Content Adaptive Tiling Method Based on User Access Preference for Streaming Panoramic Video

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***Abstract-* Tiled streaming has been proposed for delivering ultra-high resolution videos such as zoomable online lectures or panoramas. In tiled streaming, the source video is first partitioned into grid of small rectangular tile groups. Each tile group is independently encoded and compressed. When an user asks for a certain viewport at a time, the server only streams the viewed tiles to save up bandwidth. However, not much work has been done on finding the best tiling method for streaming panoramic video. This paper proposes an effective tiling algorithm for tiled streaming by using both video content and user access preference distribution. Experimental results show that the proposed tiling method can save up to 32.4% and 69.8% of average streamed bitrate compared to conventional uniform tiling scheme and simply streaming the entire panorama respectively on equi-rectangular panoramic video.**

I. Introduction

Recently, an increasing interest in study about VR (Virtual Reality) has emerged. VR involves a large range of fields including computer vision, computer graphics, video streaming, human-machine interaction and so on. This paper focuses on the streaming aspect of an interactive panoramic streaming system. The main character of streaming VR video is that the user only demands a limited part of the whole video to display on screen at a time. Therefore, tiled streaming is introduced [3] to save the bandwidth for streaming ultra-high resolution video such as panoramas. As shown in Fig. 1, the source video is firstly divided into grid of video segments such as 32 tiles (4×8). Given the user's required viewport, the server delivers streams overlapped with the user's viewable region. The client side then retrieves partial view by the received bit streams.

However, there is a trade-off in tiled streaming. The streams delivered usually cannot exactly cover a given viewport, so redundant data outside the viewport exists. Streaming these redundant parts can definitely cause a large waste of bandwidth. If the video is partitioned into smaller tiles, less redundancy can be achieved whereas the compression efficiency drops. On the contrary, larger tile size results in better compression efficiency but more redundancy.

There already existed some works studying on delivering online pan-tilt-zoom (PTZ) video lectures. Some works utilize the concept of region-of-interest (ROI) which denotes the user access frequency to the video [1], [2]. In [1], Ngo et al. proposed two methods supporting zoomable video streaming called tiled streaming and monolithic streaming respectively. Their later work [2] exploited user access patterns and encode different regions of the video with different encoding parameters based on the popularity of the region. They show that their adaptive tiling method can reduce the expected bandwidth by up to 27%.

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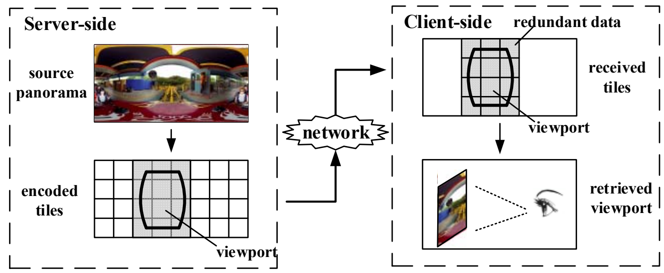


Fig. 1. Tiled streaming in an interactive VR streaming system.

As for panoramic videos, article [3] addressed different tiling method in a real-time interactive panoramic video system based on different predictive models of movement of users' viewport. About optimizing on tile size, [5] proposed a method to find the most efficient tile size for cylinder panoramic video coding subject to the target bandwidth. Yu et al. [8] proposed a content adaptive tiling method for cinematic virtual reality. Experiments showed average bitrate savings of over 18% relative to the baseline equal-area representation on an image dataset. Zare et al. [4] proposed to store two versions of the same video content at different resolutions in order to solve the latency problem. The results indicated bitrate saving from 30% to 40% when compared to streaming the entire video content.

This paper points at how to find the best tiling method to reduce the streamed bitrate. In this paper, we propose a new tiling method for tiled streaming using both video content and user access preference. Experiments show that our scheme can save up to 32.4% of the average bitrate compared to uniform tiling method on equi-rectangular format.

The rest of this paper is organized as follows. Section II addresses the tiling problem we would like to solve in this paper. Section III presents the proposed tiling algorithm. Experimental results are shown in section V and finally the conclusion is given in section VI.

II. Tiling Problem

Suppose a web-based panoramic video delivering system providing video-on-demand (VoD) service for large quantities of users. Given a panoramic source video in equi-rectangular format, we recorded all the users' historical viewpoint (center of a user's view) access frequency for every frame. Then we got frame-level user viewpoint access distribution called access probability map P.

Consider the simplest case, for example, one frame instead of a video. We denote the frame we are interested in tiling as I. The probability map P has been obtained previously. A tile map T consists of a set of non-overlapping rectangles called tiles $t_1, t_2, \dots t_n$. Each tile t_i is contained in I and all the tiles collectively cover exactly I. The probability of every viewpoint v_i or the view window of viewpoint v_i in probability map P can be directly calculated through function $p(v_i)$ with the probability map P. A set of tiles in tile map T overlapped with the FOV (field-of-view) of viewpoint v_i will be streamed when a user chooses viewpoint v_i. The cost function $c(t)$ is assigned to get the bitrate of a tile. Streamed bitrate to user i who chooses viewpoint v_i can be computed by adding the bitrate of all the overlapped tiles. So for every viewpoint in the probability map, we can compute the total bitrate of required tiles as streamed bitrate if network delay is ignored. The tiling problem is to minimize the average streamed bitrate of all the possible viewpoints in probability map P. That is to minimize:

$$\sum_{v_i \epsilon P}\left\{p(v_i)\sum_{FOV(v_i)\cap t_i\neq\emptyset} c(t_i)\right\} \qquad (1)$$

It can be easily proofed that this expression is equivalent to:

$$\sum_{t_i \epsilon T}\left\{c(t_i)\sum_{FOV(v_i)\cap t_i\neq\emptyset} p(v_i)\right\}$$

Where t_i denotes each tile contained in the tile map T, and $c(t_i)$ indicates its bitrate. $\sum_{FOV(v_i)\cap t_i\neq\emptyset} p(v_i)$ adds the probability of all the viewpoints whose view window overlaps with tile t_i to calculate the access probability of a tile t_i according to viewpoint access probability map P.

III. Proposed Tiling Method

Adaptive tiling is proposed [2] to solve the similar kind of problem but for zoomable online video lectures. They used a greedy heuristic to find a resulting tile map to reduce the expected bandwidth. However, their method has several drawbacks. The traversing order (from top-left to bottom-right) and merging method they chose are not optimal. Moreover, it is somewhat impractical to encode such small tiles on the fly to obtain the bitrate of a tile.

In order to get a more optimized solution, this paper proposes a new tiling method. We start with breaking the tile map into uniform tiles as small as possible and conduct a Bottom-Up growing procedure. The key idea of this algorithm is that the optimal growing case always has priority to grow. In order to enhance the processing efficiency of the program, we employ a function to estimate the bitrate of a tile. This section is divided into 4 subsections. Section A illustrates the bitrate-estimating function and B explains the probability-calculating function. Section C interprets the nearest growing method of one tile. Finally, D presents the whole tiling algorithm based on A, B and C.

A. Bitrate-estimating Function

The proposed tiling method requires calculating the bitrate of various blocks of different size contained in the source frame. We regard the blocks as intra-frame and use intra-frame encoding by HEVC Test Model to get the real bitrate of the blocks. Inspired by [6], the average gradient of a block is used to measure its complexity. We consider the relationship among bitrate and (block-size & block-complexity) as:

$$c(t) = F(s_t)H(g_t) \qquad (2)$$

Where F is the function between bitrate and image area (s_t), and H denotes the relationship between bitrate and image complexity (g_t) which is measured by gradient. Large quantities of experiments were carried to fit the function F and H by decoupling fitting method. That is, we first find the relationship H and then utilize H to fit function F.

B. Probability-calculating Function

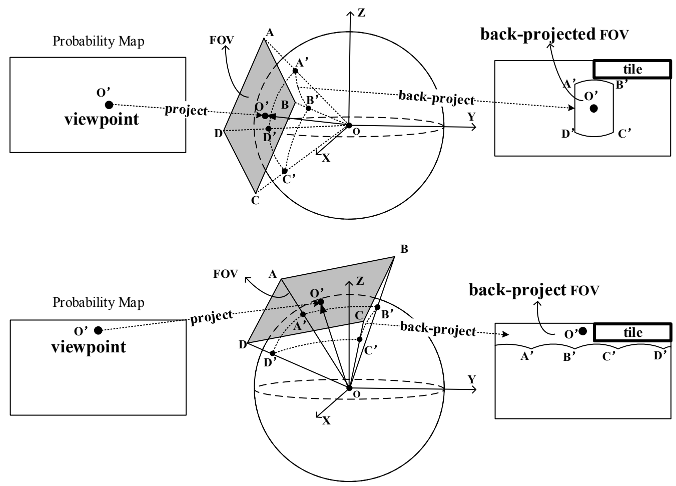


Fig. 2. Definition of Viewport/FOV of viewpoint in equi-rectangular map. The top diagram presents a non-overlapping case while the bottom shows an overlapping case

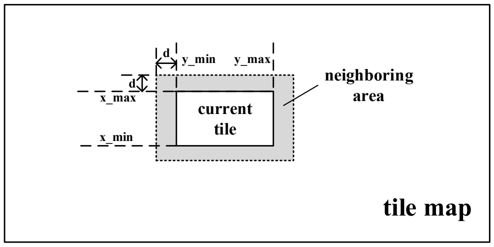
To get the viewed probability of tile t, we use probability function $p(t)$ to compute the access probability. With the user viewpoint probability map, access probability of tile t can be obtained by computing the sum of viewpoint probability whose FOV (field-of-view) overlaps with tile t. Note that if the probability map is in equi-rectangular format, the viewpoint should be projected onto a sphere first and then the spherical FOV of the viewpoint is back-projected to planar FOV to judge if it overlaps with tile t. Fig. 2 shows the projecting and back-projecting procedure. By adding all probabilities of viewpoint O' whose FOV overlaps with tile t, the viewed probability of tile t is acquired. This projecting procedure is also adaptive to other projecting model such as cube-map if the probability-calculating function $p(t)$ is properly changed.

C. Nearest Growing Choice

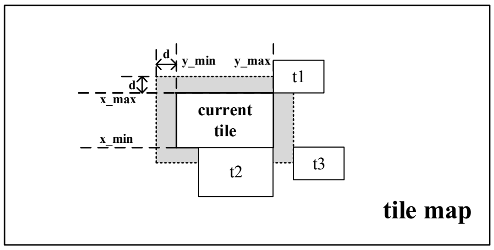
Nearest growing neighbors need to be defined first to present the growing method. Given a tile $t_{current}$, we designate its feature coordinate as $\{x_{min}, x_{max}, y_{min}, y_{max}\}$. According to the above defined coordinates, we can find all the possible growing neighbors of tile $t_{current}$. Given any other tile t_{other} with its analogously defined feature coordinate $\{x'_{min}, x'_{max}, y'_{min}, y'_{max}\}$, if the coordinates of the above mentioned two tiles satisfy any one of the following four restrictions, t_{other} is said to belong to nearest growing neighbors of

$t_{current}$:

$$\begin{gathered} x_{min} - d \leq x'_{min} \leq x_{max} + d \\ x_{min} - d \leq x'_{max} \leq x_{max} + d \\ y_{min} - d \leq y'_{min} \leq y_{max} + d \\ y_{min} - d \leq y'_{max} \leq y_{max} + d \end{gathered} \quad (3)$$



(a) Definition of neighboring area of current tile



(b) Examples of neighboring and non-neighboring tiles of current tile. t_1 and t_2 are neighboring tiles, while t_3 is not.

Fig. 3. Definition and relationship of neighboring tiles

Where d denotes the width of nearest neighboring area. Fig. 3(a) shows the definition of $\{x_{min}, x_{max}, y_{min}, y_{max}\}$, d and neighboring area. If t_{other} overlaps with neighboring area of $t_{current}$, t_{other} is said to be one of nearest growing neighbors of $t_{current}$. Fig. 3(b) shows the neighboring and non-neighboring examples of $t_{current}$. If $t_{neighbor}$ belongs to neighbors of $t_{current}$, $t_{neighbor}$ and $t_{current}$ are able to constitute a big merged tile t_{merged}. The potential merged tile t_{merged}'s feature coordinate $\{x''_{min}, x''_{max}, y''_{min}, y''_{max}\}$ can be computed by expression (4).

$$\begin{cases} x''_{min} = \min\{x_{min}, x'_{min}\} \\ x''_{max} = \max\{x_{max}, x'_{max}\} \\ y''_{min} = \min\{y_{min}, y'_{min}\} \\ y''_{max} = max\{y_{max}, y'_{max}\} \end{cases} \quad (4)$$

We use function $c(t)$ and $p(t)$ introduced in section A and section B to compute the bitrate and probability of tile $t_{current}$, $t_{neighbor}$ and t_{merged}. Then the product of bitrate and probability of a tile is calculated as its expected bandwidth. After finding out all nearest neighbors of $t_{current}$, we can compute the Normalized Growing Speed (NGS) of each $t_{neighbor}$ by the following formula:

$$NGS = \frac{\left(\sum_{t_i \in t_{merged}} c(t_i) \cdot p(t_i) - c(t_{merged}) \cdot p(t_{merged})\right)}{area(t_{merged})} \quad (5)$$

Where $t_i \in t_{merged}$ denotes any tile that is totally contained in t_{merged}. After seeking out all the growing cases, we choose the case of largest NGS as the optimal one-step nearest growing choice of tile $t_{current}$. If the largest NGS of $t_{current}$ is negative, this kind of growing case is abandoned.

D. *Proposed Tile-growing Method*

Based on the above explanations and notations, we are now ready to present the proposed tiling algorithm. The pseudocode of the proposed method is shown in Fig. 4. We begin with a tile map divided uniformly into grid of small tiles such as 10×20 tiles. In the first loop, each of the 200 tiles will be traversed to find the optimal growing choice of each tile. Then the NGS of every tile is compared to find the global optimal NGS as the consequential growing choice of the first solution, according to which we update the whole tile map. Afterwards, the big merged tile as well as other unmerged tiles is again traversed. The globally largest NGS is once again selected as the second growing solution. This iterative process will continue until no more possible growing cases can be found. The resulting tile map acquired is the optimized tile partition method for this sequence. This step-by-step growing algorithm guarantee that more optimized merging situations will always have priority to emerge than less optimized ones, which will result in a solution tile map closed to the optimal.

Algorithm: Proposed Tile-Growing Method

```
Input: probability map P and image frame I
Initialize tile map T with m × n tiles
Do
    Find all tiles including grown tiles in tile map T
    For every tile t_i do
        Find all the nearest growing neighbors of tile t_i
        Calculating NGS of each neighbor by Eq. (5)
        Find the largest NGS as the best growing case
        Judge if the largest NGS is positive
    End for
    Compare NGS of all the tiles in tile map T and select the largest
    NGS globally to update the tile map T
Until: tile map T remains unchanged
Output: resulting tile map T
```

Fig. 4. The pseudocode of proposed tiling algorithm.

IV. Experimental Results

A. *Experimental Environment*

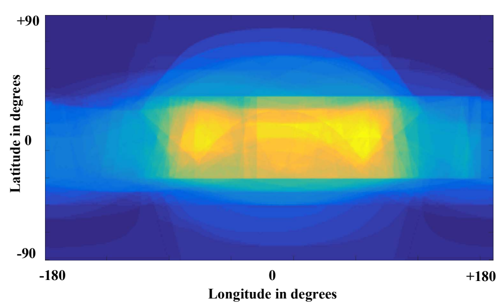


Fig. 5. The access probability map of *RollerCoaster*

The proposed tiling algorithm was estimated using 6 high resolution 3840x1920 images from SUN360 database [7]. The 6 sequences used in our experiments in equi-rectangular format are respectively called *Building, GoldenHall, RollerCoaster, SnowField, Street, Indoors* as partly shown in Fig. 8. We recorded over 100 users' viewpoint access distribution of each sequence and generated 6 viewpoint access probability maps. Fig. 5 shows one example of the probability map. We

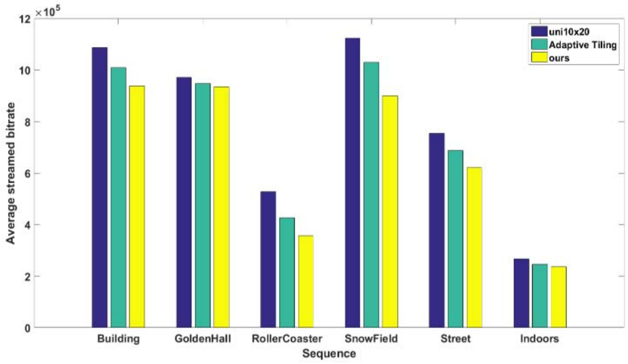


Fig. 6. Comparison of average streamed bitrate among: 1) Uniformly divided in 10x20 tiles; 2) Adaptive tiling [2]; 3) The proposed tiling method.

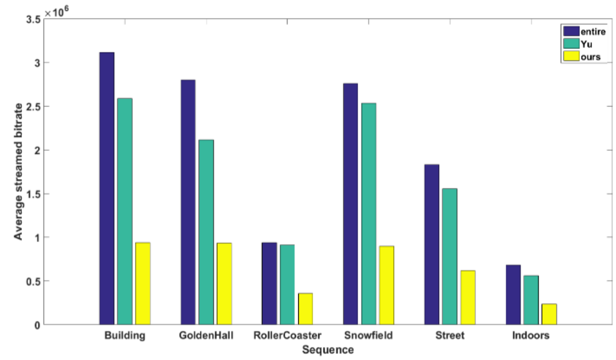


Fig. 7. Comparison of average streamed bitrate among: 1) Streaming entire panorama; 2) Yu's tiling method [9]; 3) The proposed tiling method.

conducted the proposed algorithm on the sequences accompanied with probability maps using MATLAB R2015b. The tile maps were initialized into 10x20 evenly divided tiles and then processed by the proposed tile-growing method.

B. Resulting Tile Maps

The resulting tile map are presented in Fig. 8. Because of space limitation, only 3 sequences are presented. There are some interesting observations from the tile maps. First, more popular regions tend to merge into bigger tiles, while less popular fields usually remain unchanged. Secondly, The frame content also influences tiled growing. Regions with convoluted textures are usually hard to form large tiles because that area is often not encoding-friendly. On the contrary, tiles with low image activity are more likely to merge with their neighbors.

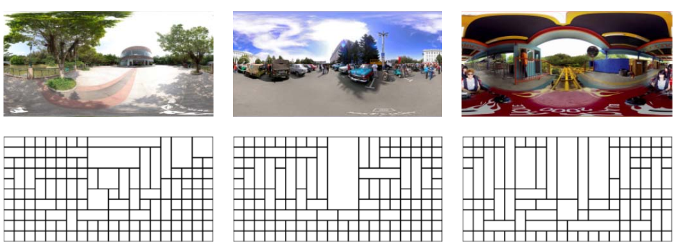


Fig. 8. Top row: test sequences (part): *Building, Street, RollerCoaster*. Bottom row: Resulting tile maps (part): *Building, Street, RollerCoaster*.

C. Average Streamed Bitrate

Actually, the accuracy of the function does not have any effect on estimating the performance of the proposed tiling method. Therefore, we can assume the proposed bitrate-estimating function Eq. (2) is accurate and then assess the streamed bitrate using the same function. Since the goal of this paper is to minimize the expression shown in Eq. (1), the metric adopted for estimating tile maps can be directly computing the result of Eq. (1). Fig. 6 compares the proposed tiling method with adaptive tiling [2] and naive 10x20 tiling. Fig. 7 compares the proposed tiling method with Yu's [8] as well as streaming the entire video. Yu's tiling only considered tiling in vertical direction, so it did not improve much compared to equi-rectangular map in terms of tiling streaming. Experimental results show that the proposed tiling method achieves: 1) up to 69.8% and average 66.2% streamed bitrate saving relative to entirely streaming; 2) up to 32.4% and average 16.5% bitrate saving compared to 10x20 uniform tile map; 3) up to 17.4% and average 8.5% bitrate saving compared to adaptive tiling [2].

V. Conclusion

In this paper, we propose a content adaptive tiling algorithm based on user view preference for server-client panoramic video streaming systems. Experimental results show that the proposed tiling method can save up to 32.4% and average 69.8% of average streamed bitrate when compared to naïve uniform tiling scheme and streaming the entire panorama respectively.

Future work targets on optimization of bitrate-estimating function for Group-of-Pictures and adaptive tiling method for panoramic video streaming. The effects of omnidirectional video on different formats are to be studied in further works.

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