How little is enough? Evaluation of user satisfaction with maps generated by a progressive transmission scheme for geospatial data

Fangli Ying, Peter Mooney, Padraig Corcoran, and Adam Winstanley

Geotechnologies Research Group,
Department of Computer Science,
National University of Ireland Maynooth (NUIM), Maynooth, Co. Kildare. Ireland
fying@cs.nuim.ie

ABSTRACT

Progressively transmission of vector data represents a promising means of delivering large amounts of geospatial data to mobile device users who are constrained by: small screen size, limited bandwidth, and limited device storage. A progressive transmission strategy works for a given spatial dataset by computing a series of level of maps at increasing detail. The theoretical approach of progressive transmission is to send every progressive level of the map. However, some users depending on their requirements may be satisfied with one of the intermediate level detail maps. This will result in a resource saving to the user in terms of both download waiting time and bandwidth. This paper discusses user trails to quantify user satisfaction with the output of this progressive transmission scheme, which is based on overall shape complexity of the geographical features in the map. Initial results indicate a significant relationship between Levels of Detail (LOD) and usability of the corresponding progressively transmitted maps.

1 INTRODUCTION

The Volunteered Geographic Information (VGI) movement has shown the potential to provide the data needed for Location-based Services (LBS) (Goodchild 2009) with OpenStreetMap (OSM) being one of the most promising VGI projects (Haklay and Weber 2008). The quality of data obtained using such a crowd-sourcing model can vary spatially which is mainly due to differences in skills, equipment, and ICT tools used by those who contribute data (Flanagin and Metzger 2008, Mooney et al. 2010). Some data may be poorly represented and consequently a poor representation of the features it represents. Transmitting vector data to mobile devices, from sources such as OSM, which can potentially contain variations in representation, presents a number of challenges including: different user interpretations of the same map; different user satisfaction with differing levels of variations and representations of maps; and different user expectations regarding the delivered spatial data on their mobile device. As outlined by Fairbairn (2006) there are many ways to measure map complexity including: spatial statistical measures, entropy and image-based indices. Our model uses shape complexity analysis (area ratio, shape circularity, vertex/node significance scores) to determine how a given vector map dataset could be progressively transmitted. Using map generalisation methods, guided by the shape complexity scores, a number of maps containing increasing levels of detail are computed and are progressively transmitted to the client. This paper describes the implementation of this progressive transmission model in a traditional client-server model. The client is a mobile device. We survey a number of users on "how usable" or "how satisfied" they are with the maps generated at selected iterative stages of the progressive transmission. We use the results of these user trials to draw some initial conclusions about the advantages of our approach. The evaluation of the outcomes of the user trials will also assist us in refining the progressive transmission model to better meet the map usability requirements of LBS users.

2 LITERATURE REVIEW AND MOTIVATION FOR THIS WORK

Due to constraints imposed by screen resolution and network bandwidth it is necessary to first transmit the most significant map details to mobile applications. Subsequent transmissions can transmit additional detail until the entire spatial dataset has been delivered successfully. Progressive transmission has many advantages including: the transmission of smaller data sizes, quick response times, and possibly the transmission of only relevant details (Bertolotto 2007). Many implementations of vector data progressive transmission have been suggested in the literature over the last decade such as: Bertolotto (2007), Buttenfield (2002), Wu et al. (2010) and Haunert et al. (2009). The maps of varying Levels of Detail (LOD), received by the user in a progressive transmission scheme, are generally created using map generalization methods. Many different forms of generalization algorithms exist. Such algorithms attempt to generate a generalization which satisfies particular goals which can be specified (van der Poorten et al. 2002). For geometric accuracy some methods of

generalization have been developed which maintain topological equivalence with the original map (van der Poorten et al. 2002). Many methods exist which attempt to preserve some shape characteristics of the original map (Wang and Muller 1998). Ontology driven generalizations methods use semantic information to determine a suitable generalizations (Kulik et al. 2005). For maps containing many polygons and lines a methodology for determining a globally suitable generalization is required. Fisher et al. (2005) proposed an approach for generalization of vector data tailored specifically for mobile devices with limited screen resolution. On-the-fly generalization, many of which are XML-based (Foerster et al., 2010, Ying et al. 2010a), may be applied to data such as OSM as it is available in an XML format. In this paper we use two generalization approaches. The well known Douglas Peucker algorithm is used for polyline simplification. For polygons it is very important to preserve shape/contour attributes for rendering on the small screen of a mobile device (Setlur et al. 2010). We employ a very well known method from the domain of computer vision which preserves a contours overall shape across levels of detail. The method by Latecki and Lakamper (2000) is a contour preserving approach to generalization of polygons. A separate issue is the software development of our approach. As outlined in Regnauld (2006) the author comments that he found "very few (generalisation) algorithms that we were able to try, in order to reuse them" and had to invest significant effort to develop algorithms. However this issue is being addressed by Neun et al. (2008) who illustrates the possible usage of generalisation support services as web services. Their WebGen framework implementation shows a great potential for enabling the interoperable, flexible and reusable deployment of generalisation algorithms.

When implementing a progressive transmission strategy it is important to perform generalization to obtain map levels which are suitable and exhibit good map usability. In Li (2006) a conceptual model was shown to assist in understanding user behavior and information preferences for LBS. Oulasvirta et al. (2011) conducted a study regarding the perceptual-interactive search people perform when using 2D and 3D maps on mobile devices. They state that mobile map applications should be friendly and with high usability. The visualization of multi-scale maps on mobile devices should also exhibit high usability. The problems of map display on mobile devices are exacerbated by the nature of spatial data, where a large information space needs to be presented and manipulated on a small screen (Tonder and Wesson 2009). In Lavie et al. (2011) the authors carried out trials of maps for in-vehicle navigation systems. The found that maps with minimal detail produced best performances and highest user evaluations. Cartographic aesthetics are also rated highly by their study participants. In map usability tests carried out by Kratz et al. (2010) the authors found that users preferred map zooming to map panning and scrolling. The authors comment that tasks such as map navigation require users to view and classify larger features of the map (in a zoomed-out state) in order to locate the point of interest they are interested in. In Harrie and Stigmar (2010) the authors provide some measures of map information that eventually should be used as constraints for the selection of data layers and in real-time generalisation. They found that measures such as the number of objects, number of points and object line length had better correspondence with human judgment than object area alone. In Rosenholtz et al. (2007) the authors warn against the "congestion" of the map and the problem of map objects "bleeding" into one another which creates visual clutter. While map designers often use color to differentiate map objects the authors find that this should be avoided as increased color variability increases visual clutter.

3 EXPERIMENTAL SETUP

In this section we describe the setup of the experiments. This includes a discussion of how our implementation of our progressive transmission model works in practice. The results from the user trials are then presented.

3.1 How our implementation of our model for progressive transmission works

The progressive transmission model is outlined in Figure 1 and described in Ying et al. (2010b).From the client device the map area for which spatial data is required is selected. The coordinates of this rectangular area are transmitted to the application server where the OSM XML is downloaded immediately. This OSM XML package is then processed server side. A Java application has been written to parse the OSMXML and create the necessary data structures to support the progressive transmission. After parsing the XML and binding the spatial data to Java objects the process of building the progressive transmission data structure begins. An array-based data structure is used where the nodes of the input spatial dataset are stored. A lookup table is maintained which manages the ordering of vertices for progressive transmission based on their removal during the generalisation process. The array-based data structures store a logical N-version model of the input dataset. The application software on the server then begins the transmission of the spatial data beginning at L0, the most generalised level and lowest level of detail. When L0 has transmitted successfully the nodes (and polygon structure information) for L1 is prepared for transmission. This

process is repeated until the final nodes of the original dataset are transmitted with LN. The nodes transmitted during L0 can be seen as the most important nodes or vertices in the overall shape structure of the polygons within the original dataset. The nodes transmitted to complete the final level LN are the most insignificant nodes of the map dataset. The user may decide that they are happy with the map representation at a given map level Lj and can abort transmission.
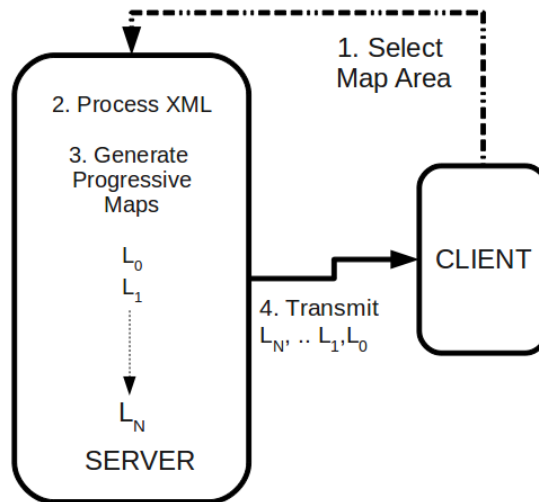

Figure 1: Schematic diagram of the implementation of our progressive transmission model
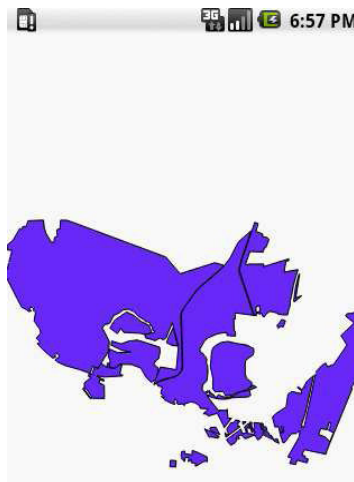
3.2 Details of User Trial Experiments

Figure 2: Screen shot of the emulation of a mobile device upon which user trials were performed

We recruited 10 users to take part in the user trials. At this time only users with a GIS background were available to take part. We ran our progressive transmission software for 10 input datasets. To ensure each user evaluated the same level Lk of the map we configured our client software to pause at 5 distinct levels: L5 the full version with no reduction in data size, L4 the original map dataset is reduced by 20% of its nodes (called r20%), L3 a further 20% reduction (called r40%), L4 a further 20% reduction (called r60%), and L5 a final 20% which represented an 80% reduction (called r80%) on the original map dataset. The delivery of the geospatial data to the rendering application on the client mobile device happens in the order L1 through to L5. A mobile phone running the Android OS was used. As learned from Rosenholtz et al. (2007) the screen display was kept simple and uncluttered. A screenshot of one of the map displays on the Android device is shown in Figure 2. The Map Datasets used in our trials were chosen as follows. We chose 10 case-study areas in OSM for map datasets. These study areas chosen exhibit variability in: shape complexities, number of features, and representation levels. We used the Processing framework (Processing, 2011) to generate the map images. In default operation of our software a user can select an area from OSM in two ways: from a

a simple web-map interface using OpenLayers or by selecting the "My Locality" option from the application menu. This sets the map center as the current position on the mobile device GPS. The OSMXML corresponding to this area is then downloaded automatically from the OpenStreetMap servers using the OpenStreetMap API. The size of the maximum bounding rectangle is limited - in our study to 2 square kilometers. The scale is set at 1:50000. To carry out an initial evaluation of our model we have omitted line features. However, line features will be included in future work. The 10 datasets selected include single polygon datasets and multi-polygon datasets. There are 4 datasets with one polygon: c42 (211 nodes), d14 (309 nodes), r16 (46 nodes), r50 (51 nodes). The remaining 6 datasets are multi-polygon and have between 277 nodes (n6) and 2172 nodes (n7). An example of this progressive transmission process applied to the N3 map dataset is shown in Figure 3. Results of the user trials were collected as follows. As users viewed the 5 levels of maps on the mobile device they filled out a questionnaire on paper. A ten point Likert scale (Duncan and Stenbeck 1987) was used in the Questionaire given to each subject with answers ranging from (1), which corresponds to "strong dissatisfaction with map", to (10) which corresponds to "strong satisfaction with map". This broad scale provides users a wide range of possible answers to correctly express their opinion. Table 1 (mean of all user scores) and Table 2 (standard deviation of all user scores) tabulate the results of the survey for all 10 users over all 10 datasets.
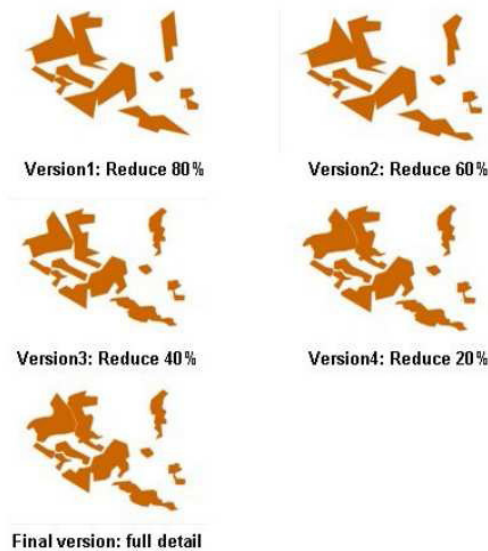

Figure 3: An example of the progressive transmission process where the user views five version of the same map.

4 FINDINGS AND DISCUSSIONS

In our experiments we attempted to quantify how satisfied users were with progressive generated maps. We also attempted to quantify if this satisfaction is sufficiently strong to introduce stopping conditions to potentially avoid having to send all of the map data. Results indicate that user satisfaction has nonlinear relationship with data reduction size. Satisfaction only reduces slightly when the data is reduced by 20% or 40% but satisfaction reduces sharply in the more simplified versions (60% and 80%). Over represented examples exhibit greater user satisfaction at greater data reduction percentages. For example the study areas r16 or r50 have large standard deviations in user satisfaction levels. We believe that when generalization approaches completion or the feature shapes are under-represented then significant poping effects occur between levels. The sharply decreasing users scores in the 60% and 80% reduced maps indicate that some of the most simplified versions are not liked by users. If a polygon is over-represented simplification is necessary to reduce the data size before transmission to a mobile device with limited capabilities. Users do not recognize additions to the map during the progressive transmission after a sufficiently good shape representation has been obtained. In regard to some specific observations there are some points which should be highlighted. The satisfaction amongst users of maps the single polygon examples (C42, D14, R16, R50) is very positive for the full version and R20% but quickly degrades for other versions. In the cases of the single polygon examples, combined with a low number of nodes used to represent the polygon, these shapes lose their shape characteristics quickly. Users commented that the generalised version of these

polygons were too sharp and jagged. For the multi-polygon the satisfaction with the maps at different levels of refinement are more

Table 1*: This table outlines the mean of all user scores for each level Li of each of the 10 map datasets used in the user trials*

Set	Final	R20	R40	R60	R80
C42	8.5	7.6	7.9	4.4	3
D14	8.6	7.2	5.3	3.9	3
N1	8.6	8.5	6.5	4.1	4.2
N2	8.2	7.3	5.9	3.8	3.2
N3	8	7.7	5.9	3.7	3.2
N4	7.9	8	8.2	8.1	8.1
N6	6.3	6.2	5.1	3.9	3.1
N7	7.9	7.9	8	6.4	3.9
R16	6.1	6.2	4.9	3	2.2
R50	6	4.7	4.1	3.2	2.3

Table 2*: This table outlines the standard deviation of all user scores for each level Li of each of the 10 map datasets used in the user trials*

Set	Final	R20	R40	R60	R80
C42	1.27	1.90	1.37	1.58	0.94
D14	1.07	1.23	2.06	1.85	1.15
N1	0.97	1.18	1.35	1.45	2.04
N2	1.03	2.11	0.32	1.69	1.14
N3	1.25	0.48	0.99	1.70	1.99
N4	2.02	1.83	1.75	1.91	1.91
N6	2.26	2.04	1.20	1.37	2.08
N7	0.74	0.57	0.67	1.96	1.52
R16	1.52	1.75	1.37	1.83	1.14
R50	1.83	1.89	1.66	1.87	2.06

spread out. For datasets N2, N4, and N7 there is high mean satisfaction with each level presented to the users. However the standard deviations of these satisfaction ratings in table 2 show a wide spread of scores for each level. This is potentially caused by the fact that these datasets are well represented (sufficient nodes). The generalised versions remove insignificant vertices from the polygons. But the polygons retain their overall structure and shape characteristics

4.1 Issues for further research work

There are a number of important issues which provide a firm basis for further research on this topic. **Additional user testing**: On the basis of the results it will be necessary to carry out more user testing. It will be necessary to attempt to determine the statistical significance of the apparent strong preference of users for better representations of the map datasets against the very heavily generalised version of the same dataset. **Generalization Research and Integration of line features**. In this paper we only considered polygons features. Currently we are including line features in our implementation of our model for progressive transmission. As the popularity of geospatial web-services grows we will be investigating the use of web services in our software implementation. For example Neun et al. (2008) describes their WebGen platform "a processing service for providing algorithms and processing power to be executed remotely". **Map appearance and aesthetics:** The projection of the map on mobile display and the aspects of visual appearance, such as colour and texture, will also be considered. This may potentially involve the integration of metrics which quantify the user's visual satisfaction with the map to guide the simplification for multi-scale representations. We will be carrying out additional user testing with more participants. These will be drawn from a wider population with different backgrounds: age, GIS skills, usage of mobile mapping, etc in an effort to validate our proposed model. In the long term this research work aims to improve the conditions for transmitting large quantities of spatial data to mobile devices. Mobile devices have to perform in the

environment where user is always on move; in the state of hurry and different situations are distracting attentions of user away from task in hand ((Frank et al., 2004). Progressive transmission strategies may be the most suitable for users who want spatial data in these types of situations.

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