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GEOREFERENCING AND OTHER STRATEGIES TO SPATIALISE INFORMATION FROM OLD MAPS – A COLLECTION OF BEST PRACTICE RECOMMENDATIONS

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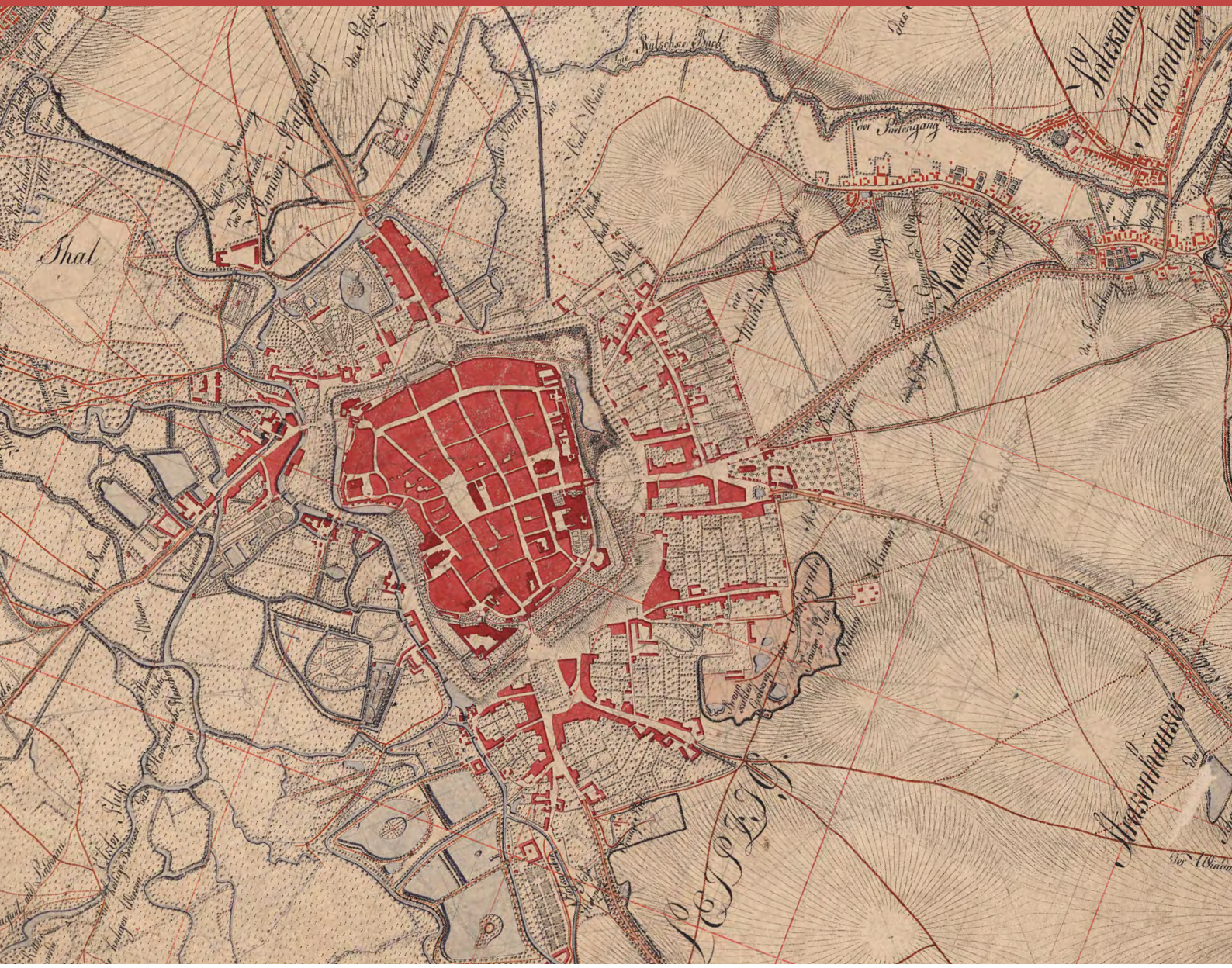

Leipzig. Map sheet 19: Meilenblätter von Sachsen Berliner Exemplar, 1:12000 (1802) Digital image: Sächsische Landesbibliothek & Staats- und Universitätsbibliothek Dresden (SLUB), Deutsche Fotothek, 01054 Dresden Original Map: Staatsbibliothek zu Berlin-Kartenabteilung Shelf mark: Kart. M 14433 - Map sheet 19

Georeferencing and other strategies to spatialise information from old maps – A collection of best practice recommendations

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Abstract

Old maps are invaluable for archaeological, historical, and environmental research on past landscapes and their changes over time. To ensure data quality and reproducibility, the availability of multidisciplinary guidelines for systematic metadata management, georeferencing, and vectorisation of old map features is crucial; however, to this date, no such guidelines exist. Key recommendations of these best practice recommendations include consistent metadata recording, clear file structures, standardised coordinate reference systems, and quality assessment for georeferencing. The emphasis is hereby on transparent procedures and documentation, based on examples, experiences, and requirements within the joint research DFG Priority Programme "On the Way to the Fluvial Anthroposphere" (SPP 2361). These recommendations offer a starting point for the development of Gold Standard guidelines for the spatialisation and standardisation of information from old maps.

1. Introduction

The comparability of data from old maps is in many respects of outstanding importance for a wide range of scientific questions (Hohensinner et al. 2013, Zielhofer et al. 2022). Old maps provide a wealth of historical information on geographical and cultural features, which proves extremely valuable for a variety of approaches to past landscapes (Stäuble et al. 2008, Schuppert 2013). The development of historical cartography has often been described and discussed (Kretschmer 1986, Ebeling 1999, Schenk 2012, Schneider 2018). The general situation of old maps in archives and their inventories has been summarised before (Wolff 1987, Zögner and Klemp 1998, Grabe 2016), however, additional old maps can always be uncovered by means of intense archival work. Old maps are promising sources for the fields of history and geoarchaeology (Horst 2008, Winiwarter 2011, Matschenz 2012, Werther 2022). From the mapping of historical settlements to the analysis of environmental change over time, old maps provide a unique perspective on past landscapes and human activities (Domaas and Møller 2009, Rödel 2010).

The theoretical principles of source criticism (Horst 2008, Schenk 2012) and spatial concepts (Ebeling 1999, Dünne 2008) are known, but not always included in-depth. (Semi-) quantitative analyses of spatial historical features are becoming more important in multi-disciplinary research projects (Werther et al. 2021, Zielhofer et al. 2022). Therefore, the integration of old maps in geographical information systems (GIS) is crucial (Bender 2009a, Bender 2009b, Pröschel et al. 2022). The georeferencing of old maps is complex. Different procedures are required, depending on how the map was recorded and what cartographic quality is available (Jenny et al. 2009, Affek 2013). Examples of exact georeferencing in highly detailed and standardised (true to scale) cartographic maps (e.g. cadastre maps, ordnance maps etc.) are available using the geodetic network (Affek 2013). Old maps from before the 18th century are often not true to the map scale and can only be georeferenced to a limited extent (Werther 2022). Instead of a geodetic network, persistent anthropogenic or natural features in maps are used as georeferencing points (Jäschke and Müller 1999, Schuppert 2013).

However, there is no available multidisciplinary guideline for best practice standards on how to spatialise and standardise information from old maps. The documentation of all required metadata is crucial for the reproducibility and comparability between data sets. Furthermore, a standardised protocol for the vectorisation of old map features is lacking.

These best practice recommendations are particularly dedicated to the graphic representation of geographical information, with a focus on the comprehensible documentation of data and metadata. They also offer suggestions for source criticism, and for clear citation and documentation, which are necessary to ensure the traceability and reproducibility of research data and results. The initiative for these recommendations is rooted in examples, experiences, and requirements within the joint research DFG Priority Programme "On the Way to the Fluvial Anthroposphere" (SPP 2361), which aims, among other things, to establish standards for the use and documentation of old map data to uncover past changes of floodplains and their anthropogenic use and modification (Werther et al. 2021). They offer a starting point for the development of Gold Standard guidelines for the spatialisation and standardisation of information from old maps in the wider scientific community. They also offer best practice recommendations for a systematic collection and analysis of data from old maps. To enhance the suitability of our recommendations

to specific project needs, additional categories can be added. The use of old map data unveils a wide range of research opportunities and we hope that these recommendations and future guidelines will help to improve the quality and reproducibility of research results in this subject. The recommendations presented here, are accompanied by a select bibliography and a list of links to online sources, which do not claim to be complete, but are intended to provide a starting point into the topic. We would like to encourage all readers to supplement the minimum standard proposed here and to provide further specific information and experience in order to improve the completeness and accuracy on the way to a Gold Standard. Recommendations, testimonials and addenda are much appreciated, please contact us via the corresponding author.

2. Documentation und metadata

To ensure reusability, transparency, and data quality, it is necessary to record fundamental metadata for every newly generated file (such as georeferenced versions, vectors, etc.) with the information taken from the original old map. The metadata information should be recorded in tabular form or as a README-file. We recommend to store the metadata information listed below in an ASCII or UTF-8 decoded text-file (e.g. .txt, .csv; a template table is attached digitally to this publication):

- **ID:** Identifier. Every old map that is going to be georeferenced or vectorised within the project should be given a specific ID. Hereby, every vectorised geometry can be connected to its source. This ID should consist of two letters (project-wise) and three following numbers, e.g. CO-001.See for example the list of SPP2361-projects below:
  - » Echaz-Eger = EE
  - » Havel-Donaumoos = HD
  - » Leipzig = LE
  - » Weschnitz = WE
  - » Upper Rhine = UR
  - » Harz = HA
  - » Wiesent = WI
  - » Coordination = CO
- **Name of original file:** e.g. example.tif
- **Comment on original file:** e.g. information about WMS-layer provenance
- **Name of map:** Name of the original map
- **Publisher/Illustrator/Client:** Text with information about the publishers/illustrators/clients etc. of the original map
- **Dating:** (Numerical) date or timespan of map creation
- **Comment Dating:** Text with additional information on the chronology of the map
- **Description:** Short description of the map with context of creation, map content, manufacturing process (e.g. drawn by hand, trigonometric measurement)
- **Archive/Shelf mark:** Archive and shelf mark of the original printed map
- **Coordinate reference system:** coordinate reference system for the georeference (EPSG code) used in the project and file used
- **Used map for georeferencing:** File used for the georeference and its scale (ID or name)
- **Name of control points file:** Name of the file with the list of control points and the coordinates of the used control points

(ASCII or UTF-8 decoded text-file (e.g. .txt, .csv, .points) or GML)

- **Transformation type:** e.g. linear, thin plate spline
- **Personal evaluation of georeferencing quality:** Text field for a personal evaluation of the quality of the georeferencing, i.e. better or worse parts of the georeferencing
- **Date of georeferencing (in ISO 8601 format:** YYYY-MM-DD)
- **Height reference system:** Information on the height reference system if specified (basis and reference system for height measurement; if possible, use EPSG code)
- **Georeferencing tool and version:** Georeferencing program used and the respective version
- **Editor's name**
- **Copyright and licences:** Notes and comments on copyright and Open-source licenses
- **URL:** URL of used WebMapServices (if applicable)
- **Accessed:** last Date of Access of the URL

We also recommend the following two-part file structure:

1. Folder "Raw_Data_Old_Maps"

All digital old maps yet to be georeferenced are to be stored here.

2. Folder "Processed_Data_Old_Maps"

All processed data, such as georeferenced maps and vectorisations of certain map contents, are to be stored here. The data is further divided into raster (..\raster) and vector files (..\vector). This concerns for example georeferenced raster data or vector data created in a Geographic Information System. A documentation folder is then to be added to each folder (..\raster\documentation; ..\vector\documentation), where, for example, vectorisation templates and metadata such as tables with file name changes and error logs of the georeferenced raster files (..\raster\documentation\error logs) are archived, if they occur during the work process.

3. 3. Coordinate reference system

The old map and georeferencing source must be in the same coordinate reference system. We recommend using the same system within projects with multiple users (SPP 2361 has agreed on the use of the projected systems EPSG:25832 and EPSG:25833). The height reference system plays an important role in vertical accuracy at the local scale, but uniform systems should also be used for cross-regional comparisons. For SPP 2361 applications, we recommend using the "German First Order Levelling Network 2016 – DHHN2016" (EPSG:7837). It is important to specify the underlying height reference system when vectorising height values from old maps.

4. 4. Accuracy, obtained scale, and geodata for georeferencing

All existing georeferenced data can be used as a basis for future georeferencing – e.g. topographic maps, field maps, other old maps, high-resolution aerial photos, and digital terrain models. In addition to the scale of the old map and the resolution of the digital copy,

the scale and resolution of the georeferencing basis are crucial for the accuracy (quality of the georeferencing) – georeferencing can never be more precise than the basis. Prior to georeferencing, the desired result and the required accuracy should be evaluated in order to adjust the effort accordingly. An appropriate (scale-related) georeferencing basis should always be used – for example, when georeferencing a large-scale visual map, ideally use field maps, cadastres or field map equivalents (e.g. high-resolution orthophotos) at a scale of 1:1,000 to 1:5,000, and in the case of small-scale maps such as overview maps, correspondingly small-scale ones.

5. Different approaches to georeferencing

5.1 Georeferencing with known coordinates

In the best-case scenario, the basis should be a georeferenced original map using official sheet line systems or known vertex coordinates. This is usually possible for the original cadastral maps and younger maps. When using WMS layers as a basis for georeferencing or vectorisation, their quality should be checked and documented according to the proposed metadata structure. The recommended method for georeferencing with known coordinates is "projective", using the "nearest neighbour" sampling method.

5.2 Georeferencing with control points

For georeferencing with the use of control points, the persistence of the points is of the utmost importance. Table 1 lists examples of persistent objects (depending on the scale of the map).

The control points for georeferencing should be as evenly distributed on the old map as possible if the goal is to georeference the entire map as accurately as possible (at least four points). In this case, it is important to also cover the periphery well. Large-scale distortions may occur in areas not covered by control points. Alternatively, the section of the map that is the focus of interest can be georeferenced in the best possible way, e.g. the floodplain area. For maps that are distorted or have an imprecisely depicted periphery, this approach can often yield better results than attempting to evenly georeference the entire map sheet. Another possibility for a better result is to use a cropped version (includes only the area of interest with sufficient control points) for further georeferencing. Regardless of the approach chosen, the number of control points depends on the desired accuracy, the complexity of the transformation and also on the number of identifiable points and their precise location. The more distorted the old map is compared to modern coordinate systems, the more points are necessary and the more complex the transformation has to be (see chapter 7.2., "Overview of transformations for georeferencing"). If the result is not satisfying, even with complex transformation methods, a localisation approach without georeferencing (chapter 5) should be considered. The chosen procedure should be documented and the control points should be provided transparently in an ASCII or UTF-8 decoded text-file (e.g. .txt, .csv, .points) or in other archive-worthy formats (e.g. GML) so that later users can carry out the same georeferencing again.

6. Localisation of map structures without georeferencing

Georeferencing often proves challenging, and in some cases, it fails to yield satisfactory results. This especially applies to hand-drawn maps from before the end of the 18th century. In these cases, it can make sense to digitise only selected map elements based on their spatial relationship to reference objects that can be reliably located (e.g. "downstream

Object	Comment on quality
Roadside crosses	Often in the same position for centuries
Top edges of embankments of hollow fields	Imprecise, but usually the only identifiable objects on extensive farmland
Changes in direction of paths	Only partially usable due to new road construction and road expansion
District boundaries	Often consistency over centuries
Buildings (e.g. churches)	Often consistency over centuries
Special building feature	Specific information on architectural features is relevant for large-scale maps
Special terrain feature (e.g. characteristic rock formations)	Persistent topographical objects

Tabelle 1: Verwendbare Referenzierungspunkte zur Georeferenzierung (ergänzt nach Schuppert 2013)

from the bridge, halfway between location A and location B"). The corresponding locations must be documented as accurately as possible. A "plausibility check (a priori probability)" should be applied. Based on qualitative information from additional (verified) sources, subjective assessments can be made while considering a basic understanding of the topography. It is important to incorporate these insights into the metadata table ("Personal evaluation of georeferencing quality").

7. 7. Vectorising map structures

To ensure comparability and traceability, the vectorisation of map elements should be standardised as accurately as possible. The vector geometry used (point, line, or area) must be selected according to the objectives and the associated processing steps. If necessary, parallel vectorisation of structures with different vector geometries is appropriate. A conversion of vector geometries is possible but may result in a loss of information.

The following attribute data should be collected for each vectorisation (a template table is attached digitally to this publication):

- **StrucType** (Structure type): Type of structure, such as "oxbow lake", "trench/ditch/moat", "mill", etc. For better comparability and comprehensibility, standard vocabularies should be used (see chapter 7.2., "INSPIRE themes")
- **RelStrucType** (Structure type reliability): Qualitative information about how reliably the type of structure was determined, e.g. certain, uncertain
- **RelStrucLoc** (Structure location reliability): Qualitative information about how reliably the structure was located, e.g. certain, uncertain, precise to the plot, etc.
- **Dat** (Dating): Dating of the structure, based on the dating of the old map used
- **RelDat** (Dating Reliability): Qualitative information about the dating reliability of the structure, including secondary in-

formation, e.g. from other old maps, historical sources, archaeological features, etc.

- **RealPlan** (Realized or Planned): Actual implementation of this structure (distinction between real and planned/unimplemented map content), e.g. planned canal route on a construction plan, etc.

- **Descrip** (Description): Free text for notes, special features etc.

- **Editor:** Name of editor

- **DateMod** (Modification Date): Date of the last vectorisation of the structure, for example in the event that vectorisation takes place over a long period of time or is edited retrospectively

- **IDSource** (Source ID): Image number/ unique ID of the old map on which the structure is located (for links and traceability)

- **Scale:** Rough scale at which digitisation was carried out (scale range from-to specified if necessary, e.g. 1:1,000-1:2,000)

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