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Notes

- Make sure you are working on assignment 0
- Textbook reference for splines:
  - Section 3.1 and Appendix B4

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Animation Principles

- Disney and co. developed certain principles (starting in the 1930's) for making good animation
  - Fluid, natural, realistic motion
  - Effective in telling the story
- Developed for traditional 2d cel animation, but equally applicable to all sorts of animation
- This course is mostly about the underlying technology for computer animation, but these are still important to have in mind

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Classic Principles

- Squash and Stretch
- Timing
- Anticipation
- Staging
- Follow-Through and Secondary Motion
- Overlapping Action and Asymmetry
- Slow In and Slow Out
- Arcs
- Exaggeration
- Appeal
- Straight-Ahead and Pose-to-Pose

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Squash and Stretch

- Rigid objects look robotic---let them deform to make the motion more natural and fluid
- Accounts for physics of deformation
  - Think tennis ball…
  - Communicates to viewer what the object is made of, how heavy it is, …
  - Usually large deformations conserve volume: if you squash one dimension, stretch in another to keep mass constant

- Also accounts for persistence of vision
  - Fast moving objects leave an elongated streak on our retinas

(squash and stretch cont'd)

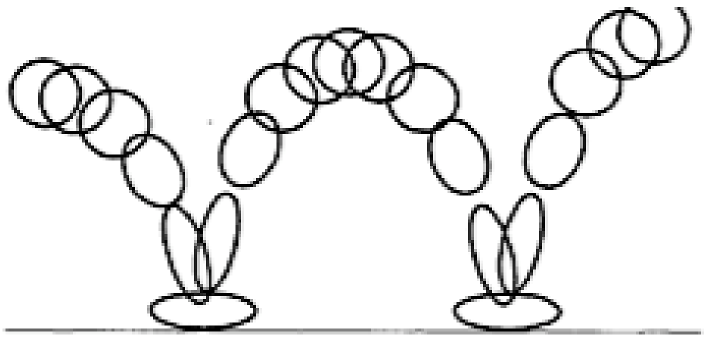

FIGURE 2. Squash & stretch in bouncing ball.

Timing

- Pay careful attention to how long an action takes -- how many frames
- How something moves --- not how it looks --- defines its weight and mood to the audience
- Also think dramatically: give the audience time to understand one event before going to the next, but don't bore them

Anticipation

- The preparation before a motion
  - E.g. crouching before jumping, pitcher winding up to throw a ball
- Often physically necessary, and indicates how much effort a character is making
- Also essential for controlling the audience's attention, to make sure they don't miss the action
  - Signals something is about to happen, and where it is going to happen

Staging

- Make the action clear
- Avoid confusing the audience by having two or more things happen at the same time
- Select a camera viewpoint, and pose the characters, so that visually you can't mistake what is going on
  - Clear enough you can tell what's happening just from the silhouettes (highest contrast)

Follow-Through and Secondary Motion

- Again, physics demands follow-through -- the inertia that's carried over after an action
  - E.g. knees bending after a jump
  - Also helps define weight, rigidity, etc.
- Secondary motion is movement that's not part of the main action, but is physically necessary to support it
  - E.g. arms swinging in jump
- Just about everything should always be in motion - "moving hold"
- Animator has to give the audience an impression of reality, or things look stilted and rigid

Overlapping Action and Asymmetry

- Overlapping action: start the next action before the current one finishes
  - Otherwise looks scripted and robotic instead of natural and fluid
- Asymmetry: natural motion is rarely exactly the same on both sides of the body, or for 2+ characters
  - People very good at spotting "twins", synchronization, etc.
  - Break up symmetries to avoid scripted or robotic feel

Slow In and Out

- Also called "easing in" and "easing out"
- More physics: objects generally smoothly accelerate and decelerate, depending on mass and forces
- Just how gradual it is helps define weight, mood, etc.
- Also helpful in emphasizing the key frames, the most important or "extreme" poses
  - Character spends more time near those poses, and less time in the transition
  - Audience gets better understanding of what's going on

Arcs

- Natural motions tend not to be in straight lines, instead should be curved arcs
  - Just doing straight-line interpolation gives robotic, weird movement
- Also part of physics
  - gravity causes parabolic trajectories
  - joints cause circular motions
  - etc.
- Keep motion smooth and interesting

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Exaggeration

- Obvious in the old Loony Tunes cartoons
- Not so obvious but necessary ingredient in photo-realistic special effects
- If you're too subtle, even if that is accurate, the audience will miss it: confusing and boring
- Think of stage make-up, movie lighting, and other "photo surrealistic" techniques
- Don't worry about being physically accurate: convey the correct psychological impression as effectively as possible

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Appeal

- Make animations that people enjoy watching
- Appealing characters aren't necessarily attractive, just well designed and rendered
  - All the principles of art still apply to each still frame
  - E.g. controlling symmetry - avoid "twins", avoid needless complexity
- Present scenes that are clear and communicate the story effectively

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Straight Ahead vs. Pose-to-Pose

- The two basic methods for animating
- Straight Ahead means making one frame after the other
  - Especially suited for rapid, unpredictable motion
- Pose-to-Pose means planning it out, making "key frames" of the most important poses, then interpolating the frames in between later
  - The typical approach for most scenes

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Extremes

- Keyframes are also called extremes, since they usually define the extreme positions of a character
  - E.g. for a jump:
    - the start
    - the lowest crouch
    - the lift-off
    - the highest part
    - the touch-down
    - the lowest follow-through
  - The frames in between ("inbetweens") introduce nothing new---watching the keyframes shows it all
  - May add additional keyframes to add some interest, better control the interpolated motion

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Computer Animation

- The task boils down to setting various animation parameters (e.g. positions, angles, sizes, …) in each frame
- Straight-ahead: set all variables in frame 0, then frame 1, frame 2, … in order
- Pose-to-pose: set the variables at keyframes, let the computer smoothly interpolate values for frames in between
- Can mix the methods:
  - Keyframe some variables (maybe at different frames), do others straight-ahead

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Layering

- Work out the big picture first
  - E.g. where the characters need to be when
- Then layer by layer add more details
  - Which way the characters face
  - Move their limbs and head
  - Move their fingers and face
  - Add small details like wrinkles in clothing, hair, …

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Splines and Motion Curves

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Motion Curves

- The most basic capability of an animation package is to let the user set animation variables in each frame
  - Not so easy --- major HCI challenges for designing an effective user interface
  - We'll ignore these issues though
- The next is to support keyframing: computer automatically interpolates in-between frames
- A motion curve is what you get when you plot an animation variable against time
  - Computer has to come up with motion curves that interpolate your keyframe values

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Splines

- Splines are the standard way to generate a smooth curve which interpolates given values
- A spline curve (sometimes just called spline) is just a piecewise-polynomial function
  - Split up the real line into intervals
  - Over each interval, pick a different polynomial
- If the polynomials are small degree (typically at most cubics) it's very fast and easy to compute with

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Knots and Control Points

- The ends of the intervals, where one polynomial ends and another one starts, are called "knots"
- A control point is a knot together with a value
- The spline is supposed to either interpolate (go through) or approximate (go near) the control points

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Hermite Splines

- Hermite splines have even richer control points: as well as a function value, a slope (derivative) is specified
  - So the Hermite spline interpolates the control values and must match the control slopes at the knots
- Particularly useful for animation---more control over slow in/out, etc.

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Smoothness

- Each polynomial in a spline is infinitely differentiable (very smooth)
- But at the junction between two polynomials, the spline isn't necessarily even continuous!
- We need to enforce constraints on the polynomials to get the degree of smoothness we want
  - Polynomial values match: continuous (C^0)
  - Slopes (first derivatives) match: C^1
  - Second derivatives match: C^2
  - Etc.

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Example: piecewise linear spline

- Restrict all polynomials to be linear
  - $f(t)=a_i(t-t_i)+b_i$ in $[t_i, t_{i+1}]$
- Enforce continuity: make each line segment interpolate the control point on either side
  - $a_i(t_i-t_i)+b_i=y_i$ and $a_i(t_{i+1}-t_i)+b_i=y_{i+1}$
- Solve to get
  - $a_i=(y_{i+1}-y_i)/(t_{i+1}-t_i)$ $b_i=y_i$
- End result: straight line segments connecting the control points
- C^0 but not C^1

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More smoothness

- To do better, we need higher degree polynomials
- For motion curves, cubic splines basically always used
- We now have three main choices:
  - Hermite splines: interpolating, up to C^1
  - Catmull-Rom: interpolating C^1
  - B-splines: approximating C^2

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Cubic Hermite Splines

- Our generic cubic in an interval $[t_i,t_{i+1}]$ is
  - $q_i(t) = a_i(t-t_i)^3+b_i(t-t_i)^2+c_i(t-t_i)+d_i$
- Make it interpolate endpoints:
  - $q_i(t_i)=y_i$ and $q_i(t_{i+1})=y_{i+1}$
- And make it match given slopes:
  - $q_i'(t_i)=s_i$ and $q_i'(t_{i+1})=s_{i+1}$
- Work it out to get

$$a_i = \frac{-2(y_{i+1}-y_i)}{(t_{i+1}-t_i)^3} + \frac{s_i+s_{i+1}}{(t_{i+1}-t_i)^2} \qquad c_i = s_i$$

$$b_i = \frac{3(y_{i+1}-y_i)}{(t_{i+1}-t_i)^2} - \frac{2s_i+s_{i+1}}{(t_{i+1}-t_i)} \qquad d_i = y_i$$

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Hermite Basis

- Rearrange the solution to get

$$y_i\left(\frac{2(t-t_i)^3}{(t_{i+1}-t_i)^3}-\frac{3(t-t_i)^2}{(t_{i+1}-t_i)^2}+1\right)+y_{i+1}\left(\frac{-2(t-t_i)^3}{(t_{i+1}-t_i)^3}+\frac{3(t-t_i)^2}{(t_{i+1}-t_i)^2}\right)$$

$$+s_i\left(\frac{(t-t_i)^3}{(t_{i+1}-t_i)^2}-\frac{2(t-t_i)^2}{(t_{i+1}-t_i)}+(t-t_i)\right)+s_{i+1}\left(\frac{(t-t_i)^3}{(t_{i+1}-t_i)^2}-\frac{(t-t_i)^2}{(t_{i+1}-t_i)}\right)$$

- That is, we're taking a linear combination of four basis functions
  - Note the functions and their slopes are either 0 or 1 at the start and end of the interval

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Breaking Hermite Splines

- Usually just specify one slope at each knot
- But a useful capability: use a different slope on each side of a knot
  - We break C^1 smoothness, but gain control
  - Can create motions that abruptly change, like collisions

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Catmull-Rom Splines

- This is really just a C^1 Hermite spline with an automatic choice of slopes
  - Use a 2nd order finite difference formula to estimate slope from values

$$s_i = \left(\frac{t_i - t_{i-1}}{t_{i+1} - t_{i-1}}\right)\frac{y_{i+1} - y_i}{t_{i+1} - t_i} + \left(\frac{t_{i+1} - t_i}{t_{i+1} - t_{i-1}}\right)\frac{y_i - y_{i-1}}{t_i - t_{i-1}}$$

  - For equally spaced knots, simplifies to

$$s_i = \frac{y_{i+1} - y_{i-1}}{t_{i+1} - t_{i-1}}$$

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Catmull-Rom Boundaries

- Need to use slightly different formulas for the boundaries
- For example, 2nd order accurate finite difference at the start of the interval:

$$s_0 = \left(\frac{t_2 - t_0}{t_2 - t_1}\right)\frac{y_1 - y_0}{t_1 - t_0} - \left(\frac{t_1 - t_0}{t_2 - t_1}\right)\frac{y_2 - y_0}{t_2 - t_0}$$

  - Symmetric formula for end of interval
- Which simplifies for equal spaced knots:

$$s_0 = 2\frac{y_1 - y_0}{\Delta t} - \frac{y_2 - y_0}{2\Delta t}$$