Virtual Reality for Ecosystem Dynamics Education

Laura Arns, Matt Brisbin, David Foldes
arns@purdue.edu, mbrisbin@purdue.edu,
dfoldes@purdue.edu
Envision Center for Data Perceptualization
Rosen Center for Advanced Computing
Purdue University

Jeffery D. Holland
jdhollan@purdue.edu
Department of Entomology
Purdue University

1. Abstract
This paper describes an immersive interactive virtual environment created to educate students about ecosystem dynamics. Traditional tools and methods for teaching theories regarding these dynamics use 2D static images that cannot adequately display to students the complex nature of the interactions taking place in the ecosystem, making it difficult to understand the underlying theory. An immersive interactive environment can help overcome these difficulties by allowing students to view a 3D simulation and interact with it in real-time to understand the effects of changes to the ecosystem.

2. Introduction
Ecological theories describe complex and dynamic systems but are conveyed to students using static visuals that do not convey these complexities. There is no intuitive link between the observation of the dynamics that inspired ecology theories and the resultant theories that are presented to students. As well, students in whole-organism ecological or environmental fields of study are likely more engaged by the study of ecology through fieldwork or work with tangible organisms than through the exclusive use of plots of results. We have created an engaging virtual reality simulation of ecological processes that conveys the dynamic nature of these systems to students in a module exploring the theory of island biogeography.

The theory of island biogeography [MacArthur and Wilson 1967] has been very influential in ecology, and is an excellent test case for virtual reality simulations of ecological systems because there are potentially multiple levels of understanding. The theory examines the change in the number of species that exist on insular habitats in response to the island size and distance from a mainland pool of potential colonizers. The actual species extant on the island may change over time while the number of species remains relatively stable. This theory is especially well-suited to a dynamic virtual reality simulation because the dynamic equilibrium in species extant is not conveyed well by static models. Using the virtual reality simulation, students will see the turnover in species happening while the equilibrium number remains constant.

Our simulation engages students by completely immersing them in the modeled environment which includes realistic environmental settings and mobile, fully-rendered organisms. This simulation experience allows students to see multi-dimensional interactions in real-time, giving them a better understanding of the underlying principles. The simulation runs in a virtual reality theater at Purdue University's Envision Center for Data Perceptualization, with a capacity of approximately 50 students when in theater mode, or approximately 7 students when in CAVE™-like [Cruz-Neira et al. 1993] mode. Section 3.1 describes this device in detail. The simulation allows students to set island size and isolation parameters and then move within the simulation as it runs. They can change their perspective by using a 6 degree-of-freedom wand (see Section 3.1) to move and view the overall dynamics as a whole from a high altitude, or fly to the island to watch species arriving and seeking resources at an individual organism level. The dynamic nature of the simulation intuitively conveys the complex and dynamic nature of ecological systems and populations. This simulation simultaneously conveys the dynamic nature of species in a realistic landscape, while a traditional two dimensional plot visibly records species diversity over time. This combination of results plot with very realistic modeled environments will allow students to better grasp the link between species turnover and a stable measure of diversity predicted by the theory.

3. Background
3.1 Virtual Reality
Virtual Reality (VR) refers to "immersive, interactive, multi-sensory, viewer-centered, three-dimensional, computer-generated environments and the combination of technologies required to build these environments" [Cruz, 1995, p. 2]. Virtual reality environments immerse users in the world they are viewing. The users are not just passive observers in the computer-generated world, but are interacting with the various components of the environment in real-time.

Envision's VR Theater (Figure 1) is a Fakespace FLEX™ system featuring three ten-foot by eight-foot panels for rear projection of large-scale 3D images. These movable screens can be easily and rapidly rearranged to form either a 10'x30' wall (theater mode) or a semi-enclosed room with three walls plus a fourth panel as the floor (CAVE™-like mode) for a 3D immersive virtual environment. Images are rear-projected onto the screens, and the user views the application through a pair of LCD active stereoscopic glasses. To provide interaction, the VR Theater is also equipped with an Intersense IS-900 wireless tracking system. The Intersense provides 6 degree-of-freedom tracking, meaning that it provides both the x, y, and z location of a tracked object, and the object's roll, pitch, and yaw rotations. For example, the tracked wand allows users to point in any direction to travel through the virtual world, or to rotate the virtual world around its vertical axis. The FLEX™ is driven using a 64-bit dual Opteron Linux PC cluster with nVidia QuadroFX4400G graphics cards. Figure 1 shows a user in the FLEX™, in theater mode.

A feature of the software used in creating the ecology simulation (see Section 4.2) is that our application can run on a variety of different types of VR hardware. In addition to devices such as the FLEX, the simulation can run on more portable types of systems such as those described in Arangarasan et al. [2003]. Such systems use less expensive passive stereoscopic technology rather than active stereo, and have only a single 6'x8' screen rather than the four walls provided by the FLEX. However, the portable systems can easily be moved to different locations such as conferences, museums, and classrooms, and are far less expensive.

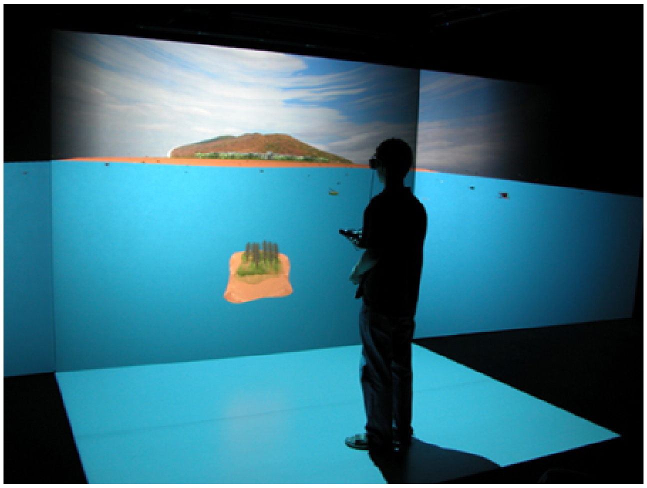

Figure 1. User with the ecosystem simulator in the FLEX, in theater mode

Virtual reality technology has been used for a variety of educational purposes, from teaching sign language to deaf children [Adamo-Villani et al. 2005] to helping students understand Newton's laws [Dede et al. 1996]. Some studies have shown that VR offers positive benefits for education and that students find the experience highly motivating [NCAC 2003; Youngblut 1997]. Bell [1995] states that scientific fields are particularly well suited to study in virtual environments as they can make abstract concepts more concrete. Although VR has been used in a wide variety of educational settings, we are unaware of any previous attempts to use VR to teach ecological dynamics.

3.2 The Ecological System

The equilibrium theory of island biogeography has had a large impact on how ecology is studied and on how nature reserves are designed [Harris 1984]. The basic premise of the theory is that an equilibrium number of extant species in an insular habitat such as an island is determined by the processes of immigration and local extinction. The rates of these processes are in turn determined by the distance of the island from a mainland pool of potential new immigrant species, and the size of the island, respectively. Larger islands are expected to be able to support larger populations within species, making them less susceptible to extirpation from stochastic phenomena and population processes. This increase in population viability leads to an increase in the time each species remains on the island and therefore also causes an increase in the number of species supported. Species on the island do still eventually become extirpated, however. As the number of species on the island increases, the extinction rate will also increase because there are more species to that could face extirpation. This leads to the shape of the extinction curve in Figure 2 [MacArthur and Wilson 1967].

The isolation, or distance of the island from the mainland determines the probability of additional species not already present on the island immigrating. Islands that are further away experience a lower rate of immigration. This lower immigration rate leads to a decreased number of species in more isolated islands. As the number of species present on the island increases, the immigration rate decreases because there are fewer potential new species that may then act as colonizers. This results in the shape of the immigration curve in Figure 2 [MacArthur and Wilson 1967]. The interplay of immigration rate decreasing and extinction rate increasing as the species richness (number of species) increases leads to a predicted species richness for an island of given size and isolation (point along x-axis where curves cross in Figure 2).

The actual identity of the species present on the island continually changes, but the opposing forces of immigration and extinction lead to a predictable number of species present at any given time. This dynamic nature of the theory is more difficult to represent and convey effectively with static models or graphs. However, the dynamic nature of the equilibrium predicted is at the center of this theory. The opposing phenomena of immigration and extinction 'push' the species number in a predictable fashion as the species richness changes, leading to a dynamic equilibrium. The value of a virtual reality teaching tool for this theory is that students are able to track the number of species supported by an island that they configure while actually observing individual species colonizing the island, competing for resources, and becoming extirpated. The dynamic nature of the equilibrium that size and isolation determines will be intuitively conveyed.

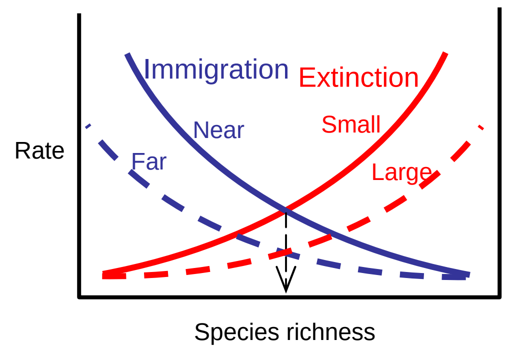

Figure 2: Predicted impact of immigration and extinction on the number of species supported. Solid lines represent a small island with low isolation. The predicted number of species is shown on the x-axis where the solid lines cross. Dashed lines represent islands with larger size or greater isolation, and the change in the equilibrium number of species.

4. Implementation

The ecology dynamics simulation was created by first modeling insects and the environment that the insects would inhabit. These models were then used with a graphics toolkit and a VR toolkit to create the application that runs in the VR Theater. The following sections describe the development in more detail.

4.1 Modeling

A total of 20 insects were selected from reference photographs along with one environment, and three islands. Since each insect's population is controlled by their behavior and success in finding resources it is hard to determine in advance exactly how many insects will be generated throughout the simulation. To deal with this issue, topology and resolution boundaries were pre-set to assure a smooth run inside the simulation. Each insect consists of no more than 100 polygons (quads) with their respective textures set at 512 x 512 pixels. The process of modeling started in Alias|Wavefront Maya 6.0 (www.alias.com) where the topology, scale, and UV unwrapping could be refined to the boundaries made earlier. Each texture was composed using Adobe Photoshop CS (www.adobe.com) and exported into the 32-bit targa format. This allowed for incorporation of alpha maps for the trees and brush in the environment as well as wing opacity on the insects themselves. Each model was then exported using Kaydara's .Fbx file format. This format has proven to preserve UV coordinates

very well so we choose it to best suit our needs in the process of transferring data from Maya to 3D Studio Max. Once each model was in Autodesk Media and Entertainment's 3D Studio Max 7.0 (www.autodesk.com) textures were re-linked and exported into Open Scene Graph format (see Section 4.2.2). Figures 3 and 4 show some example models used in the application.

Figure 3. Butterfly models used in simulation

4.2 Programming

After creating the models, a custom C++ application was written using the VRJuggler toolkit for virtual reality and the OpenSceneGraph toolkit for graphics. The following sections describe the use of these toolkits and basic application functionality.

4.2.1 VRJuggler

VRJuggler (www.vrjuggler.org) is an Open Source VR application development framework created at Iowa State University's Virtual Reality Applications Center. VRJuggler was designed as a suite of application programming interfaces that simplify all aspects of virtual reality application design and is device, platform, and system independent. VR Juggler was used in this project to handle many behind-the-scenes features. It is responsible for properly constructing a stereo viewing volume based on the FLEX's current configuration, and it communicates with a tracker that determines the location of the user's glasses so that the proper perspective is drawn. The tracker also receives inputs from a wand device that the user can use to navigate and control the environment.

4.2.2 Open Scene Graph

OpenSceneGraph (www.openscenegraph.org) is an open source 3D graphics toolkit. It is written in C++ and provides an object oriented framework on top of the OpenGL graphics programming interface. OpenSceneGraph is based on the concept of a scene graph, which allows users to easily export 3D data from popular modeling software packages into the OSG format. During production of the project, an open source exporter for 3D Studio Max, called OSGExp (http://osgexp.vr-c.dk) was used to convert model and texture information into OpenSceneGraph. A custom OSG navigation program was created for the use of this project.

Figure 4. Scorpionfly models used in simulation

Each species of modeled insect moves according to one of four turning angle distributions. At each time step of the simulation, the direction of the next movement relative to the current direction is randomly determined for each individual. The four turning angle distributions correspond to an even distribution that results in completely random movement, and three different 'normal distributions' that result in random correlated walks with different amounts of tortuosity.

In addition to flying through the virtual world, interaction is provided by allowing the user to control the size of the island. Using the wand, the user can cycle through various island sizes. Each size has a bounding area that is used to determine whether or not each insect is on the island. If an insect is not on the island, it will continue to roam the environment following the normal movement rules. If the insect is on the island, it will follow new rules that encourage it to stay within the island's boundaries.

A graphical heads-up display allows users to monitor the simulation's progress. The heads-up display provides the user with a running tally of total insects on the island, number of different species on the island, as well as a tally of each individual species on the island. This information is displayed alongside a smaller copy of each corresponding insect model. The heads-up

display is presented in the upper-right corner of the main screen, but the user can zoom in to get a better look using the wand. Figure 5 shows the virtual environment and heads-up display, and Figure 6 shows a close up of the heads-up display.

Figure 5. The mainland of the virtual environment. The heads-up display can be seen in the upper right.

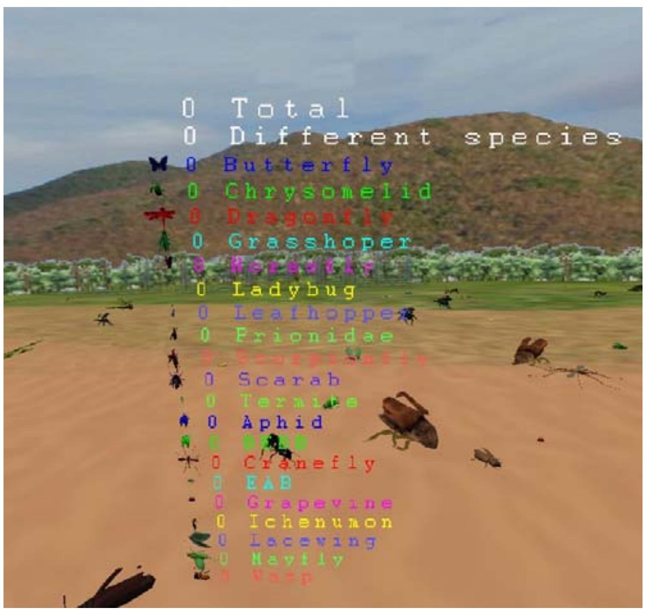

Figure 6. A close up of the heads-up display

5. Conclusions and Future Work

We have the simulation functional with all 20 insect species moving within it. Users can select one of three island sizes, and move within the simulation. A counter records the abundance of each species on the island and provides a total number of species present on the island. We are currently working to incorporate the different movement rules for different species. In order to make the size of the island have an effect on the number of species supported we are working to incorporate resources that will randomly appear only on the island and mainland. Simulated insects will have to obtain these resources in order to survive.

The theory of island biogeography was specifically chosen to facilitate evaluation of the benefits to learning that can be achieved with this technology. The effectiveness of the simulation on conveying the key ecological points of this theory will be evaluated through student quizzes. Students will have pre- and post-simulation quizzes on the theory to measure the increase in understanding attributable to the simulation. As well, we will be administering the same quizzes to a class using the currently available two-dimensional simulation while the immersive simulation is being developed. This will allow us to directly compare the increase in understanding due to the two types of simulation. The questions have been developed to cover a range of understanding, and are grouped under the first four knowledge dimensions in Bloom's taxonomy of cognitive learning processes (remember, understand, apply, and analyze) [Bloom 1956].

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