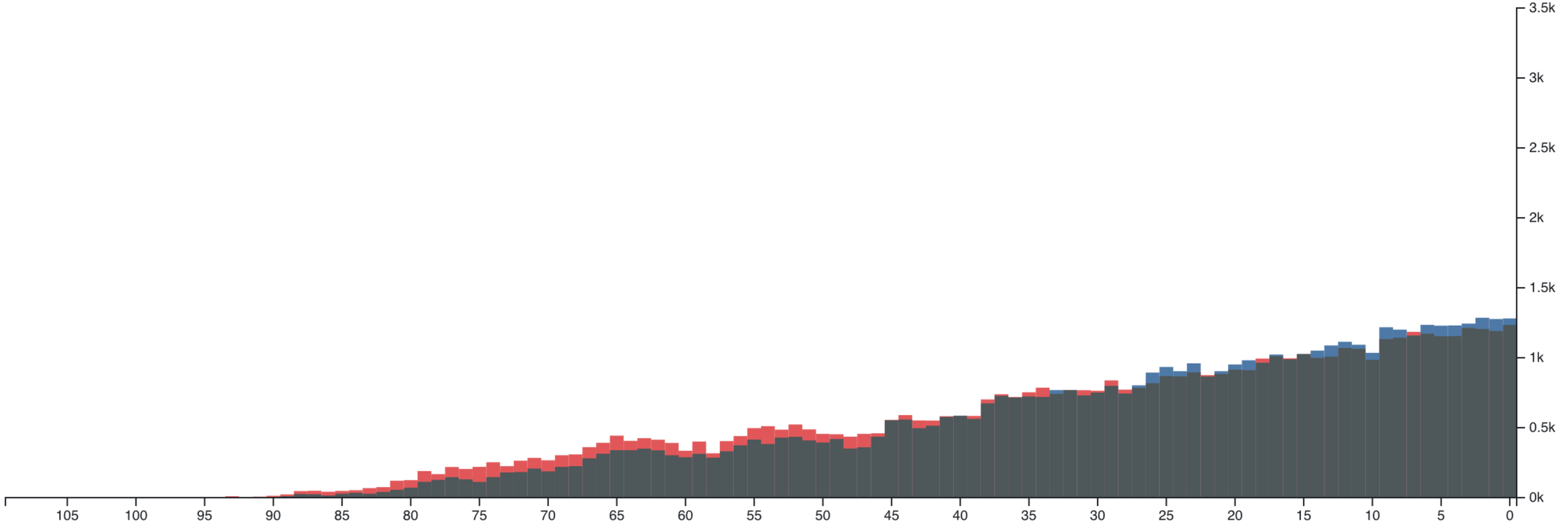
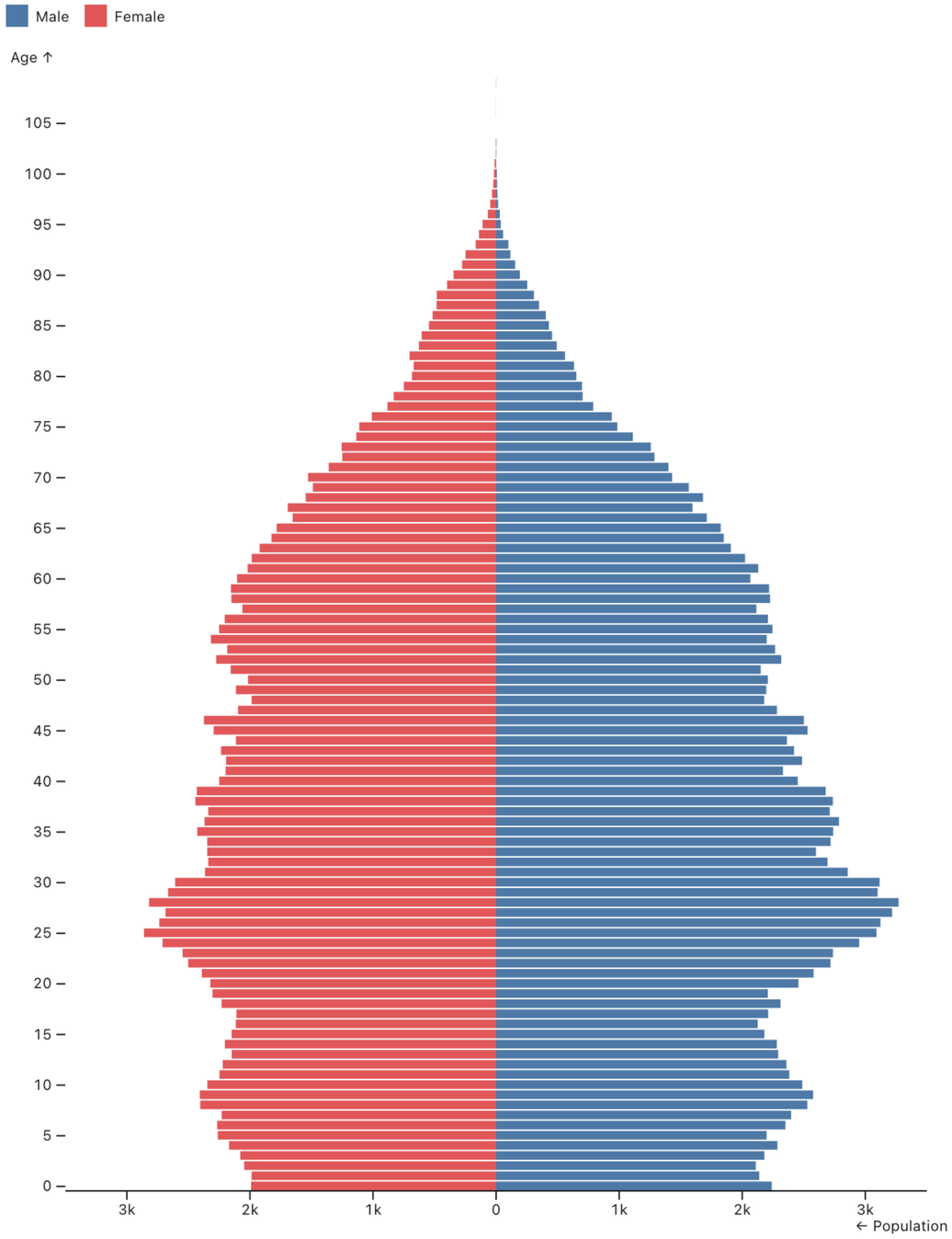
Interaction

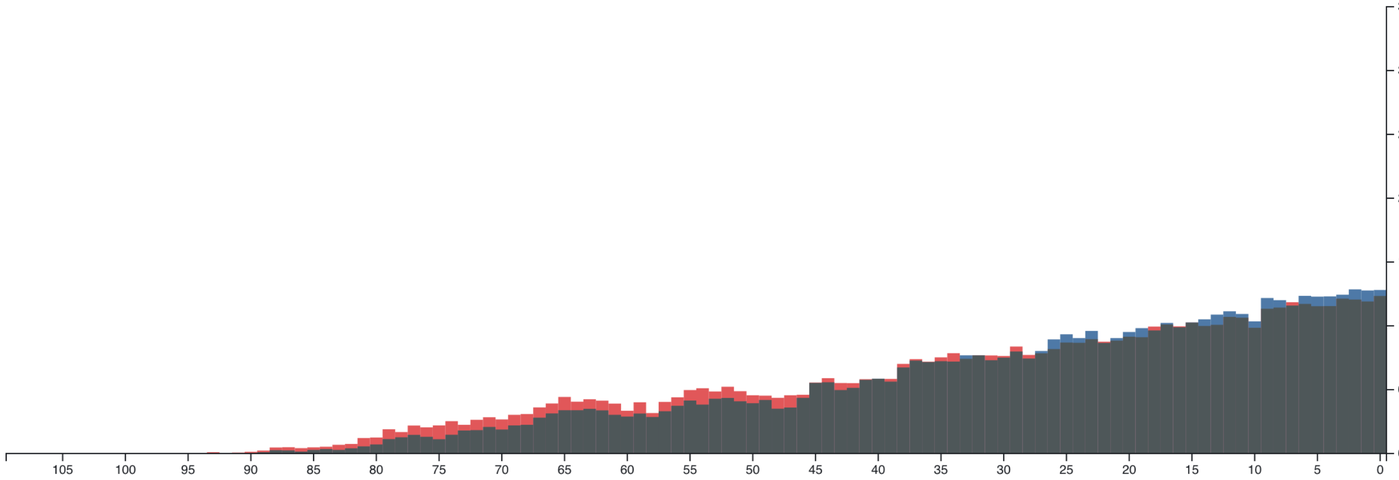
Start here

Note: *consider treating gender and sex data with more nuance than in these examples [see here]*

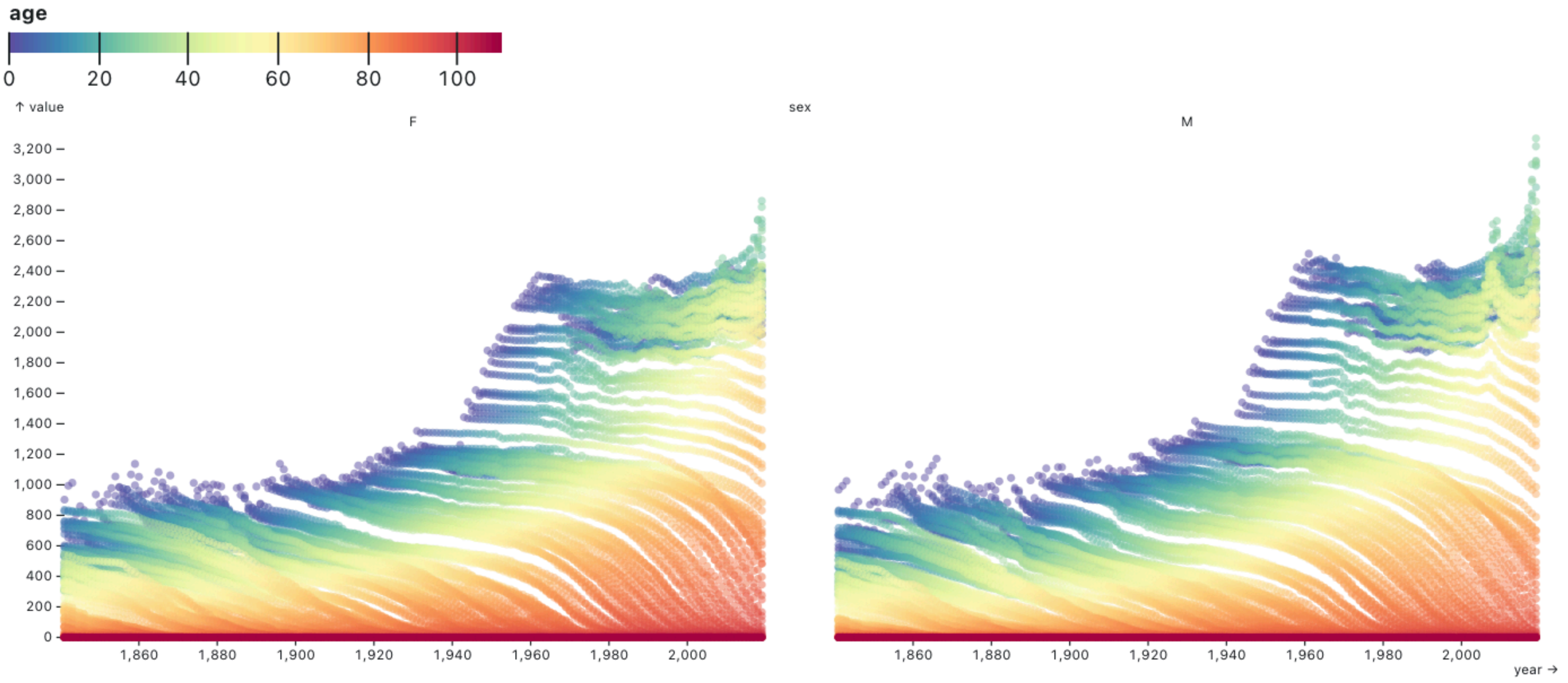

3.5k
3k
2.5k
2k
1.5k
1k
0.5k
0k
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0

Iceland's population pyramid for 2019

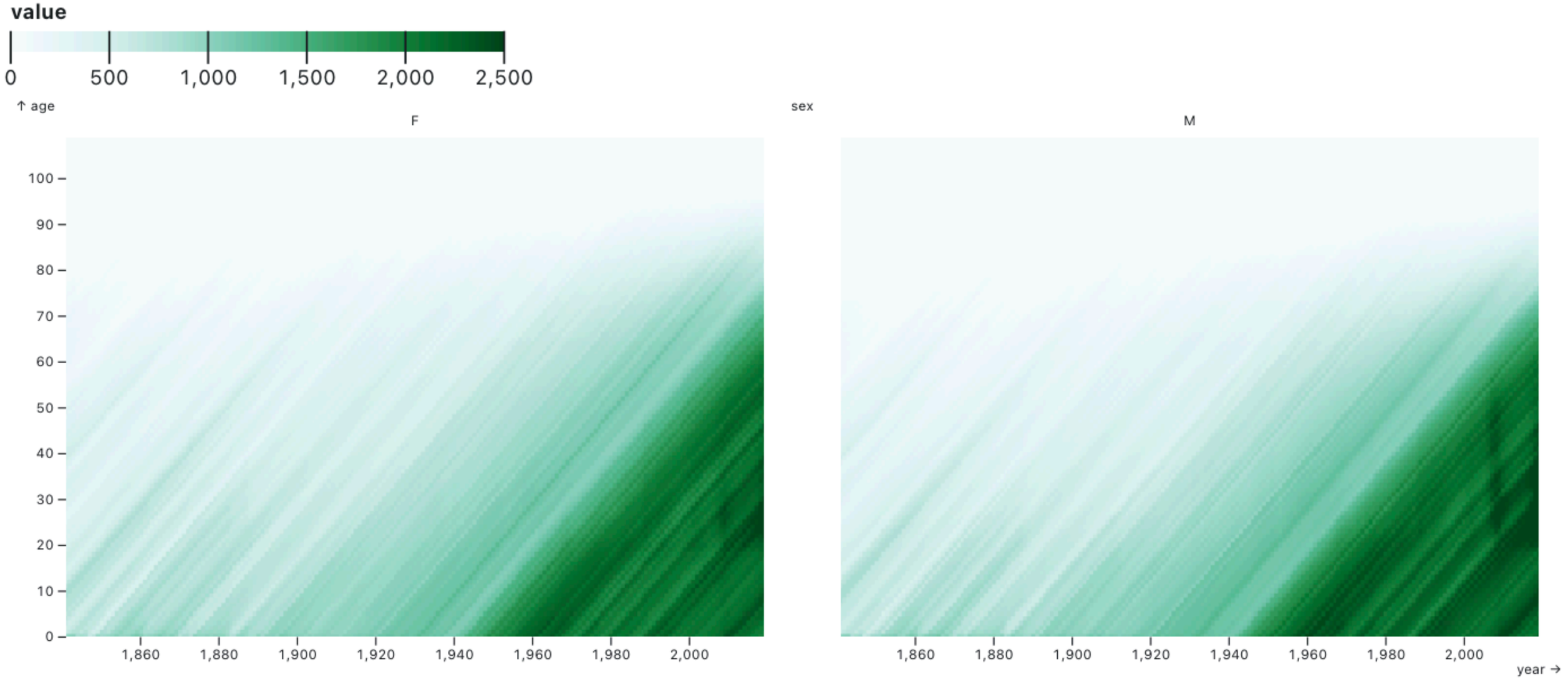




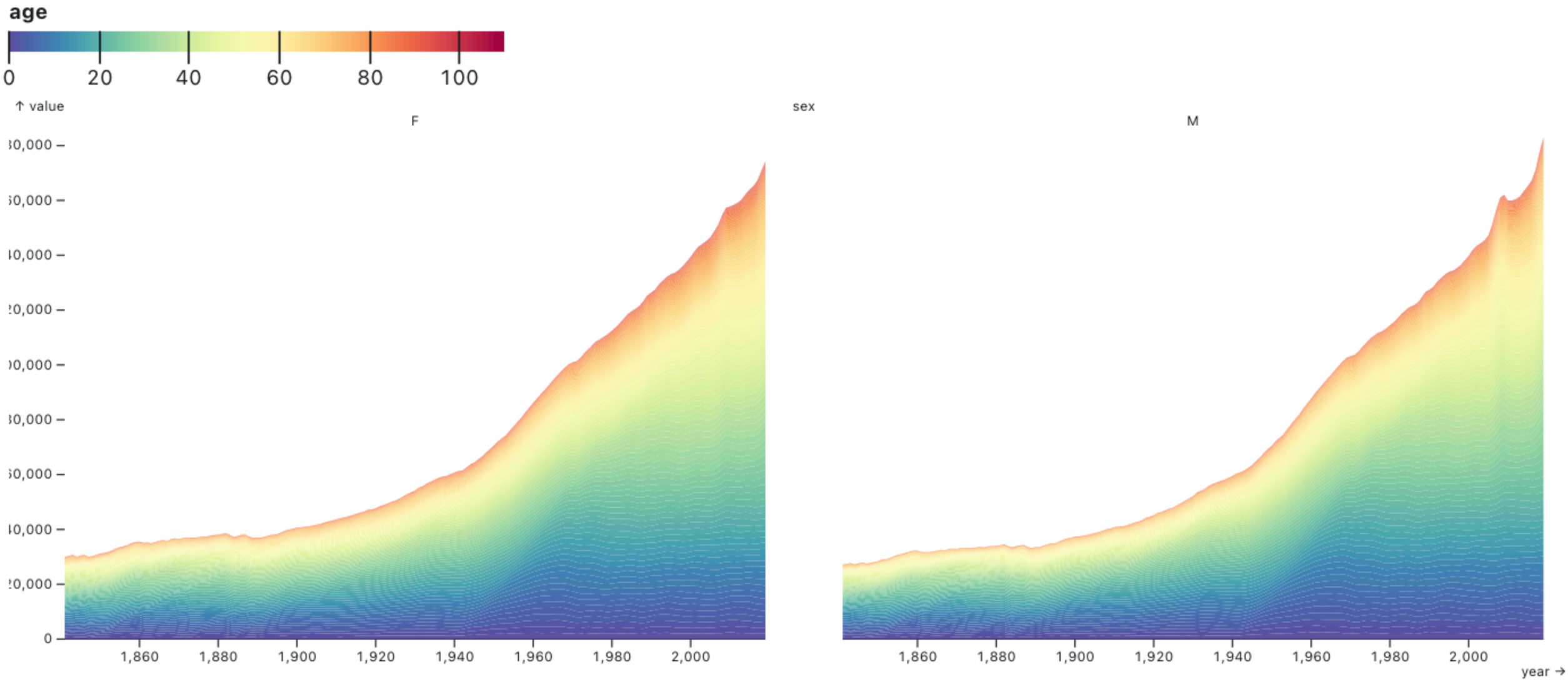
Iceland's population pyramid: 1841-2019



Iceland's population pyramid: 1841-2019



Iceland's population pyramid: 1841-2019



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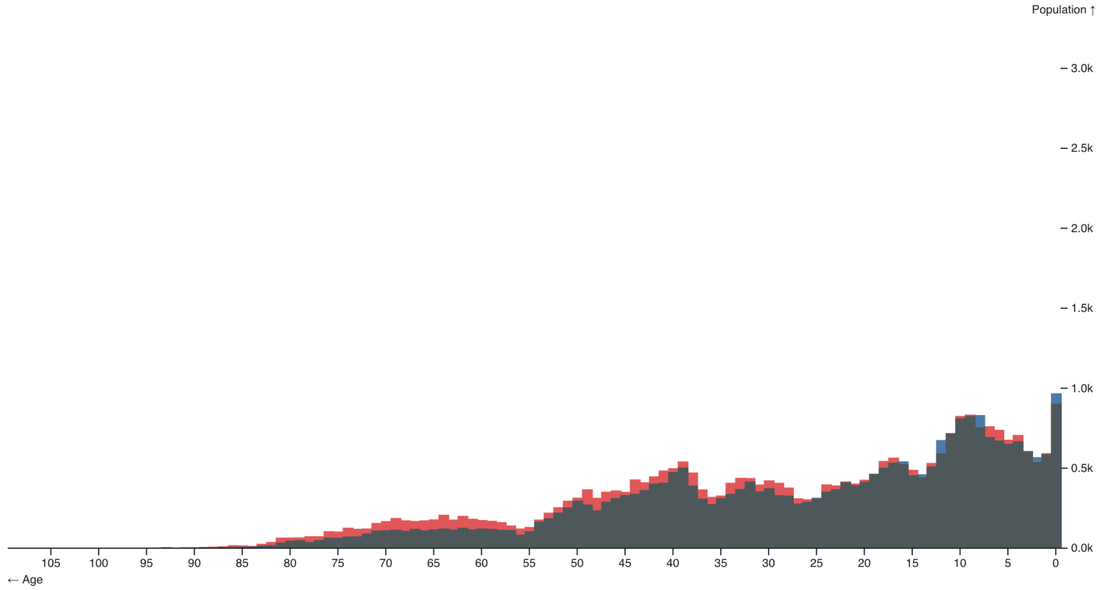
3: ▼Object {
  value: 795
  year: 1844
  age: 0
  sex: "M"
}
```


```
y = d3.scaleLinear()
    .domain([0, d3.max(data, d => d.value)])
    .range([height - marginBottom, marginTop]);
```




```
x = d3.scaleBand()
    .domain(Array.from(d3.group(data, d => d.age).keys()).sort(d3.ascending))
    .range([width - marginRight, marginLeft]);
```

band.domain(*domain*)

Domain: a,b,c,d,e,f

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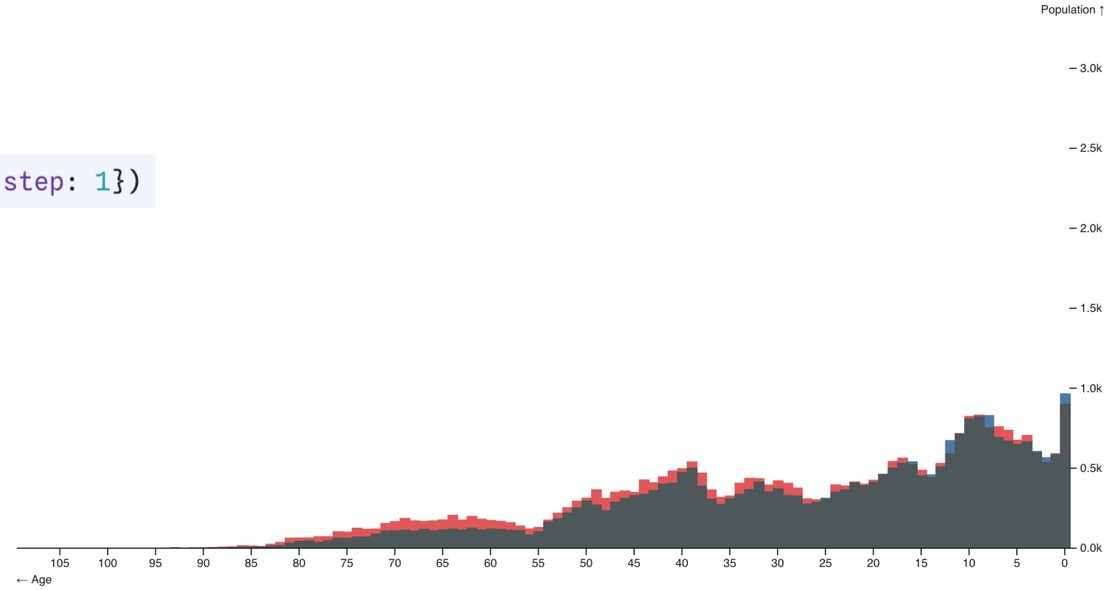
}
```

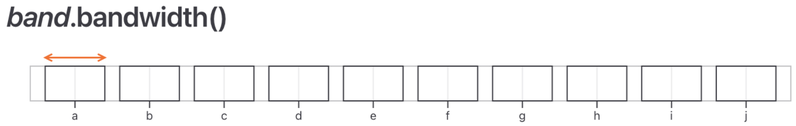

Year 1940

```
viewof year = Inputs.range([1841, 2019], {label: "Year", step: 1})
```




```
let rect = group.selectAll("rect");
rect = rect
  .data(data.filter(d => d.year === year), d => `${d.sex}:${d.age}`);
```

```
rect.enter().append("rect")
      .style("mix-blend-mode", "darken")
      .attr("fill", d => color(d.sex))
      .attr("x", d => x(d.age))
      .attr("y", d => y(0))
      .attr("width", x.bandwidth() + 1)
      .attr("height", 0);
```



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  year: 1844
  age: 0
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}
```


Year 1940

```
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```

Year 1988

```
viewof year = Inputs.range([1841, 2019], {label: "Year", step: 1})
```

```
update = {
  function update(year) {
      const svg = d3.select(chart);
      const yearStep = 1;
      const yearMin = d3.min(data, d => d.year);
      const dx = x.step() * (year - yearMin) / yearStep;

      let rect = group.selectAll("rect");
      rect = rect
        .data(data.filter(d => d.year === year), d => `${d.sex}:${d.age}`);

     const t = svg.transition()
          .ease(d3.easeLinear)
          .duration(delay);

      rect.enter().append("rect")
            .style("mix-blend-mode", "darken")
            .attr("fill", d => color(d.sex))
            .attr("x", d => x(d.age))
            .attr("y", d => y(0))
            .attr("width", x.bandwidth() + 1)
            .attr("height", 0);

      rect.exit().transition(t)
            .remove()
            .attr("y", y(0))
            .attr("height", 0);

      rect.transition()
          .ease(d3.easeLinear)
          .duration(delay)
          .attr("y", d => y(d.value))
          .attr("height", d => y(0) - y(d.value));
    }
  return update;
}
```

```
update(year)
```

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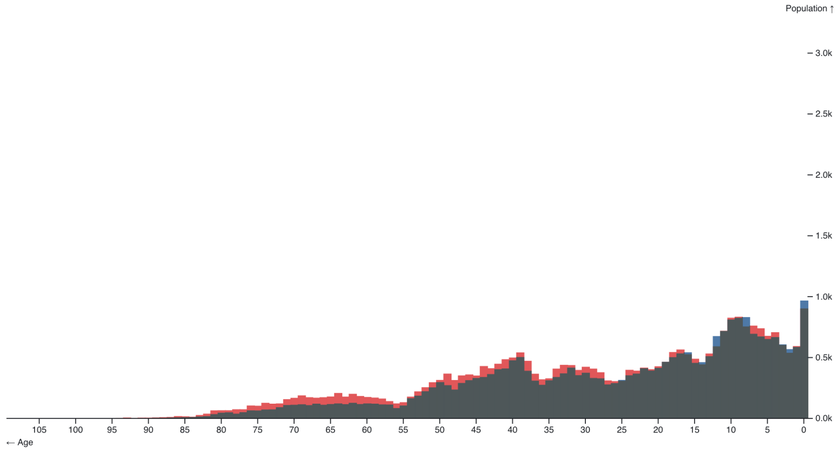

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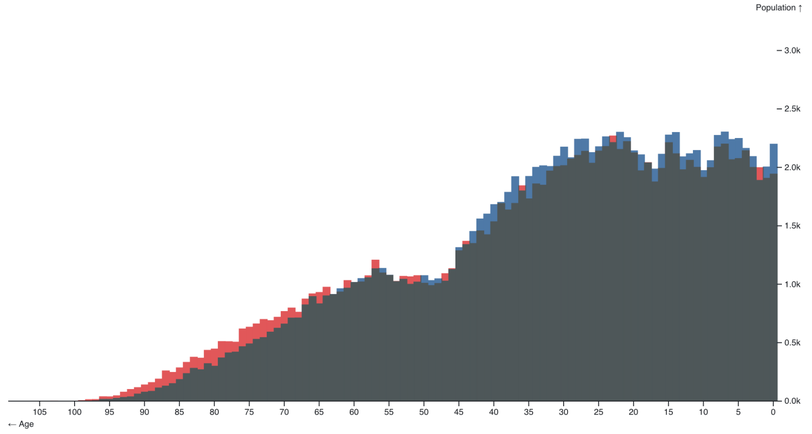


```
rect.attr("y", d => y(d.value))
    .attr("height", d => y(0) - y(d.value));
```

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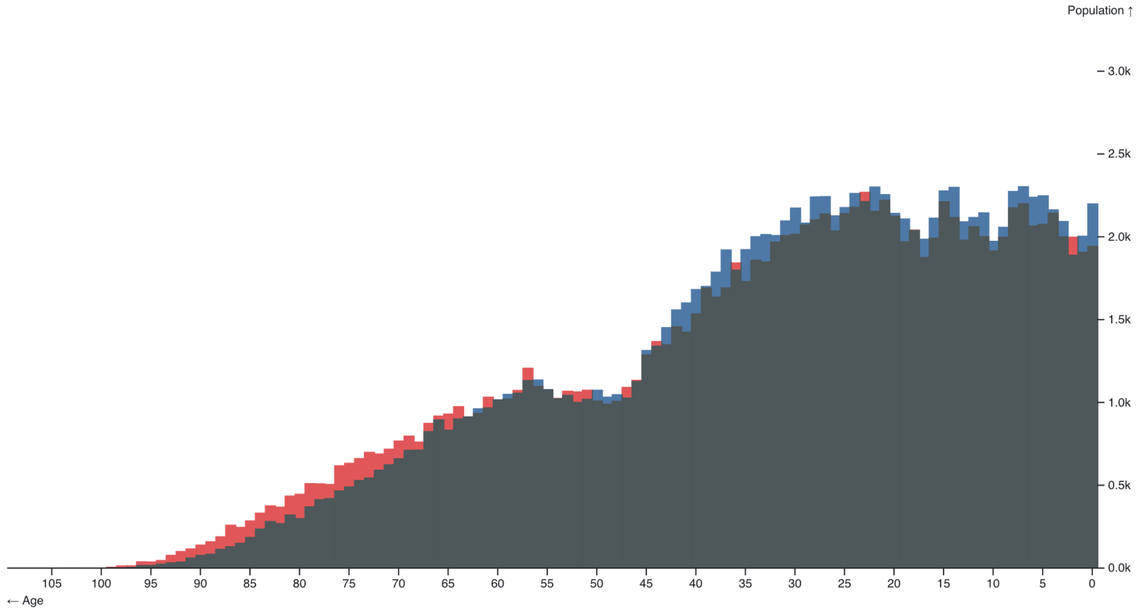


```
const dx = x.step() * (year - yearMin) / yearStep;
```

```
const dx = x.step() * (year - yearMin) / yearStep;

let rect = group.selectAll("rect");
rect = rect
  .data(data.filter(d => d.year === year), d => `${d.sex}:${d.year - d.age}`);
```

```
group.transition(t)
    .attr("transform", `translate(${-dx},0)`);
```

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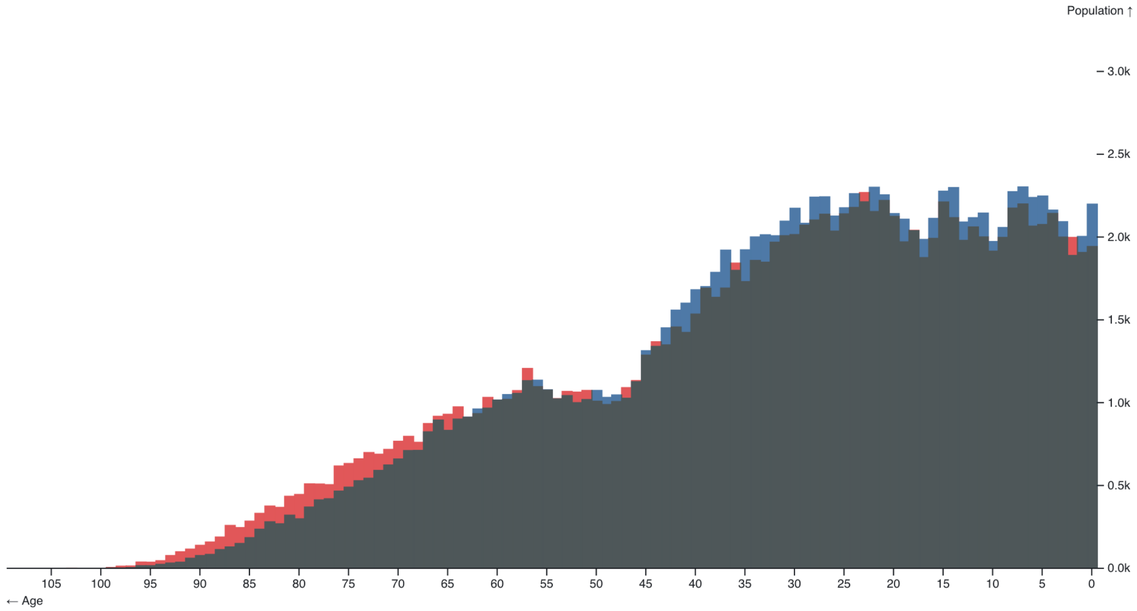
```
rect.enter().append("rect")
      .style("mix-blend-mode", "darken")
      .attr("fill", d => color(d.sex))
      .attr("x", d => x(d.age) + dx)
      .attr("y", d => y(0))
      .attr("width", x.bandwidth() + 1)
      .attr("height", 0)
      .transition(t)
      .attr("y", d => y(d.value))
      .attr("height", d => y(0) - y(d.value));
```



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```


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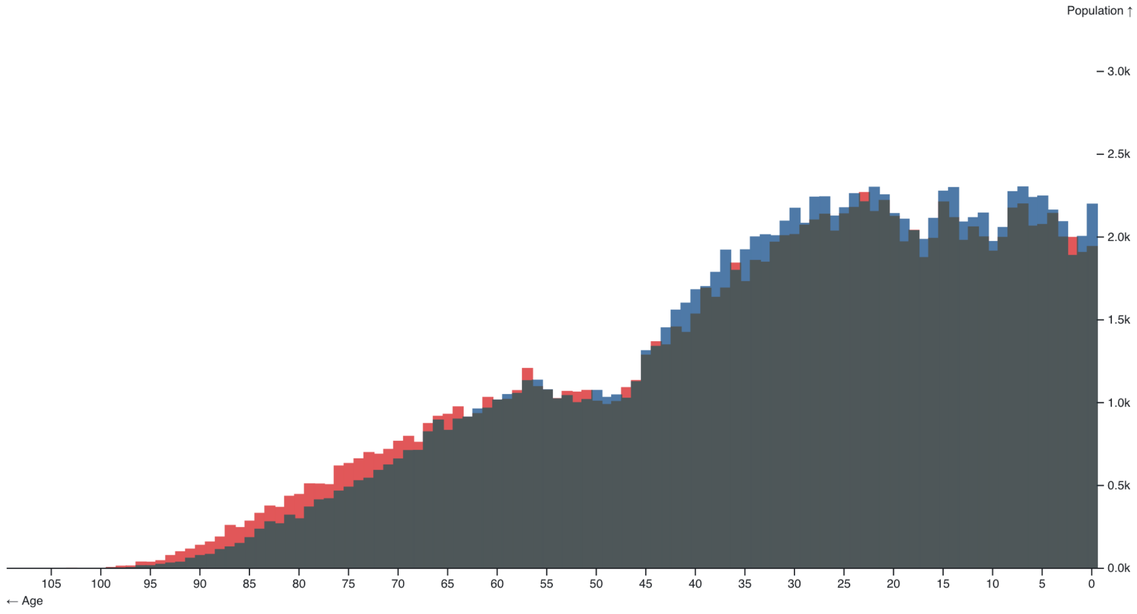
rect.exit().transition(t)
      .remove()
      .attr("y", y(0))
      .attr("height", 0);
```



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      .attr("height", 0)
      .transition(t)
      .attr("y", d => y(d.value))
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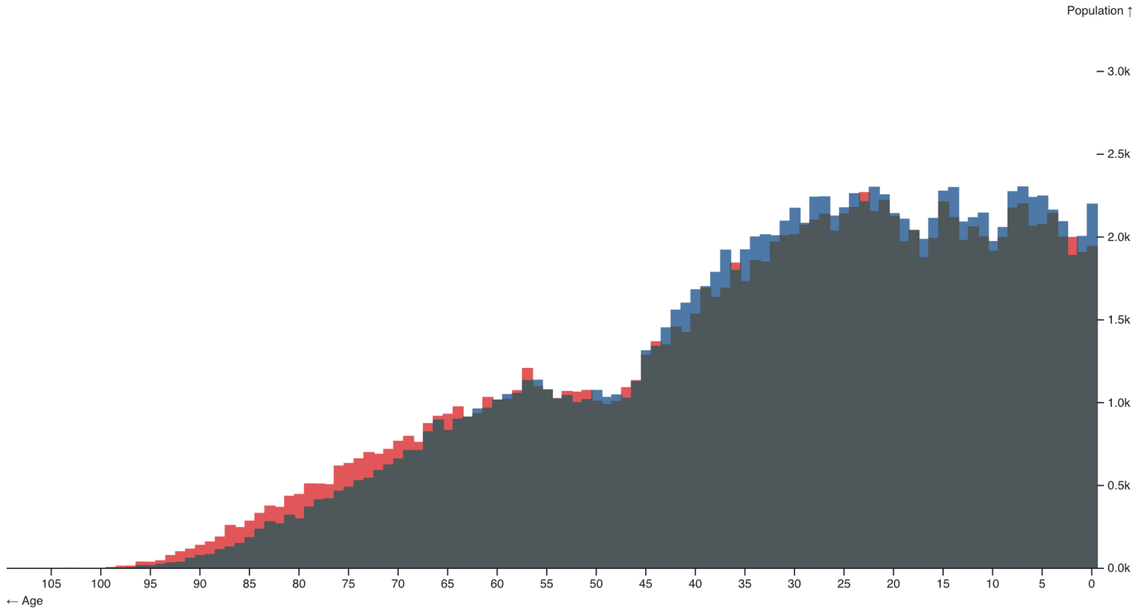

Interaction as an aesthetic mapping

- In some cases interaction allows us to simply add another “dimension”: **time**
  - Very limited in scope
  - Not always the right choice!
  - Example

Best practices for interaction

Based on slides from Cody Dunne & Miriah Meyer

- **Benefits** of interaction
    - Enables visualization of large amounts of data
    - Amplifies user cognition (supports sensemaking)
    - Increases engagement (vis becomes personal to user)
    - Increases deep learning and learning transfer

Best practices for interaction

Based on slides from Cody Dunne & Miriah Meyer

- **Drawbacks** of interaction
  - Requires human time and attention
  - Increase perceptual and exploration costs (van Wijk 2005)
  - Interaction costs (Lam 2008)
  - Multiple user studies find no increase in performance in specific situations (Ragan et al. 2012,

“Overview first, zoom and filter, and details on demand.”

- Ben Shneiderman

“The Shneiderman Mantra”

“Overview first, zoom and filter, and details on demand.”

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“The Shneiderman Mantra”

Overview—provide high-level view/summary

Zoom and Filter—enable data discovery and exploration, support search/tasks

Details on Demand—do not overwhelm the viewer. Provide extra information as needed

“Search, show context, expand on demand”

- van Ham & Perer

“Search, show context, expand on demand”
- van Ham & Perer

Search—pick subset of data to focus on.

Show context—show connected or relevant data for the user’s current interests.

Expand on demand—user chooses to expand the context in a direction of interest.

Taxonomy of interactions

Based on slides from Jeffery Heer

- **Data and view specification**
  - Filter, query, derive
- **View manipulation**
  - Select, Navigate, coordinate, organize
- **Process and provenance**
  - Record annotate, share, guide

Querying and filtering

- Determine a subset of data to highlight by applying *filters*
  - Example: Simple filtering
  - Example: ZIP codes
  - Example: baby names
  - Example: Gapminder DimpVis
  - Example: Segregation in U.S. Cities

Pointing and selection

Select an observation for more details

- Example: tooltips!
- Example: Airports
- Example: College mobility

Brushing and linking

- Select a subset of data using a brush
  - See the selected data in other views
  - Views must be *linked*
  - Example: Stocks and IMDB
  - Example: Brushable scatterplot
  - Example: Crossfiltering
  - Example: Parallel coordinates

Zooming and panning

- Allow user to manipulate the scales
  - Example: maps!
  - Example: Vega-Altair

Sorting

- Allow user to manipulate the scales
  - Example: Sortable bar plot

Scrollytelling

- Update visualization as a reader progresses through a story
  - Example: California fires

Prompting reflection

- Allow user to set their own expectations
  - Example: college mobility

Implementing interaction

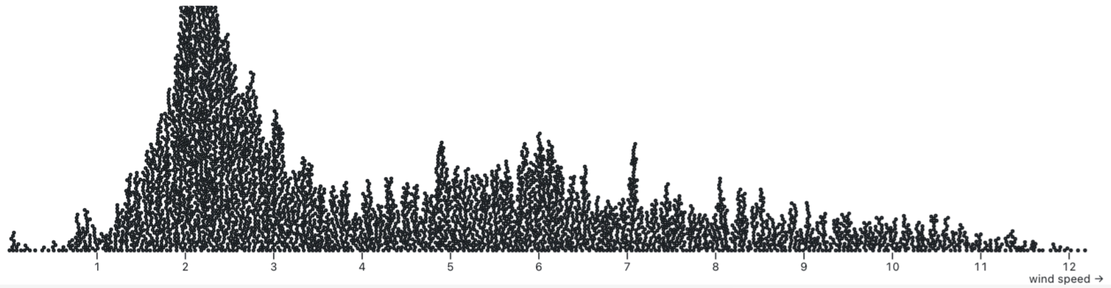
How do we implement interaction?

- Bootstrapping applet

wind speed

```
<select name="dataset-select" id="dataset-select">
    <option value="wind speed">wind speed</option>
    <option value="IMDB rating">IMDB rating</option>
  </select>
```

```
let select = document.getElementById('dataset-select');
select.addEventListener("change", (d) => updatePlot(d.target.value));
```




```
<figure id='population-figure'></figure>
```

```
let figure = document.getElementById('population-figure');
```

```
function updatePlot(dataset) {
  let populations = ({
    "wind speed": winddata.map(d => [d['speed']]),
    "IMDB rating": imdb.map(d => [d['IMDB Rating']]),
  })

  let newPlot = Plot.plot({
    height: 250,
    width: 1000,
    x: {label: dataset, domain: [Math.min(...populations[dataset]),
                                 Math.max(...populations[dataset])]},
    marks: [
      Plot.dot(populations[dataset], Plot.dodgeY({x: "0", r:1}))
    ]
  })
  figure.innerHTML = ""; // Clear the current plot
  figure.appendChild(newPlot); // Add in the new plot
}
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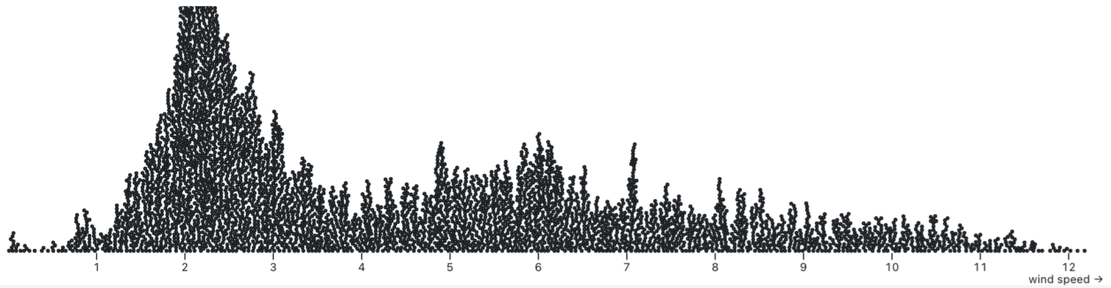
```

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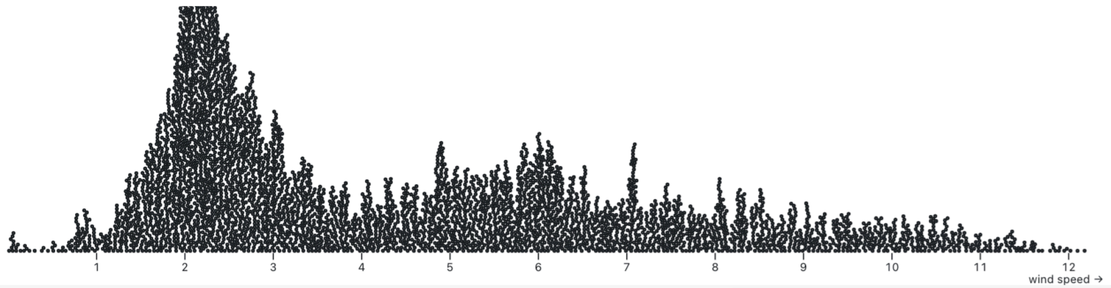


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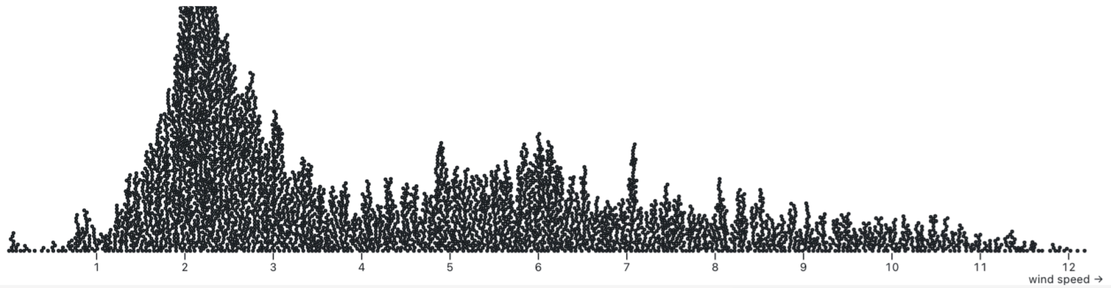


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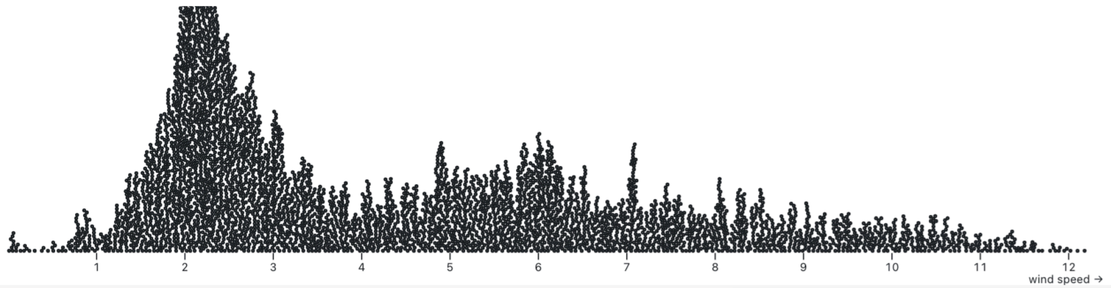


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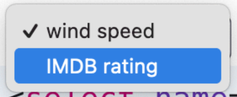


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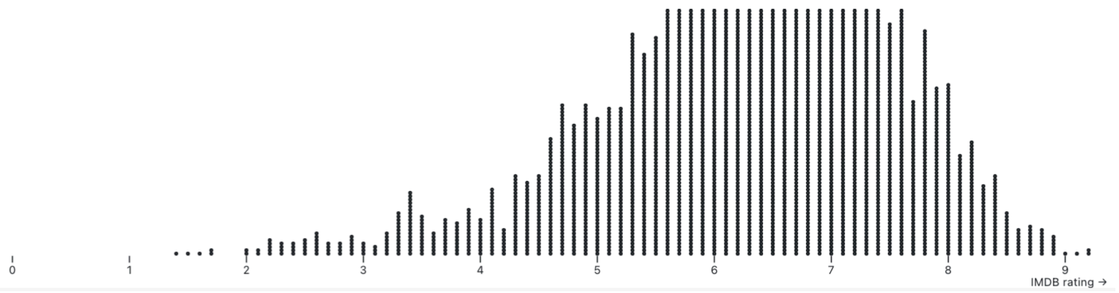
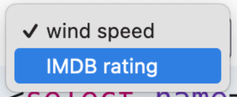
  })
  figure.innerHTML = ""; // Clear the current plot
  figure.appendChild(newPlot); // Add in the new plot
}
updatePlot(select.value);
```




```
<figure id='population-figure'></figure>
```

```
let figure = document.getElementById('population-figure');
```



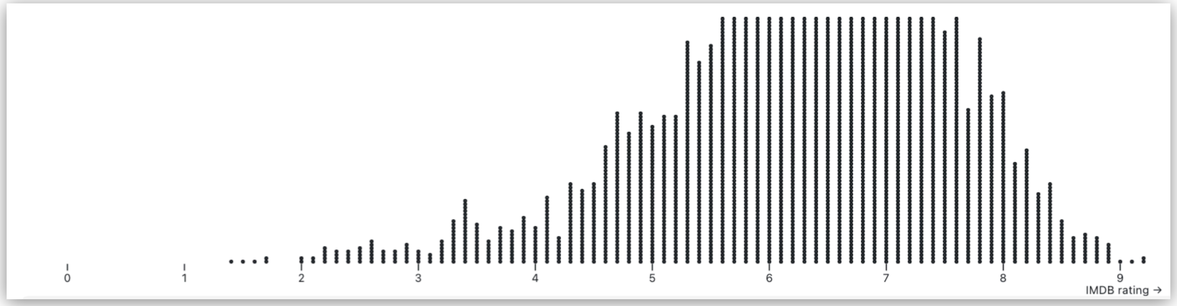

```
<select name="dataset-select" id="dataset-select">
    <option value="wind speed">wind speed</option>
    <option value="IMDB rating">IMDB rating</option>
  </select>
```

```
let select = document.getElementById('dataset-select');
```

```
select.addEventListener("change", (d) => updatePlot(d.target.value));
```

```
function updatePlot(dataset) {
  let populations = ({
    "wind speed": winddata.map(d => [d['speed']]),
    "IMDB rating": imdb.map(d => [d['IMDB Rating']]),
  })

  let newPlot = Plot.plot({
    height: 250,
    width: 1000,
    x: {label: dataset, domain: [Math.min(...populations[dataset]),
                                 Math.max(...populations[dataset])]},
    marks: [
      Plot.dot(populations[dataset], Plot.dodgeY({x: "0", r:1}))
    ]
  })
  figure.innerHTML = ""; // Clear the current plot
  figure.appendChild(newPlot); // Add in the new plot
}
updatePlot(select.value);
```




```
function updatePlot(dataset) {
  let populations = ({
    "wind speed": winddata.map(d => [d['speed']]),
    "IMDB rating": imdb.map(d => [d['IMDB Rating']]),
  })

  let newPlot = Plot.plot({
    height: 250,
    width: 1000,
    x: {label: dataset, domain: [Math.min(...populations[dataset]),
                                 Math.max(...populations[dataset])]},
    marks: [
      Plot.dot(populations[dataset], Plot.dodgeY({x: "0", r:1}))
    ]
  })
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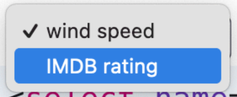
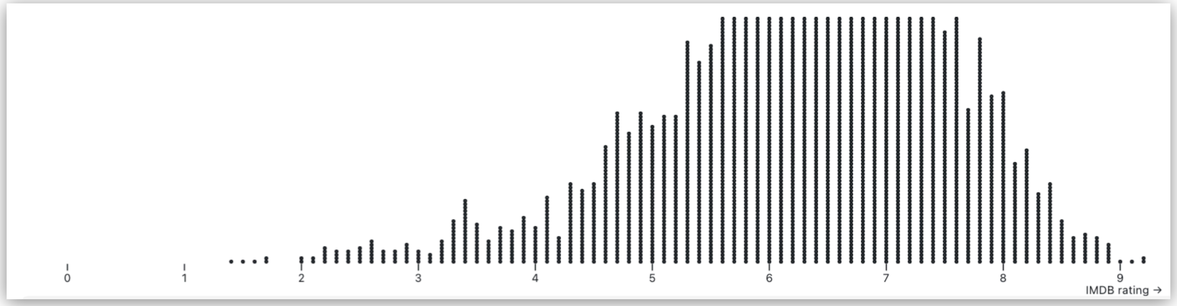



```
<select name="dataset-select" id="dataset-select">
    <option value="wind speed">wind speed</option>
    <option value="IMDB rating">IMDB rating</option>
  </select>
```

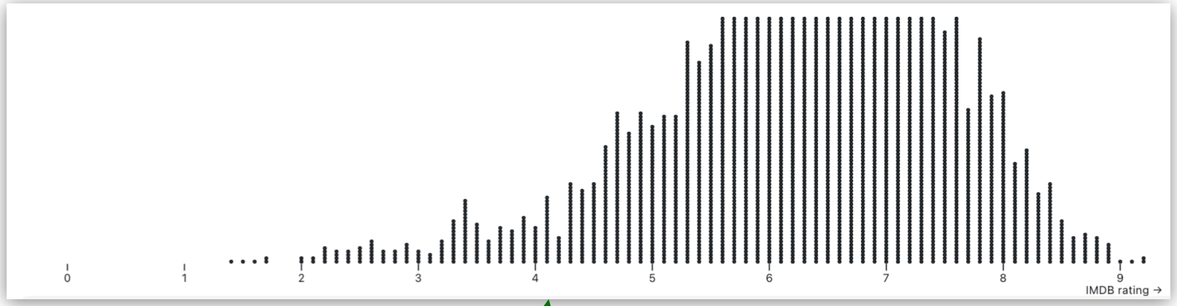
```
let select = document.getElementById('dataset-select');
select.addEventListener("change", (d) => updatePlot(d.target.value));
```




```
function updatePlot(dataset) {
  let populations = ({
    "wind speed": winddata.map(d => [d['speed']]),
    "IMDB rating": imdb.map(d => [d['IMDB Rating']]),
  })

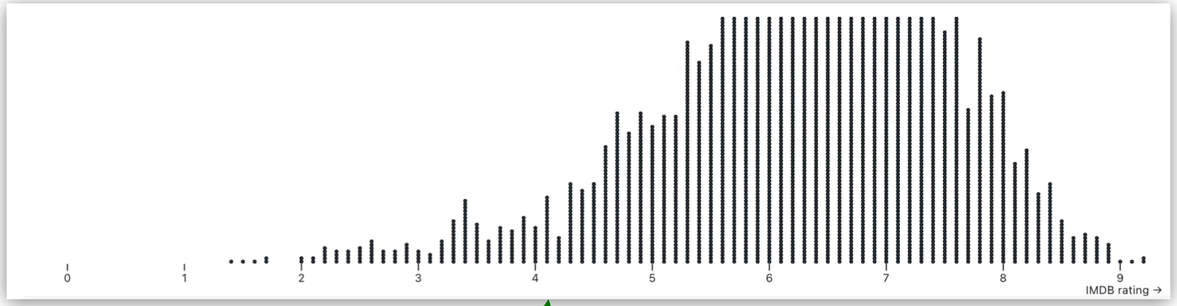
  let newPlot = Plot.plot({
    height: 250,
    width: 1000,
    x: {label: dataset, domain: [Math.min(...populations[dataset]),
                                 Math.max(...populations[dataset])]},
    marks: [
      Plot.dot(populations[dataset], Plot.dodgeY({x: "0", r:1}))
    ]
  })
  figure.innerHTML = ""; // Clear the current plot
  figure.appendChild(newPlot); // Add in the new plot
}
updatePlot(select.value);
```

IMDB rating



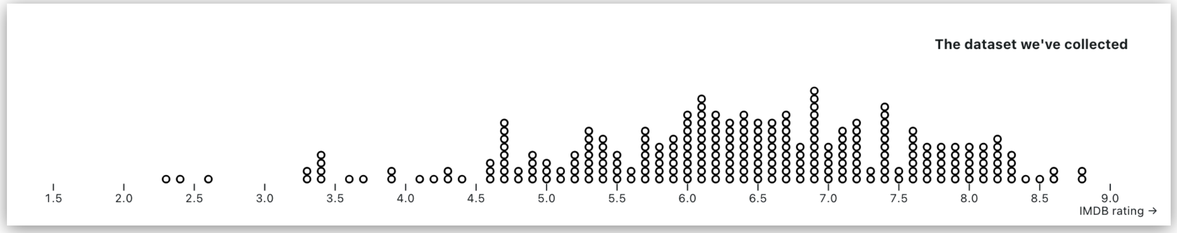
Updates

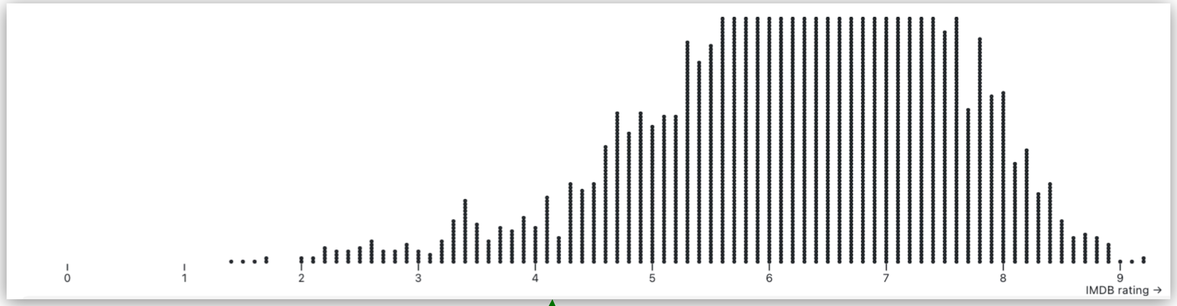
IMDB rating

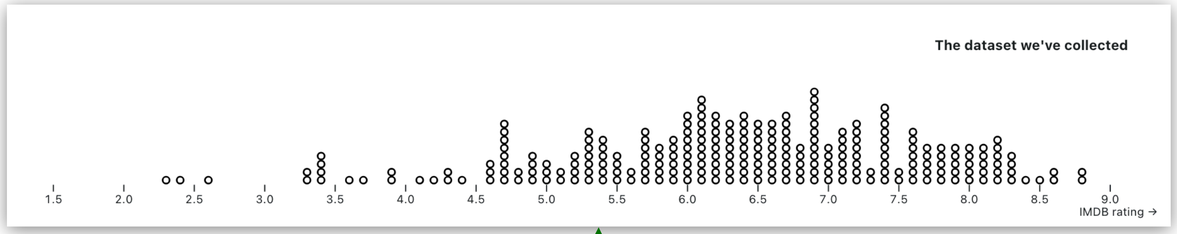


Updates

IMDB rating



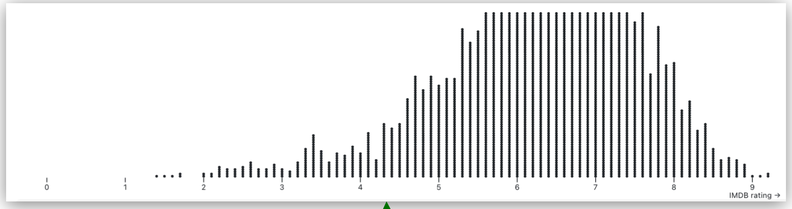


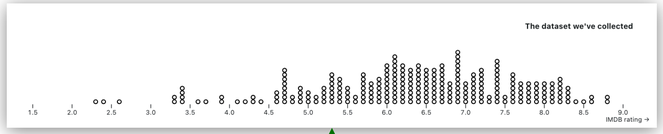


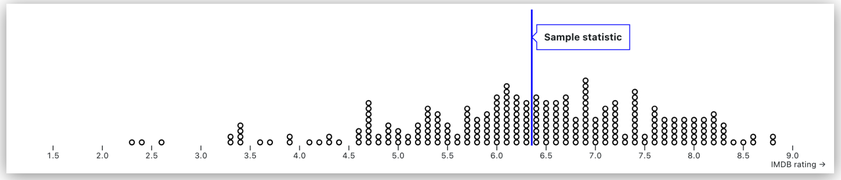
Population

Updates

IMDB rating



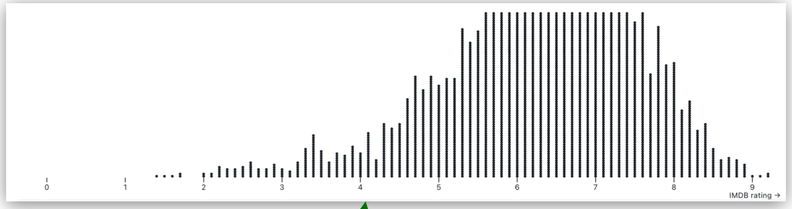


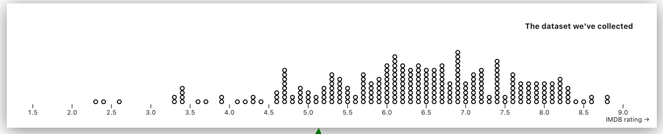


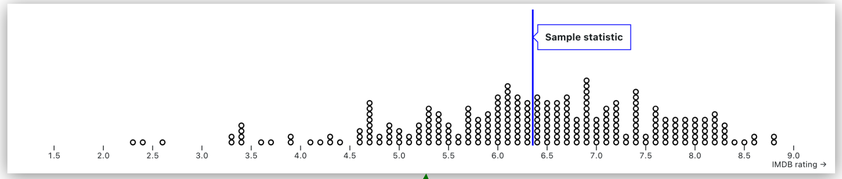
Population

Updates

IMDB rating





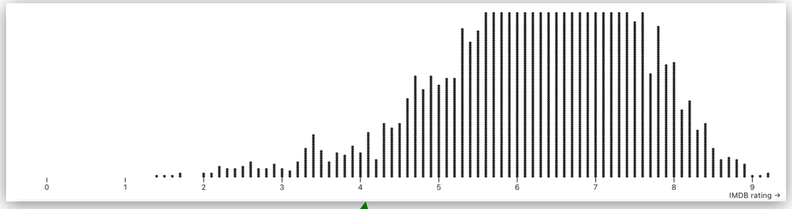


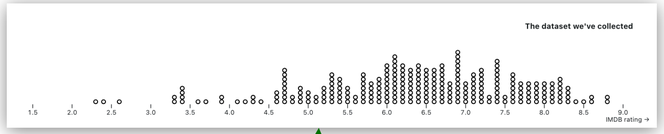
Sample

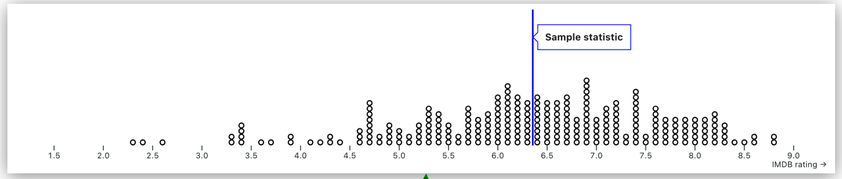
Population

Updates

IMDB rating







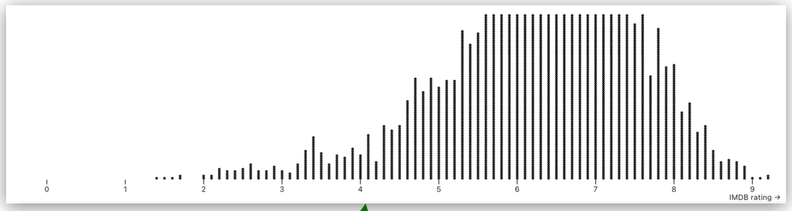
Sample

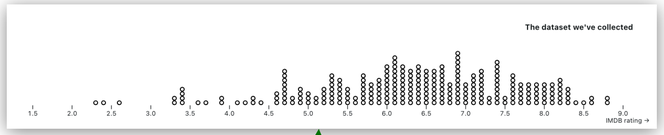
Population

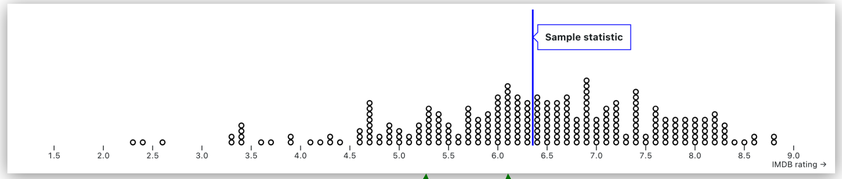
Updates

IMDB rating

Mean







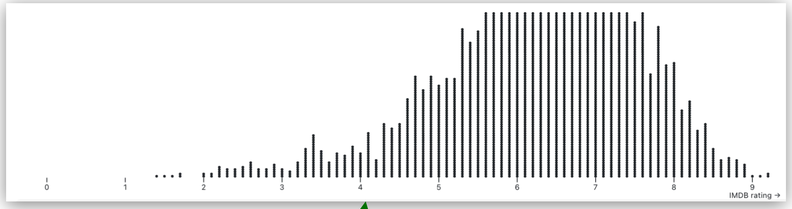
Sample

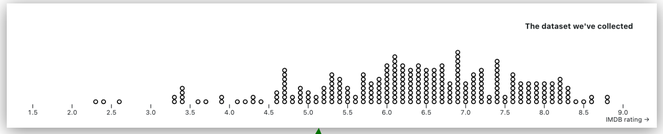
Population

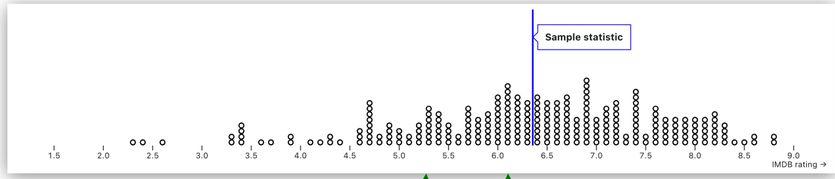
Updates

IMDB rating

Mean







Sample

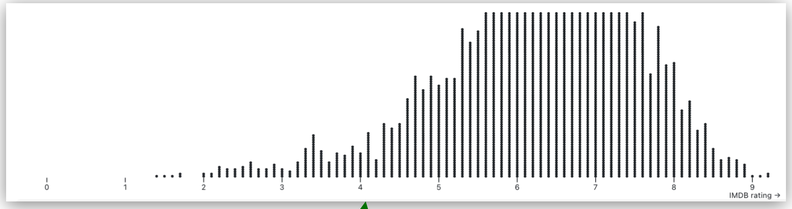
Population

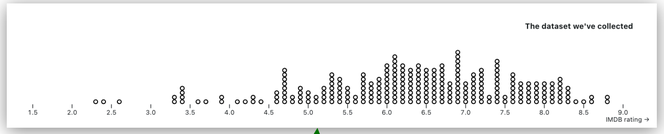
Updates

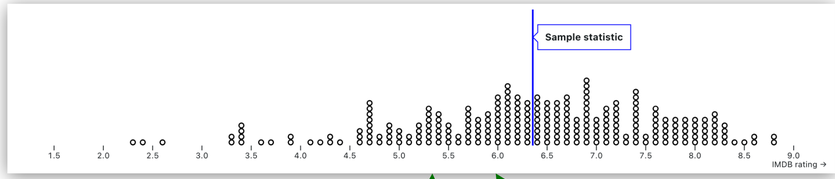
*Here our **Mean** of `IMDB rating` is 6.35*

IMDB rating

Mean







Sample

Statistic

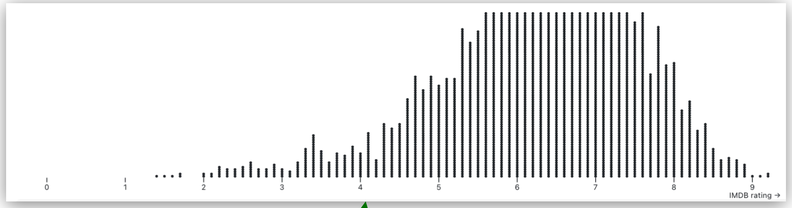
Population

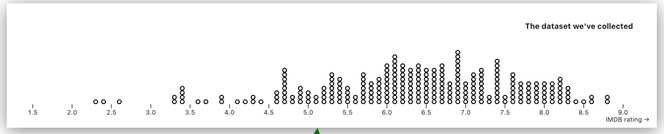
Updates

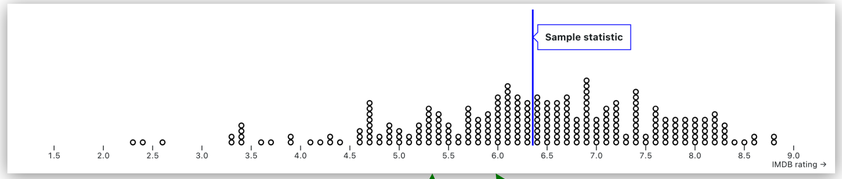
*Here our **Mean** of `IMDB rating` is 6.35*

IMDB rating

Mean







Here we needed to:

- Add *statistic* to our state
- Change *sample* code to update the *statistic*
- Change *statistic type selector* code to update text
- Change *statistic* code to update text
- ...

Sample

Statistic

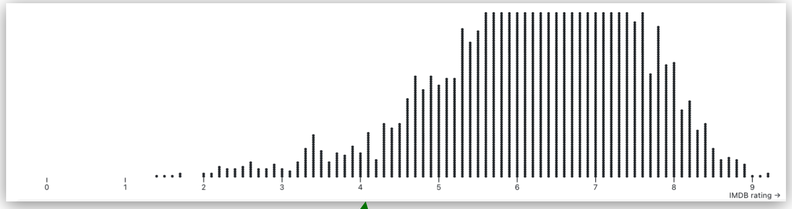
Population

Updates

*Here our **Mean** of `IMDB rating` is 6.35*

IMDB rating

Mean



Adding new components gets very complicated very quickly

Here we needed to:

- Add *statistic* to our state
- Change *sample* code to update the *statistic*
- Change *statistic type selector* code to update text
- Change *statistic* code to update text
- ...

Sample

Statistic

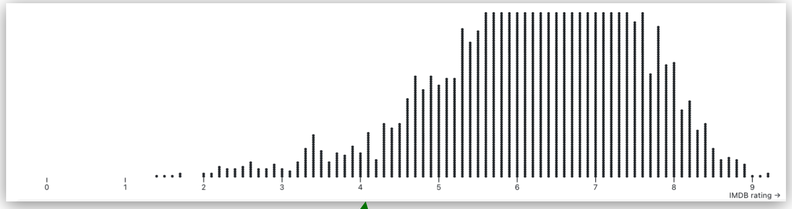
Population

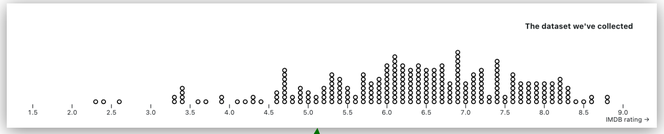
Updates

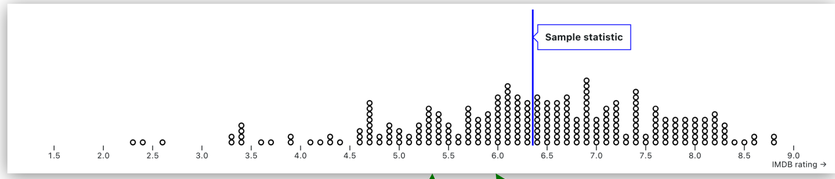
*Here our **Mean** of `IMDB rating` is 6.35*

IMDB rating

Mean







Sample

Statistic

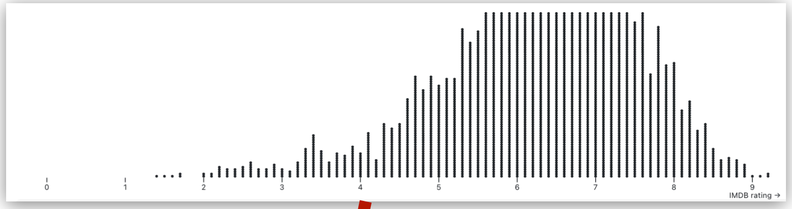
Population

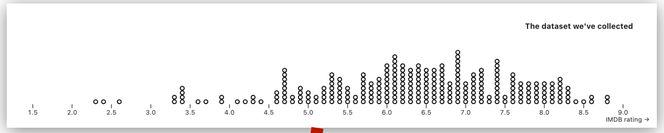
Updates

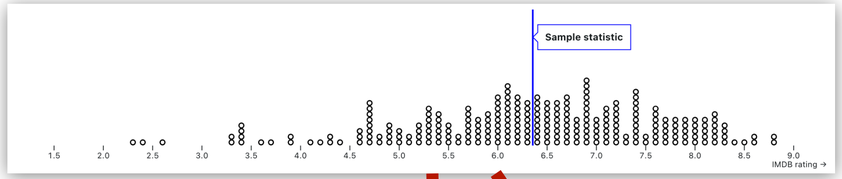
*Here our **Mean** of `IMDB rating` is 6.35*

IMDB rating

Mean







Sample

Statistic

Population

Observes

*Here our **Mean** of `IMDB rating` is 6.35*

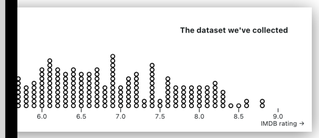
IMDB rating

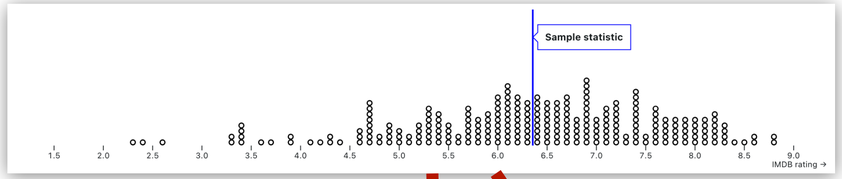
Mean

Observer pattern: *flip responsibility*

Each *component* is responsible for knowing what other pieces of state it depends on

- When parent state changes - *recompute*!





Sample

Statistic

Population

Observes

*Here our **Mean** of `IMDB rating` is 6.35*

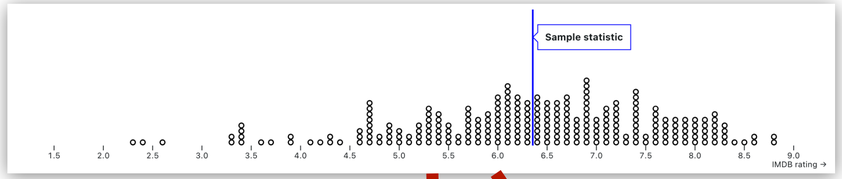
IMDB rating

Mean

Observer pattern: *implementation*

Each component *registers* itself as an observer of its parent

- When parent state changes - *signal all observers*!



Python

```python
class Observable:
    def __init__(self):
        self._observers = []

    def register_observer(self, observer) -> None:
        self._observers.append(observer)

    def notify_observers(self, *args, **kwargs) -> None:
        for observer in self._observers:
            observer.notify(self, *args, **kwargs)


class Observer:
    def __init__(self, observable):
        observable.register_observer(self)

    def notify(self, observable, *args, **kwargs) -> None:
        print("Got", args, kwargs, "From", observable)


subject = Observable()
observer = Observer(subject)
subject.notify_observers("test", kw="python")

# prints: Got ('test',) {'kw': 'python'} From <__main__.Observable object at
0x0000019757826FD0>
```

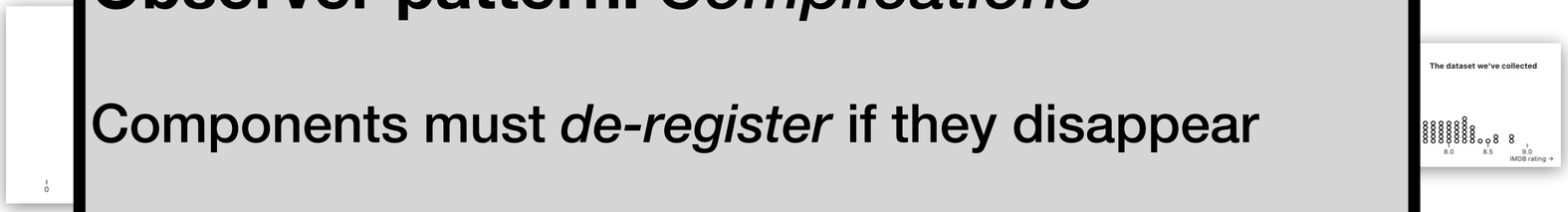
Javascript

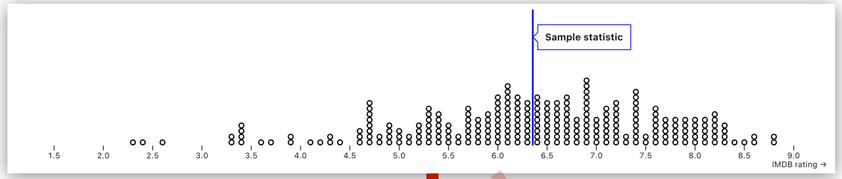
```javascript
let Subject = {
    _state: 0,
    _observers: [],
    add: function(observer) {
        this._observers.push(observer);
    },
    getState: function() {
        return this._state;
    },
    setState: function(value) {
        this._state = value;
        for (let i = 0; i < this._observers.length; i++)
        {
            this._observers[i].signal(this);
        }
    }
};

let Observer = {
    signal: function(subject) {
        let currentValue = subject.getState();
        console.log(currentValue);
    }
}

Subject.add(Observer);
Subject.setState(10);
//Output in console.log - 10
```

From Wikipedia

Observer pattern: *Complications*

Components must *de-register* if they disappear





Sample

Population

Observes

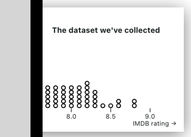
*Here our **Mean** of `IMDB rating` is 6.35*

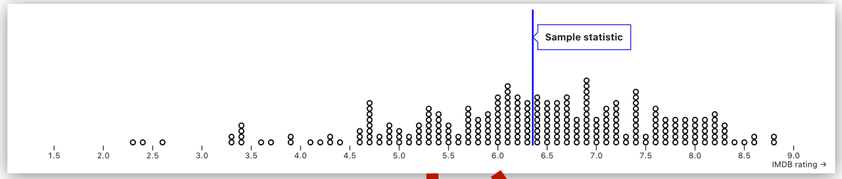
IMDB rating

Mean

Observer pattern: *Complications*

Cycles cannot be allowed!





Sample

Statistic

Population

Observes

*Here our **Mean** of `IMDB rating` is 6.35*

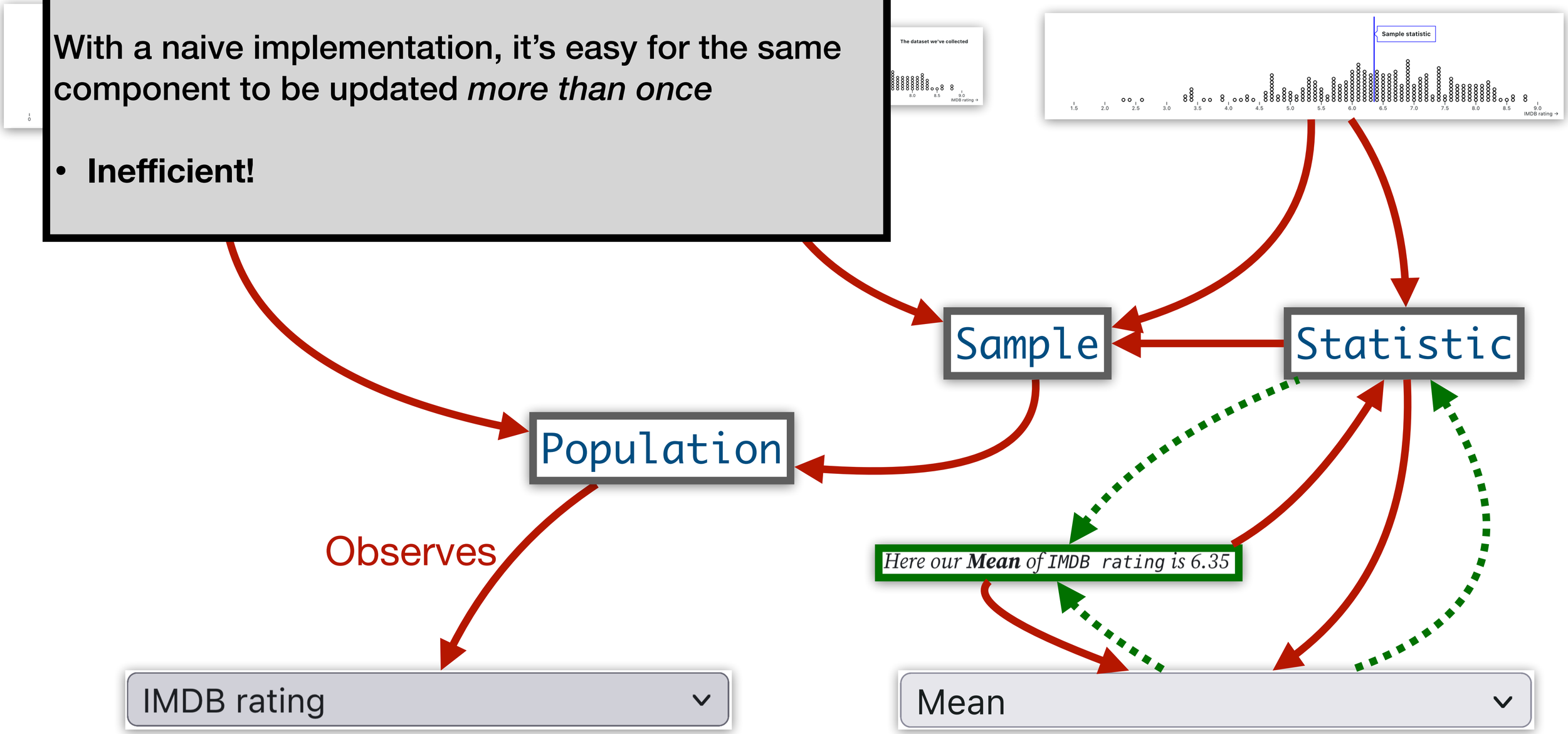
IMDB rating

Mean

Observer pattern: *Complications*

With a naive implementation, it's easy for the same component to be updated *more than once*

- **Inefficient!**



Observer pattern: *Complications*

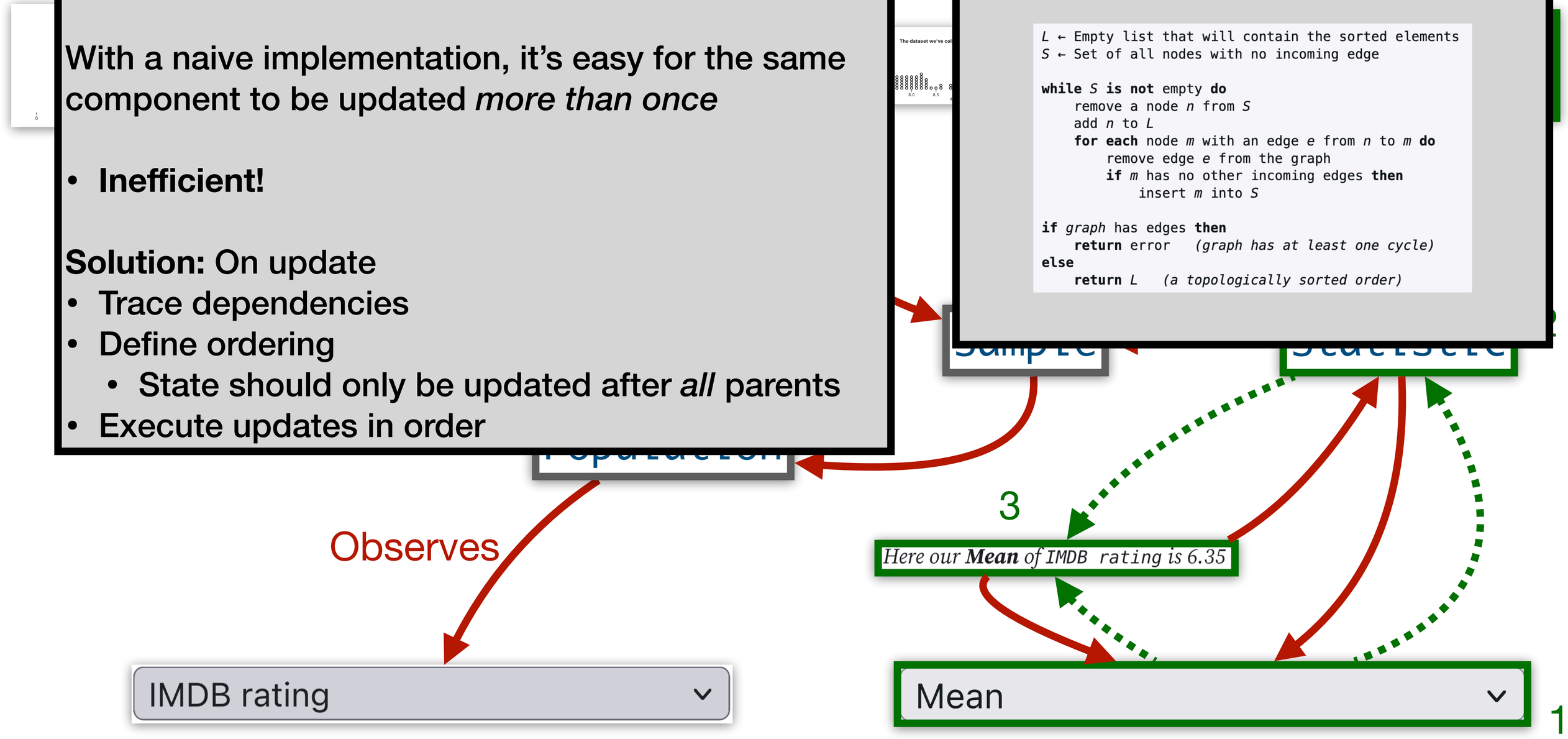
With a naive implementation, it's easy for the same component to be updated *more than once*

- **Inefficient!**

Solution: On update
- Trace dependencies
- Define ordering
  - State should only be updated after *all* parents
- Execute updates in order

Define ordering: *topological sort*

```
L ← Empty list that will contain the sorted elements
S ← Set of all nodes with no incoming edge

while S is not empty do
    remove a node n from S
    add n to L
    for each node m with an edge e from n to m do
        remove edge e from the graph
        if m has no other incoming edges then
            insert m into S

if graph has edges then
    return error   (graph has at least one cycle)
else
    return L   (a topologically sorted order)
```

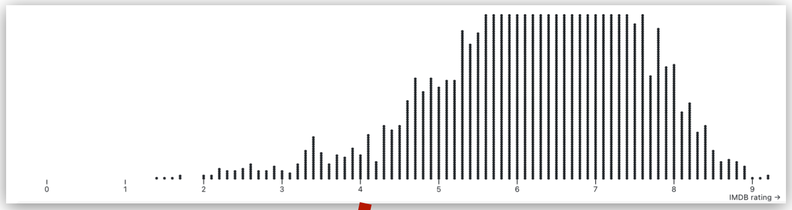


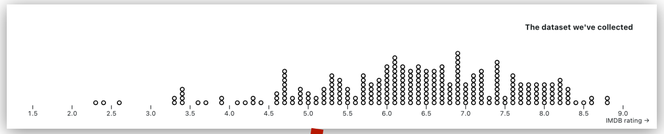
Reactive programming

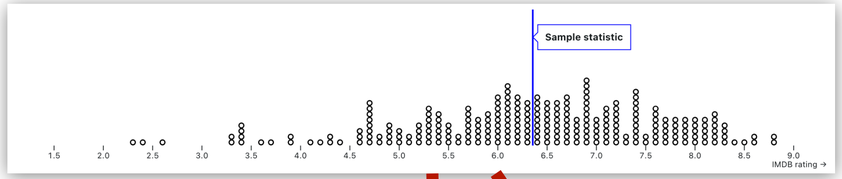
Build observer pattern into core language or framework

Reactive programming

Build observer pattern into core language or framework








```
sample = resample(population)
```

```
stat = computeStat(sample)
```

Sample

Statistic

```
population = (dataset == "wind speed") ? windpopulation : imdbpopulation;
```

Population

```
*Here our **${statistic}** of `${dataset}` is ${estimate}*
```

*Here our **Mean** of IMDB rating is 6.35*

Observes

IMDB rating

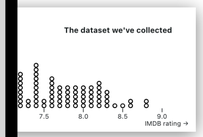
Mean

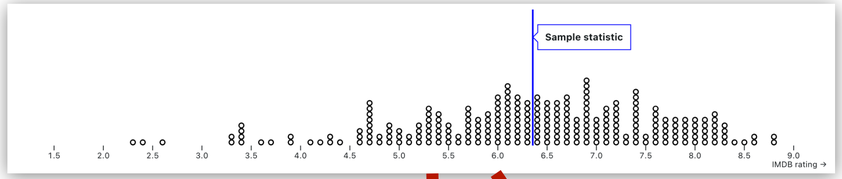
```
viewof dataset = Inputs.select(["wind speed", "IMDB rating"], {label: "Dataset"});
```

```
viewof statistic = Inputs.select(["Mean", "Median"])
```

Reactive framework

Each line re-runs when variables it uses change!



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Sample

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Population

Observes

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*Here our **${statistic}** of `${dataset}` is ${estimate}*
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*Here our **Mean** of IMDB rating is 6.35*

IMDB rating

Mean

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viewof dataset = Inputs.select(["wind speed", "IMDB rating"], {label: "Dataset"});
```

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viewof statistic = Inputs.select(["Mean", "Median"])
```
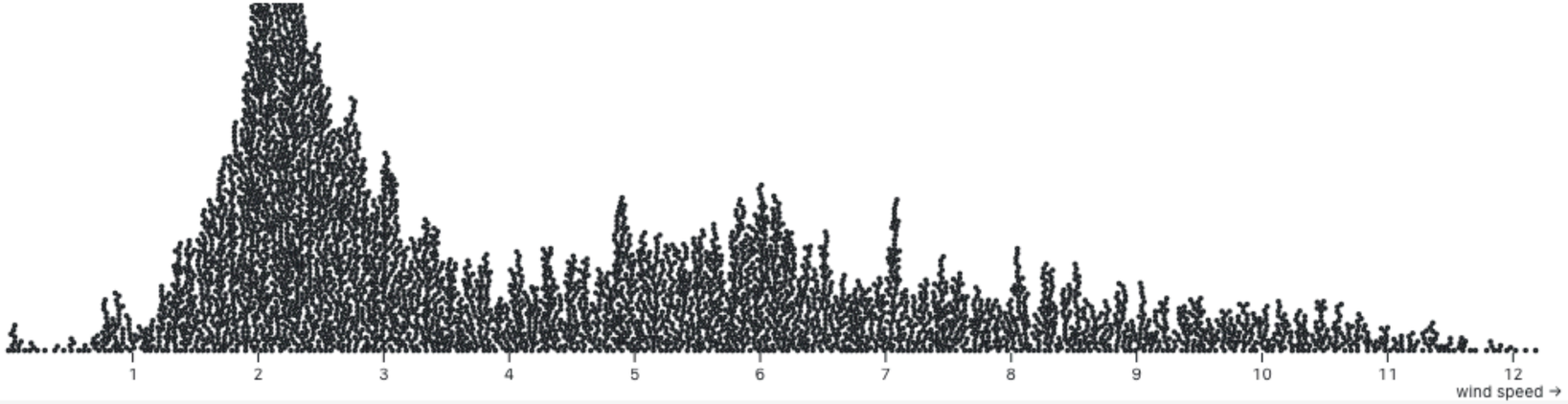

Dataset choice




```
Plot.plot({
  height: 250,
  width: 1000,
  x: {label: dataset, domain: [Math.min(...populations[dataset]),
                               Math.max(...populations[dataset])]},
  marks: [
    Plot.dot(populations[dataset], Plot.dodgeY({x: "0", r:1}))
  ]
})
```

Updated on change!

wind speed

```
viewof dataset = Inputs.select(["wind speed", "IMDB rating"])
```

```
populations = ▸ Object {wind speed: Array(4800), IMDB rating: Array(3201)}
```

```
 populations = ({
      "wind speed": winddata.map(d => [d['speed']]),
      "IMDB rating": imdb.map(d => [d['IMDB Rating']]),
    })
```

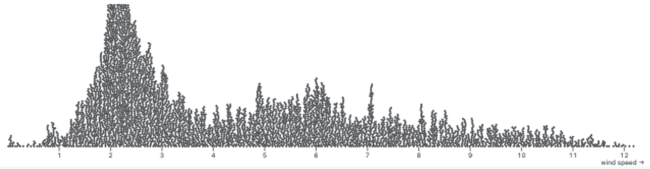
```
▸ Array(3201) [6.1, 6.9, 6.8, null, 3.4, null, 7.7, 3.8, 5.8, 7, 7, 7.5, 8.4, null, 6.8, null, 7, 6.1, 2.5, 8.9, …]
```

```
imdb.map(d => d['IMDB Rating'])
```

```
import {windpopulation, imdbpopulation, imdb, wind, winddata, tf, windspeedDistributionPlot, imdbDistributionPlot} from
"3523e4b3244dbb93"
```

Traditional

Dataset choice




```
<figure id='population-figure'></figure>
```

wind speed

```
<select name="dataset-select" id="dataset-select">
    <option value="wind speed">wind speed</option>
    <option value="IMDB rating">IMDB rating</option>
  </select>
```

```
undefined
```

```
{
  let figure = document.getElementById('population-figure');

  let select = document.getElementById('dataset-select');

  function updatePlot(dataset) {
    let populations = ({
      "wind speed": winddata.map(d => [d['speed']]),
      "IMDB rating": imdb.map(d => [d['IMDB Rating']]),
    })

    let newPlot = Plot.plot({
      height: 250,
      width: 1000,
      x: {label: dataset, domain: [Math.min(...populations[dataset]),
                                   Math.max(...populations[dataset])]},
      marks: [
        Plot.dot(populations[dataset], Plot.dodgeY({x: "0", r:1}))
      ]
    })
    figure.innerHTML = ""; // Clear the current plot
    figure.appendChild(newPlot); // Add in the new plot
  }
  updatePlot(select.value);

  select.addEventListener("change", (d) => updatePlot(d.target.value));
}
```

```
▸ Array(3201) [6.1, 6.9, 6.8, null, 3.4, null, 7.7, 3.8, 5.8, 7, 7, 7.5, 8.4, null, 6.8, null, 7, 6.1, 2.5, 8.9, …]
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imdb.map(d => d['IMDB Rating'])
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import {windpopulation, imdbpopulation, imdb, wind, winddata, tf, windspeedDistributionPlot, imdbDistributionPlot} from
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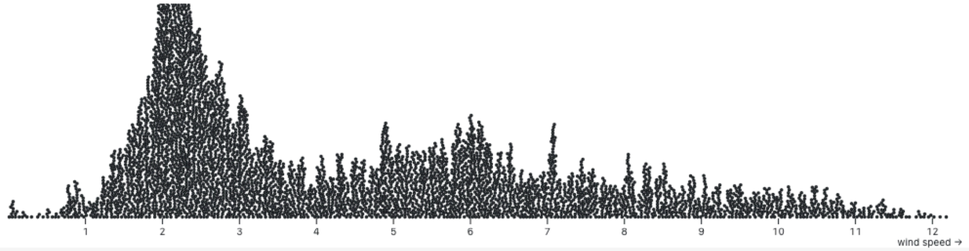
Reactive

Dataset choice

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```

Each *top-level* variable is a reactive value

- Can be computed with a *chunk* of code

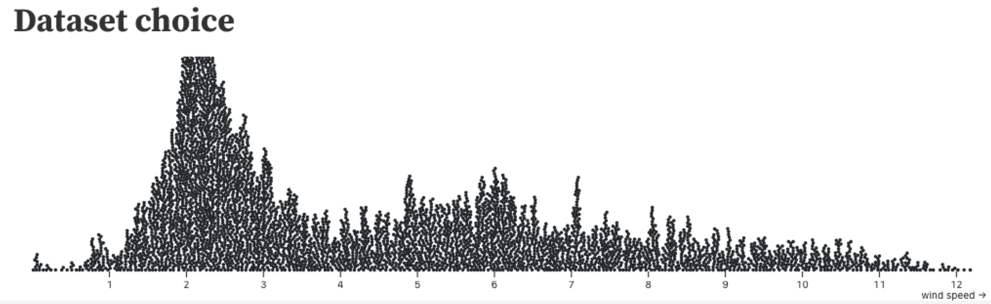
Reactive value

Dependencies

Code chunk

```
resampled = {
  resampleToggle2
  step2
  let x = resample(weights);
  let est = computeStat(x);
  estimates.push([est]);
  let output = x.arraySync();
  x.dispose()
  return output;
}
```

Reactive

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Your turn!