Visualization of multi-resolution spatial data in mobile system

Jean-Michel Follin, Alain Bouju, Frédéric Bertrand and Patrice Boursier
Laboratoire Informatique, Image, Interaction
Université de La Rochelle
{jean-michel.follin, ...}@univ-lr.fr

Introduction

Development of mobile technologies (i.e. communications and devices) allows a mobile user to have access to geographical information from anywhere through web mapping application. The served data have to be aware of the user's location and circumstances [7], i.e. they have to be context-aware.
Our works aim at extending a mobile spatial information visualization system to multi-resolution [2]. In order to adapt represented data to the user's needs, we adopt an intelligent zoom approach respecting principle of equal density of displayed data.
In section 1, we present our framework allowing multi-resolution navigation in an embedded spatial information visualization system. After a description of works related to data visualization in section 2, we propose a methodology and present first experimentations to adapt visualized Level of Detail (LoD) data to the scale of representation in section 3.

1. General architecture and formalism

Our embedded spatial information visualization system manages multi-resolution data with a strategy based on use of increments, seen as difference between two data sets with different LoDs. This incremental strategy allows reuse of already available data at different LoDs.

1.1. General architecture and basic principles

Our system is divided in two main parts. The *client* manages data visualization, user requests and communication with data server and the *server* manages the data and the access to data sources.
The system uses standard technologies: Global Positioning System (GPS) for the real-time localisation of mobile user, Personal Digital Assistants (PDAs) or pocket computer for the visualization of spatial information by the client and cellular phone (with communication standards UMTS, GPRS or GSM) for the communication between client and server. Our purpose is to minimize the amount of data exchanged between client and server [10].

The following hypothesis are made for the management of data. All data are centralized and can only be modified on server. Data transfer is performed as an answer to a client request. Management is possible on the client side: reuse of locally available data allows to display requested information without connection to the server.

Our formalism of multi-resolution data is based on an incremental strategy with notions of LoD representation, LoD operators (generalization and refinement) and increment.

1.2. Formalism of data and incremental strategy

This formalism allows reuse of locally available parts of objects during transition between different LoD, i.e. either during a zoom out (decrease of detail) or during a zoom in (increase of detail).

A *LoD representation* correspond to a geographical object version defined for a scale interval. As our study focus only on geometric aspect (and not on attribute), we consider it is a geometric object. LoD representation of an object at a level of detail lod_n can be noted o^n.

The difference $\Delta o^{n \to n \pm 1}$ is defined for a given transition between lod_n representation and lod_{n+1} or lod_{n-1} representation of the same object o.

A *LoD operator* allows to perform changes on objects geometries after a request of transition from lod_n to lod_{n-1} or lod_{n+1}.
The matching configuration correspond to the number of matched LoD representations of same real world entities (when objects are represented at both LoD). According to matching configuration, LoD operators can be seen as different spatial entity mapping procedures [1]: $1:1$, $1:n$ or $n:m$ spatial entity mapping procedures. Examples of mapping operators of generalization (1) and refinement (2) are shown in Figure 1.

The *increment* can be defined as LoD operators associated to the difference between two consecutive LoD of a

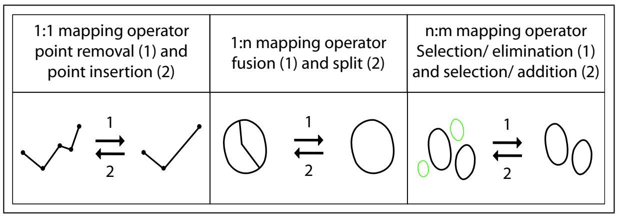

Figure 1. Different LoD operators.

single object or dataset.
In the case of $1:1$ matching configurations, the increment allowing transition from lod_n to lod_{n+1} (resp. lod_{n-1}) representation of object o can be noted by $Inc(o, n \rightarrow n+1)$ (resp. $Inc(o, n \rightarrow n-1)$).
Use of an incremental strategy allows reducing the amount of data transferred from server to client by reusing, when possible, already locally available data.
Data and transfer models suited to multi-resolution data in an embedded context and preliminary experimentations have been described in [3].

Given a sequence of gradually simplified representations of the same area, our purpose is to determine adapted scale interval for each LoD layer. We adopt an approach based on density of visualized data.

2. Visualization of multi-resolution data

Visualization in an embedded context is the exploration of data graphically in order to enhance the user's experience and understanding of the surrounding world by using mobile computing resources [7].
For the purpose of this paper we will consider devices such as Personal Digital Assistants (PDA). Typically a PDA has a display size of 4 to 5" (i.e. from 10,16 to 12,70 cm) and a display resolution from 160×160 to 240×240 pixels [9].
Visualization of multi-resolution data must be adapted to small display constraints.

2.1. Solutions of visualization

There are three possible solutions to provide mobile user with different scale maps on a single screen [6]:

- either different scale maps are viewed in the full window and the user switch between them,
- either different scale maps are simultaneously shown: large-scale map is presented in main window and small-scale is shown in a key-map,
- either different scale data are integrated and presented in a same map: peripheral (i.e. contextual) information is displayed with less detail than information in the vicinity of the user's position (i.e. in the focus) [5]. Selective reduction of information can be obtained by filtering and/ or distortion techniques.

This study is devoted to the first solution. This approach appears more interesting to visualize data on a small screen than second one and more suited to our incremental strategy than third one.

Zoom is necessary any time the user wishes to change either the visible range of data on the screen or its detail [11]. In an embedded context, scale change can also be chosen based on the user's speed, available ressources of mobile device or communication speed.
Zooming can be done in three different ways.
The *graphical zoom* is a simple change of scale factor without change of detail (fig. 2).
The *content zoom* gives more detailed information in the window of interest (fig. 3).
The *intelligent zoom* mimics the approach of the viewer to an object: when the field of vision become smaller, more detail about the displayed object appear (fig. 4).
In client-server context, it is assumed that the intelligent (or dynamic) zooming is done by requests whereas graphical (also called static) zooming is provided by the client [8].

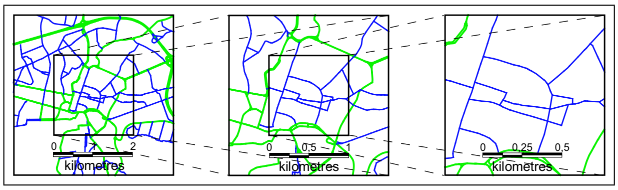

Figure 2. Graphical zoom: simple enlargement of the displayed objects when zooming.

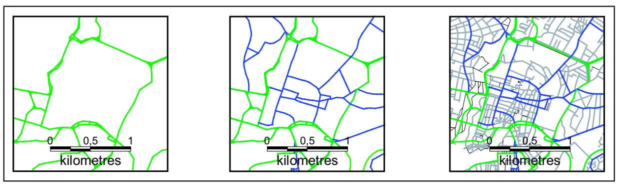

Figure 3. Content zoom: more content information in the same viewing window.

In our system, we adopt an intelligent zoom approach "which respects the known principle of equal information density" [11].

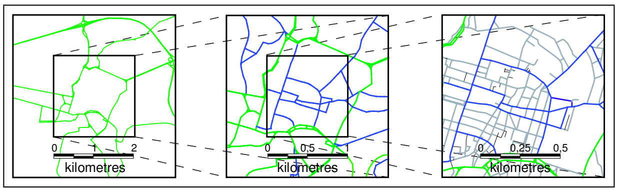

Figure 4. Intelligent zoom: adaptation of LoD data to the representation scale.

2.2. Principle of constant information density: related works

We aim at finding a balance between quantity of LoD data and the window size used to display it in order to provide appropriate level of information to the user.
Adequation between LoD of data and scale of representation is illustrated by the *principle of constant information density* known in cartography as Töpfer's radix law [4]. This law posits that the number of object per display unit should be constant as the user zooms. More generally, the amount of information should remain constant whatever the map scale is. For [12], a "well-formed application" is one that conforms to that principle.
Given a set of maps produced (manually or with a computer-assisted tool) at different scales, the multi-scale tree algorithm is proposed in [4] to automatically produce different views of the data as the user zooms. These views would have a constant number of active pixels.
Environment proposed in [12] interactively guides users in the construction of applications with constant information density. This visualization environment supports two density metrics: number of objects and number of vertices.

Such graphical density measures can be adopted in a mobile spatial visualization system in order to display LoD representation adapted for the selected scale.

3. Experimentation and simulation results

We can use information density metrics to search thresholds after which a change of LoD is necessary. If the metric for LoD representations o^n displayed on screen is greater than a given value, representations o^{n+1} of the preserved objects must be displayed instead.
Our dataset is composed of three LoD layers of a vector map representing the transportation network of La Rochelle city. It is composed of only polylines. This set of LoD layers has been produced by generalization (by selection and simplification) in order to be adapted to an incremental management of data.
Visual index of number of vertices visible on screen (i.e. covered by the viewing area) has been computed for the three LoD datasets and seven different window sizes (i.e. different representation scales) (fig. 5). We use three GPS routes (i.e. three sets of coordinates collected at regular time steps with a car equipped with GPS) in La Rochelle city to simulate the real time navigation of a vehicle.
We average visual index for the three GPS routes for each level of detail and each windows size. According to a device's display size of $12,7$ cm, the different viewing areas (from $300 * 300$ m to $1750 * 1750$ m) correspond to different scales (from about $1 : 2500$ to about $1 : 15000$). For example, on average $47,17$ vertices are viewed on screen for $lod2$ data in $1000 * 1000$ window (i.e. for a scale of about $1 : 8000$ on a PDA's screen).
Two conditions have to be verified in order to determine adapted scale ranges: respect of the principle of constant information density and a "good" level of density for the user. With average numbers ranging from 44 to 53, a similar level of displayed vertices can be observed for each LoD layer (cf. purple dotted line in fig. 5). We can consider that appropriate scales are:

- around $1 : 2500$ for $lod1$ layer,
- around $1 : 8000$ for $lod2$ layer,
- around $1 : 15000$ for $lod3$ layer.

Appropriate scale intervals for each LoD layer can be centered around these central values. An intelligent zoom respecting this adequation between LoD and scale is shown in figure 6. It illustrates zoom out operation of a mobile user. Displayed information appear to have a "good" level of density by avoiding to overload the map reader with too much data. We can notice that problems occur during a transition from $lodi$ to $lodi + 1$ when mobile user is localized on a street which disappears between these two LoD.

In addition to vertices number, we plan to use other data density metrics like number of polylines displayed for the most part in the viewing area and total length of the parts of polylines which are extended into window.

Conclusion

In a mobile spatial information visualization system, different resolution data have to be provided to user. In order to adapt these data to requested scale, we have adopted a LoD based approach with an intelligent zoom respecting the principle of constant information density. By measuring a density index, appropriate scales which respect the above

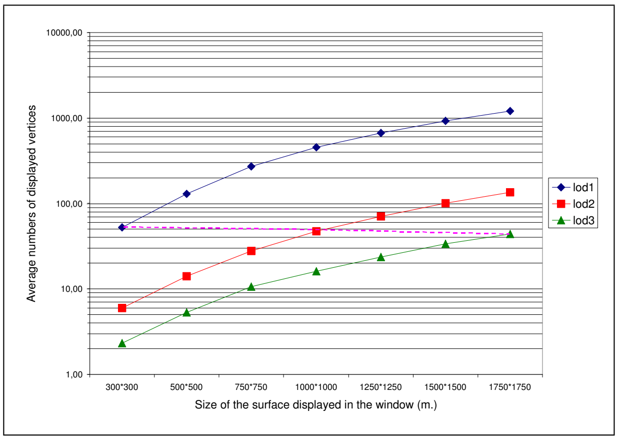

Figure 5. Average numbers of displayed vertices on a screen for different LoD data.

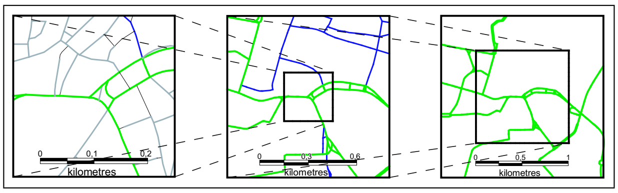

Figure 6. Intelligent zoom with constant information density.

seen principle have been chosen for each LoD layer.
For future works, factor of human perception could be taken into account with an user oriented procedure of test to define what is a "good" level of density in an embedded visualization system. Furthermore, limits of the adapted scale ranges must be determined more accurately and a way of changing LoD representations of objects during transition should be adopted.

Acknowledgment

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