Realistic fire rendering

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Chapter 1

Introduction

"*A case that can be made for fire being, next to the life process, the most complex of phenomena to understand*." - Hoyt Hottle

For centuries humans has been attracted to fire due to its attractive presence and its dangerous nature. Understanding and simulating combustion phenomena has many applications, such as in the film and computer games industries, where it is widely use in visual effects; or in the engineering community, where the modelling of combustion in engines or fire safety evaluations are frequently demanded. Computer generated examples include a particle-based technique by [Ree83] which was used in the Star Trek II film, parametric curves were used to drive the flames [LF02] in the film Shrek and, the more recent work of [HG09] based on 2D screen projection for the film Harry Potter and the Deathly Hallows. In these and in many other applications, using real flames is an expensive and hazardous endeavour.

Fire can be modelled as a fluid, however its behaviour more complex, due to its multiphase flow, chemical reactions and radiative heat transport, than other fluids, such as water or smoke, which the computer graphics community have intensively researched. As a result of the aforementioned complexity and the interdisciplinary nature of the problem, fire simulation is still an open problem in computer graphics.

A great deal of work done in the area has sacrificed complexity for interactiveness, therefore producing simplified models which hope to deceit the observer by exploiting the chaotic essence in fire motion. Nevertheless, physically-based simulations incorporate the intrinsic processes that occur in a combustion scenario:

Flame motion:

Fuel erosion: when the fuel reaches a certain temperature, it is vaporized into a gaseous state, which rises under the influence of buoyancy.

Black body radiation: the chemical species present in the fuel and the byproducts of the combustions emit energy in various wavelengths.

In order to be able to produce a realistic result, all of the preceding characteristics have to be taken into consideration. In this report a short review in the field of fire simulation and rendering is presented, a state of the art physically based rendering model by [PP06] is discussed in detail, and an implementation of the given model in Maya® is outlined.

TODO Add some fancy pictures from real, film and videogames flames and explosions TODO Explain everything in more detail and go from slower from general to technical

Chapter 2

Previous Work

In order to display a realistic fire scene in a computer generated world two differentiated stages are needed. Firstly, the fire dynamics have to be collected, this can either be done through a data capture session or simulated using a fluid solvers. Secondly, the previously gathered data is to be visualized on the screen using some rendering technique. We refer the readers to the more detailed survey on the topic, which has been recently presented by [HGH14].

2.1 Simulation

Particle-based methods were the first approach to simulate the visual animation of fire. A number of particles are emitted from certain locations, each particle has a set of attributes such as shape, velocity, color or lifetime. The first model with particle systems was presented by [Ree83], the particles speed and colour were perturbed with a Gaussian noise at each time step, and the colour was subject to an additional linear perturbation on its lifetime. Two particle systems were used in a hierarchy, one would control fire spread and the other a single explosion effect. An extension was proposed by [PP94], the authors modified the particle system such that each particle shape would be defined by a series of non-overlapping coplanar triangles. The transparency of would increase towards the outer vertices, thus providing an improved visual effect.

Noise-based methods focus on synthesizing the high fluctuation present in fire procedurally. The objective is to approximate the turbulence present in fire with an appropriate statistical model. Using a variation of Perlin noise, [Per85] presented images of a corona of flames. However, the method is limited to 2D, where the color is a combination of non-linear arbitrary functions. This work was extended by [PH89] to 3D, where they use volumetric rendering to achieve improved results.

Geometry skeleton

Data driven

Physically based simulate the fire combustion processes, including flame propagation or the chemical reactions that convert fuel into gaseous products. Incompressible flow equations were used by [SF95] to drive a fire simulation. Given initial fuel conditions, the fire spread is advected on a grid using an advection-diffusion type equation. Building on the work on a semi-Lagrangian fluid solver of [Sta99], a model which includes gaseous fuel and gaseous byproducts was proposed by [NFJ02]. In order to include the characteristics of the noise-based methods, [HSF07] combined the previous model with a set of third-order equations from detonation shock dynamics presented by [YS96]. As with the noise-based methods, this addition is visually attractive, yet it is not physically based. Capitalizing on the recent advances in GPUs parallel processing power, [HG09] proposed a fixed camera model. Particle properties are computed on a three-dimensional coarse grid, which are then projected into several view dependant two-dimensional slices. The authors' model is based on the assumption that fine variations, which are perpendicular to the projection plane, are not individually visible and, they do not affect significantly the overall flow.

Other effects directly related to fire have also been explored. [FOA03] presented a model to simulate suspended particles during explosions. An incompressible fluid model drives the motion of air and hot gases, and the suspended particles follow the their movements. Sound is a important factor to increase the believability of a finished fire animation. [CJ11] proposed a method to automatically generate plausible noise given for a given fire simulation. Low frequency sound is estimated using a physical model whose inputs are the flame front and heat release. A data driven sound synthesis approach, based on the work by [WL00], is applied to generate the high frequency content.

Erosion???

2.2 Rendering

Rendering fire is more challenging than rendering other type of participating media, the main reason being that fire is a light-emitting source. The luminescence radiated by a flame is generated by black body radiation due to the high temperature of the particles present during the combustion. In order to render fire realistically, light absorption and scattering in the media, including air, has to be taken into consideration.

2.2.1 Raster-Based

Raster-based techniques sacrifice quality in the interest of interactive frame rates. Some form of texture mapping is usually practised, usually only the surface of the flame is considered, and the illumination of the scene is approximated base on some parameter which can be easily computed such as a as well, e.g. the fire height.

[LF02]

2.2.2 Ray-Tracing-Based

Volume ray-tracing techniques offer astonishing results, however the associated computational costs are considerable. Rays are shot from the view plane and evaluated at small increments; the total radiance at origin of the ray is computed by integrating the radiance at each step size. A further drawback for ray tracing techniques, in comparison to raster-based methods, is the lack of a standard ray-tracing pipeline.

[NFJ02] [FOA03] [PP06] says ... [HG09]

Chapter 3

Methodology

Not only explain in more detail every equation, what it means, comparison with other papers and ideally improvements or were it fails at least.

3.1 Radiative Transfer Equation

3.2 Scattering

3.3 Soot Absorption

3.4 Black Body Radiation

3.5 Emission From Chemical Species

3.6 Refraction

3.7 Visual Adaptation

Chapter 4

Implementation details

4.1 Application Overview

Explain how to use the shaders and the commands

4.2 Mental Ray® Shading Approach

How mental ray shoots rays around and what is its paradigm. Add pretty pictures of ray shooting.

4.3 Shaders Internals

Talk about things like which parts are written in parallel code, instance support, shader internal memory, sparse data, how the software escalates, memory consumption, Maya integration, spectrum to rgb integration, maybe more details about units for black body radiation and everything that was not explained before

4.3.1 Fire Volume Shader

4.3.2 Fire Light Shader

4.3.3 Voxel Dataset Shader

Chapter 5

Results

Images everywhere and proper analysis of what the user is seeing, what is failing and why.

Chapter 6

Conclusions and Future work

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