URB 08 GeoSIM: An Urban Sensing System for Social Image Mapping of Urban Geolocations

URB 08.1 People

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URB 08.2 Overview

We envision GeoSIM (Geo Social Image Mapping)\(^2\) as an urban sensing system with which a group of individuals with camera-equipped mobile phones participate in collaborative/social mapping of the urban image (i.e., the texture of the urban environment) at some target geolocation (see Figure 1). The participating group, which may either consist of dedicated individuals or the general public, are directed to capture geotagged images of the urban environment. The collected images are progressively used for documentation of the dynamic urban scene in multiple spatial resolutions and at different times.

We introduced GeoSIM as a motivating application (and system) to pursue the following research objectives:

- Efficient solutions for participatory acquisition of urban visual data; and
- Effective solutions for texture mapping once the visual data is collected.

\(^2\) [http://infolab.usc.edu/projects/GeoSIM/](http://infolab.usc.edu/projects/GeoSIM/)
URB 08.3 Approach
Below, we summarize our research approach to address each of the two objectives mentioned above:

- For efficient participatory acquisition of the urban visual data, GeoSIM must plan the participation of the GeoSIM users such that the required images are taken efficiently, fast and comprehensively, while ensuring that the constraints and preferences of the participants are satisfied (to provide the social incentive for participation). Deriving the participation plan for each user involves identifying the navigation path(s) that satisfy the user constraints while maximizing the exposure of the user to uncovered sights (for fast and comprehensive texture mapping). Our approach to achieve this objective is to reduce the participatory acquisition problem to a set of novel spatiotemporal queries for multi-destination path planning with constraints (i.e., variants of TSP), as well as complex visibility/line-of-sight queries for exposure analysis along each path.

- It is important to note that path planning and visibility analysis are interdependent problems, i.e., to identify the optimal path first one needs to perform visibility study to find the best destinations from the sight-exposure perspective, while to avoid the complex (and probably infeasible) visibility study of the entire urban area from every point of view, one first needs to find the possible paths and limit the visibility study to the points of view along those paths. Instead of developing a holistic solution for these problems, we start by developing a sub-optimal solution with which we first identify the possible paths only according to the user constraints (disregarding the sight-exposure quality of the path), and thereafter, analyze each possible path for visibility and choose the path with maximum exposure.

For effective texture mapping, GeoSIM must enable merging the collected images in real time, in order to generate the evolving texture of the urban environment as new images arrive. Reconstructing generic scenes using uncalibrated images is a known difficult computer vision problem. To achieve this objective, we take a pragmatic approach by developing a stack of pipelines to be used depending on the available preexisting data. If a low resolution texture is available together with an underlying geometric model, we attempt to merge the incoming images by matching image features and incorporate the existing geometric information. In the simplest case, supposing that locally the surface of an object is planar, a robust estimation of the underlying image homography should suffice in most cases to register an incoming image with and existing texture. We integrate the geotag of the images and use the line-of-sight query to locate the faces of the objects that are visible. This computationally inexpensive approach allows for quick registration of the incoming images for already mapped zones, and also supports merging new images when these overlap with sufficient features. On the other hand, if no texture is available for a given object, but a geometric model is present, we attempt to carry out a Euclidian reconstruction using all the available images on the area and incorporate the preexisting geometrical information. The system handles requirements in terms of how many images are needed to validate a given object texture. Finally, if no information is available we attempt to reconstruct a set of plane surfaces solely based on the image information. This is the most difficult and generic case. In all cases, we use other available data sources in conjunction with the object recognition algorithms on the images to detect and segment objects such as trees that may cause undesirable results in the reconstructions and textures.

GeoSIM Architecture
GeoSIM is being built on top of GeoDec, a scalable geospatial data management engine that we have developed at USC. Figure 2 depicts the architecture of GeoSIM. To develop GeoSIM, as the first step we are extending GeoDec to GeoDec+ to support the requirements of GeoSIM. In the second (and last) step, we will develop GeoSIM as an application on top of GeoDec+ by introducing two new modules corresponding to the two research objectives mentioned above: 1) a coordination engine that plans participation of the GeoSIM users for efficient, fast and comprehensive participatory texture mapping, and 2) a texture generation engine that depending on the available preexisting data (either low resolution texture together with the underlying geometric model, only the geometric

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3 http://infolab.usc.edu/projects/geodec/
model, or no preexisting data at all), develops the urban image.

Currently, we are at the first step of the development process while planning to develop a prototype for the coordination and texture generation modules based on our research accomplishments (discussed below) to move on to the second step.

**URB 08.4 Accomplishments**

Below, we summarize our research accomplishments toward the two objectives mentioned above:

- **Toward efficient participatory acquisition**, we have investigated and developed solutions for both path planning and visibility analysis. With path planning, we focus on “on-the-fly” users participation planning in a participatory texture documentation (PTD) framework. We term this problem the UPPTD (Users Participation Planning for Texture Documentation) problem. With UPPTD, we investigate solutions to generate participation plans for the users such that all users constraints (e.g., limited participation time) are satisfied while at the same time the participation plans are optimized across users for fast urban texture documentation. We proved that UPPTD is an NP-hard problem by reducing it to the well-known orienteering problem, and accordingly, proposed an individual-based scalable (and efficient) heuristic solution for UPPTD that trades optimality of the plans to achieve on-the-fly users participation planning. With this solution, we strike a balance between optimality of the generated participation plans and the time required to generate the plans. We have studied, profiled and verified our proposed solution by both rigorous analysis and extensive experiments.

  On the other hand, for visibility analysis we formulated the problem of Approximate Visibility Query (AVQ) and developed an efficient solution for answering AVQs in dynamic environments, such as the urban environments we intend to document using GeoSIM. Visibility query is the basis of many analysis and decision-making operations in large environments. Visibility computation is time complex and the complexity escalates in dynamic environments, where the visibility-set of any viewpoint is probe to change at any time. However, exact visibility query is rarely necessary. Moreover, it is inefficient, if not infeasible, to obtain the exact result in a dynamic environment. We formally defined AVQ as follows: given a viewpoint \( v \), a distance \( \varepsilon \) and a confidence \( p \), the answer to an AVQ for the viewpoint \( v \) is an approximate visibility-set such that its “distance” from the exact visibility-set is guaranteed to be less than \( \varepsilon \) with confidence \( p \). Moreover, we proposed an approach to correctly and efficiently answer AVQ in dynamic environments. Our approach is based on the intuitive observation that there exists a significant spatial auto-correlation among visibility-sets of the viewpoints, i.e., the similarity/intersection between the visibility-sets of two points is positively correlated with the distance of the points. Therefore, one can approximate the visibility-set of a point based on those of its proximate neighbors. Accordingly, we devised a novel index structure with which we partition the space into disjoint cells and select a representative viewpoint for each cell such that the distance between the visibility-set of any given viewpoint in the cell and that of the representative viewpoint would not be more than the distance \( \varepsilon \) with confidence \( p \). Thus, the answer to the AVQ for point \( v \) can be approximated with the visibility-set of the representative point of the cell to which it belongs. Our extensive experiments showed validity of our initial observation about spatial auto-correlation of the visibility-sets as well as efficacy of our solution.

- **Because of the complexity of the problem**, we are concentrating on developing a texturing solution for the case where an initial geometry is known (for the case where an initial either poorly textured or un-textured
Once this pipeline is operational we plan to extend it as described above. We have partly developed a mobile solution where a template image is sent to users in the form of an overlay to guide the acquisition. The template is rendered from a virtual camera emulating the users’ mobile phone camera at a virtual location from within GeoDec (our GIS query and visualization software). After the image has been taken by the user, it is transformed/merged in a texture by registering the new picture with previously taken overlapping ones (provided that the lighting conditions were compatible); the registration uses the software we have integrated that computes an optimal projective transformation between planes from features extract by a scale invariant feature detector (SIFT). In parallel we are developing machine learning algorithms capable of providing a measure of quality for the images taken.

**URB 08.5 Future Directions**

Below, we enlist our future directions:

- Proceeding with step two of the GeoSIM system development as described above
- Developing other solutions for path planning and performing comparative study among existing solutions and our solutions
- Integrating our path planning solutions with visibility analysis solutions to develop a consistent solution for efficient acquisition of the visual data
- Extend visibility calculations and planning to take into account resolution, image quality, and occlusions (as detected in user generated images)
- Expand texturing to cases where no prior geometry is available and render the resulting geometry and textures in ways that shows the uncertainty in the data

**URB 08.6 External Research Partnerships**

- **Current partnership:** GeoSIM is a collaborative project between USC and UCLA.
- **Planned partnership:** As part of a large proposal to the NSF Expeditions program, we formed a large alliance including 5 schools at USC, UCLA-CENS, UCLA Joint Institute for Regional Earth System Science and Engineering (JIFRESSE), Cal-State Long Beach, Cal-State LA and Howard University. The topic of the proposal is on developing a new computing paradigm, called *GeoRealism*, and complement and expand the efforts discussed in this report.