Intelligent Interface for Synthesizing Procedural Stone Forest Landscape

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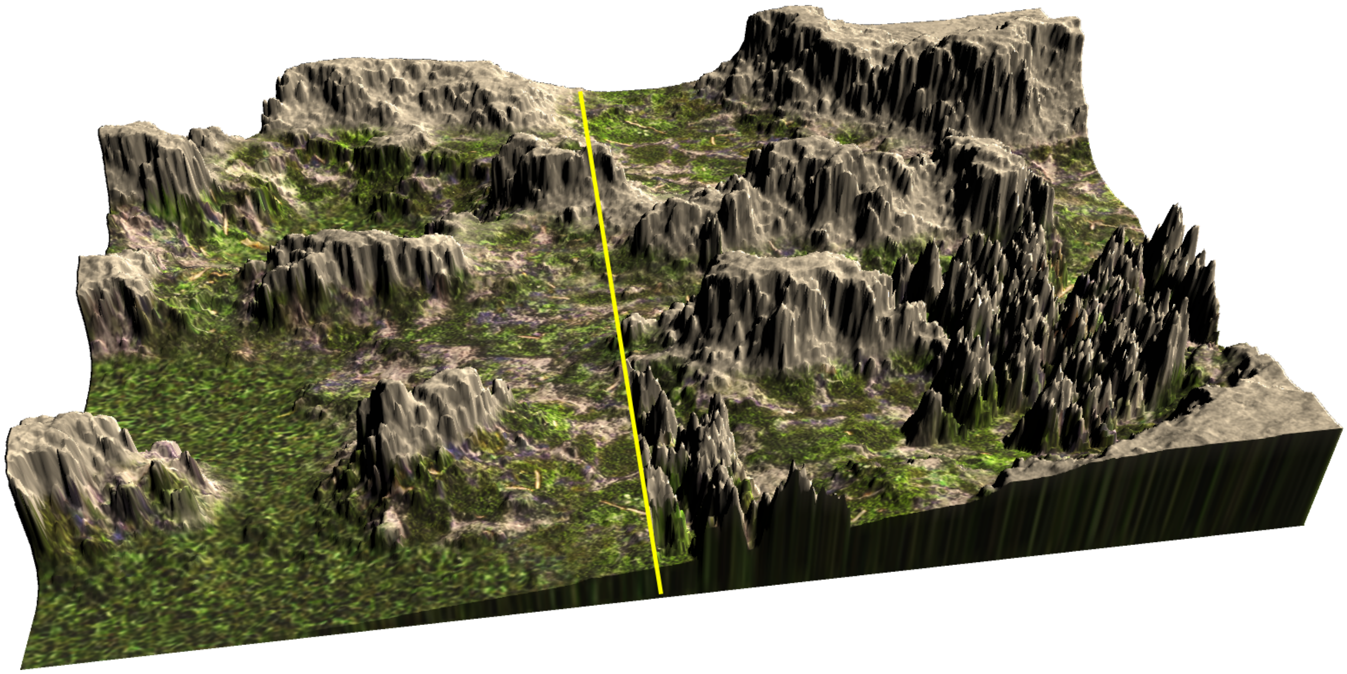

Fig. 1. Teaser. This teaser showcase the results of our approach in synthesizing realistic procedural terrain for stone forest landscape generation. The comparison unfolds between an input virtual terrain generated with existing procedural modeling techniques in the left half figure, and the synthesized output virtual stone forest terrain on the right half figure.

***Abstract*—The generation of realistic and captivating landscapes in computer graphics requires innovative approaches to recreate the complexity found in natural environments. This paper presents a novel method for synthesizing procedural terrain specifically tailored for the generation of stone forest landscapes. Stone forests, characterized by towering limestone formations resembling petrified trees, pose a unique set of challenges due to their intricate patterns and irregular structures. Our approach leverages procedural generation techniques to synthesize these landscapes using procedural modeling algorithms, providing an automated solution for applications ranging from virtual environments to video games.**

***Keywords*-procedural modeling, terrain synthesis**

I. Introduction

Stone forest landscapes [1], also known as petrified forests, limestone karst landscape or limestone forests [2], represent captivating geological formations that have captured the imagination of explorers and admirers. The allure of stone forest landscapes lies in their surreal structures, demanding sophisticated algorithms to emulate their intricate details. Traditional terrain modeling methods often fall short of capturing the complexity inherent in stone forests.

Fig. 3 shows a real photo captured from the needle-shaped limestone formations in Tsingy de Bemaraha Strict Nature Reserve [3]. Unlike traditional forests, these landscapes are characterized by towering limestone pillars, which often reach significant heights, emerge from the ground in densely packed clusters, and form intricate patterns. These landscapes are typically found in regions with karst topographywhere limestone undergoes erosion processes over time. Achieving immersive and visually stunning virtual environments such as stone forest landscapes synthesis relies heavily on the fidelity of the procedural terrain modeling approach.

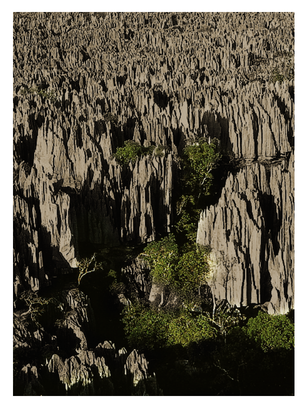

Fig. 3. Real Photo [3]

Numerous methodologies have been employed to create realistic virtual terrains and procedural landscapes. These include genetic algorithms contribute to parametric-controllable

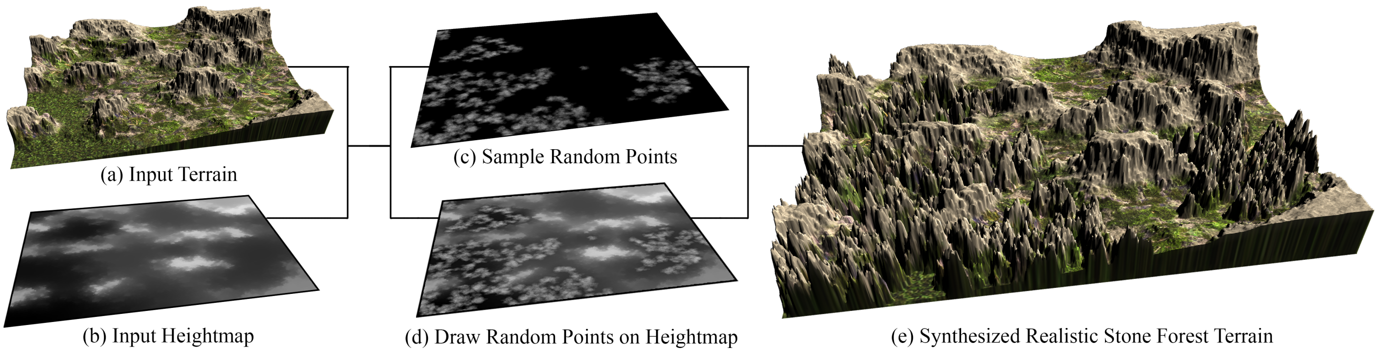

Fig. 2. Overview of our approach.

terrain models [4] that offers fine-grained control over terrain features, procedural modeling techniques [5] that employ Diffusion-limited aggregation (DLA) algorithms to generate landscapes, generative adversarial networks for terrain generation [6]–[8] that utilizing existing terrain datasets for realistic reconstructions. Virtual reality applications benefit from realistic terrain synthesis techniques that tailor procedural landscape generation for immersive virtual experiences [9]. Other approaches, such as hydrology-informed terrains [10], patch-based heightmap synthesis [11] which utilize elevation data for terrain synthesis, and volumetric terrain representations [12], contribute to the diversity of available techniques. Additionally, advancements like large-scale terrain modeling [13], cracked terrain synthesis [14], gradient terrain authoring [15], volcanic landscape simulation [16], speleothem-based 3D karst caves generation [17], marine landscape synthesis [18], and terrain point cloud rendering [19] exemplify the breadth and depth of the approaches in crafting realistic virtual terrains.

However, stone forests present a unique set of challenges that necessitate a focused investigation, and there is no existing research work that has systematically explored the procedural modeling approaches to synthesize procedural terrain for the stone forest landscape generation. Therefore, given this observation, this paper introduces a novel approach that combines procedural modeling algorithms and spatial distribution techniques to create visually stunning and realistic stone forest terrains. Fig.1 shows an example of a realistic procedural terrain for stone forest landscape generation synthesized with our approach. An original virtual terrain created with existing procedural modeling approach (left half-figure) is automatically converted into a virtual stone forest terrain (right half-figure) using our approach.

II. Technical Approach

Overview. Fig. 2 shows the overview of our approach to generating realistic stone forest terrains. Beginning with the input terrain (a) and its corresponding input heightmap (b), our method involves the strategic selection of sample random points across the terrain (c). Subsequently, in (d), these points are drawn onto the input heightmap through our proposed technical approach which will be detailed explained in this section. The output terrain is illustrated in (e), showcasing the synthesized result of realistic stone forest terrain. This final output demonstrates the efficacy of our approach in transforming input terrain into compelling and realistic virtual landscapes reminiscent of stone forests.

Stone Forest. Input terrain's heightmap is denoted as $h(u,v) \in [0,1], (u,v) \in \mathcal{R}^2$. An integer n is introduced to signify the number of levels of stone pillars within the stone forest. Two groups of parameters are defined, each parameter tuple comprising three elements: pillar count m, pillar radius r, and pillar height h. The parameter tuple for the initial pillar level is denoted as (m_0, r_0, h_0), and for the final pillar level is represented as (m_n, r_n, h_n). Within the texture coordinate space, a matrix of random points $\mathbf{P} = \{\mathbf{p}_{i,j} | \mathbf{p} \in [0,1]^2, i \in [1,n], j \in [1, m_i]\}$ are sampled for each pillar level i. Stone forest heightmap $h'(u,v)$ is:

$$h'(u,v) = h(u,v) + \sum_{i=1}^{n} \sum_{j=1}^{m_i} h_i \zeta_{\mathbf{p}_{i,j}}^{r_i}(u,v)\psi(u,v) \quad (1)$$

where $m_i = (1-t)m_0 + tm_1$, $r_i = (1-t)r_0 + tr_1$, $h_i = (1-t)h_0 + th_1$, and $t = (i-1)/(n-1)$. Heightmap scale function $\psi(u,v) = 1 - h(u,v)$, if $1 - h(u,v) > \mu$; Otherwise $\psi(u,v) = 0$. Distance compare function $\zeta_{\mathbf{p}_{i,j}}^{r_i}(u,v)$ is:

$$\zeta_{\mathbf{p}_{i,j}}^{r_i}(u,v) = \begin{cases} 1 & \delta_{\mathbf{p}_{i,j}}^{r_i}(u,v) \leq 0 \wedge \zeta_{\mathbf{p}_{i-1,j}}^{r_{i-1}}(u,v) = 1 \\ 0 & \delta_{\mathbf{p}_{i,j}}^{r_i}(u,v) > 0 \vee \zeta_{\mathbf{p}_{i-1,j}}^{r_{i-1}}(u,v) = 0 \end{cases} \quad (2)$$

where $i \geq 2$ and $\zeta_{\mathbf{p}_{1,j}}^{r_1}(u,v) = 1$, if $\delta_{\mathbf{p}_{1,j}}^{r_1}(u,v) \leq 0$; Otherwise $\zeta_{\mathbf{p}_{1,j}}^{r_1}(u,v) = 0$; $\delta_{\mathbf{p}_{i,j}}^{r_i}(u,v) = ||(u,v) - \mathbf{p}_{i,j}|| - r_i$.

III. Experiment Results

To assess the effectiveness of our proposed technical approach, a series of numerical experiments were conducted to synthesize terrains for virtual stone forest landscape generation. The implementation of our approach was carried out using Unity 3D (2019 version), and the experiments were executed on hardware configurations featuring an Intel Core i5 CPU, 32GB DDR4 RAM, and an NVIDIA GeForce GTX 1650 4GB GDDR6 Graphics Card. These experiments were conducted under default parameter settings, which included 40 levels of stone pillars denoted as $n = 40$; Parameter values for the initial and final pillar levels are $(m_0 = 500, r_0 = 0.015, h_0 = 0.1)$ and $(m_1 = 2000, r_0 = 0.005, h_0 = 0.05)$, respectively; Parameter $\mu = 0.75$.

In Fig. 4, the outcomes of synthesizing stone forest terrains are vividly illustrated across four distinct types of input terrains. Each row in the figure corresponds to a different input

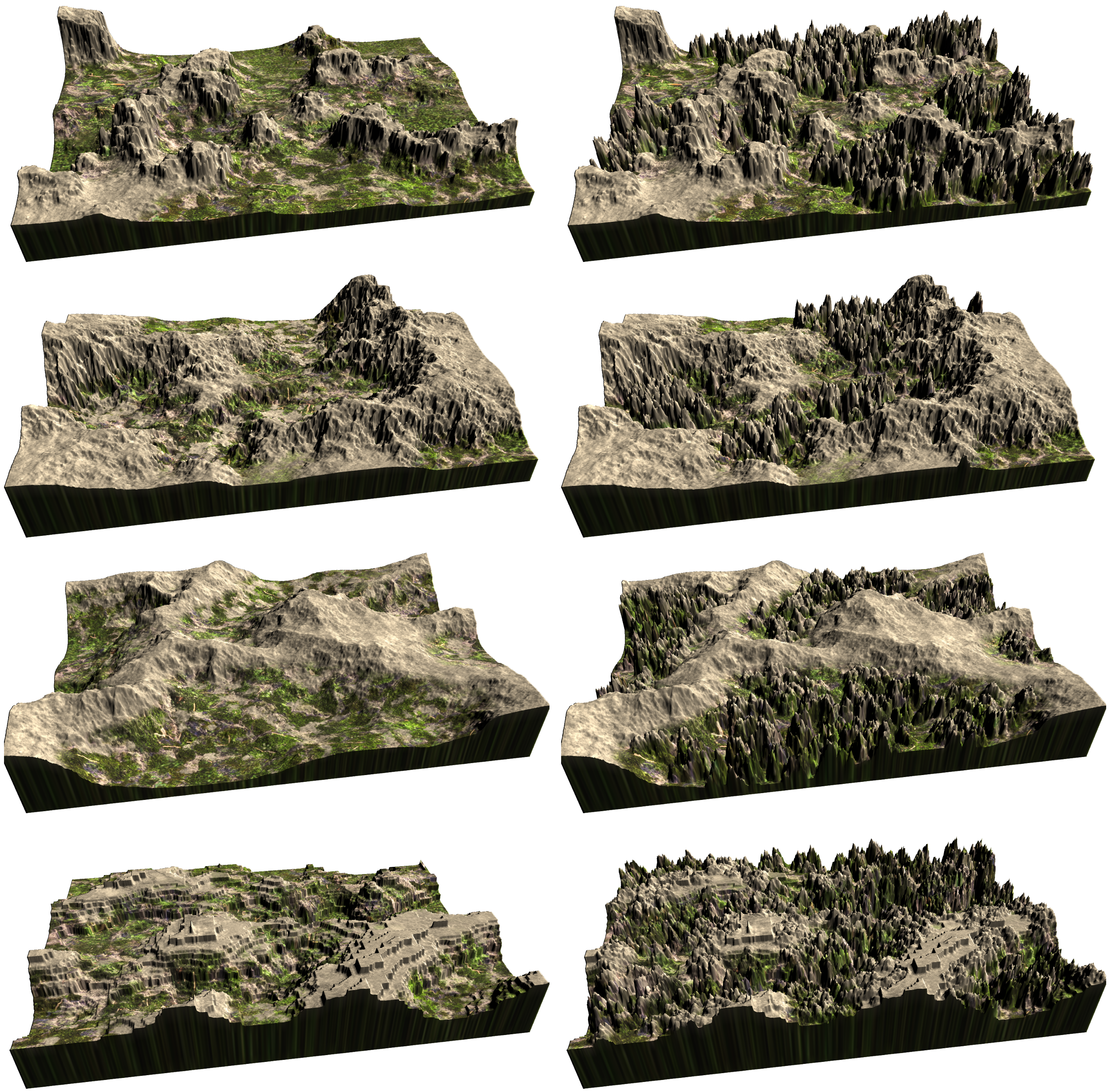

Fig. 4. Different Input Terrains. These are stone forest terrains (right) synthesized on different input terrains (left).

terrain, depicted in the left column, and its counterpart stone forest terrain synthesized using our approach is showcased in the right column. This presentation provides a comprehensive visual comparison, highlighting the efficacy of our procedural terrain generation method on diverse initial landscapes. The juxtaposition of the original input terrains with the synthesized stone forest terrains underscores the versatility of our approach in capturing the intricate details and unique characteristics inherent to stone forests across various terrain types.

In Fig. 5, a detailed exploration of the synthesized stone forest terrain is presented, offering a closer look at the intricacies of the generated landscape. The figure showcases five distinct views captured from different perspectives, each rendered from a camera placed within the virtual stone forest terrain synthesized using our procedural approach. These multiple viewpoints provide a comprehensive glimpse into the richness and complexity of the generated landscape, emphasizing the fidelity and realism achieved through our method. The diversity of view points offers a closer understanding of the terrain, accentuating the three-dimensional qualities of the stone pillars and overall topography. This comprehensive visualization underscores the robustness and adaptability of our approach in producing realistic stone forest environments from different view points.

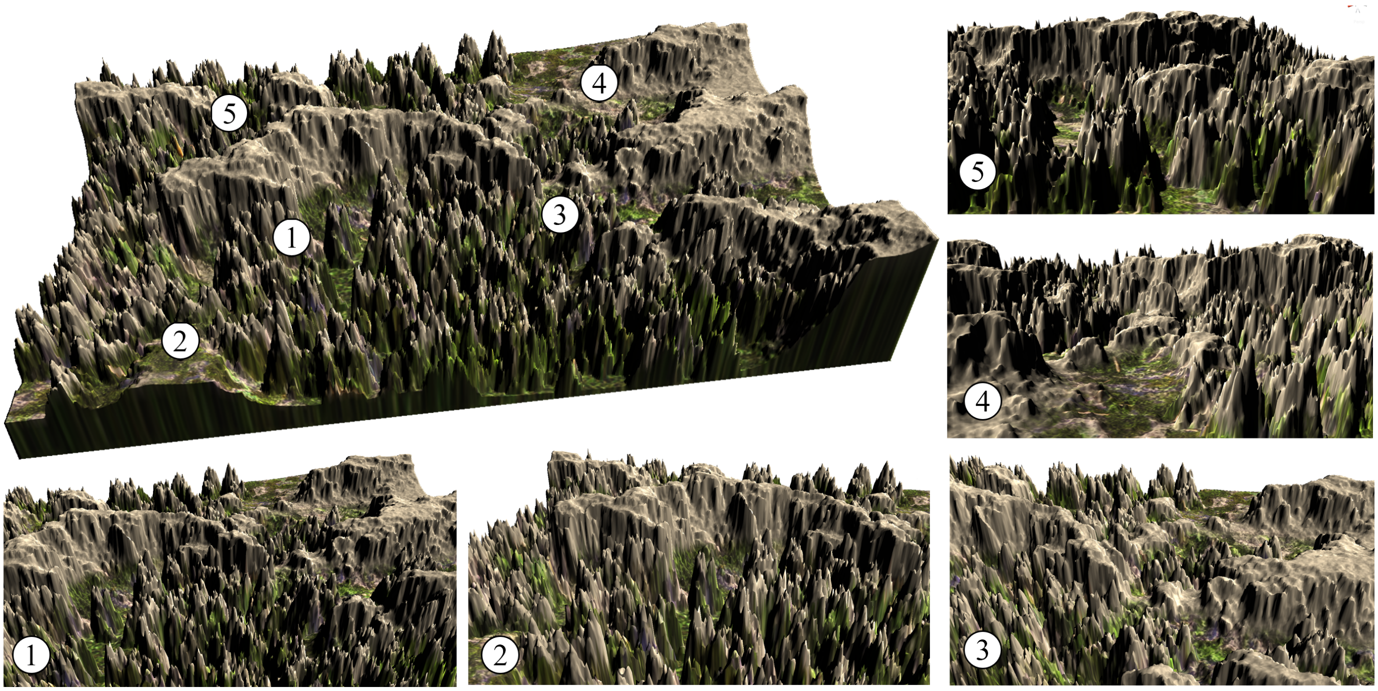

Fig. 5. Terrain Details. This figure shows the details of synthesized stone forest terrain. Five different views are rendered from five cameras placed in the virtual stone forest terrain that is synthesized with our approach.

IV. Conclusion

In this paper, we present a novel procedural terrain generation approach specifically designed for the intricate landscapes of stone forests. Through the synergistic integration of procedural algorithms and spatial distribution techniques, our method succeeded in producing terrain that is not only realistic but also visually compelling. The combination of these techniques captures the unique characteristics of stone forests, including the towering limestone pillars and intricate patterns that define these landscapes. The results demonstrate the efficacy of our approach in reproducing the complexity of stone forest terrains. Beyond its immediate applications, our method holds promise for further advancements in procedural landscape generation, serving as a valuable tool for diverse fields such as virtual reality, video games, and cinematic productions. This work lays the foundation for continued exploration in the realm of procedural terrain synthesis.

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