CSE 442 - Data Visualization

Animation

Jeffrey Heer  University of Washington
Why Use Motion?
Why Use Motion?

Visual variable to encode data
Direct attention
Understand system dynamics
Understand state transition
Increase engagement
Cone Trees [Robertson 91]
Volume Rendering [Lacroute 95]
Topics

Motion perception
Animated transitions in visualizations
Implementing animations
Perceiving Animation

Under what conditions does a sequence of static images give rise to motion perception?

Smooth motion perceived at ~10 frames/sec (100 ms).
Motion as Visual Cue

Pre-attentive, stronger than color, shape, …
More sensitive to motion at periphery
Similar motions perceived as a group
Motion parallax provide 3D cue (like stereopsis)
Tracking Multiple Targets

How many dots can we simultaneously track?
Tracking Multiple Targets

How many dots can we simultaneously track?

~4-6. Difficulty increases sig. at 6. [Yantis 92, Pylyshn 88, Cavanagh 05]
Grouped Dots Count as 1 Object

Dots moving together are grouped

http://coe.sdsu.edu/eet/articles/visualperc1/start.htm
Segment by Common Fate

http://dragon.uml.edu/psych/commfate.html

http://www.singlecell.org/july/index.html
Grouping of Biological Motion

[http://www.lifesci.sussex.ac.uk/home/George_Mather/Motion/WALK.MOV](http://www.lifesci.sussex.ac.uk/home/George_Mather/Motion/WALK.MOV)

[Johansson 73]
Motions Show Transitions

See change from one state to next

start
Motions Show Transitions

See change from one state to next

end
Motions Show Transitions

See change from one state to next

△ Shows transition better, but
〇 Still may be too fast, or too slow
□ Too many objects may move at once
　end
Constructing Narratives

http://anthropomorphism.org/img/Heider_Flash.swf
Attribution of Causality [Michotte 46]

Michotte demonstration 1. What do you see? Most observers report that "the red ball hit the blue ball." The blue ball moved "because the red ball hit it." Thus, the red ball is perceived to "cause" the blue ball to move, even though the balls are nothing more than color disks on your screen that move according to a programme.

http://cogweb.ucla.edu/Discourse/Narrative/michotte-demo.swf
Attribution of Causality [Michotte 46]

[Reprint from Ware 04]
<table>
<thead>
<tr>
<th>Animation</th>
<th>Helps?</th>
<th>Hurts?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attention</td>
<td>direct attention</td>
<td>distraction</td>
</tr>
<tr>
<td>Constancy</td>
<td>change tracking</td>
<td>false relations</td>
</tr>
<tr>
<td>Causality</td>
<td>cause and effect</td>
<td>false agency</td>
</tr>
<tr>
<td>Engagement</td>
<td>increase interest</td>
<td>“chart junk”</td>
</tr>
<tr>
<td>Calibration</td>
<td></td>
<td>too slow: boring</td>
</tr>
<tr>
<td></td>
<td></td>
<td>too fast: errors</td>
</tr>
</tbody>
</table>
Problems with Animation [Tversky]

Difficult to estimate paths and trajectories
Motion is fleeting and transient
Cannot simultaneously attend to multiple motions
Parse motion into events, actions and behaviors
Misunderstanding and wrongly inferring causality
Anthropomorphizing physical motion may cause confusion or lead to incorrect conclusions
Animated Transitions in Statistical Graphics
Log Transform
Sorting
Filtering
Month 1
Timestep

Month 2
Change Encodings
Change Data Dimensions
Change Data Dimensions
Change Encodings + Axis Scales
Data Graphics & Transitions

Visual Encoding

Change selected data dimensions or encodings

Animation to communicate changes?

Table:

<table>
<thead>
<tr>
<th>Category</th>
<th>Sales</th>
<th>Profit</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>11</td>
<td>7</td>
</tr>
<tr>
<td>B</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td>C</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>D</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>E</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>
During analysis and presentation it is common to transition between related data graphics. Can animation help? How does this impact perception?
Principles for Animation

Congruence
The structure and content of the external representation should correspond to the desired structure and content of the internal representation.

Apprehension
The structure and content of the external representation should be readily and accurately perceived and comprehended. [from Tversky 02]
Principles for Animation

Congruence
The structure and content of the external representation should correspond to the desired structure and content of the internal representation.

Apprehension
The structure and content of the external representation should be readily and accurately perceived and comprehended.

[from Tversky 02]
Principles for Animation

Congruence
Maintain valid data graphics during transitions
Use consistent syntactic/semantic mappings
Respect semantic correspondence
Avoid ambiguity

Apprehension
Group similar transitions
Minimize occlusion
Maximize predictability
Use simple transitions
Use staging for complex transitions
Make transitions as long as needed, but no longer
Principles for Animation

Congruence
Maintain valid data graphics during transitions
Use consistent syntactic/semantic mappings
Respect semantic correspondence
Avoid ambiguity

Apprehension
Group similar transitions
Minimize occlusion
Maximize predictability
Use simple transitions
Use staging for complex transitions
Make transitions as long as needed, but no longer

Visual marks should always represent the same data tuple.
**Principles for Animation**

**Congruence**
- Maintain valid data graphics during transitions
- Use consistent syntactic/semantic mappings
- Respect semantic correspondence
- Avoid ambiguity

**Apprehension**
- Group similar transitions
- Minimize occlusion
- Maximize predictability
- Use simple transitions
- Use staging for complex transitions
- Make transitions as long as needed, but no longer

Different operators should have distinct animations.
Principles for Animation

**Congruence**
Maintain valid data graphics during transitions
Use consistent syntactic/semantic mappings
Respect semantic correspondence
Avoid ambiguity

**Apprehension**
Group similar transitions
Minimize occlusion
Maximize predictability
Use simple transitions
Use staging for complex transitions
Make transitions as long as needed, but no longer

Objects are harder to track when occluded.
Principles for Animation

Congruence
Maintain valid data graphics during transitions
Use consistent syntactic/semantic mappings
Respect semantic correspondence
Avoid ambiguity

Apprehension
Group similar transitions
Minimize occlusion
Maximize predictability
Use simple transitions
Use staging for complex transitions
Make transitions as long as needed, but no longer

Keep animation as simple as possible. If complicated, break into simple stages.
Study Conclusions

Appropriate animation improves graphical perception

Simple transitions beat “do one thing at a time”

Simple staging was preferred and showed benefits
  but timing important and in need of study

Axis re-scaling hampers perception
  Avoid if possible (use common scale)
  Maintain landmarks better (delay fade out of lines)

Subjects preferred animated transitions
Animation in Trend Visualization

Heer & Robertson study found that animated transitions are better than static transitions for estimating changing values.

How does animation fare vs. static time-series depictions (as opposed to static transitions)?

Experiments by Robertson et al, InfoVis 2008
Animated Scatterplot [Robertson 08]
Task

Select two countries whose InfantMortality dropped first, then increased later.

Ctrl-Click on a country (in chart) to set an answer.

Answers set: 0/2

Next

Click on "Next" when finished (or "Give Up" if you cannot find all the answers)
Select two countries whose Infant Mortality dropped first, then increased later.

Ctrl-Click on a country (in chart) to set an answer.

Answers set: 0/2

Click on "Next" when finished (or "Give Up" if you cannot find all the answers)
Which to prefer for analysis?
For presentation?
Study: Analysis & Presentation

Subjects asked comprehension questions. Presentation condition included narration.

Multiples 10% more accurate than animation

Presentation: Anim. 60% faster than multiples

Analysis: Animation 82% slower than multiples

User preferences favor animation (even though less accurate and slower for analysis!)
Administrivia
Final Project Schedule

Proposal Fri Nov 9
Milestone Tue Nov 27
Reviews Wed Nov 28, Fri Nov 30
Deliverables Thu Dec 6
Video Showcase Fri Dec 7 (in class)

Logistics
Final project description posted online
Work in groups of up to 5 people
Start determining your project topic!
Implementing Animation
Animation Approaches

Frame-Based Animation
Redraw scene at regular interval (e.g., 16ms)
Developer defines the redraw function
Frame-Based Animation
Frame-Based Animation
Frame-Based Animation
Frame-Based Animation
Frame-Based Animation
Frame-Based Animation

circle(10,10)
Frame-Based Animation

circle(10,10)  circle(15,15)
Frame-Based Animation
Frame-Based Animation

circle(10,10)  circle(15,15)  circle(20,20)  circle(25,25)
Frame-Based Animation
Frame-Based Animation
Frame-Based Animation

circle(10,10)
Frame-Based Animation

circle(10,10)
clear()
Frame-Based Animation

circle(10,10)
circle(15,15)
clear()
Frame-Based Animation

circle(10,10)
circle(15,15)
clear()
Frame-Based Animation

circle(10,10)
clear()
circle(15,15)
clear()
circle(20,20)
Frame-Based Animation

circle(10,10)
circle(15,15)
circle(20,20)
clear()
clear()
clear()
Frame-Based Animation

circle(10,10)
clear()
clear()
clear()
circle(15,15)
circle(20,20)
circle(25,25)
Animation Approaches

Frame-Based Animation
Redraw scene at regular interval (e.g., 16ms)
Developer defines the redraw function
Animation Approaches

Frame-Based Animation
Redraw scene at regular interval (e.g., 16ms)
Developer defines the redraw function

Transition-Based Animation (Hudson & Stasko ’93)
Specify property value, duration & easing
Also called tweening (for “in-betweens”)
Typically computed via interpolation
   \[ \text{step}(\text{fraction}) \{ x_{\text{now}} = x_{\text{start}} + \text{fraction} \times (x_{\text{end}} - x_{\text{start}}); \} \]
Timing & redraw managed by UI toolkit
Transition-Based Animation

from: (10,10) to: (25,25) duration: 3sec
Transition-Based Animation

from: (10,10) to: (25,25) duration: 3 sec
Transition-Based Animation

from: (10,10) to: (25,25) duration: 3sec

dx=25-10
x=10+(0/3)*dx

x=10+(1/3)*dx
Transition-Based Animation

from: (10,10) to: (25,25) duration: 3sec

dx=25-10
x=10+(0/3)*dx
x=10+(1/3)*dx
x=10+(2/3)*dx
Transition-Based Animation

from: (10,10) to: (25,25) duration: 3sec

\[dx = 25-10\]
\[x = 10 + \frac{0}{3} \cdot dx\]
\[x = 10 + \frac{1}{3} \cdot dx\]
\[x = 10 + \frac{2}{3} \cdot dx\]
\[x = 10 + \frac{3}{3} \cdot dx\]
Transition-Based Animation

text: (10,10) to: (25,25) duration: 3sec

Toolkit handles frame-by-frame updates!

dx=25-10
x=10+(0/3)*dx
x=10+(1/3)*dx
x=10+(2/3)*dx
x=10+(3/3)*dx
D3 Transitions

Any d3 selection can be used to drive animation.
D3 Transitions

Any d3 selection can be used to drive animation.

// Select SVG rectangles and bind them to data values.
var bars = svg.selectAll("rect.bars").data(values);
D3 Transitions

Any d3 selection can be used to drive animation.

// Select SVG rectangles and bind them to data values.
var bars = svg.selectAll("rect.bars").data(values);

// Static transition: update position and color of bars.
bars
  .attr("x", (d) => xScale(d.foo))
  .attr("y", (d) => yScale(d.bar))
  .style("fill", (d) => colorScale(d.baz));
Any d3 selection can be used to drive animation.

// Select SVG rectangles and bind them to data values.
var bars = svg.selectAll("rect.bars").data(values);

// Animated transition: interpolate to target values using default timing
bars.transition()
  .attr("x", (d) => xScale(d.foo))
  .attr("y", (d) => yScale(d.bar))
  .style("fill", (d) => colorScale(d.baz));
D3 Transitions

Any d3 **selection** can be used to drive animation.

// Select SVG rectangles and bind them to data values.
var bars = svg.selectAll("rect.bars").data(values);

// Animated transition: interpolate to target values using default timing
bars.transition()
  .attr("x", (d) => xScale(d.foo))
  .attr("y", (d) => yScale(d.bar))
  .style("fill", (d) => colorScale(d.baz));

// Animation is implicitly queued to run!
D3 Transitions, Continued

bars.transition()
  .duration(500)  // animation duration in milliseconds
  .delay(0)      // onset delay in milliseconds
  .ease(d3.easeBounce)  // set easing (or “pacing”) style
  .attr("x", (d) => xScale(d.foo))
...

D3 Transitions, Continued

bars.transition()
  .duration(500)       // animation duration in milliseconds
  .delay(0)           // onset delay in milliseconds
  .ease(d3.easeBounce) // set easing (or “pacing”) style
  .attr("x", (d) => xScale(d.foo))
...

bars.exit().transition()  // animate elements leaving the display
  .style("opacity", 0)   // fade out to fully transparent
  .remove();             // remove from DOM upon completion
Easing (or “Pacing”) Functions

Goals: stylize animation, improve perception.

Basic idea is to warp time: as duration goes from start (0%) to end (100%), dynamically adjust the interpolation fraction using an easing function.
Easing (or “Pacing”) Functions

**Goals:** stylize animation, improve perception.

Basic idea is to warp time: as *duration* goes from start (0%) to end (100%), dynamically adjust the *interpolation fraction* using an **easing function**.

\[
\text{ease}(x) = x
\]  
(linear, no warp)
Goals: stylize animation, improve perception.

Basic idea is to warp time: as duration goes from start (0%) to end (100%), dynamically adjust the interpolation fraction using an easing function.

Easing (or “Pacing”) Functions

**ease(x) = x**
- (linear, no warp)

**ease(x) = s-curve(x)**
- (slow-in, slow-out)
CSS Transitions

Extends CSS with Animated Transitions

a {
  color: black;
  transition: color 1s ease-in-out;
}

a:hover {
  color: red;
}
CSS Transitions

Extends CSS with Animated Transitions

a {
    color: black;
    transition: color 1s ease-in-out;
}

a:hover {
    color: red;
}
Extends CSS with Animated Transitions

```css
a {
  color: black;
  transition: color 1s ease-in-out;
}

a:hover {
  color: red;
}
```

**CSS Transitions**

<table>
<thead>
<tr>
<th>Property</th>
<th>Duration</th>
<th>Easing</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>color</td>
<td>1s</td>
<td>ease-in-out</td>
<td>Animate color transition upon mouse in / out.</td>
</tr>
</tbody>
</table>
Summary

Animation is a salient visual phenomenon
Attention, object constancy, causality, timing
Design with care: congruence & apprehension

For processes, **static images** may be preferable

For transitions, animation has demonstrated benefits, but **consider task and timing**