animation
- big topic, we will do quick non technical survey
- field is still rapidly evolving

keyframing
- we already saw this topic
- this is the bread and butter of CG animation

Skinning
- see skinning notes
- demo d3d.palette

Simulation
- physics uses equations to describe physical processes.
- we can try to simulate these processes computationally.
- techniques: physics and computational mathematics
- some methods are slow and only work for offline animation.
- some methods can be made real-time
- hard to control the output

Particle systems
- simplest version of physics
- a large bunch of non-interacting particles
- ordinary differential equation (ODE) for the time evolution of a point
  \[ f = ma = m\dot{v} = m\ddot{x} \]  
  
- force might be gravity or wind
- can model flowing fall of water particles, or a stream of smoke particles in the air.
- Typically each particle is rendered as a semi-transparent little blob or surface.
- demo: gpu-particlesystems.de

ode integration
- Starting from an initial condition, we can discretize this ODE and march forward in time using so-called Euler steps
  \[ x_{t+h} = x_t + vt \cdot h \]
  \[ v_{t+h} = v_t + at \cdot h \]
  \[ a_{t+h} = f(x_{t+h}, t + h)/m \]
- steps must be small (often need many more than 30/sec).
- there is a whole literature of more sophisticated ways to solve an ODE.

Rigid Bodies
- upgrade from particles to solid hard finite objects (dice rolling on a table).
- need to deal with rotational issues
- wish to deal with interaction: collision detection
  - bounding hierarchies
  - must undo interpenetration
  - must have the object bounce - this requires hacked physics since real objects slightly deform and undeform.
- must deal with objects resting on objects and not endlessly bouncing
- videos

**Cloth**
- can be modeled as a grid of particles connected by springs
- can be modeled as mesh of physical triangular elements
- need forces to avoid stretching and shearing and oscillation
- also may need to track collisions.
- demo: 9:d3.cloth, 10:cloth,
- videos

**Hair**

- Hair modeling is also often similarly dealt with as a mass-spring model.
- demo 11:hair

**Deformable Materials**

- real objects are deformable
- can be modeled as volumetric objects (mesh of 3d tetrahedra).
- videos, demo:10:deformable

**Fire and Water**

- special physical equations
- modeled with combination of surface and volumetric reps.
- videos, demo:10:perlin, smoke, 11:ocean

**Human Locomotion**

- not passive objects
- much harder than previously discussed phenomenon
- ideas are used from robotics, control, and optimization
- nowadays mocap data is relied on heavily, and possibly altered or used as part of the rocket science.
- videos