InsectVR: Simulating Crawling Insects in Virtual Reality for Biology Edutainment

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Figure 1: This figure shows a novel graphical interface, InsectVR, a VR platform designed for biology edutainment that simulates crawling insects in realistic and immersive virtual environments (left). After connecting with the Unity Steam VR plugin, the user wearing Oculus Quest 2 can play with InsectVR in virtual reality (right).

ABSTRACT

In this paper, we propose InsectVR, a Virtual Reality (VR) platform designed for biology edutainment that simulates crawling insects in realistic and immersive virtual environments. InsectVR offers a unique opportunity for educators to teach biology concepts related to insects and their behavior in an engaging way. InsectVR is designed to replicate the real-world behavior of crawling insects using a realistic mathematical model called the random walk algorithm. Through InsectVR, users can observe the movement of the insects and their behavior in immersive virtual environments which can help foster users' understanding of these amazing creatures. InsectVR uses state-of-the-art VR technology to create a highly realistic insect world, which includes different types of insects and various environmental conditions. After being tested through a series of numerical experiments and preliminary user studies, InsectVR demonstrates the potential to revolutionize biology edutainment by providing users with immersive virtual experiences.

CCS CONCEPTS

• **Computing methodologies** → **Graphics systems and interfaces**; **Virtual reality**.

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KEYWORDS

random walk algorithm, insects simulation, behaviour synthesis

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1 INTRODUCTION

In recent years, the application of Virtual Reality (VR) [6, 21, 26, 27] technology in education has gained significant traction, with many institutions incorporating VR into their teaching curriculum. Inevitably, VR technology has revolutionized the way we experience digital content and has been welcomed by edutainment applications. Recent research studies demonstrate the potential to apply VR/AR technologies [1, 5, 29] or related graphical interactive technologies to different subjects in science and arts edutainment [2, 4, 9, 19]. In 2021, Li et al. [11] proposed Pen2VR, a smart pen tool interface for wire art design and edutainment in VR. During the same year, Li et al. [10] proposed MusicTXT, a text-based music notation interface for music edutainment. In 2022, Li et al. [14] proposed a creative molecular model design interface for chemistry edutainment. During the same year, Li et al. [12] proposed a drawing animal cardboard toys design interface, called AnimalDraw, for children's art edutainment. In 2023, Li et al. [15] proposed PlanetTXT, a text-based planetary system simulation interface for astronomy edutainment. During the same year, Li et al. [17] proposed SurfChessVR, an interactive chess game edutainment interface that deploys chessmen on parametric surfaces in VR. At the same time, interactive graphical interfaces for simulating theoretical computational models such as Turing Machine (TM) [13] and Quantum

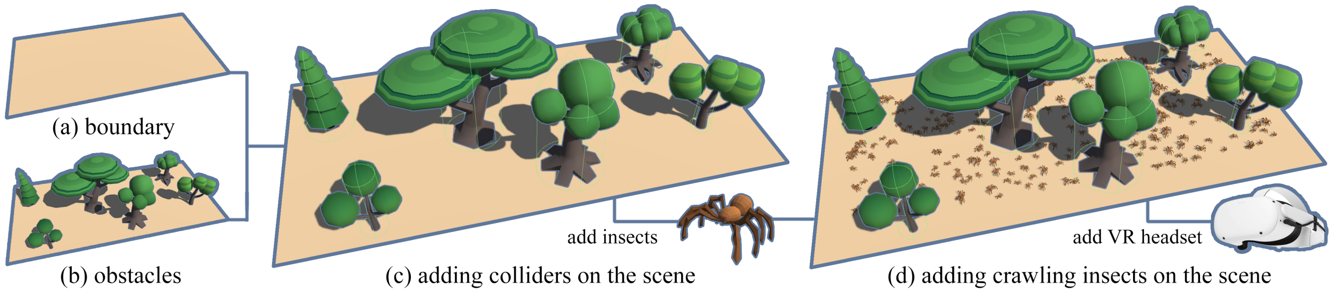


Figure 2: Overview of our approach.

Turing Machine (QTM) [16] have been proposed for computer science edutainment. Therefore, as one essential branch of science, biology is one field that has great potential to be benefited greatly from the use of VR, especially in the area of edutainment.

There are existing works [3, 18, 20, 24, 25, 28] that have successfully simulated swarms of flying insects, but none of the existing research works have conducted comprehensive experiments on simulating crawling insects in virtual reality for biology edutainment. Therefore, in this paper, we propose InsectVR, a VR platform designed for biology edutainment that simulates crawling insects in realistic and immersive virtual environments. InsectVR is a VR program that allows users to observe the crawling behavior of insects in a simulated environment. The system uses VR headsets to immerse users in a digital environment where they can see the crawling sensation of insects. This immersive experience in VR is designed to give users a deeper understanding of insect behavior in simulated virtual environments. On one hand, by implementing a classic random walk algorithm [8], InsectVR simulates the insect realistically so as to make itself an educational tool that helps students to learn about insects in an immersive way. On the other hand, InsectVR is also an entertaining tool. By experiencing the world from the perspective of an insect, students gain a unique understanding of their behavior. That way, by immersing users in a simulated environment, InsectVR provides an engaging experience that can be potentially extended into interactive games which will not only be fun but also contain educational content.

2 OVERVIEW

Figure 2 shows the overview of our approach. Given arbitrary boundary for the ground area as shown in Figure 2 (a), the obstacles manually placed in the scene as shown in Figure 2 (b), and the Capsule Collider [23] added to the obstacles in the scene as shown in Figure 2 (c), our approach procedurally adds and simulates the behaviour of crawling insects as shown in Figure 2 (d). Major steps applied during the initialization stage of the simulation process include: Randomly sampling positions on the ground within the boundary for the ground area, removing the positions contained by any obstacles colliders in the scene, and placing insects with different sizes which follow the normal distribution. After the initialization stage, the real-time simulation process of crawling insects starts. During this stage, the local motion of crawling insects is driven by a game engine component called Animator Controller [22]. The global motion of crawling insects, also called positions, is animated through a mathematical approach called random walk algorithm [7]. Random walk algorithm is applied to mimic the common behaviour of crawling insects given the environments without any attractor such as foods or habitats, simulating such behaviour includes repeating four steps: (1) calculating a random target moving orientation, (2) calculating a random target moving distance, (3) rotating to that target moving orientation, and (4) crawling forward with that target moving distance. After this random walk algorithm is implemented on the crawling insects, users wearing Oculus Quest 2 headsets can see realistic crawling insects simulations in VR.

3 TECHNICAL APPROACH

During the initialization stage of the simulation process, given arbitrary boundary for the ground area as a tuple of vectors $(\mathbf{b}_0, \mathbf{b}_1)$ and the obstacle colliders area A, the random initial position of a crawling insect at time t_0 is $\mathbf{p}(t_0) \sim U(\mathbf{b}_0, \mathbf{b}_1)$ where $\mathbf{p}(t_0) \notin A$ is uniformly sampled within the boundary. The random initial orientation of a crawling insect at time t_0 is $\theta(t_0) \sim U(-\pi, \pi)$. During the real-time simulation, for each iteration, random target orientation is calculated through $\theta(t_1) \sim U(-\pi, \pi)$ with the average target rotation time as $t_1 = \frac{\theta(t_1)-\theta(t_0)}{\mu_\omega}$, and velocity direction function $\hat{\mathbf{v}}(\theta) = (\cos(\theta), 0, \sin(\theta))$, the crawling insect's position at time t can be calculated as:

$$\mathbf{p}(t) = \mathbf{p}(t_0) + \int_{t_1}^{t} \hat{\mathbf{v}}\left(\theta(t_0) + \int_{t_0}^{t_1} \omega(t)\mathrm{d}t\right) v(t)\mathrm{d}t \qquad (1)$$

where $t_0 \le t_1 \le t \le t_2$, $t_2 = \frac{1}{\mu_v}\min[d(t), d_A(t_1, t_2)]$, and there are moving speed $v(t)$, rotating speed $\omega(t)$, and target moving distance $d(t)$ following the normal distributions as shown below:

$$(v(t), \omega(t), d(t)) \sim \left(\mathcal{N}(\mu_v, \sigma_v^2), \mathcal{N}(\mu_\omega, \sigma_\omega^2), \mathcal{N}(\mu_d, \sigma_d^2)\right) \qquad (2)$$

where μ_v, μ_ω, and μ_d are average moving speed, rotating speed, and target moving distance respectively. σ_v, σ_ω, and σ_d are standard deviations for moving speed, rotating speed, and target moving distance respectively. In our experiments, we set $\mu_v = 0.02$, $\mu_\omega = 0.01$, $\mu_d = 10$, $\sigma_v = 0.75\mu_v$, $\sigma_\omega = 0.33\mu_\omega$, $\sigma_d = 0.66\mu_d$. As shown in Figure 3, $d_A(t_1, t_2)$ is the min distance from the insect's initial position $\mathbf{p}(t_1)$ to the obstacle colliders area A calculated by solving the following equation:

$$d_A(t_1, t_2) = \min_{\exists \mathbf{q} \in A, \psi(\mathbf{q})=1} ||\mathbf{q} - \mathbf{p}(t_1)||_{\psi(\mathbf{q}) = \frac{\mathbf{q}-\mathbf{p}(t_1)}{||\mathbf{q}-\mathbf{p}(t_1)||} \cdot \frac{\mathbf{p}(t_2)-\mathbf{p}(t_1)}{||\mathbf{p}(t_2)-\mathbf{p}(t_1)||}} \qquad (3)$$

where condition function $\psi(\mathbf{q}) = 1$ ensures the direction between target moving orientation aligns with the direction of the obstacles area. This way, the avoidance of collisions between crawling insects and the obstacles in the scene is automatically ensured.

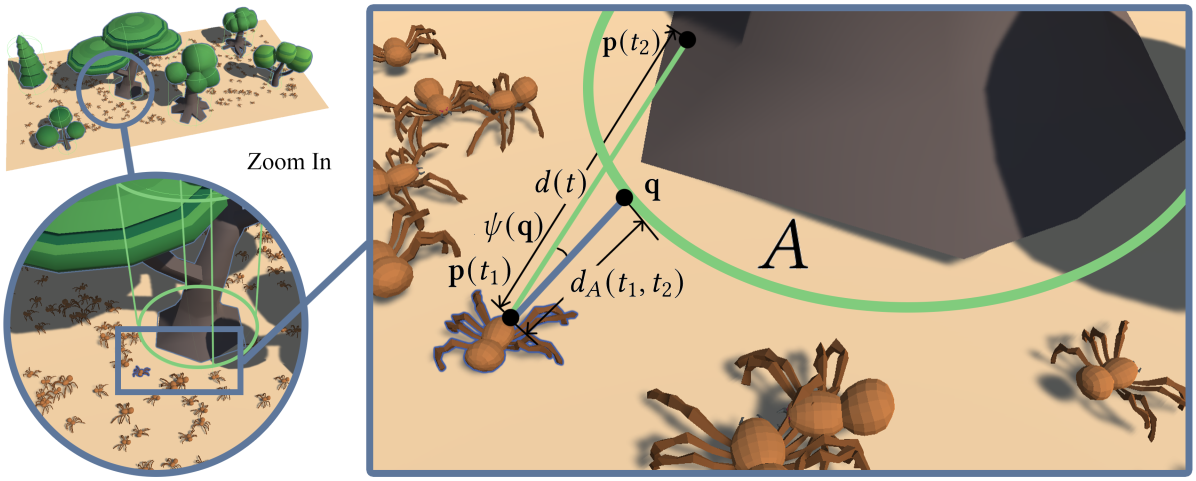


Figure 3: Collision Avoidance. This figure shows the mathematical approach to avoid the collisions between crawling insects and the obstacles in the scene where $d_A(t_1, t_2)$ is the min distance from the insect's initial position $\mathrm{p}(t_1)$ to the obstacle colliders area A and $\mathrm{p}(t_2)$ is the target position for the insect to move toward.

Normal Distributions. Crawling insect's moving speed $v(t)$, rotating speed $\omega(t)$, and target moving distance $d(t)$ follow normal distributions $\mathcal{N}(\mu_*, \sigma_*)$ with probability density function:

$$f_*(x) = \frac{1}{\sigma_* \sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu_*}{\sigma_*}\right)^2}$$

where footnote marker $*$ denotes v, ω, or d i our approach. Then, its corresponding quantile function is: $q_*(x) = \mu_* + \sigma_* \sqrt{2} F^{-1}(2x - 1)$, where $F(x)$ is the Gauss error function defined as below formula:

$$F(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} \mathrm{d}t$$

However, in order to speed up the simulation process, our approach avoids calculating the integration in Gauss error function, rather, we approximate quantile function using tangent function:

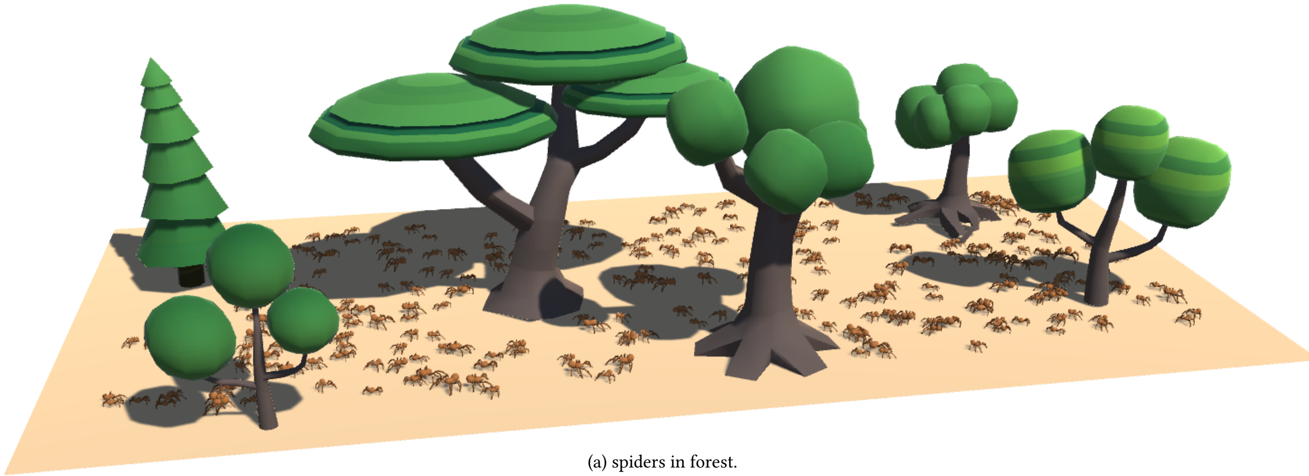
$$q'_*(x) = \mu_* + k\sigma_* \tan\left(\frac{\pi}{2}(2x - 1)\right)$$

where empirically we set $k = 0.2$, then there is $x \sim U(0, 1) \Rightarrow q'_*(x) \sim \mathcal{N}(\mu_*, \sigma_*)$.

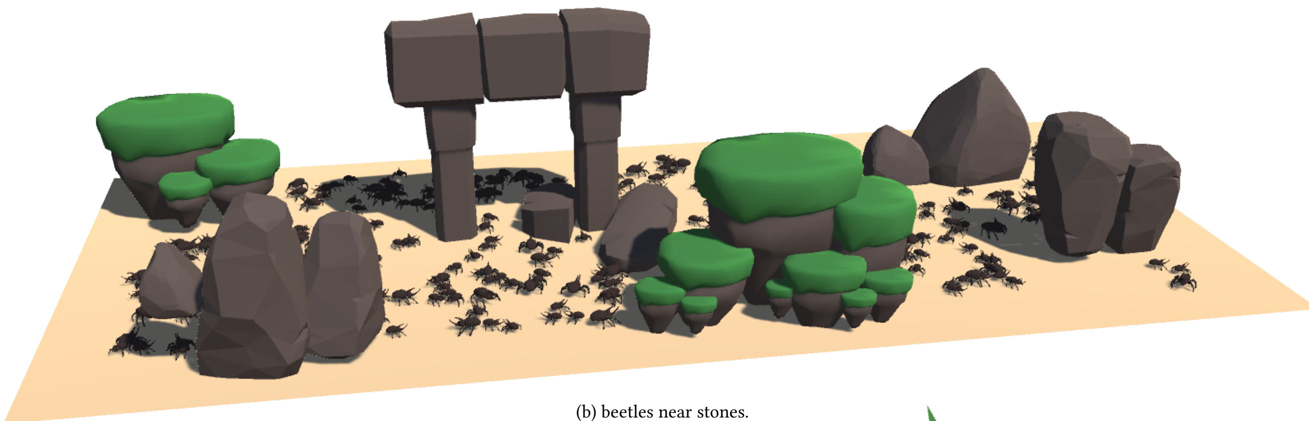
4 EXPERIMENT RESULT

In order to validate the efficacy of our proposed technical approach, a group of experiments is conducted on simulating crawling insects with different parameter settings. 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. Video of experiment results can be found through this link: https://youtu.be/PSiHekoC5D4. Figure 4 shows the first part of the experiment results which is simulating different types of crawling insects in different scenes. For this part of the experiment, the number of insects is the same and there are 300 insects set for the simulations. Figure 4 includes three subfigures, one for each type of insect in their respective environments. More specifically, they are spiders in the forest (a), beetles near stones (b), and ladybugs in bushes (b). Each subfigure shows the simulation result of crawling insects' behavior in their corresponding virtual environment, such as movement patterns and interactions with the obstacles in the environment. For example, Figure 4 (a) for spiders in forest demonstrates how the spiders randomly walk around the trees while avoiding colliding with the trees. Figure 4 (b) for beetles near stones shows how the beetles interact with their environment such as how they move around the rocks with different sizes and shapes. Figure 4 (c) for ladybugs in bushes shows how the ladybugs move through the mushrooms and the grass and how to change their behaviour depending on the presence of chunks and small stones. Overall, Figure 4 provides a visual representation of how these crawling insects behave in different environments, and how their behavior is influenced by their surroundings which demonstrates realistic simulations of crawling insects within different virtual environments. Figure 5 shows the experiment results of simulating different numbers of crawling insects in the same scene. More specifically, this part of the experiment simulates 200, 300, and 400 spiders in forest as shown in subfigure (a), (b), and (c) respectively. This experiment result shows a trend in how the distributions of the spiders change as the number of spiders in the scene increases. For example, it shows a trend as the number of spiders increases, their distributions are denser within the scene while avoiding overlapping or colliding with the obstacles. Overall, Figure 5 validates the scalability of our approach in simulating different numbers of insects in the same scene.

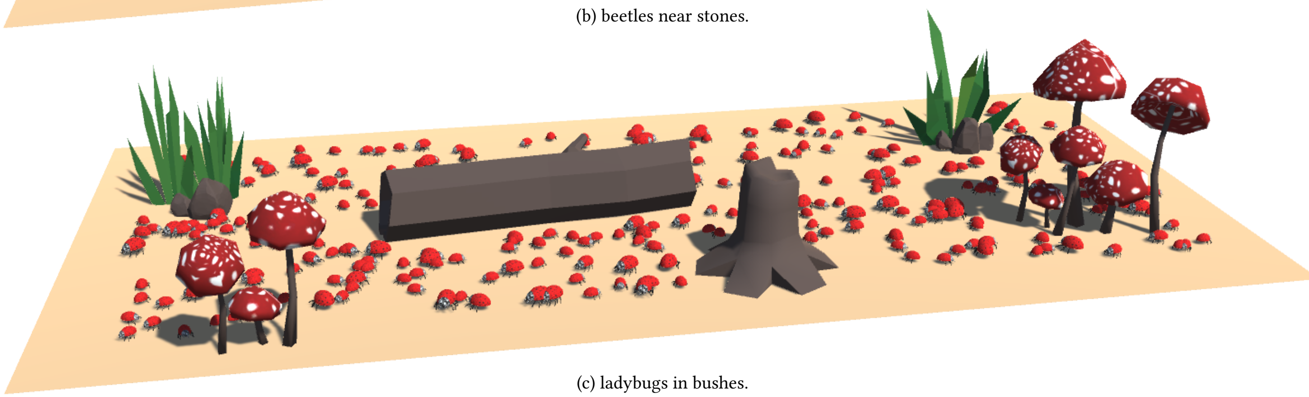
Figure 6 shows the experiment results of simulating crawling insects with different average sizes in the same scene, specifically beetles with average sizes of 0.1, 0.2, and 0.3 as shown in subfigures (a), (b), and (c) respectively. In this case, the number of total insects is the same and there are 300 insects set for this part of the experiment. This experiment result provides insights into how the behavior of crawling insects changes as their average size increases. Figure 7 shows the user's gameplay experience with InsectVR through a group of VR simulations in which the user can observe crawling



(a) spiders in forest.



(b) beetles near stones.



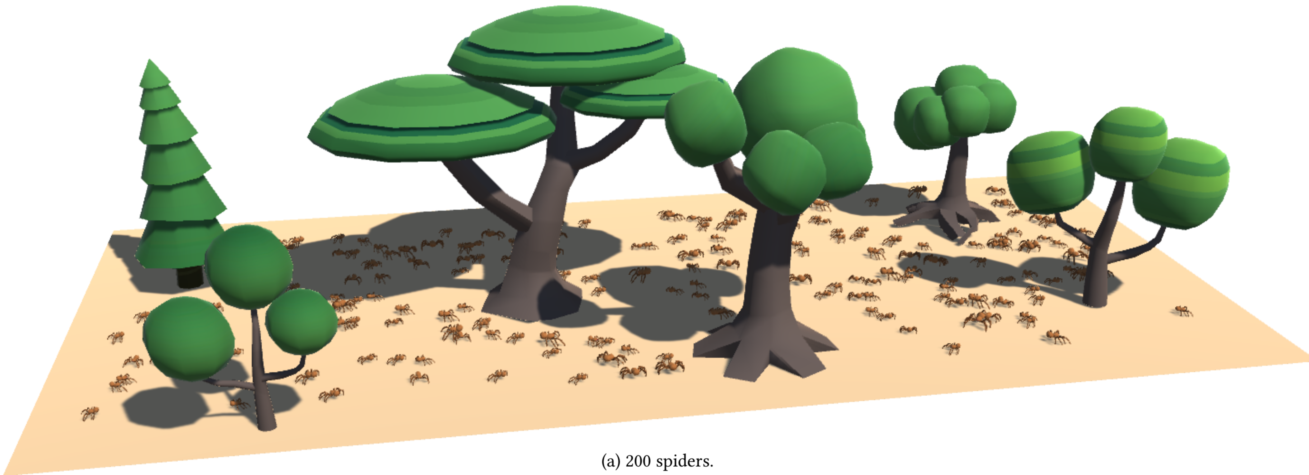
(c) ladybugs in bushes.

Figure 4: Experiment Result (Part 1). This figure shows the experiment results of simulating different types of crawling insects in different scenes. They are spiders in forest, beetles near stones, and ladybugs in bushes.

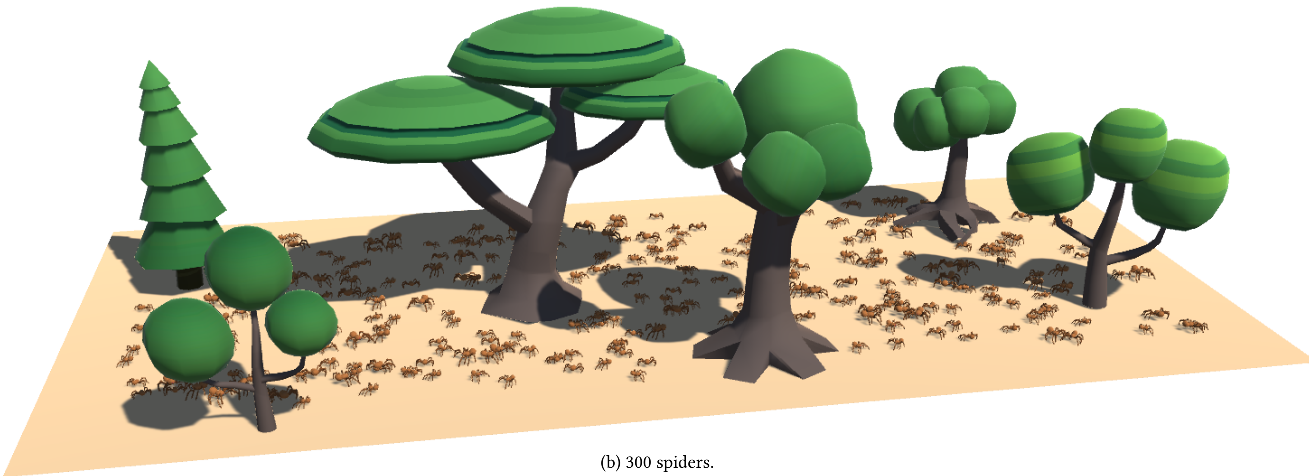
insects in immersive virtual environments. As shown in this figure, the InsectVR program is simulating the crawling ladybugs in bushes and presents the rendering of the virtual environment from the user's perspective within the simulation. Overall, Figure 7 provides insights into the user's gameplay experience with InsectVR and observing crawling insects within it. This immersive interactive experience can be useful in biology edutainment for helping users engage with VR crawling insects simulations and motivating users to explore and learn about insects-related studies in biology.

5 CONCLUSION

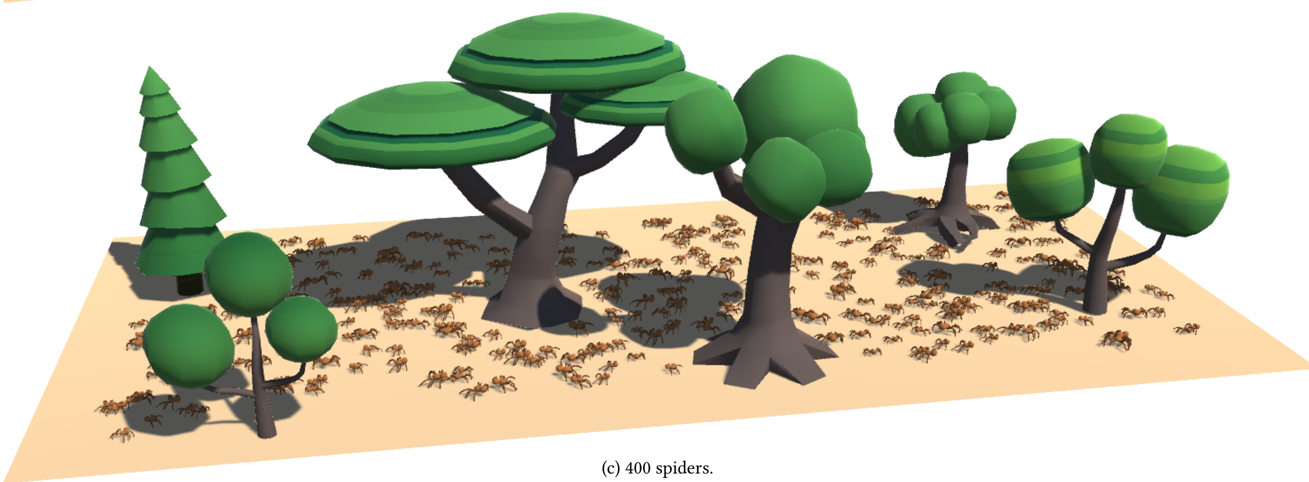
In this paper, we propose InsectVR, a VR simulator that allows users to explore the behavior of crawling insects in a virtual environment. Designed as a tool for biology edutainment, InsectVR offers an immersive and interactive experience that is both educational and entertaining. In our approach, InsectVR simulator is designed with VR headsets such as the Oculus Quest 2 and powered by state-of-the-art graphics and procedural modeling technologies. Through the VR headset and VR controllers, users can interact with



(a) 200 spiders.



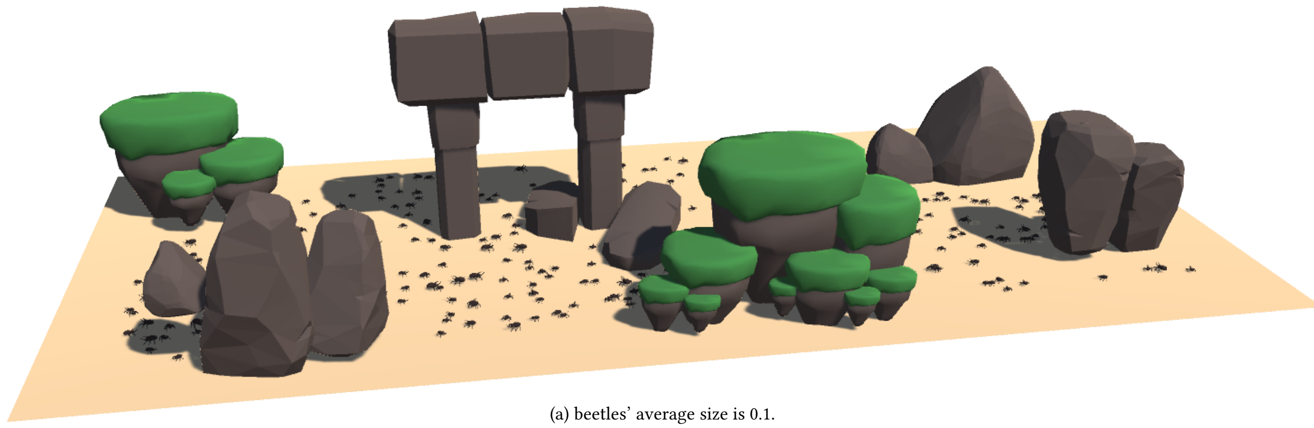
(b) 300 spiders.



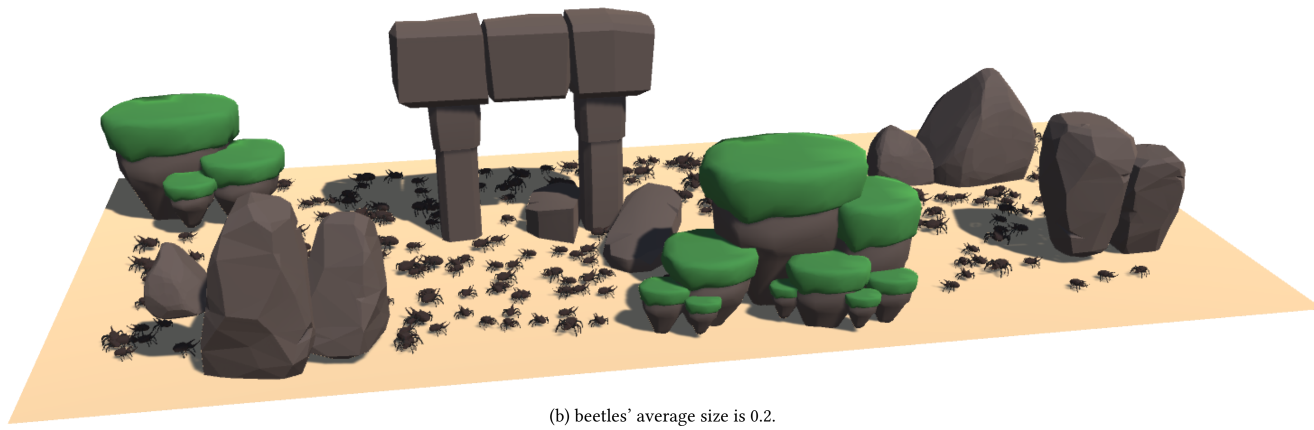
(c) 400 spiders.

Figure 5: Experiment Result (Part 2). This figure shows the experiment results of simulating different numbers of crawling insects within the same scene. More specifically, there are 200, 300, and 400 spiders respectively.

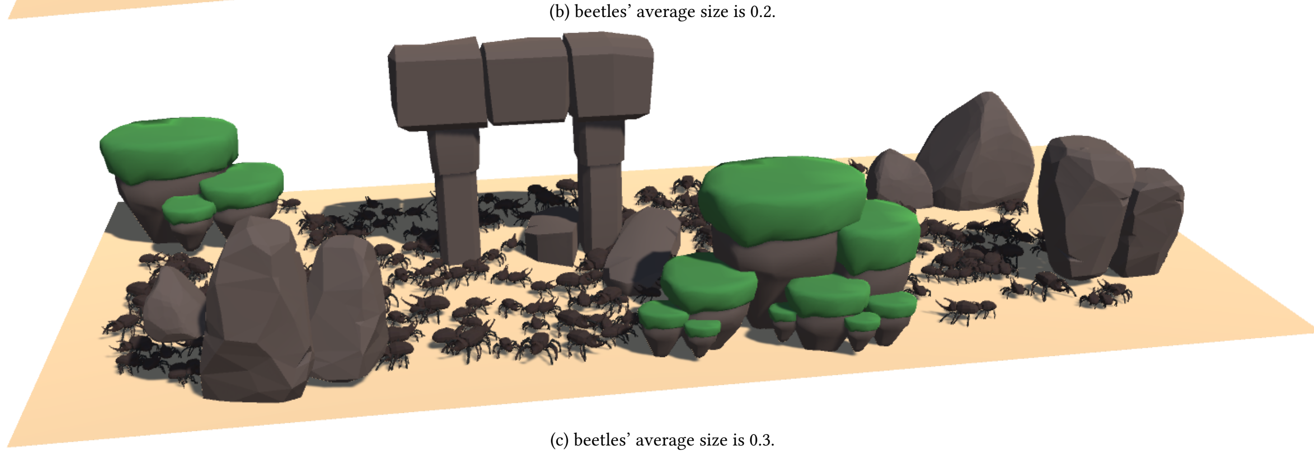
a variety of crawling insects, such as spiders, beetles, and ladybugs, and observe their behavior in a simulated natural environment. One of the key features of InsectVR is its focus on realism and accuracy. The simulator is designed to replicate the real-world behavior of crawling insects using a realistic mathematical model called the random walk algorithm which has been proposed by researchers based on scientific research and observation. As shown in our experiment result, users can learn about the biology and ecology of



(a) beetles' average size is 0.1.



(b) beetles' average size is 0.2.



(c) beetles' average size is 0.3.

Figure 6: Experiment Result (Part 3). This figure shows the experiment results of simulating crawling insects with different average sizes within the same scene. These beetles' average sizes are 0.1, 0.2, and 0.3 respectively.

these insects in a highly realistic and immersive way as InsectVR offers a generalized mathematical approach to provide a wide range of different scenarios and environments in which users can observe the crawling insects closely. For example, users can explore a forest and observe the behavior of spiders, or examine a group of ladybugs in a garden. In future work, we will extend InsectVR with more entertainment features. For example, users can compete with each other in challenges and games, such as collecting food or avoiding predators. At the same time, InsectVR will offer different levels of difficulty, so that users can choose the level that best suits their experience and skills. This will make the simulator a great tool for biology edutainment, as it combines learning with fun and engagement. Overall, InsectVR is a powerful tool for exploring and learning about the behavior of crawling insects. It offers a highly realistic and immersive experience and provides a range of different scenarios and environments to explore. As a tool for biology edutainment, InsectVR has potential to engage people of all ages and backgrounds to inspire their greater interest in natural world.

Figure 7: Preliminary User Study. This figure shows the user's gameplay experience with InsectVR. In this experiment, through Oculus Quest 2 VR headset and VR controllers, a user presents in a virtual environment and observes the simulated behaviour of crawling insects, which are ladybugs in bushes for this example.

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