FLEXIBLE CLIPMAPS FOR MANAGING GROWING TEXTURES

Dirk Feldmann, Frank Steinicke and Klaus H. Hinrichs
Visualization and Computer Graphics Research Group, University of Münster, Einsteinstr. 62, 48149 Münster, Germany

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Abstract: Previous work on large image data sets has evolved techniques for handling representations of these data that cache textures of arbitrary, but fixed, size in a limited amount of physical memory for rendering in real-time. In these approaches the texture data is usually pre-processed and arranged, for instance in a geometry-independent texture clipmap. New technologies in the area of remote sensing generate aerial images in real-time at a high rate in a patchwork-like pattern, and new images may replace previously captured image data. These patchwork-like image data can be used to create a *growing texture* which is dynamic in the sense that it may be updated in parts and grow in extension in the course of time. For such growing textures, current clipmap techniques are not appropriate.
In this paper we introduce the *Flexible Clipmap*, a technique for incrementally generating a clipmap from a large virtual texture of dynamically changing content and extent. Our technique makes use of a tile-based clipmap approach and a common spatial indexing data structure to provide access to very large growing textures. We present an evaluation of our technique in the context of a remote sensing application which demands real-time rendering of growing texture data.

1 INTRODUCTION

With the widespread use of applications like Google Earth/Maps or GIS, textures depicting large surface areas or even entire planets have become rather popular. The texture data in these applications may have sizes in the gigabyte range and thus often exceed the available physical video memory. For this reason different techniques for handling very large textures have been developed. However, in many of these applications textures are frequently treated as resources having fixed extent and static or rarely changing content. While these constraints have applied until recently, advances in image acquisition techniques makes it now possible to update such image data more frequently and at lower costs. The acquired images need to be processed to generate a single *virtual texture* which can be used for renderings of a digital model of the captured environment. Although the covered areas may be vast and the images may have high resolution, it is desirable to update the content of such a very large virtual texture in real time. Furthermore, any newly acquired image may not only update existing content, but also extend the area covered so far. In this case, the virtual texture may extend in size, hence we refer to such a kind of texture as a *growing texture*. Applications can be found in monitoring in-process image acquisition, as it is done, for example, in microscopy, robotics or aerial photography for purposes of surveying and mapping. For instance, miniature unmanned aerial vehicles (MUAVs) equipped with cameras can capture image data about arbitrary areas and transfer these images using advanced network technology to ground control stations where the data can be displayed immediately (AVIGLE, 2010). Current techniques for handling large textures, like clipmap implementations, are not able to handle such growing textures.

In this paper we present the *Flexible Clipmap (FCM)* to incrementally generate a large, virtual texture of dynamically changing content and growing extent. Our technique makes use of a tile-based clipmap approach, a common spatial indexing data structure and commodity GPUs, and is independent of the underlying geometry data.

2 RELATED WORK

If the size of textures to be displayed exceeds the hardware limits, a common and obvious solution is to divide them into smaller, manageable textures. For

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instance, Cline and Egbert proposed a simple division of the texture data, but their approach was limited by a strict dependency on texture coordinates and underlying geometry (Cline and Egbert, 1998). A clipmap, as introduced in (Tanner et al., 1998), is based on mipmaps (Williams, 1983) and keeps only portions of the entire texture mipmap in video memory. Like mipmaps, the clipmap provides a level of detail (LOD) concept and thus avoids texture aliasing. It uses a roaming window in video memory to copy only those texels which are visible to the viewer by logically centering the window around the current eye point (*clip center*). As the eye point moves, the window is updated by copying new texels using toroidal addressing (Tanner et al., 1998). This is done for each clipmap level corresponding to a texture of a size greater than a certain *clip size*. Lower levels are treated as an ordinary mipmap. No subdivision of a large texture into so-called *tiles* is required, but special hardware was employed for loading the texels into video memory. Modern GPU features have eliminated the need for special hardware, and the clipmap concept has been implemented on the GPU in vertex and fragment shaders on commodity hardware making it even more attractive for handling large textures. The *virtual texture* in (Ephanov and Coleman, 2006) also makes use of texture tiles and can employ shaders for texture mapping. It supports multi-texturing, but does not use toroidal addressing for loading tiles, the texture coordinates are still coupled to the geometry and it requires multiple texturing units, even if only a single texture is mapped. In (Seoane et al., 2007) a roaming tile cache for each level is used, which is updated using toroidal addressing and texture stacks. Geometry and texture data are kept independent from each other by computing the texture coordinates within a shader. Both approaches as well as the solution presented in (Li et al., 2009) generate complete mipmaps for each tile at each LOD. Crawfis et al. (Crawfis et al., 2007) also employ roaming tile caches for each level, toroidal addressing, texture compression and fragment programs, but they do not generate mipmaps for the tiles. They investigate different methods for clipping and level determination by utilizing fragment programs and arrays of textures to hold the relevant portions of the logical mipmap. Furthermore, they make use of a *tile map* to indicate the highest available texture resolution for each pixel to the shader for selecting the optimal clip level by binding the tile map as an additional texture. In addition, they propose the usage of more efficient texture arrays, which became available in DirectX 10 hardware. Recently, also (Barrett, 2008) and (Mittring and Crytek GmbH, 2008) have used virtual textures on modern GPUs.

Although the previously mentioned works on texture clipmaps deal with large textures of fixed extent, they do not seem to be capable to update the texture content at a frequent rate. Recently, in (Taibo et al., 2009) a method to handle large fixed-size textures of frequently changing content has been presented. However, to our knowledge none of the current techniques is able to handle growing textures.

3 THE FLEXIBLE CLIPMAP

The FCM allows to derive from a growing set of images at different locations a single virtual texture which can be rendered immediately on any geometric model. This is only possible if along with the images the information about their location in the real world is provided. Before images can contribute to the virtual texture, georeferencing and registration of the images have to be performed, and, if necessary, perspective distortions need to be reduced. In aerial imaging applications, georeferencing of the images is realized based on position and orientation data which may be provided by GPS and inertial measurement units. After this preprocessing the area covered by an image does not need to be rectangular any more, but is an arbitrary convex quadrilateral. However, a minimal enclosing axis-aligned rectangle (*bounding box*) can be computed efficiently. The undistorted image together with its bounding box and some meta information like position data, time stamp, image contrast, etc. is called a *patch*.

3.1 Requirements and Contributions

In order to handle a growing texture, the FCM cannot be confined in advance to a fixed area. Also it may easily become too large to fit entirely into video memory or even main memory and therefore it has to be partitioned, stored in secondary memory and provided with a LOD concept to avoid texture aliasing. Furthermore, for a frequently changing set of images overlapping the same area, there are lots of possibilities to decide which of the images (or parts of the images) are the “best” to contribute to the resulting virtual texture. A rating can be based, for instance, on image properties such as timestamp, contrast, brightness, signal-to-noise ratio, degree of perspective distortion, or even content. In any case, whenever “better” images are available, the affected region within the virtual texture has to be updated. To summarize, the FCM must satisfy the following requirements to address the challenges stated above:

1. Partitioning and LOD concepts have to be supported, since the virtual texture may have physical extent which exceeds hardware limits.
2. Efficient updates of the virtual texture must be possible, because updates of the underlying set of images will occur frequently.
3. The virtual texture must be capable of growing, i. e., it cannot be limited to a fixed extent.

3.2 Clipmap

The first requirement given in Section 3.1 can be achieved with texture clipmaps, since they allow to control memory consumption and provide LOD concepts. The principle of a clipmap is illustrated in Figure 1. At the lowest *clip level* $l = 0$ the clipmap (cf. (Tanner et al., 1998)) contains a portion of the texture at the highest available resolution. Like with mipmaps, going from clip level l to clip level $l+1$ the resolution of the texture decreases by a factor of 2 along each dimension. At the highest clip level $L-1$, the clipmap contains a down-sampled version of the entire texture, which is managed like a standard mipmap. During texture mapping the minification of a texel in screen space determines the clip level to be used. We implemented a variation of the clipmap similar to the one in (Crawfis et al., 2007) which makes use of fragment shaders and texture tiles without requiring any special hardware. We employ a tile map as well and make use of the explicit index-based clipping (Crawfis et al., 2007), but in contrast, we use a special approach for indexing and generating the required texture tiles. Because of the tiling approach, updates of the virtual texture are confined to few tiles only, which is helpful for achieving the second requirement stated in Section 3.1.

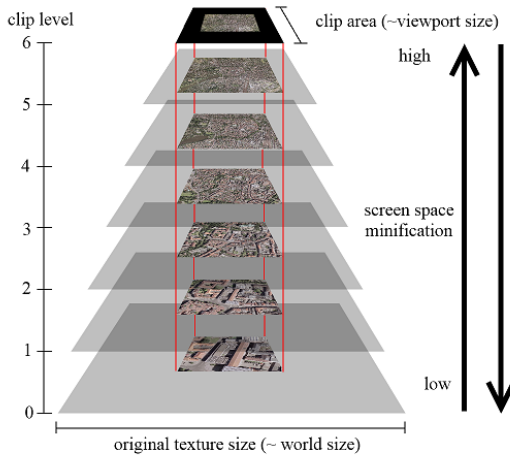
clip level
6
5
4
3
2
1
0
clip area (~viewport size)
high
low
screen space minification
detail level
low
high
original texture size (~ world size)

Figure 1: Scheme of a clipmap with $L = 7$ clip levels.

3.3 Patch Organization

In our application, the texel source for each tile is the set of patches the tile overlaps. To satisfy the second requirement from Section 3.1, we need to be able to efficiently retrieve the patches contributing to a certain tile. For this reason, the patches are stored in a spatial indexing data structure according to their bounding boxes in real-world coordinates (RWC). Since the spatial index has to support point and especially window queries, we employ the R*-tree (Beckmann et al., 1990), a variation of the R-tree (Guttman, 1984). Compared to other spatial indexing structures, the R*-tree has the advantage that it can be used as a secondary storage index, and that it is well suited for incremental construction by successive insertions as it does not require any periodic re-organizations (Samet, 2006).

Since the R*-tree stores in each node a bounding box of all elements assigned to the corresponding subtree, the bounding box for all patches is located and maintained at the root node. This bounding box given in RWC together with a given image resolution in pixels per RWC unit determine the current size of the FCM. Therefore the extent of the FCM will change when patches are inserted which do not lie completely within its current boundaries (cf. Section 3.5).

Given the bounding box of a certain tile in RWC, in order to update that tile the spatial index is queried using the bounding box, and the retrieved patches are blended into the texture tile (see Section 3.6).

3.4 Flexible Tiles Construction

In order to satisfy the third requirement from Section 3.1, the key is to provide the FCM with additional tiles whenever the underlying virtual texture becomes larger. We start numbering the L clip levels of the FCM from the most detailed level $l = 0$ to the least detailed level $l = L-1$, which contains a downsampled version of the entire texture (see Figure 1). Conceptually, we consider the virtual texture as the entire $\mathbb{R}^2$. We denote the space covered by the bounding box of the R*-tree by A, its left lower and right upper corners by ll and ru, respectively, and we mark the region $\mathbb{R}^2 \backslash A$ as *empty*.

We take an arbitrary but fixed origin $o = (o_x, o_y)$ in RWC, e. g., the starting location of the exploration or any GPS position, to span a Cartesian grid with spacing $(g_x, g_y) = (t_x/ppu_x, t_y/ppu_y)$ in x- respectively y-direction, where t_x and t_y denote the width respectively height of one tile in texels, and ppu_x and ppu_y denote the resolution in the respective direction in pixels per units. Each grid cell is identified with

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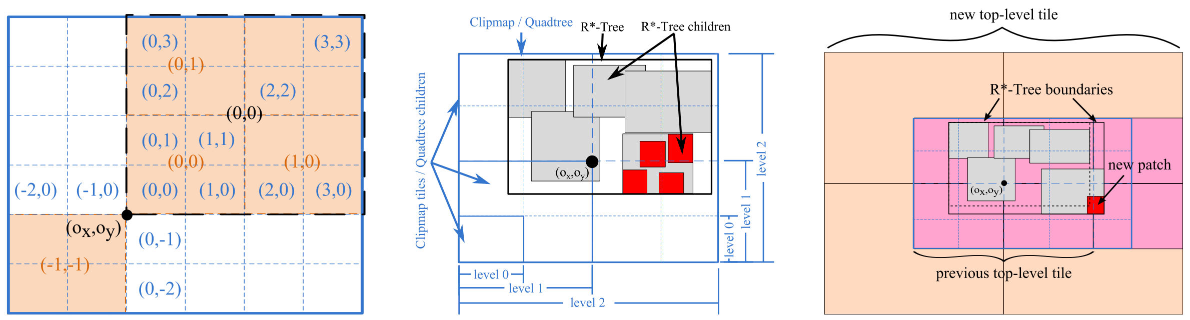

(a) indexing tiles within the FCM (b) relation of R*-tree and quadtree (c) expansion of the FCM

Figure 2: Overview of the most important concepts used for constructing the Flexible Clipmap.

exactly one texture tile at level $l = 0$ and indexed as shown in Figure 2(a). Starting with $l = 0$ at the origin, 2×2 neighbored grid cells at level l are grouped to a cell of size $2^{l+1} \cdot g_x \times 2^{l+1} \cdot g_y$, and thus conceptually a quadtree is specified. This process is repeated until A is covered in x- or y-direction by at most two grid cells each, but by at least two in one of the directions. The tiles from higher levels $0 < l < (L-1)$ are obtained by identifying each tile either with the corresponding quadtree node at the same level or with the area covered by the equivalent grid cell in RWC. Like with mipmaps, the content of each tile is determined by the content of its children, but the position of each tile in RWC is fixed.

The top-most tile at level $L-1$ requires some special attention, because as a constraint for the FCM, this level must cover A entirely while consisting of exactly 2×2 subordinated tiles (*children*). In cases of having only 1×2 or 2×1 children, the missing ones are replaced by the nearest, even empty, neighbors in the corresponding direction. If the top-level tile would be constructed from the quadtree as well, the quadtree root might be located at a level $\geq L$ and many empty children would have to be included to satisfy this constraint. Besides, the top-level tile is indexed $(0,0)$, because its quadtree node may not necessarily be the parent node of all of its children any longer, e. g., if it was formed by the nodes $((1,-1),(2,-1),(1,0),(2,0))$ at $L-1$.

Given a certain level, we can determine the tile index $n(l,r) = (n_x,n_y)$ to which a location $r = (r_x,r_y)$ in RWC belongs by the following relation:

$$n(l,r)_d = \begin{cases} \left\lfloor \frac{r_d}{2^l \cdot g_d} \right\rfloor & 0 \leq l < (L-1) \\ 0 & l = (L-1) \end{cases}, d \in \{x,y\}$$

Since L depends on the position of ll and ru at the top level $L-1$, the total number of clip levels L cannot be determined by the following quantity:

$$\hat{L} = \max_{d \in \{x,y\}} \left(\lceil \log_2(ru_d - ll_d) \rceil - \lceil \log_2(g_d) \rceil\right)$$

According to the description above, $L-2$ is the level l' where at least one of the two components of the difference of the tile indices $n(l',ru)$ and $n(l',ll)$ equals one. This is expressed in the following equation:

$$n(l',ru)_d - n(l',ll)_d = \left\lfloor \frac{ru_d}{2^{l'} g_d} \right\rfloor - \left\lfloor \frac{ll_d}{2^{l'} g_d} \right\rfloor \overset{!}{=} 1 \quad (1)$$

We actually determine the required number of clip levels L by checking if $l' = \hat{L}$ satisfies Equation 1. If it does not, l' is incremented and checked again, until a suitable l' is found.

Most important about this indexing is that $n(l,r)$ does not directly depend on A. This facilitates adding new tiles to the FCM, because each tile at each level has a unique index and conceptually already exists, though it may not contain image information. The relation of the R*-tree, A and the quadtree is illustrated in Figure 2(b).

3.5 Expanding Textures

An expansion of A into any direction is triggered by the insertion of new patches which are not completely covered by A. This leads to the addition of at least one new clip level if A then exceeds the boundaries of the current top-most tile at $L-1$ as illustrated in Figure 2(c). The total number of new clip levels depends on the extension of A. In that case, the former tile at level $L-1$ does no longer satisfy the constraint of covering at most 2×2 tiles from the next lower level, and the maximum clip level has to be increased by the number of new levels k, so we denote the former number of clip levels by L' and set $L = L' + k$. All other tiles remain unchanged with respect to their indices, with the exception of the former top-level tile at $L'-1$, because its index $(0,0)$ does not necessarily reflect the indices of subordinated tiles any longer. The entire tile is therefore discarded and then recreated from its 2×2 children, which will have been updated by then (see Section 3.6).

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3.6 Updating Tiles

In principle, tiles need to be updated as soon as they are covered by a new patch, but depending on the application, it may be sufficient to start updating affected tiles only if a certain threshold for the number of new patches has been reached or after a certain period of time. The spatial index supports easy access to all patches that contribute to a certain tile (see Section 3.3). The number of contributing patches may increase over time as well as the costs for updating one tile. Therefore, different selection criteria can be applied to discard patches which are not to contribute to the final texture, e. g., if the contrast of the image is below a certain threshold or if it is outdated. Depending on the desired quality of the resulting virtual texture and the application, it may be sufficient to update existing tiles incrementally by processing only the latest patches and blend them with the previously generated tiles. Independent of whether tiles are updated incrementally or extensively, we only update the tiles at level $l = 0$ from patches. The patches themselves are moved to secondary memory afterwards in order to free main memory. Tiles at $l > 0$ (*parents*) will be updated in increasing level order by recursively copying and scaling the respective regions covered by the tiles at $l-1$. Therefore we keep the most recently updated children from the current level in main memory until their parents have been updated. Afterwards, the parents take the role of their children, and the process is repeated until the top-most tile has been updated.

3.7 Architecture

One characteristic of clipmaps is the employment of caching and secondary storage. In the FCM, we also use a tile cache for caching an amount of $c_x(l) \times c_y(l)$ texture tiles at each clip level l in main memory. As described in (Tanner et al., 1998), the set is chosen based on the current clip center with the $c_x(l) \times c_y(l)$ neighbored tiles centered around it, and the set is identical to the *clip stack*. Its content is updated as the eye point moves by a distance greater than some threshold, and the cache is accessed using toroidal indexing on the tile indices. A smaller subset of $a_x(l) \times a_y(l)$ tiles with $a_d(l) \leq c_d(l)$ and $d \in \{x,y\}$, which are also centered around the clip center and visible to the viewer (*active area*), is copied to the *tile array* in VRAM, which is realized as a texture array, accessible by GPU shaders. The quantities $c_d(l)$ and $a_d(l)$ depend on the clip level, but are limited by some constants C_d and A_d defined by the user or the application. However, A_d must be chosen so that $a_d(0)$ times the width respectively height of one tile in texels is at least as large as the width respectively height of the application's viewport in pixels in order to avoid visible borders of lower resolution during rendering.

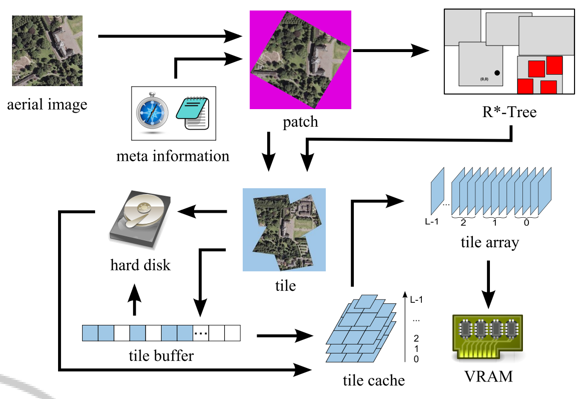

Figure 3: Overview of the architecture of the FCM.

Following the idea in (Crawfis et al., 2007), we use an extra texture, the *tile map*, which is a downscaled version of the entire virtual texture and contains at every texel the highest currently available clip level of a tile in the tile array. The position of a tile map texel is determined by the position (i. e., index) of the corresponding tile and its level. The lateral dimensions of the tile map tm_x, tm_y must satisfy Equation 2, so that each tile at level 0 is represented by at least one texel in the tile map, with L denoting the number of clip levels.

$$\log_2\left(\min_{d\in\{x,y\}}\{tm_d\}\right) \geq (L-1) \qquad (2)$$

To reduce storing and reloading tiles from secondary memory, we additionally keep a certain amount b of the tiles which were not already cached but have been loaded during updating in a *tile buffer* in main memory. This is done because the viewer is frequently tracking the regions which were recently updated, and the affected tiles will likely be needed to update the tile array in VRAM as well. Figure 3 contains a sketch of the components and entities involved in the FCM.

Whenever possible, reading from and writing to secondary memory is done in a separate thread in order to not stall the rendering and updating processes.

3.8 Rendering

Texture mapping using the FCM is implemented by GPU fragment programs. The tile array and tile map have to be bound to one texturing unit each and are accessed by the shader. The texture coordinates (u,v) are assumed to be in $[0.0, 1.0]^2$ and have to map the

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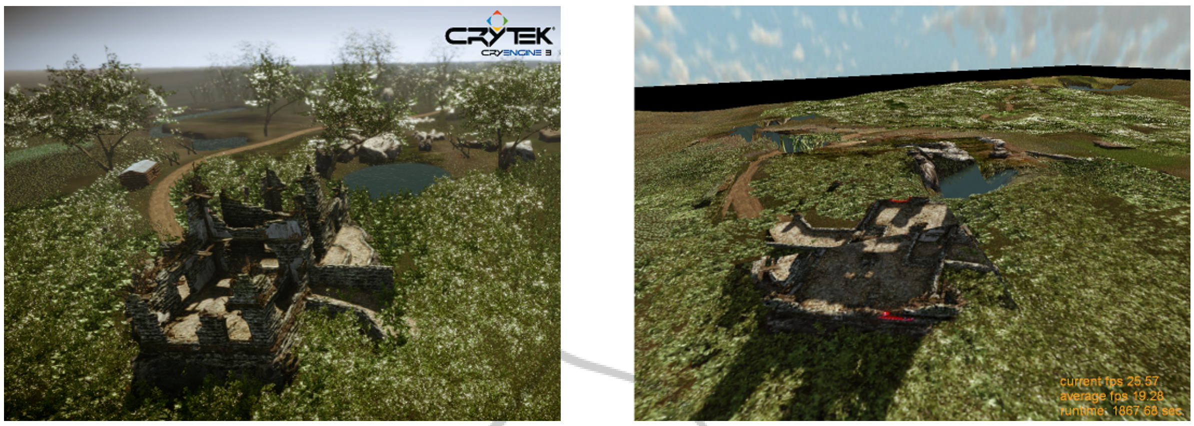

(a) simulated environment using CryEngine 3 (b) captured environment using FCM

Figure 4: Screenshots from the simulated environment and the captured environment. Black areas near the horizon in (b) have not been captured so far.

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entire $\mathbb{R}^2$, but the fragment shader transforms the coordinates so that only the area covered by A is affected by texture mapping from the FCM. For each fragment the fragment program performs a look-up in the tile map to determine the tile with the highest LOD l_{max} available in the tile array and calculates an ideal level l_{ideal} (analog to (Crawfis et al., 2007)). The calculation of the ideal level is based on the texel minification in screen space and uses a simplified anisotropic filtering method by Ewins et al. (Ewins et al., 1998). The final LOD l_f is determined as $l_f = \max(l_{max}, l_{ideal})$. If a tile could not be uploaded on time, the tile map would contain the level of the next coarser LOD available; in the worst case, at least the top-level at $L-1$ would be present.

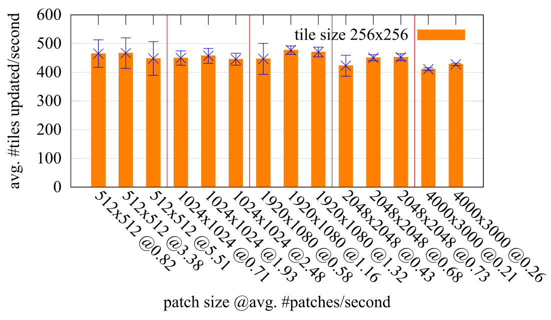
4 PERFORMANCE ANALYSIS

The proposed FCM has been developed and analyzed in the context of the AVIGLE project. One goal of this project is to capture low-altitude aerial images by a swarm of MUAVs, transfer these images to a ground mission control station, and display them immediately. The realization of this project requires the development of a novel type of MUAV, advanced swarm algorithms, network technology, and in particular fast and accurate image processing and visualization strategies. For that reason, we have developed a simulation framework (Strothoff et al., 2010), which allows to generate virtual aerial images at custom locations, orientations, resolutions and frequencies from renderings of digital 3D models using any visualization library or computer game engine like the CryEngine (Crytek GmbH, 2010). The images with added meta information are sent by a separate thread over a network via TCP to a client application where they are processed by the employed FCM. Figure 4 shows a screenshot of the simulated 3D environment (left) and a screenshot of the client application, depicting the corresponding area textured with the content from the FCM which has been derived from the virtual aerial images captured by a virtual MUAV (right).

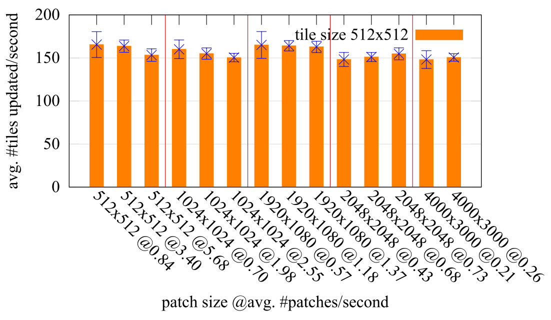
4.1 Evaluation Setup

The run-time performance of the rendering and the visual quality of the resulting texture map in the FCM depend on the following quantities: the resolution of the incoming patches in texels (p_x, p_y), the number of patches per second (*patch rate*), the number of tile updates per second (*update rate*), the resolution of the final texture in pixels per unit (*ppu*), the resolution of tiles in texels (t_x, t_y) and the sizes of the tile cache $(c_x(l), c_y(l))$, the tile buffer b and the active area $(a_x(l), a_y(l))$ in number of tiles at each level l. We analyzed the performance of the FCM in terms of the number of updated tiles per second during continuous insertion of patches, because high rates of tile updates are essential for growing and dynamically adjusting the content of the virtual texture.

In our evaluation setup, we always used a viewport/screen size of $(s_x, s_y) = (1024, 768)$ pixels, $ppu = 20$, $A_d = \lceil s_d / t_d \rceil$, $C_d = 2 \cdot A_d$ with $d \in \{x, y\}$ and $b = C_x \cdot C_y$. For each tested configuration of tile sizes, patch sizes and average patch rates, we simulated a single virtual MUAV equipped with a non-metric camera and following exactly the same path at a constant altitude of 50 m above sea level, and we performed 10 runs each to obtain means. Means are necessary, because the patches received by the



(a) tile size 256×256 texels



(b) tile size 512×512 texels

Figure 5: FCM performance in terms of tile updates/second in our evaluation setup.

client are located at random positions along the path of the virtual MUAV during different runs, as there is no synchronization between the applications. In addition, the simulator cannot guarantee to provide a certain patch rate, which also strongly depends on the resolution of the patches and the network. Tile updates were performed in every frame whenever at least one new patch was received. The simulator and the client applications were executed in parallel on a single desktop computer with an Intel i7 CPU at 2.8 GHz, a NVidia GeForce 470 GTX with 1280 MB VRAM, 6 GB RAM and 64-bit Windows 7 OS.

4.2 Results

The results of the FCM performance in terms of updated tiles per second from the setup described above for tile sizes of 256^2 and 512^2 texels and for different patch sizes at different averaged patch rates are shown in Figure 5. Error bars indicate the standard deviations. During the evaluation the FCM had at most $L = 8$ clip levels in case of 256^2 tiles and $L = 7$ in case of the 512^2 tiles after the area of A covered the entire DSM. This corresponds to a 32-bit RGBA texture of $2^{15} \times 2^{15}$ texels with a memory size of 4 GB. The most demanding configuration (4000×3000 texels@0.26) corresponds to an average data rate of $11.9\,\frac{\text{MB}}{s}$ but still achieved tile update rates of $427.59\frac{1}{s}$ respectively $150.57\frac{1}{s}$ whereas the total number of tiles in the tile array was only 85 respectively 25. This implies that the average update rates are sufficient to update the entire tile array multiple times per second and still permit interactive rendering frame rates.

5 DISCUSSION

Our evaluation has shown that the most important limiting factors in our setup were the simulation of image sources providing high resolution images at high frequency, and the transmission over the network. This prevented us from performing further measurements and determining the limits of the FCM in the given scenario. A problem arises if the patches cover the entire area of the FCM or even more, e. g., when the images are taken from high altitudes: the updates then would not be confined to few tiles and would affect the entire FCM. However, this issue can be avoided by limiting the amount of tiles updated in each frame, which is advisable anyway, because performing many tile updates between two frames would stall the rendering and reduce interactivity.

Another severe issue is caused by the 32-bit floating point precision of the texture coordinates (u, v), because they need to cover in principle the entire $\mathbb{R}^2$ (see Section 3.8). This also arises in other GPU based clipmap implementations (cf. (Ephanov and Coleman, 2006), (Taibo et al., 2009)). By deriving the geometry from the FCM as well, we could drop that constraint and map the range of $[0.0, 1.0]$ only to the visible portion of the geometry.

We used the FCM only for color mapping and single texturing, but it can be extended easily for multitexturing during single-pass rendering by adding tile arrays for every additional texture and binding them to additional texture units. Additional texture maps could also be derived from additional spatial indexes in order to immediately create large textures from different modalities like RGB and thermal images.

Furthermore, the size of the tile map can exceed the hardware limits as the number of clip levels increases (cf. Section 3.7). This can be countered by virtualizing the clip stack, as already introduced in (Tanner et al., 1998), by processing only a subset $[l_{min}, l_{max}] \subset [0, L-1]$ of clip levels which are relevant for the viewer at her current eye point. Though the tile map requires an additional texture unit, it provides a very easy LOD selection and avoids invalidating entire detail levels, if a single tile is missing(cf. (Crawfis et al., 2007)).

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6 CONCLUSIONS AND FUTURE WORK

In this article we have presented the Flexible Clipmap to dynamically generate on-the-fly a very large growing virtual texture of frequently changing content at several levels-of-detail, and we used it for instantly rendering the captured area at interactive frame rates. This permits to monitor the capturing process and to interact with the capturing devices using commodity hardware.

However, the images and the resulting texture map itself are all located in the same image plane. To derive highly detailed and therefore very large texture maps of entire 3D objects or even 3D sceneries in the same way, we must be able to handle images located in multiple image planes. In addition, the environments we are planning to capture are highly dynamic as well, and we will have to deal with ambiguous and missing image information. We will also extend the FCM to a kind of growing geometry clipmap (Losasso and Hoppe, 2004), and then create a 3D mesh of the underlying geometry in the same way we already create the texture map and thus enable completely dynamic renderings of the captured environment in real time.

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