Depicting Fire and Other Gaseous Phenomena Using Diffusion Processes

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Modelling Gaseous Phenomena

Solid Textures (Perlin, Peachy 85; Ebert, Sakas 90)

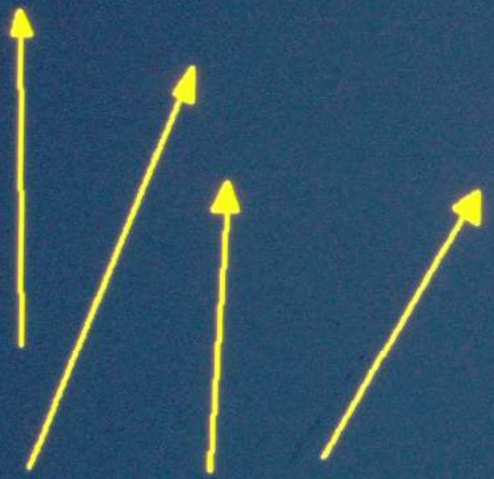
- Control Difficult
- Grid Based

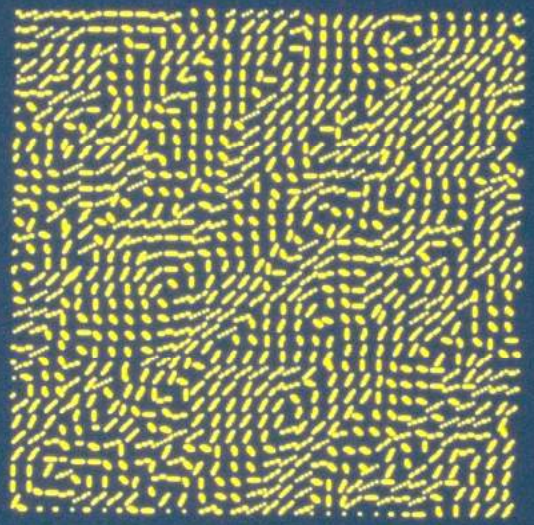
Motion Fields (Sims90, Stam+Fiume 93, Chiba+ 94)

- Easier to Control
- Particle Based

Methodology

- Multi-scale motion fields → control



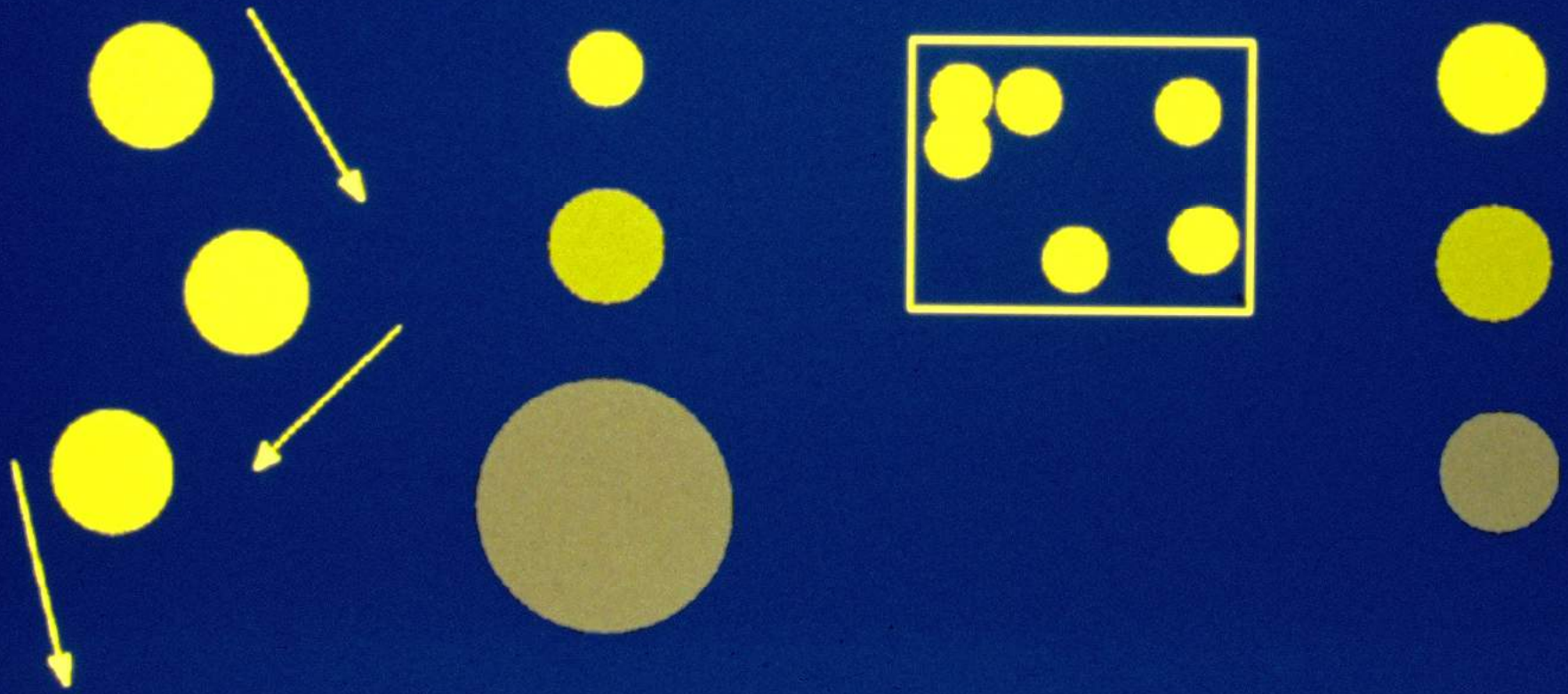


- Diffusion of density and temperature → spread
- Global illumination on blobs → rendering

Blob Solution of Diffusion Processes

Given $\mathbf{u}$, solve for θ: (θ=density or temperature)

$$\frac{\partial \theta}{\partial t} = \underbrace{-\mathbf{u}\nabla\theta}_{\text{advection}} + \underbrace{\kappa_\theta \nabla^2 \theta}_{\text{diffusion}} + \underbrace{S_\theta}_{\text{creation}} - \underbrace{L_\theta}_{\text{dissipation}}$$

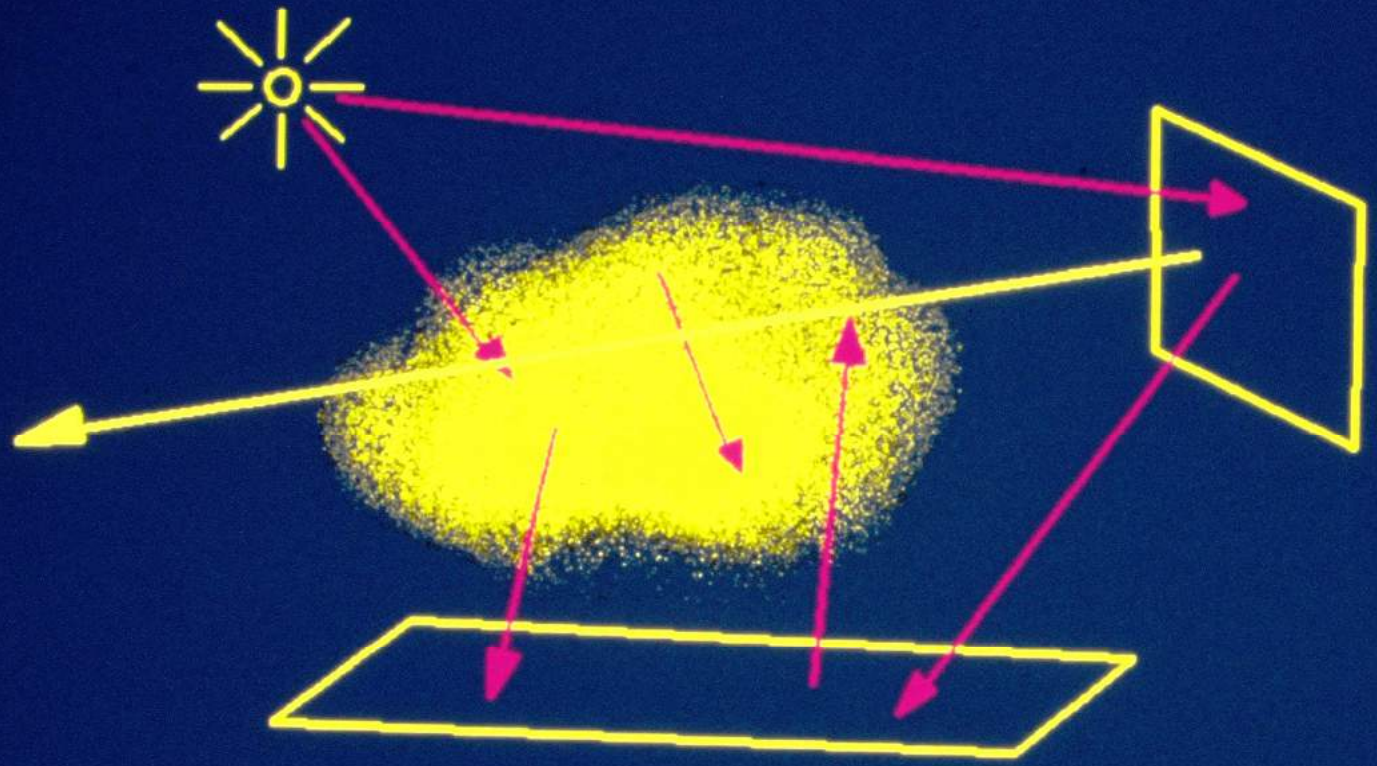


Simple Fire Spread Model

- flame heats up fuel
- heat loss due to radiation
- temperature diffuses

related work: Chiba et al 94, Perry and Picard 94

Global Illumination

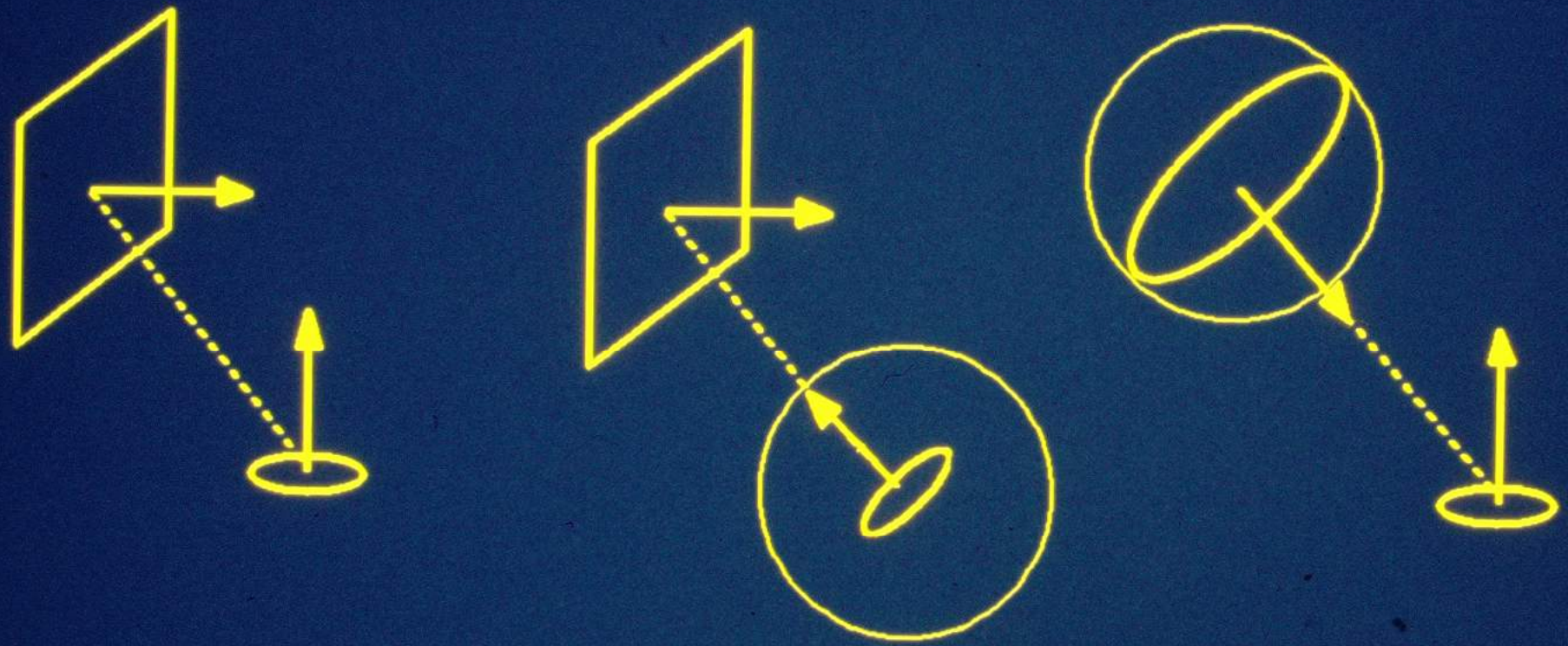


Two passes

- Compute indirect illumination
- Ray trace from the eye

Form Factors

pecial case of a patch to patch form factor:



tch → patch patch → blob blob → patch

- Speedup: shoot from clusters of blobs

Representation of Indirect Intensity

Assumptions:

- Lambertian surfaces
- Simple phase function: $p(\mathbf{s} \cdot \mathbf{s}') = 1 + \bar{\mu}\, \mathbf{s} \cdot \mathbf{s}'$

$\longrightarrow$ on each blob the indirect intensity is:

$$I_k(\mathbf{s}) = I_k^0 + \mathbf{I}_k^1 \cdot \mathbf{s}, \quad k = 1, \cdots, N$$

First Pass: Shooting Algorithm

Shoot from light sources to blobs/patches
do
    Shoot from patches to blobs/patches
    Multiple Scattering amongst blobs
    Shoot from the blobs to the patches
until *converged*

Multiple Scattering

Approximate by a diffusion process

$$\nabla \kappa_d \nabla I_d - \alpha_d I_d + S_d = 0$$

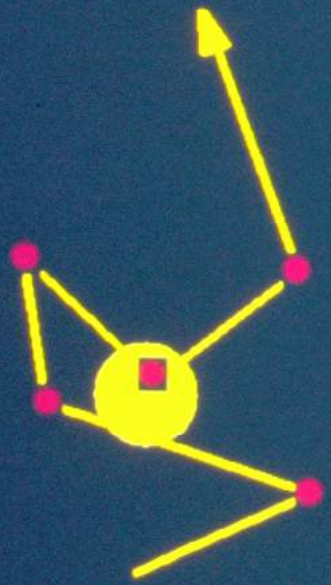
- $\kappa_d \propto$ "optical thickness"
- $\alpha_d \propto$ absorption
- $S_d \propto$ first scatter

Valid when there are many interactions

"Finite element" solution on blob representation

Second Pass: Ray Warping

tensity of each blob has to be integrated along a ray



Results

- Smoke stack
- Clouds
- Fire spread
- Smoke Emission
- Various animations

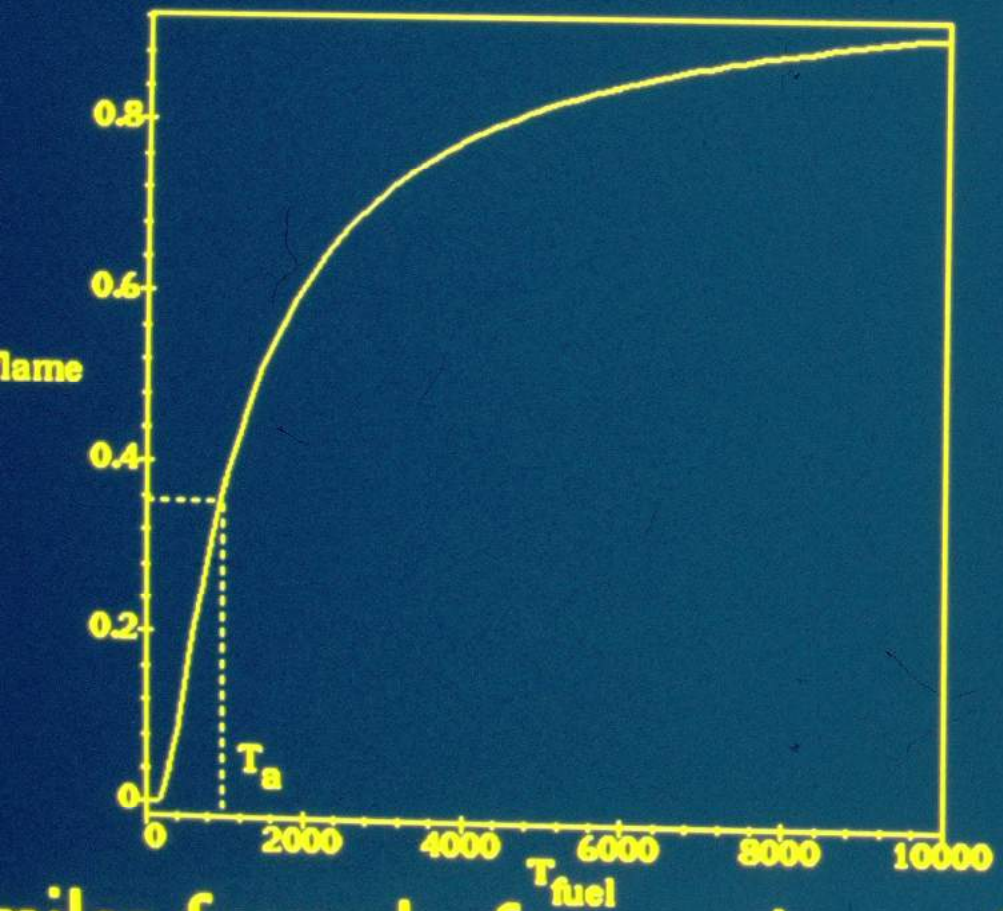
Observations and Future Work

- Improve warping for animation of very wispy gases
- Use more accurate physical models
- Three-dimensional fuels
- Automatic destruction of objects
- Explosions

Simple Fire Spread Model

se Arrhenius formula for flame production:

$$S_{\rho,\text{flame}} = L_{\rho,\text{fuel}} = \nu_a \exp\left(-T_a/T_{\text{fuel}}\right) \rho_{\text{fuel}}$$



milar formula for smoke emission

Blob Warping

Spherical shape of blobs "unnatural" in general

Our solution: backtrace blobs through wind field