Ph.D. DISSERTATION

# Visualization Design for Interactive Analysis of Premodern Textual Cadastre and Cadastral Map

# 전근대 토지대장과 지적도의 대화형 분석을 위한 시각화 설계

FEBRUARY 2016

DEPARTMENT OF ELECTIRCAL ENGINEERING & COMPUTER SCIENCE
COLLEGE OF ENGINEERING
SEOUL NATIONAL UNIVERSITY

Hyungmin Lee

# Abstract

# Visualization Design for Interactive Analysis of Premodern Textual Cadastre and Cadastral Map

Hyungmin Lee
Department of Electrical Engineering & Computer Science
College of Engineering
The Graduate School
Seoul National University

We propose an interactive visualization design tool, called JigsawMap, for analyzing and mapping historical textual cadasters. A cadaster is an official register that records land properties (e.g., location, ownership, value and size) for land valuation and taxation. Such mapping of old and new cadasters can help historians understand the social and economic background of changes in land uses or ownership. JigsawMap can effectively connect the past land survey results to modern cadastral maps. In order to accomplish the connection process, three steps are performed: (1) segmentation of cadastral map, (2) visualization of textual cadastre, (3) and mapping interaction. We conducted usability studies and long term case studies to evaluate JigsawMap, and received positive responses. We summarize the evaluation results and present design guidelines for participatory design projects with historians.

Followed by our study on JigsawMap, we further investigated on each components of our tool for more scalable map connection. First, we designed a hybrid algorithm to semi-automatically segment land pieces on cadastral map. The original JigsawMap provides interface for user to segment land pieces and the experiment result shows that segmentation algorithm accurately extracts the regions. Next, we reconsidered the visual encoding and simplified it to make textual cadastre more scalable. Since the former visual encoding relies on traditional map legend, the visual encoding can be selected based on user expert level. Finally, we redesigned layout algorithm to generate a better initial layout. We used evolution algorithm to articulate ambiguity problem of textual cadastre and the result less suffered from overlapping problem. Overall, our visualization design tool will provide an accurate segmentation result, give the user an option to select visual encoding that suits on their expert level, and generate more readable initial layout which gives an overview of cadastre layout.

**keywords : Interactive visualization, Graph layout, Image segmentation, Textual cadastre visualization, Uncertatinty visualization, Long-term case study**

**student number : 2008-20954**

# Contents

# List of Figures

# List of Tables

# Chapter 1

# Introduction

## 1.1 Background & Motivation

For studying social and economic background of changes in land uses or ownership, historical cadasters are actively used by historians and geographers. Historians refer to prior written records to learn about the social and economic aspects of past events. They often have to analyze a large amount of historical data for several years before reaching to an articulate conclusion. When the sheer volume of such records overwhelms the historians' analytical capability, only a fraction of the data is reviewed at once or the tasks are distributed among other experts for collaborative analysis. The former approach may be simpler and lead to a more rapid conclusion. However, it is difficult to generalize this conclusion. The latter approach may take a longer time before any meaningful conclusion can be drawn, but it usually generates more generalizable results in the end.

The Kyujanggak Institute for Korean Studies (KIKS) preserves many invaluable historical records of pre-modern Korean history in its archives, among which are many pre-modern cadasters (from the 17th to 19th century). A cadaster contains information about each land piece surveyed, such as its owners, shape, address, etc. The pre-modern cadasters kept in the KIKS cover most cities and urban areas in the Joseon Dynasty (the most recent and last dynasty in Korean history). Thus, they provide a valuable resource for historical analyses of the temporal and spatial changes of the land's ownership, development status, and residential areas [49]. Historians are recently digitizing pre-modern textual cadasters in order to perform scalable research.

However, there are major hurdles in analyzing these pre-modern cadasters. There are no cadastral maps accompanying the textual cadasters, i.e., there are no

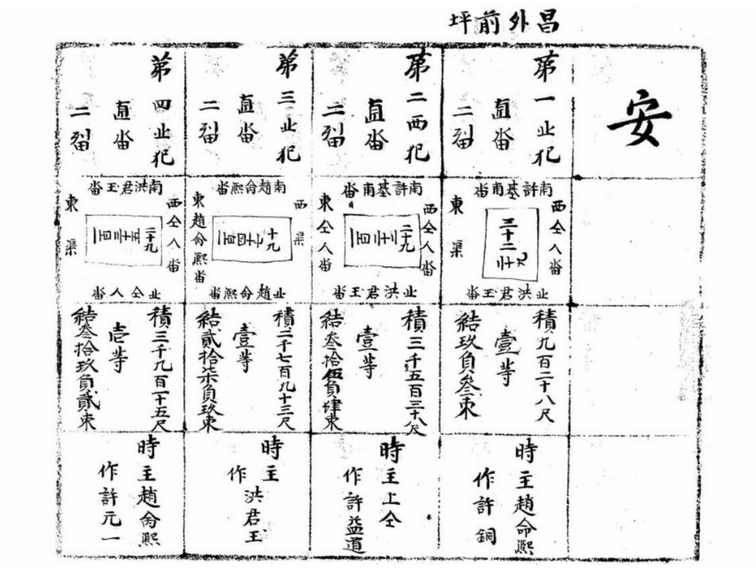



Figure 1.1 A page from pre-modern textual cadaster (books). Each column represents a land parcel and land owner, shape, area, four-neighbors and survey direction is recorded

Figure 1.2 Historian working with cadastre paper book and cadastral map to manually connect corresponding land parcels

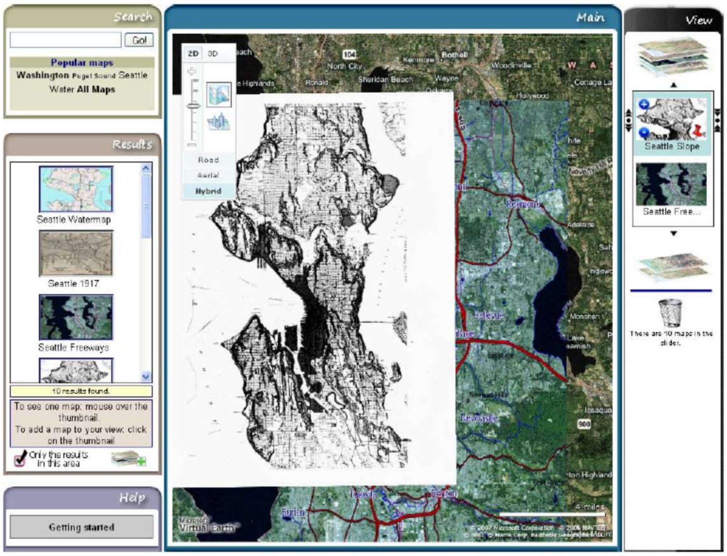
records of the terrestrial coordinates of each land piece. Instead, only the information on the approximate land survey directions and neighboring land pieces was recorded during the survey. Fortunately, there exist modern cadastral maps to which historians can refer to figure out the geographical locations of the land pieces represented only by texts. To make things worse, the volume of the pre-modern cadasters is gargantuan, because it covers the records for most of the Korean peninsula across two centuries. Due to these drawbacks, textual cadasters were seldom used in the past because they have insufficient and ambiguous geo-spatial information.

In the past, historians tried to overcome this problem by manually matching the pre-modern cadasters and modern cadastral maps using sticky notes and highlighters. This task was like placing an endless pile of jigsaw pieces on to a map. They chose a small rural village to evaluate the feasibility of an attempt to solve this large jigsaw puzzle [64]. It was labor intensive, time consuming and, thus, not scalable. They estimated that it might take several decades for a historian to manually match all of the pre-modern cadasters in the possession of the KIKS. This matching of cadasters is not only a challenging problem in Korea, but also in other Asian or European countries where historical cadasters exist. At the same time, because of the ambiguity or uncertainty involved in the matching process, designing an interactive visualization tool for this process is also closely related to research on uncertainty visualization.

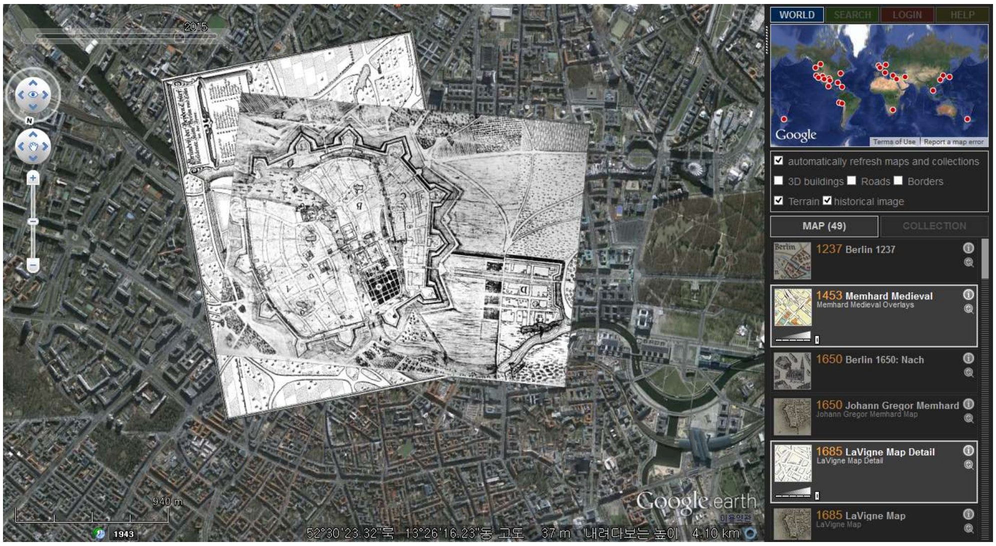
Cadastral map and cadasters have been studied by geographers for long time, but it is relatively unfamiliar technique in information visualization or human-computer interaction community. This is not abnormal circumstance since the data is often not digitized and usually advanced visualization technique is not required to analyze them. However, visualization community has great interest in studying many aspects of maps. Elias et al. registers big number of old map to find out new interesting results [23]. Hypercities perform similar technique, but their purpose is to provide an open platform for history education [41]. We believe that our research is to fill the gap between geography and visualization community and lead to interdisciplinary research by manipulating textual cadasters into a map-like structure.

Another domain that has already collaborated for long time is cartograms. Cartogram was manually drawn in early stages, and only used basic visual encodings to show statistical results. The motivation and technique differs from textual cadaster, but the generated result is similar compared to each other. Moreover, recent researches of quantitative measure indicates that it can be adapted to our field for layout assessment.

In summary, we are trying to find a scalable approach to connect textual cadaster and cadastral map. Connecting textual cadasters by hand only takes too much time and effort with human only interaction. In order to solve this issue, we target our research strategy in two point of view. First, we design the tool to be familiar to domain experts so that their research is performed continuously as they did manually. Second, we adapt techniques that was developed in former research and compose them into a hybrid pipeline. Land segmentation and cadaster layout algorithms are designed based on this guideline.




(a) Map Synthesizer [23] loads many maps in one interface and compose them into layers.




(b) Hypercities [41] provides platform to register maps into google map and share it with others for educational purpose

Figure 1.3 Map Layering tools for old map data. Composing maps has been widely studied for various reasons.

## 1.2 Main Contributions

The purpose of this study is to develop a visual design tool to map old textual cadaster and modern cadastral map. Lack of geological coordinates in pre-modern textual cadaster makes hard to perform further historical research. The main contribution of JigsawMap is to provide visual interaction to map of old and new cadasters and help historians understand the social and economic background of changes in land uses or ownership. The domain experts can effectively connect the past land survey results to modern cadastral maps. We organized the process in three steps to accomplish the mapping goal: (1) segmentation of cadastral map, (2) visualization of textual cadaster, (3) and mapping interaction. We teamed up with historians to design and develop an interactive visualization tool called JigsawMap to help them match the pre-modern cadasters with modern cadastral maps. We used a participatory design method where the historians provided constant feedback during the design process. Once the tool was built, we conducted long-term case studies with historians, in which we obtained positive feedback about JigsawMap. We summarized the evaluation results and presented design guidelines for participatory design projects with historians. Then we performed a back-up study for scalable historical research.

The first component we were interested was developing better segmentation routine. We designed a hybrid algorithm to semi-automatically segment land pieces on cadastral map. The main contribution of segmentation algorithm is that the algorithm accurately extracts the regions compared to the actual solution. And the method can be adapted to similar pre-modern cadasters that have similar condition.

Second, we reconsidered the visual encoding and simplified it to make textual cadaster more scalable. The main contribution of our approach for designing visual encoding is that we designed more scalable visual encoding that can be used for domain experts. The former visual encoding relies on traditional map legend, so visual encoding can be selected based on user expert level.

Third, we redesigned layout algorithm to generate a better initial layout. The main contribution of our approach for layout algorithm is that we redesigned the layout algorithm that is frequently used in cartograms. There is more ambiguity problem in our research and the original method is not compatible. We used evolution algorithm to articulate ambiguity problem of textual cadaster and the result less suffered from overlapping problem.

Overall, our visualization design tool will provide an accurate segmentation result, give the user an option to select visual encoding that suits on their expert level, and generate more readable initial layout that gives an overview of cadaster layout.

## 1.3 Organization of the Dissertation

This dissertation is organized as follows. In Chapter 2, we will describe the related works in map visualization, pre-modern cadastral analysis, and cartogram layout algorithms. Chapter 3 introduces overview and design rationales of mapping process using JigsawMap. Then in Chapter 4, we will describe segmentation algorithm that we designed to extract land regions of cadastral map. Chapter 5 presents textual cadastre layout algorithm that generates an initial start-up to get an overview and start matching interaction. In Chapter 6, we explain the consideration when designing visual encodings of textual cadaster. Finally, we summarize and conclude the dissertation in Chapter 7.

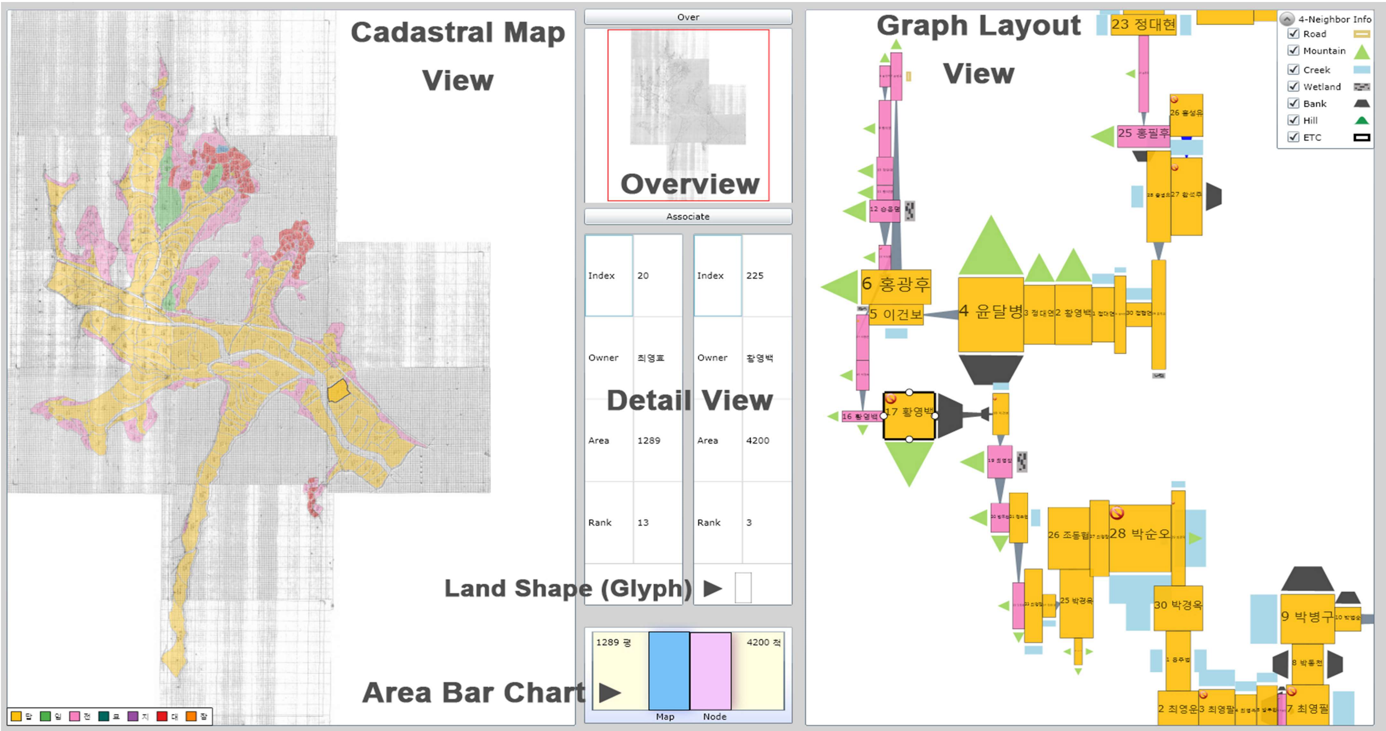



Figure 1.4 Overview of JigsawMap in the separate mode (Note that some widgets around the edge are cropped to show the main views better). The user can segment each land piece in the cadastral map view and adjust the layout of the land pieces in the graph layout view. He or she selects the matching land pieces in the two views and associates them by clicking on the "Associate" button

# Chapter 2

# Related Work

In this section, we review previous work on representation techniques and interactive visualization tools for geospatial map data. Then we review research and techniques on premodern cadastral maps. We also review previous work on interaction and layout algorithms of rectangular cartograms.

## 2.1 Map Data Visualization

There are previous works on designing mapping systems for overlaid multiple maps. MapSynthesizer [23] is a prototype map browser based on MapCruncher [24], with which users can search and compare overlaid multiple maps. MapSynthesizer is designed based on expert interviews about how people correlate maps. JigsawMap differs from MapSynthesizer in that it links a textual cadaster to a geographical map. Hypercities [41] is a web-based map browser or an open platform developed for research and education. Hypercities is also used for history research and for many courses in UCLA. Geo-temporal information including historical maps are shared and explored on this platform. MapSynthesizer and Hypercities are similar to our project, since they are also platforms for merging geo-spatial information.

Morphing a real map into a meaningful spatial layout like a Treemap [75] is one of the important research issues in geo-spatial visualization. HiVE (Hierarchical Visualization Expression) [78] has expressions for describing space-filling rectangular layouts. Among them, there is 'spatially-ordered' layout [87] that preserves the relative positions of the geographical elements in a space-filling layout. This layout can produce a Treemap from geographical map data. In JigsawMap, we

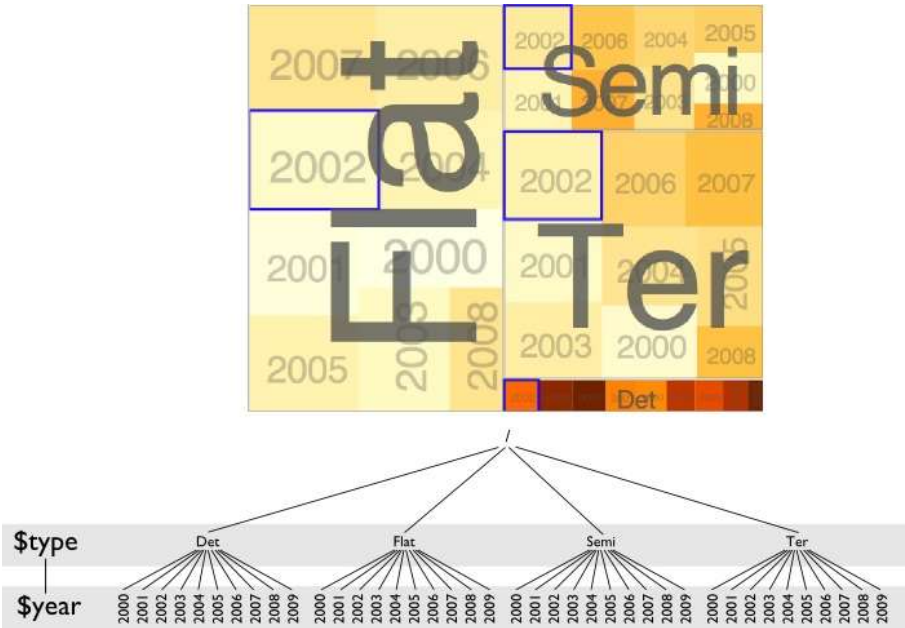



Figure 2.1 Visualization of HiVE system and its internal tree structure

have to map the spatial layout generated from an ambiguous textual geographical data onto a real map, which is a uniquely challenging task that, to the best of our knowledge, has not been addressed in the past.

## 2.2 Graph Layout Algorithms

In JigsawMap, the visualization of the textual cadasters is one of the key components. Since the textual cadasters encode the geographical relationships between the land pieces, it seems natural to visualize them using graph visualization methods. There are extensive works on generating overlap-free graph layouts [9]. Gansner et al. presented a study on graph layout algorithms that reduce the (number of) edge overlaps while preserving their hierarchy [27]. Our graph layout should preserve both the horizontal and vertical relative positional relationships, since it is composed of geospatial data. There was an attempt made to place nodes in a fixed grid first and then route edges to minimize the edge crossing, bending, length and density [68]. In our visualization, the edges cannot be rerouted, because they not only link the nodes sequentially, but also enable the direction information to be visualized. X-Y ordering [61] is a post-processing algorithm that resolves node overlaps while preserving their relative positional relationships. Since we can only partially infer the relative positional relationships among the land pieces from the cadasters, directly applying

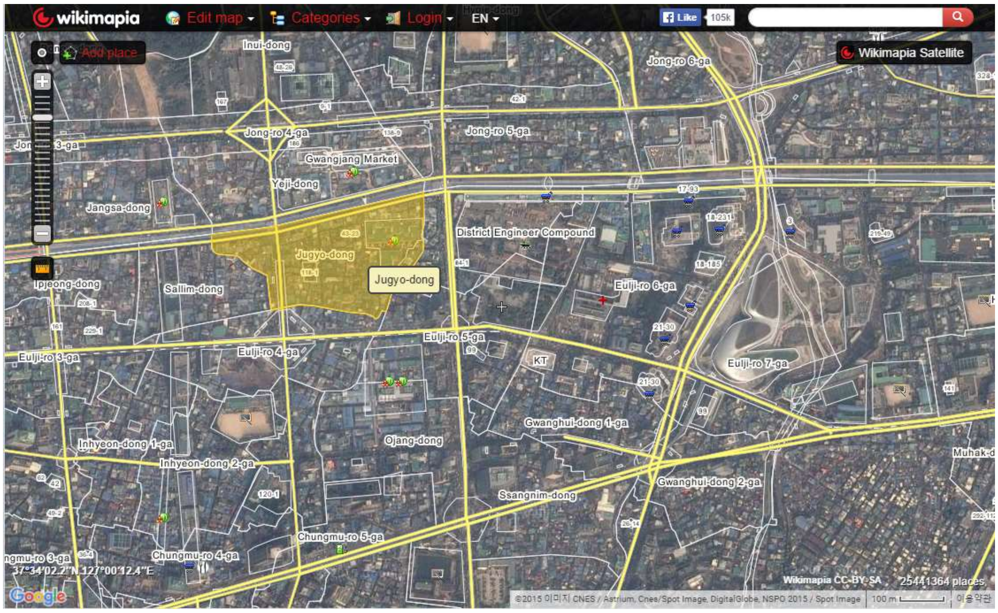



Figure 2.2 Wikimapia [86] shows marked area tagged by anonymous users

this algorithm does not guarantee a better layout.

## 2.3 Collaborative Map Editing Service

Wikimapia [86] is a collaborative mapping platform where the user can segment the world map into geographical regions in a wiki fashion. It provides a simple interface with which the user sets the boundary points to define a region. There are also similar services such as Google Map Maker [29] and OpenStreetMap [67] that collect geospatial information by segmenting the map into geometric primitives; points, lines and polygons. JigsawMap, although targeting a different domain, takes a similar approach by providing a simple sketch-based segmentation and goes one step further to automate the segmentation process.

## 2.4 Map Image Segmentation

Many automatic vectorization methods designed for processing maps have been proposed. Wu et al. extracted contour lines from topographic map-based cartography and graphics knowledge such as coordinates and symbol system [88]. Janssen et al. exploited the knowledge of cartographic rules to improve and correct the result of vectorization. Similarly, Lee et al. constructed a knowledge base, where cartographic features are contained based on different types of maps, to identify the characteristics of the input map image and apply various image-processing operations to vectorize it [56]. Frischknecht et al. used a knowledge-based template matching to extract areal objects from the scanned official Swiss topographic map [25]. There were other approaches that attempted to separate the map into constituent layers and recognize the features in different layers on the basis of symbol-specific geometrical and morphological attributes [13][19] [59].

In most case, automatic solutions usually work well for maps with high-quality images. For maps with low-quality images, most prevalent and practical solutions are interactive and semi-automatic methods. Most common way to interactively vectorize linear features is the tracking of a line from a user-specified point and the use of the additional manual interventions in case where the automatic tracking fails [89]. Bucha et al. supported snapping seed points and tracking area objects. Other techniques involve users in editing and cleaning unwanted details after segmenting the map and before the vectorization [7][8] [15] [16].

There are also many commercial software solutions such as MapGIS, R2V, VPStudio, and RxAutoImage. They still suffer from jagged and discontinuous dithering. And they also require that noises have to be removed before the vectorization. Lacroix presented the analysis of raster-to-vector software and proposed an improvement strategy in consideration to a map segmentation problem. Dharmaraj also provided a comprehensive review on commercial vectorization software [20].

In this paper, we focused on extracting polygonal land regions enclosed by boundary lines. Unfortunately, previous methods cannot be directly applied to our problem. First, they rarely consider preprocessing by assuming high-quality input images. In addition, our datasets are completely different from those used in the previous methods. For example, for contour reconstruction, most of them focused on topographic maps where contour lines never intersect each other and form closed loops. Inspired by previous works and following the guideline that recommends incorporating contextual knowledge in a document [83], we developed a customized vectorization pipeline for the cadastral maps of the Joseon dynasty in Korea [14].

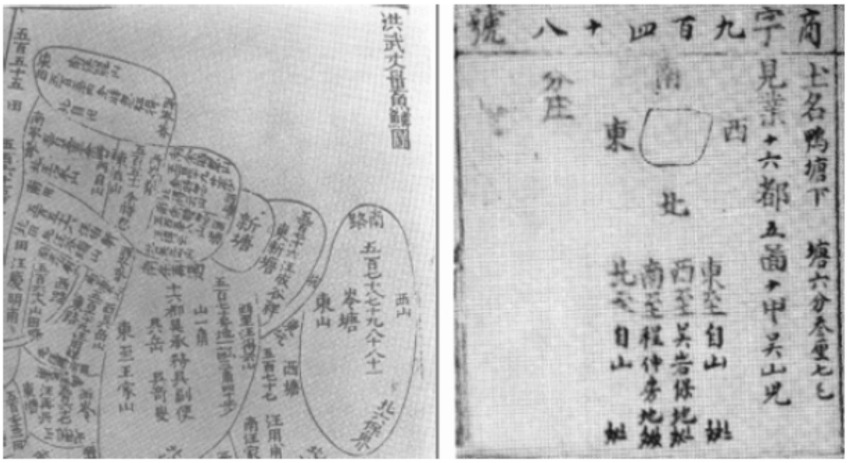



Figure 2.3 Fish-scale register from Ming dynasty in China.

## 2.5 Premodern Cadastral Maps

In the traditional practice of cartography, maps such as topographic or cadastral maps were hand-drawn on papers. Nowadays, due to the scalability and efficiency, geographical information for urban planning or resource management is processed through computer systems [56]. With the recent proliferation of GIS applications, there has been an increasing need for converting existing analog maps to vector forms [72]. The vector data has many advantages over the raster data by encoding the topological structure of a map only in the form of points and lines. In addition, it takes less storage. It is not limited by spatial resolution, and is easier to manage and update [20].

The digitization is often performed manually either through a digitizing tablet

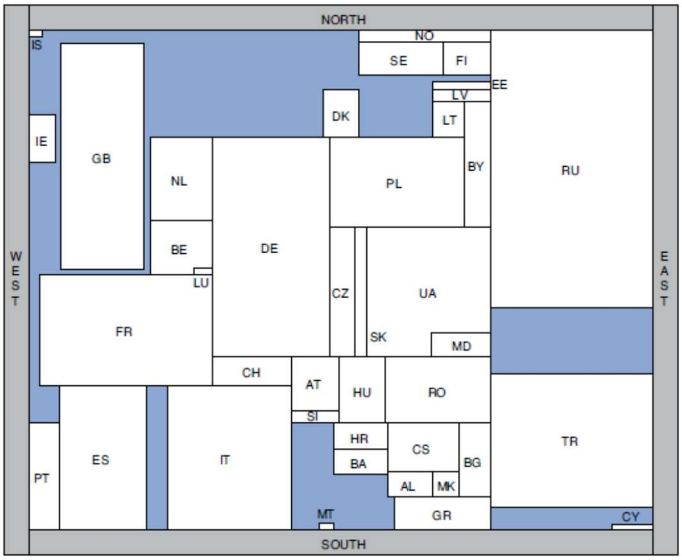



Figure 2.4 Rectangular cadastre layout [12]

with a paper map on its surface or an on-screen digitization using a scanned map [89]. Since the manual digitization is time consuming with intrinsic human errors, more advanced semi-automated or fully-automated procedures of the extraction of cartographic information from maps have been proposed [15]. Unfortunately, a fully-automatic vectorization is still a challenging task as types of maps vary considerably and human verification is almost always necessary [16]. In particular, it is considerably difficult to accurately vectorize historical maps because of its poor graphical quality caused by scanning or image compression processes, as well as the aging of the archived paper material, which often causes false coloring, blurring or bleaching problems [15][16].

## 2.6 Assessing Measures for Cartogram

Showing statistical information on top of cartogram is an important goal in geo-visualization. In our paper, we reviewed numerous techniques of measuring and adapted to textual cadastre to compare our result.

There are two types of cartograms. The first type, deformation cartograms, the input map itself is modified by appropriately pulling and pushing boundaries to change the areas of the regions on the map. In the second type, topological cartograms, the topology of the map is extracted in the form of the dual graph, and the dual graph is used to obtain a schematized layout for the map.

Cartograms can be evaluated in terms of the error in realizing the desired value by area, and in terms of the preservation of the recognizability of the input map. There are several algorithms for which one or two desirable cartogram features have been evaluated quantitatively [12]. The cognitive perception of static cartograms has been considered by Dent and Griffin and interactive cartograms were evaluated by Ware. Recently, Alam et al. reviewed former comparing methods and proposed a stand measure to globally assess cartograms [5]. We referenced some of these measures to proceed the experiment to compare cadastre layouts.

# Chapter 3

# Visualizing and Mapping Premodern Textual Cadasters to Cadastral Maps[1]

The historians who we have worked with aimed to map all pre-modern textual cadasters onto the modern cadastral maps. By connecting the two, historians can figure out the actual geospatial layout of the cadasters. If a complete mapping were established for every textual cadastre in the possession of the KIKS [53], historians would be able to use them for analyzing the temporal and spatial changes in the land ownership, land development status, and residential areas of pre-modern Korea.

In this section, we explain the two datasets and the historians' task in detail. Then, we introduce the task flow using JigsawMap and explain how the interactive tool helps each step of the historians' task thoroughly. Next, we discuss the feedback of

[1] A preliminary version of this chapter was published in CHI [57]

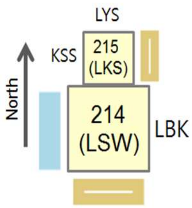
domain experts and show design guidelines that we learned from the study.

## 3.1 Textual Cadastre

Until the early 20th century, the Korean government kept the land survey data in a textual document format without using any geographical maps. The survey result was recorded in the simple format depicted in Figure 2. A land surveyor starts from an arbitral land piece in a village. She/he records the size and shape, the fertility rating used for taxation purposes, the four-neighbor (NWSE) information, and the direction in which the surveyor moved from the previous land piece during his/her survey (i.e., survey direction). Then, once the information on a given land piece was collected, she/he moves on to the next land piece. This process is repeated until she/he has the complete records of all land pieces in the village. The surveyor did not record explicit locations in the cadastre. Instead, only the estimated direction of his/her physical movement during the survey was recorded along with the four-neighbor information, resulting in a giant singly-linked list of the land pieces.

KIKS preserves about 1300 volumes of textual survey books covering two centuries (from the late 18th to early 20th). They are the only copies left in existence. The Korean government is funding research projects for the purpose of computerizing the textual land survey data to encourage scalable historical research. We learned that the historians have never seen their data in a visualization tool. The fact that they could see the data in a more intuitive and informative way and interactively manipulate the data highly motivated them to participate in the design process.

We collaborated with 4 real users – 2 Korean History professors and 2 graduates to understand each other's work. We had met them at about 2 times a week over a 6-month period. We showed our progress and made decisions based on real facts they shared with us. We also discussed about what interactive visualization tools can be capable of and showed examples to help the concept more understandable.




| Global Index | Survey Direction | 4-Neighbor Information East | West | North | South | Area | Owner |
|---|---|---|---|---|---|---|---|
| 212 | West | JRW | LBK | Road | Mountain | 783 | KMB |
| 213 | West | KMB | LSW | Road | LKS | 1445 | LBK |
| 214 | West | LBK | Creek | LKS | Road | 4080 | LSW |
| 215 | North | Road | KSS | LYS | LSW | 1924 | LKS |
| 216 | South | LKS | Creek | LSW | LYS | 2940 | KSS |

Textual Land-book Format (names are abbreviated)

Figure 3.1. Original format of a textual cadaster (right), and a concept diagram of how the record is visualized (left).

Figure 3.2. A historian mapping a pre-modern textual cadaster (books) onto a modern cadastral map (geographical map on the table) using sticky notes and highlighters.

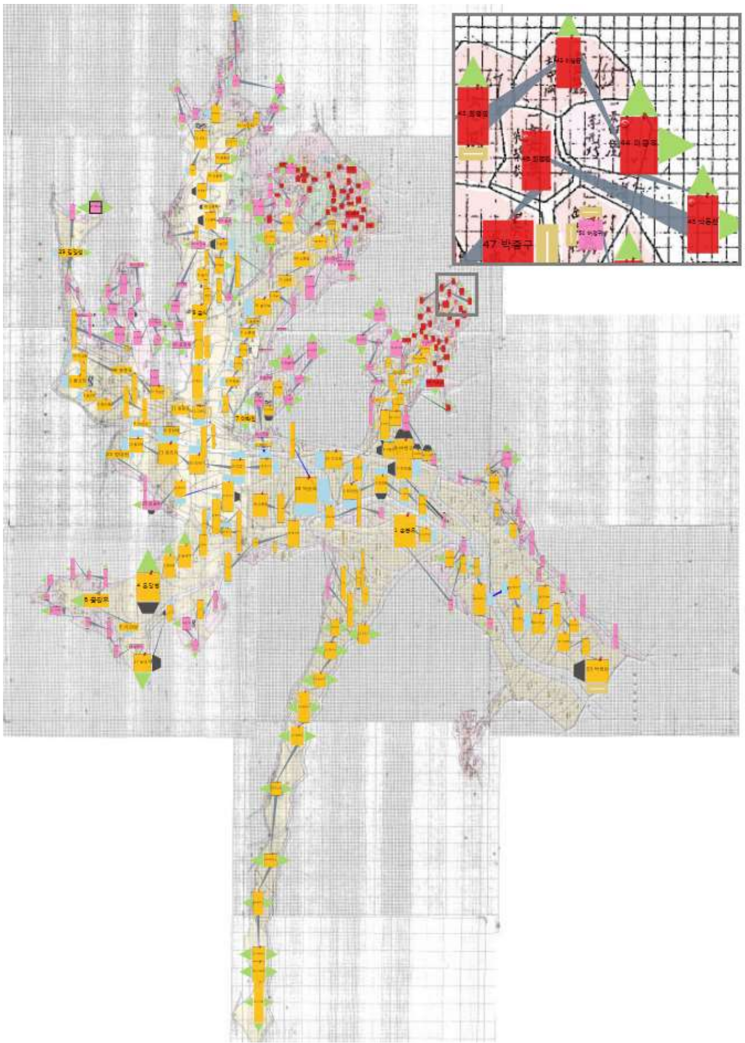


Figure 3.3. Result of a mapping task (overlapped mode). A node link diagram on a cadastral map is a visual representation of a textual cadaster. The enlarged region above is a magnified view of some land pieces.

## 3.2 Cadastral Maps

Modern cadastral maps have the location information and registered owner of each land piece. The cadastral maps used in this project were made in 1914. There is an approximately ten-year gap between the latest pre-modern textual cadasters and these cadastral maps. Historians assumed that there was no significant change during this ten year period, such as the ownership, land configuration, and land type. Thus, they chose to use these maps to connect the land pieces from the pre-modern cadasters.

## 3.3 Paper-based Mapping Process and Obstacles

The historians' mapping task begins by choosing a starting position or a land piece on a map as the first land piece in the textual cadastre. They have to guess the first land piece based only on textural information such as the neighbor information, size of land pieces, terrain description, etc. Then they traverse down the linked-list of land pieces in the textual cadastre to find more mappings to the map. However, after mapping a few more land pieces, they may notice that something is wrong, judging by the owners, land size, etc., in which case they have to try other land pieces as a starting point. This first step largely depends on the historians' intuition and they have to repeat this process until the mapping result of a starting location makes sense. Therefore, this step may take an arbitrarily long time.

Even after a mapping of the first land piece is successfully found, there are several obstacles throughout the mapping process. First, some actions are hard to undo, since the task is done manually with sticky notes and highlighters to mark on a physical paper. Second, the mapping between land pieces in a pre-modern cadastre and land pieces in a cadastral map is not always one-to-one. Multiple land pieces in the textual cadastre can be mapped to one land piece in the cadastral map. Third, for some land pieces, historians cannot find appropriate matching pieces, because of the land pieces being split into smaller pieces or the appearance of new land pieces as a result of cultivation. Fourth, some land pieces may be included in a different town in the modern cadastral map, because of changes in the town boundary. Lastly, the ambiguity of the directional information in the textual cadastre provides another set of major challenges ("north" in the record could actually mean NNE or NNW).

Due to these difficulties, it takes about one to two months for an experienced historian to build a complete mapping of a small rural village. So it may take a few historians decades to finish all of the pre-modern textual cadasters preserved in the

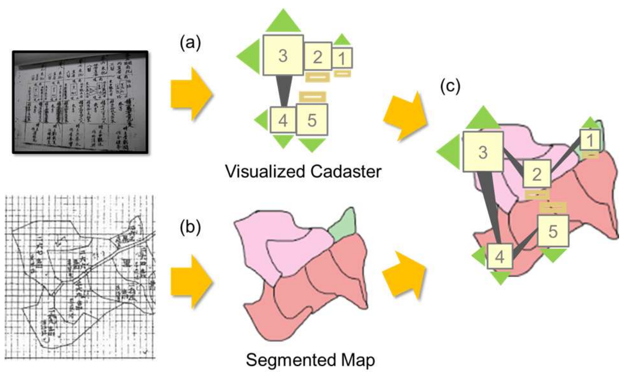



Figure 3.4 Task flow diagram. (a) Cadaster visualization (b) Cadastral map segmentation (c) Matching process

Korean history museum.

## 3.4 Task Flow in JigsawMap

JigsawMap is designed to tackle the obstacles encountered in the mapping process using highlighters and sticky notes by extending and improving upon historians' paper-based task flow. The task is divided into three stages: textual cadastre visualization, cadastral map segmentation, and an interactive matching process.

Cadastre visualization and cadastral map segmentation serve as preprocessing steps before starting the matching task. In the cadastre visualization step, a graph layout is generated from the land survey data, in order to recover the original geospatial layout of the land pieces. Each node in the graph layout contains survey information, including the owner's name, land size and its four neighbors, which is presented directly to the user to provide crucial visual cues in the matching process. Cadastral map segmentation is a process used to extract the individual land pieces from the cadastral map. Each land piece is labeled with the land owner's name, land type, and a unique identifier.

The matching task is used to associate the land pieces (nodes of the graph layout) in the textual cadastre with the land pieces (segmented regions) on the cadastral map. Now, with JigsawMap, the task can be performed more accurately and efficiently, because the graph layout of the cadastre and the segmented cadastral map reveal information that was previously invisible. The details of each stage are described in

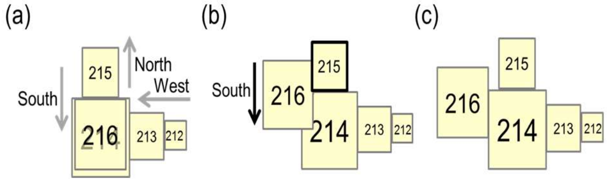


Figure 3.5 Example of node placement for the cadaster in Figure 3.1. (a) Nodes are placed according to the survey direction. 214 and 216 are overlapped. (b) Since 215 is the east neighbor of 216, 216 is shifted slightly to the NW to satisfy both the neighborhood condition and the survey direction. (c) Resolve minor node overlaps by shifting in a less-crowded direction.

the next three sections.

### 3.4.1 Visualization of Textual Cadastre

We chose the node-link diagram to visualize the textual cadastre, because the land survey information is recorded in sequential order from one land piece to another following the survey direction. The nodes resemble the sticky notes that were heavily used in the historians' manual paper-based matching task.

We developed a graph layout algorithm that generates a node-link diagram from the textual cadastre. Each node corresponds to a land piece. The size of a node is proportional to the land size of the corresponding land piece. Neighboring nodes on the survey path are connected with directional edges. We used tapered edges which are the most readable visualization [39], [39].

If the nodes are sequentially placed by following the land survey direction, some nodes will always overlap when the land survey direction reverts back to where the previous node was. This is due to the low granularity of the survey directions recorded by the surveyor. For example, overlap occurs when it is recorded that the land surveyor moved to the north and then travelled back to the south for the next land piece (Figure 3.5a).

These overlapped nodes have to be detected and moved to appropriate locations (Figure 3.5b). First, we search through the nodes nearby and choose candidates that should be moved considering their four neighbors, land owner's name and distance. Then, a node is chosen as one of the candidates if the land owner's name of the node matches one of the neighbor's names of the overlapped node. Among these candidates, the node that is closest to the overlapped node is selected. If no candidates are detected, an alternative heuristic is used: since the overlap should be resolved without changing the topological direction of the land survey direction, one of the closest diagonal directions has to be selected. For example, if it did not have any candidates, node 216 would have been located southwest of node 215, since the land survey direction is south. Finally, minor node overlaps are resolved by shifting the overlapped node slightly in a less-crowded direction (Figure 3.5c). Sometimes overlaps cannot be resolved, because the surrounding nodes are too crowded. In this

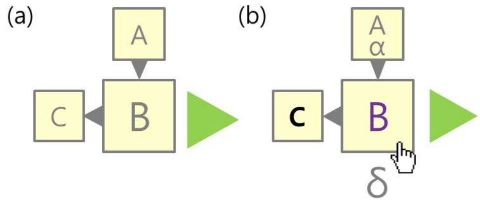



Figure 3.6 Survey direction and four neighbors. (a) Three nodes are shown as an example of visualization of a textual cadaster. (b) Names of its neighbors (C, α, δ) are shown when the mouse cursor is hovered over B. Since the west neighbor C is identical to the actual node in the west, it is highlighted in bold face. Unmatched neighbors (α and δ) are shown in normal face.

case, we intentionally allow an edge crossing to resolve the problem.

The land survey direction and four neighbors of each land piece are crucial information for the matching process. Figure 3.6 shows how we visualize the information in the node-link diagram. The four neighbors are either terrains or other land pieces. The terrain information is visualized as symbols and shown all the time. When the mouse cursor is hovered over a node, its neighboring land owner's names are shown (Figure 3.6b). When the land in its respective of the land survey direction is identical to the neighbor in the direction, the label of the matched land is shown in bold face. All non-matching labels are shown in regular face.

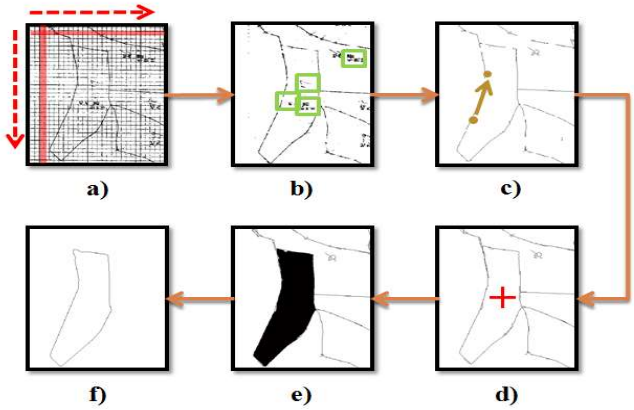



Figure 3.7 Map segmentation algorithm. (a) Remove grid lines. (b) Remove letters. (c) Close holes. (d) Select a region. (e) Region growing. (f) Construct a polygon boundary.

### 3.4.2 Cadastral Map Segmentation

While mapping from the textual cadastre to the cadastral map, historians had to mentally parse the corresponding geographic information on poor quality hand-drawn maps that were drawn about a century ago, in which the land boundaries and gridlines overlap with each other, and both are irregular and discontinuous and consist of broken pixels (Figure 3.7a). To facilitate the mapping process, it is desirable to develop a tool that extracts and labels the regions on the map. The segmented regions are color-coded based on the land types. Once labeled, researchers can easily look up the land owner.

We provide both semi-automatic and user-driven methods to segment the map image into pixel regions. Since the former method does not always produce desirable results, due to the poor quality of the map image, a sketch-based segmentation tool is provided as an alternative.

This semi-automatic segmentation process is conducted in four-stages. First, it removes the grid lines by scanning horizontally and vertically and classifying the scan lines based on the pixel intensities; if a scan line contains a pixel intensity above a certain threshold, it is considered to be a grid line (Figure 3.7a). Second, it removes characters by constructing connected components and examining each of them to find resemblance to a character; squareness and the number of branch points are used as character features (Figure 3.7b). Third, holes are closed by tracing a ray from end point to end point (Figure3.7c). In the final stage, the user selects a region to extract (Figure 3.7d). A region growing method is then applied to construct a pixel region (Figure 3.7e). In addition, if desirable, a minimum-perimeter polygon algorithm is used to construct a polygon from the pixel region (Figure 3.7f).

The sketch-based segmentation tool is used when a land piece is not extracted perfectly with the semi-automatic segmentation tool. The user can directly segment the land pieces in the following steps. First, the user sketches a land piece by dragging the mouse pointer along its boundary. Then, a child window is shown and the user needs to input the unique identifier. The child window captures the magnified view of the land piece. This view is helpful for the user to read the unique identifier on the map. After this step, the region segmented by the user is filled with color according

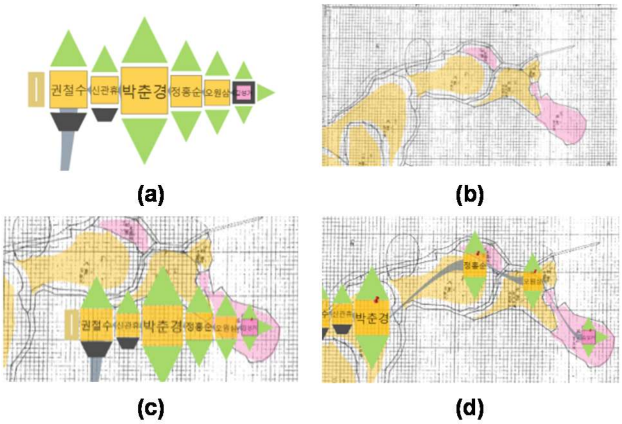



Figure 3.8 Matching process. (a) Visualized textual cadaster and (b) Segmented cadaster map. The land pieces in both (a) & (b) are surrounded by mountains. (c) The starting point is matched. (d) A few more local land pieces are sequentially.

to the land type.

### 3.4.3 Matching Process

The user performs the matching task to compare the node-link diagram with the segmented cadastral map. (Figure 3.8a, b). First, the user selects the best starting point and starts linking land pieces (Figure 3.8c) and matching nearby land pieces (Figure 3.8d) until the matching process is no longer able to proceed. The user now has to find another starting point and repeat the above steps. The user may utilize clues such as the four neighbors, terrain, etc., during the process. The detailed user interactions for this process in JigsawMap are explained in a later section.

## 3.5 Design Rationale

As a result of our observation and discussions with domain experts, we explain the rationale behind our design decisions and implementation of JigsawMap with domain experts.

(1) **Design based on task observations**

The historians formulated the task flow as they performed the task. There is a certain goal in every step of the task. We should understand these goals to design an appropriate interface or interaction. We should also find out what makes the task uncomfortable and tedious through observations.

(2) **Give the feeling of direct engagement**

The historians used highlighters and sticky notes to record their matched results on the map. To ease the learning curve of using JigsawMap, we have to support the direct manipulation of the layout through intuitive and familiar interactions with the right affordances. We decided to model the interactions based on the historians' accustomed actions with highlighters and sticky notes.

(3) **Enable search by name**

The owner names are very important hints for finding the candidate nodes for matching. Especially, at the beginning of the matching process, the historians check the owner names to find out if there are similar names in the cadastre and map. For this reason, the owner names should be searchable to provide clues for the matching process.

(4) **Visualize the invisible**

Making an automatic algorithm that finds perfectly matched results is very difficult, if not impossible. Thus, we visualize the important characteristics of the data which were inconspicuous in the original textual cadasters. With important features embossed in the overview, the user will be able to match places where the features were not visible before.

(5) **Control the amount of information to visualize**

The cadastre contains various information on the land. Visualizing such information helps understand the data, but showing too much information at once could hinder the matching process. In the design process, we had to decide the information necessary for each task. There may be information that is important to historians, but seems irrelevant to non-historians. Thus, we closely collaborated with the historians to decide which information needs to be shown for each task.

## 3.6 Evaluation

### 3.6.1 Apparatus

Our working prototype is implemented using Microsoft Silverlight 4.0. JigsawMap has two view modes: separate mode and overlapped mode. In separate mode, the user can compare the cadastral map and the visualized cadastre separately. By comparing these two views side by side, the user can skim and mark the start location candidates. The cadastral map view is in the left window and the graph layout view is on the right. Each window supports zooming and panning. The overlapped mode merges the left and right views, overlaying the visualized cadastre on the cadastral map. In this mode, the user can directly manipulate the nodes that are on top of the map. It is like putting sticky notes on top of the map. The user can switch the mode back and forth by clicking on the "Over" button.

An overview of the cadastral map and detailed views are placed in the center part of the interface. In the detailed view, the land information of the textual cadastre and cadastral map is shown. The land shape information in the cadastre is visualized with glyphs. In the cadastre, most of the land pieces are rectangular, but some of them have irregular shapes (e.g., an arc shape). The bar chart in the center shows the size of the selected land pieces in the cadastral map and cadastre. The user can check if they are of similar size using the bar chart.

### 3.6.2 Pilot Study

We did a pilot study with a Computer Science graduate student who does not have background in this kind of task. This study was done with an early prototype of JigsawMap to find usability problems or errors. We explained about the data and the purpose of our tool and showed a 3 minute demo. We allowed the participant to ask questions about the interactions of JigsawMap and the description of the data during the test.

The test took about 40 minutes. The participant matched about 70 land pieces, which is about 15% of the town. The results of the test were mostly similar to those of the Korea historians.

However, some of the matched results were not identical to those of the historians. This was mainly due to the N:1 matching cases where the participant sometimes matched too many or too few nodes to a land piece of the cadastral map (or vice versa). A meticulous examination of the land area information can resolve this problem. Unfortunately, there was no visualization that allowed differences in the land area data to be shown in the early prototype. Due to this problem, the participant commented that comparing the area information was not very intuitive, due to the irregular shaped land pieces in the cadastral map. Based on this feedback, we included the area bar chart to help the user compare the area data.

### 3.6.3 Longitudinal Evaluation

We conducted long-term case studies following the principles of MILC (Multi-dimensional In-depth Long-term Case Studies) [77], which is a participatory design method, with two historians. We had a meeting with each participant every two weeks for five months. Each meeting took about an hour. We preceded the meeting with the following protocols. First, we got the overall feedback from the historians about their two weeks experience using JigsawMap. Next, we exchanged questions. We mainly asked questions about the historical background of the data to understand the task and data better. The historians usually inquired about the functionality of JigsawMap in detail and the feasibility of their ideas on improving it. Then, we introduced and installed a new version of JigsawMap which was improved based on the feedback from the previous meeting. Finally, we observed the historians using the new version and received their initial feedback on it.

The next two sub-sections describe case studies with the two historians: a graduate student (P1) and undergraduate student (P2) from a Korean history department.

(1) **Case 1**

This user was a graduate student (P1) who has professional experience in cadastre studies. P1 was used to the manual paper-based matching task. During the evaluation, we asked P1 to use JigsawMap to match land pieces of Gayang-ri, a town surrounded by mountains.

P1 commented that the visualization of the textual cadasters is one of the most satisfactory features compared to the paper-based matching task. The clues mainly used by P1 to find a starting land piece for the matching process were: the terrain in the four neighbors (e.g., Figure 6), the similarity of the land owner names, and the irregular shaped (e.g., arc) land pieces in the cadastre. P1 stated that the area chart was very useful for checking the size of the land pieces.

P1 noted that the land information is not necessary in the matching task. According to this statement, information such as the price and fertility were excluded from the tooltip popup. In contrast, the terrain information was considered very useful and important for the matching task. Therefore, we modified the interaction to show the terrain visualization of the four neighbors in a land piece all the time. P1 also mentioned that he wanted to have keyboard shortcuts and that he is familiar with word processors and spreadsheets, so we added keyboard shortcuts based on these programs (shift / ctrl click, ctrl+c and ctrl+v).

(2) **Case 2**

P2 is an undergraduate student in a Korean history department. P2 had no experience in the matching task before and had no background information on the cadaster. A brief background explanation and tutorial of JigsawMap was given to P2 before the evaluation. P2 worked with Yogok-ri, a town located in the valleys. The feedback from P2 about the strengths of JigsawMap was similar to that of P1.

P2 noted that she used a different approach when she was unable to carry on with the task. At first, she tried to find other candidate locations that could be far away from the current place. However, she often had problems in merging different groups. If dangling nodes remain, it means that there is something wrong and discerning the correct matching will be time consuming. Thus, she decided to follow the survey direction, finding other candidates nearby when she came to a dead-end. P2 said that working this way improved the overall performance. After hearing this anecdote, P1 affirmed that it is a reasonable approach to stay on track in the survey direction.

P2 finished the matching task in about two weeks. The total time was about 20 hours, working for 2~4 hours per day. The working time included a brief seminar on the background of the cadastre and cadastral map, as well as a tutorial of JigsawMap. Considering this, P2 finished the task in a significantly shortened time compared to that taken by experts to complete the manual paper-based task.

### 3.6.4 Post Usability Test with a Domain Expert

We additionally interviewed and tested our tool with a Korean history graduate student (P3). P3 has a historical background and understood the purpose of our research, because he had been working on linking cadastre and cadastral maps manually. The whole process took about 90 minutes. First of all, we interviewed P3 for about 30 minutes about how he had worked manually. We asked P3 how he found starting points, the hints he used to find them, the progress of the research, and difficulties of the task. After the interview, we gave him a 10 minute tutorial with a demo. We asked P3 to use JigsawMap with the town he is working on as a warm-up and received initial feedback about it for 30 minutes. Lastly, P3 tested JigsawMap with a town he was not aware of and this step took about 15 minutes.

In the interview, P3 mentioned that he had been working on a town which is located in a plain with the paper-based method. P3 processed about 70 percent (of the town?) in about 2 months. P3 worked for 2~3 hours on a usual day and 5 hours on weekends. The names of the owners were a very good hint in P3’s case, in that almost 15 percent of his matched results were due to the land owner’s name. Furthermore, their family names were also reliable clues for matching. P3 stated that the natural terrains visualized as the four neighbors of the land pieces were also helpful for finding candidates. For example, a land piece surrounded by a mountain could be easily matched to the map.

## 3.7 Discussion

Historians have found significant meaning by linking cadasters to cadastral maps. Most of the findings were already known, but using JigsawMap, proved these facts in other perspective. In addition, they commented that our visualization will be useful for making further discoveries.

The fact that they first reconfirmed was that there was disagreement of land owner names. There is only about a ten year gap between the cadastral map and cadasters in our research. For this reason, the historians hypothesized that the land owner names in these two cases would be almost the same or similar. However, when the users tried to find matching land pieces by using the owner names, the result was not good. The historians concluded that the representation of the land piece was recorded by the different standards adopted at that time.

As explained previously, the land survey direction and four neighbors of the Korean pre-modern cadasters were recorded using four canonical directions (NSEW). When fulfilling the task, there were some cases where the direction information did not make sense compared with the trace of the nearby neighbors. The historians formulated a hypothesis that there may be exceptional cases of direction representation. For example, the direction where the king lived may have been expressed as north. The historians are studying the social aspects of that time to find historical evidences for this hypothesis. Another interesting finding was that there are some long, straight roads located in the modern cadastral map. The land pieces divided by these roads share the same land owner name and are usually matched to a single land piece in the textual cadastre. The historians found that these roads were newly constructed in the 20th century.

There are also finding that they did not reason yet such as land survey directions. Not all of them are related to the dynasty. For example, the land surveyor walked a long way across a big mountain, rather than finishing recording the land pieces around it first. The historians are researching these survey directions to find hidden patterns and understand any social background behind the unique survey directions.

### 3.7.1 Generalizability of Cadastral Map Mapping Problem

Mapping historical textual cadasters is not an isolated problem in Korea. Similar problems also exist in other countries such as Japan and China. In China, land information was recorded in a "fish-scale register" in the 17th century, where the land pieces were drawn like fish scales. This system also lacks the exact coordinates, so our approach is also applicable in a similar way. There are some European countries such as Ireland that have historical cadasters to analyze in conjunction with modern cadastral maps.

Connecting historical textual cadasters requires dealing with uncertainty because of the ambiguity involved in the mapping process. JigsawMap helps historians match the historical artifacts by interactively resolving the ambiguity. Since it deals with uncertainty, the interaction design in JigsawMap is closely related to the visualization of uncertain data or uncertainty visualization. We will focus on each component of JigsawMap to reduce uncertainty and increase scalability of our research. We think that our approach and design can be generalized to such a research domain as the visualization of geospatial data with uncertainty.

## 3.8 Design Guidelines When Working with Historians

We worked with the historians for about half a year and learned some rules of thumb that were useful in the design process. We generalize and suggest them as guidelines. We think that these will be useful when collaborating with historians.

(1) **Be Aware of Time Scale**

There are many different kinds of temporal data. Most data used for visualization are evenly-spaced over time and relatively short in length. However, the data used in the history field are mostly irregular in time. The time range can vary by hundreds of years. Therefore, when designing temporal or time-line visualizations for historical studies, these characteristics should be noted.

(2) **Be Concerned about Background of the Record**

During the project, we found that more than one name may represent a single person. At first we thought that the historians made some typographical errors when computerizing the materials. However, it was due to an historical issue. The historians explained that some of the letters used at that time have more than one pronunciation. In this case, there might be some background knowledge that is trivial for historians, but not for computer scientists. These unknown data properties can cause misconceptions. Thus, it is important to fully understand the background of the data to design a credible tool.

(3) **Bridge the experienced and novice users**

Expertise in the domain can have both positive and negative effects on the task performance with JigsawMap. In our study, the experienced user (P1) was inspired by the feedback from the novice user (P2) who tried to use JigsawMap in a novel way. P1 mentioned that he was so used to working manually with papers and highlighters that he tended to do the task in the same way, even when using our tool. On the other hand, novice users may receive useful tips from experienced users. Thus, if we can bridge them in the design process, we can design a system that can actually improve the performance of both groups.

(4) **Field Studies**

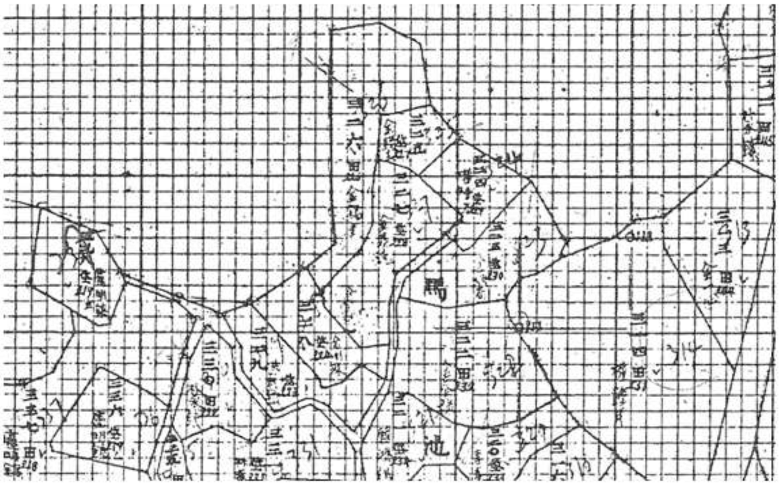
In order to verify the records of historical data, historians may go on field studies. Asking the purpose of the field study and sharing the log of the result can be a valuable process. The collected data can be proactively used in the design process.

# Chapter 4

# Accurate Segmentation of Land Regions in Historical Cadastral Maps[2]

In this chapter, we propose a novel method of extracting land regions automatically in historical cadastral maps. First, we remove grid reference lines based on the density of the black pixel with the help of the jittering. Then, we remove land owner labels by considering morphological and geometrical characteristics of thinned image. We subsequently reconstruct land boundaries. Finally, the land regions of a user's interest are modeled by their polygonal approximations. Our segmentation results were compared with manually segmented results and showed that the proposed method extracted the land regions accurately for assisting cadastral mapping in historical research.

[2] A preliminary version of this chapter was published in JVCIR [50]



| Global Index | Survey Direction | 4-Neighbor Information | | | | Area | Owner |
|---|---|---|---|---|---|---|---|
| | | East | West | North | South | | |
| 212 | West | JRW | LBK | Road | Mountain | 783 | KMB |
| 213 | West | KMB | LSW | Road | LKS | 1445 | LBK |
| 214 | West | LBK | Creek | Road | LKS | 4080 | LSW |
| 215 | North | Road | KSS | LSW | LYS | 1924 | LKS |
| 216 | West | LKS | Creek | LSW | LYS | 2940 | KSS |

Figure 4.1 A pre-modern cadastral map in KIKS - cadastral map (top) and textual cadastre (bottom).

## 4.1 Segmentation Pipeline

The example of premodern cadastral map and textual cadaster is shown in Fig. 4.1, and the proposed segmentation method is conducted in four stages as shown in Fig. 4.2. Beforehand, we preprocess the cadastral maps by scanning and resampling (Fig. 2a). In the first stage, we removed is conducted in four stages as shown in Fig. 4.2. Beforehand, we preprocess the cadastral maps by scanning and resampling (Fig. 4.2a). In the first stage, we remove grid lines by constructing scan lines and classifying them based on the density of black pixels (Fig. 4.2b). Second, the label characters, which describe the owner names of land regions, are removed based on their morphological and geometrical characteristics (Fig. 4.2c). Third, we reconstruct land boundaries by connecting end points of broken line segments (Fig. 4.2d). Finally, land regions are extracted into polygons using seeded region growing and minimum-perimeter polygon algorithm (Fig. 4.2e and 4.2f).

## 4.2 Preprocessing

The cadastral maps are hand-drawn maps. To be fed into our segmentation pipeline, we first scan them into digital images. The original map is drawn on a rectangular box, but it is often not axis-aligned. If a scanned map is severely tilted, we manually align the image by rotating it such that vertical and horizontal grid lines on the map are close to be orthogonal. Such well-aligned image is preferred when a scan line is matched into the grid line. The image is initially scanned in a high-resolution grayscale format (e.g. $5204 \times 6513$), which requires substantial time to process. We lower the resolution to 2000 pixel width and its proportional height in order to shorten the processing time while maintaining accuracy. Finally, we convert the image into a binary image to take advantage of morphological operations, which include thinning, end point detection, and connected component labeling, in the subsequent character removal and boundary reconstruction steps. In the input image, black pixels correspond to the foreground and white pixels correspond to the background. Thus, it can be easily segmented using a global thresholding technique. We used Otsu's method to compute a global threshold for the binarization.

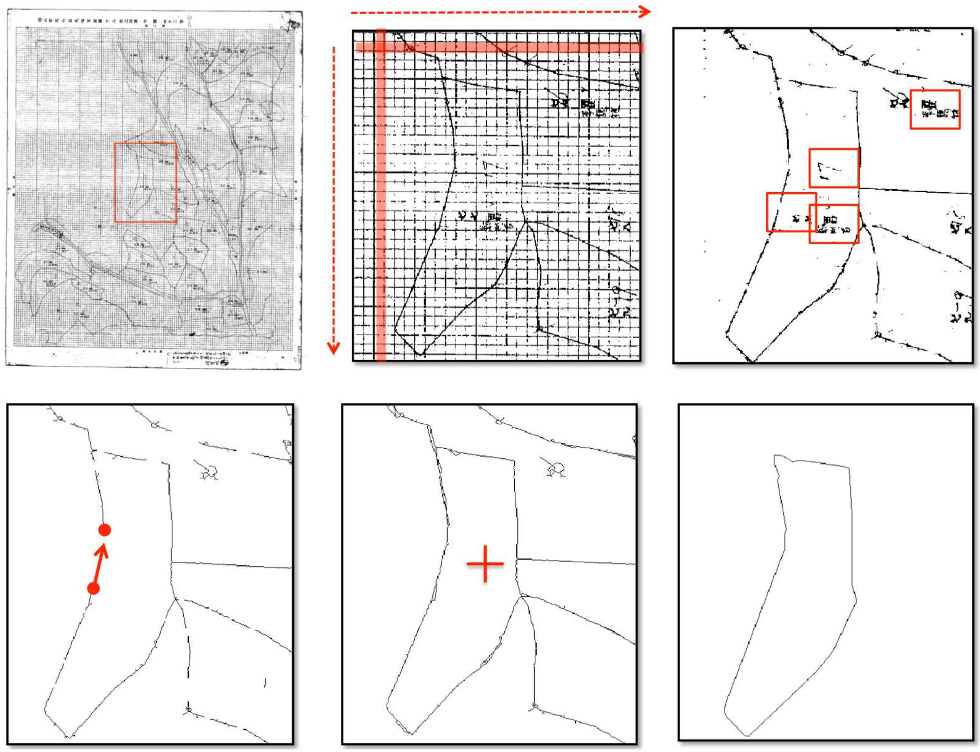


Figure 4.2 Pipeline of cadastral map segmentation.

(a) Original map image. (b) Removal of grid lines. (c) Removal of labels and pixel fragments.

(d) Reconstruction of boundaries. (e) Selection of a region of interest. (f) Generation of a polygon approximation.

In this way, it is easy to see how the blood pressure measurements fluctuate around a specific value which can be any user-defined meaningful value. The default position of the horizontal axis can be changed depending on the problem domain. For example, in case of stock data, the horizontal axis is better to be positioned at the bottom, i.e.

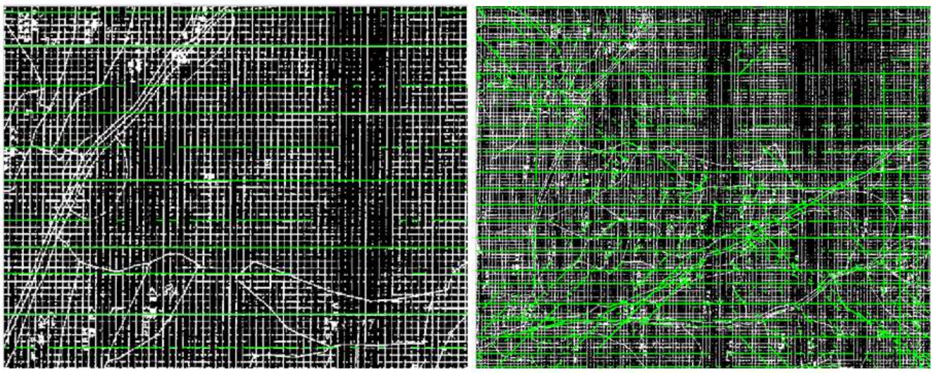
at zero.

When one measurement is exactly equal to the user-defined value that the horizontal axis represents, the graph cannot show that measurement point because the height of its corresponding bar is zero, which gives a false impression to users that it was not even measured at the time point. To remedy this problem, we made the horizontal axis a tube-like dual line with the thickness of a small number of pixels.

## 4.3 Removal of Grid Line

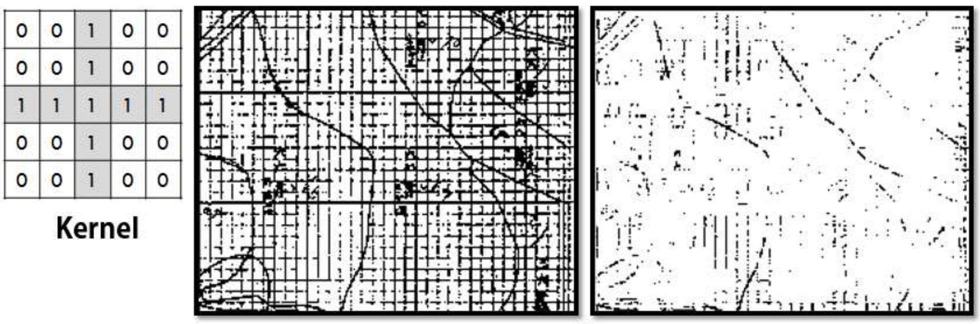
In this step, we remove dense grid lines in cadastral map images. The grid is composed of a series of horizontal and vertical lines, and is independent of land regions. The grid lines are regularly placed showing the periodicity of occurrence. Although this grid might have been a good layout reference for the cartographer, it is regarded as a noise that makes it more difficult to extract the land regions automatically.

Since the grid is not correlated with land regions, such content-independent algorithms could be employed for detecting and removing lines in an image. Unfortunately, they typically work best on clean images and are very sensitive to various types of noise. For example, Fig. 3 shows our initial trial to detect grid lines using Hough transform (HT). With the high peak threshold, HT missed a lot of grid lines (Fig. 3a). Also, by lowering the peak threshold, HT failed to detect correct grid lines by finding diagonal lines instead of connecting their intersections (Fig. 4.3b). Fig. 4.4 shows the grid detection result by a kernel based method. The kernel was designed to find a grid pattern (Fig. 4a) but was also unable to capture the exact grid lines (Fig. 4c). In lieu, it severely degraded region boundaries making the map almost illegible.



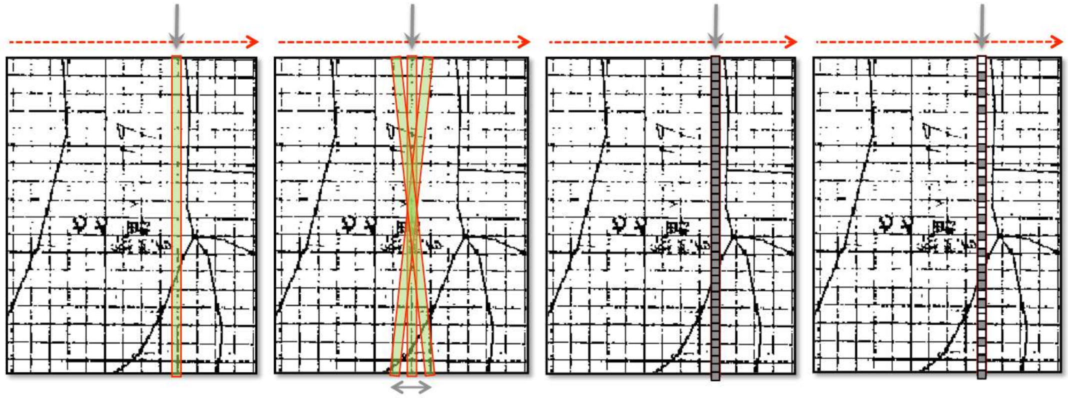
(a) (b)

Figure 4.3 Hough transform being applied to a cadastral map image..
(a) HT with high peak threshold. (b) HT with low peak threshold.




(a) (b) (c)

Figure 4.4 Pattern matching approach by filtering with a kernel. (a) A filtering kernel. (b) Original image. (c) Filtered image.



(a) (b) (c) (d)

Figure 4.5 Removal of a vertical grid line.

(a) Construction of a scan line. (b) Jittering of the scan line.

(c) Recognition of a grid line based on the density of black pixels. (d) Filtering non-grid pixels by examining neighboring pixels.

We identified two main challenges for the grid removal: 1) grid lines are severely broken due to the low quality of the map images, 2) the grid lines are overlapped with text and land regions, making the separation difficult, and 3) the line width, gap, and slope are irregular. Therefore, it is very difficult to detect the grid lines without contextual information.

There have been previous researches that leverage the contextual information to remove background lines from binary document images. Their algorithms are based on the observation that the lines are parallel and the gaps between any two neighboring lines are roughly equal. However, they have limitations as well in that the estimation error of the modeling parameters (e.g., line slope, line gap, and the position of the first line) is accumulated throughout the process. In addition, their input images are rather cleaner than ours and the background lines are printed whereas our lines were hand-drawn.

For the grid removal, we construct scan lines of varying widths horizontally as well as vertically to detect grid lines (Fig. 4.5a). For each scan line, we calculate the density of black pixels by summing up the number of black pixels over total number of pixels in the scan line. If this density is above a threshold, we regard the scan line as a grid line and clear the black pixels along the scan line (Fig. 4.5c). This density threshold is negatively correlated with the width of the scan line. The wider the line width is, the lower the density threshold is. Considering the image resolution, the optimal values of the density threshold and scan line width were empirically determined as 30% and 2 pixels, respectively. Since lines are severely broken, it is rare that the black pixels constitute more than about one third of the total pixels in a scan line.

However, due to the low quality of the original map and slanted scanned images, the grid lines are not always orthogonal to the sides of the image. Therefore, we perform the jittering of scan lines to compensate for the skewed grid lines (Fig. 4.5b). Although an increased jittering range could take care of more slated lines, it adversely affects the computational performance. Based on this observation, we chose to use 40 pixels for the jittering range by tilting the scan line pixel by pixel.

Since no prior knowledge on land regions is available for now, the grid removal algorithm removes the boundaries of land regions that overlap with the grid lines. To alleviate such unintentional removal, we examine the neighboring pixels before removing a pixel to determine if the pixel is a part of land boundaries (Fig. 4.5d). If black pixels exist around the pixel under consideration, we keep it intact as possible.

## 4.4 Removal of Characters

Next, we remove label characters and pixel fragments. The fragments are salt-n-pepper noises caused by the grid removal process as well as the poor quality of the original map. The labels are Chinese characters written inside each land region.

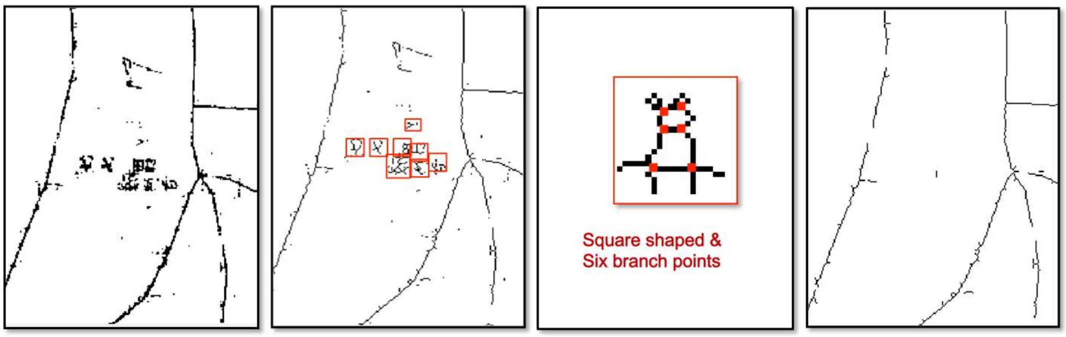



Figure 4.6 Removal of characters.

(a) Image after grid removal. (b) Thinned image with connected components.

(c) Examination of size, aspect ratio and branch point. (d) Removal of detected characters.

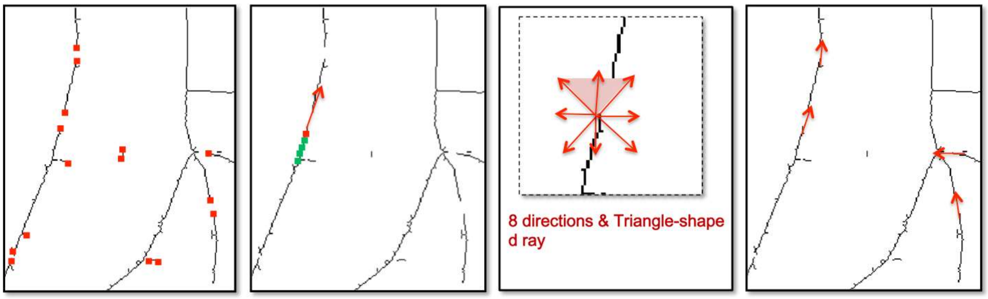
Although the labels were hand-written, the size of characters tends to be regular. They often touch land boundaries and even themselves, particularly for small land regions. The labels give important clues about the identity of owners of land regions, but they are obstacles in extracting land regions as is the same case with grid lines.

In order to extract such features, we first apply thinning to the result image after the grid removal for the detection of branch points. We then find connected components of the characters and calculate their bounding boxes. For each connected component, we examine the size and aspect ratio of its bounding box and ignore it if they are not within the defined threshold. To be recognized as a character on the map, the aspect-ratio has to be close to a square (Fig. 4.6b). To deal with the connected characters, however, we increase the aspect-ratio threshold to accept those whose width is at most two times larger than the height. Finally, we eliminate remaining components whose number of branch points is above a chosen threshold (Fig. 4.6c). Since the Chinese character has many curves crossing each other, it could have more branch points compared to other elements in the image. In addition to characters, pixel fragments are removed based on the number of pixels in each connected component; if it is less than 15 pixels, the fragment is considered as a kind of salt-n-pepper noise hence removed from the image.

## 4.5 Reconstruction of Land Boundaries

Next, we reconstruct land boundaries by connecting broken line segments. Such fragmentation was generated due to not only the noise in the original map but also the removal of overlapping pixels with grid lines and characters. It is not unusual that cartographers make annotations such as land names, symbols or grids on historical maps. They write this information on top of the map or often intentionally erase a part of it to make such notes. Such supplemental information generates broken lines when being removed in the vectorization process. Also, the noise in the original or scanned map limits the efficiency of the vectorization by producing gaps. It is necessary to restore the broken boundaries into closed loops in order to apply the final segmentation with a flood-fill operation in the next step.

Excessive grids in our datasets produce small branches along the land boundaries, making the geometric-based approach not suitable for our problem. Thus, we take an image-based approach. First, we find end points of all connected




(a) (b) (c) (d)

Figure 4.7 Reconstruction of land boundaries.
(a) Detection of end points. (b) Determination of the ray direction by considering previous pixels.
(c) Defining a search area among 8 possible directions. (d) Connection to the nearest end point; it is possible that end points can be connected to undesirable counterparts.

components in the result image of previous steps (Fig. 4.7a) using the hit-and-miss transform. For each end point, we shoot a ray whose direction is most likely to find the neighboring boundary fragment (Fig. 4.7b). To determine the ray direction, we look up previous pixels of the selected end point. We calculate the direction vector from each look–up pixel to the end point under consideration. The average direction is then used as a ray direction. We restrict the direction to 8-connectivity (Fig. 4.7c). Since it is rarely possible for this single ray to hit the counterpart end point of the neighboring boundary fragment, we parameterize the thickness of the ray to widen the search area. The shape of the search area is a right triangle where the source vertex of the ray is located at the end point. Within the search space, we find candidate end-points and simply connect the nearest one to the end point (Fig. 4.7d).

## 4.6 Generation of Polygons

The final step is to extract land regions from the reconstructed image. Our method engages a user to select a region of interest and then uses a seeded region growing (i.e. flood-fill) to derive a pixel set of the selected region. It is possible that fragments survived previous steps could result in holes in this step. To remove such holes, we perform a morphological closing operation. We then use a minimum-perimeter polygon algorithm to retrieve an approximate polygonal boundary of the region. At the end, the vertices of the polygon are saved in a csv file. We repeat this process until all the interested regions are extracted or the user is no longer able to provide a promising seed that leads to a segmented region.

## 4.7 Experimental Result

### 4.7.1 Apparatus

We tested our segmentation method on an Intel i7 laptop system with 1.73GHz and 4GB of memory. We prepared ten pre-modern cadastral maps of Mamyeong region around 18th century, all of which were from KIKS. The maps were scanned using Epson Expression 1680 scanner with 600 dpi resolution and manually axis-aligned as accurately as possible. Although our method is not limited to a certain image size, we adjusted the image width to 2000 pixel and let the height change proportionally (the pixel size was all 0.307 × 0.307 mm) to achieve the optimal performance without sacrificing overall accuracy. All datasets suffer from poor quality and noise artifacts attributed to their age and hand-drawing.

The parameters for each intermediate algorithm were the same for all datasets. For the removal of grid lines, we used 2 pixel wide grids, 30% threshold, and 40 pixel jittering range. For the removal of letters and fragments, we used 3 minimum branch points, 40×40 box size, and 15 pixels for the fragment size. For the reconstruction of boundaries, we used 25 pixel-length ray and 5 pixels for look-up. These values were empirically determined based on visual inspection for ten training datasets, which are different from the ten test datasets. The parameters are more sensitive to image resolution which we fixed in the preprocessing stage than to the image content.

### 4.7.2 Evaluation

To validate the accuracy of our segmentation method, we developed an interface that enables us to manually segment land regions in the datasets (Fig. 4.8). For each dataset, we specified as many vertices as necessary along the boundary of each region. The vertices were then used to produce a polygon which closely approximates the land region. The manual segmentation was done on the original scanned map images. In this way, we obtained the manually segmented land region, which serves as the ground truth for the accuracy assessment of our segmentation method.

Fig. 4.9 shows the result of the segmentation method applied to the fourth dataset with the scanned cadastral map. It appears that our method significantly remove irrelevant noises and accurately identified land regions from the background. We first preprocessed the cadastral map into the resampled and binarized image as shown in Fig. 4.9a.

(a) (b)

Figure 4.8 Evaluation of the segmentation method.
(a) Automatically segmented land regions. (b) Manual segmentation of a land region in the original map image

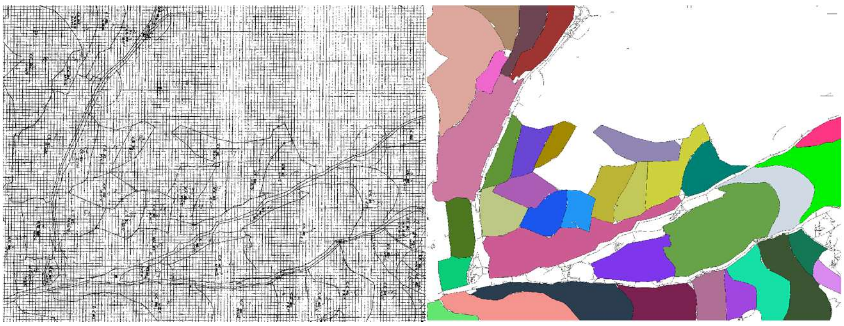
We evaluated the segmentation accuracy of our method by measuring the discrepancy between the manually segmented regions and automatically segmented ones. To assess the accuracy of our segmentation method, we employed four different evaluation metrics as follows.

$$E_{fp} = \frac{num\{A_{auto}\} - num\{A_{auto} \cap A_{manual}\}}{num\{A_{manual}\}} \times 100\%\,, \tag{1}$$

$$E_{fn} = \frac{num\{A_{manual}\} - num\{A_{auto} \cap A_{manual}\}}{num\{A_{manual}\}} \times 100\%\,, \tag{2}$$

$$E_{area} = \left( \frac{num\{A_{auto}\}}{num\{A_{manual}\}} - 1 \right) \times 100\%\,, \tag{3}$$

$$E_{sim} = \left( 1 - 2 \cdot \left( \frac{num\{A_{auto} \cap A_{manual}\}}{num\{A_{auto}\} + num\{A_{manual}\}} \right) \right) \times 100\%\,, \tag{4}$$



(a) (b)

Figure 4.9 The result of the segmentation method applied to the fourth dataset. (a) The cadastral map is scanned into a binary image. (b) Land regions are extracted into polygons

$A_{auto}$ is the set of pixels in the automatically segmented land region. The false positive error, $E_{fp}$, is the ratio of the set of pixels, in the automatically segmented region but not in the manually segmented region, to the set of pixels in the manually segmented region. The false negative error, $E_{fn}$, is the ratio of the set of pixels, in the manually segmented region but not in the automatically segmented region, to the set of pixels in the manually segmented region. $E_{area}$ is the area measurement error and the similarity error, $E_{sim}$, is defined using the similarity index.

Table 4.1 summarizes the accuracy evaluation result of ten datasets. The average number of land regions for the datasets is 38 and the average and standard deviation of the errors are shown in the table. All the errors are less than 5%, showing that our method is indeed an accurate segmentation scheme for the cadastral maps. For most datasets, $E_{fn}$ was higher than $E_{fp}$, and $E_{area}$ had negative values. This means that $A_{manual}$ is generally larger than $A_{auto}$. Based on the examination of the evaluation result images, we observed that the segmentation error occurs on the boundaries, which decrease the total area measurement for the automatically segmented region. During the preprocessing steps, land boundaries are often degraded. The resulting effect is the loss of accurate area measurement as the reconstruction step softens original boundaries. The granularity of the manual segmentation (i.e. the number of vertices) also affected the evaluation result.

## 4.8 Discussion

Our goal was to automate the segmentation process before proceeding the matching process. We reviewed various algorithms, but using each method alone did not guarantee satisfactory result. Instead, we classified the challenges to segment our dataset and organized a pipeline to solve our problem. As we showed in the result section, the pipeline we proposed was more accurate and reliable.

During our user evaluation, the domain experts commented that, although accuracy has been significantly increased compared to the initial approach, some drawbacks cause reluctance to use the automate process we proposed in the field. First, each stage in the segmentation pipeline requires parameter inputs that are not familiar to domain experts. Selecting appropriate parameter requires background knowledge in image processing. Second, after the land segmentation is complete, they have to label each land pieces manually. This task alone requires significant amount of time. We were able to automatically erase characters and grid lines, but recognizing the text with current image resolution is more complex issue and we left it for future work. We believe that algorithms such as ConvNet can be applied for accurate text recognition.

To solve the first problem, minimizing input parameters and designing intuitive interface are necessary. Showing basic explanation about segmentation algorithm and input parameters are required for historians. The algorithm is composed of long pipeline stages, so separating this part as an individual preprocessing tool can be more effective. The second problem requires direct human manipulation for accurate recognition since full automation is not available at this stage, but the dataset is large and more scalable approach is required. We believe that building a system similar to reCAPTCHA and using crowd sourcing power is a feasible way to replace current manual labeling task done by domain experts.

Table 4.1. Accuracy assessment results for land region extraction

| Dataset | Measure | $E_{fp}$ | $E_{fn}$ | $E_{area}$ | $E_{sim}$ |
|---|---|---|---|---|---|
| 1 | AVG | 1.159 | 1.560 | -0.402 | 1.362 |
| | STD | 0.712 | 0.694 | 1.038 | 0.476 |
| 2 | AVG | 1.151 | 1.826 | -0.675 | 1.494 |
| | STD | 0.813 | 0.896 | 1.198 | 0.613 |
| 3 | AVG | 2.417 | 2.334 | 0.083 | 2.372 |
| | STD | 1.325 | 0.881 | 1.636 | 0.764 |
| 4 | AVG | 1.825 | 2.631 | -0.806 | 2.238 |
| | STD | 0.899 | 0.915 | 1.092 | 0.726 |
| 5 | AVG | 1.528 | 2.730 | -1.092 | 2.127 |
| | STD | 0.362 | 1.234 | 1.168 | 0.816 |
| 6 | AVG | 1.245 | 2.676 | -1.227 | 1.977 |
| | STD | 1.169 | 1.316 | 1.190 | 1.175 |
| 7 | AVG | 2.775 | 2.738 | 0.037 | 2.755 |
| | STD | 1.521 | 1.307 | 1.754 | 1.107 |
| 8 | AVG | 2.743 | 2.919 | -0.022 | 2.799 |
| | STD | 1.948 | 1.463 | 1.981 | 1.462 |
| 9 | AVG | 1.900 | 2.811 | -0.746 | 2.340 |
| | STD | 0.934 | 1.060 | 1.723 | 0.693 |
| 10 | AVG | 1.839 | 2.952 | -1.113 | 2.407 |
| | STD | 1.516 | 1.112 | 2.208 | 0.737 |

# Chapter 5

# Approximating a Rectangular Cartogram from a Textual Cadastre

This chapter discusses the challenge of generating the graph layout of a premodern cadastre. We propose a hybrid approach to solving this problem by generating a layout that resembles a rectangular cartogram. Moreover, we review previous research on the generation of rectangular cartograms and adopt its characteristics to generate our initial layout of the textual cadastre.

## 5.1 Challenges of the Textual Cadastre Layout

As chapter 3 indicates, a textual cadastre does not contain accurate geospatial information. The initial layout is crucial for starting the process of mapping each

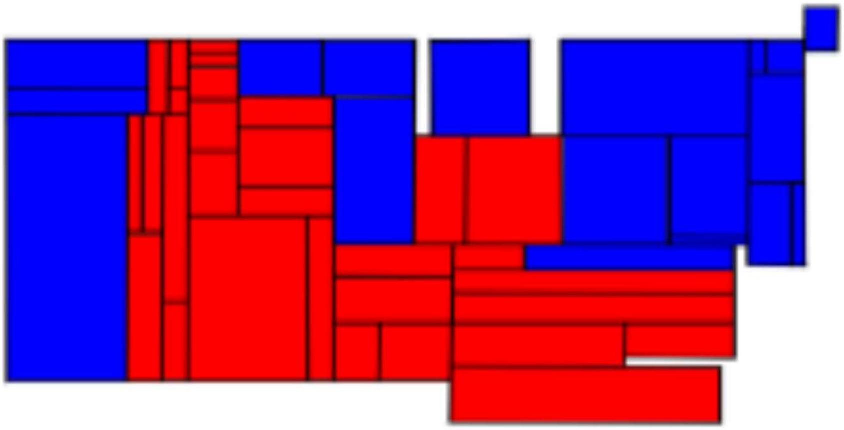


Figure 5.1 Rectangular Cartogram. The areas of the states are encoded as rectangles and their areas are distorted by the given values [5]

piece of land to the modern cadastral map. The original algorithm used in the JigsawMap prototype generated a layout that preserved the important characteristics of the land, but it was prone to many errors because of the ambiguous dataset. The survey directions only included four-direction information (north, south, east and west) and the lands were labeled by owner name rather than unique index.

Our goal was to guess the layout from the cadastre as accurately as possible so that it was more precise than the layout that the domain experts made. To assess the accuracy of our layout, we reviewed the quality measures that were used for the rectangular cartogram.

## 5.2 Quality Measures for Assessing Rectangular Cartogram

A cartogram is also called a value-by-area map. It distorts the area of a given region in order to visualize another of its variables. To generate a rectangular cartogram, its topology and area values should be known. The goal is to encode the area by the given value while constraining other distortions as much as possible. The common qualitative measures for assessing cartograms are given below. We use Figure 5.2 as an example of each measure and given formula.

(1) **Cartographic distortion**

The generated rectangular cartogram may not have the actual area expected. This error in the area is called cartographic distortion.

$$ERR \geq \sum_{i=1}^{3} \frac{|(x_{2i} - x_{2i-1})(y_{2i} - y_{2i-1}) - A_i|}{A_1}$$

(2) **Topology distortion**

The node-edge relationship can be calculated. The topology of the rectangular cartogram is given by the adjacent lands surrounding it.

(3) **Orientation distortion**

The angle error is also a common measure for determining the difference between the original map and the cartogram. It is usually combined with the topology distortion measure.

(4) **Aspect ratio**

The minimum aspect ratio of the rectangle is necessary to generate a readable

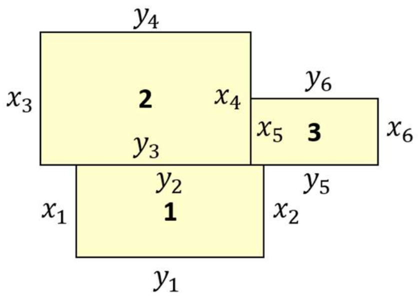



Figure 5.2 Example of constraints to optimize a rectangular cartogram

graph layout. D is a constant value.

$$(x_2 - x_1) \leq (y_2 > y_1) \cdot D$$

$$(y_2 > y_1) \leq (x_2 - x_1) \cdot D$$

The other common measures used are shape distortion and polygonal complexity, but they cannot be used for a rectangular cartogram because its rectangular shape is fixed.

## 5.3 Quality Measures for Assessing Textual Cadastre

With the exception of topology distortion, the measures that are used to assess cartograms are not available for textual cadasters. Even topology information is ambiguous because four-neighbor information is not recorded by index but by land owner name. If a person owns more than one piece of land, there is no way to disambiguate the land that is being referred to. So we used two kinds of distance measure to assess the topological error the of textual cadastre layout: four-neighbor distance error and survey sequence distance error.

Four-neighbor distance error was derived from the genetic algorithm that we used to predict neighbor candidates. As mentioned above, the land owner was ambiguous and the number of cases was very large. Therefore, we derived candidate neighbors from the genetic algorithm explained below. Based on these candidates, the layout was generated to minimize land overlaps. Then, we measured the distance between the land owner and the neighbors to evaluate how close they were.

The survey-sequence distance error was simple but necessary. This measure was derived from the distance error of the lands that were adjacent along the survey sequence. The priority of this error value was lower than that of the neighbor distance, but it was used as a secondary variable in the assessment of cadastre layouts.

## 5.4 Graph Layout Algorithm

The land position becomes prone to error because it accumulates as the surveyor proceeds. So instead of adopting the former approach, we divided the lands into groups and applied the layout algorithm to each subgroup. The textual cadastre included an administrative district that was smaller than a town, so we used it to divide the land regions.

To disambiguate the land owners, we used the evolution algorithm to explore the solution space. We selected one of the possible candidate owner names and defined it as a genotype. Then we used the topology error and total overlap area to assess the qualifying measure. We describe our algorithm in detail.

### 5.4.1 Division into Subsets

As mentioned above, one of the problems of the previous method was that the algorithm ran from the first piece of land to the end in one path. Since only four-direction information was given, the error accumulation was inevitable. So we tried to come up with an appropriate subset to divide a town and run in subsets. Fortunately, the textual cadastre format included a sub district named *jaho*, an administrative unit that was used for land taxation. It was an artificial district format, but the terrain and relationship of the owner were thoroughly considered. Hence, using *jaho* as a subset seemed to be the right choice for our technique.

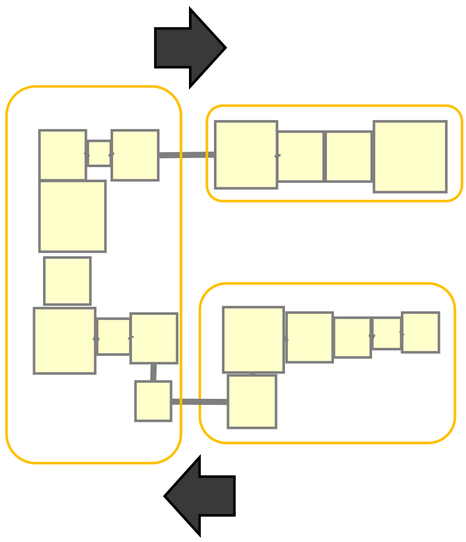


Figure 5.3 Subgrouping land regions to minimize error accumulation

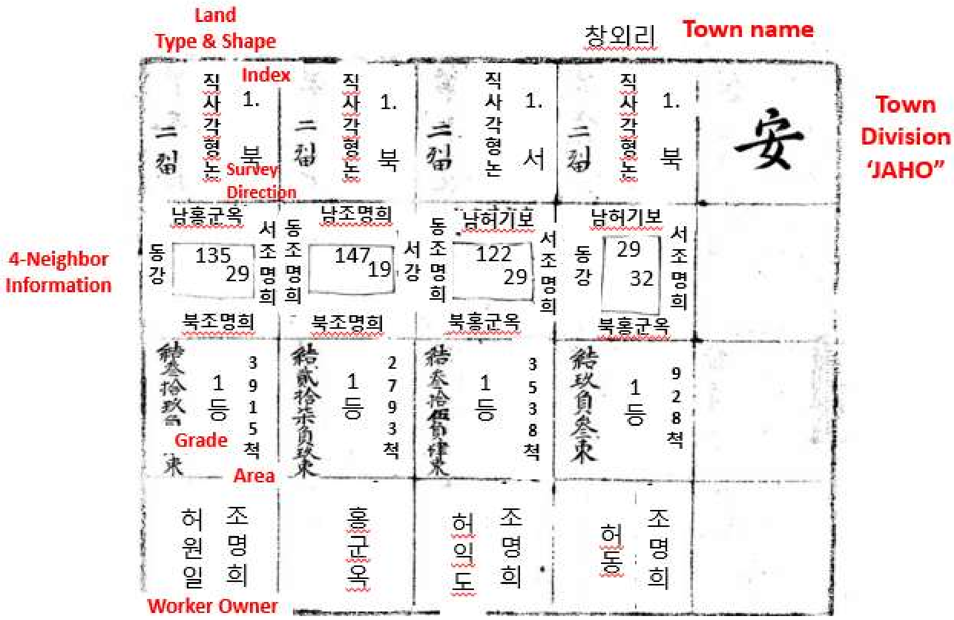



Figure 5.4 Page of textual cadaster. The town dividing unit, *jaho*, is indicated in the upper right corner.

### 5.4.2 Preprocessing for Assessing Measures

The technique we developed required the evaluation of several parameters, so we considered this step during layout generation. First, we needed to find the appropriate time, population, and iterative count of the genetic algorithm. Based on a pilot test of the genetic algorithm only, we derived two sets of parameters and used these parameters to compare cadaster layouts. Then we normalized each format so that we could compare them fairly. Our current version of JigsawMap uses Google Maps APIs, while the prototype version used the DeepZoom Project projection value of Microsoft Silverlight. Finally, we performed map registration with each other. We could not use scaling transformation because it would have deformed the area information. So we only performed translation to align the diagram.

### 5.4.3 Divide and Conquer

The purpose of the novel layout algorithm was to make fewer overlaps and generate the precise prediction of local topology. However, the global topology could have been distorted due to survey direction error. We hypothesized that, if subgroups were well clustered together, the user could easily recognize them and move them in a group unit so that the time would not increase significantly. We also assumed that our new method would reduce the Euclidean distance error and topology error. Because of this issue, we generated a tile-based global layout to maintain the group clustering.

### 5.4.4 Evolutionary Method

We applied an evolutionary method to the construction of the structural information from the textual cadastre. Due to the ambiguity the data-set involved, the global optimization method required the calculation of a tremendous number of possible permutations; genetic algorithms are known as the proper methodology for solving computationally intractable problems. In addition, we adopted the memetic GA approach by combining local optimization algorithms with the pure genetic algorithm.

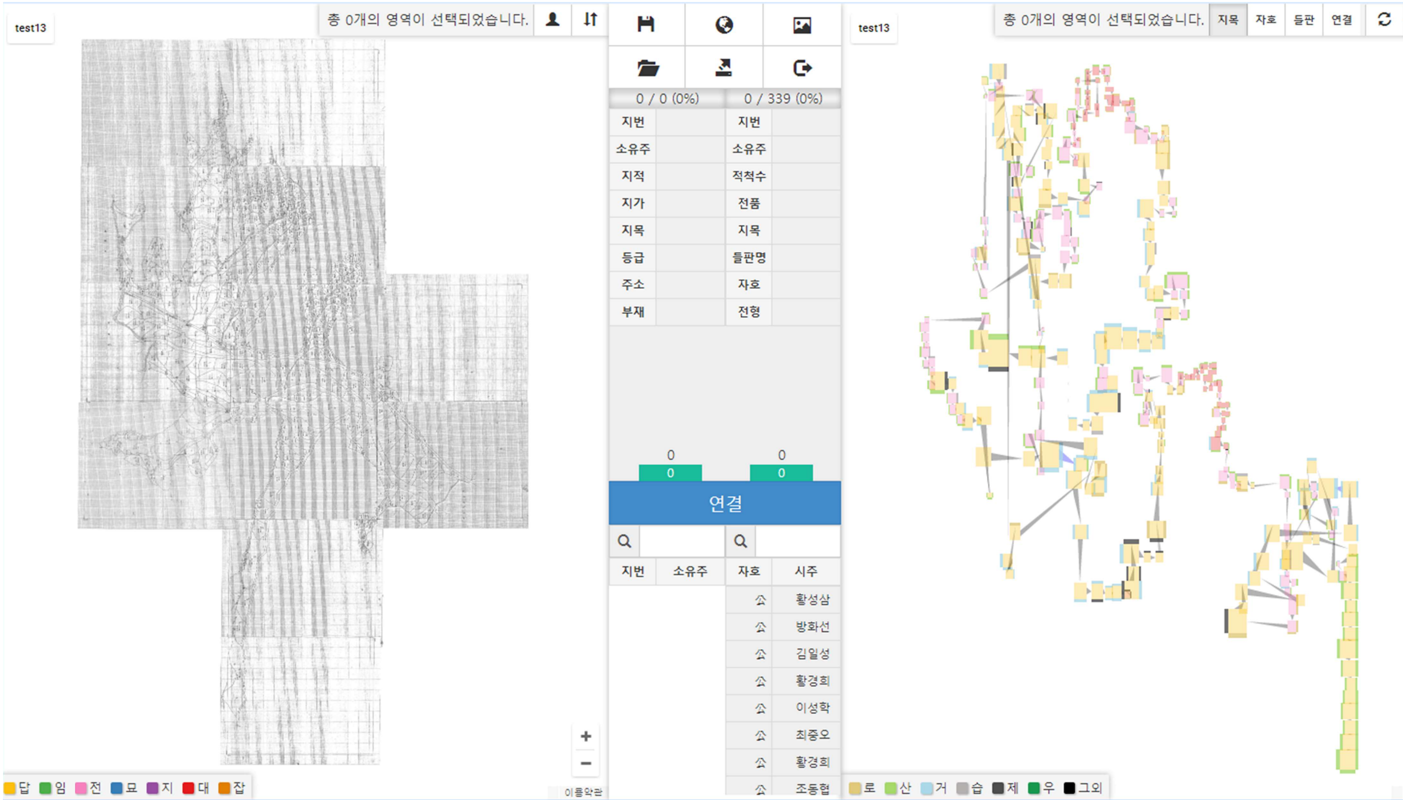



Figure 5.5 Overview of the textual cadastre layout. The layout is divided into town districts, and it is based on the genetic algorithm to find four neighbors.

The chromosome was a one-dimensional list of genes, each of which constituted land information in the textual cadastre. This structure reflected the route of the investigation. Each gene had four attributes pointing to the identities of the adjacent genes in the north, south, west, and east. Since the attribute for the direction could not be determined uniquely, we initially sampled one candidate value from the pool when creating a set of chromosomes. We calculated the fitness of the chromosome using heuristic measure algorithms according to the domain knowledge.

Since it was important to find out appropriate parameters that generates layout with high precision, we conducted repetitive experiments. The parameters were the number of chromosomes, mutation rate, and running time. The running time was a particularly important factor since we ultimately used our method for the interactive application. Therefore, we chose relatively shorter values for running time in the experiment.

### 5.4.5 Hybrid Method

In our first approach, we used the candidates generated from the evolutionary method directly to construct the layout. This design was successful for each subgroup, but it failed to reproduce the global structure. To solve this problem, we adapted the previous approach, which had been used in the prototype JigsawMap. The novel algorithm first generated a layout order based on the survey direction and added neighboring pieces of land from the candidate list.

## 5.5 Results

### 5.5.1 Pilot Test

Before sharing our work with domain experts, we conducted a pilot test to evaluate the validity of the algorithm. The participants were two non-domain experts: a computer science graduate and an anthropology graduate. We explained the interface of JigsawMap and let them use our tool for up to 20 minutes. Then we changed the layout and repeated the procedure. They commented that it was not easy to find differences at first since the data was not familiar. They identified some terrain or residential areas based on color coding and indicated that our new layout showed similar performance compared to the original layout.

### 5.5.2 Experimental Result

For the usability problem, we performed an experiment to adjust the genetic algorithm parameters and the solution converged in a reasonable amount of time. We ran the experiments as a 2 (Time: 60 seconds, 120 seconds) x 2 (Population: 10, 20) x 30 (trials). We concluded that 60 seconds were enough for candidates to converge because it was approximately maximum time for users to wait without being frustrated.

To compare the novel algorithm to the original JigsawMap layout algorithm, we performed a few measures designed for our data to validate the result of the algorithm and the solution. We assessed the sum of the topology error and the overlap area that was used in the evolution algorithm. Then we measured the bounding box that fit the total layout. The result showed that the bounding box of our new algorithm was not compact due to subgrouping and the separation of each groups, but each subgroup had less overlap and better disambiguation.

Our results in Table 5.1 show that the strength of the error value of the novel method tended to be present in the fine-grained step of the connection task. The error value was a relative distance compared to the solution data. The table indicates that half of the subgroups were qualified for a lower measure, while the other half were not. The result does not support our hypothesis.

We conducted a usability study to evaluate topology recognition; we sat close to the participant while performing the matching task, and encouraged him to use the think-aloud strategy. Figure 5.6 shows a global comparison of the previous and current layout algorithms. While observing the layout, the domain expert pointed out the southeast region of the node-link layout. Compared to the solution file, our novel algorithm maintained its relative topology. With our previous method, some land pieces were to the west of their neighbor rather than to the east (Figure 5.7).

## 5.6 Discussion

Our experiment did not support the hypothesis that proposed that the algorithm reduced the local distance error. However, the follow-up user study suggested that our algorithm preserved topology better than the algorithm of the previous research. One thing that we found interesting was that our primary goal was to minimize the accumulation of topology and distance error. We presumed that, when we accomplished our goal, the layout of the local unit (the *jaho*) would be closer to the solution. Then we expected the users to interact with the tool and organize the layout in top-to-bottom order.

However, as mentioned above, our algorithm did not significantly reduce the distance error. Instead, we found that, compared to the former layout by analyzing usability test, our method preserved local topology better. This led to the correction of the topology error that had accumulated in all the land parcels and partially restored the global structure. However, if too many people had owned more than one piece of land, the problem space would have become too large, and the evolution algorithm might not have found an appropriate solution in the current settings. In this case, adjusting the population and iteration time would have been inevitable, and the preprocessing time would have increased. This procedure only occured before the matching task started, so the domain experts stated that the time consumed during the stage was durable enough.

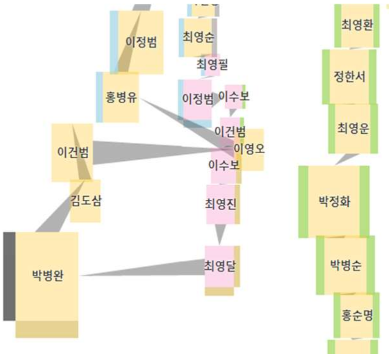
The domain experts also indicated that they had started matching tasks from regions that had distinct characteristics such as aligned rivers, residential areas, or mountain valleys. These areas were also easy to find in a reference cadastral map, so they acted as a basis for the start of a matching puzzle. The domain experts suggested that, compared to the former algorithm, this one had more places from which matching could be started. So there was a lower burden attached to guessing random places when they were stuck.

Table 5.1. Accuracy assessment results for comaprison methods.

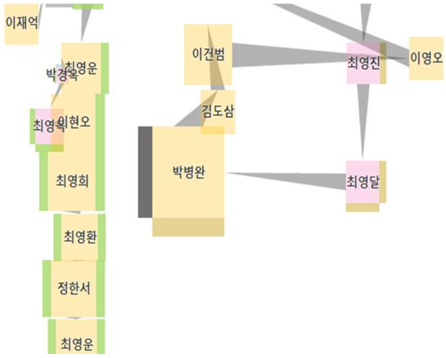
| Jaho | Measure | *E* |
|---|---|---|
| 1 | PREV | 2000.28 |
| | GA+ | 2384.88 |
| 2 | PREV | 4009.90 |
| | GA+ | 3763.40 |
| 3 | PREV | 4024.37 |
| | GA+ | 4565.22 |
| 4 | PREV | 7059.68 |
| | GA+ | 6580.02 |
| 5 | PREV | 3627.74 |
| | GA+ | 3673.53 |
| 6 | PREV | 2735.87 |
| | GA+ | 3347.98 |
| 7 | PREV | 7031.65 |
| | GA+ | 7919.54 |
| 8 | PREV | 4395.44 |
| | GA+ | 3815.90 |

(a) (b) (c)

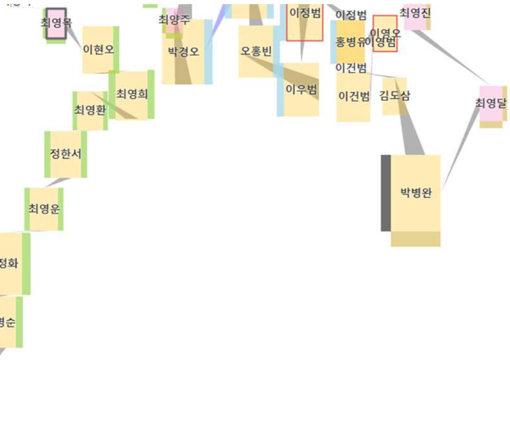
Figure 5.6 Comparison of cadastre layouts. (a) previous layout algorithm result, (b) result of algorithm described in this chapter, (c) solution layout




(a)




(b)




(c)

Figure 5.7 Enlarged view of Figure 5.6. in southeast corner. (a) previous layout algorithm result, (b) result of algorithm described in this chapter, (c) solution layout

# Chapter 6

# Design of Scalable Node Representation for a Large Textual Cadastre[3]

The scalability of the textual cadaster analyzed in our study is currently up to the town level. However, when historical studies are undertaken on a national scale, a more scalable approach is required and traditional map legend encoding should be simplified for clear visualization. In this chapter, we discuss the process of the conventional analysis of a textual cadaster. Then we propose a novel visualization based on a more compact node-link diagram that increases the scalability of the existing cadastre visualization.

## 6.1 Motivation

The scalability of the textual cadastre kept in KIKS can be compared to other big data

[3] A preliminary version of this chapter was published in TR [58]

in current fields. Most enterprises and research groups generate datasets that are too large to process. Such data is generally called big data, and its effective analysis and visualization are believed to result in unimaginable insights and values. However, there is no universal definition of big data yet because, depending upon conventional analysis practices, different domains could use different yardsticks to determine how much data to refer to as big data. The volume of textual cadasters analyzed in Korean historical studies may not be large in terms of the actual amount of data stored in a database, but the conventional analysis of the data takes long to finish. So we may argue for calling it big data in the domain. In the following section, we discuss the conventional analysis process for textual cadasters. Then we propose a novel visualization based on a more compact node-link diagram that increases the

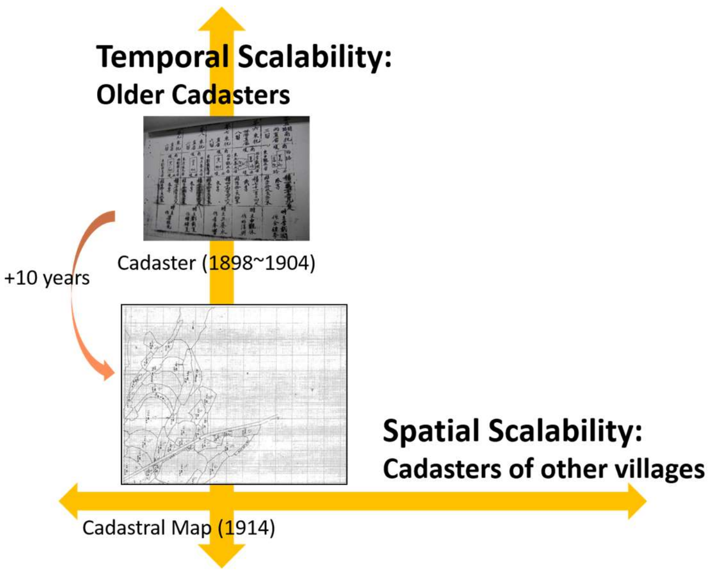



Figure 6.1 The scalability of the cadastral data in the temporal and spatial dimensions.

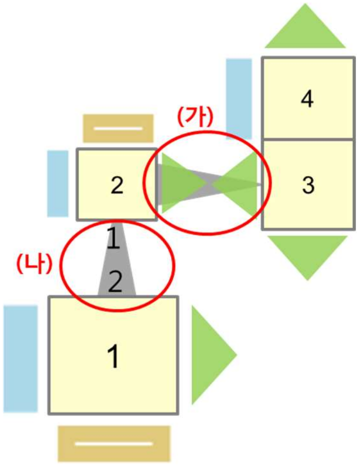



Figure 6.2 Challenges of current visual encoding in JigsawMap. The terrain gives visual illusion of separation. The circled link shows where the text is hard to read.

scalability of the existing cadastre visualization.

## 6.2 Visual Encoding in JigsawMap

Textual cadastre visualization encoding in JigsawMap is based on records of land regions and the feedback that domain experts gave during the experiment undertaken in the former research. The motivation of visualization is a node-link diagram. This is because the relationship between land regions and connecting information is intuitive for the matching of nodes and edges. The land region is often segmented in rectangles for the convenience of administrative policy. Moreover, most land is segmented in rectangles. So the shape of land pieces is also encoded in rectangles instead of circles or dots (a convention typically used in graph layouts). The textual cadaster contains four-neighbor information. So the space designated for visualizing the information should also include them. The visual encoding of terrain is derived from map legends in the original JigsawMap prototype. If the neighbor is terrain, it is expressed as a shape that is used in maps, and if it is land owner name, it is expressed as the name.

The visual encoding was maintained to preserve the familiarity of the interface for users by maintaining similar environment when they performed the task manually. There is no problem when the task is conducted on the town scale. However, when the aggregation of the neighbor town is required, a more scalable visualization is necessary. For example, wasteland may have been cultivated as farmland, and the owner may have sold the land and moved to another town. In such cases, the analysis should stretch out to neighboring towns to track the owner.

## 6.3 Challenges of Current Visual Encoding

The current visual encoding described above is designed so that historians understand the meaning of each symbol intuitively. However, there are several drawbacks to this

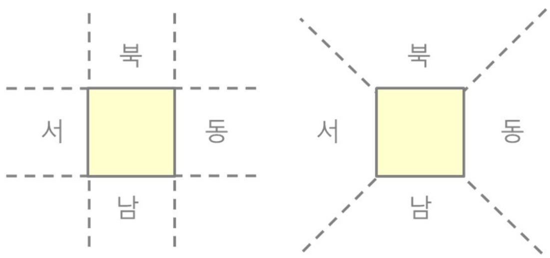



Figure 6.3 The range of four neighbors. The image on the left precisely defines the direction, but, in textual cadastre, the right covers the whole range of possiible locations.

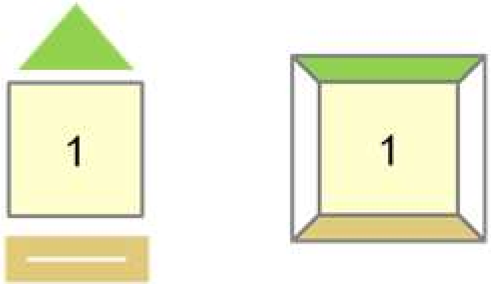



Figure 6.4 Original JigsawMap encoding (left) and novel compact visual encoding (right)

approach. First, there is a scalability problem. Each shape and text has a different area size and aspect ratio. Terrain such as mountains takes the form of triangles, whose expression requires much space. Second, current visual encoding sometimes gives the impression that the lands are not connected. Taking the example of mountain, if a small mountain exists between two land regions and they are sequentially recorded in a textual cadastre, we can consider these mountains to actually be connected. However, the visual encoding separates the lands and makes them look disconnected. This may confuse the users. Finally, the layout algorithm is designed to evade overlap for pieces of land, not for neighbors. So the land owner names may overlap and the information may be hidden, making it harder for the matching process to proceed.

## 6.4 Compact Visual Encoding

The common reason for the problems discussed in the formal section is that every piece of information given is focused on nodes. The edge only gives connection and direction information, while the node contains other details, such as land owner name and neighbors. Our data does not act like a common graph layout, so the common guideline used for node-link diagram does not fit. Since we are simplifying the visual encoding, the information of each visual component should not be lost. We should describe the constraints of the novel visual encoding first.

Edges only contain survey direction information, and there is no extra textual information to be visualized. Therefore, the portion of the edge can be reduced, and there is no need to consider space for the edge label. Next, we could simplify color and shape encoding. The current encoding of the prototype JigsawMap uses color and shape information simultaneously. Since the number of kinds of terrain was lower than 10, redundant encoding was not necessary in our case. Color was more pre-attentive than shape encoding, so we unified the shape encoding and simplified the overall shape. Finally, we tried to avoid the overlapping problem by capturing neighbors and expressing all the information as a bigger rectangle. Our graph layout

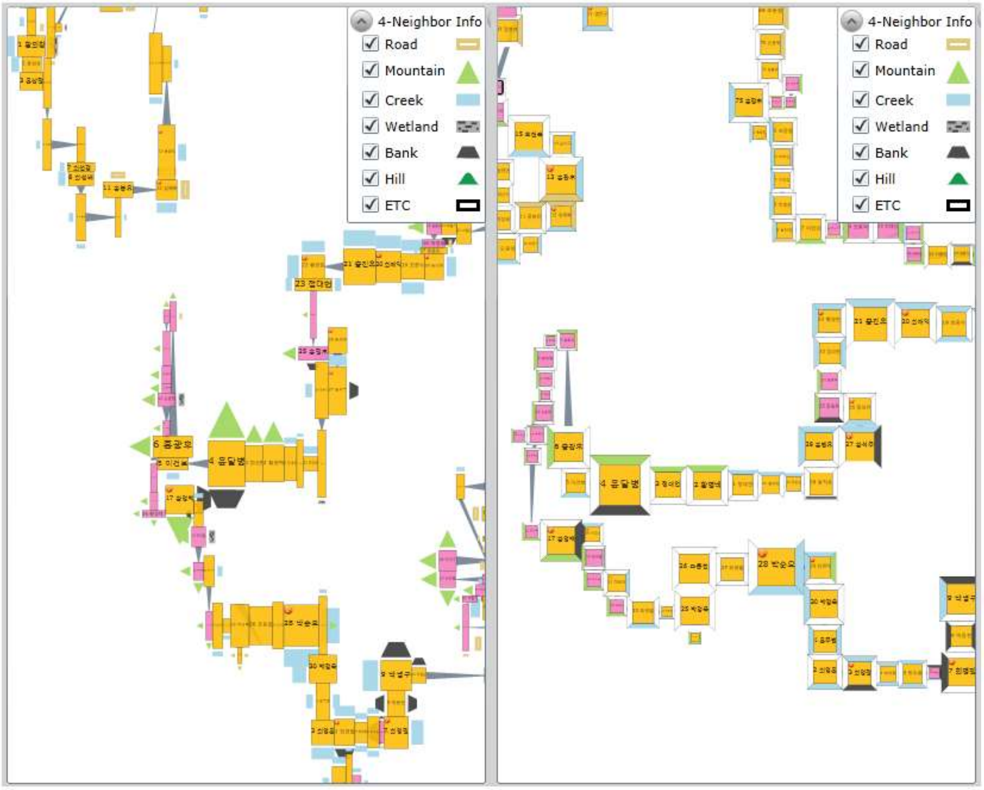



Figure 6.5 The side-by-side comparison of the original JigsawMap and the novel compact visual encoding

algorithm assumes every node to be a rectangle, so this approach is compatible and avoids overlaps for neighbor information. Inside the bigger rectangle, neighbor information is encoded as a trapezoid.

## 6.5 Results

### 6.5.1 Apparatus

To compare the new visual encoding with the original JigsawMap, we implemented it on the original JigsawMap and compared the result visually with Microsoft

Silverlight 4.0. As Figure 6.5 shows, the layout is more compact and the rectangles are closer to each other than they were on the original map. However, the connectivity visualization of terrain is weakened in the novel encoding, and, due to the coercion of the area increase, the overall layout is exaggerated in comparison to the original layout.

### 6.5.2 Evaluation

We performed a pilot study with domain experts who participated in the original JigsawMap project; we undertook this study with an early prototype of JigsawMap and the revised version to find usability problems or errors. Before the test started, we explained the difference of visual encoding between the original and novel JigsawMap. Moreover, we allowed the participant to ask questions about the interactions of JigsawMap and the description of the data during the test.

The test took about 30 minutes. The historians freely explored the tool and we encouraged them to think aloud while performing the task. After the test, they commented that the novel encoding was suitable for visualizing many towns together and required a more scalable view, but the original JigsawMap preserved the terrain information details. Furthermore, the details were more familiar since their encoding was based on map legends. Then we simulated a larger-scale version of the cadaster layout by simply concatenating neighbor towns. The experts commented that the experimental version of JigsawMap generated fewer overlaps since the visual encoding was more compact.

We compared the latter and former layout errors to determine whether the new encoding interfered with the original layout. Then we used the quantitative measure we proposed in chapter 5, the jaho unit. We used neighborhood error and survey direction error. However, both measures did not lead to a significant difference. So it is safe to use our new encoding as a reference while not neglecting the formal results.

Our results show that the error value of the novel method decreased compared to that of the formal technique. However, the domain experts pointed out that the current visual encoding was familiar and they were not willing to change the layout. We can conclude that our hybrid visualization design works well in quantitative measure but the learning curve is relatively high.

## 6.6 Discussion

The user study we conducted suggested that proposed visual encoding generated a compact and scalable layout for use. From the information visualization perspective, the color and shape encoding were redundantly used, so we simplified the shape and unified the information into color encoding only. However, the former method still had its strengths in that it was intuitive. This was because it was adapted from map legend metaphor, so the use of encoding could vary according to the circumstances.

During the study, we suggested other cartogram visualization techniques, such as the Dorling cartogram. This cartogram generation method morphed each node into a circle. In our previous study, we and the domain experts agreed to use the rectangular shape because most land pieces were farmlands and were usually divided as rectangular shapes. However, if the priority of visualizing large datasets became higher than that associated with performing the matching task, a circular cartogram could be a good option. Its polygonal complexity would be lower, and a more compact layout could be available. Furthermore, a circular cartogram could even be simplified further into a graph that solely used nodes, edges, and labels

The visual encoding we proposed can be applied using various strategies. For example, if the expressiveness of the four cardinal-direction information (survey direction and four neighbors) was expanded to eight directions, the left diagram of Figure 6.3 could be reused by including the four corners. The domain experts commented that older textual cadasters may not include information such as area information. In this case, we should assume that every piece of land has the same area. So we should modify our cadaster layout algorithm and approximate it to a grid-like coordinate system. In such a system, the land could be placed next to other land in eight possible locations, and the diagram on the left in Figure 6.3 could be used to visualize the land pieces.

# Chapter 7

# Conclusion

In this dissertation, we have proposed an interactive visualization design tool, called JigsawMap, for analyzing and mapping historical textual cadasters. Such mapping of old and new cadasters can help historians understand the social and economic background of changes in land uses or ownership. JigsawMap can effectively connect the past land survey results to modern cadastral maps. In order to accomplish the connection process, three steps are performed: (1) segmentation of cadastral map, (2) visualization of textual cadastre, (3) and mapping interaction. We conducted usability studies and long term case studies to evaluate JigsawMap, and received positive responses. We summarize the evaluation results and present design guidelines for participatory design projects with historians.

Followed by our study on JigsawMap, we further investigated on each components of our tool for more scalable map connection. First, we designed a hybrid algorithm to semi-automatically segment land pieces on cadastral map. The original

JigsawMap provides interface for user to segment land pieces and the experiment result shows that segmentation algorithm accurately extracts the regions. Next, we reconsidered the visual encoding and simplified it to make textual cadastre more scalable. Since the former visual encoding relies on traditional map legend, the visual encoding can be selected based on user expert level. Finally, we redesigned layout algorithm to generate a better initial layout. We used evolution algorithm to articulate ambiguity problem of textual cadastre and the result less suffered from overlapping problem.

In summary, our visualization design tool will provide an accurate segmentation result, give the user an option to select visual encoding that suits on their expert level, and generate more readable initial layout that gives an overview of cadastre layout. Although our approaches are limited to cases studies for Korean cadasters, further collaborations will extend our matching method to be generalized for other textual cadasters in other countries, for example, Chinese textual cadastre with fish-scale registers. The proposed encoding will increase compactness and scalability of visualization. From computer science perspective, we can generalize four neighbor layout algorithm to planning inner-plant layout planning. The map reconstruction algorithm can be used in applications such as hand-drawn or home-made video object detection.

# Bibliography


[1] M. Agrawal, D. Doermann, "Stroke-like pattern noise removal in binary document images," *International Conference on Document Analysis and Recognition*, pp.17–21, 2011

[2] C. Ahlberg, C. Williamson, and B. Shneiderman, "Dynamic queries for information exploration: An implementation and evaluation," *Proc. ACM SIGCHI Conf. Human Factors in Computing Systems (CHI'92)*, pp.619-626, 1992

[3] M.J. Alam, T.C. Biedl, S. Felsner, A. Gerasch., M. Kaufmann, S.G. Kobourov, "Linear-time algorithms for hole-free rectilinear proportional contact graph representations," *Algorithmica* 67, 1, pp.3–22, 2013

[4] M.J. Alam, T.C. Biedl, S. Felsner, M. Kaufmann, S. G. Kobourov, T. Ueckerdt, "Computing cartograms with optimal complexity," *Discrete & Computational Geometry* 50, 3, pp.784–810, 2013

[5] M.J. Alam, S.G. Kobourov, S. Veeramoni, "Quantitative Measures for Cartogram Generation Techniques," *Computer Graphics Forum, special issue on EuroVis*, Vol. 15. 2015

[6] E. Arkin, L. Chew, D. Huttenlocher, K. Kedem, J. Mitchell, "An efficiently computable metric for comparing polygonal shapes," *SODA* (1990), pp. 129–

137, 1990

[7] B. Baily, M. Riley, P. Aucott, H. Southall, “Extracting digital data from the First Land Utilisation Survey of Great Britain–Methods, issues and potential,” *Applied geography,* 31(3), pp.959-968, 2011

[8] B. Baily, “The extraction of digital vector data from historic land use maps of Great Britain using image processing techniques,” *e-Perimetron*, 2(4), pp.209-223, 2007

[9] G. Di Battista, P. Eades, R. Tamassia, and I.G. Tollis, “Algorithms for drawing graphs: an annotated bibliography,” *Computational Geometry: Theory and Applications*, 1994, 4, 5, pp.235-282, 1994

[10] M.L. Berman, “Boundaries or networks in historical GIS: Concepts of measuring space and administrative geography in Chinese history,” *Historical Geography*, 33, pp.118-33, 2005

[11] T.C. Biedl, L.E.R. Velazquez, “Orthogonal cartograms with few corners per face,” *Workshop on Algorithms and Data Structures* (2011), vol. 6844, pp. 98–109, 2011

[12] K. Buchin, B. Speckmann, S. Verdonschot, “Evolution strategies for optimizing rectangular cartograms,” *Geographic Information Science (GIS’12)*, vol. 7478, pp. 29–42, 2012

[13] Y-Y. Chiang, “Harvesting geographic features from heterogeneous raster maps,” University of Southern California, 2010

[14] Y. Chen, R. Wang, J. Qian, “Extracting contour lines from common-conditioned topographic maps,” *IEEE Transactions on Geoscience and Remote Sensing*, 44(4), pp.1048-1057, 2006

[15] Y.-Y. Chiang, L. S. Leyk, C. A. Knoblock, “Efficient and robust graphics

recognition from historical maps," *Graphics Recognition, New Trends and Challenges*. Springer Berlin Heidelberg, pp. 25-35, 2013

[16] Y.-Y. Chiang, L. S. Leyk, C. A. Knoblock, "Integrating color image segmentation and user labeling for efficient and robust graphics recognition from historical maps," *The Ninth IAPR International Workshop on Graphics Recognition*, 2011

[17] M. De Berg, E. Mumford, B. Speckmann, "On rectilinear duals for vertex-weighted plane graphs," *Discrete Mathematics 309*, 7, pp.1794–1812, 2009

[18] M. De Berg, E. Mumford, B. Speckmann, "Optimal bsps and rectilinear cartograms", *Int. J. of Computational Geometry & Applications* 20, 2, pp.203–222, 2010

[19] D.B. Dhar, B. Chanda, "Extraction and recognition of geographical features from paper maps", International Journal of Document Analysis and Recognition (IJDAR), 8(4), pp.232-245, 2006

[20] G. Dharmaraj, "Algorithms for automatic vectorization of scanned maps," University of Calgary, Department of Geomatics Engineering, 2005

[21] D. Dori, W. Liu. "Sparse pixel vectorization: An algorithm and its performance evaluation," I*EEE Transactions on Pattern Analysis and Machine Intelligence*, 21(3), pp.202-215, 1999

[22] P. Ekamper, "Using cadastral maps in historical demographic research: Some examples from the Netherlands," *The History of the Family*, 15 (1), pp.1-12, 2010

[23] M. Elias, J. Elson, D. Fisher and J. Howell, "Do I live in a flood basin?: synthesizing ten thousand maps," *In Proc. SIGCHI 2008*, ACM, pp.255-264, 2008

[24] J. Elson, Howell, J., and Douceur, J. R., "MapCruncher: integrating the world's geographic information," *SIGOPS Operating System Review* 2007, 41, 2 ACM, pp.50-59, 2007

[25] S. Frischknecht, E. Kanani, A. Carosio, "A raster-based approach for the automatic interpretation of topographic maps," *Photogrammetric Engineering & Remote Sensing*, 32, pp.523-530, 1998

[26] E. Gamma, R. Helm, R. Johnson, and J. Vlissides, "Design Patterns: Elements of Reusable Object-Oriented Software," Addison-Wesley, 1994

[27] E.R. Gansner, E. Koutsofios, S.C. North, and G.P. Vo, "A Technique for Drawing Directed Graphs," *Trans. on Software Engineering* 1993, 19, 3 IEEE, pp.214-230, 1993

[28] FIG, Statement on the Cadastre, International Federation of Surveyors, Canberra, FIG Australian Bureau 1992–95 (1995)

[29] Google Map Maker, Sep 2011. http://www.google.com/mapmaker

[30] I. Gregory, C. Bennett, V. Gilham, S. Humphrey, "The Great Britain historical GIS project: From maps to changing human geography," *Cartographic Journal*, 39 (1), pp.37-49, 2002

[31] T. Gschwandtner, W. Aigner, K. Kaiser, S. Miksch and A. Seyfang, "CareCruiser: Exploring and Visualizing Plans, Events, and Effects Interactively," *Proc. IEEE Pacific Visualization Symposium*, 2011

[32] E. Hancer, R. Samet, "Advanced contour reconnection in scanned topographic maps," *IEEE International Conference on Application of Information and Communication Technologies*, 2011.

[33] T.C. Henderson, "Segmentation and Vectorization," Analysis of Engineering Drawings and Raster Map Images. Springer New York, pp.17-31, 2014

[34] J.L.G. Henssen, I.P. Williamson, "Land registration, cadastre and its interaction a World perspective," *Federation Internationale des Geometres*, XIX International Congress, 1990

[35] J. Henssen, "Basic principles of the main cadastral systems in the world," *Proceedings of the One Day Seminar held during the Annual Meeting of Commission* 7, Cadastre and Rural Land Management, of the International Federation of Surveyors (FIG), 1995

[36] X. Hilaire, K. Tombre, "Robust and accurate vectorization of line drawings," *IEEE Transactions on Pattern Analysis and Machine Intelligence*. 28(6) , pp.890-904, 2006

[37] X. Hilaire, K. Tombre, "Improving the accuracy of skeleton-based vectorization," *Graphics Recognition Algorithms and Applications*, Springer Berlin Heidelberg, pp.273-288, 2002

[38] D. Holten, and J.J. van Wijk, "A user study on visualizing directed edges in graphs," *In Proc. SIGCHI 2009*, ACM, pp.2299-2308, 2009

[39] D. Holten, P. Isenberg, J.J. van Wijk, and J. Fekete, "An extended evaluation of the readability of tapered, animated, and textured directed-edge representations in node-link graphs", *In Proc. PacificVis 2009*, IEEE, pp.195-202, 2009

[40] O. Hori, S. Tanigawa, "Raster-to-vector conversion by line fitting based on contours and skeletons," *IEEE International Conference on Document Analysis and Recognition*, 1993

[41] Hypercities. http://hypercities.com/

[42] R.D. Janssen, R.P. Duin, A.M. Vossepoel, "Evaluation method for an automatic map interpretation system for cadastral maps," *IEEE International Conference on Document Analysis and Recognition*, 1993

[43] W. Javed and N. Elmqvist, “Stack Zooming for Multi-focus Interaction in Time-series Data Visualization,” *Proc. IEEE Pacific Visualization Symposium*, 2010

[44] W. Javed, B. McDonnel, and N. Elmqvist, “Graphical Perception of Multiple Time Series,” *IEEE Trans. Visualization and Computer Graphics*, vol. 16, no. 6, pp.927-934, 2010

[45] H. Kang, B. Shneiderman, “Visualization methods for personal photo collections: Browsing and searching in the PhotoFinder,” *Proc. IEEE International Conf. on Multimedia and Expo 2000*, pp. 1539-1542, 2000

[46] D.A. Keim, S.C. North, C. Panse, “Cartodraw: A fast algorithm for generating contiguous cartograms,” *IEEE Transactions on Visualization and Computer Graphics*, 10, 1, pp.95–110, 2004

[47] D.A. Keim, S.C. North, C. Panse, J. Schneidewind “Visualizing geographic information: Visualpoints vs. cartodraw,” *Information Visualization*, pp.58–67, 2003

[48] D.A. Keim, C. Panse, S.C. North, “Medial-axis based cartograms,” *IEEE Computer Graphics and Applications*, 25, 3, pp.60–68, 2005

[49] K. Kim, “The Grasp on the Chinchôn and the Landholder through the Land Register and the Cadastral Survey,” *KYUJANGGAK 2010*, 37 KIKS (Kyujanggak Institute for Korean Studies), pp.1-30, 2010

[50] N. Kim, J. Lee, H. Lee, and J. Seo, “Accurate Segmentation of Land Regions in Historical Cadastral Maps,” *Journal of Visual Communication and Image Representation*, 25(5), pp. 1262-1274, 2014

[51] M.V. Kreveld, B. Speckmann, “On rectangular cartograms,” *Comput. Geom*, 37, 3, pp.175–187, 2007

[52] B.C Kwon, B. Fisher, and J.S. Yi, "Visual Analytic Roadblocks for Novice Investigators," *IEEE Symp. Visual Analytics Science and Technology (VAST'11)*, 2011

[53] Kyujanggak Institute for Korean Studies, May 2013, http://kyujanggak.snu.ac.kr/

[54] L. Lam, S. Lee, and C.Y. Suen, "Thinning methodologies-a comprehensive survey," *IEEE Transactions on pattern analysis and machine intelligence*, 14(9), pp.869-885, 1992

[55] G. Larsson, "Land registration and cadastral systems," *New York: Longman Scientific and Technical*, 1991

[56] K. Lee, S. Cho, Y. Choy, "Automated vectorization of cartographic maps by a knowledge-based system," *Engineering Applications of Artificial Intelligence*, 13(2), pp.165-178, 2000

[57] H. Lee, S. Lee, N. Kim, and J. Seo, "JigsawMap: Connecting the Past to the Future by Mapping Historical Textual Cadasters," *Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems*, CHI2012, ACM, New York, NY, pp.463-472, 2012

[58] H. Lee, J. Seo, "Research on Enhancing Textual Cadaster Visualization Design Using Compact Node Representation," *Telecommunication Review*, 23(2), 2013

[59] S. Leyk, R. Boesch, "Improving Feature Extraction of Composite Cartographic Information in Low-Quality Maps," *Cartography and Geographic Information Science*, 2008

[60] J. Lin, E. Keogh, and S. Lonardi, "Visualizing and Discovering Non-Trivial Patterns in Large Time Series Databases," *Information Visualization*, vol. 4, no. 2, pp.61-82, 2005

[61] K. Lyons, A., “Cluster busting in anchored graph drawing,” *In Proc. CASCON 1992*, 1, pp.7-17, 1992

[62] A. MacEachren, F. Boscoe, D. Haug, L. Pickle, “Geographic visualization: Designing manipulable maps for exploring temporally varying georeferenced statistics,” *In IEEE Symp. on Information Visualization*, pp. 87–94, 1998

[63] W. Meulemans, A. Van Renssen, B. Speckmann, “Area-preserving subdivision schematization,” *In International Conference on Geographic Information Science (2010)*, vol. 6292, pp. 160–174, 2010

[64] H. Miyajima, “Comparative analysis of Kwangmu yang’an and Cadastral,” *Research on the Cadastral Survey in Chosôn dynasty*, Minumsa, pp.199-248, 1997

[65] Z. Mou, “Using cadastral maps in historical GIS research: the French Concession in Shanghai (1931–1941),” *Annals of GIS*, 18 (2), pp.147-156, 2012

[66] J. Nielson, "Usability 101: Introduction to Usability," at http://www.useit.com/alertbox/20030825.html

[67] OpenStreetMap, Sep 2011. http://openstreetmap.org

[68] M. Rohrschneider, C. Heine, A. Reichenbach, A. Kerren and G. Scheuermann, “A Novel Grid-Based Visualization Approach for Metabolic Networks with Advanced Focus&Context View,” *In Proc. 17th International Symposium on Graph Drawing 2009*, pp.268-279, 2009

[69] T. Saito, H. N. Miyamura, M. Yamamoto, H. Saito, Y. Hoshiya, and T. Kaseda, "Two-Tone Pseudo Coloring: Compact Visualization for One Dimensional Data," *Proc. IEEE Symp. Information Visualization*, pp.173–180, 2005

[70] S. Salvatore, P. Guitton, “Contour line recognition from scanned topographic

maps" *Journal of WSCG*,12(1-3), 2004

[71] J. Sanyal, S. Zhang, G. Bhattacharya, P. Amburn, and R. J. Moorhead, "A User Study to Compare Four Uncertainty Visualization Methods for 1D and 2D Datasets," *IEEE Trans. Visualization and Computer Graphics*, vol. 15, no. 6, pp.1209-1218, 2009

[72] S.A. Shereen, H.E. ElDeeb, and D.M. Atiya, "A new model for automatic raster-to-vector conversion", *International Journal of Engineering and Technology*, 3(3) pp.182-190, 2011

[73] B. Shneiderman, "Dynamic queries for visual information seeking," *IEEE Software*, vol. 11, no. 6, pp.70-77, 1994

[74] B. Shneiderman, "The eyes have it: A task by data type taxonomy for information visualizations," *Proc. IEEE Symp. on Visual Languages 1996*, pp. 336-343, 1996

[75] B. Shneiderman, "Tree visualization with tree-maps: 2D space-filling approach," *Trans. on Graphics 1992*, 11, 1 ACM, pp.92–99, 1992

[76] B. Shneiderman, C. Ahlberg, "Visual information seeking: Tight coupling of dynamic query filters with starfield displays," *Proc. ACM SIGCHI Conf. Human Factors in Computing Systems (CHI'94)*, pp.313-317, 1994

[77] B. Shneiderman and C. Plaisant, "Strategies for evaluating information visualization tools: multi-dimensional in-depth long-term case studies," *In Proc. AVI BELIV 2006*, ACM, pp.1-7, 2006

[78] A. Slingsby, J. Dykes, and J. Wood, "Configuring Hierarchical Layouts to Address Research Questions," *Trans. on Visualization and Computer Graphics* 2009, 15, 6, IEEE, pp.977-984, 2009

[79] J. Song, M. Cai, M. R. Lyu, S. Cai, "Graphics recognition from binary images:

one step or two steps," *IEEE International Conference on Pattern Recognition*, Vol.3, pp.135-138, 2002

[80] J. Song , F. Su , J. Chen , C. Tai , S. Cai, "Line net global vectorization: an algorithm and its performance evaluation," *IEEE Conference on Computer Vision and Pattern Recognition*, Vol.1, pp.383-388, 2000

[81] B. Speckmann, M.V. Kreveld, S. Florisson, "A linear programming approach to rectangular cartograms," *In Symposium on Spatial Data Handling (SDH'06)* , pp.527–546, 2006

[82] B. Speckmann, K. Verveek, "Necklace maps," *IEEE Transactions on Visualization and Computer Graphics*, 16, 6, pp.881–889, 2010

[83] K. Tombre, C. Ah-Soony , P. Dosch, G. Masini, S. Tabbone, "Stable and robust vectorization: How to make the right choices," *Graphics Recognition Recent Advances,* Springer Berlin Heidelberg, pp.3-18, 2000

[84] L. Wenyin, D. Dori," From raster to vectors: Extracting visual information from line drawings," *Pattern Analysis & Applications*. 2(1), pp.10-21, 1999

[85] L. Wenyin, D. Dori, "A survey of non-thinning based vectorization methods," *Advances in Pattern Recognition*, Springer Berlin Heidelberg, pp. 230-241, 1998

[86] Wikimapia, Sep 2011. http://wikimapia.org

[87] J. Wood and J. Dykes, "Spatially ordered treemaps," *Trans. on Visualization and Computer Graphics*, 14, 6 IEEE, pp.1348–1355, 2008

[88] R-Q. Wu, X-R. Cheng, C-J. Yang, "Extracting contour lines from topographic maps based on cartography and graphics knowledge," *Journal of Computer Science & Technology*, 9, 2009

[89] Y. Yang, X. An, L. Huang, "Vectorization of linear features in scanned

topographic maps using adaptive image segmentation and sequential line tracking," *Int. Arch. Photogramm. Remote Sens*. Spatial Inf. Sci. XXXIX-B4, pp.103-108, 2012

[90] K.H. Yeap, M. Sarrafzadeh, "Floor-planning by graph dualization: 2-concave rectilinear modules," *SIAM Journal on Computing*, 22, pp.500–526, 1993

[91] Y. Zheng, H. Li, D. Doermann, "A model-based line detection algorithm in documents," *Proceedings of Seventh International Conference on Document Analysis and Recognition*, pp. 44–48, 2003

[92] Y. Zheng, H. Li, D. Doermann, "Background line detection with a stochastic model," *IEEE Workshop on Computer Vision and Pattern Recognition*, 2003.

# 요약

본 논문에서는 시각화 및 상호작용을 통해 국사학자들이 연구하는 양안 자료를 연결하는 도구인 JigsawMap을 제안한다. 양안은 공식적으로 나라에서 세금 및 토지평가를 목적으로 만드는 대장이다. 이러한 양안을 현대의 지적도와 연결하게 되면 국사학자들은 이전에 연구하지 못했던 당대 토지 이용이나 소유자 관계의 연구를 통해 당시 사회 및 경제적인 배경에 대한 이해의 폭을 넓힐 수 있다. JigsawMap은 근대의 양안을 효과적으로 지적도와 연결하는 작업을 도와준다. 이 작업을 수행하기 위해선 먼저 (1) 지적도 땅을 분할하는 과정이 필요하고, (2) 문자로 표현된 양안을 시각화해야 하며 (3) 이를 연결 하는 상호작용이 지원 되야 한다. 이를 평가하기 위해 본 논문에서는 사용성 평가와 장기적인 관찰 연구를 진행하였으며, 평가 결과를 바탕으로 국사학자와 협업 시 필요한 설계 지침을 제안하였다.

본 논문에서는 또한 JigsawMap의 확장성 개선을 위한 연구를 진행하였다. 먼저 지적도를 반자동으로 분할하는 알고리즘을 설계하여 실험을 진행하였다. 그 결과 높은 정확도로 땅을 분할하여 작업의 효율성을 높일 수 있게 되었다. 그 다음으로 땅의 시각적 인코딩을 보다 확장성을 높이는 방향으로 설계하여 집약화시여 표현하는 기법을 제안하고 실험을 진행하였다. 그 결과 기존의 시각적 표현보다 보다 겹침 현상이 줄고 많은 토지를 표현할 수 있게 되었다. 그리고 마지막으로 양안의 초기 배치 알고리즘을 개선하여 보다 안정성 있는 초반 연결 작업을 진행하도록 하였다.

종합적으로 보았을 때 본 저자들의 연구는 기존의 JigsawMap에서 지적도의 분할, 양안 표현의 다각화, 그리고 초기 양안 배치 개선 방안을 모

색하였다. 본 연구 통해 국사학자들의 양안 연결의 정확성을 높이고 보다 확장성 있는 연구를 진행할 수 있게 될 것이다. 그리고 컴퓨터 공학의 관점에서 보면 본 연구에 쓰인 네 방향을 이용한 배치 연구는 산업 분야에서 공장 시설의 최적화 배치 알고리즘을 설계할 때 응용이 가능할 것으로 기대된다.

주요어 : 상호작용 시각화, 그래프 배치 알고리즘, 이미지 분할, 양안 시각화, 불확실성 가시화, 장기 사례 연구
학 번 : 2008-20954