

**Interfacing R with web technologies for interactive statistical graphics and  
computing with data**

by

**Carson Sievert**

A dissertation submitted to the graduate faculty  
in partial fulfillment of the requirements for the degree of  
DOCTOR OF PHILOSOPHY

Major: Statistics

Program of Study Committee:

Heike Hofmann, Major Professor

Dianne Cook

Jarad Niemi

Ulrike Genschel

Grayson Calhoun

Iowa State University

Ames, Iowa

2016

Copyright © Carson Sievert, 2016. All rights reserved.

ProQuest Number: 10238714

All rights reserved

INFORMATION TO ALL USERS

The quality of this reproduction is dependent upon the quality of the copy submitted.

In the unlikely event that the author did not send a complete manuscript and there are missing pages, these will be noted. Also, if material had to be removed, a note will indicate the deletion.



ProQuest 10238714

Published by ProQuest LLC (2017). Copyright of the Dissertation is held by the Author.

All rights reserved.

This work is protected against unauthorized copying under Title 17, United States Code  
Microform Edition © ProQuest LLC.

ProQuest LLC.  
789 East Eisenhower Parkway  
P.O. Box 1346  
Ann Arbor, MI 48106 – 1346

## TABLE OF CONTENTS

<b>LIST OF TABLES</b>	<b>vi</b>
<b>LIST OF FIGURES</b>	<b>viii</b>
<b>ACKNOWLEDGEMENTS</b>	<b>xxiv</b>
<b>CHAPTER 1. PROBLEM STATEMENT</b>	<b>1</b>
<b>CHAPTER 2. OVERVIEW</b>	<b>3</b>
2.1 What makes a good statistical software interface? . . . . .	3
2.1.1 Synergy between interfaces . . . . .	3
2.1.2 Synergy among programming interfaces . . . . .	8
2.2 Acquiring and wrangling web content in R . . . . .	10
2.2.1 Interfaces for working with web content . . . . .	10
2.2.2 Interfaces for acquiring data on the web . . . . .	13
2.3 Interactive statistical web graphics . . . . .	15
2.3.1 Why interactive graphics? . . . . .	15
2.3.2 Web graphics . . . . .	18
2.3.3 Translating R graphics to the web . . . . .	20
2.3.4 Interfacing with interactive web graphics . . . . .	22
2.3.5 Multiple MVC paradigms . . . . .	23

2.3.6	Hybrid MVC for one interface . . . . .	28
2.3.7	MVC for multiple interfaces . . . . .	29

## CHAPTER 3. TAMING PITCHF/X DATA WITH XML2R AND PITCHRX 33

3.1	Introduction . . . . .	34
3.1.1	What is PITCHf/x? . . . . .	34
3.1.2	Why is PITCHf/x important? . . . . .	34
3.1.3	PITCHf/x applications . . . . .	35
3.1.4	Contributions of pitchRx and XML2R . . . . .	35
3.2	Getting familiar with Gameday . . . . .	36
3.3	Introducing XML2R . . . . .	39
3.3.1	Constructing file names . . . . .	39
3.3.2	Extracting observations . . . . .	40
3.3.3	Renaming observations . . . . .	42
3.3.4	Linking observations . . . . .	44
3.3.5	Collapsing observations . . . . .	45
3.4	Collecting Gameday data with pitchRx . . . . .	46
3.5	Storing and querying Gameday data . . . . .	48
3.6	Visualizing PITCHf/x . . . . .	50
3.6.1	Strike-zone plots and umpire bias . . . . .	50
3.6.2	2D animation . . . . .	59
3.6.3	Interactive 3D graphics . . . . .	62
3.7	Conclusion . . . . .	64

## CHAPTER 4. LDAVIS: A METHOD FOR VISUALIZING AND INTERPRETING TOPICS 66

4.1	Introduction . . . . .	67
-----	------------------------	----

4.2	Related Work . . . . .	70
4.2.1	Topic Interpretation and Coherence . . . . .	70
4.2.2	Topic Model Visualization Systems . . . . .	72
4.3	Relevance of tokens to topics . . . . .	73
4.3.1	Definition of Relevance . . . . .	73
4.3.2	User Study . . . . .	74
4.4	Our Visualization System . . . . .	79
4.5	Discussion . . . . .	83
 <b>CHAPTER 5. EXTENDING GGPLOT2'S GRAMMAR OF GRAPHICS IMPLEMENTATION FOR LINKED AND DYNAMIC GRAPHICS ON THE WEB</b>		<b>84</b>
5.1	Introduction . . . . .	85
5.2	Related Work . . . . .	86
5.3	Extending the layered grammar of graphics . . . . .	89
5.3.1	Direct Manipulation of Database Queries . . . . .	90
5.3.2	Adding animation . . . . .	92
5.3.3	World Bank Example . . . . .	93
5.3.4	Implementation details . . . . .	100
5.4	Exploring performance & scope with examples . . . . .	104
5.5	Comparison study . . . . .	105
5.5.1	The Grand Tour . . . . .	105
5.5.2	World Bank Example . . . . .	109
5.6	User feedback and observations . . . . .	110
5.6.1	User perspective . . . . .	110
5.6.2	Developer perspective . . . . .	111
5.7	Limitations and future work . . . . .	111

5.8	Conclusion . . . . .	113
<b>CHAPTER 6. INTERACTIVE DATA VISUALIZATION ON THE WEB USING R</b>		<b>114</b>
6.1	Introduction . . . . .	114
6.2	Case Studies . . . . .	116
6.2.1	Exploring pedestrian counts . . . . .	116
6.2.2	Tracking disease outbreak . . . . .	128
6.2.3	Exploring Australian election data . . . . .	132
6.3	Conclusion . . . . .	137
6.4	Acknowledgements . . . . .	139
<b>CHAPTER 7. PLOTLY FOR R</b>		<b>140</b>
7.1	Two approaches, one object . . . . .	140
7.1.1	A case study of housing sales in Texas . . . . .	141
7.1.2	Extending <code>ggplotly()</code> . . . . .	153
7.2	The plotly cookbook . . . . .	160
7.2.1	Scatter traces . . . . .	160
7.2.2	Maps . . . . .	182
7.2.3	Bars & histograms . . . . .	185
7.2.4	Boxplots . . . . .	191
7.2.5	2D frequencies . . . . .	195
7.2.6	Other 3D plots . . . . .	199
7.3	Arranging multiple views . . . . .	200
7.3.1	Arranging <code>htmlwidgets</code> . . . . .	201
7.3.2	Merging plotly objects . . . . .	205
7.3.3	Navigating many views . . . . .	213
7.4	Multiple linked views . . . . .	216

7.4.1	Linking views with shiny . . . . .	216
7.4.2	Linking views without shiny . . . . .	220
7.5	Animating views . . . . .	242
7.5.1	Key frame animations . . . . .	242
7.5.2	Linking animated views . . . . .	246
7.6	Advanced topics . . . . .	251
7.6.1	Custom behavior via JavaScript . . . . .	252
7.6.2	Translating custom ggplot2 geoms . . . . .	253
7.6.3	Designing an htmlwidget interface . . . . .	256
<b>CHAPTER 8. IMPACT AND FUTURE WORK</b>		<b>259</b>
8.1	Impact . . . . .	259
8.1.1	plotly . . . . .	259
8.1.2	LDavis . . . . .	261
8.2	Future work . . . . .	261
<b>BIBLIOGRAPHY</b>		<b>263</b>

## LIST OF TABLES

Table 3.1	Structure of PITCHf/x and related Gameday data sources accessible to ‘scrape()’ . . . . .	38
Table 5.1	Characteristics of 11 interactive visualizations designed with animint. The interactive version of these visualizations can be accessed via <a href="http://sugiyama-www.cs.titech.ac.jp/~toby/animint/">http://sugiyama-www.cs.titech.ac.jp/~toby/animint/</a> . From left to right, we show the data set name, the lines of R code (LOC) including data processing but not including comments (80 characters max per line), the amount of time it takes to compile the visualization (seconds), the total size of the uncompressed TSV files in megabytes (MB), the total number of data points (rows), the median number of data points shown at once (on-screen), the number of data columns visualized (variables), the number of <code>clickSelects/showSelected</code> variables (interactive), the number of linked panels (plots), if the plot is animated, and the corresponding Figure number in this paper (Fig). . . . .	106



## LIST OF FIGURES

Figure 2.1	A basic visual depiction of linked views in a standalone web page (A) versus a client-server model (B). In some cases (A), linked views can be resolved within a web browser, which generally leads to a better user experience. In other cases (B), updating views may require calls to a web server running special software. . . . .	9
Figure 2.2	A video demonstration of interactive and dynamic techniques for visualizing high-dimensional relationships in data using the R package <b>tourbrush</b> . You can view this movie online at <a href="https://vimeo.com/148050343">https://vimeo.com/148050343</a> . . . . .	15
Figure 2.3	Four different MVC paradigms. In all the scenarios, the graph acts as the controller, but the model (i.e., the data and logic which updates the view) exists in different places. In Scenario A, a mouse hover event manipulates the model within the underlying JavaScript library. In Scenario B, a window resizing manipulates the model within the <code>HTMLwidget.resize()</code> method, defined by the widget author. In Scenario C, a mouse hover event manipulates the model within the underlying JavaScript library <i>and</i> a model defined by both the user (in R) and the widget author (in JavaScript). In Scenario D, removing outliers from the raw data may require R code to be executed. . . . .	25

Figure 2.4	Linking views in plotly with shiny (scenario B) versus without shiny (scenario A). . . . .	30
Figure 2.5	The GGobi pipeline, as described by Lawrence (2002), in comparison to a centralized pipeline. The GGobi pipeline is shown in peach color while the centralized pipeline is in both yellow and blue to point out multiple interfaces can be linked in a centralized pipeline. . . . .	31
Figure 2.6	The MVC design for linking multiple htmlwidgets with crosstalk	32
Figure 3.1	Table relations between Gameday data accessible via <code>scrape()</code> . The direction of the arrows indicate a one to possibly many relationship. . . . .	38
Figure 3.2	Density of called strikes for right-handed batters and left-handed batters (from 2008 to 2013). . . . .	52
Figure 3.3	Density of called strikes minus density of balls for both right-handed batters and left-handed batters (from 2008 to 2013). The blue region indicates a higher frequency of called strikes and the red region indicates a higher frequency of balls. . . . .	54
Figure 3.4	Probability that a right-handed away pitcher receives a called strike (provided the umpire has to make a decision). Plots are faceted by the handedness of the batter. . . . .	57
Figure 3.5	Difference between home and away pitchers in the probability of a strike (provided the umpire has to make a decision). The blue regions indicate a higher probability of a strike for home pitchers and red regions indicate a higher probability of a strike for away pitchers. Plots are faceted by the handedness of both the pitcher and the batter. . . . .	58

- Figure 3.6 The last frame of an animation of every four-seam and cutting fastballs thrown by NY Yankee pitchers Mariano Rivera and Phil Hughes during the 2011 season. The actual animation can be viewed at <http://cpsievert.github.io/pitchRx/ani1>. Pitches are faceted by pitcher and batting stance. For instance, the top left plot portrays pitches thrown by Rivera to left-handed batters. . . . 61
- Figure 3.7 The last frame of an animation of averaged four-seam and cutting fastballs thrown by NY Yankee pitchers Mariano Rivera and Phil Hughes during the 2011 season. The actual animation can be viewed at <http://cpsievert.github.io/pitchRx/ani2>. PITCHf/x parameters are averaged over pitch type, pitcher and batting stance. For instance, the bottom right plot portrays an average four-seam and average cutter thrown by Hughes to right-handed batters. . . . . 63
- Figure 3.8 3D scatterplot of pitches from Rivera. Pitches are plotted every one-hundredth of a second. Cutting fastballs are shown in red and four-seam fastballs are shown in blue. The left hand plot takes a viewpoint of Rivera and the right hand plot takes a viewpoint near the umpire. Note these are static pictures of an interactive object. . . . . 64
- Figure 4.1 The layout of LDAvis, with the global topic view on the left, and the token barcharts on the right. Linked selections allow users to reveal aspects of the topic-token relationships compactly. . . . . 69
- Figure 4.2 Dotted lines separating the top-10 most relevant tokens for different values of  $\lambda$ , with the most relevant tokens for  $\lambda = 2/3$  displayed and highlighted in green. . . . . 75

Figure 4.3	A plot of the proportion of correct responses in a user study vs. the value of $\lambda$ used to compute the most relevant tokens for each topic.	78
Figure 4.4	The user has chosen to segment the topics into four clusters, and has selected the green cluster to populate the barchart with the most relevant tokens for that cluster. Then, the user hovered over the ninth bar from the top, ‘file’, to display the conditional distribution over topics for this token. . . . .	80
Figure 5.1	Linked database querying via direct manipulation using animint. A video demonstration can be viewed online at <a href="https://vimeo.com/160496419">https://vimeo.com/160496419</a> . . . . .	92
Figure 5.2	A simple animation with smooth transitions and interactively altering transition durations. A video demonstration can be viewed online at <a href="https://vimeo.com/160505146">https://vimeo.com/160505146</a> . . . . .	94
Figure 5.3	An interactive animation of World Bank demographic data of several countries, designed using <code>clickSelects</code> and <code>showSelected</code> keywords (top). Left: a multiple time series from 1960 to 2010 of life expectancy, with bold lines showing the selected countries and a vertical grey tallrect showing the selected year. Right: a scatterplot of life expectancy versus fertility rate of all countries. The legend and text elements show the current selection: year=1979, country= {United States, Vietnam}, and region={East Asia & Pacific, North America} . . . . .	95
Figure 5.4	Animint provides a menu to update each selection variable. In this example, after typing ‘th’ the country menu shows the subset of matching countries. . . . .	97

Figure 5.5 A schematic explanation of compilation and rendering in the World Bank visualization. Top: the interactive animation is a list of 4 R objects: 2 ggplots and 2 option lists. Center: animint R code compiles data in ggplot geoms to a database of TSV files ( $\rightarrow$ ). It also compiles plot meta-data including ggplot aesthetics, animation time options, and transition duration options to a JSON meta-data file ( $\rightarrow$ ). Bottom: those data-dependent compiled files are combined with data-independent JavaScript and HTML files which render the interactive animation in a web browser ( $\rightarrow$ ). . . 101

Figure 5.6 Interactive animation of tornadoes recorded from 1950 to 2012 in the United States. Left: map of the lower 48 United States with tornado paths in 1982. The text shows the selected year, and clicking the map changes the selected state, currently Texas. Right: time series of tornado counts in Texas. Clicking a bar changes the selected year, and the text shows selected state and the number of tornadoes recorded there in that year (119 tornadoes in Texas in 1982). . . . . 102

Figure 5.7	Visualization containing 6 linked, interactive, animated plots of Central American climate data. Top: for the selected time (December 1997), maps displaying the spatial distribution of two temperature variables, and a scatterplot of these two variables. The selected region is displayed with a black outline, and can be changed by clicking a rect on the map or a point on the scatterplot. Bottom: time series of the two temperature variables with the selected region shown in violet, and a scatterplot of all times for that region. The selected time can be changed by clicking a background tallrect on a time series or a point on the scatterplot. The selected region can be changed by clicking a line on a time series. . . . .	103
Figure 5.8	Linked selection in a grand tour with animint. A video demonstration can be viewed online at <a href="https://vimeo.com/160720834">https://vimeo.com/160720834</a> .	107
Figure 5.9	Linked selection in a grand tour with ggvis and shiny. A video demonstration can be viewed online at <a href="https://vimeo.com/160825528">https://vimeo.com/160825528</a> . . . . .	108
Figure 6.1	Missing values by station. . . . .	117
Figure 6.2	An interactive bar chart of the number of missing counts by station linked to a sampled time series of counts. See here for the corresponding video and here for the interactive figure. . . . .	118

- Figure 6.3 Two frames from a grand tour of measures generated from seasonal, trend, and irregular time-series components. The first frame (the top row) displays the state of the tour roughly 16 seconds into the animation while the second frame (the bottom row) is at roughly 60 seconds. A given frame displays both a 2D projection (on the left) and the linear combination of variables used for the projection (on the right). In both frames, the Tin Alley-Swanson St (West) sensor is highlighted in red – a useful technique for tracking interesting or unusual point(s) throughout a tour. . . . . 121
- Figure 6.4 Identifying and comparing unusual sensors (Tin Alley and Swanson St) using linked highlighting between a grand tour and a parallel coordinates plot. The second frame of Figure 6.3 helped to point out Bourke St as a somewhat unusual sensor with respect to trend. Highlighting that point and linking it to a parallel coordinate plot makes it easier to compare trend across sensors and compare the other measures among sensors of interest. . . . . 122
- Figure 6.5 Linking views of seasonal trend decomposition summaries (first two rows) to the actual time series (last two rows). By linking raw counts and the hourly IQR, we can see that Tin Alley (in red) experiences relatively low traffic compared to Bourke St (in blue), and overall traffic (black). See [here](#) for the corresponding video and [here](#) for the interactive figure. . . . . 124

Figure 6.6	Seventeen time series features linked to a geographic map as well as raw counts. This static image was generated using a persistent brush to compare Tin Alley-Swanson St. (in red) to Waterfront City (in blue). In addition to being unusual in the feature space, these sensors are also on the outskirts of the city. The corresponding video and interactive figure (available <a href="#">here</a> and <a href="#">here</a> ) also includes a grand tour and raw counts by day of the year. . .	126
Figure 6.7	Sensors with high first order autocorrelation (in red) versus sensors with low autocorrelation (in blue). See <a href="#">here</a> for the corresponding video and <a href="#">here</a> for the interactive figure. . . . .	127
Figure 6.8	Linking a dendrogram of hierarchical clustering results to multiple views of the raw data. See <a href="#">here</a> for the corresponding video and <a href="#">here</a> for the interactive figure. . . . .	128
Figure 6.9	Multiple views of the Zika outbreak data. On the left-hand side is a map of the reporting locations. On the right is the overall density of suspected/confirmed cases reported per week (on a log scale), and the overall weekly median over time. . . . .	129
Figure 6.10	A comparison of the overall cases (in black) to the cases conditional on the map bounds (in red). Zooming and panning the interactive map dynamically updates the density estimates and median number of incidents. . . . .	130
Figure 6.11	Zooming and panning to a region of the map that has a negative median of overall cases (Nicaragua). A video of the zooming and panning may be viewed <a href="#">here</a> . . . . .	131
Figure 6.12	Cumulative confirmed (in red) and suspected (in blue) counts by location within 9 different countries. . . . .	132



Figure 6.13	Highlighting cumulative confirmed (in red) and suspected (in blue) counts by location within Colombia to verify re-classifications from confirmed to suspected. A video of the interactive highlighting may be viewed here. . . . .	133
Figure 6.14	Electorate demographics among the Liberal Party (in green), the Australian Labor Party (in orange), and other parties (in black). The vertical lines represent the mean value within each group. The interactive application used to generate this image may be accessed here and a video of the interactive highlighting may be viewed here. . . . .	134
Figure 6.15	Comparing voting outcomes and geographic location among the Liberal Party (in green), the Australian Labor Party (in orange), and other parties (in black). The bar chart in the upper-left hand panel shows the number of electorates won by each party. The upper-right hand panel shows the proportion of 1st preference votes for each party for given electorate. The lower-left hand panel shows the absolute difference in vote totals for each electorate. The lower-right hand panel show the locations of electorates. . .	136
Figure 6.16	Electorates that were determined by less than 10 percent of the total vote. These electorates tend to have voters that are younger, less religious, are less likely to own property, and lean towards the Labor party. . . . .	137
Figure 6.17	Electorates that experienced a close election as well as electorates with small populations (in orange). . . . .	138

Figure 7.1	Monthly median house price in the state of Texas. The top row displays the raw data (by city) and the bottom row shows 2D binning on the raw data. The binning is helpful for showing the overall trend, but hovering on the lines in the top row helps reveal more detailed information about each city. . . . .	143
Figure 7.2	Monthly median house price in Houston in comparison to other Texan cities. . . . .	146
Figure 7.3	Monthly median house price in Houston and San Antonio in comparison to other Texan cities. . . . .	149
Figure 7.4	First, second, and third quartile of median monthly house price in Texas. . . . .	151
Figure 7.5	Layering on a 4-year forecast from a exponential smoothing state space model. . . . .	152
Figure 7.6	Customizing the dragmode of an interactive ggplot2 graph. . . .	153
Figure 7.7	Adding a rangeslider to an interactive ggplot2 graph. . . . .	154
Figure 7.8	Using listviewer to inspect the JSON representation of a plotly object. . . . .	155
Figure 7.9	Using the <code>style()</code> function to modify hoverinfo attribute values of a plotly object created via <code>ggplotly()</code> (by default, <code>ggplotly()</code> displays hoverinfo for all traces). In this case, the hoverinfo for a fitted line and error bounds are hidden. . . . .	156
Figure 7.10	Leveraging data associated with a <code>geom_smooth()</code> layer to display additional information about the model fit. . . . .	158
Figure 7.11	Leveraging output from <code>StatBin</code> to add annotations to a stacked bar chart (created via <code>geom_bar()</code> ) which makes it easier to compare bar heights. . . . .	159

Figure 7.12	Leveraging output from <code>StatDensity2d</code> to add annotations to contour levels. a stacked bar chart (created via <code>geom_bar()</code> ) which makes it easier to compare bar heights. . . . .	161
Figure 7.13	Three versions of a basic scatterplot . . . . .	163
Figure 7.14	Specifying symbol in a scatterplot . . . . .	164
Figure 7.15	Mapping symbol to a factor . . . . .	165
Figure 7.16	Variations on a numeric color mapping. . . . .	166
Figure 7.17	Three variations on a numeric color mapping . . . . .	167
Figure 7.18	Three variations on a discrete color mapping . . . . .	168
Figure 7.19	Controlling the size range via <code>sizes</code> (measured in pixels). . . . .	169
Figure 7.20	A 3D scatterplot . . . . .	169
Figure 7.21	An interactive version of the generalized pairs plot made via the <code>ggpairs()</code> function from the <b>GGally</b> package . . . . .	171
Figure 7.22	A coefficient plot . . . . .	173
Figure 7.23	Median house sales with one trace per city. . . . .	174
Figure 7.24	Using <code>color</code> and/or <code>linetype</code> to differentiate groups of lines. . . . .	175
Figure 7.25	Various kernel density estimates. . . . .	176
Figure 7.26	Parallel coordinates plots of the Iris dataset. On the left is the raw measurements. In the middle, each variable is scaled to have mean of 0 and standard deviation of 1. On the right, each variable is scaled to have a minimum of 0 and a maximum of 1. . . . .	178
Figure 7.27	A path in 3D . . . . .	178
Figure 7.28	A 3D line plot . . . . .	179
Figure 7.29	A candlestick chart . . . . .	180
Figure 7.30	Plotting fitted values and uncertainty bounds of a linear model via the <b>broom</b> package. . . . .	181
Figure 7.31	A map of Canada using the default cartesian coordinate system. . . . .	182

Figure 7.32	Three different ways to render a map. On the top left is plotly's default cartesian coordinate system, on the top right is plotly's custom geographic layout, and on the bottom is mapbox. . . . .	184
Figure 7.33	A map of U.S. population density using the <code>state.x77</code> data from the <b>datasets</b> package. . . . .	185
Figure 7.34	plotly.js's default binning algorithm versus R's <code>hist()</code> default . .	187
Figure 7.35	Number of diamonds by cut. . . . .	188
Figure 7.36	A trellis display of diamond price by diamond clarity. . . . .	189
Figure 7.37	A grouped bar chart . . . . .	190
Figure 7.38	A stacked bar chart showing the proportion of diamond clarity within cut. . . . .	191
Figure 7.39	Using <code>ggmosaic</code> and <code>ggplotly()</code> to create advanced interactive visualizations of categorical data . . . . .	192
Figure 7.40	Overall diamond price and price by cut. . . . .	193
Figure 7.41	Diamond prices by cut and clarity. . . . .	193
Figure 7.42	Diamond prices by cut and clarity, sorted by price median. . . .	195
Figure 7.43	Three different uses of <code>histogram2d()</code> . . . . .	196
Figure 7.44	2D Density estimation via the <code>kde2d()</code> function . . . . .	198
Figure 7.45	Displaying a correlation matrix with <code>add_heatmap()</code> and controlling the scale limits with <code>colorbar()</code> . . . . .	199
Figure 7.46	A 3D surface of volcano height. . . . .	200
Figure 7.47	Printing multiple <code>htmlwidget</code> objects with <code>tagList()</code> . To render tag lists at the command line, wrap them in <code>browsable()</code> . . . .	202
Figure 7.48	Arranging multiple <code>htmlwidgets</code> with <code>flexbox</code> . . . . .	203
Figure 7.49	Arranging multiple <code>htmlwidgets</code> with <code>fluidPage()</code> from the <b>shiny</b> package. . . . .	204

Figure 7.50	The most basic use of <code>subplot()</code> to merge multiple plotly objects into a single plotly object. . . . .	206
Figure 7.51	Five different economic variables on different y scales and a common x scale. Zoom and pan events in the x-direction are synchronized across plots. . . . .	207
Figure 7.52	Pre-populating y axis IDs. . . . .	208
Figure 7.53	A visual diagram of controlling the <b>heights</b> of rows and <b>widths</b> of columns. . . . .	208
Figure 7.54	A joint density plot with synchronized axes. . . . .	209
Figure 7.55	Recursive subplots. . . . .	210
Figure 7.56	Multiple bar charts of US statistics by state in a subplot with a choropleth of population density . . . . .	212
Figure 7.57	Arranging multiple faceted ggplot2 plots into a plotly subplot. . . . .	213
Figure 7.58	Using plotly within a treliscope . . . . .	215
Figure 7.59	A video demonstration of plotly events in shiny. The video can be accessed here . . . . .	217
Figure 7.60	A video demonstration of linked brushing in a shiny app. The video can be accessed here and the code to run the example is here	219
Figure 7.61	A video demonstration of clicking on a cell in a correlation matrix to view the corresponding scatterplot. The video can be accessed here and the code to run the example is here . . . . .	220
Figure 7.62	Monthly median house sales by year and city. Each panel represents a city and panels are linked by year. A video demonstrating the graphical queries can be viewed here . . . . .	222
Figure 7.63	Brushing a scatterplot matrix via the <code>ggpairs()</code> function in the <b>GGally</b> package. A video demonstrating the graphical queries can be viewed here . . . . .	223

Figure 7.64	Highlighting lines with transient versus persistent selection. In the left hand panel, transient selection (the default); and in the right hand panel, persistent selection. The video may be accessed here . . . . .	225
Figure 7.65	Linking views between plotly and leaflet to explore the relation between magnitude and geographic location of earthquakes around Fiji. The video may be accessed here . . . . .	226
Figure 7.66	Selecting cities by indirect manipulation. The video may be accessed here . . . . .	228
Figure 7.67	A bar chart of cities with one or more missing median house sales linked to a time series of those sales over time. The video may be accessed here . . . . .	229
Figure 7.68	A diagram of the pipeline between the data and graphics. . . . .	230
Figure 7.69	Dynamically populating a boxplot reflecting brushed observations	233
Figure 7.70	Dynamically populating a bar chart reflecting brushed observations	234
Figure 7.71	Engine displacement versus highway miles per gallon by class of car. The linear model for each class, as well as the individual observations, can be selected by hovering over the line of fitted values. An individual observation can also be selected by hovering over the relevant point. . . . .	235
Figure 7.72	Using nested selections to highlight numerous diagnostics from different regions of the design matrix. . . . .	237
Figure 7.73	Clicking on a density estimate to highlight all the raw observations that went into that estimate. . . . .	238
Figure 7.74	A simple example of hierarchial selection . . . . .	240
Figure 7.75	Leveraging hierarchical selection and persistent brushing to paint branches of a dendrogram. . . . .	241

Figure 7.76	Animation of the evolution in the relationship between GDP per capita and life expectancy in numerous countries. . . . .	243
Figure 7.77	Modifying animation defaults with <code>animation_opts()</code> , <code>animation_button()</code> , and <code>animation_slider()</code> . . . . .	244
Figure 7.78	Animation of GDP per capita versus life expectancy by continent. The ordering of the continents goes from lowest average (across countries) life expectancy to highest. . . . .	245
Figure 7.79	Overlaying animated frames on top of a background of all possible frames. . . . .	246
Figure 7.80	Highlighting the relationship between GDP per capita and life expectancy in the Americas and tracking that relationship through several decades. . . . .	247
Figure 7.81	Comparing the evolution in the relationship between per capita GDP and life expectancy in countries with large populations (red) and small populations (blue). . . . .	248
Figure 7.82	Linking a dendrogram to a grand tour and map of the <code>USArrests</code> data to visualize a classification in 5 dimensions. . . . .	250
Figure 7.83	Using <code>onRender()</code> to register a JavaScript callback that opens a google search upon a ‘plotly_click’ event. . . . .	253
Figure 7.84	Converting <code>GeomXspline</code> from the <b>ggalt</b> package to plotly.js via <code>ggplotly()</code> . . . . .	256
Figure 8.1	CRAN downloads over the past 6 months from RStudio’s anonymized CRAN mirror download logs. Shown are common packages for interactive web graphics. . . . .	260

Figure 8.2 A screenshot of the `htmlwidgets` gallery website. This website allows you to browse R packages built on the `htmlwidgets` framework and sort widgets by the number of GitHub stars. As of writing, `plotly` has 791 stars which is the most among all `htmlwidgets`. . . . . 260

PREVIEW