Compare The Size: Automatic Synthesis of Size Comparison Animation in Virtual Reality

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Fig. 1. This figure shows the experiment results of our proposed procedural modeling approach that automatically synthesizes size comparison animation in virtual reality, users wearing VR headsets can watch size comparison animation on VR platform.

***Abstract*—Size comparison animations have proven to be an effective method for conveying information about the relative sizes of objects, making it an essential tool for various domains such as science, education, architecture, and entertainment. At the same time, Virtual Reality (VR) technology has gained significant attention in recent years, enabling users to immerse themselves in realistic digital environments. However, the manual creation of size comparison animations in VR can be time-consuming and labor-intensive. In this paper, we propose Compare The Size, an automatic synthesis approach for generating size comparison animations in virtual reality. Our propose technical approach can automatically extract size information from input 3D shapes and create procedural animations that showcase their relative sizes. The generated animations can be experienced by users in a virtual environment, providing an immersive and engaging experience. In the end, we validate our proposed approach through a series of numerical experiments and user studies.**

***Keywords*—size comparison animation, virtual reality**

I. Introduction

Size comparison animations play an important role in conveying information about the relative sizes of objects, therefore it can be an effective method for scientific visualizations in pedagogic domains for science [1]–[4], society [5], [6], architecture [7], [8], arts [9], [10], astronomy [11], etc. Meanwhile, Virtual Reality (VR) offers a compelling platform for immersive experiences, allowing users to explore virtual environments and interact with virtual objects. As a consequence, VR-powered size comparison animations have great potential in enabling users to visually compare the size of objects from smaller-scale objects to larger-scale objects and help users comprehend the relative scales of virtual objects within a virtual scene. This way, size comparison animations in VR can be applied to provide users with a more realistic sense of scale and facilitate a deeper understanding of spatial relationships between virtual objects. However, manually designing these size comparison animations can be time-consuming and labor-intensive when the number of input objects is increasing, as the animation design cost becomes high when considering dragging 3D objects and animating the camera accordingly. Therefore, there is a need for an automated approach that can generate size comparison animations efficiently and accurately.

There are existing research works focusing on applying procedural modeling approaches to automatic animation synthesis. In 2004, Deng et al. [12] proposed a novel approach for synthesizing automatic dynamic expression for speech animation. In the same year, Yamane et al. [13] proposed a novel approach for synthesizing animations of human manipulation tasks. In 2006, Wang et al. [14] applied SOMN-HMM model to automatic synthesis of 3D character animations. In 2009, Levine et al. [15] proposed a novel prosody-driven approach for synthesizing real-time body language. In the same year, Delorme et al. [16] proposed a novel animation generation process for sign language synthesis. In 2014, Ding et al. [17] proposed a novel approach for synthesizing laughter animation. In 2016, Kapadia et al. [18] proposed CANVAS, a novel interactive interface for computer-assisted narrative animation synthesis. In 2019, Gujrania et al. [19] proposed Moving In Virtual Space, a laban-inspired framework for procedural animation. In 2022, Li et al. [20] proposed Animaton, a scriptable finite automaton for animation synthesis in Unity3D game engine. However, no existing work has attempted to synthesize size comparison animations on VR-enabled game engines. Therefore, given these observations, we propose Compare The Size, an automatic synthesis approach for generating size comparison animations in virtual reality. Our propose technical approach can automatically extract size information from input 3D shapes and create procedural animations in VR that showcase the relative sizes of 3D objects. In order to provide an immersive and engaging experience, the generated animations can be presented to users through a VR platform.

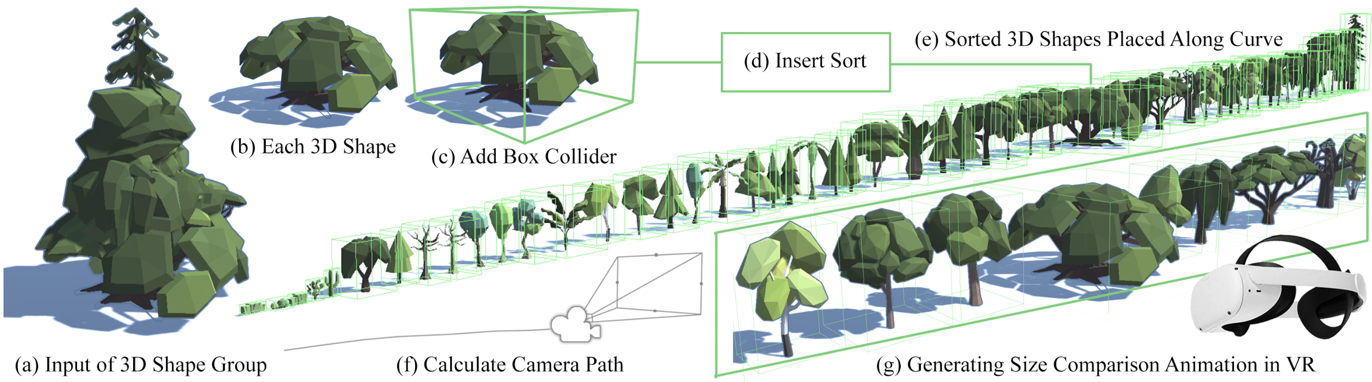


Fig. 2. Overview of our approach.

II. Overview

Figure 2 shows the overview of our approach. Given an arbitrary group of 3D shapes loaded into Unity Editor as Assets as shown in (a), firstly, for each 3D shape in the group as shown in (b), we attached a box collider component to each 3D shape by calculating that 3D shape's min-max corner according to its corresponding mesh vertices as shown in (c). Then, we sort all of the 3D shapes in the input group in ascending order according to the heights of their box colliders attached in the previous step as shown in (d). During the sorting process, we applied the insert sort algorithm which inserts the taller 3D shape after the shorter 3D shape one by one. Next, we procedurally place the sorted 3D shapes along an arbitrary parametric curve defined with a parametric equation as shown in (e). In the end, we calculate a path for the camera to navigate along the curve while remaining an adequate distance from the 3D shapes so as to generate the size comparison animation automatically as shown in (f). After connecting to SteamVR, users can watch this size comparison animation that has been automatically synthesized with our approach in virtual reality as shown in (g).

III. Technical Approach

3D Shape Sorting. In order to synthesize size comparison animation in VR, our approach sort the 3D shapes in ascending order according to their heights. Given an arbitrary group of 3D shapes loaded into Unity Editor, 3D shapes are an array of mesh vertices $\{V_1, V_2, ...\}$. Then, we attach a box collider component to each 3D shape by calculating that 3D shape's min-max corner according to its mesh vertices. Mathematically, the box collider array is calculated as:

$$B = \left\{(\mathbf{a}_i, \mathbf{b}_i) \middle| \mathbf{a}_i = \min_{\mathbf{v}\in V_i} \mathbf{v}, \mathbf{b}_i = \max_{\mathbf{v}\in V_i} \mathbf{v}, i \in [1, |V|]\right\} \quad (1)$$

Then, we sort all of the 3D shapes in the input group in ascending order according to the heights of their box colliders. We get a new array of mesh vertices $\{V'_1, V'_2, ...\}$ after applying an insert sort algorithm which inserts the taller 3D shape after the shorter 3D shape one by one, Mathematically, we have a new sorted array of mesh vertices $V' = \{..., V'_i, V'_{i+1}, ...\}$ s.t. $\forall i \in [1, |V| - 1], \exists V_j = V'_i, \exists V_k = V'_{i+1}, \Rightarrow (\mathbf{b}_k - \mathbf{a}_k)_y > (\mathbf{b}_j - \mathbf{a}_j)_y$. Correspondingly, we represent the new box collider array for the sorted 3D shapes as $B' = \{(\mathbf{a}'_i, \mathbf{b}'_i)\}$.

3D Shape Placement. After the 3D shapes are sorted according to their heights, we procedurally place the sorted 3D shapes along an arbitrary parametric curve defined with a 3D parametric equation $\mathbf{f}(t) \in \mathbb{R}^3$, where $t \in [0, 1]$. In order to distribute the 3D shapes along the parametric curve uniformly according to their size, in our approach, we place the sorted 3D shapes at the positions of $\{\mathbf{f}(t_1), \mathbf{f}(t_2), ...\}$ along the parametric curve according to the knots $\{t_1, t_2, ...\}$ where:

$$t_i = \frac{\sum_{j=1}^{i-1}(\mathbf{b}'_j - \mathbf{a}'_j)_x + (\mathbf{b}'_{j+1} - \mathbf{a}'_{j+1})_x}{\sum_{j=1}^{|V'|-1}(\mathbf{b}'_j - \mathbf{a}'_j)_x + (\mathbf{b}'_{j+1} - \mathbf{a}'_{j+1})_x} \quad (2)$$

Camera Navigation Path. In order to generate the size comparison animation automatically, after the sorted 3D shapes have been procedurally placed along a parametric curve from the previous steps, we synthesize a navigation path for the camera to move along that parametric curve while remaining an adequate distance from the 3D shapes and an appropriate moving speed between the 3D shapes. Let the camera's original direction set as $\mathbf{r}$, then navigation path for the camera $\mathbf{p}(t)$ is calculated form the following equation:

$$\mathbf{p}(t) = \mathbf{f}(t') + \kappa\mathbf{r}(\mathbf{b}'(t') - \mathbf{a}'(t'))_y \quad (3)$$

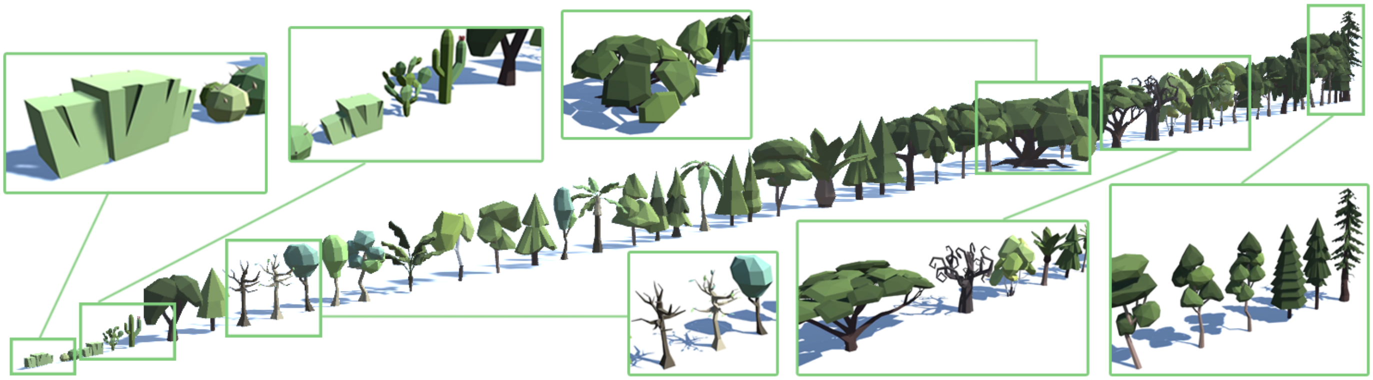
where κ is distance scale factor and t' is the time integrated with the time speedup proportional to the size of 3D shapes:

$$t' = \tau \int_0^t (\mathbf{b}'(t) - \mathbf{a}'(t))_x \mathrm{d}t \quad (4)$$

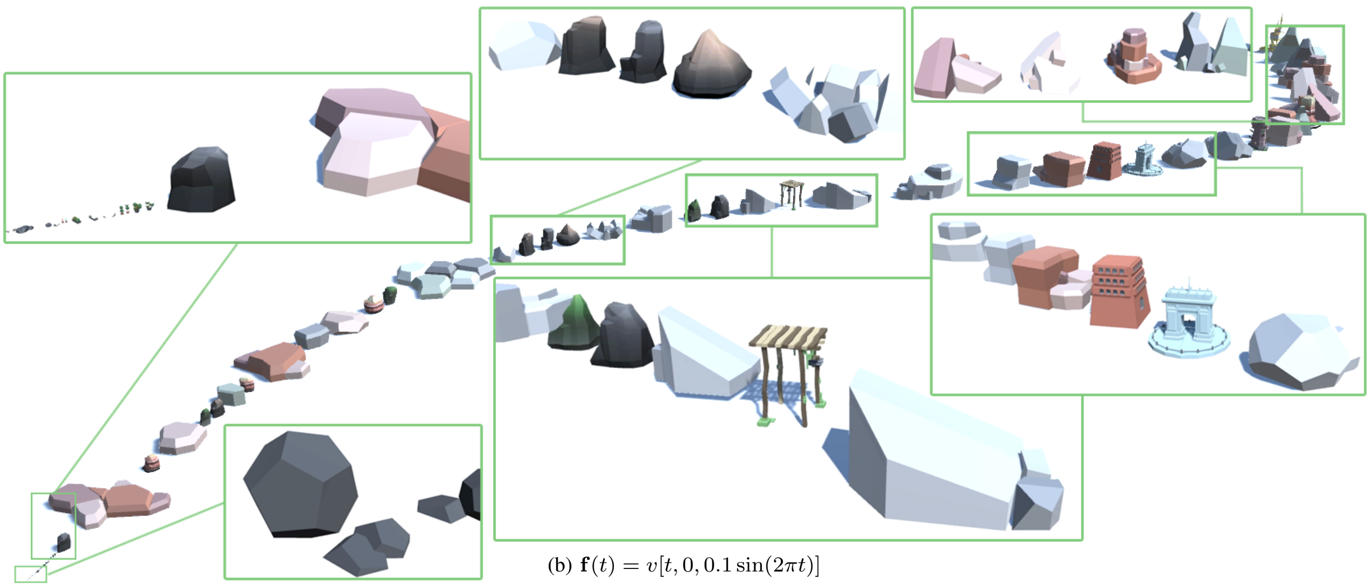
where τ is time speed scale factor, $\mathbf{a}'(t)$ and $\mathbf{b}'(t)$ are interpolated from the sorted 3D shape array's box collider array $B' = \{(\mathbf{a}'_i, \mathbf{b}'_i)\}$ using the knots calculated with Eq. 2.

IV. Experiment Results

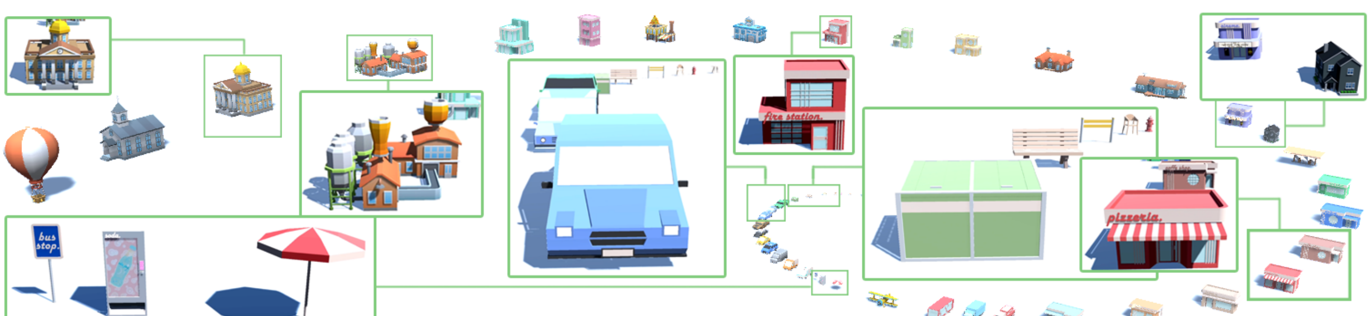
We implemented our proposed approach using Unity 3D with the 2019 version and generate these experiment results with the hardware configurations containing Intel Core i5 CPU, 32GB DDR4 RAM, and NVIDIA GeForce GTX 1650 4GB GDDR6 Graphics Card. Figure 3 shows the experiment results of synthesizing size comparison animations in VR.



(a) $\mathbf{f}(t) = \mathbf{v}t$, $\mathbf{v} = [200, 0, 0]$.



(b) $\mathbf{f}(t) = v[t, 0, 0.1\sin(2\pi t)]$



(c) $\mathbf{f}(t) = v\alpha[\cos(\alpha), 0, \sin(\alpha)]$, $\alpha = (8\pi t)^{0.6}$

Fig. 3. Experiment Results of Synthesizing Size Comparison Animation in Virtual Reality.

Figure 3 figure is divided into three rows, for each row, there is one experiment result of size comparison animation synthesized with our proposed approach. Figure 3 (a) shows the size comparison animation synthesized for 55 virtual tree models with following settings: parametric equation $\mathbf{f}(t) = \mathbf{v}t$ where $\mathbf{v} = [200, 0, 0]$, distance scale factor $\kappa = 4$, and time speed scale factor $\tau = 0.03$. Green rectangles highlight the zoom-in figures which are screenshots from the synthesized animation video. As we can see from the result, the virtual trees are uniformly placed along a straight line, and the heights of these trees are increasing as the timeline is progressing.

Figure 3 (b) shows the size comparison animation synthesized for 76 virtual stone models with following settings: parametric equation $\mathbf{f}(t) = v[t, 0, 0.1\sin(2\pi t)]$ where $v = 100$, distance scale factor $\kappa = 8$, and time speed scale factor $\tau = 0.15$. As we can see from the result, the virtual stones are uniformly placed along a sine curve, and the heights of these stones are increasing as the timeline is progressing. Figure 3 (c) shows the size comparison animation synthesized for 48 virtual city scene objects with following settings: parametric equation $\mathbf{f}(t) = v\alpha[\cos(\alpha), 0, \sin(\alpha)]$ where $\alpha = (8\pi t)^{0.6}$, $v = 30$, distance scale factor $\kappa = 5$, and time speed scale factor $\tau = 0.04$. As we can see from the result, the virtual city scene objects are uniformly placed along a spiral curve, and the heights of these city scene objects are increasing as the timeline is progressing. These three experiment results validate the effectiveness and accuracy of our proposed approach for size comparison animation synthesis.

User Study. Figure 4 shows the experiment result of a preliminary user study that tests the user's experience in watching our synthesized size comparison animations in VR. For this study, we choose high-quality VR headsets of Oculus Quest 2 and hand controllers to deliver an immersive virtual experience. During the study, three real-time size comparison animations are automatically synthesized in VR according to those three experiment settings specified in Figure 3 which cover different numbers of various objects and size differences. This study focuses on investigating and understanding the user experience of watching these synthesized animations in a VR context. These animations are synthesized with our approach to showcase scale relationships, such as comparing the size of virtual trees, stones, or city scene objects. According to the user's feedback, watching size comparison animations in VR is more immersive and impressive than watching size comparison animations on a flat screen. Therefore, this user study validates the effectiveness of our proposed approach. Video recording of this preliminary user study can be found through this link: https://youtu.be/m2xRLoIJ38w

V. Conclusion

In this paper, we propose Compare The Size, an automatic synthesis approach for generating size comparison animations in virtual reality. Our propose technical approach can automatically extract size information from given 3D shapes and create procedural animations in VR that showcase the relative sizes of 3D objects. After validating the effectiveness and accuracy of our proposed approach through a series of numerical experiments and user studies, it has been proven that size comparison animations in VR can be applied to provide users with a more realistic sense of scale and facilitate a deeper understanding of spatial relationships between virtual objects. Our research contributes to the field of virtual reality by providing a practical and efficient automated solution for generating size comparison animations. By leveraging 3D mesh process techniques and procedural modeling algorithms, our approach can handle a wide range of objects, making it applicable to simplify the process of creating size comparison animations in VR, reducing the burden on VR content developers and exploring the potential to streamline the creation process that allows for the rapid development of size comparison animations in various VR applications. Future work may involve refining the system's accuracy and expanding its capabilities to support more complex scenarios and diverse objects. Further improvements can be made to enhance the accuracy of camera motion and incorporate user feedback for iterative refinement. This research opens up new possibilities for providing users with a better understanding of size relationships in immersive virtual environments.

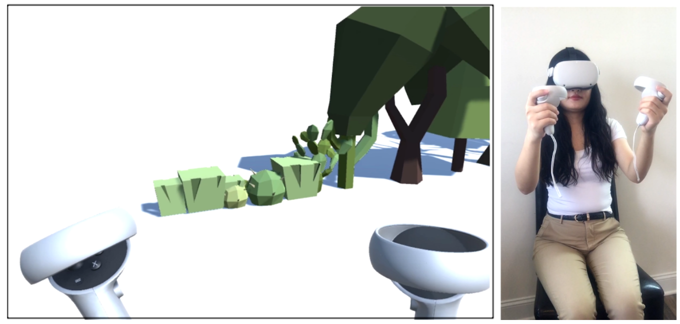


Fig. 4. User Study. This figure shows the user's experience in watching our synthesized size comparison animations in VR.

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