

IN4MATX 133: User Interface Software

Lecture:
Software & Visualization
Tools

Goals for this Lecture

By the end of this lecture, you should be able to...

- Describe the concepts of threshold and ceiling in software tools and what tool designers should be striving to create
- Explain the relative threshold and ceilings of visualization tools like Protovis, D3, and Vega-Lite
- Describe common visualization primitives like marks, axes, and scales
- Implement simple visualizations with Vega-Lite

Today is a *very* narrow slice
of visualization

If you want more, take IN4MATX 143

Sequential programs (command line)

- Program takes control, prompts for input
- Person waits on the program
- Program says when it is ready for more input, which the person then provides



Sequential programs (command line)

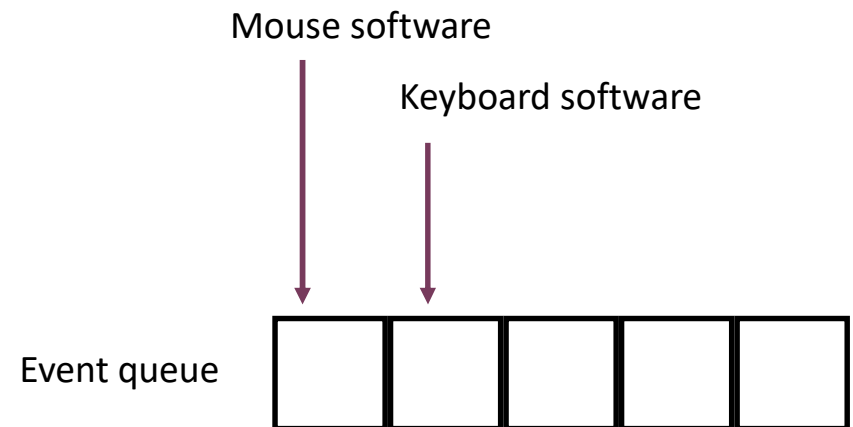
```
while true {  
    print "Prompt for Input"  
    input = read_line_of_text()  
    output = do_work()  
    print output  
}
```

- Person is literally modeled as a file



Event-driven programming

- A program waits for a person to provide input
- All communication is done via events
 - Mouse down, item drag, key up
- All events go in a queue
 - Ensures events are handled in order
 - Hides specifics from applications



Basic interactive software loop

- All interactive software has this loop somewhere

```
do {  
    e = read_event();    ←Input  
    dispatch_event(e);  ←Processing  
    if (damage_exists())  
        update_display(); ←Output  
} while (e.type != WM_QUIT);
```

Basic interactive software loop

- Maybe if you've made a game, you've built this loop
- But imagine you had to write this loop every time you wanted to write a webpage, desktop app, or mobile app
- Instead, we rely on tools to handle common operations

```
do {  
    e = read_event();  
    dispatch_event(e);  
    if (damage_exists())  
        update_display();  
} while (e.type != WM_QUIT);
```


Example: a button

- What's behind a button?
 - Set X and Y boundaries
 - Check if mouse down is within those boundaries
 - Check if mouse up is *also* within those boundaries
 - If so, then fire an event
- What if you had to program this sequence every time you wanted to add a button to your website?



Understanding tools

What is a user interface tool?

- Software or libraries which help you build a user interface
 - Bootstrap is a user interface tool, designed to help make interfaces responsive
 - Angular, React, etc. are all user interface tools

Understanding tools

We use tools because they...

- Identify common or important practices
- Package those practices in a framework
- Make it easy to follow those practices
- Make it easier to focus on the application we're building

Understanding tools

Tools enable...

- Faster and more iterative design
- Better implementation than without the tool
- Consistency across applications using the same tool

Understanding tools

Why is designing tools difficult?

- Need to understand the core practices and problems
- Those are often evolving with technology and design
- The tasks people are trying to solve change quickly, so tools struggle to keep up

Brad Myers, Scott E. Hudson, and Randy Pausch. TOCHI, 2000. Past, present, and future of user interface software tools. <https://doi.org/10.1145/344949.344959>

Understanding tools

Key terms

- Threshold: How hard to get started
- Ceiling: How much can be achieved
- Path of least resistance: Tools influence what interfaces are created
- Moving targets: Changing needs make tools obsolete

Brad Myers, Scott E. Hudson, and Randy Pausch. TOCHI, 2000. Past, present, and future of user interface software tools. <https://doi.org/10.1145/344949.344959>

Threshold

How hard to get started

- Some tools are harder to pick up
- Depends on what a person knows already
 - A new programming language adds to the threshold
 - If a tool borrows concepts from another popular tool, it will be easier for many people to pick up

Ceiling

How much can be achieved

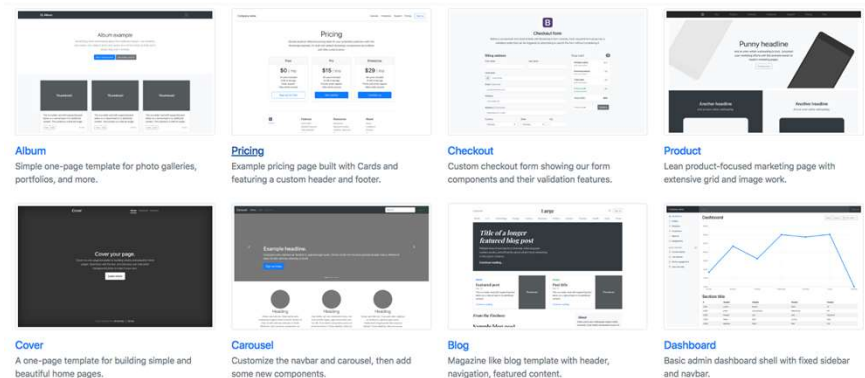
- Tools restrict what's possible
 - Your program could do much more if it had direct access to the bits on your computing device

Brad Myers, Scott E. Hudson, and Randy Pausch. TOCHI, 2000. Past, present, and future of user interface software tools. <https://doi.org/10.1145/344949.344959>

Path of least resistance

Tools influence what interfaces are created

- Remember the concern that all Bootstrap pages look similar?
- Linguistic Relativity
 - Or...the Sapir-Whorf Hypothesis
 - Roughly, some thoughts in one language cannot be expressed or understood in another language
- In UI, our tools frame how we think about interaction and design



Brad Myers, Scott E. Hudson, and Randy Pausch. TOCHI, 2000. Past, present, and future of user interface software tools. <https://doi.org/10.1145/344949.344959>

Moving targets

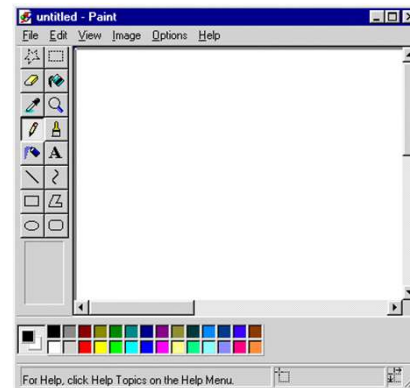
Changing needs make tools obsolete

- Codification eventually constrains design
 - Our understanding of how people interact with technology improves
 - New technology comes along to change the needs of tools
 - Example: Virtual reality has wildly different interactions and tool needs

Brad Myers, Scott E. Hudson, and Randy Pausch. TOCHI, 2000. Past, present, and future of user interface software tools. <https://doi.org/10.1145/344949.344959>

Threshold and ceiling

- It's all relative; no absolute measure
- Tools should be *low threshold*
 - Easy to pick up
- But tools should also be *high ceiling*
 - Can do a lot
- The best tools are both
 - Photoshop introduces tutorials, etc. to lower the threshold



Ok, so what does any of this
have to do with visualization?

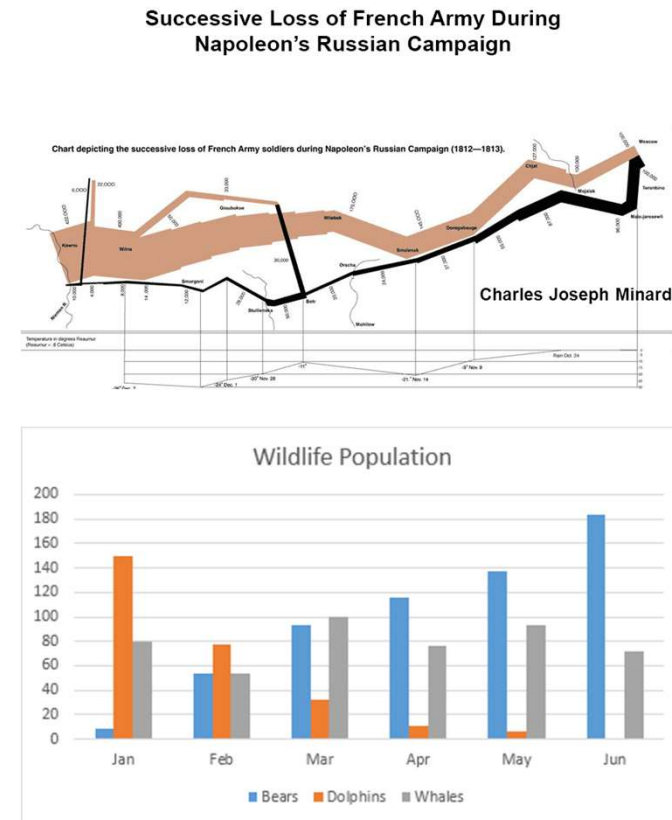
Scalable Vector Graphics (SVG)

- XML format for specifying graphics
 - Looks somewhat like HTML
 - Most browsers can render them
- Composed of lines, circles, rectangles, etc.

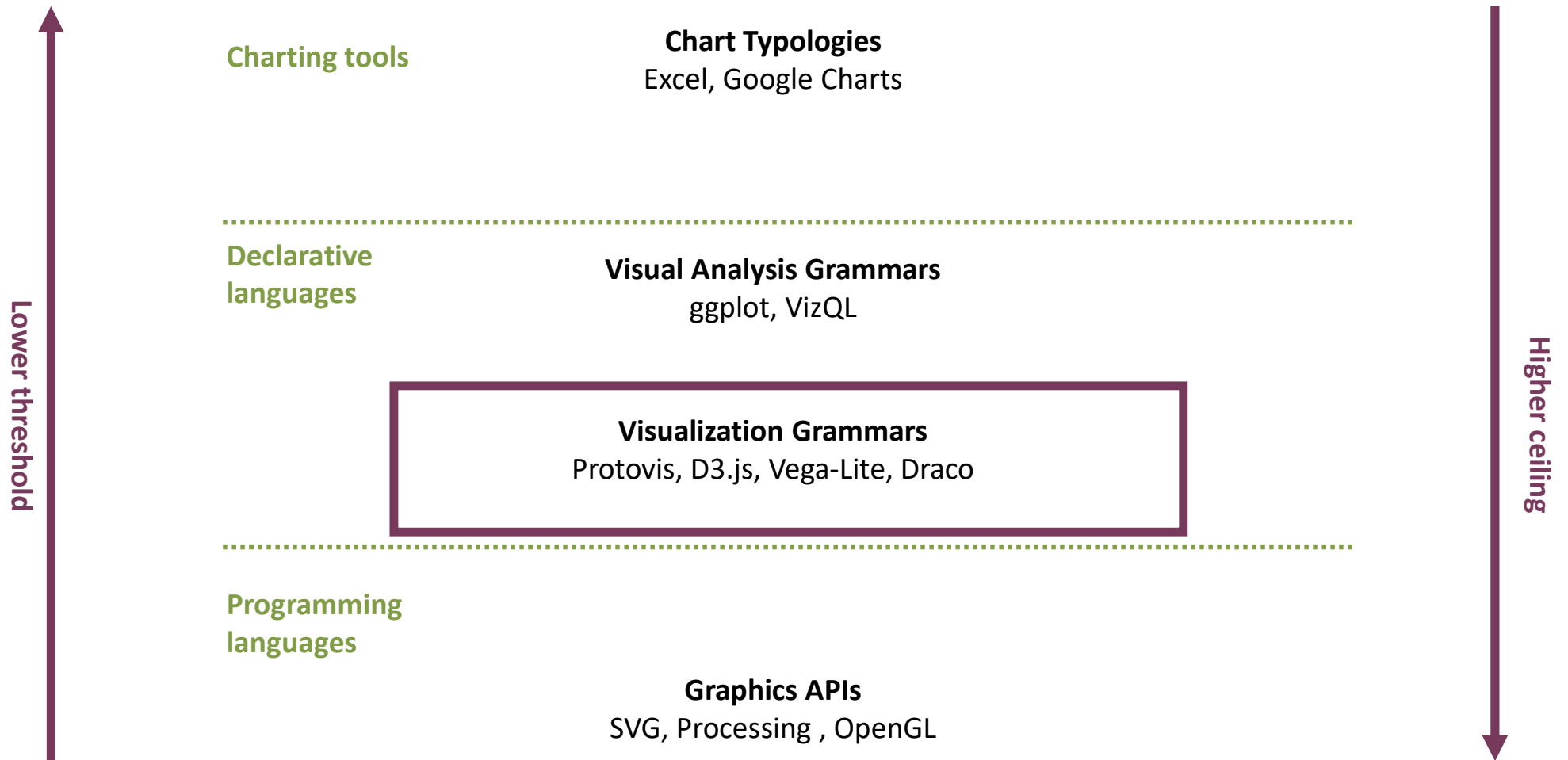
```
<svg width="100" height="100">  
  <circle cx="50" cy="50" r="40" stroke="green" stroke-  
width="4" fill="yellow" />  
</svg>
```

Visualization tools

- Are governed by the same principles
- Scaleable vector graphics (svg)
 - High ceiling, but high threshold
- Microsoft excel
 - Low threshold, but low ceiling



<https://www.edwardtufte.com/tufte/posters>



Declarative languages

- Programming by describing *what*, not *how*
- Separate specification (*what you want*) from execution (*how it should be computed*)
- Contrasts to **imperative** programming, where you must give explicit steps

Declarative languages

HTML



Markup
language

CSS



Styling
language

JS



Programming
language

Declarative languages



Declarative
language



Declarative
language



Imperative
language

Declarative languages

HTML



```
<main class="container">
  <div class="row">
    <div class="col-3">A</div>
    <div class="col-6">B</div>
    <div class="col-4">C</div>
    <div class="col">D</div>
    <div class="col">E</div>
  </div>
</main>
```

What should be rendered, but not how

JS



```
var array = ['1', 'fish', 2, 'blue'];
array[5] = 'dog';
array.push('2');
array[2] = array[array.length - 1] - 4;
array[0] = typeof array[2];
array[4] = array.indexOf('blue');

console.log(array.join('*'));
```

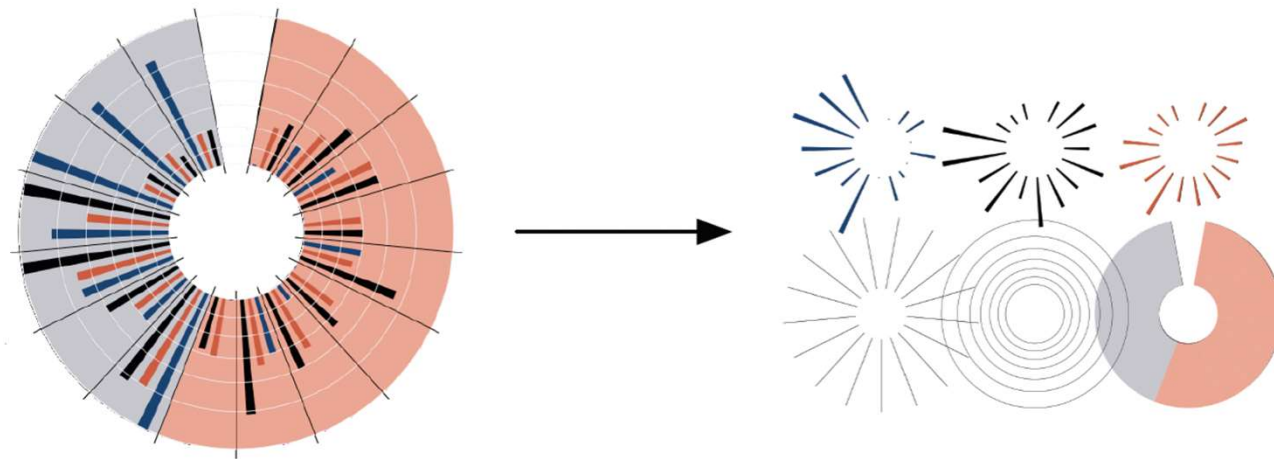
Step-by-step

Why declarative languages?

- Faster iteration, less code, lower threshold
- Can be generated programmatically
- Generally considered easier to learn than programming/imperative languages like JavaScript

Protovis

- Initial grammar for visualization
- A composition of data-representative marks
 - Self-contained JavaScript model (doesn't export to SVG or anything else)

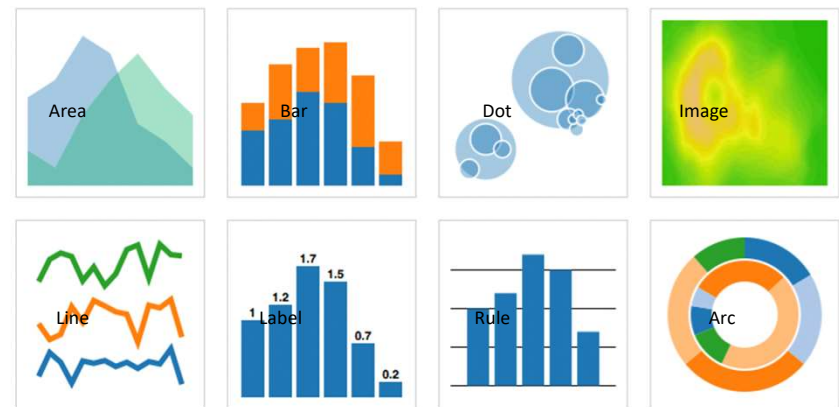


Michael Bostock, Jeffrey Heer. IEEE Vis, 2009. Protovis: A Graphical Toolkit for Visualization.

<https://doi.org/10.1109/TVCG.2009.174>

Protovis

- Marks: graphical primitives
 - Marks specify how content should be rendered

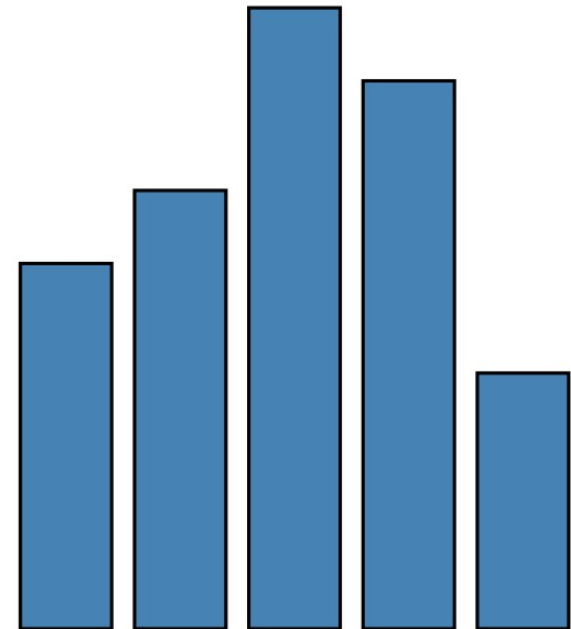


Michael Bostock, Jeffrey Heer. IEEE Vis, 2009. Protovis: A Graphical Toolkit for Visualization.

<https://doi.org/10.1109/TVCG.2009.174>

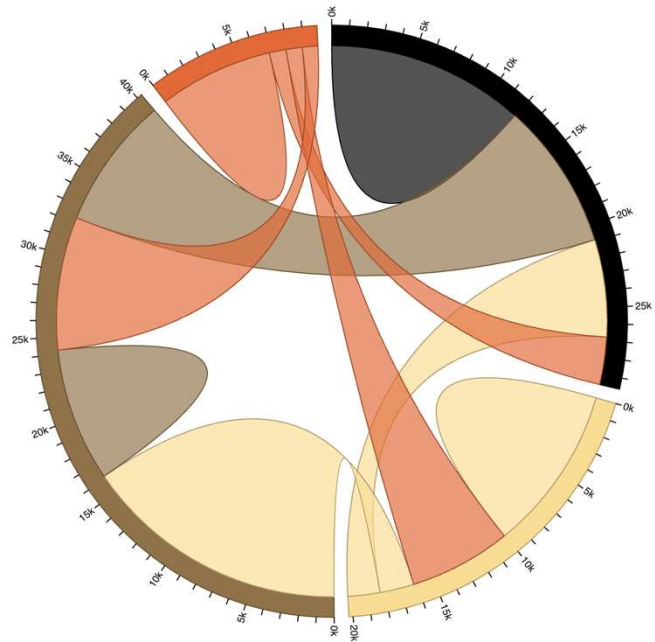
Protovis

```
var vis = new pv.Panel();
vis.add(pv.Bar) ← Mark
  .data([1, 1.2, 1.7, 1.5,
0.7])
  .visible(true)
  .left((d) => this.index * 25)
  .bottom(0)
  .width(20)
  .height((d) => d * 80) ← Literally specifies which pixel
  .fillStyle("blue")      each bar should start at and
  .strokeStyle("black")   how many pixels tall it should
  .lineWidth(1.5);        be
vis.render();
```



D3

- Binds data directly to a web page's DOM by editing a SVG
 - More expressive! Can make anything an SVG can make
 - Enables interactivity, can access mouse & keyboard events through the same tools as a browser
 - Much more complex...



Michael Bostock, Vadim Ogievetsky, Jeffrey Heer. IEEE Vis, 2011. D3: Data Driven Documents.

<http://doi.ieeecomputersociety.org/10.1109/TVCG.2011.185>

D3

```
var svg = d3.select(DOM.svg(width, height));
```



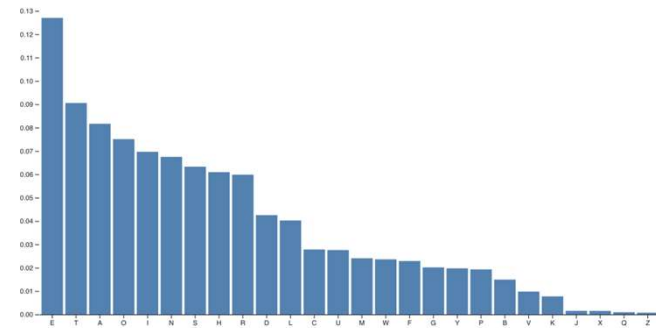
Find SVG in the DOM

```
svg.append("g")
  .attr("fill", "steelblue")
  .selectAll("rect").data(data).enter()
  .append("rect")
    .attr("x", d => x(d.name))
    .attr("y", d => y(d.value))
    .attr("height", d => y(0) -
y(d.value))
    .attr("width", x.bandwidth());
```

← No more mention of marks!

```
svg.append("g")
  .call(xAxis);
```

```
svg.append("g")
  .call(yAxis);
```

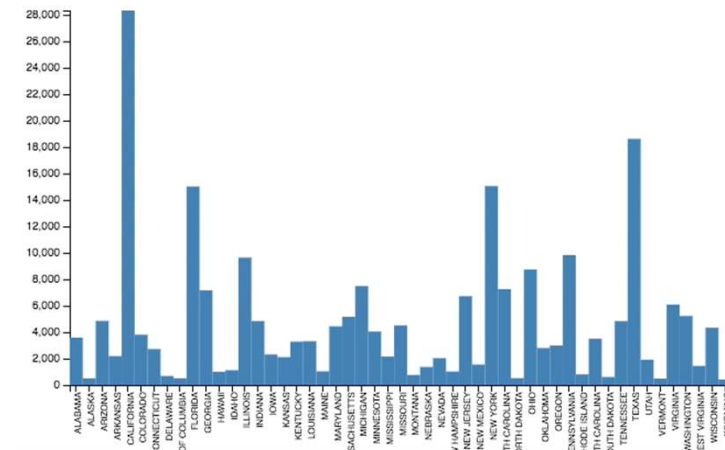


Michael Bostock, Vadim Ogievetsky, Jeffrey Heer. IEEE Vis, 2011. D3: Data Driven Documents.

<http://doi.ieeecomputersociety.org/10.1109/TVCG.2011.185>

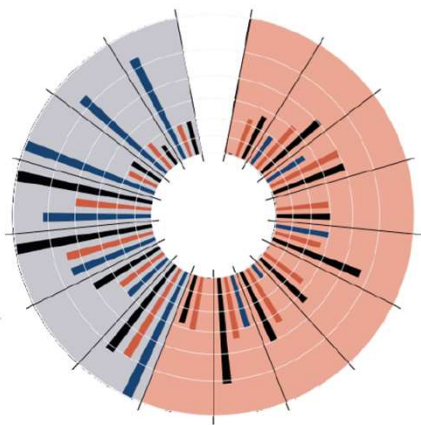
D3

~118 lines of code,
plus data in a separate file

[illegible]

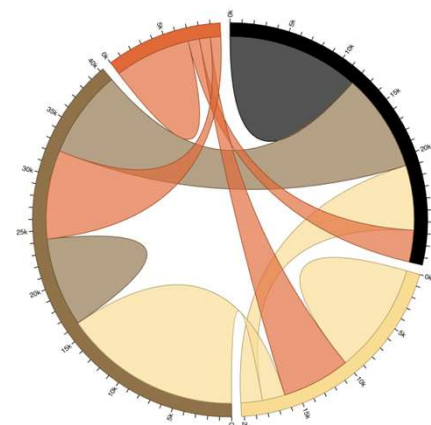
Michael Bostock, Vadim Ogievetsky, Jeffrey Heer. IEEE Vis, 2011. D3: Data Driven Documents.

<http://doi.ieeecomputersociety.org/10.1109/TVCG.2011.185>



D3

Protovis
Low(er) ceiling



D3
High(er) ceiling

Compared to excel, etc., both have a high ceiling
But both have a pretty high threshold!

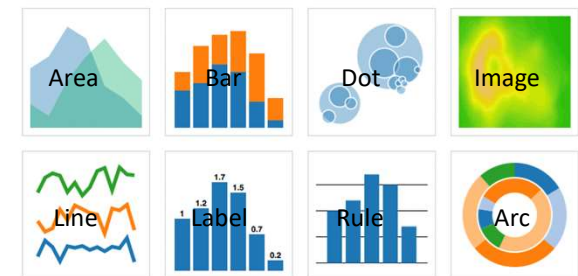
Vega-Lite: lowering the threshold

Lowering the threshold

- Goal: “create an *expressive* (high ceiling) yet *concise* (low threshold) declarative language for specifying visualizations”

Vega-Lite

- Grammar of graphics
 - Data: input data to visualize
 - Mark: Data-representative graphics
 - Transform: whether to filter, aggregate, bin, etc.
 - Encoding: mapping between data and mark properties
 - Scale: map between data values and visual values
 - Guides: axes & legends that visualize scales

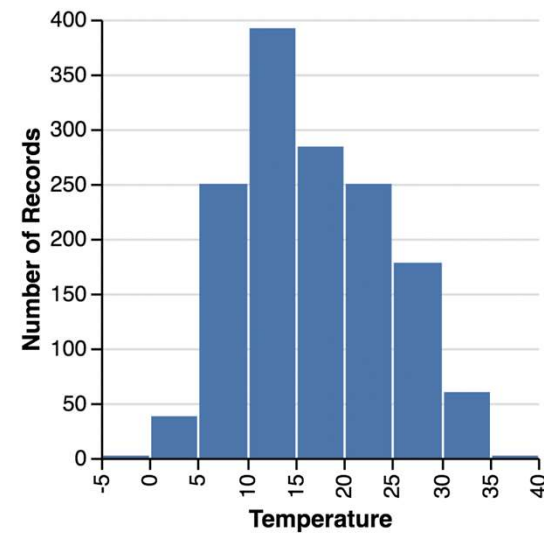


Arvind Satyanarayan, Dominik Moritz, Kanit Wongsuphasawat, Jeffrey Heer. IEEE Vis, 2017. Vega-Lite: A Grammar of Interactive Graphics

<https://doi.org/10.1109/TVCG.2016.2599030>

Vega-lite

Making a histogram



Arvind Satyanarayan, Dominik Moritz, Kanit Wongsuphasawat, Jeffrey Heer. IEEE Vis, 2017. Vega-Lite: A Grammar of Interactive Graphics

<https://doi.org/10.1109/TVCG.2016.2599030>

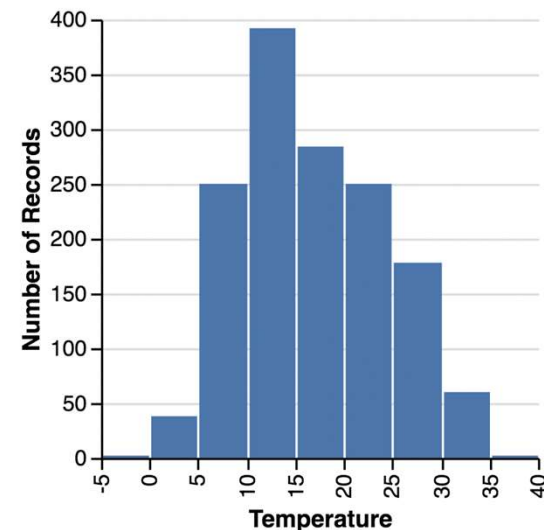
JSON file

```
[
  {
    "date": "2015/01/01",
    "weather": "sun",
    "temperature": 1.1999999999999997
  },
  {
    "date": "2015/01/02",
    "weather": "fog",
    "temperature": 2.8
  },
  {
    "date": "2015/01/03",
    "weather": "fog",
    "temperature": 3.35
  },
  {
    "date": "2015/01/04",
    "weather": "fog",
    "temperature": 6.949999999999999
  },
  {
    "date": "2015/01/05",
    "weather": "fog",
    "temperature": 10.8
  },
  ...
]
```

Vega-lite

Histogram = (Bar with x=binned field, y=count)

- Bin records by their temperature
- Count how many records fall into each bin
- Render those bins as vertical bars



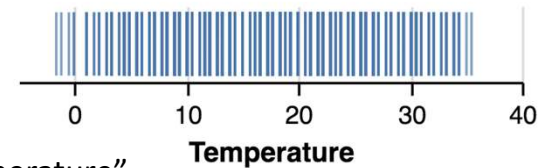
Arvind Satyanarayan, Dominik Moritz, Kanit Wongsuphasawat, Jeffrey Heer. IEEE Vis, 2017. Vega-Lite: A Grammar of Interactive Graphics

<https://doi.org/10.1109/TVCG.2016.2599030>

Vega-lite

Histogram = (Bar with x=binned field, y=count)

```
{  
  data: {url: "weather-seattle.json"},  
  mark: "tick",  
  encoding: {  
    x: {  
      field: "temperature",  
      type: "quantitative"  
    }  
  }  
}
```



Four types:

quantitative (numerical)

temporal (time)

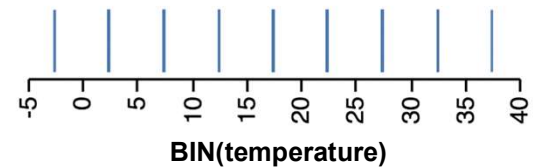
ordinal (ordered)

nominal (categorical)

Vega-lite

Histogram = (Bar with x=binned field, y=count)

```
{
  data: {url: "weather-seattle.json"},
  mark: "tick",
  encoding: {
    x: {
      bin: true, ← Bin values by x dimension
      field: "temperature",
      type: "quantitative"
    }
  }
}
```

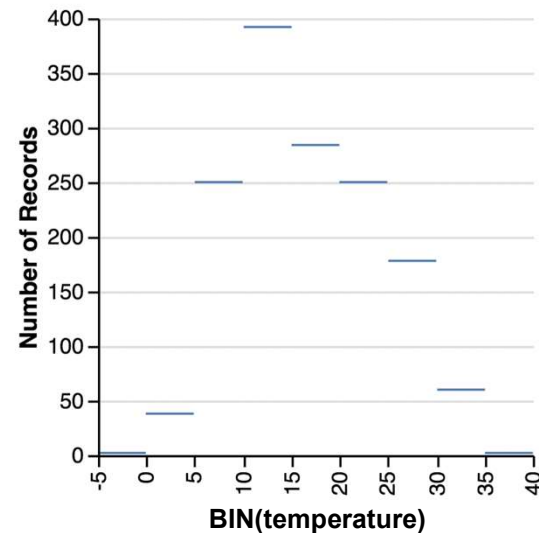


Vega-lite

Histogram = (Bar with x=binned field, y=count)

```
{
  data: {url: "weather-seattle.json"},
  mark: "tick",
  encoding: {
    x: {
      bin: true,
      field: "temperature",
      type: "quantitative"
    },
    y: {
      aggregate: "count",
      type: "quantitative"
    }
  }
}
```

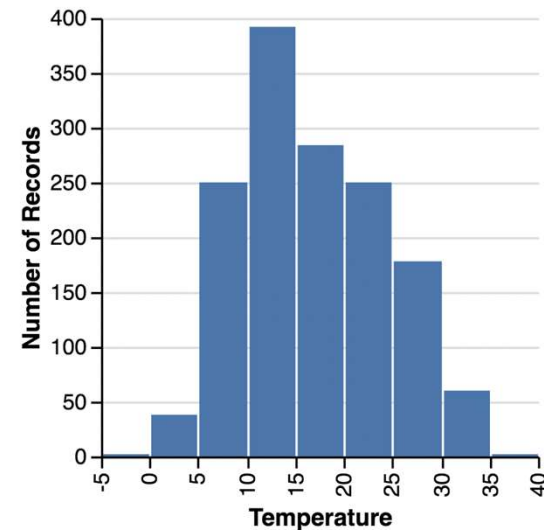
y should aggregate the
bins by counting how many
values are in them



Vega-lite

Histogram = (Bar with x=binned field, y=count)

```
{
  data: {url: "weather-seattle.json"},
  mark: "bar", ← Change the mark to a bar
  encoding: {
    x: {
      bin: true,
      field: "temperature",
      type: "quantitative"
    },
    y: {
      aggregate: "count",
      type: "quantitative"
    }
  }
}
```



Arvind Satyanarayan, Dominik Moritz, Kanit Wongsuphasawat, Jeffrey Heer. IEEE Vis, 2017. Vega-Lite: A Grammar of Interactive Graphics

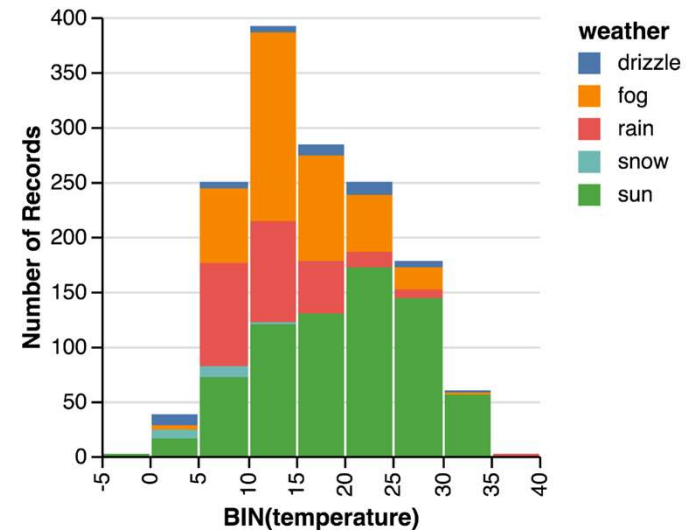
<https://doi.org/10.1109/TVCG.2016.2599030>

Vega-lite

Histogram + Color

```
{
  data: {url: "weather-seattle.json"},
  mark: "bar",
  encoding: {
    x: {
      bin: true,
      field: "temperature",
      type: "quantitative"
    },
    y: {
      aggregate: "count",
      type: "quantitative"
    },
    color: {
      field: "weather",
      type: "nominal"
    }
  }
}
```

← Set the color to follow the weather field



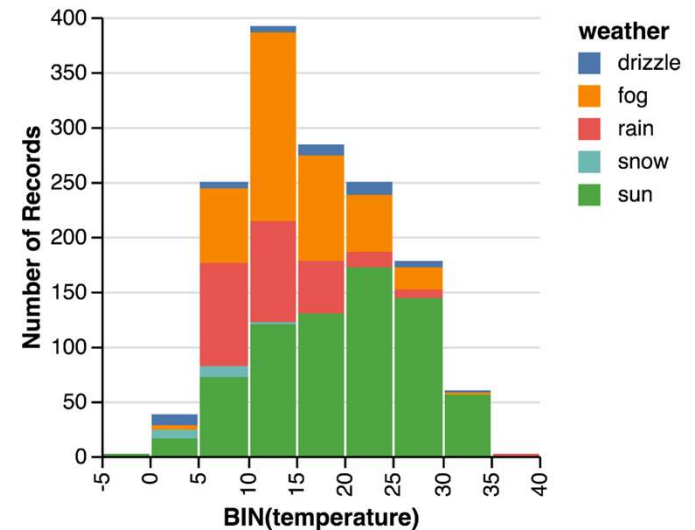
Arvind Satyanarayan, Dominik Moritz, Kanit Wongsuphasawat, Jeffrey Heer. IEEE Vis, 2017. Vega-Lite: A Grammar of Interactive Graphics

<https://doi.org/10.1109/TVCG.2016.2599030>

Vega-lite

“Sensible defaults”

- The field chose reasonable defaults for presenting the data
 - We didn't specify what colors to use
 - Or how wide bins should be
 - Or how to label the axes
 - Or that the bars should be stacked
 - ...



Arvind Satyanarayan, Dominik Moritz, Kanit Wongsuphasawat, Jeffrey Heer. IEEE Vis, 2017. Vega-Lite: A Grammar of Interactive Graphics

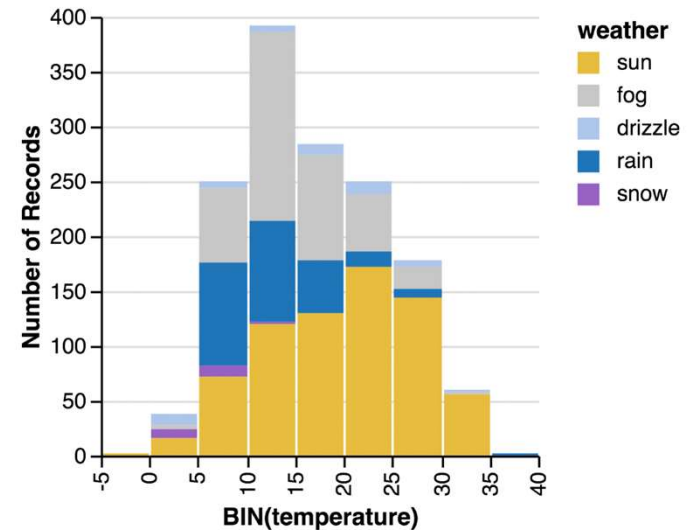
<https://doi.org/10.1109/TVCG.2016.2599080>

Vega-lite

Overriding the sensible defaults

```
{
  data: {url: "weather-seattle.json"},
  mark: "bar",
  encoding: {
    x: {
      bin: true,
      field: "temperature",
      type: "quantitative"
    },
    y: {
      aggregate: "count",
      type: "quantitative"
    },
    color: {
      field: "weather",
      type: "nominal"
    },
    scale: {
      domain: ["sun", "fog", "drizzle", "rain", "snow"],
      range: ["#e7ba52", "#c7c7c7", "#aec7e8",
              "#1f77b4", "#9467bd"]
    }
  }
}
```

Set our own color scale



Arvind Satyanarayan, Dominik Moritz, Kanit Wongsuphasawat, Jeffrey Heer. IEEE Vis, 2017. Vega-Lite: A Grammar of Interactive Graphics

<https://doi.org/10.1109/TVCG.2016.2599030>

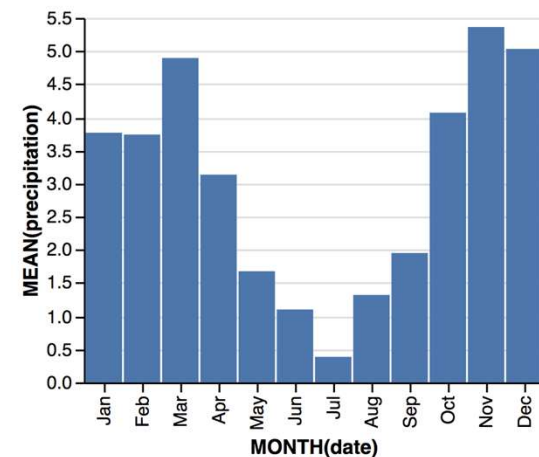
Vega-lite

Monthly precipitation

```
{
  data: {url: "weather-seattle.json"},
  mark: "bar",
  encoding: {
    x: {
      timeUnit: "month", field: "date",
      type: "quantitative"
    },
    y: {
      aggregate: "mean",
      field: "precipitation",
      type: "quantitative"
    }
  }
}
```

Field is a date string ("2018-10-17"),
but display and bin it as a month

Aggregate by the mean



Sensible defaults: Vega-lite's secret

- Threshold is lower
 - More concise definitions, less to understand up front
- Ceiling remains the same
 - The sensible defaults can be overridden
- A downside: visualizations made with Vega-Lite look similar
 - The path of least resistance Vega-Lite provides influences what visualizations people make and what they look like

Downside: path of least resistance

- The path of least resistance: tools influence what is created
- Sensible defaults make Vega-Lite visualizations look similar to one another
 - These defaults *can* be overwritten, but are they in practice?
- Similar concern to the widespread adoption of grid frameworks

Goals for this Lecture

By the end of this lecture, you should be able to...

- Describe the concepts of threshold and ceiling in software tools and what tool designers should be striving to create
- Explain the relative threshold and ceilings of visualization tools like Protovis, D3, and Vega-Lite
- Describe common visualization primitives like marks, axes, and scales
- Implement simple visualizations with Vega-Lite