Radiosity in flatland made visibly simple:
Using the visibility complex for lighting simulation of dynamic scenes in flatland

Frédo Durand Rachel Orti Stéphane Rivière Claude Puech
iMAGIS*/ GRAVIR-IMAG

Radiosity is a global illumination method that takes into account all the light inter-reflections between the objects of a scene. It is particularly suitable for interior scenes. Nonetheless, recent applications such as architectural simulation or lighting design require the ability to modify the scene and also to deal with complex environments. This requirement has motivated research efforts in visibility processing [13] since visibility calculations are very important in the radiosity method. The most time-consuming part corresponds to the computation of the form factors which represent, for two given parts of objects, the amount of light energy leaving one part that arrives at another one. Previous work has also attempted to deal with dynamic environments [3, 1, 2] but still suffers some limitations in the case of moving objects. Time-coherence is not accurately treated and a lot of unnecessary re-computations are performed. No method has yet been proposed which exactly identifies the form factors whose re-computation is strictly necessary.

The video shows the use of the visibility complex for radiosity calculation. The visibility complex is a data structure representing the visibility relationships between objects in the plane which allows one to efficiently compute the form factors between objects for a given scene. In the case of dynamic environments, it will allow one to efficiently update only the modified form factors. This study in 2D will permit better understanding of the intricate visibility interactions for dynamic scenes, a step necessary for the development of truly efficient algorithms for radiosity in dynamic 3D environments. Some research in lighting simulation has already been carried out in 2D for discontinuity meshing and radiosity calculations, see e.g. [5, 6].

1 The radiosity method

The radiosity method, based on the principle of heat transfer between surfaces, simulates the balance of light energy between radiating surfaces for illumination computations [12]. The light exchanges between surfaces are modeled by a system of equations. Surfaces are assumed to be Lambertian (i.e. to reflect incident light uniformly in all directions). To set up the system of equations, the environment is divided into small areas (or patches). The radiosity B_i of a patch i is supposed to be constant over i, and can be expressed, for an environment discretized into n patches, as: $B_i = E_i + \rho_i \sum_{j=1}^{n} B_j F_{ij}$, where E_i is the light emitted from the patch P_i, ρ_i is the reflectivity of this patch, and F_{ij} is the form factor between the patches P_i and P_j, that is, the fraction of energy leaving P_i that arrives at P_j.

The accuracy of the radiosity solution depends on the discretization (or mesh) of the environment. An appropriate method is to position the elements (or patches) according to a discontinuity mesh whose boundaries are placed on the radiosity discontinuities caused by occlusions [5]. However this meshing strategy traditionally requires many geometric calculations which make it expensive to use.

2 The visibility complex

The *visibility complex* was introduced in [7] as an extension of the tangent visibility graph. It is a partition of the set of maximal free segments of a 2D scene according to their visibility. It was first studied for scenes of convex curved objects. In this video we consider scenes composed of simple polygons.

An efficient way to visualize such a structure is to represent the segments in a dual space where a line $y = ax + b$ in the scene is represented by the point (a, b) in this dual space. Thus, the set of lines going through a point of the scene is a line in the dual space. We represent the dual space in R^3, the third dimension being used only to separate dual points representing segments sharing a same supporting line (which would otherwise be represented by a same dual point).

The visibility complex is a 2D cellular complex. Its faces are 2D components of maximal free segments touching the same two objects. Its edges are 1D components of segments passing through one vertex of a polygon of the scene, and its vertices are segments passing through two vertices of polygons.

An optimal construction algorithm has been proposed in [8] for scenes of convex objects in time $O(m + n \log n)$ and space $O(n)$ where n is the number of objects and m the number of vertices of the complex. In the case of simple polygons, the optimal algorithm proposed in [11] has the same complexity with n the total number of vertices of the

*BP 53, 38041 Grenoble Cedex 09, France
Frederic.Durand@imag.fr, Rachel.Orti@imag.fr,
Stephane.Riviere@imag.fr, Claude.Puech@imag.fr
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polygons in the scene. It has been implemented and has been used to produce some images of this video.

For a clearer visual introduction in the case of convex objects, see [4].

3 Radiosity in flatland with the visibility complex

The computation of the form factor in 2D is simpler since it can be expressed analytically. Using the "string rule" – a formula established in thermal engineering – the form factor between two elements C_i and C_j (i.e. two portions of curves) becomes a quantity proportional to the difference between the lengths of *crossed* curves and the lengths of *un-crossed* curves stretched between the endpoints of C_i and C_j. This quantity can be computed in the dual space by using the vertices of the face associated with the elements C_i and C_j. The visibility complex also allows one to easily compute the discontinuity mesh since each discontinuity in the scene is associated with one of its vertices.

We have implemented a program which uses these concepts to compute the radiosity solution of 2D polygonal scenes. The application to dynamic scenes has not yet been implemented but we have proposed in [9] an extension to the algorithm implemented for the static case, which allows us to update efficiently only the modified form factors when an object is moving. Two cases may occur: (1) the visibility complex is topologically unchanged: only the form factors concerning elements on the moving object must be recomputed; (2) the visibility between some objects has changed: the complex must be updated, some faces are destroyed (the corresponding form factors become null), and other ones are created (requiring the computation of the corresponding form factors).
The images presented in the video to illustrate what happens in the dynamic case have been performed by computing a new visibility complex and a new radiosity solution from scratch. The first implementation has been carried out for the static case with the visibility complex for convex objects and demonstrates the usefulness of the visibility complex for radiosity computation [10].

4 Script

A short introduction to the radiosity method is given before a brief review of the visibility complex in the case of polygonal scenes. The notions of duality, faces, edges, vertices and so on are reviewed. Then we introduce the notion of a form factor, and express it in terms of the "string rule." An efficient way to compute the form factors between all the mutually visible objects is given that uses the visibility information stored in the complex. The problem of aliasing that causes too many subdivisions of the edges of the polygons of the scene is illustrated, and we show that a discontinuity mesh can cope with it. We indicate that the discontinuity mesh is in fact given by the set of vertices of the complex. After describing the displacement of the dual lines when the scene is modified, an example of a change in the topology of the complex when three points become aligned is detailed. Only the interesting portion of the complex is shown in the neighborhood of the dual point associated with the segments going through the three points. Finally, we show the 2D radiosity solution of a simple scene and its relationship with the visibility complex when an object is moving.

5 Production

The images of 3D radiosity were computed by Nicolas Holzschuch who deserves all our thanks, as well as George Drettakis who advised and supported us for this work. The images of the 3D representation of the complex and of 2D radiosity were computed on a Silicon Graphics workstation with two interactive programs and then transferred to a Macintosh where the editing was performed with Adobe Premiere. Some of the diagrams were manually created.

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