Computational Analysis of Big Data

Week 2

A Data Scientist's most fundamental tools

Data visualization

1
1000

1
1000

.

This is data

It's usually some (large) file full of text and numbers

Terminal — less — 107×37


```
<?xml version="1.0" encoding="UTF-8"?>
<gpx version="1.1" creator="Garmin Connect"
  xsi:schemaLocation="http://www.topografix.com/GPX/1/1 http://www.topografix.com/GPX/1/1/gpx.xsd http://ww
w.garmin.com/xmlschemas/GpxExtensions/v3 http://www.garmin.com/xmlschemas/GpxExtensionsv3.xsd http://www.ga
rmin.com/xmlschemas/TrackPointExtension/v1 http://www.garmin.com/xmlschemas/TrackPointExtensionv1.xsd"
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  xmlns:gpxx="http://www.garmin.com/xmlschemas/GpxExtensions/v3" xmlns:xsi="http://www.w3.org/2001/XMLSchem
a-instance">
  <metadata>
    <link href="connect.garmin.com">
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activity_65197512.gpx
```

This is GPS data

It's usually some (large) file full of text and numbers

Terminal — less — 107×37

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<gpx version="1.1" creator="Garmin Connect"
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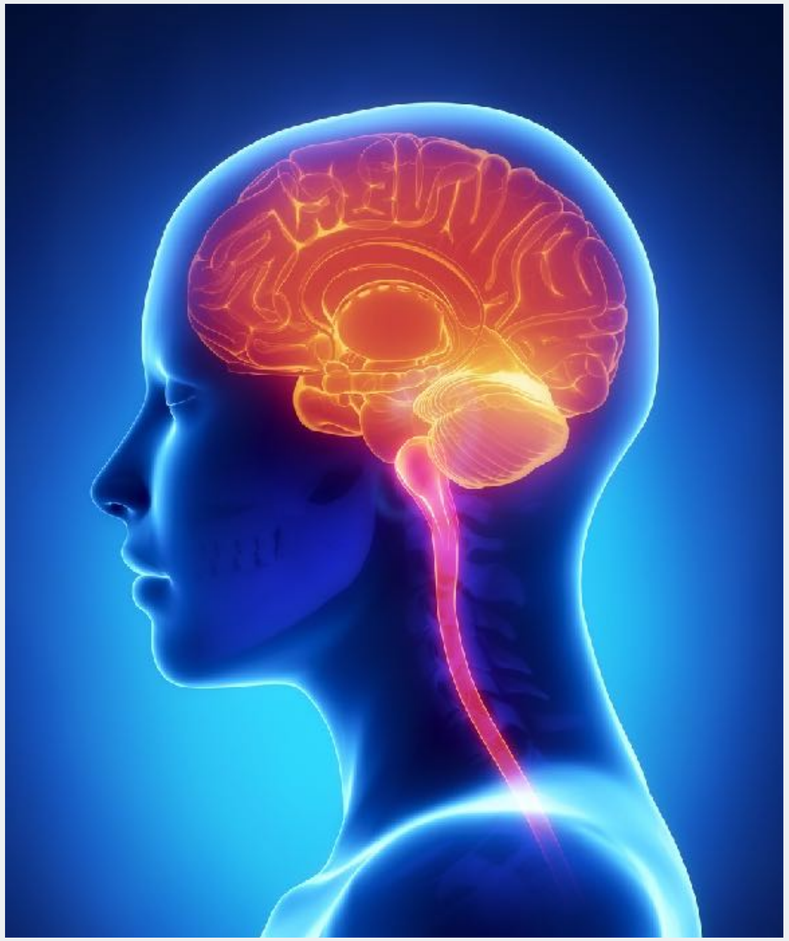
```

And if you're lucky there is also some kind of `<markup>`

Most raw data is incomprehensible to humans

We have:

- Narrow spectrum of data that we can process and understand
- Limited memory for processing new information
- Limited attention for undertaking focussed tasks

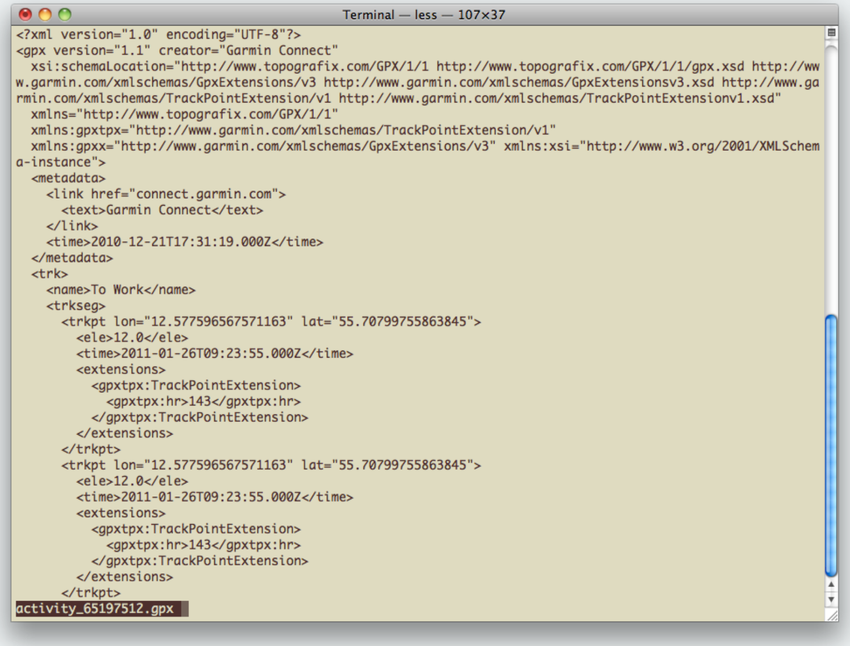


The human eye is made for advanced pattern recognition

It can:

- Immediately recognize a pattern in a highly complex image
- Quickly spot things that deviate from patterns (outlier detection)
- Process streams of images and recognize patterns over time

Data must be rendered in human-friendly format



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?

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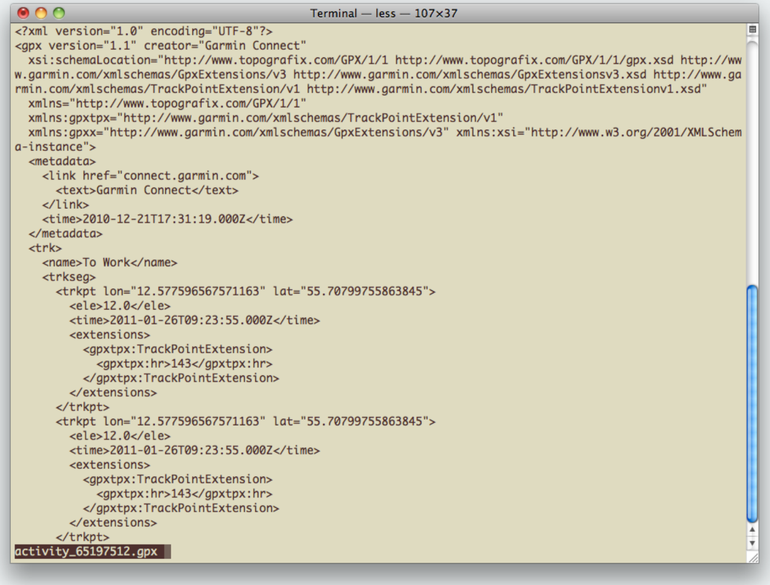

→

	lat	lon
0	55.784332	12.525468
1	55.784437	12.525030
2	55.784435	12.525043
3	55.784224	12.525565
4	55.784437	12.525031
5	55.784411	12.525055
6	55.784397	12.525070
7	55.784215	12.525537
8	55.784416	12.525059
9	55.784147	12.525530
10	55.784417	12.525063
11	55.784222	12.525535
12	55.784415	12.525052
13	55.784152	12.525590
14	55.784411	12.525054
15	55.784387	12.525093
16	55.784255	12.525532
17	55.784406	12.525060
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19	55.784353	12.525407
20	55.784414	12.525059
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22	55.784410	12.525083
23	55.784192	12.525557
24	55.784406	12.525053
25	55.784411	12.525060
26	55.784243	12.525500
27	55.784400	12.525066
28	55.784408	12.525056
29	55.784168	12.525580
...	...	...

→

?

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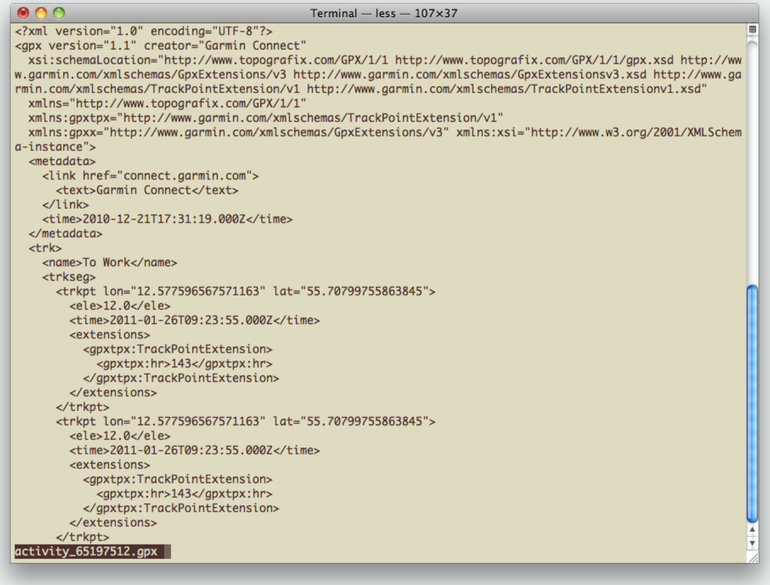


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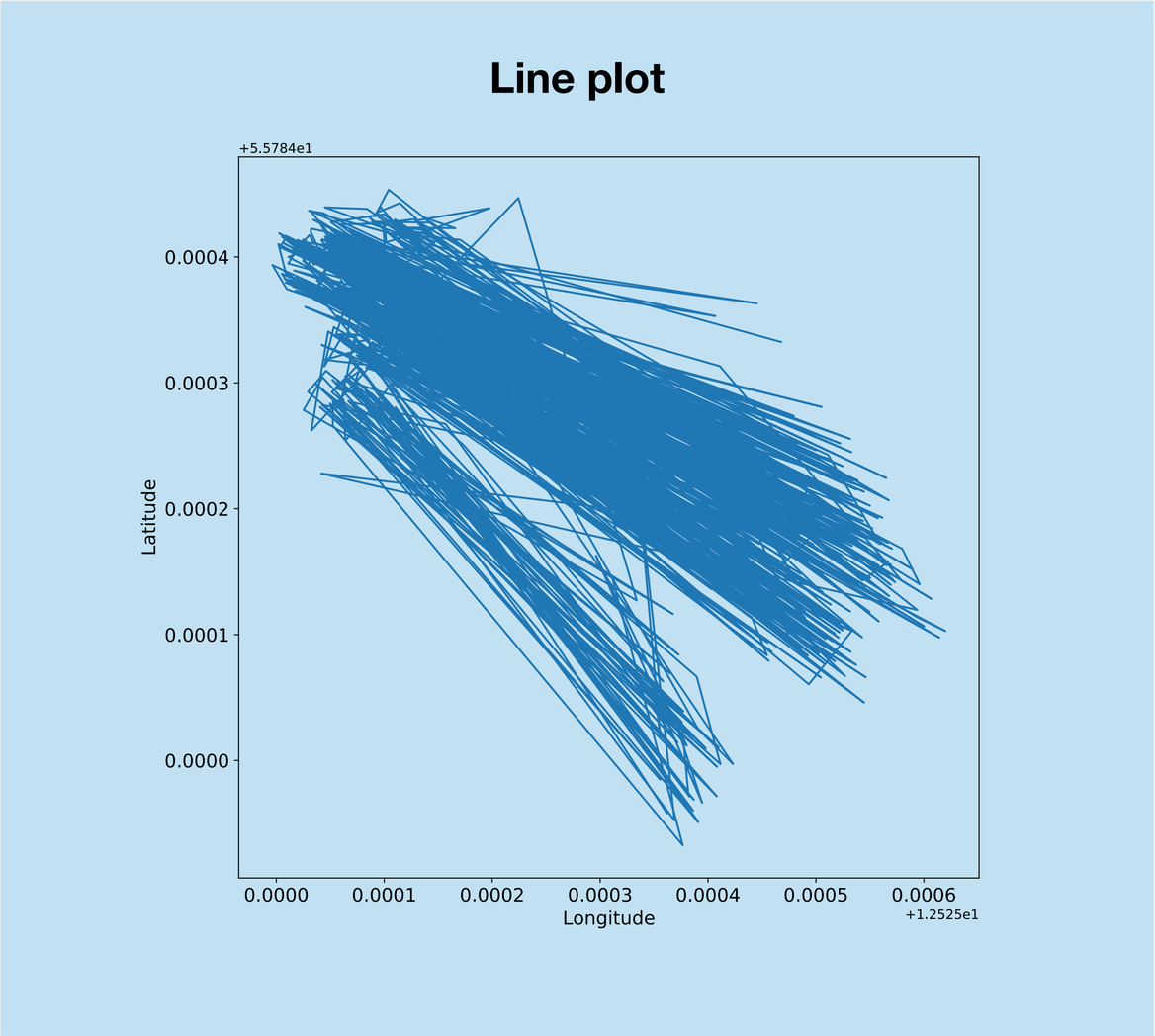

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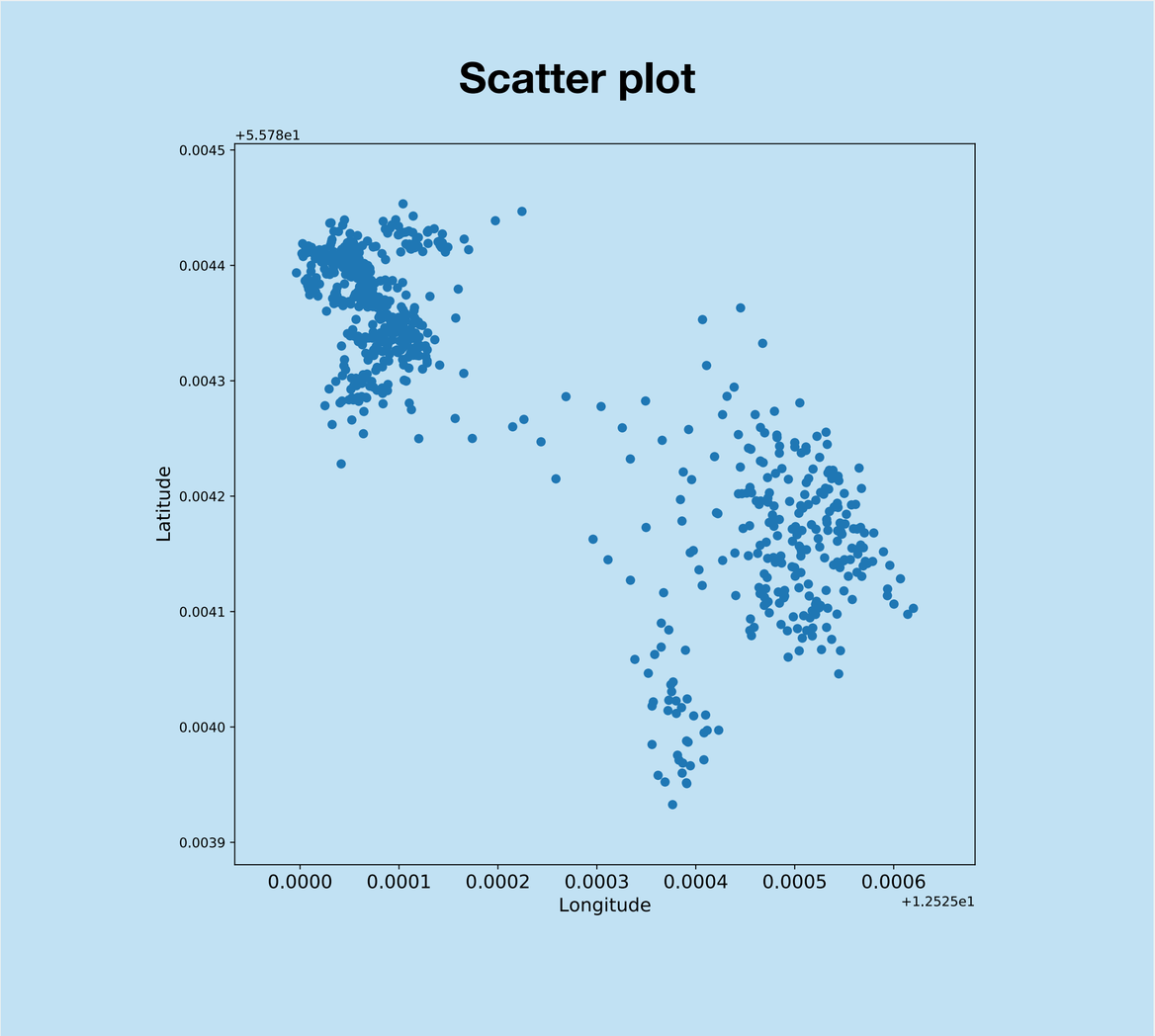

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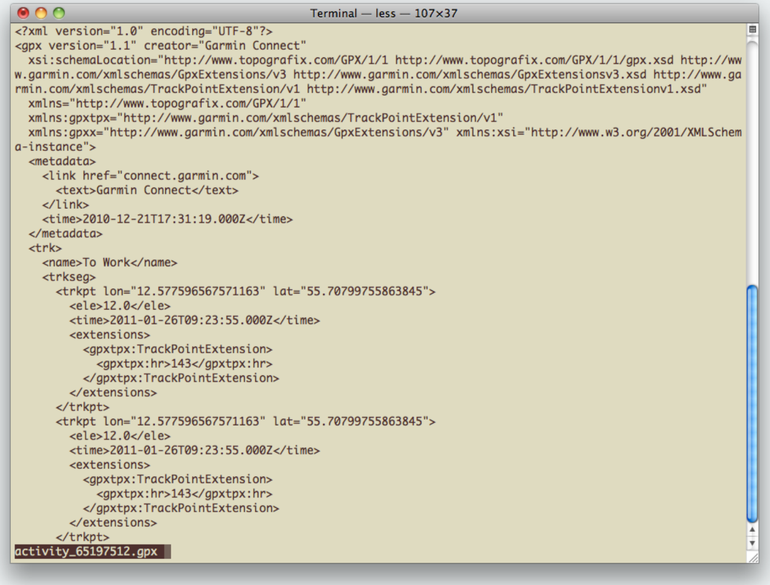


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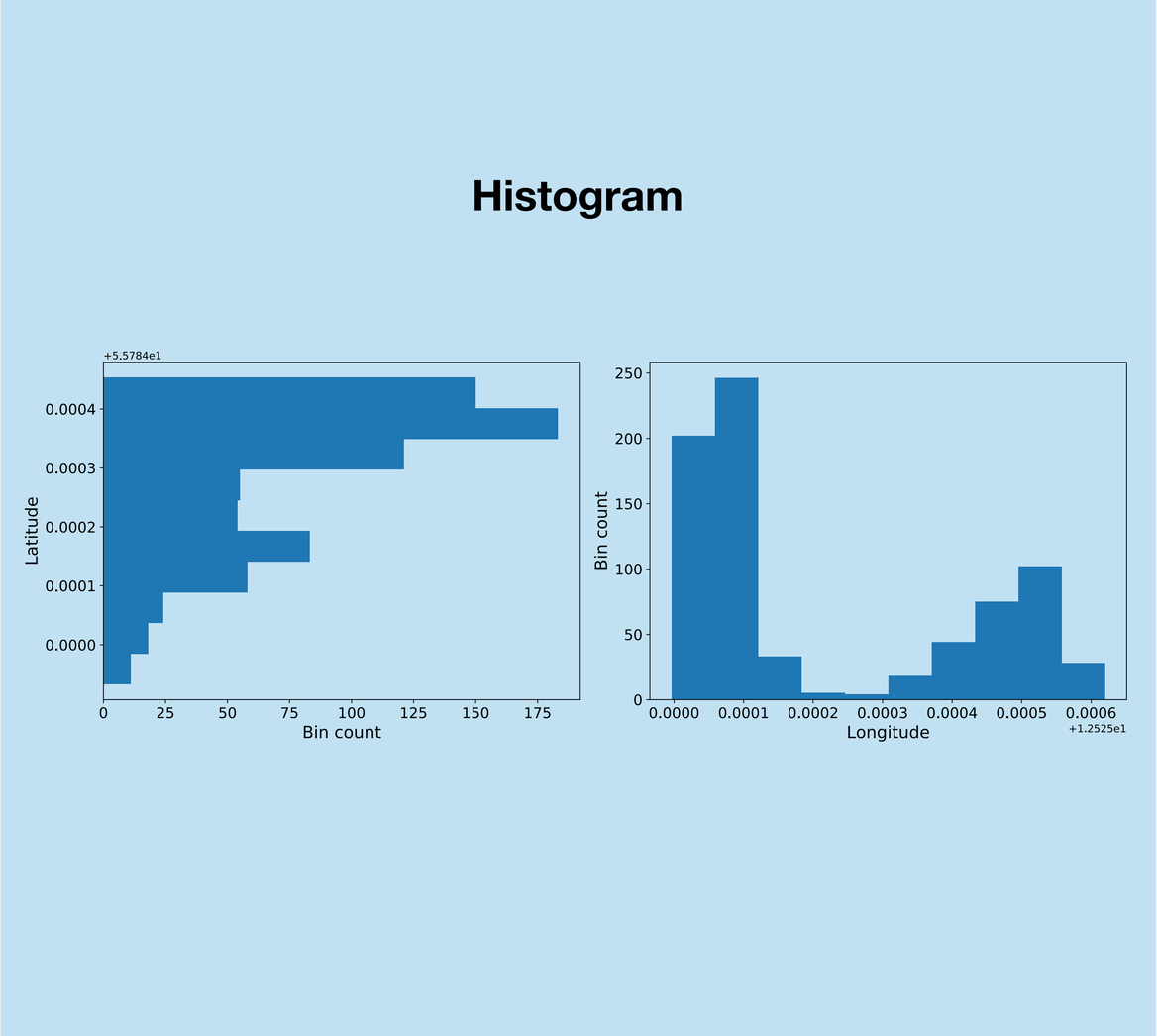

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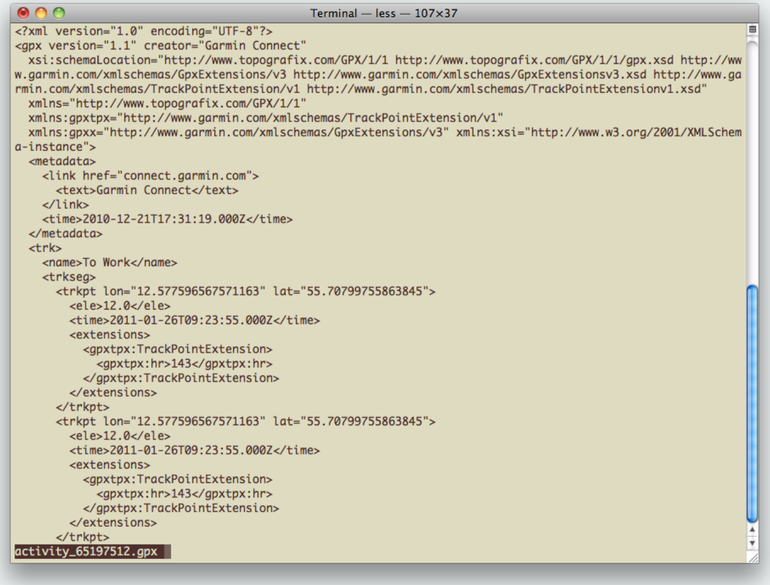


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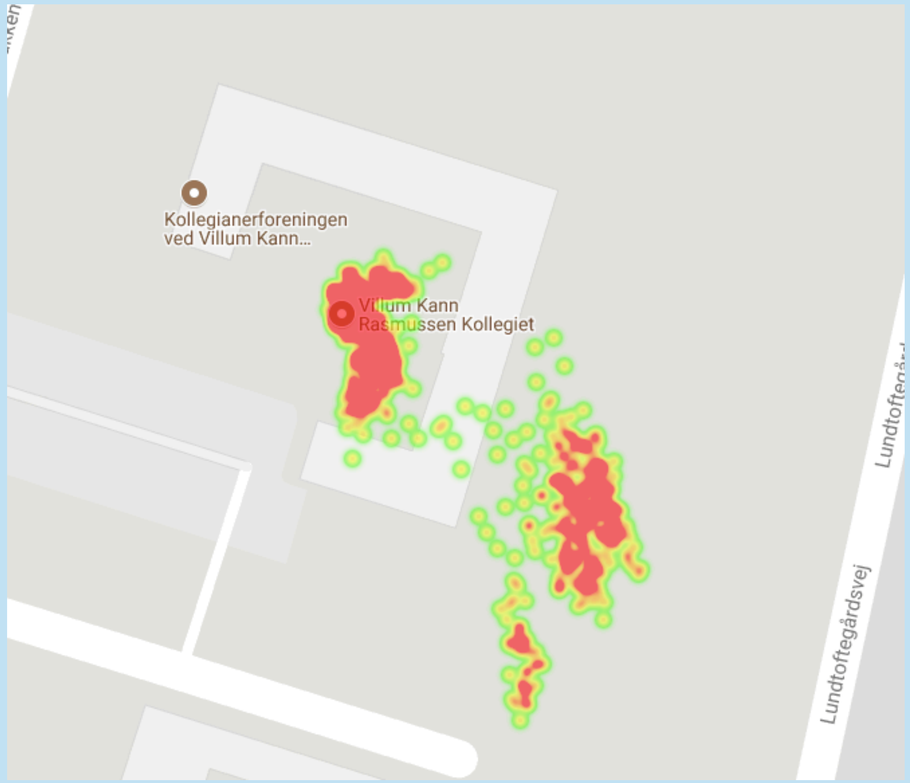
→

Heatmap



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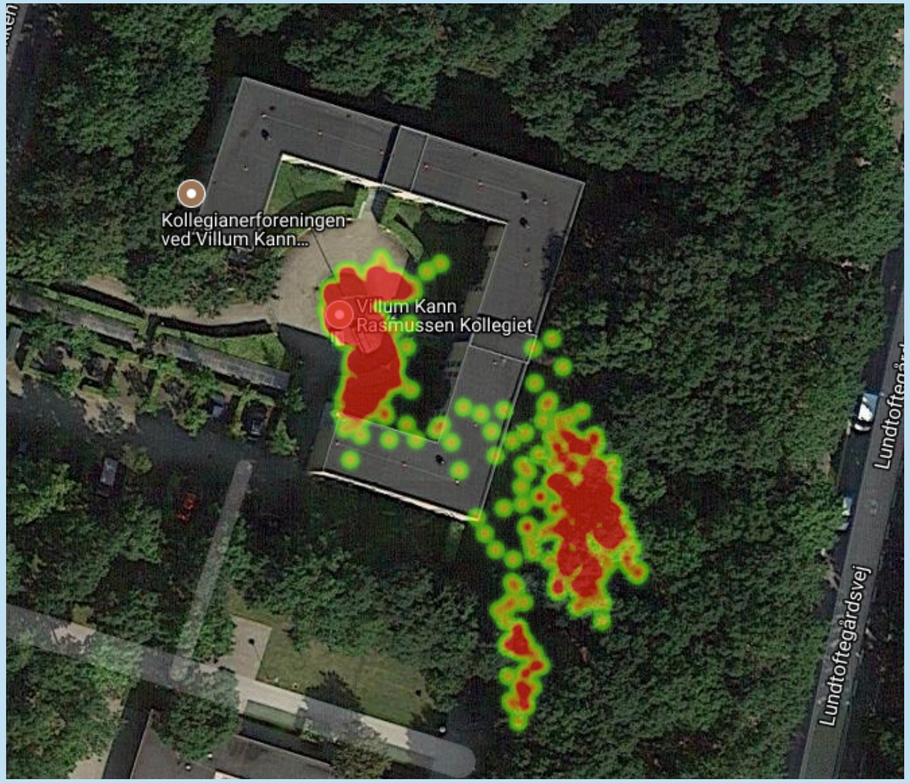
        </extensions>
      </trkpt>
activity_65197512.gpx
```

→

	lat	lon
0	55.784332	12.525468
1	55.784437	12.525030
2	55.784435	12.525043
3	55.784224	12.525565
4	55.784437	12.525031
5	55.784411	12.525055
6	55.784397	12.525070
7	55.784215	12.525537
8	55.784416	12.525059
9	55.784147	12.525530
10	55.784417	12.525063
11	55.784222	12.525535
12	55.784415	12.525052
13	55.784152	12.525590
14	55.784411	12.525054
15	55.784387	12.525093
16	55.784255	12.525532
17	55.784406	12.525060
18	55.784402	12.525065
19	55.784353	12.525407
20	55.784414	12.525059
21	55.784220	12.525534
22	55.784410	12.525083
23	55.784192	12.525557
24	55.784406	12.525053
25	55.784411	12.525060
26	55.784243	12.525500
27	55.784400	12.525066
28	55.784408	12.525056
29	55.784168	12.525580
...	...	...

→

Heatmap



Data must be rendered in human-friendly format

Terminal — less — 107×37

```
<?xml version="1.0" encoding="UTF-8"?>
<gpx version="1.1" creator="Garmin Connect"
  xsi:schemaLocation="http://www.topografix.com/GPX/1/1 http://www.topografix.com/GPX/1/1/gpx.xsd http://ww
w.garmin.com/xmlschemas/GpxExtensions/v3 http://www.garmin.com/xmlschemas/GpxExtensionsv3.xsd http://www.ga
rmin.com/xmlschemas/TrackPointExtension/v1 http://www.garmin.com/xmlschemas/TrackPointExtensionv1.xsd"
  xmlns="http://www.topografix.com/GPX/1/1"
  xmlns:gpxtpx="http://www.garmin.com/xmlschemas/TrackPointExtension/v1"
  xmlns:gpxx="http://www.garmin.com/xmlschemas/GpxExtensions/v3" xmlns:xsi="http://www.w3.org/2001/XMLSchem
a-instance">
  <metadata>
    <link href="connect.garmin.com">
      <text>Garmin Connect</text>
    </link>
    <time>2010-12-21T17:31:19.000Z</time>
  </metadata>
  <trk>
    <name>To Work</name>
    <trkseg>
      <trkpt lon="12.577596567571163" lat="55.70799755863845">
        <ele>12.0</ele>
        <time>2011-01-26T09:23:55.000Z</time>
        <extensions>
          <gpxtpx:TrackPointExtension>
            <gpxtpx:hr>143</gpxtpx:hr>
          </gpxtpx:TrackPointExtension>
        </extensions>
      </trkpt>
      <trkpt lon="12.577596567571163" lat="55.70799755863845">
        <ele>12.0</ele>
        <time>2011-01-26T09:23:55.000Z</time>
        <extensions>
          <gpxtpx:TrackPointExtension>
            <gpxtpx:hr>143</gpxtpx:hr>
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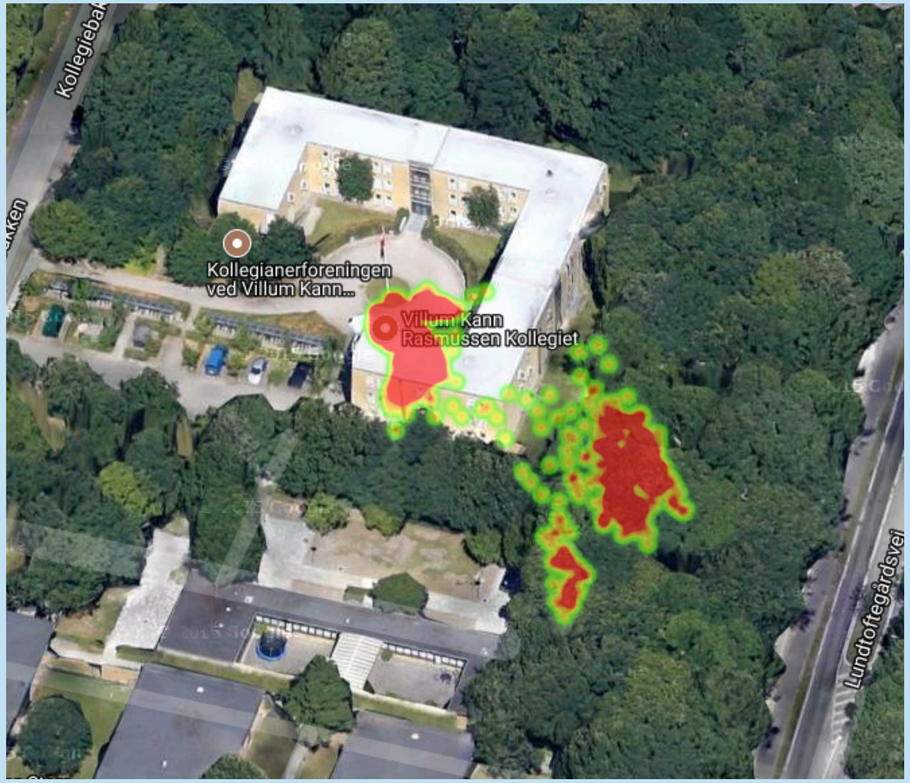
Heatmap



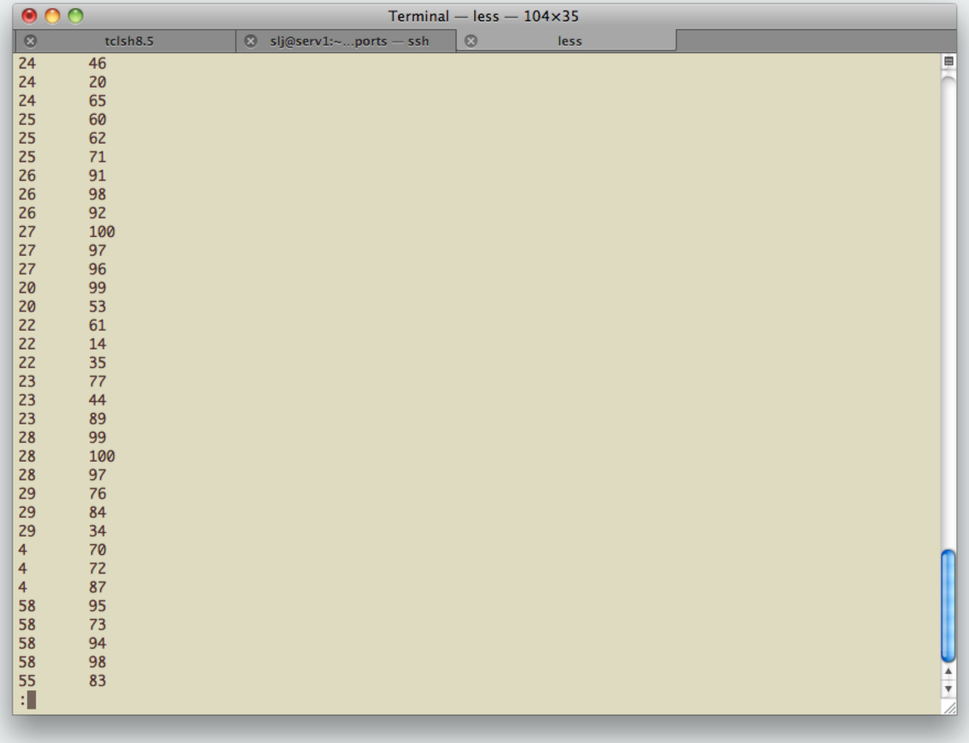
Relational data

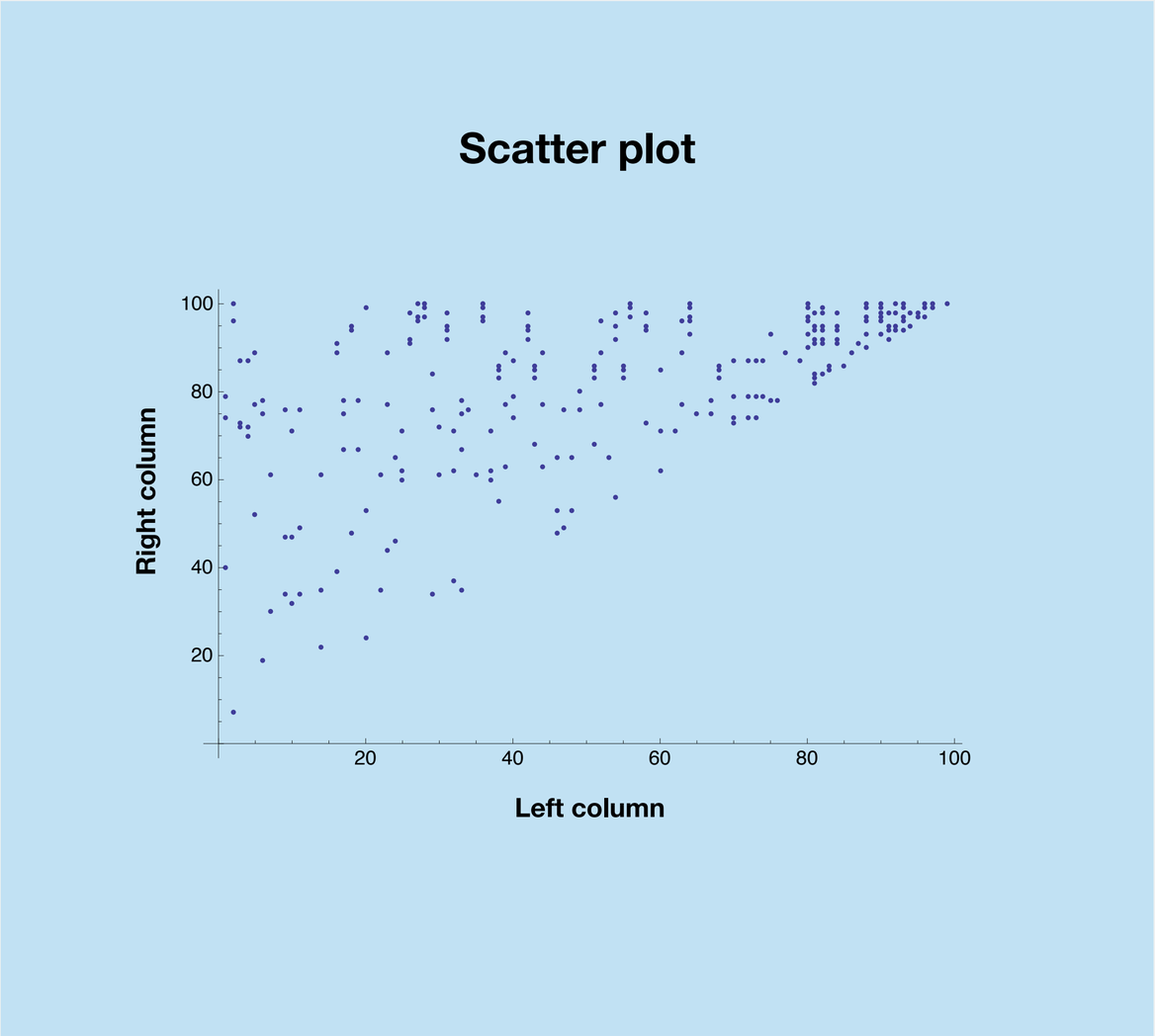
Terminal — less — 104×35

tclsh8.5 | slj@serv1:~...ports — ssh | less

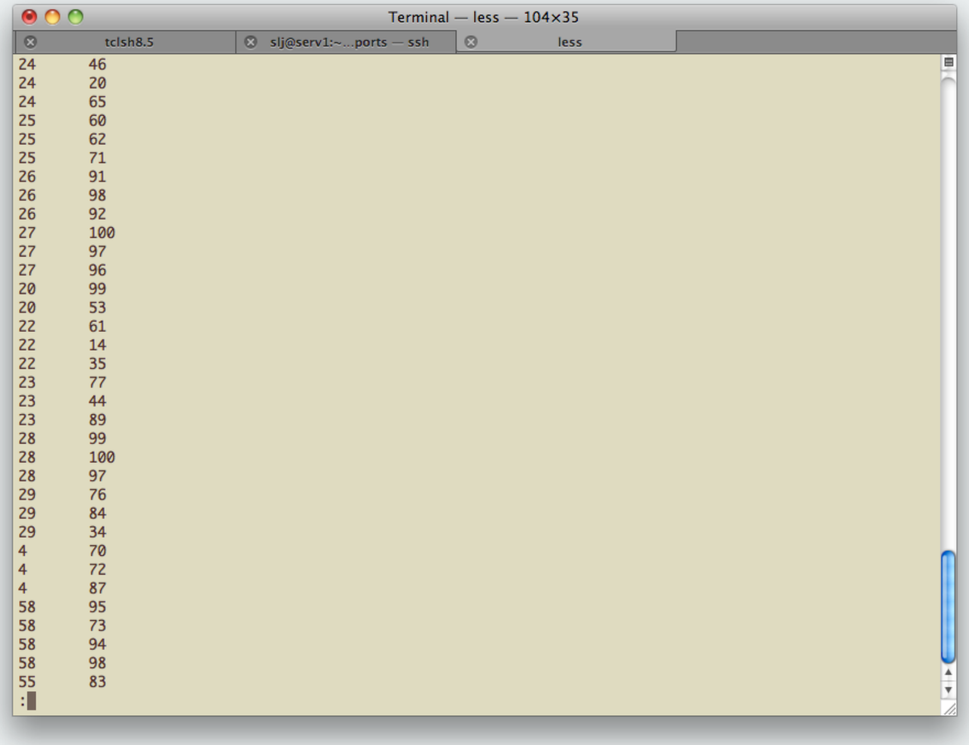
```
24      46
24      20
24      65
25      60
25      62
25      71
26      91
26      98
26      92
27      100
27      97
27      96
20      99
20      53
22      61
22      14
22      35
23      77
23      44
23      89
28      99
28      100
28      97
29      76
29      84
29      34
4       70
4       72
4       87
58      95
58      73
58      94
58      98
55      83
:
```

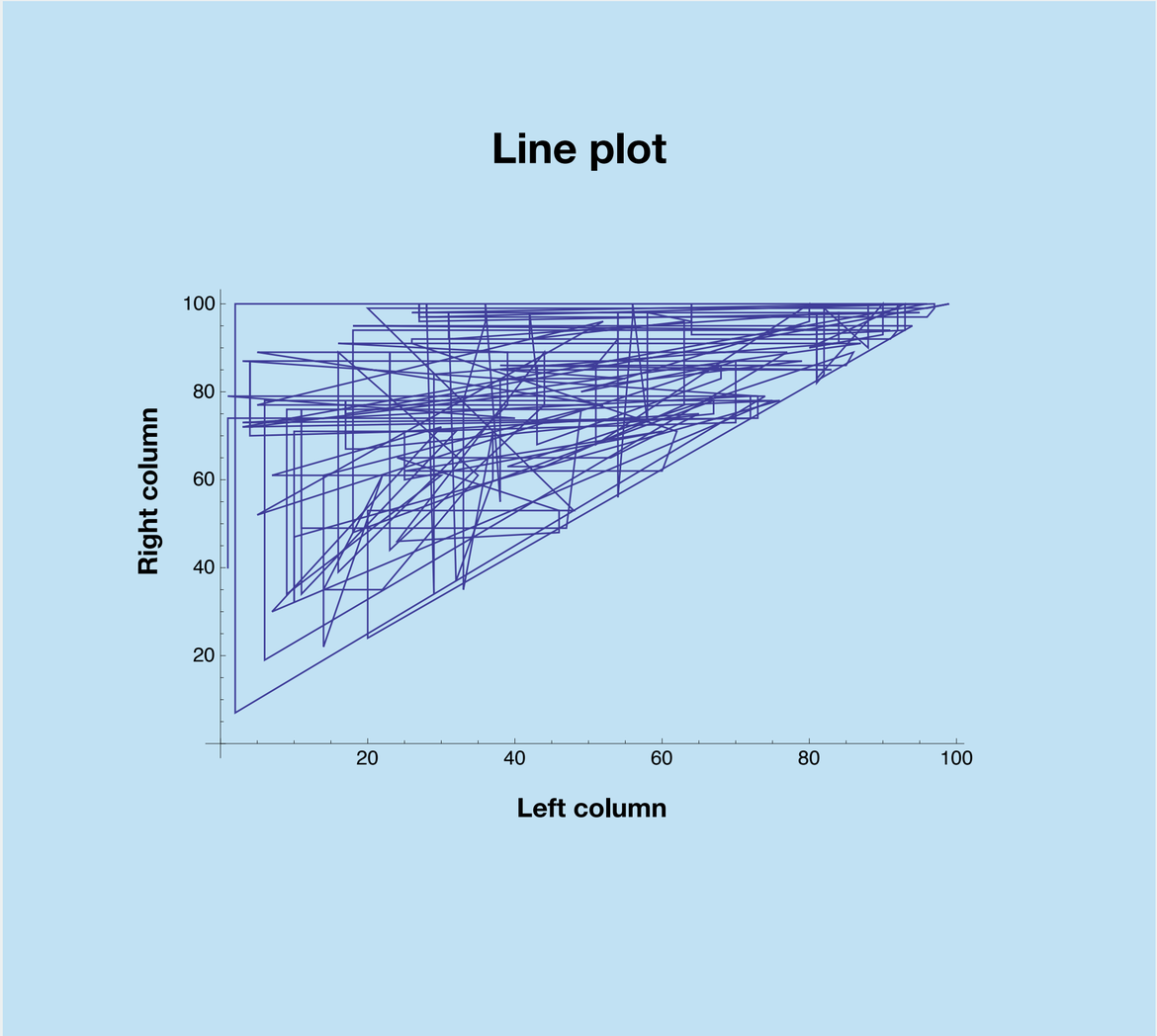
Relational data



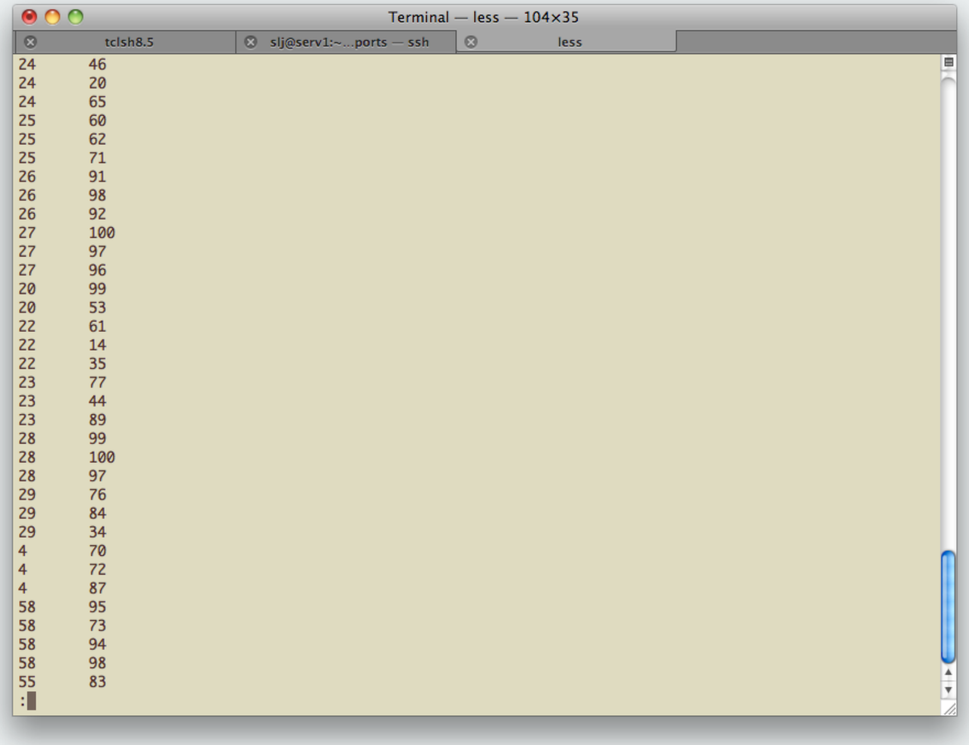


Relational data





Relational data




```
24      46
24      20
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25      71
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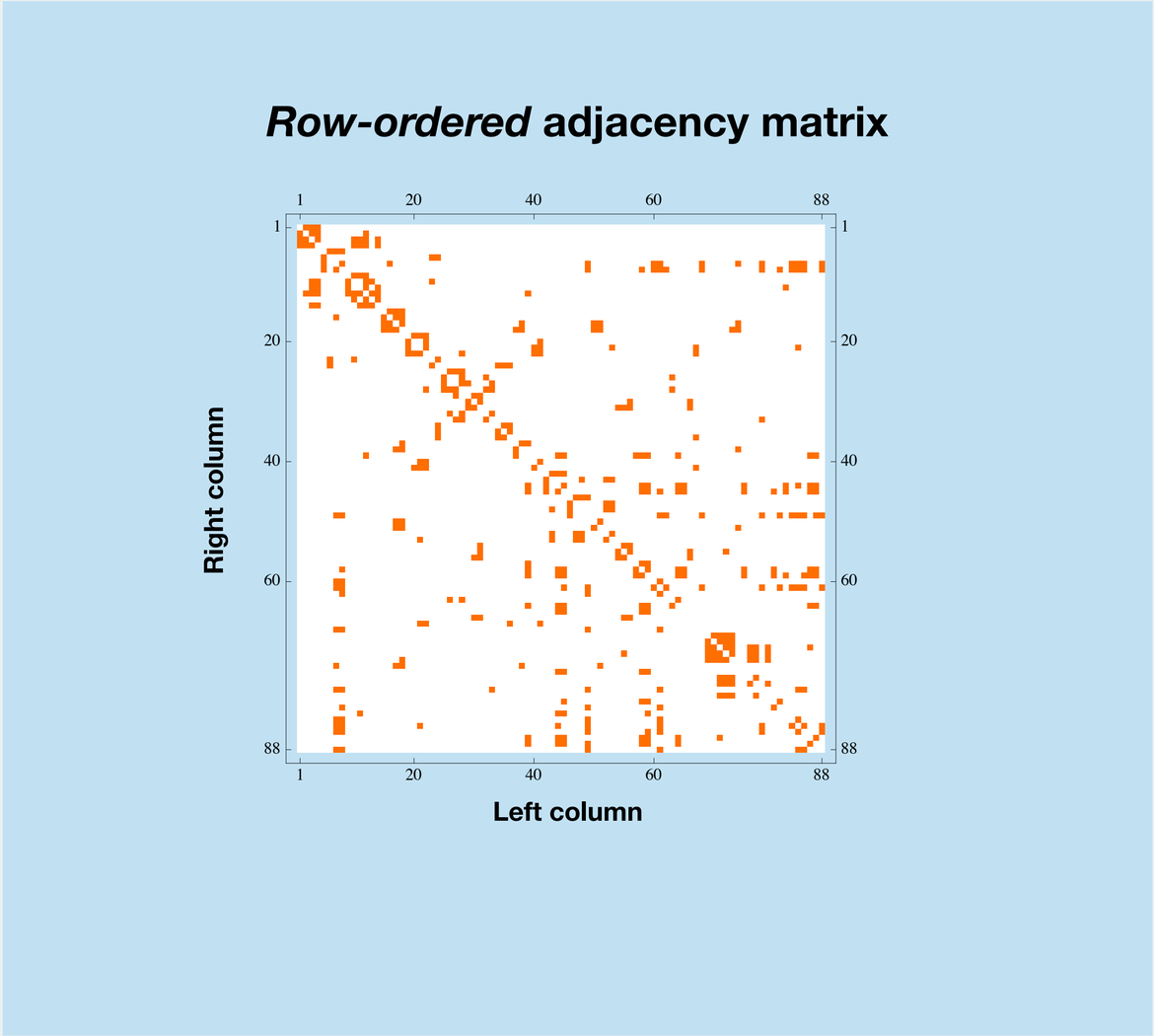
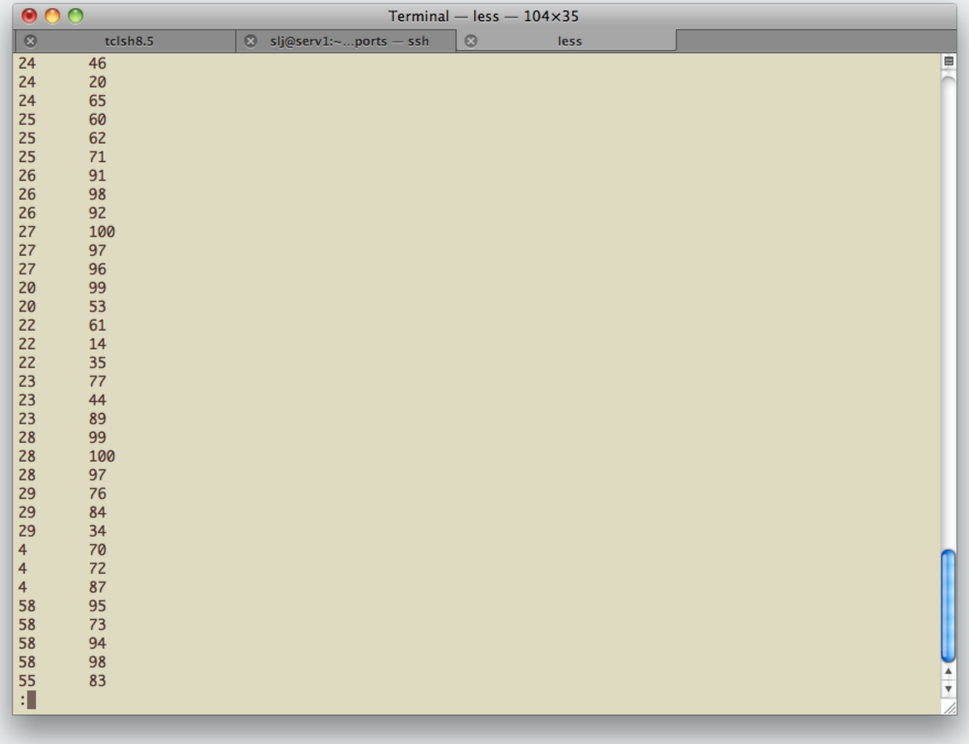
26      92
27      100
27      97
27      96
20      99
20      53
22      61
22      14
22      35
23      77
23      44
23      89
28      99
28      100
28      97
29      76
29      84
29      34
4       70
4       72
4       87
58      95
58      73
58      94
58      98
55      83
:
```

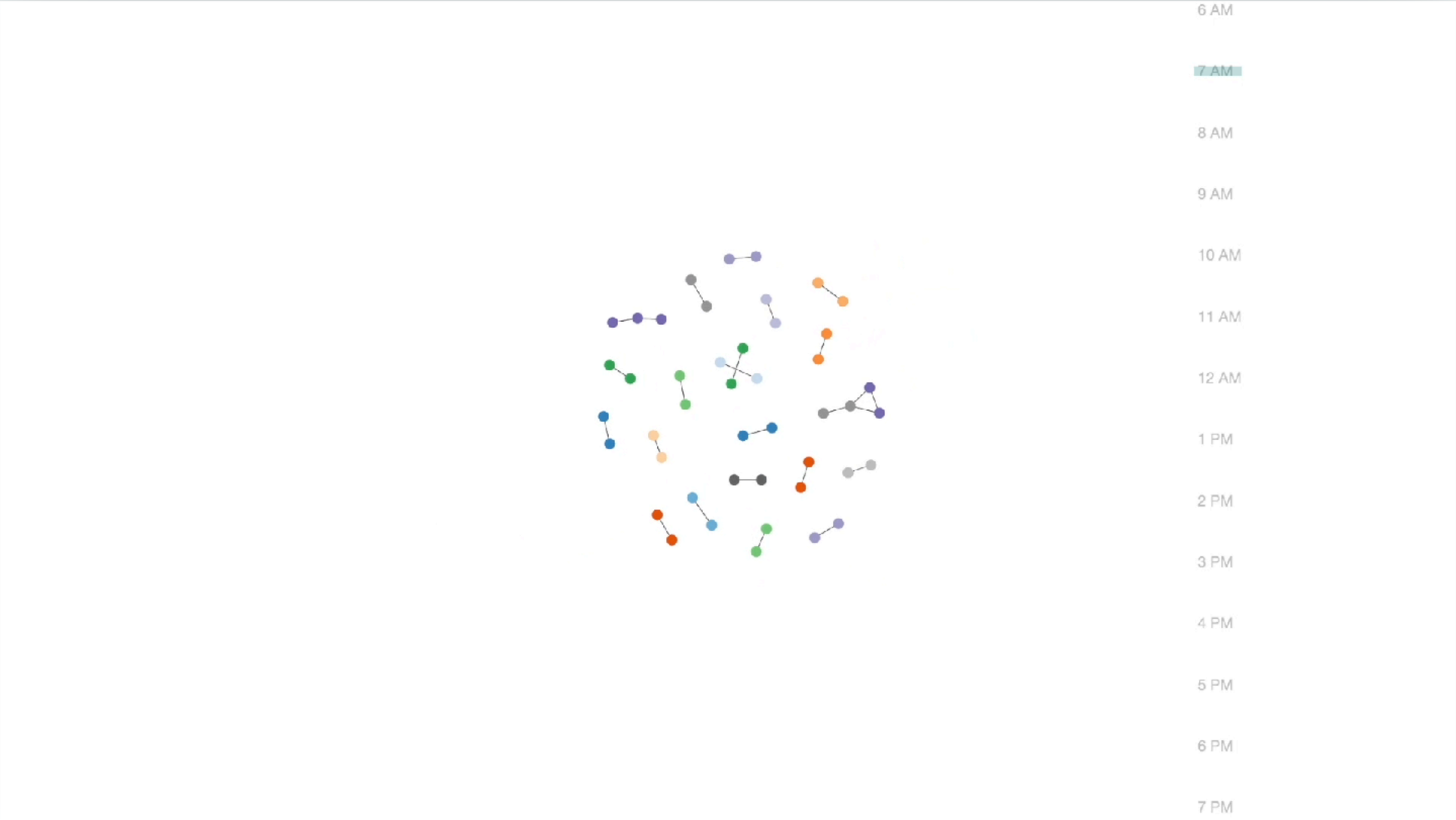


Relational data



Network

Very complex data that changes in time!



link

link

Most fancy visualizations break down to very simple things

For understanding how data is distributed

- Histograms
- Kernel density plots
- Box plots/violin plots
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For understanding interrelations in highly connected data

- Networks

Linear algebra

Linear algebra

A principled and scalable method for manipulating data

Linear algebra

A principled and scalable method for manipulating data

Objects

- Scalars
- Vectors
- Matrices

Everything is a Tensor!

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scalar

0D

```
In [2]: print np.random.randint(1, 100)
Last executed 2018-01-25 11:52:52 in 5ms
82
```

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In [2]: print np.random.randint(1, 100)
Last executed 2018-01-25 11:52:52 in 5ms
82
```

vector

1D

```
In [3]: print np.random.randint(1, 100, size=3)
Last executed 2018-01-25 11:53:37 in 5ms
[83 80 84]
```

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matrix

2D

```
In [4]: print np.random.randint(1, 100, size=(3, 3))
Last executed 2018-01-25 11:54:38 in 4ms
[[99 47 77]
 [15 82  9]
 [59 55 48]]
```

scalar

0D

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```

matrix

2D

```
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Last executed 2018-01-25 11:54:38 in 4ms
[[99 47 77]
 [15 82  9]
 [59 55 48]]
```

3D–tensor

3D

```
In [5]: print np.random.randint(1, 100, size=(3, 3, 3))
Last executed 2018-01-25 11:55:19 in 5ms
[[[45 11 73]
  [84 50 88]
  [13 22 97]]

 [[10  5 12]
  [27 23 76]
  [43 84 53]]

 [[86 58 61]
  [71 95 86]
  [92 19 68]]]
```

Linear algebra

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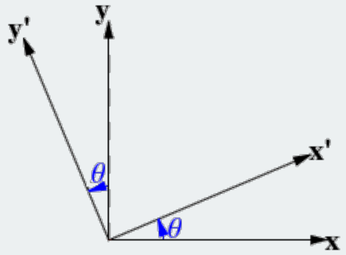
Operations

- Products: ***dot***, *cross*
- Elementwise: *addition*, *subtraction*, *multiplication*, *division*
- Mutations: *transpose*, *inverse/pseudo-inverse*, *scaling*, *rotation*

$$\begin{bmatrix} a & b & c \\ d & e & f \\ g & h & i \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} ax + by + cz \\ dx + ey + fz \\ gx + hy + iz \end{bmatrix}$$



used frequently for basis transformation

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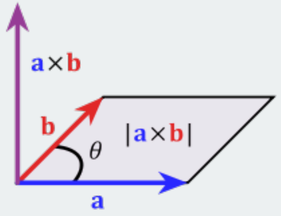

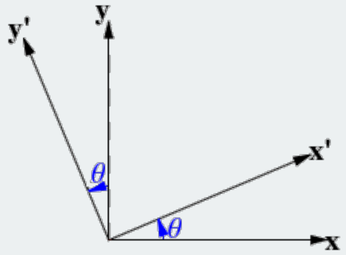

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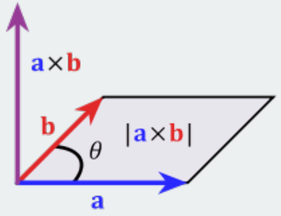

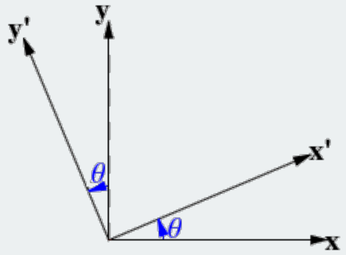

used frequently for basis transformation

$$\begin{bmatrix} a & b & c \\ d & e & f \\ g & h & i \end{bmatrix} \quad \textbf{Original matrix}$$

$$\begin{bmatrix} a & b & c \\ d & e & f \\ g & h & i \end{bmatrix}^T \Rightarrow \begin{bmatrix} a & d & g \\ b & e & h \\ c & f & i \end{bmatrix}$$

Statistics

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A set of tools and jargon for describing data

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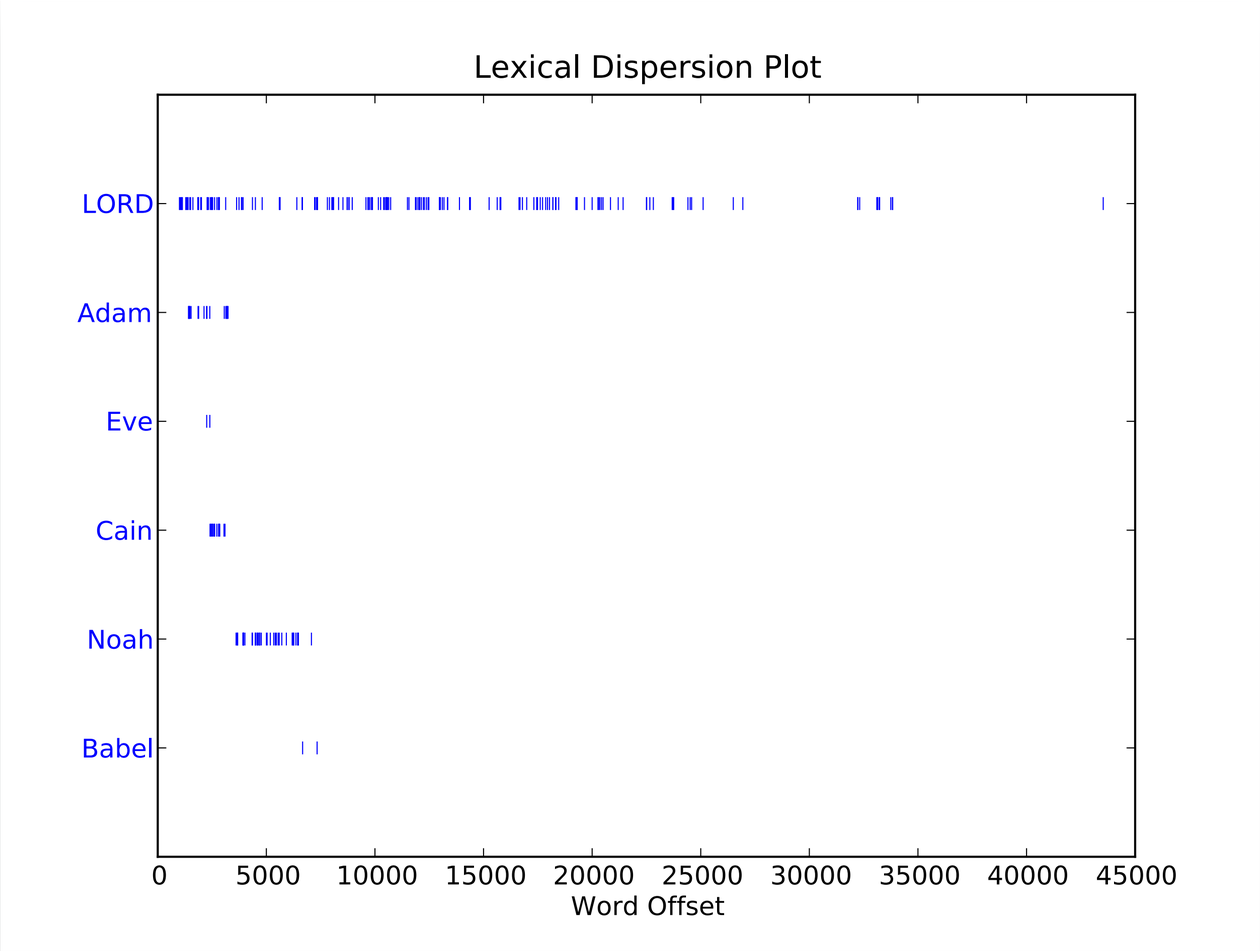

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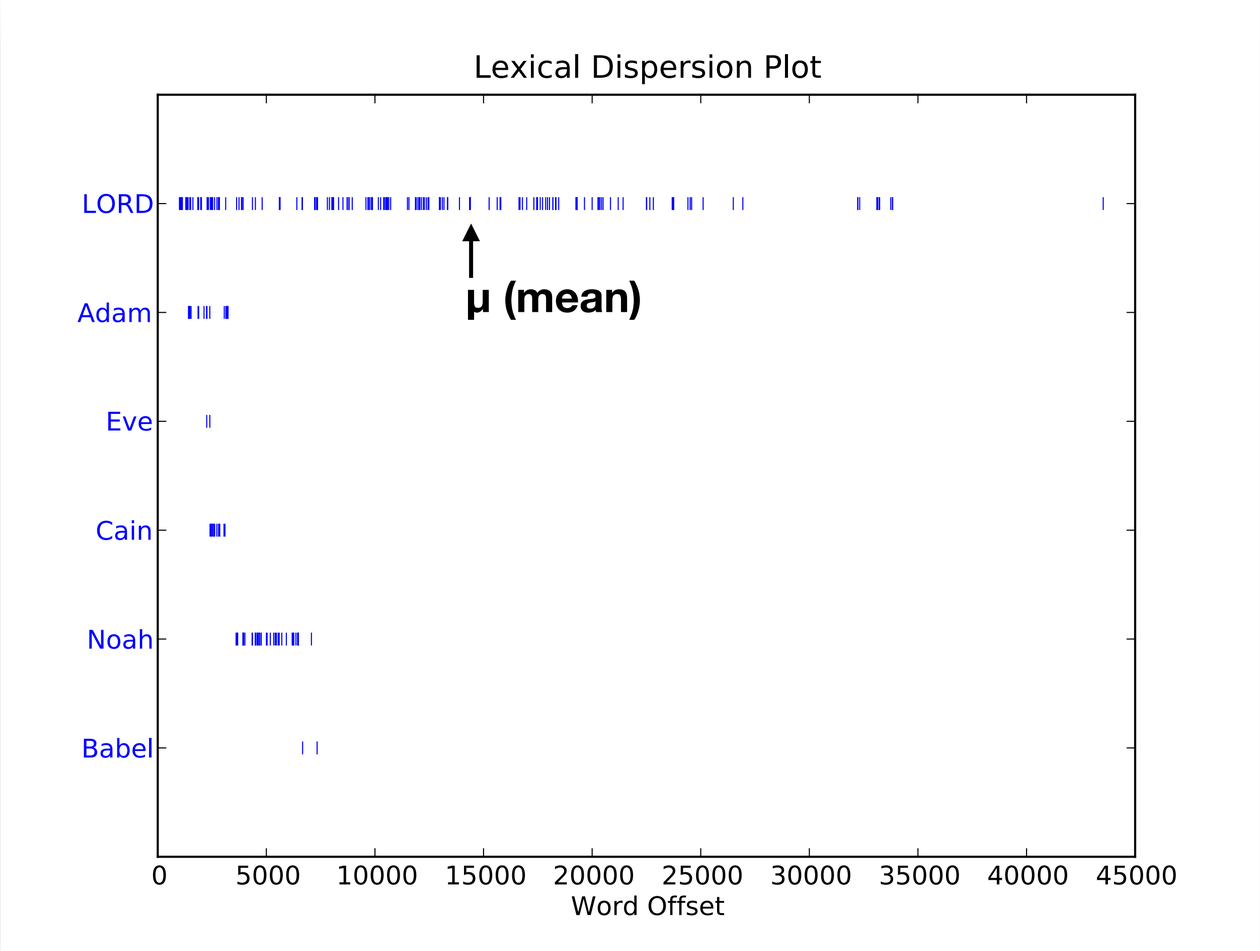
$$\mu = \frac{\textbf{Sum of values}}{\textbf{Number of values}}$$



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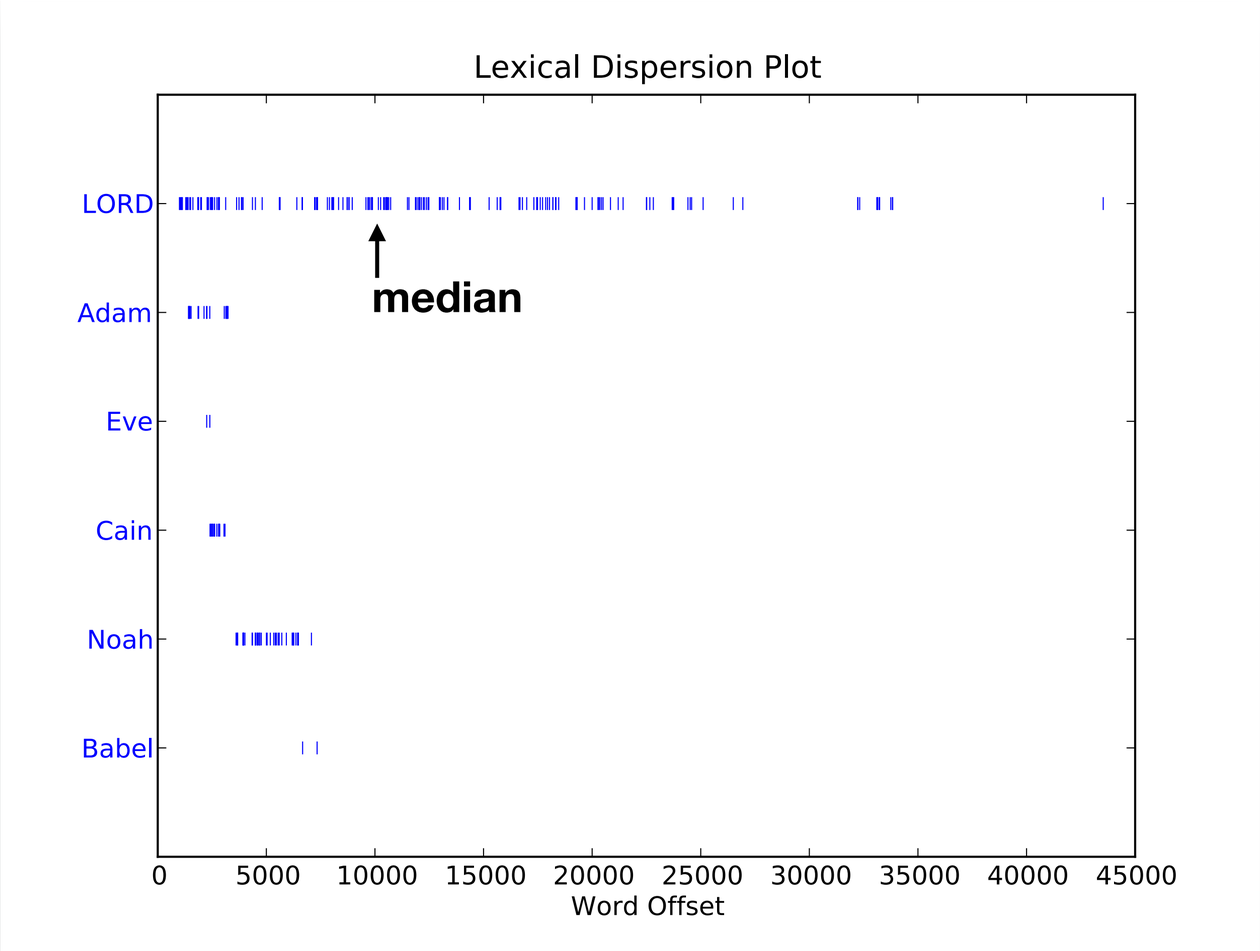
median = Middle number in ordered list



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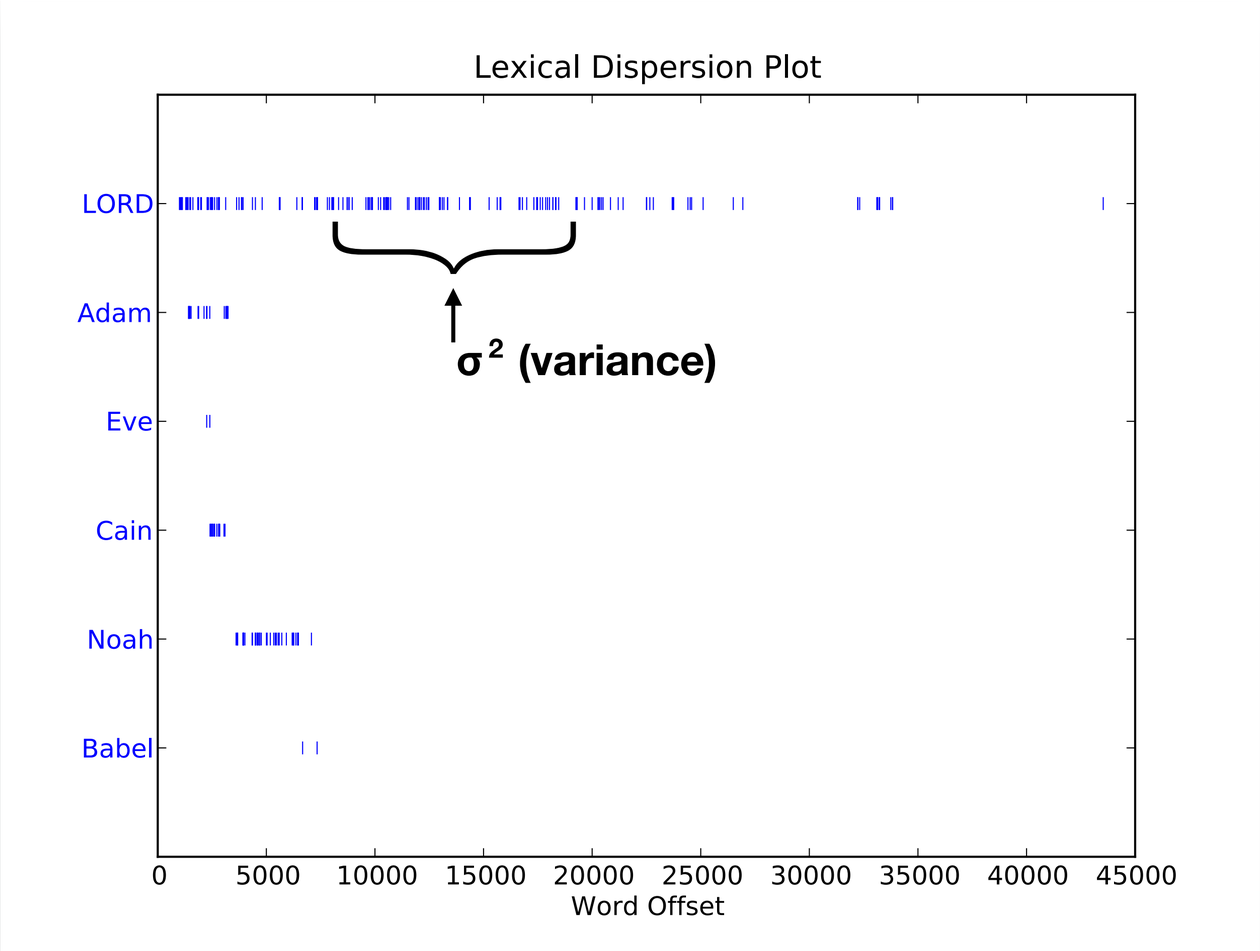
$$\sigma^2 = \frac{1}{N-1} \sum_{i=1}^{n} (x_i - \mu)^2$$



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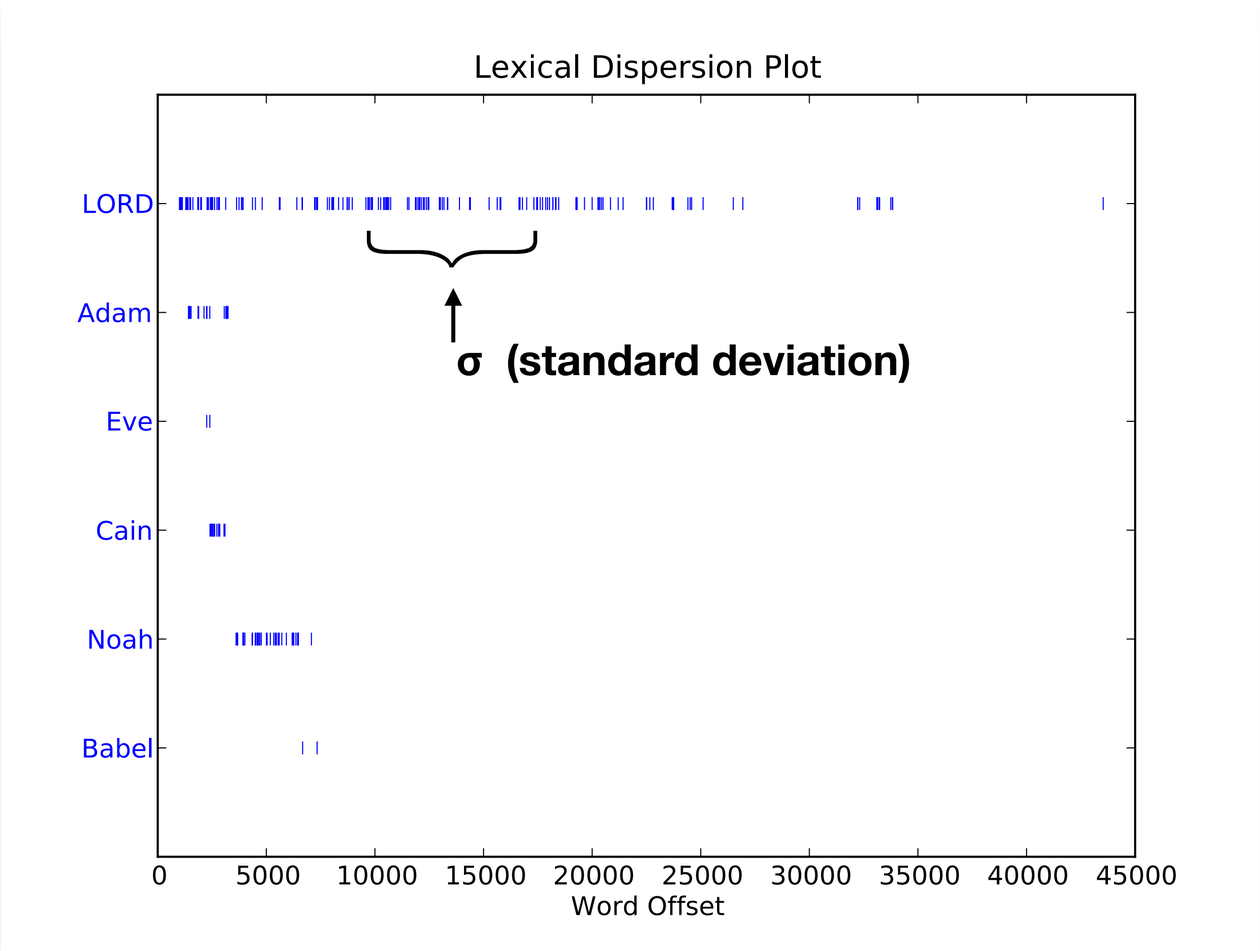
$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{n}(x_i-\mu)^2}$$



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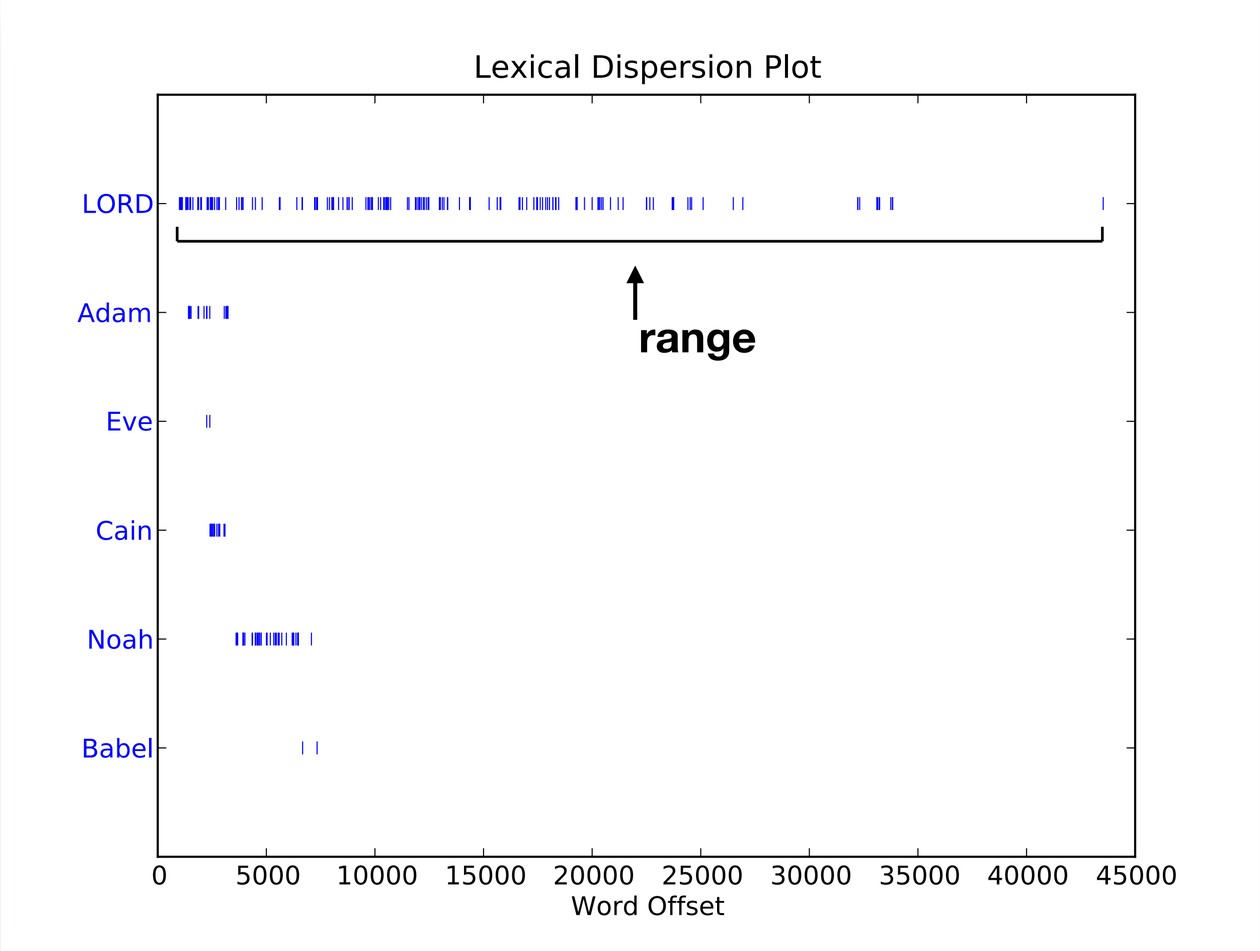
range = max(value) - min(value)



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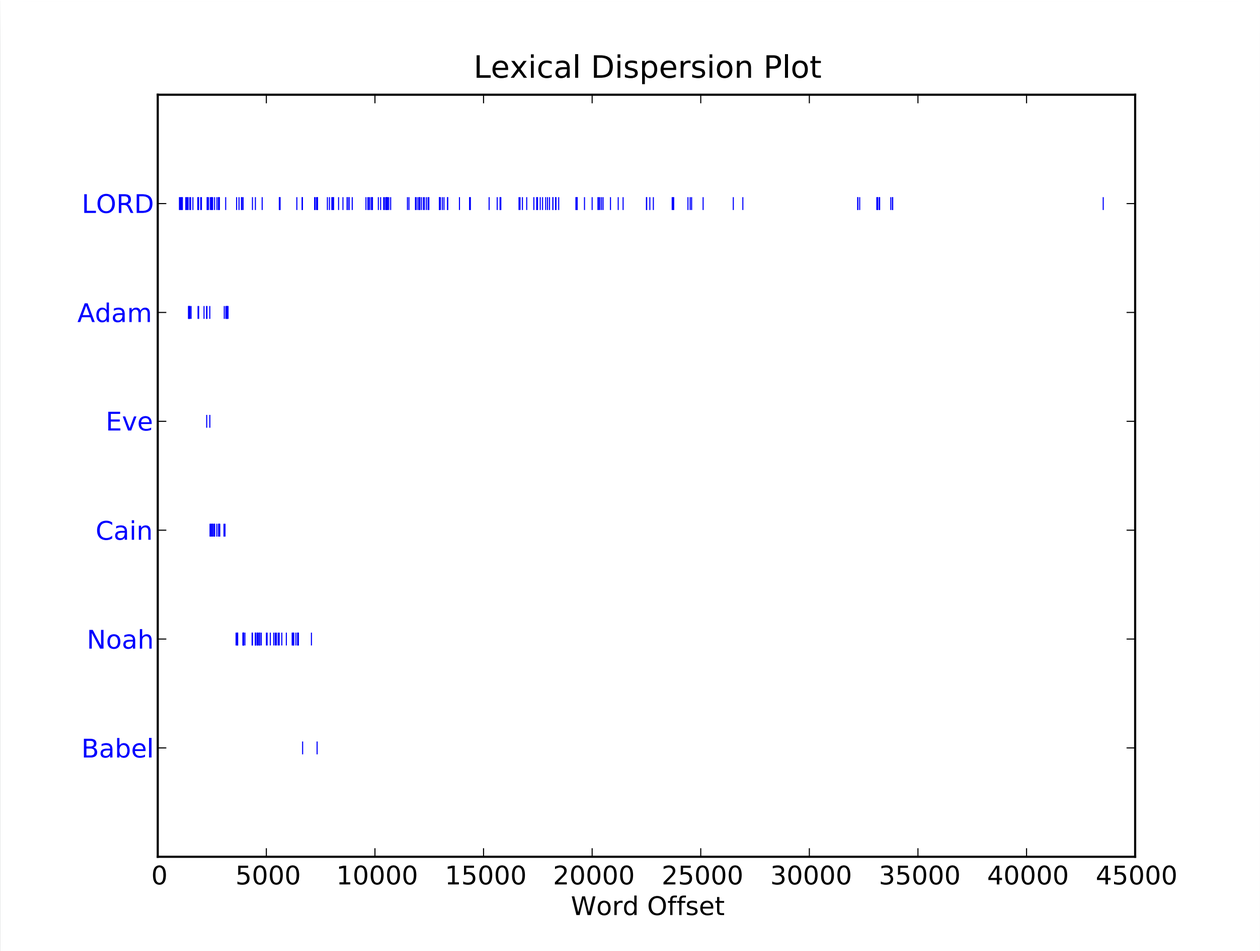
$$\textbf{cov(X, Y)} = \frac{1}{n}\sum_{i=1}^{n}(x_i - \mu_X)(y_i - \mu_y)$$



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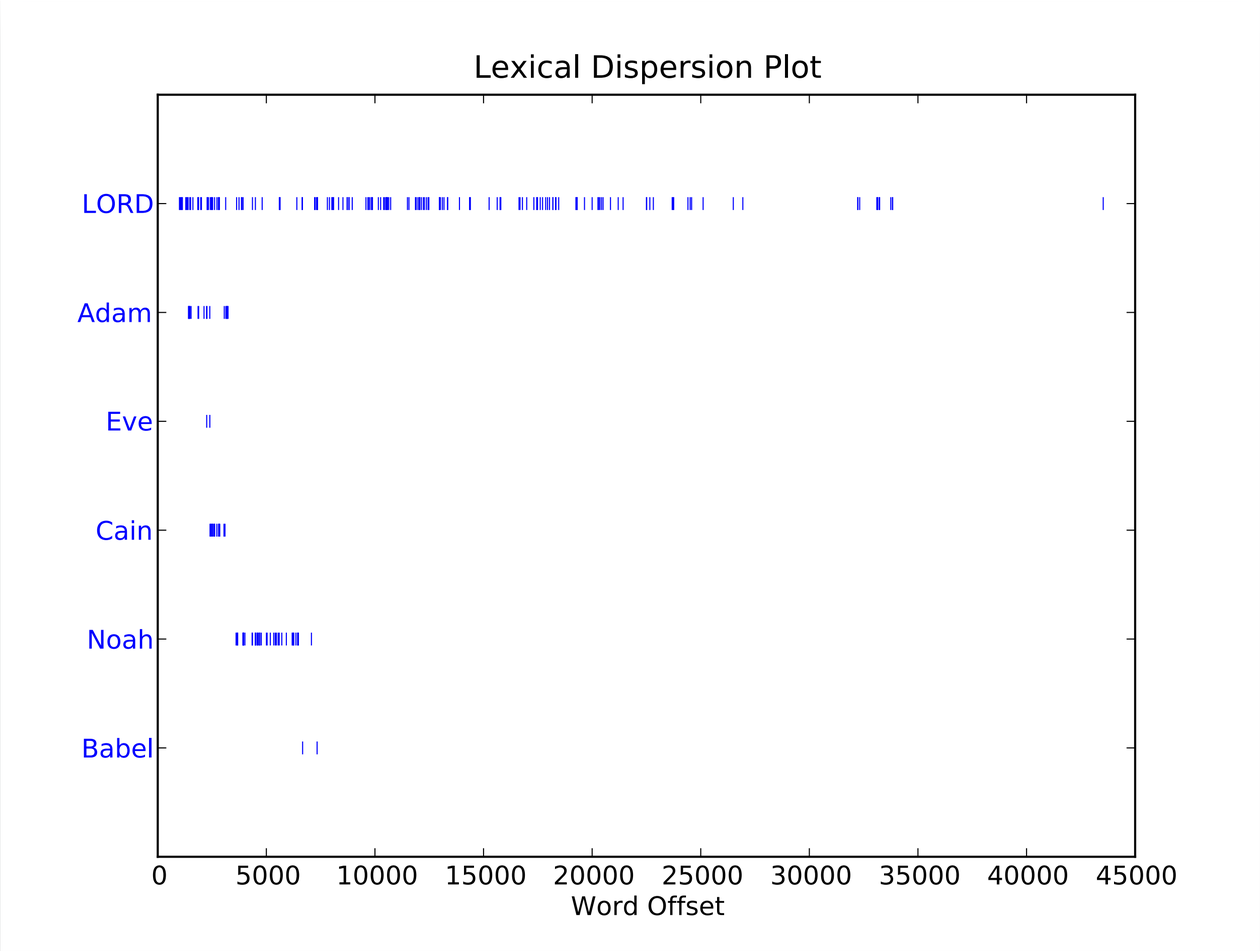
$$\textbf{cor(X, Y)} = \frac{cov(X,Y)}{\sigma_X \sigma_Y}$$



Probability theory

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Formalized framework for dealing with randomness

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Important concepts

- Discrete vs. continuous
- Distribution and process
- Random and stochastic
- Normalization
- Probability functions
  - Probability *mass* function (pmf)
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  - *Cumulative density* function (cdf)

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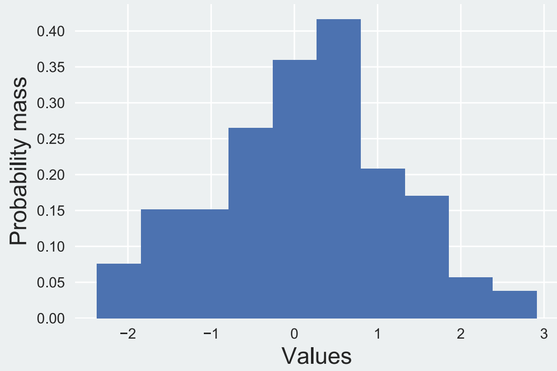
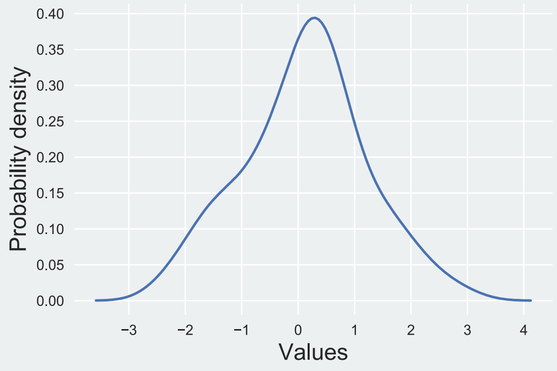
Discrete



Continuous



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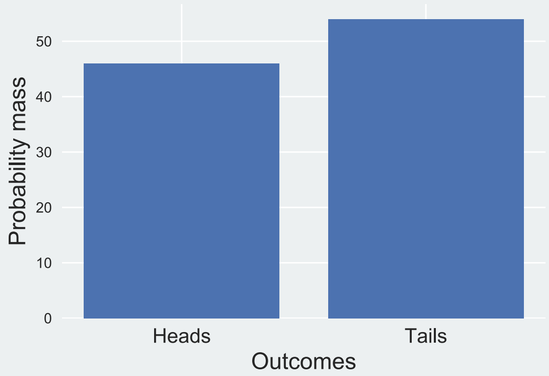
Distribution



Process

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Formalized framework for dealing with randomness

Important concepts

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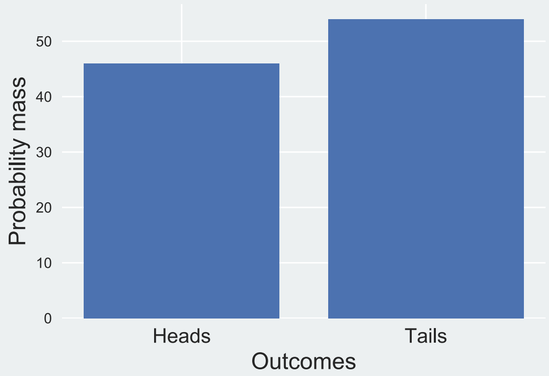
  - *Cumulative density* function (cdf)

A **variable** is *random*



A **process** is *stochastic*

Otherwise the two words mean the same

Probability theory

Formalized framework for dealing with randomness

Important concepts

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- Random and stochastic
- **Normalization**
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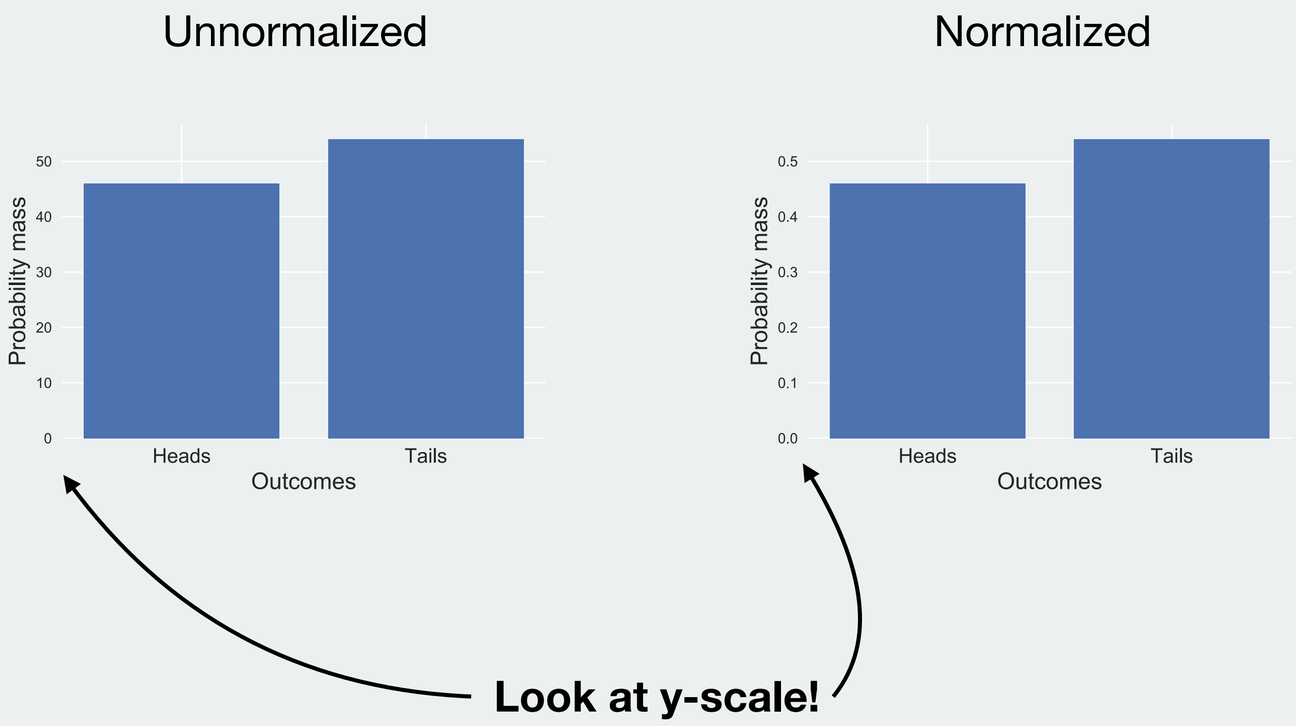
  - Probability *mass* function (pmf)
  - Probability *density* function (pdf)
  - *Cumulative density* function (cdf)



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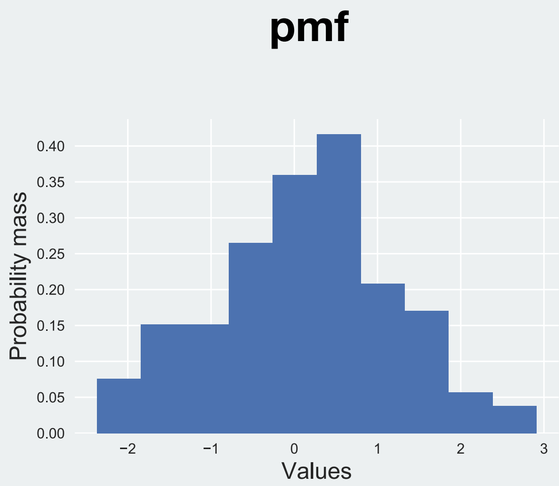

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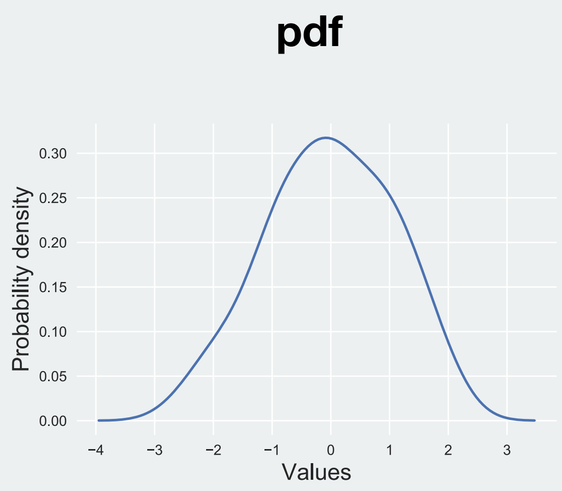

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