Interactive Computer Graphics

Lecture 17: Fire

Amorphous Objects

Amorphous objects are still a major challenge in computer graphics.

- Fire,
- Smoke
- Water
- Clouds
- &c.

They are the subject of current research - marketable in computer games and films.

Polygons

Texture mapping polygons is fast and acceptable for short lived effects.

Overlay an flame point with a series of textured polygons (25 for a one second effect)

Using polygons and fixing up the lighting

To make things more realistic we need to introduce secondary light sources at the point of the fire.

Limitations of Polygons

Polygon fires are:

Difficult to sustain for for long periods

Difficult to spread or change shape

Difficult to introduce translucency

Though they are fast and therefore good for interactive graphics.

Modeling Fire

Modeling fire is computationally expensive, but can produce better effects.

Flames are incandescent gases at the point of reaction between air (oxygen) and combustible material.

The visual appearance and shape changes (due to diffusion) are functions of temperature pressure and density.

Modeling the physics accurately is difficult

Particle Systems

One solution is to approximate flame - and other amorphous objects - by a discrete set of small particles.

Particles can have:

- Mass
- Position
- Velocity
- Temperature
- Shape (not often used)
- Lifetime

Particle Creation

Particles can be created according to a probability distribution.

They can be given an initial velocity and a lifetime

Depending on the simulation their movement can be determined by dynamics.

Example - (water not fire!)

New particles created each frame

- the number created per frame is normally distributed

Each particle has an initial downward velocity

- again normally distributed

Each successive frame each particle is acted on by a “wind” force to the right

Particle Dynamics

Newtonian particles: **f** = m **a** (NB **f** and **a** are vectors)

$$\mathbf{a} = d\mathbf{v}/dt = d^2\mathbf{x}/dt^2$$

Given **f** we need to find the change in position **x** so we need to integrate.

But since we are working in frame intervals we can use a simple approximation.

$$\mathbf{v}_{t+1} = \mathbf{a}_t \,\Delta t + \mathbf{v}_t$$

$$\mathbf{x}_{t+1} = \mathbf{v}_t \,\Delta t + \mathbf{x}_t$$

Accuracy is not as important as effect!

Practical particle system algorithm

```
for each video frame
{   generate new particles;
    remove old particles;
    for each particle
    {   resolve forces by vector addition;
        calculate a, v, x
        apply rendering algorithm;
    }
}
```

Enhancements - 1

Introduce damping:

$\mathbf{f} = m\mathbf{a} + s\mathbf{v}$

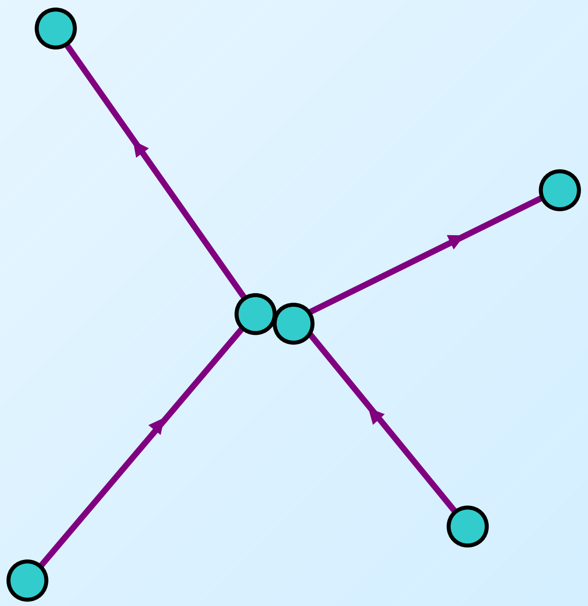
s is a scalar constant called damping or friction

for a gas it relates to the viscosity

An easy enhancement

Enhancements - 2

Allow particles to collide



Problems:

Sub frame calculation required

Particle shape and size needed

Large number of particle/particle checks needed

Simple Rendering

Project particles to the view frame, then

1. Single point for each particle
2. Blob for each particle
3. Streak for each particle
   (line of motion during the frame)
4. Blend particle projection with the raster
   (translucency)

Rendering

Particle Colour

1. Make colour particle age dependent
   (simple to implement)

2. Make colour temperature dependent
   (requires modeling the temperature)

The wrath of Khan

Strong contender for the worst film of 1982.

First use of a particle system to model fire:

Reeves, (1983) Particle systems - a technique for modelling a class of fuzzy objects. Computer Graphics (SIGGRAPH 1983) 17(3):359-376

(the next few images are from the paper)

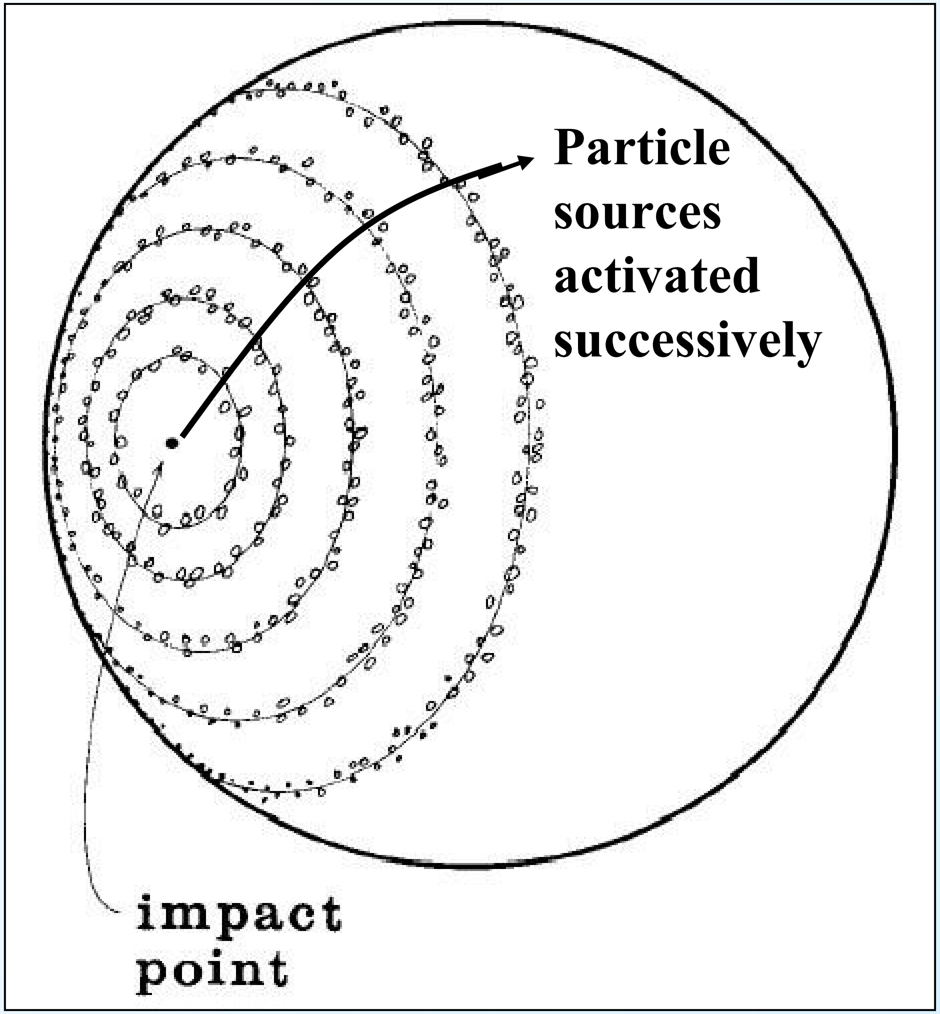
The Wrath of Khan - Storyboard

The genesis project

A barren planet is to be brought to life by dropping a bomb on it.

Doesn't sound very likely to me.

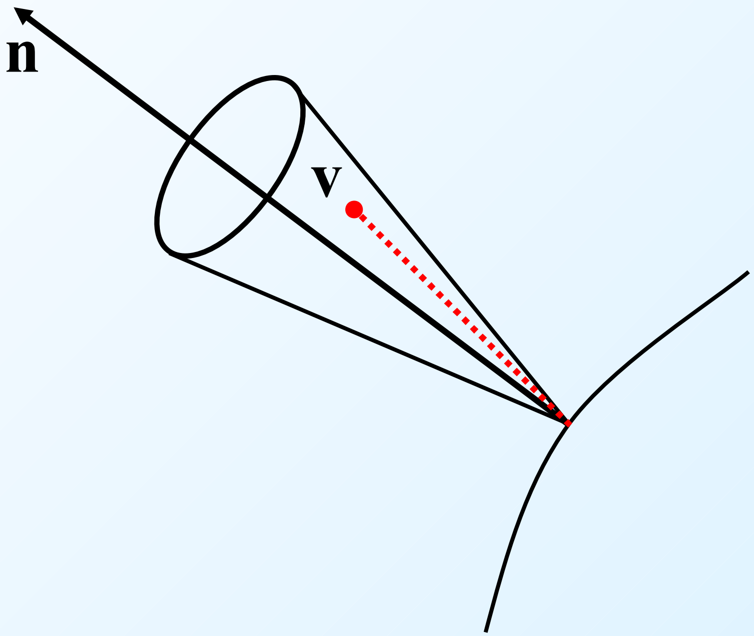
The Wrath of Khan - overview



Many particle systems starting at different times to simulate the flames spreading

In total around 750,000 particles

The Wrath of Khan - Particle Initialisation

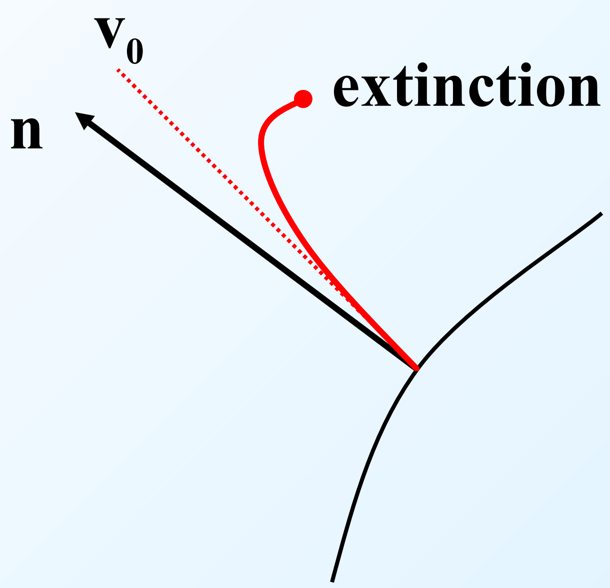


Velocity magnitude distributed normally

Magnitude diminishes with time

Velocity direction distributed about the normal

The Wrath of Khan - Particle Dynamics



Gravitational force pulling the particles towards the planet.

Particle lifetime short to prevent a whole parabola being visible

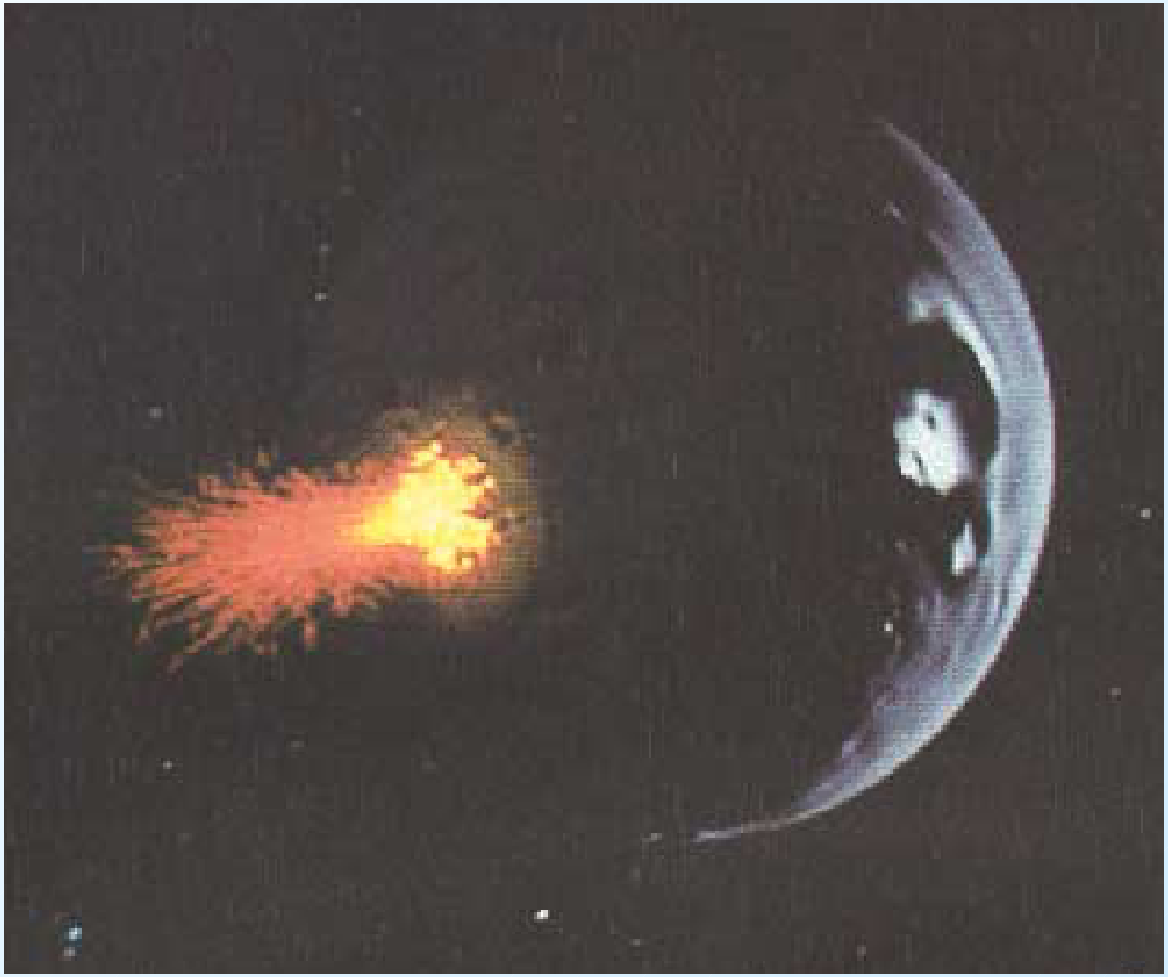
The Wrath of Khan- Rendering

Planet rendered first - fake light source above the particle system to create the light emitted by the flames.

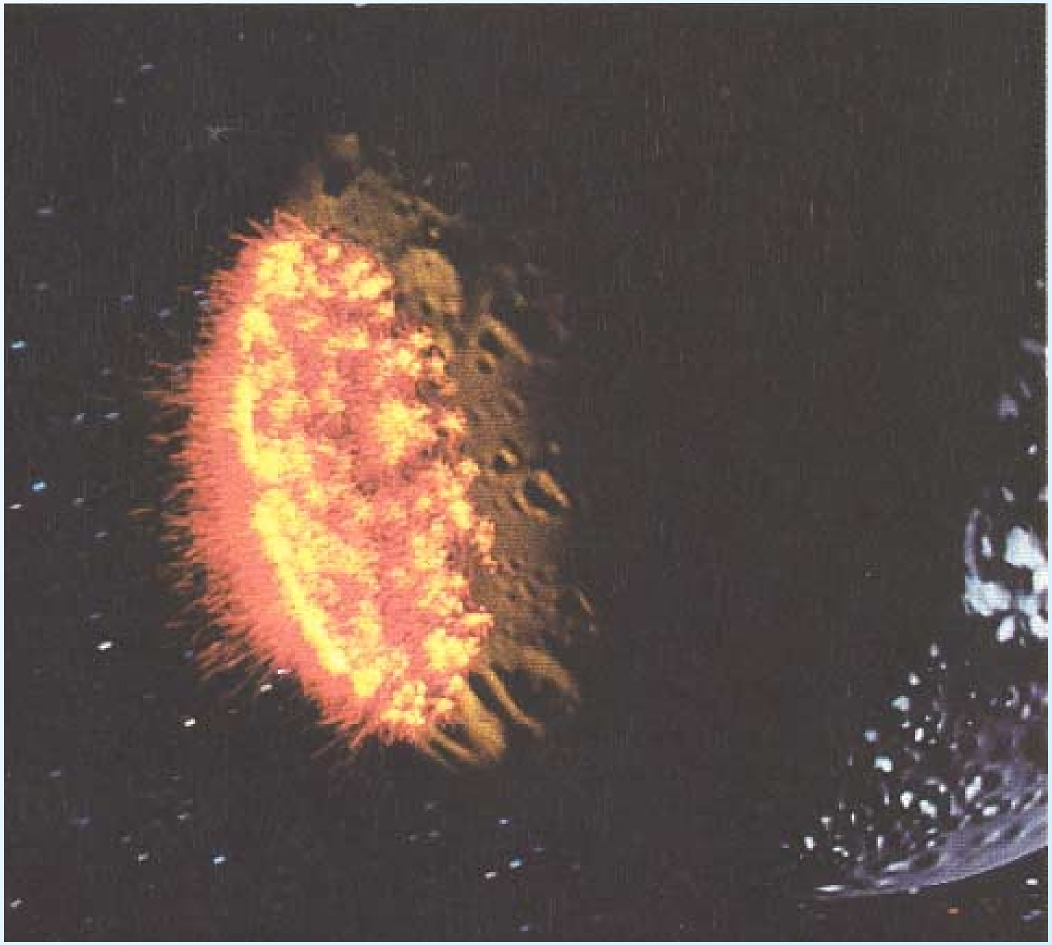
Line segment for each particle projected and drawn over the planet image, motion blur applied

Colour time dependent, yellow to red

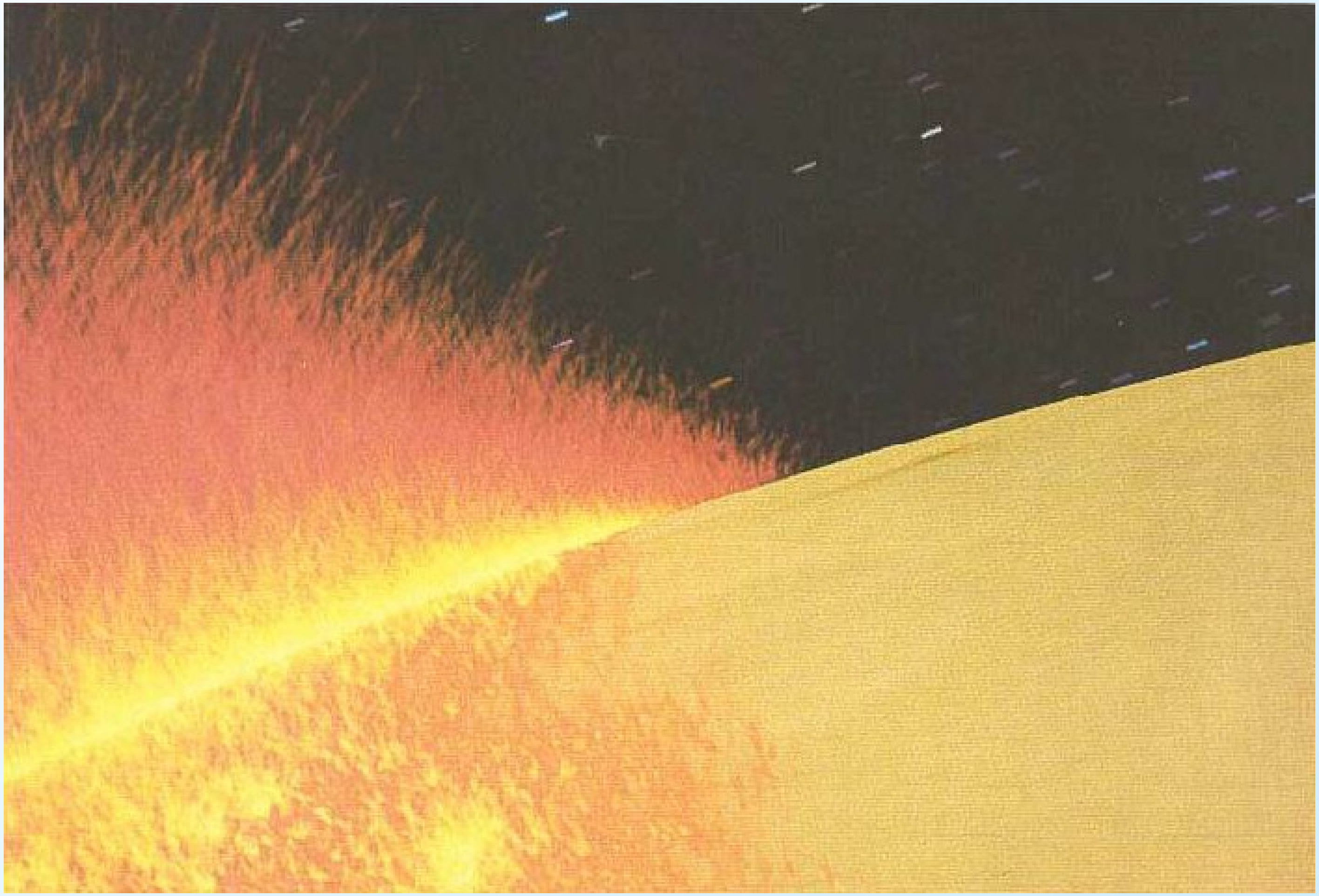
How did it look? Good Explosion!



Effective flame spread



Close up it looks like the edge of a carpet!



Particles in Real Time - Quake

1. A pre-rendered bitmap

2. Real time rendered glow

3. Animated glowing particles

Where Next - Modelling

Particle systems are very flexible modelling tools capable of simulating a lot of effects.

The particle modelling in the Wrath of Khan was simple and effective, but there might be some benefit in incorporating more features.

Temperature

Gases cool as they expand - particles move slower at lower temperature.

Gas expansion is related to pressure differential.

The possibilities are endless and there have been lots of ideas tried.

Where next - rendering

The real failure in the Wrath of Khan is the rendering.

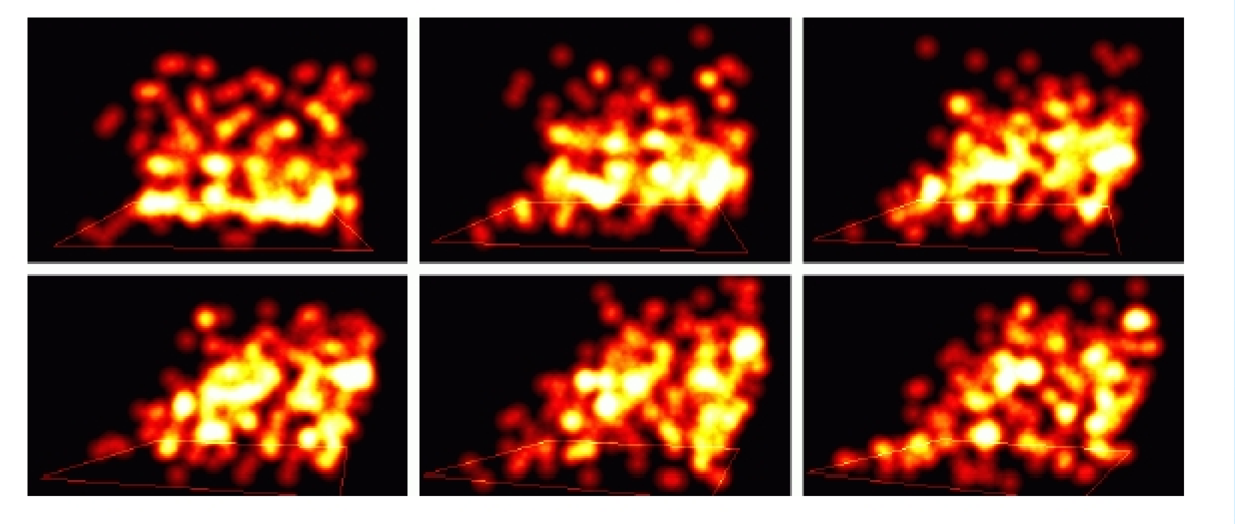
Straight line segments are not a visual characteristic of incandescent gases

The lines are very much apparent where the particle density is low

Bitmap Splatting (Laur and Hanrahan 1991)

Render the particles as splats rather than lines.

Each splat has a pattern with degrees of opacity at each pixel



Rendering by Engell-Nielsen and Madsen, University of Copenhagen

Ray tracing - Blobs

Blobs can be thought of as 3D splats

Particles are treated as the centre of blobs and the flame dynamics can be modelled by the particles

Blobs can be warped in 3D to produce a less regular appearance for the fire.

Ray Tracing Blobs is volume rendering

As the ray travels through a blob it adopts a proportion of the blob colour.

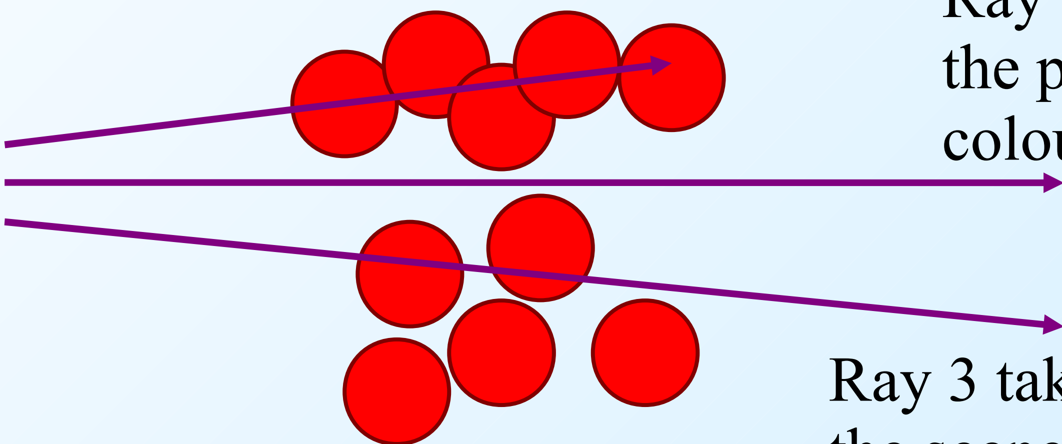
It may travel through the whole particle field and take up a proportion of the scene behind

Alternatively it can terminate within the particle field in places where it is denser.

Ray tracing particle fields

Ray 1 takes all its colour from the particle field. The background is occluded

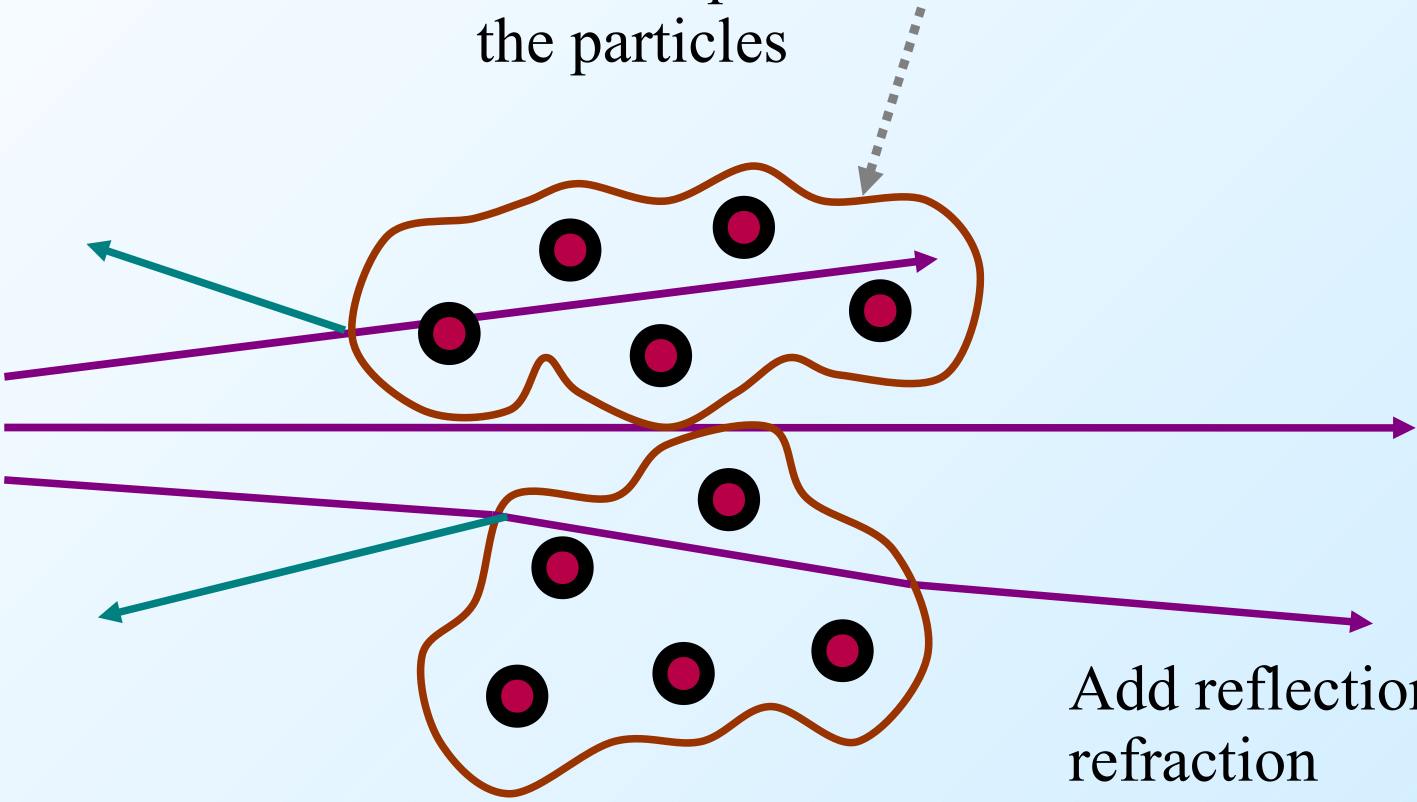
Ray 2 passes unchanged through the particle field and takes it colour from the scene behind



Ray 3 takes part of its colour from the scene behind and part from the particle field

Further possibilities - Implicit Surfaces

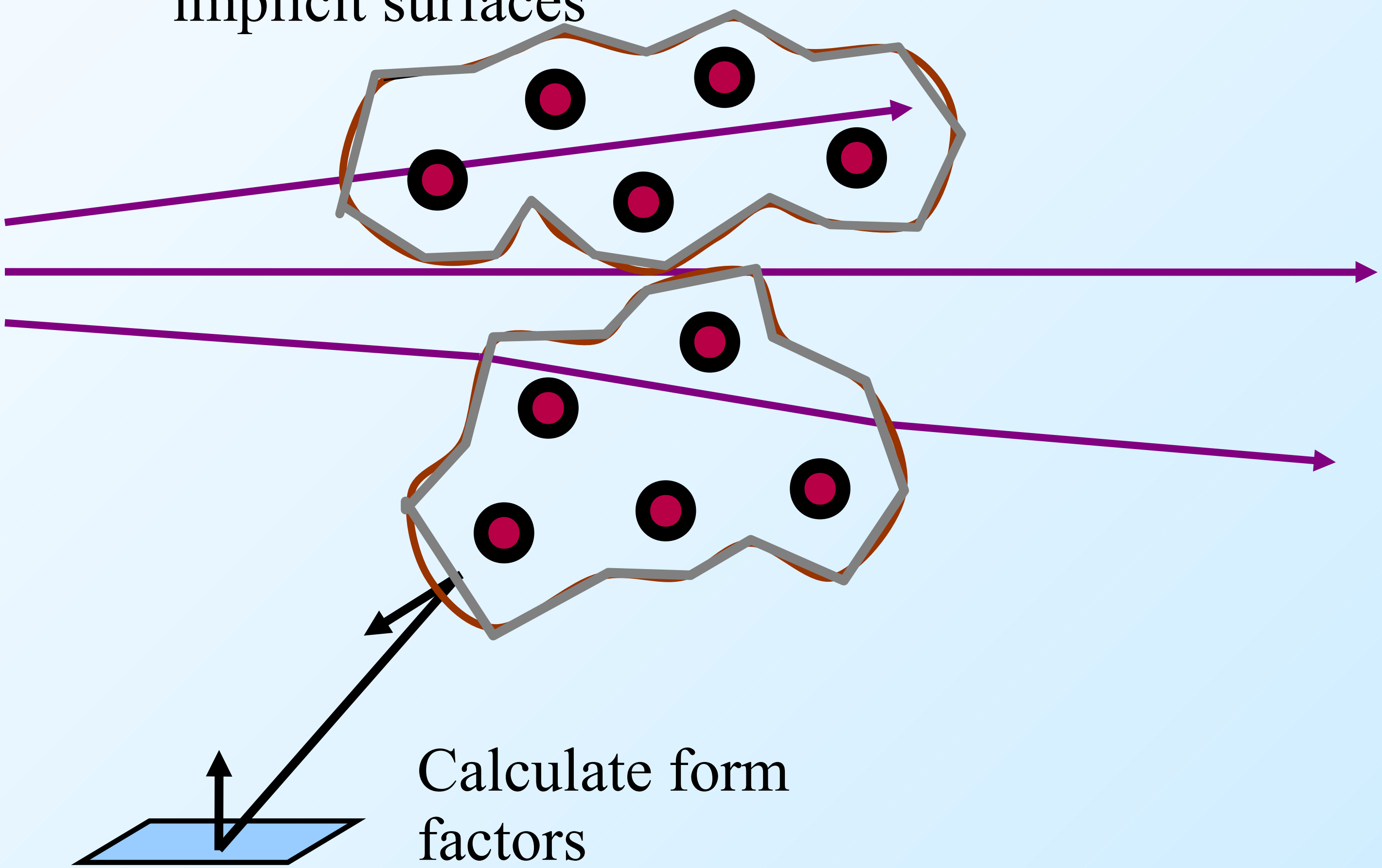
Fit an implicit surface over the particles



Add reflection and refraction

Further possibilities - Radiosity

Polygonise (triangulate) the implicit surfaces



Calculate form factors

Where to Next - Particle movement

Particle movement can be controlled by simulation of physical laws - eg diffusion Particles diffuse from less dense to more dense regions.

Compute a force field by

- Dividing the particle space into voxels
- Calculating the particle density in each voxel
- Giving each particle a small diffusion force drawn randomly using the distribution of the particles in the surrounding voxels.

Force fields

Using diffusion forces can create a more natural particle movement than gravity, and can also be used to model temperature since particles cool as they diffuse.

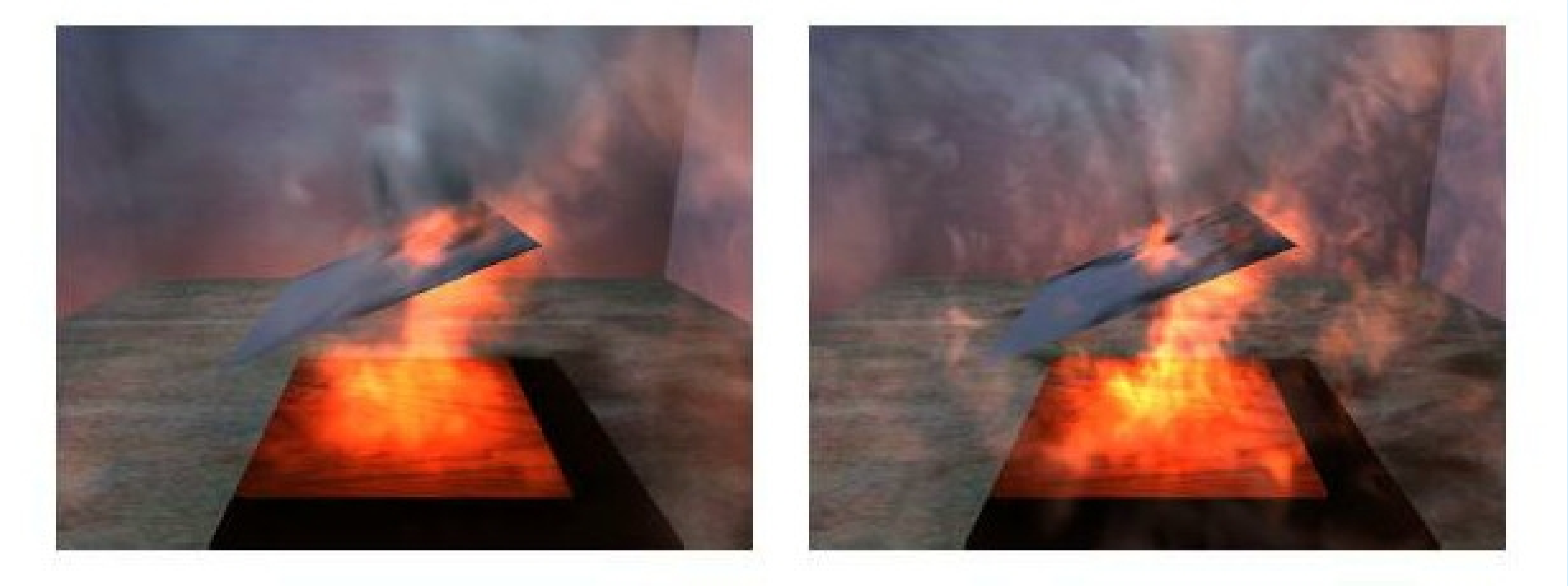
Forces can also be applied to simulate the effect of temperature gradient.

Velocity Fields

More spectacular effects, such as vortices, can be incorporated using velocity fields.

These can be computed using the Navier-Stokes equation from fluid mechanics which is a differential equation connecting velocity with pressure, viscosity and forces at each point in a fluid in motion.

Flames with radiosity and blob shadows



Engell-Nielsen and Madsen

University of Copenhagen

(http://www.it-c.dk/~beyond/Animations/index.html)