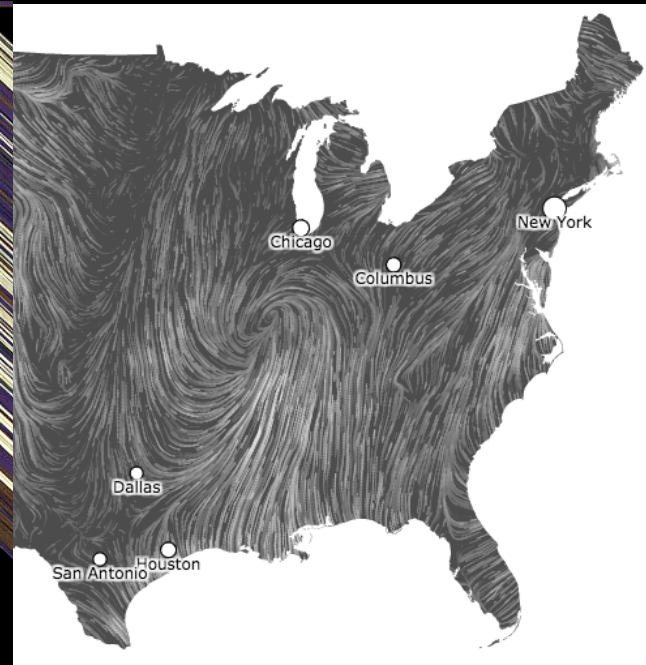
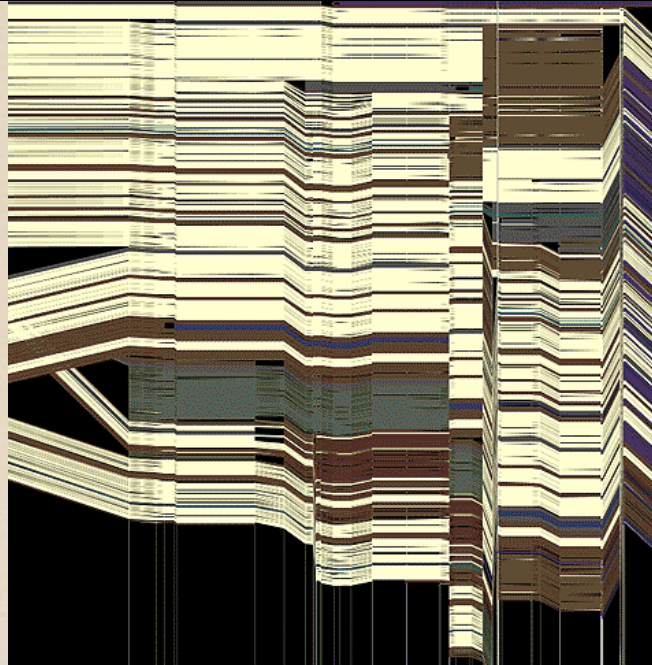
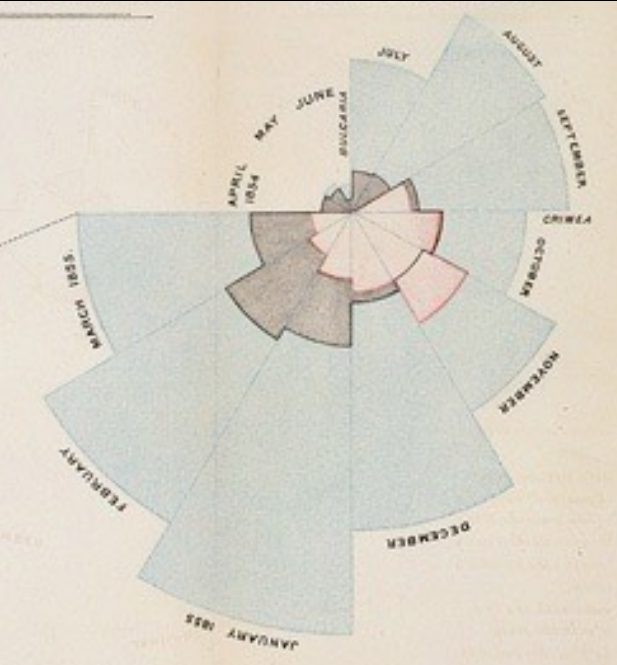


CSE 442 - Data Visualization

Animation



Jeffrey Heer University of Washington

Why Use Motion?

Visual variable to encode data

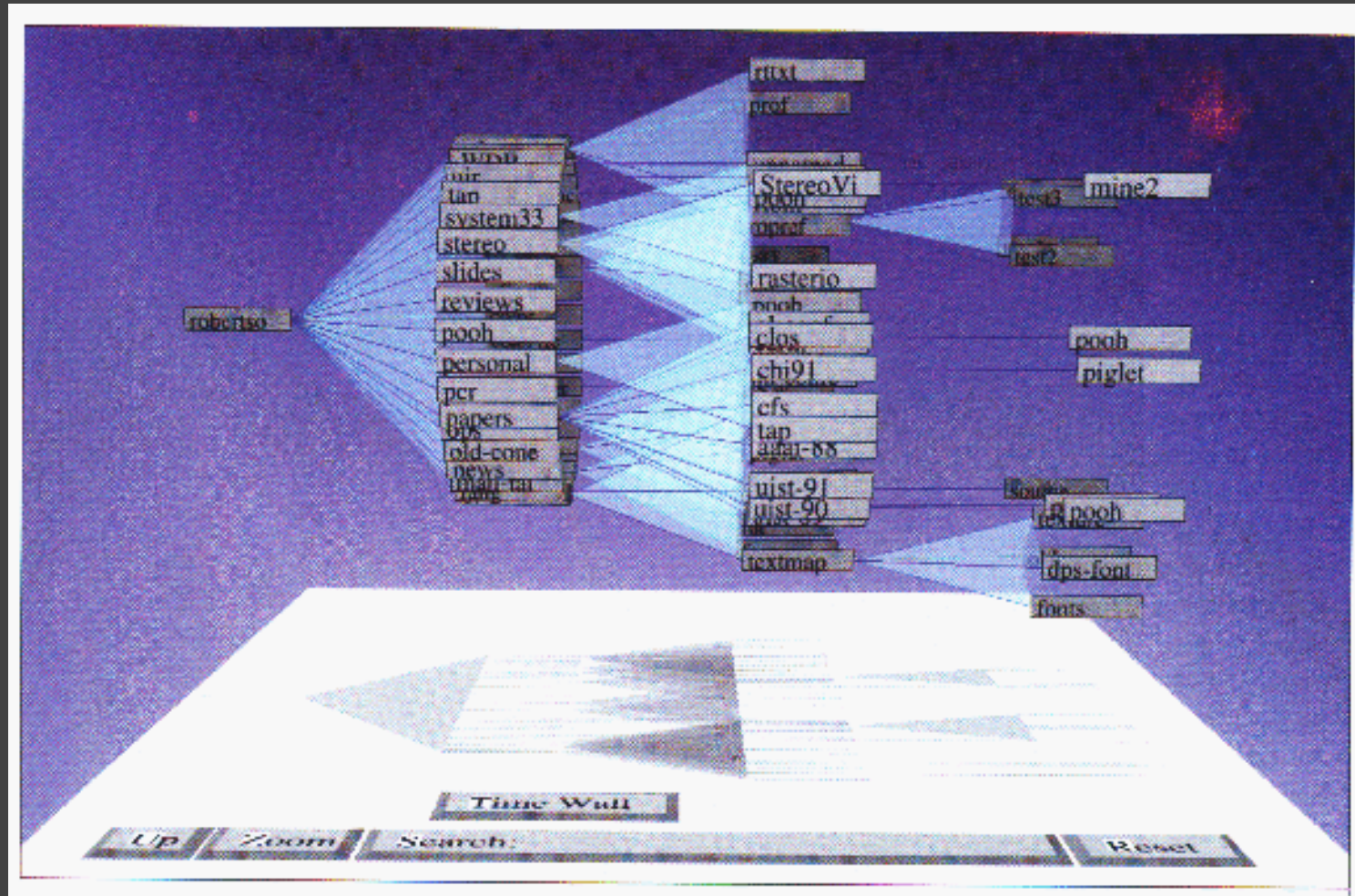
Direct attention

Understand system dynamics

Understand state transition

Increase engagement

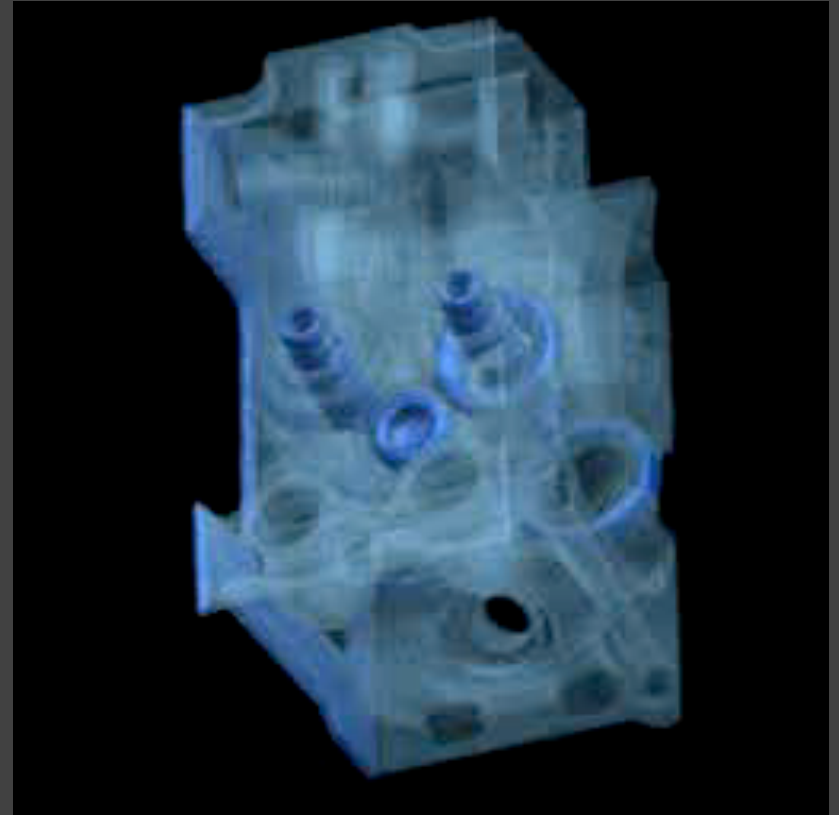
Cone Trees [Robertson 91]



[Video](#)

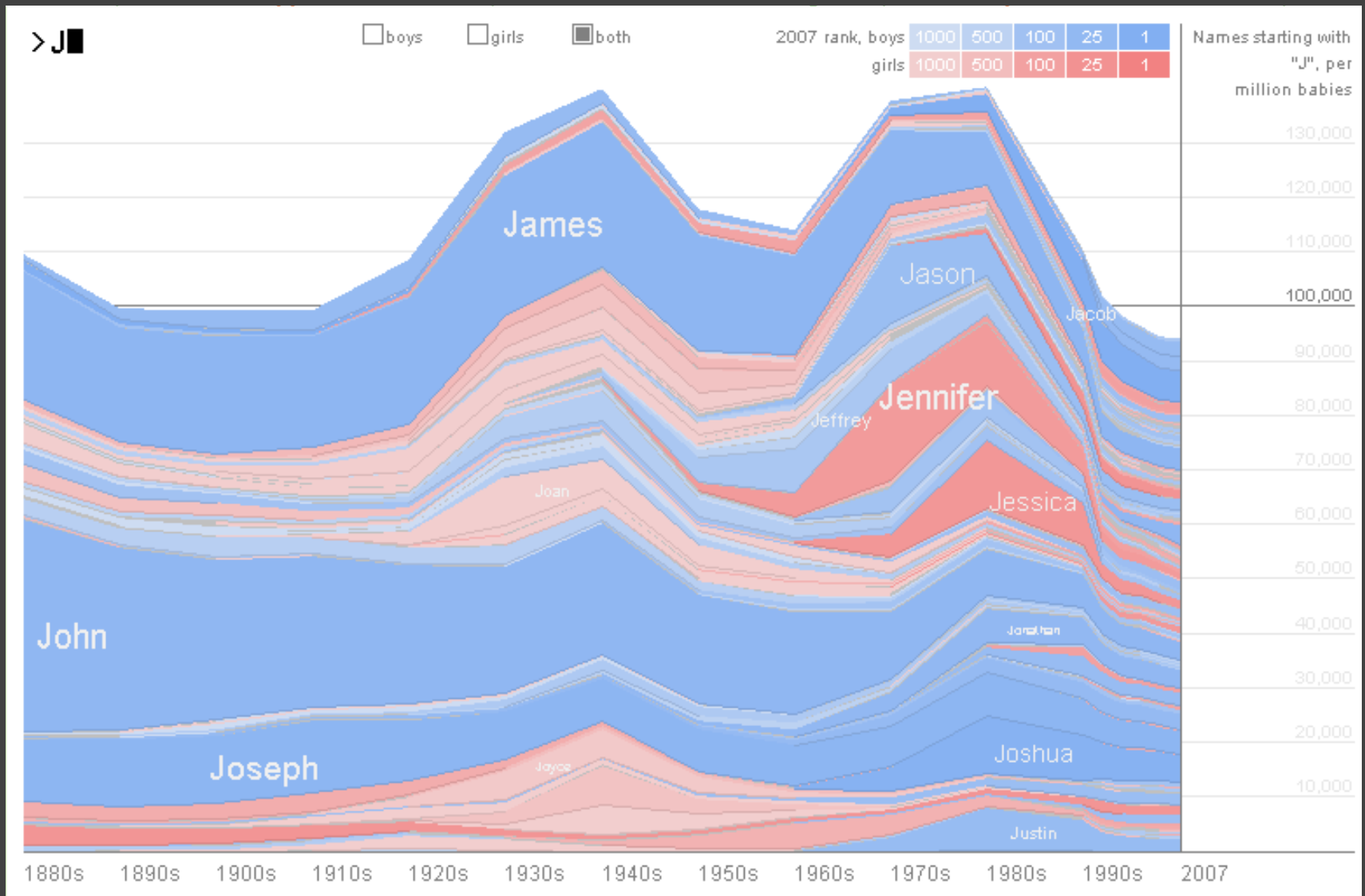


Volume Rendering [Lacroute 95]



Video

NameVoyager [Wattenberg 06]



Topics

Motion perception

Animated transitions in visualizations

Implementing animations

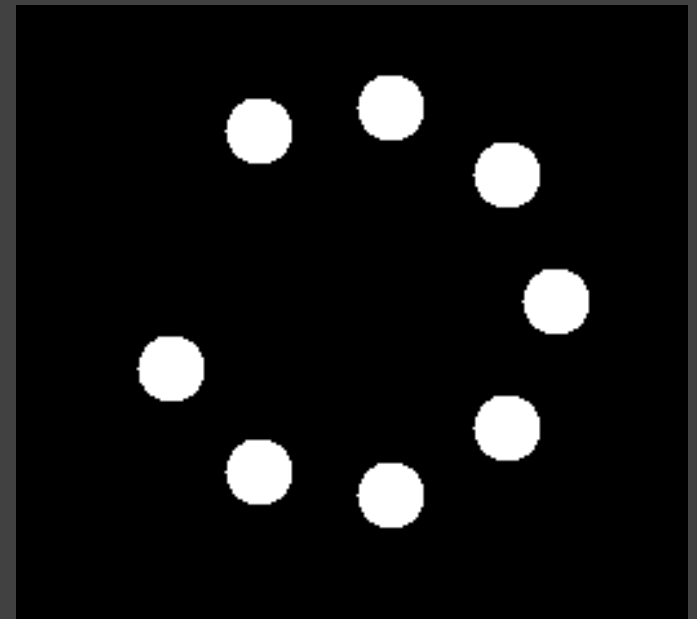
Motion Perception

Perceiving Animation

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

Motion is perceived at about
~10 frames/sec (100 ms).

But this does not have to be
smooth motion! We can tell
that frames are discrete yet
still perceive movement.



Motion as Visual Cue

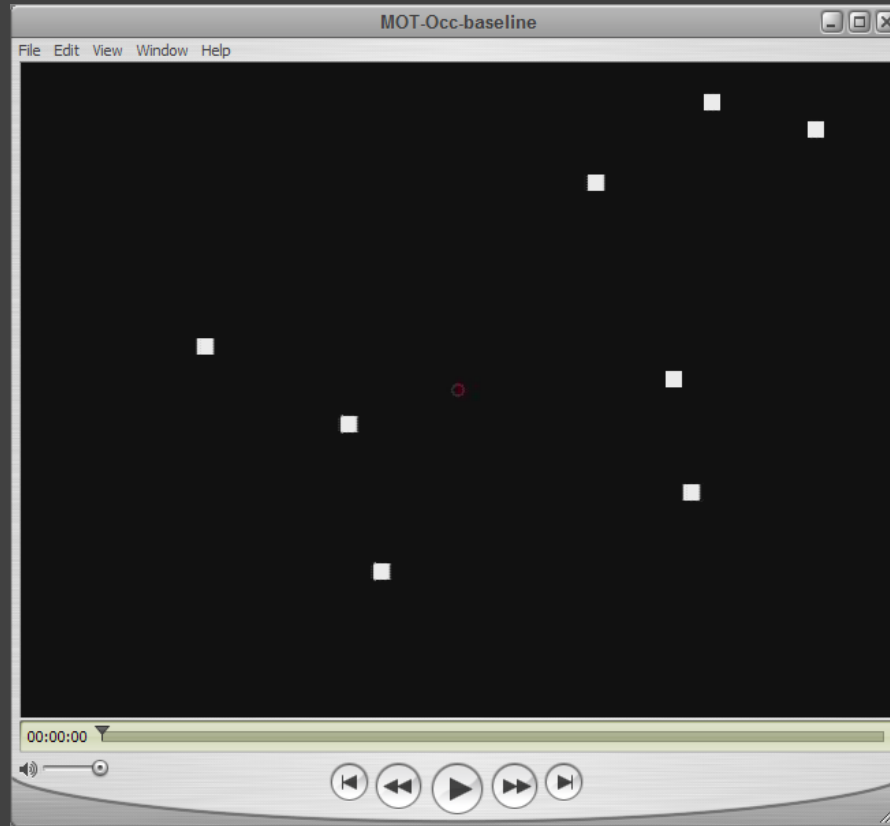
Pre-attentive, stronger than color, shape, ...

More sensitive to motion at periphery

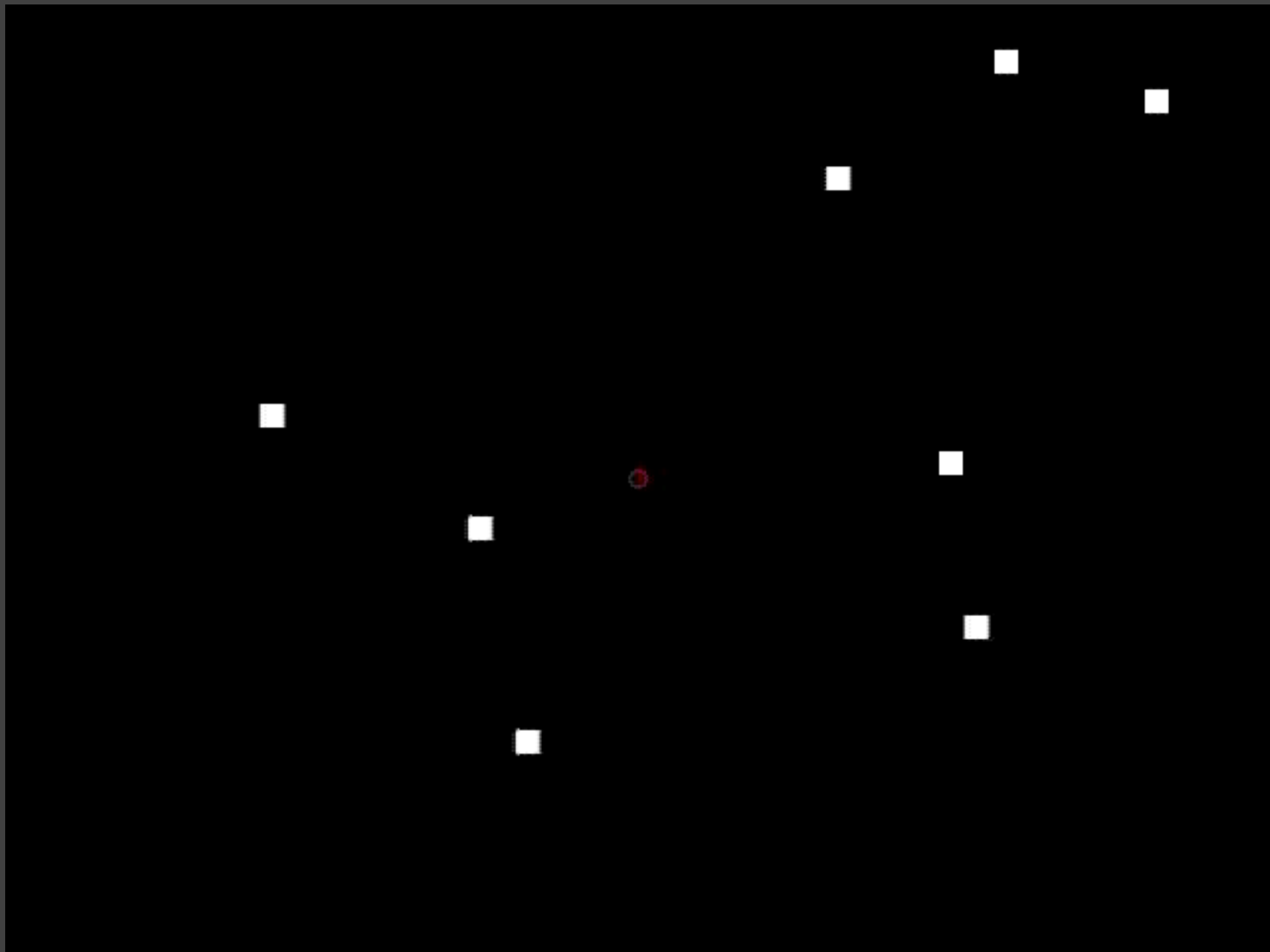
Similar motions perceived as a group

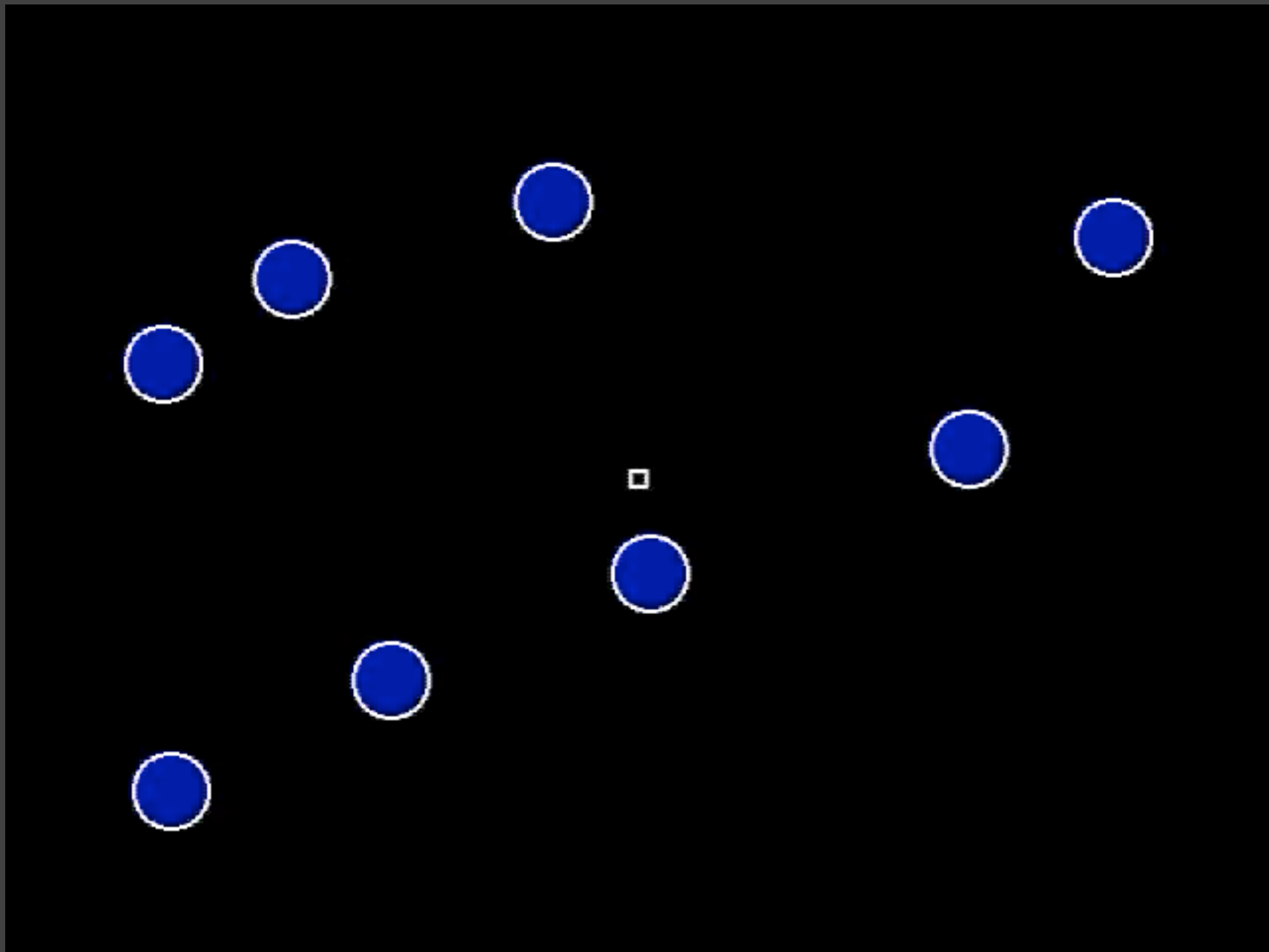
Motion parallax provide 3D cue (like stereopsis)

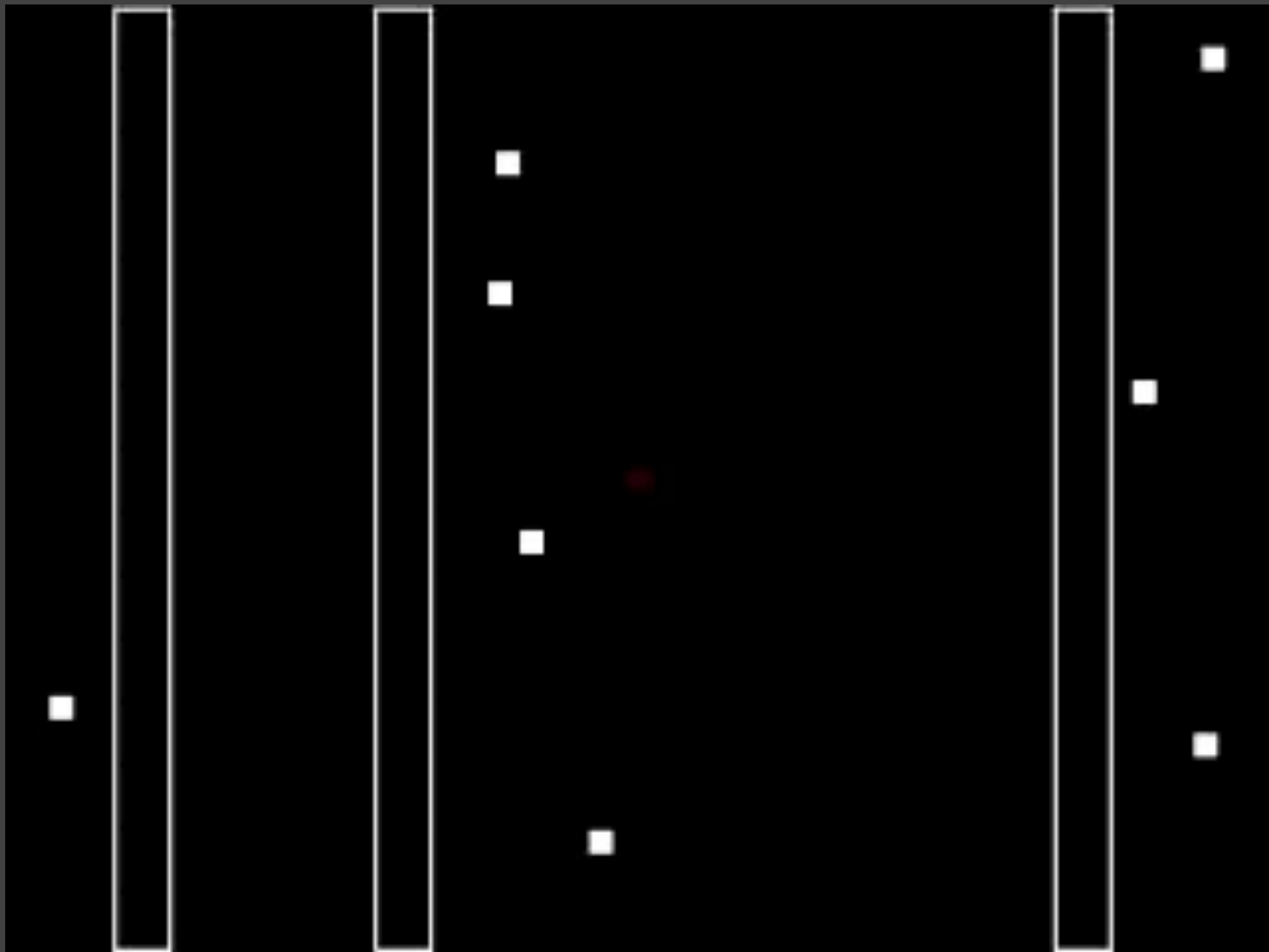
Tracking Multiple Targets

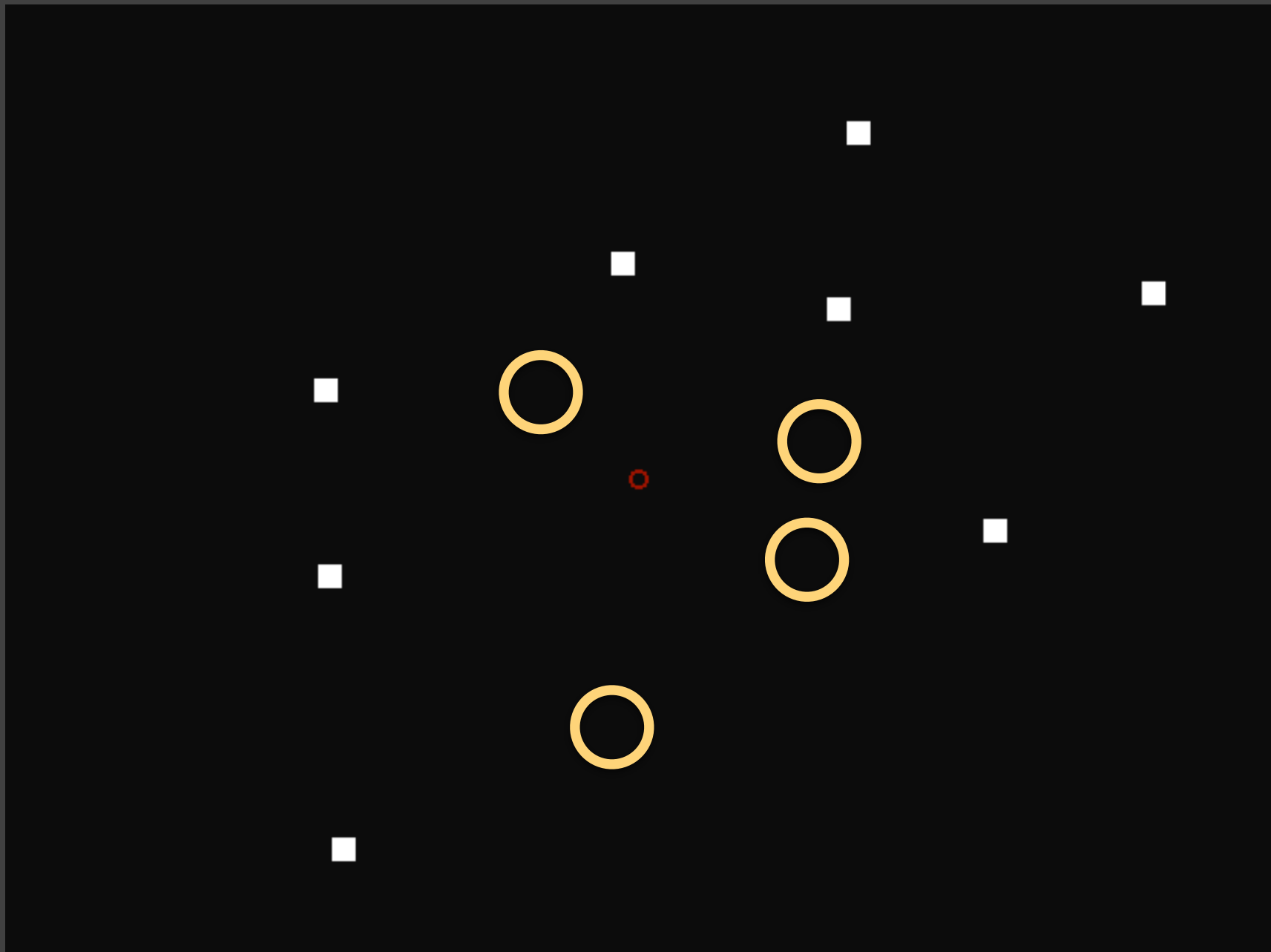


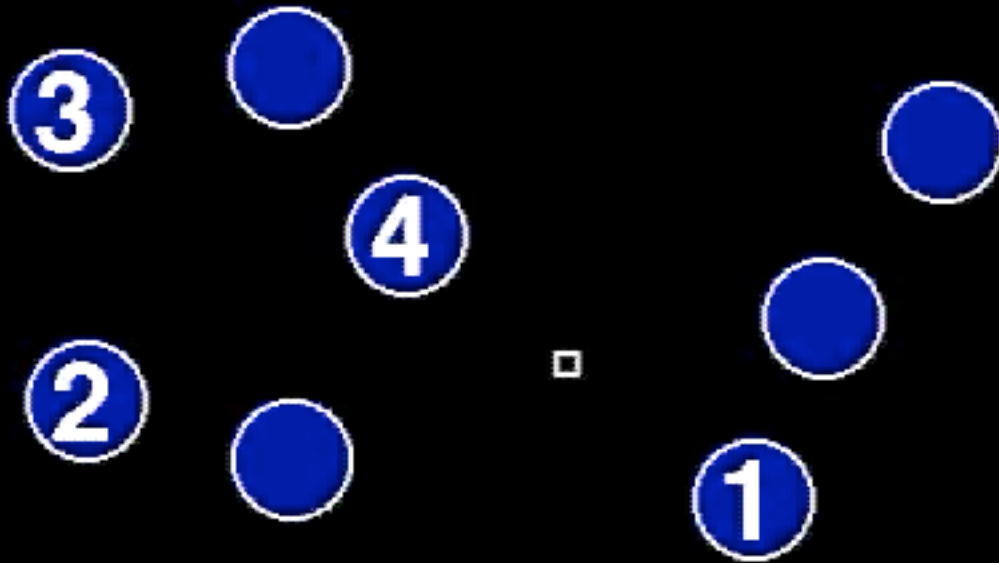
How many dots can we simultaneously track?



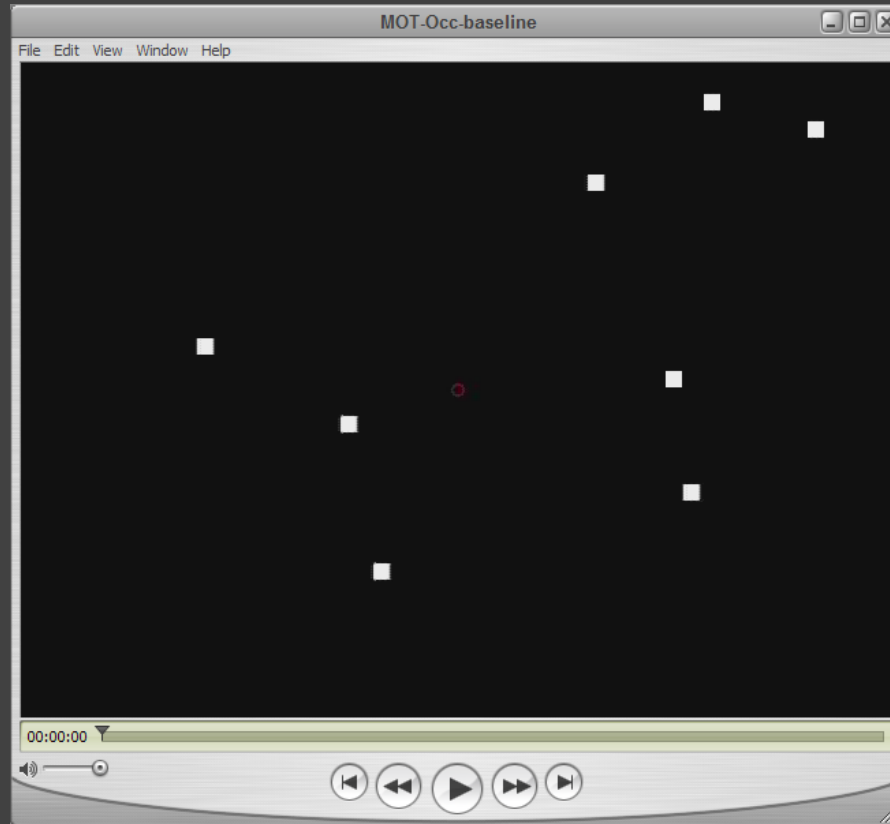








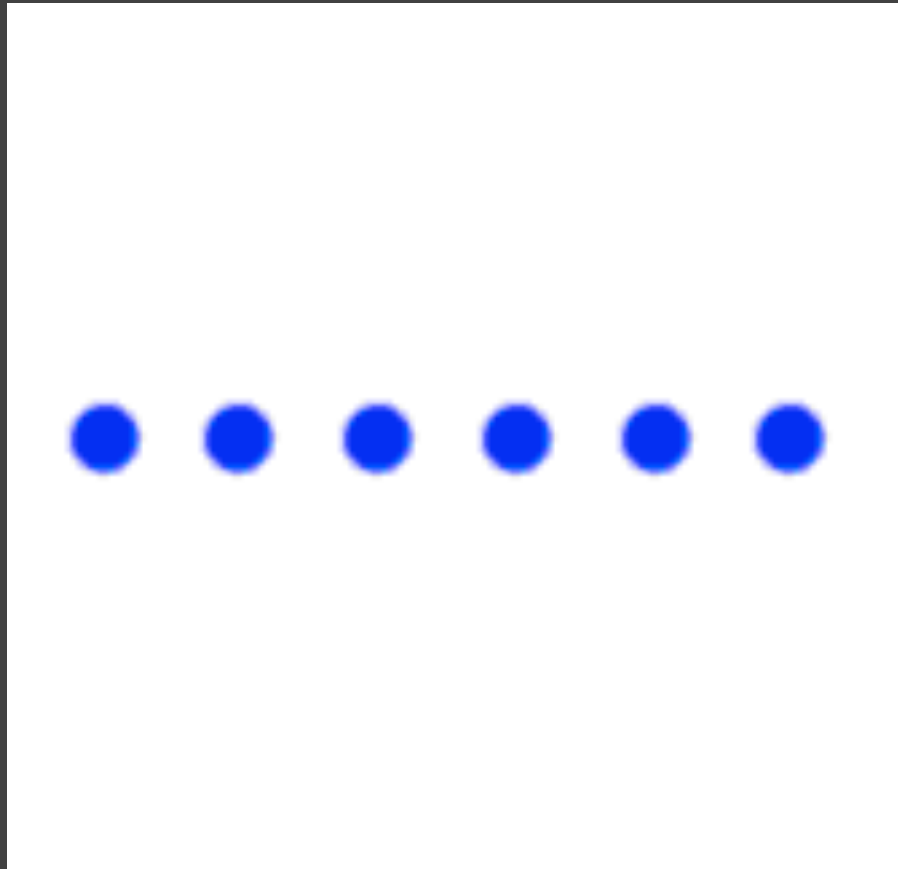
Tracking Multiple Targets



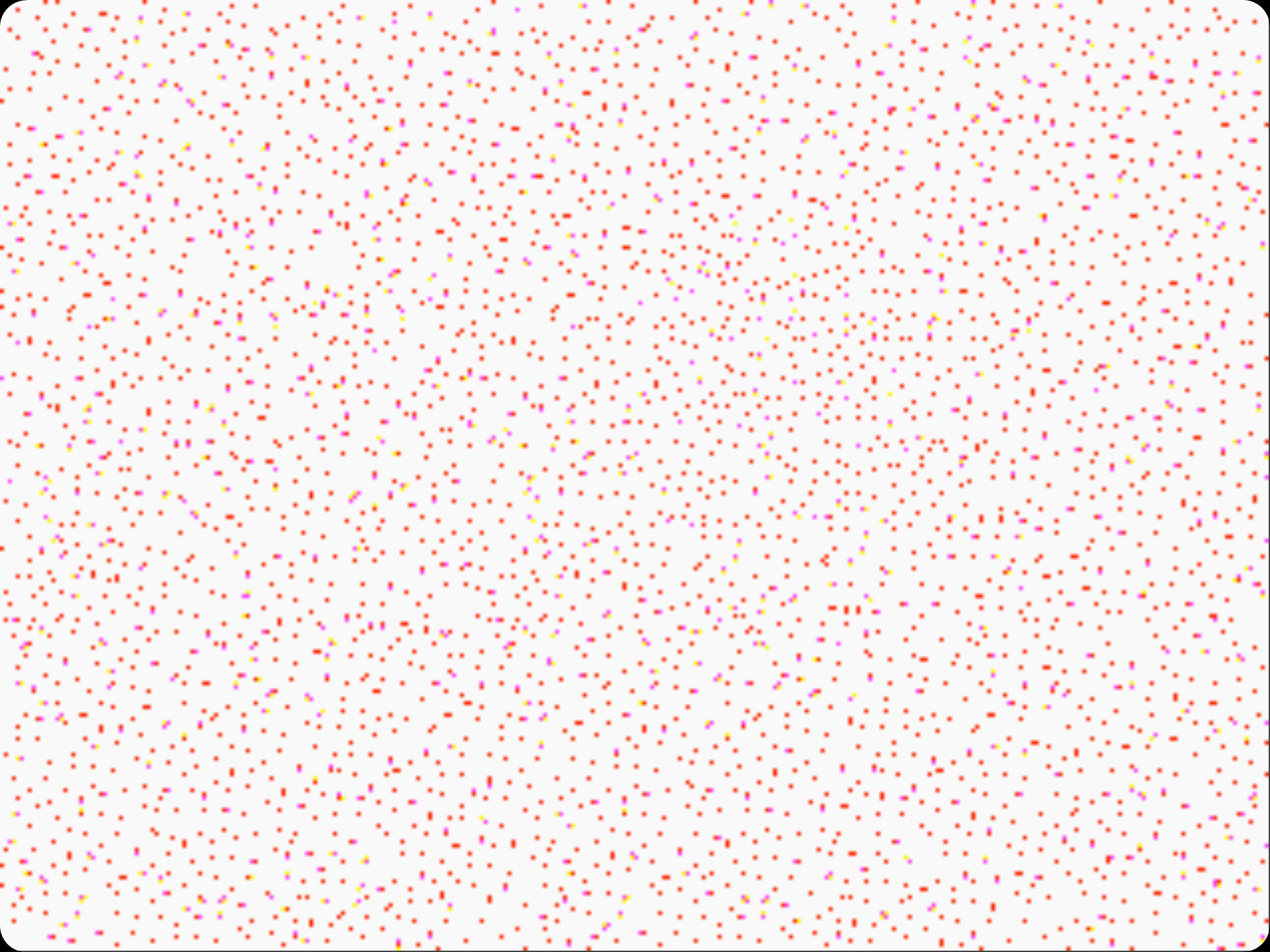
How many dots can we simultaneously track?

~4-6. Difficulty increases sig. at 6. [Yantis 92, Pylyshn 88, Cavanagh 05]

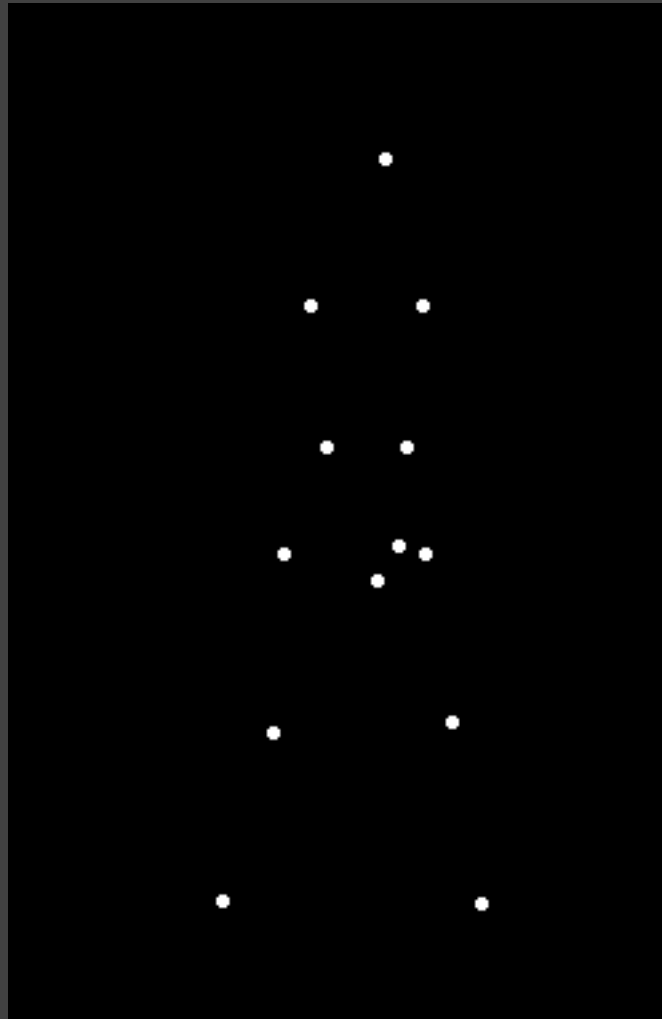
Grouped Dots Count as 1 Object



Dots moving together are grouped



Grouping of Biological Motion



[Johansson 73]

http://www.lifesci.sussex.ac.uk/home/George_Mather/Motion/WALK.MOV

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



start

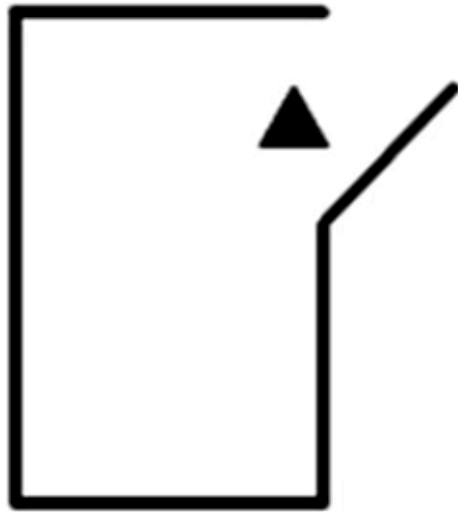
end

Shows transition better, but

Still may be too fast, or too slow

Too many objects may move at once

Constructing Narratives [Heider 44]



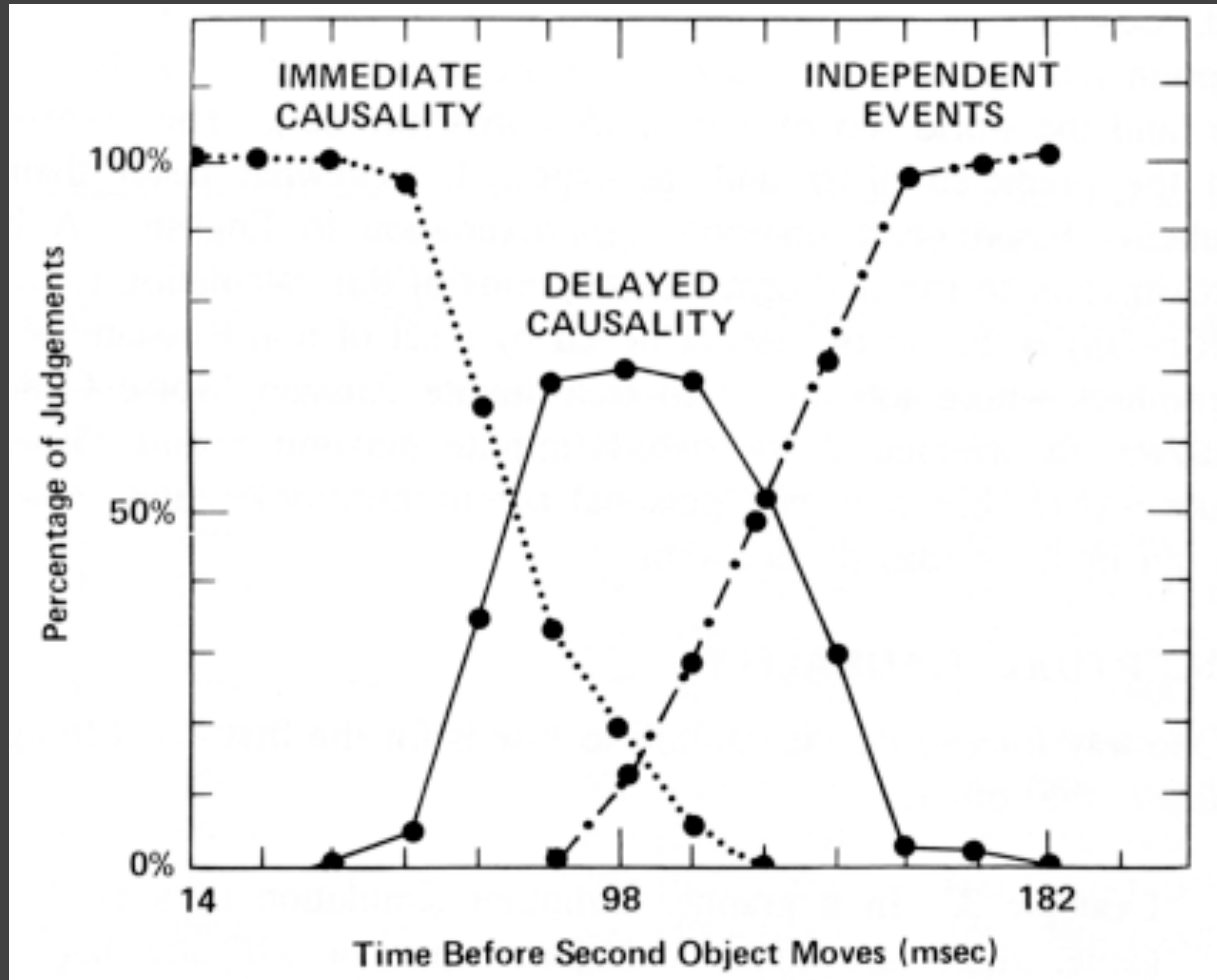
Attribution of Causality [Michotte 46]

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]

Animation

Helps?

Hurts?

Attention

direct attention

distraction

Constancy

change tracking

false relations

Causality

cause and effect

false agency

Engagement

increase interest

"chart junk"

Calibration

too slow: boring

too fast: errors



Problems with Animation [Tversky]

Difficult to estimate paths and trajectories

Motion is fleeting and transient

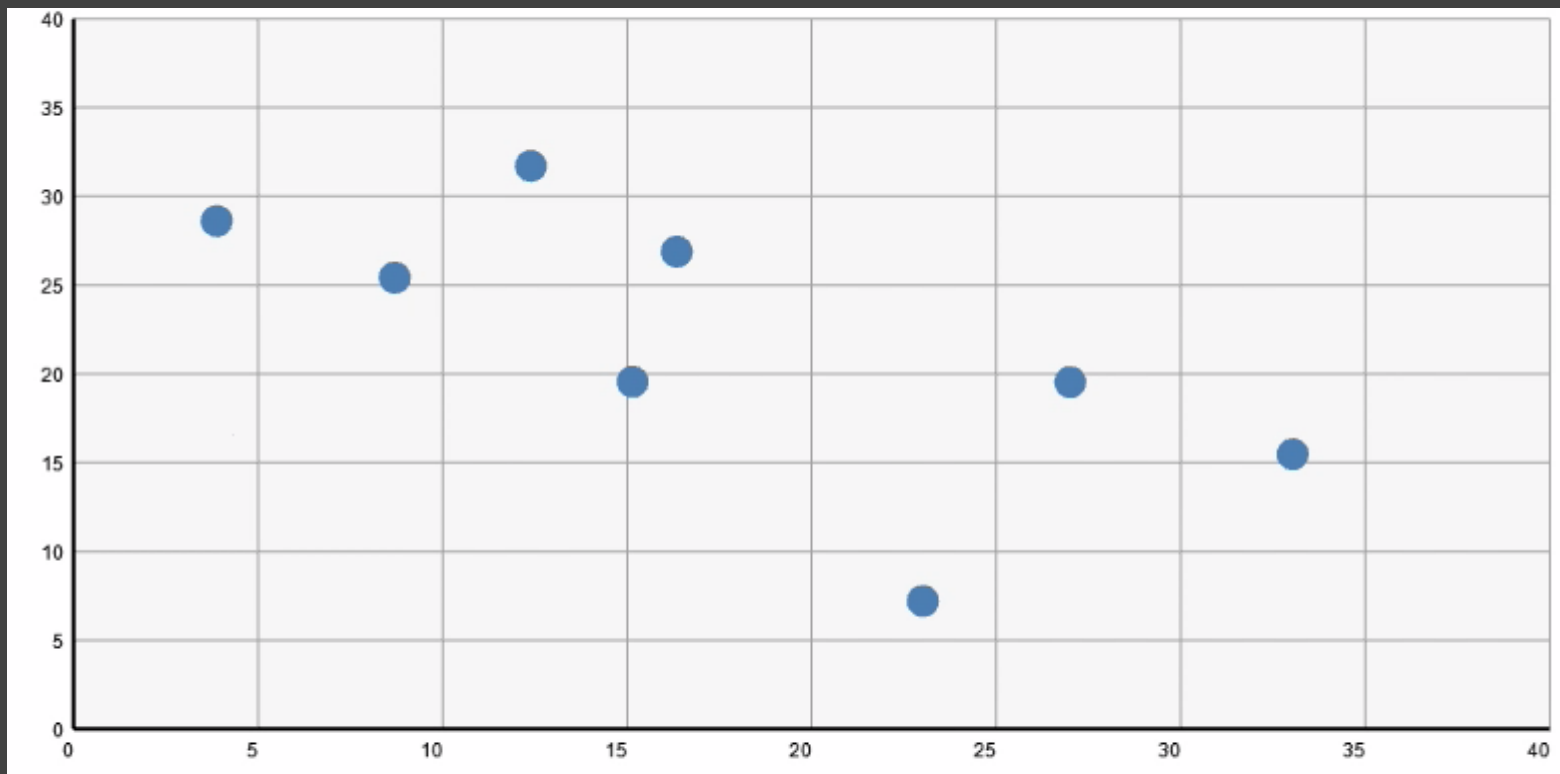
Cannot simultaneously attend to multiple motions

Parse motion into events, actions and behaviors

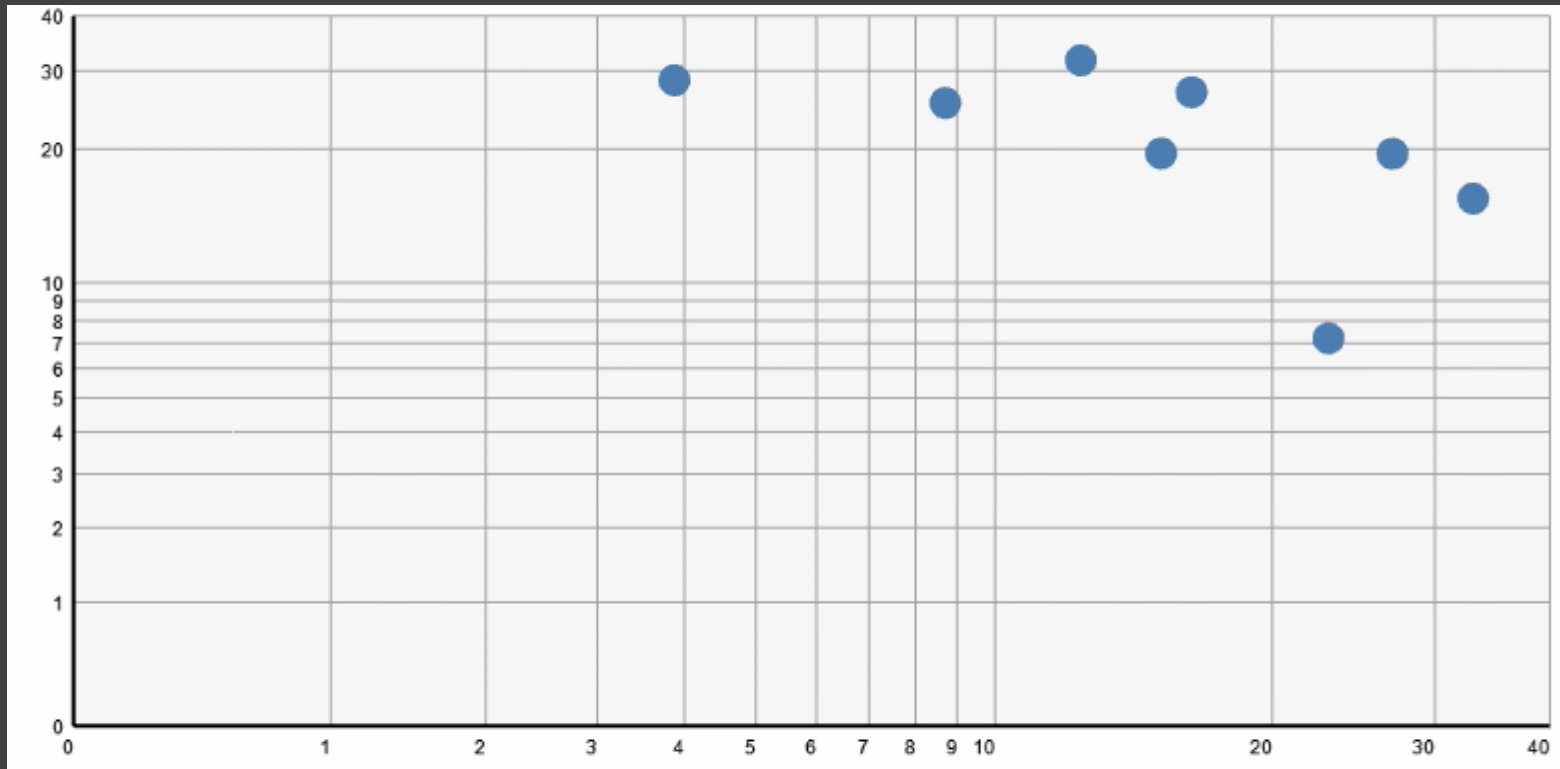
Misunderstanding and wrongly inferring causality

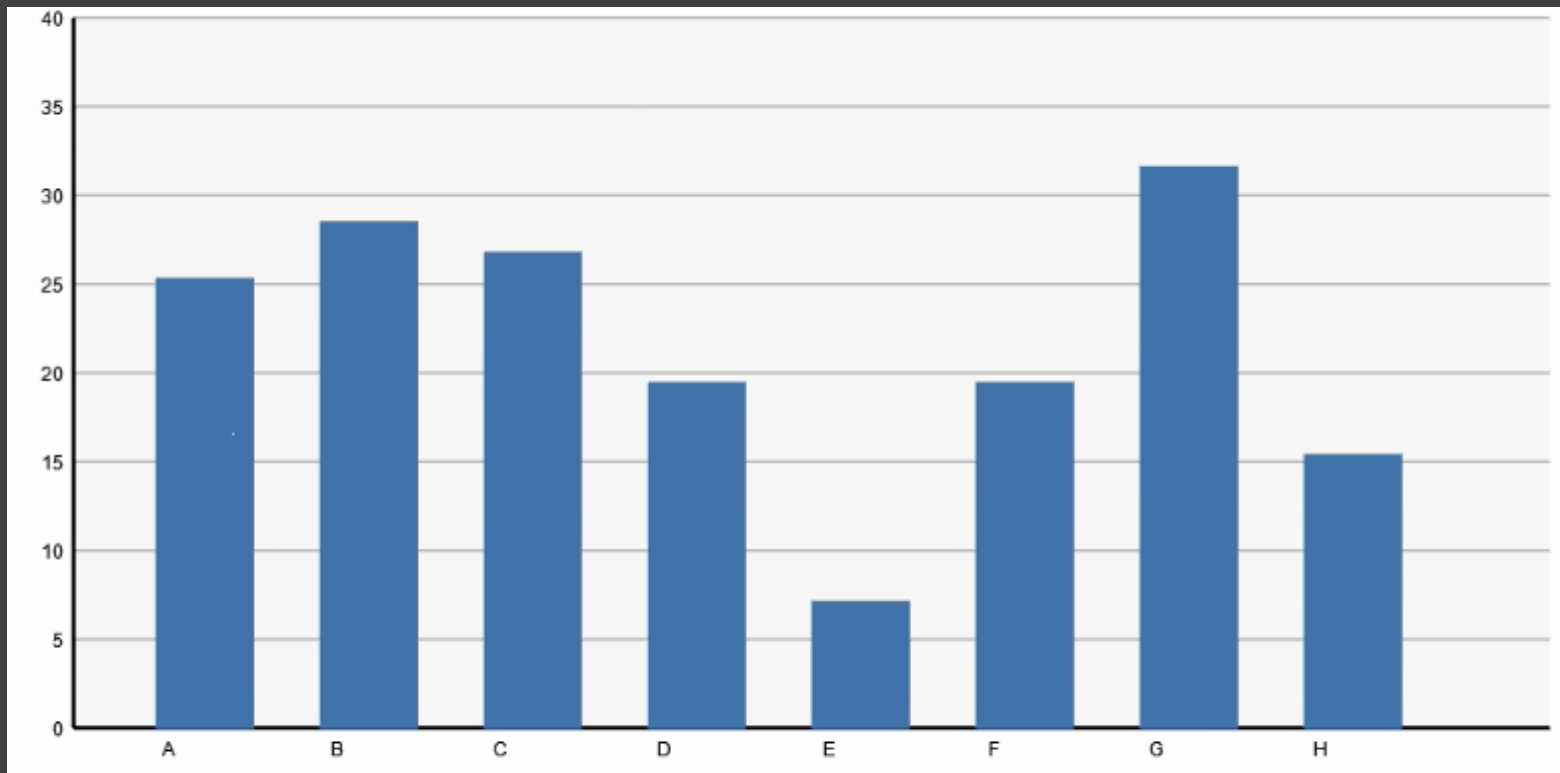
Anthropomorphizing physical motion may cause confusion or lead to incorrect conclusions

Animated Transitions in Statistical Graphics

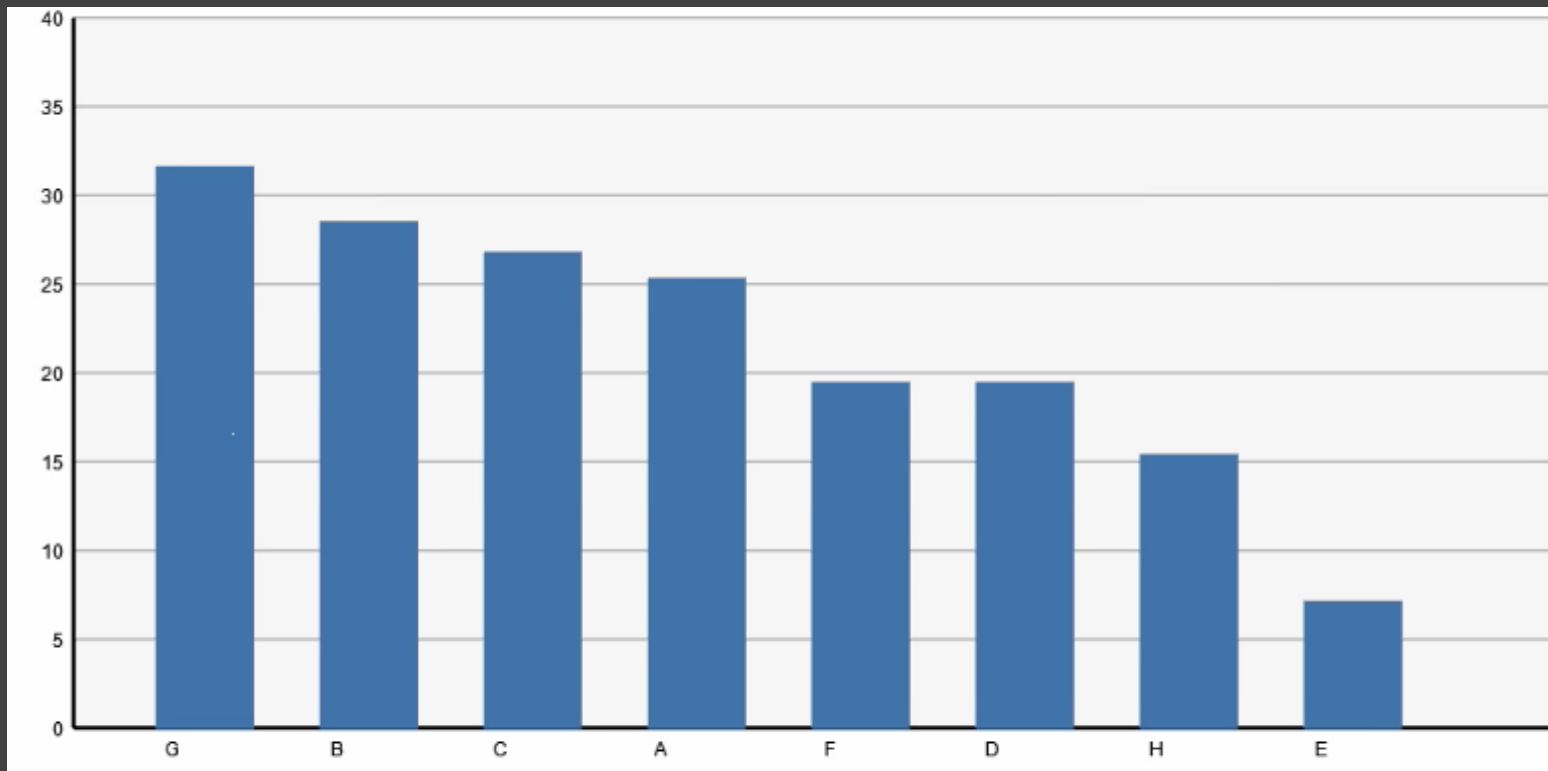


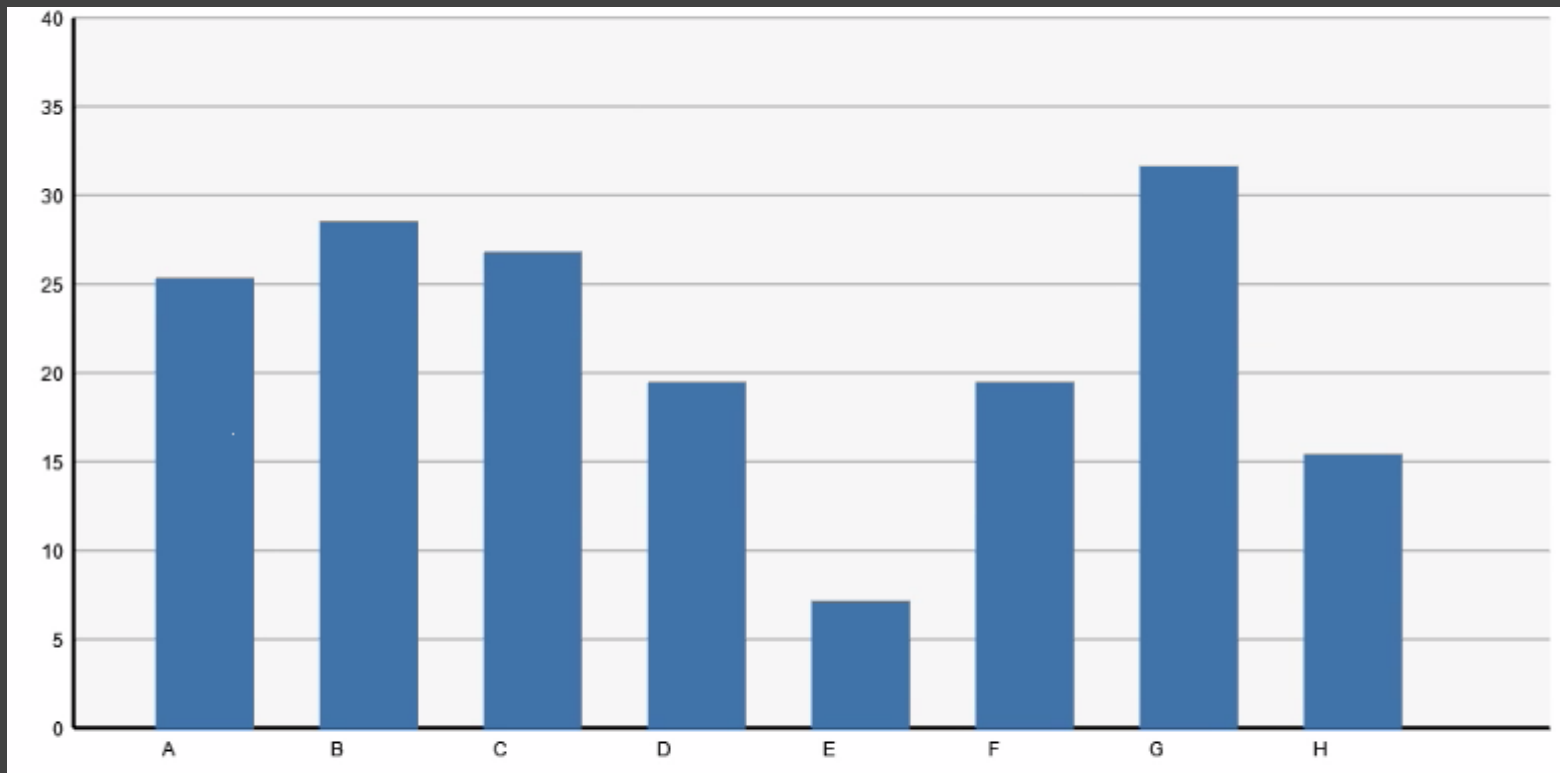
Log Transform



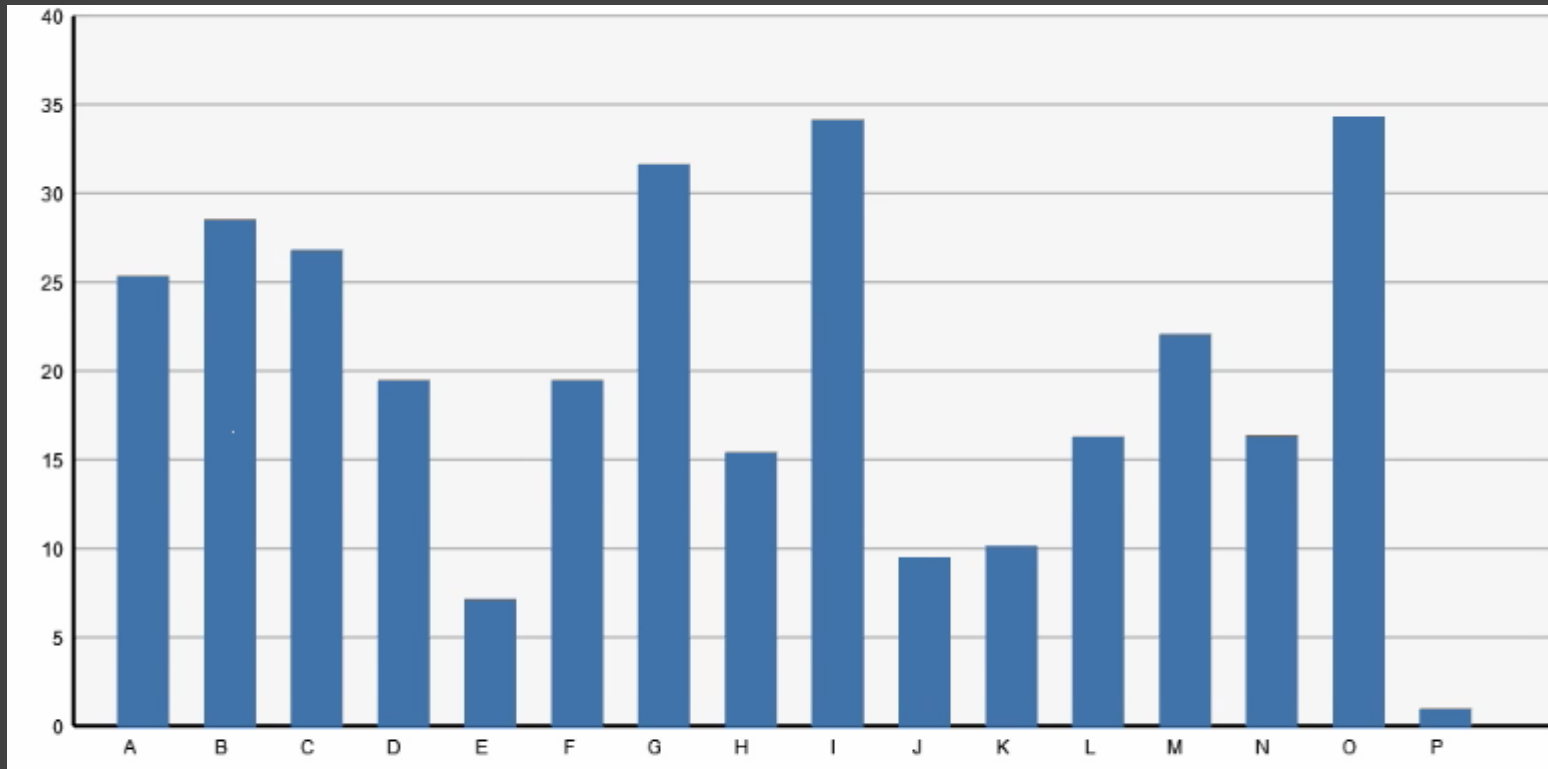


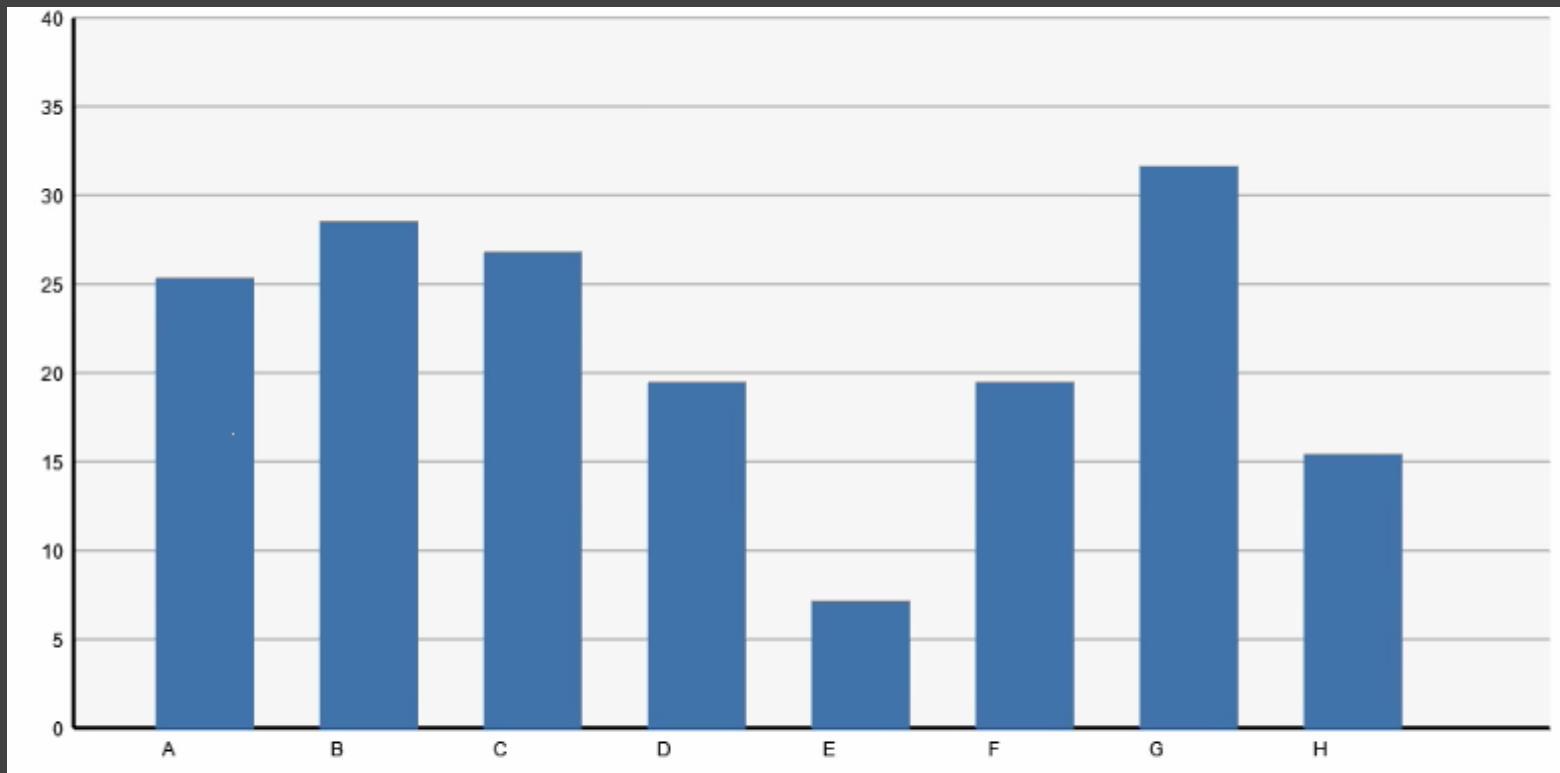
Sorting

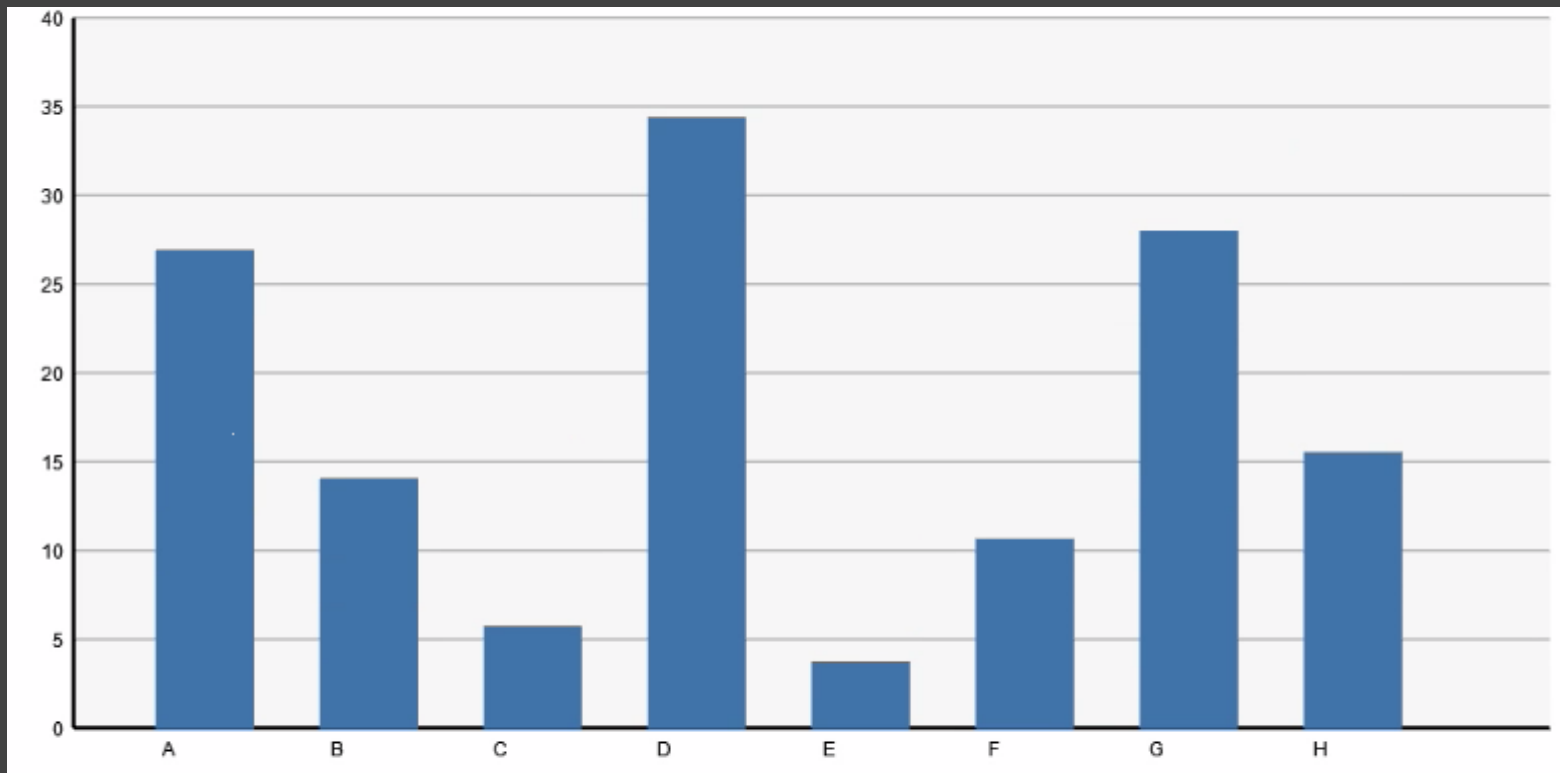


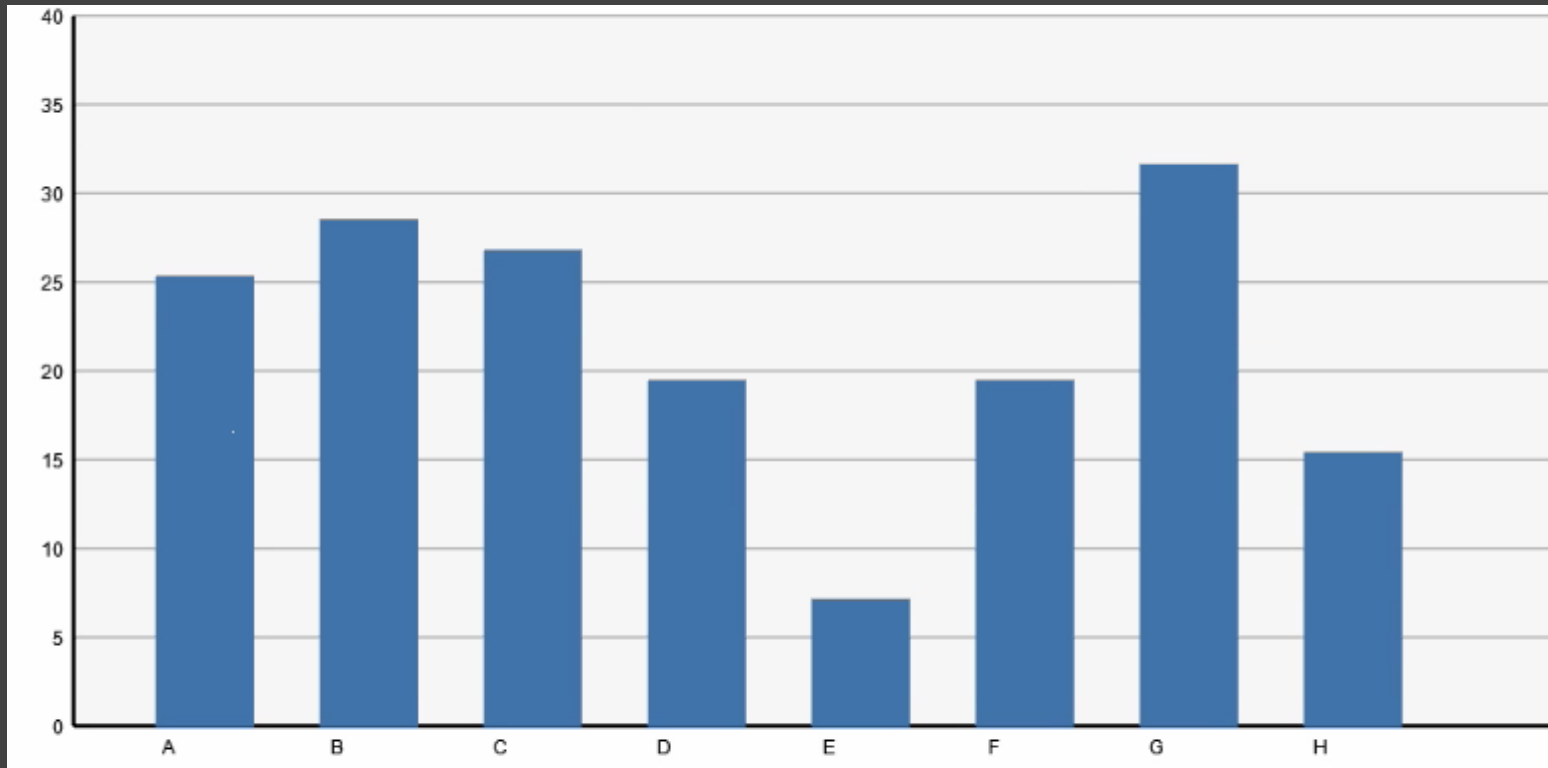


Filtering



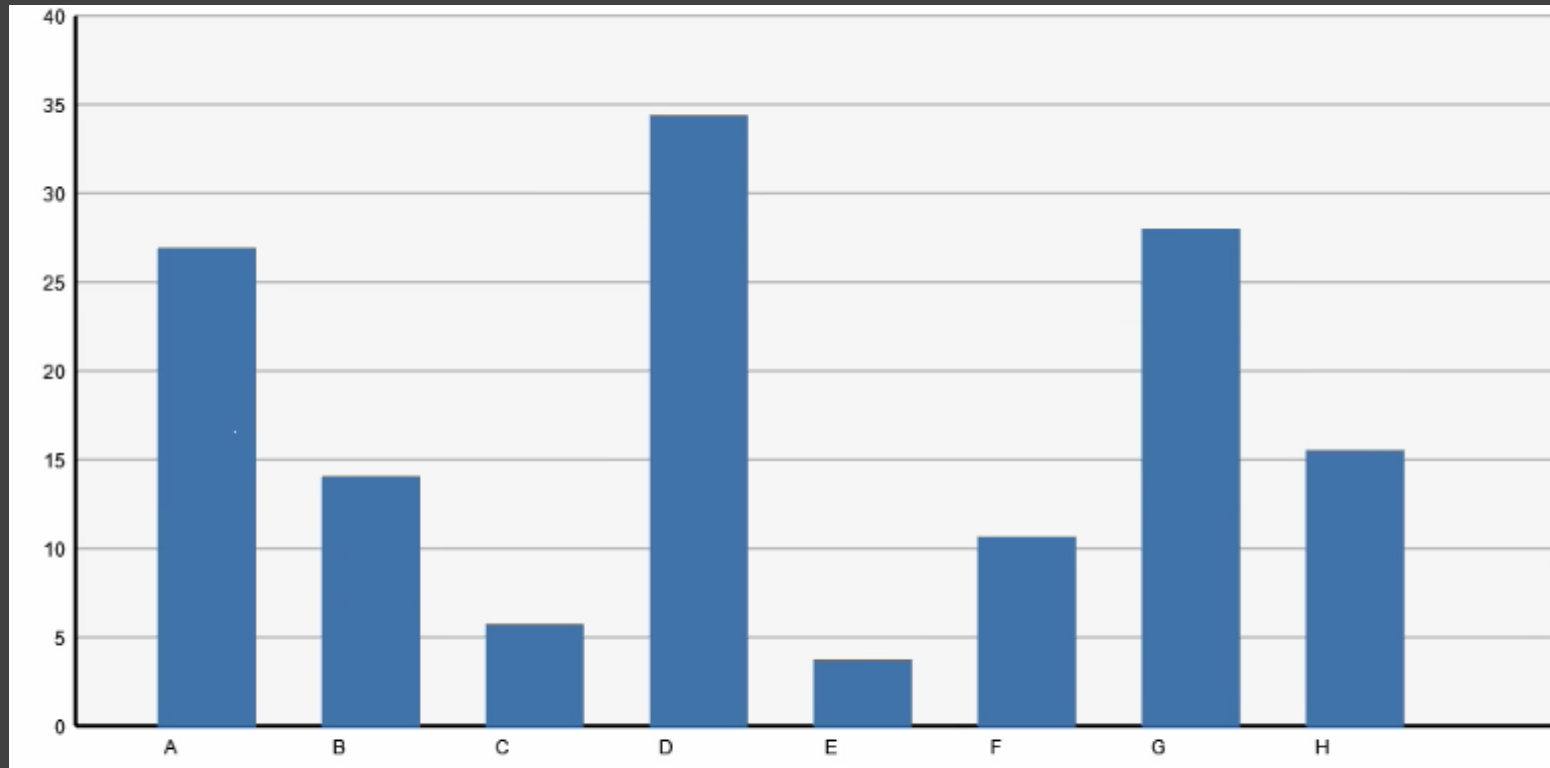




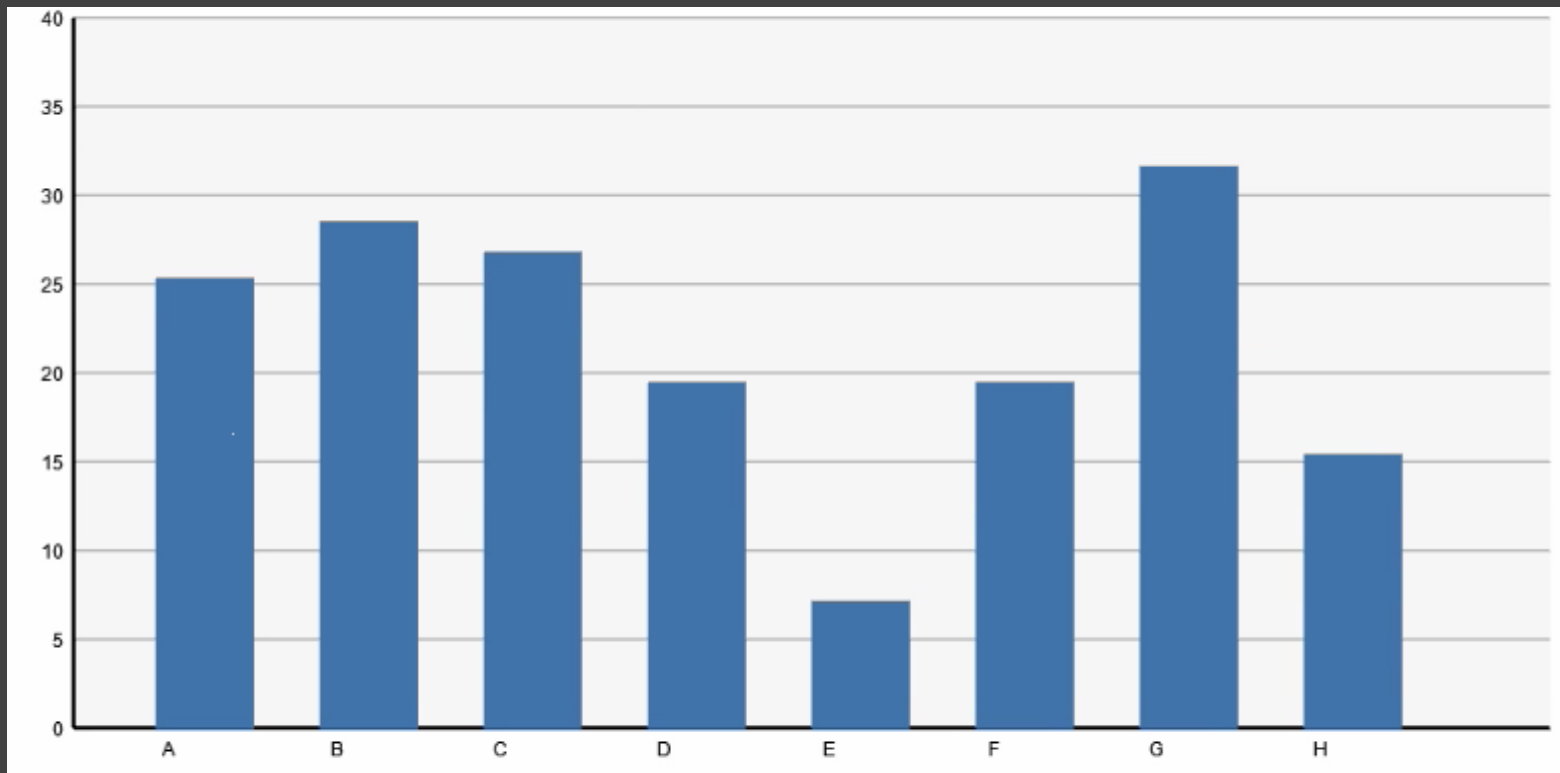


Month 1

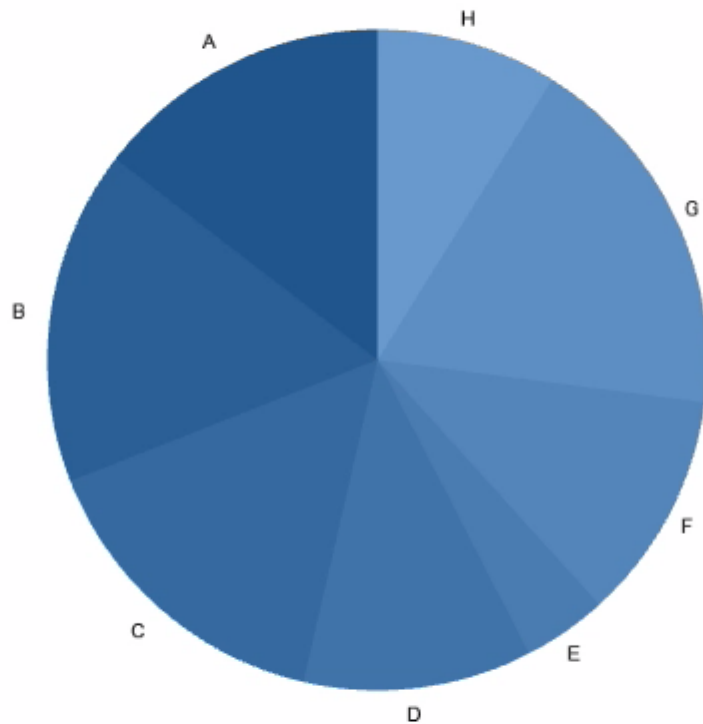
Timestep

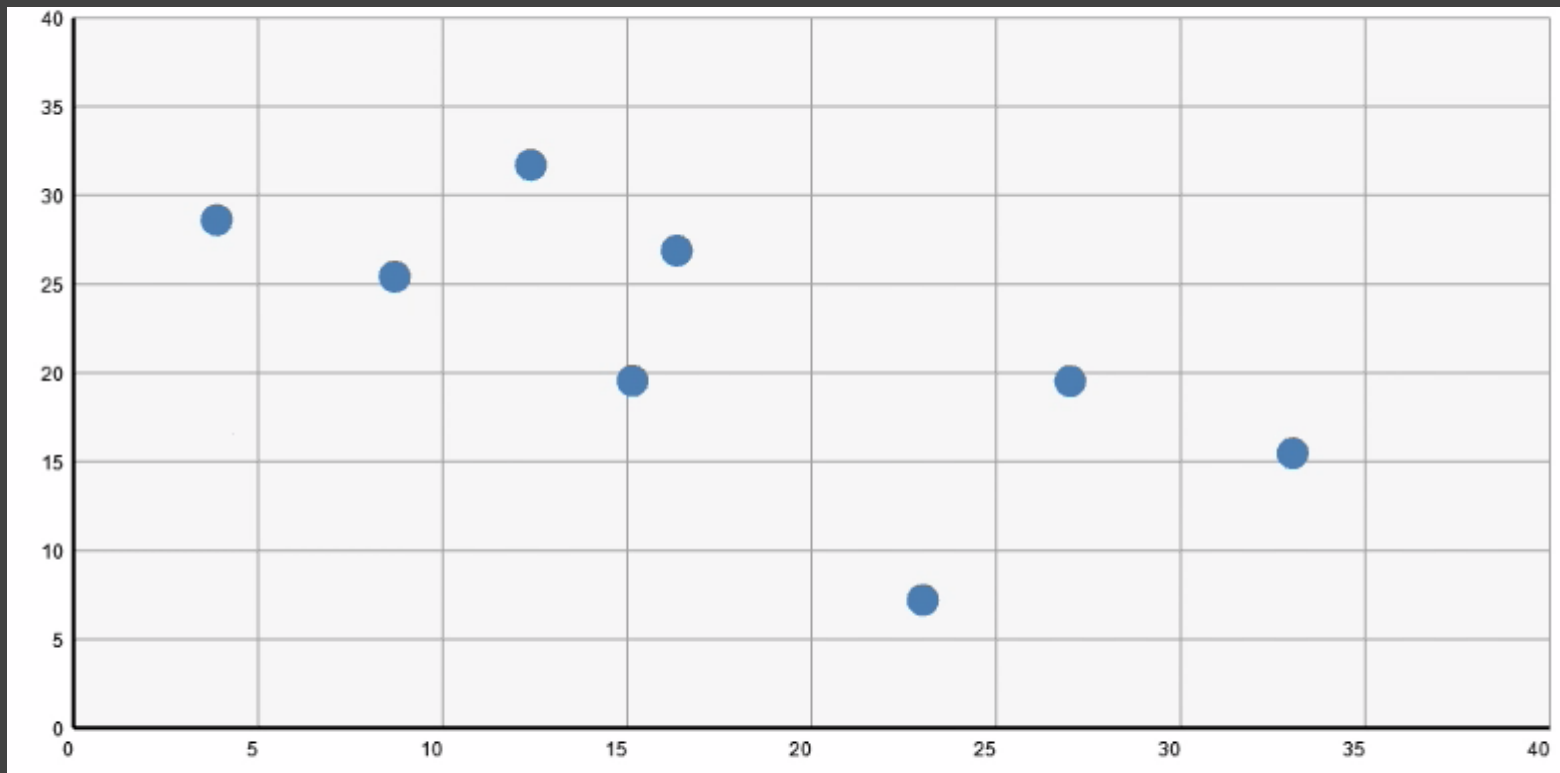


Month 2

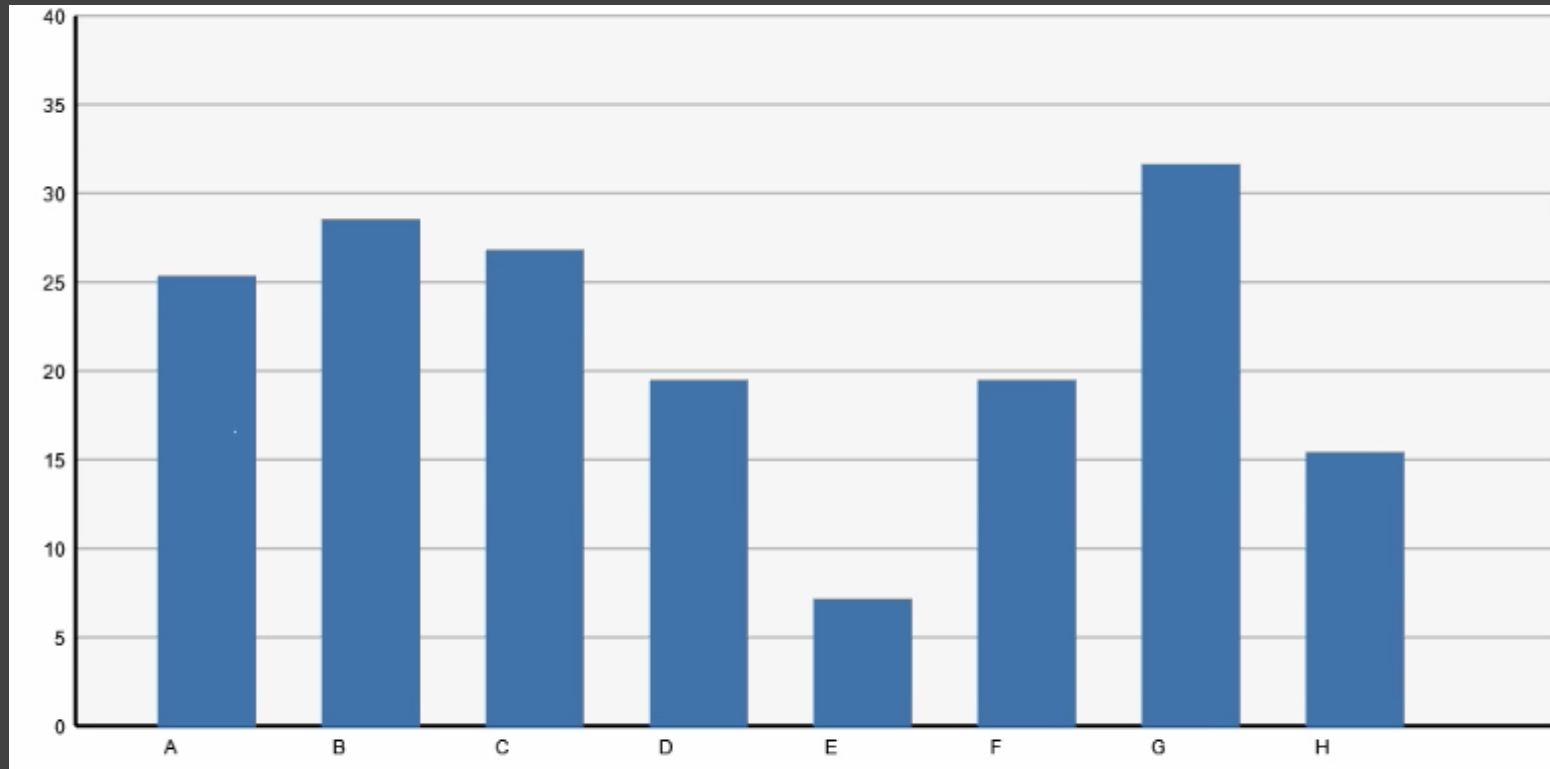


Change Encodings

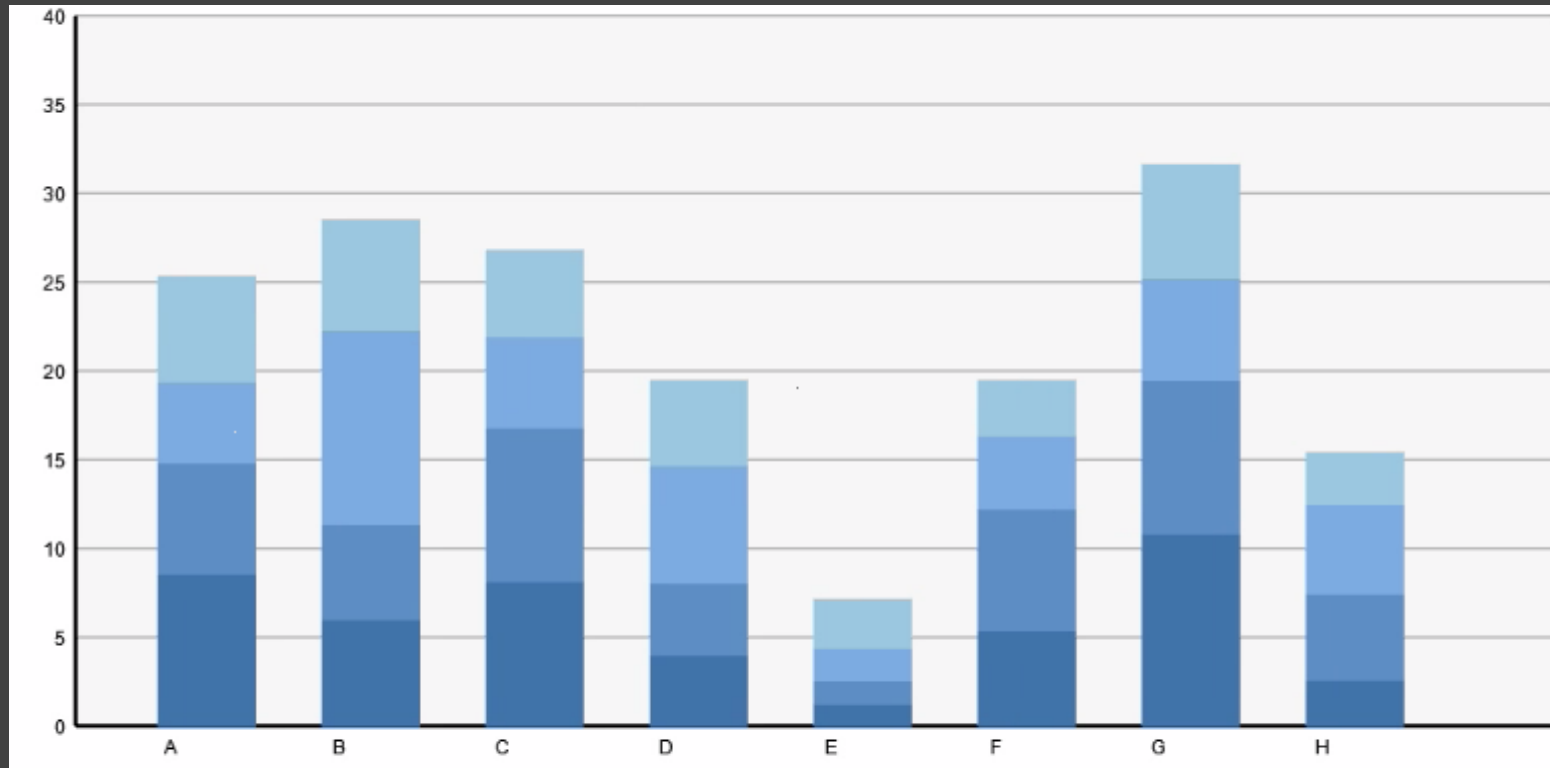




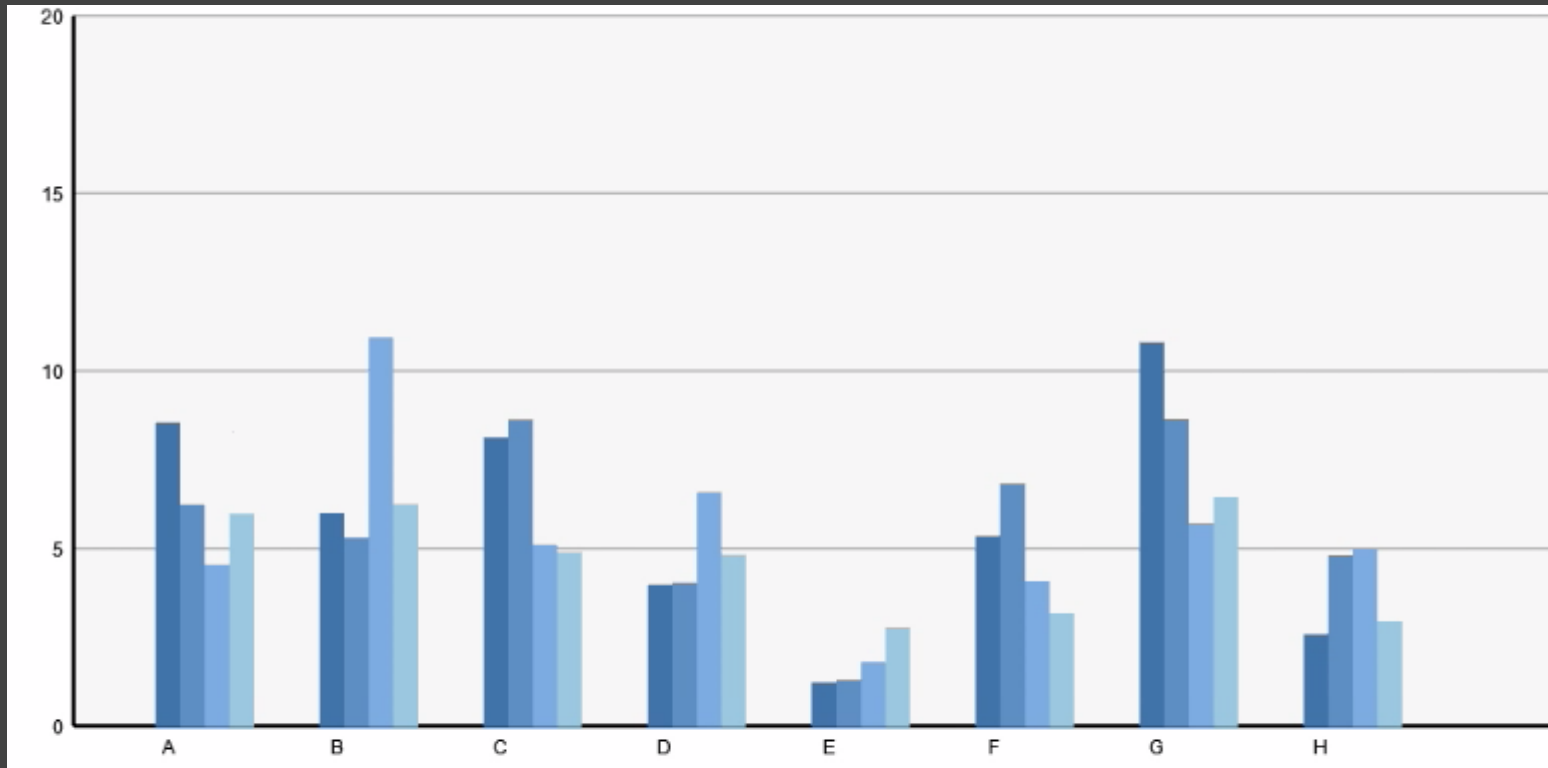
Change Data Dimensions



Change Data Dimensions



Change Encodings + Axis Scales

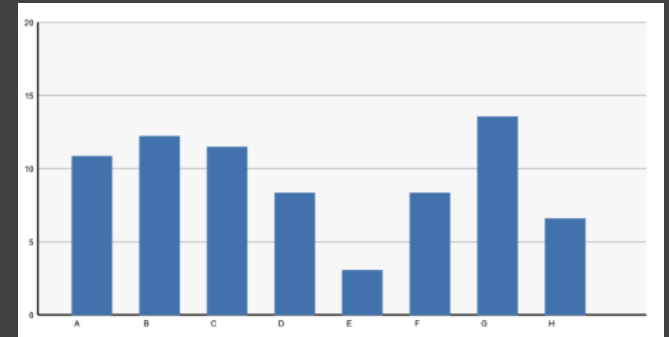


Data Graphics & Transitions

Category	Sales	Profit
A	11	7
B	13	10
C	12	6
D	8	5
E	3	1



Visual Encoding



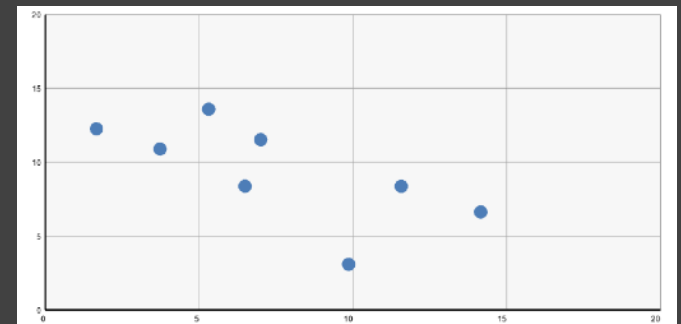
Change selected data dimensions or encodings



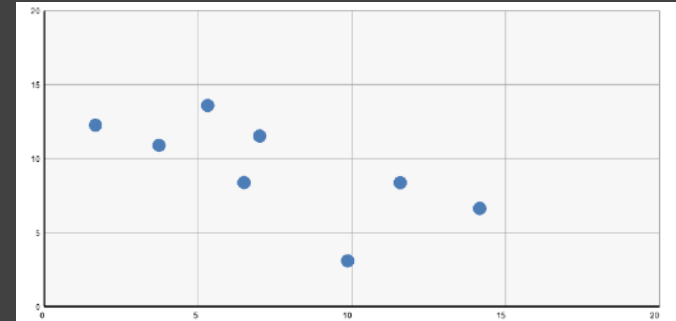
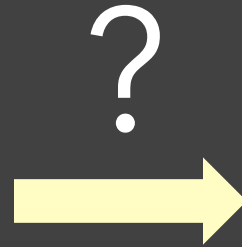
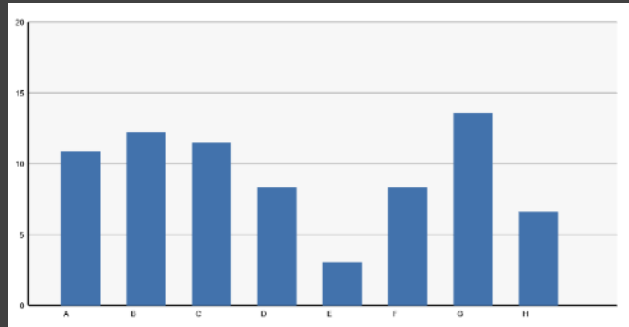
Category	Sales	Profit
A	11	7
B	13	10
C	12	6
D	8	5
E	3	1



Animation to communicate changes?



Transitions between Data Graphics



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

Expressiveness?

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

Apprehension

Effectiveness?

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

[from Tversky 02]

Principles for Animation [Heer]

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 [Heer]

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 [Heer]

Congruence

Maintain valid data graphics during transitions

Use consistent syntactic/semantic mappings

Respect semantic correspondence

Avoid ambiguity



Different operators should have distinct animations.

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 [Heer]

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 [Heer]

Congruence

Maintain valid data graphics during transitions

Use consistent syntactic/semantic mappings

Respect semantic correspondence

Avoid ambiguity

Apprehension

Group similar transitions

Minimize occlusion

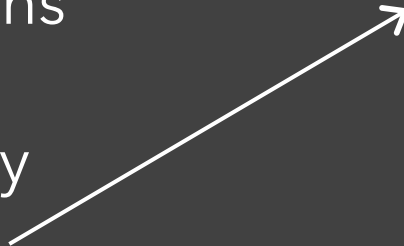
Maximize predictability

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.



Animated Transitions in Statistical Data Graphics

**Jeffrey Heer
George G. Robertson**

Microsoft
Research

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)

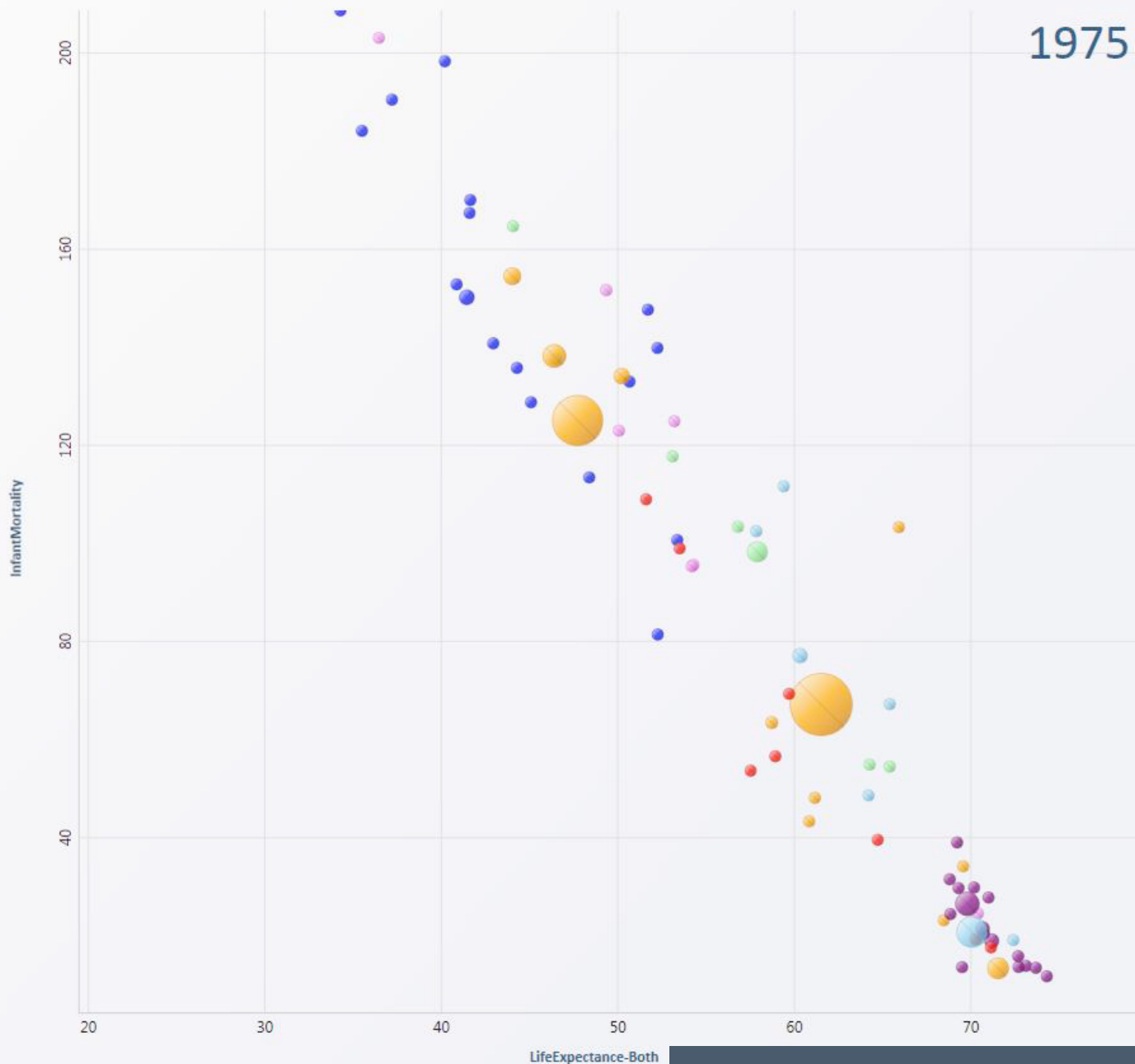
Subjects preferred animated transitions

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
(10 Year Test-of-Time Award at InfoVis 2018!)



1975

Color Legend (continent)

- Africa
- Asia
- Europe
- Middle East
- North America
- Oceania
- South America

Task

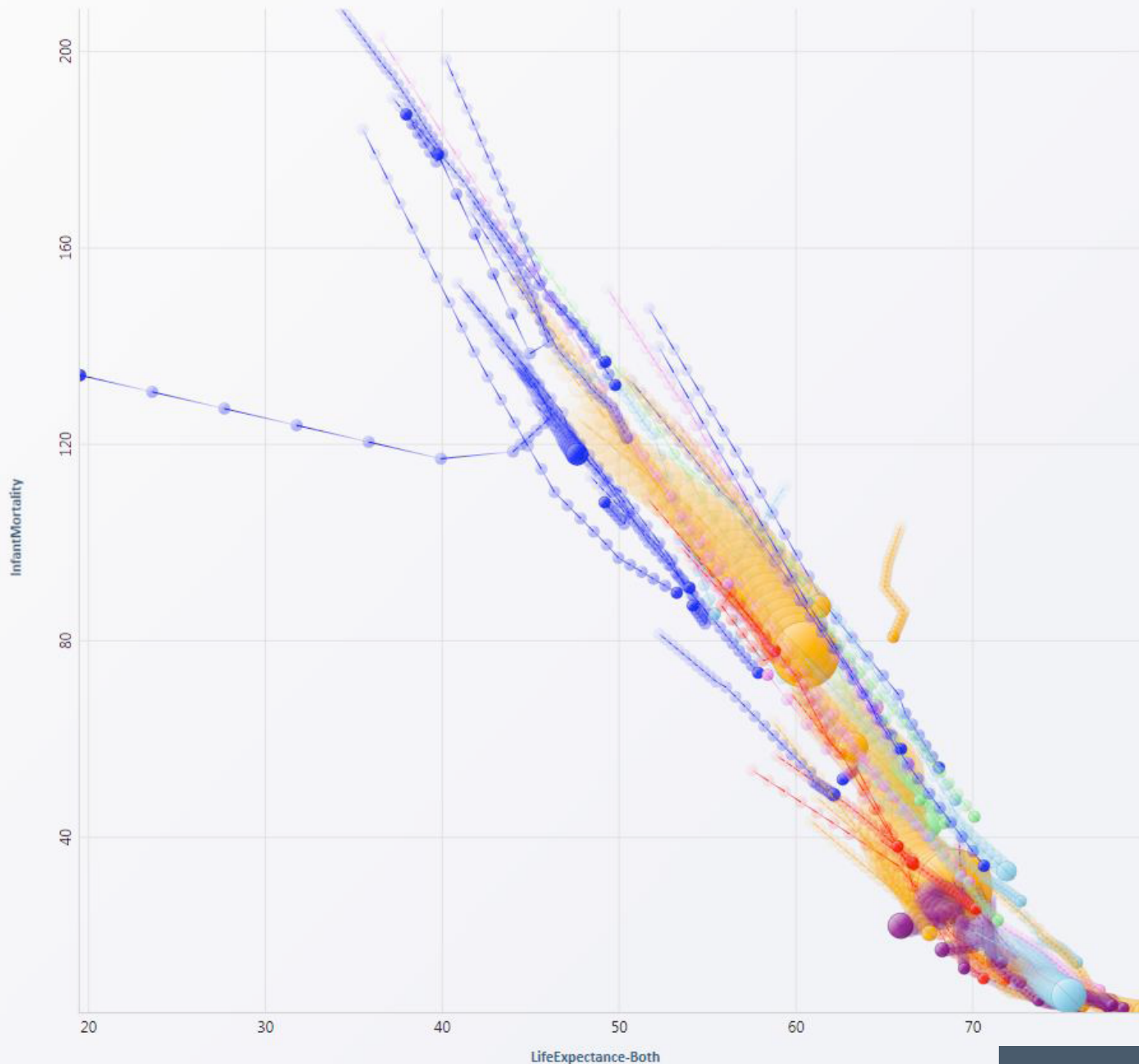
Select two countries with decreasing InfantMortality, but little change in life expectancy.

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)



Color Legend (continent)

- Africa
- Asia
- Europe
- Middle East
- North America
- Oceania
- South America

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

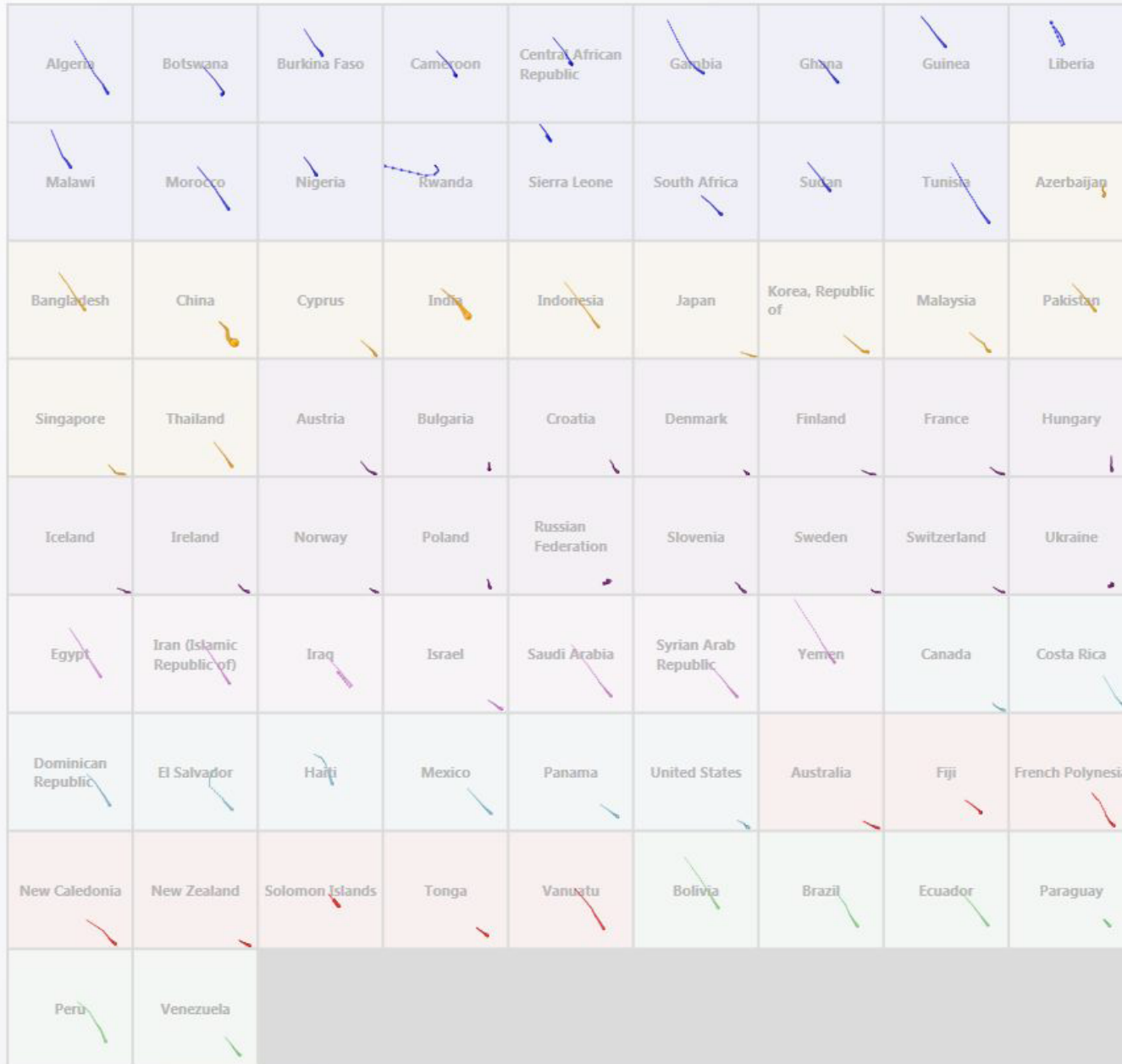
Next

Click on "Next" when finished (or "Give Up" if you cannot find all the answers)

Give Up

Next

InfantMortality



LifeExpectance-Both

Color Legend (continent)

- Africa
- Asia
- Europe
- Middle East
- North America
- Oceania
- South America

Task

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

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

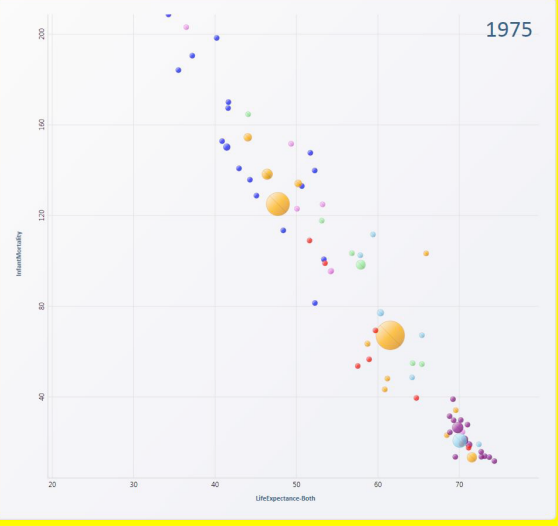
Answers set: 0/2

Next

Click on "Next" when finished (or "Give Up" if you cannot find all the answers)

Give Up

Next



Color Legend (continent)

- Africa
- Europe
- Middle East
- North America
- Oceania
- South America

Task

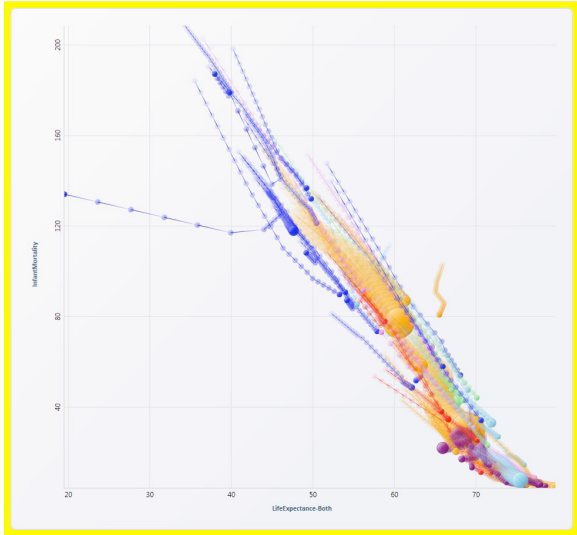
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Click on "Next" when finished (or "Give Up" if you cannot find all the answers)



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- Africa
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- South America

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)



Color Legend (continent)

- Africa
- Europe
- Middle East
- North America
- Oceania
- South America

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)

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!)

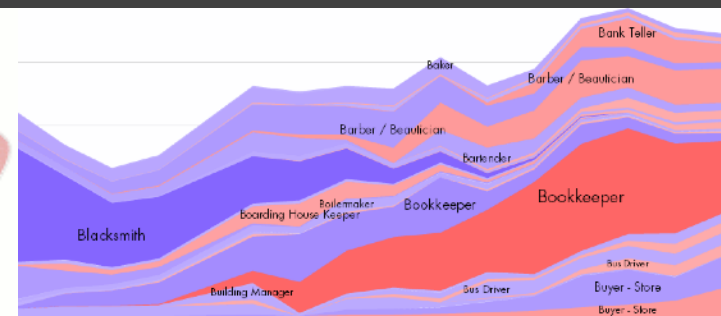
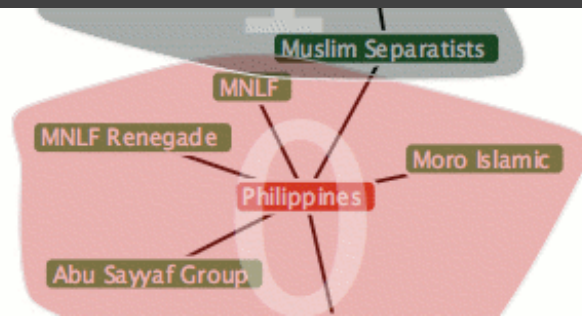
Administrivia

A3: Interactive Prototype

Create an interactive visualization. Choose a driving question for a dataset and develop an appropriate visualization + interaction techniques, then deploy your visualization on the web.

Due by *11:59pm* on **Monday, Feb 14.**

Work in project teams of 3-4 people.



Implementing Animation

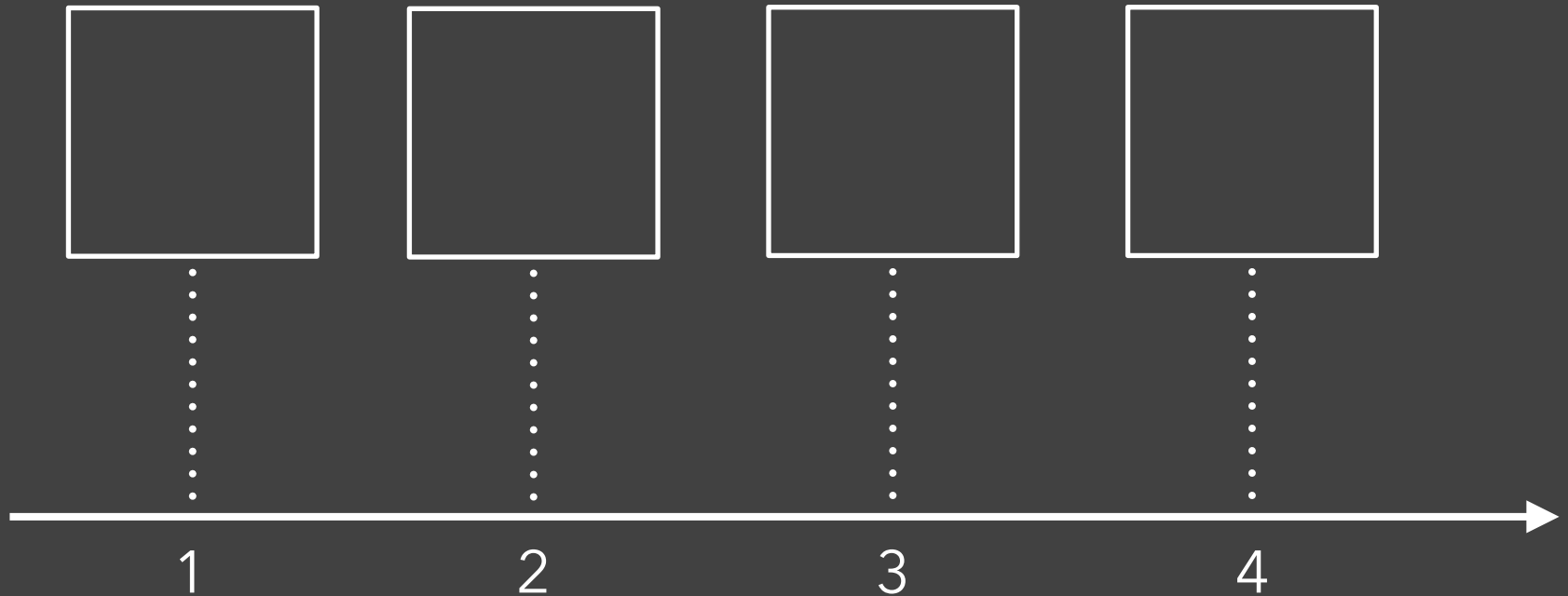
Animation Approaches

Frame-Based Animation

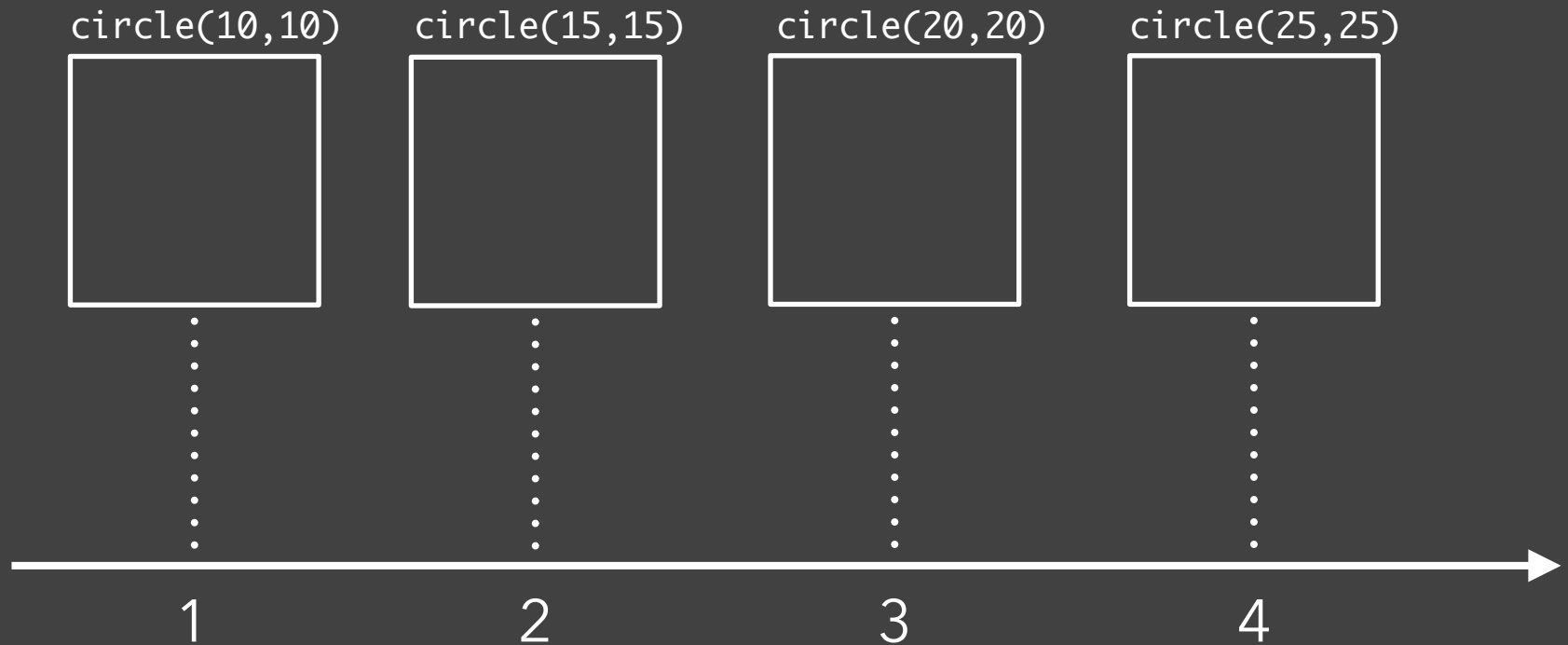
Redraw scene at regular interval (e.g., 16ms)

Developer defines the redraw function

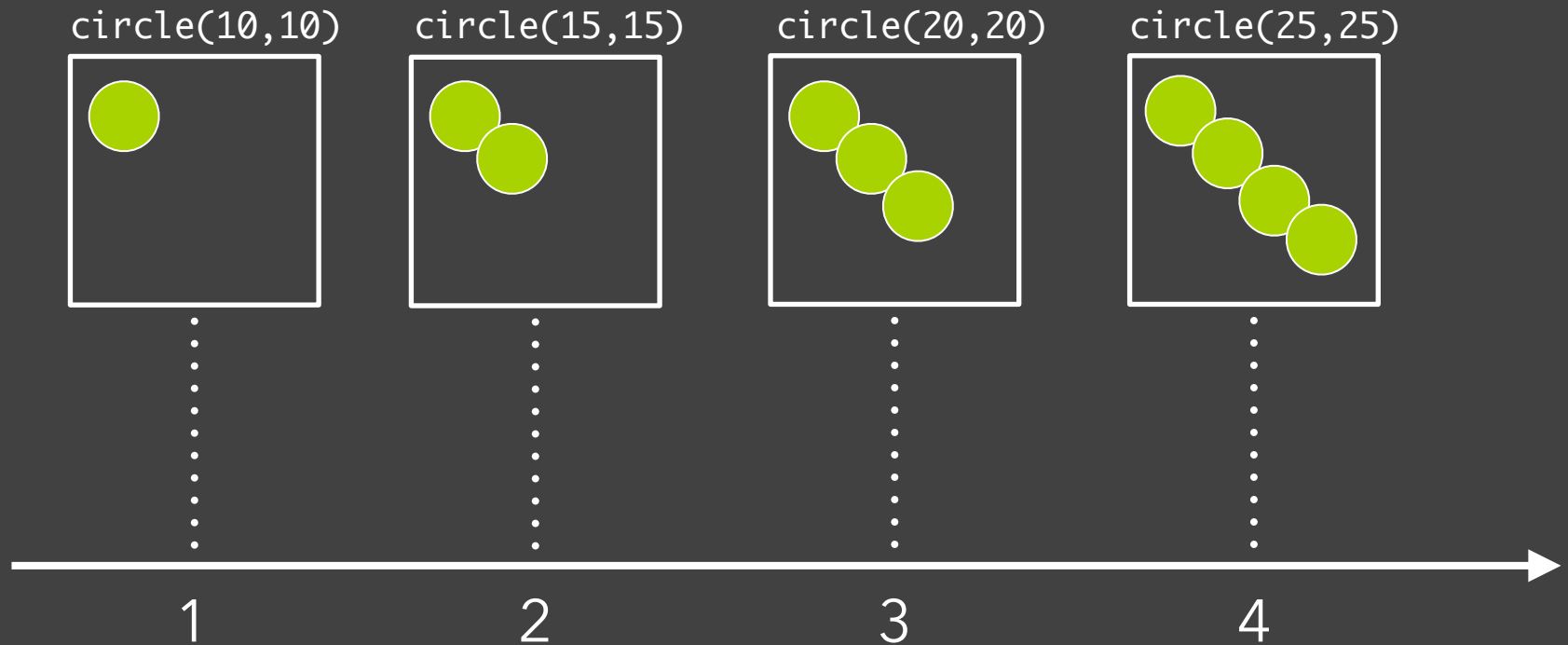
Frame-Based Animation



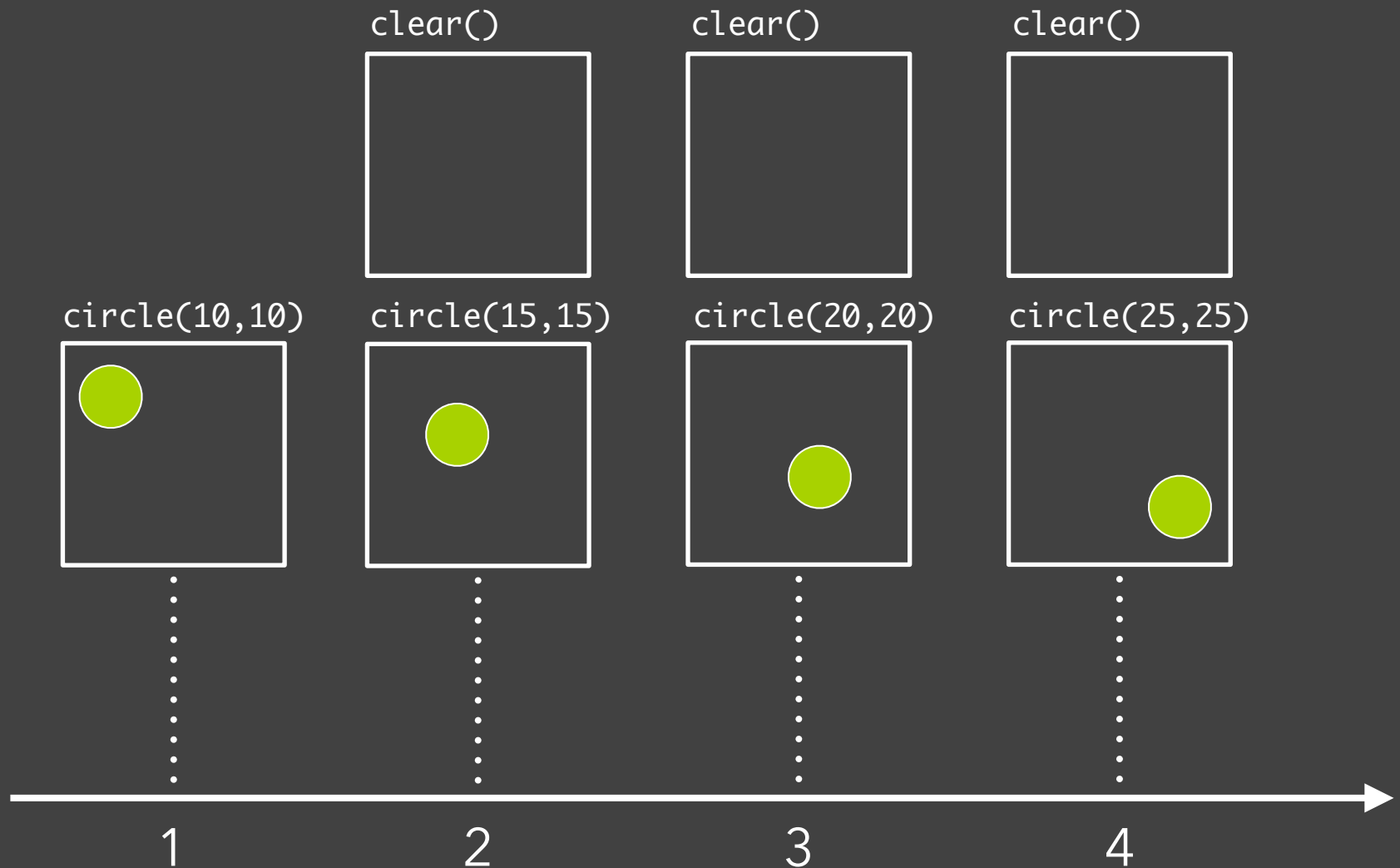
Frame-Based Animation



Frame-Based Animation



Frame-Based Animation



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")

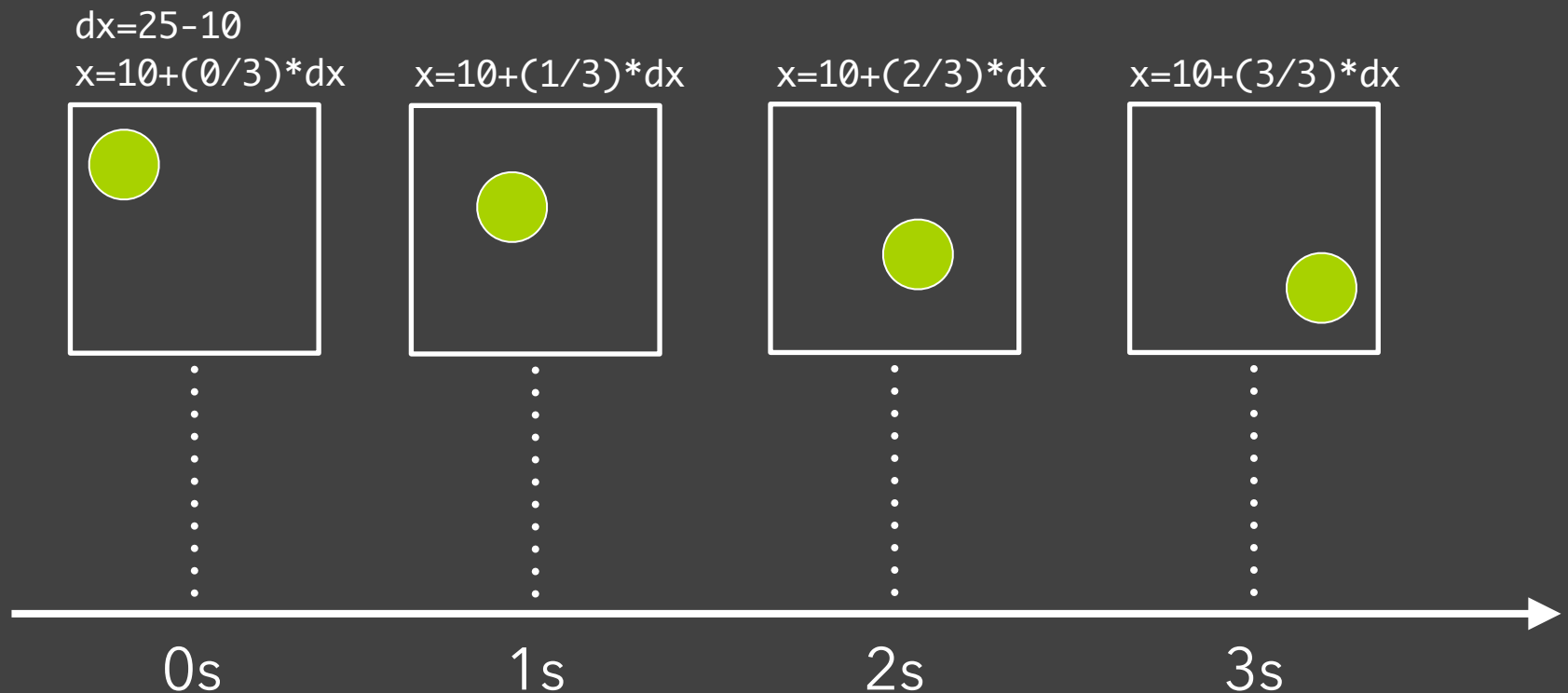
Typically computed via **interpolation**

```
step(fraction) {  $x_{\text{now}} = x_{\text{start}} + \textit{fraction} * (x_{\text{end}} - x_{\text{start}});$  }
```

Timing & redraw managed by UI toolkit

Transition-Based Animation

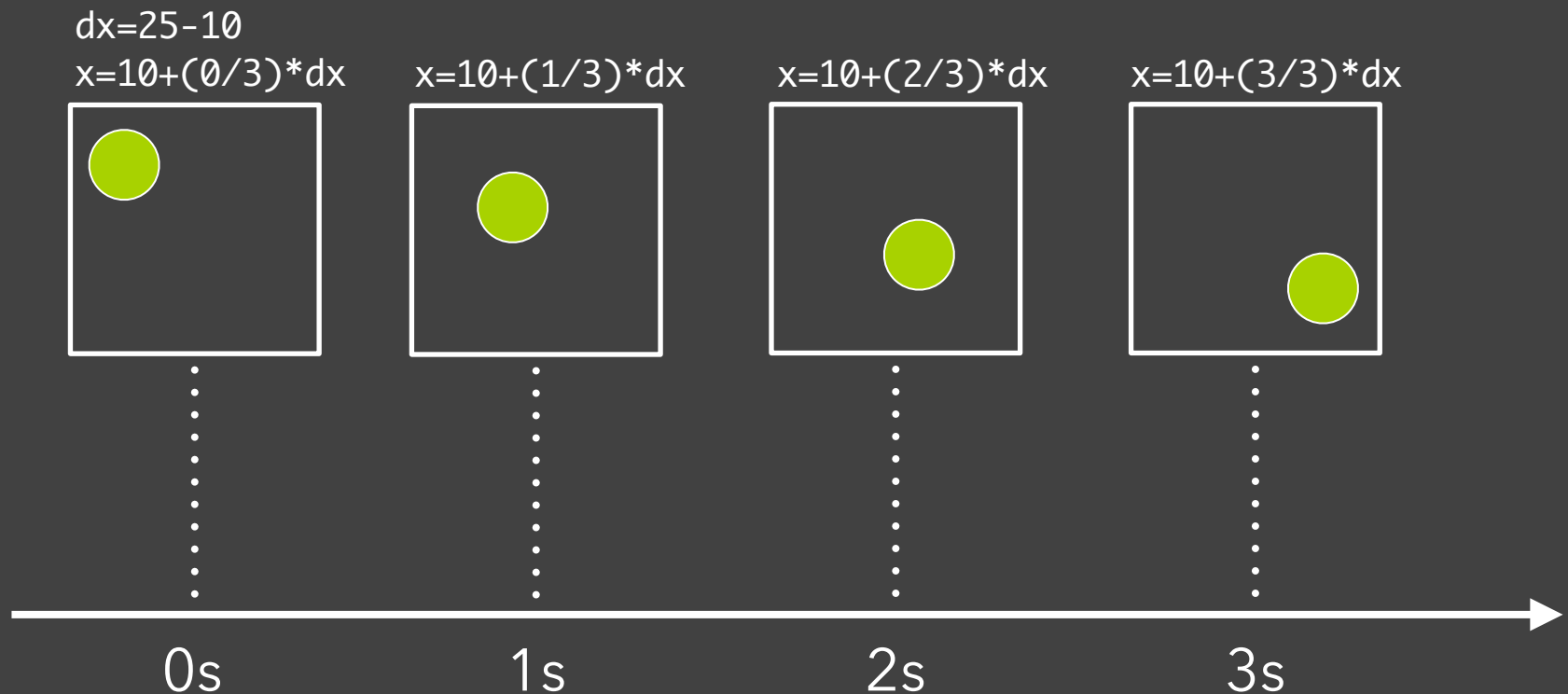
from: (10,10) to: (25,25) duration: 3sec



Transition-Based Animation

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

Toolkit handles frame-by-frame updates!



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));
```

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));
```

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

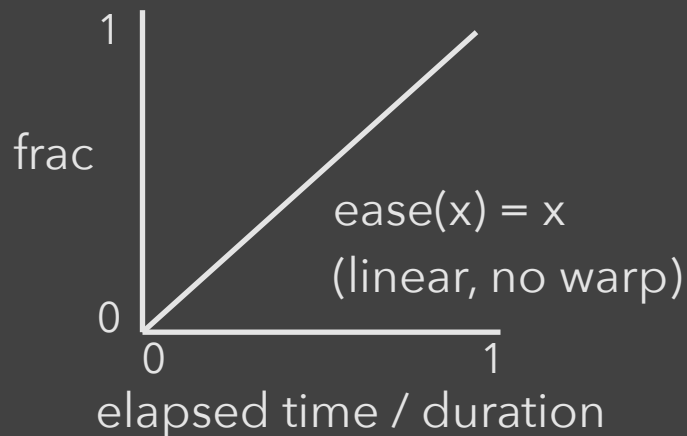
Goals: stylize animation, improve perception.

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

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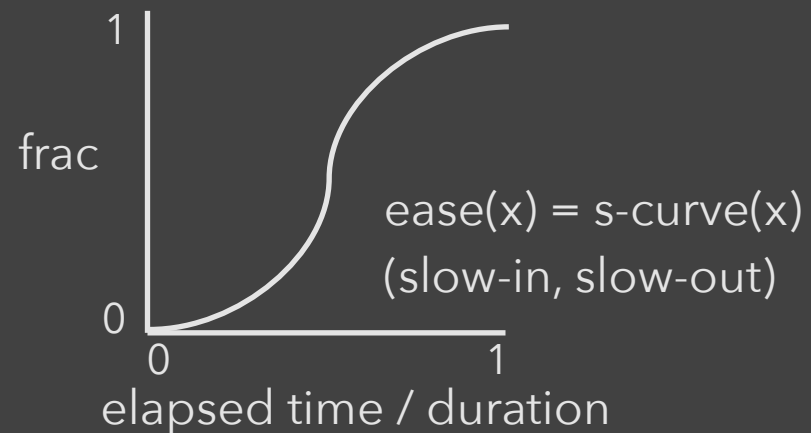
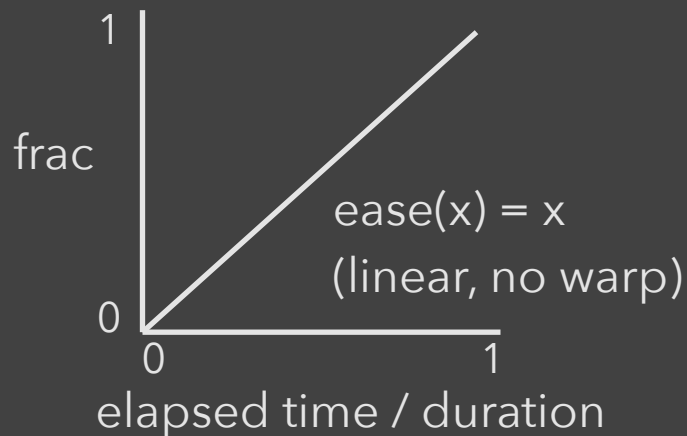
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Easing (or "Pacing") Functions

Goals: stylize animation, improve perception.

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easeInSine

easeOutSine

easeInOutSine

easeInQuad

easeOutQuad

easeInOutQuad



easeInCubic

easeOutCubic

easeInOutCubic

easeInQuart

easeOutQuart

easeInOutQuart



easeInQuint

easeOutQuint

easeInOutQuint

easeInExpo

easeOutExpo

easeInOutExpo



easeInCirc

easeOutCirc

easeInOutCirc

easeInBack

easeOutBack

easeInOutBack



easeInElastic

easeOutElastic

easeInOutElastic

easeInBounce

easeOutBounce

easeInOutBounce



<http://easings.net/>

CSS Transitions

Extends CSS with Animated Transitions

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

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

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↑ **Property** ↑ **Easing**

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Duration ↓
↑ **Property** ↑ **Easing**

```
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```

← **Animate color transition upon mouse in / out.**

Summary

Animation is a salient visual phenomenon

Attention, object constancy, causality, timing

Design with care: congruence & apprehension

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