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Geographical Information Systems (GIS)
—
an introduction

Rostock University
Faculty for Agricultural and Environmental Sciences
Chair for Geodesy and Geoinformatics
Prof. Dr.-Ing. Ralf Bill


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Lecturer
Prof. Dr.-Ing. Ralf Bill

- 1972-1979: studied Geodesy at University for Applied Sciences Mainz and the Technical Universities in Berlin and Karlsruhe.
- 1982: Dr.-Ing. TU Karlsruhe.
- 1979-1985: Research assistant TU Karlsruhe.
- 1985-1989: GIS development engineer Wild, Heerbrugg (CH).
- 1989-1994: Leader of the research group on GIS Stuttgart University .
- Since 1994: Professorship in Geodesy and Geoinformatics Rostock University.
- Since 1999: Leader STZ Geoinformatik Rostock



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Goal of the lectures and exercises

- Lectures
 - introduce state-of-the-art and recent developments in GIS
 - illustrate applications of GIS
 - provide a foundation for own studies and application activities in agro-biodiversity

- Exercises
 - develop skills for own GIS research and application
 - give a short introduction in practical usage of QGIS software
 - help to understand UN SDGs





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Content

- Introduction
 - Basic terms/definitions
- State of research and development
- Methods
 - Spatial referencing - coordinates
 - Data, data types and the Geo-object
 - Dimensions
 - IMAP – the processing chain in a GIS
 - Products and standards
- Applications
 - From LIS, EIS, NIS, .. to ..IS
 - Agriculture, Forestry etc.
- Research
- Take home message
- Literature

**Introduction to
spatial information processing**
Ralf Bill (Editor)



Textbook for international GIS courses




Internal Report, Volume 17, 2019
Rostock University
Faculty of Agricultural and Environmental Sciences,
Chair of Geodesy and Geoinformatics

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INTRODUCTION

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❖ BASIC TERMS / DEFINITIONS



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Information =
data + context

what °C where 

which  12 who 


when  ??? how 

- ! **Data** in the classical sense of computer science are simply signs, which are stored, compared, processed and written by a computer.

- ! **Information** is purpose-related knowledge resulting from rules and knowledge of those being familiar with the data in order to be able to create facts and interpretable results in a given context.

Reference: Bill, 2016

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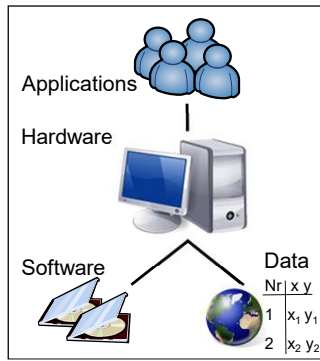


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System

- ! In the sense of **abstract system theory**, a **system** stands for an articulated whole that is closed off from its environment by a shell (**system boundary**) and has a certain relationship to it.
- A system usually breaks down into **individual elements**, which under certain circumstances can also be related to each other, but which themselves can in turn be regarded as systems (subsystems).

- In computer science a **system** is a combination of **hardware** und **software**, combined in such a way that they can be regarded as a unit being feasible to solve specific **applications** based on relevant **data**.



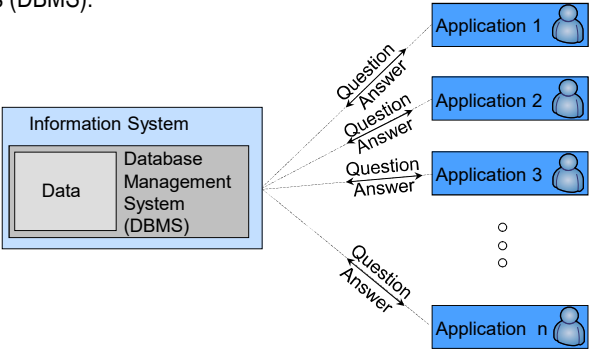
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Information systems


- A **system** is a set of elements that are interrelated.
- **Information systems** are general tools to manage and analyse data.
- **Information systems** are based on databases and their database management systems (DBMS).



! ● An **information system** is basically a “question / answer” system for a set of data.


Reference: Bill, 2016

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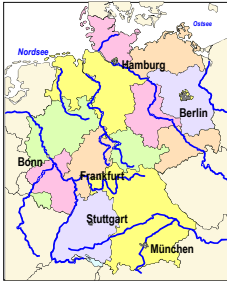


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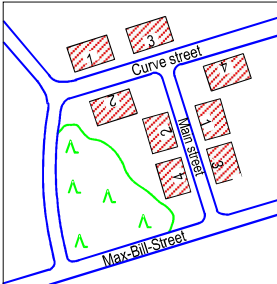
'Geo' – the magic linking element




a) global



b) regional




c) local (horizontal)



ge|o..., Ge|o...,
(greek. gē, gaīa) "Earth"

! ● All information in a GIS is somehow related to the Earth or parts of it.
⇒ It is spatially referenced.

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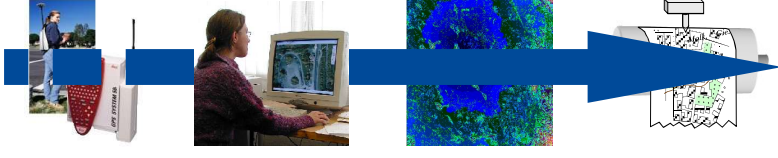
Definition Geographical Information System (GIS) I

! GIS is a **computer-based system** to

- **I** Input,
- **M** Manage,
- **A** Analyse and
- **P** Present


spatial information.

I	Hardware
M	Software
A	Data
P	User



I M A P

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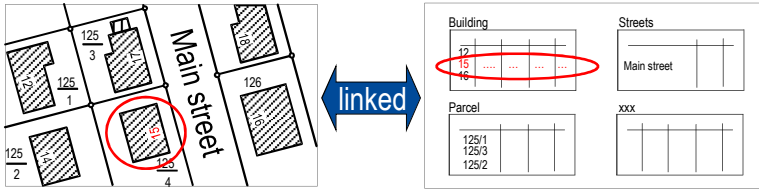


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Definition GIS II Map + DB in the computer

- Map = (carto-)graphic data
- Database = attributes, describing data




linked

- Feature (or object)-oriented modeling
 - Feature: *Agricultural field plot*
 - Feature ID
 - Geometry: *Perimeter polygon* $(x_1, y_1, \dots, x_n, y_n)$
 - Topology: *Area, neighbours*
 - Attributes: *Owner, current crops, area size ..*
 - Graphical representation: light yellow



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Geoinformatics
Spatial Information Science

- ! "Geoinformatics (or Spatial Informatics, Spatial Information Science) is dedicated to the **development and application of methods and concepts of computer science to space-related problems**.
- The common core element of geoinformatics is the **spatial reference**.
- Geoinformatics deals with the **nature, function and provision of geoinformation and its applications**.
- The knowledge gained in this way is incorporated into the technology of **geographical information systems (GIS)**."


Source: Definition 1.8 in R. Bill (2016), Page 17 (translated);
www.geoinformatik.uni-rostock.de, N. Bartelme (2005), N. de Lange (2006)

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STATE OF RESEARCH AND DEVELOPMENT

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GIS:
State-of-the-art


- **GIS technology**
 - developments benefit from general IT
 - Internet and World Wide Web
 - Hardware /Software development (Client/Server, DBMS, mobile components ..)
 - based on standards (ISO), specifications (OGC) and legal regulations
 - uses OGC Web Services such as WMS, WFS etc.
 - relies on national Spatial Data Infrastructures (SDI)

⇒ **Acceptable hardware/software for ubiquitous GIS applications**

- **Geodata and GIS products**
 - Wide range of geodata available on the market worldwide
 - fosters Open Data
 - GIS product variety on the market
 - fosters Open Source
 - Interoperability for data, services and products
 - ...

⇒ **Efficient product and data portfolio**

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GIS:
State-of-the-art

- **Applications**
 - GIS is used for a huge variety of spatial problems
 - GIS replaces analogue maps in many fields => digitalisation
 - Classical domains such as cadaster, topography, environment, utilities
 - The public is using GIS
 -

⇒ **GIS is integrated in day-by-day workflows**

- **Research topics**
 - New data capture methods (e.g. geosensor networks/Internet-of-things)
 - Mobile usage
 - Spatio-temporal analysis methods (e.g. Big data, spatial data mining)
 - Public usage (e.g. social media, location as a service)
 - Real-time applications
 - ...

⇒ **Still a lot of challenging research topics for the future**

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Methods

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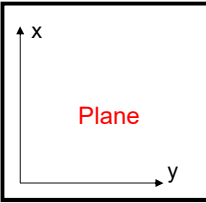
❖ SPATIAL REFERENCING COORDINATES

http://media.merchantcircle.com/23841905/world-globe_full.jpeg

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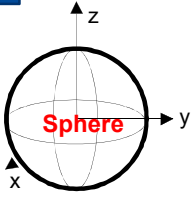

The Earth – a complex figure and its approximations

! • **Mathematical description** ← x, y, z




Plane

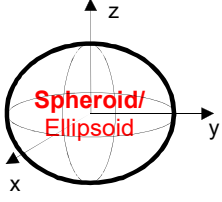
→ **Eratosthenes**



Sphere

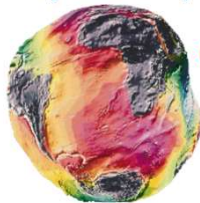


← **Newton**



Spheroid/
Ellipsoid

• **Physical description**




Geoid

← **Z**

Potential (x,y,z) in Earth gravity field is constant

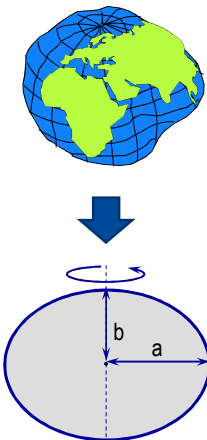
Source: GFZ Potsdam, Germany

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Reference ellipsoids as earth's substitutes


- Mathematical geometrical substitute figures for the earth, created by rotating an ellipse around its axis, being defined by its semi-minor and semi-major half axis.
- 3 types of spheroids/ellipsoids:
 - conventional defined ellipsoids (arc measurements)
 - regional best-fitting ellipsoids (astro-geodetic system)
 - global ellipsoids (mean earth surface approximation, geocentric equipotential ellipsoid)

Ellipsoid	Year	semi-major axis a [m]	semi-minor axis b [m]
Bessel (Germany)	1841	6.377.397	6.356.079
Clarke (GB)	1866	6.378.206	6.356.584
Hayford (USA)	1924	6.378.388	6.356.912
Krassowskij (Russia)	1942	6.378.245	6.356.863
GRS 80/WGS 84	1980	6.378.137	6.356.752



Reference: Resnik/Bill 2018

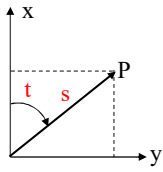
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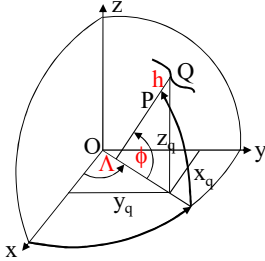


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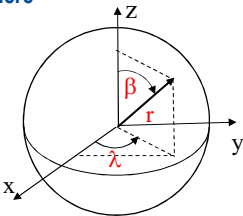
Coordinate System (CS) in 2D or 3D

- ! • **Polar coordinates** versus cartesian coordinates
 - Plane
- **Ellipsoidal polar coordinates** versus ellipsoidal cartesian coordinates
 - Ellipsoid






- Sphere



Reference: Bill, 2016

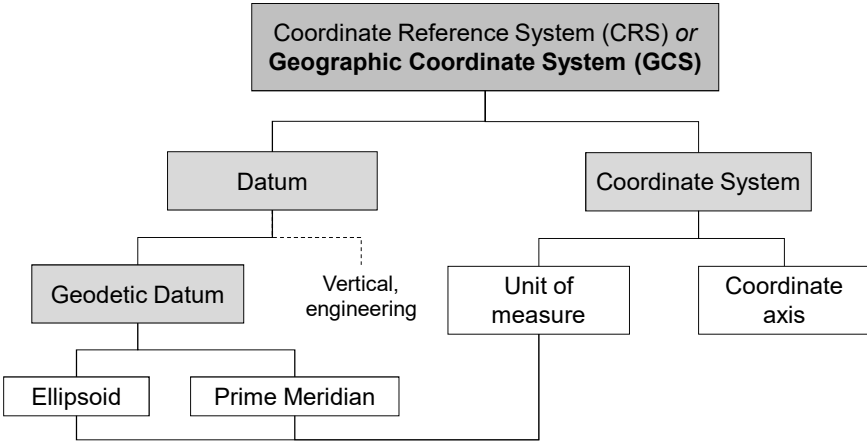
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Coordinate reference system (CRS)

- ! • Often named “Geographical coordinate system (GCS)”



Reference: Bill, 2016, ISO19111:2002 Geographic Information—Spatial Referencing by Coordinates

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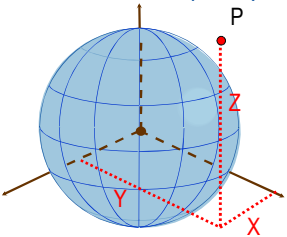


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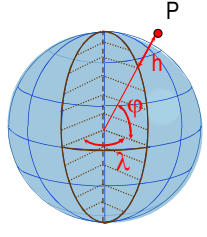
World Geodetic System 1984 (WGS 84)

- Global reference system in the form of a **geodetic coordinate reference system**.
- Coordinate system with **metric coordinate specifications**.
- **Geodetic datum** is defined by a **global ellipsoid** (also named WGS'84).
- The **orientation of the coordinate axes** is defined so that:
 - the **x-axis** of the cartesian system **passes through the Greenwich prime meridian**,
 - the **xy-plane** is **placed in the equatorial plane**,
 - the **z-axis** **coincides** with the **central axis of the earth rotation**.

Cartesian coordinates (X, Y, Z)




Ellipsoidal coordinates (ϕ, λ, h)



WGS 84 is
used by GNSS
worldwide !

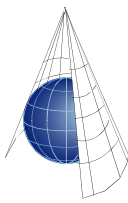
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Projections of the earth's surface on a plane

- ! ● A **map projection** is used to portray all or part of the curved earth on a flat surface. This cannot be done without some distortion. Every projection has its own set of advantages and disadvantages. There is no "best" projection. **"no flat map can be both: length equivalent and conformal."**
- Selection of **reference figures**



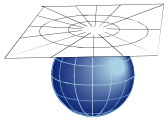
Conical projection:

- formed by considering a **cone** tangential to the ellipsoid.
- **Lambert projection** as an example.



Cylindrical projection:

- special case of the conical projection: cone becomes a **cylinder**.
- **Universal Transverse Mercator (UTM) projection** as the most widely used of all projections.





Azimuthal projection:

- special case of the conical projection, cone degenerates to a **plane**
- **Stereographic projection** is an example.

Reference: Resnik/Bill 2018

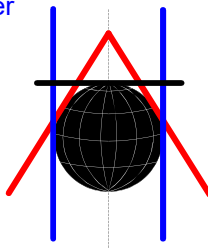
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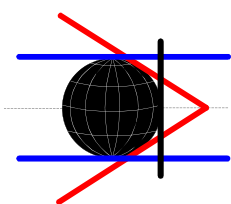
Projections of the earth's surface on a plane

! • Selection of the **orientation of the reference figures**

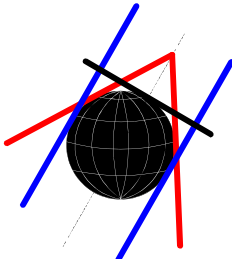
Normal





Transversal



Arbitrary (slanting)

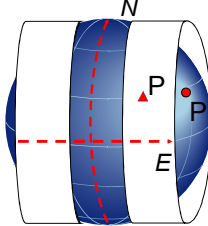


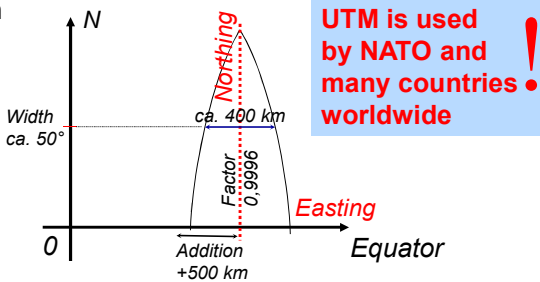
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Universal Transversal Mercator (UTM) Projection

! • Transversal cylinder projection






• Coordinate conversion

	Geographical coordinates		UTM Coordinates (WGS 84)	
Point	Longitude (° ' ")	Latitude (° ' ")	Easting (m)	Northing (m)
Aachen	6 05 03	50 46 33	32 294 431	5 628 951
Rostock	12 05 57	54 04 18	33 310 204	5 995 387
Oldenburg	8 13 03	53 09 36	32 447 681	5 890 355

https://www.engineeringtoolbox.com/utm-latitude-longitude-d_1370.html

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UTM Properties Example: Germany

Criteria	Universal Transversal Mercator (UTM)
a. Related to the earth figure	GRS80/ETRS89-Ellipsoid
b. Projected on ..	Cylinder
c. Reference mapping figure	Cutting cylinder
d. Orientation	Transversal
e. Stripe width	Each 6° a new cylinder
f. Stripe numbers	60 cylinders in total around the earth
g. Projection properties	True to length at the cutting meridian, in total conformal
h. Zones in Germany	Zone 32, 33
i. Northing counted from	Equator
j. Easting formed by	Reference number [°] = Zone, Mean meridian 500000m

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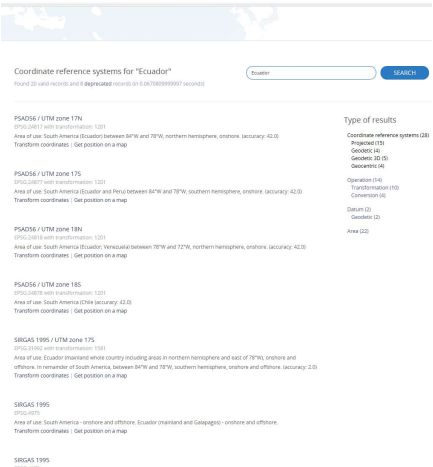


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Coordinate Reference Systems Example: Ecuador

- To get an overview which CRS is used in a country use the **EPSG Geodetic Parameter Dataset**, a structured dataset of Coordinate Reference Systems and Coordinate Transformations
- European Petroleum Survey Group (EPSG)
- Now: Surveying and Positioning Committee of the International Association of Oil & Gas Producers


- **EPSG database (https://epsg.io/)**



The screenshot shows the search results for "Ecuador" in the EPSG database. It lists several coordinate reference systems (CRS) with their respective codes and descriptions. The results include:

- PSAD56 / UTM zone 17N**: Area of use: South America (Ecuador) between 84°W and 78°W, northern hemisphere, spheroid, accuracy: 42.0. Transformation: coordinates | Get position on a map.
- PSAD56 / UTM zone 17S**: Area of use: South America (Ecuador and Peru) between 84°W and 78°W, southern hemisphere, spheroid, accuracy: 42.0. Transformation: coordinates | Get position on a map.
- PSAD56 / UTM zone 18N**: Area of use: South America (Ecuador, Venezuela) between 78°W and 72°W, northern hemisphere, spheroid, accuracy: 42.0. Transformation: coordinates | Get position on a map.
- PSAD56 / UTM zone 18S**: Area of use: South America (Ecuador) accuracy: 42.0. Transformation: coordinates | Get position on a map.
- SIRGAS 1995 / UTM zone 17S**: Area of use: Ecuador (mainland and Galapagos) including areas in northern hemisphere and east of 78°W, southern and offshore, in remainder of South America, between 84°W and 78°W, southern hemisphere, spheroid and offshore, accuracy: 2.0. Transformation: coordinates | Get position on a map.
- SIRGAS 1995**: Area of use: South America - southern and offshore, Ecuador (mainland and Galapagos) - southern and offshore, Transformation: coordinates | Get position on a map.
- SIRGAS 1995**: Area of use: South America - southern and offshore, Ecuador (mainland and Galapagos) - southern and offshore, Transformation: coordinates | Get position on a map.

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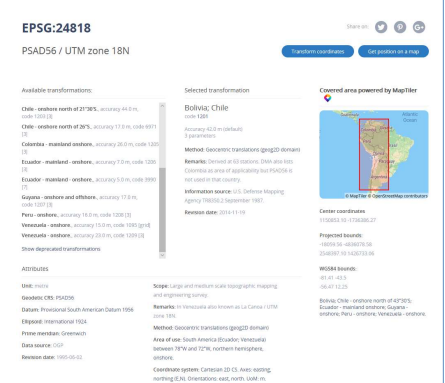


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Coordinate Reference Systems Example Ecuador


```

PROJCS["PSAD56 / UTM zone 18N",
GEOGCS["PSAD56",
DATUM["Provisional_South_American_Datum_1956",
SPHEROID["International 1924",6378388,297,
AUTHORITY["EPSG","7022"]],
TOWGS84[-288,175,-376,0,0,0,0],
AUTHORITY["EPSG","6248"]],
PRIMEM["Greenwich",0,
AUTHORITY["EPSG","8901"]],
UNIT["degree",0.0174532925199433,
AUTHORITY["EPSG","9122"]],
AUTHORITY["EPSG","4248"]],
PROJECTION["Transverse_Mercator"],
PARAMETER["latitude_of_origin",0],
PARAMETER["central_meridian",-75],
PARAMETER["scale_factor",0.9996],
PARAMETER["false_easting",500000],
PARAMETER["false_northing",0],
UNIT["metre",1,
AUTHORITY["EPSG","9001"]],
AXIS["Easting",EAST],
AXIS["Northing",NORTH],
AUTHORITY["EPSG","24818"]]
                
```



EPSG:24818
PSAD56 / UTM zone 18N

Available transformations:

- Chile - eastward - eastward, accuracy 10.0 m, code 100118
- Chile - westward - westward, accuracy 10.0 m, code 100119
- Colombia - eastward - eastward, accuracy 20.0 m, code 100118
- Ecuador - eastward - eastward, accuracy 10.0 m, code 100118
- Ecuador - westward - westward, accuracy 10.0 m, code 100119
- Guyana - eastward and offshore, accuracy 10.0 m, code 100118
- Venezuela - eastward - eastward, accuracy 10.0 m, code 100118

Selected transformation:

Bolivia - Chile
code 100118
Accuracy: 10.0 m (eastward), 10.0 m (westward)
Method: Geocentric translations (geogD domain)
Remarks: Derived from US mapping. Data also sets Central meridian of application to WGS84 and used in that country.
Information source: US Defense Mapping Agency (DMSP), September 1987.
Revision date: 2011-11-19

Center coordinates:
108265.16, 1704822.27
108265.16, 1704822.27


PROJCS: ["PSAD56 / UTM zone 18N", GEOGCS: ["PSAD56", DATUM: ["Provisional South American Datum 1956", SPHEROID: ["International 1924", 6378388, 297, AUTHORITY: ["EPSG", "7022"], TOWGS84: [-288, 175, -376, 0, 0, 0, 0], AUTHORITY: ["EPSG", "6248"], PRIMEM: ["Greenwich", 0, AUTHORITY: ["EPSG", "8901"], UNIT: ["degree", 0.0174532925199433, AUTHORITY: ["EPSG", "9122"], AUTHORITY: ["EPSG", "4248"], PROJECTION: ["Transverse Mercator"], PARAMETER: ["latitude_of_origin", 0], PARAMETER: ["central_meridian", -75], PARAMETER: ["scale_factor", 0.9996], PARAMETER: ["false_easting", 500000], PARAMETER: ["false_northing", 0], UNIT: ["metre", 1, AUTHORITY: ["EPSG", "9001"], AXIS: ["Easting", EAST], AXIS: ["Northing", NORTH], AUTHORITY: ["EPSG", "24818"]]

Each component has an EPSG code !

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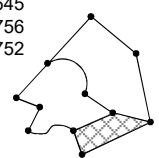
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Primary metric: direct spatial reference (CRS)

- ISO 19111: 2019 Geographic information — Referencing by coordinates (formerly ISO 19111:2007)
- Features described by coordinates or construction rules
 - Properties:
 - + defined metrics
 - + defined reference system
 - + high accuracy expected
 - multidimensional search criteria

Coordinates


x	y	z
64695.740	23685.123	123.768
64623.546	23626.876	125.645
64593.341	23653.265	122.756
64695.740	23685.123	121.752
x	y	
64695.740	23685.123	
64623.546	23626.876	
64593.341	23653.265	
64695.740	23685.123	



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Metric

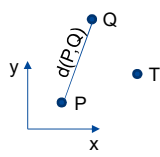
- mathematics for coordinates

! Definition:


- A metric on a set X is a **mapping $d: X \times X$ on \mathbb{R}_0** with the following **properties** for any P, Q, T from X
 - Idempotence:** $d(P, Q) = 0$ if $P=Q$
 - Symmetry:** $d(P, Q) = d(Q, P)$
 - Triangle inequality:** $d(P, Q) \leq d(P, T) + d(T, Q)$
- A pair (X, d) means **metric space**.

Common distance functions:

- Vector data: **Euclidean distance:** $d_E = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$
- Raster data with: $d_1 = |i - k|$ $d_2 = |j - l|$ mit $P(i, j)$ und $Q(k, l)$
 - City Block distance:** $d_4 = d_1 + d_2$
 - Chessboard distance:** $d_8 = \max(d_1, d_2)$
 - Euclidean distance: $d_E = \sqrt{d_1^2 + d_2^2}$




N.4



Neighbourhood type


N.8



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Secondary metric:

indirect spatial reference

- ISO 19112:2019 Geographic information — Spatial referencing by geographic identifiers (formerly ISO 19112:2003)**
- Features described by some kind of identifiers
 - Properties:
 - + 1-dimensional search criteria
 - weakly-defined metric
 - indirect reference system
 - low, variable accuracy
- Examples

Addresses

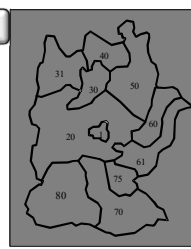
Telephone book

Addresses	Telephone book
...	Glock Manfred 244 72 10
...	Isegrimweg 25 659 10 25
...	Glock Udo 493 27 11
...	Fildersweg 29 264 54 55
...	Glocke Eckhard 62 66 23
...	Heuweg 9a
...	Glockenbring G.
...	Schellberg 7
...	Glockler H.
...	Einsteinstr. 29
...	...

Site names

Code numbers


Ecuador
Quito
Rostock
Andes



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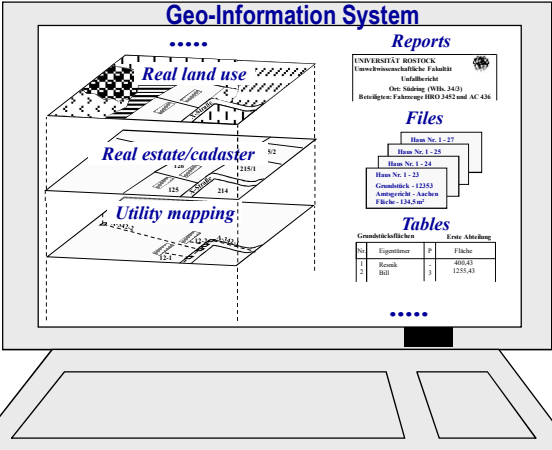
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Spatial references – the important link

- Around 80% of all branch-specific administrative, logistic, and strategic activities in an enterprise, governmental organisation and our daily life have a spatial reference.



Geo-Information System

Real land use

Real estate/cadaster

Utility mapping

Reports


UNIVERSITÄT ROSTOCK
Landesvermessungsamt Falschbitz
Infalldirichte
Ort: Ständig (10/10/16.16.2)

Files


Haus Nr. 1 - 27
Hans Nr. 1 - 24
Hans Nr. 1 - 23
Grundstück - 12353
Anlageort - Aachen
Fläche - 124,6m²

Tables


Gesamtschichten		Erste Abstrang	
Nr.	Eigentümer	Pf.	Fläche
1	Rauk	3	602,43
2	Bill	3	1255,43




Engineering and planning



Administration and government



Utility and services




Decision makers and citizens

....

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❖ DATA, DATA TYPES AND THE GEO-OBJECT

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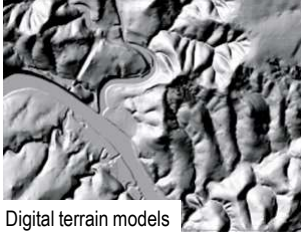


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Data in a GIS



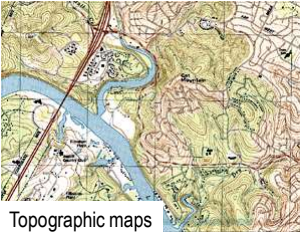
Contour lines



Digital terrain models



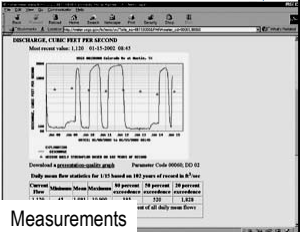
Satellite imagery



Topographic maps

stadtbereich code	stadtbereich bezeichnung	anzahl 3.6
A	Hansa-Vertel	702
J	Gartenstadt-Stadtweide	259
B	Stadtweide	196
R	Warnemünde	125
A	Gartenstadt-Altstadt	23
F	Evershagen	447
L	Südstadt	279
U	Strand-Ort	33
E	Lüthen Klein	362
O	Hirschmändorf	213
G	Scharnt	299
S	Tollernwinkel	425
W	Stadtrinde	875
M	Beserow	50
H	Rüdenhagen	280
T	Gehlsdorf	148
n	Grims Klein	364
	sennew-Ort	22
	zippelner-Tor-Vorstadt	466
	obenthagen	359


Census data



Measurements

Source: http://erg.usgs.gov/isb/pubs/gis_poster/

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





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Data types in GIS: Geometrical data

! Geometrical elements are **points, lines and polygons** in vector form, pixels in raster form.

- They are defined in a **coordinate reference system** and describe the **shape and position** of objects.
- They may occur in analogue and/or digital, vector and/or raster form.
- **Coordinates** carry the geometric information.
- **Mathematical basis:** Computational geometry

Element	Vector		Raster	
	Digital	Analogue	Digital	Analogue
Point	x,y-coord.	•	Pixels	
Line	x,y-coord.-sequence	/	Pixels	
Polygon	closed x y coord.-sequence		Pixels	

Properties :


Vector data

- according to object lines
- logical structure
- well-known methods of acquisition
- small amount of data

Raster data

- according to position
- limited logical structure
- simple data acquisition
- large amount of data

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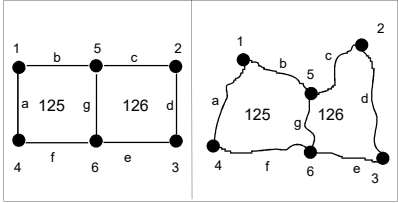


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Data types in GIS: Topological data

- ! ● Topological elements are **nodes** (0-cells), **edges** (1-cells) and **meshes** (2-cells).
- Describe geometry without coordinates (so-called **neighbourhood relations**) and are invariant towards topologic transformations.
- The **edge** carries the topological information.
- **Mathematical basis:** Topology, Graph theory

Geometrically not equal
.. but ..
Topologically equal




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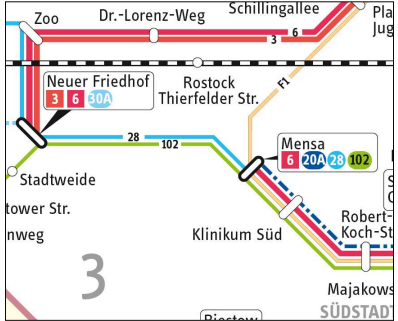
Geometry versus topology

- **Geometry**




- a city map is a geometrical representation
- ⇒ One can measure distances and directions in it!!

- **Topology**



- a public traffic schema plan is a topological representation
- ⇒ One can find connections/relations in it!!

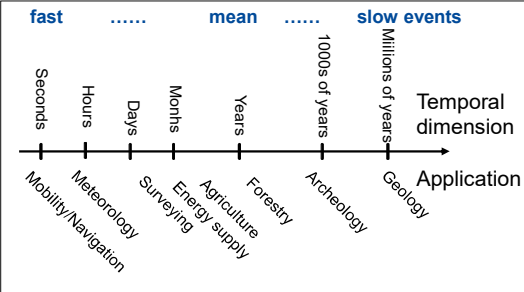
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Data types in GIS: Time and dynamics

- ! • defines **temporal reference system**.
- Feature as an **event** within a certain interval.
- Feature has a **time stamp**.
- **Mathematical basis:** Time series analysis



The diagram illustrates the temporal dimension with a horizontal axis. Above the axis, time scales are marked: 'fast' (Seconds, Hours, Days), 'mean' (Months, Years), and 'slow events' (1000s of years, Millions of years). Below the axis, corresponding applications are listed: 'Mobility/Navigation' (under Seconds), 'Meteorology' (under Hours), 'Surveying' (under Days), 'Energy supply' (under Months), 'Agriculture' (under Years), 'Forestry' (under 1000s of years), 'Archeology' (under Millions of years), and 'Geology' (under Millions of years).

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Data types in GIS: Attributes, semantics


- ! • Attributes, descriptive data, special data.
- Name all **non-geometric elements** such as text, numbers, measurements etc.
- Are captured in a special context to solve special problems.
- Occur in analogue form as well as digital.
- **Mathematical basis:** Set theory, Relational algebra.

Analogue	Digital
Protocols	Data bases
Registers	Information systems
Notes	Files
..	..

Point number Street name Parcel number Grey values

128	A-street	128/1	64=field 64,126,32=forest
-----	----------	-------	------------------------------

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Data types in GIS: Graphical descriptions


- Graphic data = geometry data + graphical descriptions (styles)
- Graphical descriptions such as symbols, hatching, grey scales, line sizes, polygon fill etc.
- **Basis:** Cartography, Visualisation

Object repres.	Attribute-type	Fill type	Line type	Symbol type		
Attribute type:	Font	Height	Width	Orient.	Distanc.	Direction
Fill type:	Pattern	Border line	Area fill	Scale		
Line type:	Type	Repeating symbols	Parallel Lines	Color	Scale	
Symbol type:	Primitives	Masking	Origin	Scale		

- are found in analogue form (e.g. map) and digital form (e.g. screen graphic).
- usually have additional text elements in order to match standard graphic elements.

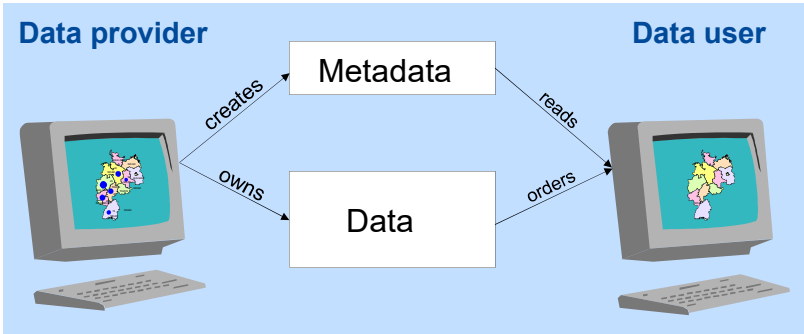
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Metadata


- **ISO 19115:2003 Geographic information — Metadata**
- Metadata is information used to describe information, i.e. information that is necessary to make the data usable in an information system.
- **Who offers what and how much, about what, how, in what context and at which conditions?**



```

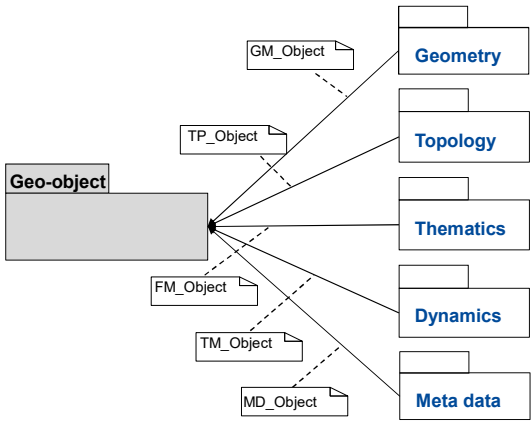
graph LR
    subgraph DP [Data provider]
        M1[Metadata]
        D1[Data]
    end
    subgraph DU [Data user]
        M2[Metadata]
        D2[Data]
    end
    DP -- creates --> M1
    DP -- owns --> D1
    DU -- reads --> M2
    DU -- orders --> D2
    
```

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Geo-object / spatial feature

- ! has
 - geometrical properties
 - topological properties
 - thematical properties
 - temporal properties
- is described by meta information.
- has an object identifier (key).
- belongs to a feature/object class.




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Discrete or continuous geo-objects

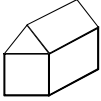
- ! • Discrete phenomena: Features with well-defined borders and spatial extent
 - z.B. Building, parcel, street, agricultural field plot.
 ⇒ **Vector data**
- ! • Continuous phenomena varying in space and in most cases not sharply defined
 - e.g. soil types, temperature distributions or terrain surfaces.
- **Fields (Coverages)** may be described:
 - discrete:
 - using triangles or grid cells (⇒ **Raster data**)
 - or **Tesselations** (such as Thiessen-Polygonen)
 - continuous:
 - using the form of functions (e.g. interpolation functions), connecting spatial positions with attribute values, e.g. trend surfaces.

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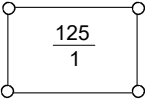


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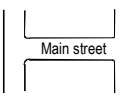
Basic object classes and spatial references



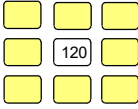
Buildings
Coordinates
Street, House No.
Real Estate No.




Parcels
Coordinates
Street, House no.
Real Estate No.




Streets
Coordinates
Street Name
Address



Building Blocks
Coordinates
Street Names
Block No.




Quarters
Coordinates
Name
Postal code



City
Coordinates
Name
Postal code

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An example for modeling: Geo-object „Building“

- **Data modeling: Building**

```

Building {
  ObjectID

  + Geometry (coordinates of the perimeter in 2 D)

  + Topology (is of type mesh in 2 D, has neighbouring buildings)

  + Thematics (has owner, number of floors, usage, value)

  + Dynamics (year of construction)

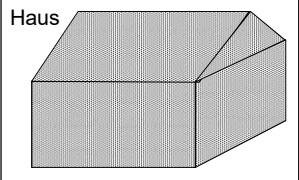

  + Metadata (created by, at datum, ..)

  + belongs to Class „Buildings“
}
    
```

- **Visualisation modeling: Building**

```

Building {
  has graphical description (black broderline with two-dimensional hatching)
  for visualisation in a thematic large scale map
}
    
```

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❖ DIMENSIONS

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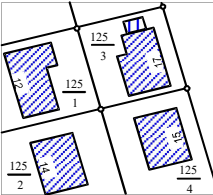

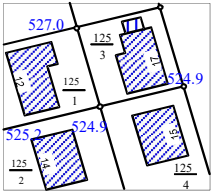
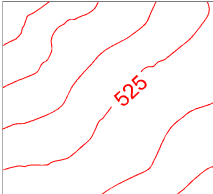
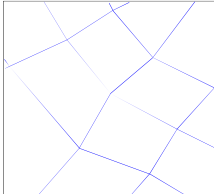
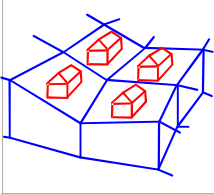
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Geometrical dimension

<p>2D - Planimetry</p> 	<p>2D+1D - Planimetry + DTM (no link between position and height)</p> 	<p>2.5D - x,y,z</p> 
<p>3D-Line model (Planimetry+ link to DTM)</p> 	<p>3D-facet model</p> 	<p>3D-Volume model</p> 

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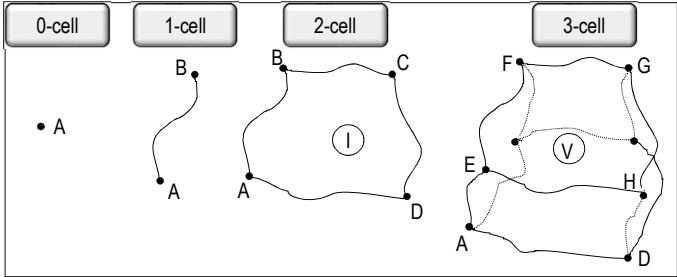
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Topological dimension

- Nodes (0-dimensional)
- Edges (1-dimensional)
- Meshes (2-dimensional)
- Solids (3-dimensional)

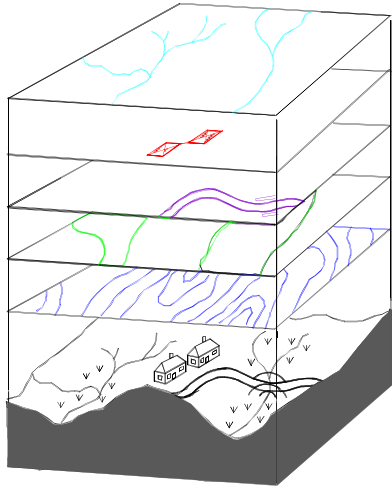


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Thematical dimension



Natural waters

Settlement areas

Traffic

Land usage


Rain fall

Real world

}

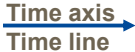
Dimension
N=5

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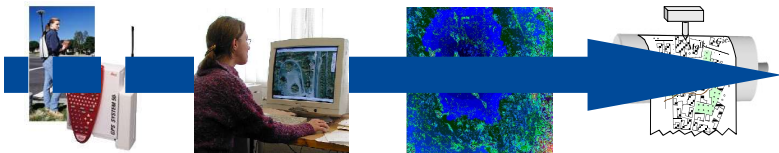
Temporal dimension

- 1-dimensional (1D-time, t)
- Combination with space results in 4-dimensional space-time (4D-time, (x; y; z; t))
- In applications we differentiate between:
 - 2D+time (x; y; t)
 - 2,5D+time (x; y; z = f(x,y); t)
 - 3D+time = 4D (x; y; z; t)


 Time axis
 Time line

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I M A P

❖ IMAP – THE PROCESSING CHAIN IN A GIS



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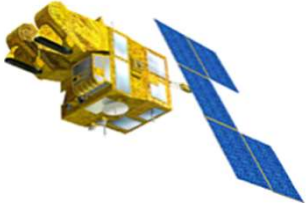
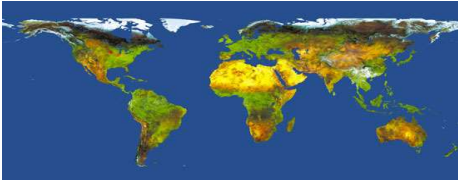


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Input / capture of information in GIS

- Getting the data/information into the system by:
 - Geodetic methods
 - Photogrammetric methods
 - Remote sensing
 - Digitising/scanning
 - Attribute data collection
 - Integrating existing digital information
 - ... and
- defining their spatial reference system.

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Example SDG: Existing digital information

un sustainable development goals data download

Ungefähr 26.400.000 Ergebnisse (0,57 Sekunden)

Global SDG Indicators Database - UNSD
<https://unstats.un.org/sdgs/indicators/database/> ▼ Diese Seite übersetzen
 ... to data compiled through the UN System in preparation for the Secretary-General's annual report on "Progress towards the Sustainable Development Goals".

Data Series (selected 1 of 356) Geographic Areas (selected 255 of 255) Years 2005 to 2015

☑ Select from all series
 ☑ Search and select indicators

☑ All

- ☑ **GOAL 4** Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
- ☑ **GOAL 5** Achieve gender equality and empower all women and girls
- ☑ **GOAL 6** Ensure availability and sustainable management of water and sanitation for all
- ☑ **GOAL 7** Ensure access to affordable, reliable, sustainable and modern energy for all
- ☑ **TARGET 7.1** By 2030, ensure universal access to affordable, reliable and modern energy services
- ☑ **TARGET 7.2** By 2030, increase substantially the share of renewable energy in the global energy mix
- ☑ **INDICATOR 7.2.1** Renewable energy share in the total final energy consumption
 - ☑ Renewable energy share in the total final energy consumption (%) EG_FEC_RNEW

Indicator 7.2.1, Series: Renewable energy share in the total final energy consumption (%) EG_FEC_RNEW

Country	Units	2005	2006	2007	2008	2009	2010	2011
Alghanistan	PERCENT	48.86 ^f	37.14 ^f	33.86 ^f	21.34 ^f	17.81 ^f	14.84 ^f	11.49 ^f
Albania	PERCENT	36.87 ^f	31.71 ^f	32.10 ^f	35.91 ^f	37.22 ^f	37.12 ^f	35.96 ^f
Algeria	PERCENT	0.58 ^f	0.41 ^f	0.41 ^f	0.39 ^f	0.31 ^f	0.26 ^f	0.18 ^f
American Samoa	PERCENT	0.00 ^f	0.00 ^f	0.00 ^f	0.00 ^f	0.00 ^f	0.00 ^f	0.00 ^f
Andorra	PERCENT	16.90 ^f	17.49 ^f	16.94 ^f	17.42 ^f	17.52 ^f	19.09 ^f	18.97 ^f
Angola	PERCENT	70.95 ^f	65.02 ^f	61.60 ^f	58.11 ^f	55.75 ^f	54.19 ^f	52.72 ^f
Anguilla	PERCENT	0.14 ^f	0.12 ^f	0.12 ^f	0.12 ^f	0.12 ^f	0.12 ^f	0.13 ^f

earthdata.com/downloads/50m-cultural-vectors/



Free vector and raster map data at 1:10m, 1:50m, and 1:110m scales

Home Features Downloads Blog Forums Corrections Ab

• Downloads

1:50m Cultural Vectors

[Download all 50m cultural themes](#) (7.59 MB) version 4.1.0

Files have been downloaded 273,533 times.

NOTE: Version number indicates the update cycle when that theme was last updated. An older version number indicates updates have not been necessary since then.

Admin 0 - Countries

There are 247 countries in the world. Greenland as separate from Denmark. Most users will want this file instead of sovereign states.

[Download countries](#) (756.04 KB) version 4.1.0


[Download without boundary lakes](#) (772.6 KB) version 4.1.0

[About](#) | [Issues](#) | [Version History](#)

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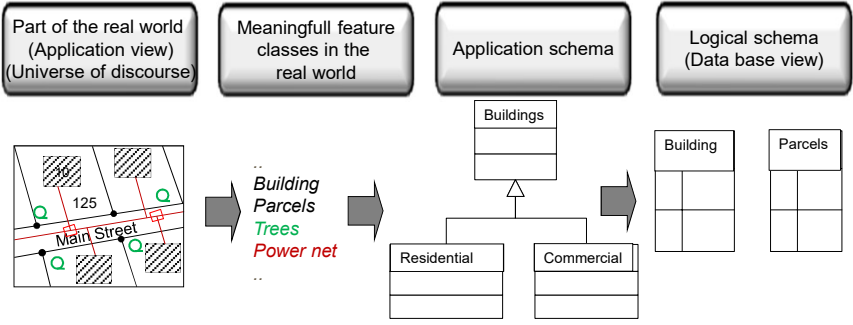


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Management/Modeling of information in GIS

- Data models
 - Modeling languages
 - Relational data models
 - Object-oriented modelling
- Data management
 - Data bases/information systems
 - Relational/object-relational DBs

Modeling at different levels: From an application oriented view to the database view



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From real world to digital models in the computer

Real world

↓

Abstraction

Data model	Process model
Layers Feature classes Properties	Functions Workflow Analyses

Information oriented
Task oriented


↓

Interpretation
Presentation

Visualisation model

Symbolisation	Drawing specifications	Map series
---------------	------------------------	------------

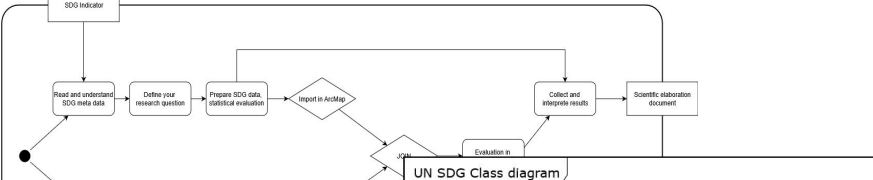
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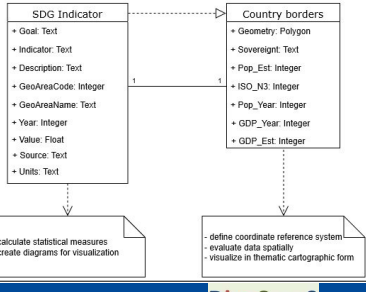
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SDG: Modeling the real world


- UML activity diagram (Processes)
- UML class diagram (Feature classes)



The activity diagram illustrates the process of working with SDG indicators. It starts with 'Read and understand SDG meta data' and 'Country borders, read and understand meta data'. These lead to 'Define your research question' and 'Country borders'. Both then lead to 'Prepare SDG data, statistical evaluation' and 'Import in ArcGIS'. This is followed by a decision diamond 'Evaluation in', which leads to 'Collect and interpret results' and finally 'Scientific elaboration document'.




The class diagram shows two classes: 'SDG Indicator' and 'Country borders'. 'SDG Indicator' has attributes: Goal (Text), Indicator (Text), Description (Text), GeoAreaCode (Integer), GeoAreaName (Text), Year (Integer), Value (Float), Source (Text), and Units (Text). 'Country borders' has attributes: Geometry (Polygon), Sovereignty (Text), Pop_Est (Integer), ISO_N3 (Integer), Pop_Year (Integer), GDP_Year (Integer), and GDP_Est (Integer). There is a 1-to-1 association between them. Notes indicate that 'SDG Indicator' involves calculating statistical measures and creating visualization diagrams, while 'Country borders' involves defining coordinate reference systems and evaluating data spatially for thematic cartographic forms.




UNIFIED MODELING LANGUAGE

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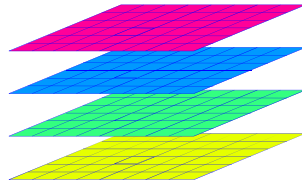
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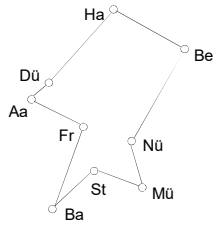


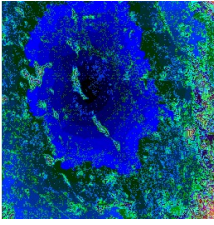
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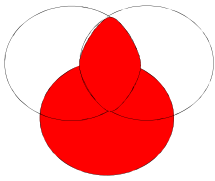
Analysis of information in GIS


- Geometrical methods
- Topological methods
- Temporal methods
- Statistical methods
- Set methods
- Models and simulation













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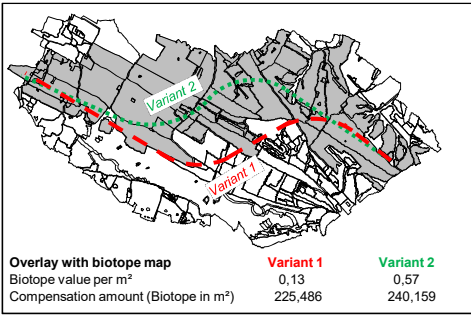
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Basic problem of spatial analysis

- Given a user-defined task and an information system with **data on different phenomenon A, B, C, ...**
- **Establish function(s)** through which the available data may be involved and manipulated to provide the required output (e.g. presentations such as maps, graphs, reports, ...) related to the problem


Link: $U = f(A, B, C \dots)$

- Functions f
 - Selection/Boolean operations
 - Algebraic terms
 - Reclassification
 - Polygon overlay
 - ...



Overlay with biotope map	Variant 1	Variant 2
Biotope value per m ²	0,13	0,57
Compensation amount (Biotope in m ²)	225,486	240,159

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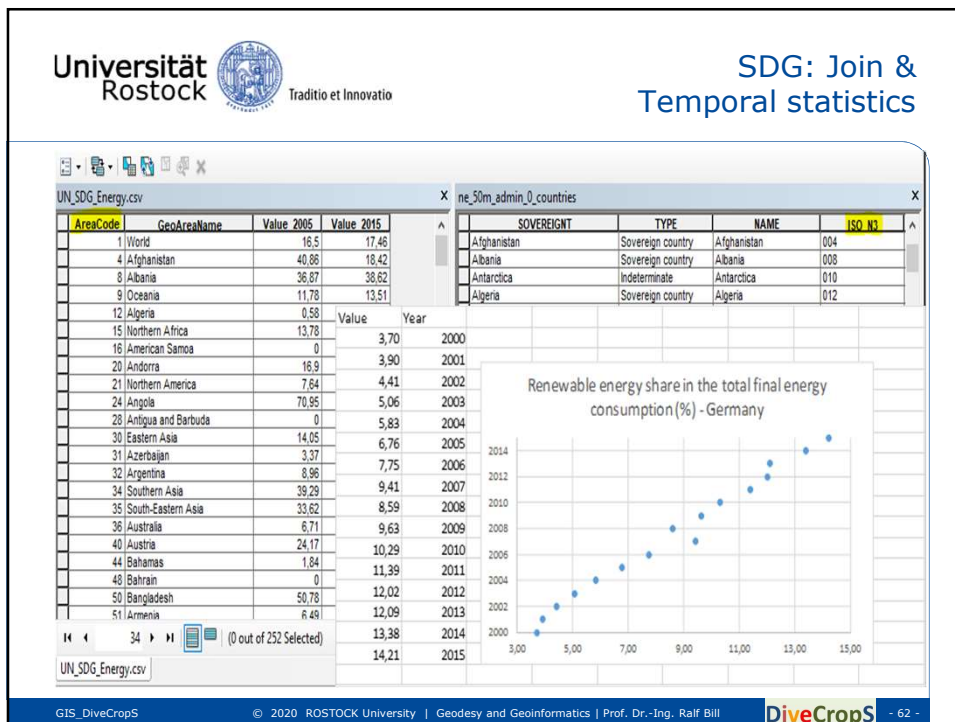
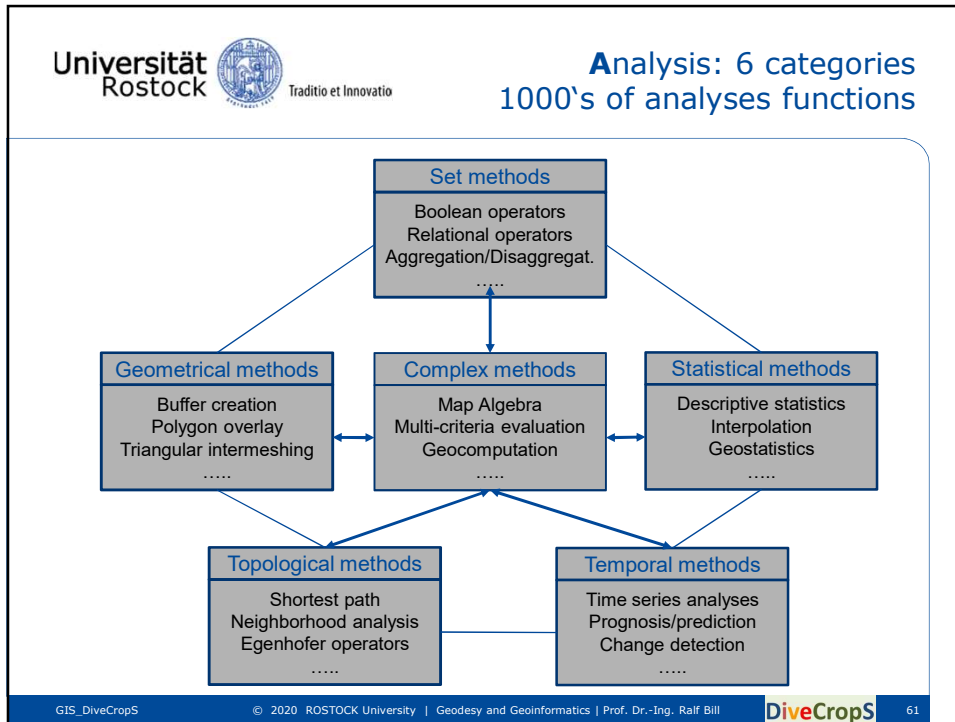
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5 questions a GIS can answer!

1. **Location:** What is at a given location?
 - to find out what exists at a particular location (place name, zip code or address).
2. **Condition:** Where does something occur?
 - use spatial analysis to find a location where certain conditions are satisfied (e.g., an unforested section of land at least 2,000 square meters in size, within 100 meters of a road, and with soils suitable for supporting buildings).
3. **Trends:** What has changed since ...?
 - combination of the first two to find the differences within an area over time.
4. **Patterns:** What spatial patterns exist?
 - May determine whether cancer is a major cause of death among residents near a nuclear power station. Just as important, you might want to know how many anomalies there are that do not fit the pattern and where they are located.
5. **Modeling/Simulation:** What if ...?
 - to determine what happens, for example, if a new road is added to a network. Answering this type of question requires geographic as well as other information.

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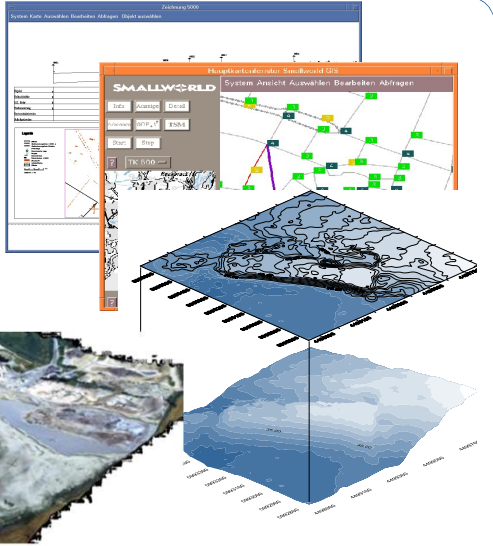





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Presentation / visualisation of information in GIS

- In analogue form:
 - Maps
 - Detail- and overview plans
 - Sketches
 - Map diagrams
 - Business graphics
 - Perspectives
 - Imagery
 - Length-/transversal profiles
 - Reports
 - Statistics
 - Tables
 - Others



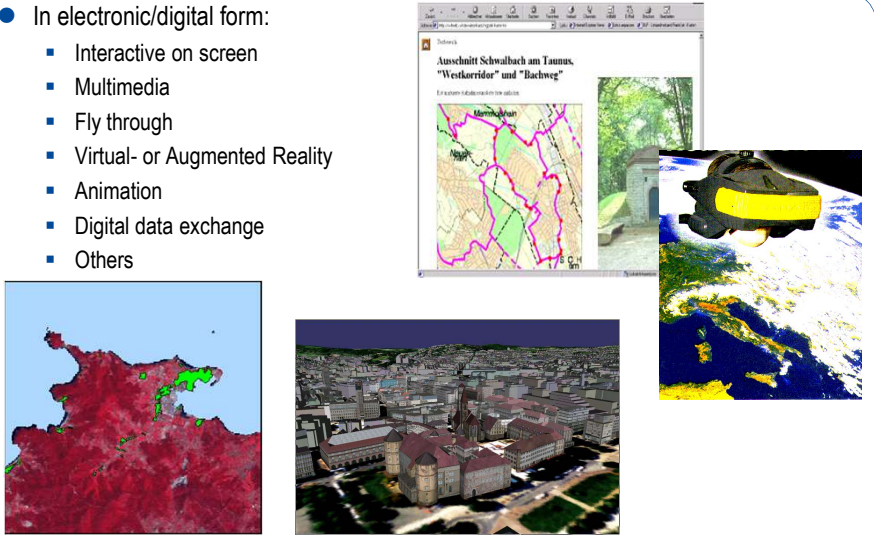
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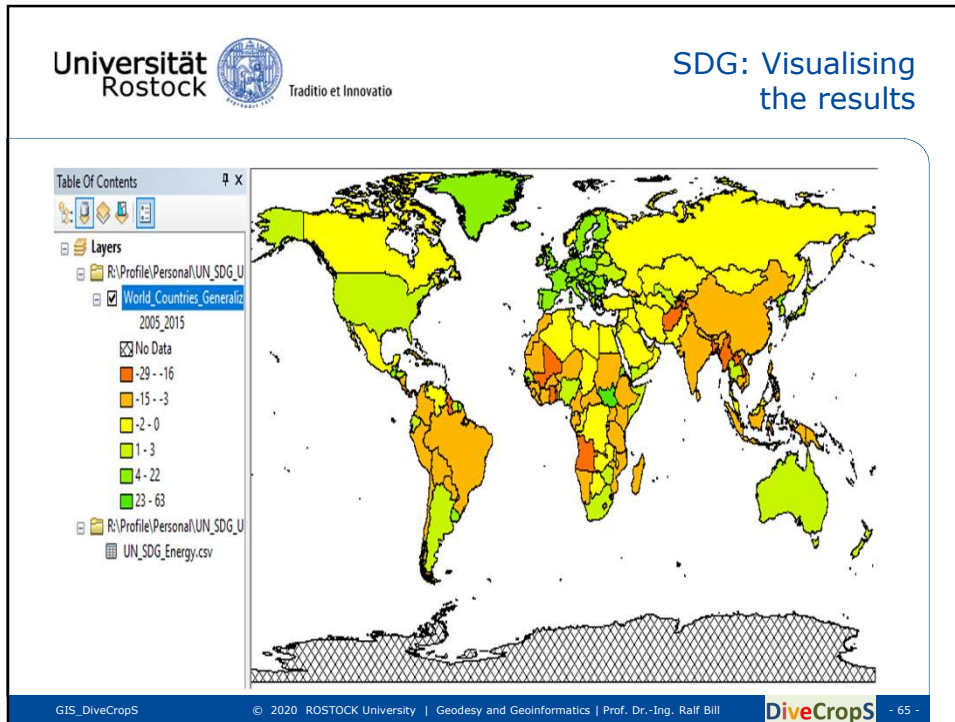
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Presentation / visualisation of information in GIS

- In electronic/digital form:
 - Interactive on screen
 - Multimedia
 - Fly through
 - Virtual- or Augmented Reality
 - Animation
 - Digital data exchange
 - Others




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❖ PRODUCTS AND STANDARDS


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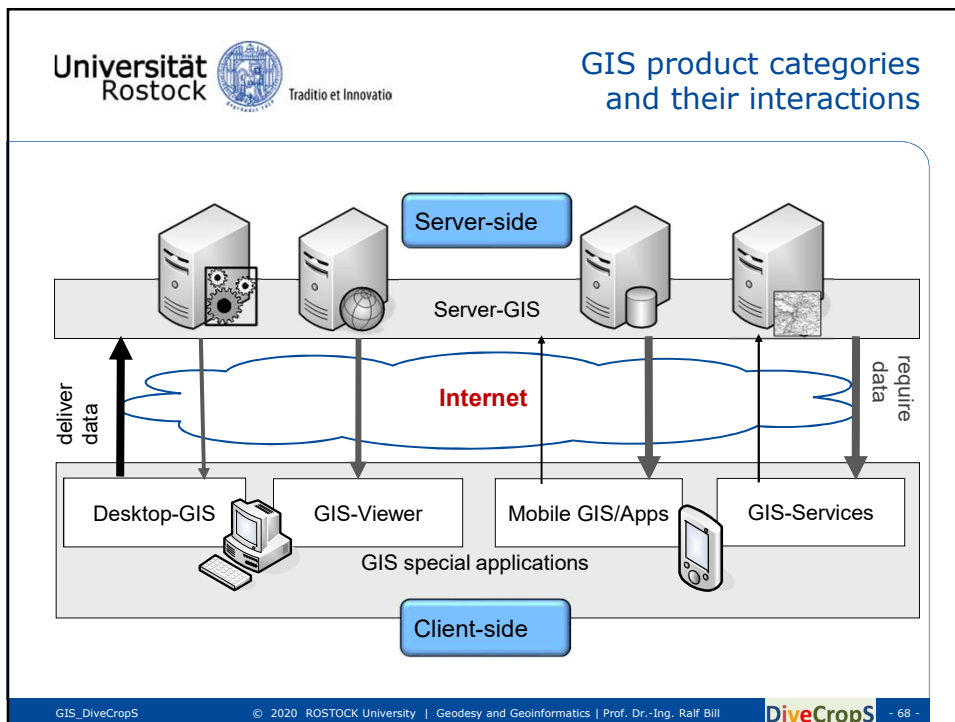
GIS desktop products


- Commercial products:
 - ESRI ArcGIS
 - Autodesk AutoCad Map 3D
 - Smallworld GIS
 - Intergraph G/Technology
 -
- Open Source products:
 - Quantum GIS
 - Geographic Resources Analysis Support System (GRASS)
 - OpenJUMP
 -





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Standardisation

- de-jure ⇔ de-facto
- Formal ⇔ technical

- Products: Paperware
- Goal: Formalisation and Interoperability

DIN EN ISO 19115

DIN

Geoinformation –
Referenzmodell (ISO 19115:2003)
Englisches Fassung ISO 19115:2003

Geographic Information –
Reference Model (ISO 19115:2003)
English version EN ISO 19115:2003

Informations géographiques –
Modèle de référence (ISO 19115:2003)
Version anglaise EN ISO 19115:2003

Open Geospatial Consortium Inc.

Date: 2006-03-15

Reference number of this document: OGC® 06-042

Version: 1.3.0


Category: OpenGIS® Implementation Specification

Editor: Jeff de la Beaujardiere

OpenGIS® Web Map Server Implementation Specification

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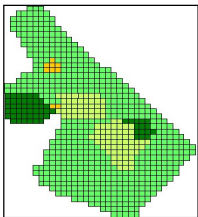


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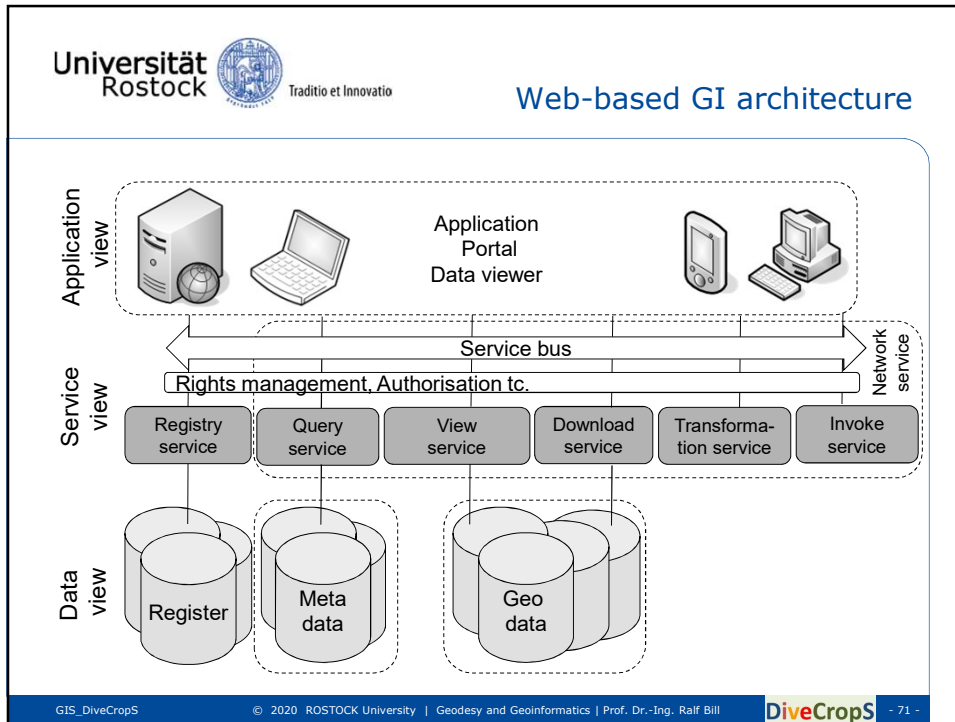
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Open Geospatial Consortium: OGC Web Services

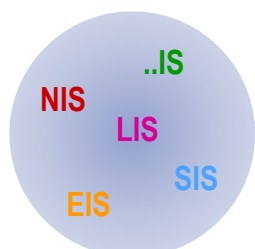
- **OGC Web Map Service (WMS)**
 - Access to raster maps/imagery (GIF/PNG/JPG)
- **OGC Web Feature Service (WFS)**
 - Access to features/vector data (GML)
- **OGC Web Coverage Service (WCS)**
 - Access to raster coverages
- and many others

<https://www.ogc.org/>
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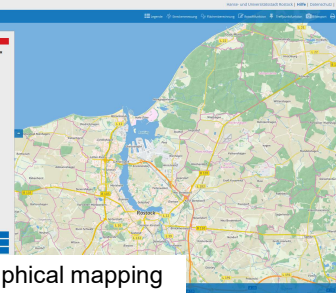
FROM LIS, EIS, NIS, .. TO ..IS

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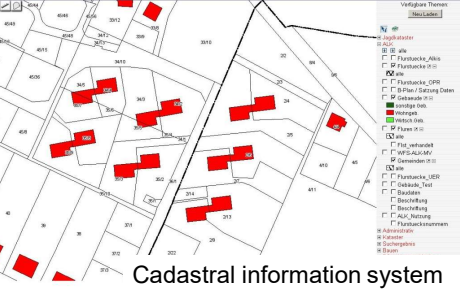

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Land information systems / Mapping

- A **land information system (LIS)** is an instrument for decision-making in law, administration and economy as well as a tool for planning and development. It consists of a data collection containing land and topography-related data for a specific region. It includes procedures and methods for the systematic collection, updating, processing and implementation of this data. The basis of a LIS is a uniform, spatial reference system for the stored data, which also facilitates the linking of the data stored in the system with other geodata.




Topographical mapping



Cadastral information system

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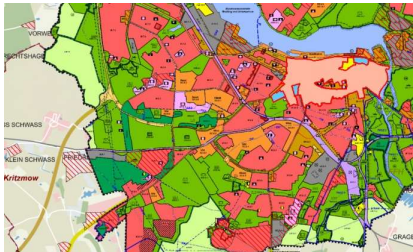


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Planning information systems

- A **spatial planning and information system** is an instrument for decision-making and a tool for planning and development. It consists of data collections on population, economic and settlement development, infrastructure development, land use and resources, which are incorporated into regional development programmes. The procedures and methods for collecting, updating and implementing these data are also an essential part of the information system. The basis is the uniform spatial reference, linking the various types of data with each other.




Zoning plan City of Rostock



Detailed plan Pirmasens

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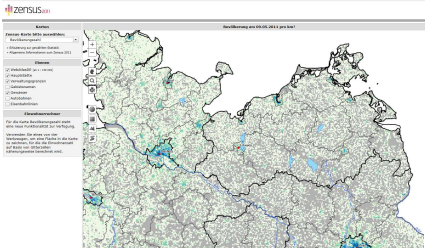


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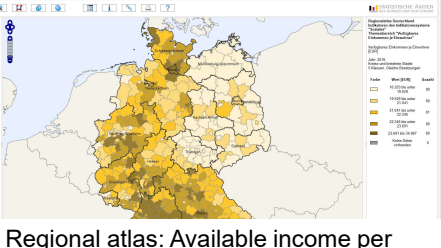
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Statistical information systems

- A **statistical information system (SIS)** provides data obtained through statistical methods and collected using official statistics, business statistics, statistics from associations and statistics from scientific institutions. The data is subject to special legal data protection regulations. In addition to the factual reference, the time reference (key date or period) and the spatial reference are the main characteristics of the statistical information. Users of statistical information systems range from public administrations (governments, parliaments, municipal institutions) to the economy and its associations, scientific institutions and the




Census 2011: Population density/km²



Regional atlas: Available income per inhabitant

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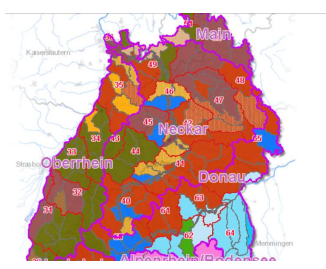


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Environmental information system

- An **environmental information system (EIS)** is an extended GIS that serves to collect, store, process and present spatial, temporal and content-related data to describe the state of the environment with regard to pressures and hazards and to form the basis for environmental protection measures. (Page & Jaeschke & Pillmann, 1990).




Federal reporting system: Water types



Messstellen in Deutschland

Monitoring network
Local gamma dose rate

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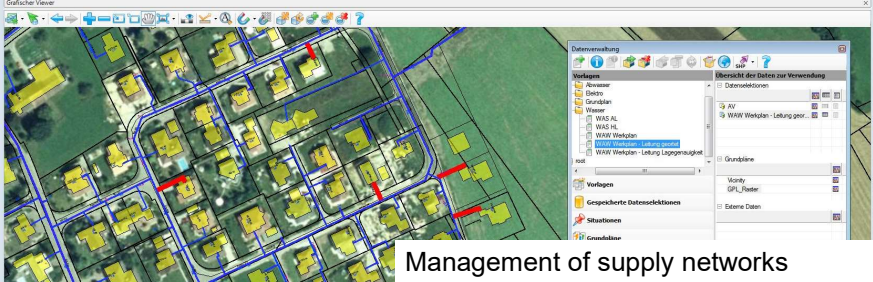


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Network/Utility information systems

- A **network information system (NIS)** is an instrument for the collection, management, analysis and presentation of equipment data in supply and disposal companies. This includes data on the network and facilities for supply and disposal as well as customer data. The supply network with its operating resources, the existing relationships between them and the processes running on them are modelled, recorded, evaluated and visualised. The network documentation usually refers to the network topology, which must be given in a uniform reference framework. NIS are used for network planning, network operation and maintenance (FM systems).



Management of supply networks


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..IS characteristics


GIS type	Data type	Dimension				Scale
		Geometry	Topology	Thematics	Temporal	
LIS	Vector/ (Raster)	2D, 2.5D, 3D	2 (Meshes) 3 (Solids)	low	static	large-small
NIS	Vector	2D, 2.5D	0 (Nodes) 1 (Edges) 2 (Meshes)	mean	static	large-mean
SIS	Vector/ Raster/ Hybrid	2D-(3D)	2 (Meshes) 3 (Solids)	large	static to slowly changing	large-small
EIS	Vector/ Raster/ Hybrid	2D-3D	2 (Meshes) 3 (Solids)	large	static to highly dynamic	large-small

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AGRICULTURE, FORESTRY ETC.

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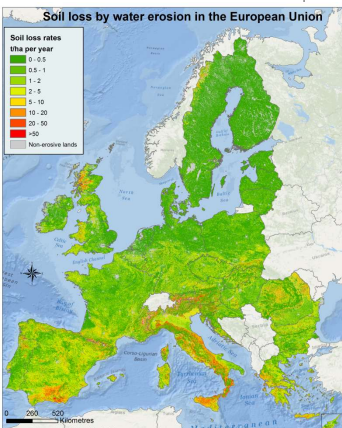
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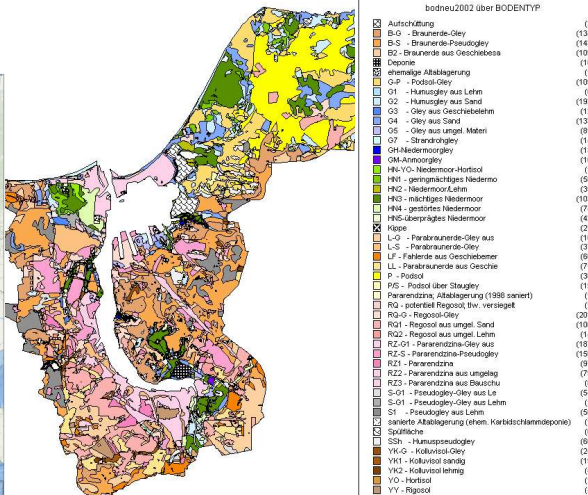
Agricultural IS - Soil information

- Soil loss by water erosion in EU
- Soil type mapping in Rostock




Soil loss rates
t/ha per year

Sickelstadt Images, ESRI World Terrain Base




bodneu2002 über BODENTYP

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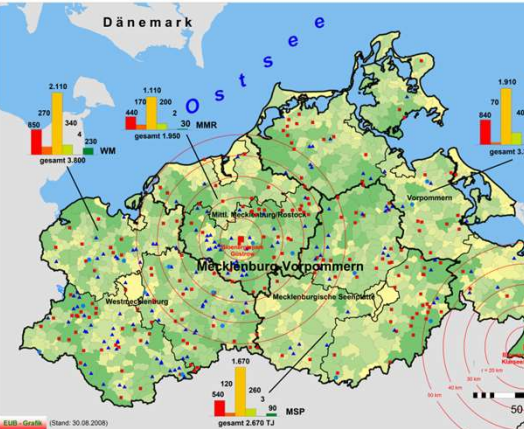
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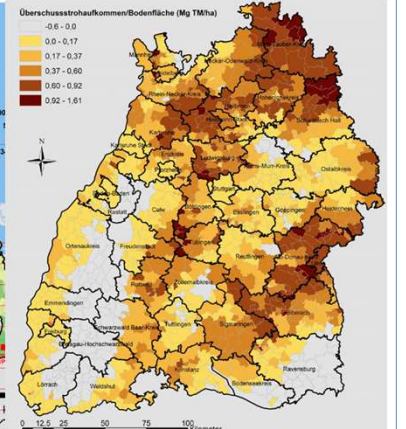
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Agricultural IS - Renewable energies

- Power production from biomass
- Energy production from organic waste




EUS - Graph (Stand: 30.08.2008)



Überschussstrohaukommen/Bodenfläche (Mg TM/ha)

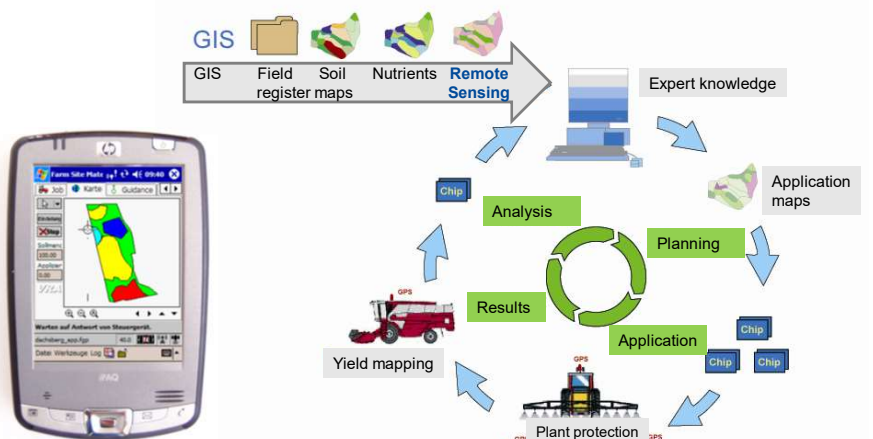
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Agricultural IS – Smart/Precision Farming



Goal:
Ubiquitous control

Source: Korduan et al. 2000 changed

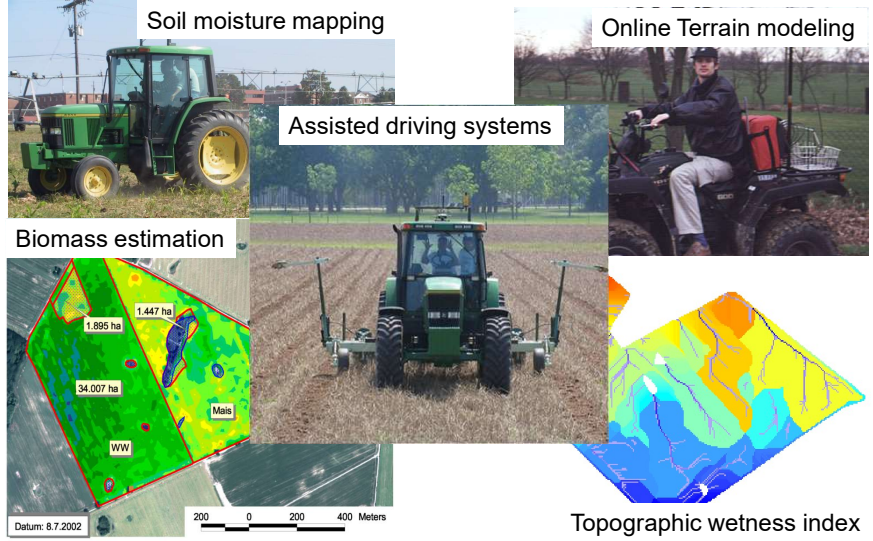
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Agriculture – Smart/Precision Farming



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Forestry

● Forest mapping

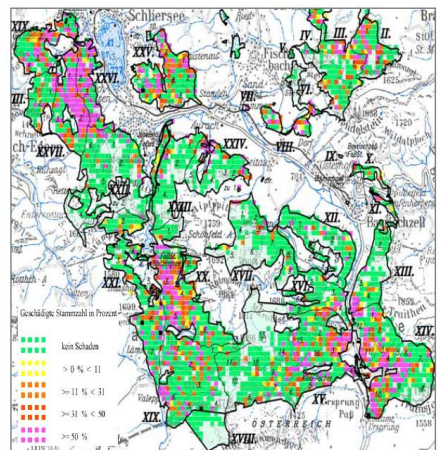
Thematik: Erstellen einer Faktkarte entsprechend der forstwirtschaftlichen Spezifik hinsichtlich Lein- und Flächengrößen mit dem GIS TRASS



Legende

— Gemeindegrenze	— Bestandesart der Unterabteilung
○ Ortswahl	— Holzboven, Hauptbaumart ALN, Altersklasse 2-3
□ angrenzender Landweid	— Bestandesart der Unterabteilung
△ angrenzender Waldweid	— Holzboven, Hauptbaumart ALN, Altersklasse 2-3
— Abteilung	— Bestandesart der Unterabteilung
— Bestandesart der Unterabteilung	— Holzboven, Hauptbaumart LARCHE
— Holzboven, Hauptbaumart EICHE, Altersklasse 1-2	— Altersklasse 2-3
— Bestandesart der Unterabteilung	— Bestandesart der Unterabteilung
— Holzboven, Hauptbaumart EICHE, Altersklasse 3-4	— Holzboven, Hauptbaumart FICHE, Altersklasse 1-2
— Bestandesart der Unterabteilung	— Bestandesart der Unterabteilung
— Holzboven, Hauptbaumart BUCHE, Altersklasse 3-4	— Holzboven, Hauptbaumart FICHE, Altersklasse 2-3
— Bestandesart der Unterabteilung	— Bestandesart der Unterabteilung
— Holzboven, Hauptbaumart ALN, Altersklasse 3-4	— Fichtenwald, 5-10er Brüche, öffentlich im Eigentum

● Forest inventory



Gewichtete Stammzahl in Prozent

■ kein Schaden
■ > 0 % < 11
■ > 11 % < 31
■ > 31 % < 50
■ > 50 %

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RESEARCH

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5 driving forces in a digital world of the future

Mobile

Location

Big Data

Sensors

Social Media

Scoble, R., Israel, S. (2013).

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Sensors – new ways of data acquisition

Artenfinder

Photo: Hitachi







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Social media


- Connecting people
- Users as prosumers (producers and consumers of data)
- Data on individuals (data protection issues)

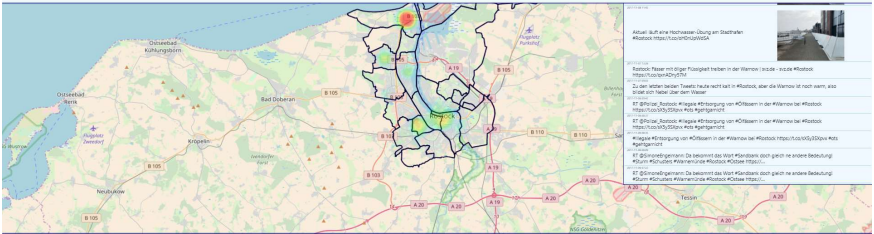







Twitter monitor Rostock

Historisch ▾

10/10/2017 - 00:52 8/11/2017 - 23:43





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Mobile

- Our mobile devices (Smartphone/Tablet) will become classical user interfaces to GIS.










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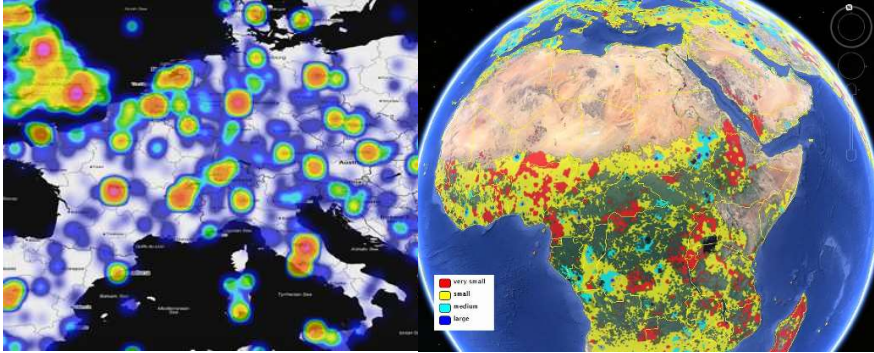
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Big data

- Big data: extremely large data sets that may be analysed computationally to reveal patterns, trends, and associations, especially relating to human behaviour and interactions.
- **5 V's: Variety, Volume, Veracity, Velocity, Value**
- Data analytics, data driven science



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TAKE HOME MESSAGE


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GIS
– in simple terms –

- is a computer-based system capable of holding and using **data describing places on the earth**.
- **links spatial data with context** about a particular feature on the earth.
- doesn't hold maps or pictures - it runs a **database**. The heart of any GIS is the database through which questions such as what a feature is, where it is, and how it relates to other features can be answered.
- gives you the ability to **associate information with a feature on the earth** and to **create new relationships** that can determine the suitability of various sites for development, evaluate environmental impact, identify the best location for a new facility, and so on.
- turns **data** into information and **information** into **knowledge** by spatial analysis.
- encourages **cooperation and communication** among different users.
- is an **analytical tool**.
- stores the data from which you can **draw a desired view to suit a particular purpose**.

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LITERATURE

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Literature

- Textbooks



Ralf Bill
Grundlagen der Geo-Informationssysteme
6., völlig neu bearbeitete und erweiterte Auflage
Wichmann



GEOGRAPHIC INFORMATION SYSTEMS & SCIENCE



MICHAEL N. DEMERS
GEOGRAPHIC INFORMATION SYSTEMS




Principles of Geographical Information Systems
Peter A. Burrough and Rachael A. McDonnell
Spatial Information Systems and Geostatistics

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eLearning


- Open Educational Resources

Various methods can be roughly divided into 2 groups: (a) fundamental and methods (see Bill, 2019; chapter 7; see, de-Brith et al., 2018)

1. **Geometric methods** are essentially based on the mathematical foundations of geometry. They are characterized by calculating with coordinates. Important functions are the distance and area calculation (e.g. for parcels of a municipality), the zone or buffer generation (e.g. around a planned route), the point-in-polygon check - explained in the video (e.g. measuring points in a district), the polygon overlay (e.g. parcels versus real land use, see video) and the **triangular interpolation** (e.g. digital terrain models).




Point in Polygon




Polygon Overlay

2. **Topological methods** are based on neighborhood relations; they essentially use graph theory as a mathematical basis. They can be used to express neighborhood relations (two parcels bordering each other without using coordinates). A well-known function is the calculation of the shortest paths in a network (e.g. a pipeline network).



<https://learn.opengeoedu.de/en/gis/>



<http://www.spatialanalysisonline.com/>

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PROJECT DIVECROPS

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DAAD

- Funded by:
 - DAAD – deutscher akademischer Austauschdienst (German Academic Exchange Service)
- Project duration:
 - 01.01.2019 - 31.12.2022
- Coordinator:
 - apl. Prof. Dr. habil. Bettina Eichler-Löbermann, Pflanzenbau, Universität Rostock (UROS)

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<https://www.auf.uni-rostock.de/professuren/h-w/pflanzenbau/divecrops/>

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