Chapter 1
Introduction

Until the mid-1980s, computer graphics was mainly concerned with offline rendering. Many techniques, such as radiosity and ray tracing were developed to create photorealistic still images, often taking hours to compute.

Yet many applications call for interactive image synthesis. Initial systems could only provide simple wireframe views, but the true potential of interactive 3D graphics became soon apparent. A huge effort was undertaken to improve the speed and quality of interactive techniques. The biggest leap forward was the introduction of hardware support by companies like SGI, which offered high-end workstations with hardware-accelerated 3D graphics. Soon a new direction of research was born: *real-time rendering*. Many new application areas, such as Virtual Reality, benefitted and still benefit from the advances in this field of research.

Although interactive 3D graphics became more and more commonplace, hardware 3D support could only be found in high-end workstations until the mid-1990s. Then 3D games like Quake appeared, and soon graphics hardware became available for the mass PC market. The first PC 3D graphics cards mainly tried to catch up with developments in the high-end market. After only a few years, at the end of the century, PC graphics started to take the lead. Nowadays, at the end of 2002, low-end PC graphics hardware is capable of handling over 300 million vertices per second, and the fill rate achieves several gigapixels per second. This increase in performance also raises expectations of higher and more realistic image quality. Today, realistic shading is one of the main areas in research on real-time rendering.

In this dissertation, we introduce a set of new techniques and algorithms using graphics hardware that allow for high quality, real-time shading and rendering of objects with complex material properties. These algorithms can achieve results in real-time that are of comparable quality to offline rendering and were considered

Figure 1.1: *Brushed metal head in a forest environment and a furry bunny.*

impossible to achieve in real-time before.

1.1 Problem Statement

Creating realistic images requires several important factors:

- Accurate material properties must be used to create convincing simulations of reality.
- The complex light transport between objects and object regions must be simulated, e.g. self-shadowing or interreflections.
- Fine surface detail must be visible, or otherwise the results look too “smooth”.

We focus on these areas which we summarize as *realistic, real-time shading and rendering of objects with complex materials*. This is a hard problem, as descriptions of realistic materials are often mathematically complex, whereas graphics hardware is optimized for performing simple operations quickly. Furthermore, we want to avoid simplifications that are often used in real-time rendering, such as the omission of area light sources.

In Figure 1.1 on the left, one can see an example of a brushed metal bust that takes lighting from the entire environment into account but also considers self-shadowing and even interreflections. On the right one can see a furry bunny, which is an extreme example of the previously mentioned “fine surface detail”. This is the kind of results we want to achieve. As we show in this dissertation, these results can be realized in real-time if certain restrictions apply. We propose different algorithms to deal with objects illuminated by point and area lights, including bump and displacement mapping. These algorithms have different advantages and disadvantages. There is not **the one** algorithm that can be used in all cases. Depending on the application, one or the other might be better suited.

1.2 Main Contributions

Throughout the course of this dissertation, parts have already been published at different conferences and in journals [Heidrich00b, Kautz00d, Kautz00c, Kautz01b, Kautz02b, Sloan02]. This thesis builds on these publications, presents them in a common framework, and includes improvements and updated results.

The main contributions of this thesis can be summarized as follows:

- An algorithm for advanced real-time local illumination from point or directional light sources, which allows to change the appearance of the surface on a per-texel basis, including the variation of the normal in order to also achieve bump mapping effects.

- An algorithm for self-shadowing in bump maps from point or directional light sources, which can be used on top of other bump mapping algorithms (including our proposed bump mapping algorithm).

- A unified notation for classifying (prefiltered) environment mapping techniques, which are used to create glossy reflections for real-time applications. Our unified notation allows a better comparison of these methods.

- A fast hierarchical environment map prefiltering technique that can be used together with all previously proposed prefiltering techniques. A second filtering method for environment maps, which employs graphics hardware and which works in real-time but can only be used for certain reflection models.

- An interactive environment mapping technique based on spherical harmonics, which, unlike all other techniques, works for arbitrary material properties but assumes low-frequency lighting.

- A method for adding self-shadowing and interreflections to our spherical harmonics environment mapping technique, which achieves real-time rates for diffuse materials and is still interactive for arbitrary BRDFs. This technique is also applied to volumes and bump maps.

- A real-time method for simulating fine surface detail using displacement mapping.

1.3 Chapter Overview

First we will review the necessary background material in Chapter 2, and present related work in Chapter 3. In Chapter 4 we give an overview of our proposed algorithms, classify them according to a set of criteria, and apply this classification to other related algorithms as well.

Then, we deal with local illumination in Chapter 5 and Chapter 6, i.e. with bump mapping and self-shadowing in bump maps.

The next chapters deal with global illumination as we call it, i.e. with environment mapping techniques that allow to achieve glossy reflections not only from point lights but actual environments. We first classify existing techniques using a unified notation in Chapter 7, and then propose fast filtering algorithms for these techniques in Chapter 8. In Chapter 9, we propose an environment mapping technique that does not require filtering in the traditional sense and works with arbitrary anisotropic materials. This is then extended to include self-shadowing and interreflections in Chapter 10.

Finally, we deal with surface detail by exploiting graphics hardware to do real-time displacement mapping, see Chapter 11. We will conclude this thesis in Chapter 12.