PDHonline Course C423 (15 PDH)

GIS Applications in Water Resources and Environmental Engineering

Instructor: Steve Ramroop, Ph.D.

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PDH Online | PDH Center

5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone: 703-988-0088
www.PDHonline.com

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COURSE CONTENT – Lecture 3

Course C423 is a practical GIS course with particular reference to applications in Water Resources and Environmental Engineering, addressing some of the basic, yet common GIS needs in these two fields. The course describes the availability of free databases and public domain GIS software, and their use in performing common GIS processing tasks that are relevant to Water Resources and Environmental Engineering. The ability to search, download and make use of such data sets and software is presented within the context of this course. The course consists of 5 lectures, which start off with introductory level material in Lecture 1, and progressively builds up through the remaining four lectures. A basic awareness of the concept of GIS is desirable but not required as a pre-requisite for this course.

The following topics are covered in this 3rd lecture of Course C423:

- Common GIS processing tasks that include:
  - Creation of data types;
  - Conversion between data types; and
  - Analysis of data sets.
- Conversion of projection systems between data types.

1. GIS Processing

There exists a wide variety of free GIS data sets that can be accessed via the Internet that is unknown to the average GIS user. Such data sets will be addressed in terms of the downloading of the GIS files from databases and review of its attributes, while performing simple tasks. For example, creating a buffer around a project site, and importing various GIS data into the buffer area to perform simple analyses relevant to Water Resources and Environmental Engineering.

GIS processing is an all-in-one service to ensure optimal spatial data management and analysis for geospatial and related integrity management tasks.

The core of GIS is the analytical capabilities of the system. The distinguishing characteristic of a GIS system from other information system is in its spatial analysis functions. Although the data input is, in general, the most time consuming part, the utility of GIS lies in the subsequent data analysis function. The analysis functions use the spatial and non-spatial attributes in the database to answer questions about the real world. Geographic analysis facilitates the study of real-world processes by developing and applying models. Such models illuminate the underlying trends in geographic data and thus make new information available. Results of geographic analysis can be communicated with the help of maps, reports, or both.

The organization of database into map layers is not simply for reasons of organizational clarity; rather it also serves to provide rapid access to data elements required for geographic analysis. The objective of geographic analysis is to transform data into useful information to satisfy the requirements or objectives of decision-makers at all levels in terms of detail. An important use of the analysis is the possibility of predicting events in other locations or at another point in time.

Figure 1 shows a Land Change Modeler. It provides an integrated environment for land cover change analysis and prediction. To predict future scenarios, an artificial neural network is employed to model environmental variables related to changing land cover. Both hard and soft scenarios of change are provided to assess future projections. A hard prediction models a single realization while a soft prediction maps the spatial pattern and potential for change.

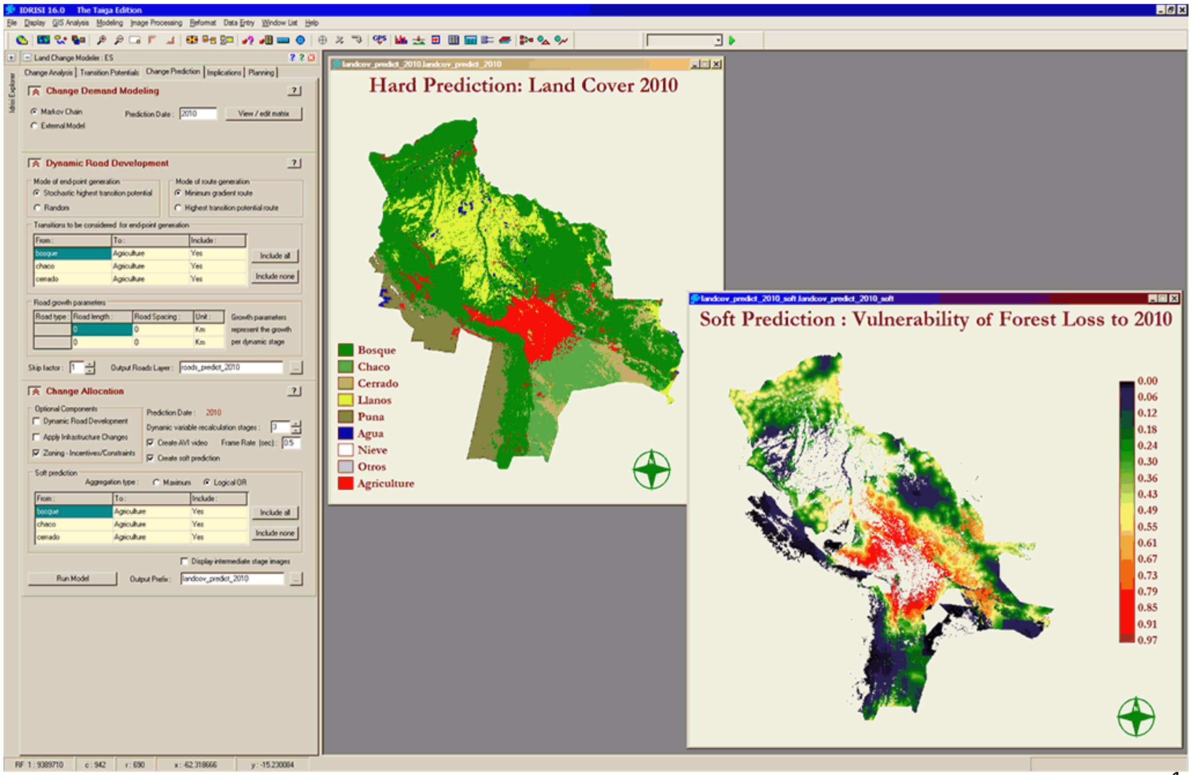


Figure 1: Land Allocation and Prediction with Land Change Modeler using IDRISI [1]

1.1 Creation of data types

Data is collected for use in GIS applications. There are various data categories which are as follows:

- Global positioning systems (GPS);
- Photogrammetry;
- Land Surveying data sets e.g. Total Stations, automatic levels.
- Census;
- Geospatial internet sites;
- Satellite imagery e.g. LandSAT, SPOT.
- LIDAR; and
- Digitize hardcopy maps.

Global positioning systems is a space-based global navigation satellite system (GNSS) that provides reliable location and time information in all weather and at all times and anywhere on or near the Earth when and where there is an unobstructed line of sight to four or more GPS satellites. It is maintained by the United States government and is freely accessible by anyone with a GPS receiver. In addition to GPS, other systems are in use or under development. The Russian GLObal NAvigation Satellite System (GLONASS) was for use by the Russian military only until 2007. GLONASS is a radio-based satellite navigation system operated for the

[1] http://www.clarklabs.org/applications/environmental-modeling.cfm

Russian government by the Russian Forces. It is an alternative and complementary to the United States' GPS.

Photogrammetry is the practice of determining the geometric properties of objects from photographic images. In the simplest example, the distance between two points that lie on a plane parallel to the photographic image plane can be determined by measuring their distance on the image, if the scale (s) of the image is known. This is done by multiplying the measured distance by 1/*s*.

A more sophisticated technique, called **stereophotogrammetry**, involves estimating the three-dimensional coordinates of points on an object. These are determined by measurements made in two or more photographic images taken from different positions.

Land surveying is the technique and science of accurately determining the terrestrial or three-dimensional position of points and the distances and angles between them. These points are usually on the surface of the Earth, and they are often used to establish land maps and boundaries for ownership or governmental purposes. To accomplish their objective, **surveyors** use elements of geometry, engineering, trigonometry, mathematics, physics, and law.

Land surveying can include associated services such as mapping and related data accumulation, construction layout surveys, precision measurements of length, angle, elevation, area, and volume, as well as horizontal and vertical control surveys, and the analysis and utilization of land survey data.

The basic tools used in Land surveying are a tape measure for determining shorter distances, a level to determine height or elevation differences, and a theodolite, set on a tripod, to measure angles (horizontal and vertical), combined with the process of triangulation. Starting from a position with known location and elevation, the distance and angles to the unknown point are measured. A more modern instrument is a total station, which is a theodolite with an electronic distance measurement device (EDM). A total station can also be used for leveling when set to the horizontal plane.

Geospatial internet sites are varied based upon the organization type and they all have multiple data types. To give an idea of its extent, the following is a list of common internet accessible sites, shown in Table 1 below.

Organization	Website
ESRI	http://www.esri.com/data/free-data/index.html
Bureau of Land Management	http://www.blm.gov/nstc/gis/GISsites.html
US Census Bureau	http://www.census.gov/geo/www/tiger/tgrshp2010/tgrshp2010.html
USGS	http://www.usgs.gov/pubprod/data.html#data
Geo Community	http://data.geocomm.com/catalog/

Table 1: Common GIS Internet sites

Satellite imagery is varied and comes in multiple formats and applications. Two common satellites used to collect imageries are: LANDSAT[2] and SPOT[3] satellite. They are typically land resource earth satellites that use multi-spectral and thematic sensors to sense and collect reflective energies of features on the earth surface.

There are other satellites available, a sample of which is shown in Table 2 below. The full list of existing satellites and future satellites can be viewed at the following website:
http://ilrs.gsfc.nasa.gov/satellite_missions/list_of_satellites/

[2] http://landsat.gsfc.nasa.gov/
[3] http://www.spotimage.com/web/en/210-about-us.php

Satellite Name	Satellite ID	SIC Code	NORAD Number	NP Indicator	Bin Size (Seconds)	Altitude (Km)	Inclination (deg)	First Data Date
Ajisai	8606101	1500	16908	5	30	1485	50	13-Aug-1986
Apollo11 Sea of Tranquility	0000100	N/A	N/A	2	variable	356,400	5	20-Aug-1969
Apollo14 Fra Mauro	0000102	N/A	N/A	2	variable	356,400	5	07-Feb-1971
Apollo15 Hadley Rille	0000103	N/A	N/A	2	variable	356,400	5	01-Sep-1971
Beacon-C	6503201	317	1328	3	15	927	41	02-Jan-1976
BLITS	0904907	5558	35871	5	30	832	98.77	24-Sep-2009
Cryosat-2	1001301	8006	36508	3	15	720	92	20-Apr-2010
COMPASS-M1	0701101	2001	31115	9	300	21,500	55.5	04-Dec-2008
Envisat	0200901	6179	27386	3	15	800	98	10-Apr-2002
ERS-2	9502101	6178	23560	3	15	800	99	24-Apr-1995
Etalon-1	8900103	0525	19751	9	300	19,105	65	26-Jan-1989
Etalon-2	8903903	4146	20026	9	300	19,135	65	13-Jul-1989
GIOVE-A	0505101	7001	28922	9	300	23,916	56	03-Apr-2009
GIOVE-B	0802001	7002	32781	9	300	23,916	56	26-Apr-2008
GLONASS-102	0606201	9102	29670	9	300	19,140	65	04-May-2007
GLONASS-109	0706503	9109	32395	9	300	19,140	65	04-May-2007
GLONASS-110	0804601	9110	33378	9	300	19,140	65	28-May-2008
GLONASS-115	0806702	9115	33467	9	300	19,140	65	04-May-2007
GLONASS-118	0907003	9118	36113	9	300	19,140	65	04-Jan-2010

Table 2: List of satellites

LIDAR (**Li**ght **D**etection **A**nd **R**anging) is an optical remote sensing technology that measures properties of scattered light to find range and/or other information of a distant target. The prevalent method to determine distance to an object or surface is to use laser pulses. Like the similar radar technology, which uses radio waves, the range to an object is determined by measuring the time delay between transmission of a pulse and detection of the reflected signal. LIDAR technology has application in Geomatics, archaeology, geography, geology, geomorphology, seismology, forestry, remote sensing and atmospheric physics.

LIDAR data is a collection of points which is collectively called a “Point Cloud”. The USGS[4] has LIDAR data which is available online for use. The USGS free LIDAR data set is shown in Figure 2 below.

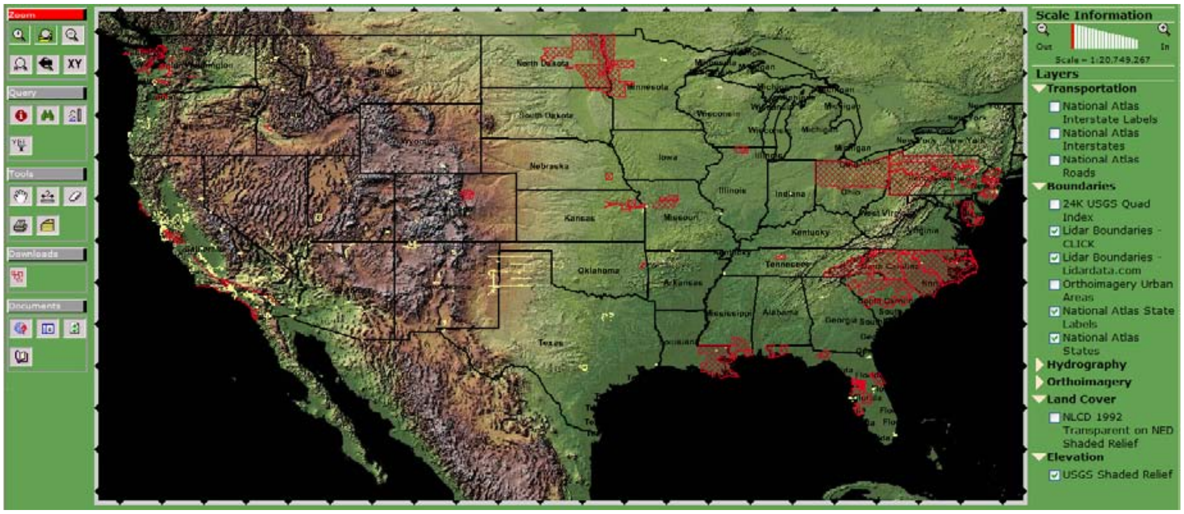


Figure 2: USGS Internet LIDAR data

Digitized hardcopy maps is a common method used to convert hardcopy maps into digital data sets. Types of Digitizing:

- **Manual Digitizing:** Also called ‘Heads-down digitizing.’ This is done using a digitizing tablet. The operator manually traces all the lines from a hardcopy map and creates an identical digital map on the computer. It is very time consuming and the level of accuracy is also not very good.
- **Heads-up Digitizing:** This is similar to manual digitizing in the way that lines have to be drawn manually but directly on the computer screen. Hence, the level of accuracy increases and time taken decreases.
- **Interactive tracing method:** This is an improvement over Heads-up digitizing in terms of speed and accuracy.
- **Automatic Digitizing:** This refers to automated raster to vector conversion using image processing and pattern recognition techniques. In this technique the computer traces all the lines, which results in high speed and accuracy along with improved quality of images.

1.2 Conversion between data types

Some of the data types are open, meaning that they have a published specification and can be used to write applications and utilities that work with the format. Other data types are closed, requiring the vendor provided Application Program Interface

[4] http://lidar.cr.usgs.gov/

(API). Of course, this is a concern only if users want to write their own applications and utilities. If users are content with using the out–of-the-box applications available, someone else has done the hard work for them.

Although it is not important to understand data type definitions before use , it does help to know a bit about them so users can determine whether their in-house software supports the data type. The common data types that are typically used in GIS applications were discussed in an earlier lecture (Lecture 2?). Such data types are sometimes readily used in some GIS software, while others require conversions. A listing of some of the common conversions is as follows:

- Web services
- GRASS
- ArcGIS
  - CAD
  - DGN
  - JPEG
  - DEM
- PostGIS

Web services

A "data type" commonly encountered is data deliverable over the Web. This category of data is often referred to as W*S. The moniker W*S is attached to standards for delivering geospatial data over the Web and includes Web Mapping Service (WMS), Web Features Service (WFS), and Web Coverage Service (WCS). A good chunk of the web mapping applications use data from a W*S service. For example ESRI has their ArcGIS online[5] map service which is a standard map services available at no cost for internal (personal or within an organization) and noncommercial, external use. There are basemaps, demographic maps, reference maps, and specialty maps.

Many desktop applications include support for at least one WMS. This allows users to include data from across the Internet in their mapping projects. The good thing is users don't have to understand the standard or how it works; users just use it and get good data for free. Further technical information on the standards for WMS, WFS, and WCS, can be found on the Open Geospatial Consortium[6] website.

GRASS

GRASS GIS software uses its own format for storing both raster and vector data. Data in GRASS is organized by location and mapset, making it easy to structure user data collection in a way that can be more easily managed.

GRASS is a topological GIS. This means that adjacent geographic components in a single vector map are related. For example, in a non-topological GIS, if two areas shared a common border, that border would be digitized two times and also stored in duplicate. In a topological GIS, this border exists once and is shared between two areas.

In GRASS, the following vector objects are defined:

- point: a point;
- line: a directed sequence of connected vertices with two endpoints called nodes;
- boundary: the border line to describe an area;
- centroid: a point within a closed boundary;
- area: the topological composition of centroid and boundary;
- face: a 3D area;
- kernel: a 3D centroid in a volume (not yet implemented);
- volume: a 3D corpus, the topological composition of faces and kernel (not yet implemented).

[5] http://www.esri.com/software/arcgis/arcgisonline/standard-maps.html
[6] http://www.opengeospatial.org/standards

GRASS provides both vector and raster import/export functions for a range of formats. To provide perspective on the capabilities, Table 3 shows a partial list of the import commands and formats supported by GRASS.

Command	Explanation
r.in.arc	Converts an ESRI ARC/INFO ASCII raster file (GRID) into a (binary) raster map layer
r.in.ascii	Converts ASCII raster file to binary raster map layer
r.in.aster	Imports, georeferences, and rectifies an ASTER image
r.in.gdal	Imports a GDAL-supported raster file into a binary raster map layer
r.in.srtm	Imports Shuttle Radar Topography Mission (SRTM) .hgt files into GRASS
r.in.wms	Downloads and imports data from WMS servers
v.in.ascii	Creates a vector map from ASCII points file or ASCII vector file
v.in.db	Creates new vector map (point layer) from database table containing coordinates
v.in.dxf	Converts AutoCad DXF files to GRASS format
v.in.e00	Imports an ArcInfo export file .e00 to GRASS format
v.in.garmin	Downloads waypoints, routes, and tracks from a Garmin GPS receiver into a vector map
v.in.gpsbabel	Downloads waypoints, routes, and tracks from a GPS receiver or a GPS ASCII file into a vector map using formats supported by gpsbabel
v.in.ogr	Converts OGR-supported formats into a GRASS vector map

Table 3: GRASS Import commands

From the list of commands there are a lot of options for getting data into GRASS. Similarly for exporting data out of GRASS, there are also a lot of options and the major commands are all of the form r.out.* for rasters and v.out.* for vectors.

ArcGIS

ArcGIS has an extension called **ArcGIS Data Interoperability**. It is an extension to ArcGIS Desktop that enables users to easily use and distribute data in many formats. Users can take advantage of the spatial extract, transform, and load (ETL) capabilities to eliminate barriers to data sharing and provide accurate spatial data to your users. ArcGIS Data Interoperability, can:

- **Read more than 110 spatial data formats** including GML, XML, WFS, Autodesk DWG/DXF, MicroStation Design, MapInfo MID/MIF and TAB, Oracle and Oracle Spatial, and Intergraph GeoMedia Warehouse.
- **Write Geodatabase features,** including 3D Multipatch features with textures and multimedia feature attachments, into any geodatabase.

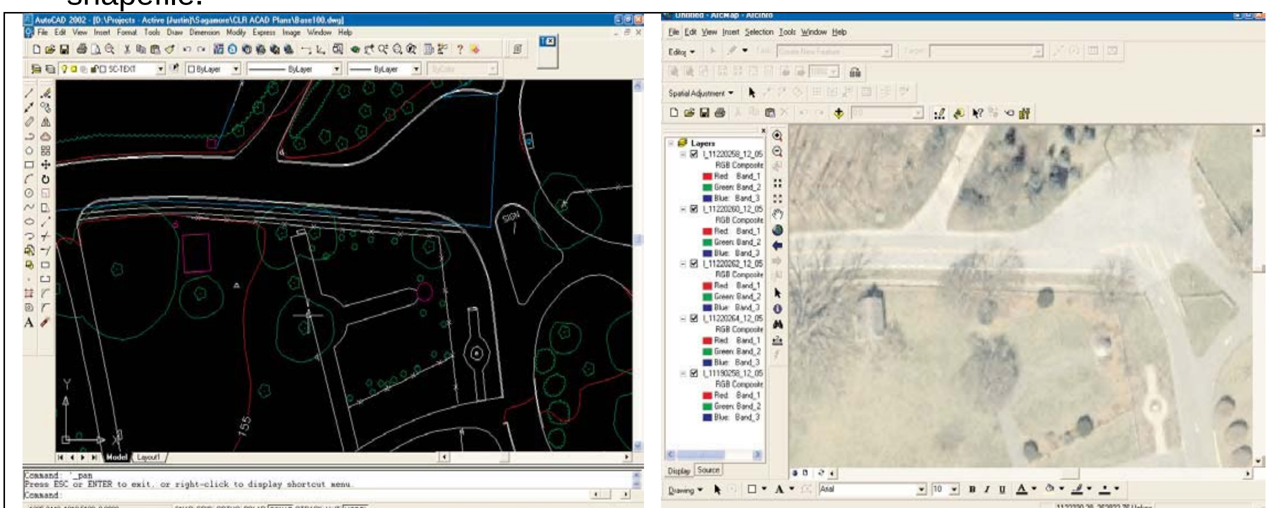
- ❖ **Write CAD data formats** including AutoCAD drawings in the Esri Specification for CAD (ESD) standard to interoperate with CAD with virtual geodatabase feature classes.
- ❖ **Write spatial DBMS tables** including SQL Server 2008, Oracle Spatial, PostGreSQL/PostGIS, Informix Spatial, and DB2 Spatial.
- ❖ **Create spatial data formats** based on known file-based formats.
- ❖ **Share data with anyone** by exporting to more than 70 spatial data formats.
- ❖ **Build complex spatial ETL processes** using FME Workbench, a semantic data translation engine with more than 240 specialized transformers for data transformation, migration, validation, and distribution.
- ❖ **Incorporate these formats and ETL processes** in the geoprocessing framework using tools, ModelBuilder, and scripts.

Apart from the ArcGIS extension which is commercially available, there are also routines which are available in the standard ArcGIS out-of-the box installation to transform some of the common GIS data types such as:

- ❖ CAD and DGN
- ❖ JPEG
- ❖ Compressed spatial data

CAD and DGN to ArcGIS

In Figure 3 is shown the conversion of an AutoCAD file to that of an ArcGIS shapefile.



CAD	ArcGIS

Figure 3: CAD to ArcGIS conversion

Computer-aided design (CAD) data is a file-based data source. Users can connect directly to CAD files and manage them as read-only datasets without using conversion tools in ArcGIS software.

CAD data is organized into a geodatabase-enforced schema comprising five generic feature classes: annotation, multipatch, point, polygon, and polyline. Alongside the generic feature classes, AutoCAD drawings (version 2007 or higher) may include subset feature classes that are uniquely named and contain entity-linked attributes.

When users add a CAD feature class to ArcMap, ArcScene, or ArcGlobe, all standard map functions are enabled, including attribute tables and labeling functions. Users can snap to geometry, substitute symbology, and use it with all geoprocessing tools that accept feature classes or layers as input. CAD data is shown in Figure 4 which shows AutoCAD .dwg files and Microstation .dgn files.

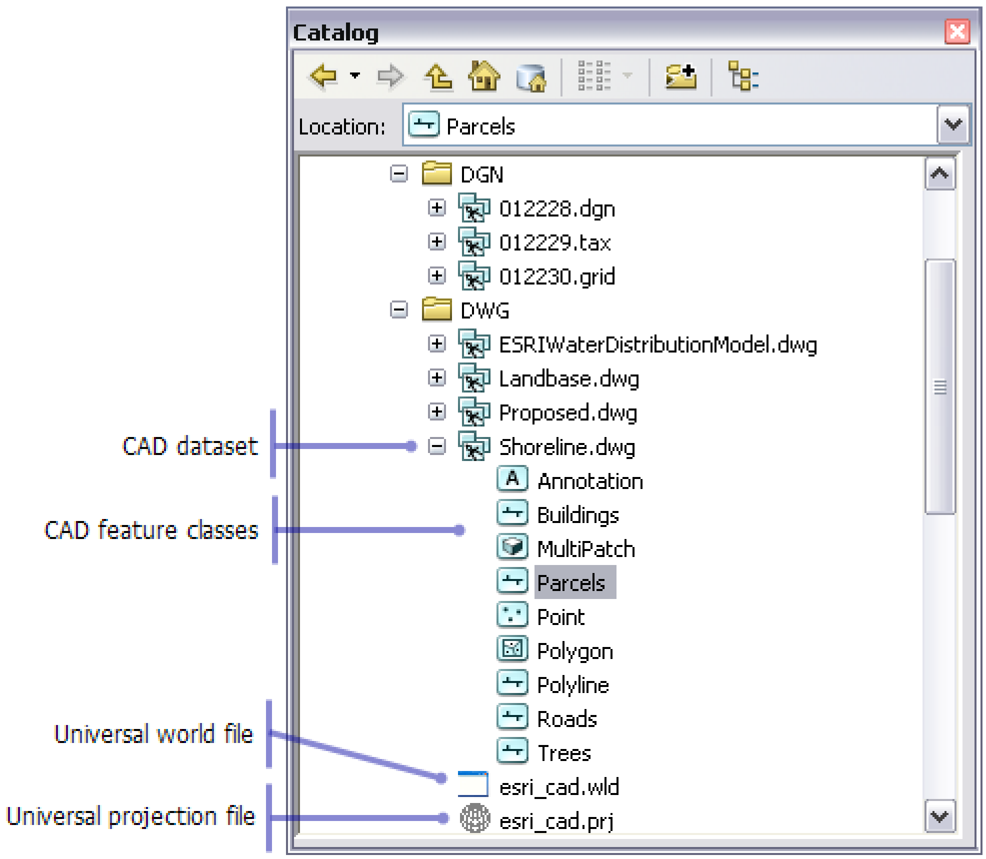


Figure 4 AutoCAD .dwg files and Microstation .dgn files in ArcCatalog

To perform the CAD to GIS conversion there are various steps that need to be taken depending upon what conversions is required.

CAD feature layers:

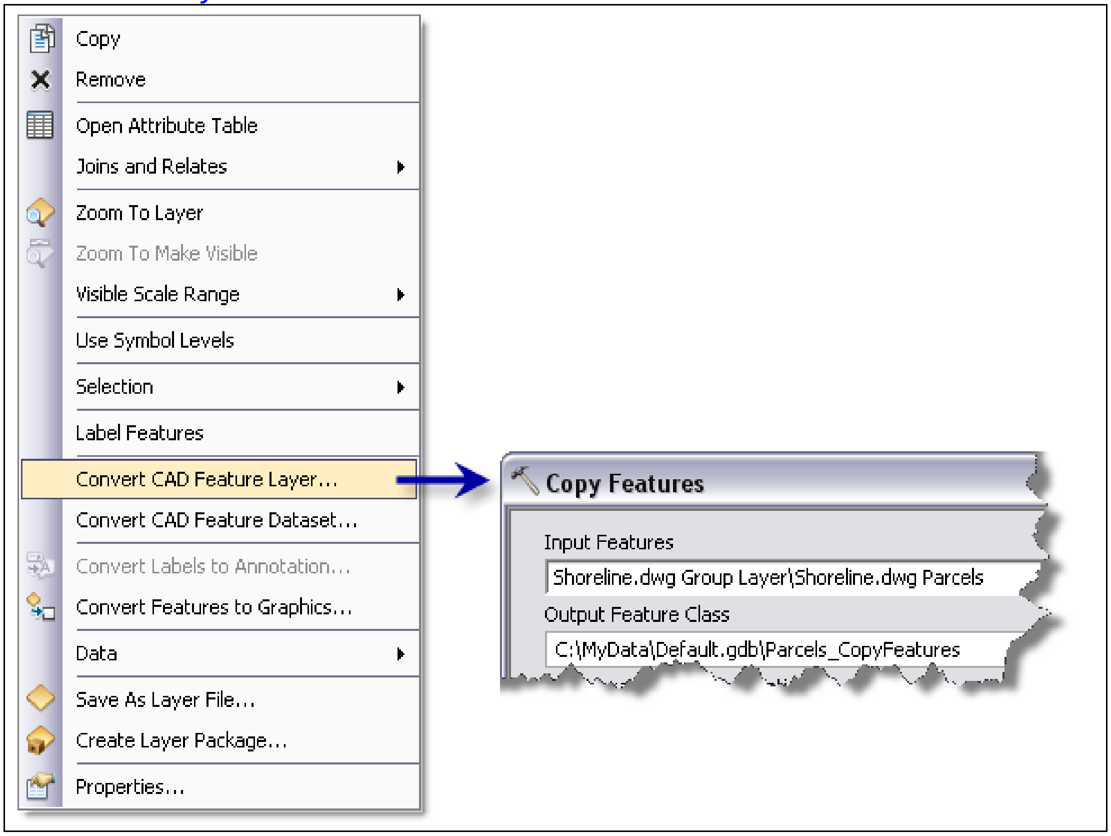


Figure 5 CAD feature layers

The above diagram (Figure 5) shows how to import CAD data in ArcMap. Right-click the CAD feature layer in the table of contents and click Convert CAD Feature Layer from the shortcut menu. Use the Copy_Features tool to import a CAD feature class or feature layer to a geodatabase feature class. This tool also accepts selections as input.

CAD feature datasets:

To import an entire CAD drawing in ArcMap, right-click the CAD feature layer in the table of contents and click Convert CAD Feature Dataset from the shortcut menu.

Use the CAD To Geodatabase tool to bulk load entire CAD datasets to an existing geodatabase. This tool automates a series of conversion procedures that includes importing CAD annotation and merging identical feature class names, types, and attribution. The tool accepts multiple CAD files as input in mixed DWG and DGN formats. Figure 6 shows the conversion of Cad to feature datasets.

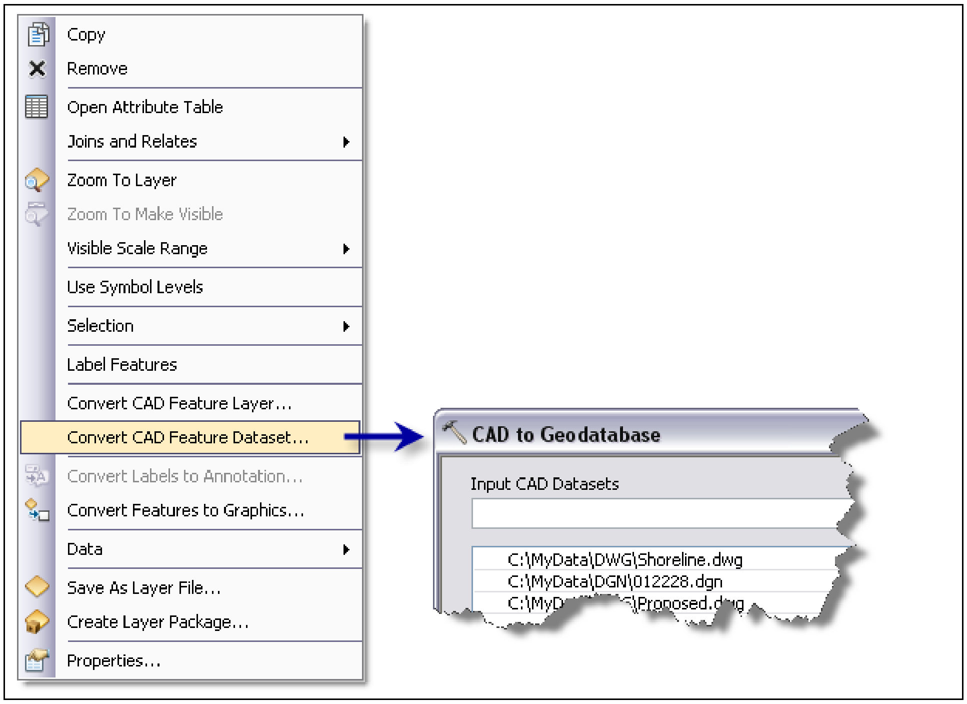


Figure 6: CAD feature datasets

CAD annotation layers:

To import CAD annotation in ArcMap, right-click the CAD annotation layer in the table of contents and click Convert to Geodatabase Annotation from the shortcut menu.

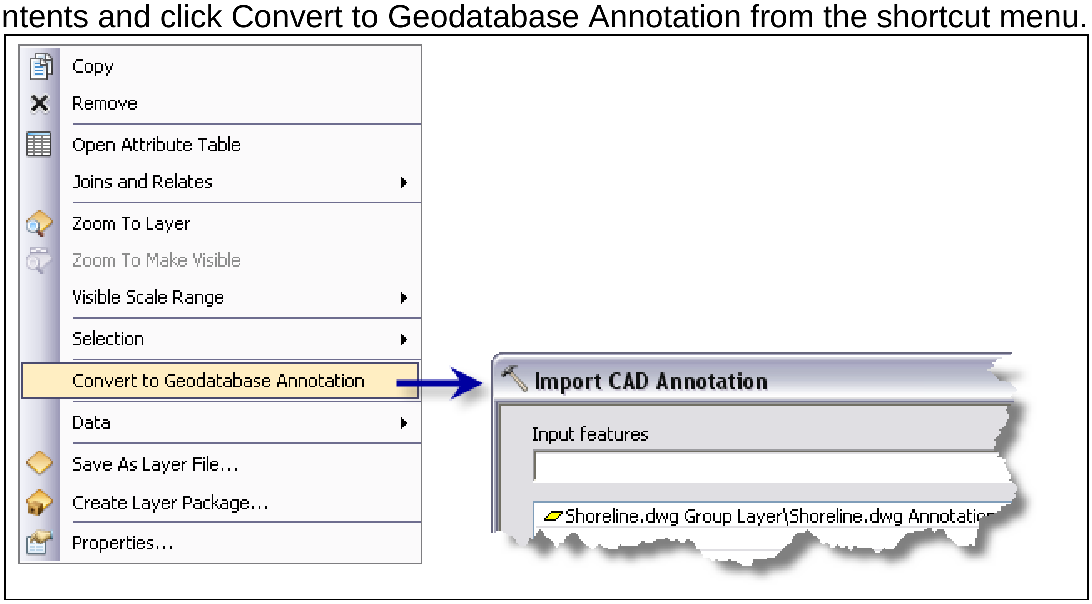


Figure 7 CAD annotation layers

Exporting geodatabase information to a CAD file:

Users can export feature classes, feature layers, or shapefiles to native AutoCAD or MicroStation CAD formats with the Export To CAD tool. The tool creates new CAD files or appends data to existing CAD files. To export data from ArcMap, right-click the feature layer in the table of content and click Data > Export to CAD from the shortcut menu. Figure 8 shows the steps which are required.

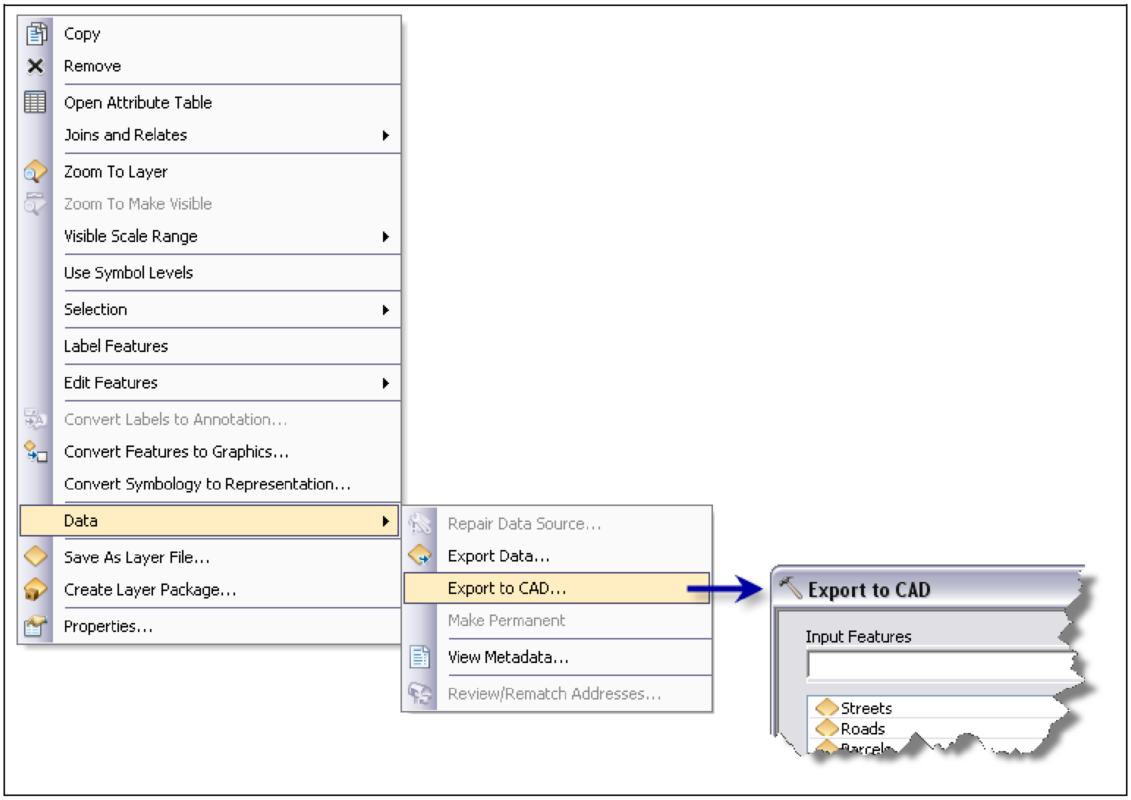


Figure 8: Exporting geodatabase information to a CAD file:

Basic operation of the tool requires the input feature, output CAD format, and output path and file name. Users can export data directly or combine the tool with other tools in a geoprocessing model or script to automate conversion tasks.

Apart from the number of out-of-the-box tools which are available in the standard ArcGIS software, there are a number of shapefile converters available online.

- **DXF to Shapefile Converter**[7] – this is a tool for converting AutoCad DXF (Data eXchange Format) files into ESRI Shapefiles, the format used by ArcMap and MapWindow. This software is open source under the General Public License (GPL) and was created using two other open-source tools: dxflib and MapWinGIS.

- **Arcv2CAD**[8] – converts ArcView / ESRI shape (.SHP) files to AutoCAD DXF and DWG formats. This is a commercial tool which allows shapefiles to be read by virtually all CAD software, eg AutoCAD, MicroStation, QikDraw, Visio, as well as many other Mapping and Graphics software, e.g. CorelDraw, Surfer, World Construction Set.

- **Arcv2CAD[9] –** Arcv2CAD converts ArcView / ESRI Shape files to AutoCAD DXF and DWG formats allowing shapefiles to be read by virtually all CAD software.

- **Arcv2SHP[10] –** ArcView to SHP translator (10 trial uses available in demo).

- **CADTools[11] –** A number of tools to aid in working with CAD files in ArcView. This is free software. These include: a utility to make a theme for each layer or level, an interactive world file creation tool, a tool to convert annotation to points, and tools to associate text and attributes with their bounding CAD polygons.

- **DXF to Shapefile Converter 2.0.0.56**[12] – This is free software.

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[7] http://www.wanderingidea.com/content/view/12/25/
[8] http://www.rockware.com/product/overview.php?id=183
[9] http://www.guthcad.com.au/avdlinfo.htm
[10] http://software.geocomm.com/translators/arcview/
[11] http://software.geocomm.com/translators/arcview/
[12] http://www.brothersoft.com/dxf-to-shapefile-converter-165891.html

JPEG

In computing, JPEG is a commonly used method of compression for digital photography (image). JPEG compression is used in a number of image file formats. JPEG/Exif is the most common image format used by digital cameras and other photographic image capture devices; along with JPEG/JFIF, it is the most common format for storing and transmitting photographic images on the World Wide Web.

There are a number JPEG converters which are used to create shapefiles. Table 4 shows examples of such JPEG converters.

Name	website
Blaze ImgConvert 2.05	http://3d2f.com/programs/54-306-blaze-imgconvert-download.shtml
AutoImager 3.06	http://3d2f.com/programs/7-250-autoimager-download.shtml
ContextConvert Pro 3.0	http://3d2f.com/programs/13-735-contextconvert-pro-download.shtml

Table 4: JPEG shapefile converters

PostGIS

PostGIS is an open source software program that adds support for geographic objects to the PostgreSQL object-relational database. PostGIS follows the Simple Features for SQL specification from the Open Geospatial Consortium. In effect, PostGIS "spatially enables" the PostgreSQL server, allowing it to be used as a backend spatial database for geographic information systems (GIS), much like ESRI's SDE or Oracle's Spatial extension.

If GIS data is of PostGIS data type then conversion to other data types is an easy task. An example of a converter is DXF to PostGIS[13]. This is an easy to use utility designed to help convert DXF files to PostGIS geometry tables. A single DXF file is converted to a PostgreSQL - PostGIS SQL script to create and populate five tables, using the AutoCAD information of point, line, polyline, text, circle, insert, and layer.

Compressed spatial data:

Whether users' spatial data comes from a web site, the data is transported via an ftp site or found in the lab spatial data library, and it will most likely come in one of the archive formats described below. Before users can view the data it must be converted to a shape file, coverage, grid, image or tin. The following are some of the common data types which are typically available on the Internet:

[13] http://www.softpedia.com/dyn-postdownload.php?p=131305&t=0&i=1

- **.zip** – Windows zip format. Use Winzip or Pkware to extract the files from the .zip file. The .zip file will in most cases self-extract if you double-click on the .zip file.
- **.gz** – Files with the exension .gz or .tar.gz are compressed and can be uncompressed with Window Winzip or Pkware.
- **.Z** – A Unix compressed file. Use the *uncompress* command on a Unix workstation to uncompress this file. Example: Uncompress the file rivers.tar.Z At the Unix prompt type : *uncompress rivers.tar.Z*
- **.tar** – *A Unix archive format. The .tar file usually contains many files. To un-tar the file rivers.tar, use the following command at the Unix prompt: tar –xvf rivers.tar*
- **.e00** – *This is an ArcInfo export file. Coverages are often transported as .e00 files for easy transfer between folders on the workstation. Coverages that are not in export format must be copied using the copy command in ArcInfo.*

2. Conversion of projection systems

Conversions describe a mapping between two coordinate systems of different type. All conversion parameters are known a priori and are used as constants. When applying conversions to Coordinate Reference Systems, the datum doesn't change.

A projection method is a conversion describing the mapping from a mathematical earthmodel (spheroid such as a sphere or ellipsoid) to the plane. It is not possible to map from a curved surface such as a sphere or ellipsoid to a plane without distortion. There are several map projection methods available, including more than 200 methods in the published literature. Some of these methods are briefly described below.

There are different possibilities for describing the properties and characteristics of map projections. These can be based upon:

- mathematical or geometrical properties:
    - extrinsics (e.g. shape and aspect of the mapping surface)
    - intrinsics (e.g. distortion behaviour as conformity, aqual area condition)
- applying map projection methods for specific purposes - e.g. area of usage (dimension, position on the earth, shape of the region):
    - choosing the map projection that has minimal errors when transforming the spherical 3-d earth onto a 2-d flat surface

All GIS software has the ability to perform the conversion between map projections. The conversion can be:

- 2D conversion
    - Cartesian to Polar
    - Polar to Cartesian
- 3D conversion
    - cartesian to cylindrical
    - cylindrical to cartesian
    - cartesian to spherical
    - spherical to cartesian
    - cartesian to ellipsoidal
- Conversion of measurement units

The intent of performing data conversion is to have all of the data layers for a given GIS application using the same coordinate system. The result of having different coordinate systems is shown in Figure 9, where the same area is mapped using different coordinate systems. A list of the various available map projections can be obtained at:
http://www.mapref.org/MapProjectionMethods.html

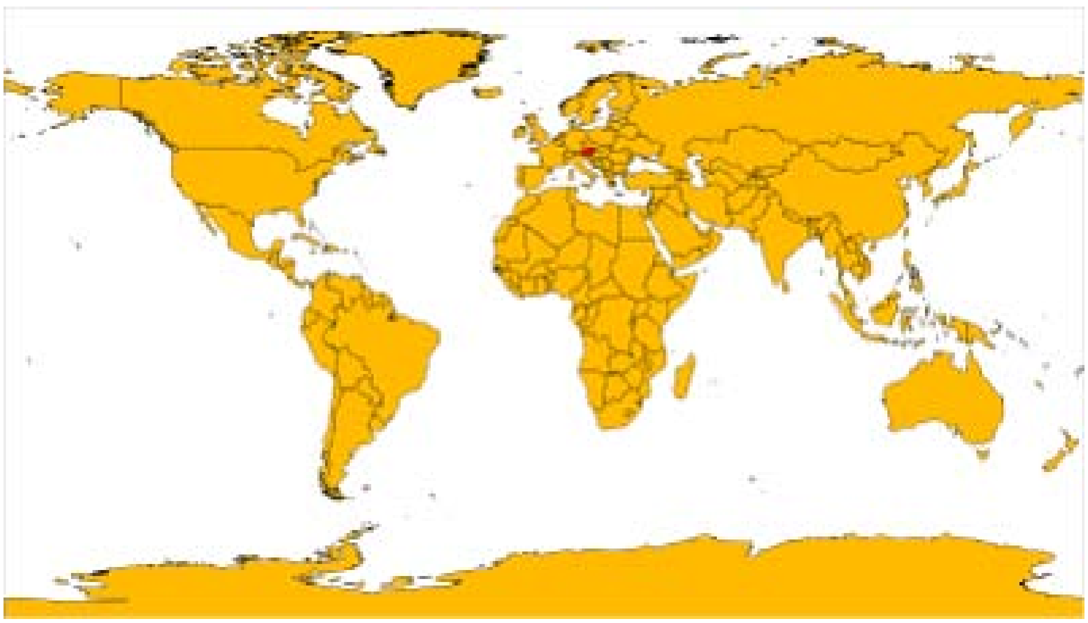

Figure 9: Effect of different coordinate systems