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

\[
\nabla u = \phi
\]

\[
\nabla^2 P = \frac{1}{\delta t} \left( \nabla \cdot u^* - \phi \right)
\]
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

\[
dH/dt = \alpha h r^2 (T - Y)
\]
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)