Global Illumination 7

7.1 Introduction

Global illumination is the physically based simulation of light transport used to generate realistic synthetic images. The word *global* refers to the fact that the simulation takes into account all the reflections of light leaving the sources, as opposed to *local* illumination models where light is allowed to reflect once only before reaching the observer (Figure 7.1). The difference between the results of these two simulation types can be compelling. Colour Plate 7.1 shows how global illumination can provide a strong improvement in both realism and visual richness, adding colour bleeding, reflections, refractions and caustics. For this reason, even if the general solution of the light transport equations is still computationally expensive, some global illumination capabilities are starting to be incorporated in almost all commercial rendering packages. After a brief theoretical introduction, this chapter discusses the practical problems associated with the implementation of a global illumination system into a general purpose renderer. In particular, the topics include an overview of the difficulties emerging from the integration of a physical simulation process into a programmable shading environment, the definition of an appropriate theoretical framework, and a detailed description of the most powerful algorithms needed for the solution of the problem.

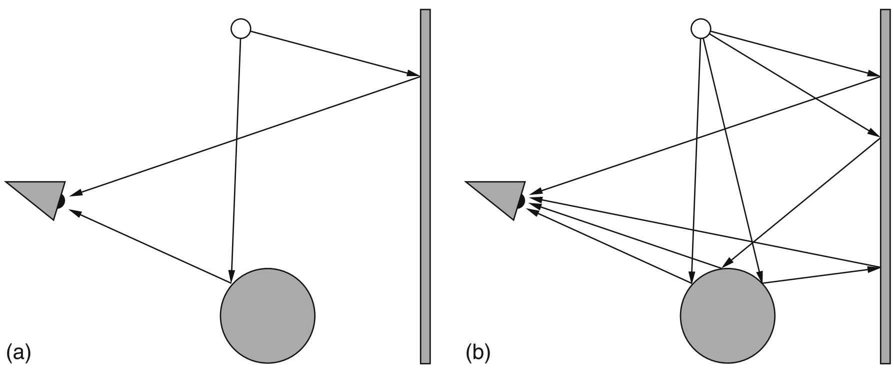

Figure 7.1 (a) Local illumination, (b) Global illumination.

7.2 Light Transport Theory

In this section we will explain the foundations of light transport theory needed for the development of any correct global illumination algorithm.

Throughout history, the behaviour of light has been described using several mathematical models of different complexity, that have been formulated in order to explain an increasing number of lighting phenomena. Currently, we can group the existing descriptions of light into three main categories:

- **Geometric optics.** Geometric optics. describes light propagation in terms of rays. It can model emission, absorption, reflection and refraction, both at the interfaces between different materials and inside participating media.
- **Wave optics.** Wave optics stems from the electromagnetic interpretation of light. In addition to the phenomena explained by geometric optics it can model diffraction, interference and polarization.
- **Quantum optics.** Quantum optics describes light in terms of photons which interact with matter according to the laws of quantum physics. It can model all the light propagation phenomena we can observe in nature, including fluorescence, phosphorescence, non-linear optics, and relativistic effects due to gravitational fields.

Since most of the attention in computer graphics is focused on the production of images that have a realistic appearance with respect to our perceptual visual system, the interest of the graphics community has been almost exclusively restricted to the simulation of those optical phenomena which belong to the human scale, disregarding micro- and macroscopic effects which cannot be usually seen by our eyes. This has eventually led to the choice of geometric optics as the natural framework for the study and development of most global illumination methods, including the ones presented in this book. Though it is certainly possible to construct scenes which cannot be correctly rendered within the limitations of geometric optics, such scenes occur rarely in the production environment, and hence are of limited interest. In the following section we will show how the light transport problem can be expressed under the assumptions at the base of this model. For now, we will concentrate on light transport in a vacuum: effects due to participating media will be considered in Section 7.8.

7.2.1 Basic Definitions

Before embarking on the bulk of the subject, we will describe some mathematical entities that will be extensively used throughout the following text.

First of all we need to define the main domains we are going to operate on, that is to say the *scene geometry* M, the *sphere of directions* Ω, and the *ray space* R. M is assumed to be a finite set of oriented differentiable surfaces in $\mathbb{R}^3$, while Ω is simply the set of unit-length vectors $\{\omega \in \mathbb{R}^3 \mid |\omega| = 1\}$, and R is the set product $M \times \Omega$. Additionally, if $\mathbf{x}$ is a point in M and $n(\mathbf{x})$ is its surface normal, we will split Ω in the *upward* and *inward* hemispheres, Ω_+ and Ω_-, defined by:

$$\Omega_+ := \{\omega \in \Omega \mid \omega \cdot n(\mathbf{x}) > 0\} \tag{7.1}$$