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ÚSTAV POČÍTAČOVÉ GRAFIKY A MULTIMÉDIÍ

PhD Thesis

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Polohově závislé plánování přenosu dat pro aplikace procházení distribuovanou virtuální scénou

Location-aware data transfers scheduling for distributed virtual walkthrough applications

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1. INTRODUCTION

Imagine a mobile application which renders a 3D scene such as foreign city or large landscape. The data for rendering the scene is downloaded from network via mobile data connection. A user of such application is exploring these places, moving towards the points of interest or is moving all around. In this thesis, a new location-aware data transfers scheduling method which increases the rendered image quality and data transfers efficiency is proposed for the users of such applications.

The main bottleneck of these applications (called distributed virtual walkthrough applications) is network connection. It is affected by restrictions such as high latency and low bandwidth. To reduce a low network bandwidth the multi-resolution data representation is needed. First much coarser resolution of the scene is downloaded, followed by finer resolutions successively. The negative impact of low bandwidth and high latency should be further reduced with the help of priority determination and data prefetching algorithms.

Therefore, the goal of the proposed scheduling algorithm is to compute priorities of missing data for rendering the current view and to additionally prefetch some scene data in advance to achieve both the high image quality and data transfers efficiency.

As the mobile devices can be easily personalized and their position can be determined using embedded GPS module, the priority of the current missing data and prefetching can be determined from the predicted user location.

2. STATE OF THE ART

The data transfers scheduling is a complex process which depends on both scene data representation and rendering algorithm used.

2.1. Visibility determination

Scheduling methods for DVW applications widely use area of interest (AOI) determination algorithms [1], [2], [3], [4]. Instead of downloading complete scene, it is sufficient to transfer only data in spherical area around an observer. Objects inside this area can be regarded as objects from potentially visible set (PVS) with high download priority. In [5] the AOI is divided to sections with different download priority taking into account the view frustum and the distance from the observer. The AOI based scheduling methods are not suitable for more complex scenes such as terrains. Marvie et al.[6] used PVS to schedule data transfers for complex virtual scene divided to cells by a regular grid. Download priority of PVS of adjacent cells is determined by simple ray-casting method based on last two viewpoints. The visibility determination is also used to eliminate transferring of scene parts which are invisible.

2.2. Motion function

Data transfers scheduling algorithms based on motion functions use vector representation of object motion, position and direction. Motion functions can be classified into linear and nonlinear [7], which are more accurate than the linear methods. Chim et al.[3] proposed exponential weighted moving average (EWMA) motion prediction scheme which assigns different weights to past motion vectors where more recent vectors have higher weights. CyberWalk [8] uses the EWMA scheme to achieve at least a minimum resolution of the scene. Scheduling algorithm proposed in [9] selected objects to be sent to the client device based on integral of a benefit measure along predicted path. The prediction is made at server and is based on the assumption that once a particular type of motion is started, it will continue in the near future. This approach does not consider any previous positions. A motion-aware approach which uses the state-of-the-art recursive motion function [7] for efficient evaluation of continuous queries on 3D object databases is described in [10]. The predicted positions here are used to determine download priorities of progressively recorded objects inside a virtual scene so that only exact portion of each object will be downloaded based on the computed priorities. In [11] an algorithm for speculative prefetching of terrain tiles is presented. It predicts viewpoint motion by fitting a spline through a list of last positions so the tiles that are predicted to become visible in the near future can be prefetched in advance.

2.3. Next location prediction

Next location prediction (NLP) methods make the assumption that there is a certain regularity in the movement patterns so they are not completely random [12]. Only in [13] were mentioned advantages of NLP method for virtual environments. Here, a hybrid method, where a combination of a mouse motion prediction and NLP based on statistical approach is used to reduce latency. As the statistics are collected from zone to zone within a scene divided by regular grid, the information about continuous movement is lost.

In [14] a simple Markov model is used to estimate transition probabilities between adjacent cells based on movement history database. In [15] the Markov chain of order *m* is used to increase prediction accuracy. Work [15] and [16] cluster GPS data into frequently visited locations called points of interests (POI [17]). Clustering to POIs is not suitable for DVW applications, because the granularity of requested prediction for common rendering algorithms is much higher. Mixed Markov-chain model [18] has been proposed to model behavior of individual pedestrians as well as a group of pedestrians with similar behavior. It uses combination of Markov chain and Hidden Markov model (HMM) to construct the universal predictor. This approach has higher quantity compared to stand-alone Markov chain based methods, but the HMM method has high training complexity.

3. OBJECTIVES

The main goal of this thesis is to propose a method for scheduling of data transfers for distributed virtual walkthrough applications which is based on proposed location-aware prediction scheme. The proposed scheduling algorithm keeps both data transfers efficiency and rendered image quality as high as possible.

Consequently, the main contribution of this thesis is the proposed complex prediction scheme evaluated in pre-defined multi-resolution virtual environment. The proposed prediction scheme can be characterized as follows:

- exploits next location prediction methods
- is adaptive according to multi-resolution data representation
- solves the case when no trajectory pattern is found
- evaluates prediction queries within the client-server environment

The scheduling algorithm based on the top of this prediction scheme is designed so that the prediction results is used to compute the priorities and data prefetching so that both data transfers efficiency and rendered image quality is as high as possible.

4. PROPOSED SOLUTION

4.1. Prediction scheme

A combination of a Markov chain based predictor and a k-state predictor are originally adopted as the next location prediction methods for distributed virtual walkthrough applications. Both the Markov chain based predictor and k-state predictor predicts next user location based on user's current local movement pattern. The Markov chain based predictor runs at server whereas the k-state predictor models behaviour of each individual user and runs at client. Current local movement pattern is used to found all the matching movement patterns stored remotely from all users or locally by individual user.

Compared to motion functions, the next location prediction methods have low prediction rate (prediction quantity). It means that it is not always guaranteed that a prediction query returns a prediction result. This can happen if the user behaviour is unknown. The unknown behaviour can happen in the case of insufficient information about past user movements (typically a new user) or in the case of change in user behaviour. Prediction result can be also marked as not confident if, for example two opposite movement directions have similar probability. If a probability distribution of following particular locations has too high variance then it is not reasonable for data transfers scheduling algorithm to prefetch any data in advance. If the prediction scheme did not return any prediction result, this thesis proposes to extend the next location prediction methods with the state-of-the-art recursive motion function to overcome the low prediction rate problem.

This prediction scheme is performed with different sampling rate of user movement which allows the predicted result to be related with appropriate resolution of the scene data. It allows the scheduling mechanism to compute priority or to prefetch data at the resolution which is required by the rendering algorithm.

4.2. Scheduling algorithm

The main goal of the proposed scheduling algorithm is to achieve effective data transfer with maximum rendering quality during scene exploration. We use a hybrid client-server communication approach, where both client and server can compute priority of missing scene parts (data tiles) or prefetch them in advance.

The rendering algorithm always exactly determines data tiles which are needed to render the current view. As the user continuously moves through the scene, the rendering algorithm generates requests to download tiles which are not available in cache memory. The scheduling algorithm first requests tiles at coarser resolutios, continuing to the finer resolutions.

The predicted location from the proposed prediction scheme is used to compute the priority of both missing data tiles for rendering the current view and for rendering the future view. The priority is determined from the distance of center of the missing data tiles and a reference location which is moved along the predicted direction outside the rendered scene. The less the distance is, the higher the priority.

The prefetching can take its place only if all the missing data tiles for rendering the scene from the current view are already downloaded. Then, all the potentially missing data tiles for rendering the scene from the predicted position are downloaded starting from the much coarser resolution and continue to the finer.

Base on where the prediction scheme succeeded, both the client and server can determine the priority of current missing tiles or prefetch them in advance.

5. RESULTS

Several experiments concern the evaluation of the prediction accuracy and quantity of the proposed prediction scheme, and evaluation of the location-aware data transfers scheduling algorithm. The experiment are set so that various network restrictions are simulated and the rendered image quality and data transfers efficiency are evaluated for each experiment.

The purpose of the experiments is to prove that the proposed scheduling algorithm outperforms state-of-the-art recursive motion prediction method for data transfers scheduling in distributed virtual walkthrough applications. The parameters which are measured are the prediction accuracy and quantity of the proposed prediction scheme, and the effect of the prediction scheme to the rendered image quality and data transfers efficiency during walkthrough the scene.

5.1. Input trajectories dataset

Input trajectories are obtained from the well known Open street map project. These GPS trajectories are projected using a Mercator projection into a 2D space of location tiles at various resolutions. Thus, each GPS trajectory can be encoded by a sequences of location tiles. Further local movement patterns are determined for each tile from each trajectory (see Figure 1.).

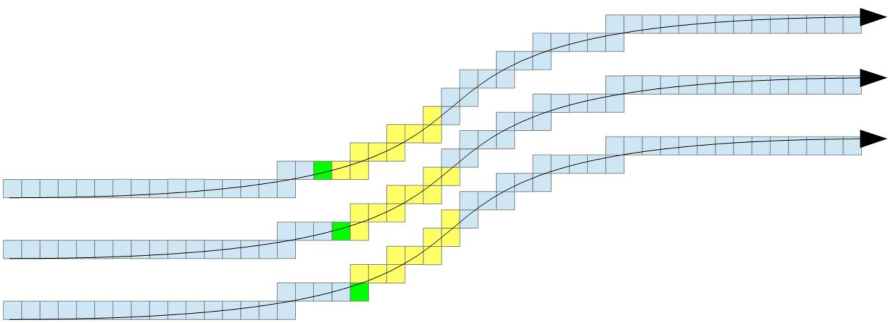

Figure 1. Three local movement patterns for the green cells at length of nine directions.

5.2. Prediction accuracy and quantity

Eight directions are used to match the current movement pattern with the stored local movement patterns. The change of accuracy, when the length of the matched sequence of directions is longer than 6 is small.

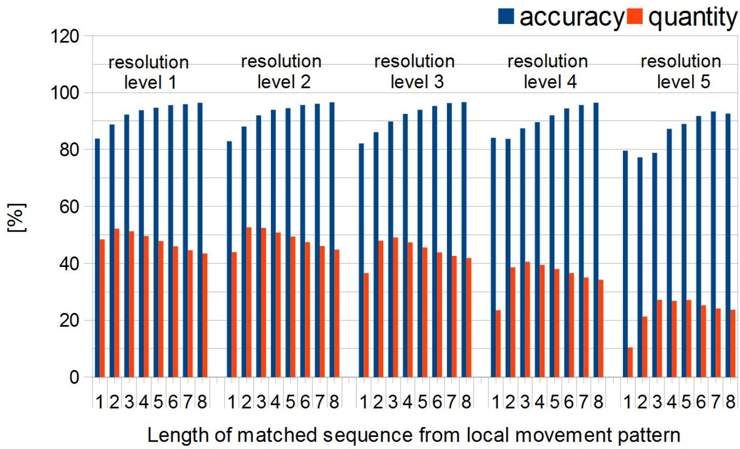

Figure 2. Accuracy and quantity of Markov chain predictor for different length of matched sequence of directions for five resolutions of the location tiles.

The prediction quantity is highest for matched sequences of directions with length from two to three direction over all resolution levels as is shown in Figure 2. The quantity is lower for shorter lengths because the predictions are often marked as not confident (confidence threshold is selected at 90%) and also for longer length, because less matched patterns were found.

Accuracy and quantity were evaluated also for the 2-state predictor as is show in Figure 3. It is constructed from all local movement patterns gathered over all input trajectories. The 2-state predictor has lower accuracy and increased quantity for the shortest lengths of the local movement patterns. Compared to the Markov chain based predictor, there is no drop off in prediction quantity for the shortest local movement patterns. It is because the 2-state predictor misses the confidence estimation method which is used in the Markov chain based predictor.

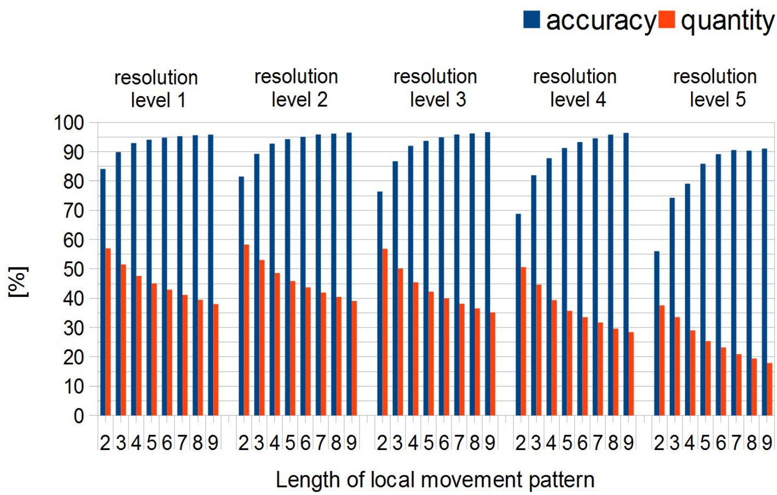

Figure 3. Accuracy and quantity of 2-state predictor for different length of matched sequence of directions for five resolutions of the location tiles.

Based on this observation about the confidence, it can be said that the weaker the confidence estimation method is (e.g. the confidence threshold), the lower the accuracy. A prediction by partial matching (PPM) is additionally used to solve the case that no matching local movement pattern was found. With the PPM, the higher the order of the PPM is (i.e. the length of the shortening), the higher the quantity is, but the lower the accuracy.

Even though the prediction accuracy of the highest PPM order at the first resolution level is relatively low, it is still higher than prediction accuracy of the state of the art recursive motion function used as the next location predictor. The prediction accuracy of the recursive motion function is 55% and quantity is 97%. We use 6 past GPS locations to create the state-of-the-art recursive motion function based predictor and we use it only for prediction at the finest resolution of the locations. The accuracy of simple linear predictor is 39% and its quantity is 99%.

5.3. Scheduling scheme evaluation

The goal of the proposed scheduling scheme is to keep both rendered image quality and data transfers efficiency as high as possible during walkthrough the described virtual environment.

The rendered image quality is defined as the ratio between the time the data tiles are available for rendering and the time the data tiles are needed for rendering. The data transfers efficiency is defined as the ratio between the amount of downloaded data tiles and how these data tiles contribute to the rendered image quality.

Several experiments were proposed to measure the impact of the location-aware data transfers scheduling scheme to the rendered image quality and data transfers efficiency. In these experiments, the parameters which are changed are motion speed of user, network latency and connection bandwidth. In the experiments, the results of the proposed scheduling scheme are compared against a scheduling scheme based on the recursive motion prediction only and against a scheduling scheme which has 100% accuracy and quantity of the prediction.

5.3.1. Slow moving user, high bandwidth and high latency

In the first experiment (see Figure 4), the rendered image quality and data transfers efficiency are measured for motion speed which was set to 60km/h, network bandwidth to 2000kbps and latency to 100ms.

The (2SP+MCH+RMF) is the declaration of the proposed scheduling scheme, the RMF (NOP) stands for the recursive motion function used only for the finest resolution level and no prediction (NOP) for the coarser resolutions, where the priority of missing data tiles for rendering the current view is determined from the distance between the current user position and the centers of the missing data tiles. The less the distance is, the higher the priority is. The 2SP(100%) stands for the 2-state predictor which has 100% accuracy and 100% quantity of prediction.

As the user is moving slowly and the bandwidth is high, all the data tiles for all resolutions can be downloaded in time they ar needed for rendering so the prefetching can download some data tiles in advance. The rendered image quality and data transfers efficiency is high for the three last levels for all three scheduling schemes. The quality of both (2SP+MCH+RMF) and the 2SP(100%) schemes is twice higher compared to the RMF(NOP) scheme.

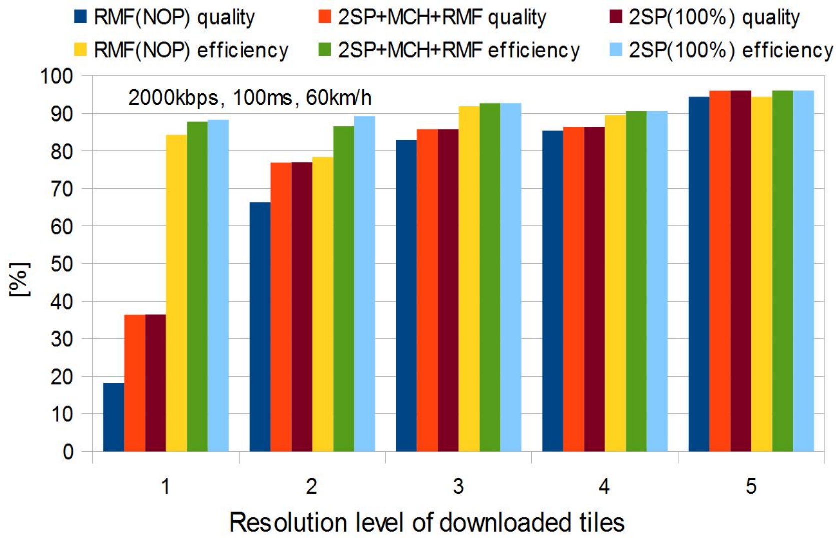

Figure 4. Rendered image quality and data transfer efficiency between various scheduling methods.

The efficiency of all three schemes is similar over all the resolution levels. The efficiency of the RMF(NOP) is also high, because there is no data tiles prefetched in advance and the speed is sufficiently high so the requested tiles for rendering the current view are downloaded relatively fast.

The efficiency of the RMF(NOP) scheduling scheme is slightly higher for the first level compared to the second level, because the downloaded data tiles for the first level are more utilized during rendering.

The effect of the RMF on computation of download priority of tiles at the first resolution level is evaluated as well. Instead of using the RMF for the first resolution level, the priority of the data tiles is computed using the distance from the current user position and the centers of the missing data tiles. The rendered image quality drops down from the 18.2% to 3% and the data transfer efficiency drops down from 84% to only 23.4%. From this result, even the accuracy of the RMF is not as high as the accuracy of the next location prediction methods, it is still very useful for determining the download priority of the missing data tiles.

5.3.2. Fast moving user, high bandwidth and high latency

In the second experiment the motion speed is set to 130km/h which simulates a fast moving user on a highway. The results show (see Figure 5) that no data prefetching is applied here, because the complete set of data tiles over all resolution levels was not downloaded during rendering.

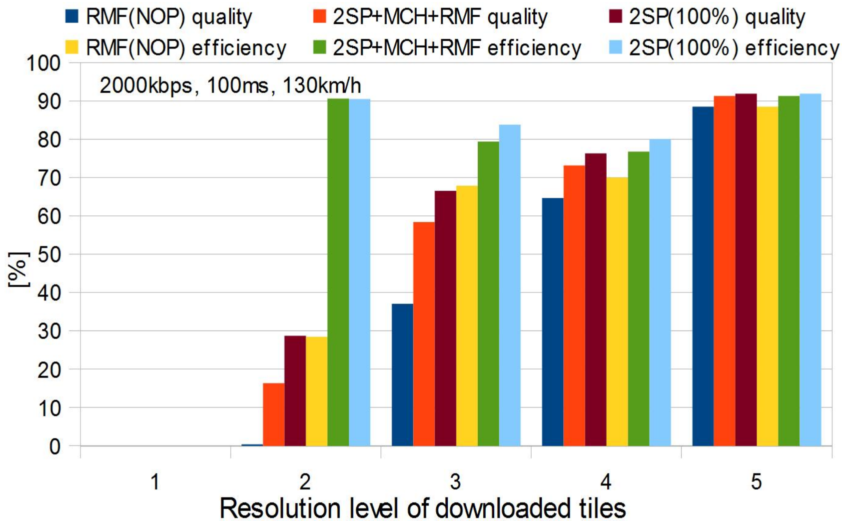

Figure 5. Rendered image quality and data transfer efficiency between various scheduling methods.

Here, the 2SP(100%) scheme has almost twice a higher quality compared to both (2SP+MCH+RMF) scheme for the second resolution level and is higher over all the resolution levels. The rendered image quality of the RMF(NOP) is very low for the second and third levels.

The efficiency of the (2SP+MCH+RMF) is significantly better compared to the RMF (NOP) scheme for the second resolution level. The efficiency of the RMF(NOP) scheme is very low for the second level because considering the quality of the RMF(NOP) scheme at the second level, the data tiles which were downloaded are not used for rendering. The reason that they are not used is that they are downloaded too late and are no more needed for rendering.

The efficiency of the (2SP+MCH+RMF) and the 2SP(100%) is similar over all resolution levels. From this results, it can be said that the proposed (2SP+MCH+RMF) scheme keeps both the rendered image quality and data transfers efficiency high considering the rendering algorithm and the rendered data.

5.3.3. Fast moving user, low bandwidth and zero latency

For the last experiment, the motion of user is set again to 130km/h, but with low bandwidth and zero latency. This experiment shows the effect to quality and efficiency of the proposed (2SP+MCH+RMF) scheduling scheme at low bandwidth networks and for fast moving users (see Figure6).

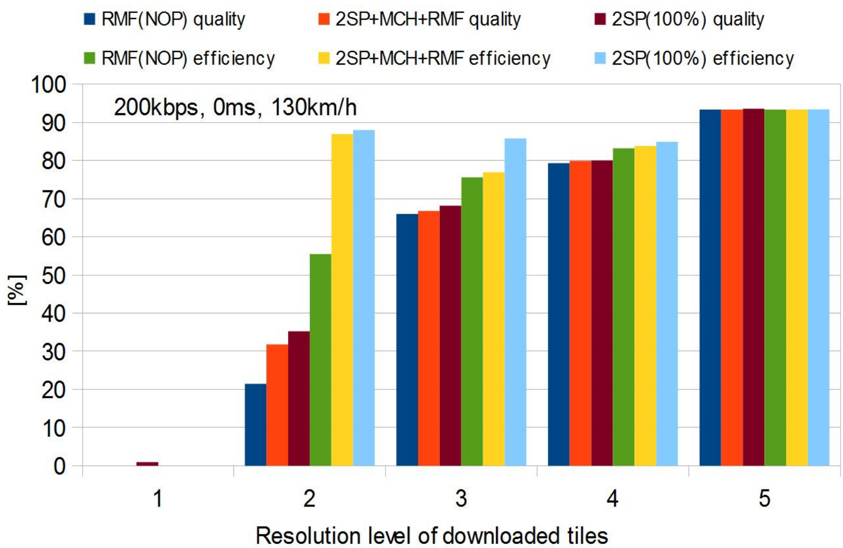

Figure 6. Rendered image quality and data transfer efficiency between various scheduling methods.

The results show that the 2SP(100%) scheme outperforms both the proposed (2SP+MCH +RMF) and the RMF (NOP) scheme. The quality of the proposed (2SP+MCH+RMF) scheme is much higher compared to the RMF(NOP) scheme at the second resolution level. The quality of all the three schemes is similar over the last three levels, because the bandwidth is sufficient to download the data tiles fast so the download priority plays a less important role in this case.

The data transfers efficiency of the (2SP+MCH+RMF) and the 2SP(100%) is much higher compared to the RMF (NOP) scheme for the second level. But the efficiency of the RMF(NOP) scheme is much better compared to the previous experiment. It is because the network delay is set to zero in this experiment. It has the consequences that the data tiles which started to be downloaded will be downloaded sooner compared to the second experiment. Therefore, they will be used for rendering for a longer time.

5.3.4. Summary of the scheduling scheme results

The results from the three experiments performed show that the proposed data transfers scheduling scheme corresponds to the expected results. It means the scheduling algorithm keeps both the data transfers efficiency and rendered image quality as high as possible. The results also show that the proposed scheduling algorithm significantly outperforms the scheduling scheme based on the state-of-the-art recursive motion function in all experiments. Compared to the ideal scheduling scheme, the proposed scheduling algorithm has very similar efficiency, but the ideal scheme outperforms the proposed algorithm in quality in some cases.

The contributions of the proposed scheduling algorithm which is based on the proposed prediction scheme are the following. First the increased quality is advantageous for users, because the scene is rendered in higher detail and second the efficiency of the data transfers allows to render the scene in higher detail with less transferred data which can be beneficial in case of pre-paid data limits.

6. CONCLUSIONS

The goal of this thesis was to propose and experimentally evaluate a new location-aware data transfers scheduling algorithm which utilizes the proposed prediction scheme to increase both the rendered image quality and data transfers efficiency within the pre-defined multi-resolution client-server environment.

The proposed prediction scheme uses the combination of the Markov chain based predictor and the 2-state predictor as the next location predictors in the client server environment. The predictors are trained from real trajectories using local movement patterns.

The experimental evaluation of the proposed location-aware data transfers scheduling algorithm outperforms the state-of-the-art scheduling scheme which is based on the recursive motion function. The data transfers efficiency of the proposed algorithm is very similar to the scheduling scheme which is based on the ideal predictor. Compared to the state-of-the-art scheduling method, the efficiency of the proposed method is about 60% bigger for the second resolution level for the fast moving user and high latency networks. The image quality of the proposed method is approximately two times bigger than the quality of the state-of-the-art method in the same setup, but also two times lower compared to the ideal prediction scheme. If the network restrictions are relatively negligible and the user is moving slow, the proposed method outperforms the state-of-the-art approach two times in quality. For low bandwidth networks, the increase of quality of the proposed method over the state-of-the-art method is 10% and the data transfer efficiency increases about 33%.

The significant increase of the efficiency and quality of the proposed method over the state-of-the-art method is advantageous, because the scene can be rendered in higher detail whereas the amount of transferred data is smaller compared to the state-of-the-art scheduling scheme. It can be beneficial in case of pre-paid limits on data connections.

The advantages of the proposed scheduling scheme which exploits the next location prediction methods is that it is adaptive to behaviour of individual users. The disadvantage is that the next location predictors depend on the knowledge database which needs to be kept up to date. Especially the Markov chain based predictor evaluated at server needs GPS trajectories collected by all users of the system. This can be potentially problematic as the users of the system have to be asked to agree with that. On the other hand, the trajectories at the server can be stored as anonymous records.

Further research can be focused on exploitation of temporal information in the proposed prediction scheme. It can further increase the prediction accuracy which, in effect leads to the better data transfers scheduling. Another area which should receive a high degree of attention is how the predicted locations can be used to solve cache invalidation in devices with limited storage space.

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APPENDIX A

Scene streaming and rendering

The following video shows the streaming and rendering of the terrain

http://www.youtube.com/watch?v=s8Ge-Vro96I&feature=youtu.be

The following video shows the rendering of the terrain from top view

http://www.youtube.com/watch?v=ZUzSy49gsPU&feature=youtu.be

APPENDIX B

Figure 7. Rendered terrain with buildings from user view on iPad 2 device. The data are streamed from remote server using the scheduling and prefetching mechanism proposed in this thesis.

Figure 8. Rendered scene on iPad 2 device

Figure 9. Bird view of the rendered scene.

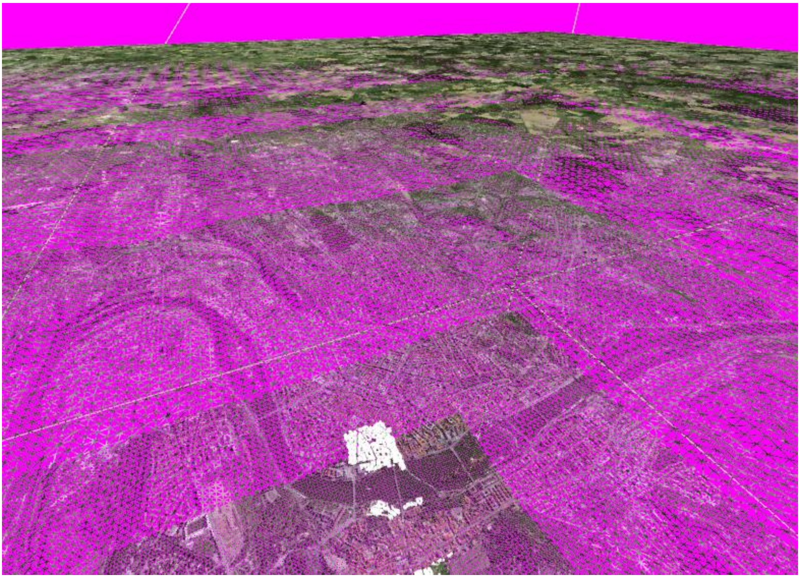

Figure 10. Wire-frame rendering of the terrain.

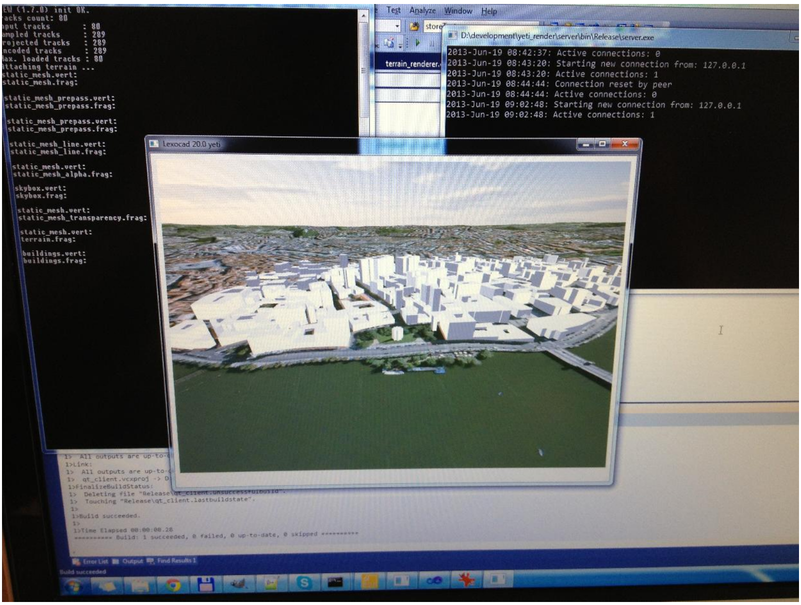

Figure 11. Rendering of the terrain on windows.

CURRICULUM VITAE

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