Interactive Computer Graphics

Lecture 16: Fire

Amorphous Objects

Amorphous objects are still a major challenge in computer graphics.

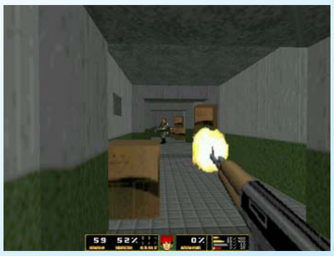
- Fire,
- Smoke
- Water
- Clouds
- &c.

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

Polygons

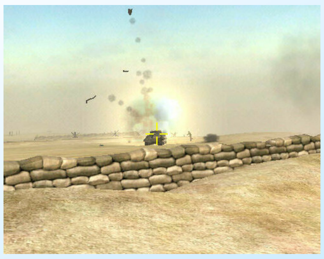
Texture mapping polygons is fast and acceptable for short lived effects.

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 having temperature pressure and density.

The visual appearance and shape changes (due to diffusion) are functions of these.

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

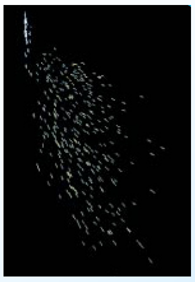
Particle Creation

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: $\mathbf{f} = m\,\mathbf{a}$ (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:

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

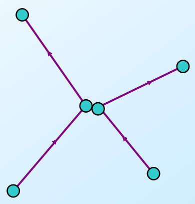
s is a scalar constant called damping or friction

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)

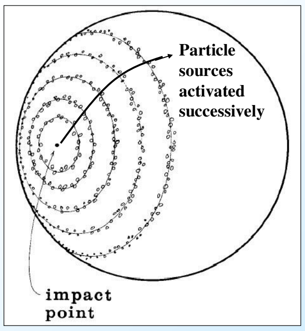
The Wrath of Khan - Storyboard

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.

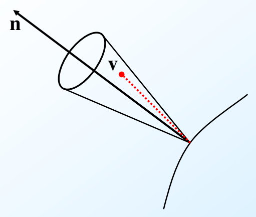
The Wrath of Khan - overview



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

In total around 750,000 particles

The Wrath of Khan - Particle Initialisation

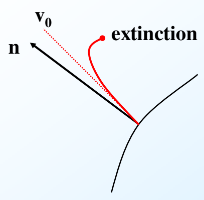


Velocity magnitude distributed normally

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

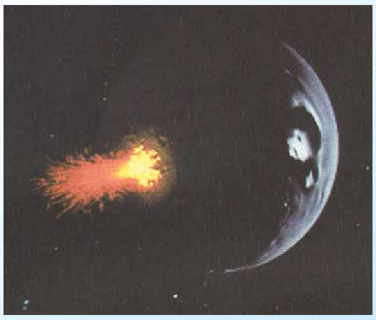
The Wrath of Khan- Rendering

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

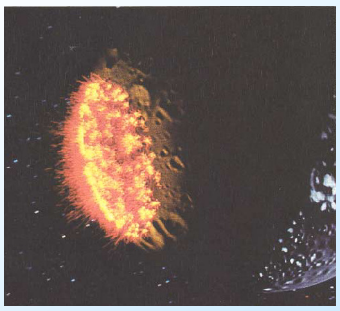
Line segment for each particle projected and drawn over the planet image, motion blur applied

Colour time dependent, yellow to red

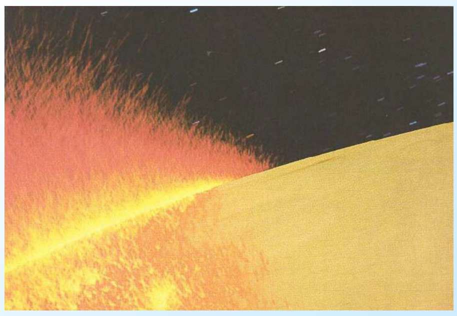
How did it look? Good Explosion!



Effective flame spread



Close up it looks like the edge of a carpet!

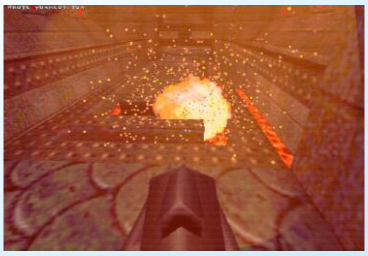


Particles in Real Time - Quake

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.

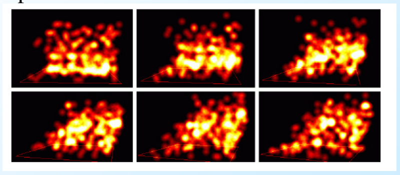
Straight line segments are not a visual characteristic of incandescent gases

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

Bitmap Splatting

Render the particles as splats rather than lines.

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



Laur and Hanrahan 1991

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.

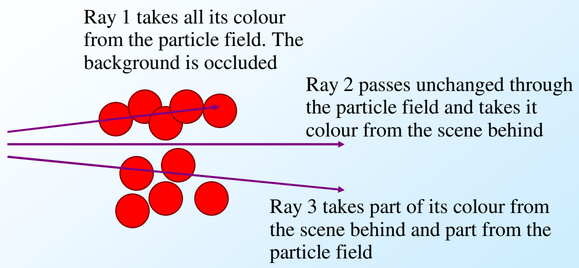
Ray Tracing Blobs is volume rendering

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

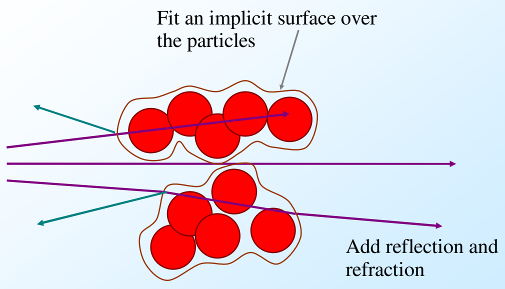
It may travel through the whole particle field and take up a proportion of the scene behind

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

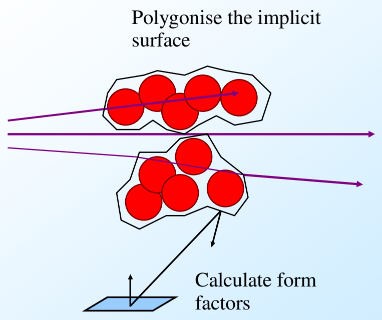
Ray tracing particle fields


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

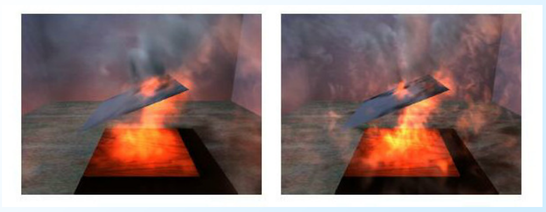
Further possibilities - Implicit Surfaces


Fit an implicit surface over the particles
Add reflection and refraction

Further possibilities - Radiosity



Flames with radiosity and blob shadows



Engell-Nielsen and Madsen

University of Copenhagen

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

Tutorial 8: Radiosity

1. *Form factors*:

In a radiosity scene the patches are triangular. Two patches are defined as follows:

Patch	Points		
i	(10, 12, 8)	(10, 13, 8)	(10, 11, 9)
j	(5, 6, 12)	(5, 6, 13)	(8, 6, 12)

Assuming that these two patches are visible from each other calculate the two form factors F_{ij} and F_{ji}. (Use the centroid of each triangle, $\frac{1}{3}(\mathbf{P}_1 + \mathbf{P}_2 + \mathbf{P}_3)$, to estimate the distance)

2. *The Hemicube*:

A hemicube is defined by the top plane $z = 1$ and side planes $x = 1$, $y = 1$, $x = -1$, $y = -1$. Assume that the hemicube pixels all have area ΔA. Derive a formula for the delta form factors of the pixels on the side planes in terms of the distance r of their centre to the origin (Hint: evaluate $\cos\phi$ using a dot product).

3. *The Hemisphere*:

A form factor is to be computed by a ray casting algorithm. Rays are to be cast from the centre of the patch with the aim of finding the nearest patch visible by that ray.

The rays are defined by the spherical polar coordinates (θ, ϕ) and are to be spaced at equal intervals of 1 degree ($\pi/180$ radians) in the range $0 < \theta < 180^\circ$, $0 < \phi < 180^\circ$.

If the rays are thought to pass through a unit hemisphere which is divided into approximately square patches around each ray, derive a formula for the delta form factor for the ray.

4. *r-refinement*:

An r-refinement scheme for a triangular mesh moves each point in the direction of greatest change. Let (**P**, B) represent the pairing of a point **P** with a radiosity value of B. Let its neighbours be represented by the pairs ($\mathbf{P}_1$, B_1), ($\mathbf{P}_2$, B_2), ($\mathbf{P}_3$, B_3) and ($\mathbf{P}_4$, B_4).

One suggestion for refining the mesh is to find the direction of greatest change by adding up the vectors

$$|B_1 - B|(\mathbf{P}_1 - \mathbf{P}) \quad |B_2 - B|(\mathbf{P}_2 - \mathbf{P}) \quad |B_3 - B|(\mathbf{P}_3 - \mathbf{P}) \quad |B_4 - B|(\mathbf{P}_4 - \mathbf{P})$$

Suggest a way in which the distance each point should be moved. Given the following points:

Point	Coordinate	Radiosity
P	(20, 6, 0)	30
$\mathbf{P}_1$	(10, 10, 0)	50
$\mathbf{P}_2$	(10, 30, 0)	20
$\mathbf{P}_3$	(15, 2, 0)	30
$\mathbf{P}_4$	(10, 0, 0)	50

use your method to determine how to move point **P**