3D GIS

3D Data

This module explores how to represent geospatial data in multiple dimensions, from traditional 2D vector and raster models through 2.5D representations to fully 3D geometries. We'll examine the coordinate systems that anchor our data, the various data models we use to store geographic information, and the tools and techniques for converting between different representations.

Module Topics

1. Datums and projections review
2. 2D data review
3. 2.5D data
4. 3D data models: point clouds, and voxels, meshes, multipatch, integrated meshes
5. 3D layers for the web
6. 3D tiles
7. Data type conversion

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These are the topics covered in this module.

Datums and Projections Review

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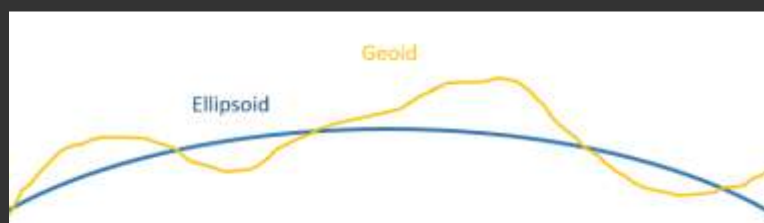
Before diving into 3D concepts, let's quickly review some fundamental concepts in geodesy and projections. These concepts form the foundation for all spatial data. Understanding datums and coordinate systems is critical because every piece of geospatial data we work with is referenced to one of these systems. This section is a review of material covered in our GIScience course.

Datums

- The Earth is not perfectly round! It is an oblate spheroid
- Geoid = Accounts for the fact that the gravitational force differs over the Earth. Models Earth as a bumpy surface
- Ellipsoid (Spheroid) = Earth surface modelled as an oblate spheroid



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Let's start with the concept of a datum. The Earth is not perfectly round: it is an oblate spheroid, meaning it's wider at the equator than it is from pole to pole. But this simplified shape doesn't fully capture reality either. Due to variations in mass distribution around the globe, gravitational pull is stronger in some places than others. This irregular gravitational field creates an undulating surface called the geoid, which more accurately represents mean sea level. However, the geoid is complex and difficult to work with mathematically, so we simplify it further to an ellipsoid or spheroid: a mathematical surface that can be described with equations and parameters. When we combine this ellipsoid with actual ground survey measurements, we create a datum.

Datums

- There are different models
  - NAD27 = North American Datum of 1927
  - NAD83 = North American Datum of 1983
  - WGS84 = World Geodetic System of 1984
- Think of these as different mathematical representations of the Earth

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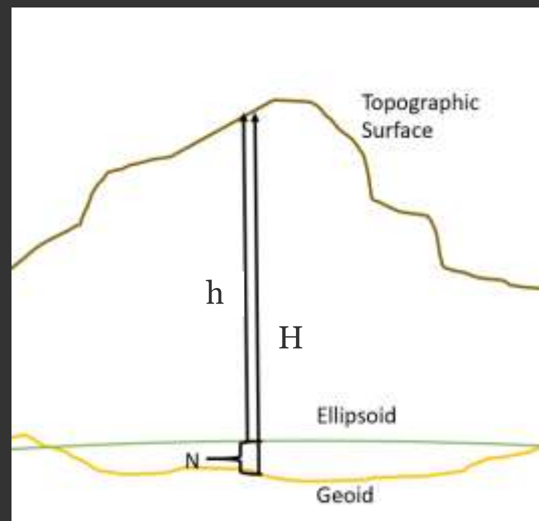
There are several important datums you'll encounter, particularly if you work with North American data. NAD27, the North American Datum of 1927, was established based on surveying done in the early 20th century with that era's measurement technology. NAD83, created in 1983, updated this with more precise measurements and adjusted for plate tectonics. WGS84, the World Geodetic System of 1984, is the global standard used by GPS and most online mapping systems. Each of these is fundamentally a different mathematical model or representation of the Earth's surface. When you're working with geospatial data, it's critical to know which datum your data are referenced to.

Vertical Datums

- **Orthometric Height (H)** = height above geoid
- **Ellipsoidal Height (h)** = height above ellipsoid
- **N** = difference between ellipsoidal and orthometric heights

$$h = H + N$$

$$H = h - N$$



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Vertical datums describe how we measure elevation. There are two key measurements here. Ellipsoidal height, denoted as lowercase 'h', is the height above the ellipsoid—the mathematical surface we just discussed. Orthometric height, denoted as 'H', is the height above the geoid, or roughly above mean sea level. The difference between these two is called N. This relationship is expressed as h equals H plus N. Understanding this distinction is important because GPS gives you ellipsoidal heights, but most traditional surveying and engineering work uses orthometric heights.

Common Vertical Datums

- National Geodetic Vertical Datum of 1929 (NGVD29)
- North American Vertical Datum of 1988 (NAVD88)

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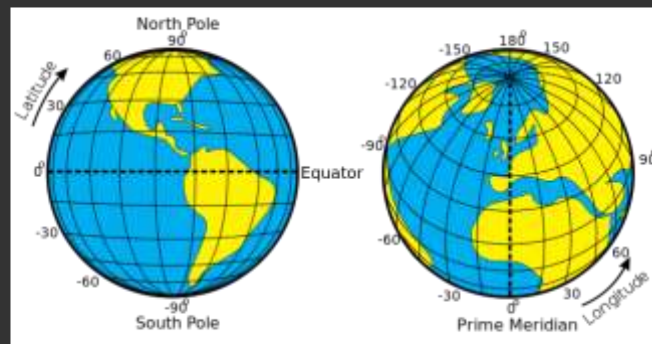
In North America, we have two main vertical datums in common use. NGVD29, the National Geodetic Vertical Datum of 1929, was based on tide gauge measurements from that era. NAVD88, the North American Vertical Datum of 1988, is the newer standard with more accurate measurements and better accounts for the actual geoid surface. Similar to horizontal datums, it's important to know which vertical datum your elevation data are referenced to.

Geographic Coordinate Systems (GCS)

Latitude (Parallels)
- Measures north to south
- 90° in each hemisphere
- Increases as you go north in the northern hemisphere
- Increases as you go south in the southern hemisphere
- Zero is Equator

Longitude (Meridians)
- Measures east to west
- 180° in each hemisphere
- Increases as you go east in the eastern hemisphere
- Increases as you go west in the western hemisphere
- Zero is Prime Meridian



https://commons.wikimedia.org/wiki/File:Latitude_and_Longitude_of_the_Earth.svg

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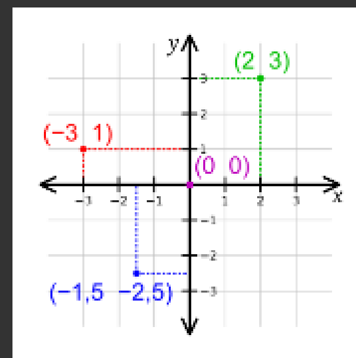
A geographic coordinate system uses latitude and longitude to specify locations on the Earth's surface in degrees. Latitude measures north-south position using parallels, with 0 degrees at the equator and 90 degrees at each pole. Longitude measures east-west position using meridians, with 0 degrees at the Prime Meridian near Greenwich, England, and 180 degrees on the opposite side of the globe. Both measurements increase as you move away from these reference lines. Latitude and longitude are angular measurements—they tell you direction and relative position, but not actual distances in ground units like meters or feet.

Viewing the 3D Earth on a 2D surface

- Map projections allow us to view the 3D Earth on a 2D surface
- Earth is mathematically projected to a surface that can be made flat
- We now make measurements in distance or length units as opposed to degrees
- A Cartesian coordinate system
- We call these surfaces Map Projections



https://commons.wikimedia.org/wiki/File:Cartesian_coordinate_system_(comma).svg

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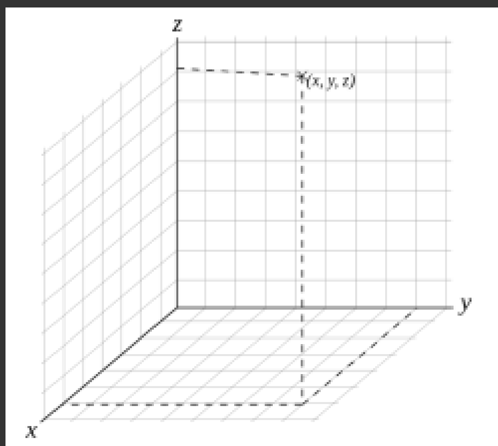
Map projections mathematically transform the curved surface of the Earth onto a flat surface that we can print or display. There are many different projection methods, each with different characteristics. The key advantage of a map projection is that it allows us to work with a Cartesian coordinate system—a standard x, y system where we can measure distances, areas, and angles in consistent ground units. Instead of degrees of latitude and longitude, we now have measurements in meters or feet.

Coordinates in 3-D space



x, y, z

https://commons.wikimedia.org/wiki/File:Cartesian_with_grid.svg

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In three-dimensional space, we extend the Cartesian coordinate system to include a z-axis. This gives us x, y, z coordinates in 3D space. The x and y axes define horizontal position, while z represents elevation or height. This is the foundation for all 3D GIS work. When we talk about 3D data models, we're essentially working with coordinate systems that include these three spatial dimensions.

Geographic vs. Projected Coordinate Systems

Image from ArcGIS API for JavaScript

Image from ArcGIS API for JavaScript

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Here's a visual comparison of geographic versus projected coordinate systems. On the left, you see how latitude and longitude are distributed across the globe in degrees. On the right, you see how a projected coordinate system transforms this to a flat surface with uniform grid cells. The key difference is that in a geographic coordinate system, the degree spacing changes depending on latitude, but in a projected system, your grid cells are uniform in size.

Why do we use map projections?

- Allow us to represent the Earth of a flat surface
- Allow us to make measurements on flat maps (Distance, Area, X/Y Coordinates)
- Measures of length and angle are uniform

Geographic coordinate system (Degrees)

Latitude and longitude are not uniform across the Earth's surface

Image from ArcGIS API for JavaScript

Projected coordinate system (Cartesian)

Measures of length and angle are uniform

Image from ArcGIS API for JavaScript

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Why do we use map projections? There are several important reasons. First, they allow us to represent the 3D Earth on a 2D surface, which is essential for creating maps and doing spatial analysis. Second, they let us make measurements on flat maps, which is impossible with pure latitude and longitude. Third, most importantly for our work, measures of length and angle become uniform and consistent. In a geographic coordinate system using degrees, one degree of latitude always represents the same distance on the ground, but one degree of longitude varies dramatically depending on your latitude. Near the poles, it's much smaller; at the equator, it's the largest. Projected coordinate systems solve this problem by using uniform ground units.

2D Data Models Reviews

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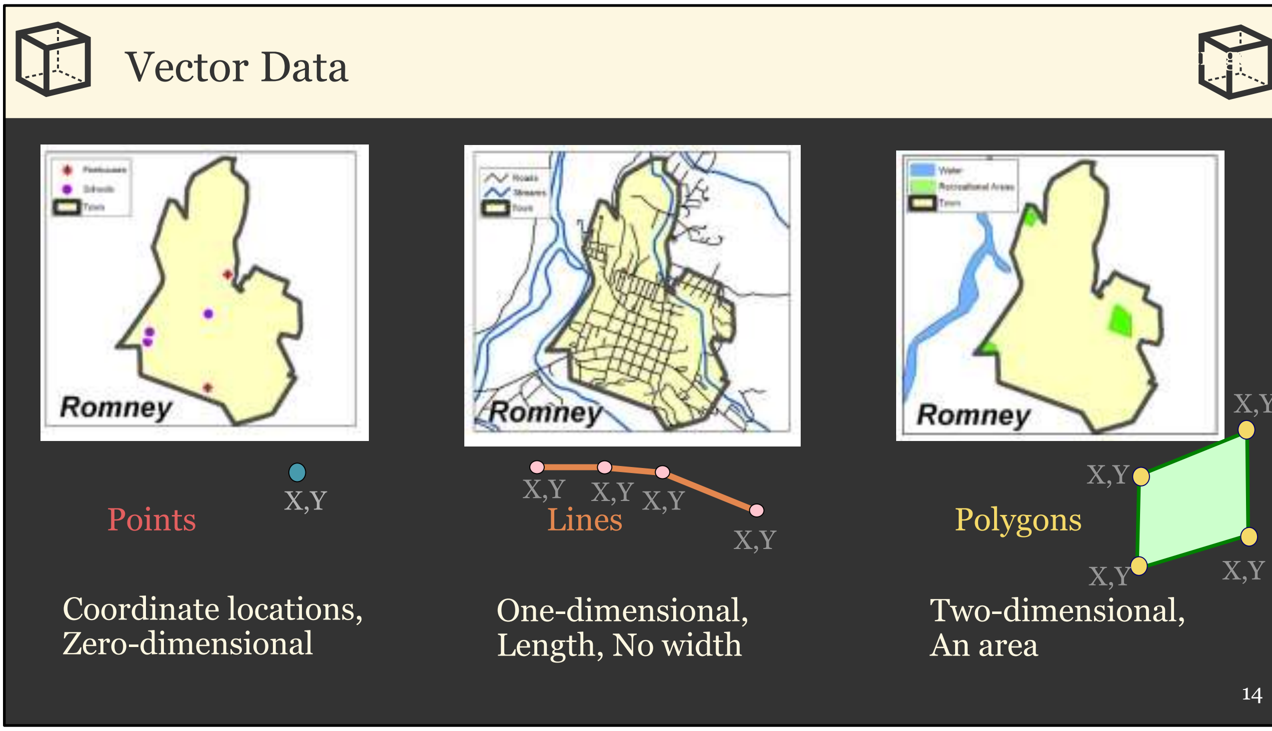
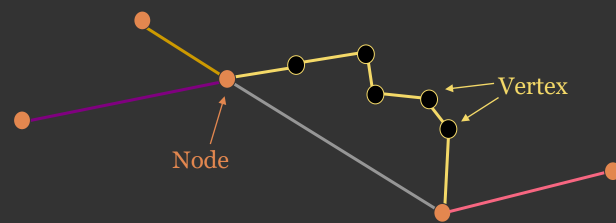
Now we're moving into 2D data models, which are the traditional way of representing geographic information. Understanding 2D models is essential because they form the basis for more complex 3D representations.



There are three fundamental types of 2D vector data: points, lines, and polygons. Points are the simplest: they're zero-dimensional features represented by a single x,y coordinate pair. Points are useful for features such as well locations, city centers, or sample sites. Lines are one-dimensional features that have length but no width. They're represented by a series of x,y coordinate pairs connected together and are useful for representing roads, rivers, utility lines, or any other linear features. Polygons are two-dimensional features that enclose an area, represented by a closed series of coordinate pairs. They're used for parcels, administrative boundaries, lakes, forest stands, or any other area features. All three types can have associated attributes in a database that describe properties of the features.

Vector Data Structure

- Vector data are made up of connected vertices.
- End vertices are called nodes.
- Vertices can be connected as lines and polygons.



A computer uses relationships between features to build geometric features that are spatially referenced.

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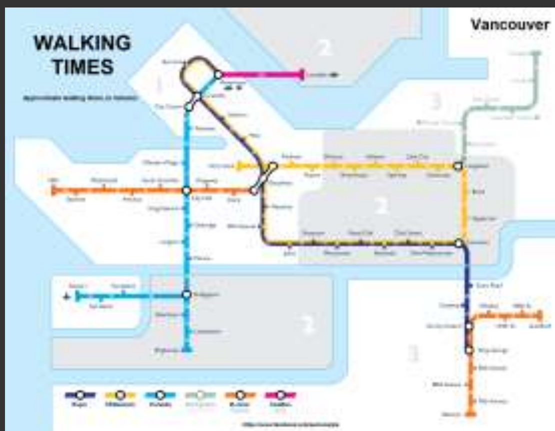
Vector data are constructed from connected vertices and edges. A vertex is a point in the coordinate system. When two vertices are connected, they create an edge or line segment. When vertices are connected to form a closed shape, they create a polygon. The vertices at the ends of a line segment are called nodes. The computer maintains the relationships between vertices to construct these geometric features. For example, a polygon's vertices must be in a specific order and the line must close on itself. The computer understands these relationships and uses them for spatial operations like determining if a point is inside a polygon or whether two lines intersect.

Topology



http://www.insidevancouver.ca/2016/04/04/vancouver-map-showing-walking-times-between-skytrain-stations-and-b-line-stops/

Study of properties of geometric objects that remain invariant under certain transformations such as bending or stretching (Massey, 1967)

Examples:

- Adjacent to
- Incident with

Topology and Topography are different!

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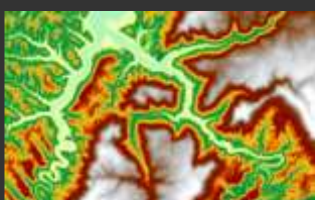
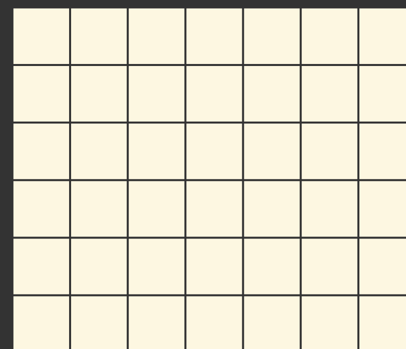
Topology is the study of properties that remain unchanged under certain transformations. In GIS, topology defines the spatial relationships between features. Two important topological relationships are 'adjacent to', meaning features share a boundary or edge, and 'incident with', meaning features meet at a point. Topology is different from topography; topography refers to the physical features and elevation of the landscape. Understanding topology is crucial for spatial analysis because many GIS operations depend on maintaining correct topological relationships.

Raster Data

- Like a matrix or array of data
- Origin generally defined as coordinates of upper-left corner
- Cells have defined height and width relative to the coordinate system/projection





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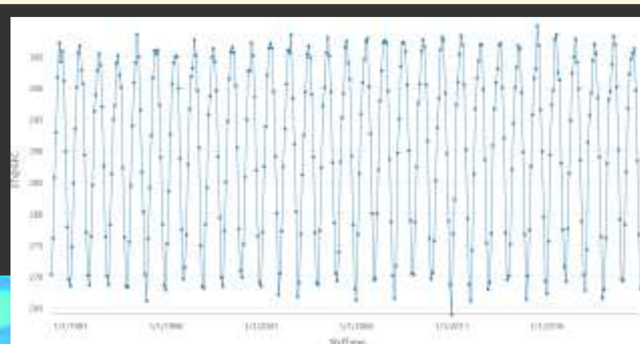
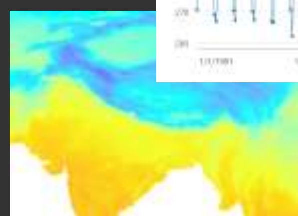
Now let's discuss raster data, which is fundamentally different from vector data. Raster data is organized as a regular grid of cells, like a matrix or array. Each cell has a defined height and width based on your coordinate system and projection. The origin, or the location where coordinates are zero, is typically defined as the upper-left corner of the raster. Each cell in the grid contains a value that represents some phenomenon at that location, whether that's elevation, temperature, vegetation type, or any other characteristic. Raster data are particularly good for continuous phenomena and are very efficient for certain types of analysis and storage.

Multidimensional Raster Grids

- Store more than three dimensions
- Commonly used in climate, atmospheric, and oceanographic science
- Time
- Depth
- Multiple variables
- Common Formats
  - GRIP, HDF, NetCDF, CRF





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Rasters can extend beyond three dimensions into multidimensional arrays. These are particularly common in climate, atmospheric, and oceanographic science. A 4D or higher dimensional raster might include time as an additional dimension, so you have multiple time steps at each x,y location. It might include depth or altitude, creating a 3D space-time volume. And it might include multiple variables (e.g., temperature, pressure, and humidity) all stored together. Common formats for multidimensional raster data include GRIB, HDF, NetCDF, and CRF formats, which are specifically designed to efficiently store and access this type of data.

2.5 D Data Models Reviews

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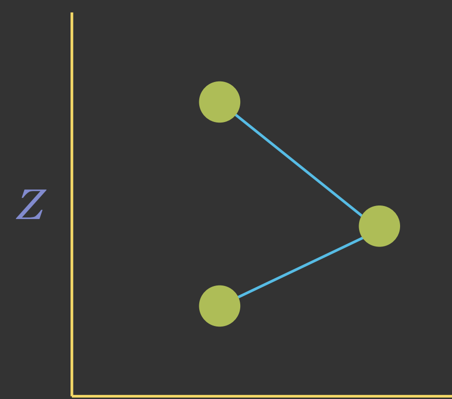
We're now moving into 2.5D data models. The term '2.5D' is somewhat imprecise, but it generally describes data that has 2D horizontal extent but includes elevation or some other third dimension.

z-enabled

- 2D coordinates + *z* coordinate
- *z* is part of vertex geometry, not an attribute table column
- *z* could be:
  - Elevation relative to a vertical datum
  - Height above ground surface
  - Some other continuous measure



Two coordinates can't be at the same *x*, *y* position and have different *z*-coordinates

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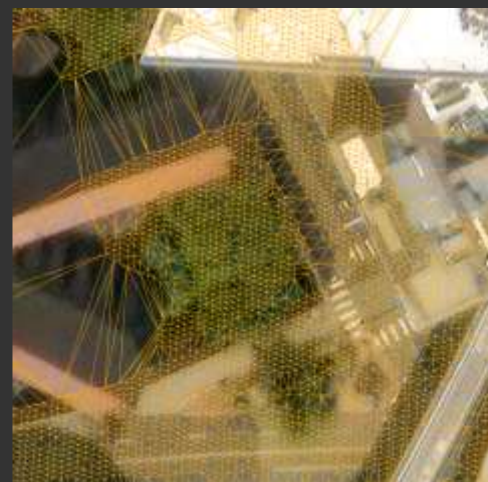
Z-enabled vector data adds a z-coordinate to each vertex. Unlike storing elevation in an attribute table, the z-coordinate is actually part of the geometry: it's part of the vertex definition itself. This is an important distinction because it means the spatial operations and topological relationships can take the z-coordinate into account. The z value might represent elevation relative to a vertical datum, height above the ground surface, or some other continuous measure.

One key constraint of z-enabled vector data is that two vertices cannot occupy the same x,y location with different z values: each x,y position can have only one z value. This works fine for terrain representation but breaks down in true 3D environments where you might have features at different heights in the same location.

Triangulated Irregular Network (TIN)

- TINs (Triangulated Irregular Network)
- Good for representing terrain data
- A space filling model



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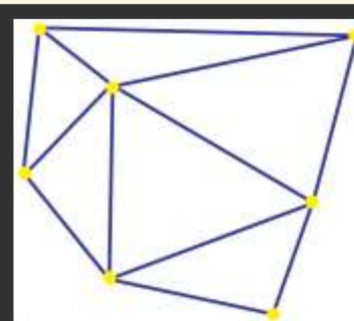
Triangulated Irregular Networks, or TINs, are a specialized 2.5D data structure particularly good for representing terrain. A TIN is built by connecting measured elevation points to form triangles. The triangles completely fill the space: they're contiguous and non-overlapping. This creates what's called a 'space-filling model'.

The advantages and disadvantages compared to raster data are important to understand. TINs are efficient for storing terrain where you have measurements at irregular intervals because they concentrate data where it's needed rather than forcing regular grids. However, they're more complex to work with computationally and not as suitable for certain types of analysis.

Triangulated Irregular Network (TIN)

- Connect measurement points to form a triangle (face)
- Can also include contours and/or breaklines
- Lines connecting points = edges
- Can be used to represent a terrain (or other continuous surfaces)
- Pros and cons compared to raster data



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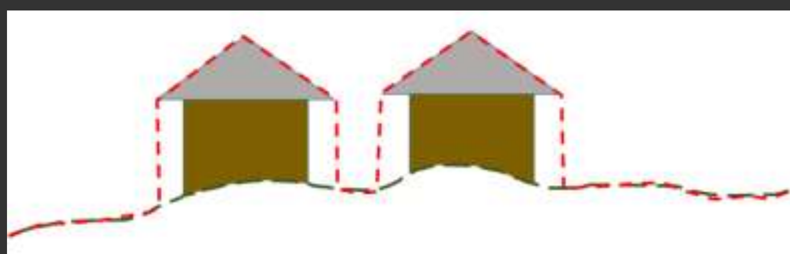
Building a TIN involves several steps. You start with your measurement points and connect them to form triangles; this creates the faces of the TIN. The lines connecting the points are the edges. You can also incorporate contours or breaklines into the triangulation to ensure important features like ridges or stream channels are properly represented. The triangulation creates a continuous surface that interpolates between the measurement points. This surface can be used to estimate elevations at any location or to perform terrain analysis.

Elevation Data

- DTM (Digital Terrain Model) = A representation of a terrain surface calculated by measuring elevation values at a series of locations
- DEM (Digital Elevation Model) = A model of the terrain surface
- DSM (Digital Surface Model) = Ground surface + objects above the ground surface



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There are three different types of elevation data models: DTMs, DEMs, and DSMs.

A Digital Terrain Model, or DTM, is specifically a representation of the bare earth surface: the ground itself without any vegetation or human-made structures.

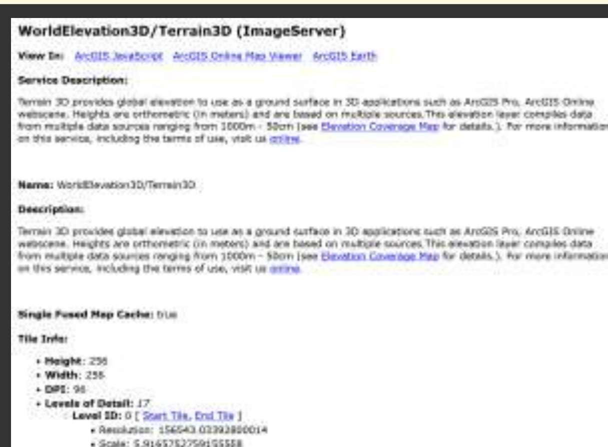
A Digital Elevation Model, or DEM, is a more general term that can refer to any model of the terrain surface, and the distinction between DTM and DEM is not always consistent in the literature.

A Digital Surface Model, or DSM, includes everything on the surface (e.g., buildings, forests, and powerlines). This distinction is critical when you're working with lidar data or other elevation sources, because they inherently capture the surface model, not the bare earth.

ESRI Default DTM

- ESRI World Elevation Services
- Hosted via ArcGIS Online
- Varied sources

Data Type	ArcGIS Map Service
Server	https://elevation3d.arcgis.com/arcgis/rest/services/WorldElevation3D/Terrain3D/ImageServer
Service Name	WorldElevation3D/Terrain3D
Is Cached	Yes
Vertical Units	Meter


WorldElevation3D/Terrain3D (ImageServer)

View In: ArcGIS JavaScript ArcGIS Online Map Viewer ArcGIS Earth

Service Description:

Terrain 3D provides global elevation to use as a ground surface in 3D applications such as ArcGIS Pro, ArcGIS Online webscene. Heights are orthometric (in meters) and are based on multiple sources. This elevation layer compiles data from multiple data sources ranging from 1000m - 50cm (see Elevation Coverage Map for details.). For more information on this service, including the terms of use, visit us online.

Name: WorldElevation3D/Terrain3D

Description:

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Single Fused Map Cache: true

Tile Info:

- **Height:** 256
- **Width:** 256
- **DPI:** 96
- **Levels of Detail:** 17
  - **Level ID:** 0 [Start Tile, End Tile]
    - Resolution: 156543.03392800014
    - Scale: 5.91657527591555E8

https://developers.arcgis.com/rest/elevation/

https://www.esri.com/arcgis-blog/products/analytics/analytics/introducing-esris-world-elevation-services

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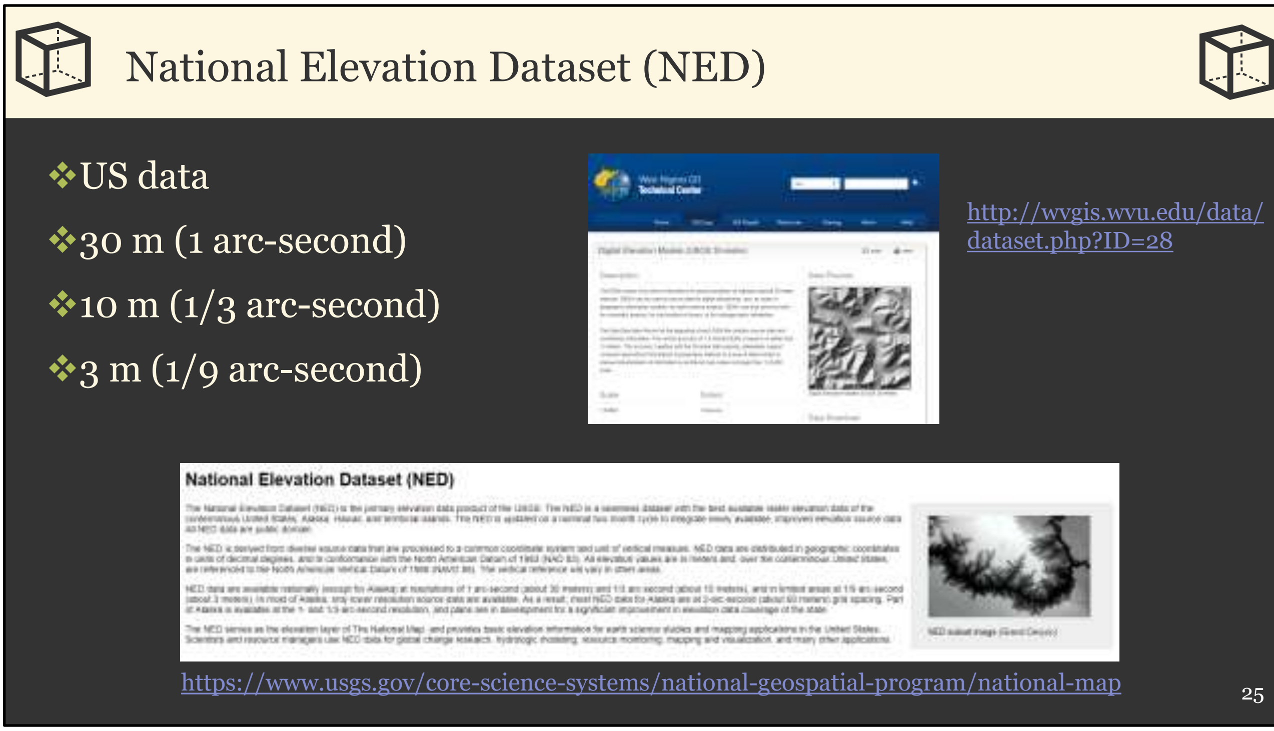
ESRI's World Elevation Services provide a convenient hosted source of elevation data accessible through ArcGIS Online. This service combines data from multiple sources to provide global coverage. The imagery shows the global elevation dataset as it appears in ESRI's default DTM service. While convenient, be aware that when you use hosted services you're depending on ESRI's data selection and processing choices, which may not be optimal for your specific application.



The National Elevation Dataset, or NED, provides US elevation data at multiple resolutions. The 30-meter resolution, also called 1 arc-second, has been the standard for many years and is freely available. Higher spatial resolutions are available in many areas: 10 meters or 1/3 arc-second resolution in some regions, and 3 meters or 1/9 arc-second in others. These higher spatial resolutions are increasingly available as lidar collection expands. The NED is hosted and distributed through the USGS.

USGS 3DEP Program

- Free elevation data download
- Draws from a variety of data sources
- A replacement for the National Elevation Dataset (NED)

https://www.usgs.gov/3d-elevation-program https://nationalmap.gov/3DEP/

The USGS 3DEP, which stands for 3D Elevation Program, provides free elevation data downloads. The data are generated using lidar in the contiguous United States, Hawaii, and US territories and are ifsar-based in Alaska.

The 3DEP program is essentially the replacement for the National Elevation Dataset, bringing more modern standards and higher spatial resolution data. You can browse and download 3DEP data through the National Map website.

Shuttle Radar Topography Mission

- SRTM (Shuttle Radar Topography Mission)
- Radar-based
- February 2000
- 11-day mission
- Mapped 80% of world at 90 m resolution
- 30 meter over US

https://www.jpl.nasa.gov/missions/shuttle-radar-topography-mission-srtm/

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The Shuttle Radar Topography Mission, or SRTM, was a NASA mission in February 2000 that collected radar-based elevation data during an 11-day space shuttle mission. The mission mapped about 80% of the Earth's land surface at 90-meter resolution. Over the United States, SRTM data are available at 30-meter spatial resolution, which was state-of-the-art at the time but is now considered relatively coarse. The 90-meter data were later processed to 30-meter products for areas outside of the United States. SRTM data are still widely available and useful, particularly for global applications where higher spatial resolution data aren't available.

ASTER Global Digital Elevation

- Photogrammetric
- Derived from the Advanced Spaceborne Thermal Emission Reflectance Radiometer (ASTER) onboard Terra
- Global coverage
- 30 m

https://asterweb.jpl.nasa.gov/gdem.asp

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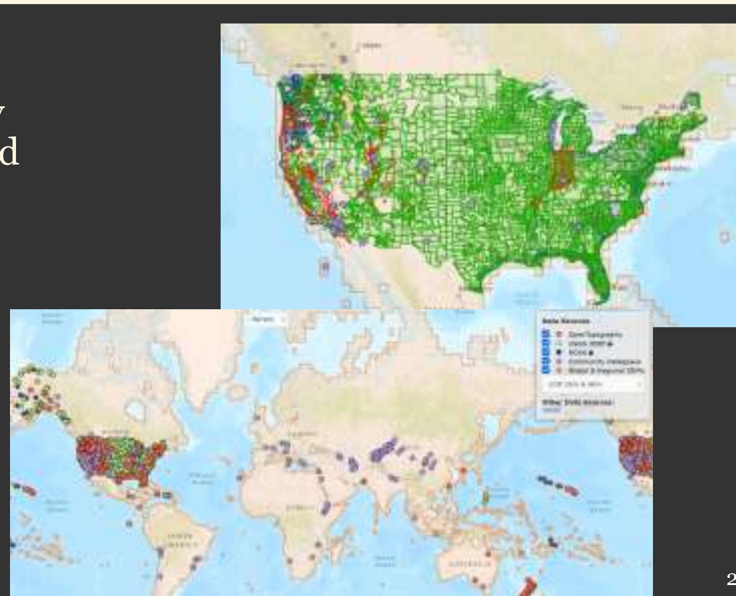
ASTER, the Advanced Spaceborne Thermal Emission Reflectance Radiometer, is an instrument aboard the Terra satellite. It provides photogrammetric elevation data, meaning elevation is derived from stereo imaging rather than radar or lidar. ASTER Global Digital Elevation data provides global coverage at 30-meter resolution, making it valuable where other elevation sources aren't available.

OpenTopography

OpenTopography
High-Resolution Topography Data and Tools

- NSF-funded
- Provides access to a variety of lidar datasets and derived products
- Additional access for researchers and students
- Download or access programmatically
- Includes processing and analytics tools



https://opentopography.org/

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OpenTopography is an NSF-funded project that provides access to lidar and other topography datasets along with processing and analysis tools. OpenTopography is particularly valuable because lidar data can be very challenging to download and process on your own: the file sizes are large, and the formats can be complex. OpenTopography provides processed point clouds, derived products like DEMs and TINs, and web-based tools for analysis. You can both download data and access it programmatically through their API, making it useful both for desktop work and for workflows that need to access data computationally.

Structure from Motion (SfM)

❖Terrain data created from overlapping drone imagery

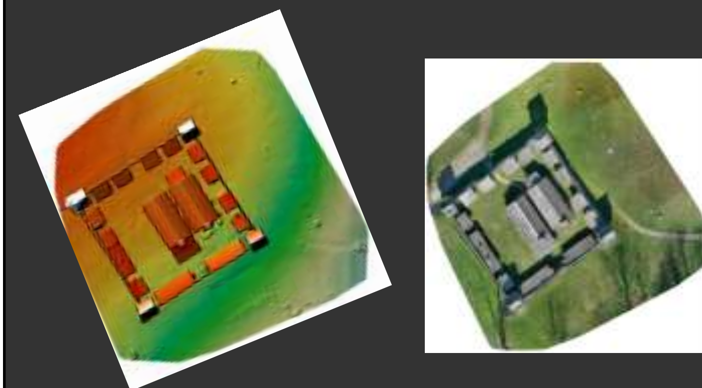

Image provided by Rachael Taylor

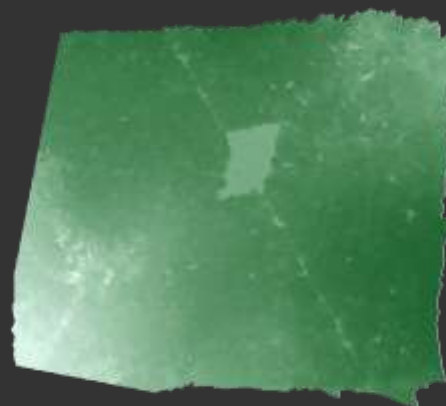

Image provided by NRAC

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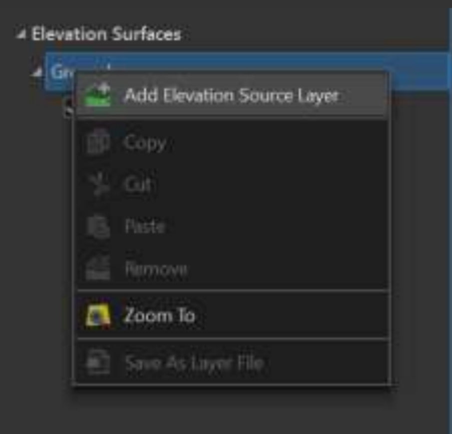
Structure from Motion, or SfM, is an increasingly popular technique for generating elevation data. Rather than using lidar or radar, SfM uses overlapping aerial imagery captured from a drone or aircraft. The overlapping images are processed computationally to identify matching points across images, and the geometric relationships between these matched points are used to reconstruct the 3D positions. This generates a point cloud of terrain data without needing expensive lidar hardware. SfM elevation data are becoming increasingly common in research and practice because drones are accessible and the software to process SfM data is becoming more user-friendly and available.

Changing the elevation source in ArcGIS Pro

- Scene View → Contents → Elevation Surfaces → Ground → Add Elevation Source Layer



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Here's a practical example of how to set elevation sources in ArcGIS Pro. In the Scene pane, you can navigate to Contents, then to Elevation Surfaces. From there you can choose to add an elevation source layer. This allows you to specify which elevation dataset to use for your 3D visualization. This is crucial because different elevation sources may have different characteristics, coverage areas, or spatial resolutions, and choosing the appropriate source affects your analysis results.

3D Data Models

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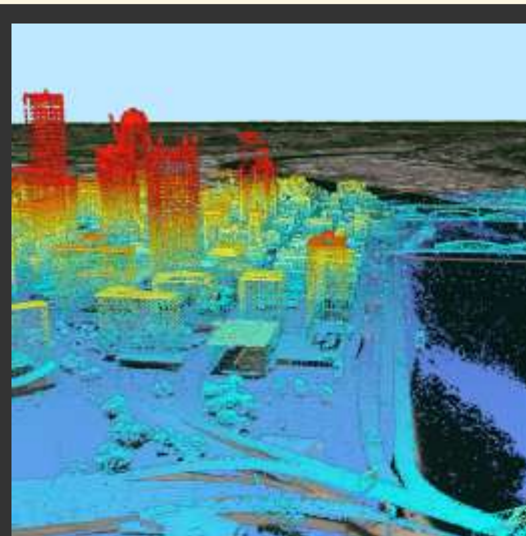
3D data models are data structures specifically designed to represent full three-dimensional information, not just 2D data with elevation values.

Point Clouds

- Collection of *x*, *y*, *z* coordinates
- Can have additional attributes
- Can be referenced to a local coordinate system
- Can be referenced to a true geographic or projected coordinate system
- Often generated using lidar or photogrammetry



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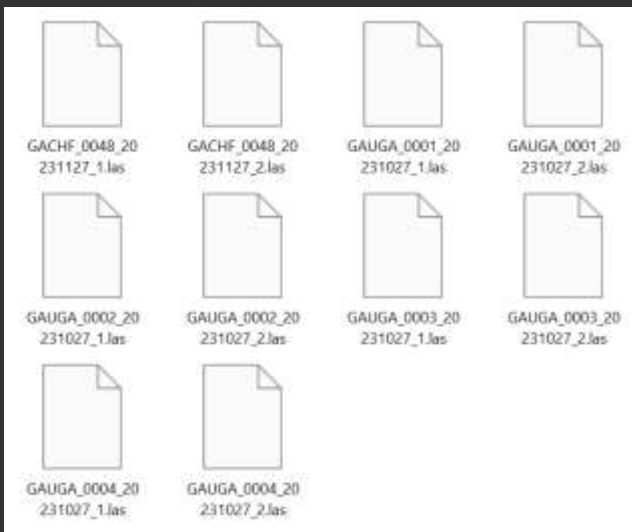
A point cloud is a collection of x, y, z coordinates, typically generated from lidar or photogrammetry sources. Each point represents a location in 3D space where a measurement was taken. Point clouds often contain millions or even billions of points. Each point can have associated attributes beyond just the coordinates (e.g., lidar points typically include intensity values and classification information). Point clouds can be referenced to local coordinate systems or to geographic or projected coordinate systems, depending on how they were collected. The beauty of point clouds is that they're completely general—they can represent any 3D phenomenon without requiring any assumptions about the data structure.

Point Cloud File Formats



- .las
- .e57
- .pcd
- .ptx

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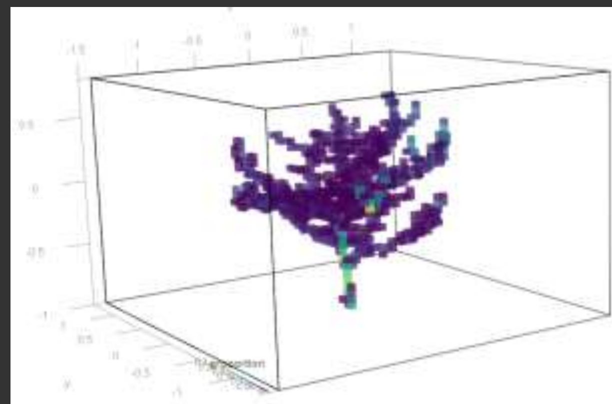
Point cloud data are stored in various formats, and it's important to know the strengths and weaknesses of each. The LAS format is the standard in the lidar industry and is handled well by most GIS and 3D software. The E57 format is another important format that includes metadata and additional information beyond just point coordinates. The PCD format is commonly used in robotics and computer vision applications. The PTX format is sometimes used by terrestrial laser scanner systems. Each format has different capabilities, metadata structures, and compression options.

Voxels

- Cells → Cubes
- Each unit is a volume
- Length in all three dimensions does not need to be the same
- Can store a value or multiple values at each location



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Voxels are a 3D extension of the pixel concept. If a pixel is a 2D cell in a raster, a voxel is a 3D cubic cell in a volumetric grid. Unlike raster cells, which often have the same height and width, voxels can have different dimensions in the x, y, and z directions. For example, you might have cells that are 5 meters in x and y but 1 meter in z. Each voxel can store a value or multiple values, representing whatever phenomenon you're modeling. Voxels are particularly useful when you have volumetric data like 3D atmospheric models or subsurface geological models.

Mesh

- True 3D geometry
- Still made up of vertices connected into faces
- Commonly triangles, but some software allow for other geometries

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A mesh is a true 3D geometric model made up of vertices connected into faces. While it's mathematically similar to 2D polygon geometry, it extends the concept fully into 3D. Most meshes are made up of triangular faces, though some software allows other polygon types. Each vertex has x, y, and z coordinates, and the faces are defined by which vertices they connect. Meshes are the standard representation in 3D graphics software and game engines because they're efficient to render and manipulate.

Mesh File Formats

- .obj
- .stl
- .ply
- .fbx
- .dae
- .gltf/.glb

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There are several standard mesh file formats you should be familiar with. OBJ is a simple, widely-supported text format. STL, the Stereolithography format, is standard in 3D printing and CAD. PLY, the Polygon File Format, is flexible and can store additional attributes per vertex. FBX is a proprietary but widely-used format developed by Autodesk that supports complex hierarchies and animations. DAE is the COLLADA format for interchange of 3D assets. GLTF and GLB are newer web-friendly formats designed for efficient transmission and web-based 3D viewing.

Multipatch

- Vector data with 3D geometry
- Single feature made up of connected patches
- Each feature can have associated attributes
- Primarily used in ESRI software
- Stored as a feature class in a geodatabase

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Multipatch is an ESRI-specific data structure for 3D geometry. Unlike meshes which are general 3D objects, a multipatch is specifically a feature class with 3D geometry where each feature is a single connected surface made up of patches. Each feature has associated attributes in a database table, making multipatches appropriate for structured GIS work where you're managing discrete 3D objects with properties. Multipatches are stored in geodatabases, which is ESRI's native data management system.

Integrated Mesh

- 3D mesh
- One surface (not individual features)
- Can be colorized or texturized
- Commonly created from photogrammetry or lidar
- Texturized with imagery
- Treated as 3D image

https://www.arcgis.com/home/item.html?id=3816389e961d4fac8b787068d0e3e2d1

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An integrated mesh is a specialized 3D layer type, typically created from photogrammetry or lidar data. Unlike other data types that represent individual features, an integrated mesh is a single continuous 3D surface. Integrated meshes are often created from drone or aerial photogrammetry and may be textured with imagery to provide photorealistic 3D visualization. They're treated as complete 3D images rather than as structured geometric features, making them ideal for visualization but less suitable for feature-based analysis.

Layers for the Web

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With the increasing adoption of web-based GIS, 3D data has moved to the web. ESRI and other platforms have developed web-friendly ways to serve and visualize 3D data. Understanding these web-based 3D layer types is important if you're publishing your work for broader audiences.

Layer Types

- ESRI Environment
  - Publish as a hosted 3D layer from a scene layer package (SLPK)
  - 3D tiles package as .3tz

https://www.esri.com/arcgis-blog/products/arcgis-online/3d-gis/3d-object-layer-a-comprehensive-overview

https://doc.arcgis.com/en/arcgis-online/reference/scene-layers.htm

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ESRI provides several mechanisms for serving 3D data on the web. You can publish a hosted 3D layer from a scene layer package, which is an SLPK file: a compressed package containing 3D geometry and related files. Alternatively, 3D data can be packaged as .3tz files for alternative services. These formats are optimized for efficient transmission and rendering on the web.

Layer Types

- 3D Object = similar to a multipatch feature class
- 3D Point = large set of point features with automatic thinning
- Building = complex digital building models
- Gaussian Splat Layers = realistic visualization of 3D geometry
- Mesh = integrated meshes on the web
- Point Cloud = point clouds
- Voxel = raster-based

3D layer type	Supports associated feature layer (editable)	Supports SLPK (read only)	Supports 3tz (read only)
3D object	Yes	Yes	Yes
3D point	Yes	Yes	No
Building	Yes	Yes	No
Gaussian splat	No	No	Yes
Mesh	No	Yes	Yes
Point cloud	No	Yes	No
Voxel	No	Yes	No

https://www.esri.com/arcgis-blog/products/arcgis-online/3d-gis/3d-object-layer-a-comprehensive-overview
https://doc.arcgis.com/en/arcgis-online/reference/scene-layers.htm

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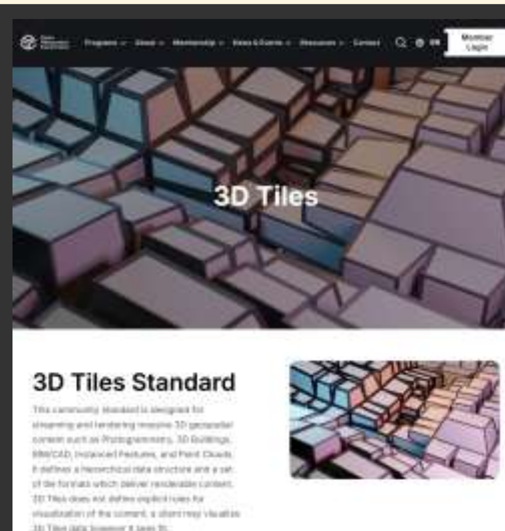
There are several different 3D layer types available in ESRI's web services, each optimized for different types of data. The 3D Object layer type is similar to a multipatch feature class and works well for discrete objects like buildings. The 3D Point layer is optimized for large sets of point features and uses automatic thinning to manage performance at different zoom levels. The Building layer is a specialized type for complex digital building models. Gaussian Splat Layers, relatively new, provide realistic visualization of 3D geometry using Gaussian splatting, a technique from computer graphics. Mesh layers handle integrated meshes on the web. Point Cloud layers serve actual point cloud data. Voxel layers provide web-based access to volumetric raster data. The table shows which formats and packages are supported by each layer type, which is important when you're deciding how to package your 3D data for web delivery.

Open Standards

❖3D Tiles

https://docs.ogc.org/cs/22-025r4/22-025r4.html

https://www.ogc.org/standards/3dtiles/



Open Geospatial Consortium

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3D Tiles is an open standard for streaming and rendering 3D geospatial data on the web. It's maintained by the Open Geospatial Consortium (OGC), which is the same organization that oversees standards like GeoJSON and Web Feature Service (WFS). 3D Tiles is designed to handle massive datasets efficiently by dividing the data into tiles that can be streamed and cached. Understanding 3D Tiles is important if you're working with web-based 3D applications or want to publish 3D data using open standards rather than proprietary formats.

Data Model Conversion

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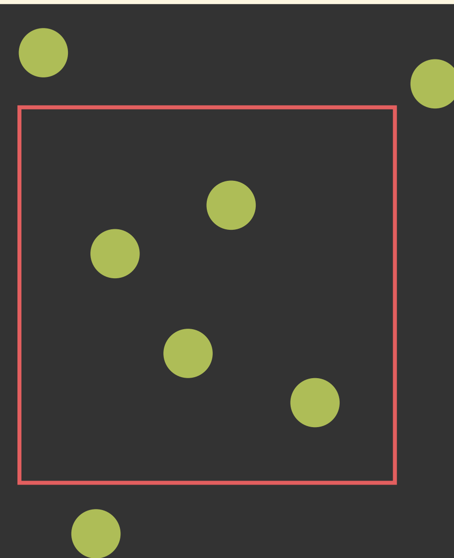
Different situations call for different data structures, and you'll frequently need to convert from one representation to another.

Point Cloud to Raster

- Interpolation Methods
  - Nearest Neighbor
  - Inverse Distance Weighting
  - Spline
  - Kriging
- Occupied or unoccupied
- Count of points
- Point Cloud → TIN → Raster
- Calculate a statistic from points falling into raster cell
  - Mean, median, minimum, maximum, sum, standard deviation, range, interquartile range, etc.
  - Must determine how to deal with cells without associated points



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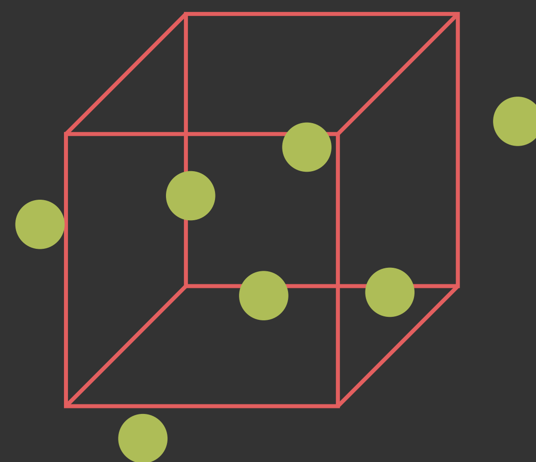
Converting point cloud data to raster format is a common operation. You might do this to reduce the volume of data for storage or analysis, or to create a continuous surface from discrete measurements. There are several approaches: you can simply mark which raster cells are occupied by points and which are unoccupied, you can store the count of points in each cell, or you can calculate a statistic from all the points falling into each raster cell (i.e., mean, median, minimum or maximum elevation, standard deviation, or other statistics).

A critical decision when voxelizing or rasterizing point data is what to do with empty cells, or those that don't contain any points. You might leave them as null values, assign a default value like zero, or use interpolation to fill gaps based on surrounding data.

Point Cloud Voxelization

- Occupied or unoccupied
- Count of points
- Calculate a statistic from points falling into voxel cell
  - Mean, median, minimum, maximum, sum, standard deviation, range, interquartile range, etc.
  - Must determine how to deal with cells without associated points



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Point cloud voxelization is similar to rasterization but works in 3D. You divide your 3D space into cubic voxel cells and then determine what point data falls into each cell. Like rasterization, you can mark occupancy, count points, or calculate statistics from points in each voxel. And like rasterization, you must decide how to handle empty voxels.

Dealing with Gaps

- Leave empty (Null, NA, or NoData)
- Assign a default value (e.g., 0)
- Fill gap via interpolation

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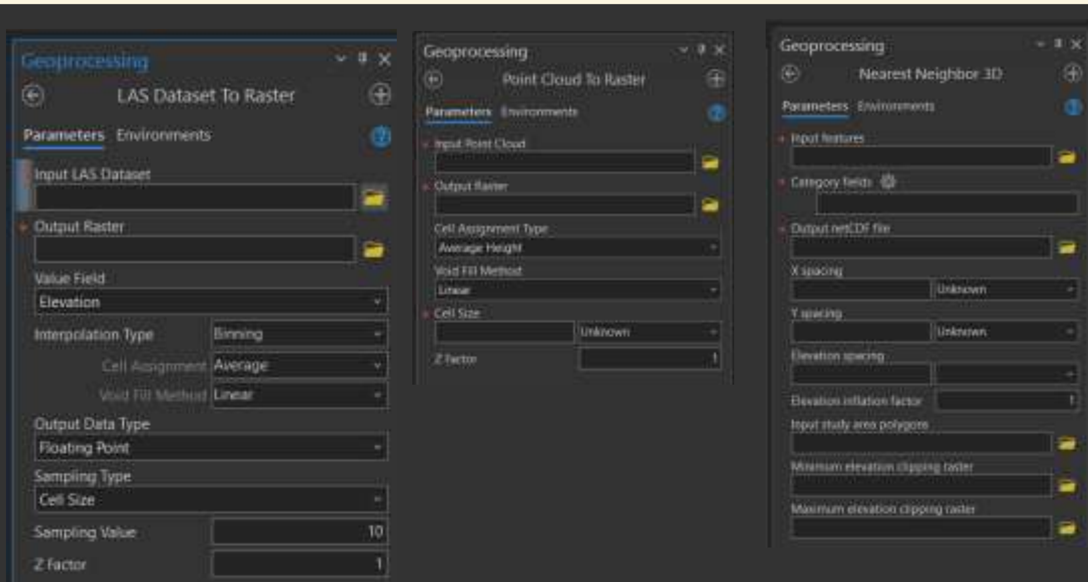
Dealing with gaps in voxelized or rasterized data is a critical consideration. You have three main options. You can leave cells empty with null values, which is honest to your data but creates problems for many analysis operations. You can assign a default value like zero, but this can introduce bias depending on what zero means in your context. Or you can fill gaps via interpolation using values from surrounding cells. Each approach has tradeoffs that depend on your specific application and the nature of your data.

Tools in ArcGIS Pro



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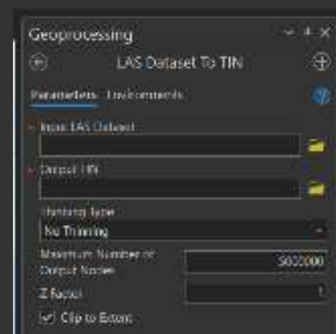
ArcGIS Pro provides tools for performing these data model conversions. These tools handle much of the complexity of conversion and are worth exploring if you work regularly with elevation or 3D data. Understanding the underlying concepts is crucial for using these tools effectively.

Point Cloud to TIN

- ❖Points define edges
- ❖Can apply thinning
- ❖Can incorporate breaklines



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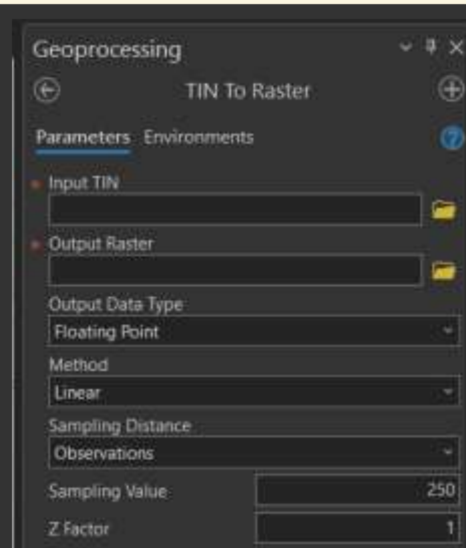
Converting a point cloud to a TIN involves using the points to define the vertices of triangles. You can apply thinning to reduce the number of points used, which is important for computational efficiency when working with massive point clouds. You can also incorporate breaklines (i.e., lines representing features like ridge crests, slope breaks, or stream channels that you want to ensure are properly represented in the triangulation).

TIN to Raster

- ❖ Linear: calculates cell values by applying linear interpolation to the TIN triangles
- ❖ Natural Neighbors: calculates cell values by using natural neighbors interpolation of TIN triangles



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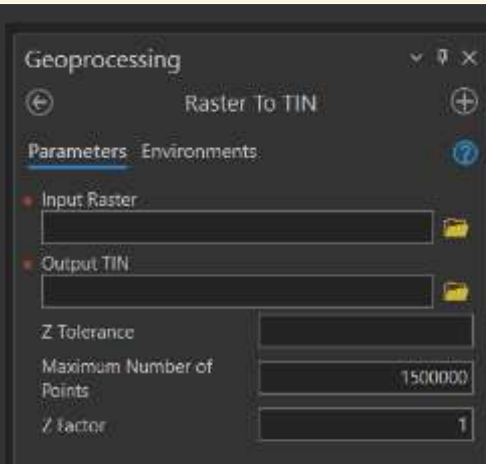
Converting a TIN to raster can be done using different interpolation methods. Linear interpolation calculates cell values by applying linear interpolation across the triangular faces of the TIN. Natural Neighbors interpolation uses a more sophisticated approach where the influence of surrounding TIN points varies with proximity and the local geometry. Both approaches produce smooth continuous surfaces from the TIN representation.

Raster to TIN



- Create TIN that does not deviates from raster cell values only within a defined *z* tolerance
- Points are derived from cell center and gradually added until tolerance is met
- Can set a maximum number of points to use

https://desktop.arcgis.com/en/arcmap/latest/tools/3d-analyst-toolbox/how-raster-to-tin-works.htm

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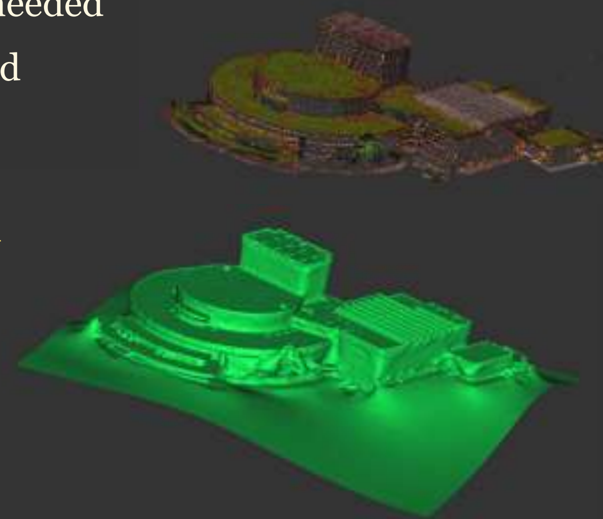
Converting a raster to a TIN is sometimes necessary. You first create a TIN that, importantly, does not deviate from the original raster cell values by more than a defined tolerance. Points are selected from the raster cell centers and gradually added until the tolerance is satisfied. You can set a maximum number of points to use, which prevents the resulting TIN from having unnecessary complexity.

Point Cloud Meshing

- Clean or simplify point cloud as needed
- Downsample or smooth as needed
- Build surface
  - Delaunay Triangulation
  - Poisson Surface Reconstruction
  - Ball Pivoting Algorithm
  - Alpha Shapes



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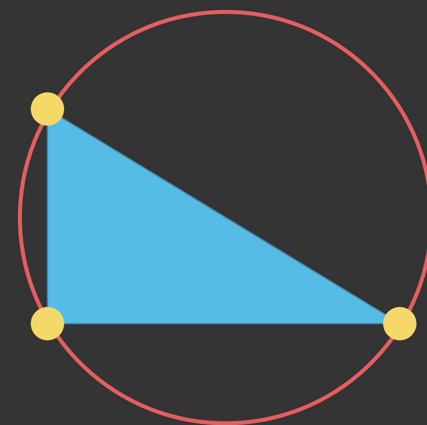
Converting point clouds to mesh representations is an important technique for creating 3D models from raw data. The process involves several steps. First, you clean or simplify the point cloud as needed, removing noise or outliers. You might downsample to reduce the number of points or smooth the data to reduce noise. Then you build a surface using one of several algorithms.

Delaunay Triangulation is a traditional approach. Poisson Surface Reconstruction is particularly good for complex 3D shapes. The Ball Pivoting Algorithm is another option. Alpha Shapes provide another approach. Each has different strengths and produces different results.

Delauney Triangulation

- Generate a set of triangles such that the no circumcircle of any triangle contains any other points in the dataset
- Circumcircle = circle that passes through all three vertices of a triangle
- Maximizes the minimum angle, creating well-shaped triangles that avoid thin, sliver triangles
- Good for terrain surface and 2.5 D data
- For true 3D data can use Delaunay tetrahedralization



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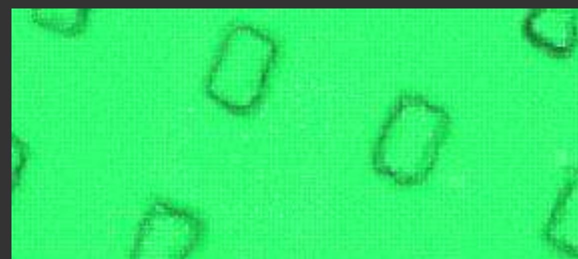
Delaunay Triangulation is a widely-used method for creating triangle meshes from point data. The key property of Delaunay triangulation is that no point in the dataset lies inside the circumcircle of any triangle. A circumcircle is simply the circle that passes through all three vertices of a triangle. This property is important because it maximizes the minimum angle of triangles, avoiding thin, sliver triangles that can cause problems. Delaunay triangulation works well for terrain surfaces and 2.5D data. For true 3D data, you can use Delaunay tetrahedralization, which extends the concept to three dimensions.

Poisson Surface Reconstruction

- Treats points and their normals as samples of a vector field
- Solve a Poisson equation to estimate the surface
- Attempt to define volume inside and outside of an object; surface defines interior and exterior
- Generate mesh from the surface
- Good for true 3D data
- Good for closed features/volumes
- Points must have normals



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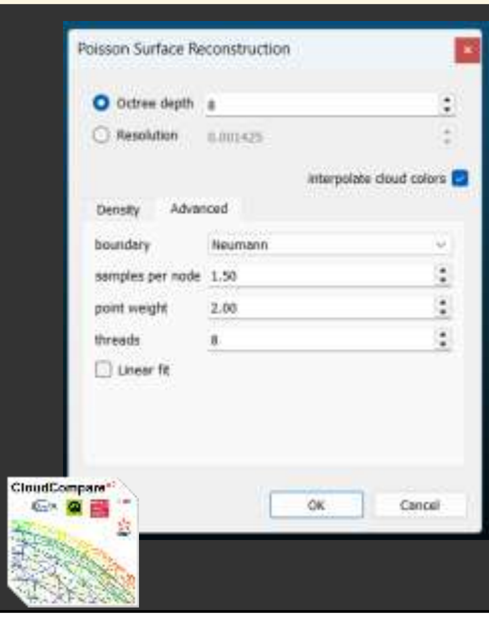
Poisson Surface Reconstruction is a more sophisticated approach particularly well-suited for true 3D data and closed features. The algorithm treats points and their surface normals as samples of a vector field and solves a Poisson equation to estimate the overall surface. This approach attempts to define a volume inside and outside the objects and derives the surface as the boundary between inside and outside. A mesh is then generated from this surface. Poisson reconstruction works well for creating complete models from point clouds, particularly when you're trying to capture complex 3D objects.

Poisson Surface Reconstruction



- Parameters
  - Octree Depth = octree resolution/level-of-detail
  - Point Weight = balance between point fitting and smoothness
  - Samples per Node = number of points per octree cell

https://www.cloudcompare.org/doc/wiki/index.php/Poisson_Surface_Reconstruction_(plugin)

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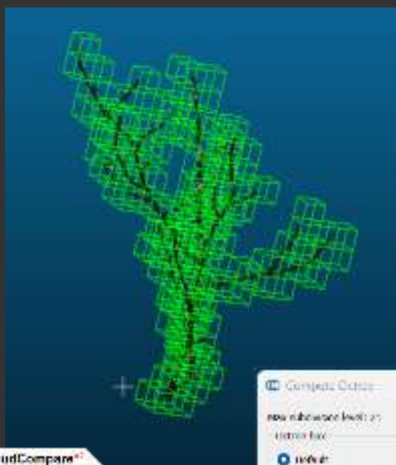
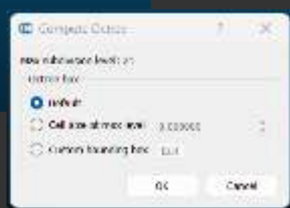
Poisson Surface Reconstruction has several important parameters. Octree Depth controls the resolution or level-of-detail of the reconstruction—higher values give more detail but take longer to compute. Point Weight balances how closely the reconstruction fits the original points versus how smooth the resulting surface is. Samples per Node controls how many points are used per octree cell. Adjusting these parameters allows you to tune the reconstruction to match your data and requirements.

Octree





- Nested cubic volumes
- Tree-based data structure
- Aids in spatial indexing, neighbor searches, downsampling, and compression
- User can control the number of levels generated

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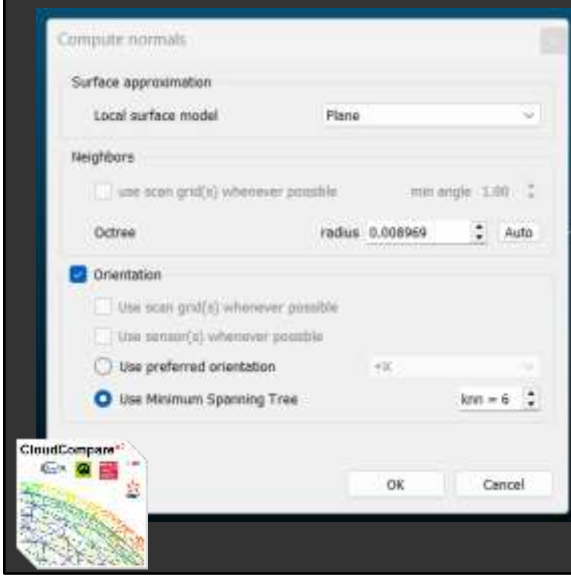
An octree is a tree-based spatial indexing structure that subdivides 3D space into nested cubic volumes. Octrees are fundamental to many 3D algorithms because they provide efficient spatial indexing and enable fast neighbor searches, downsampling, and compression. Understanding octrees is important because many 3D processing algorithms use them, and the octree parameters often need to be tuned for your specific data.

Normals



- Vectors perpendicular to a defined surface for each point

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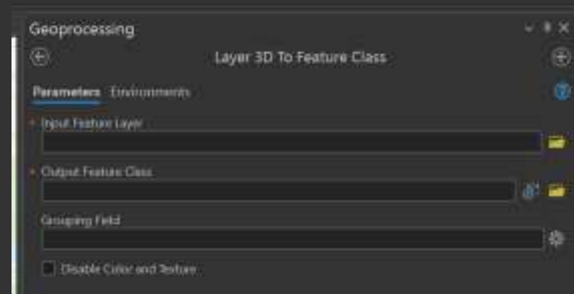
Normals are vectors perpendicular to the surface at each point. In 3D graphics and surface reconstruction, surface normals are critical because they define the orientation of the surface. Many surface reconstruction algorithms, particularly Poisson reconstruction, require normals as input. If your point cloud doesn't have normals, they can be estimated computationally based on the local neighborhood of each point.

Layer 3D to Feature Class

- 2D vector → 3D symbology → Multipatch
- Layer 3D To Feature Class Tool



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The final conversion we'll discuss is converting 3D layer data back to vector features. This uses ESRI's Layer 3D to Feature Class tool. You might do this to extract specific features from a 3D model for further analysis or to convert a 3D visualization back into a structured feature database. The conversion extracts the geometry from the 3D layer and stores it as a standard feature class with geometry and attributes.

This is the end of this lecture module.

Please return to the West Virginia View Webpage for additional content.

Thanks! Hope you found this useful.