Extended Competition Rules for Interacting Plants

Monssef Alsweis
University of Konstanz
Department of Computer and Information Science
78457 Konstanz, Germany

Alsweis@inf.uni-konstanz.de

ABSTRACT

The goal of this paper is the interactive and realistic rendering of 3D competing plant covering a landscape. We introduce the so-called FON-Model as a new method for the visualization and simulation of competing plant root systems in which the overlapping area of the depleted-zone between competing root systems is quantatively found. We visualize different conditions for the resource competition between plant root systems. Additionally, we present an improved model for the competition for light that is dependant upon the translucency of the plant foliage and the density of the plant skeleton. In connection to it we introduce a new competition simulations for nurse plants. Finally, we simulate and visualize competition between a healthy plant and a plant that at one point in time becomes sick. As results, our method greatly increases the reality of the rendered landscape and allows rendering of large landscapes in interactive environments.

1 INTRODUCTION

Modeling and visualization of natural phenomena has taken an important position in the world of computer graphics. Plant modeling and ecosystem simulation is considered a main field in the area of rendering of natural phenomena. In our approach we investigated competition between different plant species in the under ground and above ground zone. The results of our findings are used to simulate and visualize ecosystems more realistically.

This paper is an extension of our previous work in [1] and [2]. In [1] a new method for the simulation and visualization of the development of plant populations is described in that the competition of natural resources between plants is simulated in two major areas: symmetric and asymmetric competition. The symmetric competition represents the root competition for resources, and the asymmetric competition represents the trunk, branch, and leaf competition for light. In [2] we presented an extension to [1], which illustrates the visualization of competition based on nine conditions of interaction between plants.

Our approach addresses four major areas of ecosystem visualizations. In the first part, we develop a new method to compute the root competition between neighboring plants by producing different types of root systems, which are utilized in the geometric simulation model of the root architecture.

In the second part of our approach, we simulate the competition for the light that is caused by the tree geometry and foliage characteristics. Here the competition is not always considered as an asymmetric competition. Since, the competition for light degrades slowly during the symmetric and asymmetric interval.

Some positive neighbor effects are protecting neighbors from excessive solar radiation and resultant water loss and providing mechanical support and protection from herbivores [3]. The classic example of positive neighbor effects is that of "‘nurse plants"’ in arid systems [18]. In this main part we will simulate and will visualize the competition between the nurse plants and other species of plants.

In the last part of our approach, a new type of competition is simulated and visualized. This type of competition takes place between a healthy plant and a plant that becomes sick at a certain time during the simulation process. To render a large scene of different types of plants in real-time, we use the Wang Tile method [11] for the visualization of the 3D plant architecture.

2 PREVIOUS WORKS

A number of approaches and procedures were already applied and implemented to simulate and visualize large plant ecosystems. The most prominent are classified in three major categories: modelling a single plant, composing and modeling a large plant population, and visualizing a scene in real-time.

Modelling of a Single Plant: In 1968, Aristid Lindenmayer proposed a method for the simulation of the development of multi-cell organisms, the so-called L-System [20]. Przemyslaw Prusinkiewicz advanced the idea of L-Systems and made considerable progress in modeling, simulation and visualization of the development of plants. Other approaches followed [22, 21] and in [14] Deussen und Lintermann improved the modelling process of a single plant with their X-frog software. In order to simulate a slowly dying plant, we used the X-frog software with different leaf textures.

Modelling Large Complex Plant Populations: Simulation and visualization of a natural scene with thousands of plants was introduced to computergraphics in [13], where also the terrain was modelled, and to give the scene a realistic appearance different types of single plants were distributed according to the nature of their environment. In [19] a multilevel model was used to simulate and visualize a natural scene. In the present work Wang-Tiles were used [11] that allow to render even quite complex scenes efficiently.

Efficient Rendering: To render a complex natural scene in real-time, in [11] a non-periodic tiling method was applied. The plants are distributed to each tile with a 2D Poisson distribution. In [12] a new method was proposed to cover an area with realistic appearing forests for real-time rendering. Here, dense forests were simulated that corresponded to continuous non-repetitive areas, which were filled with thousands of trees. Behrendt et al. in [5] introduced techniques for the realistic real-time rendering of complex landscapes that consist of highly detailed plant models. Benes et al. [6, 8, 7]

Light interaction: There have been several methods for computing the light interaction among plant, cf. [16] however, for an efficient simulation of larger areas a simpler model is needed. We restrict ourselves to such a model that uses an approximation of the plant shape to determine the received light.

Figure 1: The FON Model for the under ground area.

3 THE FON MODEL

To represent a plant in our work, we applied the FON (Field-of-Neighborhood) Model, which was defined by Berger [9]. In the FON model, each plant has a circular

Figure 2: The FON Model. The zone of influence (R_{FON}) depends on the diameter of the trunk (R_{basal}).

zone of influence (ZOI). The radius of the zone determines the distance, in which the neighboring plants influence each other. Each plant is represented by its position, size, and age. Additionally, each plant has two zones of influence, see Figs. 1 and 2. The first zone represents the under ground competition (root competition), and the second represents the above ground competition (the competition for light.) When computing the two zones, the amount of resources for the under ground and the amount of light for the above ground are taken into consideration. To determine the zone of influence, we use a non-linear function of the basal radius [9, 2].

$$R_{FON} = a\,(R_{basal})^b \tag{1}$$

R_{FON} is the radius of the influence zone of the single plant. R_{basal} is the radius of the single plant, see Fig. 2. a and b are constants and depend on the intensity of the resources in the under ground and on the intensity of the light in the above ground. If the field in which the plants are cultivated is fertile, a and b will be small and the under ground zone and competition will be small as well [4]. In the other case, a and b will be large and consequently the under ground zone will be large as well, which will cause the competition among ressources.

4 MODEL AND METHOD

The growth of a single plant depends on its effective size, maximum size, and maximum growth rate. The possible growth rates of the single plant are denoted by GR as done in [4, 2]. They are defined as follows:

$$GR = \frac{MGR.R_{Basal}}{R_{Max}}(1 - \frac{R_{basal}}{R_{Max}}) \quad (2)$$

MGR is the maximum growth rate of the plant. R_{Max} is the maximum size of the plant. R_{basal} is the effective radius of the trunk see Fig.2. GR is the growth rate of the plant without considering the competition with its neighbor. In order to define the growth rate $\triangle R_{Basal}$ for different competition systems, and to show the results we apply a method presented in [4]:

$$\triangle R_{Basal} = GR.C \quad (3)$$

Whereas C equals the competition factor. It is determined as follows:

$$C = \begin{cases} 1-2\varphi_i & : \quad \varphi_i <= 0.5 \\ 0 & : \quad \varphi_i > 0.5 \end{cases} \quad (4)$$

Whereas φ_i is the competition factor in interval $[0,1]$. It can be determined for different systems of competition as described in the following paragraphs.

4.1 Competition for Light

The competition between neighbouring plants for light occurs, if the plant shoots are overlapping. This overlapping causes a deficiency for the light that is needed by the small plants. In Figs. 3 and 4 we see that the small plant under the tree in Fig. 3 receives only a part of the light (symmetric competition for light). In contrast, the small plants under the tree in Fig. 4 do not receive any part of the light (asymmetric competition for light).

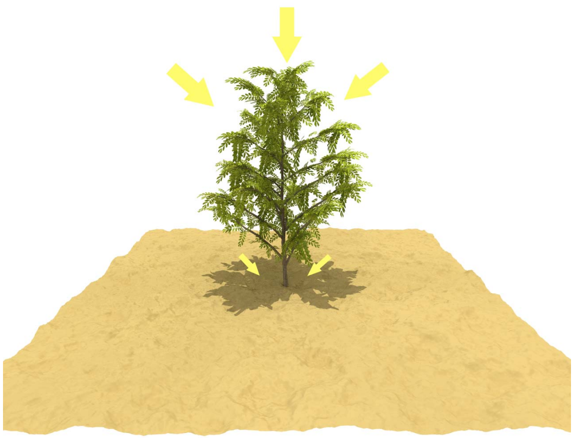


Figure 3: A non-dense tree lets the small plants receive light, which is passing through the foliage

Consequently, the competition occurs either symmetric or asymmetric or it is a mixture of both. This depends on the mean factor L_{fac} of the large plant. The

Figure 4: A dense tree creates a dark shadow, therefore the small plants do not receive light.

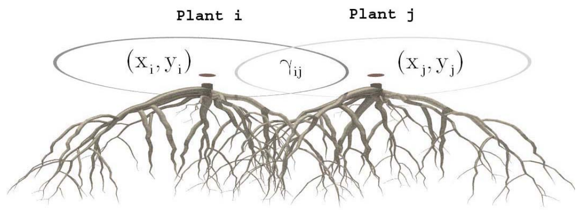


Figure 5: The geometry of the spatial competition between the individual plants i and j with position (x_i, y_i) and (x_j, y_j) is a function of the overlapping area γ_{ij}.

competition for the light α_i [9, 1] is determined by accounting for the density of the overlapping $IN(i,j)$ between the plants i and j as follows [2]:

$$\alpha_i = \frac{\sum_{j=1}^{n} \frac{3\beta_{ij}}{IN(i,j)}}{A_i} \quad (5)$$

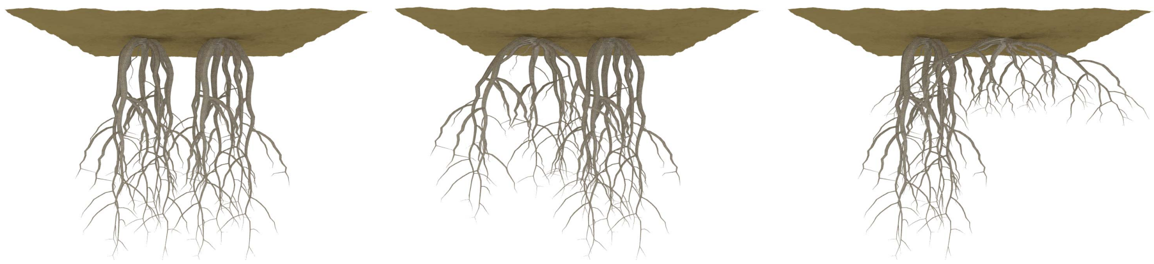
Whereas A_i is the size of the plant i in Fig.5. n is the number of plants that overlap with the i th plant. β_{ij} is determined as follows:

$$\beta_{ij} = (5 + L_{fac})\frac{\gamma_{ij}}{10} \quad (6)$$

Whereas γ_{ij} is the size of the overlapping area between plant i and plant j (see Fig. 5). $L_{fac} \in [0,5]$ is the translucency factor. If $L_{fac} = 0$, the competition for light is considered symmetric. If $L_{fac} = 5$, the competition is considered asymmetric.

4.2 Competition for Resources

The competition for resources depends on different factors such as the root density, the extend of the root area, and the plasticity either during the root growth or in the characteristics of the enzymes [10]. In order to render



(a) (b) (c)

Figure 6: Three different root competition systems. In (a) the competition is between deep and deep root systems. In (b) the competition is between non-deep and deep root systems. In (c) the competition is between deep and flat root systems.

and visualize this competition, the root density and the root area are computed. The competition between deep root systems and flat root systems is only half of the competition with other root systems [15] [17].

For the rendering and visualization of the competition for the resources, the competition is considered as the symmetric competition. In [23] it is limited to nine conditions, see Tab.1. Fig.6 illustrates the three conditions of this table (deep with deep, deep with medium deep and deep with flat roots).

	F	C	T
F	FF	FC	FT
C	CF	CC	CT
T	TF	TC	TT

Table 1: This table shows the nine conditions that presents the competition of three different root systems. Whereas F, C, and T present flat, non-deep, and deep root systems.

The competition for the resource σ_i with consideration to the root size and the root density factor T_f is defined in the following equation [1, 2]:

$$\sigma_i = \frac{\gamma_{ij}}{2.A_i}(1+\frac{T_f}{10}) \tag{7}$$

Whereas $T_f \in [0,10]$ is the root size and root density factor. Here the symmetric competition is an interval of $[\frac{\gamma_{ij}}{2.A_i}\ \frac{\gamma_{ij}}{A_i}]$.

4.3 Nurse Plants

Some desert plant can only establish themselves in close proximity to a larger plant, usually a shrub, because the shade of the larger plant provides protection from the intense solar radiation and resultant heat and transpiration that a seedling otherwise would experience. Therefore the small plants developed their system, in order to position their seeds under the shrub. Plant establishment in deserts is largely determined by negative effects of a superabundant plant resource "‘solar radiation"’ for which plants in other environments compete (see the Fig.10).

4.4 The Competition Between Healthy and Sick Plants

In order to simulate and visualize the competition between a healthy and a sick plant or other plants that suddenly started deteriorating at a certain time during the competition process, the competition factors for both healthy and sick plants are taken into account. The influence of the sick plant onto the healthy plant lessens gradually. The competition of resources between sick and healthy plants is ascertained as follows:

$$\sigma_i = \frac{\gamma_{ij}}{2A_i} + \gamma_{ij}T_r \tag{8}$$

Whereas $T_r = T_k + T_g, T_r \in [0..1]$ combines sickness factors and health factors. T_k gradually diminishes with time; consequently, the healthy plants grow without competition. T_g does not change over time.

4.5 General Competition

The general competition between plants is a weighted combination of symmetric and asymmetric competition:

$$\varphi_i = p\alpha_i + (1-p)\sigma_i \tag{9}$$

Whereas φ_i is the general competition of the i plant from its neighbor. $p \in [0\ 1]$ is the part of the competition for the resources in the general competition.

5 RESULTS

Fig. 7 illustrates the competition for light between non-dense trees and different small plants. It is shown that the small plants can grow under that tree, because they receive a part of the light. In Fig. 8 we visualize the competition for light between a dense tree and different small plants. In this picture we see that the small plants cannot grow, since they do not receive sufficient light.

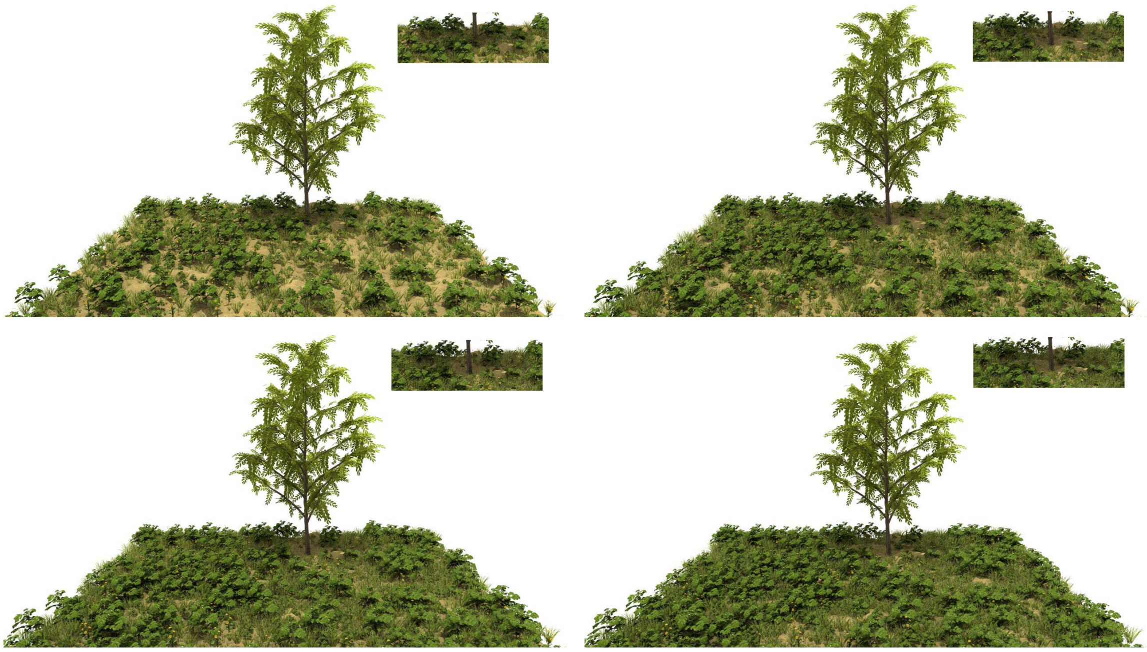


Figure 7: Four stages illustrate the competition for light between non-dense trees and different small plants.

In Fig. 9 the competition for resources between dense tree roots and flat tree roots is illustrated. We note that the flat roots grow slow as a cause of the overlapping with the deep roots, since the deep roots are stronger than the flat roots.

In Fig. 10 the competition for the nutrients is simulated under the nurse plants. Here the Nurse plant has positives influence on the small plants. The small plants affect negativ on others. Therefore the equation 9 is modified slightly by now subtracting $(1-p)\sigma_i$.

In Figure 11 we show that the sicker plant allows the other plant to grow quicker, because the competition degrades with time.

Applying our method, we produced natural scenes, in which the competition between different plants and resources is simulated. We have illustrated these scenes in the accompanying video in order to visualize the implementation of our system in the following steps:

- The competition for light between a non-dense tree and different small plants.
- The competition for light between a dense tree and different small plants.
- The competition for resources for different root systems.
- The competition between sick and healthy plants.
- The competition between nurse plants and small plants.

The accompanying video shows that thousands of small plants were rendered with large trees for different conditions of resource competition. To render growth of thousands of plants interactively in real-time, we used the Wang Tile method.

REFERENCES

[1] M. Alsweis and O. Deussen. Modeling and visualization of symmetric and asymmetric plant competition. *Natural Phenomena 2005. Eurographics Association in coorperation with ACM/SIGGRAPH.*, pages 83–88, 2005.

[2] M. Alsweis and O. Deussen. Efficient simulation of vegetation using light and nutrition competition. *Simulation und Visualisierung 2006, Magdeburg.*, pages 83–88, 2006.

[3] A.R.Berkowitz, C.D.Canham, and V.R.Kelly. Competition vs. facilitation of tree seedling growth and survival in early successional communities. *Ecology*, pages 1156–1168, 1995.

[4] S. Bauer, U. Berger, H. Hildenbrandt, and V. Grimm. Cyclic dynamics in simulated plant populations. *Proceedings. Biological sciences / The Royal Society.*, 269(1508):2443–2450, 2002.

[5] Stephan Behrendt, Carsten Colditz, Oliver Franzke, Johannes Kopf, and Oliver Deussen. Realistic real-time rendering of landscapes using billboard clouds. *Computer Graphics Forum*, 24:507–516, 2005.

[6] B. Benes. An Efficient Estimation of Light in Simulation of Plant Development. In *Computer Animation and Simulation'96*, Springer Computer Science, pages 153–165. Springer–Verlag Wien New York, 1996.

[7] B. Benes. A Stable Modeling of Large Plant Ecosystems. In *Proceedings of the International Conference on Computer Vision and Graphics*, pages 94–101. Associoation for Image Processing, 2002.

[8] B. Benes and E. Mill'an. Virtual Climbing Plants Competing for Space. In Nadia Magnenat-Thalmann, editor, *IEEE Proceedings of the Computer Animation 2002*, pages 33–42. IEEE Computer Society, 2002.

[9] U. Berger and H. Hildenbrandt. A new approach to spatially explicit modelling of forest dynamics: Spacing, ageing and neighbourhood competition of mangrove trees. *Ecological Modelling*, 132:287–302, 2000.

[10] Brenda B. Casper and Robert B. Jackson. Plant competition underground. *Annual Review of Ecology and Systematics*, 28:545–570, 1997.

[11] Michael F. Cohen, Jonathan Shade, Stefan Hiller, and Oliver Deussen. Wang tiles for image and texture generation. *Proceedings of ACM SIGGRAPH.*, pages 287 – 294, July 2003.

[12] Philippe Decaudin and Fabrice Neyret. Rendering forest scenes in real-time. In *Rendering Techniques '04 (Eurographics Symposium on Rendering)*, pages 93–102, June 2004.

[13] O. Deussen, P. Hanrahan, B. Lintermann, R. Mech, M. Pharr, and P. Prusinkiewicz. Realistic modeling and rendering of plant ecosystems. *SIGGRAPH, Orlando, Florida, Proceedings of ACM*, pages 275 – 286, 1998.

[14] O. Deussen and B. Lintermann. A modelling method and user interface for creating plants. In *Proc. Graphics Interface 97*, pages 189–198, May 1997.

[15] Rubio Gerardo, Walk Tom, Ge Zhenyang, Yan Xiaolong, Liao Hong, and Lynch Jonathan P. Root gravitropism and below-ground competition among neighbouring plants: A modelling approach. *Annals of Botany*, 88(5):929–940, 2001.

[16] William Van Haevre, Fabian Di Fiore, Philippe Bekaert, and Frank Van Reeth. A ray density estimation approach to take into account environment illumination in plant growth simulation. In *SCCG '04: Proceedings of the 20th spring conference on Computer graphics*, pages 121–131, New York, NY, USA, 2004. ACM Press.

[17] Jr. James F. Cahill. Interaction between root and shoot competition vary among species. *Proceedings. Oikos*, 99:101–112, 2002.

[18] J.G.Franco-Pizana, T.E.Fulbright, D.T.Gardiner, and A.R.Tipton. Shrub emergence and seedling growth in microenvironments created by prosopis glandulosa. *Journal of Vegetation Science*, 7(2):257–264, 1996.

[19] Brendan Lane and Przemyslaw Prusinkiewicz. Generating spatial distributions for multilevel models of plant communities. *Proceedings of Graphics Interface*, pages 69–80, 2002.

[20] A. Lindenmayer. Mathematical models for cellular interaction in development. *Parts I and II. Journal of Theoretical Biology*, 18:280 – 315, 1968.

[21] Lars Mündermann, Yvette Erasmus, Brendan Lane, Enrico Coen, and Przemyslaw Prusinkiewicz. Quantitative modeling of arabidopsis development. *Plant Physiology*, 139:960–968, 2005.

[22] Przemyslaw Prusinkiewicz. Modeling and visualization of biological structures. *In Proceedings of Graphics Interface*, pages 128–137, 1993.

[23] Ge Zhenyang, Luo Xiwen, and Jonathan P Lynch. Computer modeling of the effect of root architecture on competition for diffusive nutrient uptake with neighboring root systems. *International Conference on Agricultural Engineering*, pages 161–167, 1999.

Figure 8: Competition for light between dense trees and different small plants.

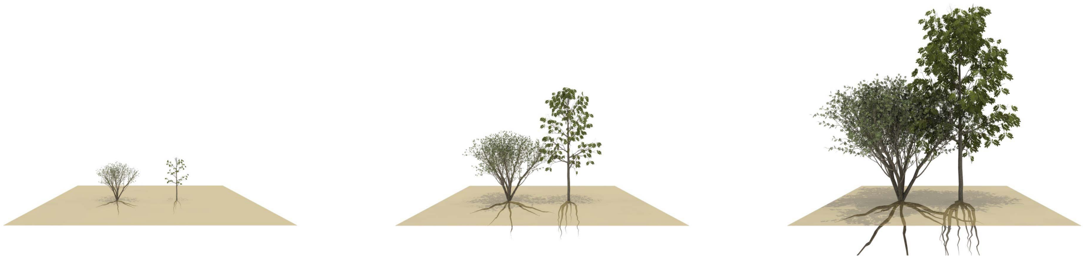


Figure 9: Competition for resources between dense tree roots and flat tree roots.

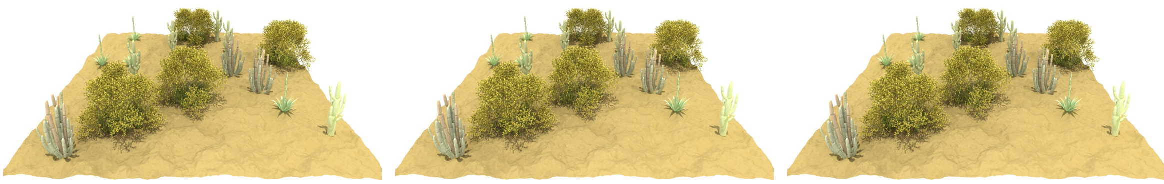


Figure 10: Competition for resources between nurse plants and small plants.

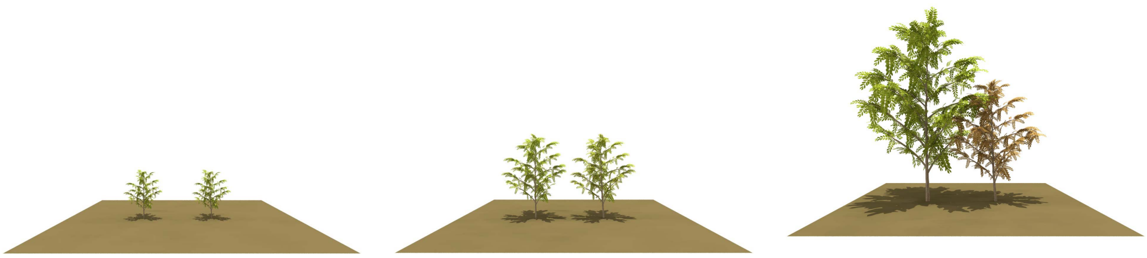


Figure 11: Competition between a sicker plant and a healthy plant.