Turbulent Wind Fields For Gaseous Phenomena

Jos Stam
Eugene Fiume

Department of Computer Science
University of Toronto
Toronto, Canada

Various Gaseous Phenomena

- Steam from coffee cup
- Cigarette smoke
- Clouds
- Human head (?)

Previous Work In Animating Gases

Animate Gas Directly

- Solid Textures (Ebert 90)
- Spectral Synthesis (Sakas 92)

⇒ Expensive & Control Difficult

Use Wind Fields

- Smooth Wind Fields (Sims 90)
- Turbulent Wind Fields (Shinya & Fournier 92)

⇒ Physics-Based

A New Model

Three interlocking models:

- Wind field model
- Interaction of gas with wind
- Rendering of the gas

Features of the implementation:

- Interactive modelling of wind field and gas motion
- Efficient and realistic rendering

Two-Scale Wind Field Model

$$\mathbf{u} = \mathbf{u}_{smooth} + \mathbf{u}_{turbulent}$$

- Smooth Field: "sketch" of motion
- Turbulent Field: realistic detail

inverse FFT method

Convolution of an uncorrelated field $\mathbf{W} = (W_1, W_2, W_3)$ in frequency domain:

$$
\begin{aligned}
U_1 &= H_{11} W_1 \\
U_2 &= H_{12} W_1 + H_{22} W_2 \\
U_3 &= H_{13} W_1 + H_{23} W_2 + H_{33} W_3
\end{aligned}
$$

Space-time field is then obtained by

$$\mathbf{u}(\mathbf{x}, t) = \text{inverseFFT}\{\mathbf{U}(\mathbf{k}, \omega)\}$$

$\mathbf{k}$ = spatial frequency

ω = temporal frequency

Animation of Gas

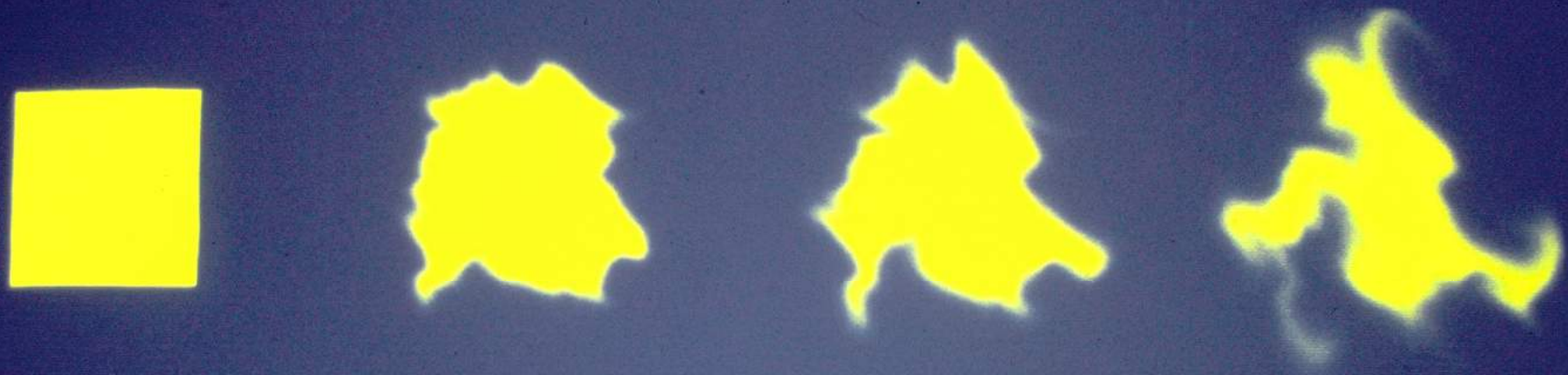
Model the gas as a density distribution $\rho(\mathbf{x}, t)$ of mass.

Evolution given by an advection-diffusion equation:

$$\frac{\partial \rho}{\partial t} = \underbrace{-\mathbf{u}\nabla\rho}_{\text{advection}} + \underbrace{\kappa\nabla^2\rho}_{\text{diffusion}} - \underbrace{\alpha\rho}_{\text{dissipation}}$$

Equation is linear in ρ

Solve Using Finite Differences



Disadvantages:

- 3D grid is memory intensive
- computationally expensive
- no interactive modelling

Model Gas as a Fuzzy Blobby

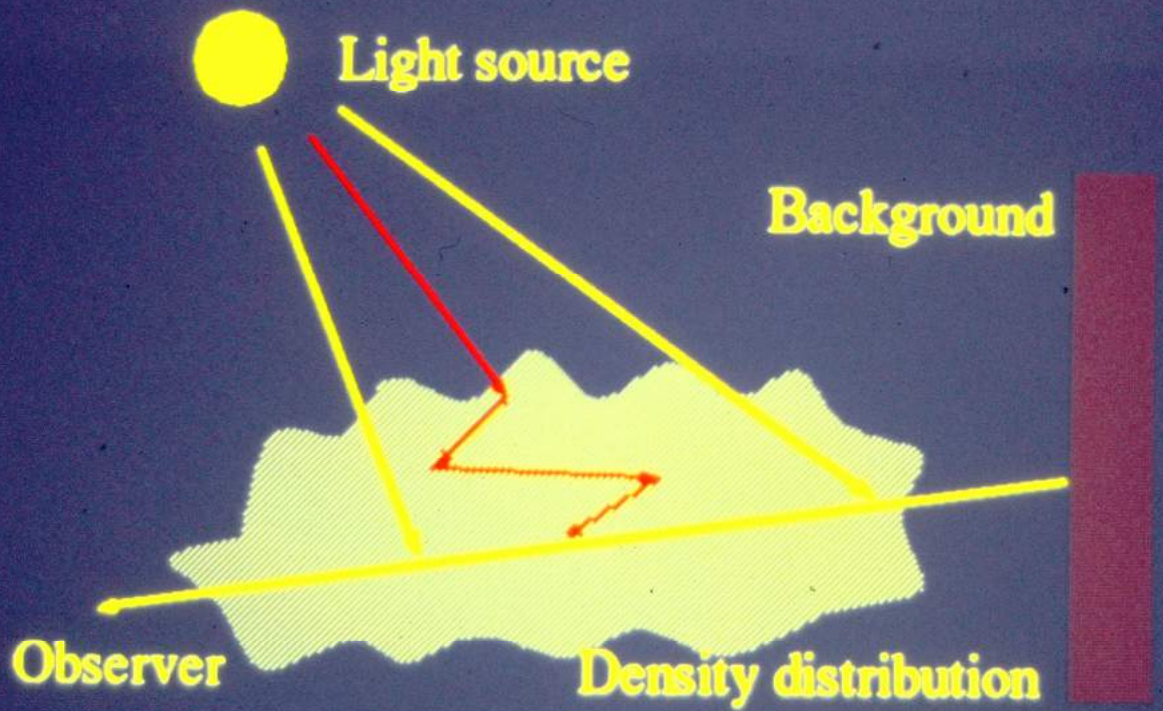
Effect on each blob:

Advection: centres move along wind field

Diffusion: size expands

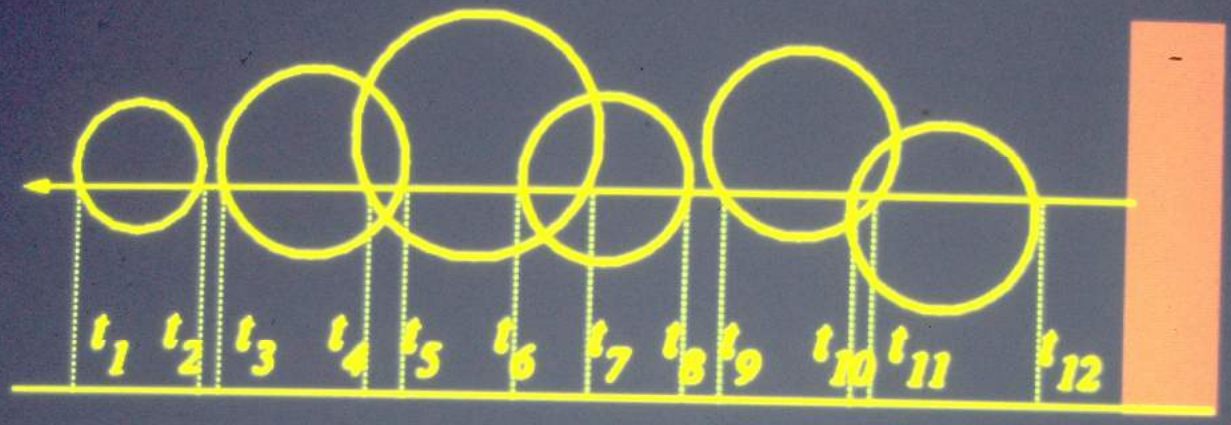
Dissipation: mass decays

Rendering of Gas



- Ignore multiple-scattering.
- Can be efficiently implemented in a ray-tracer.

Render from Front to Back



$\tau_{total} = 1$

$I_{gas} = 0$

for $i = 1$ to $N - 1$ do

$I_{gas} = I_{gas} + \tau_{total}(1 - \tau_i)I_i$

$\tau_{total} = \tau_{total}\ \tau_i$

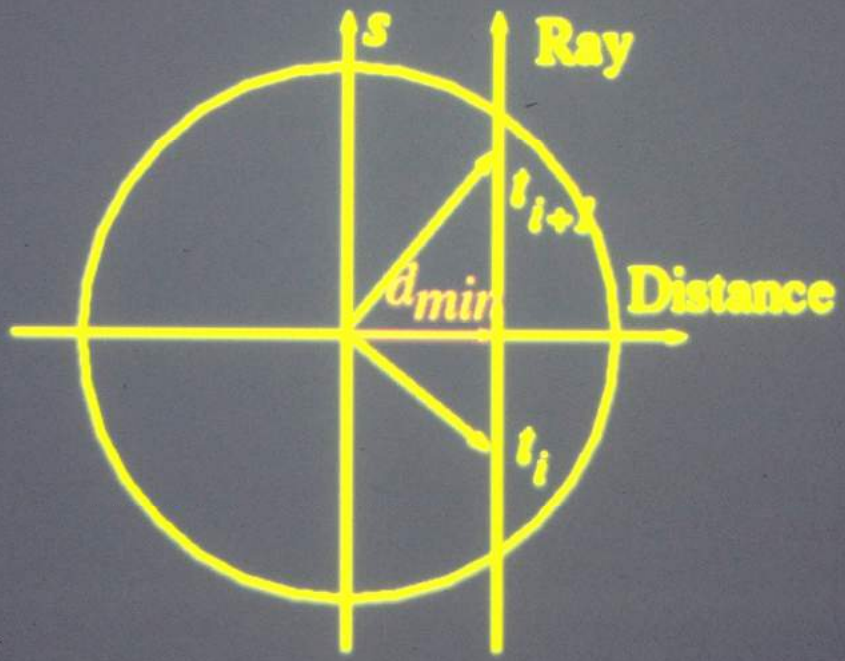
end for

$I_{total} = I_{gas} + \tau_{total}\ I_{background}$

Efficient Computation of τ_i

$$\tau_i = T(d_{min}, t_{i+1}) - T(d_{min}, t_i)$$

$$T(d,t) = \exp\left(-\int_0^t \rho(R(s))\, ds\right)$$



Use table lookup.

Results

- Slice of a wind field
- Interactive wind field modelling
- Interaction with objects
- Three coloured trails of smoke
- Coffee steam
- Cigarette smoke
- Turbulent morphing

Future Work

- More general turbulence
- Interaction between scales
- Multiple-scattering
- Improve performance of rendering
- Other gaseous phenomena
- Use wind fields to animate other phenomena