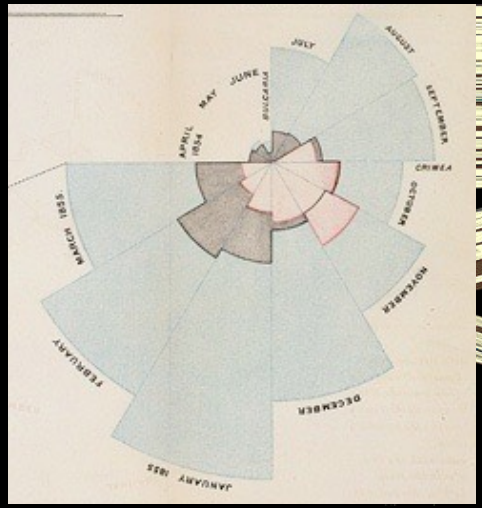
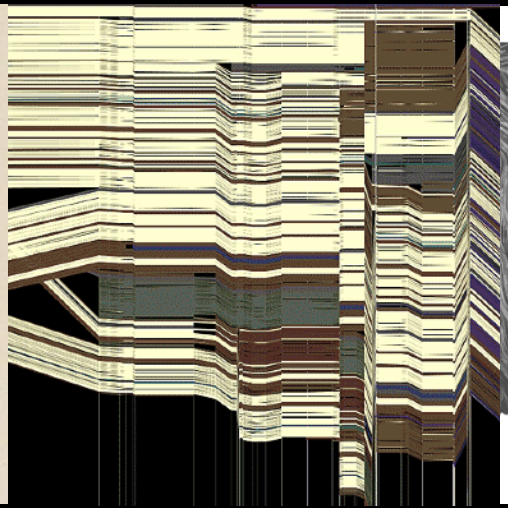
CSE 512 - Data Visualization

Data Transformation





Jeffrey Heer University of Washington

Session Outline

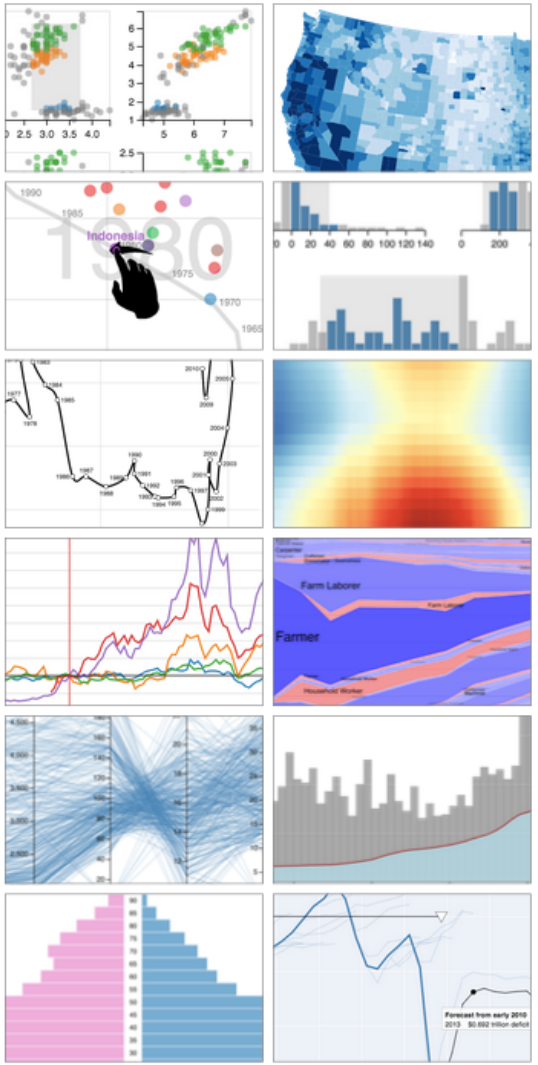
Data Models

Data Tables & Transformations

Data Wrangling & Profiling

Visualizing Distributions

Dimensionality Reduction



Data Models

Data Models / Conceptual Models

Data models are formal descriptions
Math: sets with operations on them
Example: integers with + and x operators

Conceptual models are mental constructions
Include semantics and support reasoning

Examples (data vs. conceptual)
1D floats vs. temperatures
3D vector of floats vs. spatial location

Types of Variables

Physical Types

Characterized by storage format

Characterized by machine operations

Example: bool, int32, float, double, string, …

Abstract Types

Provide descriptions of the data

May be characterized by methods / attributes

May be organized into a hierarchy

Example: plants, animals, metazoans, …

Taxonomy of Data Types (?)

1D (sets and sequences)
Temporal
2D (maps)
3D (shapes)
nD (relational)
Trees (hierarchies)
Networks (graphs)

Are there others?

The eyes have it: A task by data type taxonomy for information visualization
[Shneiderman 96]

Nominal, Ordinal & Quantitative

Nominal, Ordinal & Quantitative

N - Nominal (labels or categories)

- Fruits: apples, oranges, …

Nominal, Ordinal & Quantitative

N - Nominal (labels or categories)

- Fruits: apples, oranges, …

O - Ordered

- Quality of meat: Grade A, AA, AAA

Nominal, Ordinal & Quantitative

N - Nominal (labels or categories)

- Fruits: apples, oranges, …

O - Ordered

- Quality of meat: Grade A, AA, AAA

Q - Interval (location of zero arbitrary)

- Dates: Jan, 19, 2006; Location: (LAT 33.98, LONG -118.45)
- Only differences (i.e., intervals) may be compared

Nominal, Ordinal & Quantitative

N - Nominal (labels or categories)

- Fruits: apples, oranges, …

O - Ordered

- Quality of meat: Grade A, AA, AAA

Q - Interval (location of zero arbitrary)

- Dates: Jan, 19, 2006; Location: (LAT 33.98, LONG -118.45)
- Only differences (i.e., intervals) may be compared

Q - Ratio (zero fixed)

- Physical measurement: Length, Mass, Time duration, …
- Counts and amounts

Nominal, Ordinal & Quantitative

N - Nominal (labels or categories)

- Operations: =, ≠

O - Ordered

- Operations: =, ≠, <, >

Q - Interval (location of zero arbitrary)

- Operations: =, ≠, <, >, -
- Can measure distances or spans

Q - Ratio (zero fixed)

- Operations: =, ≠, <, >, -, %
- Can measure ratios or proportions

From Data Model to N, O, Q

Data Model
32.5, 54.0, -17.3, …
Floating point numbers

Conceptual Model
Temperature (°C)

Data Type
Burned vs. Not-Burned (N)
Hot, Warm, Cold (O)
Temperature Value (Q-interval)

Dimensions & Measures

Dimensions (~ independent variables)
Often discrete variables describing data (N, O)
Categories, dates, binned quantities

Measures (~ dependent variables)
Data values that can be aggregated (Q)
Numbers to be analyzed
Aggregate as sum, count, avg, std. dev…

Not a strict distinction. The same variable may be treated either way depending on the task.

Example: U.S. Census Data

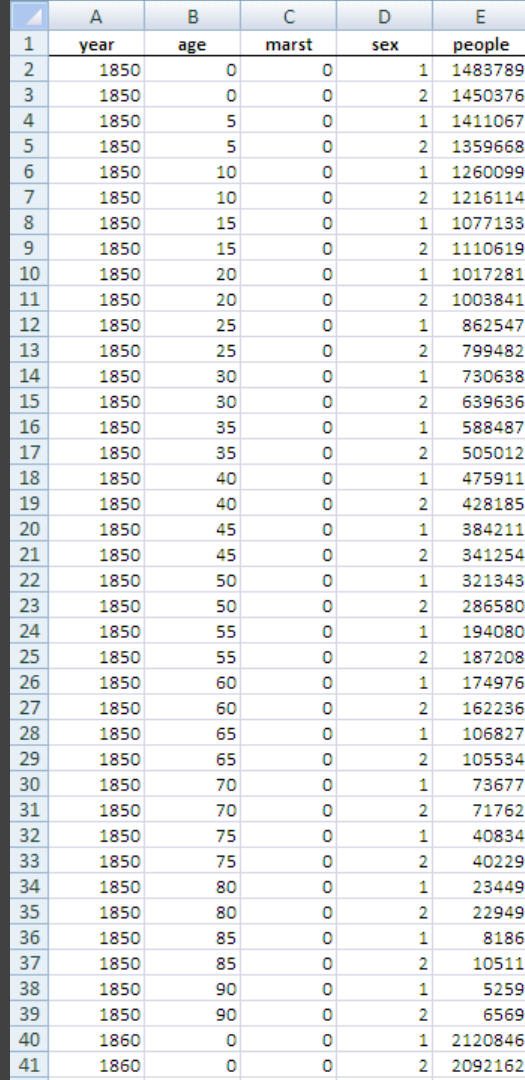
Example: U.S. Census Data

People Count: # of people in group
Year: 1850 – 2000 (every decade)
Age: 0 – 90+
Sex: Male, Female
Marital Status: Single, Married, Divorced, …

Example: U.S. Census

People Count
Year
Age
Sex
Marital Status

2,348 data points



	A	B	C	D	E
1	year	age	marst	sex	people
2	1850	0	0	1	1483789
3	1850	0	0	2	1450376
4	1850	5	0	1	1411067
5	1850	5	0	2	1359668
6	1850	10	0	1	1260099
7	1850	10	0	2	1216114
8	1850	15	0	1	1077133
9	1850	15	0	2	1110619
10	1850	20	0	1	1017281
11	1850	20	0	2	1003841
12	1850	25	0	1	862547
13	1850	25	0	2	799482
14	1850	30	0	1	730638
15	1850	30	0	2	639636
16	1850	35	0	1	588487
17	1850	35	0	2	505012
18	1850	40	0	1	475911
19	1850	40	0	2	428185
20	1850	45	0	1	384211
21	1850	45	0	2	341254
22	1850	50	0	1	321343
23	1850	50	0	2	286580
24	1850	55	0	1	194080
25	1850	55	0	2	187208
26	1850	60	0	1	174976
27	1850	60	0	2	162236
28	1850	65	0	1	106827
29	1850	65	0	2	105534
30	1850	70	0	1	73677
31	1850	70	0	2	71762
32	1850	75	0	1	40834
33	1850	75	0	2	40229
34	1850	80	0	1	23449
35	1850	80	0	2	22949
36	1850	85	0	1	8186
37	1850	85	0	2	10511
38	1850	90	0	1	5259
39	1850	90	0	2	6569
40	1860	0	0	1	2120846
41	1860	0	0	2	2092162

Census: N, O, Q-Interval, Q-Ratio?

People Count	Q-Ratio
Year	Q-Interval *(O)*
Age	Q-Ratio *(O)*
Sex	N
Marital Status	N

Census: Dimension or Measure?

People Count	Measure
Year	Dimension
Age	Depends!
Sex	Dimension
Marital Status	Dimension

Census Data Demo

demo link: us-population-1850-2000

Data Tables & Transformations

Relational Data Model

Represent data as a **table** (or *relation*)

Each **row** (or *tuple*) represents a record
  Each record is a fixed-length tuple

Each **column** (or *field*) represents a variable
  Each field has a *name* and a *data type*

A table's **schema** is the set of names and types

A **database** is a collection of tables (relations)

Relational Algebra [Codd '70] / SQL

Operations on Data Tables: table(s) in, table out

Relational Algebra [Codd '70] / SQL

Operations on Data Tables: table(s) in, table out

Project (`select`): select a set of columns

Filter (`where`): remove unwanted rows

Sort (`order by`): order records

Aggregate (`group by`, `sum`, `min`, `max`, …):

partition rows into groups + summarize

Combine (`join`, `union`, …):

integrate data from multiple tables

Relational Algebra [Codd '70] / SQL

Project (`select`): select a set of columns

```
select day, stock
```

day	stock	price
10/3	AMZN	957.10
10/3	MSFT	74.26
10/4	AMZN	965.45
10/4	MSFT	74.69

day	stock
10/3	AMZN
10/3	MSFT
10/4	AMZN
10/4	MSFT

Relational Algebra [Codd '70] / SQL

Filter (`where`): remove unwanted rows

```
select * where price > 100
```

day	stock	price
10/3	AMZN	957.10
10/3	MSFT	74.26
10/4	AMZN	965.45
10/4	MSFT	74.69

day	stock	price
10/3	AMZN	957.10
10/4	AMZN	965.45

Relational Algebra [Codd '70] / SQL

Sort (`order by`): order records

```
select * order by stock
```

day	stock	price
10/3	AMZN	957.10
10/3	MSFT	74.26
10/4	AMZN	965.45
10/4	MSFT	74.69

day	stock	price
10/3	AMZN	957.10
10/4	AMZN	965.45
10/3	MSFT	74.26
10/4	MSFT	74.69

Relational Algebra [Codd '70] / SQL

Aggregate (`group by`, `sum`, `min`, `max`, ...):

```
select stock, min(price) group by stock
```

day	stock	price
10/3	AMZN	957.10
10/3	MSFT	74.26
10/4	AMZN	965.45
10/4	MSFT	74.69

stock	min(price)
AMZN	957.10
MSFT	74.26

Relational Algebra [Codd '70] / SQL

Join (`join`) multiple tables together

day	stock	price
10/3	AMZN	957.10
10/3	MSFT	74.26
10/4	AMZN	965.45
10/4	MSFT	74.69

stock	min
AMZN	957.10
MSFT	74.26

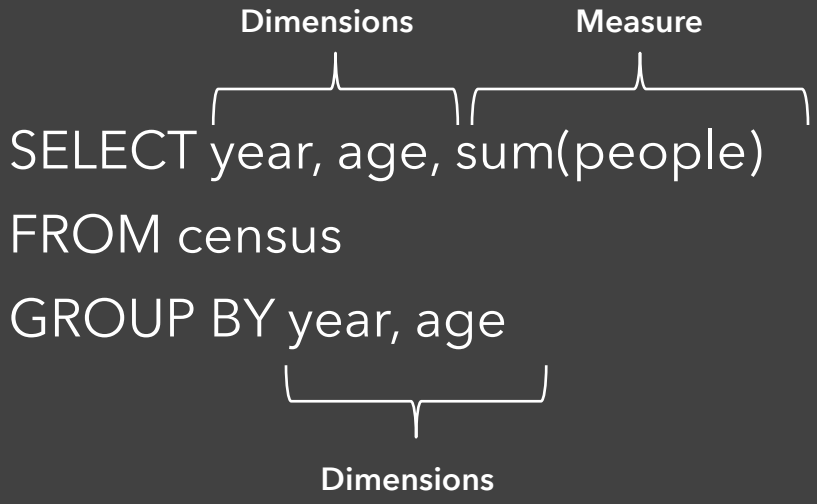
day	stock	price	min
10/3	AMZN	957.10	957.10
10/3	MSFT	74.26	74.26
10/4	AMZN	965.45	957.10
10/4	MSFT	74.69	74.26

```
select t.day,t.stock,t.price,a.min
from table as t, aggregate as a
where t.stock = a.stock
```

Roll-Up and Drill-Down

Want to examine population by year and age?

Roll-up the data along the desired dimensions

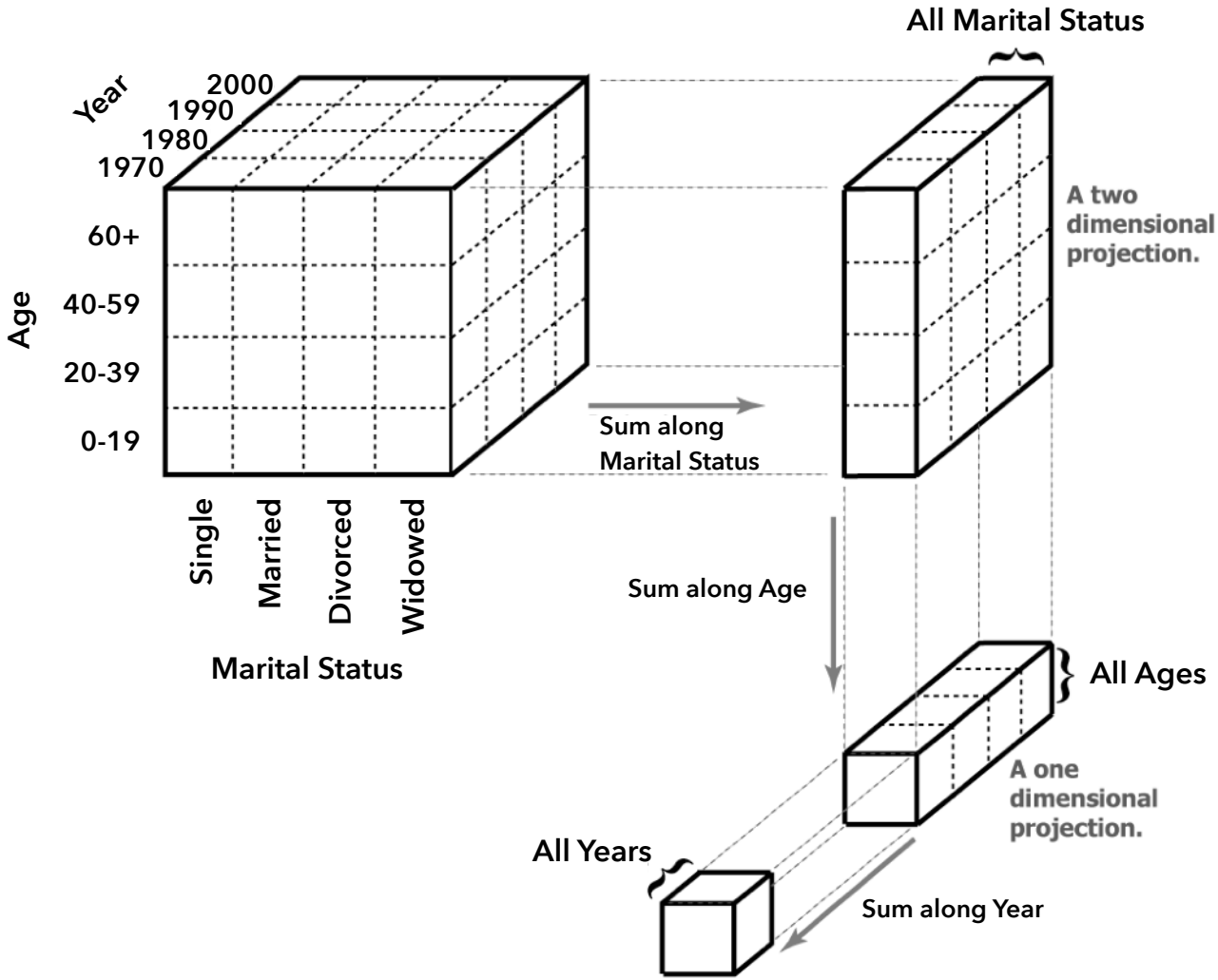


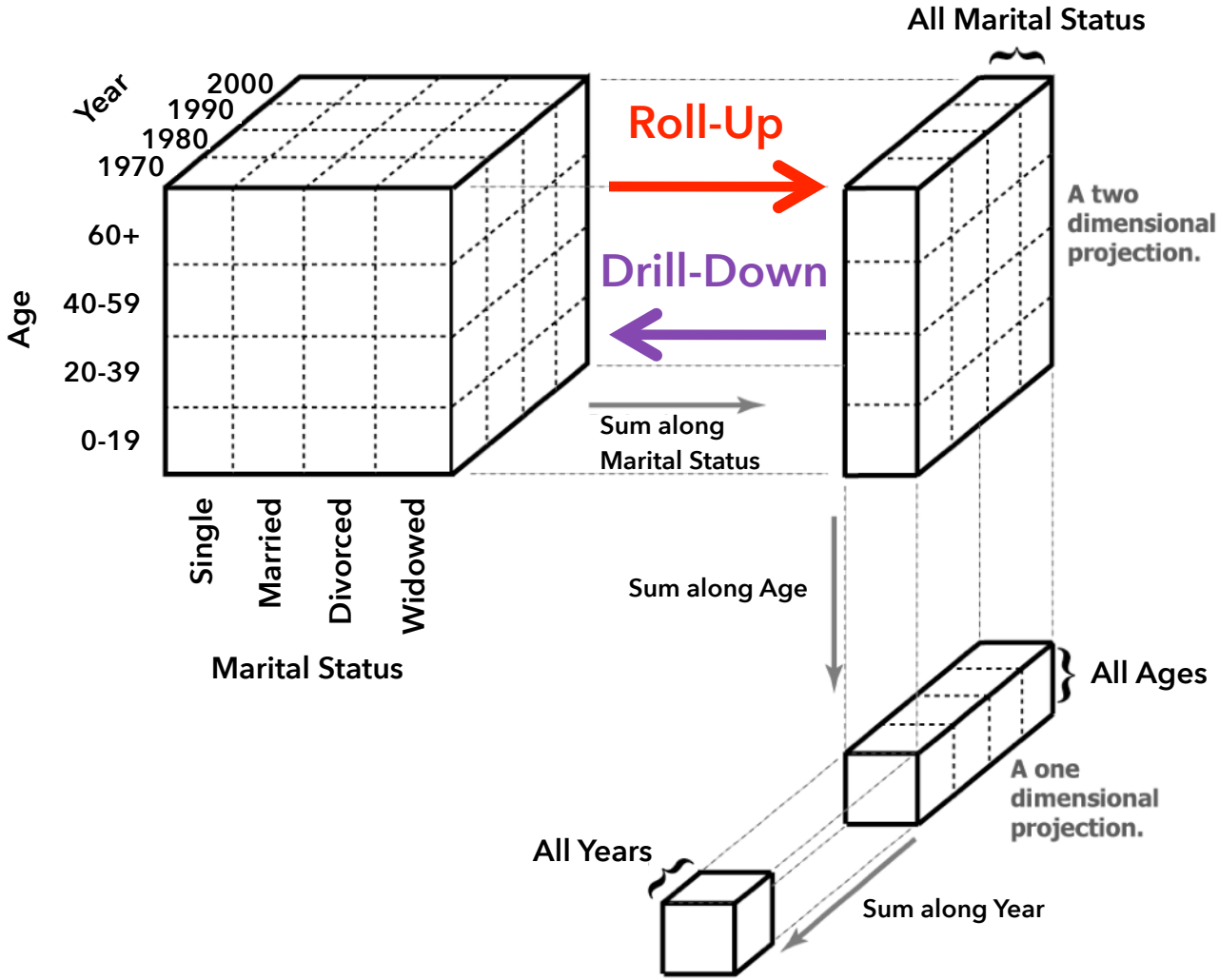
Roll-Up and Drill-Down

Want to see the breakdown by marital status?

Drill-down into additional dimensions

```
SELECT year, age, marst, sum(people)
FROM census
GROUP BY year, age, marst
```


All Marital Status
Year
2000
1990
1980
1970
Age
60+
40-59
20-39
0-19
Single
Married
Divorced
Widowed
Marital Status
A two dimensional projection.
Sum along Marital Status
Sum along Age
All Ages
A one dimensional projection.
All Years
Sum along Year


All Marital Status
Year
2000
1990
1980
1970
Roll-Up
A two dimensional projection.
Drill-Down
Age
60+
40-59
20-39
0-19
Sum along Marital Status
Single
Married
Divorced
Widowed
Marital Status
Sum along Age
All Ages
A one dimensional projection.
All Years
Sum along Year

ORIGINAL

YEAR	AGE	MARST	SEX	PEOPLE
1850	0	0	1	1,483,789
1850	5	0	1	1,411,067
1860	0	0	1	2,120,846
1860	5	0	1	1,804,467
. . .				

PIVOTED (or CROSS-TABULATION)

AGE	MARST	SEX	1850	1860	. . .
0	0	1	1,483,789	2,120,846	. . .
5	0	1	1,411,067	1,804,467	. . .
. . .					

Which format might we prefer? Why?

Tidy Data [Wickham 2014]

How do rows, columns, and tables match up with observations, variables, and types? In “tidy” data:

1. Each variable forms a column.
2. Each observation forms a row.
3. Each type of observational unit forms a table.

The advantage is that this provides a flexible starting point for analysis, transformation, and visualization.

Our pivoted table variant was not “tidy”!

(This is a variant of normalized forms in DB theory)

Common Data Formats

CSV: Comma-Separated Values (d3.csv)

```
year,age,marst,sex,people
1850,0,0,1,1483789
1850,5,0,1,1411067
...
```

Common Data Formats

CSV: Comma-Separated Values (d3.csv)

```
year,age,marst,sex,people
1850,0,0,1,1483789
1850,5,0,1,1411067
...
```

JSON: JavaScript Object Notation (d3.json)

```
[
 {"year":1850,"age":0,"marst":0,"sex":1,"people":1483789},
 {"year":1850,"age":5,"marst":0,"sex":1,"people":1411067},
 ...
]
```

Common Data Formats

CSV: Comma-Separated Values (d3.csv)

```
year,age,marst,sex,people
1850,0,0,1,1483789
1850,5,0,1,1411067
...
```

JSON: JavaScript Object Notation (d3.json)

```
[
 {"year":1850,"age":0,"marst":0,"sex":1,"people":1483789},
 {"year":1850,"age":5,"marst":0,"sex":1,"people":1411067},
 ...
]
```

Binary Formats: Arrow, Parquet, …

Data Wrangling

I spend more than half of my time integrating, cleansing and transforming data without doing any actual analysis. Most of the time I'm lucky if I get to do any "analysis" at all.

Anonymous Data Scientist
from our 2012 interview study

Big Data Borat
@BigDataBorat

Following

In Data Science, 80% of time spent prepare data, 20% of time spent complain about need for prepare data.

Bureau of Justice Statistics - Data Online
http://bjs.ojp.usdoj.gov/

Reported crime in Alabama

Year	Population	Property crime rate	Burglary rate	Larceny-theft rate	Motor vehicle theft rate
2004	4525375	4029.3	987	2732.4	309.9
2005	4548327	3900	955.8	2656	289
2006	4599030	3937	968.9	2645.1	322.9
2007	4627851	3974.9	980.2	2687	307.7
2008	4661900	4081.9	1080.7	2712.6	288.6

Reported crime in Alaska

Year	Population	Property crime rate	Burglary rate	Larceny-theft rate	Motor vehicle theft rate
2004	657755	3370.9	573.6	2456.7	340.6
2005	663253	3615	622.8	2601	391
2006	670053	3582	615.2	2588.5	378.3
2007	683478	3373.9	538.9	2480	355.1
2008	686293	2928.3	470.9	2219.9	237.5

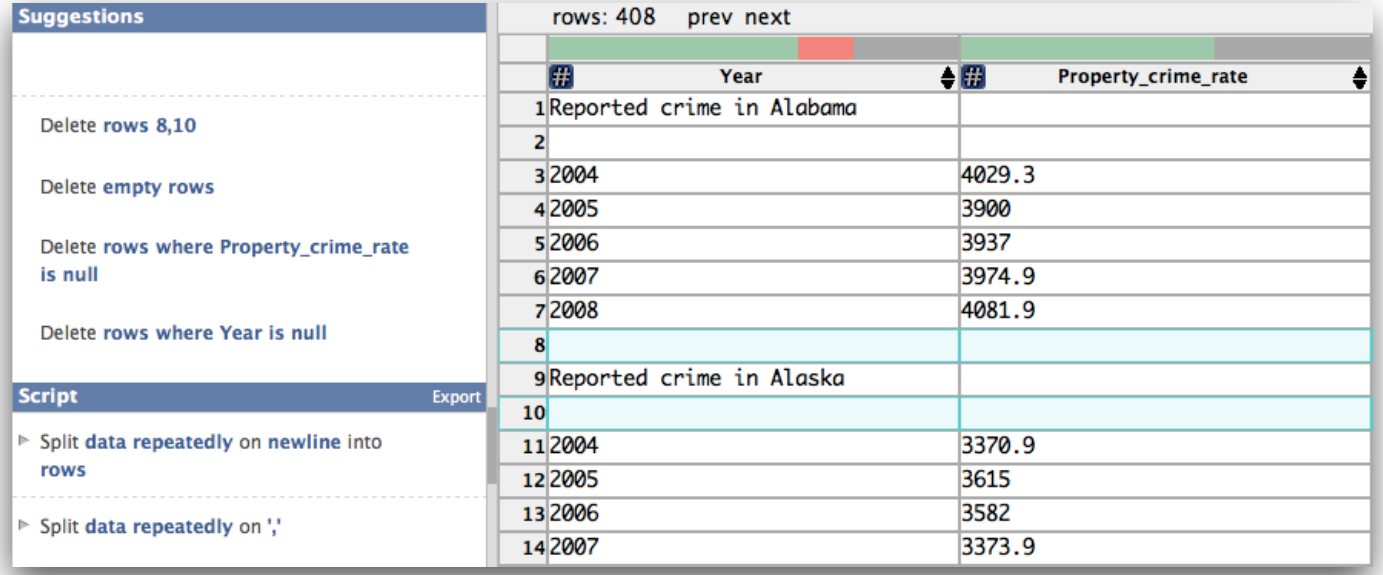
Reported crime in Arizona

Year	Population	Property crime rate	Burglary rate	Larceny-theft rate	Motor vehicle theft rate
2004	5739879	5073.3	991	3118.7	963.5
2005	5953007	4827	946.2	2958	922
2006	6166318	4741.6	953	2874.1	914.4
2007	6338755	4502.6	935.4	2780.5	786.7
2008	6500180	4087.3	894.2	2605.3	587.8

Reported crime in Arkansas

Year	Population	Property crime rate	Burglary rate	Larceny-theft rate	Motor vehicle theft rate
2004	2750000	4033.1	1096.4	2699.7	237
2005	2775708	4068	1085.1	2720	262
2006	2810872	4021.6	1154.4	2596.7	270.4
2007	2834797	3945.5	1124.4	2574.6	246.5
2008	2855390	3843.7	1182.7	2433.4	227.6

DataWrangler



Wrangler: Interactive Visual Specification of Data Transformation Scripts

Kandel et al. [CHI 2011]

Split | Cut | Extract | Edit | Fill | Translate | Drop | Merge | Wrap | Delete | Promote | Fold | Pivot | Transpose

Transform Suggestions

Transform Script Export

- Split **data repeatedly** on **newline** into **rows**
- Split **data repeatedly** on **'tab'**

	# split	# split1	# split2	# split3	# sp
1	Reported crime in Alabama				
2					
3	Year	Population	Property crime rate	Burglary rate	Larceny-theft
4	2004	4525375	4029.3	987	2732.4
5	2005	4548327	3900	955.8	2656
6	2006	4599030	3937	968.9	2645.1
7	2007	4627851	3974.9	980.2	2687
8	2008	4661900	4081.9	1080.7	2712.6
9					
10	Reported crime in Alaska				
11					
12	Year	Population	Property crime rate	Burglary rate	Larceny-theft
13	2004	657755	3370.9	573.6	2456.7
14	2005	663253	3615	622.8	2601
15	2006	670053	3582	615.2	2588.5
16	2007	683478	3373.9	538.9	2480
17	2008	686293	2928.3	470.9	2219.9
18					
19	Reported crime in Arizona				
20					

ROWS: 458

Split Cut Extract Edit Fill Translate Drop Merge Wrap Delete Promote Fold Pivot Transpose

Transform Suggestions

- Delete row 2
- Delete empty rows
- Delete rows where split is null
- Delete rows where split1 is null
- Delete rows where split2 is null
- Delete rows where split3 is null
- Fold using 2 as a key

Transform Script Export

- Split data repeatedly on newline into rows
- Split data repeatedly on 'tab'

	# split	# split1	# split2	# split3	# sp
1	Reported crime in Alabama				
2					
3	Year	Population	Property crime rate	Burglary rate	Larceny-theft
4	2004	4525375	4029.3	987	2732.4
5	2005	4548327	3900	955.8	2656
6	2006	4599030	3937	968.9	2645.1
7	2007	4627851	3974.9	980.2	2687
8	2008	4661900	4081.9	1080.7	2712.6
9					
10	Reported crime in Alaska				
11					
12	Year	Population	Property crime rate	Burglary rate	Larceny-theft
13	2004	657755	3370.9	573.6	2456.7
14	2005	663253	3615	622.8	2601
15	2006	670053	3582	615.2	2588.5
16	2007	683478	3373.9	538.9	2480
17	2008	686293	2928.3	470.9	2219.9
18					
19	Reported crime in Arizona				
20					

ROWS: 458

Split Cut Extract Edit Fill Translate Drop Merge Wrap Delete Promote Fold Pivot Transpose

Transform Suggestions

- Delete **row 2**
- Delete **empty rows**
- Delete **rows where split is null**
- Delete **rows where split1 is null**
- Delete **rows where split2 is null**
- Delete **rows where split3 is null**
- Fold using **2** as a key

Transform Script Export

- Split **data repeatedly** on **newline** into **rows**
- Split **data repeatedly** on **'tab'**

	# split	# split1	# split2	# split3	# sp
1	Reported crime in Alabama				
2					
3	Year	Population	Property crime rate	Burglary rate	Larceny-theft
4	2004	4525375	4029.3	987	2732.4
5	2005	4548327	3900	955.8	2656
6	2006	4599030	3937	968.9	2645.1
7	2007	4627851	3974.9	980.2	2687
8	2008	4661900	4081.9	1080.7	2712.6
9					
10	Reported crime in Alaska				
11					
12	Year	Population	Property crime rate	Burglary rate	Larceny-theft
13	2004	657755	3370.9	573.6	2456.7
14	2005	663253	3615	622.8	2601
15	2006	670053	3582	615.2	2588.5
16	2007	683478	3373.9	538.9	2480
17	2008	686293	2928.3	470.9	2219.9
18					
19	Reported crime in Arizona				
20					

ROWS: 458

Split Cut Extract Edit Fill Translate Drop Merge Wrap Delete Promote Fold Pivot Transpose

Transform Suggestions

Transform Script Export

- Split **data repeatedly** on **newline** into **rows**
- Split **data repeatedly** on **'tab'**
- Delete **empty rows**

	# split	# split1	# split2	# split3	# sp
1	Reported crime in Alabama				
2	Year	Population	Property crime rate	Burglary rate	Larceny-theft
3	2004	4525375	4029.3	987	2732.4
4	2005	4548327	3900	955.8	2656
5	2006	4599030	3937	968.9	2645.1
6	2007	4627851	3974.9	980.2	2687
7	2008	4661900	4081.9	1080.7	2712.6
8	Reported crime in Alaska				
9	Year	Population	Property crime rate	Burglary rate	Larceny-theft
10	2004	657755	3370.9	573.6	2456.7
11	2005	663253	3615	622.8	2601
12	2006	670053	3582	615.2	2588.5
13	2007	683478	3373.9	538.9	2480
14	2008	686293	2928.3	470.9	2219.9
15	Reported crime in Arizona				
16	Year	Population	Property crime rate	Burglary rate	Larceny-theft
17	2004	5739879	5073.3	991	3118.7
18	2005	5953007	4827	946.2	2958
19	2006	6166318	4741.6	953	2874.1
20	2007	6338755	4502.6	935.4	2780.5

ROWS: 357

Split Cut Extract Edit Fill Translate Drop Merge Wrap Delete Promote Fold Pivot Transpose

Transform Suggestions

- Delete **row 2**
- Delete **rows where split = 'Year'**
- Delete **rows where split1 = 'Population'**
- Delete **rows where split2 = 'Property crime rate'**
- Delete **rows where split3 = 'Burglary rate'**
- Delete **rows where split4 = 'Larceny-theft rate'**
- Promote row **2** to header

Transform Script Export

- Split **data repeatedly** on **newline** into **rows**
- Split **data repeatedly** on **'tab'**
- Delete **empty rows**

	# Year	# Population	# Property_crime_rate	# Burglary_rate	# Larceny-
1	Reported crime in Alabama				
2	Year	Population	Property crime rate	Burglary rate	Larceny-theft
3	2004	4525375	4029.3	987	2732.4
4	2005	4548327	3900	955.8	2656
5	2006	4599030	3937	968.9	2645.1
6	2007	4627851	3974.9	980.2	2687
7	2008	4661900	4081.9	1080.7	2712.6
8	Reported crime in Alaska				
9	Year	Population	Property crime rate	Burglary rate	Larceny-theft
10	2004	657755	3370.9	573.6	2456.7
11	2005	663253	3615	622.8	2601
12	2006	670053	3582	615.2	2588.5
13	2007	683478	3373.9	538.9	2480
14	2008	686293	2928.3	470.9	2219.9
15	Reported crime in Arizona				
16	Year	Population	Property crime rate	Burglary rate	Larceny-theft
17	2004	5739879	5073.3	991	3118.7
18	2005	5953007	4827	946.2	2958
19	2006	6166318	4741.6	953	2874.1
20	2007	6338755	4502.6	935.4	2780.5

ROWS: 357

Split Cut Extract Edit Fill Translate Drop Merge Wrap Delete Promote Fold Pivot Transpose

Transform Suggestions

Transform Script Export

- Split **data repeatedly** on **newline** into **rows**
- Split **data repeatedly** on **'tab'**
- Delete **empty rows**
- Promote row **2** to header

	# Year	# Population	# Property_crime_rate	# Burglary_rate	# Larceny-
1	Reported crime in Alabama				
2	2004	4525375	4029.3	987	2732.4
3	2005	4548327	3900	955.8	2656
4	2006	4599030	3937	968.9	2645.1
5	2007	4627851	3974.9	980.2	2687
6	2008	4661900	4081.9	1080.7	2712.6
7	Reported crime in Alaska				
8	Year	Population	Property crime rate	Burglary rate	Larceny-theft
9	2004	657755	3370.9	573.6	2456.7
10	2005	663253	3615	622.8	2601
11	2006	670053	3582	615.2	2588.5
12	2007	683478	3373.9	538.9	2480
13	2008	686293	2928.3	470.9	2219.9
14	Reported crime in Arizona				
15	Year	Population	Property crime rate	Burglary rate	Larceny-theft
16	2004	5739879	5073.3	991	3118.7
17	2005	5953007	4827	946.2	2958
18	2006	6166318	4741.6	953	2874.1
19	2007	6338755	4502.6	935.4	2780.5
20	2008	6500180	4087.3	894.2	2605.3

ROWS: 356

Split Cut Extract Edit Fill Translate Drop Merge Wrap Delete Promote Fold Pivot Transpose

Transform Suggestions

- Delete row 8
- Delete rows where Year = 'Year'
- Delete rows where Population = 'Population'
- Delete rows where Property_crime_rate = 'Property crime ...
- Delete rows where Burglary_rate = 'Burglary rate'
- Delete rows where Larceny-theft_rate = 'Larceny-theft ra...
- Fill row 8 with values from the left

Transform Script Export

- Split data repeatedly on newline into rows
- Split data repeatedly on 'tab'
- Delete empty rows
- Promote row 2 to header

	# Year	# Population	# Property_crime_rate	# Burglary_rate	# Larceny-
1	Reported crime in Alabama				
2	2004	4525375	4029.3	987	2732.4
3	2005	4548327	3900	955.8	2656
4	2006	4599030	3937	968.9	2645.1
5	2007	4627851	3974.9	980.2	2687
6	2008	4661900	4081.9	1080.7	2712.6
7	Reported crime in Alaska				
8	Year	Population	Property crime rate	Burglary rate	Larceny-theft
9	2004	657755	3370.9	573.6	2456.7
10	2005	663253	3615	622.8	2601
11	2006	670053	3582	615.2	2588.5
12	2007	683478	3373.9	538.9	2480
13	2008	686293	2928.3	470.9	2219.9
14	Reported crime in Arizona				
15	Year	Population	Property crime rate	Burglary rate	Larceny-theft
16	2004	5739879	5073.3	991	3118.7
17	2005	5953007	4827	946.2	2958
18	2006	6166318	4741.6	953	2874.1
19	2007	6338755	4502.6	935.4	2780.5
20	2008	6500180	4087.3	894.2	2605.3

ROWS: 356

Split Cut Extract Edit Fill Translate Drop Merge Wrap Delete Promote Fold Pivot Transpose

Transform Suggestions

- Delete **row 8**
- Delete **rows where Year = 'Year'**
- Delete **rows where Population = 'Population'**
- Delete **rows where Property_crime_rate = 'Property crime ...**
- Delete **rows where Burglary_rate = 'Burglary rate'**
- Delete **rows where Larceny-theft_rate = 'Larceny-theft ra...**
- Fill **row 8** with values from **the left**

Transform Script Export

- Split **data repeatedly** on **newline** into **rows**
- Split **data repeatedly** on **'tab'**
- Delete **empty rows**
- Promote row **2** to header

	# Year	# Population	# Property_crime_rate	# Burglary_rate	# Larceny-
1	Reported crime in Alabama				
2	2004	4525375	4029.3	987	2732.4
3	2005	4548327	3900	955.8	2656
4	2006	4599030	3937	968.9	2645.1
5	2007	4627851	3974.9	980.2	2687
6	2008	4661900	4081.9	1080.7	2712.6
7	Reported crime in Alaska				
8	Year	Population	Property crime rate	Burglary rate	Larceny-theft
9	2004	657755	3370.9	573.6	2456.7
10	2005	663253	3615	622.8	2601
11	2006	670053	3582	615.2	2588.5
12	2007	683478	3373.9	538.9	2480
13	2008	686293	2928.3	470.9	2219.9
14	Reported crime in Arizona				
15	Year	Population	Property crime rate	Burglary rate	Larceny-theft
16	2004	5739879	5073.3	991	3118.7
17	2005	5953007	4827	946.2	2958
18	2006	6166318	4741.6	953	2874.1
19	2007	6338755	4502.6	935.4	2780.5
20	2008	6500180	4087.3	894.2	2605.3

ROWS: 356

Split Cut Extract Edit Fill Translate Drop Merge Wrap Delete Promote Fold Pivot Transpose

Transform Suggestions

Transform Script Export

- Split **data repeatedly** on **newline** into **rows**
- Split **data repeatedly** on **'tab'**
- Delete **empty rows**
- Promote row **2** to header
- Delete **rows where Year = 'Year'**

	# Year	# Population	# Property_crime_rate	# Burglary_rate	# Larceny-
1	Reported crime in Alabama				
2	2004	4525375	4029.3	987	2732.4
3	2005	4548327	3900	955.8	2656
4	2006	4599030	3937	968.9	2645.1
5	2007	4627851	3974.9	980.2	2687
6	2008	4661900	4081.9	1080.7	2712.6
7	Reported crime in Alaska				
8	2004	657755	3370.9	573.6	2456.7
9	2005	663253	3615	622.8	2601
10	2006	670053	3582	615.2	2588.5
11	2007	683478	3373.9	538.9	2480
12	2008	686293	2928.3	470.9	2219.9
13	Reported crime in Arizona				
14	2004	5739879	5073.3	991	3118.7
15	2005	5953007	4827	946.2	2958
16	2006	6166318	4741.6	953	2874.1
17	2007	6338755	4502.6	935.4	2780.5
18	2008	6500180	4087.3	894.2	2605.3
19	Reported crime in Arkansas				
20	2004	2750000	4033.1	1096.4	2699.7

ROWS: 306

Split | Cut | Extract | Edit | Fill | Translate | Drop | Merge | Wrap | Delete | Promote | Fold | Pivot | Transpose

Transform Suggestions

- Extract from **Year** between positions **18, 25**
- Extract from **Year** on **'Alabama'**
- Extract from **Year** after **'in '**
- Extract from **Year** after **' in '**
- Extract from **Year** after **'crime in '**
- Extract from **Year** after **' any word in '**
- Cut from **Year** between positions **18, 25**

Transform Script Export

- Split **data repeatedly** on **newline** into **rows**
- Split **data repeatedly** on **'tab'**
- Delete **empty rows**
- Promote row **2** to header
- Delete **rows where Year = 'Year'**

	# Year	Abc extract	# Population	# Property_crime_rate	# Burgla
1	Reported crime in Alabama	Alabama			
2	2004		4525375	4029.3	987
3	2005		4548327	3900	955.8
4	2006		4599030	3937	968.9
5	2007		4627851	3974.9	980.2
6	2008		4661900	4081.9	1080.7
7	Reported crime in Alaska				
8	2004		657755	3370.9	573.6
9	2005		663253	3615	622.8
10	2006		670053	3582	615.2
11	2007		683478	3373.9	538.9
12	2008		686293	2928.3	470.9
13	Reported crime in Arizona	Arizona			
14	2004		5739879	5073.3	991
15	2005		5953007	4827	946.2
16	2006		6166318	4741.6	953
17	2007		6338755	4502.6	935.4
18	2008		6500180	4087.3	894.2
19	Reported crime in Arkansas	Arkansa			
20	2004		2750000	4033.1	1096.4

ROWS: 306

Split Cut Extract Edit Fill Translate Drop Merge Wrap Delete Promote Fold Pivot Transpose

Transform Suggestions

Transform Script Export

- Split **data repeatedly** on **newline** into **rows**
- Split **data repeatedly** on **'tab'**
- Delete **empty rows**
- Promote row **2** to header
- Delete **rows where Year = 'Year'**
- Extract from **Year** after **'in '**

	# Year	Abc extract	# Population	# Property_crime_rate	# Burgla
1	Reported crime in Alabama	Alabama			
2	2004		4525375	4029.3	987
3	2005		4548327	3900	955.8
4	2006		4599030	3937	968.9
5	2007		4627851	3974.9	980.2
6	2008		4661900	4081.9	1080.7
7	Reported crime in Alaska	Alaska			
8	2004		657755	3370.9	573.6
9	2005		663253	3615	622.8
10	2006		670053	3582	615.2
11	2007		683478	3373.9	538.9
12	2008		686293	2928.3	470.9
13	Reported crime in Arizona	Arizona			
14	2004		5739879	5073.3	991
15	2005		5953007	4827	946.2
16	2006		6166318	4741.6	953
17	2007		6338755	4502.6	935.4
18	2008		6500180	4087.3	894.2
19	Reported crime in Arkansas	Arkansas			
20	2004		2750000	4033.1	1096.4

ROWS: 306

Split Cut Extract Edit Fill Translate Drop Merge Wrap Delete Promote Fold Pivot Transpose

Transform Suggestions

Transform Script Export

- Split **data repeatedly** on **newline** into **rows**
- Split **data repeatedly** on **'tab'**
- Delete **empty rows**
- Promote row **2** to header
- Delete **rows where Year = 'Year'**
- Extract from **Year** after **'in '**

	# Year	Abc extract	# Population	# Property_crime_rate	# Burgla
1	Reported crime in Alabama	Alabama			
2	2004		4525375	4029.3	987
3	2005		4548327	3900	955.8
4	2006		4599030	3937	968.9
5	2007		4627851	3974.9	980.2
6	2008		4661900	4081.9	1080.7
7	Reported crime in Alaska	Alaska			
8	2004		657755	3370.9	573.6
9	2005		663253	3615	622.8
10	2006		670053	3582	615.2
11	2007		683478	3373.9	538.9
12	2008		686293	2928.3	470.9
13	Reported crime in Arizona	Arizona			
14	2004		5739879	5073.3	991
15	2005		5953007	4827	946.2
16	2006		6166318	4741.6	953
17	2007		6338755	4502.6	935.4
18	2008		6500180	4087.3	894.2
19	Reported crime in Arkansas	Arkansas			
20	2004		2750000	4033.1	1096.4

ROWS: 306

Split Cut Extract Edit Fill Translate Drop Merge Wrap Delete Promote Fold Pivot Transpose

Transform Suggestions

	# Year	Abc extract	# Population	# Property_crime_rate	# Burgla
1	Reported crime in Alabama	Alabama			
2	2004		4525375	4029.3	987
3	2005		4548327	3900	955.8
4	2006		4599030	3937	968.9
5	2007		4627851	3974.9	980.2
6	2008		4661900	4081.9	1080.7
7	Reported crime in Alaska	Alaska			
8	2004		657755	3370.9	573.6
9	2005		663253	3615	622.8
10	2006		670053	3582	615.2
11	2007		683478	3373.9	538.9
12	2008		686293	2928.3	470.9
13	Reported crime in Arizona	Arizona			
14	2004		5739879	5073.3	991
15	2005		5953007	4827	946.2
16	2006		6166318	4741.6	953
17	2007		6338755	4502.6	935.4
18	2008		6500180	4087.3	894.2
19	Reported crime in Arkansas	Arkansas			
20	2004		2750000	4033.1	1096.4

ROWS: 306

Transform Script Export

- Split **data repeatedly** on **newline** into **rows**
- Split **data repeatedly** on **'tab'**
- Delete **empty rows**
- Promote row **2** to header
- Delete **rows where Year = 'Year'**
- Extract from **Year** after **'in '**

Split Cut Extract Edit Fill Translate Drop Merge Wrap Delete Promote Fold Pivot Transpose

Transform Suggestions

- Fill extract with values from above
- Fill extract with values from below
- Drop extract
- Fold extract using header as a key
- Fold extract using 1 as a key
- Fold extract using 1, 2 as keys
- Fold extract using 1, 2, 3 as keys

Transform Script Export

- Split data repeatedly on newline into rows
- Split data repeatedly on 'tab'
- Delete empty rows
- Promote row 2 to header
- Delete rows where Year = 'Year'
- Extract from Year after 'in '

	# Year	Abc extract	# Population	# Property_crime_rate	# Burgla
1	Reported crime in Alabama	Alabama			
2	2004	Alabama	4525375	4029.3	987
3	2005	Alabama	4548327	3900	955.8
4	2006	Alabama	4599030	3937	968.9
5	2007	Alabama	4627851	3974.9	980.2
6	2008	Alabama	4661900	4081.9	1080.7
7	Reported crime in Alaska	Alaska			
8	2004	Alaska	657755	3370.9	573.6
9	2005	Alaska	663253	3615	622.8
10	2006	Alaska	670053	3582	615.2
11	2007	Alaska	683478	3373.9	538.9
12	2008	Alaska	686293	2928.3	470.9
13	Reported crime in Arizona	Arizona			
14	2004	Arizona	5739879	5073.3	991
15	2005	Arizona	5953007	4827	946.2
16	2006	Arizona	6166318	4741.6	953
17	2007	Arizona	6338755	4502.6	935.4
18	2008	Arizona	6500180	4087.3	894.2
19	Reported crime in Arkansas	Arkansas			
20	2004	Arkansas	2750000	4033.1	1096.4

ROWS: 306

Split Cut Extract Edit Fill Translate Drop Merge Wrap Delete Promote Fold Pivot Transpose

Transform Suggestions

Transform Script Export

- Split **data repeatedly** on **newline** into **rows**
- Split **data repeatedly** on **'tab'**
- Delete **empty rows**
- Promote row **2** to header
- Delete **rows where Year = 'Year'**
- Extract from **Year** after **'in '**
- Fill **extract** with values from **above**

	# Year	Abc extract	# Population	# Property_crime_rate	# Burgla
1	Reported crime in Alabama	Alabama			
2	2004	Alabama	4525375	4029.3	987
3	2005	Alabama	4548327	3900	955.8
4	2006	Alabama	4599030	3937	968.9
5	2007	Alabama	4627851	3974.9	980.2
6	2008	Alabama	4661900	4081.9	1080.7
7	Reported crime in Alaska	Alaska			
8	2004	Alaska	657755	3370.9	573.6
9	2005	Alaska	663253	3615	622.8
10	2006	Alaska	670053	3582	615.2
11	2007	Alaska	683478	3373.9	538.9
12	2008	Alaska	686293	2928.3	470.9
13	Reported crime in Arizona	Arizona			
14	2004	Arizona	5739879	5073.3	991
15	2005	Arizona	5953007	4827	946.2
16	2006	Arizona	6166318	4741.6	953
17	2007	Arizona	6338755	4502.6	935.4
18	2008	Arizona	6500180	4087.3	894.2
19	Reported crime in Arkansas	Arkansas			
20	2004	Arkansas	2750000	4033.1	1096.4

ROWS: 306

Split | Cut | Extract | Edit | Fill | Translate | Drop | Merge | Wrap | Delete | Promote | Fold | Pivot | Transpose

Transform Suggestions

- Extract from **Year** between positions **0, 17**
- Extract from **Year** on **'Reported crime in'**
- Extract from **Year** on **'Reported crime any word '**
- Extract from **Year** on **'Reported crime any lowercase word '**
- Extract from **Year** on **'Reported any word in'**
- Extract from **Year** on **'Reported any word any word '**
- Cut from **Year** between positions **0, 17**

Transform Script Export

- Split **data repeatedly** on **newline** into **rows**
- Split **data repeatedly** on **'tab'**
- Delete **empty rows**
- Promote row **2** to header
- Delete **rows where Year = 'Year'**
- Extract from **Year** after **'in '**
- Fill **extract** with values from **above**

	# Year	Abc extract1	Abc extract	# Population	# Property_
1	Reported crime in Alabama	Reported crime in	Alabama		
2	2004		Alabama	4525375	4029.3
3	2005		Alabama	4548327	3900
4	2006		Alabama	4599030	3937
5	2007		Alabama	4627851	3974.9
6	2008		Alabama	4661900	4081.9
7	Reported crime in Alaska	Reported crime in	Alaska		
8	2004		Alaska	657755	3370.9
9	2005		Alaska	663253	3615
10	2006		Alaska	670053	3582
11	2007		Alaska	683478	3373.9
12	2008		Alaska	686293	2928.3
13	Reported crime in Arizona	Reported crime in	Arizona		
14	2004		Arizona	5739879	5073.3
15	2005		Arizona	5953007	4827
16	2006		Arizona	6166318	4741.6
17	2007		Arizona	6338755	4502.6
18	2008		Arizona	6500180	4087.3
19	Reported crime in Arkansas	Reported crime in	Arkansas		
20	2004		Arkansas	2750000	4033.1

ROWS: 306

Split Cut Extract Edit Fill Translate Drop Merge Wrap Delete Promote Fold Pivot Transpose

Transform Suggestions

- Delete **rows where Year starts with 'Reported crime in'**
- Delete **rows where Year contains 'Reported crime in'**
- Extract from **Year** between positions **0, 17**
- Extract from **Year** on **'Reported crime in'**
- Extract from **Year** on **'Reported crime any word '**
- Extract from **Year** on **'Reported crime any lowercase word '**
- Extract from **Year** on **'Reported any**

Transform Script Export

- Split **data repeatedly** on **newline** into **rows**
- Split **data repeatedly** on **'tab'**
- Delete **empty rows**
- Promote row **2** to header
- Delete **rows where Year = 'Year'**
- Extract from **Year** after **'in '**
- Fill **extract** with values from **above**

	# Year	Abc extract	# Population	# Property_crime_rate	# Burgla
1	Reported crime in Alabama	Alabama			
2	2004	Alabama	4525375	4029.3	987
3	2005	Alabama	4548327	3900	955.8
4	2006	Alabama	4599030	3937	968.9
5	2007	Alabama	4627851	3974.9	980.2
6	2008	Alabama	4661900	4081.9	1080.7
7	Reported crime in Alaska	Alaska			
8	2004	Alaska	657755	3370.9	573.6
9	2005	Alaska	663253	3615	622.8
10	2006	Alaska	670053	3582	615.2
11	2007	Alaska	683478	3373.9	538.9
12	2008	Alaska	686293	2928.3	470.9
13	Reported crime in Arizona	Arizona			
14	2004	Arizona	5739879	5073.3	991
15	2005	Arizona	5953007	4827	946.2
16	2006	Arizona	6166318	4741.6	953
17	2007	Arizona	6338755	4502.6	935.4
18	2008	Arizona	6500180	4087.3	894.2
19	Reported crime in Arkansas	Arkansas			
20	2004	Arkansas	2750000	4033.1	1096.4

ROWS: 306

Split Cut Extract Edit Fill Translate Drop Merge Wrap Delete Promote Fold Pivot Transpose

Transform Suggestions

Transform Script Export

- Split **data repeatedly** on **newline** into **rows**
- Split **data repeatedly** on **'tab'**
- Delete **empty rows**
- Promote row **2** to header
- Delete **rows where Year = 'Year'**
- Extract from **Year** after **'in '**
- Fill **extract** with values from **above**
- Delete **rows where Year starts with 'Reported crime in'**

	# Year	Abc extract	# Population	# Property_crime_rate	# Burgla
1	2004	Alabama	4525375	4029.3	987
2	2005	Alabama	4548327	3900	955.8
3	2006	Alabama	4599030	3937	968.9
4	2007	Alabama	4627851	3974.9	980.2
5	2008	Alabama	4661900	4081.9	1080.7
6	2004	Alaska	657755	3370.9	573.6
7	2005	Alaska	663253	3615	622.8
8	2006	Alaska	670053	3582	615.2
9	2007	Alaska	683478	3373.9	538.9
10	2008	Alaska	686293	2928.3	470.9
11	2004	Arizona	5739879	5073.3	991
12	2005	Arizona	5953007	4827	946.2
13	2006	Arizona	6166318	4741.6	953
14	2007	Arizona	6338755	4502.6	935.4
15	2008	Arizona	6500180	4087.3	894.2
16	2004	Arkansas	2750000	4033.1	1096.4
17	2005	Arkansas	2775708	4068	1085.1
18	2006	Arkansas	2810872	4021.6	1154.4
19	2007	Arkansas	2834797	3945.5	1124.4
20	2008	Arkansas	2855390	3843.7	1182.7

ROWS: 255

Split Cut Extract Edit Fill Translate Drop Merge Wrap Delete Promote Fold Pivot Transpose

Transform Suggestions

Data
Script

Comma-Separated Values (CSV)

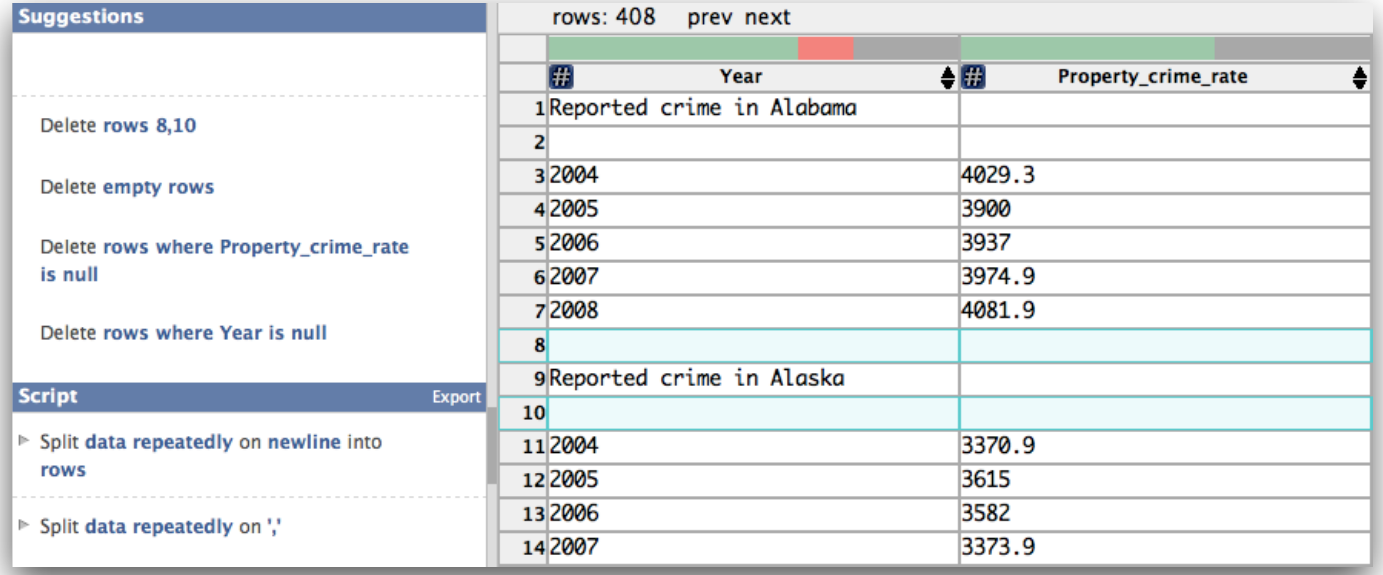
Back to Wrangling

```
Year,extract,Population,Property_crime_rate,Burglary_rate,Larceny-
theft_rate,Motor_vehicle_theft_rate
2004,Alabama,4525375,4029.3,987,2732.4,309.9
2005,Alabama,4548327,3900,955.8,2656,289
2006,Alabama,4599030,3937,968.9,2645.1,322.9
2007,Alabama,4627851,3974.9,980.2,2687,307.7
2008,Alabama,4661900,4081.9,1080.7,2712.6,288.6
2004,Alaska,657755,3370.9,573.6,2456.7,340.6
2005,Alaska,663253,3615,622.8,2601,391
2006,Alaska,670053,3582,615.2,2588.5,378.3
2007,Alaska,683478,3373.9,538.9,2480,355.1
2008,Alaska,686293,2928.3,470.9,2219.9,237.5
2004,Arizona,5739879,5073.3,991,3118.7,963.5
2005,Arizona,5953007,4827,946.2,2958,922
2006,Arizona,6166318,4741.6,953,2874.1,914.4
2007,Arizona,6338755,4502.6,935.4,2780.5,786.7
2008,Arizona,6500180,4087.3,894.2,2605.3,587.8
2004,Arkansas,2750000,4033.1,1096.4,2699.7,237
2005,Arkansas,2775708,4068,1085.1,2720,262
2006,Arkansas,2810872,4021.6,1154.4,2596.7,270.4
2007,Arkansas,2834797,3945.5,1124.4,2574.6,246.5
2008,Arkansas,2855390,3843.7,1182.7,2433.4,227.6
2004,California,35842038,3423.9,686.1,2033.1,704.8
2005,California,36154147,3321,692.9,1915,712
2006,California,36457549,3175.2,676.9,1831.5,666.8
2007,California,36553215,3032.6,648.4,1784.1,600.2
2008,California,36756666,2940.3,646.8,1769.8,523.8
2004,Colorado,4601821,3918.5,717.3,2679.5,521.6
2005,Colorado,4663295,4041,745.1,2736,560
2006,Colorado,4753377,3441.8,682,2325.1,434.8
2007,Colorado,4861515,2991.3,588.5,2061.1,341.7
2008,Colorado,4939456,2856.7,571.4,2013.7,271.6
2004,Connecticut,3498966,2684.9,456.1,1908.3,320.5
2005,Connecticut,3500701,2579,435.5,1840,303
2006,Connecticut,3504809,2575.442.6,1839.8,292.6
```

Transform Script Export

- Split **data repeatedly** on **newline** into **rows**
- Split **data repeatedly** on **'tab'**
- Delete **empty rows**
- Promote row **2** to header
- Delete **rows where Year = 'Year'**
- Extract from **Year** after **'in '**
- Fill **extract** with values from **above**
- Delete **rows where Year starts with 'Reported crime in'**

DataWrangler



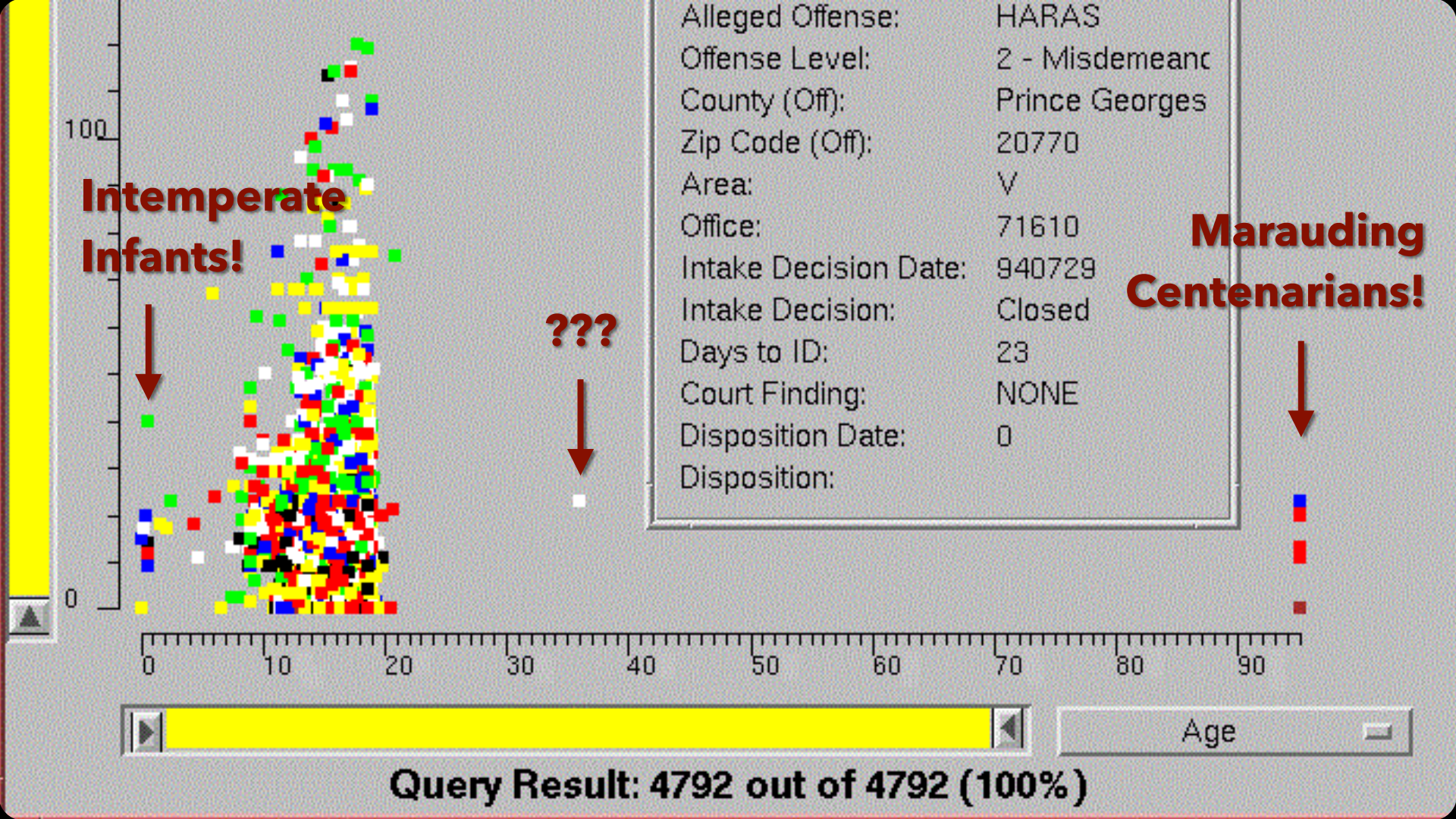
Wrangler: Interactive Visual Specification of Data Transformation Scripts

Kandel et al. [CHI 2011]

The first sign that a visualization is good is that it shows you a problem in your data.

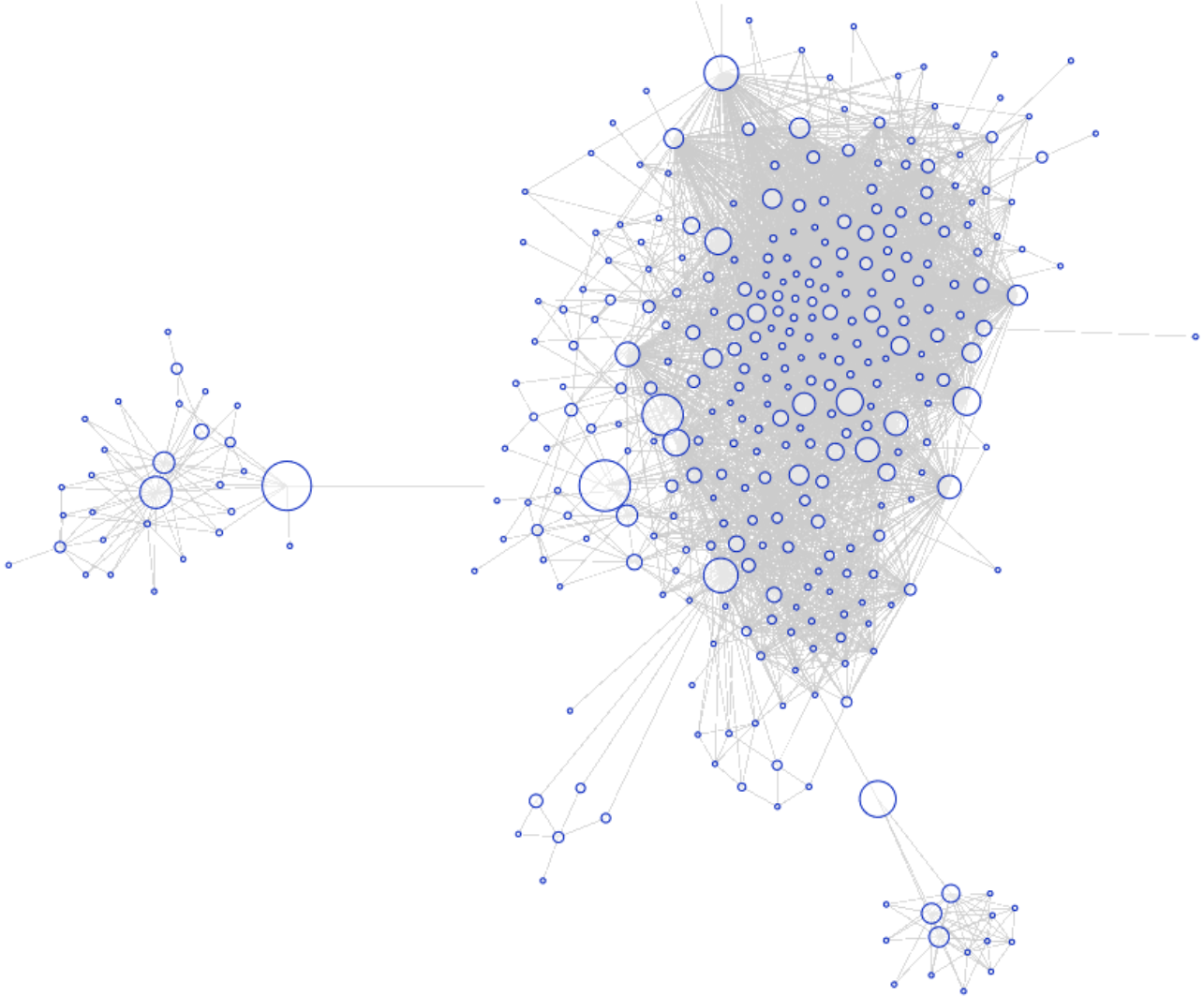
Every successful visualization that I've been involved with has had this stage where you realize, "Oh my God, this data is not what I thought it would be!" So already, you've discovered something.

Martin Wattenberg [ACM Queue '09]


Alleged Offense: HARAS
Offense Level: 2 - Misdemeanc
County (Off): Prince Georges
Zip Code (Off): 20770
Area: V
Office: 71610
Intake Decision Date: 940729
Intake Decision: Closed
Days to ID: 23
Court Finding: NONE
Disposition Date: 0
Disposition:
Intemperate Infants!
???
Marauding Centenarians!
100
0
0 10 20 30 40 50 60 70 80 90
Age
Query Result: 4792 out of 4792 (100%)

None

Edge centrality filters:



Graph Viewer

Graph Viewer

Roll-up by:

All

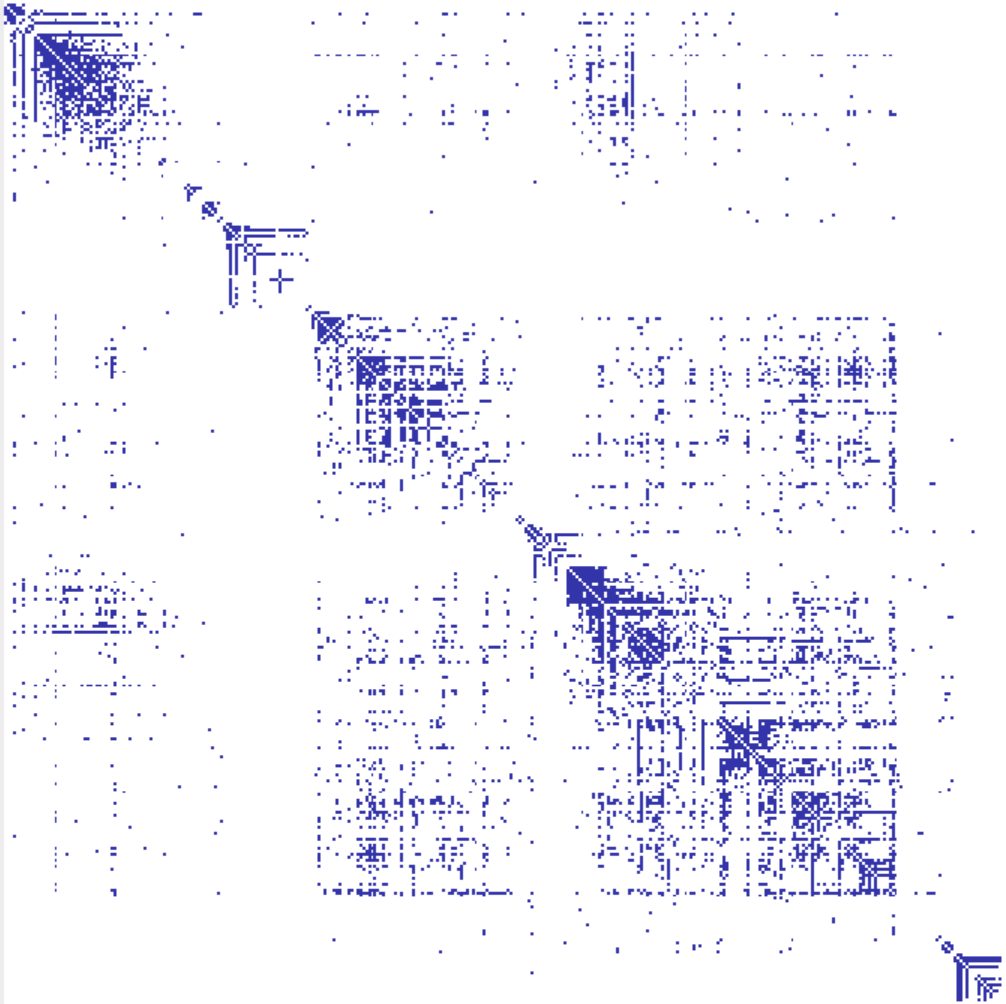
Visualization:

Matrix

Sort by:

Linkage

Edge centrality filters:



Graph Viewer

Graph Viewer

Roll-up by:

All

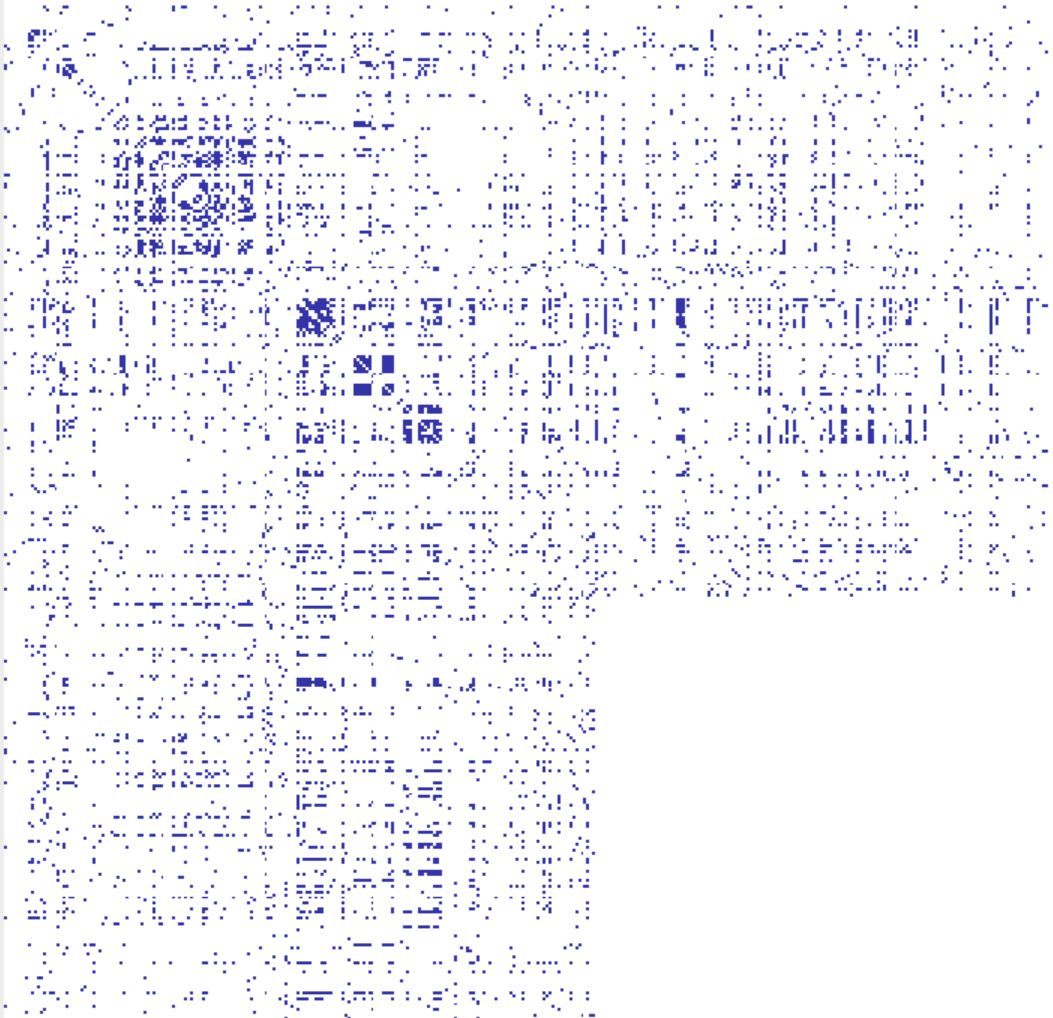
Visualization:

Matrix

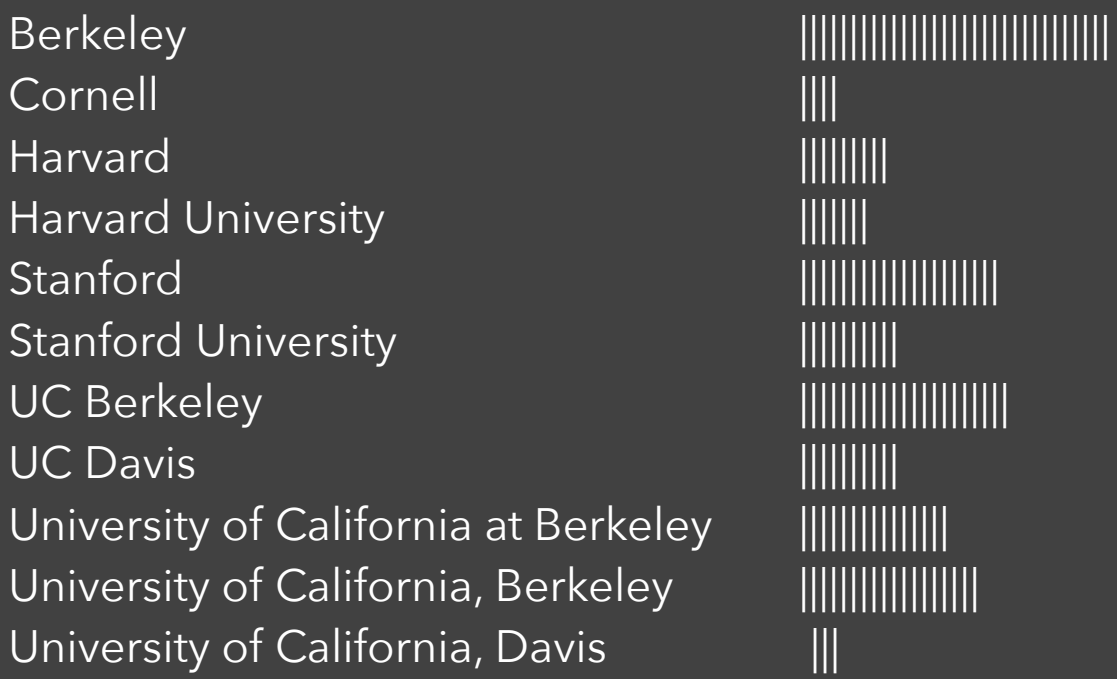
Sort by:

None

Edge centrality filters:



Visualize Friends by School?



Data Quality Hurdles

Missing Data	no measurements, redacted, …?
Erroneous Values	misspelling, outliers, …?
Type Conversion	e.g., zip code to lat-lon
Entity Resolution	diff. values for the same thing?
Data Integration	effort/errors when combining data

Anticipate problems with your data!

Data Wrangling Tools

Libraries

JavaScript: Arquero

Python: Pandas, Polars

R: dplyr

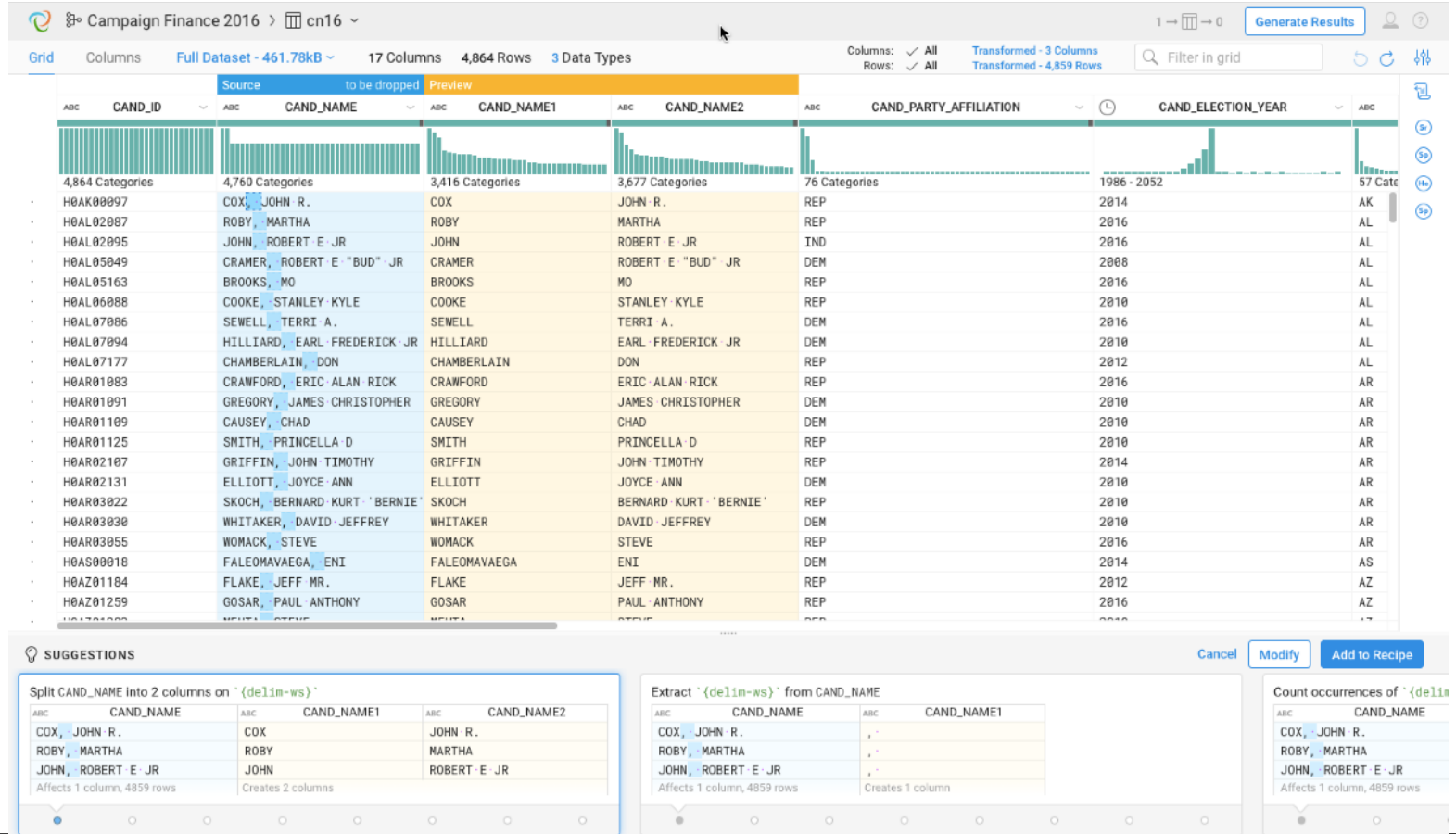
Databases

DuckDB + SQL queries

Graphical Tools

We'll look at some of these next!

Trifacta Wrangler (now part of Alteryx)



AWS Glue DataBrew

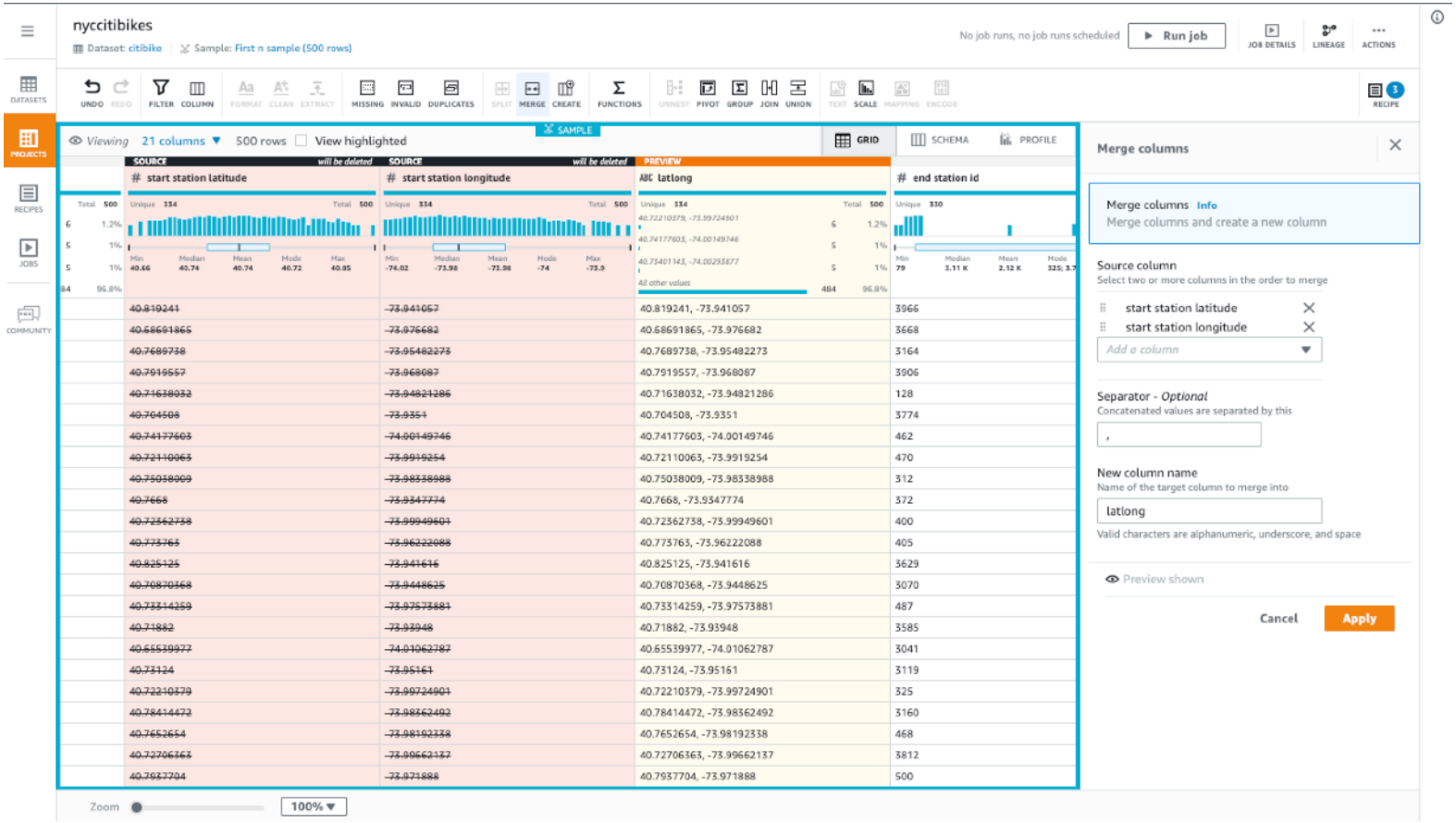
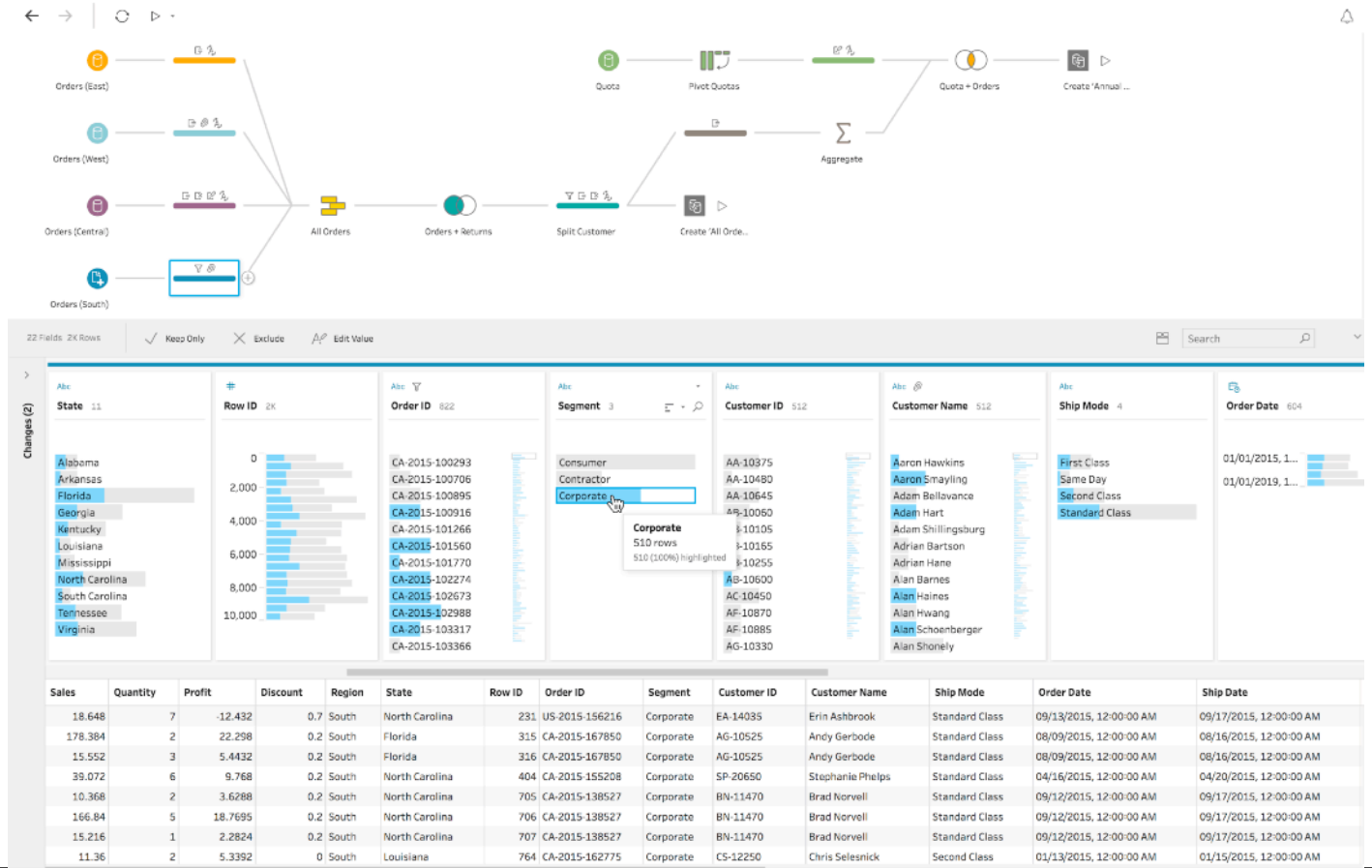
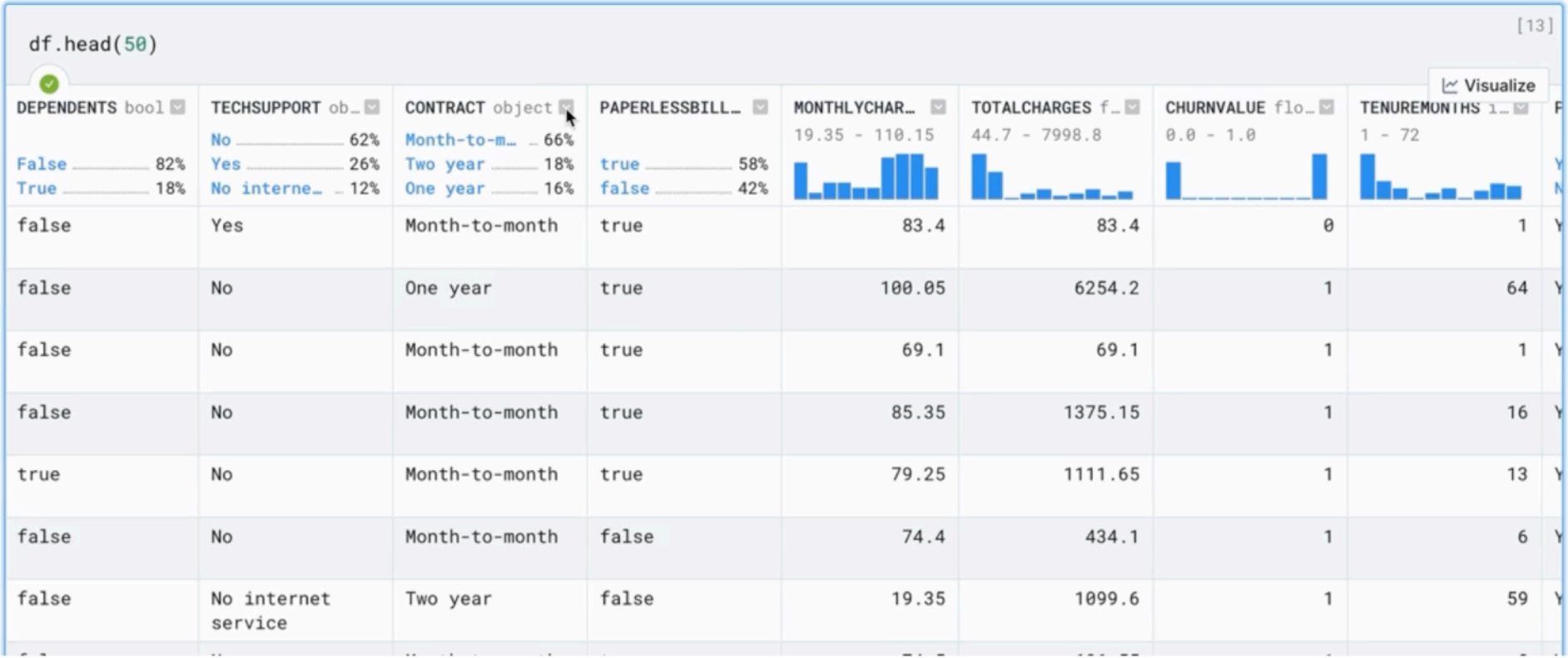


Tableau Prep



Deepnote



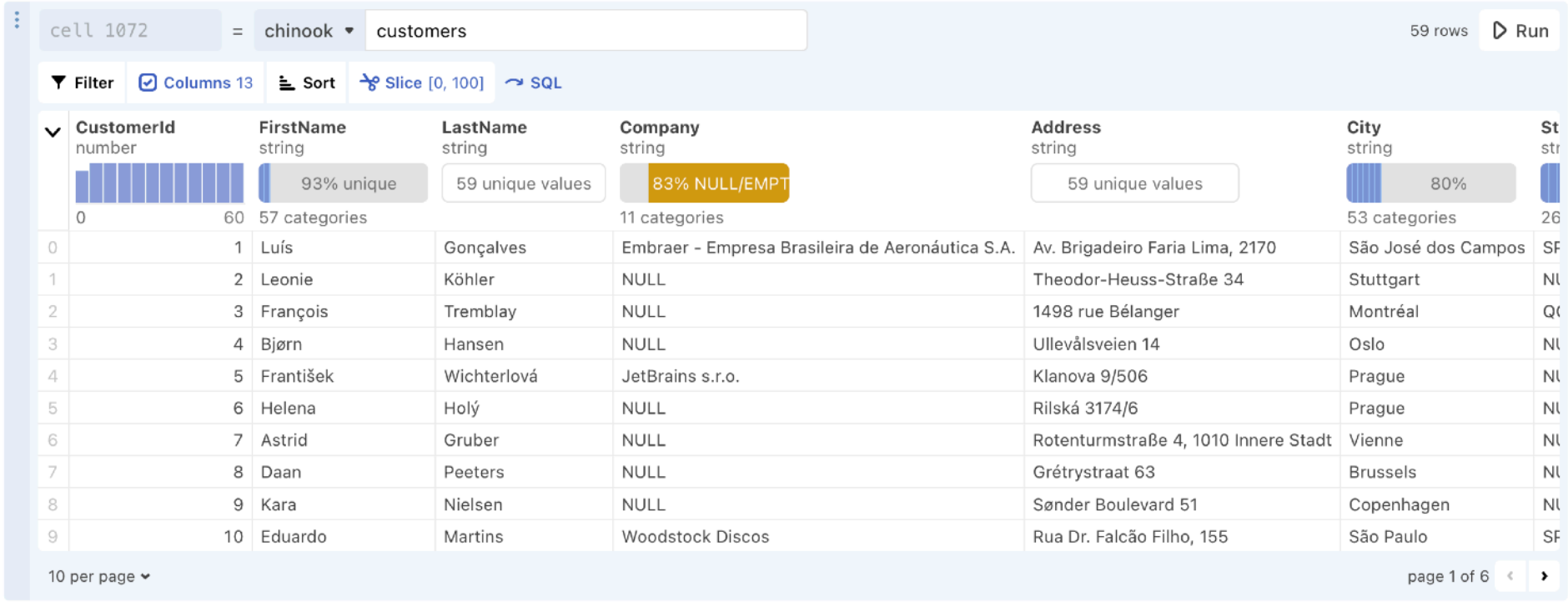
df.head(50)

[13]

Visualize

DEPENDENTS bool	TECHSUPPORT ob…	CONTRACT object	PAPERLESSBILL…	MONTHLYCHAR…	TOTALCHARGES f…	CHURNVALUE flo…	TENUREMONTHS i…	P
False 82% True 18%	No 62% Yes 26% No interne… 12%	Month-to-m… 66% Two year 18% One year 16%	true 58% false 42%	19.35 - 110.15	44.7 - 7998.8	0.0 - 1.0	1 - 72	Y N
false	Yes	Month-to-month	true	83.4	83.4	0	1	Y
false	No	One year	true	100.05	6254.2	1	64	Y
false	No	Month-to-month	true	69.1	69.1	1	1	Y
false	No	Month-to-month	true	85.35	1375.15	1	16	Y
true	No	Month-to-month	true	79.25	1111.65	1	13	Y
false	No	Month-to-month	false	74.4	434.1	1	6	Y
false	No internet service	Two year	false	19.35	1099.6	1	59	Y

Observable Data Table Cells

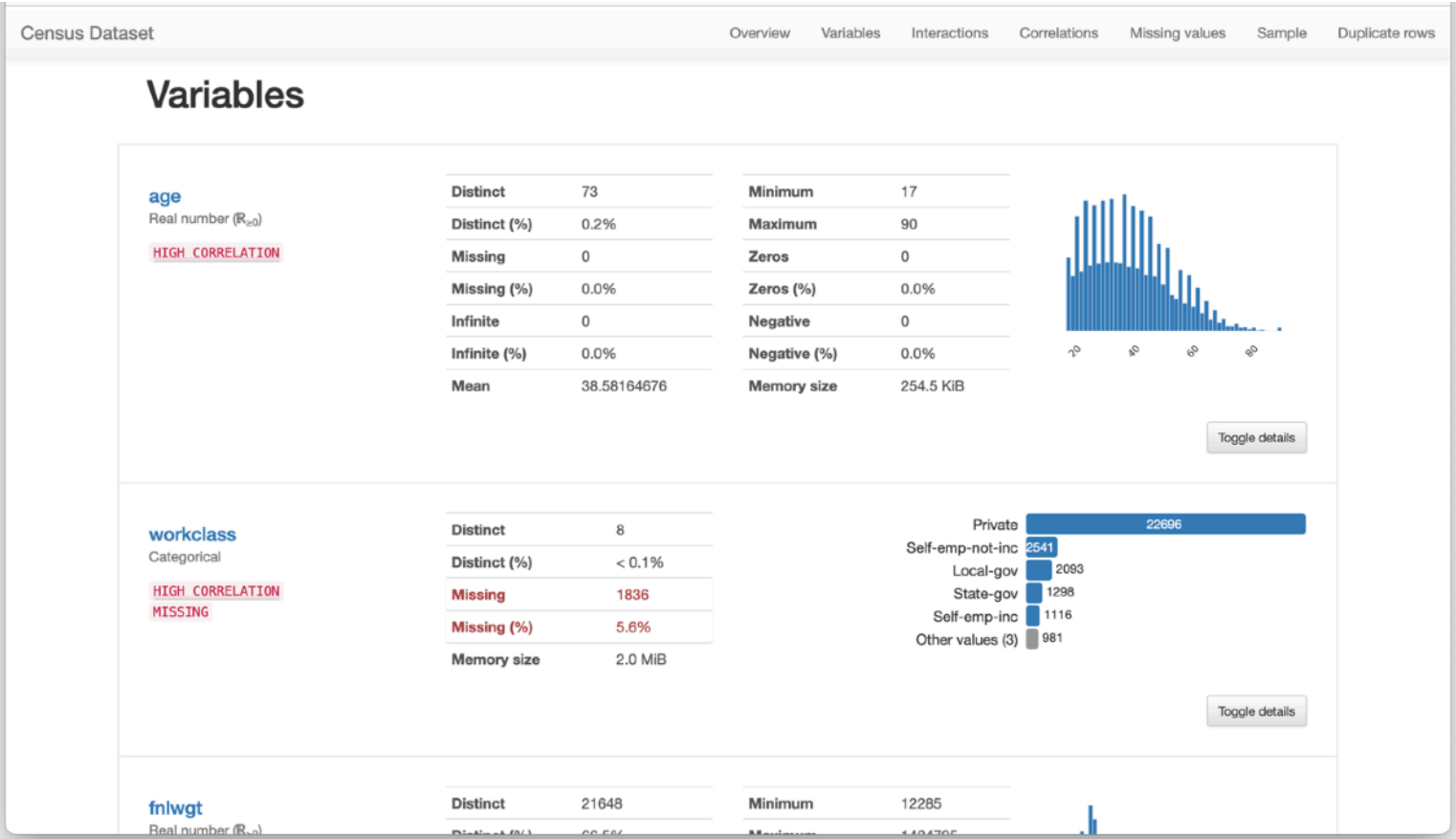


Quak widget usable in Jupyter Notebooks

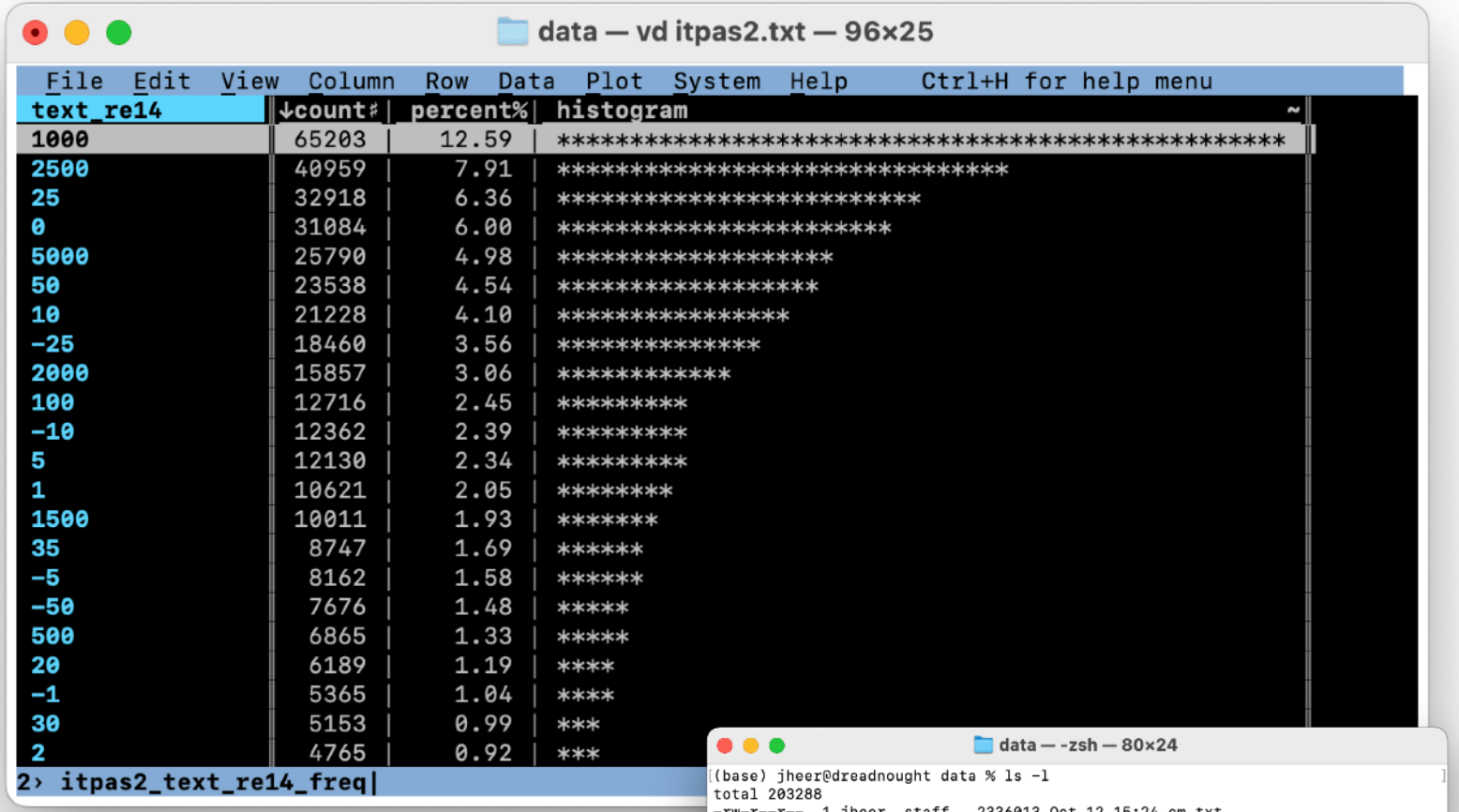
	name utf8 unique 22 categories	nationality utf8 207 categories	sex utf8 male female female	height float64 ⌀1.2 2.3	weight int64 ⌀20 180	sport utf8 28 categories	gold int64 0 5.5	silver int64 0 -
0	A Lam Shin	KOR	female	1.68	56	fencing	0	
1	Aauri Lorena Bokesa	ESP	female	1.8	62	athletics	0	
2	Abbey Weitzeil	USA	female	1.78	68	aquatics	1	
3	Abbie Brown	GBR	female	1.76	71	rugby sevens	0	
4	Abby Erceg	NZL	female	1.75	68	football	0	
5	Abdoulkarim Fawzi...	CMR	female	1.8	67	volleyball	0	
6	Abigel Joo	HUN	female	1.83	76	judo	0	

Reset 3,420 of 11,538 rows

Pandas Profiling



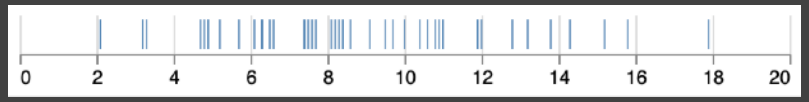
VisiData


data — vd itpas2.txt — 96×25
File Edit View Column Row Data Plot System Help Ctrl+H for help menu
text_re14 ↓count# percent% histogram
1000 65203 12.59 **********
2500 40959 7.91 ********
25 32918 6.36 *******
0 31084 6.00 *******
5000 25790 4.98 ******
50 23538 4.54 ******
10 21228 4.10 *****
-25 18460 3.56 *****
2000 15857 3.06 ****
100 12716 2.45 ***
-10 12362 2.39 ***
5 12130 2.34 ***
1 10621 2.05 ***
1500 10011 1.93 ***
35 8747 1.69 **
-5 8162 1.58 **
-50 7676 1.48 **
500 6865 1.33 **
20 6189 1.19 *
-1 5365 1.04 *
30 5153 0.99 *
2 4765 0.92 *
2› itpas2_text_re14_freq
data — -zsh — 80×24
(base) jheer@dreadnought data % ls -l
total 203288
-rw-r--r-- 1 jheer staff 2336013 Oct 12 15:24 cm.txt
-rw-r--r-- 1 jheer staff 814306 Oct 12 15:24 cn.txt
-rw-r--r--@ 1 jheer staff 90781486 Oct 12 15:25 itpas2.txt
(base) jheer@dreadnought data % vd cn.txt

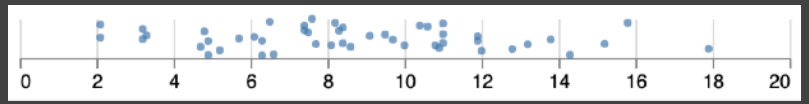
Visualizing Distributions

Distribution Visualizations

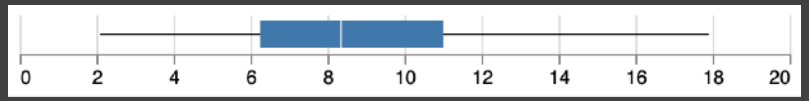
Strip Plot



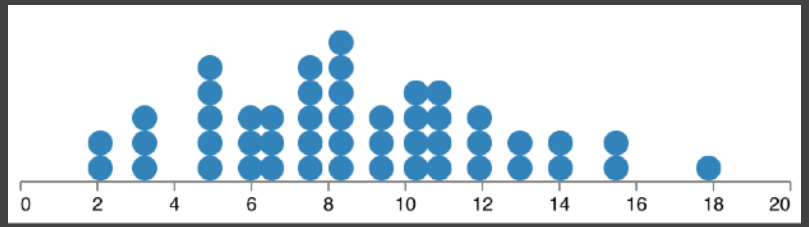
Jittered Plot



Box Plot



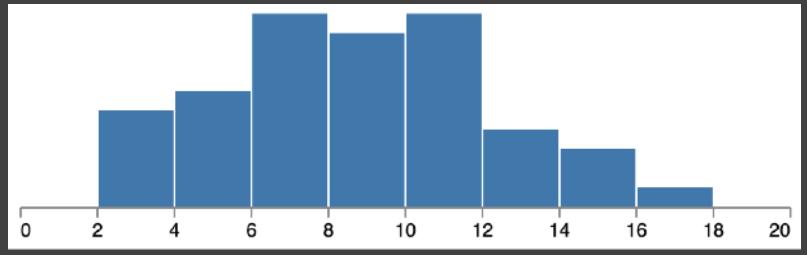
Dot Plot



Distribution Visualizations

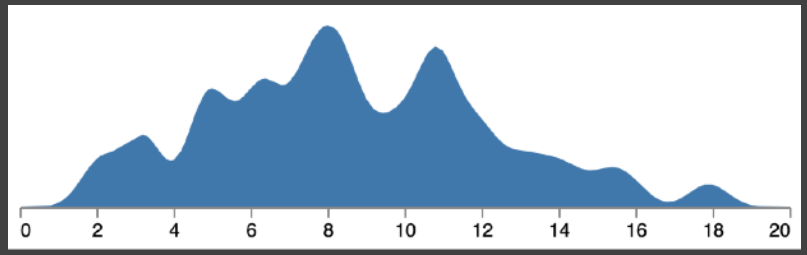
Histogram

bin size = 2



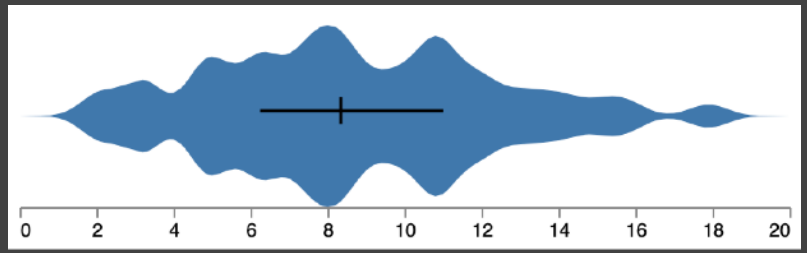
Density Plot

kde, σ = 0.5



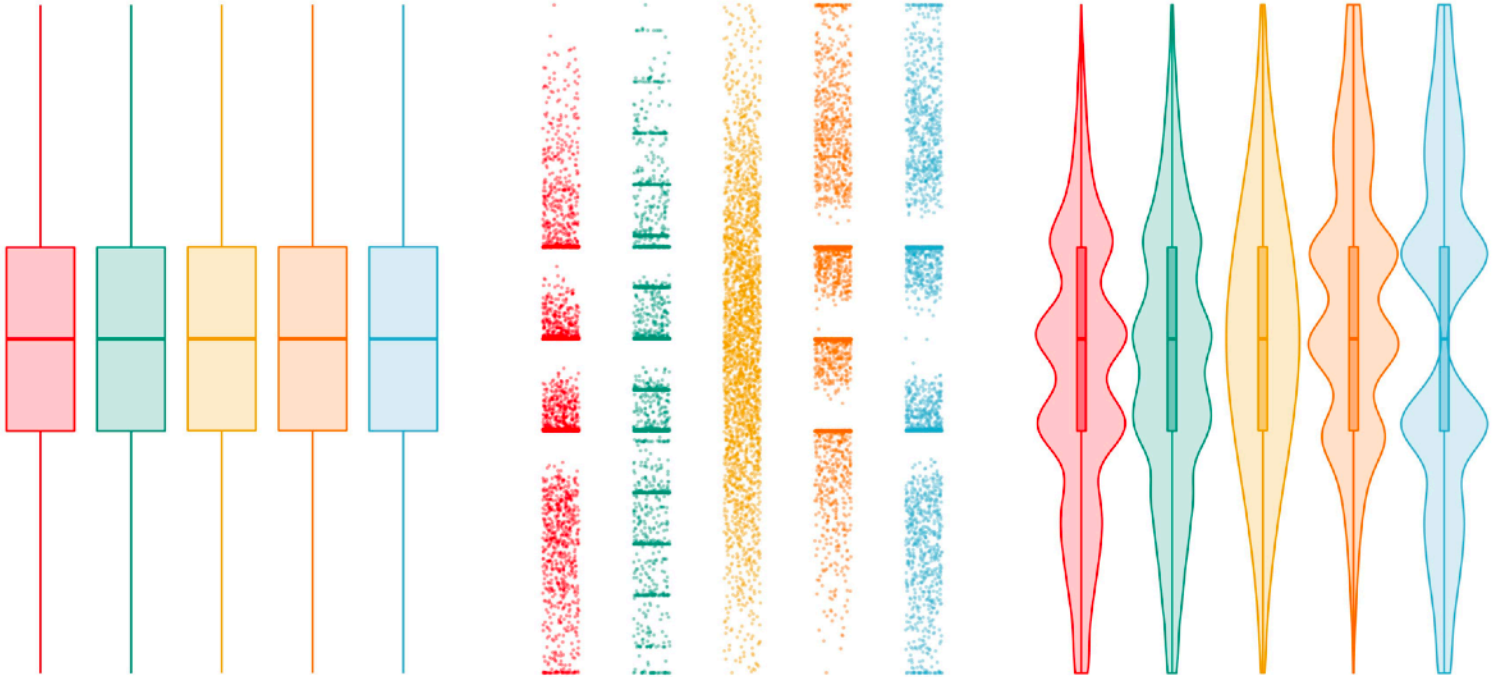
Violin Plot

kde, σ = 0.5



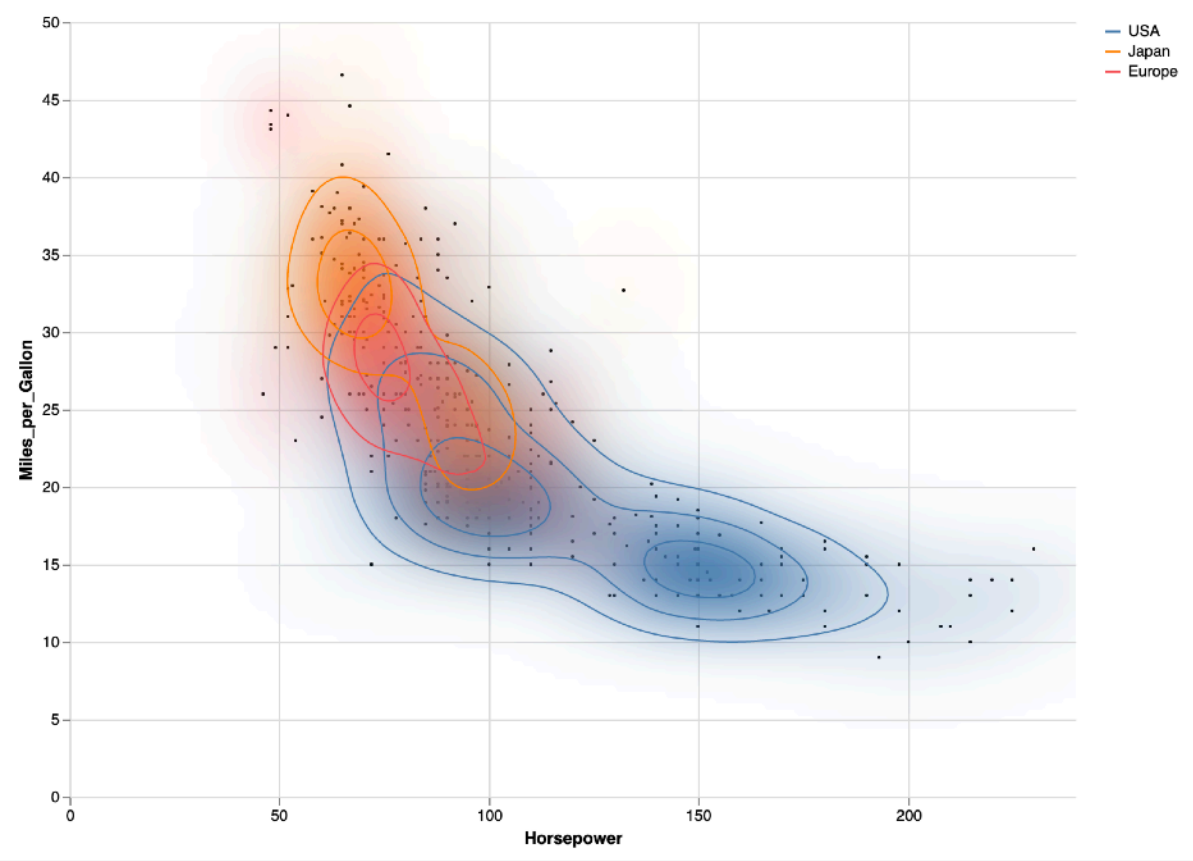
Identical boxplots, different distributions

Boxplots are great. They show medians and ranges and enable comparison of different groups. However, boxplots can be misleading. Different datasets can have the same descriptive statistics (left), but quite different underlying distributions (middle).
Therefore, it is crucial to visualize the distribution in addition to descriptive statistics. Violin plots with integrated boxplots are great for this.



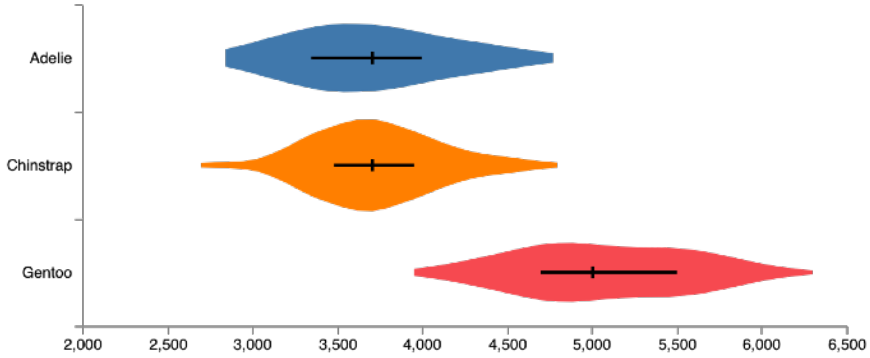
@MBozukova | #30DayChartChallenge | Day 27 - educational
Data source: {datasauRus} R package

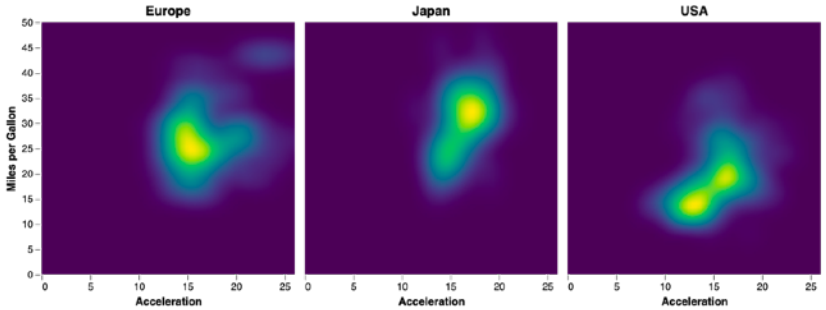
Now in 2D! Heatmaps, Contours

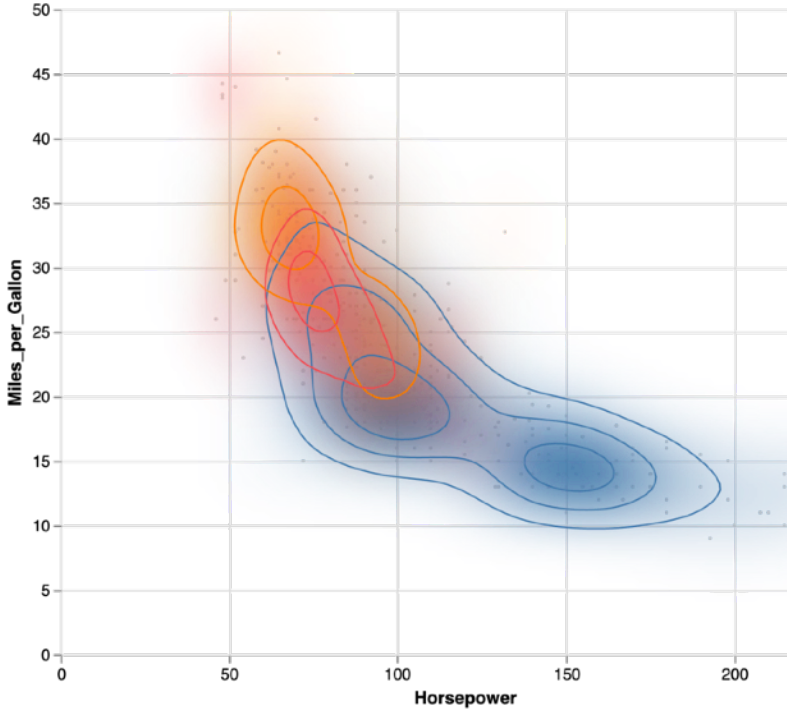


Kernel Density Estimation (KDE)

Enables violin plots, heat maps, contour plots…





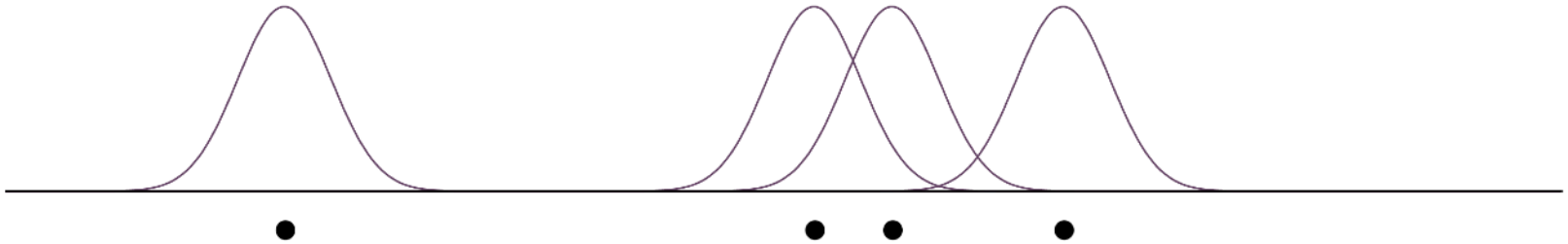


Kernel Density Estimation

For a set of input data points…

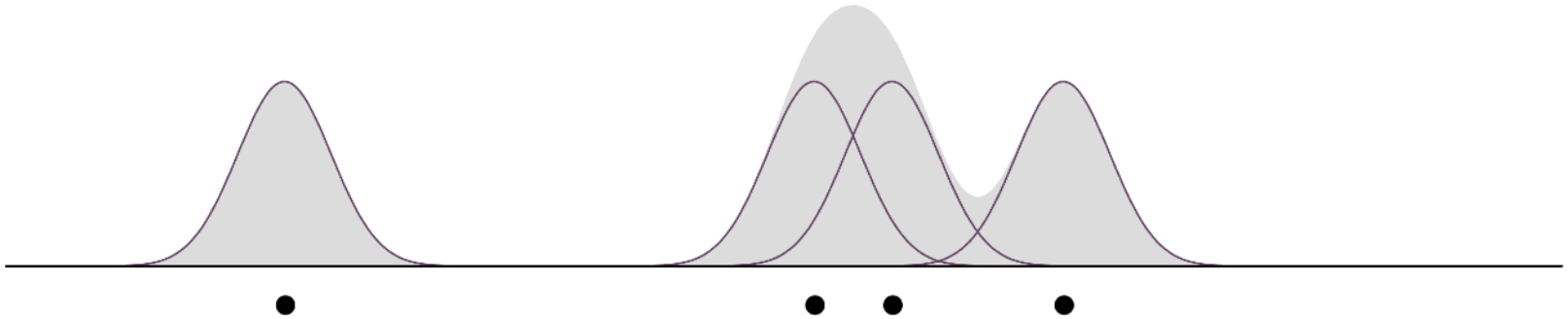
Kernel Density Estimation

Represent each point with a “kernel” distribution



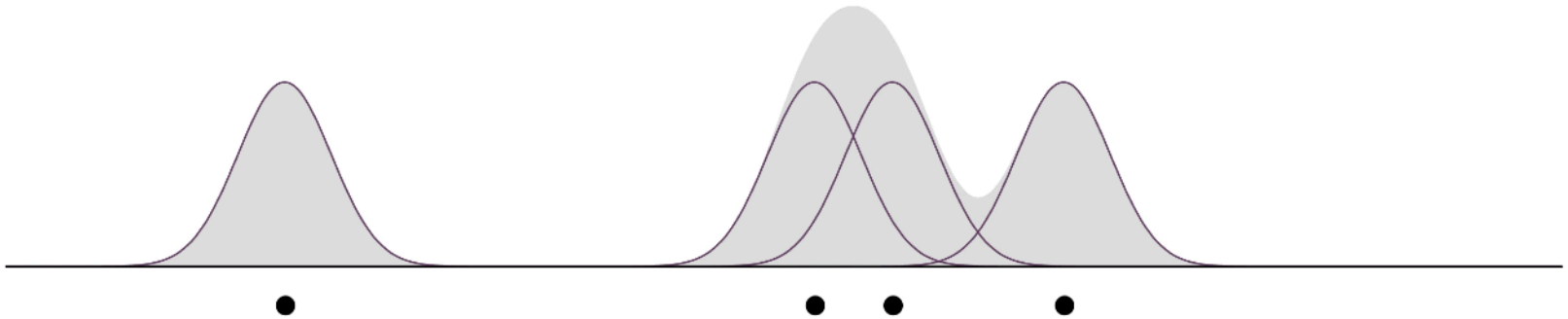
Kernel Density Estimation

Sum the kernels to form a density estimate



Kernel Density Estimation

Sized by bandwidth (standard deviation)



Dimensionality Reduction

Dimensionality Reduction (DR)

Project nD data to 2D or 3D for viewing. Often used to interpret and sanity check high-dimensional representations fit by machine learning methods.

Different DR methods make different trade-offs: for example to **preserve global structure** (e.g., PCA) or **emphasize local structure** (e.g., nearest-neighbor approaches, including t-SNE and UMAP).

In contrast, multidimensional scaling (MDS) attempts to **preserve pairwise distances**.

Reduction Techniques

LINEAR - PRESERVE GLOBAL STRUCTURE

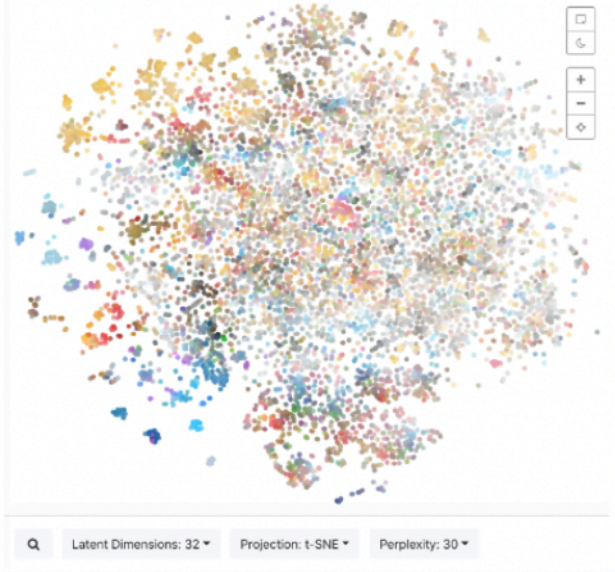
Principal Components Analysis (PCA)
Linear transformation of basis vectors, ordered by amount of data variance they explain.

NON-LINEAR - PRESERVE LOCAL TOPOLOGY

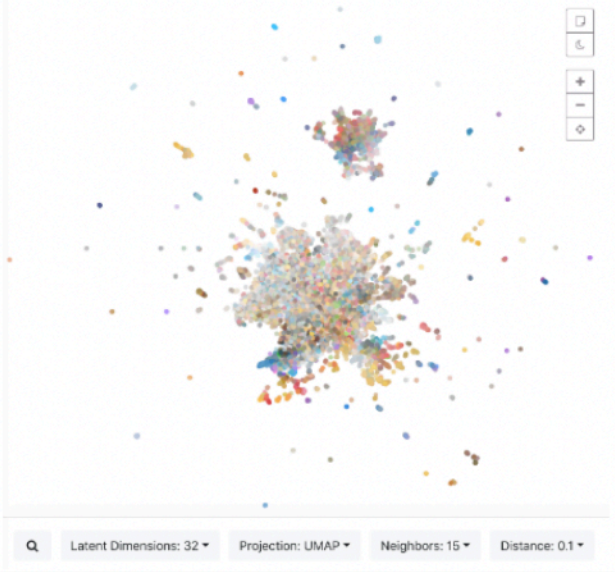
t-Dist. Stochastic Neighbor Embedding (t-SNE)
Probabilistically model distance, optimize positions.

Uniform Manifold Approx. & Projection (UMAP)
Identify local manifolds, then stitch them together.

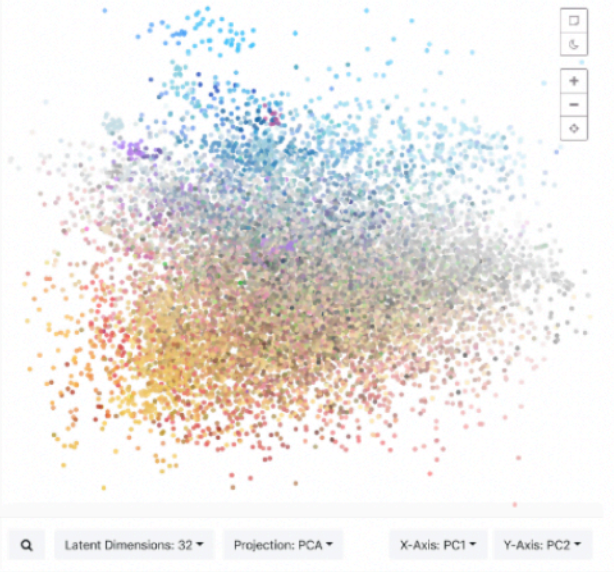
Mapping Emoji Images



t-SNE

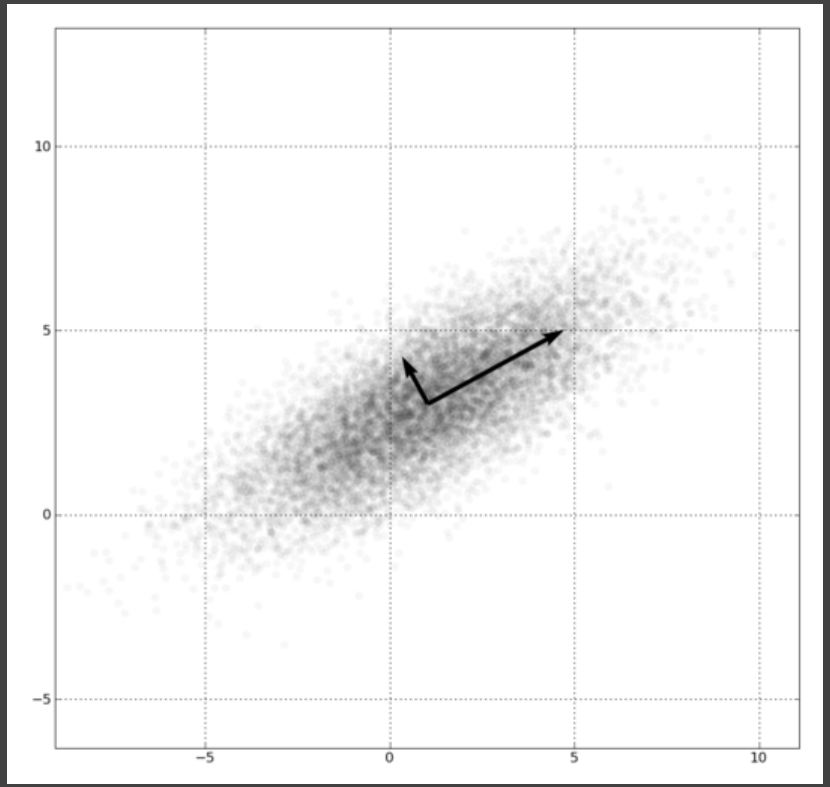


UMAP



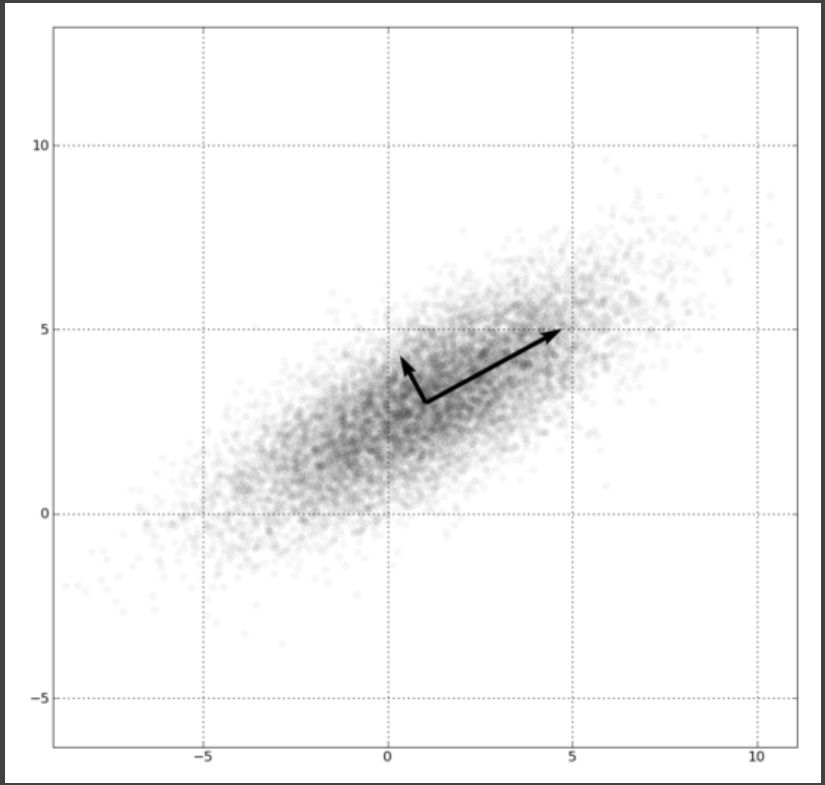
PCA

Principal Components Analysis



1. Mean-center the data.
2. Find ⊥ basis vectors that maximize the data variance.
3. Plot the data using the top vectors.

Principal Components Analysis

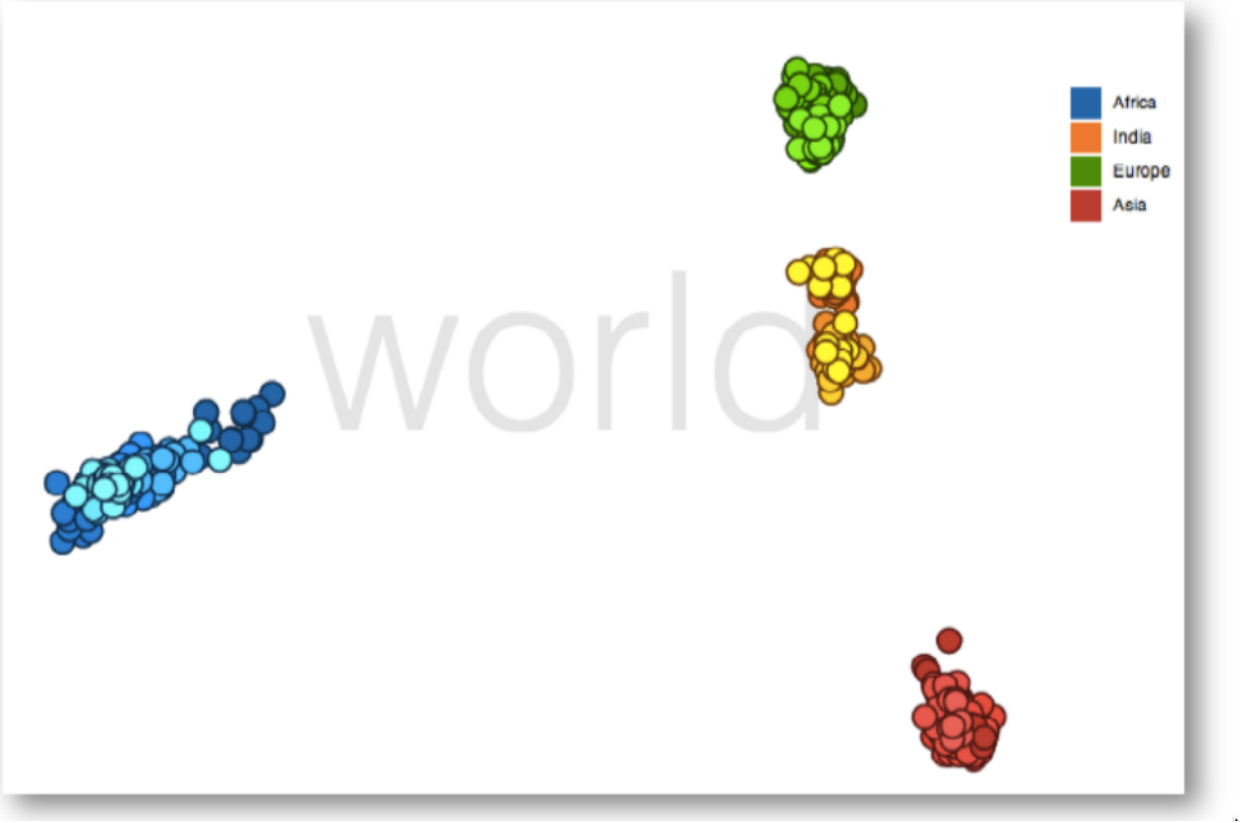


Linear transform: scale and rotate original space.

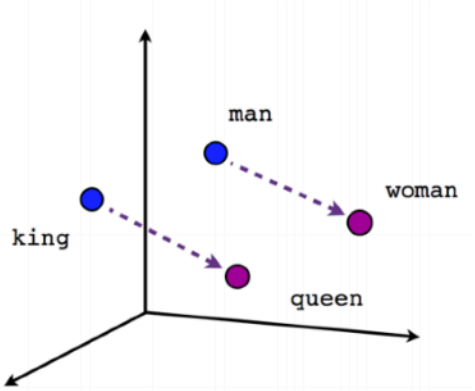
Lines (vectors) project to lines.

Preserves global distances.

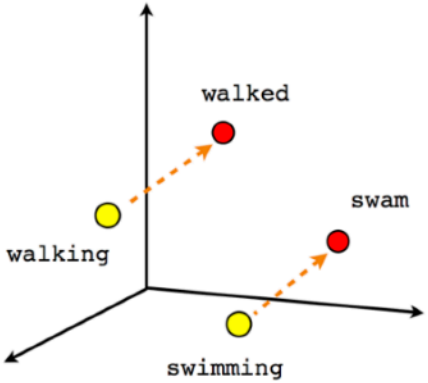
PCA of Genomes [Demiralp et al. '13]



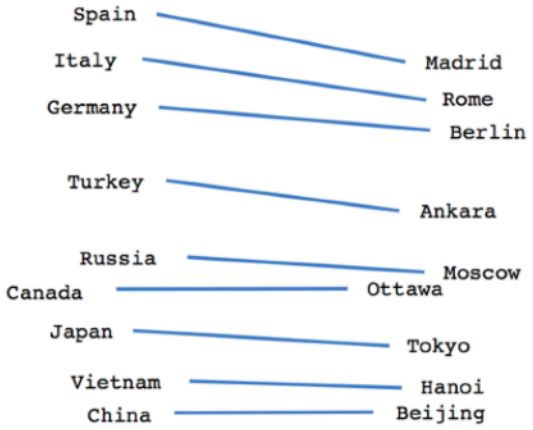
Vector Space Word Embeddings (word2vec, GloVe)



Male-Female



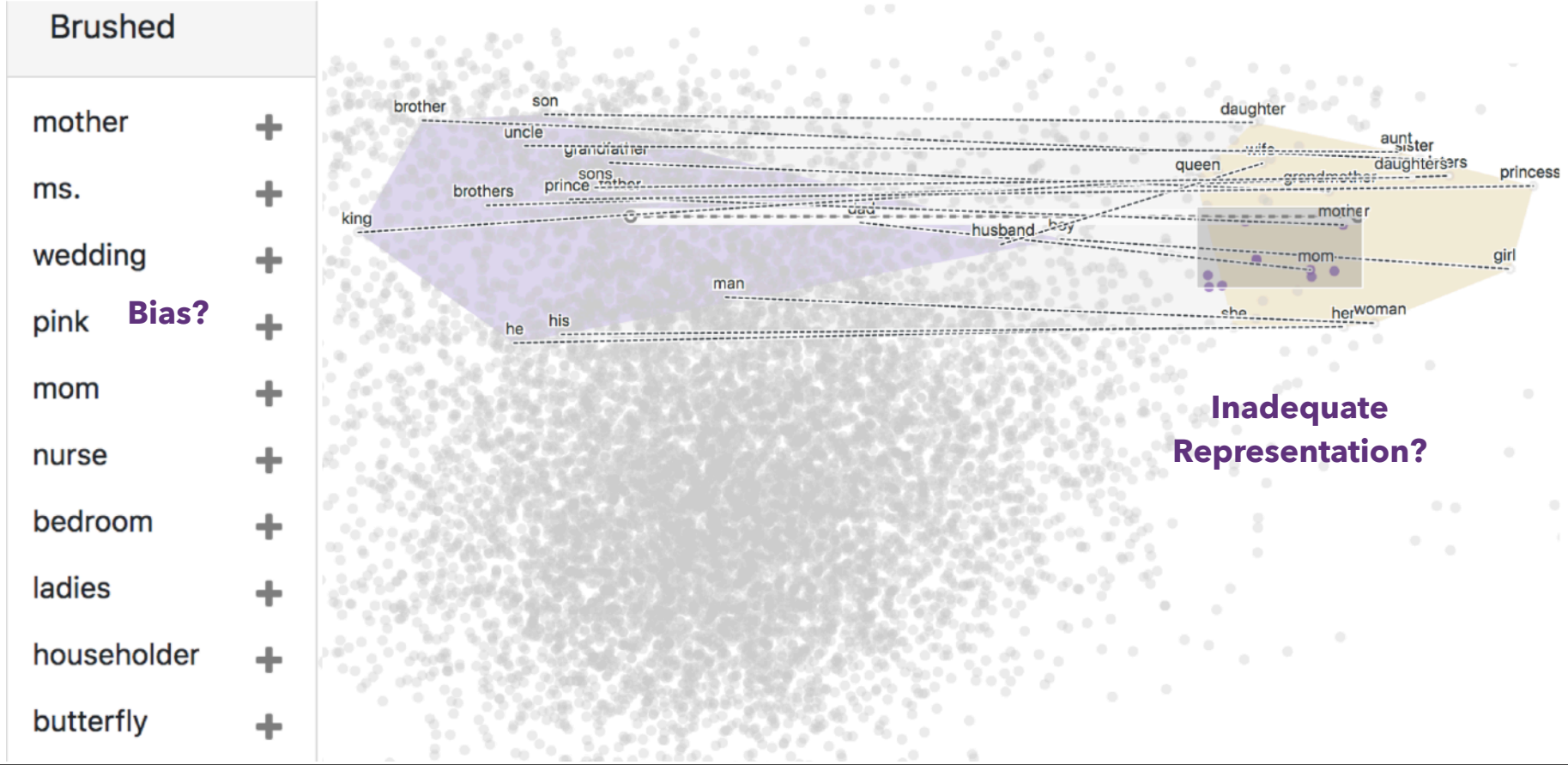
Verb tense



Country-Capital

Mapping Machine-Learned Latent Spaces

[Liu et al. 2019]



Non-Linear Techniques

Distort the space, trade-off preservation of global structure to emphasize local neighborhoods. Use topological (nearest neighbor) analysis.

Two popular contemporary methods:

t-SNE - probabilistic interpretation of distance

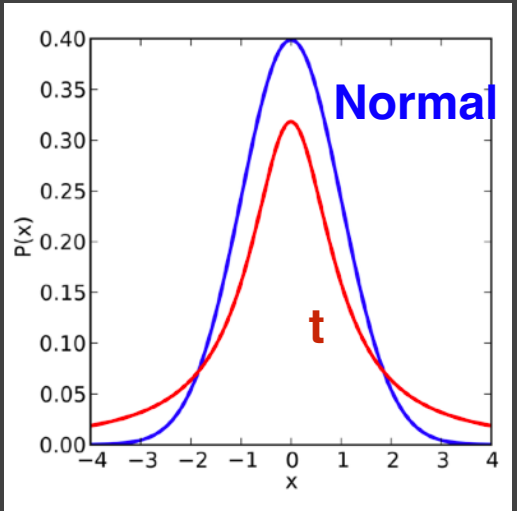
UMAP - tries to balance local/global trade-off

t-SNE [Maaten & Hinton 2008]

1. Model probability **P** of one point “choosing” another as its neighbor in the original space, using a Gaussian distribution defined using the distance between points. Nearer points have higher probability than distant ones.

t-SNE [Maaten & Hinton 2008]

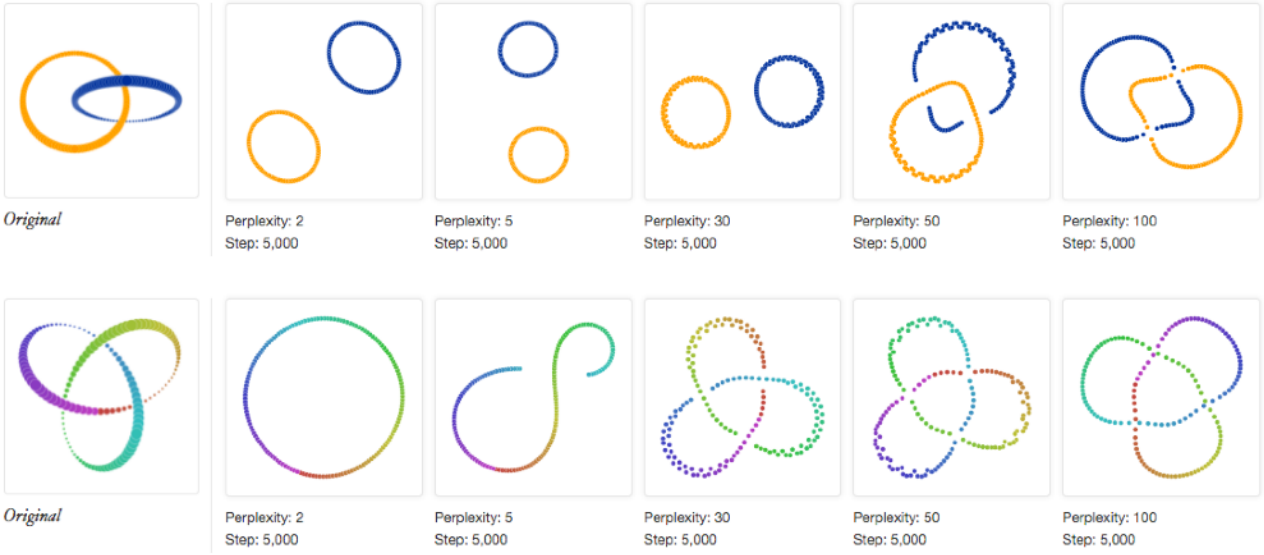
2. Define a similar probability **Q** in the low-dimensional (2D or 3D) embedding space, using a Student's *t* distribution *(hence the "t-" in "t-SNE"!)*. The *t*-distribution is heavy-tailed, allowing distant points to be even further apart.



t-SNE [Maaten & Hinton 2008]

1. Model probability **P** of one point "choosing" another as its neighbor in the original space, using a Gaussian distribution defined using the distance between points. Nearer points have higher probability than distant ones.
2. Define a similar probability **Q** in the low-dimensional (2D or 3D) embedding space, using a Student's *t* distribution *(hence the "t-" in "t-SNE"!)*. The *t*-distribution is heavy-tailed, allowing distant points to be even further apart.
3. Optimize to find the positions in the embedding space that minimize the Kullback-Leibler divergence between the **P** and **Q** distributions: *KL(P || Q)*

Visualizing t-SNE [Wattenberg et al. '16]

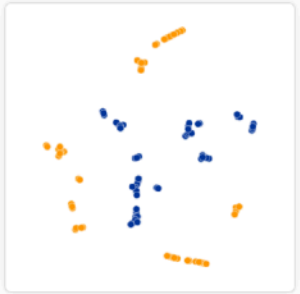


Results can be highly sensitive to the algorithm parameters!

Are you seeing real structures, or algorithmic hallucinations?

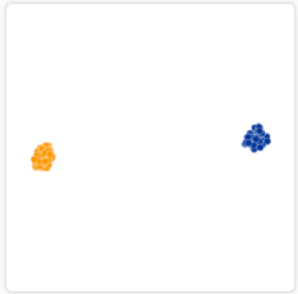
Hyperparameters matter!

Original

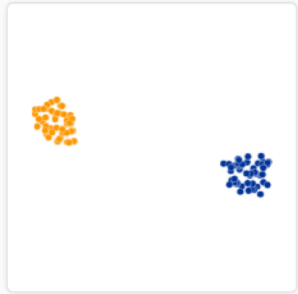


Perplexity: 2
Step: 5,000

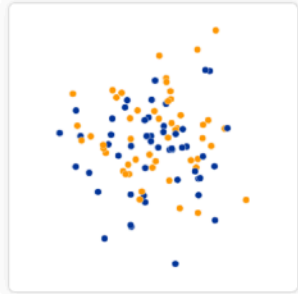
Perplexity: 5
Step: 5,000



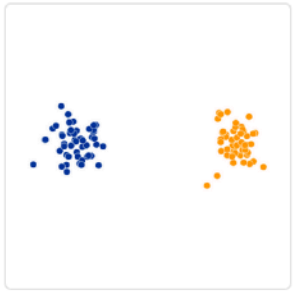
Perplexity: 30
Step: 5,000



Perplexity: 50
Step: 5,000



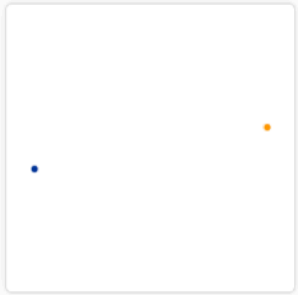
Perplexity: 100
Step: 5,000



Original

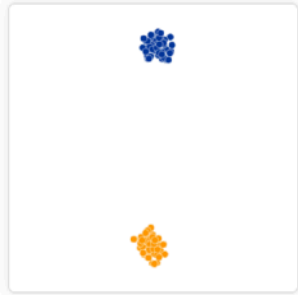
Perplexity: 30
Step: 10

Perplexity: 30
Step: 20



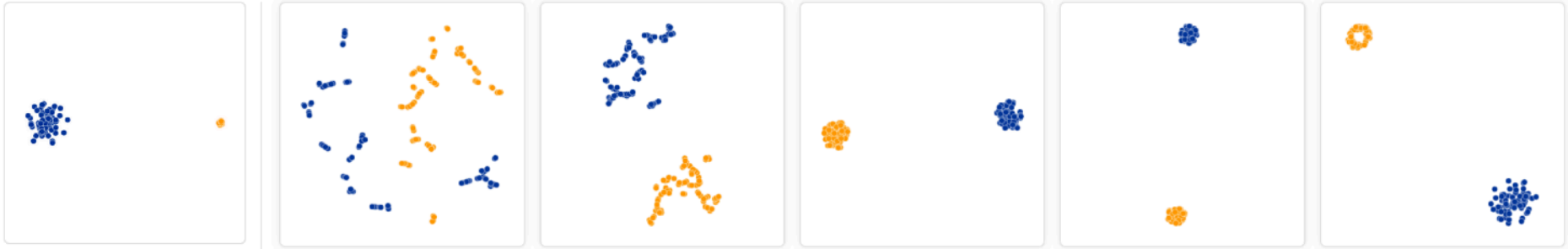
Perplexity: 30
Step: 60

Perplexity: 30
Step: 120



Perplexity: 30
Step: 1,000

Cluster sizes mean nothing…



Original

Perplexity: 2
Step: 5,000

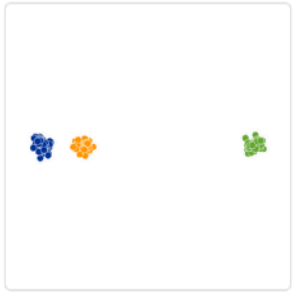
Perplexity: 5
Step: 5,000

Perplexity: 30
Step: 5,000

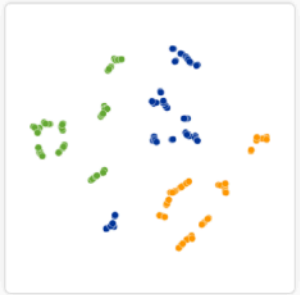
Perplexity: 50
Step: 5,000

Perplexity: 100
Step: 5,000

Cluster distances are illusive

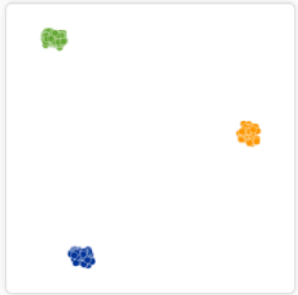


Original

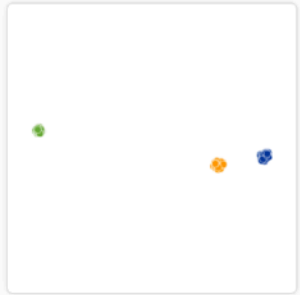


Perplexity: 2
Step: 5,000

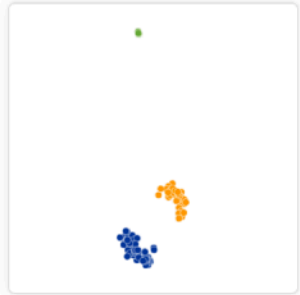
Perplexity: 5
Step: 5,000



Perplexity: 30
Step: 5,000

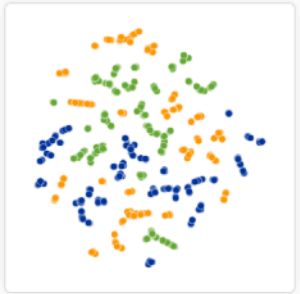


Perplexity: 50
Step: 5,000



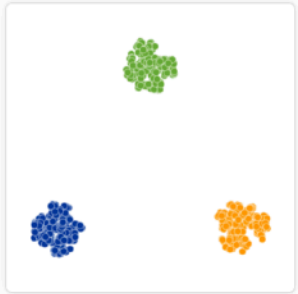
Perplexity: 100
Step: 5,000

Original

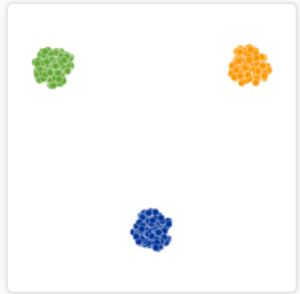


Perplexity: 2
Step: 5,000

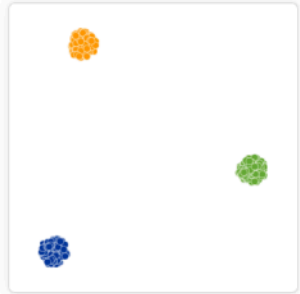
Perplexity: 5
Step: 5,000



Perplexity: 30
Step: 5,000



Perplexity: 50
Step: 5,000



Perplexity: 100
Step: 5,000

Random noise may not look like it

Original

Perplexity: 2
Step: 5,000

Perplexity: 5
Step: 5,000

Perplexity: 30
Step: 5,000

Perplexity: 50
Step: 5,000

Perplexity: 100
Step: 5,000

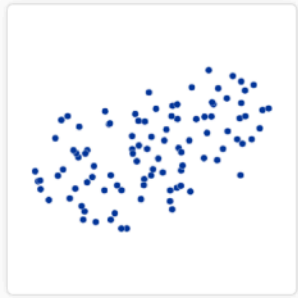
You can see shapes, sometimes

Original

Perplexity: 2
Step: 5,000

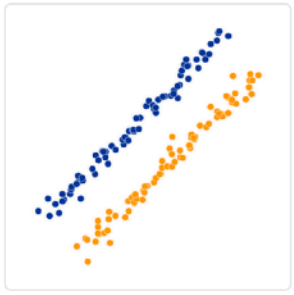
Perplexity: 5
Step: 5,000

Perplexity: 30
Step: 5,000



Perplexity: 50
Step: 5,000

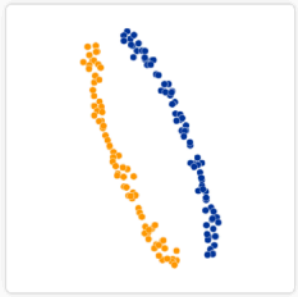
Perplexity: 100
Step: 5,000



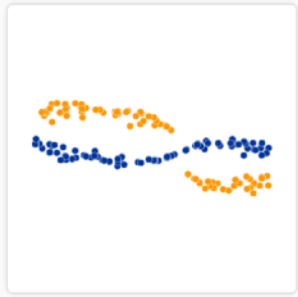
Original

Perplexity: 2
Step: 5,000

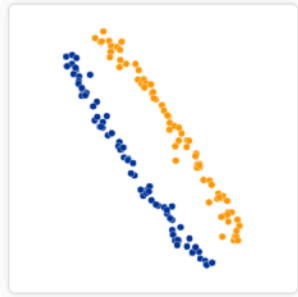
Perplexity: 5
Step: 5,000



Perplexity: 30
Step: 5,000

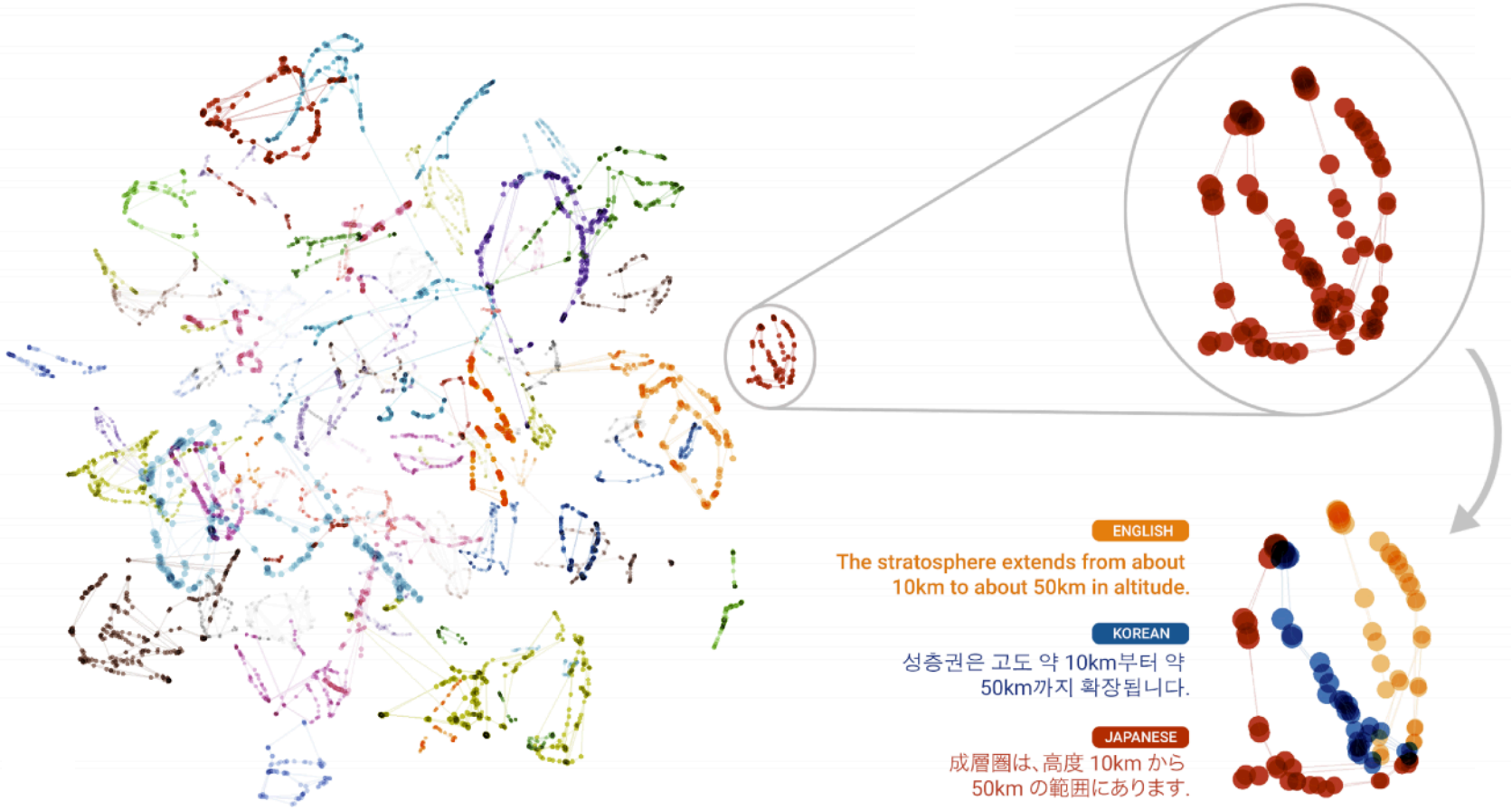


Perplexity: 50
Step: 5,000



Perplexity: 100
Step: 5,000

Multi-Lingual Word Embedding [Google 2016]



UMAP [McInnes et al. 2018]

Form weighted nearest neighbor graph, then layout the graph in a manner that balances embedding of local and global structure.

“Our algorithm is competitive with t-SNE for visualization quality and arguably preserves more of the global structure with superior run time performance.” - McInnes et al. 2018

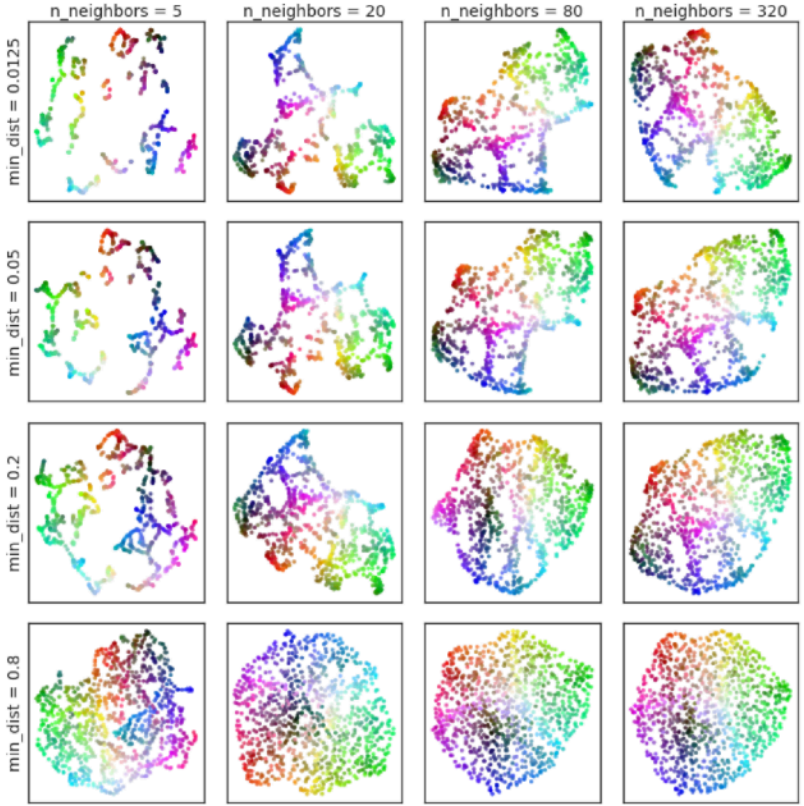


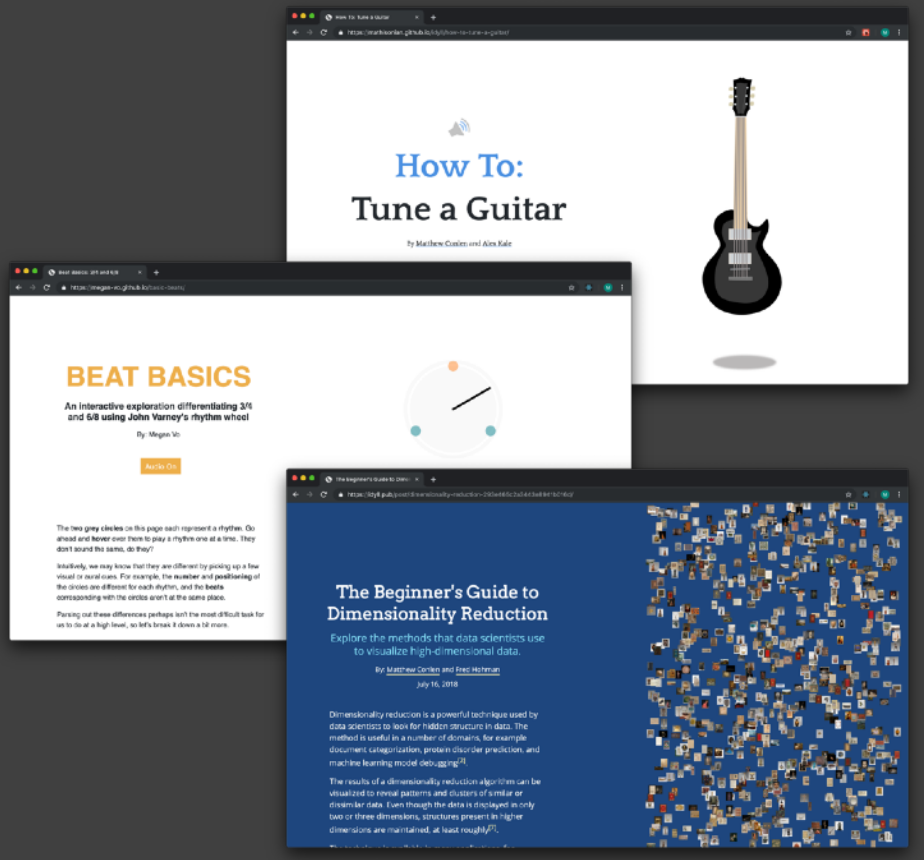
Figure 1: Variation of UMAP hyperparameters n and min-dist result in different embeddings. The data is uniform random samples from a 3-dimensional color-cube, allowing for easy visualization of the original 3-dimensional coordinates in the embedding space by using the corresponding RGB colour. Low values of n spuriously interpret structure from the random sampling noise – see Section 6 for further discussion of this phenomena.

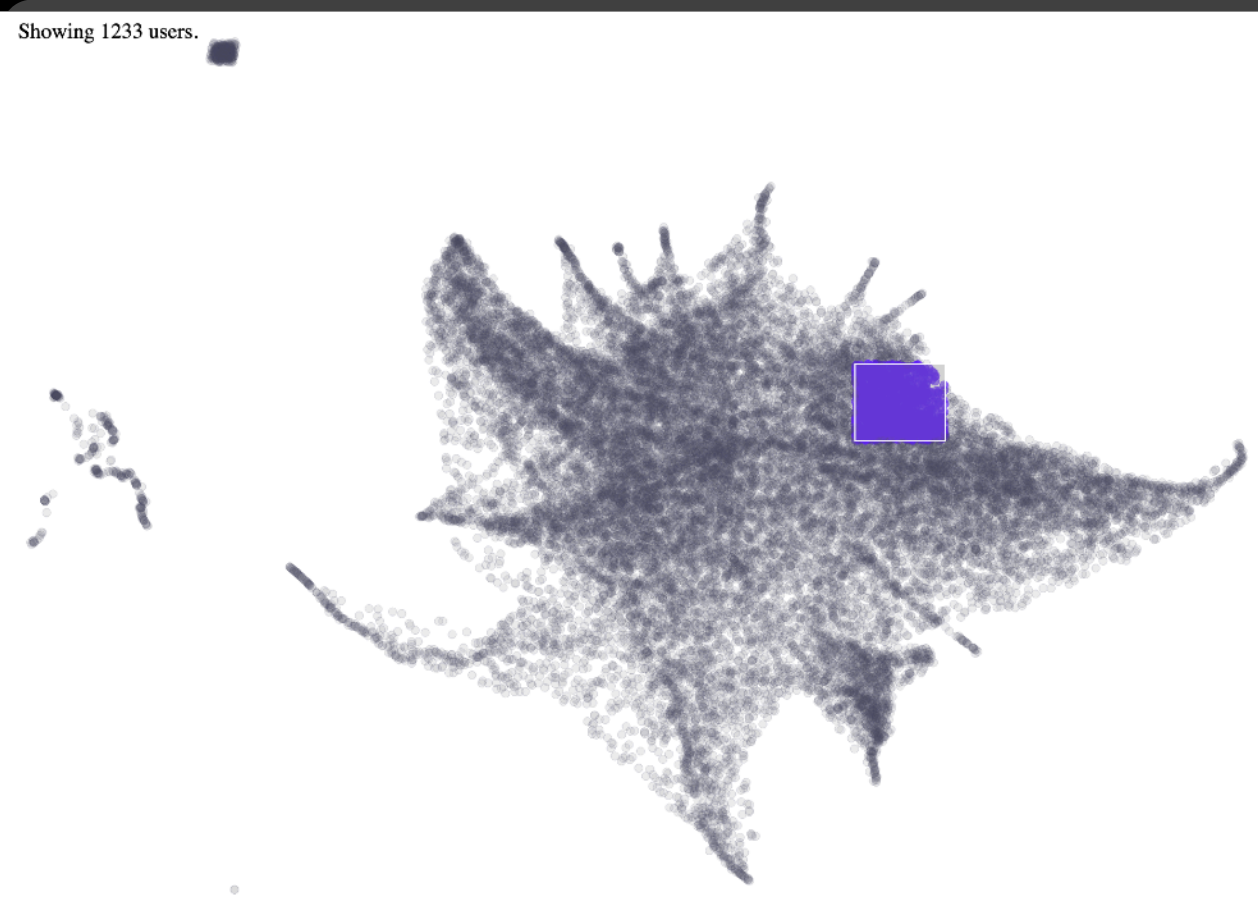
User Engagement with Interactive Articles

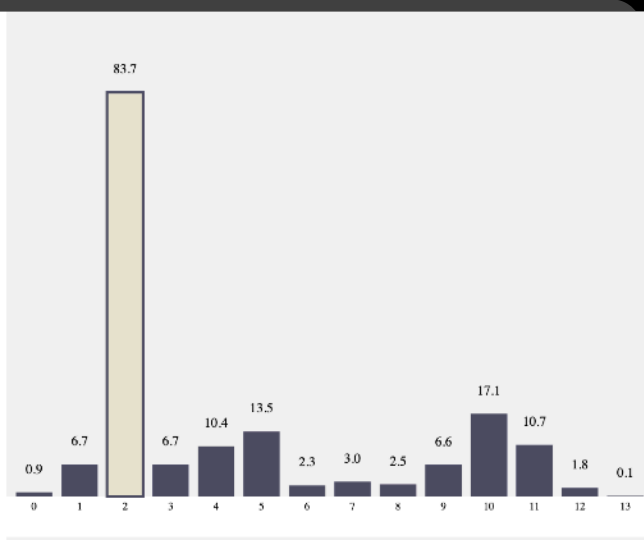
Provide an overview of usage patterns of interactive features.

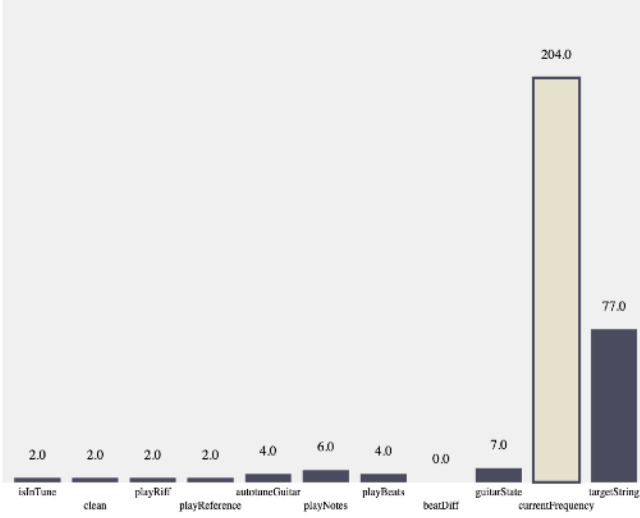
Identify variations in usage

Represent reader sessions as a feature vector with:
- time spent in each section
- count of variable changes

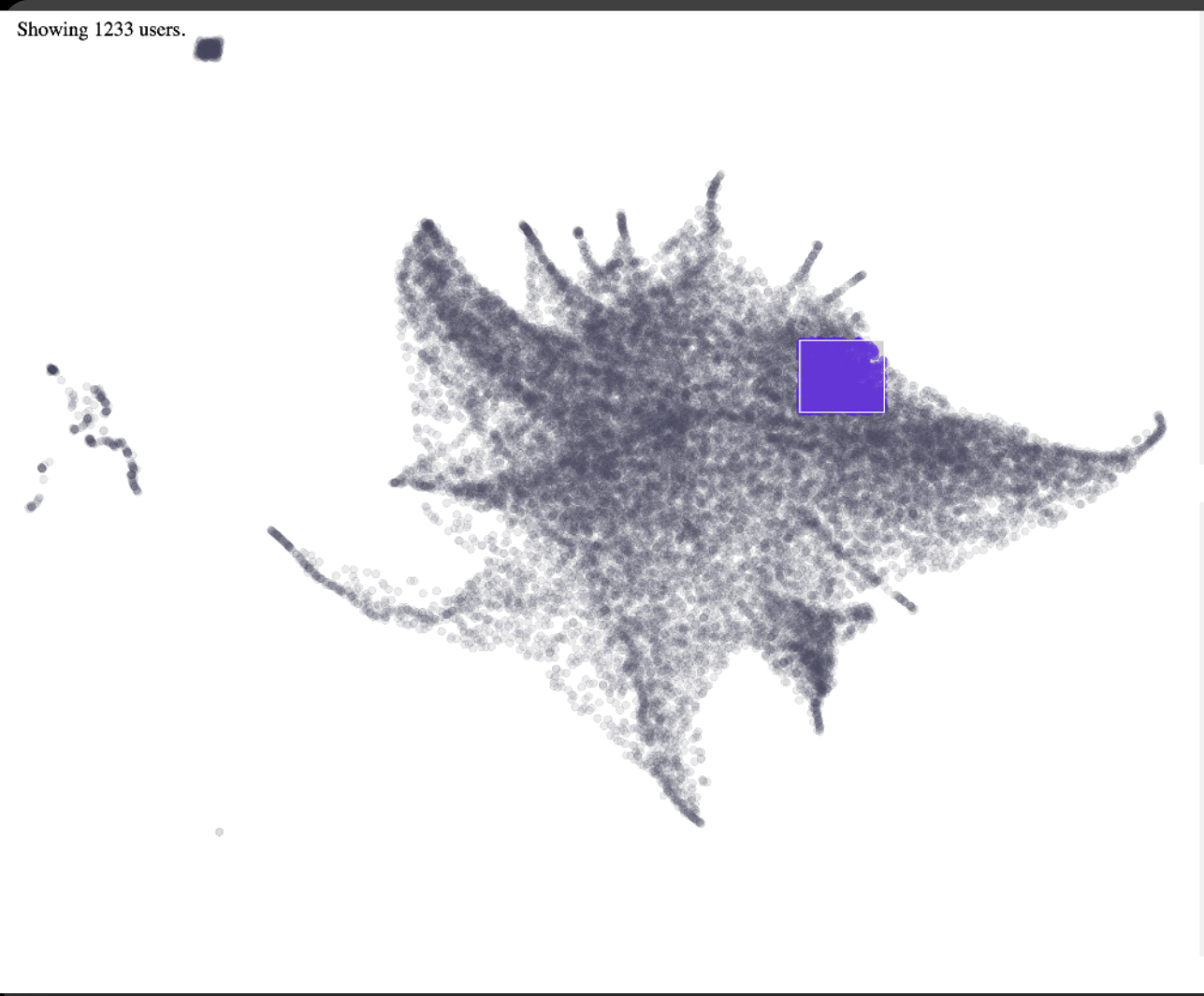


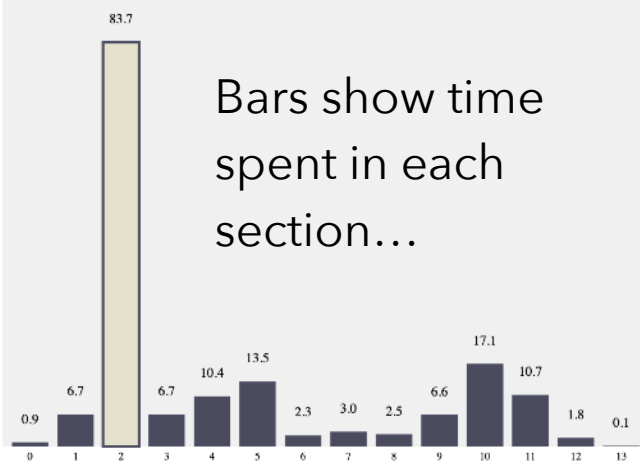




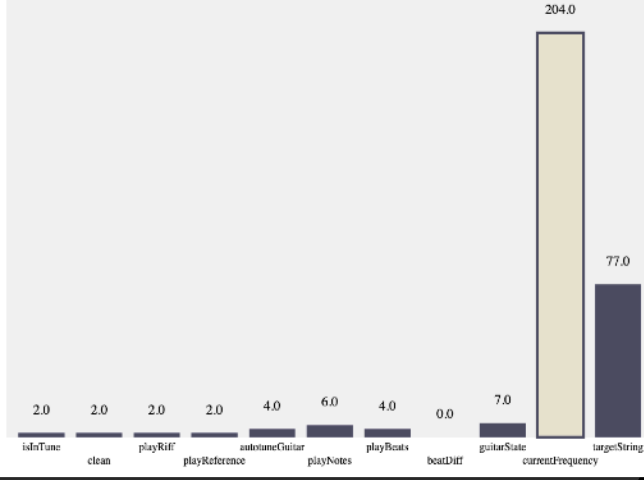


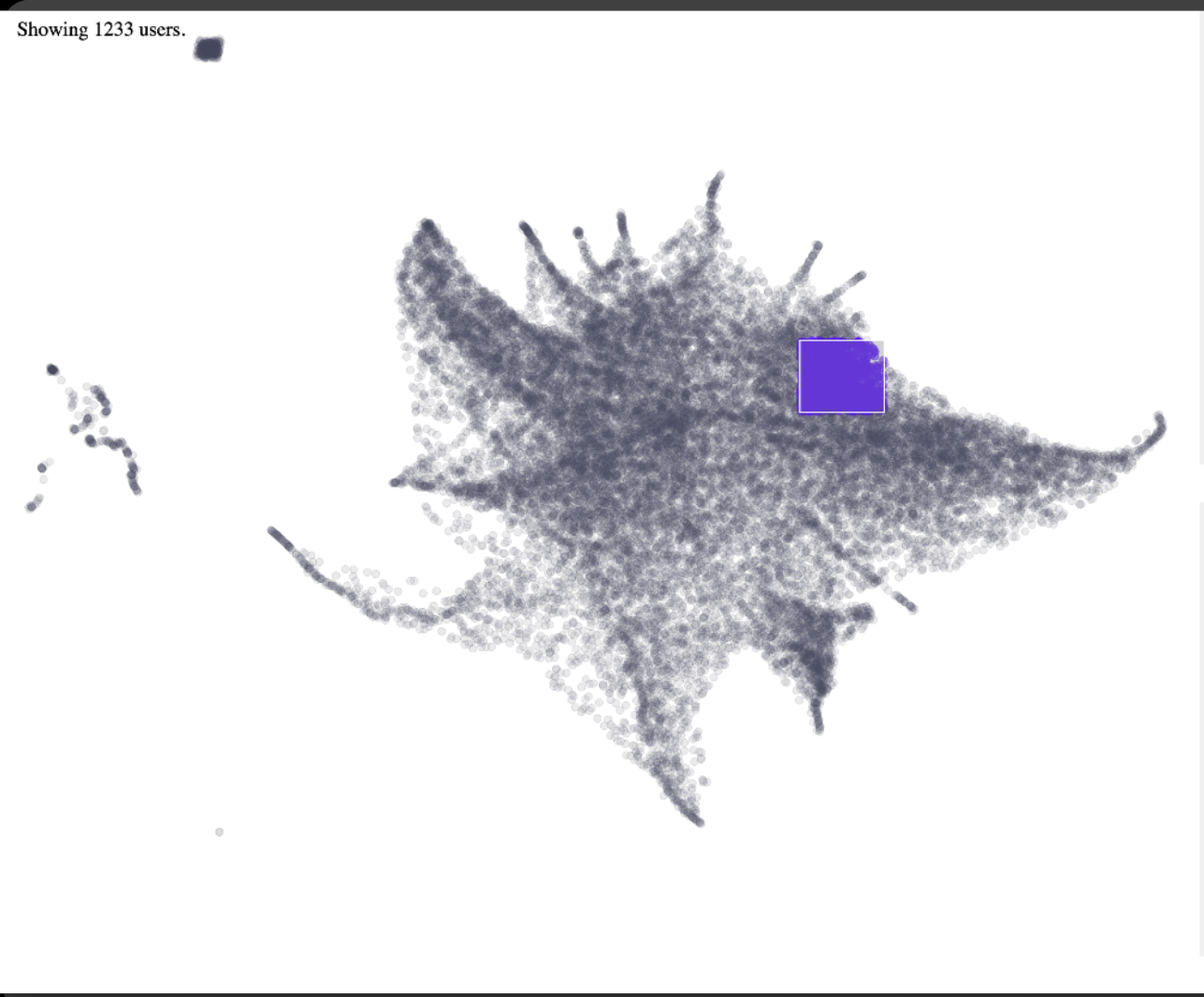
Each point represents a readers session, projected via UMAP.

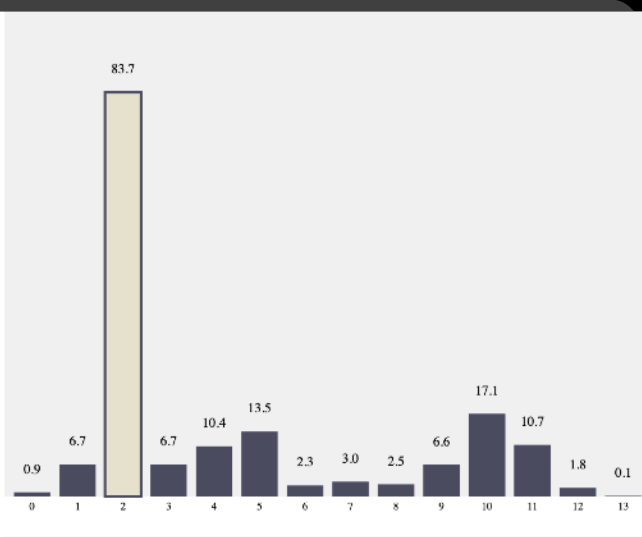




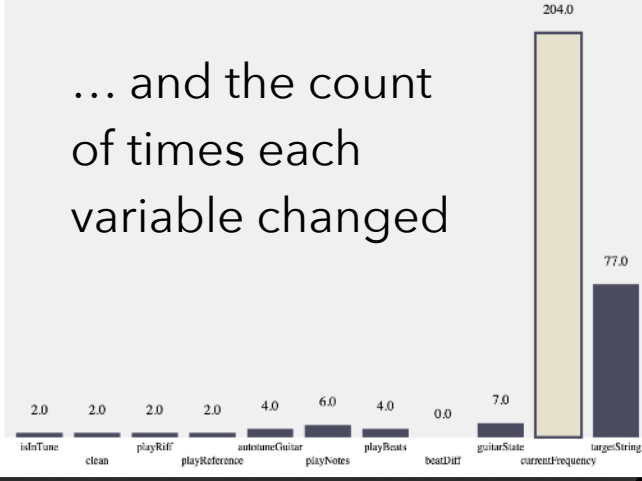
Bars show time spent in each section…





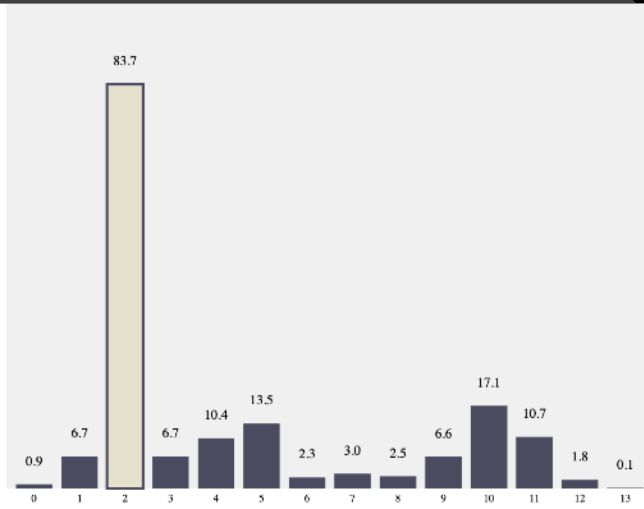


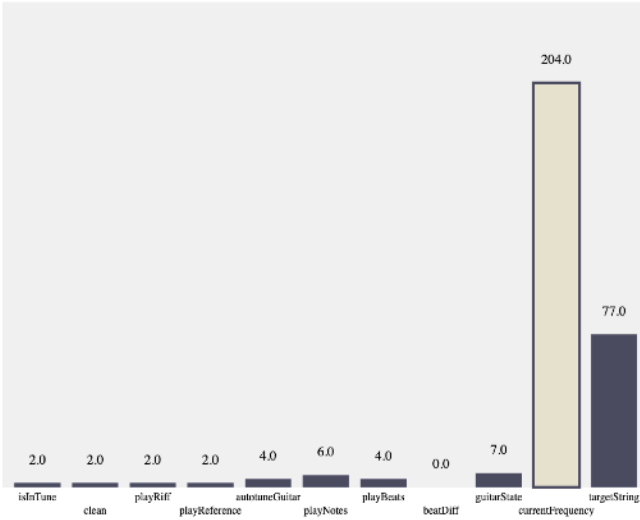
… and the count of times each variable changed

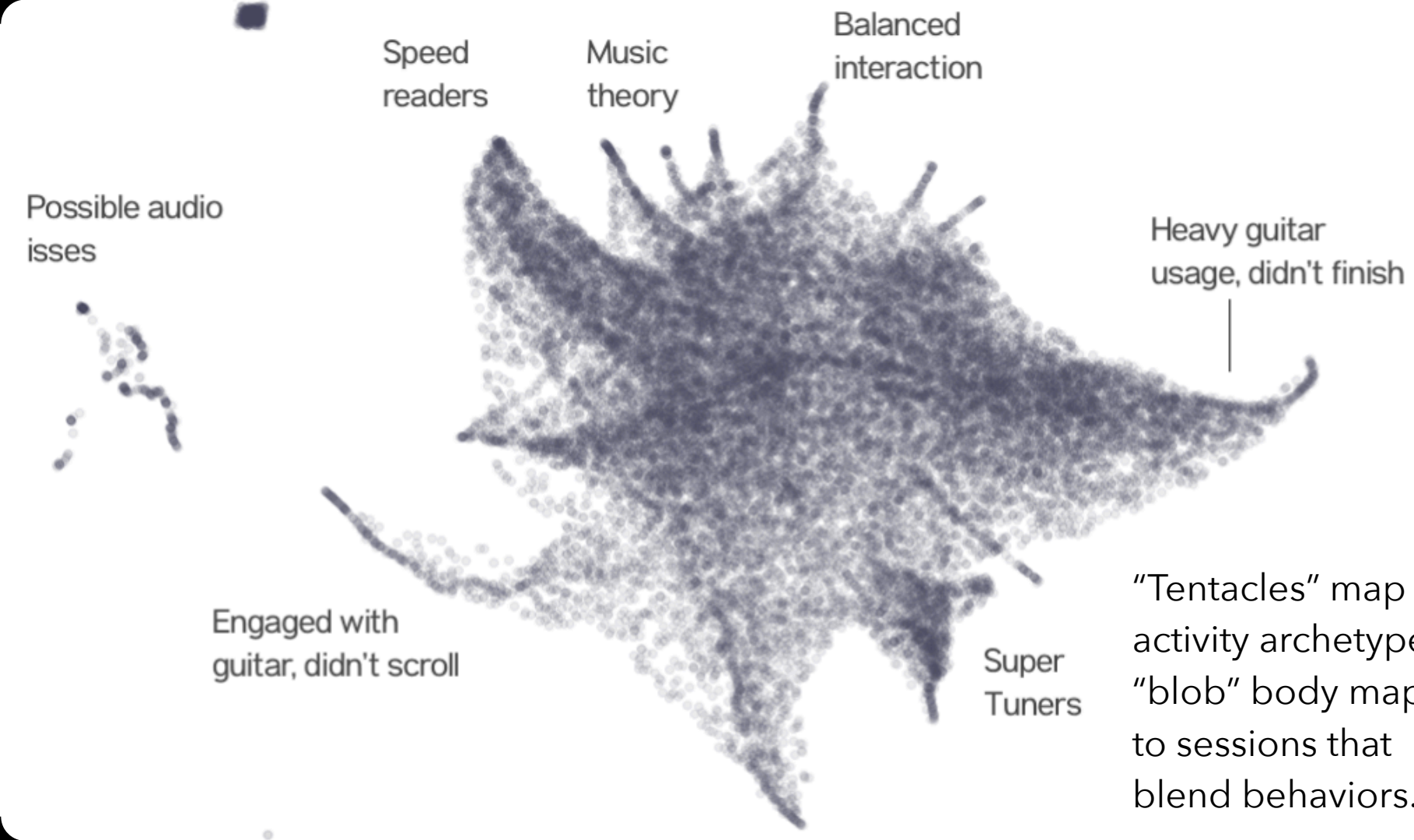


Showing 1233 users.

Brushing to select a subset of sessions.

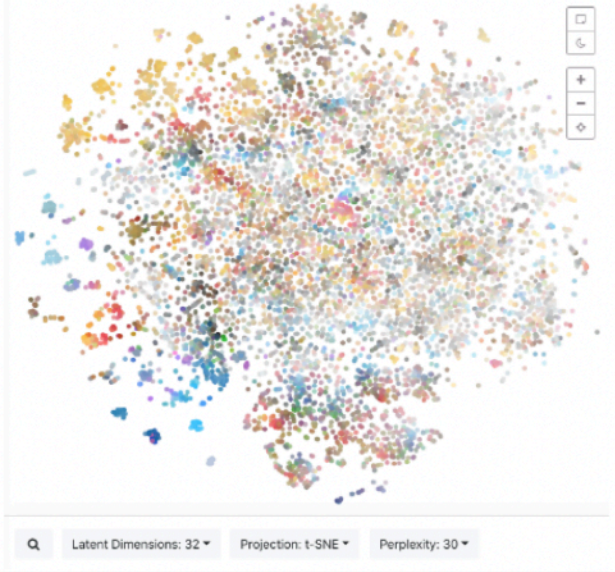




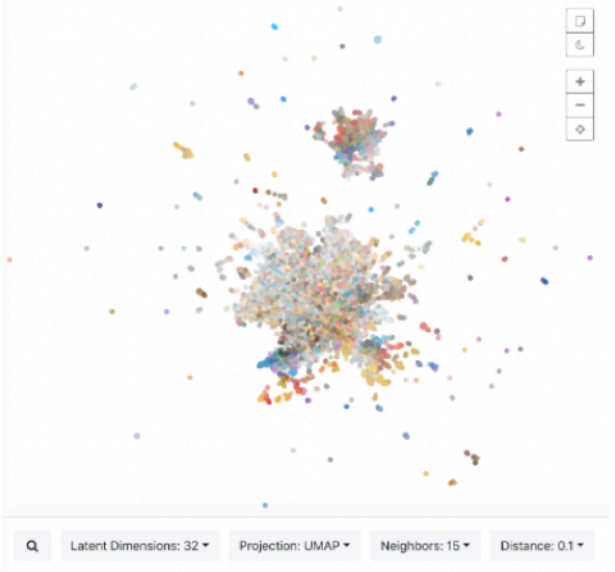


“Tentacles” map to activity archetypes, “blob” body maps to sessions that blend behaviors.

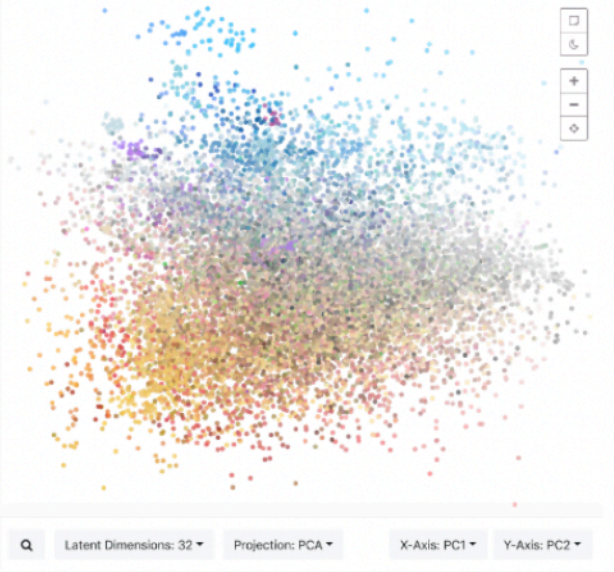
Mapping Emoji Images



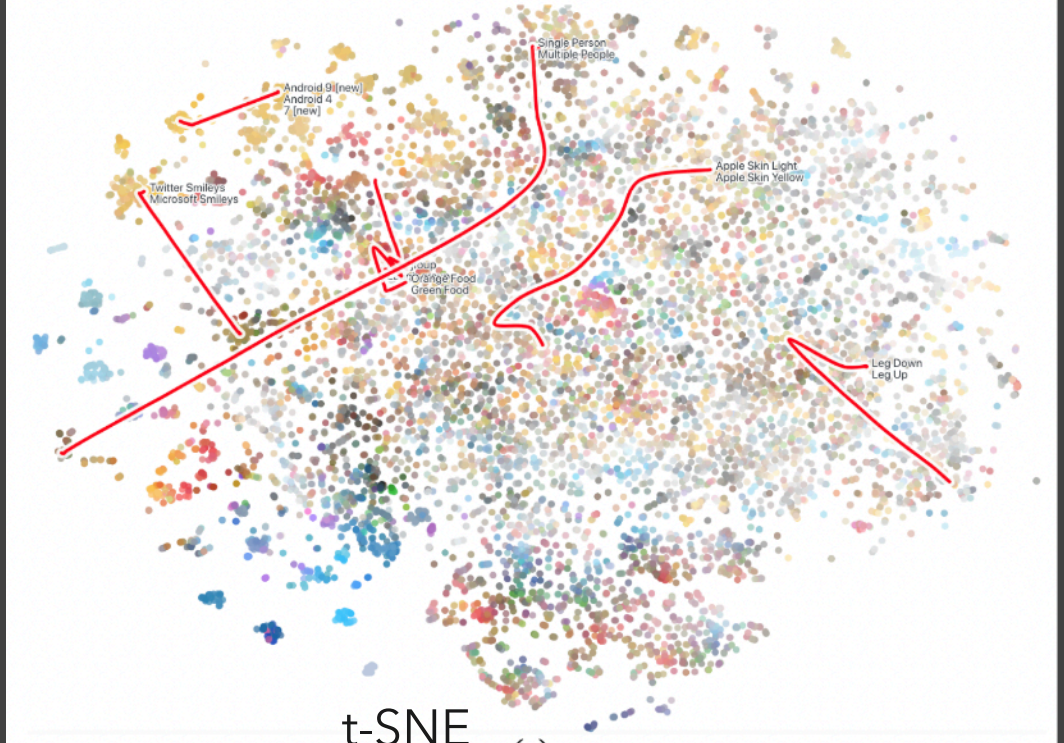
t-SNE



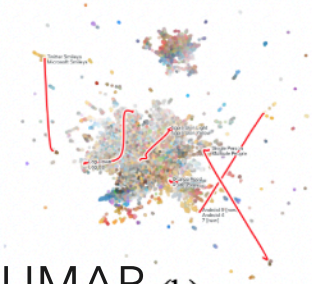
UMAP



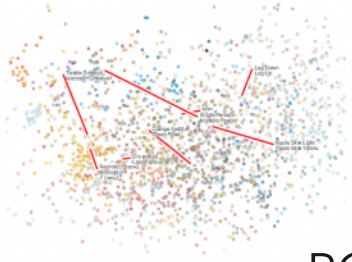
PCA



t-SNE (a)

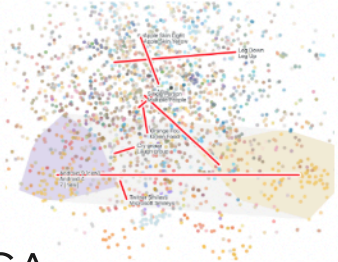


UMAP (b)



(c)

PCA



(d)

Dimensionality Reduction Issues

Reproducible?

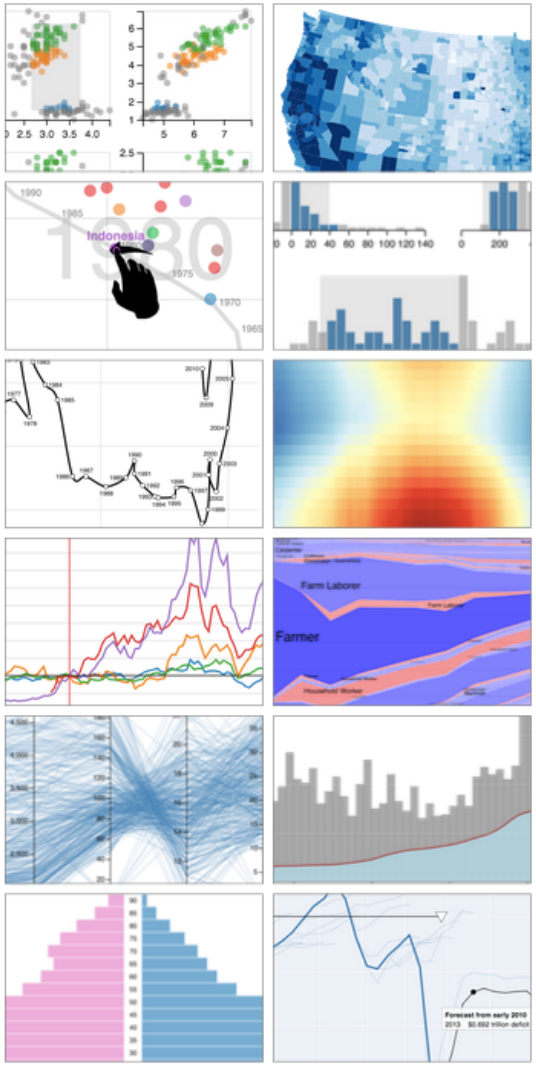
Projections are *data-dependent*. Fitting a new projection with different data can give rise to different results.

Reusable?

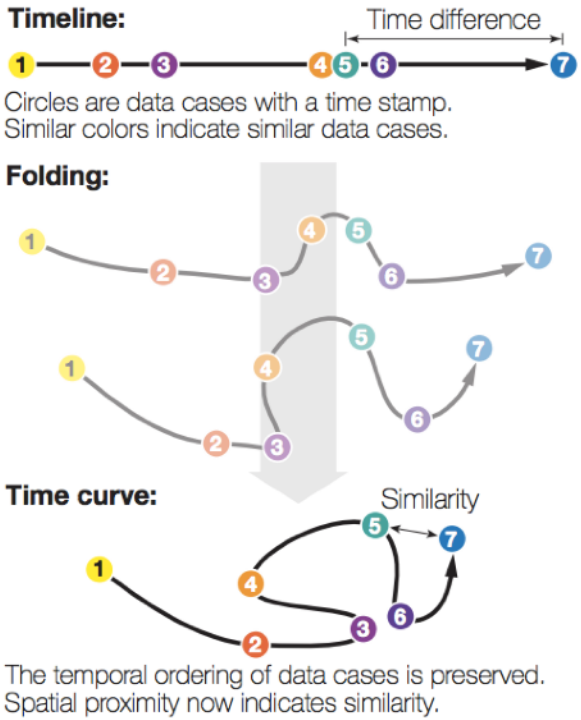
PCA and UMAP provide reusable projection functions that can map new points from high-D to low-D. t-SNE (and others, like MDS) do not provide this.

Interpretable?

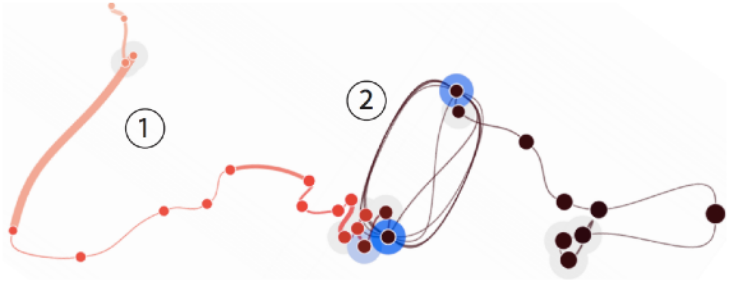
DR plots are hard to interpret! Try multiple methods and hyperparameter settings. Inspect via interaction!



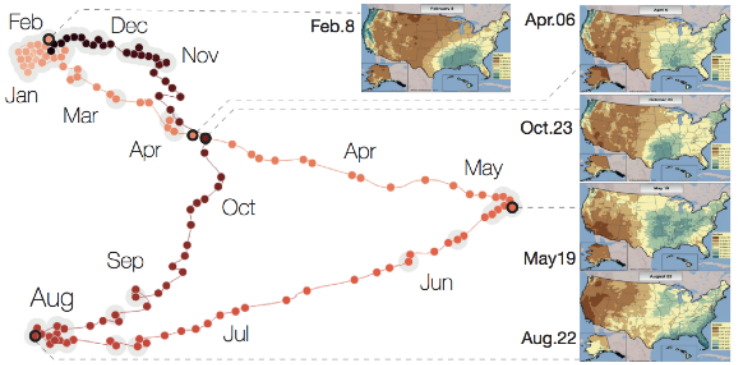
Time Curves [Bach et al. '16]



(a) Folding time



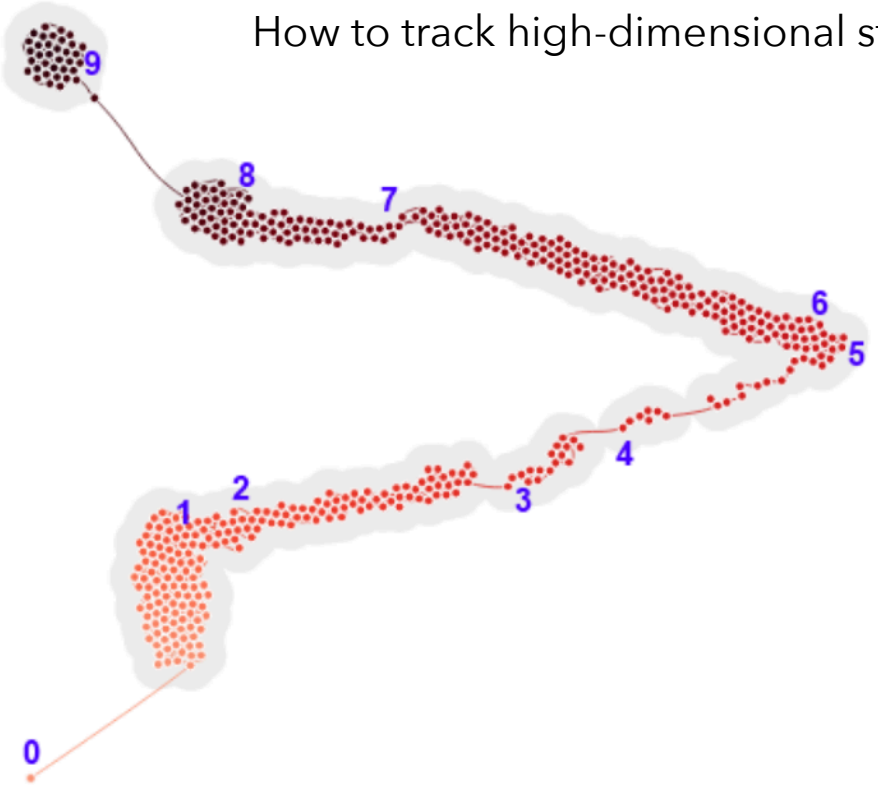
Wikipedia "Chocolate" Article



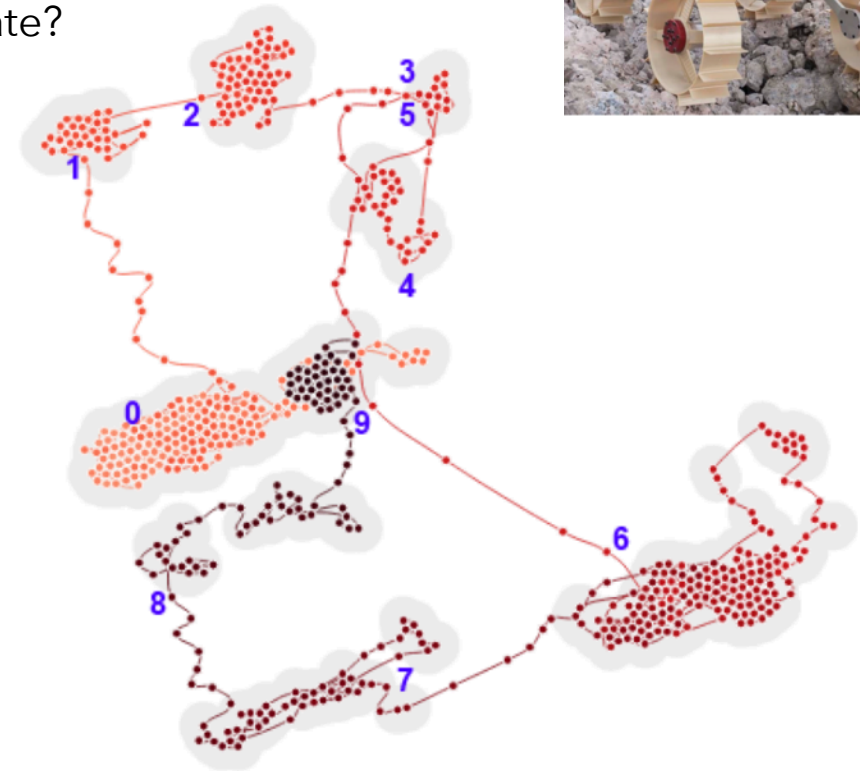
U.S. Precipitation over 1 Year

Rover Telemetry [Guy '16]

How to track high-dimensional state?



Using Raw Multi-D Data

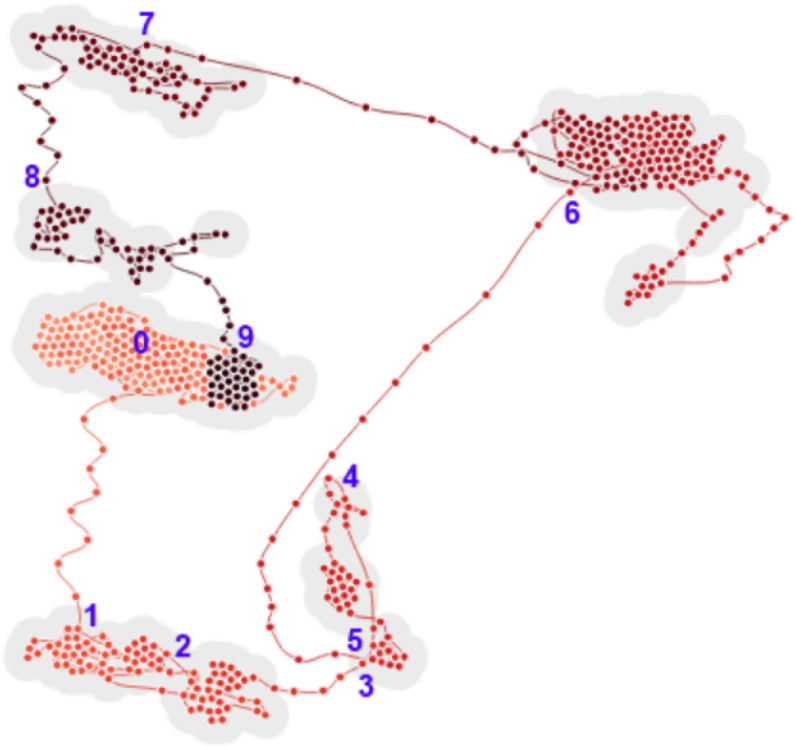


Using Pearson Correlation Matrix

Rover Telemetry [Guy '16]

How to track high-dimensional state?

Event Number	Timestamp	Event Description
0	0s	Rover begins traveling forward along smooth terrain.
1	188s	Rover begins descending into crater.
2	223s	Rover loses line of sight with lander and packet drops begin.
3	287s	Rover enters shade, causing temp, comms, and power drops.
4	300s	Rover begins traversing smooth bottom of crater.
5	330s	Rover begins climbing out of crater.
6	343s	Rover exits shade; continues uphill.
7	534s	Rover emerges from crater and enters smooth terrain.
8	594s	Rover enters choppy terrain.
9	643s	Rover wheel has fault; rover stops moving.



Using Spearman Correlation Matrix