Illumination model for landscapes

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Problem statement

1 Ambient light

Ambient light is an illumination effect caused by diffusion of light rays. The intensity of the ambient light for the whole environment is a direction-independent constant, but the illumination caused by ambient light in scenes composed of mostly diffuse surfaces is not constant. E. g., in a diffusely lit room the illumination changes over wall surfaces — it is darker near room corners. A similar effect is a shadow under the car in a cloudy day.

There are some illumination models that take into account ambient light in a proper way. most of them suffer from the performance slowdown when executed on large scenes.

2 Ambient light models review

In **ray tracing** *(Whitted, 1979)* a ray of light is traced in a backwards direction. That is, we start from the eye or camera and trace the ray through a pixel in the image plane into the scene and determine what it hits. The pixel is then set to the color values returned by the ray. Ray tracing is a powerful universal method for producing photorealistic images. Unfortunately, ray tracing algorithm is very slow (it's very similar to a "brute force" algorithm).

Radiosity *(Goral, Torrance, Greenberg, 1984)* is an application of the finite element method for solving the rendering equation for scenes with purely diffuse surfaces. Unlike ray tracing algorithms which handle all types of light paths, typical radiosity methods account only for paths which leave a light source and are reflected diffusely some number of times (possibly zero) before hitting the eye.

Obscurance *(Zhukov, Iones, Kronin, Sbert, 1998)* technology it developed to produce natural-looking lighting effects in a much faster way than radiosity and ray tracing. From the physics of light transport point of view, obscurance expresses the lack of secondary (reflected) light rays coming to the specific parts of the scene thus making them darker. This is unlike radiosity where secondary reflections are accounted to increase the intensity. Unlike radiosity and ray tracing, obscurance model is a non-photorrealistic one, but obtains visually very pleasant images.

Our goal is to achieve fast method for landscape illumination. Usually applications visualizing large landscapes (such as training simulators or computer games) don't need a photorealistic image quality. So by the time the best model for landscape illumination is obscurance model.

3 Obscurance illumination model

At first, let's assume that there are no specific light sources in the scene. Let P be a point on the surface in the scene, ω a direction in the normal hemisphere Ω with center P, aligned with the surface normal at P and lying in the outer part of the surface (fig. 1). We also need some monotonous increasing smooth function $\rho(L)$ with following properties:

$$\rho(0) = 0, \quad \lim_{L \to +\infty} \rho(L) = 1.$$

I. e. something like $\rho(L) = 1 - e^{-kL}$.

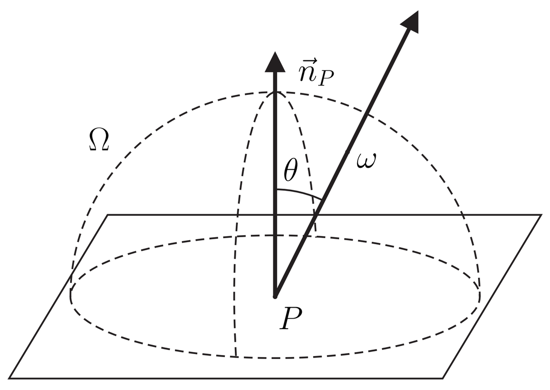

Figure 1. Hemisphere Ω

Obscurance of the point P is defined as follows:

$$W(P) = \frac{1}{\pi} \iint_{\omega \in \Omega} \rho(L(P, \omega)) \cos\theta \, ds_\omega,$$

where $L(P, \omega)$ is a distance to the first intersection in direction ω from point P.

Thus, the obscurance of a point P is the weighted average length of a chord originating from the point (the length of the chord is measured between P and the first intersection point with a surface in the scene). Obviously, for any surface point P: $0 \le W(P) \le 1$. Obscurance value 1 means that the point is fully open, while a value of 0 means the point is fully closed.

We have for the reflected intensity at point P:

$$I(P) = k_A(P) I_A W(P),$$

where I_A is the intensity of the ambient light for the whole environment, $k_A(P)$ is the diffuse reflectance for ambient light in point P.

In case of there are several light sources in scene, intensity at point P can be written as

$$I(P) = (I_A + I'_S(P)) k_A W(P) + k_D(P) I_S(P),$$

where I_S and I'_S — intensities of direct illumination from *all visible* light sources and indirect illumination coming from *all* light sources respectively, k_D — diffuse reflection coefficient.

Figure 2. Temple with $I(P) = k_A(P) I_A$ (constant ambient light)

Figure 3. Temple with $I(P) = k_A(P) I_A W(P)$ (obscurance model)

Landscape illumination

1 The idea

The landscape is a surface in $\mathbb{R}^3$. It is differs from other surfaces in the way it can be thought of as a function $\mathbb{R}^2 \to \mathbb{R}$. Let Φ be a contiguous function of landscape. We try to find approximation value of obscurance $\tilde{W}$ using some smooth function Ψ:

$$\tilde{W}(x, y) = 1 - \tilde{\rho}(\Psi(x, y) - \Phi(x, y)).$$

Function $\tilde{\rho}$ is a some modification of function ρ described in a previous part:

$$\tilde{\rho}(L) \equiv 0 \text{ for } L < C \text{ and } \tilde{\rho} \equiv \rho(L - C) \text{ for } L \ge C,$$

where C is a some empiric constant (usually negative).

2 How to construct Ψ?

At first we discuss analogous problem in 2D. Landscape analog in 2D is a contiguous function φ of one variable. Let's construct smooth function ψ — 2D analog of Ψ.

Bad solution. The easiest solution is let ψ to be a linear approximation of φ (fig. 4). But this solution rarely yields good result.

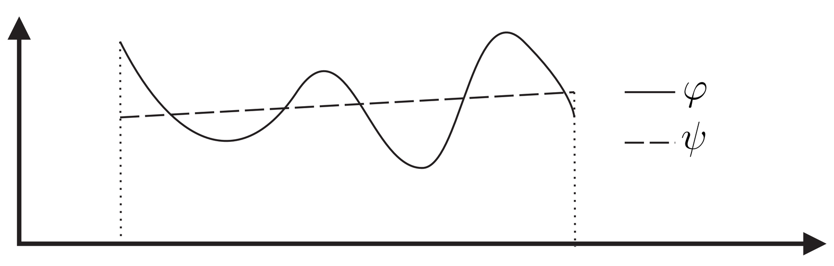

Figure 4. Bad solution

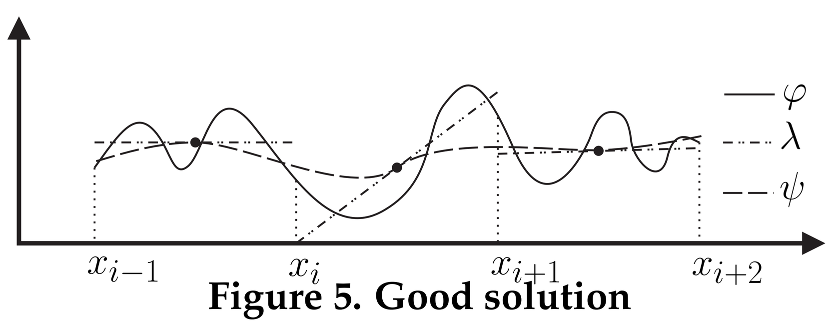

Figure 5. Good solution

Good solution. Better solution consists of two steps. Firstly, let's break graph of φ to same pieces and construct piecewise-linear function λ that is a linear approximation of φ on each piece.

Secondly, let construct a *cubic spline* function ψ using values of λ and λ' in middle points on pieces as pivots (fig. 5). Cubic spline function φ is automatically smooth.

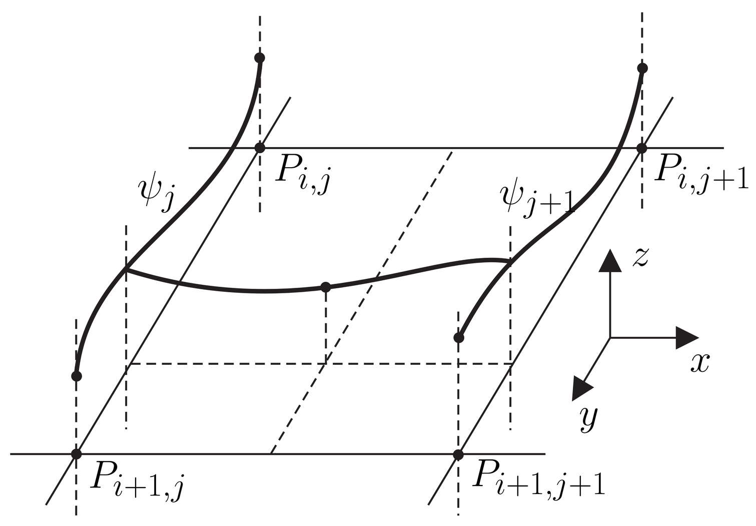

Figure 6. Cubic spline surface

Now we let's modify 2D solution to use it in 3D. As in 2D solution we start from breaking surface into same square pieces. Then we should construct function Λ that is a plane approximation of Φ on each square piece. We may construct a cubic spline surface using values of Λ, $\partial\Lambda/\partial x$, $\partial\Lambda/\partial y$ as pivots. To interpolate point height between four pivots we should use *bicubic interpolation* (fig. 6).

Example. Let's display this method on some landscape (fig. 7). Firstly we can't imagine the relief of surface cause there are no shadows. On second image we construct Λ (red planes). On third image we construct spline surface (blue net). At the end we apply expression for $\tilde{W}$ to compute obscurance and then calculate intensity of light for all points of landscape. Now we have landscape with understandable relief.

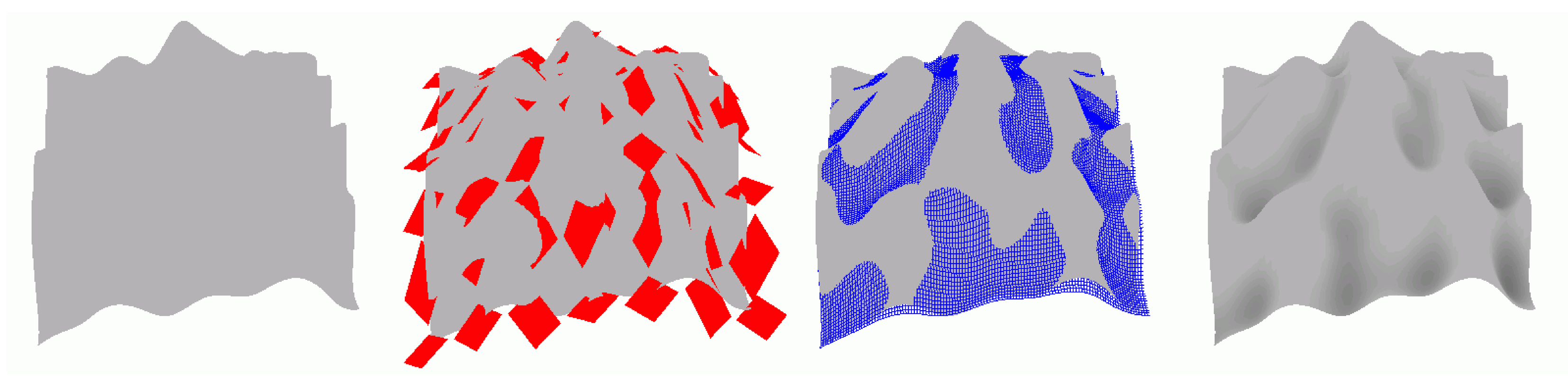

Figure 7. Construction of Ψ

3 Results

We discovered the heuristics algorithm for obcurance computation for landscapes with $O(N)$ complexity, where N is number of points where obscurance should be computed. The algorithm has 2 degrees of freedom that may be changed in fine-tuning to produce quality results: selection of function $\tilde{\rho}$ and size of square pieces.

Below you can see two "before/after" examples this technique application.

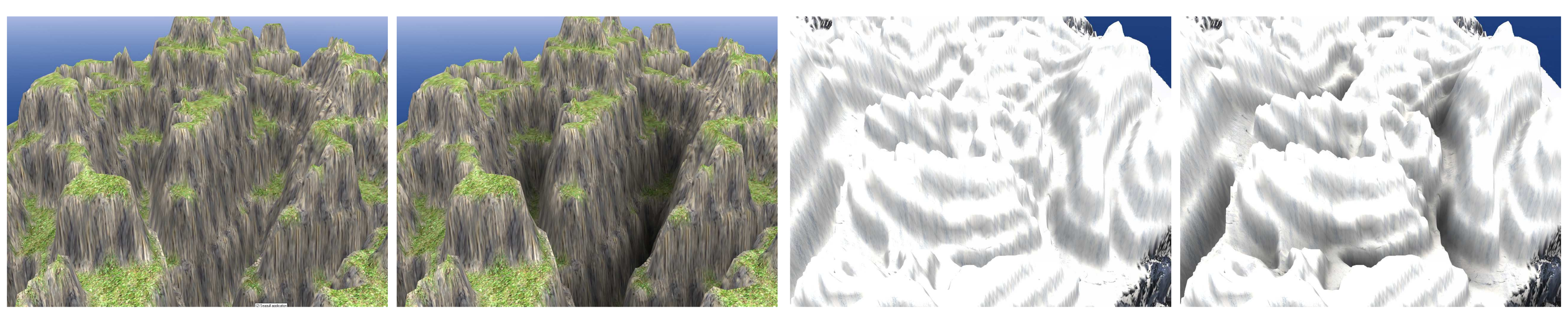

Figure 8. Two examples of landscape illumination