Building a grammar for statistical graphics in Clojure

Kevin Lynagh
Keming Labs @lynaghk

2012 November 9
Øredev
Malmö, Sweden

Agenda

Agenda

4 Data Visualization

Agenda

A Grammar of Graphics

Agenda

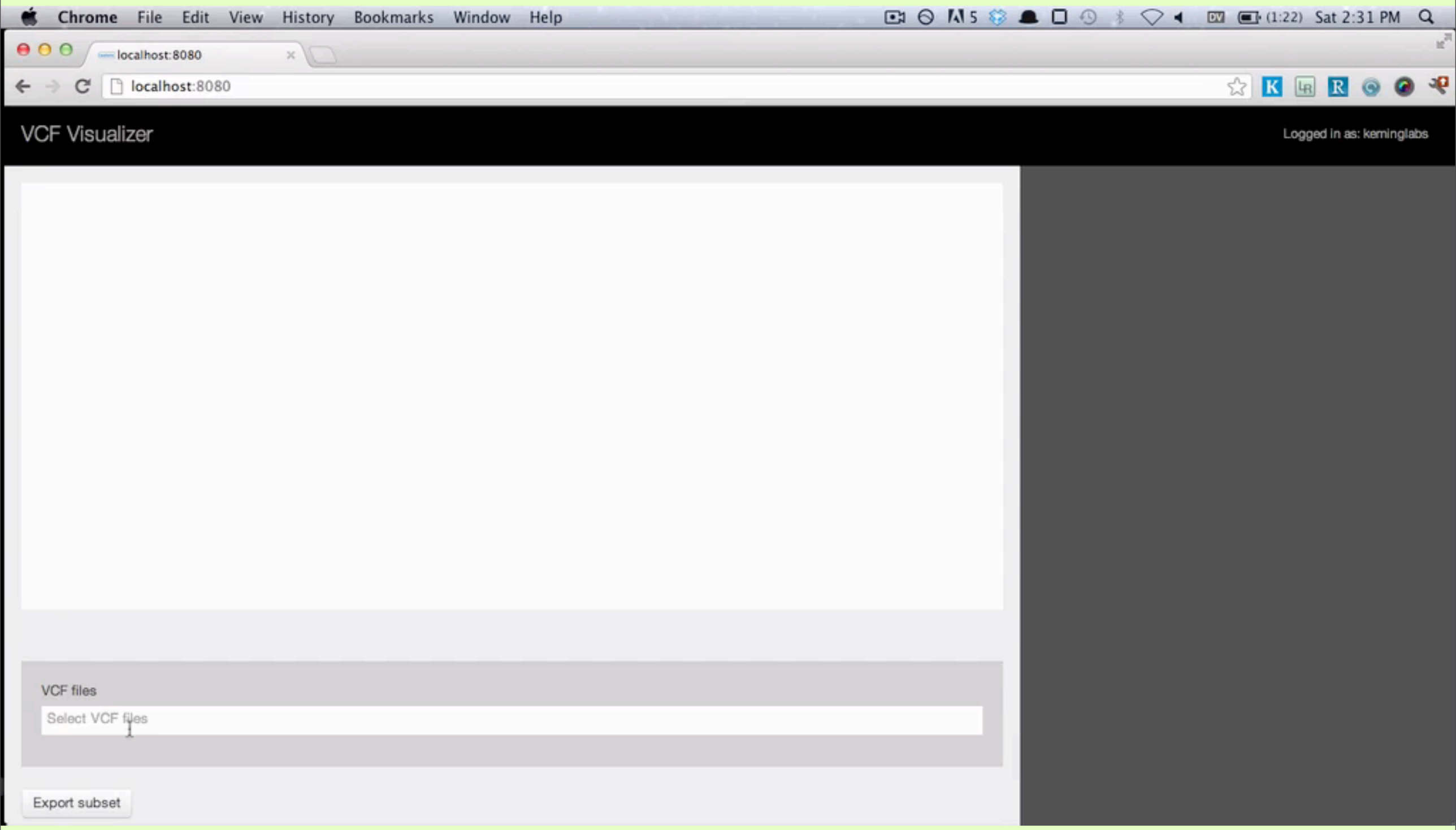
1 Data Visualization

what + why + how

Wind energy


Turbine: 18 vem/winergy
Speed: 1463.74 RPM
Power: 1450.00 kW
Main Bearing Vibration (mg)
Ring Gear Vibration (mg)
Intermediate Speed Shaft Generator End Bearing Vibration (mg)
High Speed Shaft Rotor End Bearing Vibration (mg)
High Speed Shaft Generator End Bearing Vibration (mg)
Generator Drive End Bearing Vibration (mg)
Generator Non-Drive End Bearing Vibration (mg)
Oil Particle count
0
100
200
300
400
500
600
1
10
100
1000
10000
100000

Bioinformatics



Doc & patient, *meet* Data

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Find flights by:

Stops	Price	Airline: Alaska Airlines	American Airlines	Multiple Carriers	Delta Air Lines
Non-stop		$257 total $278	$257 total $278	$257 total $285	$287 total $308
1 stop		The lowest fare is shown above. Still want more options? Show all flights			

Fares are per person in US dollars, using e-tickets. Total fare includes airfare taxes and fees .
Additional baggage charges may apply.
Some itineraries require paper tickets with an additional charge. Changes after booking are subject to change fees.

Sort flights by: **Lowest price** | Departure time | Shortest flight

Airport codes

Change Search

From City name or airport
PDX
incl. nearby airports

To City name or airport
SJC
incl. nearby airports

Leave
03/15/12
Depart
Anytime

Showing **lowest priced flights** (45 flights out of 180 total) See all 180 flights

Select **$257** + $21 taxes & fees = $278 USD per person NO BOOKING FEES PRICE ASSURANCE

Leave **Thu, Mar 15** — **Alaska Airlines 400**
Depart:**6:10am** Portland, OR (PDX)
Arrive:**7:55am** San Jose, CA (SJC)
Non-stop Economy | 1hr 45min | Boeing 737 | View seats
Choose this departure

Return **Sun, Mar 18** — **Alaska Airlines 2546**
operated by HORIZON AIR DBA ALASKA HORIZON
Depart:**6:15am** San Jose, CA (SJC)
Arrive:**8:19am** Portland, OR (PDX)
Choose this return

hipmunk

PDX ← → CPH, Nov 5 ← → Nov 12 | Search for hotels in Copenhagen Denmark | New Search

1 PDX → CPH on Mon, Nov 05 | 2 CPH → PDX on Mon, Nov 12

Watch Fare | Sort By: Agony | Price | Duration | Departure | Arrival | Airlines

	Portland	11am	5pm	11pm	5am	11am	5pm
	Copenhagen	8pm	2am	8am	2pm	8pm	2am
From $1148		United · ORD · Lufthansa · SAS					
From $1158		SEA · Lufthansa* · FRA · SAS					
From $1222		United · ORD · SAS · ARN · SAS					
From $1255				United · EWR			
From $1303		United · EWR · SAS*					
From $1326		United · Lufthansa · SAS*					
From $1326		Air · YVR · Air Canada · LHR · SAS					
From $1329		United · ORD · Swiss · ZRH · Swiss					
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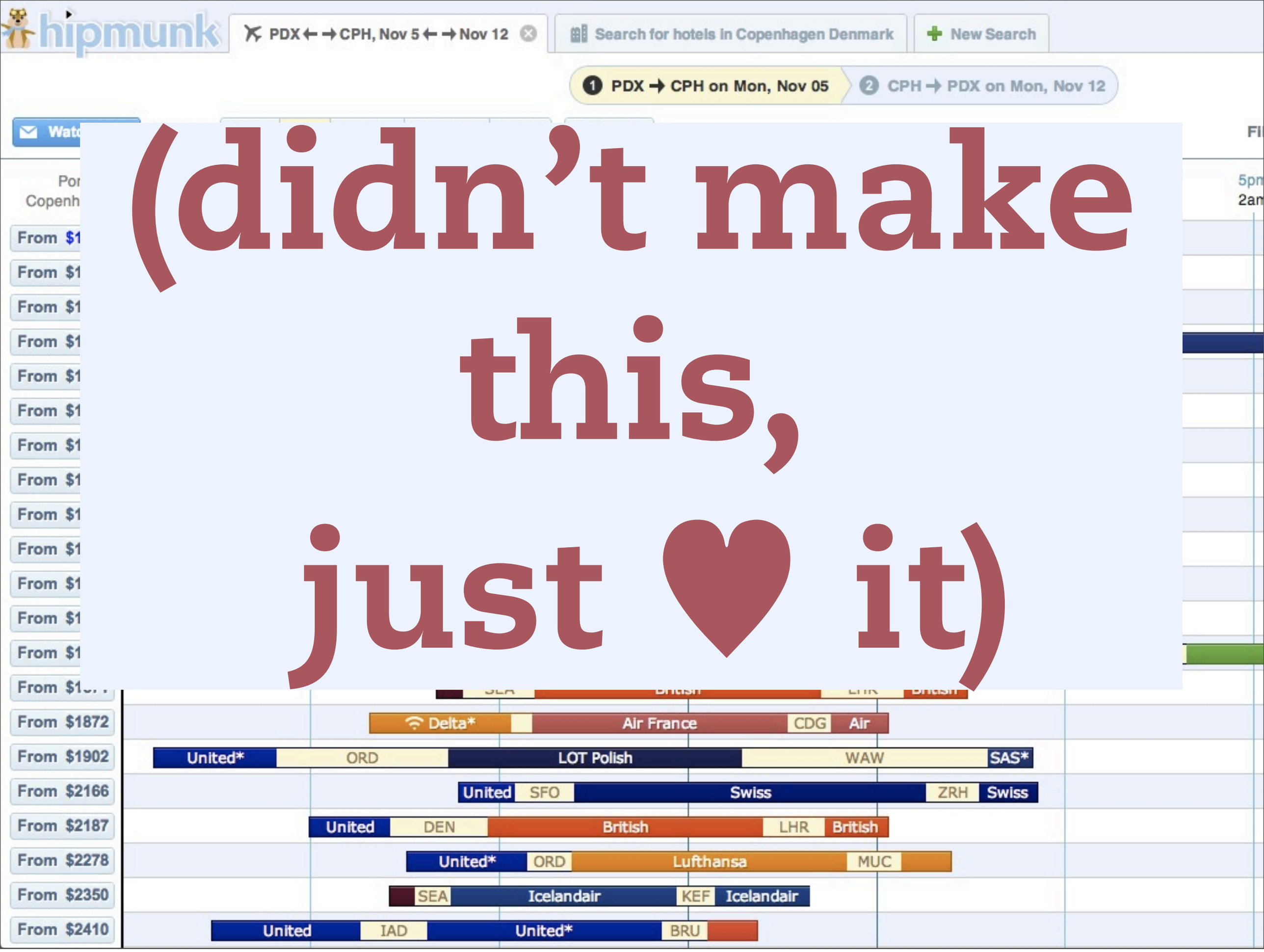
From $1333		United · ORD · United · LHR · SAS					
From $1346		United · SFO · Lufthansa · FRA · SAS*					
From $1509		SEA · Lufthansa* · FRA					
From $1619				United · EWR			
From $1671		SEA · British · LHR · British					
From $1872		Delta* · Air France · CDG · Air					
From $1902		United* · ORD · LOT Polish · WAW · SAS*					
From $2166		United · SFO · Swiss · ZRH · Swiss					
From $2187		United · DEN · British · LHR · British					
From $2278		United* · ORD · Lufthansa · MUC					
From $2350		SEA · Icelandair · KEF · Icelandair					
From $2410		United · IAD · United* · BRU					

Saturday, November 10, 12


hipmunk
PDX ← → CPH, Nov 5 ← → Nov 12
Search for hotels in Copenhagen Denmark
New Search
1 PDX → CPH on Mon, Nov 05
2 CPH → PDX on Mon, Nov 12
(didn't make this,
just ♥ it)
From $1872
Delta*
Air France
CDG
Air
From $1902
United*
ORD
LOT Polish
WAW
SAS*
From $2166
United
SFO
Swiss
ZRH
Swiss
From $2187
United
DEN
British
LHR
British
From $2278
United*
ORD
Lufthansa
MUC
From $2350
SEA
Icelandair
KEF
Icelandair
From $2410
United
IAD
United*
BRU

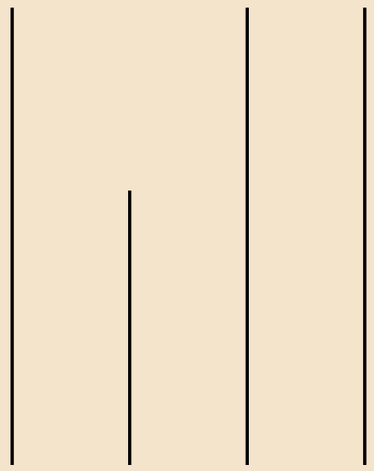
How

(theory)

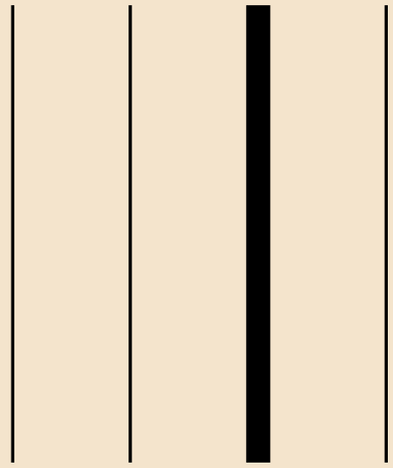
Data

Visual

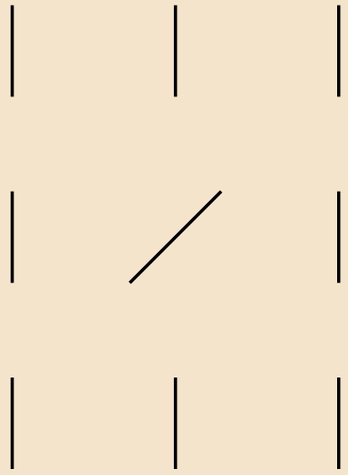
Length



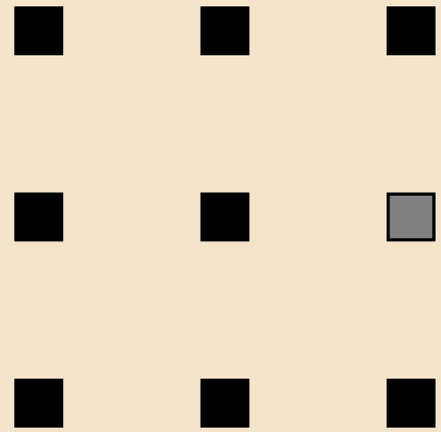
Width



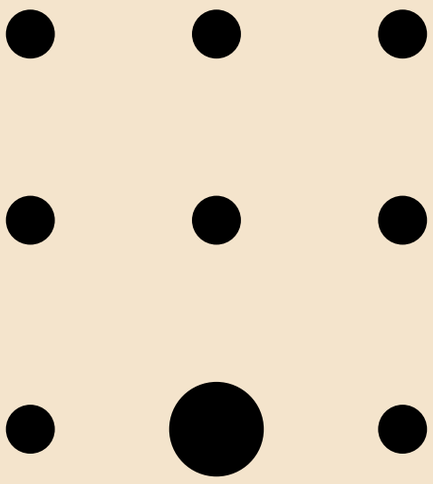
Orientation



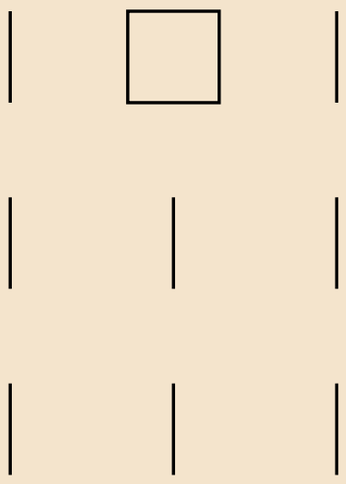
Intensity



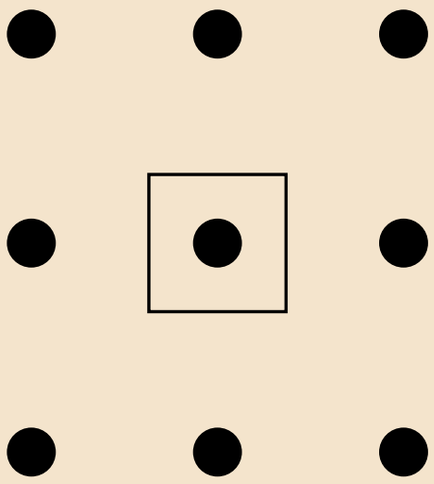
Size



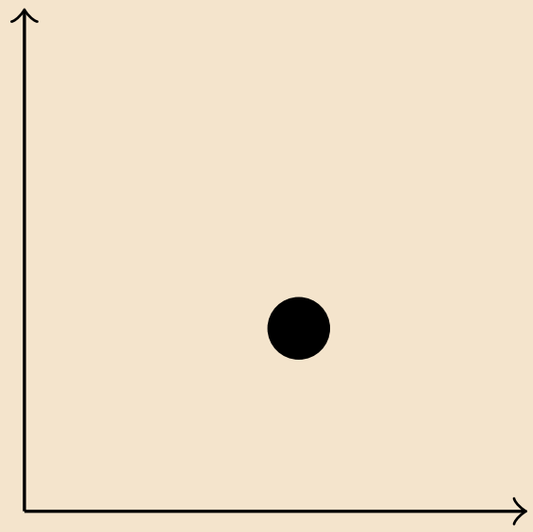
Shape



Enclosure



2-D position



hipmunk

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Watch Fare | Sort By: Agony | Price | Duration | Departure | Arrival | Airlines

	Portland	11am	5pm	11pm	5am	11am	5pm
	Copenhagen	8pm	2am	8am	2pm	8pm	2am
From $1148		United · ORD · Lufthansa · SAS					
From $1158		SEA · Lufthansa* · FRA · SAS					
From $1222		United · ORD · SAS · ARN · SAS					
From $1255				United · EWR			
From $1303		United · EWR · SAS*					
From $1326		United · Lufthansa · SAS*					
From $1326		Air · YVR · Air Canada · LHR · SAS					
From $1329		United · ORD · Swiss · ZRH · Swiss					
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From $1619				United · EWR			
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From $1872		Delta* · Air France · CDG · Air					
From $1902		United* · ORD · LOT Polish · WAW · SAS*					
From $2166		United · SFO · Swiss · ZRH · Swiss					
From $2187		United · DEN · British · LHR · British					
From $2278		United* · ORD · Lufthansa · MUC					
From $2350		SEA · Icelandair · KEF · Icelandair					
From $2410		United · IAD · United* · BRU					

Saturday, November 10, 12

2D Position

Time

Cost

Saturday, November 10, 12

2D Position

hipmunk

Watch Fare | Sort By | Agony | Price | Duration | Departure | Arrival | Airlines

Portland
Copenhagen

11am 8pm | 5pm 2am | 11pm 8am | 5am 2pm | 11am 8pm | 5pm 2am

From $1148	United		ORD		Lufthansa				SAS		
From $1158		SEA		Lufthansa*				FRA		SAS	
From $1222	United		ORD		SAS			ARN	SAS		
From $1255						United			EWR		
From $1303	United		EWR		SAS*						
From $1326		United			Lufthansa				SAS*		
From $1326			Air	YVR		Air Canada			LHR	SAS	
From $1329		United		ORD		Swiss			ZRH	Swiss	
From $1329			Air	YVR		Lufthansa*			FRA	SAS*	
From $1333			United		ORD		United			LHR	SAS
From $1346		United		SFO		Lufthansa			FRA	SAS*	
From $1509			SEA		Lufthansa*				FRA		
From $1619						United			EWR		
From $1671				SEA		British			LHR	British	
From $1872				Delta*		Air France			CDG	Air	
From $1902	United*			ORD		LOT Polish			WAW		SAS*
From $2166			United		SFO		Swiss			ZRH	Swiss
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From $2278			United*		ORD		Lufthansa			MUC	
From $2350				SEA		Icelandair			KEF	Icelandair	
From $2410	United			IAD		United*			BRU		

Width

Flight duration

Width

hipmunk

PDX ← → CPH, Nov 5 ← → Nov 12 | Search for hotels in Copenhagen Denmark | New Search

1 PDX → CPH on Mon, Nov 05 | 2 CPH → PDX on Fri, Nov 09

Watch Fare | Sort By | Agony | Price | Duration | Departure | Arrival | Airlines | Fi

	Portland Copenhagen	11am 8pm	5pm 2am	11pm 8am	5am 2pm	11am 8pm	5pm 2am
From $1148	United · ORD · Lufthansa · SAS						
From $1158	SEA · Lufthansa* · FRA · SAS						
From $1222	United · ORD · SAS · ARN · SAS						
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From $1329	United · ORD · Swiss · ZRH · Swiss						
From $1329	Air · YVR · Lufthansa* · FRA · SAS*						
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From $1346	United · SFO · Lufthansa · FRA · SAS*						
From $1509	SEA · Lufthansa* · FRA						
From $1619	United · EWR						
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From $1872	Delta* · Air France · CDG · Air						
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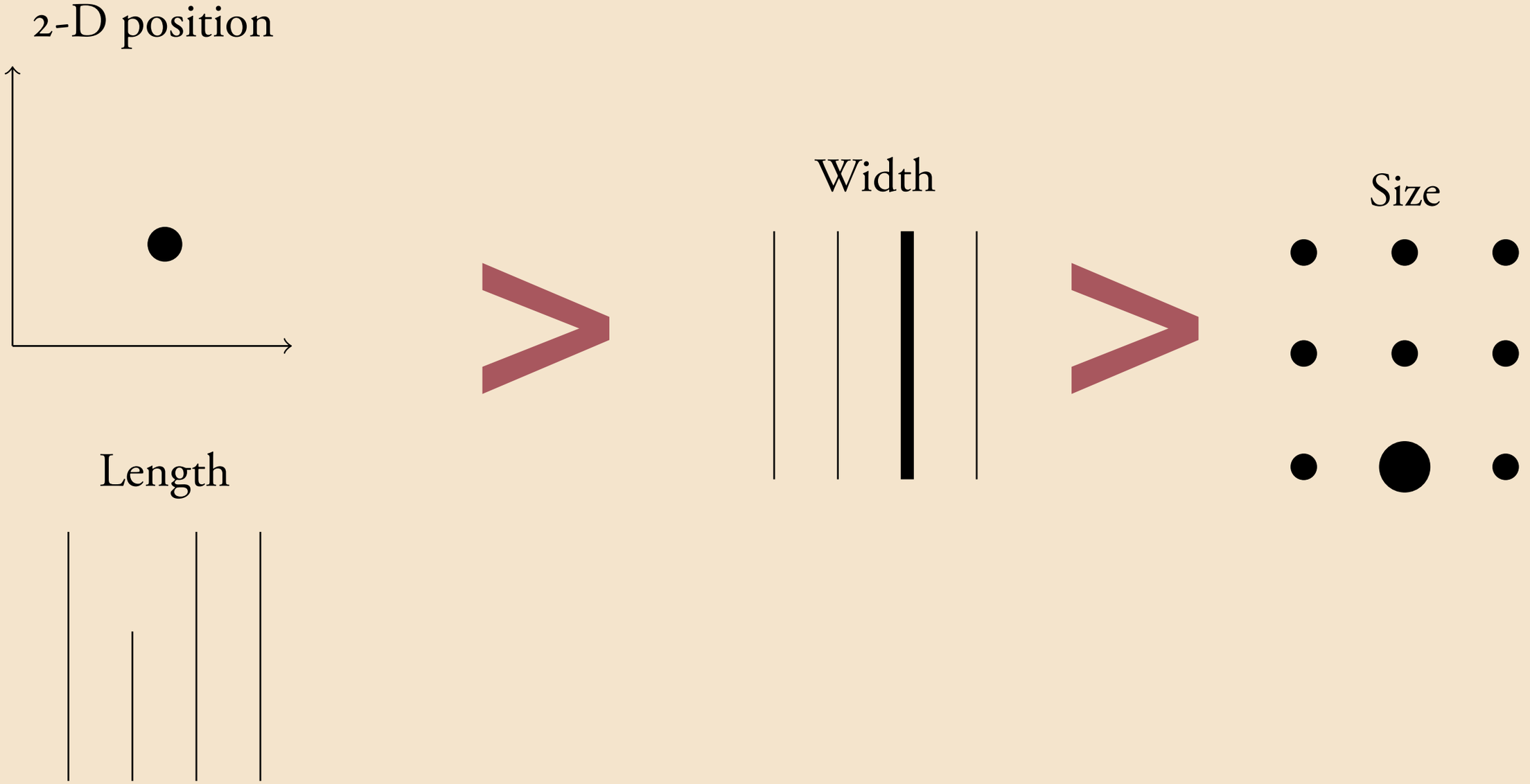
From $2187	United · DEN · British · LHR · British						
From $2278	United* · ORD · Lufthansa · MUC						
From $2350	SEA · Icelandair · KEF · Icelandair						
From $2410	United · IAD · United* · BRU						

Saturday, November 10, 12

12 Lessons

Some aesthetics are better than others



Have

a

Thesis

How

(practice)

Off the rack

Sales Data - Microsoft Excel

Sheet | Insert | Page Layout | Formulas | Data | Review | View

PivotTable | Table | Column | Line | Pie | Bar | Area | XY (Scatter) | Other Charts | Picture | IGX Graphic | Shapes | Hyperlink | Text Box | Header & Footer | WordArt | Signature Line | Object | Symbol

Tables | Charts | Illustrations | Links | Text

H18

Total Sales by Store

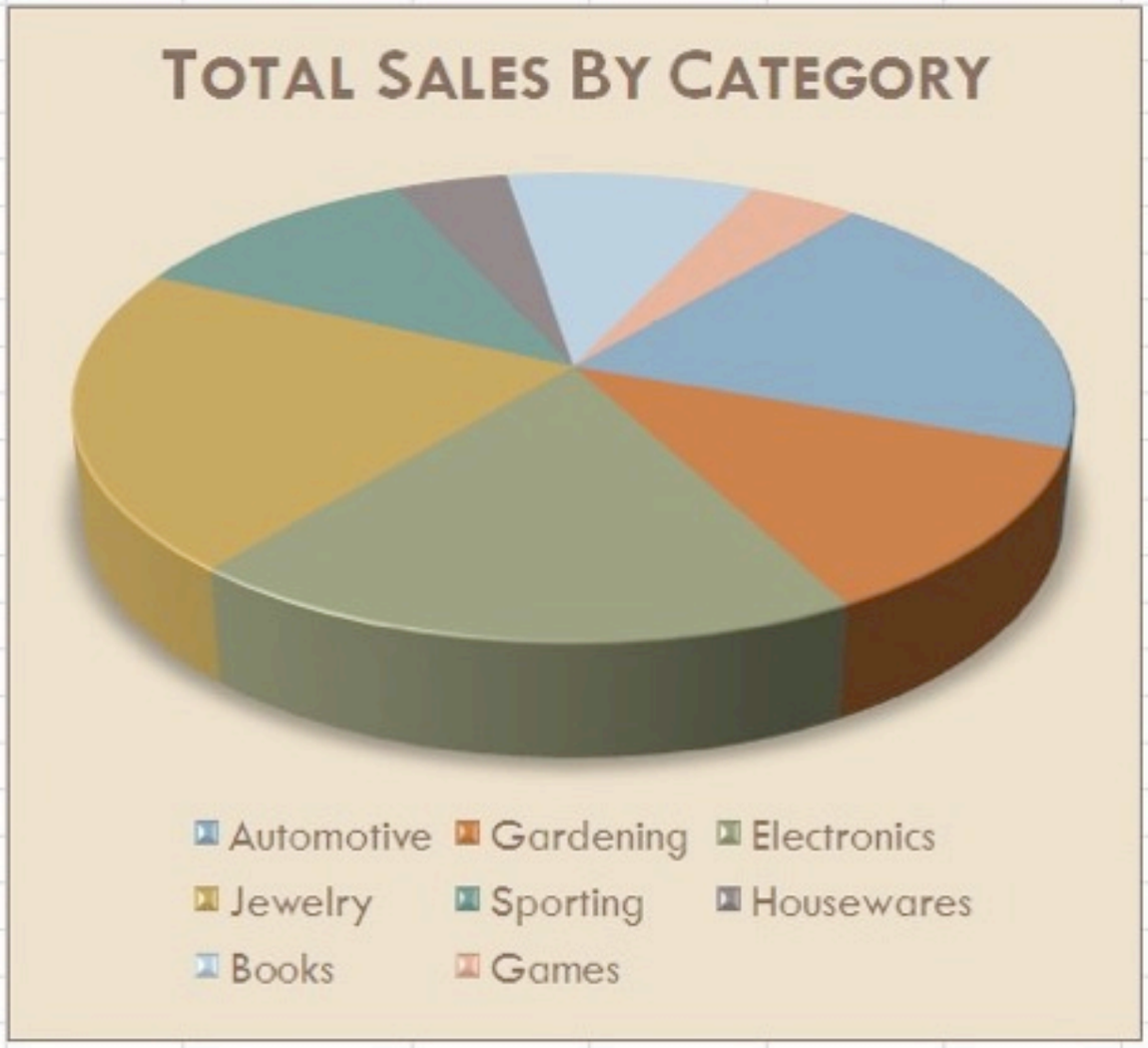
Store	Sales
Store 1	$ 313,765
Store 2	$ 107,160
Store 3	$ 351,751
Store 4	$ 131,047
Store 5	$ 252,136
Store 6	$ 167,462
Store 7	$ 210,073
Store 8	$ 308,092
Store 9	$ 97,492
Store 10	$ 393,484
Store 11	$ 396,891
Store 12	$ 151,168
Store 13	$ 251,390
Store 14	$ 392,776
Store 15	$ 259,654
Store 16	$ 225,184
Store 17	$ 335,785

Total Sales by Region

Region	Sales
West	$ 1,718,258
South	$ 534,389
Midwest	$ 1,009,268
East	$ 900,431
Total	**$ 4,162,346**

Total Sales by Category

Category	Sales
Automotive	$ 86,285
Gardening	$ 52,048
Electronics	$ 83,026
Jewelry	$ 93,035
Sporting	$ 50,016
Houseware	$ 19,149
Books	$ 42,247
Games	$ 18,420



Summary | Data

Ready

100%

Illustrator File Edit Object Type Select Effect View Window Help

No Selection Stroke: 1 pt Uniform 2 pt. Oval Style: Opacity: 100 %

Untitled-1 @ 200% (CMYK/Preview)

- Column Graph Tool (J)
- Stacked Column Graph Tool
- Bar Graph Tool
- Stacked Bar Graph Tool
- Line Graph Tool
- Area Graph Tool
- Scatter Graph Tool
- Pie Graph Tool
- Radar Graph Tool

Keynote File Edit Insert Slide Format Arrange View Play Window Share Help

2012_oredev — Edited

New Play View Text Box Shapes Table Charts Comment Share

Auto-shrink Stroke:

Master Slides

Indivisible

Cyan

Ash

Slides

20

21

22

23

24

Column Break

Text Box
Shape
Table
Function
Chart
Smart Build
Connection Line

Comment
Text Hyperlink

Choose... ⇧⌘V

Column
Stacked Column
Bar
Stacked Bar
Line
Area
Stacked Area
Pie
Scatter
Mixed
2-Axis

3D Column
3D Stacked Column
3D Bar
3D Stacked Bar
3D Line
3D Area
3D Stacked Area
3D Pie

Bespoke

Photo by **Scott Schuman**,
The Sartorialist

D3: Data Driven Documents (2011)

Mike Bostock Jeffrey Heer Vadim Ogievetsky

$\mathbb{D}^3$: Data-Driven Documents

Michael Bostock, Vadim Ogievetsky and Jeffrey Heer

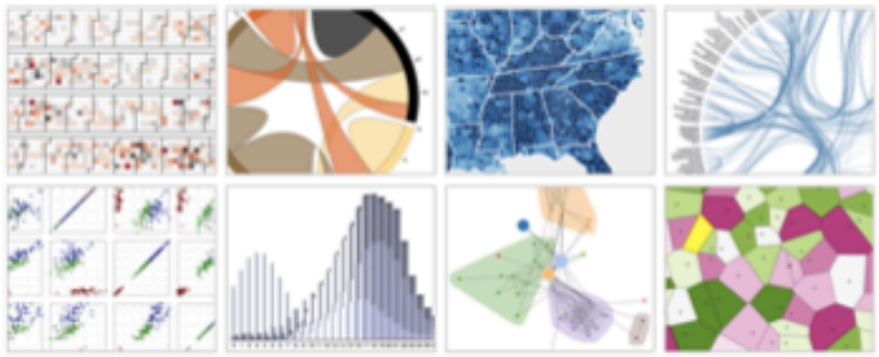


Fig. 1. Interactive visualizations built with D3, running inside Google Chrome. From left to right: calendar view, chord diagram, choropleth map, hierarchical edge bundling, scatterplot matrix, grouped & stacked bars, force-directed graph clusters, Voronoi tessellation.

Abstract—Data-Driven Documents (D3) is a novel representation-transparent approach to visualization for the web. Rather than hide the underlying scenegraph within a toolkit-specific abstraction, D3 enables direct inspection and manipulation of a native representation: the standard document object model (DOM). With D3, designers selectively bind input data to arbitrary document elements, applying dynamic transforms to both generate and modify content. We show how representational transparency improves expressiveness and better integrates with developer tools than prior approaches, while offering comparable notational efficiency and retaining powerful declarative components. Immediate evaluation of operators further simplifies debugging and allows iterative development. Additionally, we demonstrate how D3 transforms naturally enable animation and interaction with dramatic performance improvements over intermediate representations.

Index Terms—Information visualization, user interfaces, toolkits, 2D graphics.

1 Introduction

When building visualizations, designers often employ multiple tools simultaneously. This is particularly true on the web, where interactive visualizations combine varied technologies: HTML for page content, CSS for aesthetics, JavaScript for interaction, SVG for vector graphics, and so on. One of the great successes of the web as a platform is the (mostly) seamless cooperation of such technologies, enabled by a shared representation of the page called the *document object model* (DOM). The DOM exposes the hierarchical structure of page content, such as paragraph and table elements, allowing reference and manipulation. In addition to programming interfaces, modern browsers include powerful graphical tools for developers that display the element tree, reveal inherited style values, and debug interactive scripts.

Unfortunately, this blissful interoperability is typically lost with visualization toolkits due to encapsulation of the DOM with more specialized forms. Rather than empowering direct manipulation of the existing model, such toolkits [2, 9, 18] supplant it with custom scenegraph abstractions. This approach may provide substantial gains in *efficiency*—reducing the effort required to specify a visualization—but it incurs a high opportunity cost: it ignores developers' knowledge of standards, and the tools and resources that augment these standards.

The resulting cost to *accessibility*—the difficulty of learning the representation—may trump efficiency gains, at least for new users. Scarcity of documentation and ineffectual debugging exacerbate the problem, impeding users from gaining deeper understanding of toolkit abstractions and limiting the toolkit's potential. Systems with intermediate scenegraph abstractions and delayed property evaluation can be particularly difficult to debug: internal structures are exposed only when errors arise, often at unexpected times.

Furthermore, intermediate representations may diminish *expressiveness*—the diversity of possible visualizations—and introduce substantial runtime overhead. Certain tasks that could be offloaded to a more suitable tool, such as specifying fonts via CSS, may be stymied by encapsulation. Similarly, while graphical features such as clipping may be supported by the underlying representations, they may not be exposed by the toolkit. Even if extensibility is available as a means for greater expression, it requires in-depth knowledge of toolkit internals and poses a substantial barrier to the average user.

Our awareness of these issues comes in part from thousands of user observations over the two years since releasing Protovis [2], despite our attempt to balance expressiveness, efficiency and accessibility. We now refine these three goals with specific objectives:

Compatibility. Tools do not exist in isolation, but within an ecosystem of related components. Technology reuse utilizes prior knowledge and reference materials, improving accessibility. Offloading a subset of tasks to specialized tools can improve efficiency, avoiding the generality and complexity of a monolithic approach. And, full access to

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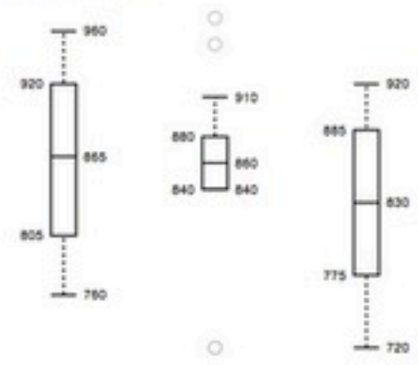
Email: {mbostock,vad,jheer}@stanford.edu.

Manuscript received 31 March 2011; accepted 1 August 2011; posted online 23 October 2011; mailed on 14 October 2011.
For information on obtaining reprints of this article, please send email to: tvcg@computer.org.

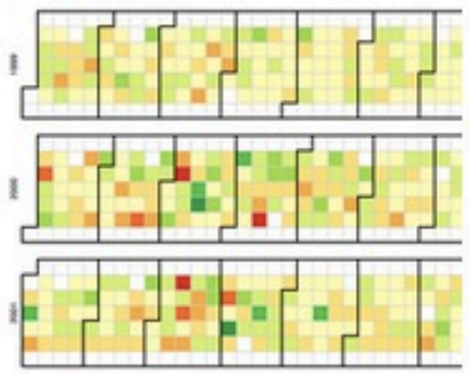
Box Plots



Bubble Chart

Bullet Charts

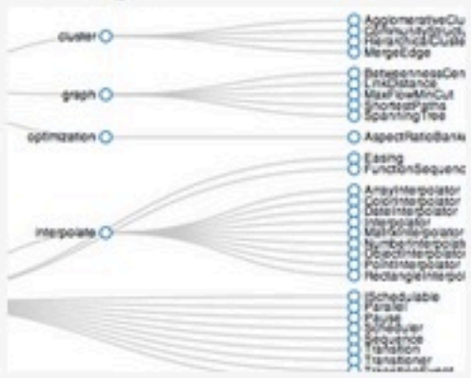
Calendar View



Non-contiguous Cartogram

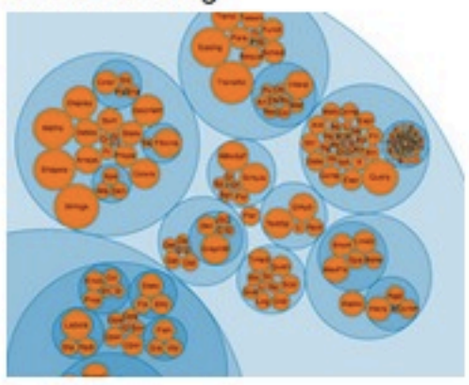
Chord Diagram

Dendrogram

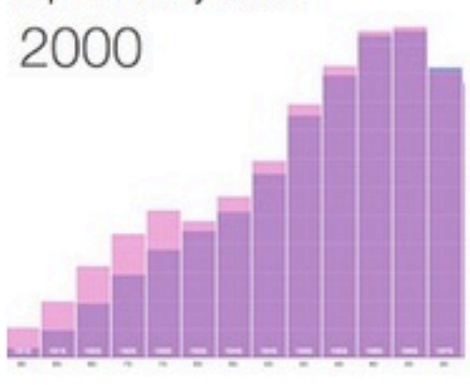


Force-Directed Graph

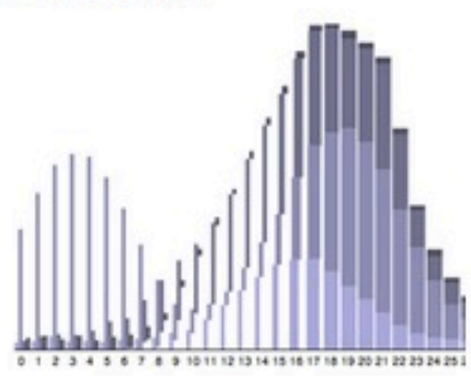
Circle Packing



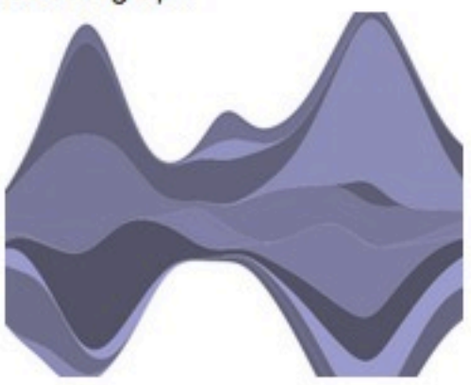
Population Pyramid



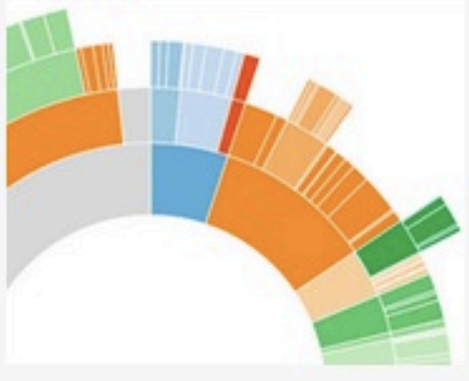
Stacked Bars



Streamgraph



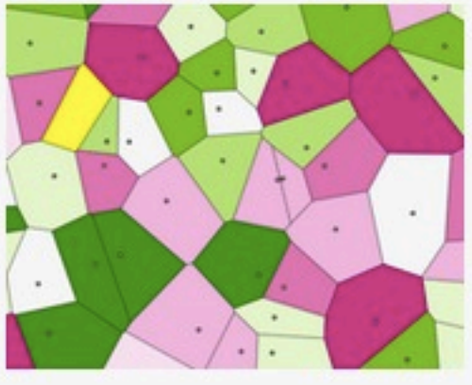
Sunburst



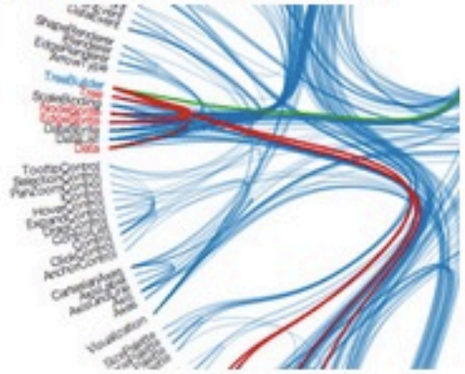
Node-Link Tree

Treemap

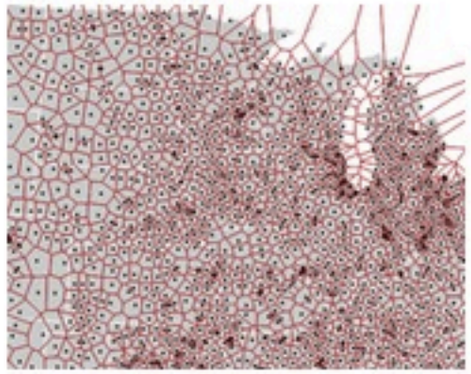
Voronoi Diagram



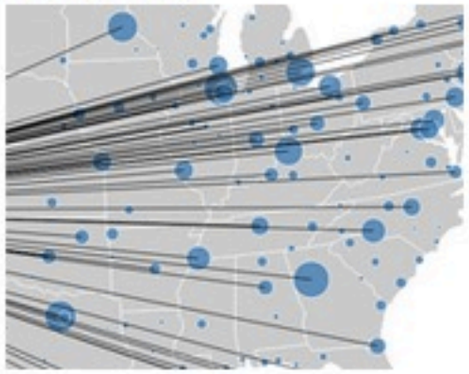
Hierarchical Edge Bundling



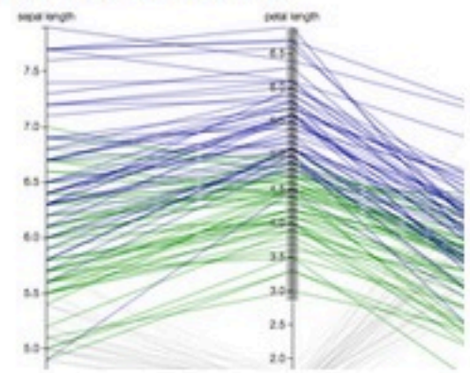
Voronoi Diagram



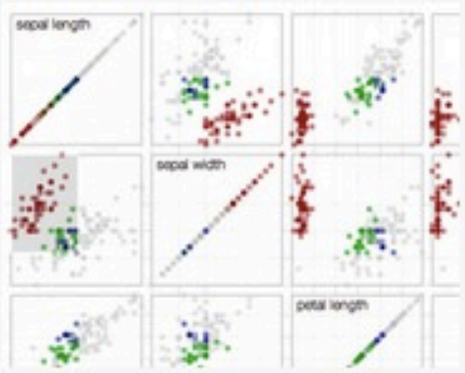
Symbol Map



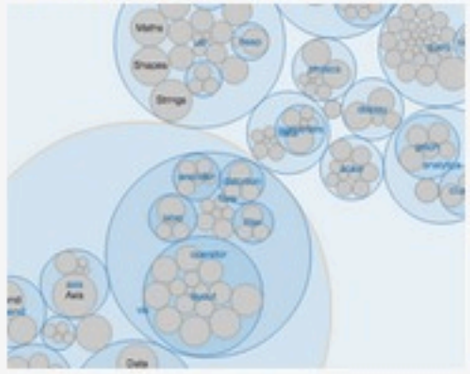
Parallel Coordinates



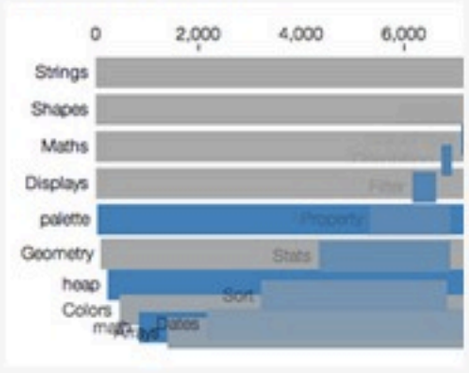
Scatterplot Matrix



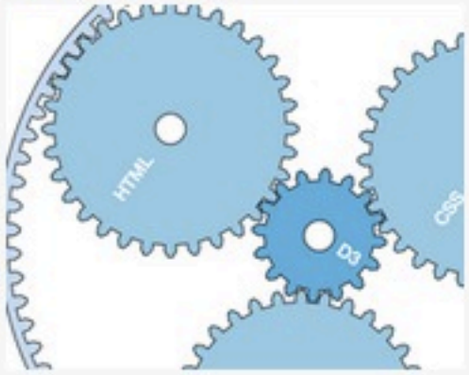
Zoomable Pack Layout



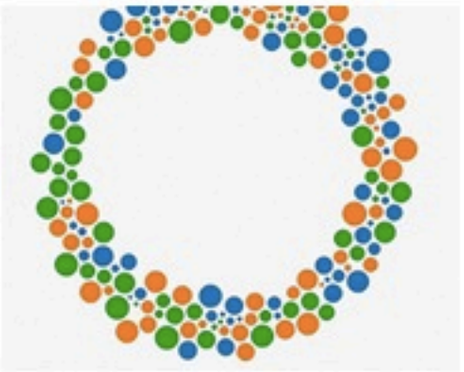
Hierarchical Bars



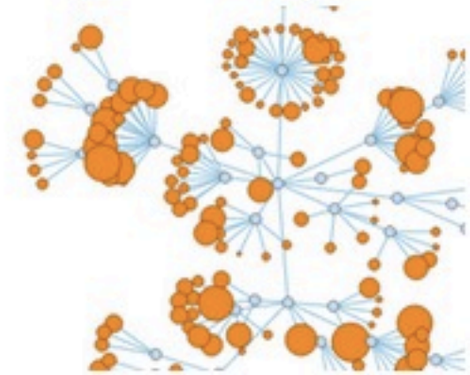
Epicyclical Gears



Collision Detection



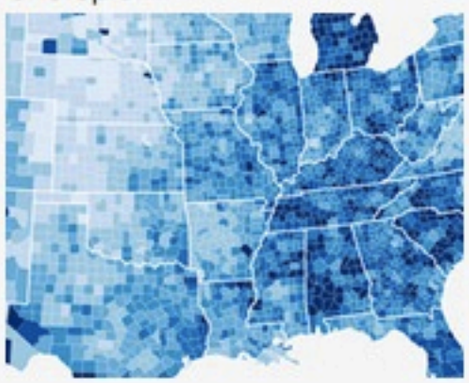
Collapsible Force Layout



Force-Directed States

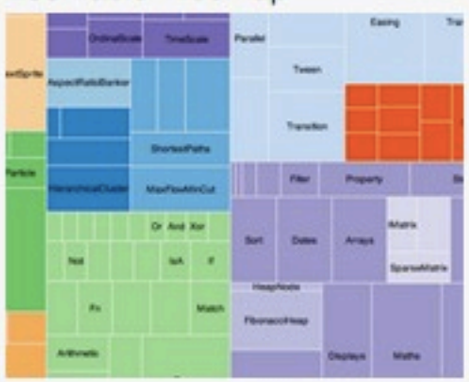
Azimuthal Projections

Choropleth

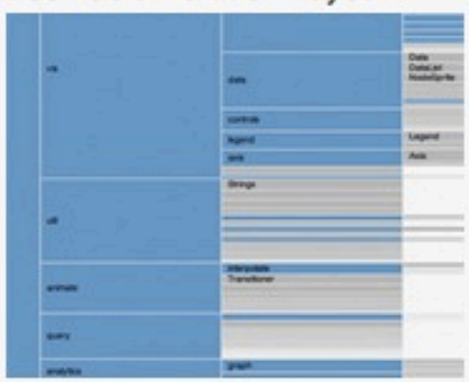


Collapsible Tree Layout

Zoomable Treemap



Zoomable Partition Layout



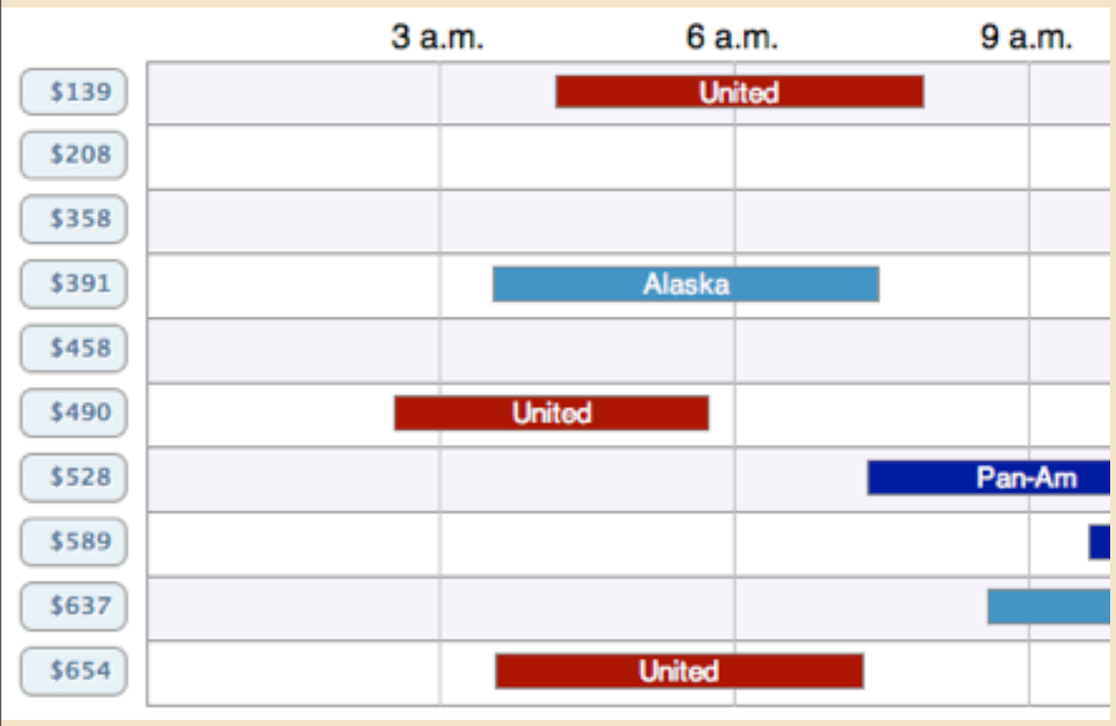
Zoomable Area Chart

Calendar View

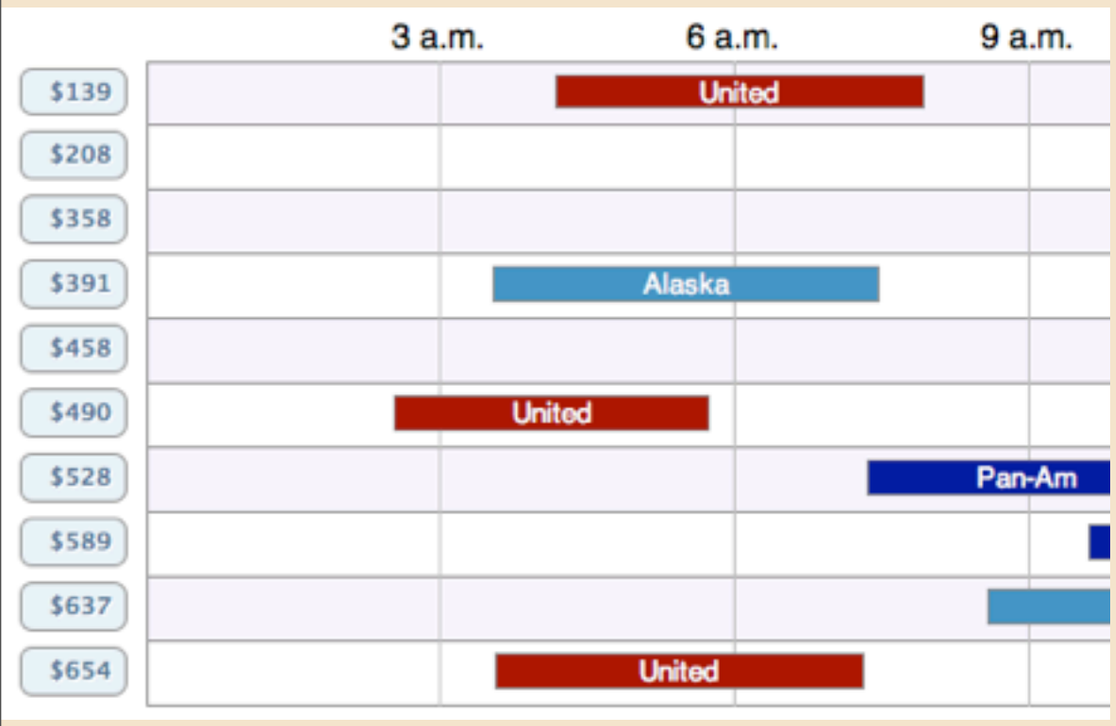
Rotating Cluster Layout

Sankey Diagram

Bespoke

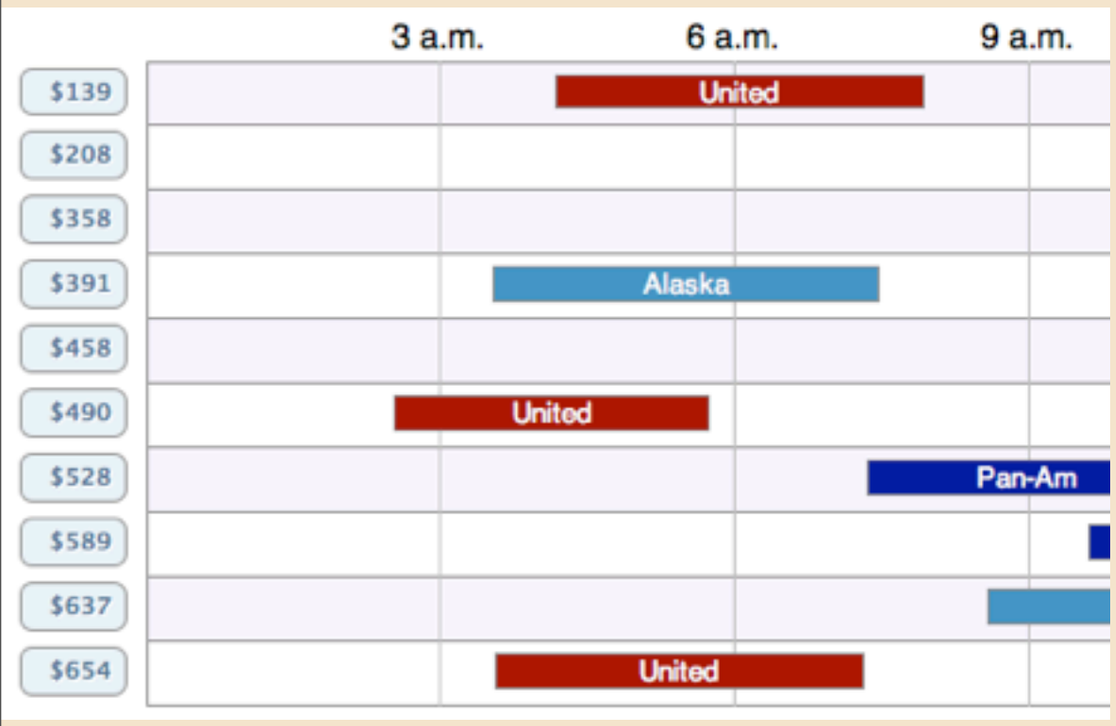

3 a.m.
6 a.m.
9 a.m.
$139
$208
$358
$391
$458
$490
$528
$589
$637
$654
United
Alaska
United
Pan-Am
United

Bespoke



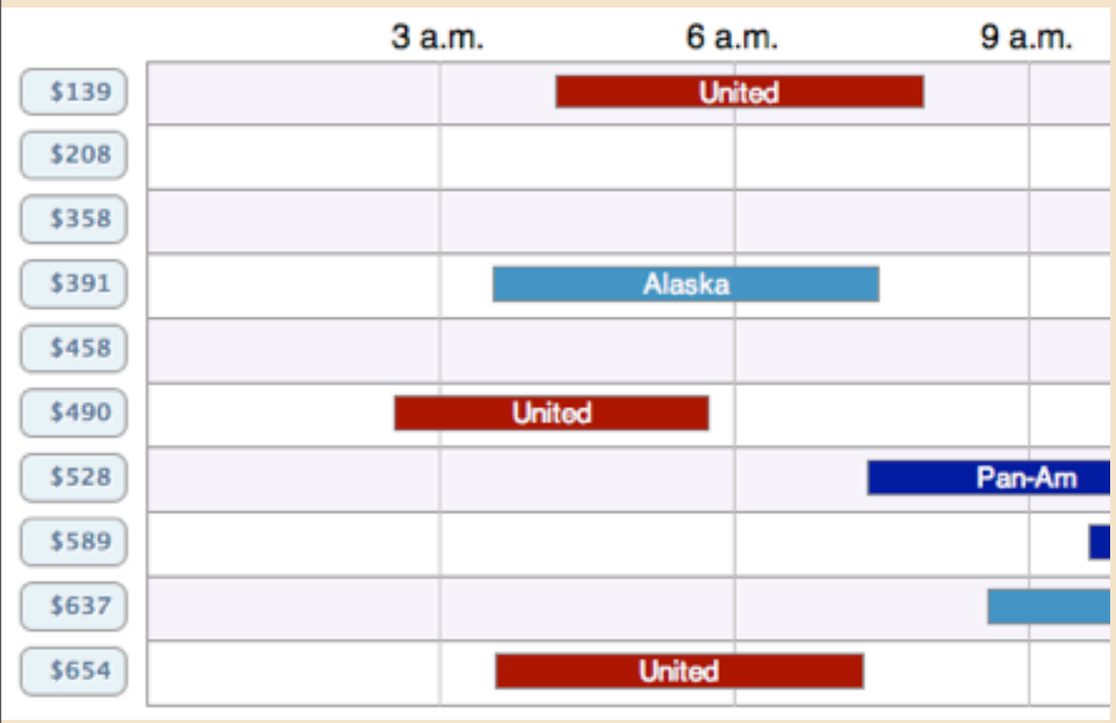

```
(map flight-data
  (fn [{:keys [price carrier depart arrive]}]
      [:div.row
        [:button.price (str "$" price)]
        [:div.flight
          {:style {:left  (time-scale depart)
                   :width (time-scale (- arrive depart))}
           :carrier carrier}
          [:span carrier]]]))
```

Bespoke




```
(map flight-data
  (fn [{:keys [price carrier depart arrive]}]
      [:div.row
        [:button.price (str "$" price)]
        [:div.flight
          {:style {:left  (time-scale depart)
                   :width (time-scale (- arrive depart))}
           :carrier carrier}
          [:span carrier]]]))

(map [[3 "3 a.m."] [6 "6 a.m."] [9 "9 a.m."]
      [12 "Noon"] [15 "3 p.m."] [18 "6 p.m."]]
     (fn [[t label]]
        [:div.tick {:style {:left (time-scale t)}}
          [:div.grid-line]
          [:span.label label]]))
```

Bespoke




```
(map flight-data
  (fn [{:keys [price carrier depart arrive]}]
      [:div.row
        [:button.price (str "$" price)]
        [:div.flight
          {:style {:left  (time-scale depart)
                   :width (time-scale (- arrive depart))}
           :carrier carrier}
          [:span carrier]]]))
```

```
(map [[3 "3 a.m."] [6 "6 a.m."] [9 "9 a.m."]
      [12 "Noon"] [15 "3 p.m."] [18 "6 p.m."]]
  (fn [[t label]]
    [:div.tick {:style {:left (time-scale t)}}
      [:div.grid-line]
      [:span.label label]]))
```

```
#axis
  .tick
    position: absolute
    height: 100%
    .label
      display: block
      position: relative
      top: -1.3em
      left: -2.5em
      width: 5em
      text-align: center
      font-family: sans-serif
    .grid-line
      position: absolute
      width: 1px
      height: 100%
      top: 0px
      background-color: hsl(0,0%,70%)
      z-index: 1
```

```
#flights
  .flight
    z-index: 2
    -webkit-transi
ease-out
.price
  position: absolu
  text-align: righ
  width: 50px
  height: 80%
  top: 10%
  left: -60px

.flight
  position: absolu
  height: 60%
  top: 20%
  text-align: cent
  border: 1px soli
  span
    color: white
    font-size: 0.8
    font-family: s

@mixin carrier-col
$color)
  flight[carrier=
  background-col
```

General

(hard to use)

Specific

(not expressive)

<canvas>
Java2D
D3.js
<svg>

?

Excel
Highcharts

General

(hard to use)

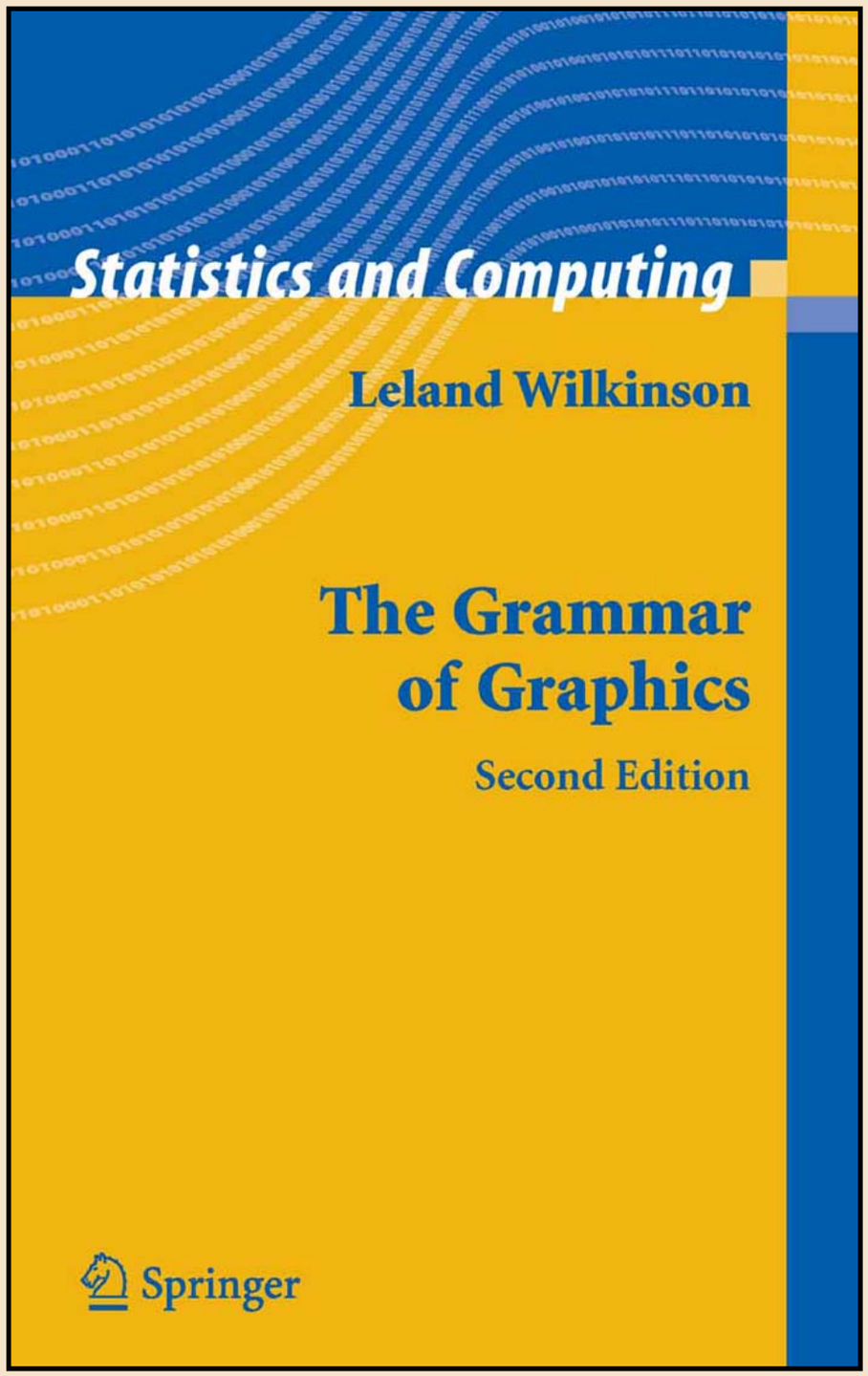
Specific

(not expressive)

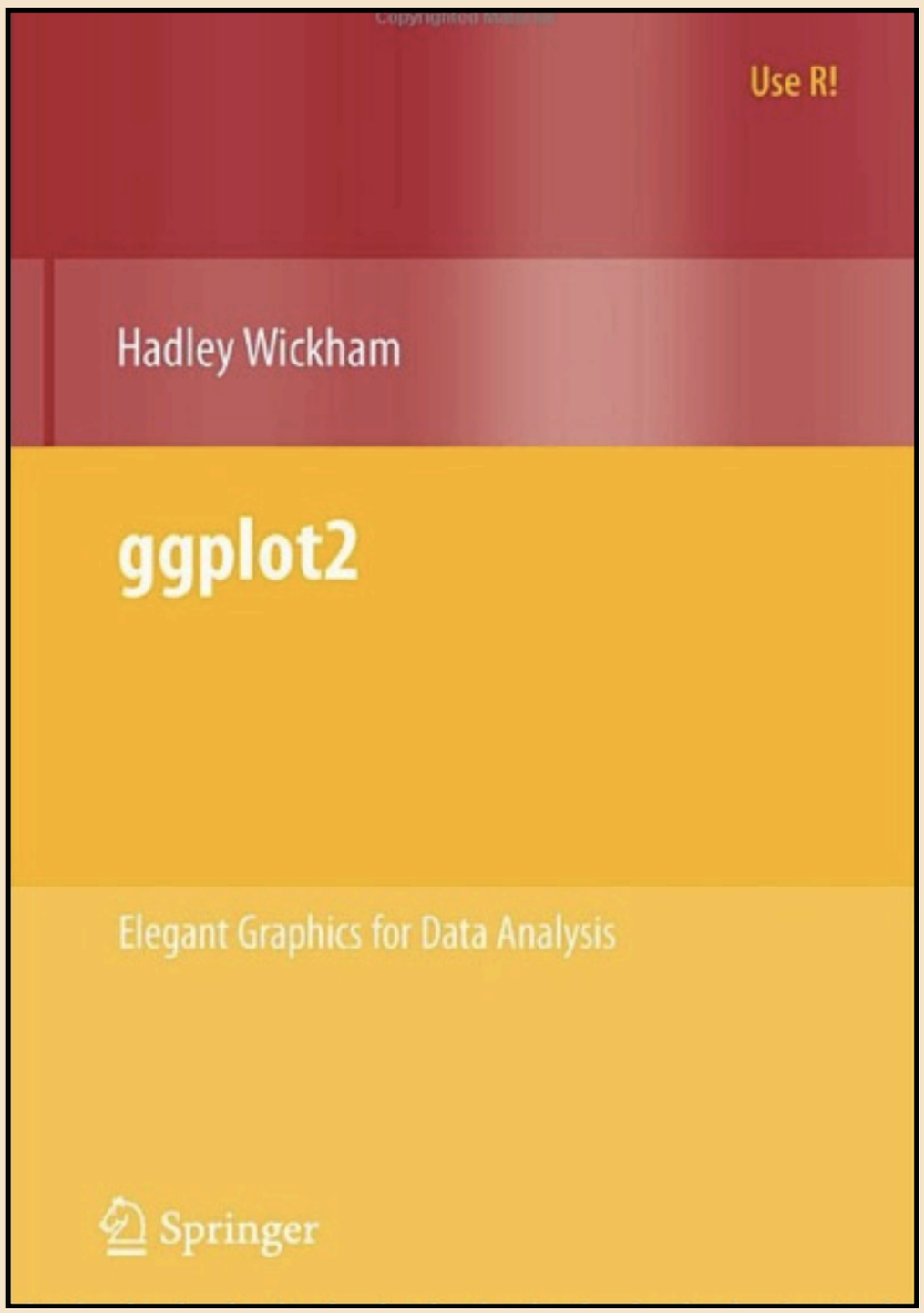
Agenda

A Grammar of Graphics

The Grammar of Graphics (1999)



ggplot2 (2005)

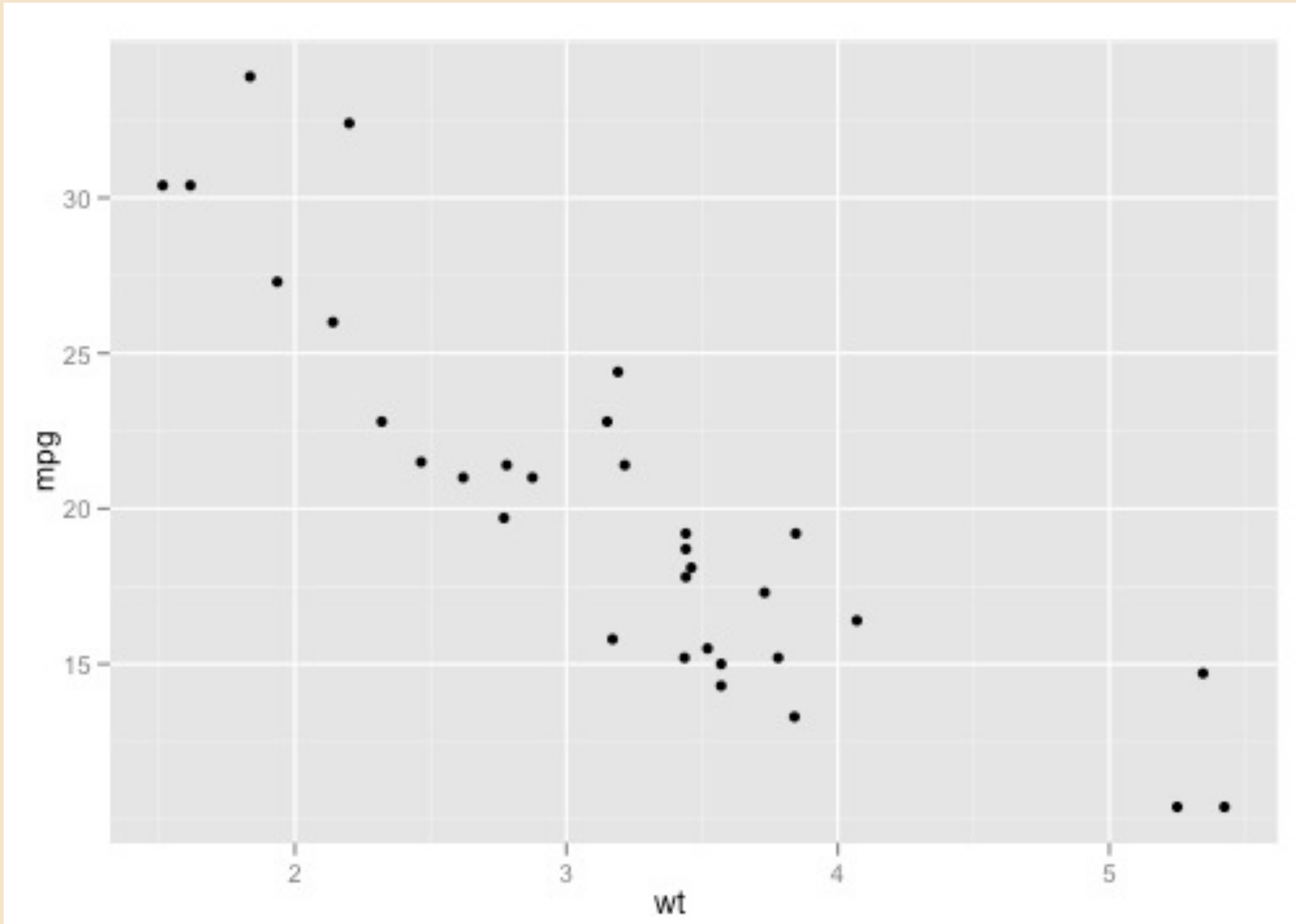


Motor Trend cars dataset

```
                  mpg cyl disp  hp drat    wt ...
Mazda RX4        21.0   6  160 110 3.90 2.62 ...
Mazda RX4 Wag    21.0   6  160 110 3.90 2.88 ...
Datsun 710       22.8   4  108  93 3.85 2.32 ...
                  ...........
```

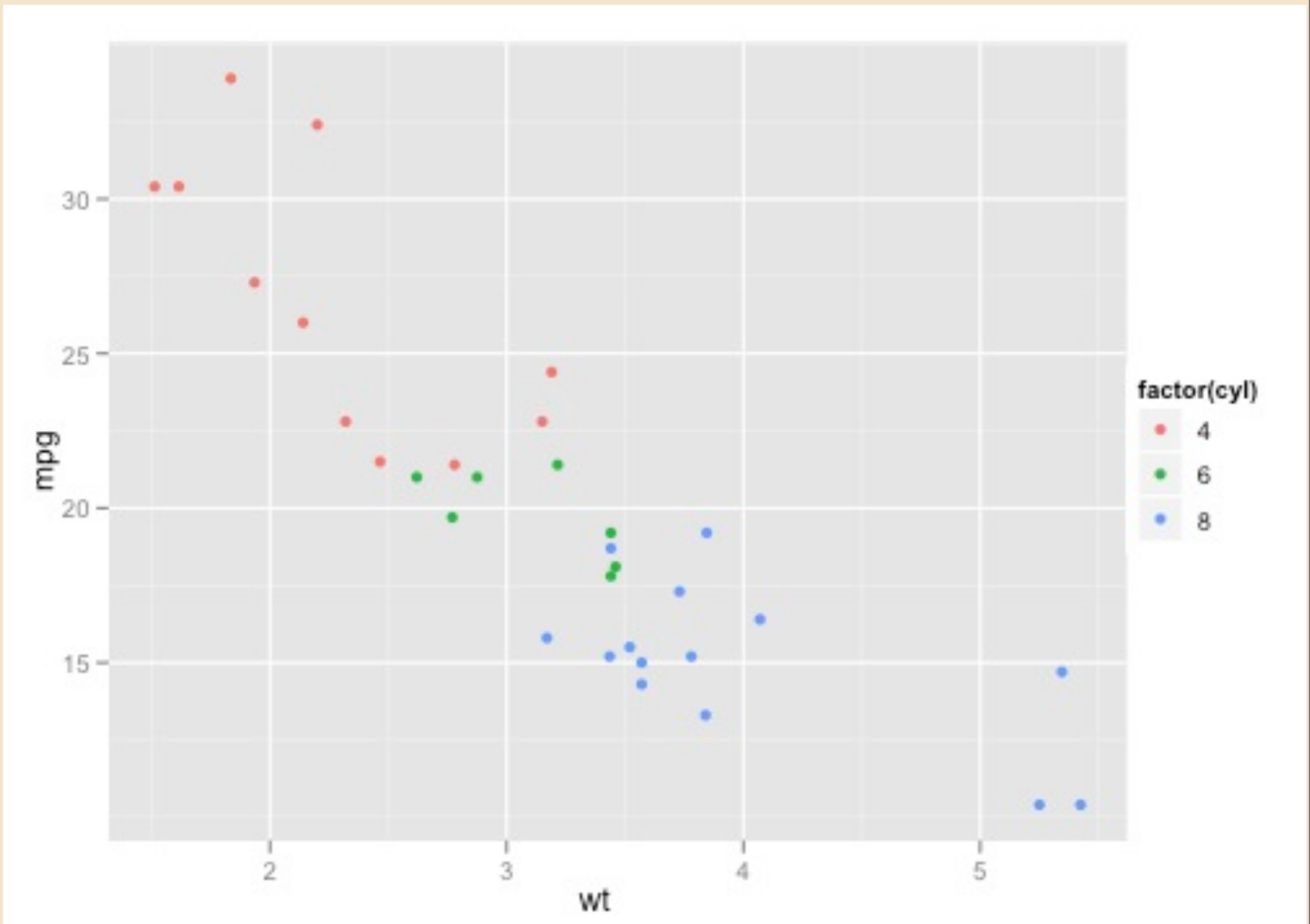
Exploratory

```
ggplot(mtcars, aes(wt, mpg))
  + geom_point()
```



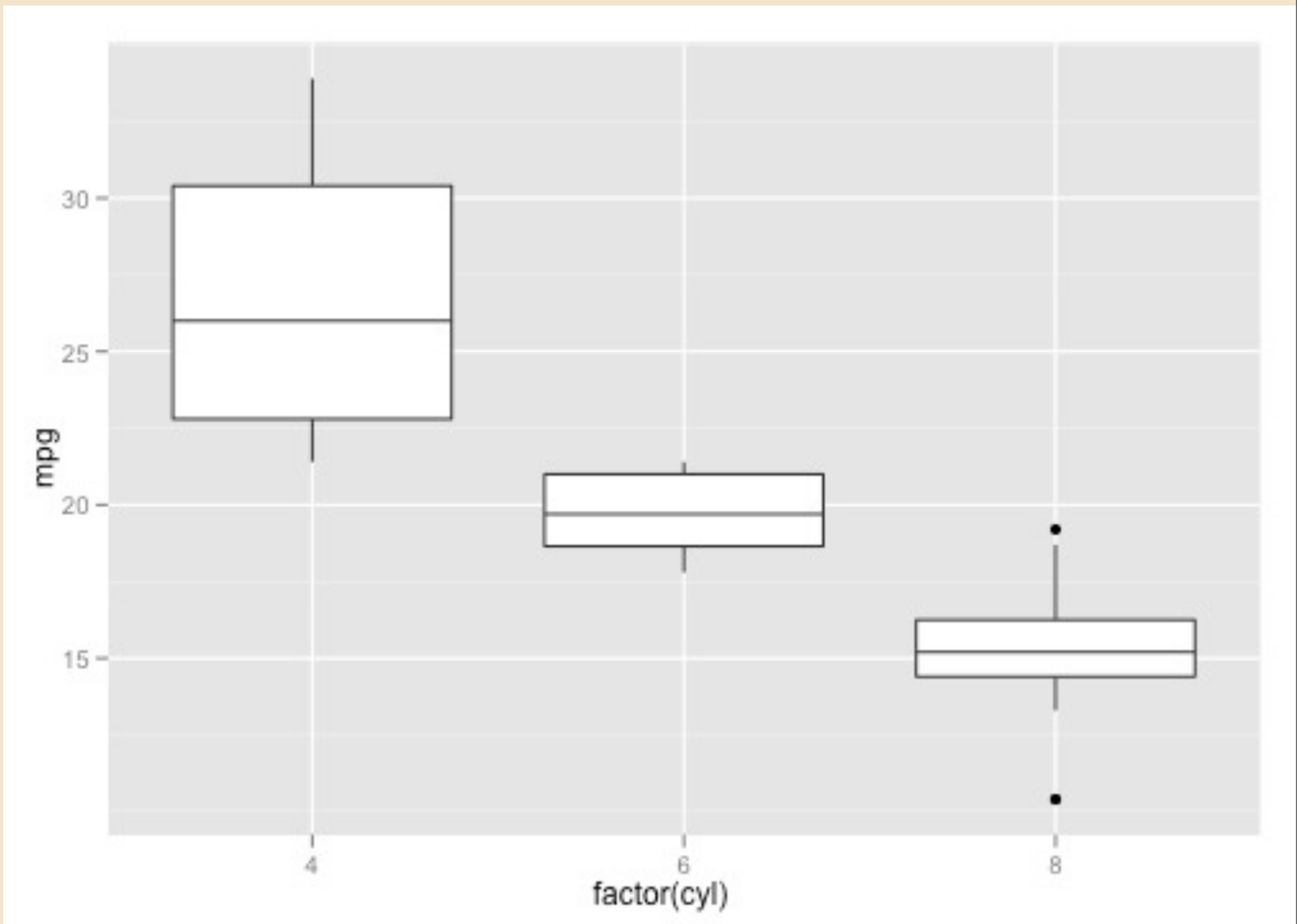
Exploratory

```
ggplot(mtcars, aes(factor(cyl), mpg))
  + geom_point(aes(colour = factor(cyl)))
```



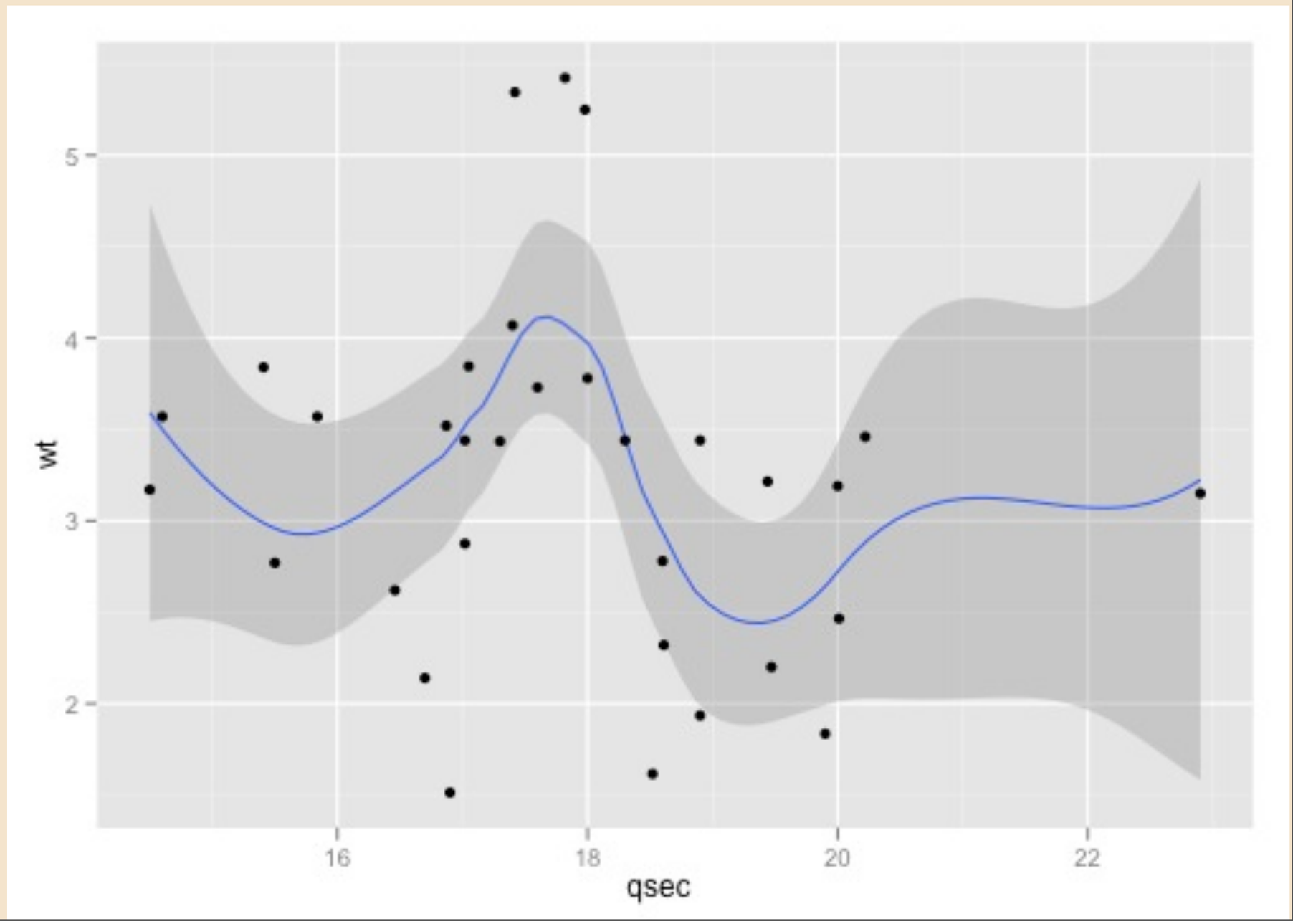
Exploratory

```
ggplot(mtcars, aes(wt, mpg))
  + geom_boxplot()
```



Exploratory

```
ggplot(mtcars, aes(qsec, wt))
  + stat_smooth() + geom_point()
```




Java

python


Scala

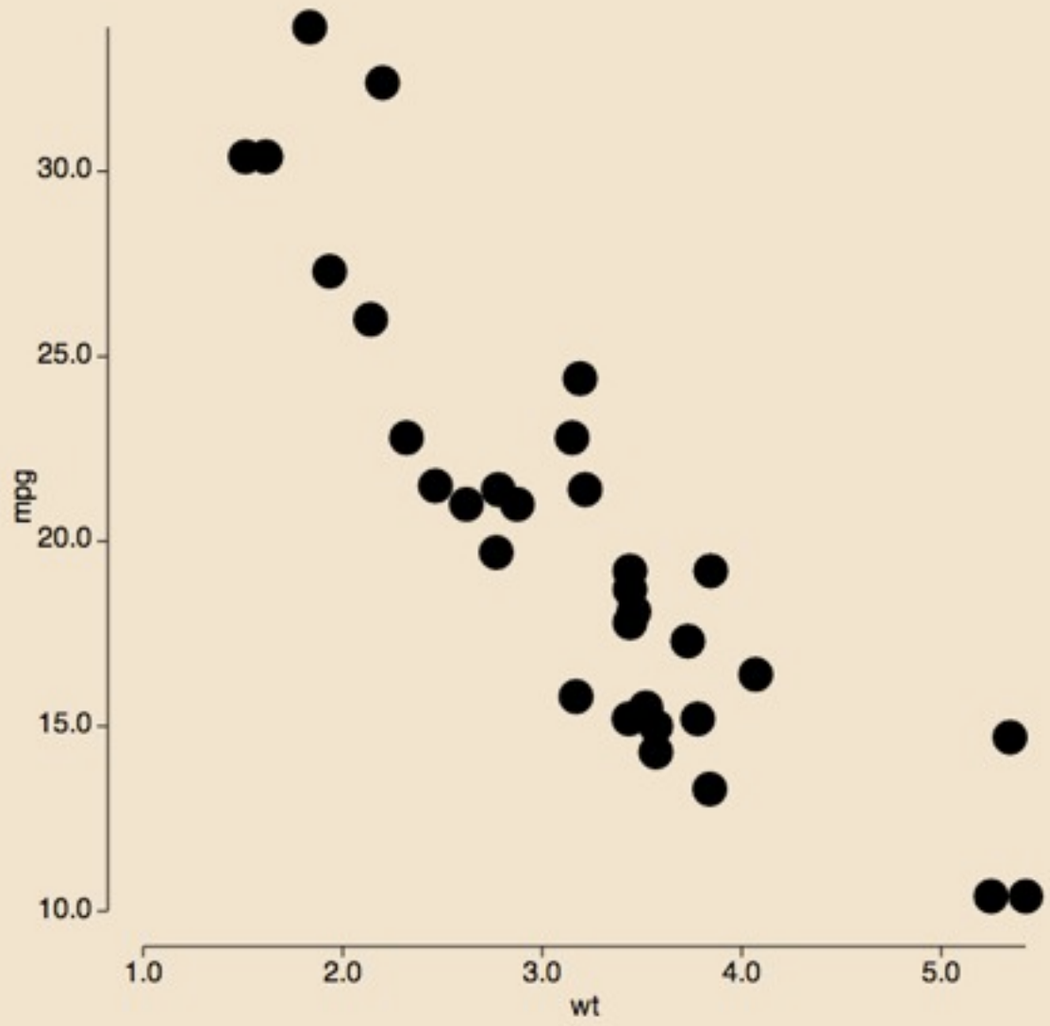

jetty://


JRuby


hadoop

complected

draw_scatterplot(data)



complected

draw_scatterplot(data)

calculate scale extents
calculate tick marks
curve fitting
calculate statistics
draw points
draw guides
draw labels
...

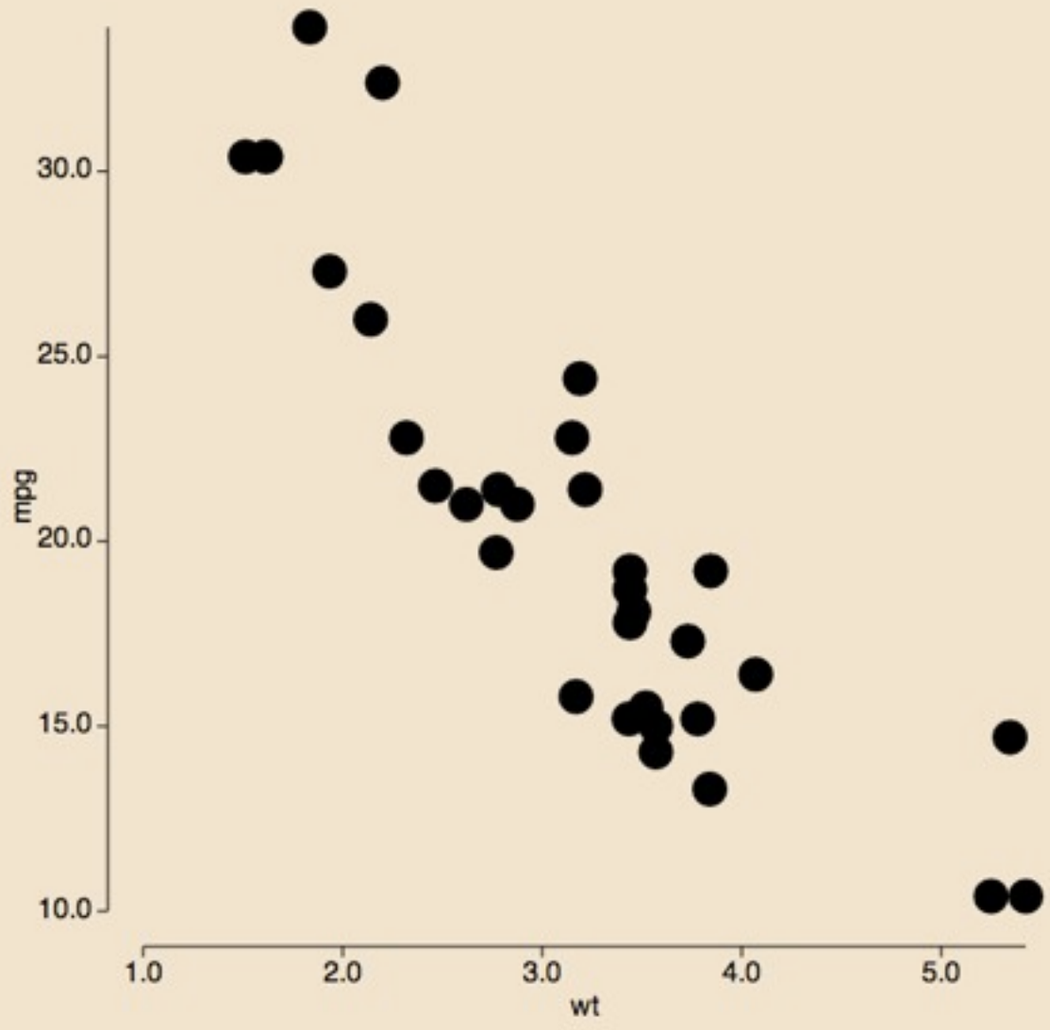
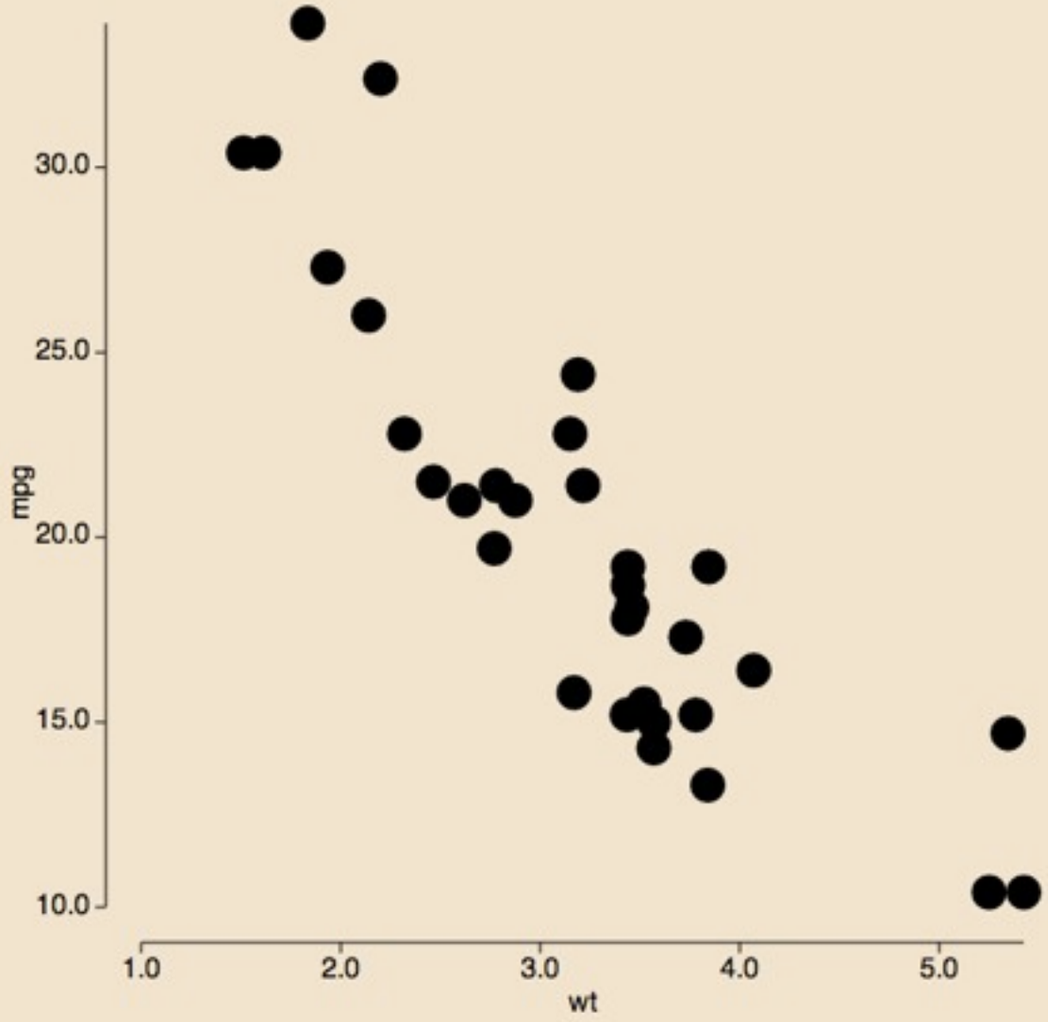


Photo by **Earth to Donna**, *Pintrest*

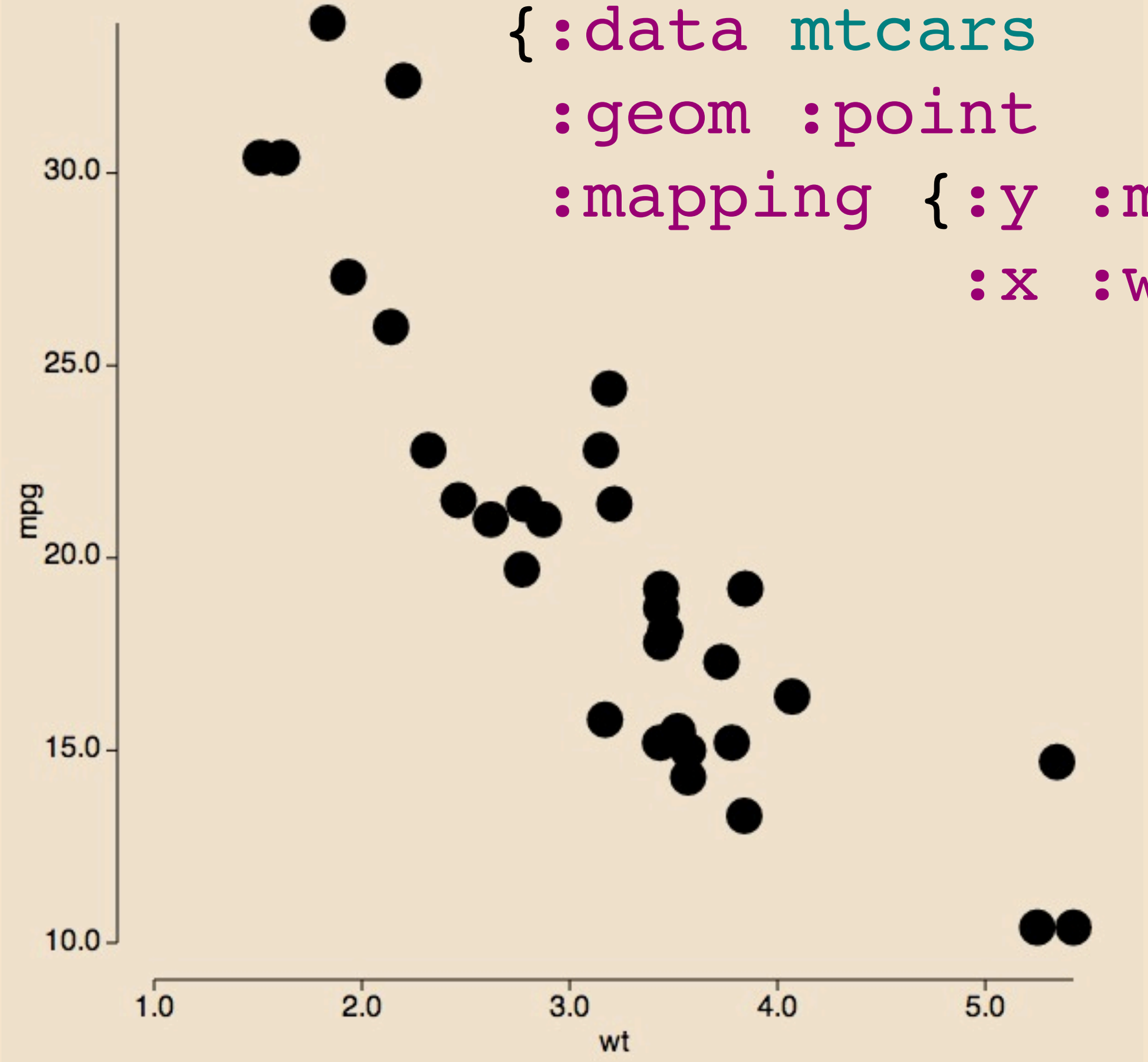
Decomplect

A graphic consists of:

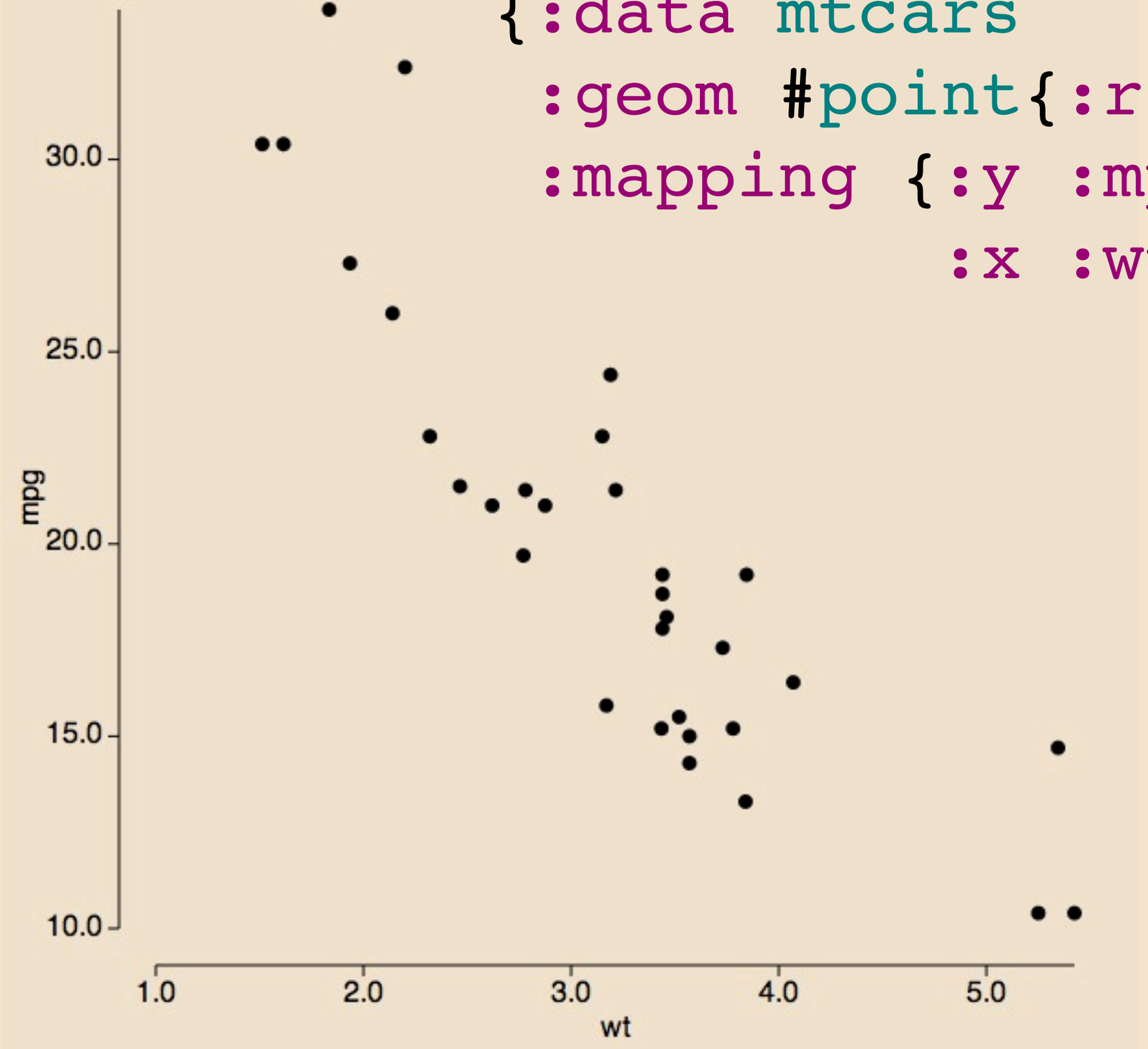
- Data
- Geometry
- Aesthetic mappings
- Statistics
- Groupings
- Scales



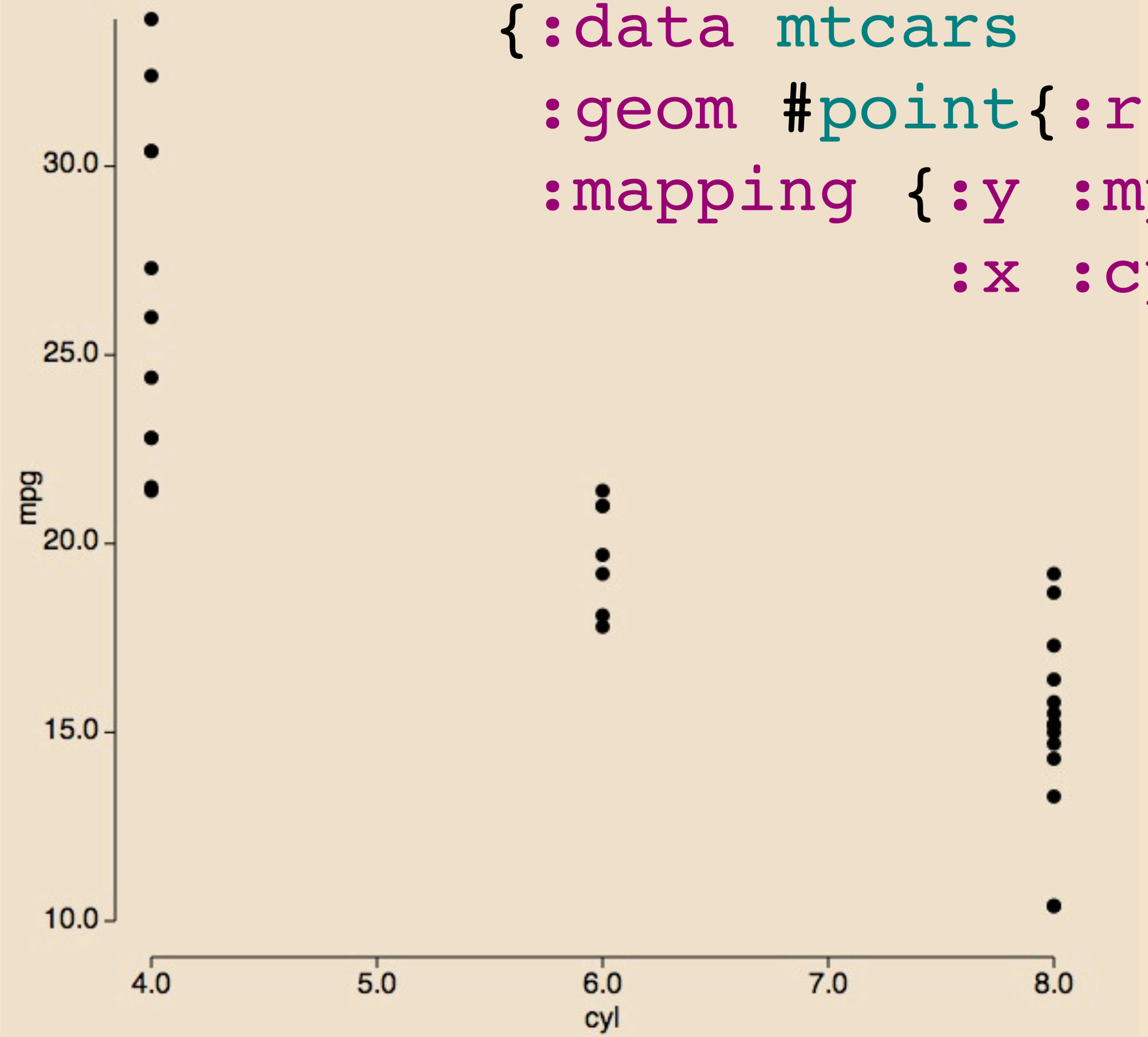
```
{:data mtcars
 :geom :point
 :mapping {:y :mpg
           :x :wt}}
```



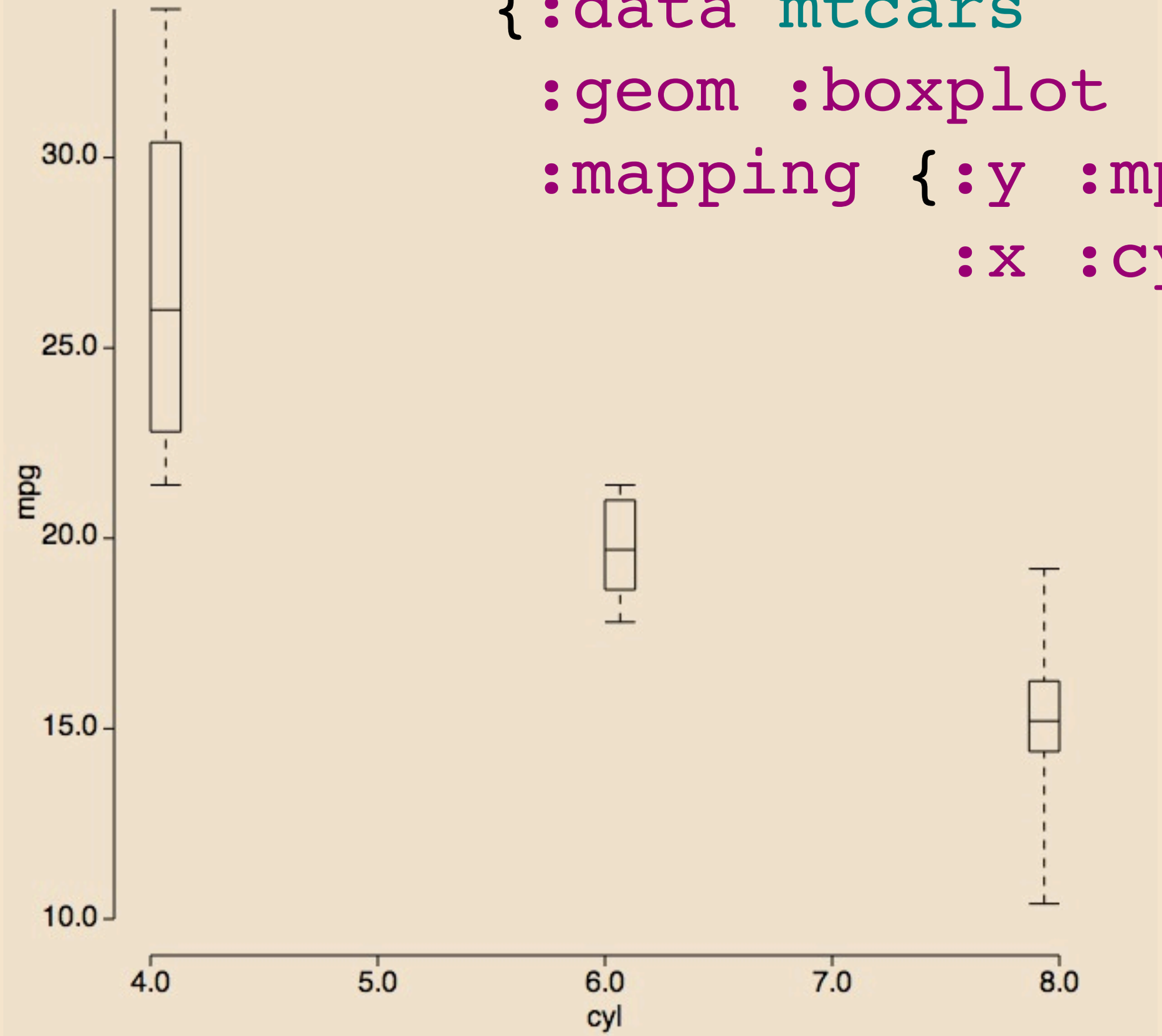
```
{:data mtcars
 :geom #point{:radius 4}
 :mapping {:y :mpg
           :x :wt}}
```



```
{:data mtcars
 :geom #point{:radius 4}
 :mapping {:y :mpg
           :x :cyl}}
```



```
{:data mtcars
 :geom :boxplot
 :mapping {:y :mpg
           :x :cyl}}
```



Data

all the things

API Support

```
{:data mtcars
 :mapping {:x :wt :y :mpg}
 :geom :point}
```

API Support

```
{:data => mtcars,
 :mapping => {:x => :wt, :y => :mpg},
 :geom => :point}
```

API Support

```
{"data": mtcars,
 "mapping": {"x": "wt", "y": "mpg"},
 "geom": "point"}
```

U can haz

Programming

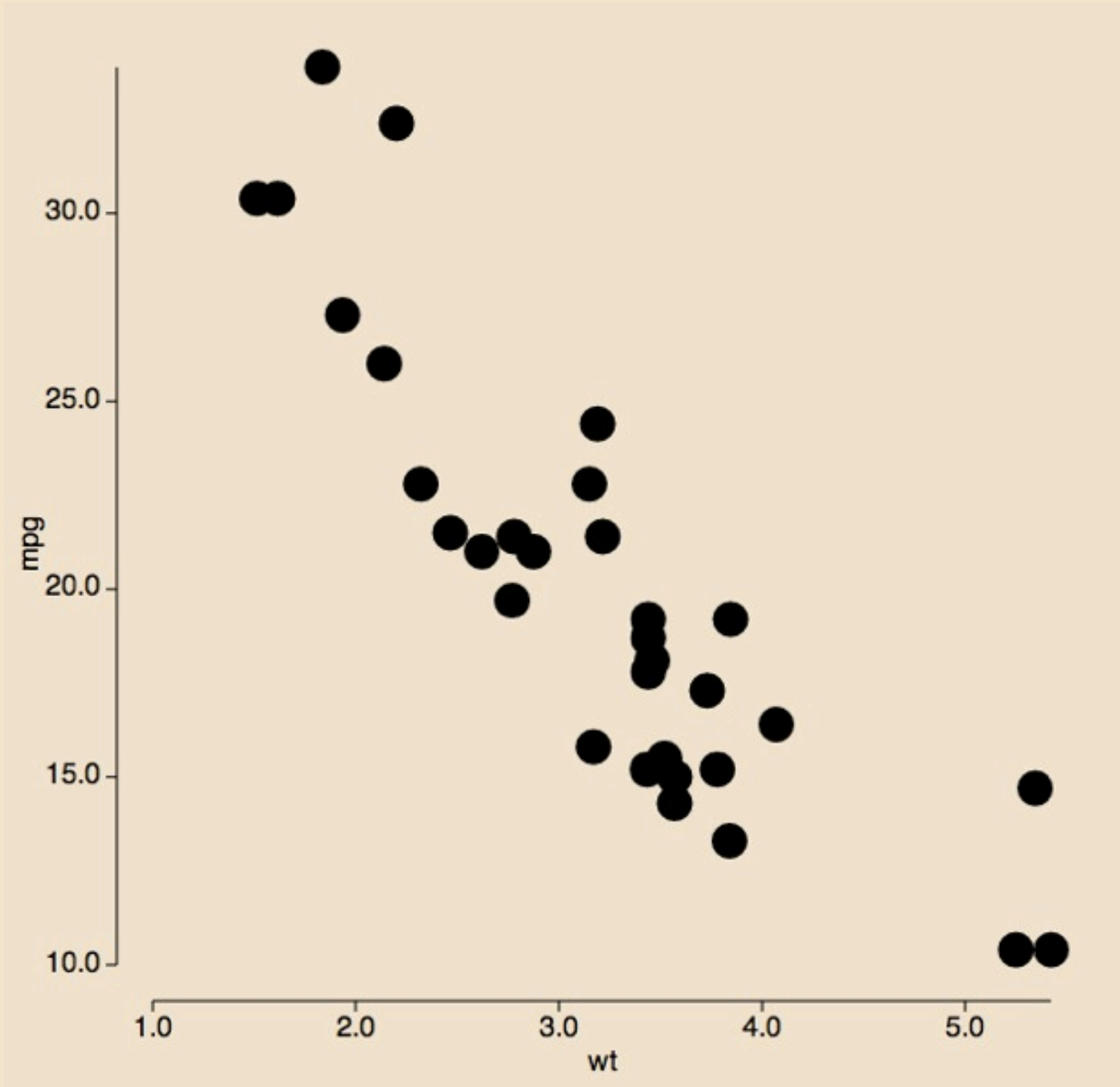
Spec --> Plot --> SVG/PDF/PNG

```
{:data mtcars
 :mapping {:x :wt :y :mpg}
 :geom :point}
```

Spec --> **Plot** --> SVG/PDF/PNG

```
{:height 500, :width 500, :title "",
 :layers ({:geoms
           (#point {:x 2.62, :y 21, :radius 10
                    :fill nil, :stroke nil}
            #point {:x 2.875, :y 21, :radius 10
                    :fill nil, :stroke nil}
            ...),
           :mapping {:x :wt, :y :mpg}}),
 :scales
 {:x #linear{:domain [1.513 5.424], :label :wt},
  :y #linear{:domain [10.4 33.9], :label :mpg}}}
```

Spec --> Plot --> **SVG**/PDF/PNG



Spec --> **Plot** --> SVG/PDF/PNG

```
{:height 500, :width 500, :title "",
 :layers ({:geoms
           (#point {:x 2.62, :y 21, :radius 10
                    :fill nil, :stroke nil}
            #point {:x 2.875, :y 21, :radius 10
                    :fill nil, :stroke nil}
            ...),
           :mapping {:x :wt, :y :mpg}}),
 :scales
 {:x #linear{:domain [1.513 5.424], :label :wt},
  :y #linear{:domain [10.4 33.9], :label :mpg}}}
```

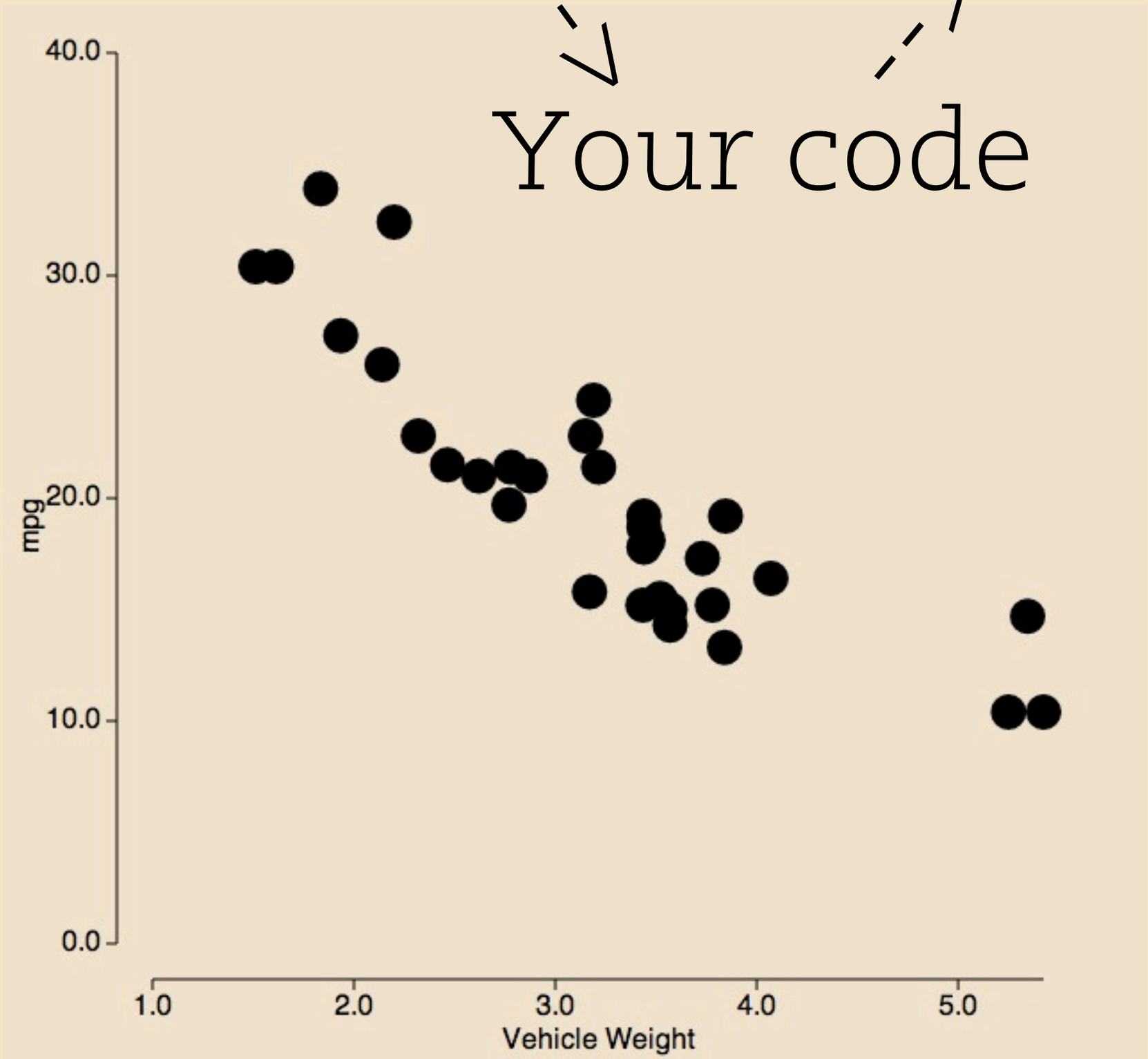
Spec --> Plot SVG/PDF/PNG

Your code

```
(-> {:data mtcars
     :mapping {:y :mpg, :x :wt}
     :geom :point}

    compile

    (assoc-in [:scales :y :domain] [0 40])
    (assoc-in [:scales :x :label] "Vehicle Weight")

    render!)
```

Spec --> Plot **SVG**/PDF/PNG

Your code



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A graphic consists of:

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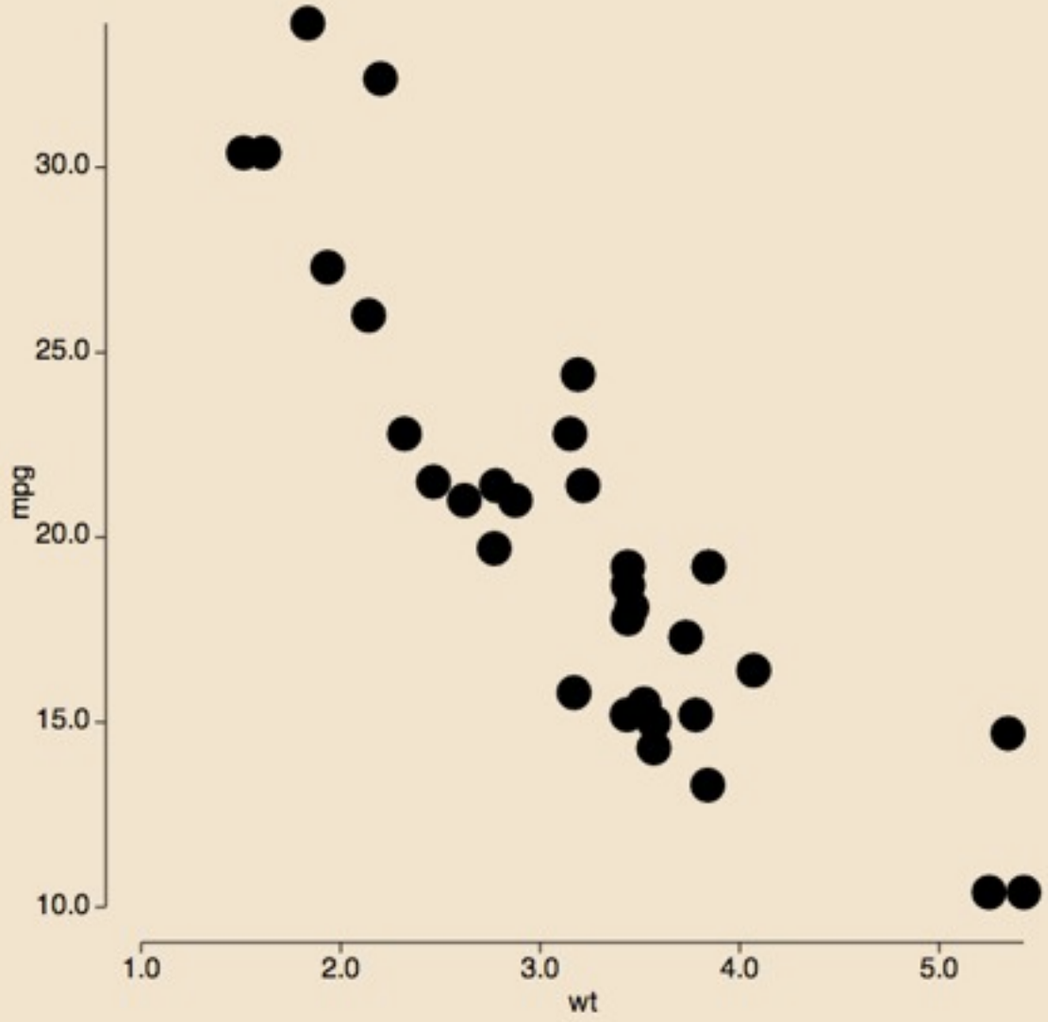

A

grammar

lets you

say

A

grammar

lets you

think

Kevin Lynagh

Keming Labs @lynaghk