Animation

• Persistence of vision:
  – The visual system smoothes in time. This means that images presented to the eye are perceived by the visual system for a short time after they are presented. In turn, this means that if images are shown at the right rate (about 20-30 Hz will do it), the next image replaces the last one without any perceived blank space between them.

• Visual closure:
  – a sequence of still images is seen as a motion sequence if they are shown quickly enough - i.e. smooth motion between positions is inferred
Keyframing

From “It’s a magical world”, Watterson, 1996
Result
Basic techniques

- **Keyframing:**
  - generate frames by drawings, interpolate between drawings
- **Stop motion:**
  - put model in position, photograph, move, photograph, etc.
- **Compositing:**
  - generate frames as mixtures of video sequences
- **Morphing:**
  - mix video sequences while modifying shapes
- **Procedural animation:**
  - use some form of procedural description to move object
Keyframing - issues

- Generating frames by hand is a huge burden -- 1 hr of film is 3600x24 frames
- Skilled artists generate key frames, inbetweeners generate inbetween frames
- Changes are hideously expensive
- Natural interpolation problem -- interpolate various variables describing position, orientation, configuration of objects

Figure 10.4 Three keyframes. Three keyframes representing a ball on the ground, at its highest point, and back on the ground.

From “The computer in the visual arts”, Spalter, 1999
Linear interpolation

Figure 10.5 Inbetweening with linear interpolation. Linear interpolation creates inbetween frames at equal intervals along straight lines. The ball moves at a constant speed. Ticks indicate the locations of inbetween frames at regular time intervals (determined by the number of frames per second chosen by the user).

From "The computer in the visual arts", Spalter, 1999
Figure 10.9  Inbetweening with nonlinear interpolation. Nonlinear interpolation can create equally spaced inbetween frames along curved paths. The ball still moves at a constant speed. (Note that the three keyframes used here and in Fig. 10.10 are the same as in Fig. 10.4.)
Modify the parameter, too

A use for parameter continuous interpolates here. Notice that we don’t necessarily need a physical ball.

Figure 10.10  Inbetweening with nonlinear interpolation and easing. The ball changes speed as it approaches and leaves keyframes, so the dots indicating calculations made at equal time intervals are no longer equidistant along the path.

From “The computer in the visual arts”, Spalter, 1999
A variety of variables can be interpolated

Position

Position and orientation

Position and scale

From “The computer in the visual arts”, Spalter, 1999
From "The computer in the visual arts", Spalter, 1999
Position and orientation:

note that the position travels along a motion path

From “The computer in the visual arts”, Spalter, 1999
Various path specifications:

perhaps by interactive process;
two issues:
building the path
where are the keyframes?

From “The computer in the visual arts”, Spalter, 1999
Interpolating orientation gives greater realism. Notice that the tangent to the motion path gives a great cue to the orientation of the object.
Stop motion

• Very important traditional animation technique
• Put model in position, photograph, move, photograph, etc. e.g. “Seven voyages of Sinbad”, “Clash of the titans”, etc.
  – Model could be
    • plastic
    • linkage
    • clay, etc.
• Model work is still very important e.g. “Men in Black”
• Computerizing model work is increasingly important
  – issue: where does configuration of computer model come from?
From “The computer Image”, Watt and Policarpo, 1998
Motion capture

- Instrument a person or something else, perhaps by attaching sensors
- Measure their motion
- Link variables that give their configuration to variables that give configuration of a computer model
Compositing

- Overlay one image/film on another
  - variety of types of overlay

Simple overlay - spaceship pixels replace background pixels

From “The computer in the visual arts”, Spalter, 1999
Compositing

Spaceship pixels replace background pixels if they are not white (white is “dropped out”)

From “The computer in the visual arts”, Spalter, 1999
Compositing

Spaceship pixels replace background pixels if they are darker

From “The computer in the visual arts”, Spalter, 1999
Compositing

Light areas are more transparent - blending

From “The computer in the visual arts”, Spalter, 1999
Compositing

• Note that human intervention might be required to remove odd pixels, if the background doesn’t have a distinctive colour.

• One can buy sets of images which have been segmented by hand.

From “The computer in the visual arts”, Spalter, 1999
Morphing

• Simple blending doesn’t work terribly well for distinct shapes
• Idea: map the one shape to the other, while blending

From “The computer Image”, Watt and Policarpo, 1998
Morphing

From “On growth and Form”, D’Arcy Thompson
Morphing

- Another use for the deformation encoding shown earlier
- From “The computer Image”, Watt and Policarpo, 1998
Morphing

From “The computer Image”, Watt and Policarpo, 1998
Procedural animation

- **Kinematics**
  - the configuration of a chain given its state variables
  - e.g. where is the end of the arm if angles are given?
- **Inverse kinematics**
  - the state variables that yield the configuration
  - e.g. what angles put the end of the arm here?

From “The computer Image”,

[Diagram of a two-link manipulator with angles \( \theta_1 \) and \( \theta_2 \) and lengths \( l_1 \) and \( l_2 \) with end point \( X(x, y) \).]
Inverse Kinematics

From “The computer Image”, Watt and Policarpo, 1998
Inverse Kinematics

When 3D Models Meet
the embarrassing social consequences of lacking inverse kinematics

From “The computer in the visual arts”, Spalter, 1999
Inverse kinematics

- Endpoint position and orientation is: $e(\theta)$

- Central Question: how do I modify the configuration variables to move the endpoint in a particular direction?

  $$\delta e = \begin{pmatrix} \frac{\partial e_1}{\partial \theta_1} & \ldots & \frac{\partial e_1}{\partial \theta_k} \\ \frac{\partial e_6}{\partial \theta_1} & \ldots & \frac{\partial e_6}{\partial \theta_k} \end{pmatrix} \delta \theta = J \delta \theta$$

- $J$ is the Jacobian
- If rank($J$) $< 6$, then
  - some movements aren’t possible
  - or more than one movement results in the same effect
- If $k>6$ then the chain is redundant
  - more than one set of variables will lead to the same configuration
Procedural animation

• Generate animations using procedural approach
  – e.g. “Slice and dice” existing animations to produce a more complex animation
  – e.g. use forward kinematics and a hierarchical model (doors swinging in our original hierarchical model)
  – e.g. construct a set of forces, etc. and allow objects to move under their effects.
    • particle models
    • waves
    • collision and ballistic models
    • spring mass models
    • control - flocking, etc.
Dynamics - Particle systems

- There is a source of particles
  - move under gravity, sometimes collisions
  - sometimes other reactions
- Example: fireworks
  - particles chosen with random colour, originating randomly within a region, fired out with random direction and lasting for a random period of time before they expire
  - or explode, generating another collection of particles, etc

- Example: water
  - very large stream of particles, large enough that one doesn’t see the gap

- Example: grass
  - fire particles up within a tapered cylinder, let them fall under gravity, keep a record of the particle’s trail.
Particle explosion

Particle water
Particle Torch

Now replace particle centers with small blobs of colour in the image plane

http://www.arch.columbia.edu/manuals/Softimage/3d_learn/GUIDED/PARTICLES/p_first.htm
Collisions

- Natural dynamic model - objects move freely under gravity till they collide
- Collisions with point particles are easy
- Collisions with more complex shapes are not
  - spheres are an exception
  - hierarchy helps
- For accurate simulation of physical dynamics, it is essential to identify the first collision.
Dynamics - Springs and Masses

- Objects are modelled as a line/grid/lattice of masses
- Masses are connected by linear springs
- Energy in a linear spring is \( k(l-l_r)^2 \)
  - here \( k \) is the spring constant and \( l_r \) is the rest length
- This yields system of differential equations for the state of the object (position and velocity of the masses)
- Objects can be controlled by changing rest lengths of springs
Spring mass fish

Figure 4.1: The biomechanical fish model. Black dots indicate lumped masses. Lines indicate deformable elements at their natural, rest lengths.

Due to Xiaoyuan Tu, http://www.dgp.toronto.edu/people/tu
Spring Mass fish swimming
Dynamics - more interesting dynamics

• Solid mechanics
  – fractures, sound, etc
  – springs and masses don’t work well

• Deforming objects
  – jelly
  – cloth (hard)
  – muscle
  – skin
  – hair
Procedural animation - flocking

- We’d like objects to move in schools and not hit things.
- Abstraction - particle with a steerable rocket.
- 3 goals
  - Separation: steer to avoid crowding local flockmates.
  - Alignment: steer towards the average heading of local flockmates.
  - Cohesion: steer to move toward the average position of local flockmates.
- Each generates a separate acceleration request
- How to accelerate?
  - weighted sum
    - but there is a limited amount of acceleration available
  - accumulate acceleration in priority order until vector is too long, then trim back the last component.
Boids

http://www.red.com/cwr/boids.html
Random offsets and subdivisions

- Subdivision using random offsets gives quite good terrain models
- Trick:
  - mesh rough model of terrain
  - subdivide, applying random offsets, but limiting the distance between the offset and the original model
  - Gives a terrain that “looks familiar”
Procedural modelling

- Seashells
- Plants
- Terrain
Fractal Terrains

http://members.aol.com/maksoy/vistfrac/sunset.htm
L-Systems

L-Systems

Plant development

productions

L-System plant growing

Flowers at side branches

Monopodial branching - raceme

Flowers at the apex

A → I[A]F

Sympodial branching - cyme

Procedural waves
Turbulence/Perlin noise

• Many natural textures look like noise or “smoothed” noise (marble, flames, clouds, terrain, etc.)

• Issue:
  – obtain the right kind of smoothing

• Strategy:
  – construct noise functions at a variety of scales
    • do this by drawing samples from a random number generator at different spacings
  – form a weighted sum

• Usually:
  – space the noise in octaves (i.e. interelement spacing goes as \((1/2)^i\) - this means frequency goes as \(2^i\))
  – amplitude in sum goes as \(p^i\), where \(p\) is a parameter called persistence.
  – persistence is commonly \(2^i\)

• 3D Turbulence yields animations for clouds, fog, flames
Some noise functions are created in 2D.

Adding all these functions together produces a noisy pattern.
To create more interesting and complicated textures, you should try mixing several Perlin functions. This texture was created in two parts. Firstly a Perlin function with low persistence was used to define the shape of the blobs. The value of this function was used to select from two other functions, one of which defined the stripes, the other defined the blotchy pattern. A high value chose more of the former, a low value more of the latter. The stripes were defined by multiplying the first Perlin Function by some number (about 20) then taking the cosine.

A marbled texture can be made by using a Perlin function as an offset to a cosine function:

```
texture = cosine( x + perlin(x,y,z) )
```

Very nice wood textures can be defined. The grain is defined with a low persistence function like this:

```
g = perlin(x,y,z) * 20
grain = g - int(g)
```

The very fine bumps you can see on the wood are high frequency noise that has been stretched in one dimension.

```
bumps = perlin(x+50, y+50, z+20)
if bumps < .5 then bumps = 0 else bumps = 1
```

References


Intel Developer Site article about using the new MMX technology to render Perlin Noise in real time.

**Ken Perlin’s Homepage**: [http://mrl.nyu.edu/perlin/](http://mrl.nyu.edu/perlin/)

I assume the person responsible for Perlin Noise. He has an interesting page with lots of useful links to texturing and modeling.
The following textures were made with 3D Perlin Noise:

- Standard 3 dimensional perlin noise, 4 octaves, persistence 0.25 and 0.5

- Low persistence. You can create harder edges to the perlin noise by applying a function to the output.

- To create more interesting and complicated textures, you should try mixing several Perlin functions. This texture was created in two parts. Firstly a Perlin function with low persistence was used to define the shape of the blobs. The value of this function was used to select from two other functions, one of which defined the stripes, the other defined the bumpy pattern. A high value chose more of the former, a low value more of the latter. The stripes were defined by multiplying the first Perlin Function by some number (about 20) then taking the cosine.

- A nearly texture can be made by using a Perlin function as an offset to a cosine function.

  \[ \text{texture} = \cos( x + \text{perlin}(x,y,z) ) \]
Flame: Compute intensity of point based on distance from center in x. Scale it based on distance in y. Add turbulence. Use 3-D turbulence to animate. Here is an example of a flame with added turbulence.

Conclusions:
- Lots of interesting effects can be gained by adding turbulence
- Need to play with degree and scale to get most realistic images
- Ties together a lot of topics in graphics (fractals, texture, color, curves)
Terrain, clouds generated using procedural textures and Perlin noise
http://www.planet-side.co.uk/ -- tool is called Terragen
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Terrain, clouds generated using procedural textures and Perlin noise
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Procedural texture synthesis

- Example: Markov synthesis of text
- Use image as a source of examples
  - Choose pixel values by matching neighbourhood, then filling in
  - Matching process
    - look at pixel differences
    - count only synthesized pixels
out it becomes harder to read.

It's not very clear what the text is saying.
From “Image quilting for texture synthesis and transfer”, Efros and Freeman, SIGGRAPH 2001
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From “Image quilting for texture synthesis and transfer”, Efros and Freeman, SIGGRAPH 2001
From “Image quilting for texture synthesis and transfer”, Efros and Freeman, SIGGRAPH 2001
From “Image analogies”, Herzmann et al, SIGGRAPH 2001
From “Image analogies”, Herzmann et al, SIGGRAPH 2001
From “Image analogies”, Herzmann et al, SIGGRAPH 2001
From “Image analogies”, Herzmann et al, SIGGRAPH 2001