Computer Graphics

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Computer Animation

Principles of Traditional Animation

To create “good” animations it is essential to understand the principles of traditional animation developed for over 80 years

1. Squash and stretch
2. Timing
3. Anticipation
4. Staging
5. Follow through and overlapping action
6. Straight ahead action and pose-to-pose action
7. Slow in and out
8. Arcs
9. Exaggeration
10. Secondary action
11. Appeal

Walt Disney

Figure 1: "Walt Disney, cropped from photo of him shaking hands with Robert Taylor / World-Telegram photo by Alan Fisher."

Hayao Miyazaki

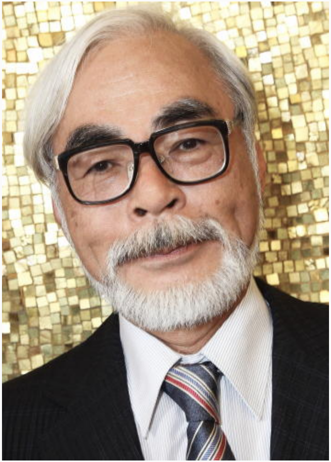


Figure 2: "A close-up photo of famous Japanese animator Hayao Miyazaki at the 2008 Venice Film Festival." by Thomas Schulz licensed under CC BY-SA 2.0

Squash and Stretch

- Emphasizes an objects rigidity during movement
- Only the most rigid objects do not change shape during movement
- All living objects do change shape during an action (tennis ball)
- Squash and stretch of an object must preserve the total volume of an object
- Squash and stretch defines the rigidity of a material, e.g. as a bouncing ball which squashes a lot on impact if made of a soft material and barely changing shape if rigid
- Can also refer to folding/unfolding, e.g. of a spring
- Can be used as an alternative to motion blur to avoid strobing effects

Timing

- The speed of an action can provide meaning and reflect the weight and size of an object
- Action fast enough to avoid divergence of attention
- Action slow enough for the audience to be able to read and understand it
- The weight of an object can be changed by manipulating the acceleration and deceleration of an object
- Heavy objects have a large resistance to changes in their motion
- Light objects have a low resistance to changes in their motion
- Timing is crucial for an action to be convincing
- Emotional state of a character defined by movement (lethargic, relaxed, excited, nervous)

Timing

Consider two drawings of a head, one of it leaning towards the left shoulder and one of it leaning towards the right shoulder. Each in between drawing can change the meaning of the action

- No inbetweens: The character got hit by an extreme force
- One inbetween: The character got hit by a hard punch
- Two inbetween: The character has a nervous tic
- Three inbetween: The character is dodging a hard punch
- Four inbetween: The character orders someone to come over
- Five inbetween: The character notes someone to come over friendly
- Six inbetween: The character follows the movement of an object
- Seven inbetween: The character is trying to get a better look at something

Anticipation

- Every action consists of three parts
  1. The preparation of the action, i.e. the **anticipation**
  2. The action itself
  3. The termination of the action
- Every action must be anatomically prepared, e.g. pull back a foot before swinging it
- The preparation is communication to the audience that some action is going to happen and greps their attention
- The preparation for an action is used to lead the attention of the audience to where the action is going to happen
- Helps that the observer does not miss fast actions

Staging

- Staging is the presentation of an idea such that it is unmistakably clear
- Leading the attention of the viewers to the correct position at the right moment
- Only one action should be seen at a time to ensure the audience does not miss it
- Contrasts help to guide the viewer
  - In a still scene movement will attract attention
  - In a busy scene something still will attract attention
- Changing the pace of actions to switch attention between multiple characters
- Staging in silhouette, i.e. allowing actions to take space on the 2D screen

Follow Through and Overlapping Action

- Actions rarely come to a sudden stop, e.g. a hand throwing a ball quntinues moving after releasing the ball
- On a complex body not all parts move simultaneous
- Some parts lead an action, e.g. eyes move before the head turns
- Lose parts will follow the motion, drag behind and continue a motion beyond the point where the leading part stopped, e.g. a scarf
- Overlapping refers to maintaining a continuous flow of actions instead of letting each action terminate before starting a new one

Straight Ahead Action and Pose-to-Pose Action

Two main approaches can be used in traditional animation

1. Straight ahead action
    - Some knowledge required how scene fits into story and what is going to happen
    - The animator starts with the first drawing and adds one after another until the scene is complete
    - Allows for a lot of creativity and creates spontaneous actions
2. Pose-to-pose action
    - The animator plans the actions
    - Creates poses and relates them in size and timing and then fills the inbetweens
    - In computer animation one refers to poses as keyframes

Slow In and Out

- Deals with the spacing in between poses (keyframes)
- Second- and third-order continuity of motion
- Grouping the inbetweens closer to the poses creates a slowing in to the next pose and slowing out of the current one
- In modern animations splines are used and the slow in and out is achieved by adjusting the tension, bias and continuity of the splines
- Avoid overshoots when using splines

Arcs

- In nature arcs are often the most economical route by which an action can be performed
- Arcs make animations smoother and less stiff
- If in a fast paced action the arcs would not be visible tricks can be used to make them visible, e.g. motion blur (light saber)
- Path and timing should be separated to avoid a flattening out of the spatial path by adjustments made in the spline

Exaggeration

- Aim is to distill the essence of any action such that the audience will understand it
- Similar to a mime artist or clown
- Exaggeration refers to any component of a scene (its design, the shape of objects, the action, the emotion, the color, or sound)
- Some parts of a scene must remain natural as a ground of comparison for the viewer
- Used to further highlight an action and draw attention

Exaggeration

Figure 3: "Publicity photo of Charlie Chaplin for Modern Times."

Secondary Action

- Secondary actions are those resulting from a first one
- They are usually kept subordinate, i.e. they do not dominate a scene
- E.g. Astronouts are pressed against their seats due to the rocket accelerating
- Facial expressions can also be secondary actions
- Secondary actions usually have a delay to the primary action

Appeal

- Appeal is for animated characters what charisma is for actors
- Refers to everything a viewer likes to see, e.g. pleasing design, simplicity, little flaws, exaggerated proportions
- Poses should be unsymmetrical to avoid wodden and stiff characters
- Characters should be recognizable and believable, e.g. the rat Rémy in Ratatouille walks upright because he does not want to spoil the taste of food he eats with his front feets

Apppeal

Figure 4: "Edgar the eggplant." by creozavr licensed under CC0 1.0

Computer animation

- Computer animation uses the same principles as traditional animation with the aim of automating much of the process
- Trade-off between direct control and manual work
- Instead of direct drawing often parameters are set, which change the appearance or pose of a character or object
- Information required by the algorithm should be as intuitive as possible
- Simplification wherever possible, e.g. a model of a car should be implemented such that the rotation of the wheels match the current speed of the car

Keyframing

- At any given moment the 3D scene is specified by a set of numbers describing all varying scene parameters
- Time points may be chosen as the animator sees fit
- Time points for different parameters may be the same but may also completely differ
- The idea of key framing is to describe these parameters not for all given moments but fix them only at certain key time points and use interpolation in between
- Interpolation methods should incorporate the traditional principles
- With respect to computer graphics some interpolation methods have advantages over others in the sense that they do not create undesired or unpredictable results (self intersection, loop forming, singularities)

Splines

- A tool used by draftsmen to draw a smooth curve was a stiff piece of metal, which could be bend into the desired shape
- In mathematics the same idea is used such that we refer to a piecewise polynomial functions as spline
- In CG splines are often used for parameter interpolation and smoothing
- Interpolated data might have any dimension
- Usually additional parameters are used to control the "tension" or "stiffness" of the curve
- Many splines exist and only a small subset with suitable properties is used in computer graphics

Catmull–Rom Spline

Consider two points $p_1, p_2 \in \mathbb{R}^2$ and control points $p_0, p_3 \in \mathbb{R}^2$. These can be used to define the centripetal $\alpha = 0.5$, standard $\alpha = 0$ or chordal $\alpha = 1$ Catmull-Rom spline from p_1 to p_2 by

$$\gamma(t) = \frac{t_2 - t}{t_2 - t_1} b_1 + \frac{t - t_1}{t_2 - t_1} b_2, \ t \in [t_1, t_2], \tag{1}$$

where

$$\begin{aligned}
b_1 &= \frac{t_2 - t}{t_2 - t_0} a_1 + \frac{t - t_0}{t_2 - t_0} a_2 \\
b_2 &= \frac{t_3 - t}{t_3 - t_1} a_2 + \frac{t - t_1}{t_3 - t_1} a_3 \\
a_1 &= \frac{t_1 - t}{t_1 - t_0} p_0 + \frac{t - t_0}{t_1 - t_0} p_1 \\
a_2 &= \frac{t_2 - t}{t_2 - t_1} p_1 + \frac{t - t_1}{t_2 - t_1} p_2 \\
a_3 &= \frac{t_3 - t}{t_3 - t_2} p_2 + \frac{t - t_2}{t_3 - t_2} p_3 \\
t_{i+1} &= \|p_{i+1} - p_i\|_2^{\frac{\alpha}{2}} + t_i,
\end{aligned}$$

$t_0 = 0$ and $i = 0, 1, 2, 3$

Catmull–Rom Spline

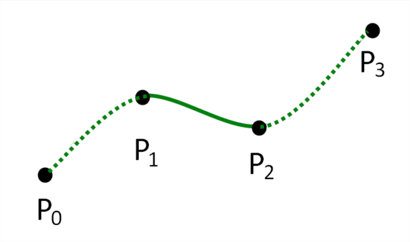


Figure 5: "Catmull-Rom Spline Interpolation with 4 Points" by Hadunsford licensed under CC BY-SA 3.0

Remarks
In CG one usually uses the centripetal Catmull-Rom spline

- No self intersection
- No loop forming
- No cusps (singularities)

Motion Control

- Motion can be described directly by a number of key positions (e.g. $\mathrm{p}_1, \mathrm{p}_2 \in \mathbb{R}^3$), which then can be used to define a spline $\mathrm{p} : [0, 1] \to \mathbb{R}^3$
- In order to ensure natural motion it is important to move along the spline at
    - a constant speed $s(t) = vt$
    - an accelerated speed $s(t) = vt + \frac{1}{2}at^2$
- To achieve this one can calculate the arc length

$$s(u) = \int_0^u \left\| \frac{\mathrm{dp}(v)}{\mathrm{d}v} \right\|_2 \mathrm{d}v \tag{2}$$

  and if possible invert it to obtain $u(s)$
- One can then control the speed/acceleration along the arc by concatenation of these mappings

$$\mathrm{p}(u(s(t))) \tag{3}$$

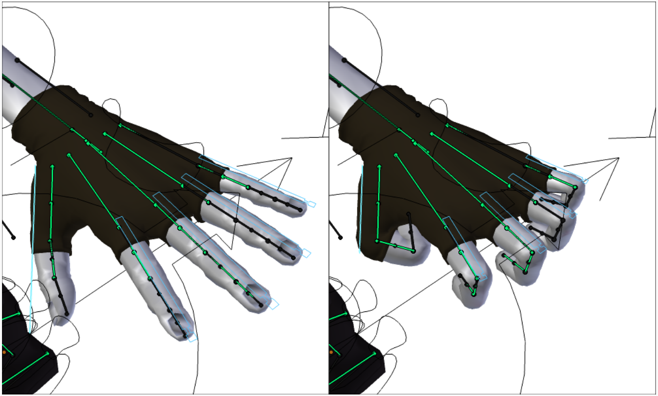


Figure 6: "OpenGL render of the hand rig of the main character in the open source project Sintel. Made in Blender and the GIMP" by Ben Dansie licensed under CC BY-SA 3.0

Motion Control - Skeletal Animation

- In case one wants to animate figures one usually uses a skeleton to model the kinematic restrictions of a body
- All possible positions of the skeleton can then usually described by a set of parameters $P \subset \mathbb{R}^n$
- The world space position of a certain part of the skeleton (say the finger) can be described by a function

$$\mathrm{F} : P \to \mathbb{R}^3 \tag{4}$$

- For the movements to comply with the kinematic restrictions they are usually described by splines $\mathrm{p} : [0, 1] \to P$
- In this case the arc length in world space is given by

$$s(u) = \int_0^u \left\| \frac{\mathrm{dF}\left(\mathrm{p}(v)\right)}{\mathrm{d}v} \right\|_2 \mathrm{d}v \tag{5}$$

- One can control the movement along the arc by

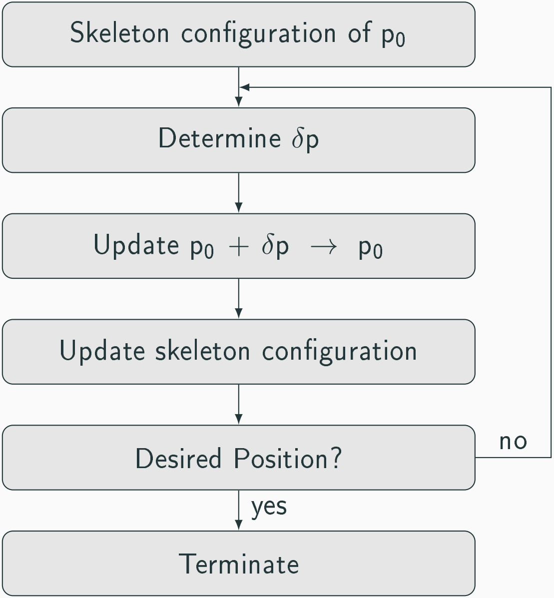
$$\mathrm{F}(\mathrm{p}(u(s(t)))) \tag{6}$$

- Often one does not want to manually set all the parameters of the skeleton but instead define positions, e.g. of the finger tip
- The skeleton offers many degrees of freedom, such that many skeletal configurations have the finger at the same location
- The automatic determination of only one unique movement is called **inverse kinematics**
- Starting at a configuration $\mathsf{p}_0 \in P$, which corresponds to the starting position of the finger tip $x_0 = \mathsf{F}(\mathsf{p}_0)$ we can change the internal parameters by a small amount $\delta\mathsf{p}$ which corresponds to a small motion into the direction

$$\delta\mathsf{x} = J_{\mathsf{F}}(\mathsf{p}_0)\delta\mathsf{p}, \tag{7}$$

where $J_{\mathsf{F}}(\mathsf{p}_0)$ is the Jacobian of F at position p_0

Motion Control - Skeletal Animation



Motion Control - Skeletal Animation

- In **inverse kinematics** we ask how to change the parameters to move our fingertip along a certain direction
- We cannot simply use the linear system to answer this question since
    1. The linear system is underdetermined
    2. $\mathrm{p} + \delta\mathrm{p}$ might not necessarily lie in P
- Optimization methods can be used instead
- Alternatives to this approach are
    - Hand crafting of motions
    - Motion capturing

Physics-Based Animation

- Some objects are difficult to animate realistically (fluids, cloth, relativistic effects)
- In these cases one can use the physical laws that govern the world around us in animation
- These laws often come as ordinary or partial differential equations
- Finite differences forward simulation possible but not without problems
  - Stability (Choice of starting conditions can produce vastly different results)
  - Choice of step size
- Effective usage requires a significant understanding of the underlying physical phenomena

Figure 7: "A water drop." by José Manuel Suárez licensed under CC BY 2.0

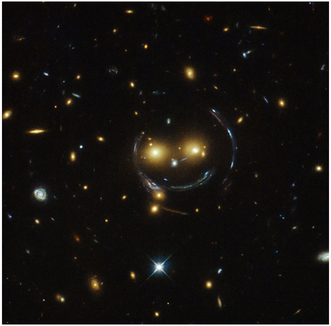


Figure 8: In the centre of this image, taken with the NASA/ESA Hubble Space Telescope, is the galaxy cluster SDSS J1038+4849 — and it seems to be smiling. You can make out its two orange eyes and white button nose. In the case of this "happy face", the two eyes are very bright galaxies and the misleading smile lines are actually arcs caused by an effect known as strong gravitational lensing.

Groups of Objects

- In case one wants to animate not a single character or object but a rather large group artificial intelligence (AI) systems take over the task of the animator
- For a group of some objects an AI with high or moderate intelligence can be used
- As the size of the group grows the AI of each individual gets fewer floating point operations per second
- Limited intelligence is often sufficient to create a coordinated and “goal” driven behaviour

Groups of Objects

Figure 9: "The flock of starlings acting as a swarm. The radio masts at Anthorn are visible for the moment." by John Holmes licensed under CC BY-SA 2.0