Towards Smart Sketch Maps for Community-driven Land Tenure Recording Activities

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Abstract

While sketching is widely deemed to be a powerful interface for expressing and recording land tenure information, many significant challenges must be addressed in order to automatically, or semi-automatically, interpret free-hand sketches. We present progress on our system which is being developed to facilitate sketch-based land tenure record creation in community based approaches. Given the community focus taken in this project it was necessary to address such issues as developing an effective visual language for sketching based on a well-defined model of the domain from the communities' perspectives; providing tools to recognise hand drawn elements of the visual language; deriving appropriate spatial representations based on qualitative spatial relations; and integrating the data from the sketch maps into a base topographic map. The paper outlines the main goal, workflows and components of our system for which we have already created prototype implementations for several of the components.

Keywords: Sketch map, land tenure, qualitative spatial representation, sketch map alignment.

1 Introduction

There is a growing urgency in the need to record land rights and tenure information in both urban and rural regions across the globe. According to some experts, up to 70% of land in many developing countries is not recorded in national land registries (Lemmen, 2010). At the same time countries such as Kenya, which are experiencing rapid urban growth around many of the urban centers, millions of parcels remain administratively unrecognised, leaving many land users and dwellers vulnerable and insecure (Lemmen, 2010). The technological dimension of this challenge is an important aspect: recording and mapping systems and processes that have been developed for European and Western contexts have thus far failed as effective tools for addressing the specific requirements in contexts such as rural Kenya and, more broadly, the East African region.

To help alleviate some of the technological challenges of this problem, we have proposed a system, called the Smart Sketch Maps land tenure recording tool, to support a bottom-up approach to land tenure recording. In this approach data about land relationships and rights are produced directly by members of the communities whose relationships and rights to the land are in question. Often facilitated by non-governmental organisations, the bottom-up approach involves participatory community mapping exercises in which the main output is a map of all the relevant features describing their lands (Knight et al., 2010).

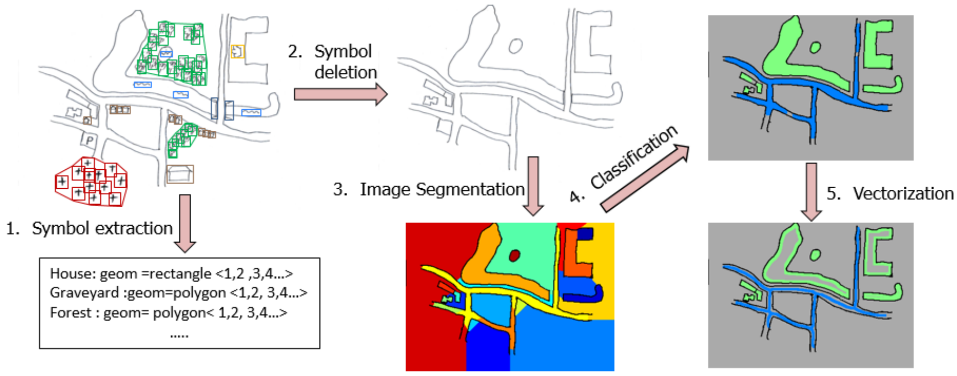
Our system allows users to submit a hand drawn sketch map produced during a community mapping exercise and then integrates some of the information in the sketch map into an underlying topographic base map. This, we expect, will expedite the community mapping allowing for several rounds of such an exercise to be carried out in short order. The system introduces two main improvements to the process: 1) the process of manually digitizing a community sketch map is time consuming and error prone - the automatic integration of sketched data can address this, 2) once an initial exercise has been performed, subsequent updates can be submitted to the system by the community without requiring a facilitator's presence.

In the following section we present a detailed description of the components of the system and we close the paper with conclusions and outlook in Section 3.

2 The Smart Sketch Maps System

The primary objective of the Smart Sketch-Map system is to provide a sketch-based recording tool for collecting land tenure information within the context of rural and peri-urban communities. The tool is composed of several components which come together to provide a single function: integrating the user's sketch into a base topographic dataset. In this section we describe each these components and outline how they work.

Figure 1: Sketch recognition framework for Smart Sketch Maps.



2.1 A specialized domain model and a visual language for sketching

Rather than working with unstructured, freehand sketches, we have opted for prescribing a visual sketch language. The challenge is in defining a visual language that is expressive enough to capture a variety of salient concepts, while not being "visually verbose" resulting in cluttered sketches that are difficult to interpret.

Pre-defined sets of symbols are generated each of which represents a specific class of features (e.g. tree, dwelling, etc.). The set of features, their relations and associated concepts form a local domain model that can express the local view of land tenure issues. The domain model documents the spatial concepts that users (e.g. pastoralists) consider important for their everyday activities, and in describing land and land relationships. This way the system is adaptable to the local cultural contexts of different communities as maps for each community are processed using the domain model developed for that community.

In the visual language symbols can be used during sketching to represent object positions within the map. Groups of symbols can represent aggregate objects such a forests or woodlots and symbols may also be used to simply apply semantics to objects with extended geometric representation (E.g. in Figure 1 before step 1 wavy symbols denote water and the class is applied to the entire closed region surrounding that symbol as shown in Figure 2). Extended objects are specified by contours. E.g. line objects represent streets and regions represent lakes.

Like the domain model, symbols of the visual language are developed separately for each community before the tool can be used by that community. Thus the sketching interface is customizable to fit the local context.

2.2 Sketch recognition

What makes smart sketch maps "smart" is that explicitly drawn spatial object are identified and assigned a semantic category. This makes them amenable to manipulation and deeper analysis. To achieve this "semantic recognition" a sketch map must first be segmented and the resulting segments classified into some semantic category.

Recognizing contours and individual symbols is necessary to identify specific features such as trees, houses, and water bodies. For this task we are exploring three main approaches. We have implemented a prototype symbol recogniser that is capable of identifying and extracting a variety of symbols (trees, houses, water body symbols, grazing symbols, etc.). Our prototype is implemented on top of OpenCV, using a combination of template based matching and supervised learning using Haar cascades to generate object classifiers. It generates bounding polygons as vector geometries for each identified objects (see Figure 1, step 1).

To identify objects that represent aggregate concepts such as forests, the system generates regions (i.e the forest area) for the groups of matched symbols that are spatially clustered using polygonal clustering methods – in this case the CLARANS approach of Ng & Han (2002). For other spatially extended objects (i.e. streets, large landmarks, and water bodies), the system uses specialized image recognition and interpretation methods developed by Broelemann (Broelemann & Jiang, 2013; Broelemann, 2011) and generates their vector representations (Steps 3 – 5 in Figure 1).

2.3 Qualitative representation

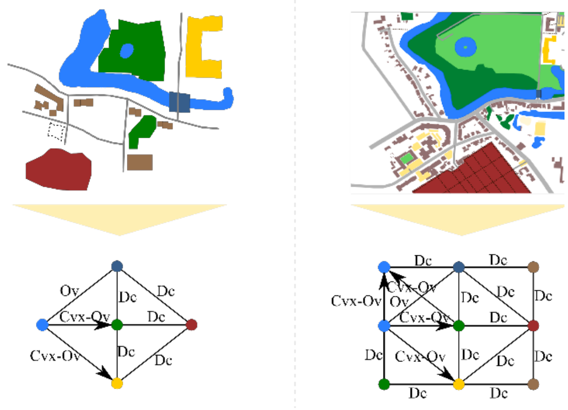
The information presented in sketch maps is based on human-perception rather than numerical measurements. Therefore, represented information is schematized, distorted, and generalized (Tversky, 1981; Tversky, 1993). These cognitive distortions are neither random nor solely due to a lack of detailed information (Tversky, 1993). As such the spatial representations used in the Smart Sketch Maps approach are qualitative.

In a qualitative representation of a map, only relevant qualitative relations are used to describe the map. By contrast, geometric representations that specify the exact location of every point of an object within a fixed frame of reference can be said to be quantitative (or numerical).

In our qualitative map, each object is represented as a node devoid of any explicit geometry (See Figure 2). The node is annotated with domain specific data by assigning it a class in the domain model along with values for any applicable attributes of that class. In the examples in Figure 2, the class assignment is represented by the color of each node such as green for forest, blue for water body, and golden-yellow for castle.

The locations of objects in a qualitative spatial representation are expressed in terms of their spatial relations with other

Figure 2: Qualitative representation of sketch maps



objects in the configuration. The spatial relations become attributes or labels for arcs joining the nodes. That is, for every pair of nodes there is an arc labeled with the set of spatial relations that hold between the objects represented by those nodes. There are many spatial relations within our model and others which may be derived from the domain model. An example of such relations are the set of topological relations derived from the spatial interactions of the participating objects. In Figure 2 three relations, Cvx-Ov, Ov, and Dc are used to illustrate how the arc labeling is done. A Cvx-Ov labeled arc from a node *x* to a node *y* states that the convex hull of object *x* overlaps object *y* and an Ov labeled arc indicates the stronger constraint that there is an overlap between the actual objects *x* and *y*. Relation Dc indicates that the two objects have no points in common.

It is worth commenting that the sets of relations used in our representations are not necessarily disjoint nor mutually exclusive as can be seen from the pairs of relations Cvx-Ov and Ov on one hand, and Cvx-Ov and Dc on the other.

While there exist many qualitative spatial relations that can be derived from geometric data, we seek to use only a limited set of relations that balance the level of precision in the information they capture against the extent of the distortions inherent in sketch maps. This is important for the task of aligning the sketch maps to topographic maps. Investigations into representations that perform well with respect to this balance have been reported in Wang and Schwering (2016) and Schwering et al. (2014).

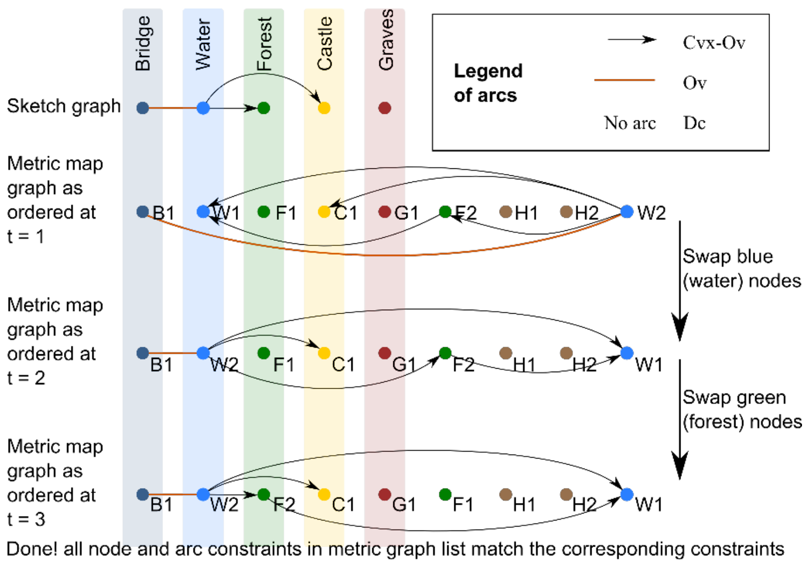
To derive the spatial relations several tools are being used including the constraint logic programming engine CLP-QS (Schultz and Bhatt 2014) and custom written qualifiers. Because the instances created are graphs the open source graph database Neo4J is used as a data store for the qualitative representations.

2.4 Qualitative Alignment

The main reason for using a qualitative representation for sketch maps is to be able to successfully align them to an existing base topographic map. The premise is that similar spatial configurations must have similar annotations and spatial relations for each object. Here object annotations and spatial relations can be seen as constraints on a configuration so that finding the best alignment becomes finding a correspondence between objects that minimizes constraint violations, i.e. a graph matching problem.

A simple way to see the process is by listing all nodes of the sketch map graphs in any desired order and inserting a labelled arc between any two nodes connected by an arc in the original graph (See Figure 3). The alignment then involves similarly listing the metric map nodes and then permuting them so that the first *n* nodes in the metric map list together with their out-going arcs correspond to the first *n* nodes of the sketch map list

Figure 3: Aligning a sketch map to a metric map can be done by iteratively suggesting a matching and improving on it by swapping out a metric map node that has constraints that are inconsistent with constraints of the sketch map node to which it is currently matched.



together with their out-going arcs in a way that minimizes the differences between corresponding constraints.

As seen in Figure 3, the node annotations serve to limit the set of metric map nodes to which a sketch map node can be matched. Arc labels then provide the necessary constraints to ensure that similar parts of the two configurations are matched together. Similarity in this case is measured using the similarity metrics of Nedas and Egenhofer (2008).

Several heuristics can be employed for finding the best solution for the alignment problem. We developed a metaheuristic approach in (Chipofya et al. 2016) which uses so-called Local Compatibility Matrices to compute two heuristic estimates, one for predicting the next node to match (in Figure 3 this would correspond to swapping out a matched node) and a second estimate to correct for the optimistic value of the first estimate after the swap. The heuristics have shown promising results and were able to match the maps in Figure 4 exactly using topological relations and cardinal direction relations alone.

2.5 Visualization of sketched information in a topographic map context

One challenge with the use of analog sketch maps as a mode for user interaction with the system is that there will typically be only one interaction between the software and the user which will occur when the user submits the sketch map. In addition there are limited options for providing feedback. But for land tenure purposes an important aspect of the data is that it reflects the intended information being provided. Therefore a critical requirement for the smart sketch maps system is a tool for visualizing the results of the alignment.

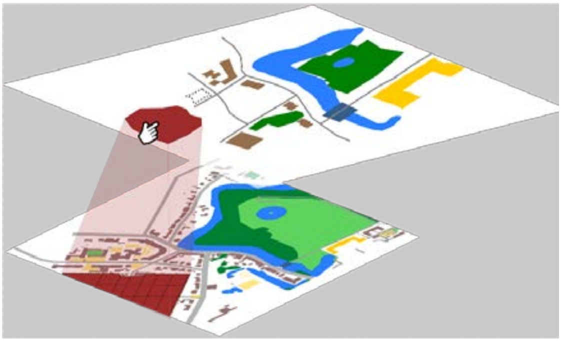
We see two main challenges in providing appropriate visual feedback to a user who has submitted a sketch map to the system. First a visualization must communicate the information effectively so that a user understands the map at a glance. This will require experimenting and testing with different techniques following human computer interaction design approaches such as those used by Stevens et al. (2013). That involves not only designing the visual layout of the data but also considering different physical devices on which to render the visual output including paper.

The second challenge is that before generating any visual feedback, all non-visible artefacts drawn in the sketch map, such as boundaries, must be computed within the metric map. For this we intend to use tools such as CLP-QS to generate vector geometries that satisfy the constraints in the qualitative representations of the original maps. Both of these tasks are work in progress. An example prototype for interactively visualizing the alignment between the maps of Figure 2 is shown in Figure 4.

3 Conclusion

The system described in this paper is intended to support sketch based user input for land record creation as well as editing. We have outlined the main aspects that enable the system to accept a sketch map and align it with a topographic base map effectively grounding sketched artefacts in the user's reality.

Figure 4: providing visual feedback to users remains a major challenge. In this figure a perspective overlay is used to show how the sketch map projects onto the base map.



Parts of our approach can be traced back to the works of Nedas and Egenhofer (2008), Wallgrün et al. (2010) and Schwering et al. (2014) but distinguishes itself in that we look at a complete workflow starting from the recognition phase to the integration and visualization phase. Our work builds on these previous results, integrating their critical aspects into a single, multi-component system with a very specific application. We trust that this work has the capacity to demonstrate the value and practicability of analogue sketching as a user interaction mode for Geospatial Information Systems.

The application to land tenure recording in rural and peri-urban regions in East Africa provides a real use case for evaluating our approach. At the moment a domain model and visual language are being developed for three different Masai communities in Kajiado County, Kenya.

Our work is still in its early stages but this paper serves to demonstrate that the solutions proposed are practical and build on well-established methods. The challenges remaining as outlined throughout the text will be the main focus of our work in the coming months and years.

Acknowledgement

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