Physically based animation

- General idea
  - take physical models, make assumptions, solve
  - render solution
- Influential areas
  - we’ve seen
    - particles,
    - collision+ballistic
  - Others
    - fluids (includes gasses)

Example: Suspended particle explosion

- There is hot gas, moving under forces generated by
  - burning
  - momentum
  - changes in pressure
  - viscosity
  - etc.
- In the gas, there are particles that
  - move
  - heat and cool
- Render by rendering the particles

Feldman, O'Brien, Arikan, 03

Incompressible, inviscid moving fluids

- Important
  - compressible, viscous fluids are hard to model
  - compressible flow doesn't happen at low mach numbers
  - compression is important in explosions, but very hard to model
    - and most undesirable in hollywood style explosions
  - "dry water"

Dry water

- Euler equations
  - Mass is conserved
  - Change of momentum is due to
    - change of pressure
    - external forces

Solving dry water

- Set up a grid
  - values of u, P at grid vertices
- Get intermediate velocity field
  - by taking a small time step, ignoring pressure effects
  - we will choose a pressure field to correct this to be an incompressible flow
- Correct the intermediate velocity field

Modified dry water

- For an explosion, we must have some fluid expansion
  - at points of detonation
  - we do not want to allow the fluid to expand everywhere,
    - or couple this to the fluid’s dynamics
    - pressure waves

- So the pressure update step changes

Particles in the fluid

- Move
- Heat

Particle fluid interactions

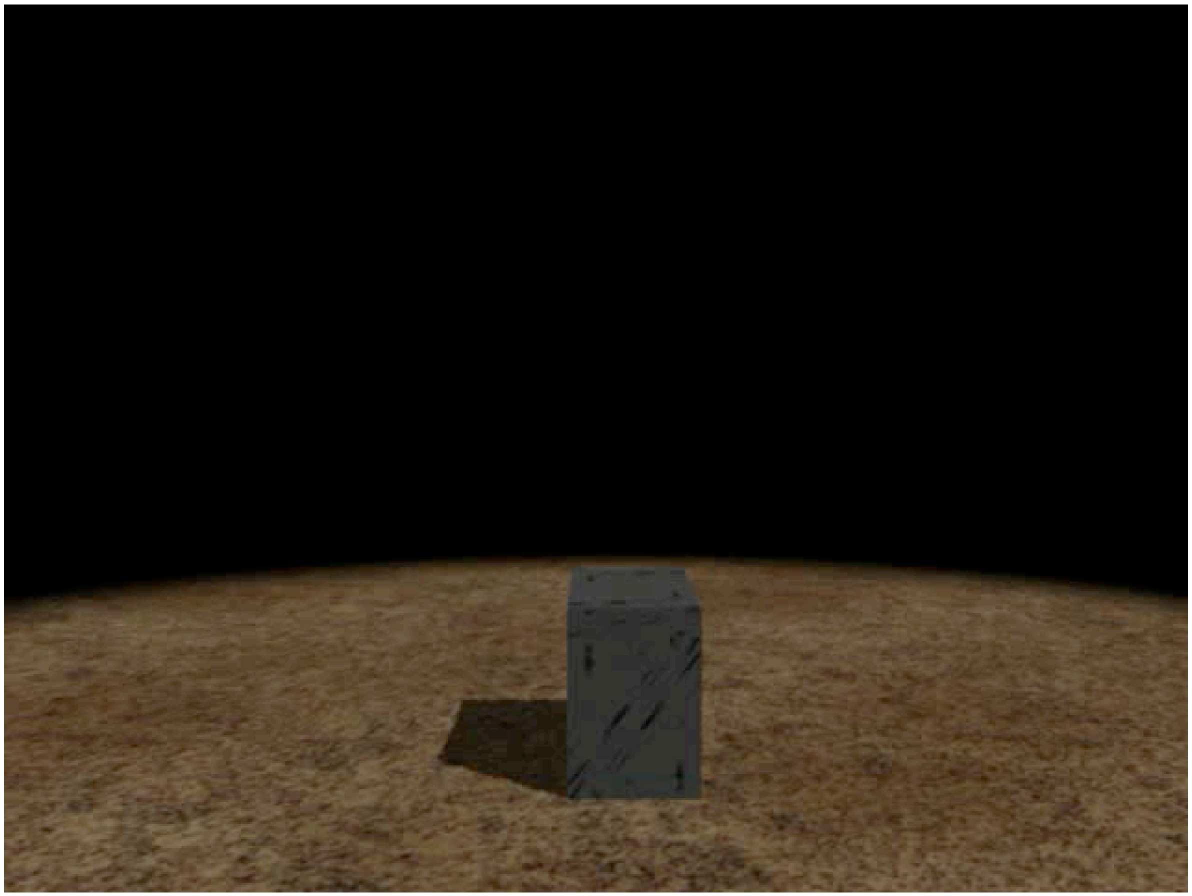
- Drag on particle
  - force in opposite direction applied to fluid
  - low mass - no drag
- Thermal exchange
  - heat transfer to a particle from fluid
  - transfer goes both ways
  - T - fluid temperature field

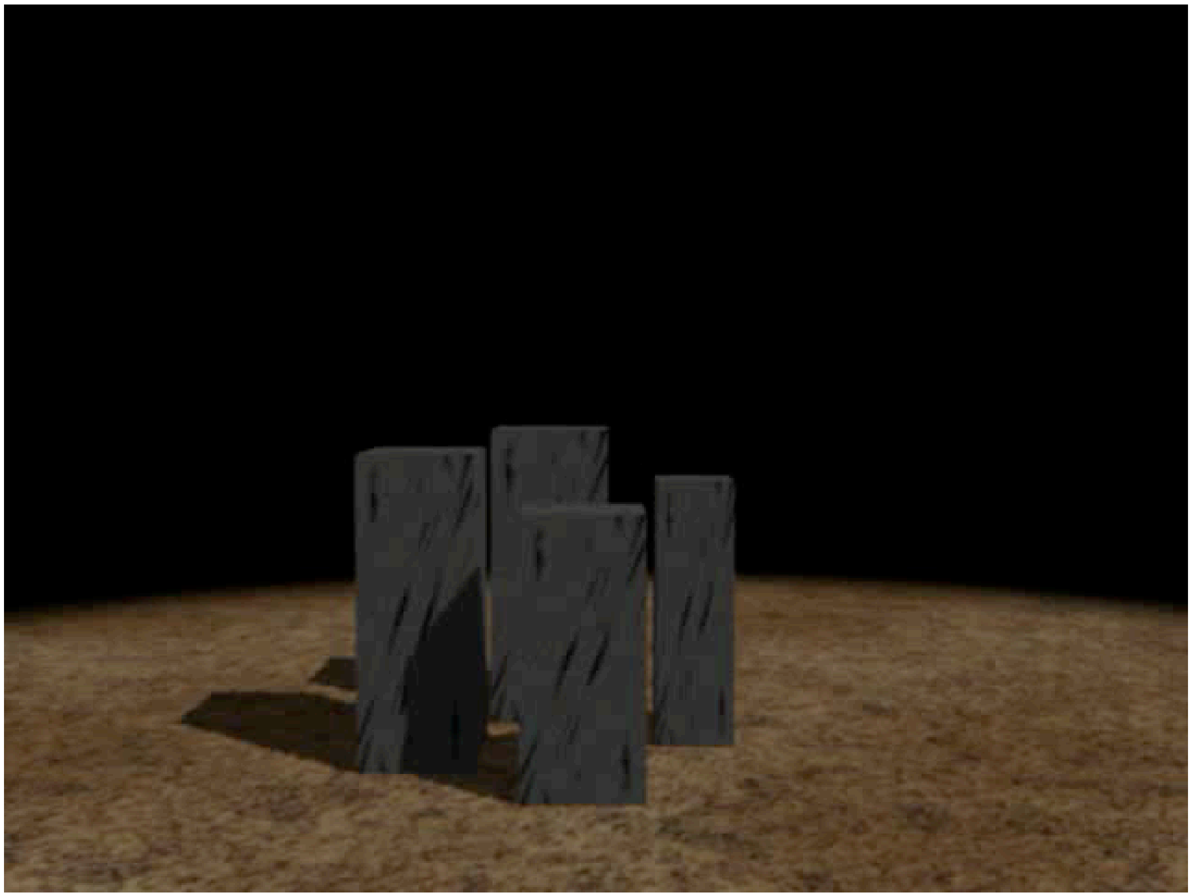
Particle behaviour

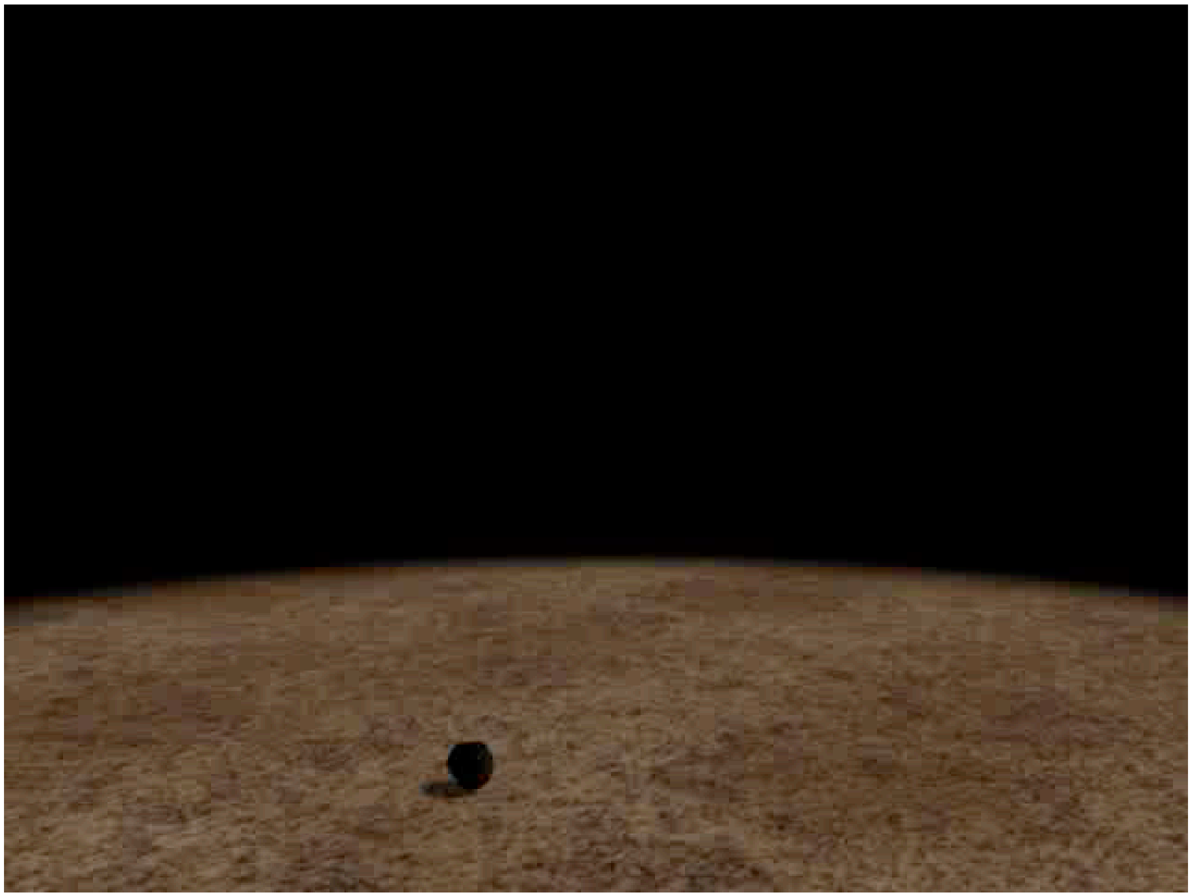
- Particles burn
  - Simplified combustion
    - combustion is independent of oxygen
    - independent of temperature
    - products do not depend on temperature
- Model
  - Particle ignites when its temperature exceeds a fixed threshold
  - fixed amount of fuel
  - dies when its mass is zero
- Products
  - Heat
  - Gas

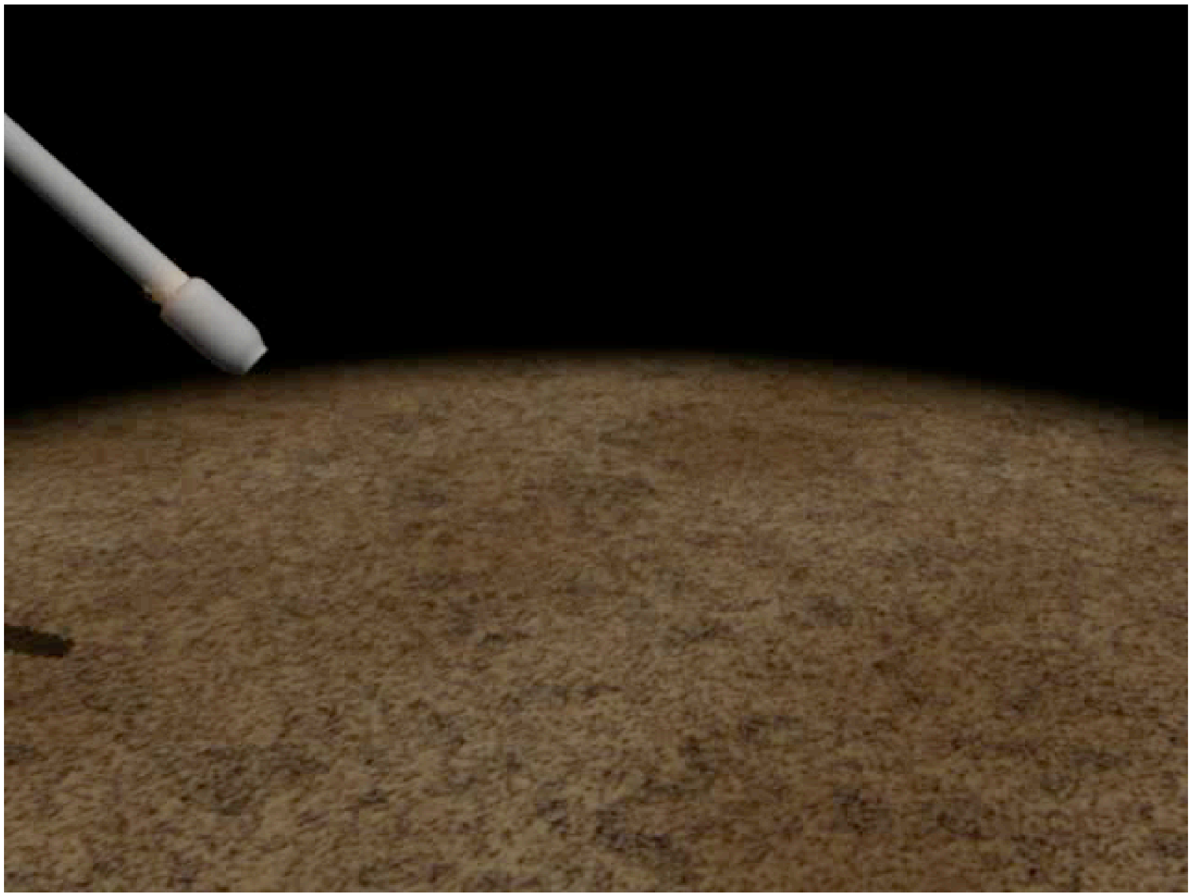
Products of combustion

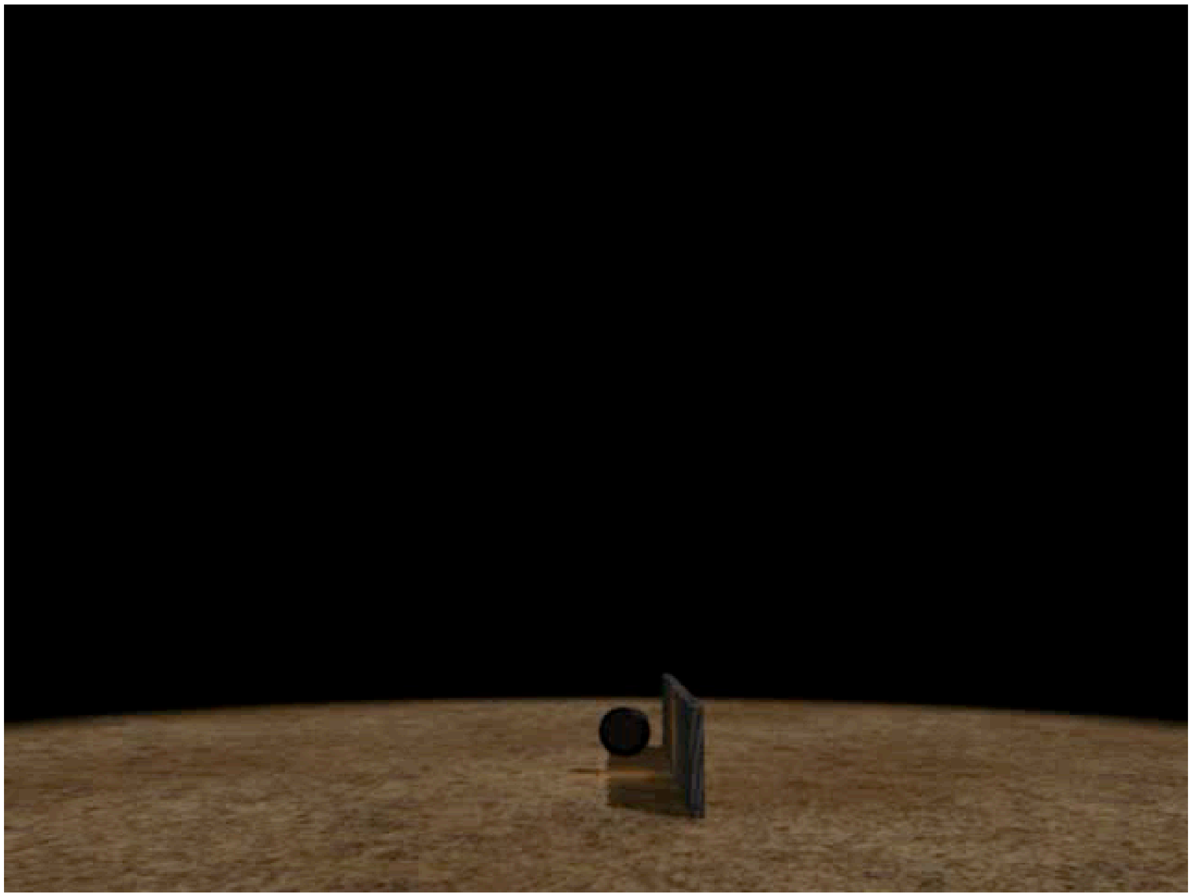
- Heat
- Gas
- Soot
  - this builds up to a threshold - then a soot particle is released.

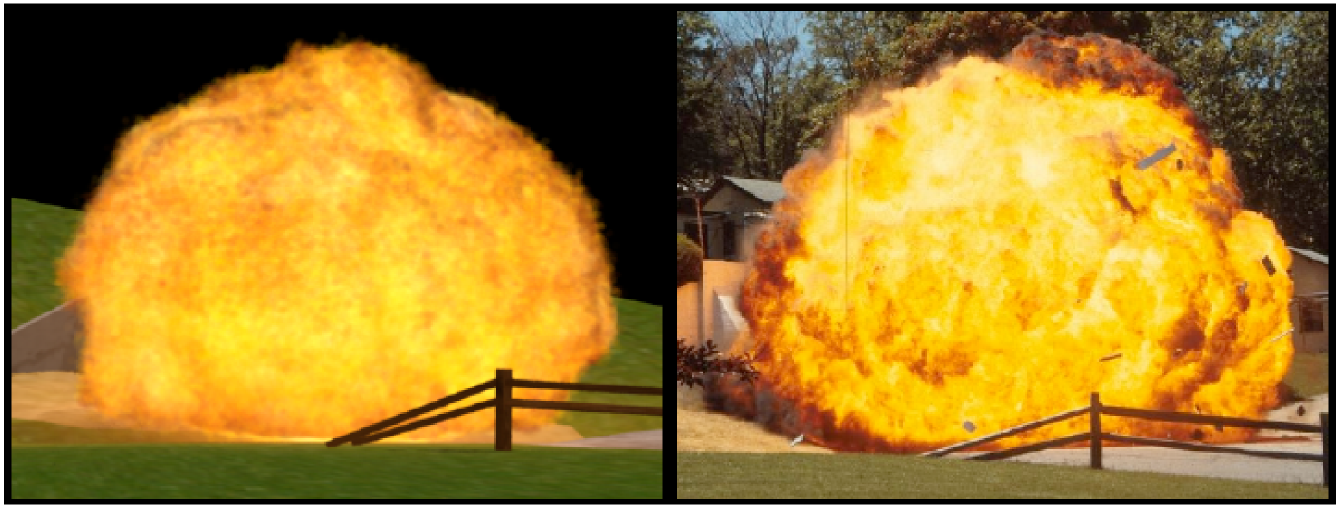


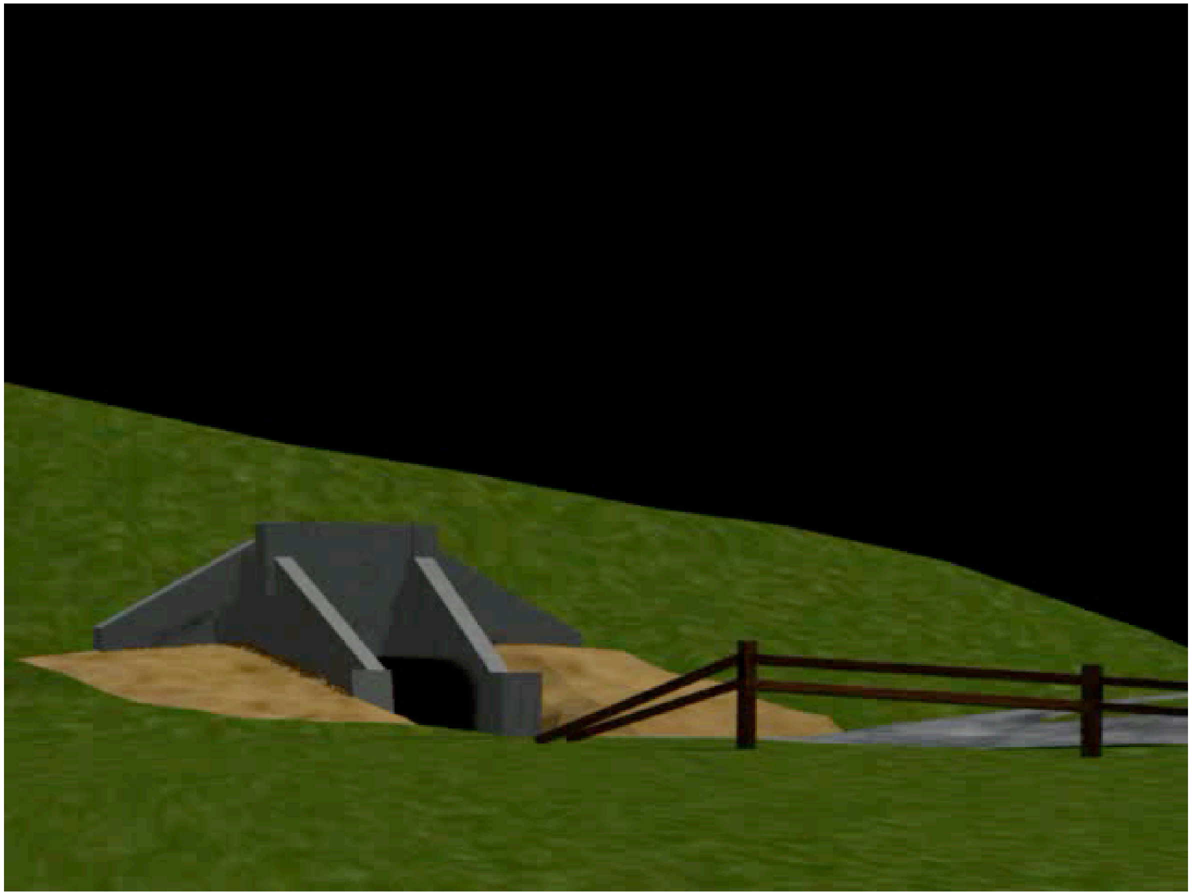


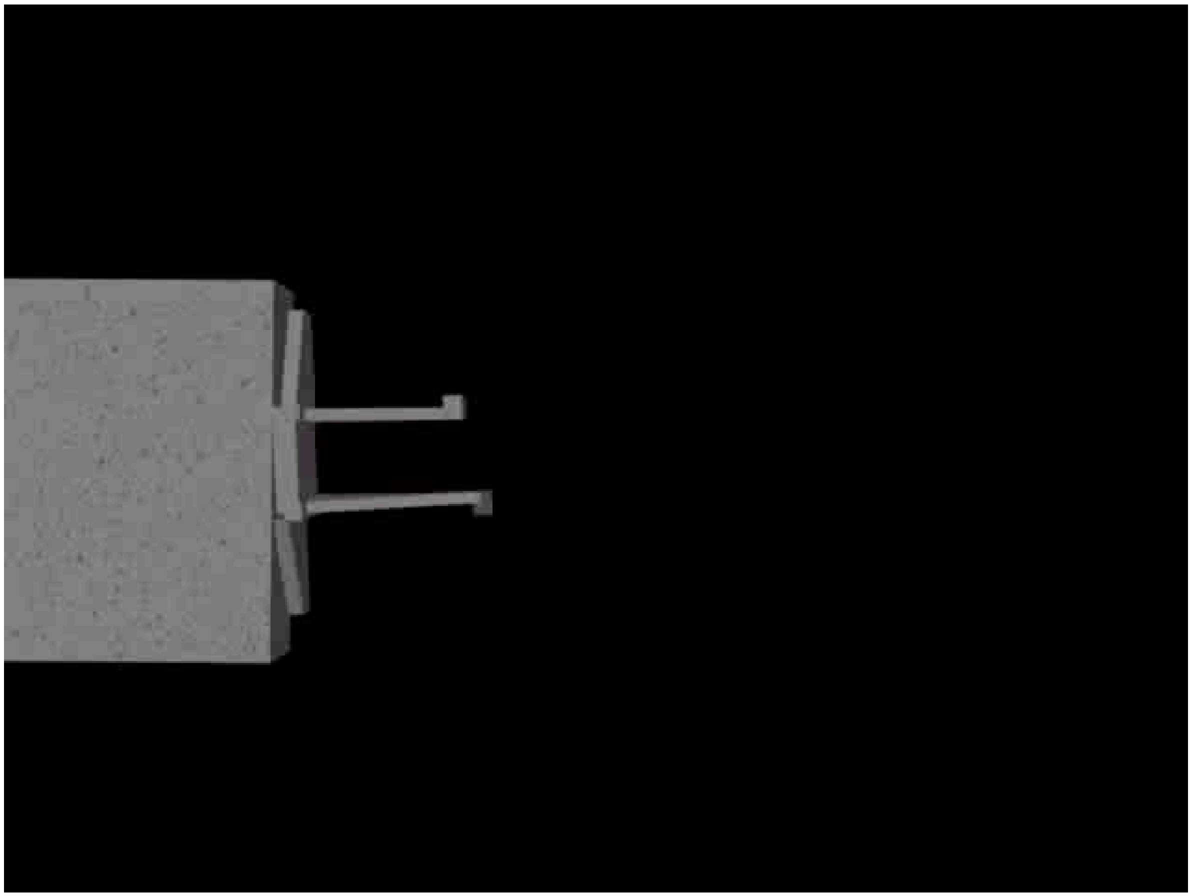












Advection

Further phenomena

- Smoke
  - simulate the fluid flow
  - smoke is distributed (rather than particles)
  - Temperature and density are constant at an element
    - i.e. are advected
  - Buoyancy
    - heavy smoke sinks, hot gas rises

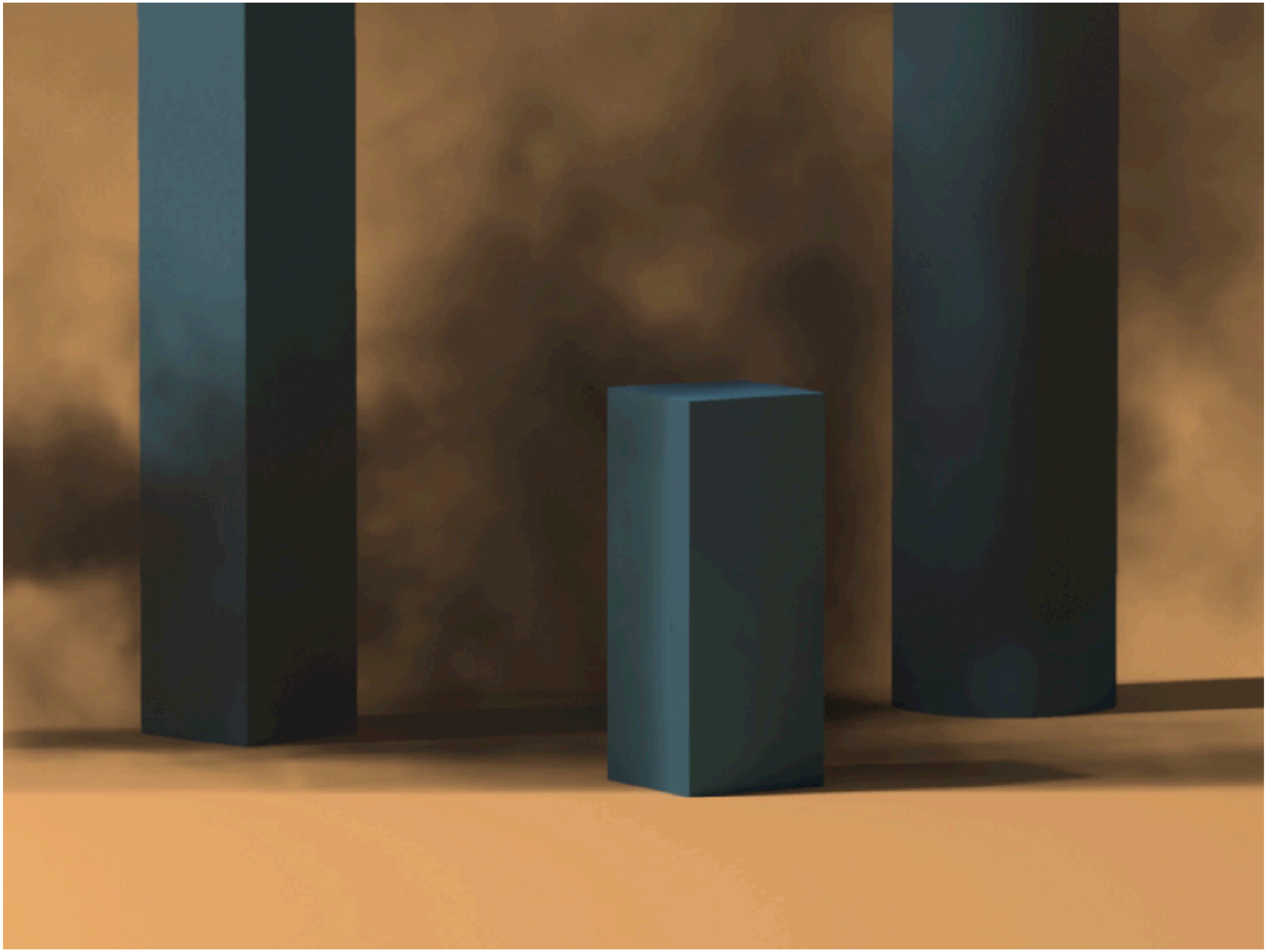
Fedkiw, Stam, Jensen 01

Vortices and vorticity confinement

- Smoke tends to produce vortices
  - hard to get fine vortices with a coarse grid
  - vortices tend to die out too fast with simple integrators
    - this is called damping
  - strategy
    - estimate where vortices are being suppressed
    - insert a “paddle wheel” force

Rendering Smoke

- Phenomena
  - in/out scattering
  - extinction
- Strategy
  - photon map
  - march along rays



Examinable material

- Rendering
  - ray tracing in all its forms
  - sampling and aliasing
  - shading models
  - including general radiometry
  - diffuse interreflections and finite element methods
  - random integration
    - for area light sources
    - for final gathering
    - for path tracing
  - photon maps
  - texture synthesis
  - procedural shading
  - procedural texturing

Examinable material

- Curves and surfaces
  - Bezier, de Casteljau
  - B-splines, de Boor
  - tensor products
  - subdivision
- Animation
  - particle systems and Forward Euler
  - ballistic motion and collisions
    - ideas, rather than exact formulation of dynamics
  - collision
  - Human motion
    - motion graphs
  - incompressible fluids (without viscosity)