Accurate Graphical Representation of Plant Leaves

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Abstract

We present a simple and practical method for rendering leaves and other translucent parts of plants. In contrast to other translucent materials, plant leaves usually are thin, though highly textured. An adaptation of rendering methods for translucent materials in combination with a set of predefined textures allows us to represent plants realistically. A hardware-based approximation of the shading-method enables us to render even highly complex plants efficiently.

1 Introduction

Representing nature in computer graphics images is a beautiful and challenging task. Unfortunately, the enormous geometric complexity of plants limited the use of larger outdoor scenes in realistic image generation in the past. Recently, some efforts have been made to deal with this challange. Deussen et al. [6] presented methods for efficiently representing plants by approximate instancing. Prusinkiewicz demonstrated efficient modelling methods for complex plant scenes using bounding approximations [16]. In [5] an efficient point and line based Level-of-detail approach was presented that allows the authors to render even complex scenes with hundreds of millions of polygons interactively on a standard PC using custom graphics hardware.

Plants are also very complex in their optical behaviour. The presented synthetic images so far lacked faithfull simulating of these properties. On the other hand, there has been much effort to simulate leaf optics in botany, the proposed methods are not very efficient and fail to show the quality and complexity of scenes that are desirable especially in computer graphics. Nevertheless, these methods offer us some hints regadring adaptation of efficient rendering methods for translucent materials which have been proposed in last years in the area of computer graphics.

In our paper we present a practical approach for an improved representation of such phenomena. The approach is based on a set of specially obtained textures that are combined with a biologically motivated optical model for leaves. Firstly, we sketch relevant work in botany and describe simulation methods for leaves, in the second part efficient rendering methods for translucent materials are discussed. Our model is then presented, results are discussed and some further ideas are outlined.

2 Optical models for plant leaves

A leaf is usually modelled by four layers with different optical properties [18]. The upper and lower epidermis cover the leaf, in the interior a layer of elongated palisade parenchyma is arranged densely in parallel to the incident radiation (cf. Figure 1).

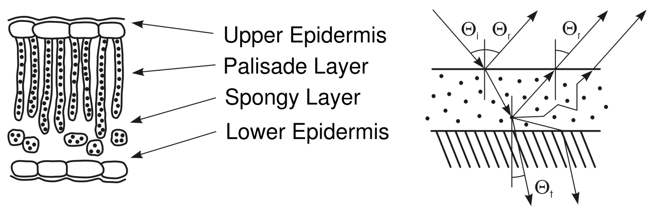

Figure 1: (a) Leaf interior b) scattering of light in an optical layer

The light passes through these cells into the spongy layer of the leaf. The elliptical cells, which are interspersed with intercellular air spaces cause internal scattering of the incident radiation and distribute the light within the leaf. This is important for an optimal absorption of the light by the leaf's mesophyll. Each of the layers cause reflection, refraction and scattering.

Several studies have been conducted to capture the optical properties of real plant leaves. In some papers the spectral reflection of leaves was measured, in a sophisticated experiment of the European Union a set of values was obtained from various species [10]. The aim of many studies is to fit simulation models to what was measured by using real leaves.

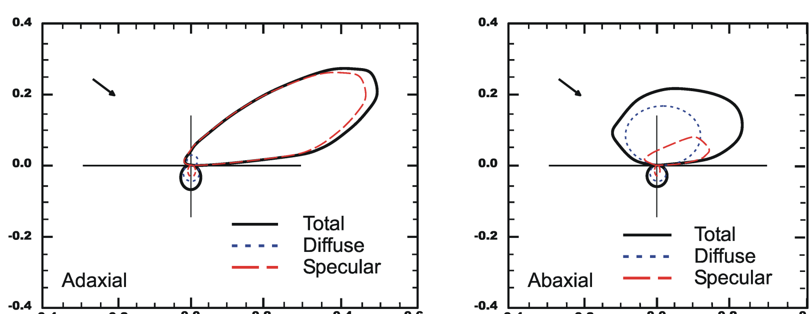

Figure 2: (a) Reflection and transmission from upper side (adaxial); b) from lower side (abaxial). Taken from [4]

Brakke[4] measured angular reflection and transmission (diffuse and specular) of leaves. He investigated several tree types and obtained some general results (cf. Figure 2): The diffuse component of the scattered light comes from the inside of the leaf, whereas the specular component arises mainly from the surface. The difference between adaxial and abaxial reflection is caused by the different surface characteristics of the leaf –the upper side is waxed whereas the lower side is rough– and by the inner structure which contains more scattering interfaces at the lower side. This is different for the near infrared spectrum which is not so much of interest here.

In a stochastic model, Tucker and Garatt[17] model the four layers by a Markov chain, four light states are defined –solar, reflected, absorbed, and transmitted– and for each transition between two layers a transition probability from each light state to any other is given. In a simpler model the layers are defined by an absorption coefficient and a scattering coefficient. Using the Kubelka-Munk scattering theory this is accurate enough to simulate general leaf properties[19].

For a long time, Biologists have been interested in more sophisticated simulation models. A simple form of light interaction with cells using light rays was performed by Haberland [8]. First studies on light interaction with entire leaves have been made by Allen et al [1]. Their model, which consists of circular cells embedded in air, was improved by Kumar and Silva[14] who added two more internal layers to the model. Govaerts et al.[7] implemented ray tracing procedures which extend the models to real 3D-structures (see also[11]).

Baranoski and Rokne[2] presented several methods for ray tracing leaves. They used a stochastic forward ray tracing method they called ABM (**A**lgorithmic **B**idirectional surface scattering **D**istribution function), which followed up photons in the interior of a leaf. The model has five parameters that describe the optics of a leaf: η_c (refractive index of upper epidermis), ob (oblateness of epidermis cells), η_m (refractive index of mesophyll cell wall), t_m (thickness of mesophyll tissue), c concentration of pigments, η_a (refractive index of lower epidermis). The model faithfully returns the reflection and absorption of leaves but due to its stochastic nature many photons are needed to obtain results with low noise. In [3] an improved method (the Foliar Scattering Model, FSM) is presented that uses predefined scale factors that correspond to spectral reflectances and transmittances of foliar tissues. These factors are computed using the ABM method and speed up calculation about a factor of 5-10. The rendering of some leaves still needs about 95 minutes on an SGI R10000 (cf. [3]).

3 Rendering translucent plant leaves

In computer graphics, the general problem of subsurface scattering was discussed in a number of papers. A first model was introduced by Hanrahan and Krüger [9] who computed scattering in a homogenous material and derived an analytic expression for single scattering. Pharr and Hanrahan [15] use several scattering functions to model scattering. Direct rendering based on these models is very time consuming, especially if highly scattering materials are used. Jensen et al. [13] propose an efficient method for subsurface scattering. The scattering process is separated in a single scattering term $L^{(1)}$ and a diffusion approximation term L_d:

$$L(x,\vec{\omega}) = L^{(1)}(x,\vec{\omega}) + L_d(x,\vec{\omega}).$$

The single scattering term can be computed exactly by sampling the material and computing the out scattering radiance

$$L^{(1)}(x,\vec{\omega}) = \int_A \int_{2\pi} S^{(1)}(x_i,\vec{\omega_i},x,\vec{\omega}) L_i(x_i,\vec{\omega_i})(\vec{N}\cdot\vec{\omega}) d\vec{\omega_i} dA(x_i).$$

To model arbitrary geometry, Jensen et al. [13] use a Monte Carlo integration along the refracted outgoing ray. An uniformly distributed random number $\xi \in [0,1]$ is selected and converted into a random outgoing distance $s'_o = \log(\xi)/\sigma_t(x_o)$ inside the material from the actual sample position x_o. The outscattered radiance is

$$L^{(1)}(x_o,\vec{\omega_o}) = \frac{\sigma_s\, F\, p(\vec{\omega_i},\vec{\omega_o})}{\sigma_{tc}} e^{-s'_i\sigma_t(x_i)} e^{-s'_o\sigma_t(x_o)} L_i(x_i,\vec{\omega_i})$$

where s'_i is the distance that the sample ray moves through the material (cf. [13]), $p(\vec{\omega_i},\vec{\omega_o})$ is the phase function and F Fresnel term. The multiple scattering term is approximated by a dipole light source, e.g. two light sources, one real positive light source inside the material at a depth of $z_r = 1/\sigma'_t$ and another virtual and negative light source above the material. The influence of both light sources together approximates quite nicely the behaviour of multiple scattered media. In [12] an improvement of the technique is presented. A two pass algorithm samples in the first pass the irradiance by shooting samples nearly uniformly into the surface. With any sample its associated area is stored together with an irradiance estimate. In the second pass for each sample the contributions from all samples are computed using an hierarchical data structure.

In contrast to other translucent materials, plant leaves are usually very thin and highly textured. This makes it necessary to modify the presented subsurface scattering model. Scattering is mostly forward scattering and the multiscatter term can be neglected. A simple but fast approximation of subsurface scattering is obtained by computing L in the following way

$$L = L^{(1)} + L_d = (1 + e^{-s_i} e^{-s_o}) L_i(x_i,\vec{\omega_i}) \cdot (\vec{N}\cdot\vec{\omega_i}) \tag{1}$$

In this case the single scattering and diffusion is approximated by a diffuse light source as indicated by the measurements of Figure 2. The reflected light is modelled by specular reflection, also obtained from the measurements of real plant leaves.

In the following, we will use this model as a good approximation for subsurface scattering. Though the scattering term is important for the visual appearance, much more is contributed to the visual result using a set of specially obtained textures that represent the spatial modulation of reflection and transmission.

4 Rendering Leaves

For our leaf model we use three layers: one for each surface and a scattering layer for the scattering interior, this is sufficient as our experiments show. In a pre-processing step we obtain seven textures from the real leaf. Two of them are photographies from the leaf's front side and back side. Due to the curvature of most leaves it is hard to obtain good textures by scanning. Instead we put the leaves under water and illuminate them by a light source. This allows us to avoid any specular reflections on the leaf that would destroy the texture. On the other hand the area light minimized shading in curved areas at the border of the leaf (cf Figure 3(a) and (b)).

Additionally, a transparency scan is obtained which represents the leaf's through light filtering (subfigure (c)). This scan can be obtained surprisingly simple by a standard scanner with through light extension. The scan is used in two ways: a grey-scale version of the image is directly used as an extinction map controlling how much light is absorbed by the leaf, the thickness map is a blurred version of this image and controls the diameter of the three layers of our model. The size of each of the layers is a fixed percentage of this thickness value as indicated by the user.

(a) (b) (c) (d) (e) (f) (g)

Figure 3: Textures used for rendering plant leaves: a) adaxial diffuse reflection; b) abaxial diffuse reflection; c) translucency; d) alpha map; e) thickness map; f) extinction map; g) bump map.

Additionally, an alpha mate (d) is used to allow arbitrary shaped plant leaves in combination with raytracing. In a standard raytracing scheme, specular reflection is computed for the whole underlying geometry. In the case of plants one wants to reduce the geometry and modeles the leaves as simple as possible, often only two triangles are used. The leaf geometry is then given by the leaf texture, the alpha channel has only two states: opaque and fully transparent. The bump map is used to model the small structures on the surface of the leaf. Small veins cannot be represented by geometry, instead the bump map changes the surface normal and generates an illusion of such structures.

The raytracing procedure for rendering the leaf can be outlined as follows: If the virtual viewer is at the same side of the leaf as the light source, according to the position the front or backside of the leaf is taken and the intensity is computed due to our scattering model. If the light is at the opposite side of the leaf, we do not distinguish between the two directions as our experiments did not show any significant difference of through light images obtained from both sides. This is also indicated by Fig. 2: in both subimages the diffuse through light term has the same shape, indicating a symmetric relation – at least in the visible spectrum.

for each ray through **do begin**
    obtain thickness and extinction value from maps
    alter surface normal according to bump map
    for each of the three layers do **do begin**

Figure 4: A plant rendered from different sides using our model.

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        refract ray at border of layer
        compute step width from current thickness value according to [13]
        for each step through volume do begin
            for each light source do begin
                compute light path length inside the leaf
                reduce light intensity exponentially according to path length
                    and extinction value
                if light source and viewer are at same side of laef
                    then modulate value by front or backside texture rsp.
                    else modulate value by through light texture
            end
        end
    end
    for each light source do begin
        add multiscatter term as ambient factor (if neccessary)
        if light source is at the same side as viewer then add specular term
    end
end
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As noted above, the scheme is a specialized variant of the approach proposed by Jensen et al. [13]. During our tests, we encountered some problems especially related to leaves. If a light source moves around the leaf, due to the thin geometry of the leaf popping artefacts can occur during the transition from backlight and front light situation. This is circumvented by smooth blending between these cases. Also reflection and transmission values had to be altered manually for different plants as measured values are only available for some species that are visually not very interesting. In Figure 5 a small bush is shown that demonstrates the visual properties of our model. Rendering time for each image was about 5 minutes on a Pentium 4 processor with 2 GHz.

Figure 5: Small bush rendered with translucency.

5 Future works

In the future we will extend our model to illuminate larger plants such as trees. Spatial data structures are needed here to cope with the enormous amount of geometry. Also a hardware oriented approximation of the lighting model will be developed to enable real-time illumination of complex plant scenes.

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