Animation

- Overall goals
- Traditional animation
- Computer-assisted animation
- Computer-generated animation
  - *Key framing*
  - *Forward kinematics*
  - *Inverse kinematics*
  - *Procedural animation*
  - *Motion capture*

Our Approach to Animation

We create motion just like movie projectors

- Display a sequence of still images in rapid succession
- Creates the illusion of continuous motion
- Typically want 30 frames/sec (fps); definitely more than 10 fps

Given some parameterized geometric model

- For every frame, we calculate the correct parameter values
- And we draw the scene in its current state

We "just" need to figure out how to specify / control these parameters

Some Overall Goals in Animation

Realistic motion

- A special case of the overall photorealism motive

Flexibility and expressiveness

- Want to support the widest possible range of animation
  - *A system that can produce only a single walking motion is boring*

Ease of control

- A model that's impossible to control does animators little good

Traditional (Manual) Animation

Every frame is created individually by a human

- That's 24 frames/sec at traditional movie speeds
  - *Roughly 130,000 frames for a 1.5 hr movie*

A general pipeline evolved to support efficiency

- Start with a ***storyboard***
  - *A set of drawings outlining the animation*
- Senior artists sketch important frames – ***Keyframes***
  - *Typically occur when motion changes*
- Lower-paid artists draw the rest of the frames – ***in-betweens***
- All line drawings are painted on ***cels***
  - *Generally composed in layers, hence the use of acetate*
  - *Background changes infrequently, so it can be reused*
- Photograph finished ***cel-stack*** onto film

Computer-Assisted Cel Animation

Cel animation has been in use a long time (e.g., at Disney)

- But we can use computers to help expedite the process
- Draw sketches with digital systems
- Use digital paint programs for coloring
- Can even try to generate the in-betweens automatically

Computer-assisted systems are now common

- Disney makes heavy use of digital drawing, painting, compositing
- 2D in-betweening is hard to get right
  - *Morphing a 2D sketch doesn't give the impression of 3D*
  - *Humans are still much better at this*

Computer-Generated Animation

This is the kind of animation in which we are most interested

- Start with some 3D model of the scene
- Vary parameters to generate desired pose for all objects
- Render scene to produce one frame
- Repeat for all 130,000 frames

So how will we control these parameters?

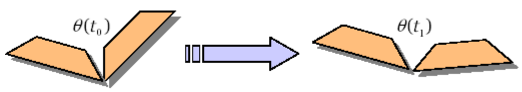
- ***Manually*** set them for each frame
- ***Key-framing***
- Generate them ***procedurally***
- ***Motion capture***
- ***Physical simulation***
- ***Behavioral animation*** (e.g., follow the fish ahead)

Key-Framing

We've associated a set of parameters with our model

- Positions, orientations, joint-angles, etc.
- We view each of these as a function of time

In key-framing, we specify parameter values at specific times and let the computer interpolate the in-between values

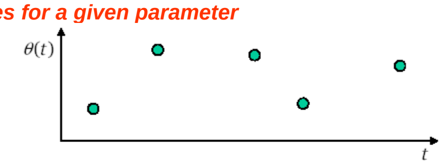


How do we accomplish this interpolation?

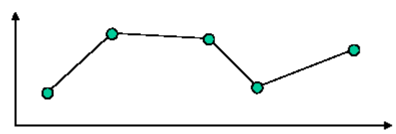
Interpolating Motion Parameters

We have specified some fixed values for a given parameter

- These are the key-frame values



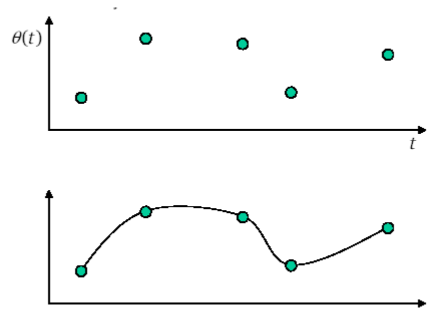
- Try linear interpolation



- But this generally produces undesirable motion
  - *During each interpolated span, we move with constant velocity and then change velocity at each key point*
  - *This is highly non-physical*
- What else might we try?

Interpolating Motion Parameters

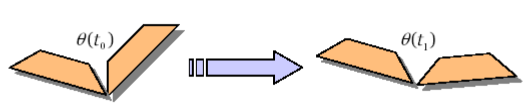
We want some higher-order interpolating curve



Creating Key-Frames

What about the specification of these parameters?

- How do I get my articulated figure into my desired pose?

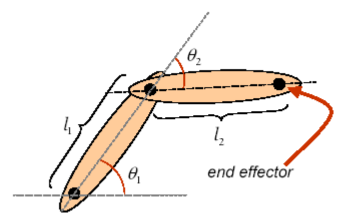


Forward Kinematics

Position of end effector is a function of the state of all joints

- More formally: $\mathbf{x} = \mathbf{f}(\theta)$
  - $\boldsymbol{x}$: *position of end effector*
  - $\boldsymbol{\theta}$: *angles of joints*
- For this simple 2D example:

$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} g(\theta_1, \theta_2) \\ h(\theta_1, \theta_2) \end{bmatrix}$$



Forward Kinematics

Given an articulated human, how do we make it wave?

- Rotate the shoulder into position
- And then the elbow
- And then the wrist
- Etc.
- And finally re-balance other parts of the body

This is tedious

- We'd much rather directly move the hand

We can use inverse kinematics

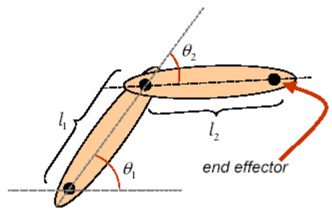
- Let the user drag the tip of the hand into place
- Determine joint angles from hand position

Inverse Kinematics

Automatically derive joint angles from end effector position

- Forward kinematics: $\mathbf{x} = \mathbf{f}(\theta)$
- Inverse kinematics: $\theta = \mathbf{f}^{-1}(\mathbf{x})$
- For this simple 2D example:

$$\begin{bmatrix} \theta_1 \\ \theta_2 \end{bmatrix} = \begin{bmatrix} g^{-1}(x,y) \\ h^{-1}(x,y) \end{bmatrix}$$



Inverse Kinematics

Real humans are much more complex than our simple example

- A human has around 200 degrees of freedom
- The mapping of parameters to effector positions is non-linear
- Inverting this function is not possible
- Must rely on numerical methods

Suppose we specify locations for end effectors

- We need to compute a model configuration to achieve pose
  - *There may be many parameter settings that work*
    - Need to pick a “best” one
      - minimize work
      - maintain balance
      - etc.
  - *Alternatively, there may not be any parameter settings that work*
    - Need to pick one that is “close enough”
- Both involve some kind of optimization algorithm

What Key-Framing Doesn't Address

Control point selection

- How often do we need to specify a key value?
- What precise key values work best?

Key value interpolation

- What interpolation method will give us what we want?

Physical constraints

- How do we avoid non-physical motion?
  - *360° head twists, infinite instantaneous accelerations, …*
- How do we know that two objects don't interpenetrate?
- How do we maintain contact at appropriate points?
  - *Feet must touch the floor when walking*

Procedural Animation

To specify procedural animation

- Write some code – the animator as programmer
  - *Input: current time*
  - *Output: parameter value*
- Usually combine lots of little procedures together
  - *One procedure for walk, one for run, one for hop, …*

There is a clear tradeoff between procedures and interaction

- If it's simple, we can probably quickly do it interactively
- If it's complex and regular, coding is probably quicker

Demo: Ken Perlin's procedural actors

- http://www.mrl.nyu.edu/~perlin/experiments/emotive-actors

Motion Capture

Currently a popular way of creating motions

- Strap a bunch of sensors on a person and record their motion
  - *Several technologies available*
    - Instrumented exoskeletons
    - Magnetic
    - Optical
- Track the location of several reference points
- Convert this to joint angles and map to articulated model
- But it can be hard to edit

Motion Capture

Optical motion capture

Computer-Generated Animation

Physical simulation

- Particle dynamics
- Spring-mass systems
- Fluids
- Rigid-body dynamics
- Articulated dynamics

Behavioral animation

Physical Simulation

We usually want realistic looking motion

- People are extremely experienced at observing body language
- They pick up on unnatural human motion instantly

Some of the methods we've discussed can achieve realism

- If our animator makes good enough key frames
- Or we write good enough procedural scripts
- Or we attach a bunch of sensors on an actor

But there's another good alternative

- Why not just ***simulate the relevant physical laws*** ?
- Then we'll know that the motion is natural
- And we'll still have decent control over it

Dynamics

Direct physical simulation (e.g., with Newton's laws of motion)

- Specify positions, masses, forces,…
- Apply relevant laws to compute accelerations, velocities, and positions as a function through time
  - *We can express the relevant laws as differential equations*

$$\mathbf{f} = m\mathbf{a} \rightarrow \frac{d^2\mathbf{x}}{dt^2} = \frac{\mathbf{f}}{m} \quad \text{or} \quad \ddot{\mathbf{x}} = \frac{\mathbf{f}}{m}$$

- And in general we must solve them numerically

Caveat

Keep in mind that we don't always want to mimic nature

- Exact replication of reality isn't always artistically interesting
- We can invent our own physical laws
  - *"Cartoon laws of physics"*
  - *In particular, phantom forces are easy to add*

We may want to mimic the motion of a golf ball

- But how do we make sure it lands in the hole for a "hole-in-one", if that is what the animator wants his golfer to do?

The Cartoon Laws of Physics

(Originally "O'Donnell's Laws of Cartoon Motion", Esquire, 6/80)
[often quoted from "IEEE Institute", 10/94; V.18 #7 p.12]

1. ***Any body suspended in space will remain in space until made aware of its situation.***
   Daffy Duck steps off a cliff, expecting further pastureland. He loiters in midair, soliloquizing flippantly, until he chances to look down. At this point, the familiar principle of 32 feet per second per second takes over.
   (Exception: This does not apply to cool characters who've never studied law.)
   (Appendum: Any species capable of flight, upon distraction of vertigo, will lose ability of flight. Conversely, any two feathers held in each hand and waved will (temporarily) give flight to any character that does so.)

2. ***Any body in motion will tend to remain in motion until solid matter intervenes suddenly.***
   Whether shot from a cannon or in hot pursuit on foot, cartoon characters are so absolute in their momentum that only a telephone pole or an outsize boulder retards their forward motion absolutely. Sir Isaac Newton called this sudden termination of motion the stooge's surcease.

3. ***Any body passing through solid matter will leave a perforation conforming to its perimeter.***
   Also called the silhouette of passage, this phenomenon is the speciality of victims of directed-pressure explosions and of reckless cowards who are so eager to escape that they exit directly through the wall of a house, leaving a cookie-cutout-perfect hole. The threat of skunks or matrimony often catalyzes this reaction.

4. ***The time required for an object to fall twenty stories is greater than or equal to the time it takes for whoever knocked it off the ledge to spiral down twenty flights to attempt to capture it unbroken.***
   Such an object is inevitably priceless, the attempt to capture it inevitably unsuccessful.

5. ***All principles of gravity are negated by fear.***
   Psychic forces are sufficient in most bodies for a shock to propel them directly away from the earth's surface. A spooky noise or an adversary's signature sound will induce motion upward, usually to the cradle of a chandelier, a treetop, or the crest of a flagpole. The feet of a character who is running or the wheels of a speeding auto need never touch the ground, especially when in flight.

6. ***As speed increases, objects can be in several places at once.***
   This is particularly true of tooth-and-claw fights, in which a character's head may be glimpsed emerging from the cloud of altercation at several places simultaneously. This effect is common as well among bodies that are spinning or being throttled.
   A `wacky' character has the option of self-replication only at manic high speeds and may ricochet off walls to achieve the velocity require.

7. ***Certain bodies can pass through solid walls painted to resemble tunnel entrances; others cannot.***
   This trompe l'oeil inconsistency has baffled generations, but at least it is known that whoever paints an entrance on a wall's surface to trick an opponent will be unable to pursue him into this theoretical space. The painter is flattened against the wall when he attempts to follow into the painting. This is ultimately a problem of art, not of science.
   (Corollary: Portable holes work.)

8. ***Any violent rearrangement of feline matter is impermanent.***
   Cartoon cats possess even more deaths than the traditional nine lives might comfortably afford. They can be decimated, spliced, splayed, accordion-pleated, spindled, or disassembled, but they cannot be destroyed. After a few moments of blinking self pity, they reinflate, elongate, snap back, or solidify.
   (Corollary 1: A cat will assume the shape of its container.)
   (Corollary 2: Cartoons cats have the uncanny ability to emit piano sounds when their teeth are transformed into piano keys after having a piano dropped on them.)

9. ***Everything falls faster than an anvil.***
   Examples too numerous to mention from the Roadrunner cartoons.

10. ***For every vengeance there is an equal and opposite revengeance.***
    This is the one law of animated cartoon motion that also applies to the physical world at large. For that reason, we need the relief of watching it happen to a duck instead.