK**). The ED values are calculated.

### 22.3 Task: Field Statistics

11. To view the distribution of the calculated values, right-click the `ED` field name → **Statistics**.
12. Examine the histogram and metrics (Mean, Max, Min). Close the window.

## 23 Part 3: Joining Tables (Many-to-One)

**Joining** appends the fields of one table (the source) to another (the target) based on a common field (key). This creates a temporary, single table view.

### 23.1 Task: Join Land-cover Names

13. Add the non-spatial table `CLC_legend.dbf` from your data folder. (It appears under **Standalone Tables** in Contents).
14. Examine the table. The field `CLC_CODE` contains the same codes as the `CODE` attribute in the `Land-cover` layer.
15. Right-click **Land-cover** → **Joins and Relates** → **Add Join. . .**
16. Set the Join parameters:
    - **(1) Input Table:** Land-cover (The target)
    - **(2) Input Join Field:** `CODE`
    - **(3) Join Table:** `CLC_legend` (The source)
    - **(4) Output Join Field:** `CLC_CODE`
17. Click **OK**.
18. Open the `Land-cover` attribute table and scroll right. The fields from `CLC_legend` (e.g., `LABEL1`, `LABEL2`) are now appended.
19. Save your work.

# 24 Part 4: Select and Export Data

You use **SQL (Structured Query Language)** syntax in the **Select by Attributes** tool to select subsets of features, which can then be exported as a new layer.

## 24.1 Task: Select and Export Agricultural Areas

18. In the `Land-cover` table, click **Select by Attributes**.
19. Build the query expression to select only Agricultural Areas:

    CLC_legend.LABEL1 = 'Agricultural areas'

20. Click **Apply**. The matching rows are selected.
21. Right-click the `Land-cover` layer → **Data** → **Export Features**.
22. Specify an output name, such as `Agriculture`, and click **OK**. The new layer, containing only the selected features, is added to the map.

## 24.2 Task: Conditional Attribute Calculation (Importance)

You will now categorize the `Agriculture` polygons based on land-cover type (`LABEL2`) and Edge Density (`ED`).

22. In the `Agriculture` attribute table, add a new **Text** field named `Importance`.
23. **Category LOW (Arable land):**
    - Select by Attributes:
      CLC_legend.LABEL2 = 'Arable land'
    - With features selected, right-click the `Importance` field → **Calculate Field**.
    - Enter the expression: `"LOW"` (use quotation marks for text).
    - Clear the selection.
24. **Category HIGH (Pastures with ED > 150):**
    - Select by Attributes:

      CLC_legend.LABEL2 = 'Pastures' AND ED > 150

    - Calculate Field: `"HIGH"`
    - Clear the selection.
25. **Category MEDIUM (Remaining features):**
    - Select by Attributes (using logic operators `AND` and `OR`):

      (CLC_legend.LABEL2 = 'Pastures' AND ED <= 150) OR CLC_legend.LABEL2 = 'Heterogeneous agricultura

    - Calculate Field: `"MEDIUM"`
26. Clear the selection and verify that all rows now have a value for `Importance`.

# 25 Part 5: Summary Statistics

The **Summary Statistics** tool calculates aggregated values (Sum, Mean, Min, Max, Count) based on categories (Case Fields).

31. Open **Geoprocessing** and search for **Summary Statistics** (or right-click `Importance` field → **Summarize**).
32. Calculate total area per Importance category:
    - **Input Table:** `Agriculture`
    - **Output Table:** `SUM_AGRI.DBF`
    - **Statistics Field:** `Area_Ha` (**Statistic Type**: **SUM**)
    - **Case field:** `Importance`
33. Click **OK**. Open the new table `SUM_AGRI.DBF`.
34. **Frequency** represents the number of records (polygons) used to calculate the sum for that category.
35. Calculate statistics for the original Land-cover layer (total area, min/max/mean ED) grouped by `LABEL3`.
36. Remove the existing join: Right-click `Land-cover` → **Joins and Relates** → **Remove Join** → **CLC_legend**.

# 26 Part 6: Relate Tables

A **Relate** defines a persistent link between two tables without appending data, allowing you to select matching records in one table by selecting records in the other.

37. Add the table `Surveyor.dbf`.
38. Right-click `Surveyor` → **Joins and Relates** → **Add Relate...**
39. Set the Relate parameters (The link is **many-to-one**):
    - **Input Table:** `Surveyor`
    - **Input Relate Field:** `SURV`
    - **Relate Table:** `Land-cover`
    - **Output Relate Field:** `SURV_ID`
40. Click **OK**.
41. Open the `Surveyor` table and select a record (e.g., Uhlik Jaroslav).
42. Click the **Related Data** button (↘) and select the related `Land-cover` layer. Only the polygons surveyed by that person are selected in the map and displayed in the table.
43. Use the reverse function: Select a polygon on the map → Open Land-cover table → Click **Related Data** → Select `Surveyor`. This shows the single matching surveyor record.
44. Save your work.

# 27 Part 7: Joining Data by Location (Bonus)

A **Spatial Join** links attributes between layers based on their geographic relationship (e.g., containment, proximity) and creates a new layer as output.

44. Add the point layer `CONTROL_POINTS` (field `CODE_L2` is the land-cover code from the sample).
45. Right-click `CONTROL_POINTS` → **Joins and Relates** → **Spatial Join...**
46. Configure the Spatial Join:
    - **Target Features:** `CONTROL_POINTS` (Points)
    - **Join Features:** `Land-cover` (Polygons)
    - **Output Feature Class:** `Join_CLC_control`
    - **Match Option:** **Intersect** (or **Containment** for better accuracy)
47. Click **OK**.
48. Open the `Join_CLC_control` table. It contains attributes from both the control points (`CODE_L2`) and the polygon it falls within (`CODE`).
49. Perform an attribute query to find classification errors (where the recorded code does not match the polygon code):

    $$\text{CODE\_L2} <> \text{CODE}$$
50. Examine the selected results to determine the number of mismatches (errors).
51. Save your work and close ArcGIS Pro.

Spatial Analysis

**Lesson Objectives**

- Combine multiple datasets into one using the **Merge** tool.
- Extract features to a defined boundary using the **Clip** tool.
- Overlay two datasets to create new features at the intersection using the **Intersect** tool.
- Calculate geometric properties and **summarize** them based on categories (grid units).
- Create proximity polygons around features using the **Buffer** tool.
- Remove overlapping areas from a layer using the **Erase** tool.

## 28 Part 1: Prepare Data (Merge)

You have forest data split into three separate layers by county. You will combine them into a single, comprehensive layer using the **Merge** tool.

1. Copy data for this lesson to your personal folder.
2. Open ArcGIS Pro and add layers: `GRID_5km`, `Study_area`, and the three forest layers (`Forest_Plzen`, `Forest_PlzenN`, `Forest_Rokycany`).
3. Open the **Geoprocessing** pane (**Analysis** → **Tools**).
4. Search for the **Merge** tool (found in **Data Management Tools** → **General**).
5. Configure the tool:
   - **Input Datasets:** Select the three forest layers.
   - **Output Dataset:** Browse to your output folder and name the new layer `Forests`.
6. Click **Run**.
7. Switch off the three original forest layers. The new `Forests` layer contains all features.

## 29 Part 2: Extract Features (Clip)

You will trim both the `Forests` layer and the `GRID_5km` layer to match the boundaries of the `Study_area` polygon using the **Clip** tool.

6. In the **Geoprocessing** pane, search for the **Clip** tool (found in **Analysis Tools** → **Extract**).
7. **Clip the Forests layer:**
   - **Input Features:** `Forests`
   - **Clip Features:** `Study_area` (The boundary)
   - **Output Features:** `Forests_study_area`
   - Click **Run**.
8. Turn off the original `Forests` layer.
9. **Clip the Grid layer:**
   - **Input Features:** `GRID_5km`

- **Clip Features:** `Study_area`
- **Output Features:** `GRID_study_area`
- Click **Run**.

10. Switch off the original `GRID_5km` layer.

# 30 Part 3: Data Overlay (Intersect)

To calculate the Edge Density (ED) per grid unit, you first need to cut the forest features by the grid boundaries. The **Intersect** tool preserves only the overlapping geometry and transfers attributes from both inputs.

13. In the **Geoprocessing** pane, search for the **Intersect** tool (found in **Analysis Tools** → **Overlay**).
14. Configure the Intersect:
    - **Input Features:** Select both `GRID_study_area` and `Forests_study_area`.
    - **Output Features:** `GRID_forest`
15. Click **Run**.
16. Explore the `GRID_forest` layer's geometry and attribute table. Each original forest polygon has been split wherever it crosses a grid boundary, and the table contains the `ID` attribute from the grid layer.
17. Save your Project.

# 31 Part 4: Geometry Attributes and Summarization

To calculate Edge Density ($ED =$ Perimeter/Area) for each grid unit, you must first calculate the area and perimeter of the newly intersected polygons and then aggregate (sum) these values by the grid `ID`.

## 31.1 Task: Calculate Geometry

16. In the `GRID_forest` attribute table, add two new fields: `LEN` (Double) and `AREA_FOR` (Double).
17. Calculate the perimeter (length) for `LEN`: Right-click `LEN` → **Calculate Geometry. . .** → **Perimeter length**, **Meters**.
18. Calculate the area for `AREA_FOR`: Right-click `AREA_FOR` → **Calculate Geometry. . .** → **Area**, **Square Meters**.

Task: Summarize by Grid ID

17. Right-click the `Id` field heading in the `GRID_forest` table and select **Summarize**.
18. Configure the Summary Statistics:
    - **Input Table:** `GRID_forest`
    - **Output Table:** `Sum_GRID.DBF`
    - **Statistics Field(s):** Select `LEN` and `AREA_FOR`. Set **Statistic Type** to **Sum** for both.
    - **Case field:** `Id`
19. Click **OK**. The new table `Sum_GRID` is added.

Task: Calculate Edge Density (ED)

19. Open the `Sum_GRID` table and add a new field named `ED` (Double).
20. Right-click the `ED` field → **Calculate Field**.
21. Enter the expression: `!SUM_LEN! / !SUM_AREA_FOR!`
22. Click **Apply**.
23. Explore the ED values using **Statistics**.

Task: Join for Visualization

22. Join the summary table back to the spatial layer: Right-click `GRID_study_area` → **Joins and relates** → **Add Join**.
23. Set the common join field to `Id` for both the `GRID_study_area` and the `Sum_GRID` table.
24. Click **OK**.
25. You can now symbolize `GRID_study_area` using the joined `ED` values (Bonus).
26. Save your Project.

# 32 Part 5: Buffering Features

The **Buffer** tool creates a proximity zone around features.

25. Add the line layer `Train_plan` (representing the planned corridor).
26. In the **Geoprocessing** pane, search for the **Buffer** tool (found in **Analysis Tools** → **Proximity**).
27. Configure the Buffer:
    - **Input Features:** `Train_plan`
    - **Output Feature Class:** `Train_corridor`
    - **Distance: 20 Meters** (resulting in a 40m total width).
28. Click **Run**.
29. Save your Project.

# 33 Part 6: Updating Features (Erase)

The **Erase** tool removes the area of the Erase Feature from the Input Feature.

31. In the **Geoprocessing** pane, search for the **Erase** tool (found in **Analysis Tools** → **Overlay**).
32. Configure the Erase:
    - **Input Features:** `Forests_study_area` (The forest you want to modify)
    - **Erase Features:** `Train_corridor` (The area you want to remove)
    - **Output Feature Class:** `Forest_update`
33. Click **OK**.
34. Switch off the original `Forests_study_area` to see the newly created gap in the `Forest_update` layer.

Classification and Advanced Symbology

**Lesson Objectives**

- Display **qualitative data** using Unique Values (choropleth).
- Display **quantitative data** using Proportional Symbols and Graduated Colors.
- Understand and apply **Normalization** for density and ratio maps.
- Display multivariate data using **Charts** (e.g., bar charts).
- Compare and select appropriate **Classification Methods** (e.g., Natural Breaks, Quantile, Standard Deviation).
- Format and round legend labels.

# 34 Part 1: Symbology – Qualitative Data

**Qualitative data** represents categories or types (e.g., names, colors, subregions). The best way to visualize this on a map is typically using the **Unique Values** symbology, resulting in a choropleth map where areas are distinctly colored.

## 34.1 Task: Display European Subregions

1. Copy data for `Lesson08` to your personal folder.
2. Open ArcGIS Pro and save the new empty project to `Lessons08`.
3. Create a **New Map**. Rename it to **Europe - regions**.
4. Add layers `EU_Capitals` and `EU_Countries`. Rename the layers to `Capitals` and `Countries`.
5. **Symbolize by Unique Values:** Right-click `Countries` → **Symbology**.
6. Set **Primary Symbology** to **Unique values**.
7. Set **Field 1** to `SUBREGION`.
8. Click **More** and uncheck <**Show all other values**> (this removes any records without a subregion listed).
9. Choose distinct colors/symbols for each subregion.

# 35 Part 2: Symbology – Quantitative Data

**Quantitative data** represents numeric measures or counts (e.g., population, area). Methods include Proportional Symbols (for raw values) and Graduated Colors (for classified, often normalized, values).

## 35.1 Task: Proportional Symbols (Capitals Population)

9. Select the `Capitals` layer. On the **Appearance** tab → **Symbology** → **Proportional Symbols**.
10. Set the **Field** to `POP` (Population counts).
11. Set **Minimum size** to 1.0 and **Maximum size** to 20.0.
12. The symbol size is determined directly by the raw population value, with no data classification required.

13. Label the capitals: On the **Labeling** tab, set the **Field** to `NAME_ASCI` and check **Label Features In This Class**.
14. Save your map document.

## 35.2 Task: Graduated Colors (Population Density)

Graduated Colors requires **Normalization** to display meaningful data like density or ratios, instead of raw counts which are often misleading.

12. Insert a **New Map**. Rename it to **Population**. Add the `Countries` layer.
13. Select the `Countries` layer. On the **Appearance** tab → **Symbology** → **Graduated Colors**.
14. Set the **Field** to `POPULATION` (raw count).
15. Make a copy of the `Countries` layer. Rename the copy to **Countries − density**.
16. **Normalize for Density:** For the `Countries - density` layer:
    - Set the **Field** to `POPULATION`.
    - Set the **Normalization** field to `SQKM`.
17. The map now displays **Population Density** (Population / Area), which is a normalized, meaningful measure.

## 35.3 Task: Ratio Map (Sex Ratio)

To display a ratio of two attributes (e.g., Females to Males), you normalize the numerator by the denominator.

18. Make a copy of the `Countries` layer. Rename it to **Countries-Sex ratio**. Switch off other layers.
19. **Display Sex Ratio (Females/Males):**
    - Set the **Field** to `FEMALES`.
    - Set the **Normalization** field to `MALES`.
20. Set the number of **Classes** to **2**.
21. Change the class break by clicking the first row in the column **Upper value** and retyping the value to **1.000**.
22. Set appropriate hatched symbols or colors.

**Sex Ratio $<$ 1.000:** Fewer females than males (Male predominance).

**Sex Ratio $\geq$ 1.000:** Equal or more females than males (Female predominance).

## 35.4 Task: Multivariate Data (Charts)

Charts (or graphs) allow you to display multiple related attributes simultaneously for each feature.

20. Make a copy of the `Countries` layer. Rename it to **Countries–Age Structure**.
21. On the **Appearance** tab → **Symbology** → **Charts**.
22. In the **Fields** column, select all attributes starting with `AGE_0_14`, `AGE_15_29`, etc.
23. **Normalize for Fraction:** Set the **Normalization** field to `POPULATION`. (This displays the fraction of people in each age class, rather than the raw counts).
24. Choose an appropriate **Color scheme**.

# 36 Part 3: Quantitative Data – Classification Methods

**Classification** divides the range of attribute values into non-overlapping intervals (classes) to assign symbols. The choice of classification method greatly impacts map interpretation.

## 36.1 Task: Explore Classification Methods

22. Create a **New Map**. Rename it to **US Population Growth**.
23. Add the layer `US_Counties` to the map.
24. Display **Population Growth** (POP1997 normalized by POP1990) using **Graduated colors**.
25. In the **Symbology** pane, under **Method**, experiment with the available classification methods. The histogram shows how well the breaks (**black lines**) fit the data distribution.

Table 1: Comparison of Classification Methods

| Method | How Breaks are Set |
|---|---|
| **Natural Breaks (Jenks)** | Minimizes variance within each class and maximizes variance between classes. |
| **Equal Interval** | Divides the full range of values into classes of equal size. |
| **Quantile** | Puts an equal number of features (counties) into each class, regardless of value range. |
| **Geometric Interval** | Creates class breaks based on a geometric series; each class range increases by a constant mu |
| **Standard Deviation** | Creates classes based on distance from the mean value (e.g., $\pm 1$ standard deviation). |

## 36.2 Task: Format Labels

28. Once you select an appropriate method, format the label rounding.
29. In the **Symbology** pane, click the **Advanced symbology options** tab.
30. Under **Rounding** $\rightarrow$ **Number of decimal places**, type **2**.
31. The numbers in the legend and Contents pane are now rounded, improving readability.
32. Save and exit.

**Lesson Objectives**

- Classify quantitative data using **Defined Interval** and format labels as percentages.
- Create a new map **Layout** in ArcGIS Pro.
- Insert and activate a **Map Frame** and adjust its extent and scale.
- Add essential map elements: **Title, North Arrow, Scale Bar, and Legend**.
- Add a **Graticule** (coordinate grid) for orientation.
- Create a map **Inset** (locator map) using a second Map Frame.
- Set export options and **Export** the final map as a PDF.

# 37 Part 1: Classification and Symbology

You will create a choropleth map showing the proportion of land covered by nature protected areas in European states.

## 37.1 Task: Data Classification

1. Open ArcGIS Pro and save the new project to `Lesson09`.
2. Download the data, add a folder connection, and add layers `Cntries`, `Capitals`, and `World_cntries` to the map.
3. Zoom to the extent of the `Cntries` layer.
4. Select the `Cntries` layer and open the **Symbology** pane.
5. **Display Protected Area Proportion:**
   - Choose **Graduated colors**.
   - **Field:** The field representing the area of protected land (e.g., PA_AREA).
   - **Normalization:** The field representing the total area of the country (e.g., AREA).
6. **Set Classification Method:**
   - **Method: Defined interval**.
   - **Interval Size: 0.05** (This creates classes 0% – 5%, 5% – 10%, etc.)

## 37.2 Task: Format Labels as Percentage

6. In the **Symbology** pane, click **Advanced symbology options**.
7. Under **Rounding** → **Format Labels. . .** :
   - **Category: Percentage**.
   - Check **Number represents a fraction**.
   - Set **Rounding** → **Number of decimal places** to **2**.
8. Choose an appropriate symbol for `Capitals` (e.g., point symbol) and save your project.

## 38 Part 2: Preparing the Layout

The **Layout View** is where all map elements are arranged for printing or export.

9. On the **Insert** tab, click **New Layout**. Choose **Size A4, Orientation Landscape**.
10. On the **Insert** tab, click **Map Frame** and select your current map. Draw the map frame onto the layout page.
11. To modify the map extent (zoom/pan), click **Layout** → **Activate**. Deactivate by clicking the Layout tab again.
12. Adjust the map frame size and position using the corner handles, leaving space on the right for the legend and on the top-left for the title.
13. Rename the primary map frame to `Europe`.

## 39 Part 3: Adding Title and Text

Map text provides context and metadata.

15. On the **Insert** tab → **Graphics and Text**, choose **Straight text**.
16. Add the **Title**: `Proportion of nature protected areas`. Set the font large (e.g., 25 pt, bold).
17. Add a **Subtitle** (e.g., `European States`) and format it smaller (e.g., 15 pt, bold).
18. Select both the title and subtitle (Hold Shift) and right-click → **Align** → **Align left**.
19. Add **Metadata** (e.g., Data source, Projection, Creator, Date) in the bottom right corner (e.g., 10 pt font).

## 40 Part 4: Adding Standard Map Elements

Map elements provide orientation and scale information.

20. **North Arrow:** Click **Insert** → **North Arrow**. Choose a simple symbol and place it in the top right corner of the map frame.
21. Double-click the North Arrow → **Properties** → **Type** and set the orientation to **True North**.
22. **Scale:** Set a round number scale for the map: In the Map Frame scale box, type **23000000** and press Enter.
23. **Scale Bar:** Click **Insert** → **Scale bar** → Choose **Alternating Scale bar 2 metric**.
24. **Format Scale Bar:**
    - **Label Text:** km
    - **Division Value: 500**
    - **Number of subdivisions: 2**
25. **Legend:** Click **Insert** → **Legend**. Place it on the right side of the page.
26. **Clean up Legend:** In the **Contents** pane, uncheck the `World_cntries` layer (base map). Right-click the Legend → **Convert to Graphics**. Make `World_cntries` visible again.
27. **Edit Legend Text:** In the **Contents** pane, rename the layer `Cntries` to Countries. Double-click the field name in the Legend contents to change PA_AREA/AREA to Proportion of protected area.

# 41 Part 5: Graticule and Export

30. **Add Graticule:** With the `Europe` map frame selected, click **Insert** → **Grid** → **New Grid** → **Black Horizontal Label Graticule**. (Since a graticule is added, you can remove the North Arrow as it provides primary orientation).

31. **Export Map:** Click **Share** tab → **Export Layout**.

32. Choose **PDF** format and save it to your project folder.

# 42 Part 6: Map Inset

An inset map provides detailed context for a specific area (the Alps in this case).

33. Insert a **New Map** and rename it to `Alps`. Copy `Capitals` and `World_countries` to it.

34. Add the layer PA_Alps and rename it to Protected Areas – Alps. Zoom to its extent.

35. Click **Insert** → **Map Frame** and select the new `Alps` map. Place it on the right side of the layout, below the main legend.

36. Adjust the scale of the `Alps` map frame to $\mathbf{1 : 5,000,000}$.

37. With the `Alps` map frame active, insert a new **Legend** and a **Scale Text** element, placing them near the inset map.

38. **Bonus (Background):** Right-click the `Europe` map frame → **Properties** → **Display** → **Background** and choose a light blue color to represent the ocean.

**Lesson Objectives**

- Understand the structure of **Raster Data** (cells/pixels).
- Differentiate between thematic (discrete) and continuous rasters.
- Access and use spatial data from public **GIS Servers** (ArcGIS Server, ArcGIS Online).
- Perform **Georeferencing** on a spatially unreferenced image using Ground Control Points (GCPs).
- Evaluate transformation accuracy using the **Root Mean Square (RMS) Error**.

# 43 Part 1: Rasters

The **raster data model** represents the world as a grid of cells (pixels) arranged in rows and columns. Each cell holds a single value.

## 43.1 Task: Explore Raster Types

1. Open ArcGIS Pro and add layers `CLC06.tif` and `DEM` from the data folder. Order the layers so `DEM` is above `CLC06`.
2. `CLC06` (Corine Land Cover) is a **thematic/discrete** raster, where cell values represent land cover *types* (codes). It has an attribute table listing land cover classes.
3. `DEM` (Digital Elevation Model) is a **continuous** raster, where cell values represent *terrain height* (real numbers). It typically does not have an attribute table.
4. Open the **Layer Properties** → **Source** tab for `CLC06` and find:
   - **Cell size:** (e.g., $25 \times 25$ meters)
   - **Columns, rows:** (e.g., $10,000$ columns, $15,000$ rows)
5. Find the same information for the `DEM` raster. Compare the cell sizes by zooming in until the individual pixels are visible.

## 43.2 Task: Raster Symbology

11. Select the `DEM` layer. Open the **Symbology** pane.
12. Under **Primary symbology**, select **Classify**. This groups the continuous height values into visual classes, making the terrain easier to interpret.
13. Add the unreferenced aerial image Suchdol_1950s.png from the data folder. (You may need to use **Zoom to layer** to find it.)

# 44 Part 2: Using Data from a Public GIS Server

**GIS Servers** allow data sharing over the internet using standards like **Web Map Service (WMS)**. You will use these servers to acquire **reference data** for georeferencing.

### 44.1 Task: Connect to ArcGIS Server (CUZK)

16. On the **Insert** tab, click **Connections** → **Server** → **New ArcGIS Server**.
17. In the **Server URL** box, type:

    http://ags.cuzk.cz/arcgis1

18. Click **OK**. A new server connection (`arcgis1 on ags.cuzk`) is added to your **Catalog** pane.
19. From the **Catalog**, add the `ortofoto` service from this server to your map. This is your modern, correctly georeferenced imagery for the Czech Republic.

### 44.2 Task: Access ArcGIS Online Data

19. On the **Map** tab, click **Add data**.
20. Under **Portal**, select **ArcGIS Online**.
21. Search for CZUPRAHA and find the service CZUPraha_GIS_ED. Click **Add**.
22. The layer georef_poi (Control Points) is added, marking key, identifiable locations.
23. Switch off the `DEM` and `CLC06` layers. Zoom to the Suchdol area where the control points are visible.
24. Save your project.

## 45 Part 3: Georeferencing a Raster

**Georeferencing** is the process of assigning correct map coordinates to a spatially unreferenced image by creating links between the unreferenced image and known locations on a referenced map.

### 45.1 Task: Add Control Points

21. In the **Contents** pane, select the unreferenced layer: Suchdol_1950s.
22. Click the **Imagery** tab → **Georeference** to open the dedicated tab.
23. Click **Fit to Display** to place the raster in the current view.
24. Use **Move**, **Scale**, and **Rotate** tools to roughly align the Suchdol_1950s image over the ortofoto background.
25. Click the Add Control Points tool.
26. Create Links (GCPs): For each control point:
    - **1**$^{st}$ Click: A known location on the Suchdol_1950s (source/unreferenced image).
    - **2**$^{nd}$ Click: The identical location on the ortofoto background (target/referenced data).
27. Repeat this process for all four control points (using the georef_poi layer as a guide).
28. Use the L key to quickly toggle the transparency of the source raster to check alignment.

## 45.2 Task: Evaluate and Save

27. Click the Control Point Table button.
28. Examine the **Total Root Mean Square (RMS) Error**. This value indicates the accuracy of the transformation based on the consistency of your control points. A lower RMS error suggests better consistency among the links.
29. Note the default transformation method: **1st Order Polynomial (Affine)**, which requires a minimum of three control points for translation, scaling, and rotation.
30. If the error is large, delete poor control points in the table and re-add them.
31. Once satisfied, on the **Georeference** tab, click Save. This saves the transformation information (a world file) with the existing raster file.