Ecological Plant Distributions for More Realistic Virtual Environments

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Achieving realistic distribution of plants in a virtual environment can be a daunting task. Plant growth, competition and adaptability should often be considered. An important step in going from reality to simulation is the simplification of real-world events into manageable calculations and combined data. In the case of the real-time simulation described in this paper, such distillation helps to grow plants rapidly while delivering more realistic results, where common stochastic methods fail to. Usability is also considered; generate new species and plant seeds while watching the growth in real-time.

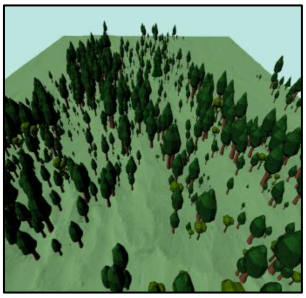

Figure 1: 3D view of four tree species competing.

1.1 Introduction

There are many ways to generate plants for large scale scenes. Stochastic methods are fast, they usually happen at compile-time, but need ways to achieve realistic growth. This often becomes complicated, especially when calculating competition and adaptability to a changing environment. Common stochastic methods fail to deliver realistic results, as demonstrated by Bradbury et al. (2015). Another way to distribute plants is in real-time. Plants grow individually with variable competition, growth, fitness and environmental impacts, mimicking reality.

Simulating plant growth and seed distribution in a simulated ecological environment comes with many considerations. The ecological plant distribution simulation presented in this paper considers only the factors with largest effects on plant growth to keep it viable as a real-time simulation while minimizing deviation from reality, more on this from Ch'ng (2009). Another consideration is the effect of plant-to-plant competition. Dead plants for example can provide their immediate environment with nutrients as they decay or simply be directly removed upon death. The latter is used in this approach to simplify nutrients calculations.

There are user benefits to having the plant growth in a real-time simulation. It enables visual feedback on adaptability and distribution. For the implementation presented in this paper the user can plant seeds, edit global environmental factors and generate new species, all while watching the growth in real-time.

1.2 Related Work

Unified data is having one variable describing many things. Nutrients can be categorized in micro and macro and further into specific nutrients like nitrate and phosphate. This is important to have in mind when making a program that should simulate many different species in different environments. Such generality simplifies modifications to the program. Ch'ng (2009) focuses on just that for his simulation. Bradbury et al. (2015) take his approach and make it more user friendly. They compare many different methods for plant growth in virtual environments and their paper is highly recommended to read for in depth comparisons.

1.3 Implementation

The simulation is implemented in C++ using OpenGL (v. 4.6) for graphics. Users can switch between 3D and 2D. It runs on Windows 10 but could easily be converted to support Linux. Time is set to months and years, where one month is one twelfth of a year and one year is, by default, one second.

1.3.1 Program Flow

The program works in a similar way to the one developed by Ch'ng (2009). Plants are individualistic and grouped by species. This enables both fine control at instance level and clustered control. Rainfall, soil and height are defined as greyscale 2D images (maps) which enables good control for regional edits (Fig. 2 to 4). Rainfall and soil range from zero to one and height is converted to meters. An XML file is used for species data, which is saved as genotypes. Plants have access to their specific genotype and the maps, and can use these for calculating effects and adaptabilities. The world is presented in either 2D or 3D and plants grow visually. In my case, one pixel on the maps equals one meter.

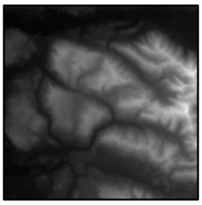

Figure 2: Heightmap.

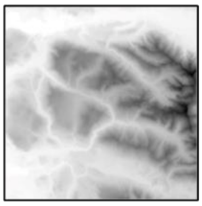

Figure 3: Rainfall-map.

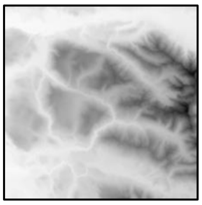

Figure 4: Soil-map.

1.3.2 Plant Effects, Fitness and Growth

Plants are affected by local effects (rainfall, soil and height maps), competition and global effects (sunlight and temperature). There are three types of competition. Nutrients, spacing and sunlight. Instead of calculating nutrients the way Ch'ng (2009) does it, a formula developed by Schwinning and Weiner (1998) for size asymmetry is used. This formula can be added to other effects as well but has some performance costs associated with it. Space is increased by 0.1 per bigger plant in competition (Ch'ng (2011)) and 0.01 for smaller plants. Shade only adds 0.1 per bigger plant and is subtracted from sunlight. Competing plants are determined by a plant's growth and position.

Temperature is in Celsius and works as a gradient, subsiding with 0.6°C per 100 meters. Moisture works the same but degrades with 0.1 per 100 meters. Rainfall is considered as added moisture.

Ch'ng (2009) presents a calculation for plant fitness. All effects are converted to a range from zero to one using an adaptability measure and are then multiplied into a fitness value. In my case, this value determines growth; crown radius and height growth are multiplied by the fitness. All species have maximum crown radius and height. Maximum growth per year is defined by these divided by maximum age so that the plants can grow during their whole lifetime.

1.3.3 Seeds

Seeds are spawned within a radius of a fertile plant and have varying incubation duration. This way they start growing at varying time points. Meanwhile they check for fitness, it is possible for seeds to die before they start growing as plants. Since months are part of the time control, plants can be set to spawn seeds at specific months. The number of seeds is determined by the plants fitness and if there is a production break, spawn every five years for example.

1.3.4 Species

Data for all species are gathered from many different sources. Sizes and ages from Pretzsch et al. (2015), adaptability and preferred growing places from HOME Stratosphere (2020) and some more. This data is gathered in an XML file and read when the program starts.

1.3.5 Usage

Users can plant seeds anywhere in the world with selected radius and amount. Planted seeds are added the same way as regular seeds and decay in environments unsuitable to them. Users can therefore not plant plants in areas unfitting to them. In order to start planting, they need to first select a species from a list.

With a species selected, they can also generate a new species that has some variation to the selected one (Fig. 5). This way it becomes a new species but is not a totally random one, which most likely would be unsuitable to the environment.

Global factors are editable, namely sunlight, temperature, nutrients and moisture (Fig. 5). The first two are actual, they tell the world what value to use for each adapting plant. The latter two are additive since they can change regionally with maps.

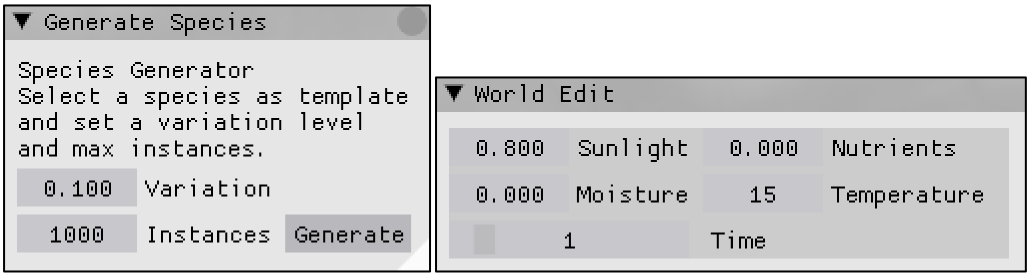

Figure 5: A species generator and a world edit window for editing in real-time. Moisture and Nutrients are additives while Sunlight and temperature are actual.

1.4 Tests

Four species are added to demonstrate the program; pine (red), oak (blue), maple (brown) and balsam fir (green). In the first test, balsam fir is planted first and grown in. Later the other species are added, and the simulation is run for a little while. Since the balsam fir was established first and has a relatively high space tolerance, the other species are outcompeted and have a hard time to survive (Fig. 6). For this test, the maps are the ones in figure 2 to 4.

In test two, moisture and nutrients are evened out and the same in the whole world. Rainfall map and soil map are one colour. Now all plants are planted at the same time. The species have more space to grow and are now limited by max instances per species instead of the environment. Still, balsam fir seems to grow most from the starting point (Fig. 7). This can be caused by the high maturity age (fewer seed dispersals) and tolerance to crowds. The heightmap is the same as test one (Fig. 2) and has no impact.

By lowering moisture and increasing temperature the scene looks different again. Oak has more space to grow big while balsam fir grows much smaller and dies rapidly on very specific patches, where it barely survives (Fig. 8). The maps are the same as test one (Fig. 2 to 4).

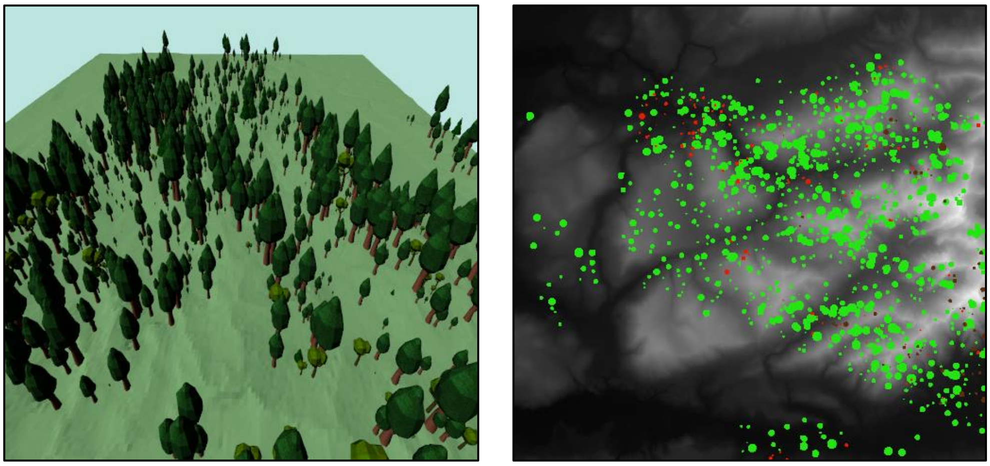

Figure 6: 3D and 2D view of first test. Balsam fir is outcompeting the others.

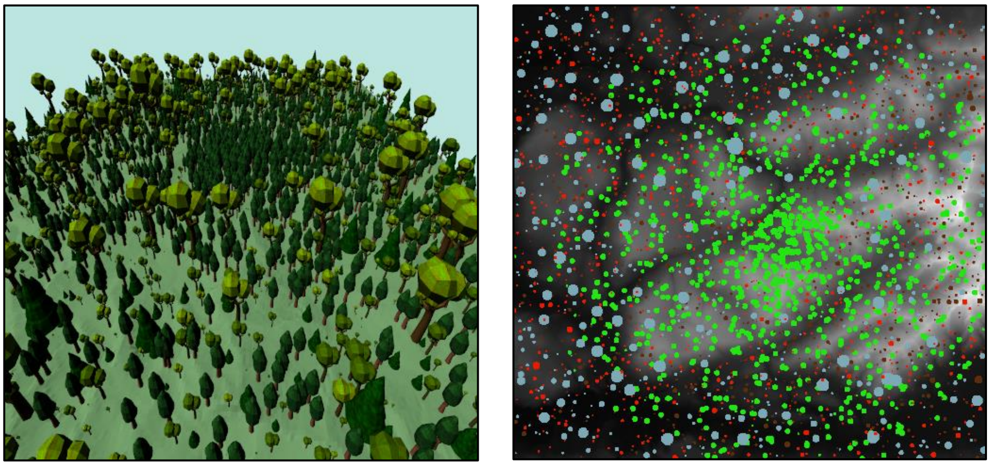

Figure 7: 3D and 2D view of second test. More habitable space means more plants survive and less competition.

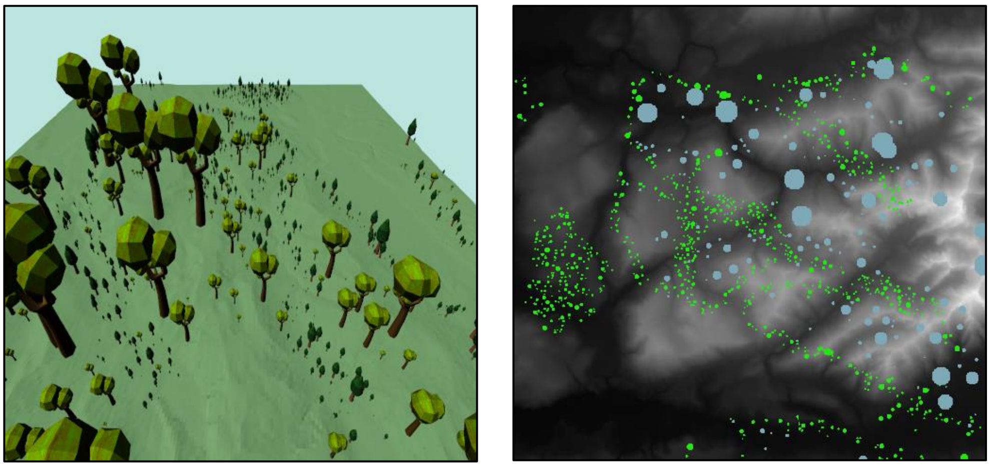

Figure 8: 3D and 2D view of third test. Balsam fir is not growing well while oak grows big.

1.5 Future Improvements and Conclusion

While my implementation borrows ideas from Ch'ng (2009), it has many differences to his. Calculations are different with more focus on seeds and age of maturity, I use OpenGL and instancing, users can switch between 3D and 2D in real time and I use a different program layout. Still, the user experience is similar. I use maps, xml for storing species and the same way of calculating fitness and adaptability. It would be interesting to try out some different approaches like edits and generation of terrain instead of read-only maps and reading species data from a database instead of a handwritten xml file. Bradbury et al. (2015) do some of this and it seems more practical. My program would benefit from further tests with more species and more calculations for effects.

Another improvement is planting multiple species at the same time. It is possible now by pausing the simulation, but it is not obvious. Some things that are not possible are the erasing of plants with the mouse in real time and letting the user draw areas that are done and skip update on all plants in these regions. They would improve performance and add to the benefit of the user experience.

Plants in my simulation grow based on multiple ecological factors. Distribution is accomplished by seeds and growth is calculated by the plants. The result is more realistic plant behaviour and growth.

1.6 References

1. Ch'ng, Eugine. A behavioral agent model for synthesizing vegetation distribution patterns on 3D terrains. PUBLISHED IN: Applied Artificial Intelligence (2009) 23:78–102. BY: Taylor & Francis Group, LLC. URL: http://dx.doi.org/10.1080/08839510802573616
2. Ch'ng, Eugine. Realistic placement of plants for virtual environments. PUBLISHED IN: IEEE Computer Graphics and Applications 31 (2011) 66–77 BY: IEEE Computer Society. URL: http://dx.doi.org/10.1109/MCG.2010.42
3. Pretzsch, Hans, et al. Crown size and growing space requirement of common tree species in urban centres, parks, and forests. PUBLISHED IN: Urban Forestry & Urban Greening 14 (2015) 466-479. BY: ELSEVIER GmbH. URL: https://www.sciencedirect.com/science/article/pii/S1618866715000473
4. Bradbury, Gwyneth A, et al. Guided Ecological Simulation for Artistic Editing of Plant Distributions in Natural Scenes. PUBLISHED IN: Journal of Computer Graphics Techniques Vol. 4, No. 4, (2015). URL: http://jcgt.org/published/0004/04/02/
5. Schwinning, Susanne. Weiner, Jacob. Mechanisms determining the degree of size asymmetry in competition among plants. PUBLISHED IN: Oecologia (1998) 113:447-455. BY: Springer-Verlag. URL: https://link.springer.com/article/10.1007/s004420050397
6. OpenGL. VERSION: 4.6 (2019) URL: https://www.opengl.org/
7. 60 Different Types of Trees. PUBLISHED IN: Gardens and Landscaping BY: HOME Stratosphere. ACCESSED: 2020-02-05 URL: https://www.homestratosphere.com/types-of-trees/

1.7 Appendix: Example of Balsam fir XML


```xml
<plant name="Balsam fir" objFileDir="resources/objects/Pinetree_v2_LOD_0.obj"
textureFileDir="resources/textures/Pinetree_v2_Diffuse.png" maxInstances="1000">
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            <ageOfMaturity>25</ageOfMaturity>
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            <maxAge>245</maxAge>
            <maxCrownRadius>5.2</maxCrownRadius>
            <maxHeight>17</maxHeight>
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            <heightGrowth>0.07</heightGrowth>
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    <adaptabilities>
            <altitude>0,40,1900</altitude>
            <moisture>0.4,0.67,0.95</moisture>
            <nutrients>0.1,0.3,0.8</nutrients>
            <sunlight>0.24,0.40,0.92</sunlight>
            <temperature>-40,5,25</temperature>
            <space>0.0,0.3,0.5</space>
            <seedsSpawnMonths>8,9</seedsSpawnMonths>
    </adaptabilities>
</plant>
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