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Geoinformation in Environmental Modelling

Geospatial data issues

ENY-C2005
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15.2.2019
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Topics today

- Uncertainty in geoinformatics

  and what it means in data quality and analysis results

- SDI – Spatial Data Infrastructures
  - Metadata – description of data and data quality
  - SDI architecture with network services
  - Standards for geographic data

Examples of potential exam questions relating to this lecture

- Paikkatiedon verkkopalvelut ovat keskeinen osa INSPIRE-direktiivin toimeenpanoa ja paikkatiedon infrastuktuuria yleensäkin. Nimeä nämä verkkopalvelut, ja selitä mihin niitä tarvitaan.
- Network services for geographic data are an essential part of the implementation of INSPIRE directive and of spatial data structures in general. Name these network services, and explain what they are needed for.

- Mitä paikkatiedon metadata on, mihin sitä tarvitaan ja mikä sen pääasiallinen sisältö on?
- What is metadata of geographic data, what is it needed for, and what are the main contents of it?

- Kuvaile, millä tavoilla epävarmuus voi ilmetä geoinformatiikassa ketjussa ”Conception – Measurement and representation – Analysis”. Tarkastele asiaa sekä diskreettien kohteiden että jatkuvien ilmiöiden ja sekä sijainnin että ominaisuuksien osalta.
- Describe the ways in which uncertainty can appear in geoinformatics in the chain “Conception – Measurement and representation – Analysis”. Consider this from the viewpoints of both discrete objects and fields as well of spatial and attribute data.

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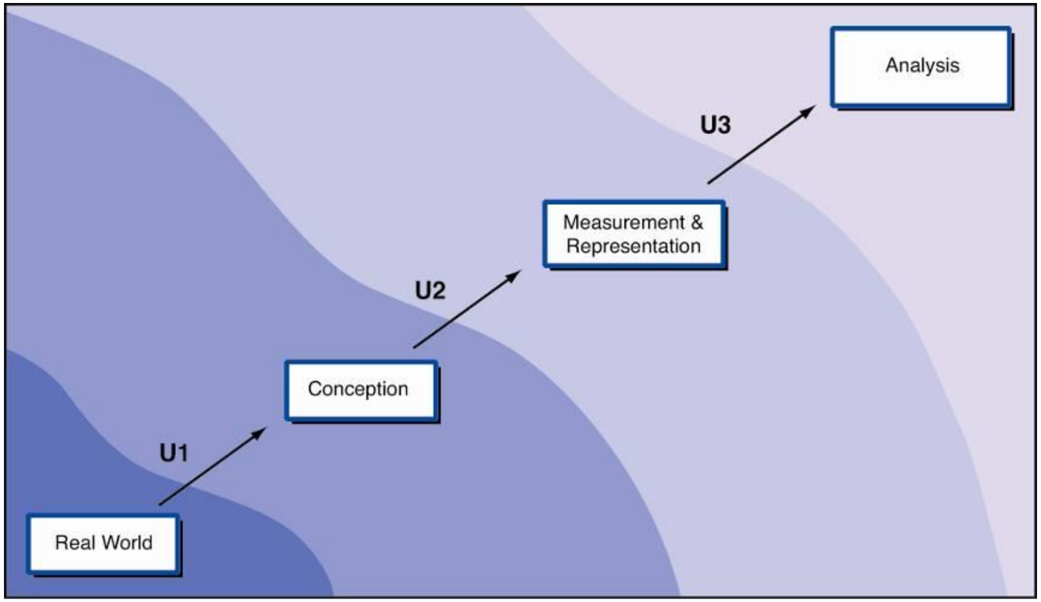
Uncertainty



Longley et al. (2015) Ch. 5

- in concept design

  cf. the lecture of Data modelling

- in representation

- in analysis

Uncertainty

- "Geographic data is a representation of the real world"
  - However, it captures only a very limited fraction of the **complex and infinitely detailed** variation of features and characteristics, at a time.
  - Our understanding of the process of real world is limited, and thus the **models** as well as the **methods** used in analysis of data in most cases strongly approximate the real processes.

➢ It is impossible to make a perfect representation of the world, so uncertainty about it is inevitable
  - Uncertainty is more than error, for example, inaccuracy, ambiguity, vagueness,…

- Need for *a priori* understanding of data and sensitivity analysis

Longley et al. (2015) Ch. 5.1

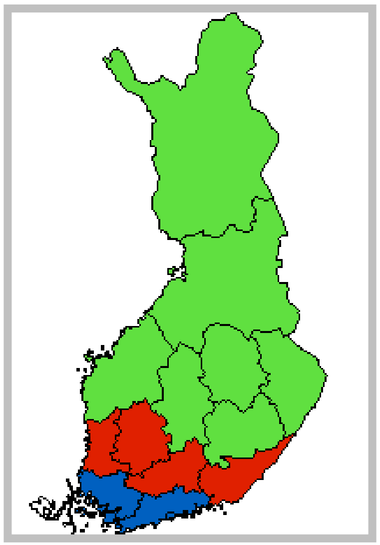
Uncertainty: Conception

- Units of analysis
  - *Natural* geographic units (Or rather, *usable* units?)
    - When variation is continuous in space (vs. discrete), where are the boundaries of a cluster?
  - Discrete objects
    - Aggregation, unit size
- Vagueness (epämääräisyys)
  - Robustness of labelling (i.e. which class/category)
    - e.g. forest zones: what makes a pine woodland?
  - Is the boundary of the zone clear and well-defined?
- Ambiguity (monitulkintaisuus)
  - Indirect indicators
  - Differences in classifications and definitions
    - Makes the comparison between two datasets difficult
- *Very often, subjective decisions*

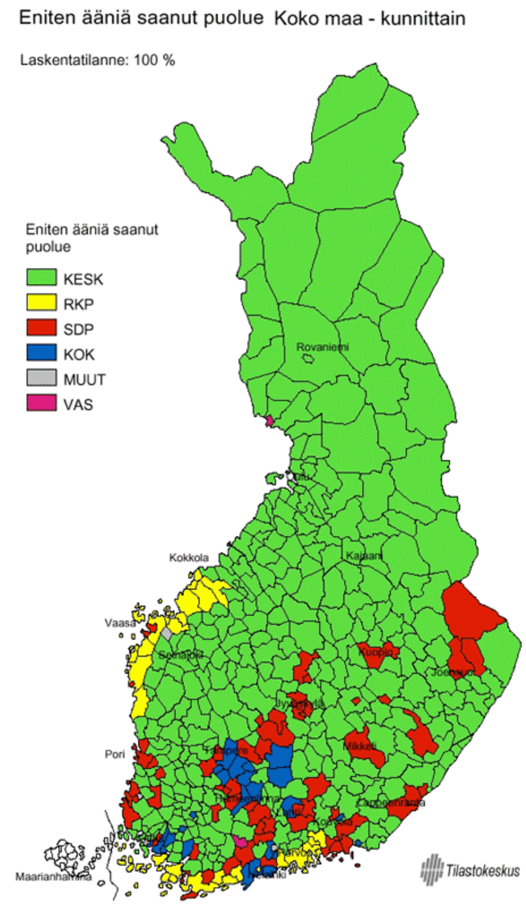
Longley et al. (2015) Ch. 5.2

Example: Scale of geographic units matters

Kunnallisvaalit 2000



Area units make a difference!



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Example: Scale and Spatial Autocorrelation

Number of geographic areas	Correlation
48	0,2189
24	0,2963
12	0,5757
6	0,7649
3	0,9902

- Relationships typically grow stronger when based on larger geographic units

Longley et al. (2015) Ch. 5.2

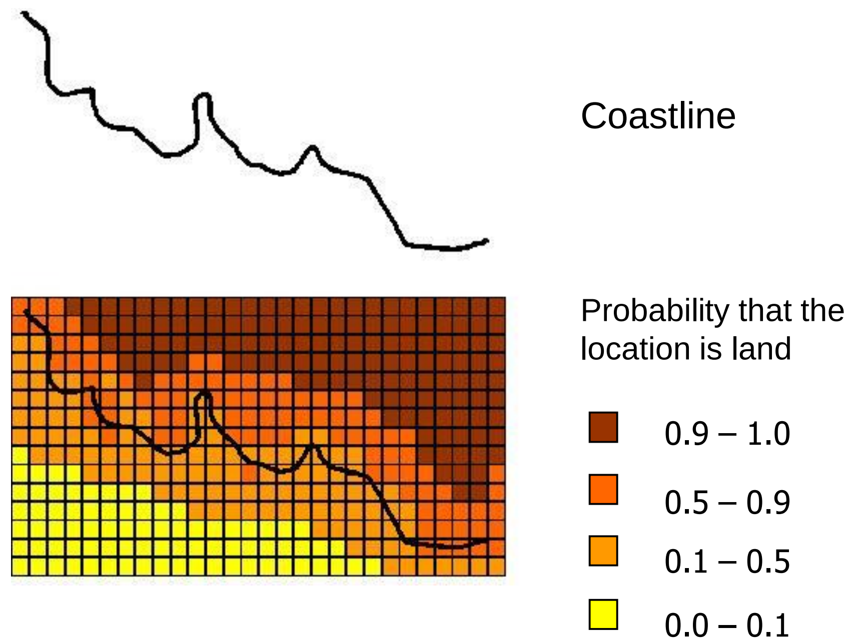
Fuzzy Approaches to Uncertainty

- In fuzzy set theory, it is possible to have partial membership in a set
  - membership can vary, e.g. from 0 to 1
  - this adds a third option to classification: yes, no, and maybe
- Fuzzy approaches have been applied to the mapping of soils, vegetation cover, and land use
  - Instead of clear borders, there are zones of different probabilities
  - Moving borders, e.g. coastline (tides of oceans, lakes shrinking in dry season)

Longley et al. (2015) Ch. 5.2

Uncertainty: Representations

- Representational models filter reality differently
  - Vector
  - Raster



Statistical measures of uncertainty: nominal case

Misclassification matrix (confusion matrix):
Measure of the accuracy of nominal attributes

– compares recorded classes (the *observations*) with classes obtained by some more accurate process, or from a more accurate source (*the reference*)
– Examining every unit may not be practical ⇒ sampling

Statistics (see the following example)

- Percent correctly classified
  – total of diagonal entries divided by the grand total
  – 209/304 = 68.8 %
  – but chance would give a score of better than 0
- Kappa statistic (equivalence) yhtäpitävyyskerroin
  – normalized to range from 0 (chance) to 100 %
  – evaluates to 58.3 %

Longley et al. (2015) Ch. 5.3

Example of a **misclassification matrix** or **confusion matrix** of land use data.
A grand total of 304 samples have been checked. The rows of the table correspond to the land use class of each sample as recorded in the database, and the columns to the class as recorded in the field. The numbers appearing on the principal diagonal of the table (from top left to bottom right) reflect correct classification.

As in the field

As in the database

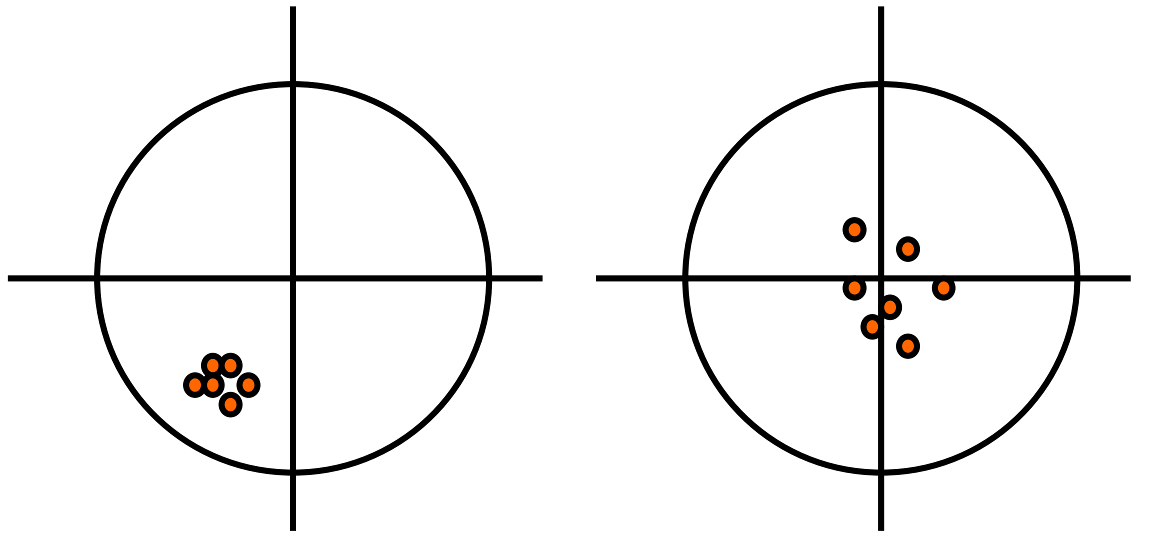
	A	B	C	D	E	Total
A	80	4	0	15	7	106
B	2	17	0	9	2	30
C	12	5	9	4	8	38
D	7	8	0	65	0	80
E	3	2	1	6	38	50
Total	104	36	10	99	55	304

Measurements of uncertainty: Interval/Ratio Case

- Errors distort measurements by small amounts
- Accuracy (ulkoinen tarkkuus)
  - refers to the amount of distortion from the true value
- Precision (sisäinen tarkkuus)
  - refers to the variation among repeated measurements
  - Also refers to the number of significant digits (in reporting)

- Reporting of a measurement should reflect its accuracy
  - “Not too many decimals”, remove excess precision by rounding
  - E.g. measurement accurate to 1 m $\Rightarrow$ no decimal places

Longley et al. (2015) Ch. 5.3



The term *precision* is often used to refer to the repeatability of measurements. In both diagrams six measurements have been taken of the same position, represented by the center of the circle. On the left, successive measurements have similar values (they are *precise*), but show a bias away from the correct value (they are *inaccurate*). On the right, precision is lower but accuracy is higher.

Measuring Accuracy

- Root Mean Square Error
  - that is, the square root of the average squared error
  - The primary measure of accuracy in map accuracy standards and GIS databases
    - E.g. elevations in a digital elevation model might have an RMSE of 2 m
  - The abundances of errors of different magnitudes often closely follow a Gaussian or normal distribution
    - The range between –1 standard deviation and +1 standard deviation encloses 68 % of the area under the Gaussian curve, indicating that 68 % of observations will fall between these limits.
    - 1,96 x standard deviation for 95 % reliability

Longley et al. (2015) Ch. 5.3

A rule of thumb for positional accuracy

Positions measured from maps are accurate to about 0,5 mm on the map. Multiplying this by the scale of the map gives the corresponding distance on the ground.

Map scale	Ground distance corresponding to 0.5 mm map distance
1:2500	1.25 m
1:5000	2.5 m
1:10 000	5 m
1:25 000	12,5 m
1:50 000	25 m
1:100 000	50 m
1:250 000	125 m
1:1 000 000	500 m

Of limited use on digital maps

Correlation of Errors

- *Absolute* positional errors may be high
  - reflecting the technical difficulty of measuring distances from the Equator and the Greenwich Meridian
  - $(x',y') = (x+\boldsymbol{\delta}_1 x,\ y+\boldsymbol{\delta}_2 y)$
- *Relative* positional errors over short distances may be much lower
  - positional errors tend to be strongly correlated over short distances, especially if measurements result from the same process

  $\Rightarrow \boldsymbol{\delta}_1$ and $\boldsymbol{\delta}_2$ are ~ the same in the examined area
  - as a result, positional errors can largely cancel out in the calculation of properties such as distance or area

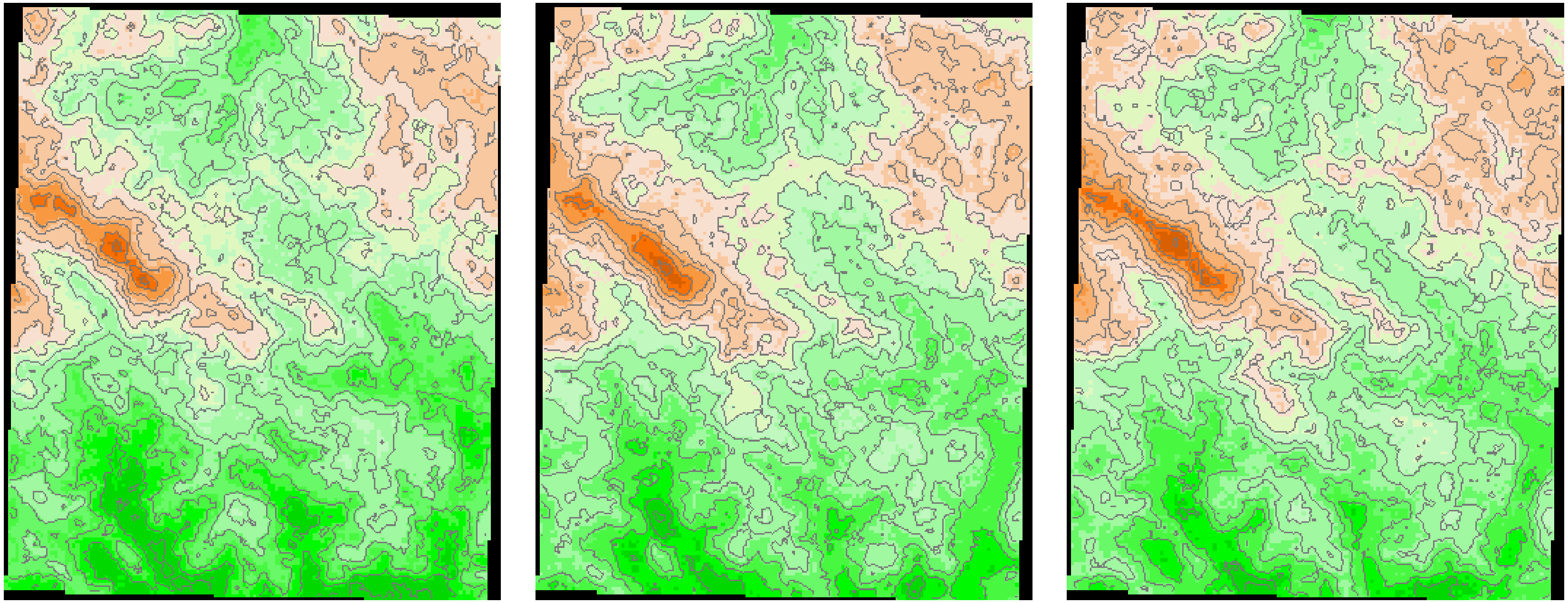
Longley et al. (2015) Ch. 5.3

Uncertainty in the analysis

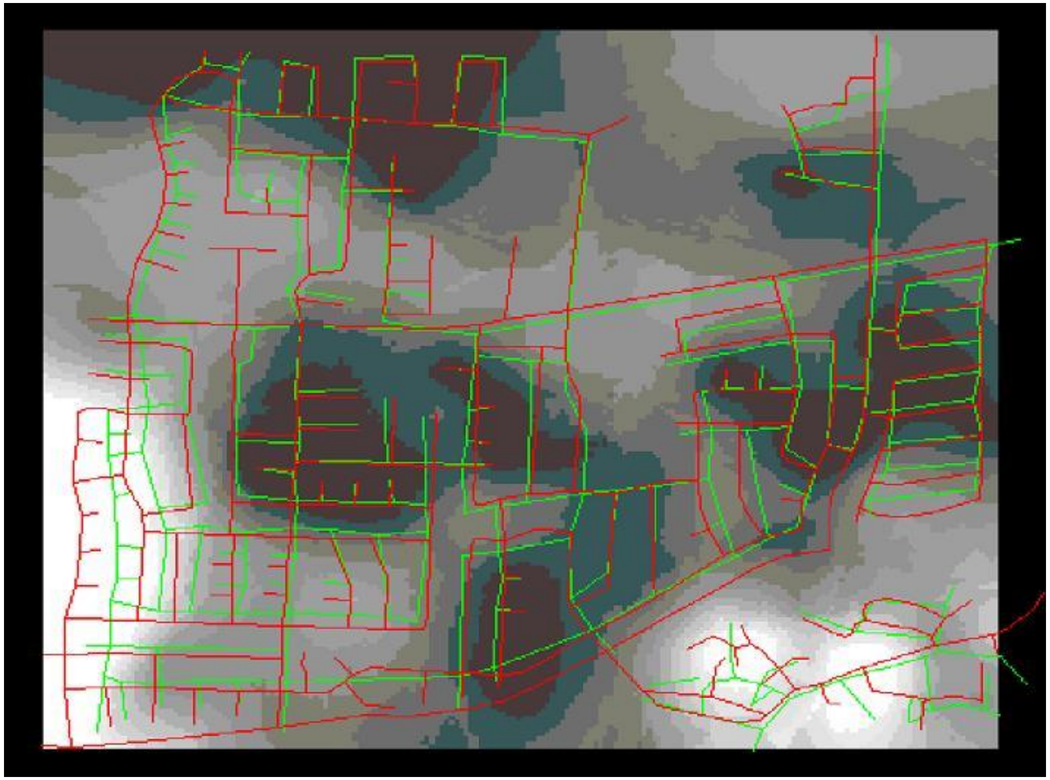
- The effects of errors and uncertainty on the analysis results
  - Almost every input to a GIS is subject to error and uncertainty
    - Location measuring, concept model, rounding, sampling, interpolation, …
  - In principle, every output (= analysis result) should have confidence limits or some other expression of uncertainty
  - Also: how well do the modelling and analysis methods suit to the real world case?

- Internal validation: Error propagation (virheen kasautuminen)
  - **Simulation** to evaluate the impacts of uncertainty on results: generate a series of realizations, taking into account what is known about the situation, such as values with…
    - mean equal to the measured value, standard deviatiation equal to the known RMSE, preserving spatial autocorrelation.

Longley et al. (2015) Ch. 5.4



Three realizations of a model simulating the effects of error on a digital elevation model. The three data sets differ only to a degree consistent with known error. **Error has been simulated** using a model designed to replicate the known error properties of this data set – the distribution of error magnitude, and the spatial autocorrelation between errors.



- External validation: data integration
  - – combining datasets with different lineages may reveal unsuspected errors when overlaid

Example of an overlay of two street datasets from different sources.
Note the background colour: dark, where the correspondence between the two datasets is good, light where it is poor

Aggregated areal units: MAUP

Modifiable areal unit problem

- Scale + aggregation = MAUP
  - can be investigated through **simulation** of large numbers of **alternative zoning** schemes
  - as an approach of internal validation

Longley et al. (2015) Ch. 5.4

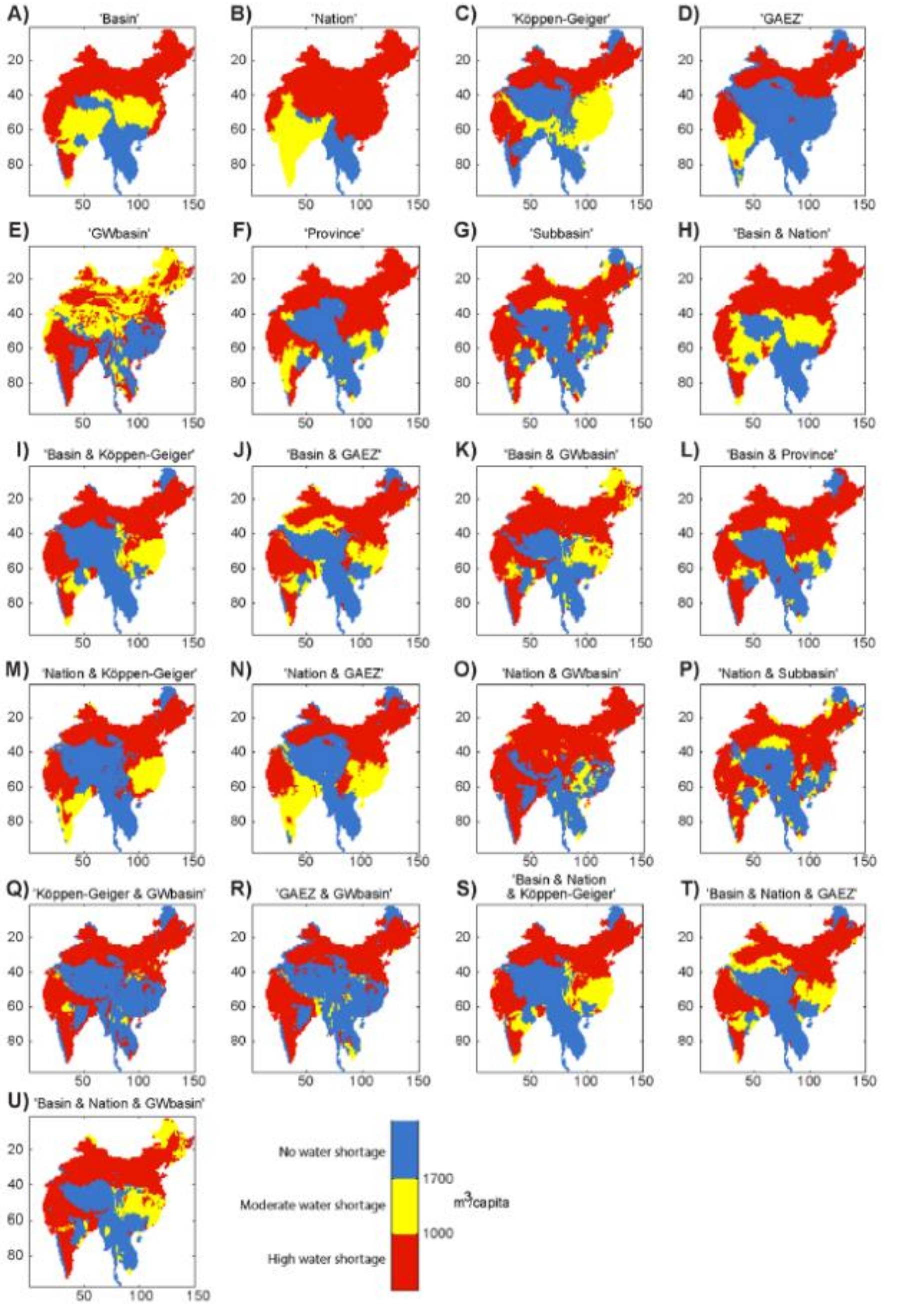


Figure 3. Water shortage expressed in terms of available water resources per capita (m^3/cap/year) with different zonings.

Our analysis reinforces the view that results of spatial studies are sensitive to the zoning system used.
This means that the selection of the scale and the areal units of analysis cannot be considered an independent and neutral part of the spatial assessment, as it may have a major influence on assessment results.

Salmivaara, A., Porkka, M., Kummu, M., Keskinen, M., Guillaume, J. H. A., Varis, O. (2015). Exploring the Modifiable Areal Unit Problem in Spatial Water Assessments: A Case of Water Shortage in Monsoon Asia. Water 7(3): 898-917.

Living with Uncertainty

- It is easy to see the importance of uncertainty in GIS
  - but much more difficult to deal with it effectively
  - but we may have no option, especially in disputes that are likely to involve litigation
- Data obtained from others should never be taken as truth
  - efforts should be made to determine quality
- Effects on GIS outputs are often much greater than expected
  - there is an tendency to regard outputs from a computer as the truth..
- Use as many sources of data as possible
  - and cross-check them for accuracy
- Be honest and informative in reporting results
  - add plenty of caveats and cautions

Longley et al. (2015) Ch. 5.5

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SDI – Spatial Data Infrastructure

Why and what it is

Metadata and data quality description

INSPIRE directive and network services

Some examples of standards – and why

Why Spatial Data Infrastructure(s)

- Geographic data resources are valuable
  - Collecting data is typically costly
  - Some data are impossible to collect without special techniques or without authorities
  - Data are often needed consistently across large areas
    - Nation-wide, or across international regions,…

- Data does not wear out in use, copying data is cheap
  - So, why not share and reuse it

- We need to know what data resources are available
  - What kinds of data, are they fit for my purpose?

… and to get them in use

What is SDI?

"*An SDI is a coordinated series of agreements on technology standards, institutional* ***arrangements****, and* ***policies*** *that enable the discovery and use of geospatial information by users and for purposes other than those it was created for*." (Kuhn, W. 2005)

Metadata – description of data

- “data about data”, or rather “information about data”

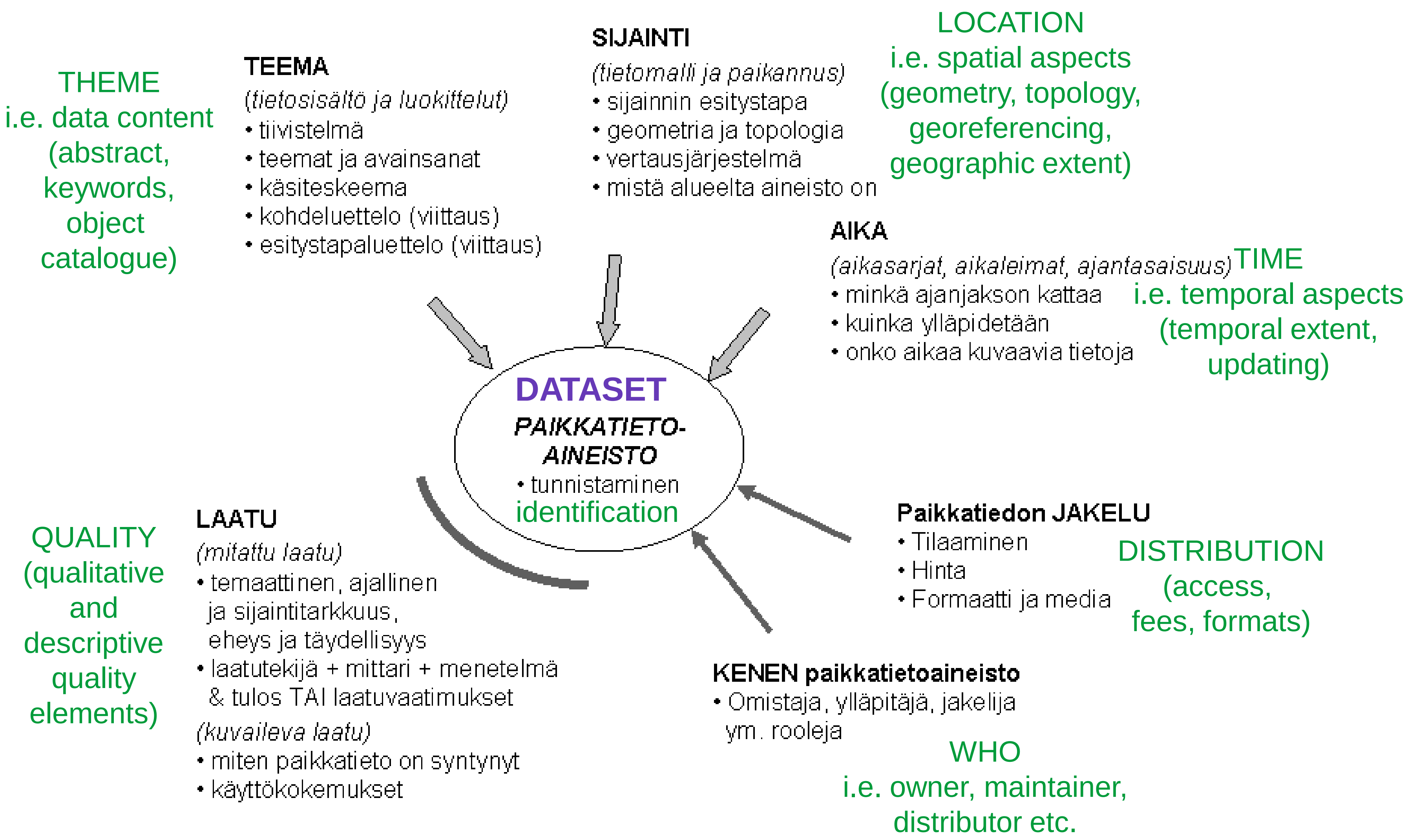
Metadata standard defines the structure and elements of description
⇒ Standard descriptions allow comparison of datasets by metadata

- JHS 158 (2005/2012) Paikkatiedon metatiedot (Metadata for the Geographic Information) JHS julkisen hallinnon suositus (Recommendation for the public administration) in Finnish, but with English terms of ISO 19115 in annexes 1-3 (see Annex 2)

- ISO 19115-1:2014 Geographic Information – Metadata – Part 1: Fundamentals
  - ISO 19115-2:2009 Extensions for imagery and gridded data
  - ISO 19131:2007 Data product specifications
- INSPIRE
  - Implementation rules for metadata (~subset of ISO 19115)

What we need to know about data

Framework of metadata content



What we need to know about data

Fitness of datasets for integration

- Consequences of geometric modelling
  - e.g. gridded data (resolution & origin and orientation) & vector data
  - e.g. measurement points, sample points – effects of interpolation
  - Notice: the coordinate reference systems

- Consistency on the level of detail ~ scale, generalization of datasets
  - do datasets fit geographically

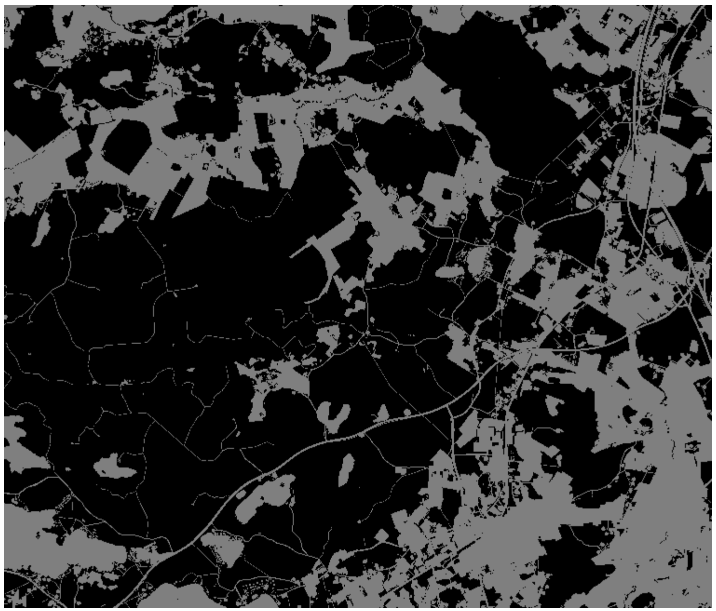
- Semantic consistency (cf. conceptual model)
  - object classes, classifications of attributes/variable
  - enumeration units

- Consistency in quality
  - Up-to-dateness, or rather the consistency of dates,
    e.g. when integrating real-time data with static framework data (such as, traffic data for real-time navigation & road network: construction and maintenance work)

Up-to-dateness example

- Two maps of the same location, which is more up to date?

Consistency of dates example



The field data in the 2015 **products were up-dated to correspond the situation on 31 July, 2015**. The length of the up-dating period was calculated for each field plot from the date of the field measurement to the up-dating date 31 July, 2015. The start of the tree growth was supposed to be on May 1.

Source: National forest inventory, Natural Resources Institute Finland

Reporting of data quality

- Several ISO standards give guidelines to data quality measurements; specific standards for geoinformation
- Description by quality elements and subelements
  - Qualitative and descriptive (overview) quality elements
- Quality measures for each (sub)element
  - e.g. Completeness
  - e.g. Spatial accuracy: RMSE
  - e.g. Thematic accuracy: confusion matrix

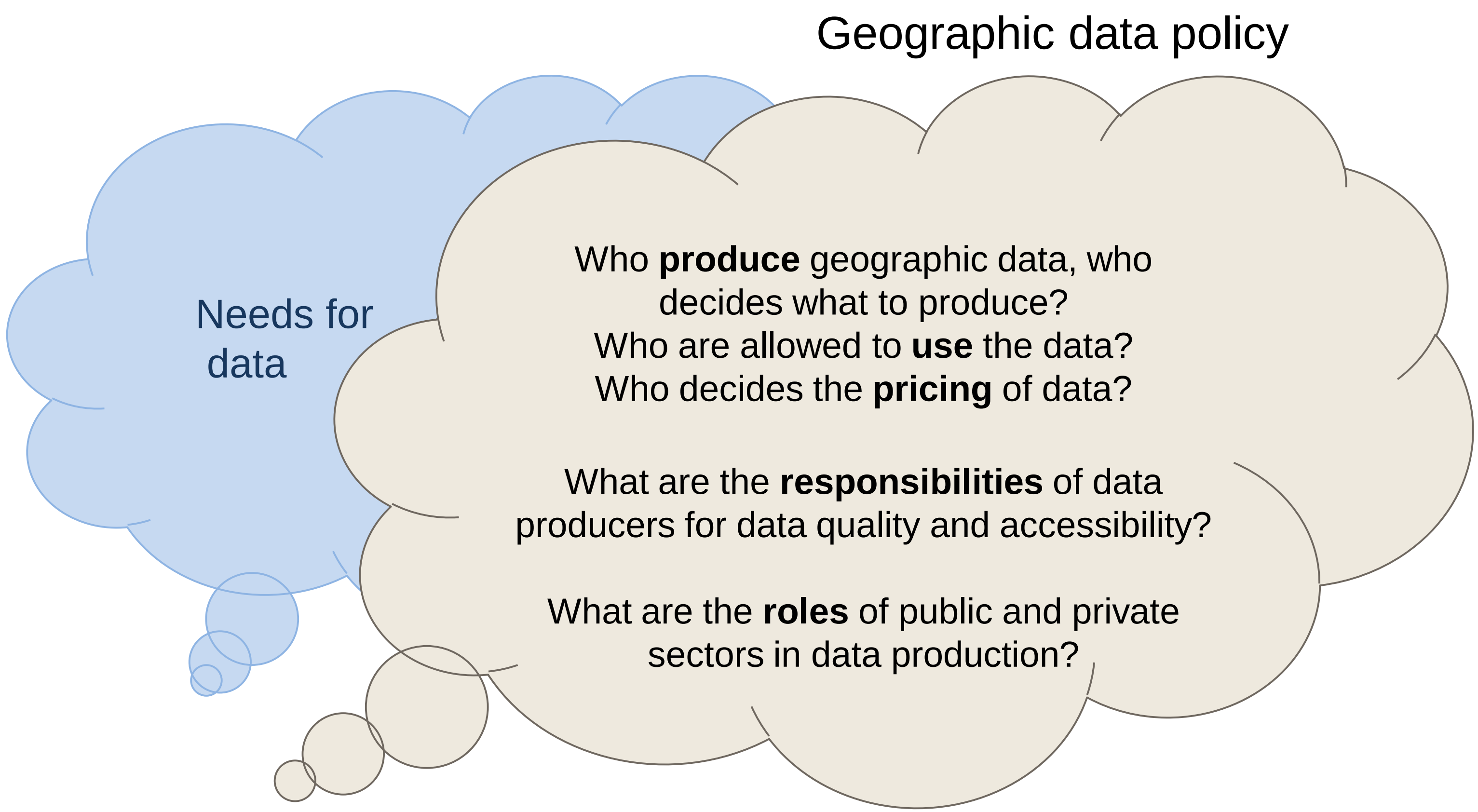
- JHS 160 (2006/2012) Paikkatiedon laadunhallinta (Quality Management for Geographic Information) based on earlier ISO 191xx standards, in Finnish
- ISO 19157:3013 Geographic information – Data quality

Data quality element	Data quality subelement QUANTITATIVE DATA QUALITY
Completenss (Täydellisyys)	Commission (Ylimääräinen tieto)
	Omission (Puuttuva tieto)
Logical consistency (Looginen eheys)	Conceptual consistency (Käsitteellinen eheys)
	Domain consistency (Arvojoukkoeheys)
	Format consistency (Formaattieheys)
	Topological consistency (Topologinen eheys)
Positional accuracy (Sijaintitarkkuus)	Absolute or external accuracy (Absoluuttinen sijaintitarkkuus)
	Gridded data position accuracy (Rasteritiedon sijaintitarkkuus)
	Relative or internal accuracy (Suhteellinen sijaintitarkkuus)
Temporal accuracy (Ajallinen tarkkuus)	Accuracy of a time measurement (Ajan mittauksen tarkkuus)
	Temporal consistency (Ajallinen eheys)
	Temporal validity (Ajanmukaisuus)
Thematic accuracy (Temaattinen tarkkuus)	Classification correctness (Luokittelun oikeellisuus)
	Non-quantitative attribute correctness (Ei-kvantitatiivisen ominaisuustiedon oikeellisuus)
	Quantitative attribute accuracy (Kvantitatiivisen ominaisuustiedon oikeellisuus)

JHS 160

<table>
<tr><th>Data quality element</th><th>Data quality subelement OVERVIEW DATA QUALITY</th></tr>
<tr><td rowspan="2">Lineage
(Historiatiedot)
- information about the events or source data used in constructing the data specified by the scope or lack of knowledge about lineage</td><td>Process history
(Prosessointihistoria)
- information about an event or transformation in the life of a dataset including the process used to maintain the dataset</td></tr>
<tr><td>Source
(Alkuperätiedot)
- information about the source data used in creating the data specified by the scope</td></tr>
<tr><td colspan="2">Purpose
(Käyttötarkoitus)
- summary of the intentions with which the resource(s) was developed</td></tr>
<tr><td colspan="2">Usage
(Käyttökokemukset)
- provides basic information about specific application(s) for which the resource(s) has/have been or is being used by different users</td></tr>
</table>

Geographic data policy – rules of the game for SDI



INSPIRE Directive

"Infrastructure for Spatial Information in Europe"

- To make existing data to be available & services on these data
- Rights & responsibilities
  - implemented in the national legislation and policies

- reasoning by environmental issues but, in practice, covers widely the core spatial data

- directive published in May 2007, since then implementation actions
  - available in all EU languages
    - **Direct link to the text in English** http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:108:0001:0014:EN:PDF
    - **And in Finnish** https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:108:0001:0014:FI:PDF
    - **For other languages, go to** http://eur-lex.europa.eu/, **choose the language, and search 'inspire'**

Network services

INSPIRE Directive, Chapter 4

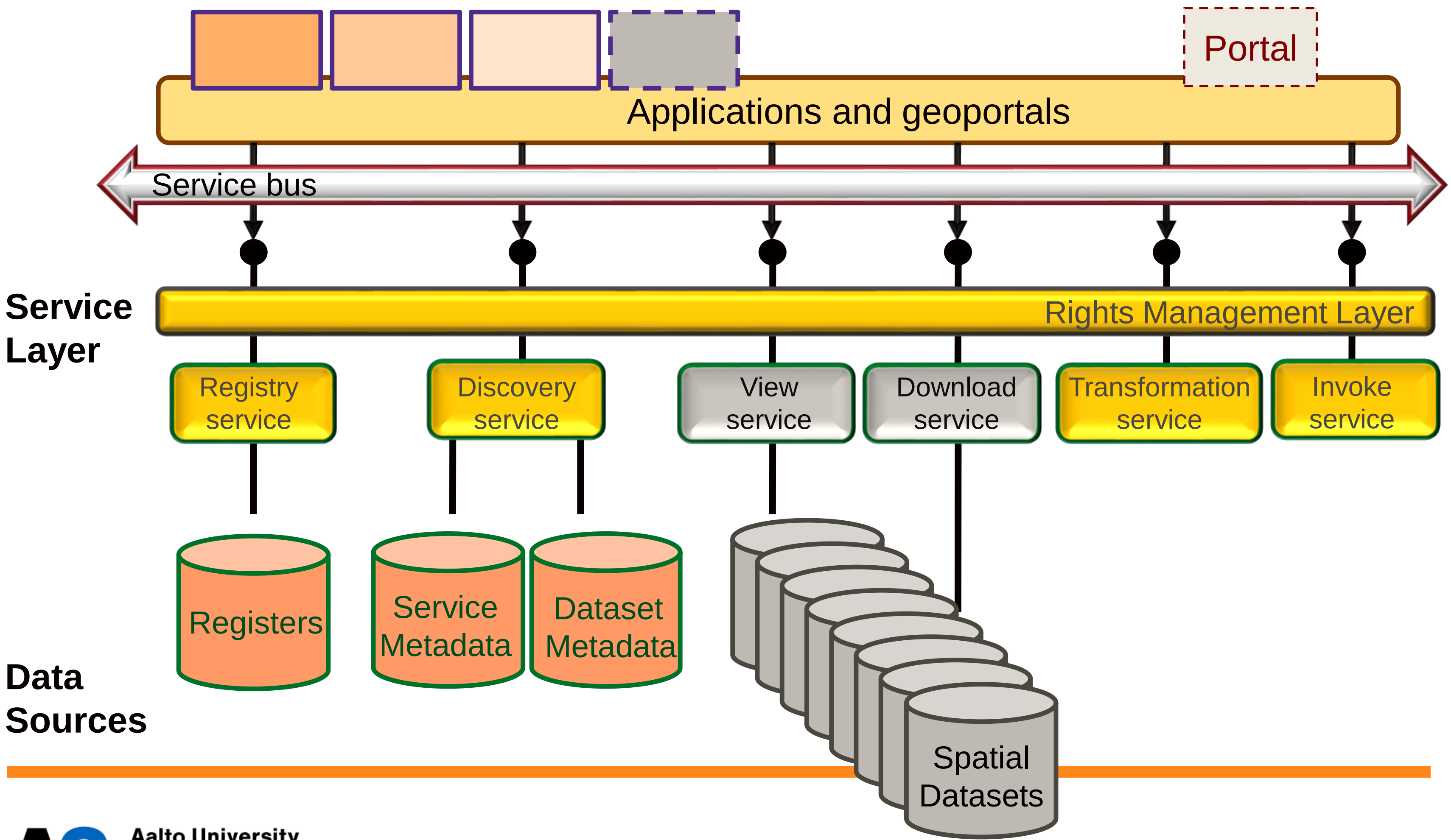
- Discovery services (hakupalvelu)
  - to search for spatial data sets and services on the basis of the content of the corresponding metadata and to display the content of the metadata

- View services (katselupalvelu)
  - to display, navigate, zoom in/out, pan, or overlay viewable spatial data sets and to display legend information and any relevant content of metadata
    - the interface services (rajapintapalvelut) built on WMS (Web Map Service) standard

- Download services (latauspalvelu)
  - enabling copies of spatial data sets, or parts of such sets, to be downloaded and, where practicable, accessed directly:
    - the interface services (rajapintapalvelut) built on WFS (Web Feature Service) standard
  - File download needed when you need datasets in your GIS analysis

- Transformation services (muunnospalvelu)
  - to enable interoperability

INSPIRE Technical Architecture



Role of metadata in SDI
Discovery service

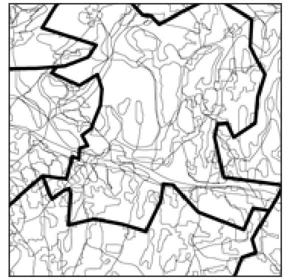
- INSPIRE directive, Introductory statement (15)

  "The loss of time and resources in searching for existing spatial data or establishing whether they may be used for a particular purpose is **a key obstacle** to the full exploitation of the data available. "

- SDI viewpoint on metadata (from the SDI Cookbook , GSDI = Global SDI)

  "for the benefit of society in *getting into use* the vast investments on geographic data resources, *reducing duplicated* data production, and *maintaining the value* of data over time by making data available for a wide variety of applications"

Discovery service



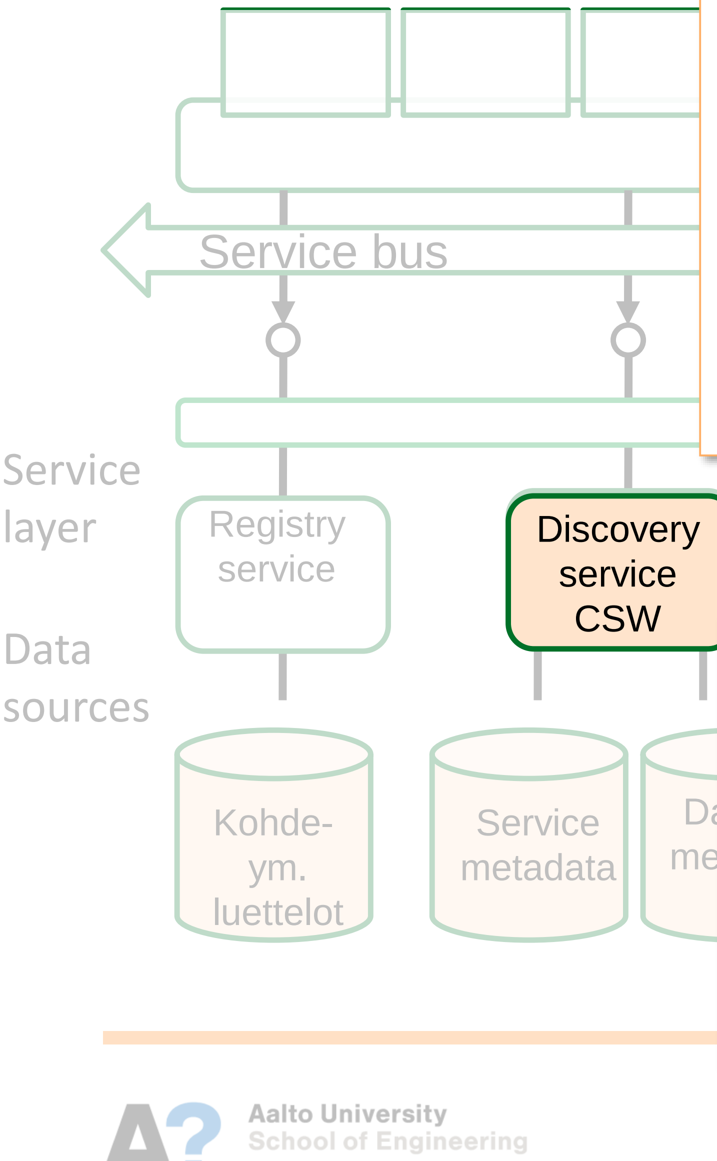
General map 1:1 000 000, vector

General map 1:1 000 000 is a dataset depicting the terrain covering the whole of Finland. The most important target groups are water systems, traffic route networks and administrative borders. The administrative borders, the nomenclature and the traffic route network are updated every year and other elements every 5 years.

General map 1:1 000 000 is used as an approach map in travel, excursion and outdoor recreation applications of mobile devices and Internet services as well as source material for different map products.

General map 1:1 000 000 product description

coordinate system:	ETRS-TM35FIN (KKJ / YKJ on request)
format:	ESRI shape, MapInfo
file:	zip-packed (shape 34,8 Mt, MapInfo 30,4 Mt)



CSW, Catalog service web
discovery services make it possible to search for spatial datasets and services on the basis of the content of the corresponding metadata and to display the content of the metadata

standard for the service

ArcGIS Enterprise Portal Server Data Stores Cloud Sign In English

ArcGIS for INSPIRE

Home | Get Started | INSPIRE Services

Get Started / Desktop components

CSW Client

ArcGIS 10.6 | Other versions

The **CSW Client** tool enables Geoportal discovery functionality for your ArcMap and Explorer for ArcGIS applications. It also provides search capabilities for OGC Catalog Service for the Web (CS-W) catalogs directly through ArcMap and Explorer for ArcGIS. Once resources are returned, it can be viewed or downloaded. Additionally, if the resources are live services, they can be added to the ArcMap document or Explorer for ArcGIS Globe.

The **CSW Client** tool is now maintained separately as an open source product on Github.

Feedback on this topic?

Source: http://enterprise.arcgis.com/en/inspire/latest/get-started/csw-clients.htm https://www.avoindata.fi/data/en_GB/dataset

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International benchmarks

There are no International benchmarks that match this search

Collection Type

- Open Data (1357)
- Interoperability Tools (318)

Tags

- yhteentoimivuus (162)
- väestö (141)
- sukupuoli (68)
- kartat (64)
- liikenne (61)

Search datasets...

1,675 datasets found

Order by: Relevance

Base map of the City of Espoo

This dataset provides the base map of Espoo.

14.02.2019 Espoon kaupungin tekninen ja ympäristötoimi / kaupunkitekniikan keskus XML

Traffic Volumes in Helsinki

This dataset provides data on the volume of traffic in Helsinki.

14.02.2019 Helsingin kaupunkiympäristön toimiala CSV

Sastamalan asemakaavayhdistelmä

Sastamalan ajantasa-asemakaava on koostekartta hyväksytyistä ja lainvoiman saaneista asemakaavoista. Aineisto on tuotettu lainvoimaisten asemakaavojen pohjalta. Päivitys ja ylläpito jatkuvaa.

13.02.2019 Ulkoinen lähde: Paikkatietohakemisto WFS

One person househoulds in Helsinki by sex, age and district in 2004-

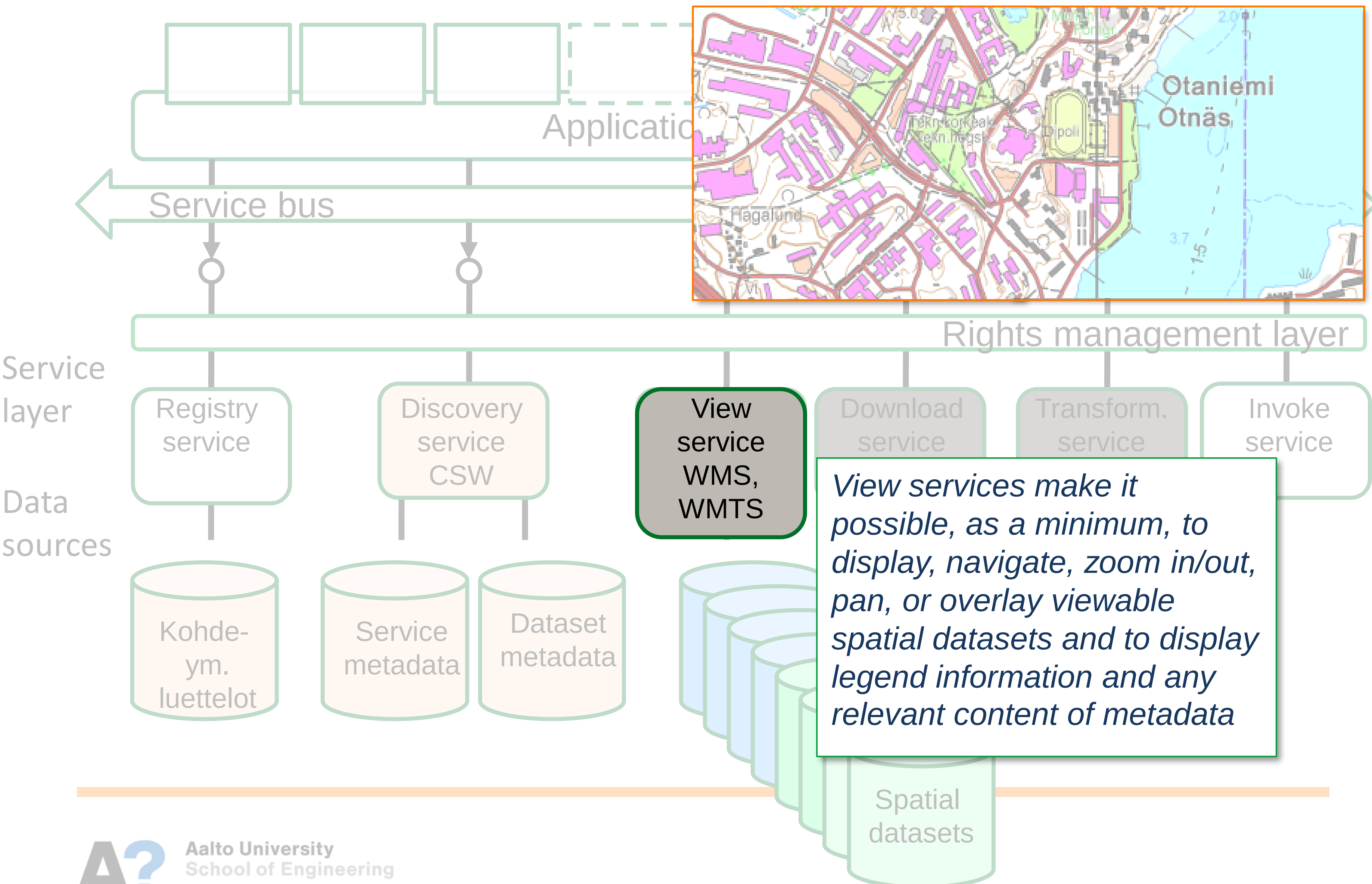
This dataset provides data about one person househoulds in Helsinki by sex, age and district in 2004-.

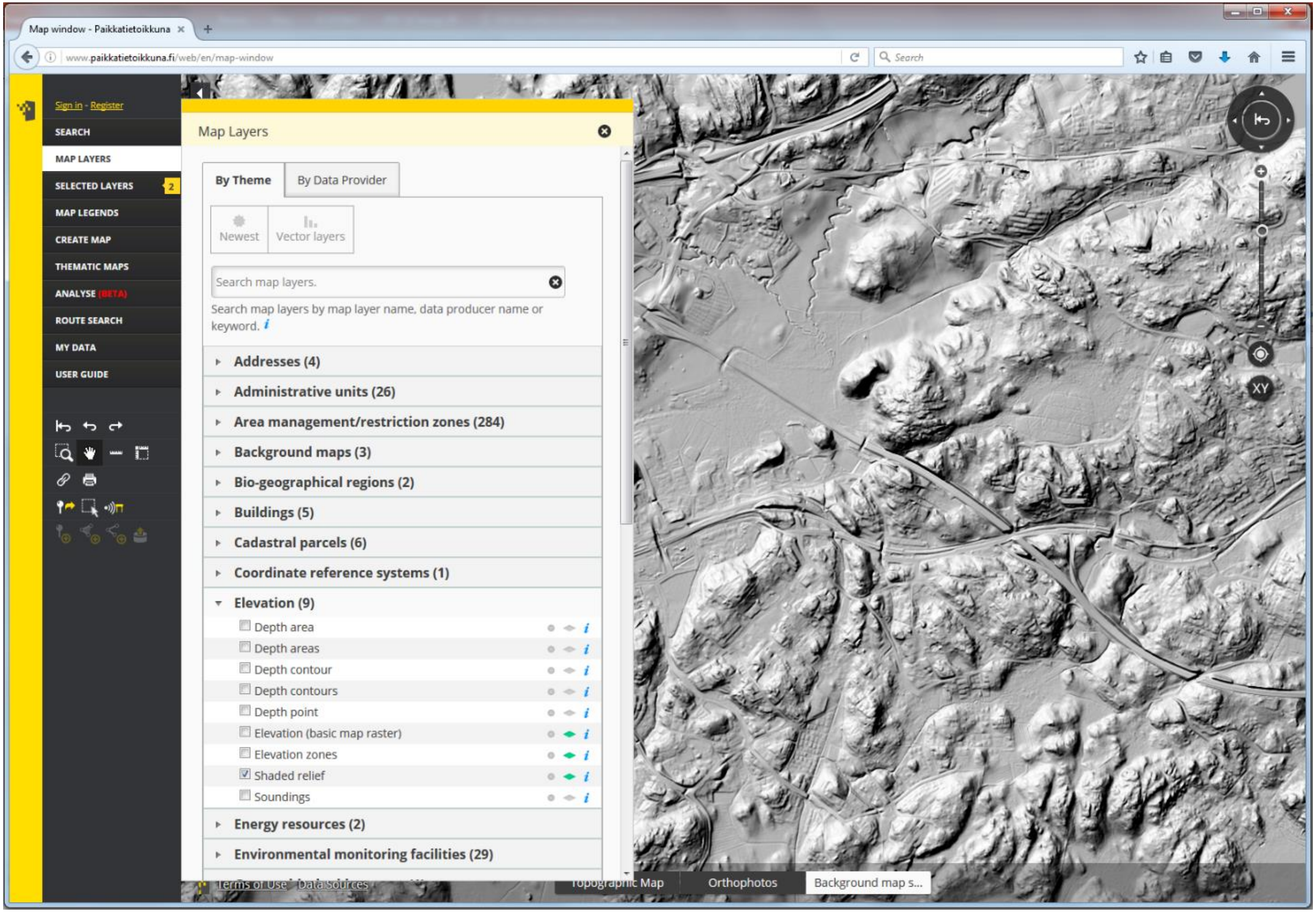
12.02.2019 Helsingin kaupunginkanslia XLS

Buildings in Espoo 31.12.2002-

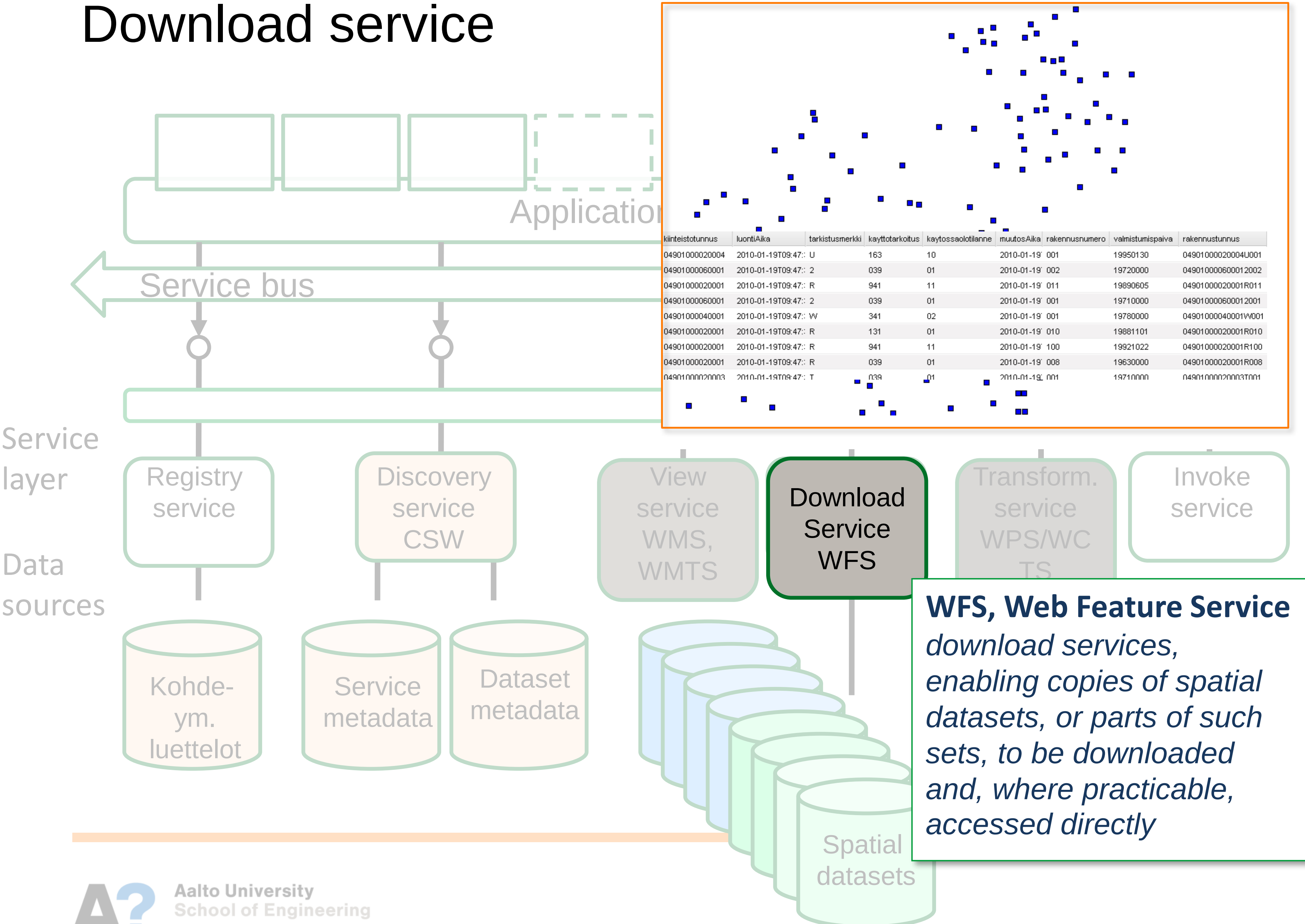
Background information
Open data and interoperability are steered by Ministry of Finance. Opendata.fi portal is managed by Population Register Centre.

View service




Map window - Paikkatietoikkuna
www.paikkatietoikkuna.fi/web/en/map-window
Sign in - Register
SEARCH
MAP LAYERS
SELECTED LAYERS
2
MAP LEGENDS
CREATE MAP
THEMATIC MAPS
ANALYSE (BETA)
ROUTE SEARCH
MY DATA
USER GUIDE
Map Layers
By Theme
By Data Provider
Newest
Vector layers
Search map layers.
Search map layers by map layer name, data producer name or keyword.
Addresses (4)
Administrative units (26)
Area management/restriction zones (284)
Background maps (3)
Bio-geographical regions (2)
Buildings (5)
Cadastral parcels (6)
Coordinate reference systems (1)
Elevation (9)
Depth area
Depth areas
Depth contour
Depth contours
Depth point
Elevation (basic map raster)
Elevation zones
Shaded relief
Soundings
Energy resources (2)
Environmental monitoring facilities (29)
Terms of Use
Data sources
Topographic Map
Orthophotos
Background map s...
XY

Download service



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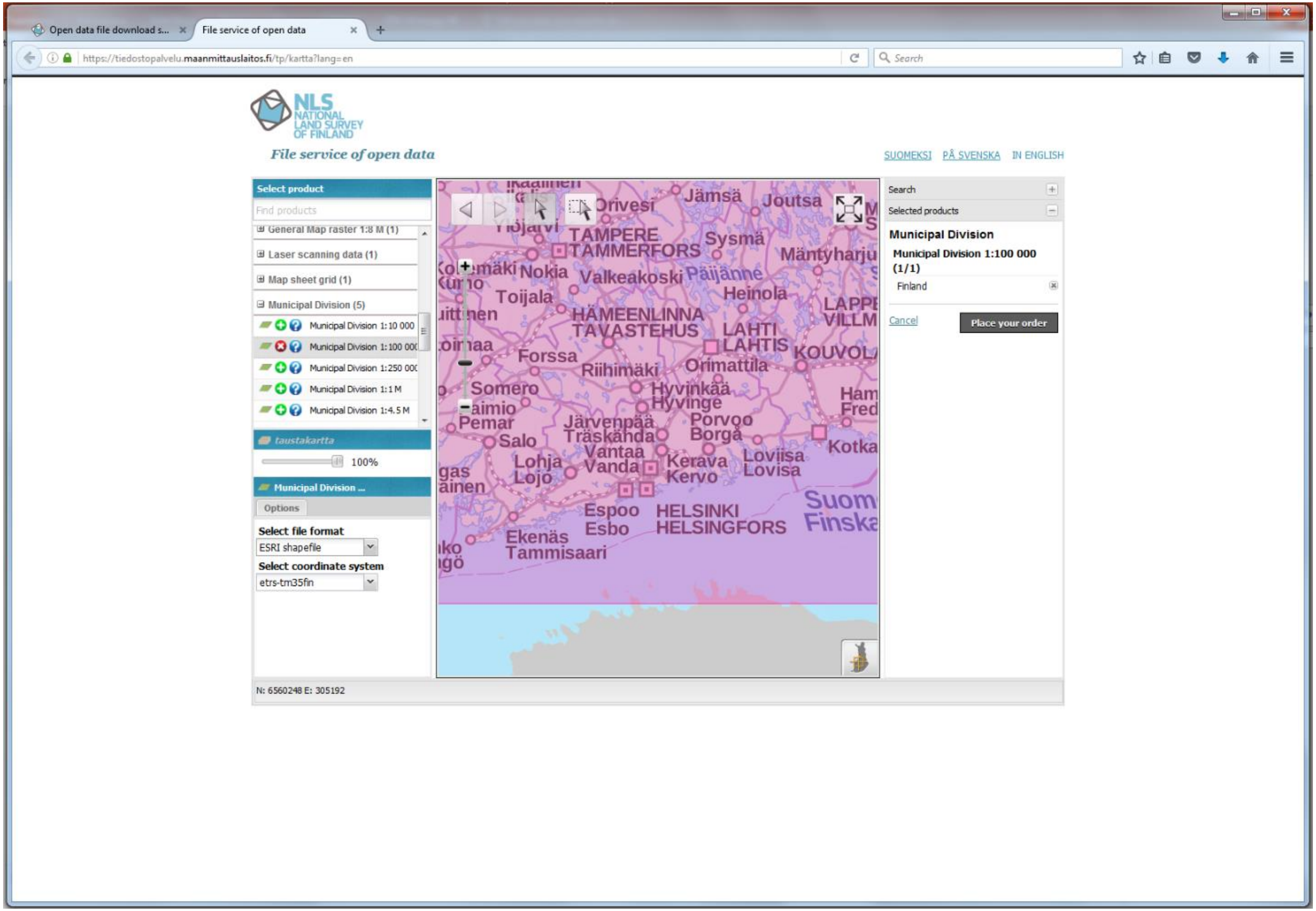
WFS, Web Feature Service

download services, enabling copies of spatial datasets, or parts of such sets, to be downloaded and, where practicable, accessed directly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Map sheet grid (1)
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Standards for geographic data

- ISO/TC 211 Geographic information www.isotc211.org
  - ISO 19100 standard series; working since 1994;
    ~ 50 standards (or technical specifications) and the number is increasing
  - aims at shared use of geographic data and interoperability of GISs

- CEN/TC 287 Geographic information
  - now adopting the ISO 19100 standards to Europe (as profiles)
  - in Finland, SFS automatically implements CEN standards to SFS's

- OGC Open Geospatial Consortium www.opengeospatial.org
  - a non-profit, international, voluntary consensus standards organization of about 400 members (administrative units, companies, institutes, universities…)
  - ***interoperability*** computing standards

… standards for geographic data

- JHS in Finland www.jhs-suositukset.fi
  - Julkisen hallinnon suositus Recommendation for Public Administration
  - by JUHTA, a cooperation committee of Ministry of Interior and municipalities
  - several JHS recommendations relevant to SDI (all in Finnish):
    - Coordinate reference systems JHS 153, 154, 163
    - Metadata on geographic data JHS 158
    - Quality of geographic data JHS 160
    - Modelling of geographic data for transfer JHS 162
    - Data product specification guidelines JHS 177
    - Guidelines for network services JHS 178, 180
    - About geographic data: postal addresses JHS 106, identifiers of buildings, municipalities, real property JHS 104, 110, 138, etc.
    - Land use classification incl in JHS 186
    - … on-going work

Example of a standard: Simple features

- OGC specification of spatial elements in geographic data
  - To enable transfer of data and interoperability of GIS applications at the level of basic geometric elements and their handling

Including:

- The core geometry types and methods:
  - Methods for testing spatial relations between geometric objects
    - Boolean operators; whether the relation exists or not (e.g. within, overlaps, intersects)
  - Methods that support spatial analysis of geometric objects
    - operators returning a new geometry or a metric value (e.g. distance, buffer, intersection)

Brief presentation in Longley et al. (2015) Ch. 9.5 (p. 202-205)

Simple Feature Access - Part 1: Common architecture

Spatial relations and methods

Topological queries
⇒ Boolean value

- Equals – same geometries
- Disjoint – geometries share common point
- Intersects – geometries intersect
- Touches – geometries intersect at common boundary
- Crosses – geometries overlap
- Contains – geometry completely contains
- Within – geometry within
- Overlaps – geometries of same dimension overlap
- Relate – intersection between interiors or boundaries

a.Intersects(b) ⇔ ! a.Disjoint(b)

a.Contains(b) ⇔ b.Within(a)

Spatial analysis operations
⇒ Geometry (or distance)

- Distance – shortest distance*
- Buffer – geometric buffer
- ConvexHull – smallest convex polygon geometry
- Intersection – points common to two geometries
- Union – all points in geometries
- Difference – points different between two geometries
- SymDifference – points in either, but not both of input geometries

Reading for the lecture

- Longley et al. (2015): Chapter 5 and 9.5
- INSPIRE Network Services Architecture, Ch. 5-6
  http://inspire.ec.europa.eu/reports/ImplementingRules/network/D3_5_INSPIRE_NS_Architecture_v3-0.pdf