

Computational Analysis of Big Data

Week 2

A Data Scientist's most fundamental tools

More specifically: Visualization, linear algebra and statistics

Visualization ○ ○ ○ ○ ○

Linear algebra ○ ○

Statistics ○

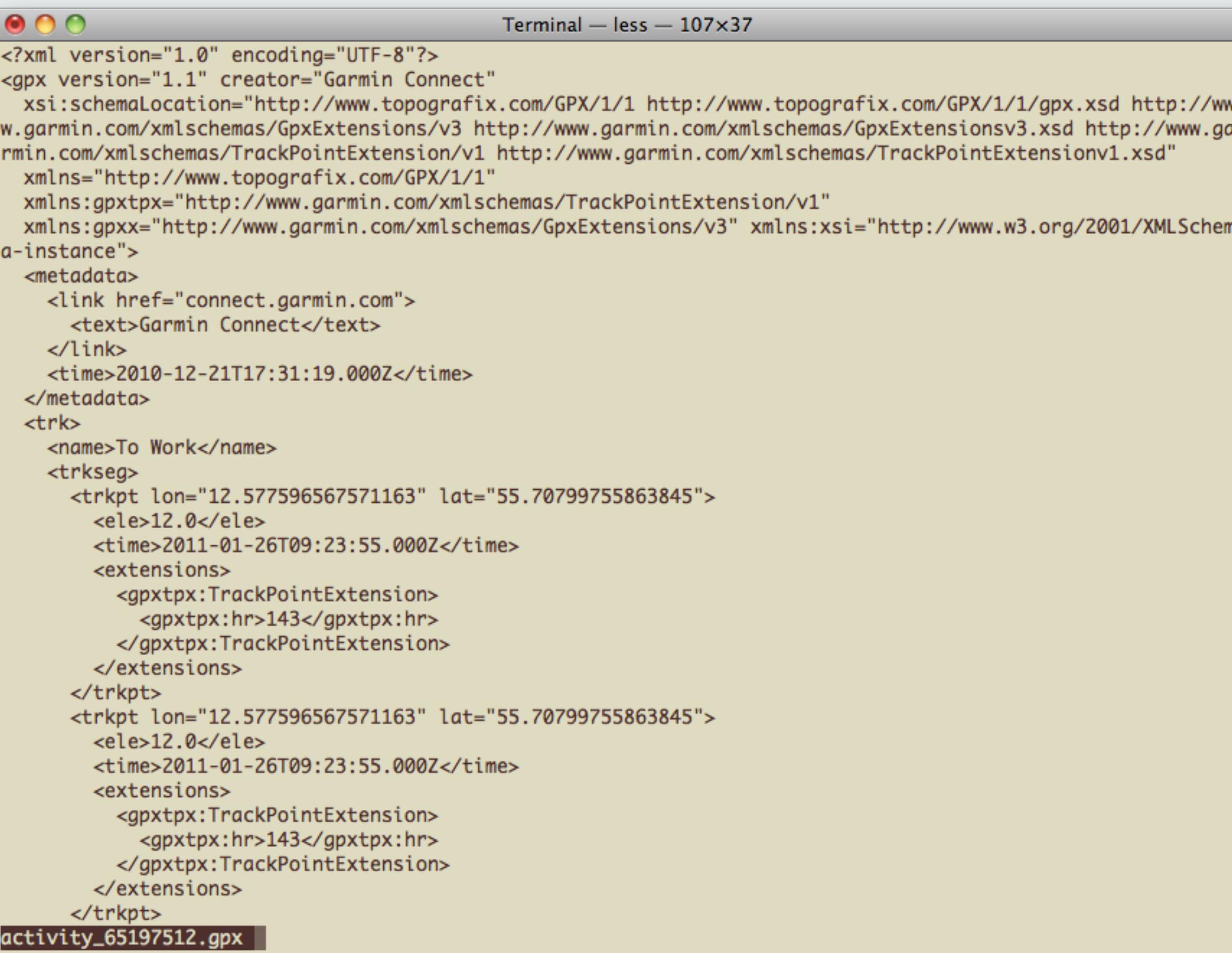
1
1000

1
1000

.

This is data

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



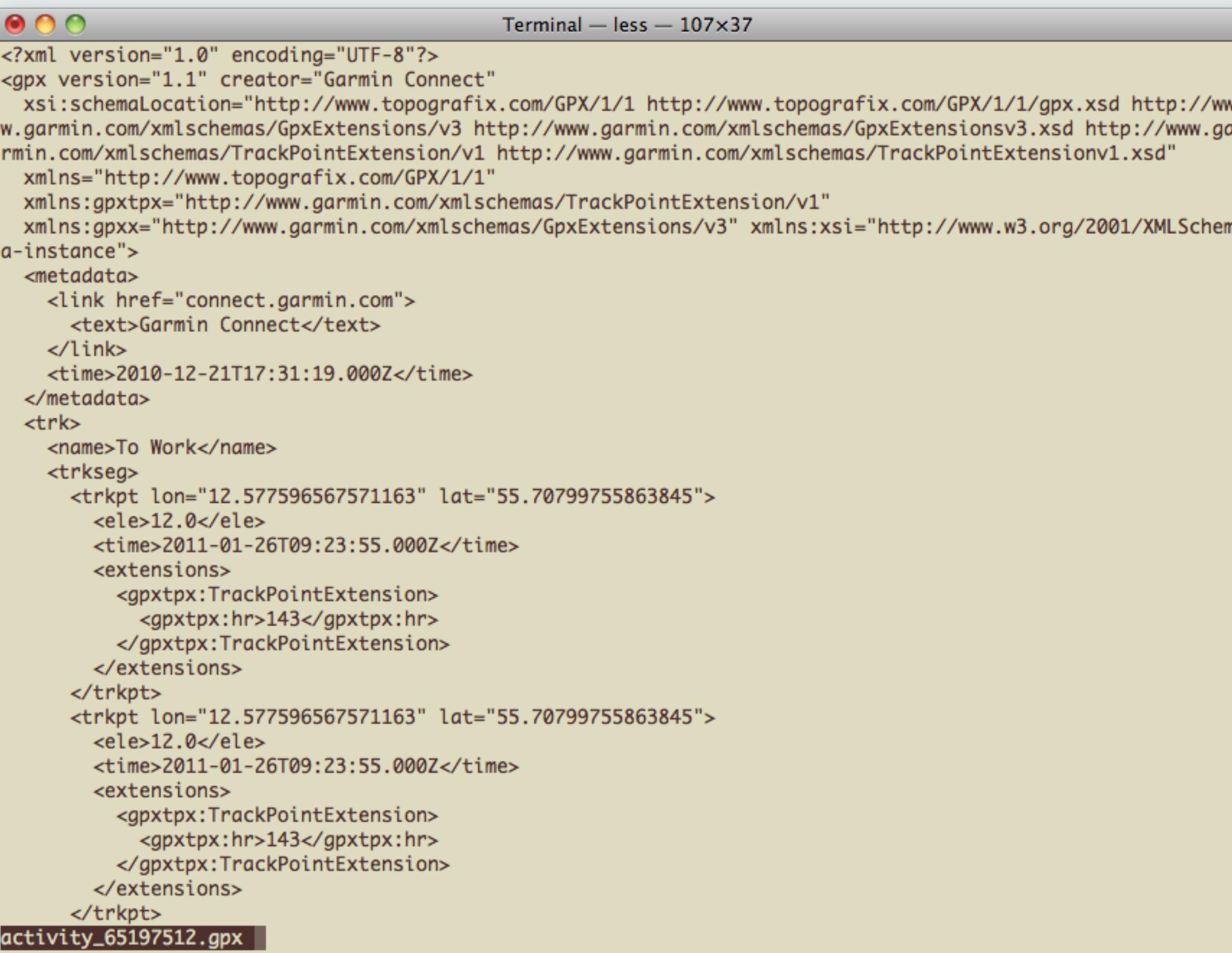
The screenshot shows a terminal window titled "Terminal — less — 107x37". The window displays the contents of a GPX (GPS Exchange Format) XML file named "activity_65197512.gpx". The XML code is as follows:

```
<?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://www.garmin.com/xmlschemas/GpxExtensions/v3 http://www.garmin.com/xmlschemas/GpxExtensionsv3.xsd http://www.garmin.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/XMLSchema-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>
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            <gpxtpx:hr>143</gpxtpx:hr>
          </gpxtpx:TrackPointExtension>
        </extensions>
      </trkpt>
    </trkseg>
  </trk>
</gpx>
```

The terminal window has a scroll bar on the right side. The file name "activity_65197512.gpx" is visible at the bottom of the terminal window.

This is GPS data

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



A screenshot of a terminal window titled "Terminal — less — 107x37". The window displays an XML file named "activity_65197512.gpx". The XML code describes a GPS track with two points. The first point is at coordinates (12.577596567571163, 55.70799755863845) with elevation 12.0 and time 2011-01-26T09:23:55.000Z. It includes a "gpxtpx:TrackPointExtension" element with a "gpxtpx:hr" value of 143. The second point is identical. The file ends with the closing tag of the first point.

```
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<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://www.garmin.com/xmlschemas/GpxExtensions/v3 http://www.garmin.com/xmlschemas/GpxExtensionsv3.xsd http://www.garmin.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"
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        <extensions>
          <gpxtpx:TrackPointExtension>
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          </gpxtpx:TrackPointExtension>
        </extensions>
      </trkpt>
    </trkseg>
  </trk>
</gpx>
```

activity_65197512.gpx

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:

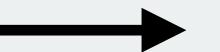
- Immediately **recognize patterns** in highly complex images
- Notice **outliers**
- Process streams of images and recognize **patterns over time**



Data must be rendered in human-friendly format



A screenshot of a Mac OS X terminal window titled "Terminal — less — 107x37". The window displays a large block of XML code representing a GPX file. The XML includes metadata like the creator ("Garmin Connect") and a timestamp ("2010-12-21T17:31:19.000Z"). It also contains track segments with points, each with coordinates (lon, lat), elevation (ele), time, and extensions (gpxtpx:TrackPointExtension). The file is named "activity_65197512.gpx".



?

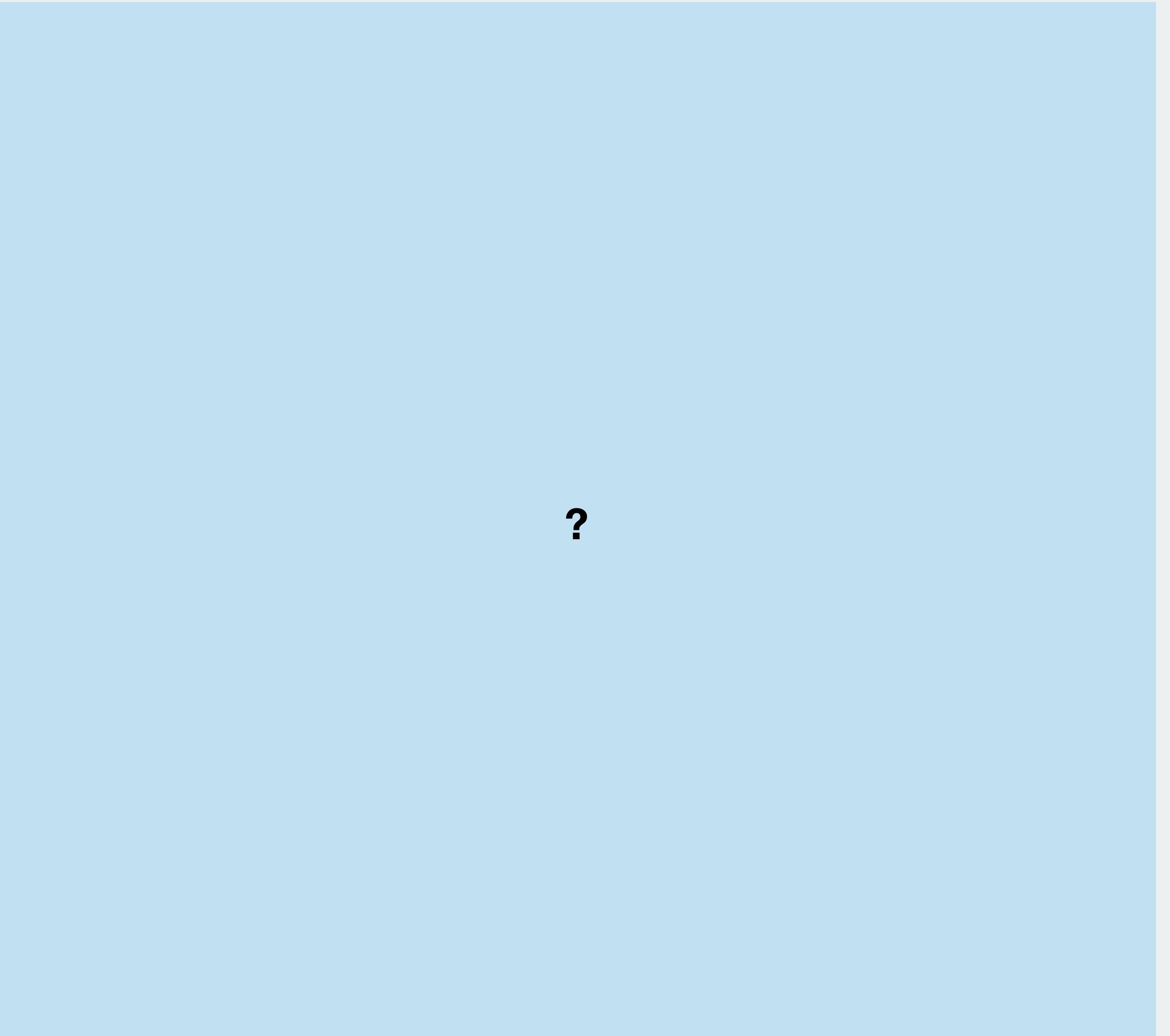
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  xmlns="http://www.topografix.com/GPX/1/1"
  xmlns:gpxpx="http://www.garmin.com/xmlschemas/TrackPointExtension/v1"
  xmlns:gpxx="http://www.garmin.com/xmlschemas/GpxExtensions/v3" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
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  </metadata>
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    <name>To Work</name>
    <trkseg>
      <trkpt lon="12.577596567571163" lat="55.70799755863845">
        <ele>12.0</ele>
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        </extensions>
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      <trkpt lon="12.577596567571163" lat="55.70799755863845">
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          </gpxtpx:TrackPointExtension>
        </extensions>
      </trkpt>
    </trkseg>
  </trk>

```



	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
...



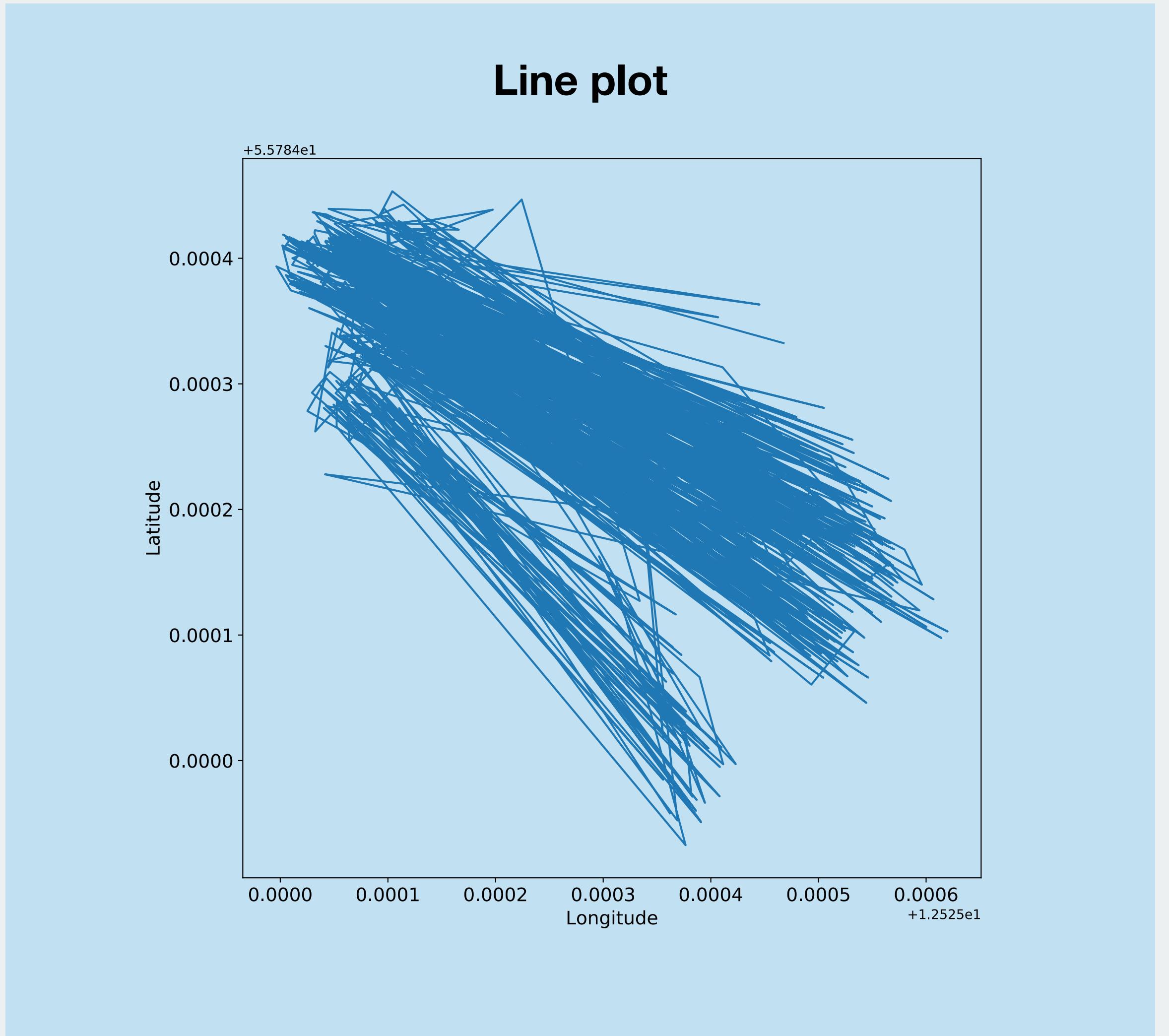
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activity_65197512.gpx

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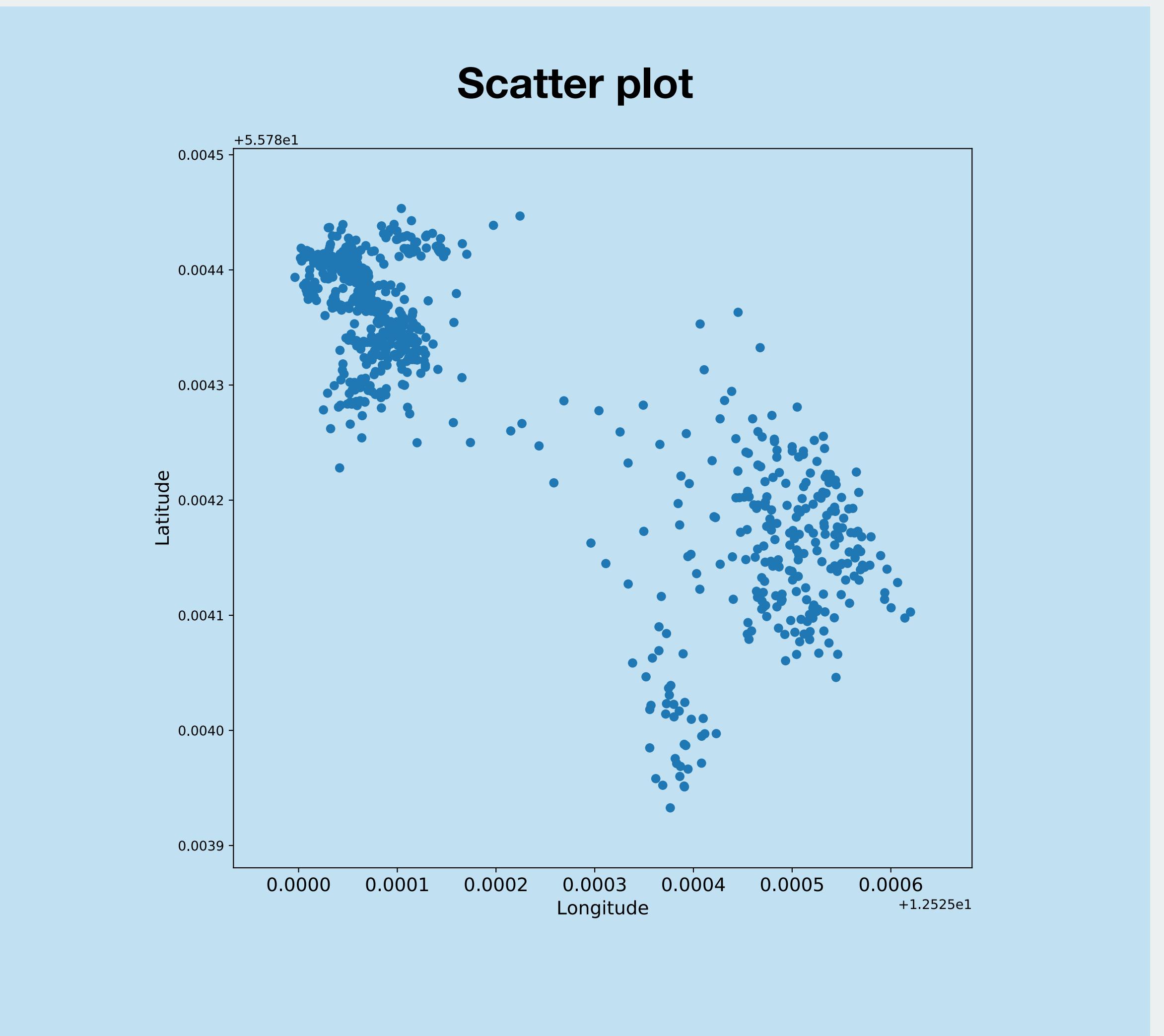
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  xmlns:gpxpx="http://www.garmin.com/xmlschemas/TrackPointExtension/v1"
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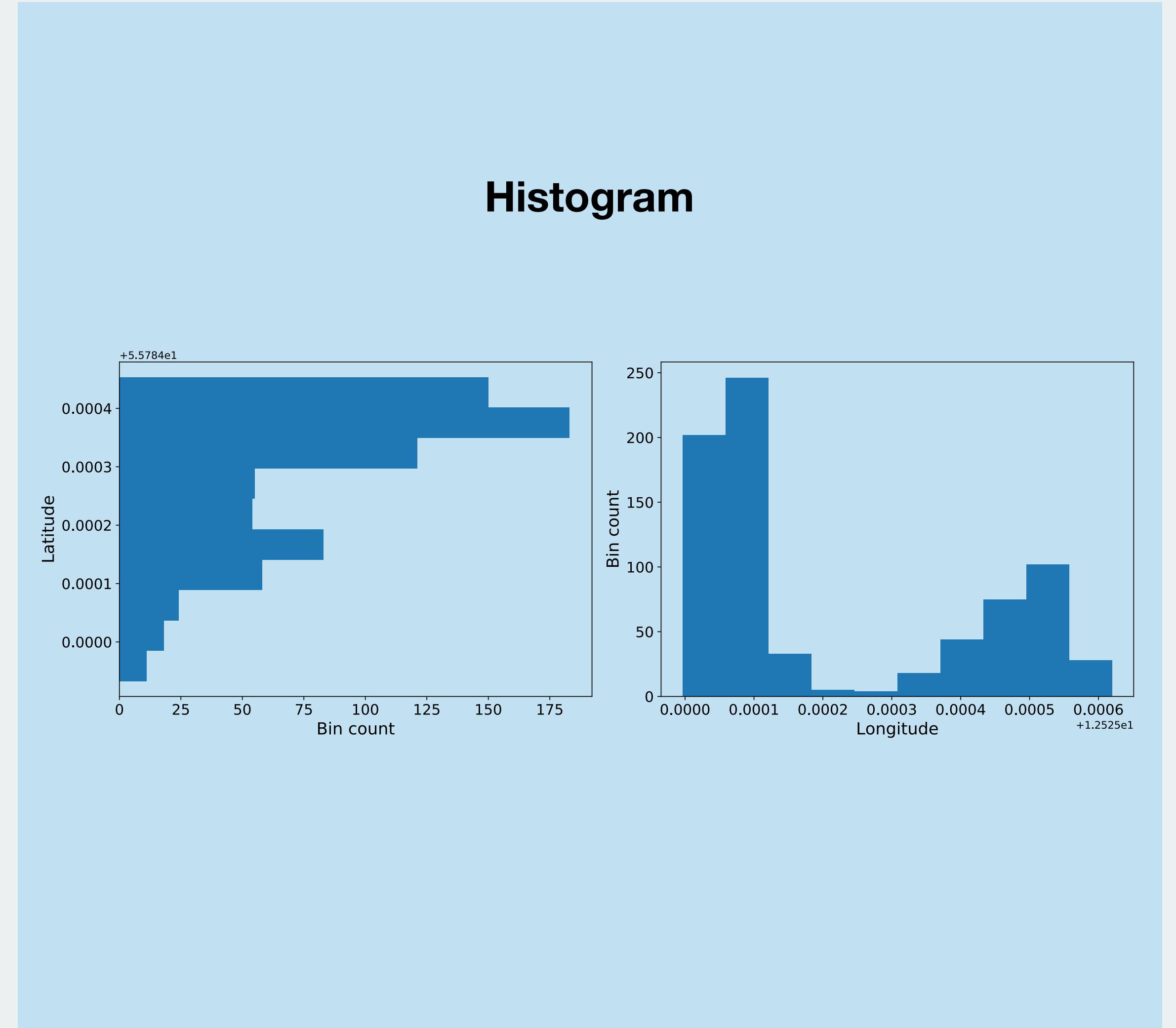
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...



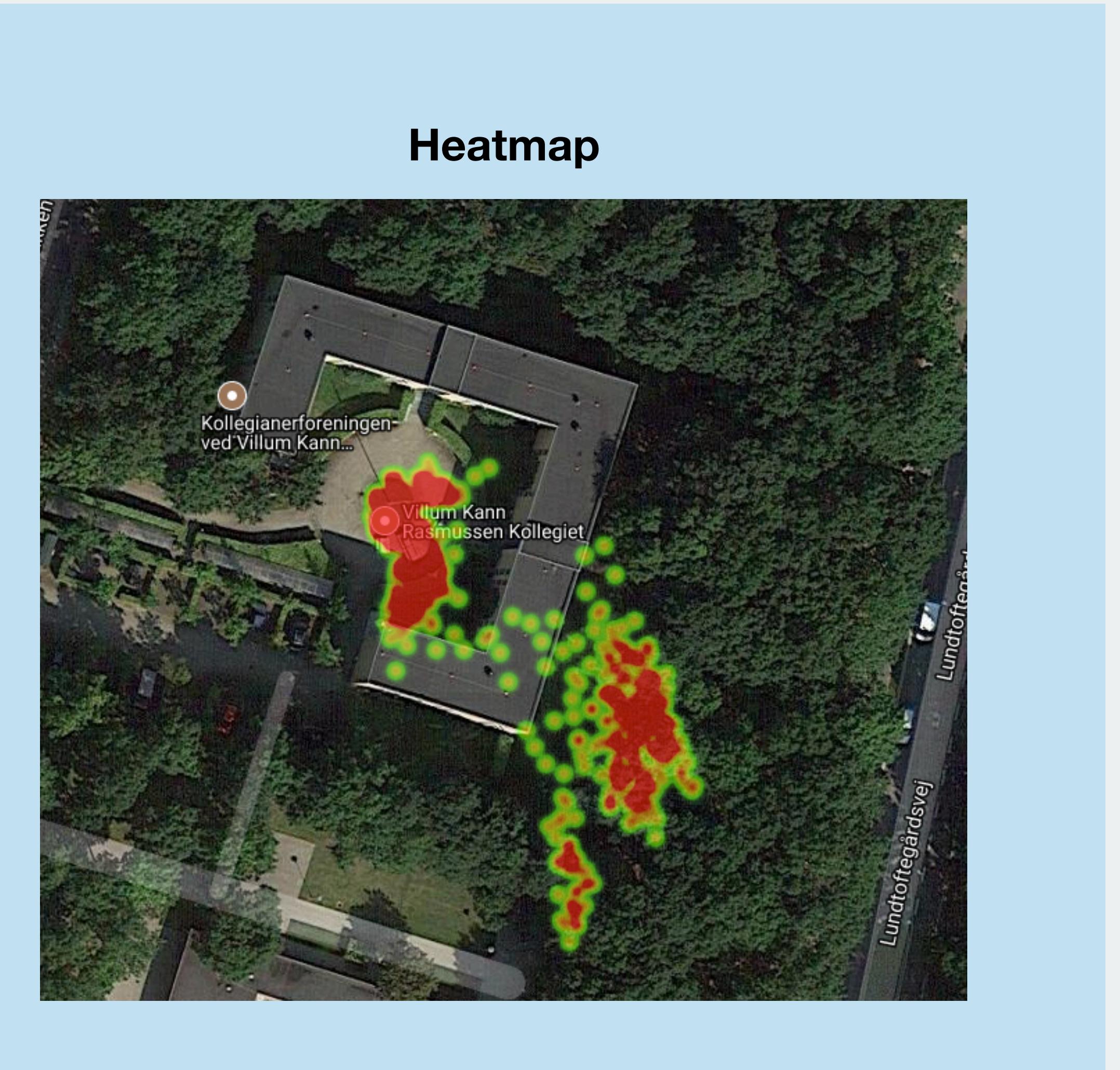
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<?xml version="1.0" encoding="UTF-8"?>
<gpx version="1.1" creator="Garmin Connect"
  xsi:schemaLocation="http://www.topografix.com/GPX/1/1 http://www.topografix.com/GPX/1/1/gpx.xsd http://www.garmin.com/xmlschemas/GpxExtensions/v3 http://www.garmin.com/xmlschemas/GpxExtensionsv3.xsd http://www.garmin.com/xmlschemas/TrackPointExtension/v1 http://www.garmin.com/xmlschemas/TrackPointExtensionv1.xsd"
  xmlns="http://www.topografix.com/GPX/1/1"
  xmlns:gpxpx="http://www.garmin.com/xmlschemas/TrackPointExtension/v1"
  xmlns:gpxx="http://www.garmin.com/xmlschemas/GpxExtensions/v3" xmlns:xsi="http://www.w3.org/2001/XMLSchema-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>
          <gpxpx:TrackPointExtension>
            <gpxpx:hr>143</gpxpx:hr>
          </gpxpx:TrackPointExtension>
        </extensions>
      </trkpt>
      <trkpt lon="12.577596567571163" lat="55.70799755863845">
        <ele>12.0</ele>
        <time>2011-01-26T09:23:55.000Z</time>
        <extensions>
          <gpxpx:TrackPointExtension>
            <gpxpx:hr>143</gpxpx:hr>
          </gpxpx:TrackPointExtension>
        </extensions>
      </trkpt>
    </trkseg>
  </trk>
</gpx>
```

activity_65197512.gpx

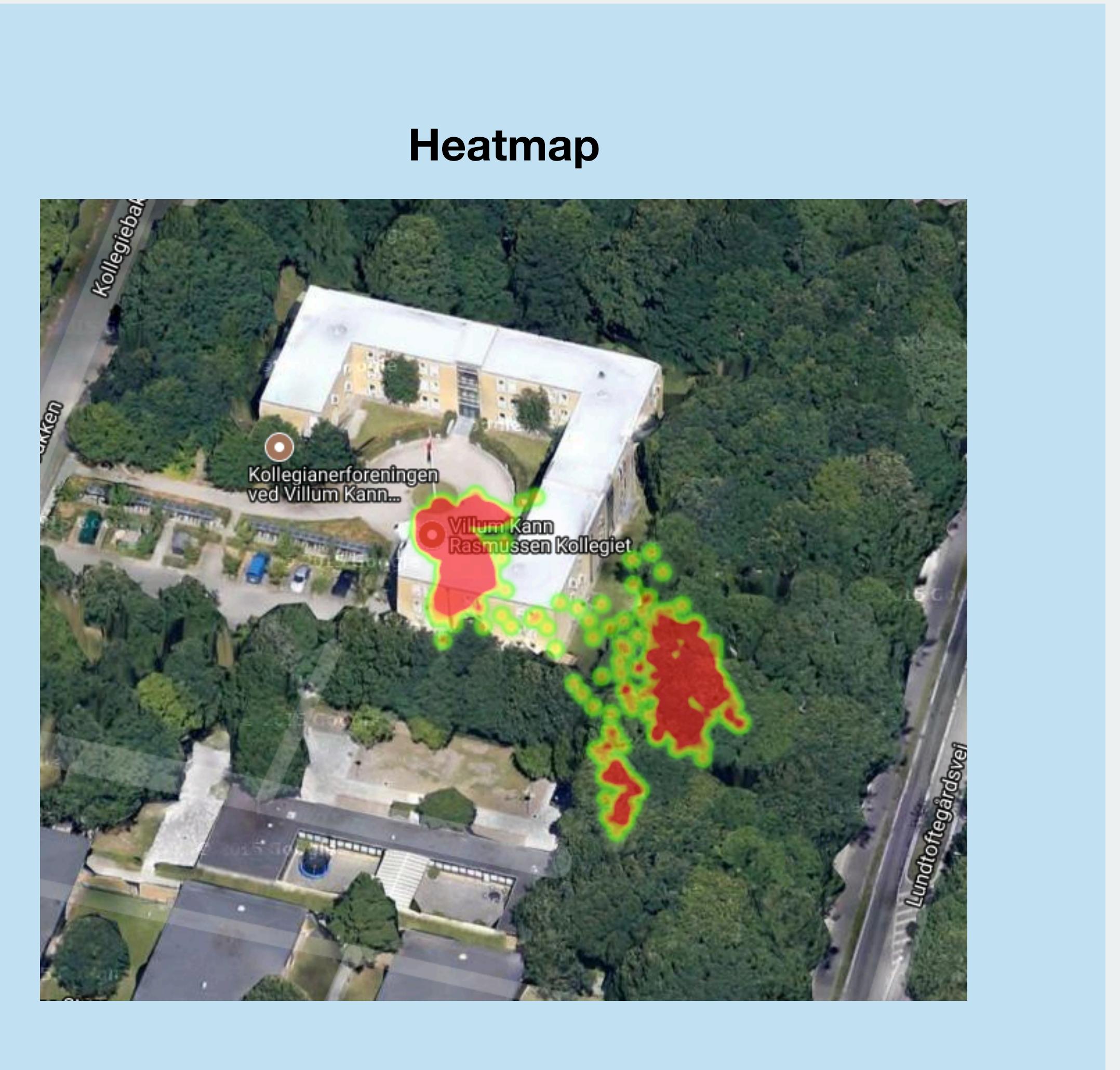
	lat	lon
0	55.784332	12.525468
1	55.784437	12.525030
2	55.784435	12.525043
3	55.784224	12.525565
4	55.784437	12.525031
5	55.784411	12.525055
6	55.784397	12.525070
7	55.784215	12.525537
8	55.784416	12.525059
9	55.784147	12.525530
10	55.784417	12.525063
11	55.784222	12.525535
12	55.784415	12.525052
13	55.784152	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
...



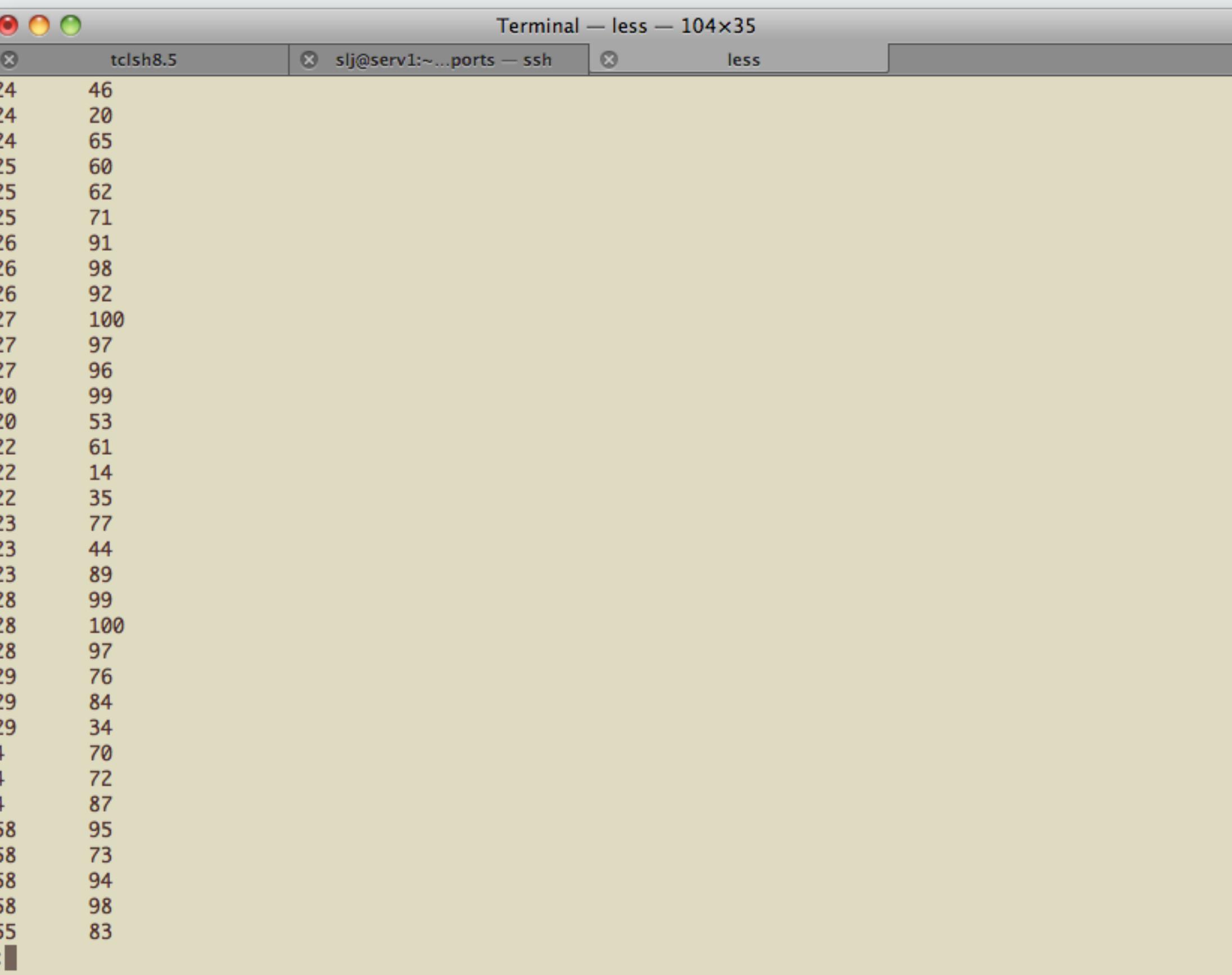
Data must be rendered in human-friendly format

```
Terminal — less — 107x37
<?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://www.garmin.com/xmlschemas/GpxExtensions/v3 http://www.garmin.com/xmlschemas/GpxExtensionsv3.xsd http://www.garmin.com/xmlschemas/TrackPointExtension/v1 http://www.garmin.com/xmlschemas/TrackPointExtensionv1.xsd"
  xmlns="http://www.topografix.com/GPX/1/1"
  xmlns:gpxpx="http://www.garmin.com/xmlschemas/TrackPointExtension/v1"
  xmlns:gpxx="http://www.garmin.com/xmlschemas/GpxExtensions/v3" xmlns:xsi="http://www.w3.org/2001/XMLSchema-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>
          <gpxpx:TrackPointExtension>
            <gpxpx:hr>143</gpxpx:hr>
          </gpxpx:TrackPointExtension>
        </extensions>
      </trkpt>
      <trkpt lon="12.577596567571163" lat="55.70799755863845">
        <ele>12.0</ele>
        <time>2011-01-26T09:23:55.000Z</time>
        <extensions>
          <gpxpx:TrackPointExtension>
            <gpxpx:hr>143</gpxpx:hr>
          </gpxpx:TrackPointExtension>
        </extensions>
      </trkpt>
    </trkseg>
  </trk>
</gpx>
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
...



Relational data

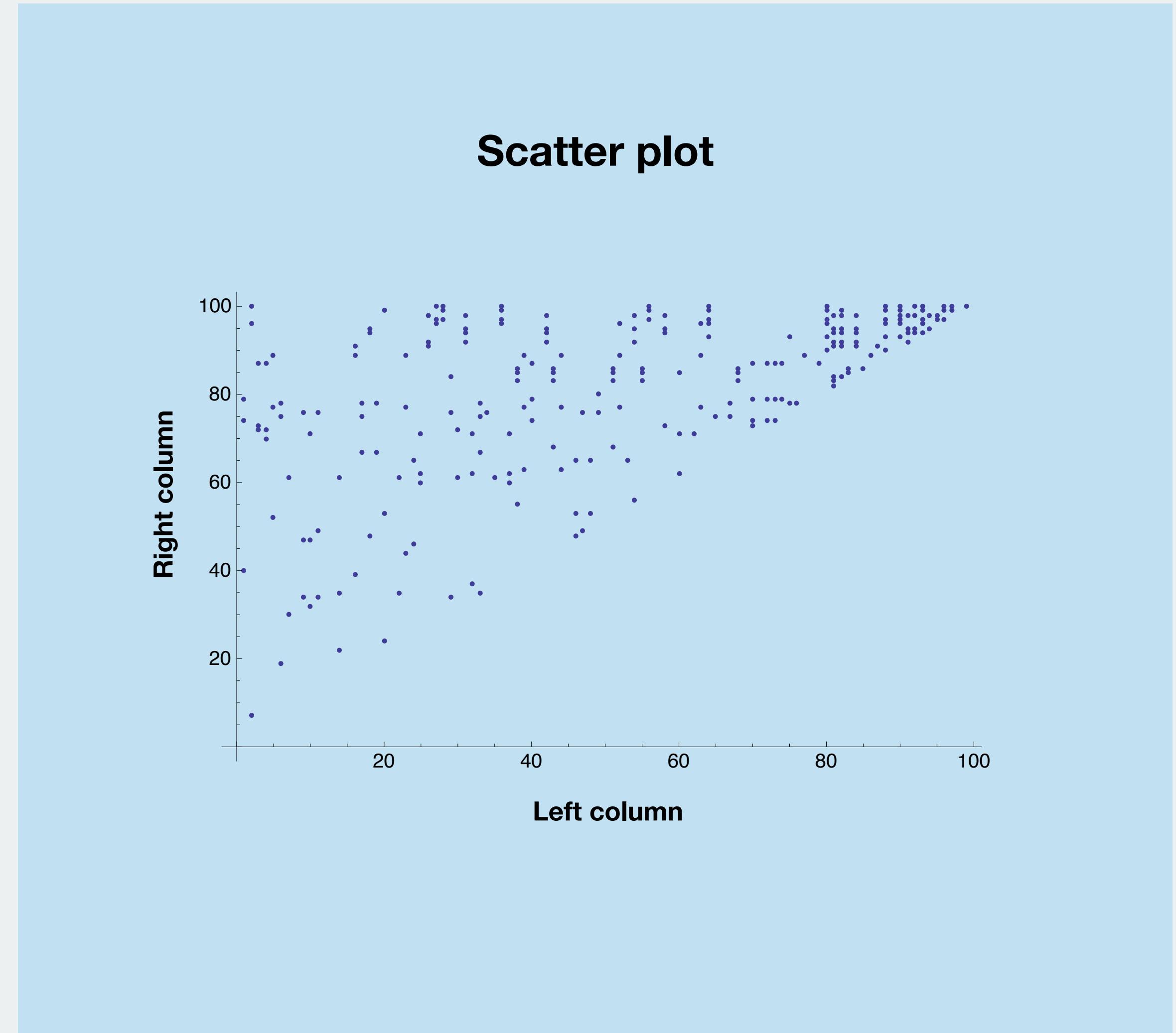


A screenshot of a Mac OS X Terminal window titled "Terminal — less — 104x35". The window has three tabs: "tclsh8.5", "slj@serv1:~...ports — ssh", and "less". The "less" tab is active and displays a list of approximately 50 numerical values, likely integers, arranged vertically. The values range from 4 to 100, with some duplicates. A vertical scroll bar is visible on the right side of the terminal window.

```
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
:
```

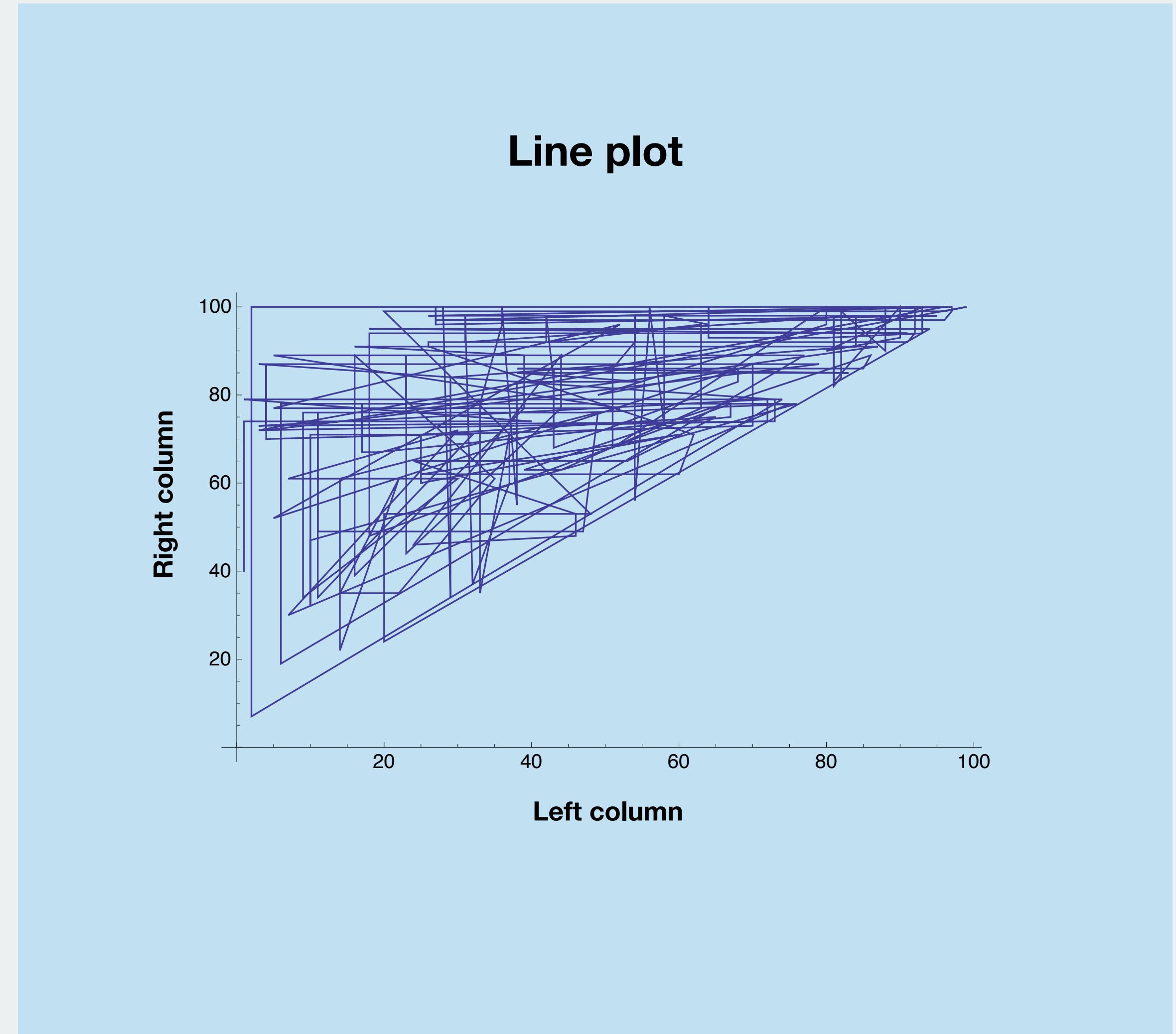
Relational data

```
Terminal — less — 104x35
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

```
Terminal — less — 104x35
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
:|
```

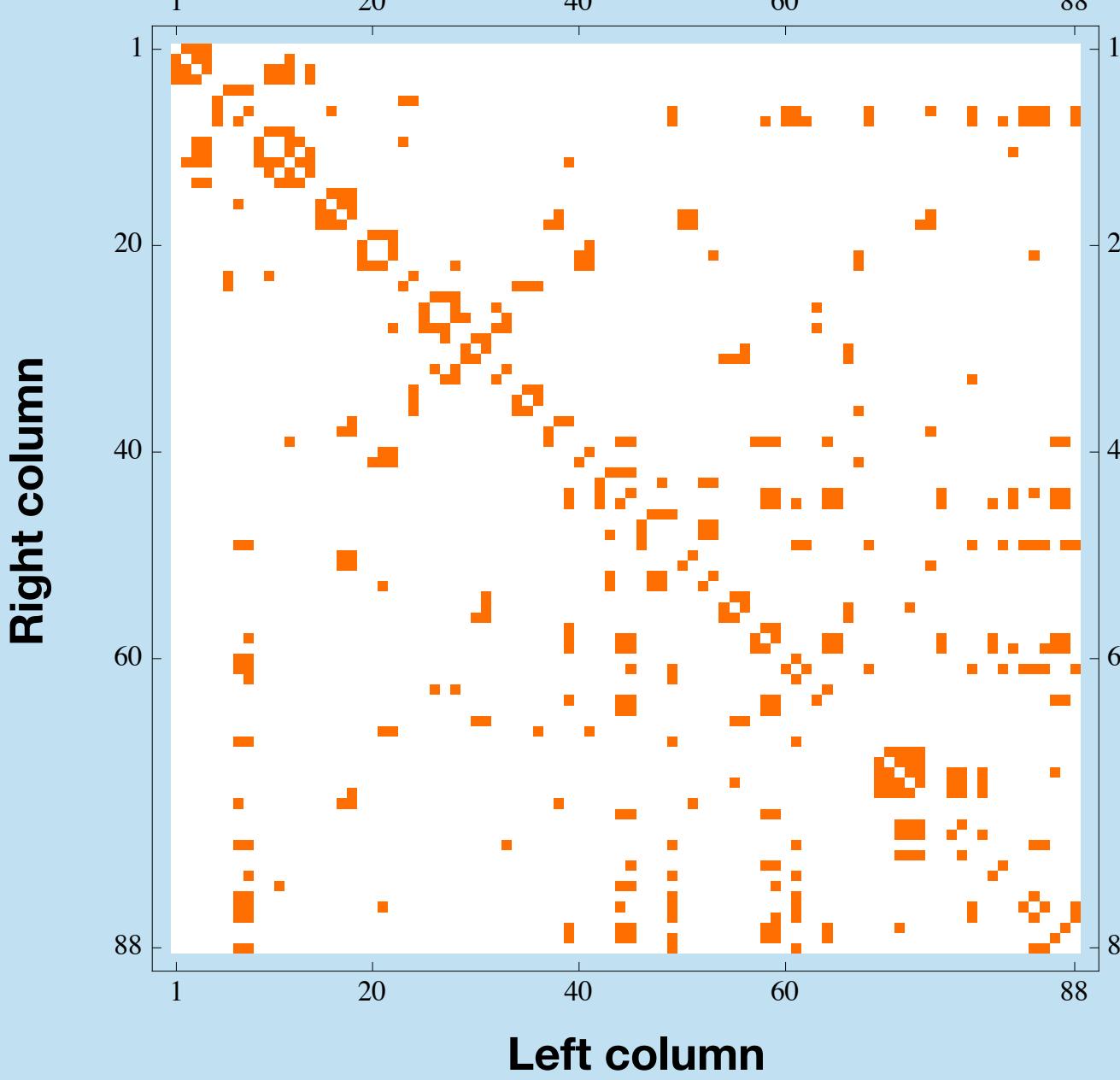


Relational data

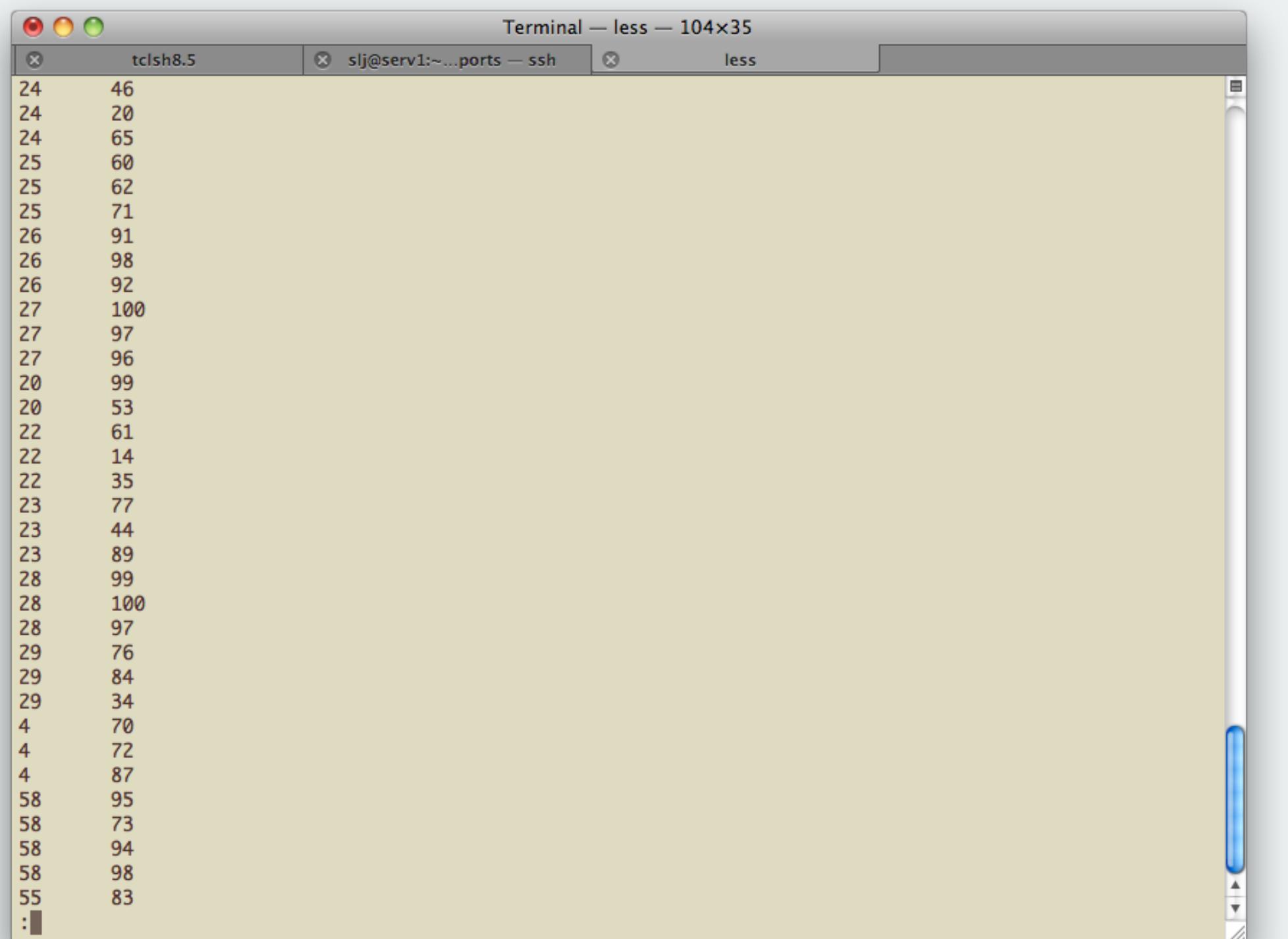
```
Terminal — less — 104x35
tclsh8.5      slj@serv1:~...ports — ssh      less
24 46
24 20
24 65
25 60
25 62
25 71
26 91
26 98
26 92
27 100
27 97
27 96
20 99
20 53
22 61
22 14
22 35
23 77
23 44
23 89
28 99
28 100
28 97
29 76
29 84
29 34
4 70
4 72
4 87
58 95
58 73
58 94
58 98
55 83
:
```



Row-ordered adjacency matrix



Relational data

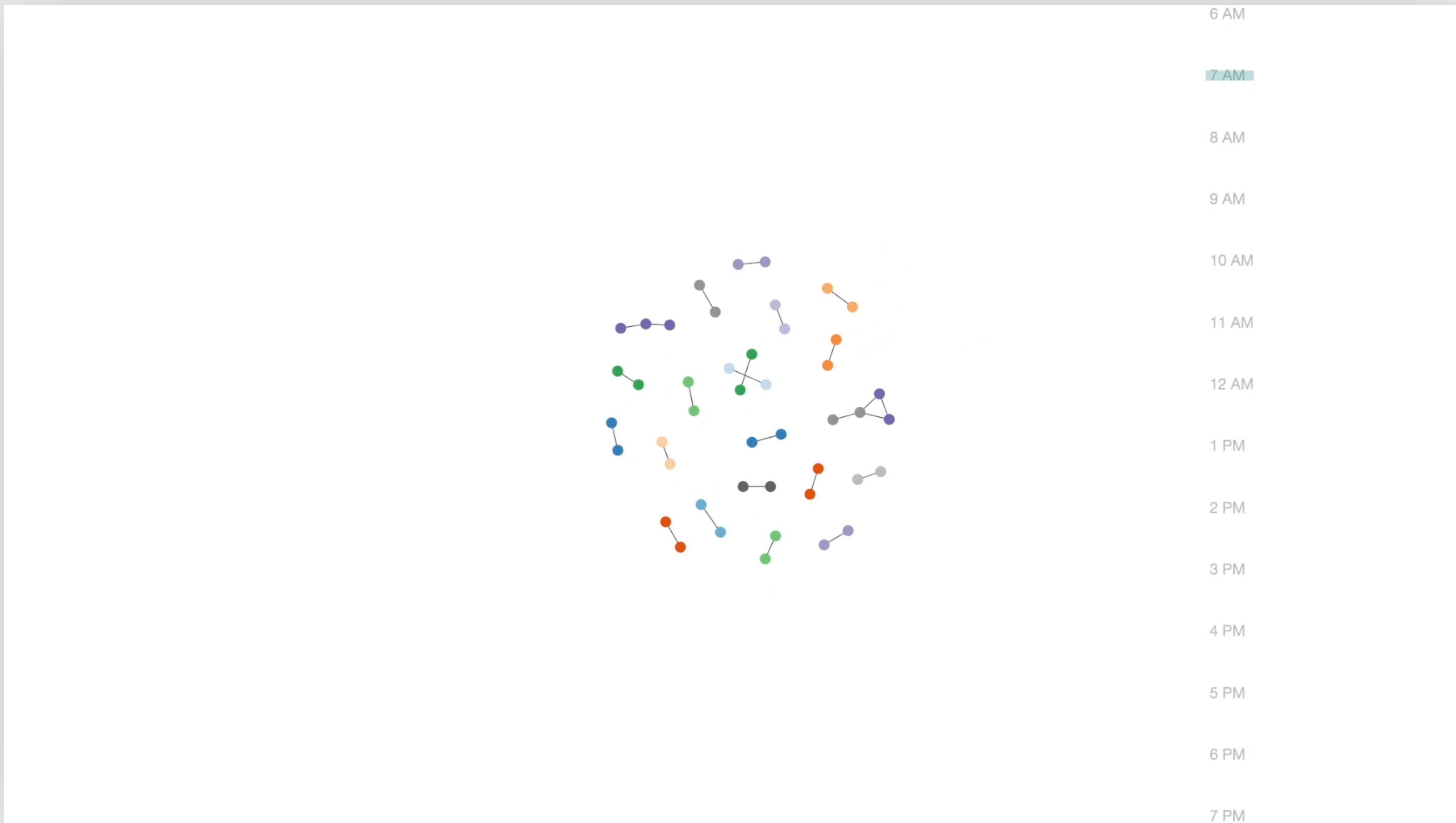


A screenshot of a Mac OS X terminal window titled "Terminal — less — 104x35". The window contains a list of numerical values, likely port numbers, displayed in two columns. An arrow points from this terminal window to the word "Network" on the right side of the slide.

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
:	

Network

Very complex data that changes in time!



Most fancy visualizations break down to very simple things

For understanding how
data is **distributed**

- Histograms
- Kernel density plots
- Box plots/violin plots
- Heatmaps

Most fancy visualizations break down to very simple things

For understanding how
data is **distributed**

- Histograms
- Kernel density plots
- Box plots/violin plots
- Heatmaps

For understanding
how variables in
data **relate and**
develop

- Scatter plots
- Pairs plot
- Time series plot
- Line plot
- Bar plot

Most fancy visualizations break down to very simple things

For understanding how
data is **distributed**

- Histograms
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- Box plots/violin plots
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For understanding
how variables in
data **relate and**
develop

- Scatter plots
- Pairs plot
- Time series plot
- Line plot
- Bar plot

For understanding
complex structure in
interconnected data

- Networks

Linear algebra

Linear algebra

Tools for manipulating tabular data

Linear algebra

Tools for manipulating tabular data

Objects

- Scalars
- Vectors
- Matrices

**Everything is
a Tensor!**

Linear algebra

Tools for manipulating tabular data

Objects

- Scalars
- Vectors
- Matrices

**Everything is
a Tensor!**

scalar

0D

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

Linear algebra

Tools for manipulating tabular data

Objects

- Scalars
- Vectors
- Matrices

**Everything is
a Tensor!**

scalar

0D

```
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]
```

Linear algebra

Tools for manipulating tabular data

Objects

- Scalars
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- Matrices

**Everything is
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0D

scalar

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

1D

vector

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

2D

matrix

```
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]]
```

Linear algebra

Tools for manipulating tabular data

Objects

- Scalars
- Vectors
- Matrices

**Everything is
a Tensor!**

0D

scalar

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

1D

vector

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

2D

matrix

```
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]]
```

3D

3D-tensor

```
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]]]
```

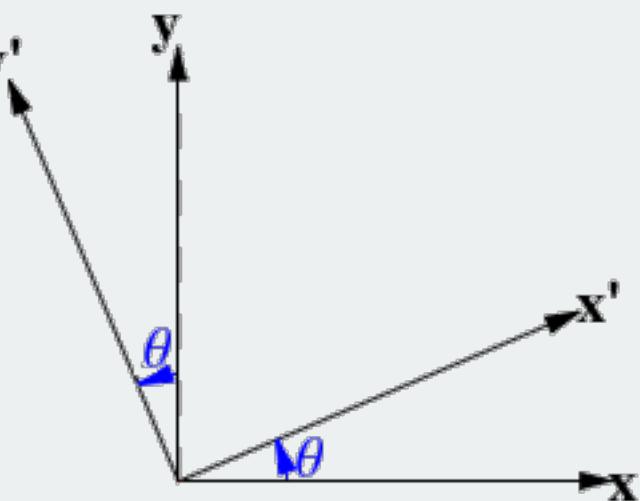
Linear algebra

Tools for manipulating tabular data

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

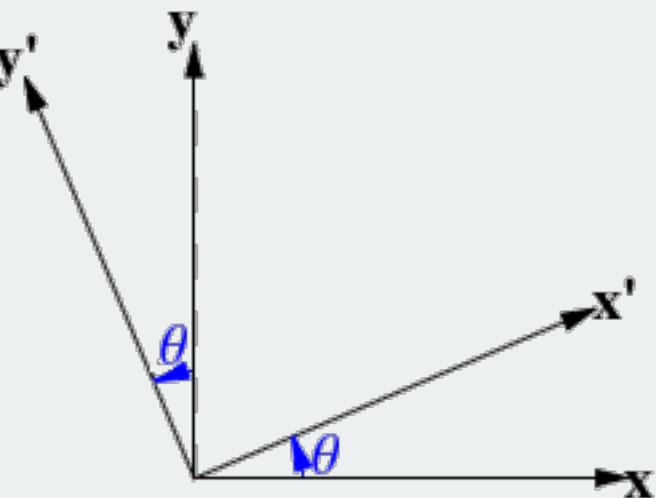
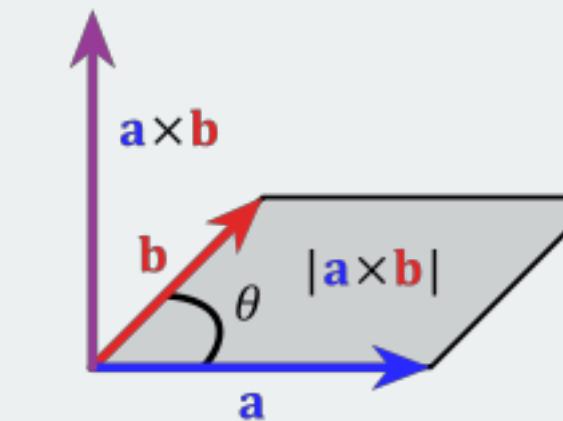
Linear algebra

Tools for manipulating tabular data

Operations

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- Elementwise: *addition*, *subtraction*, *multiplication*, *division*
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used frequently for
basis transformation

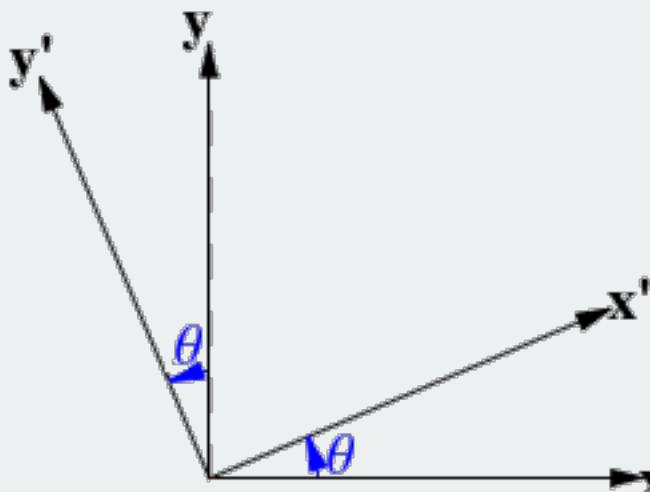
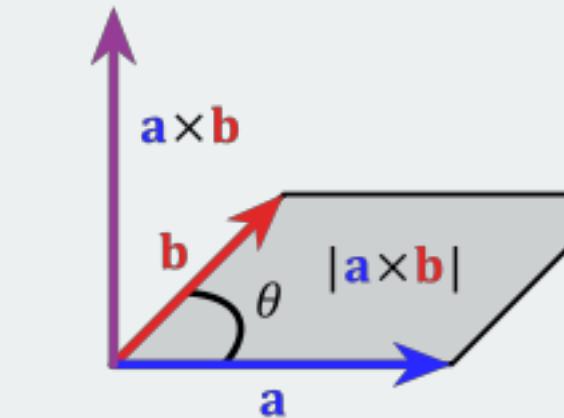
Linear algebra

Tools for manipulating tabular data

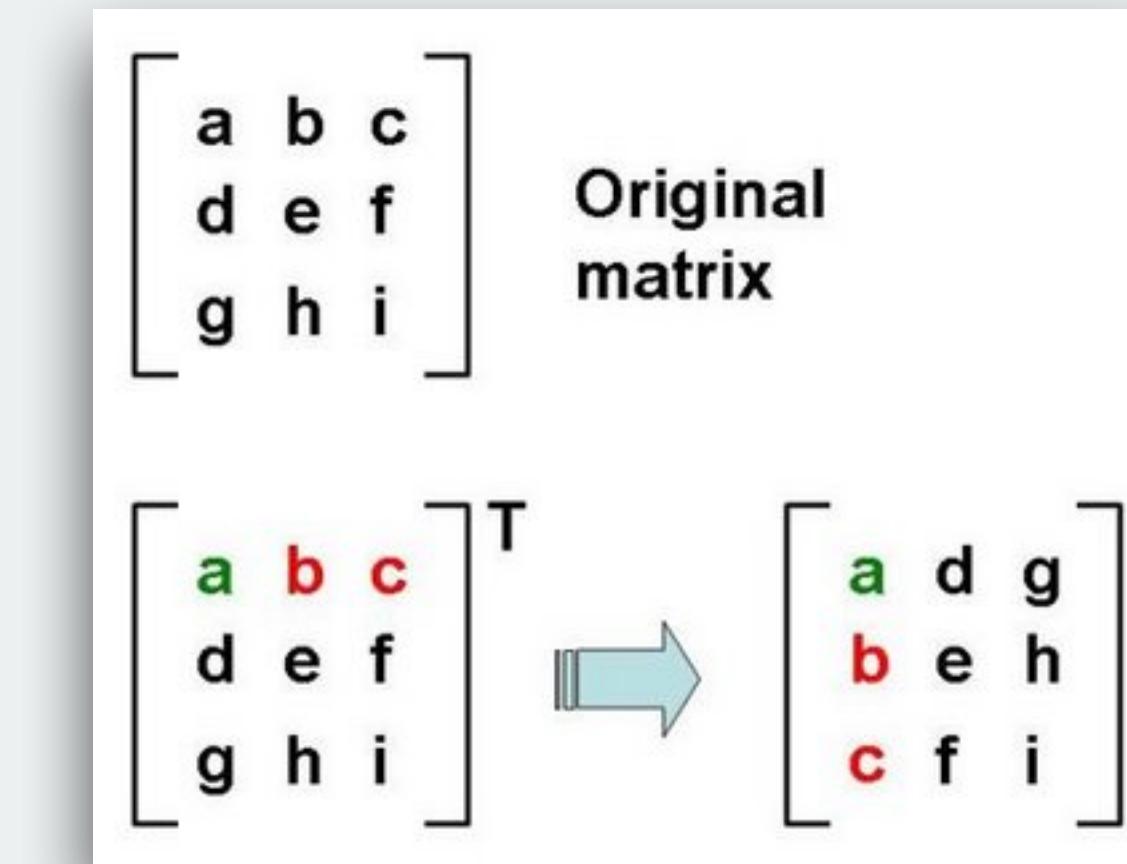
Operations

- 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

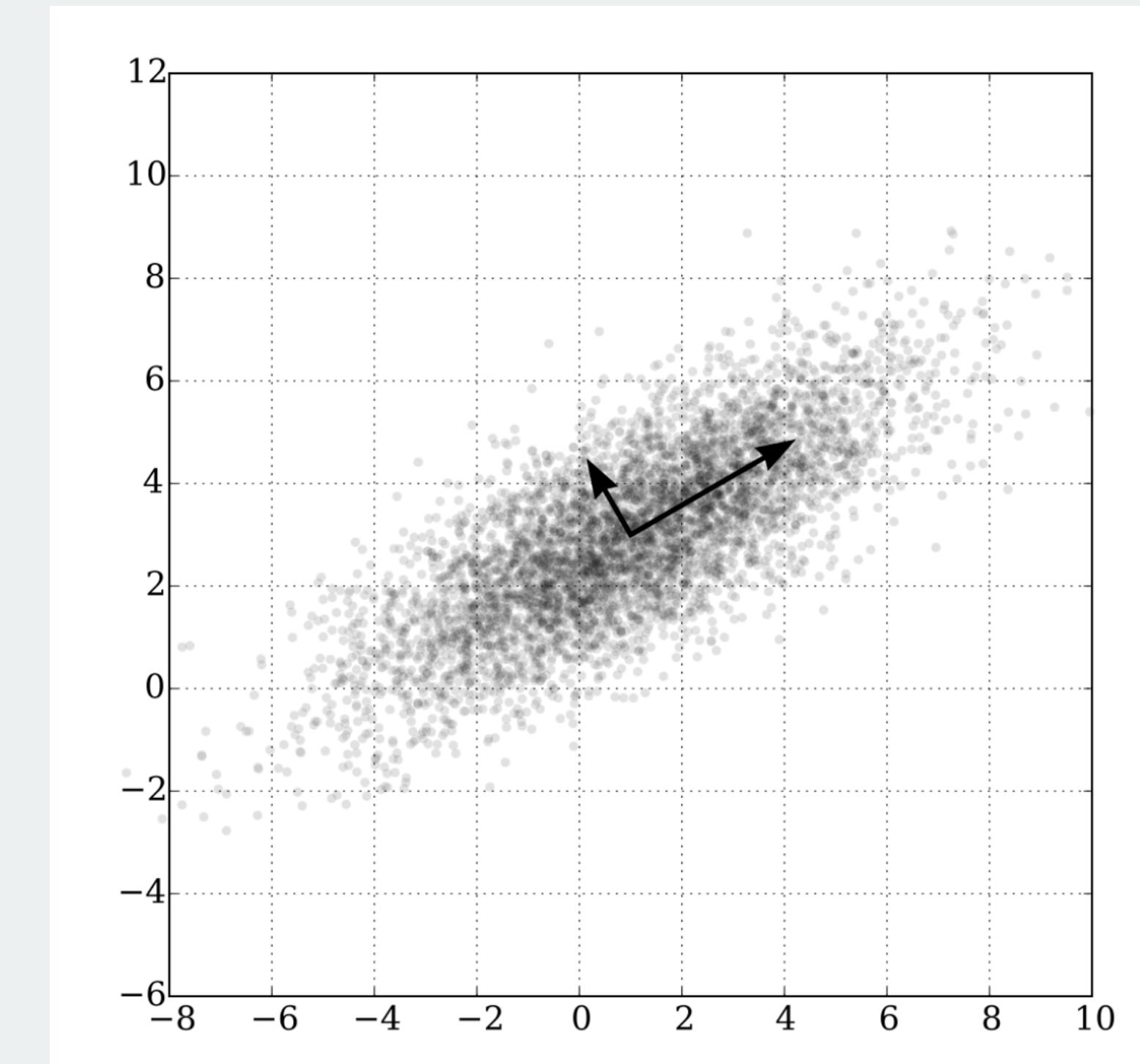


Linear algebra

Tools for manipulating tabular data

Tools

- **Principal Component Analysis (PCA)**
- Archetypal Analysis
- Non-negative matrix factorization
- ... many more

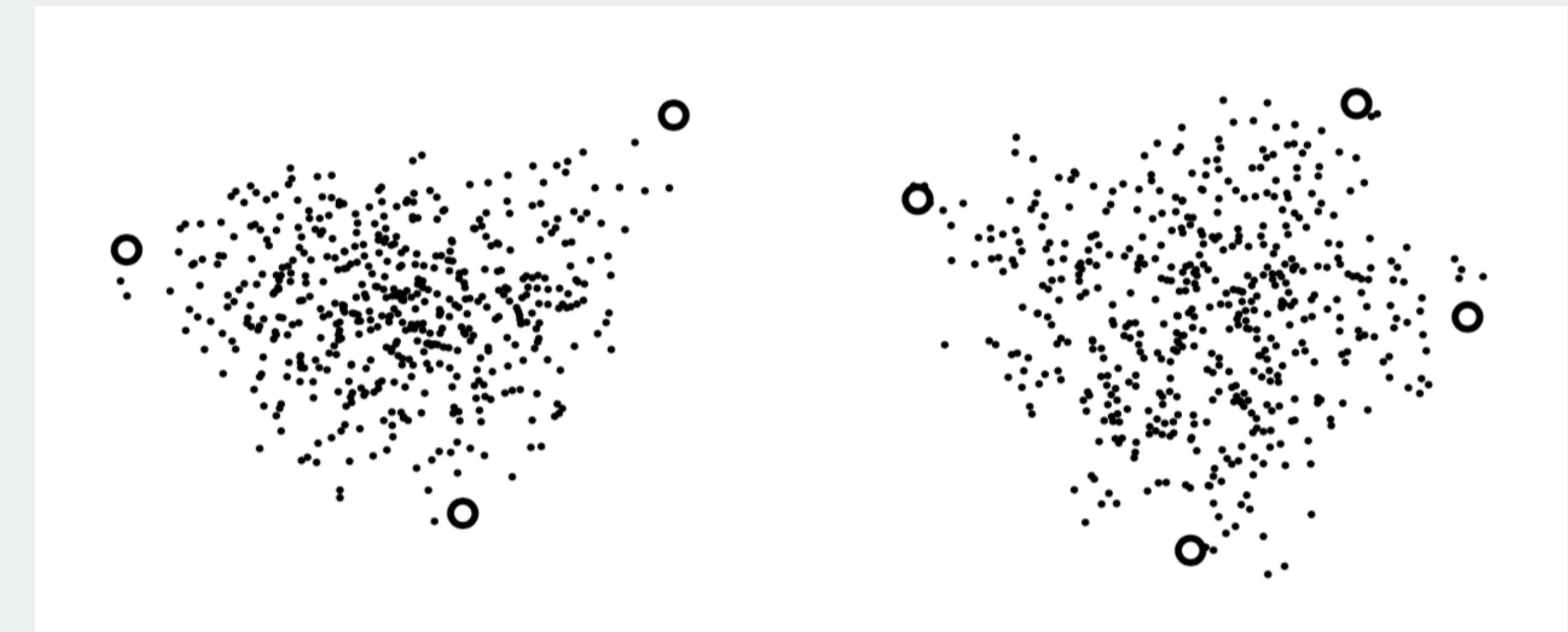


Linear algebra

Tools for manipulating tabular data

Tools

- Principal Component Analysis (PCA)
- **Archetypal Analysis**
- Non-negative matrix factorization
- ... many more

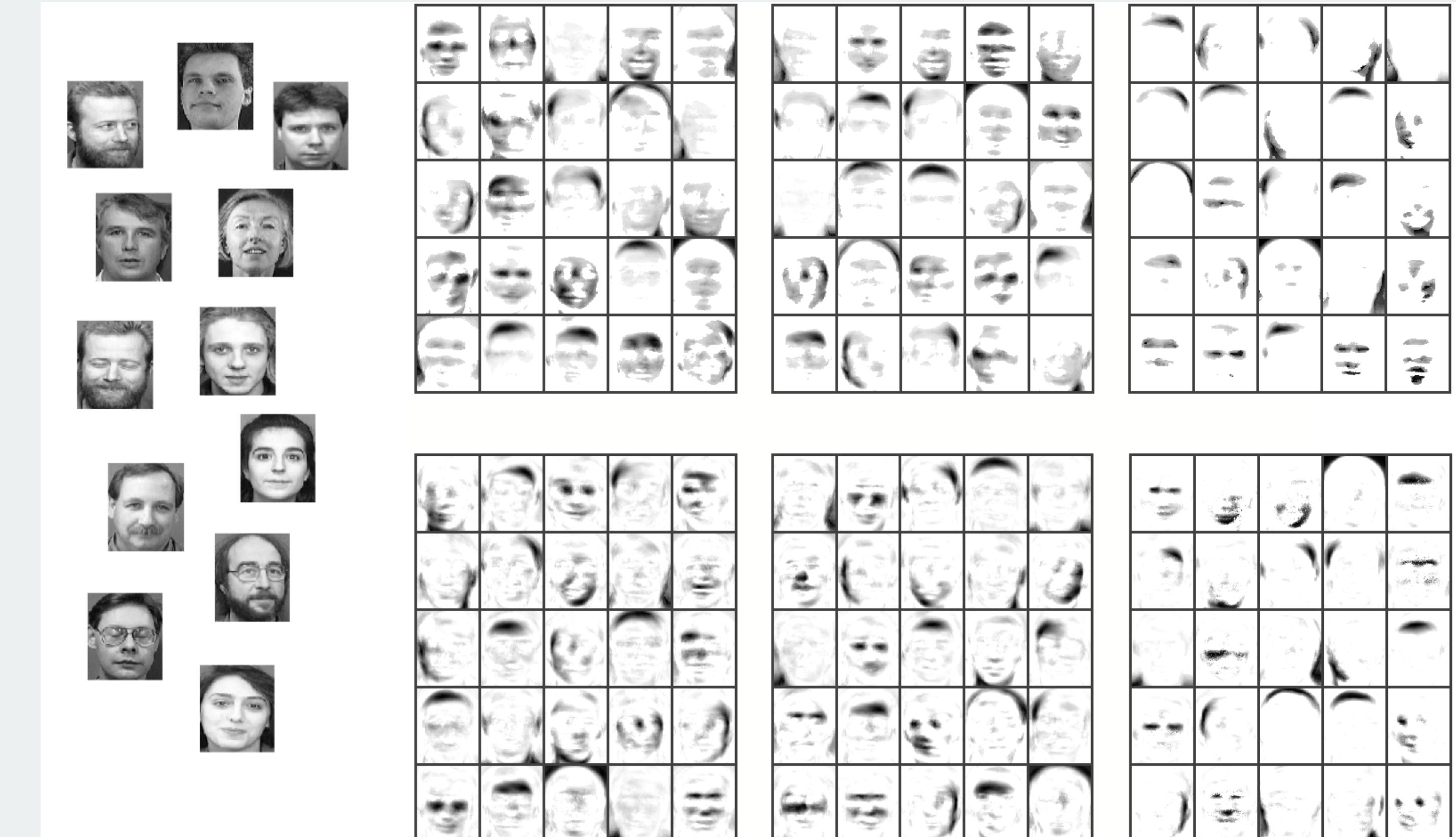


Linear algebra

Tools

- Principal Component Analysis (PCA)
- Archetypal Analysis
- **Non-negative matrix factorization**
- ... many more

Tools for manipulating tabular data



Statistics

Statistics

Framework for describing data

Statistics

Framework for describing data

Vocabulary

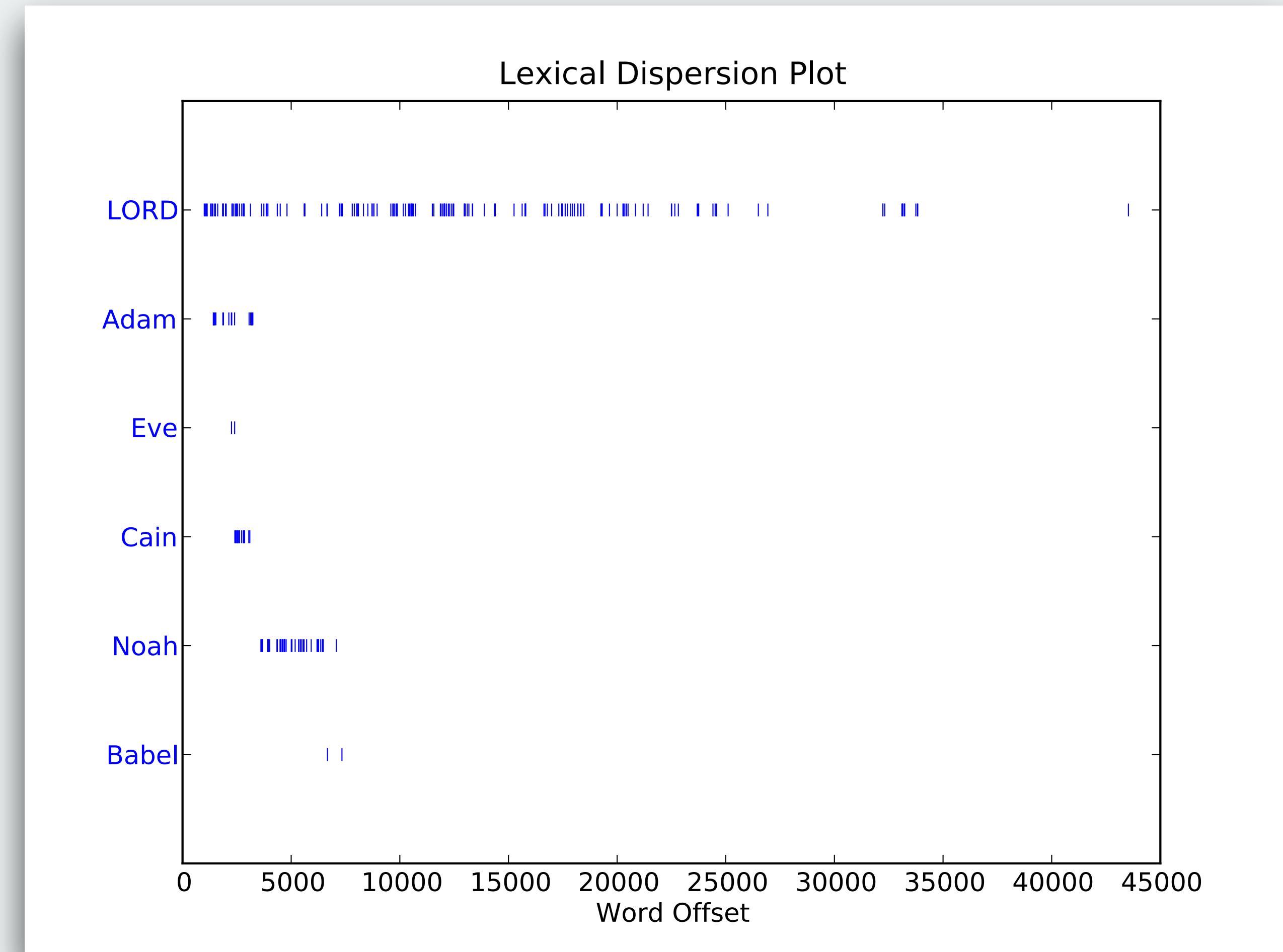
- Mean, median
- Variance, standard deviation, range
- Correlation, covariance

Statistics

Vocabulary

- Mean, median
- Variance, standard deviation, range
- Correlation, covariance

Framework for describing data



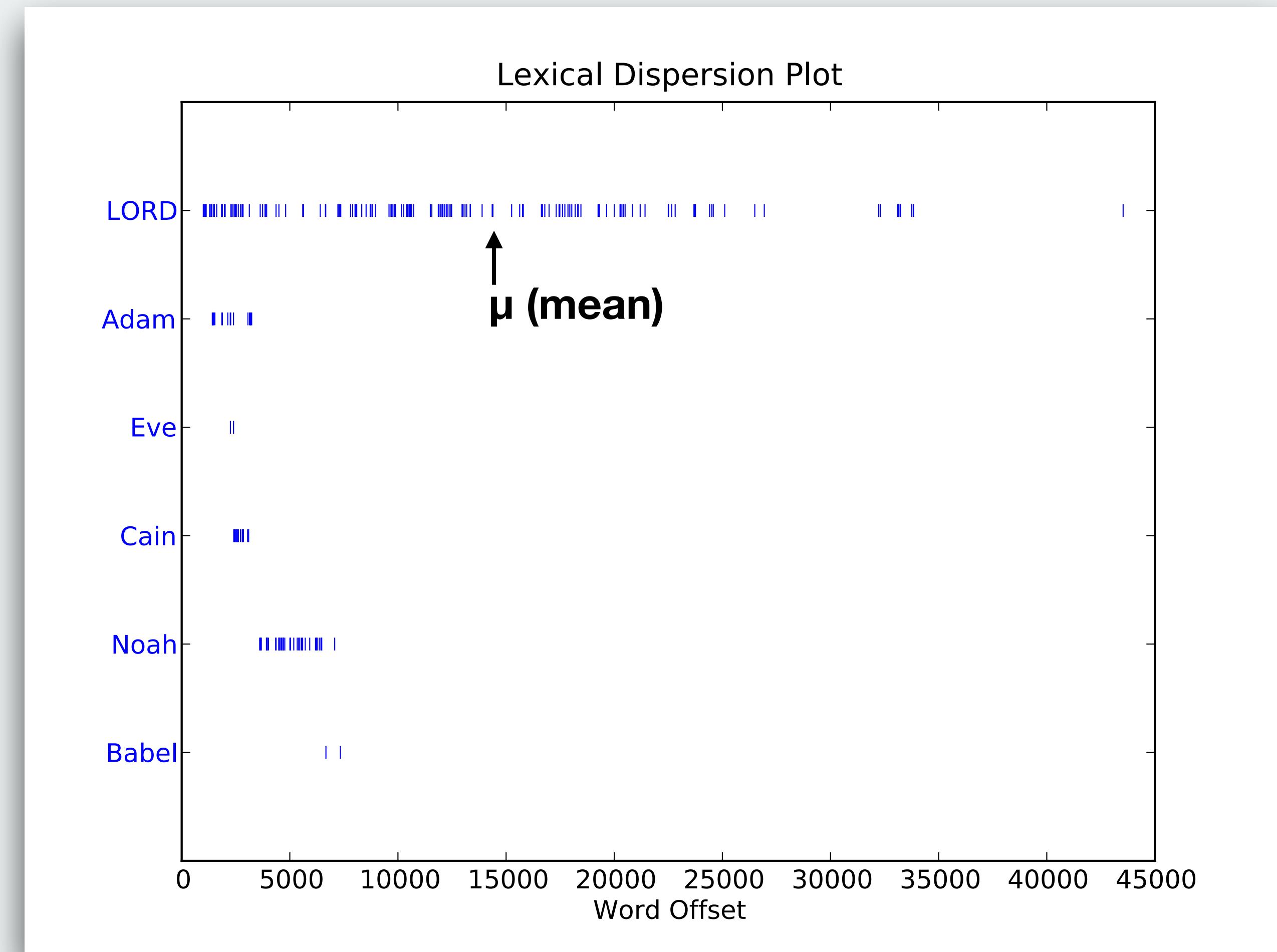
Statistics

Vocabulary

- **Mean**, median
- Variance, standard deviation, range
- Correlation, covariance

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

Framework for describing data



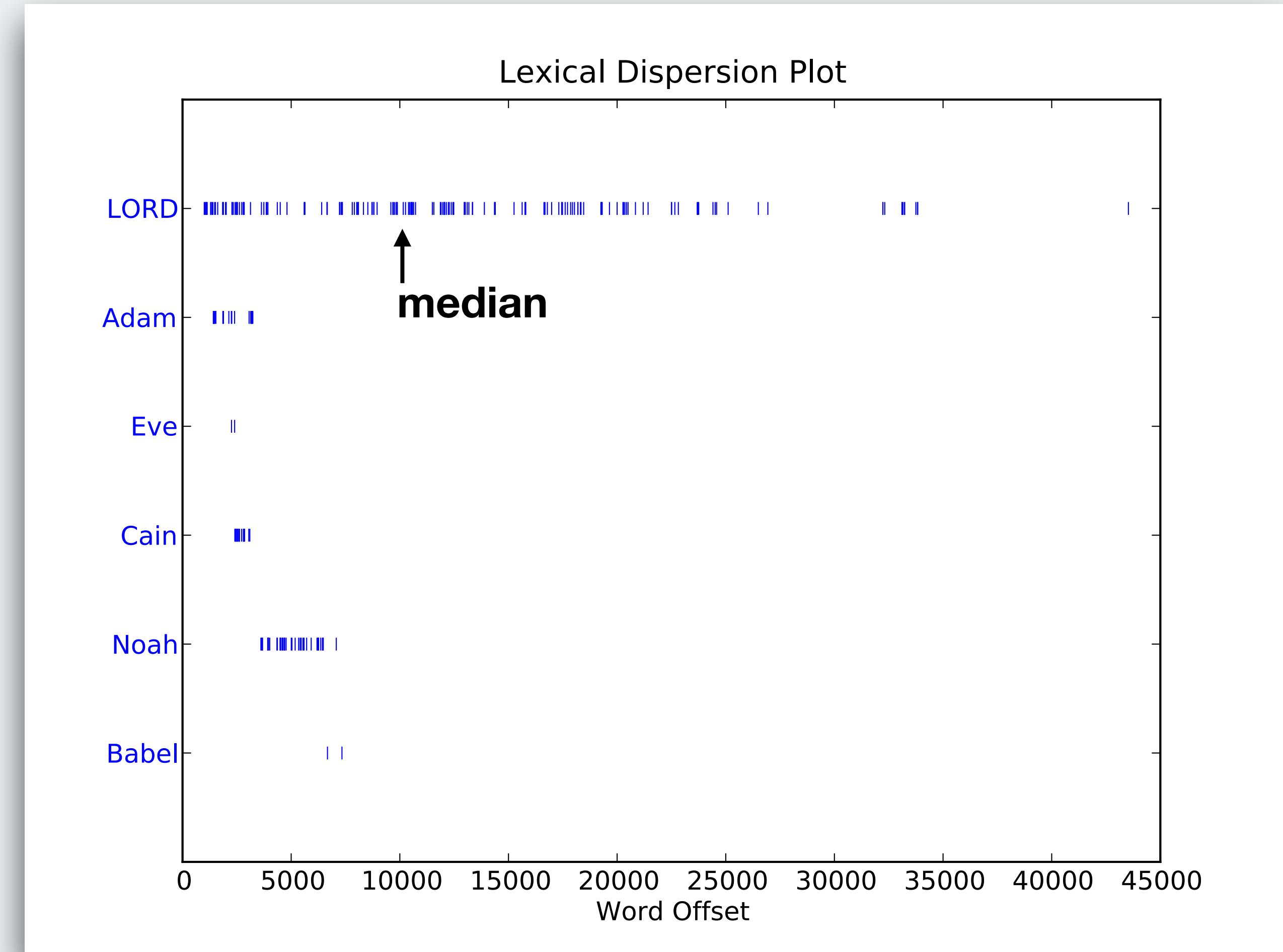
Statistics

Framework for describing data

Vocabulary

- Mean, **median**
- Variance, standard deviation, range
- Correlation, covariance

median = Middle number
in ordered list



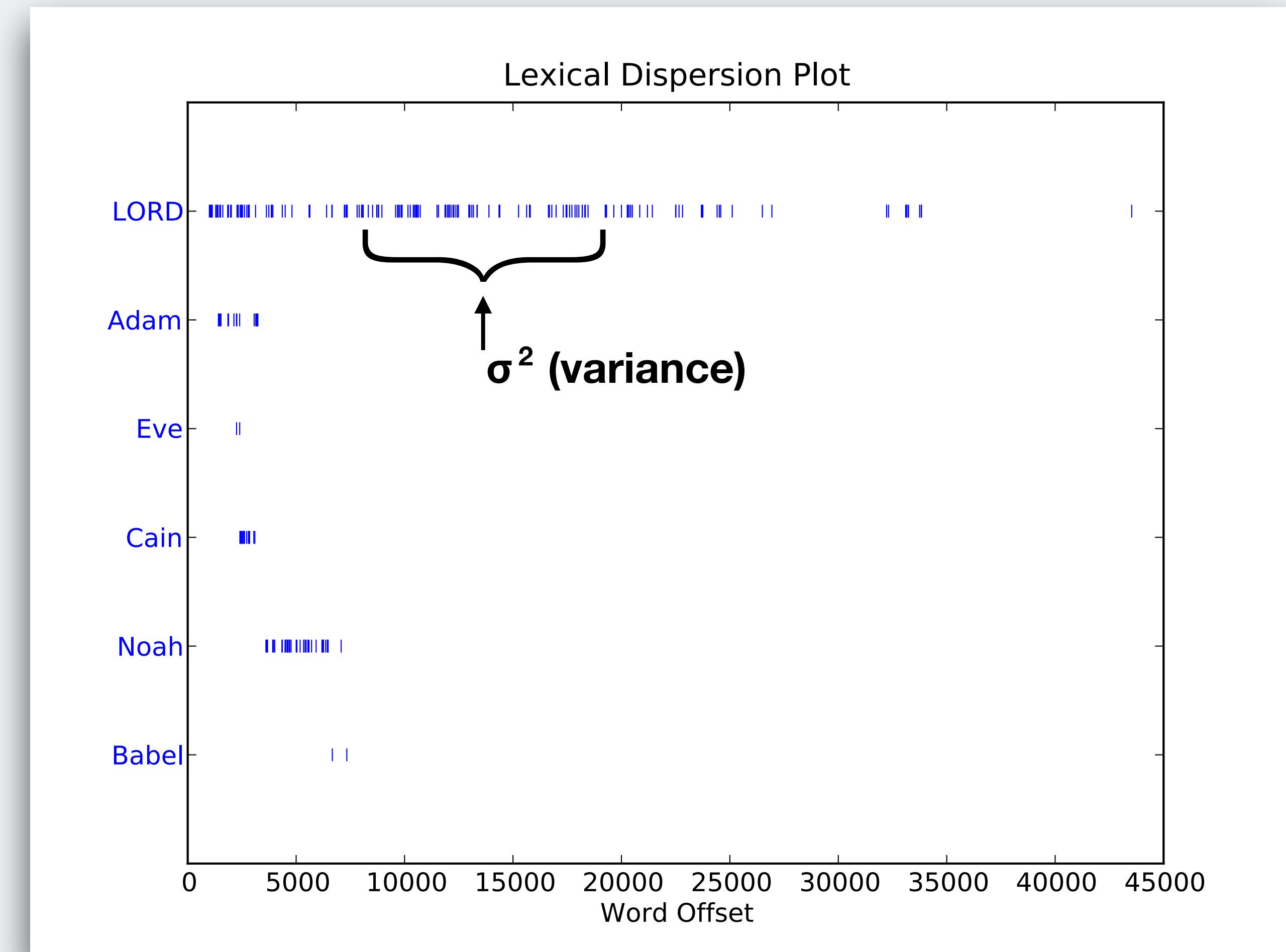
Statistics

Vocabulary

- Mean, median
- **Variance**, standard deviation, range
- Correlation, covariance

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

Framework for describing data



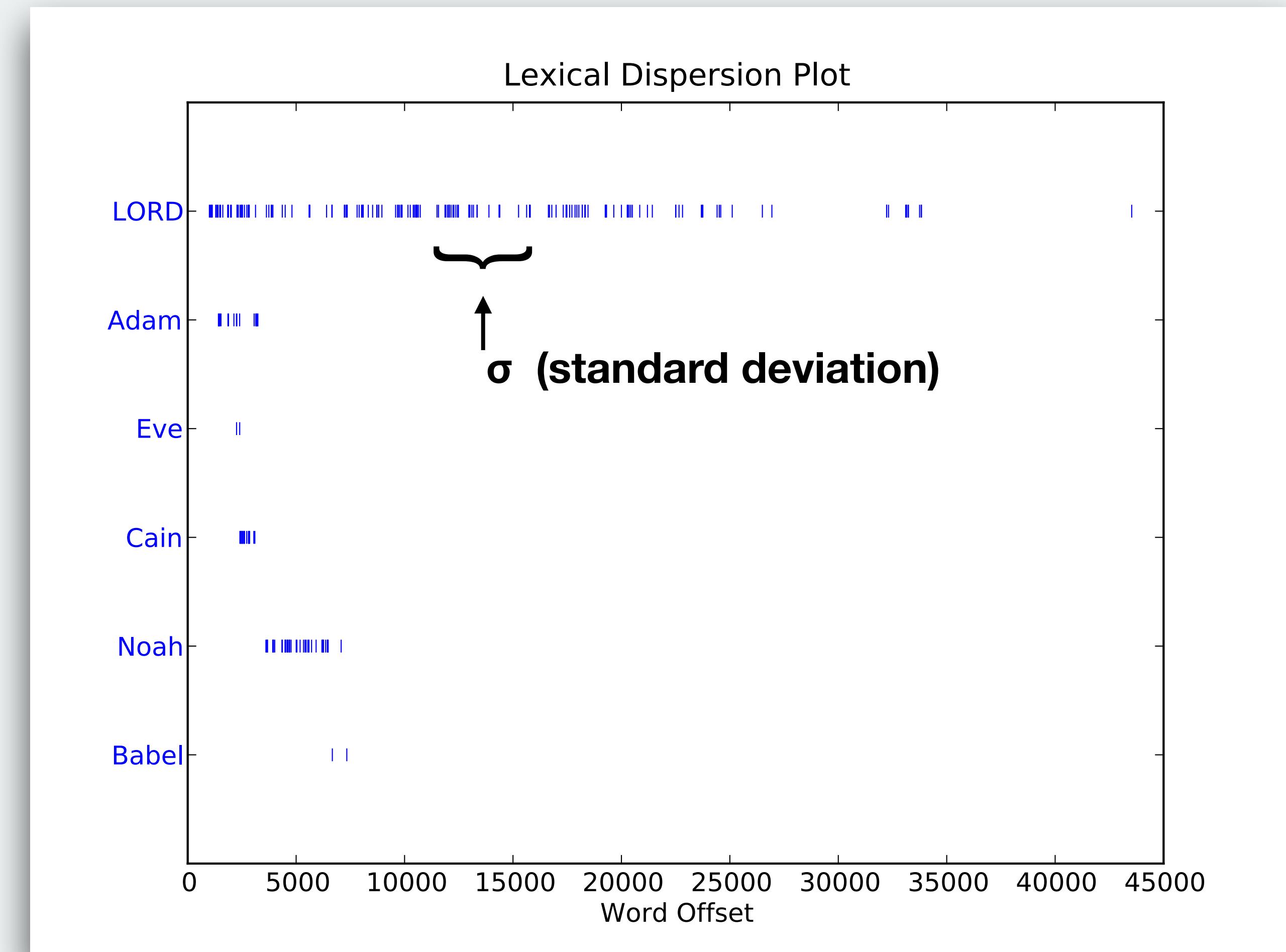
Statistics

Vocabulary

- Mean, median
- Variance, **standard deviation**, range
- Correlation, covariance

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

Framework for describing data



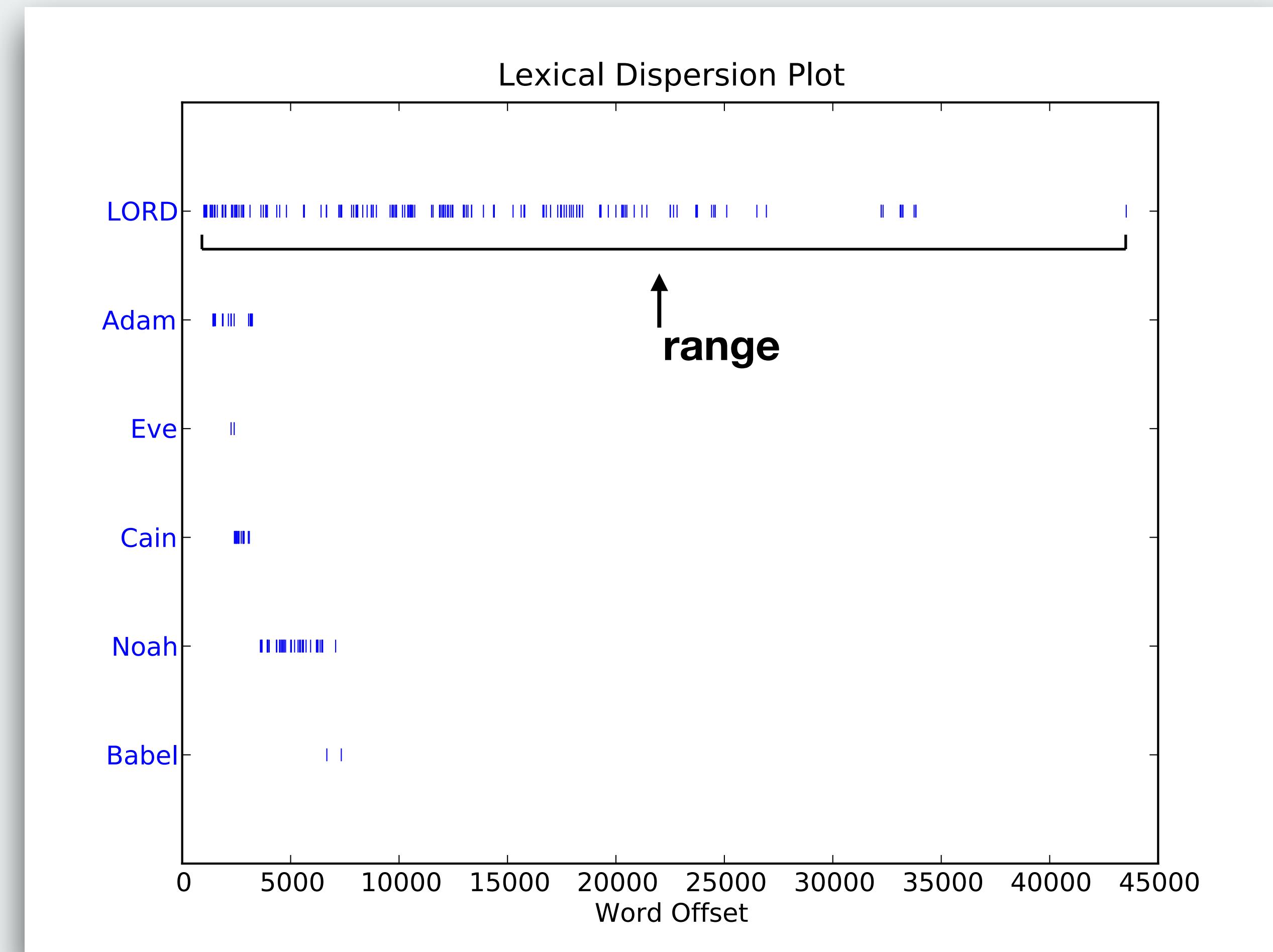
Statistics

Framework for describing data

Vocabulary

- Mean, median
 - Variance, standard deviation, **range**
 - Correlation, covariance

range = **max(value)** - **min(value)**



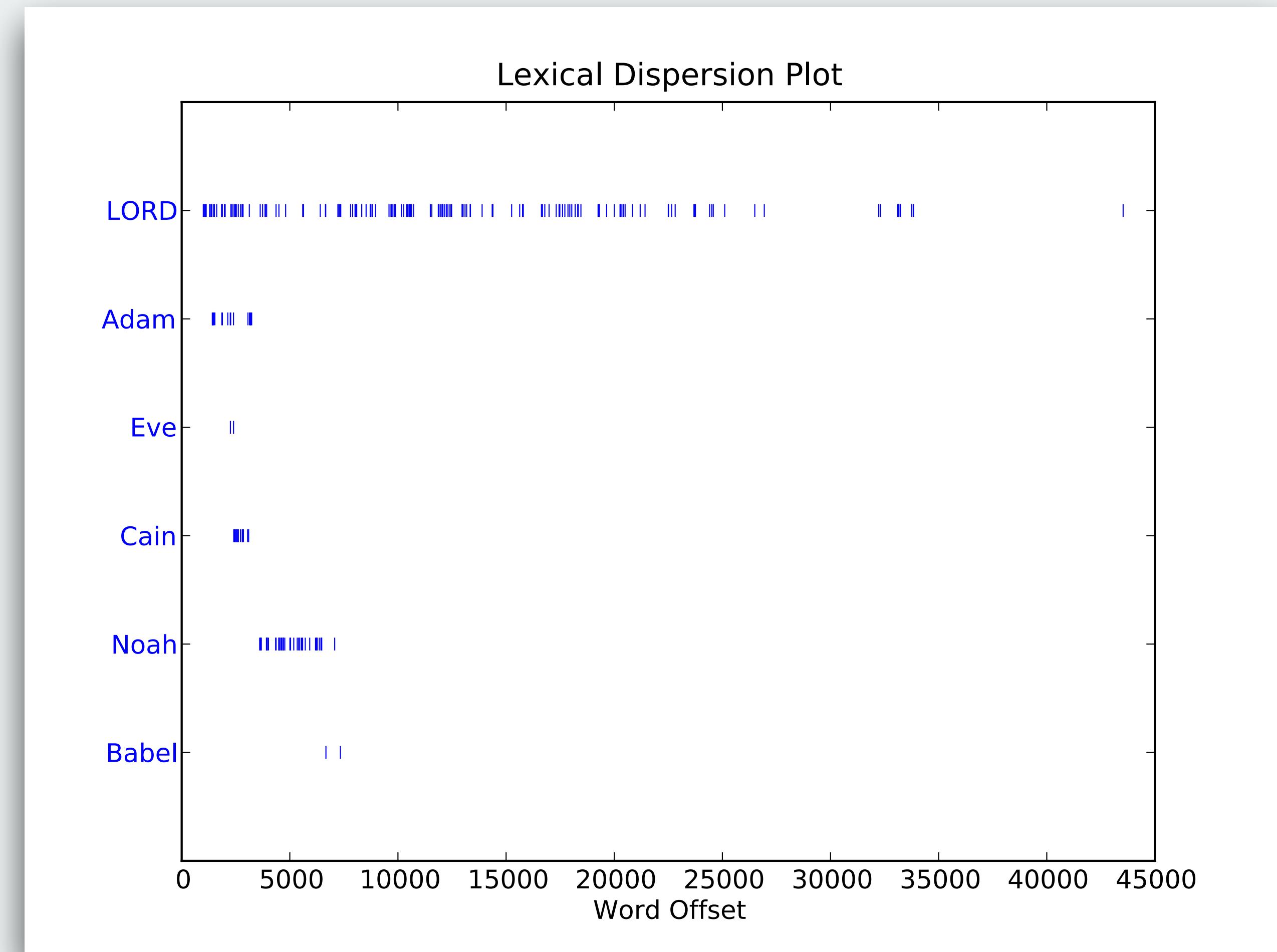
Statistics

Vocabulary

- Mean, median
- Variance, standard deviation, range
- Correlation, **covariance**

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

Framework for describing data



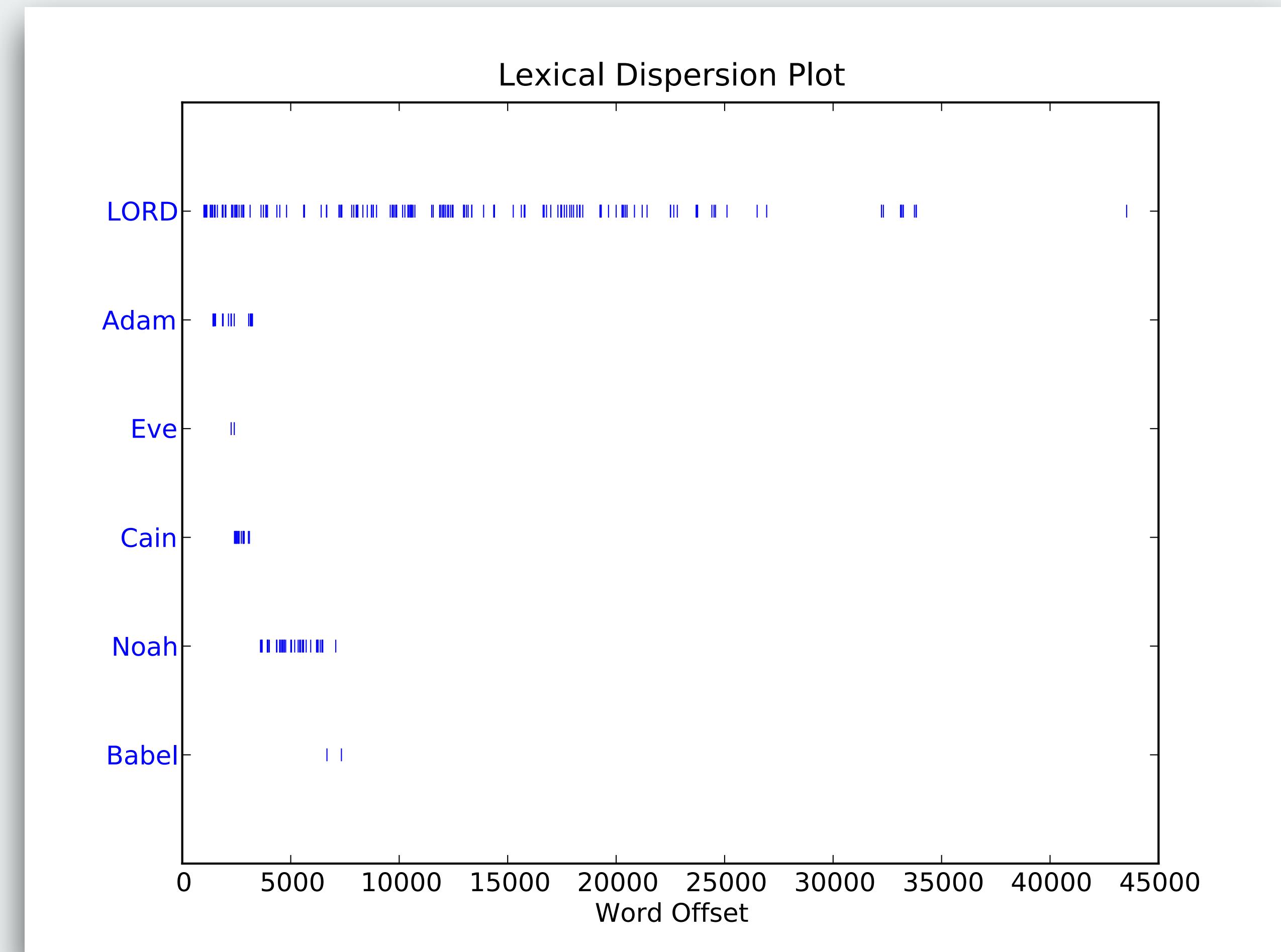
Statistics

Vocabulary

- Mean, median
- Variance, standard deviation, range
- **Correlation**, covariance

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

Framework for describing data

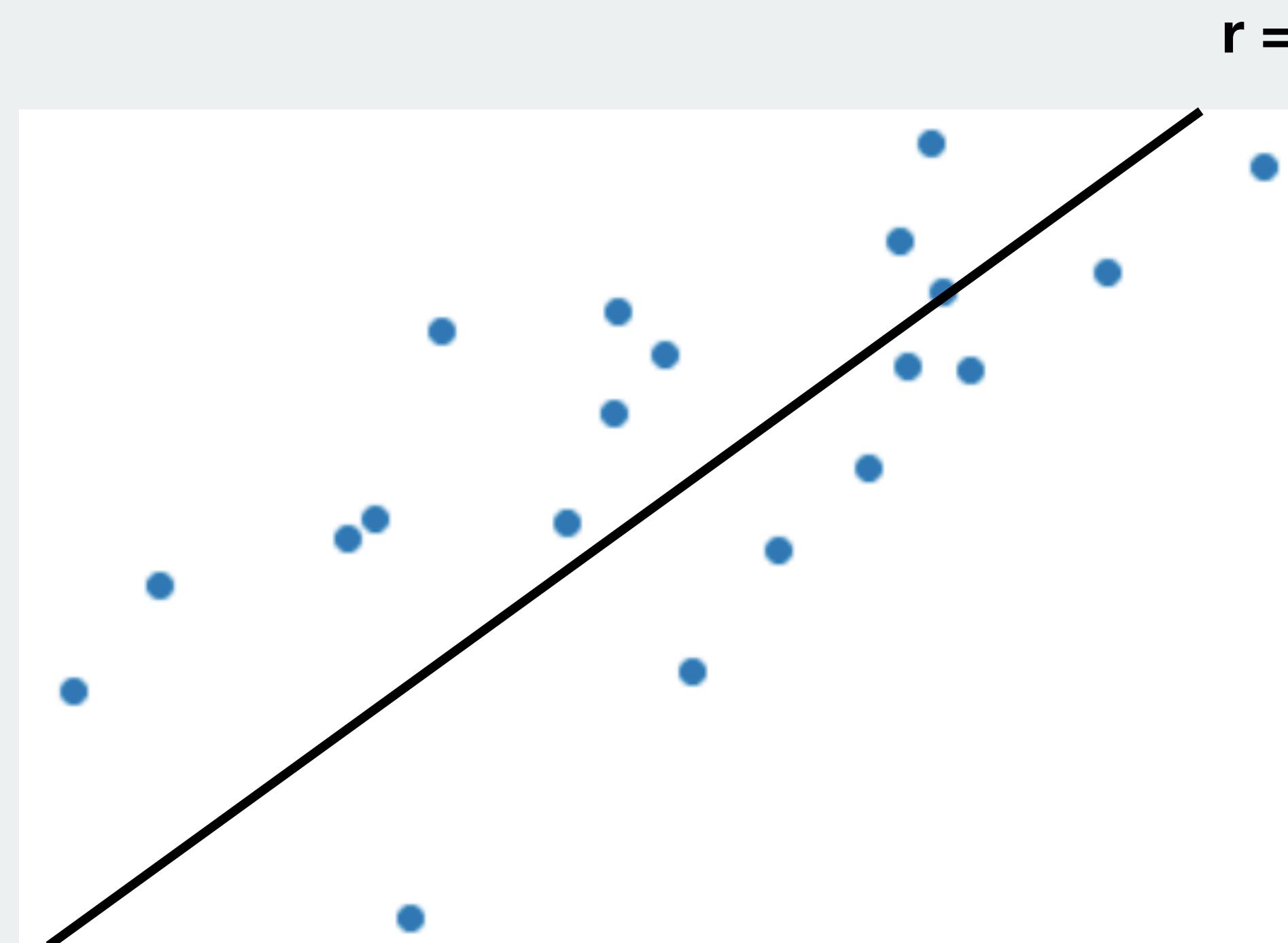


Statistics

Framework for describing data

Tools

- Hypothesis testing

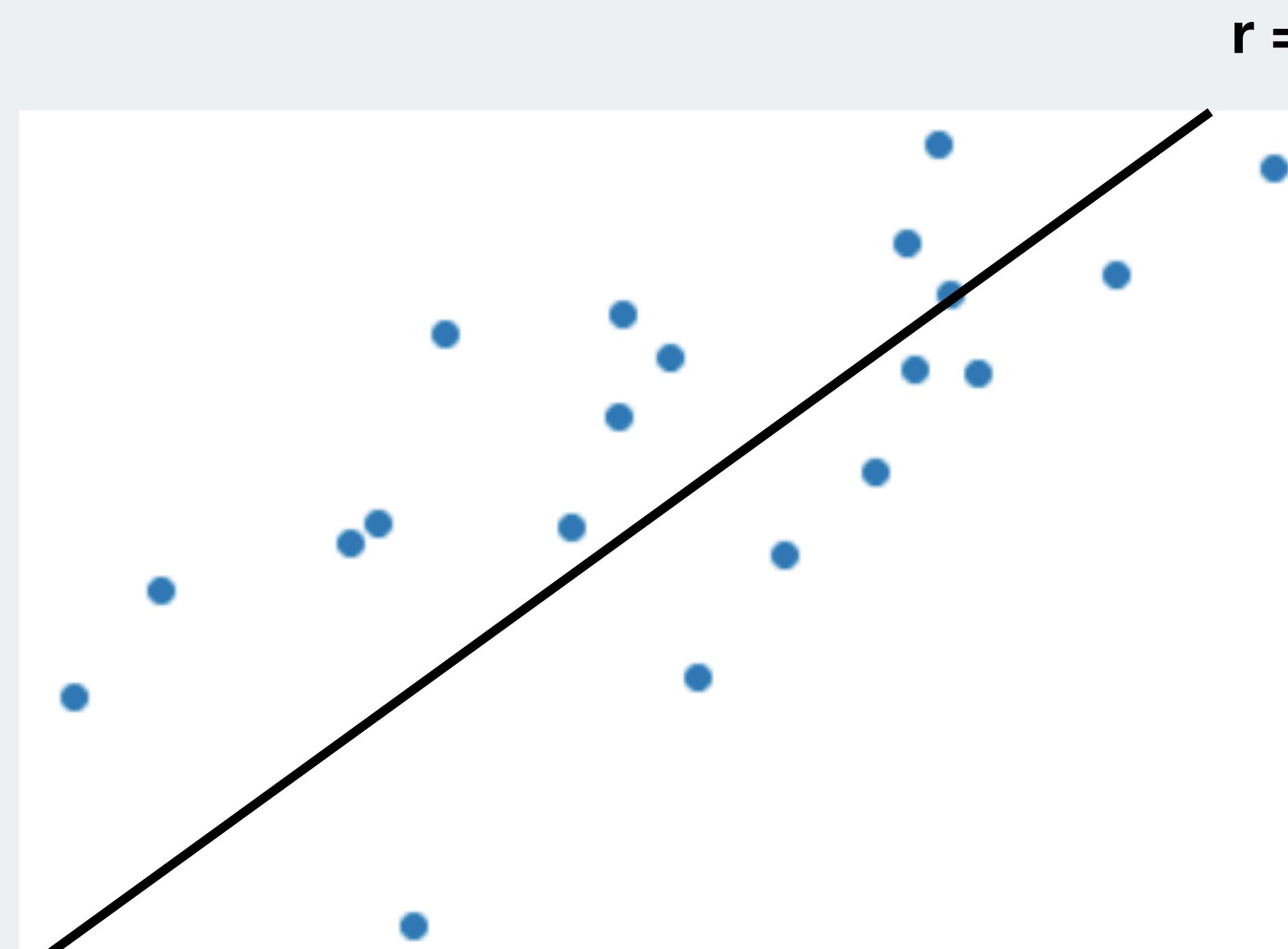
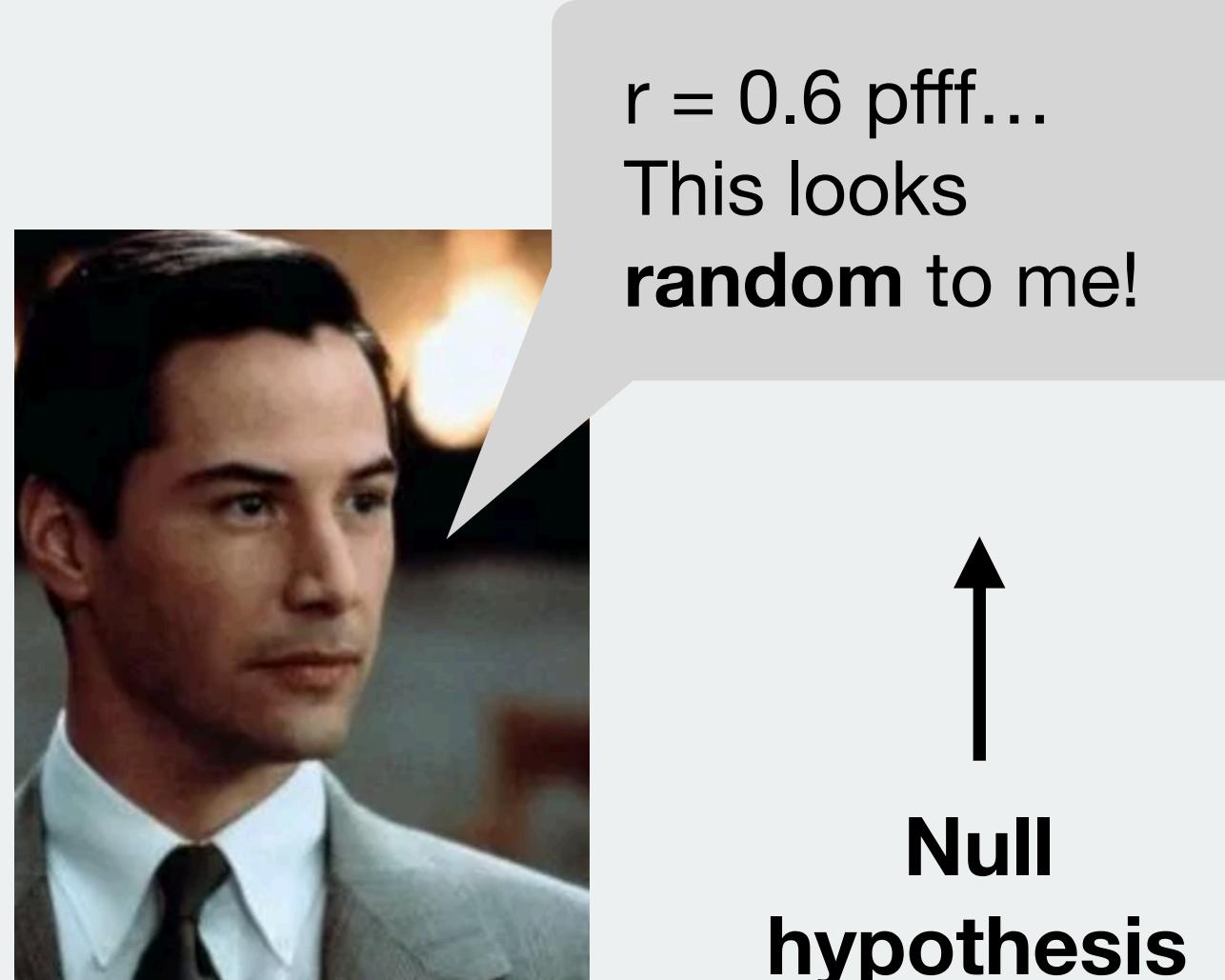


Statistics

Framework for describing data

Tools

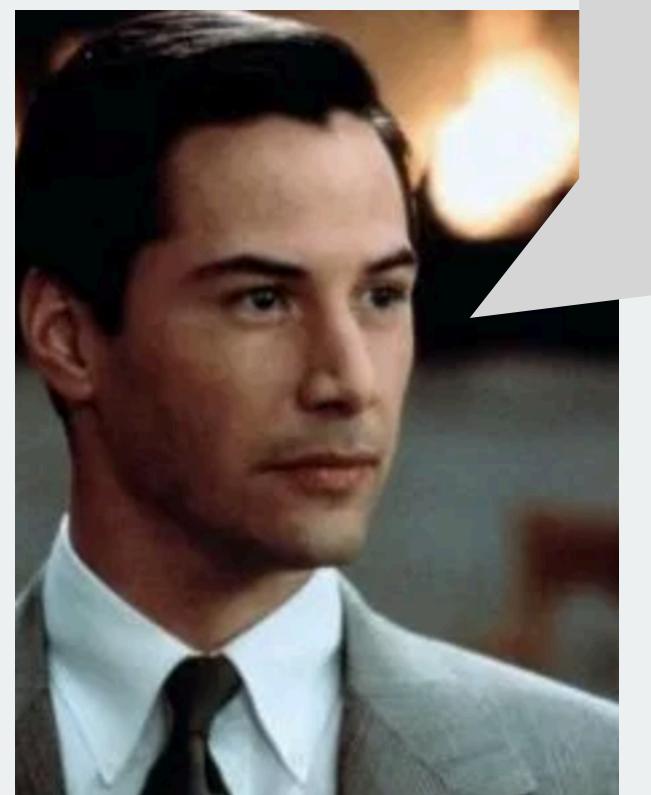
- Hypothesis testing



Statistics

Tools

- Hypothesis testing

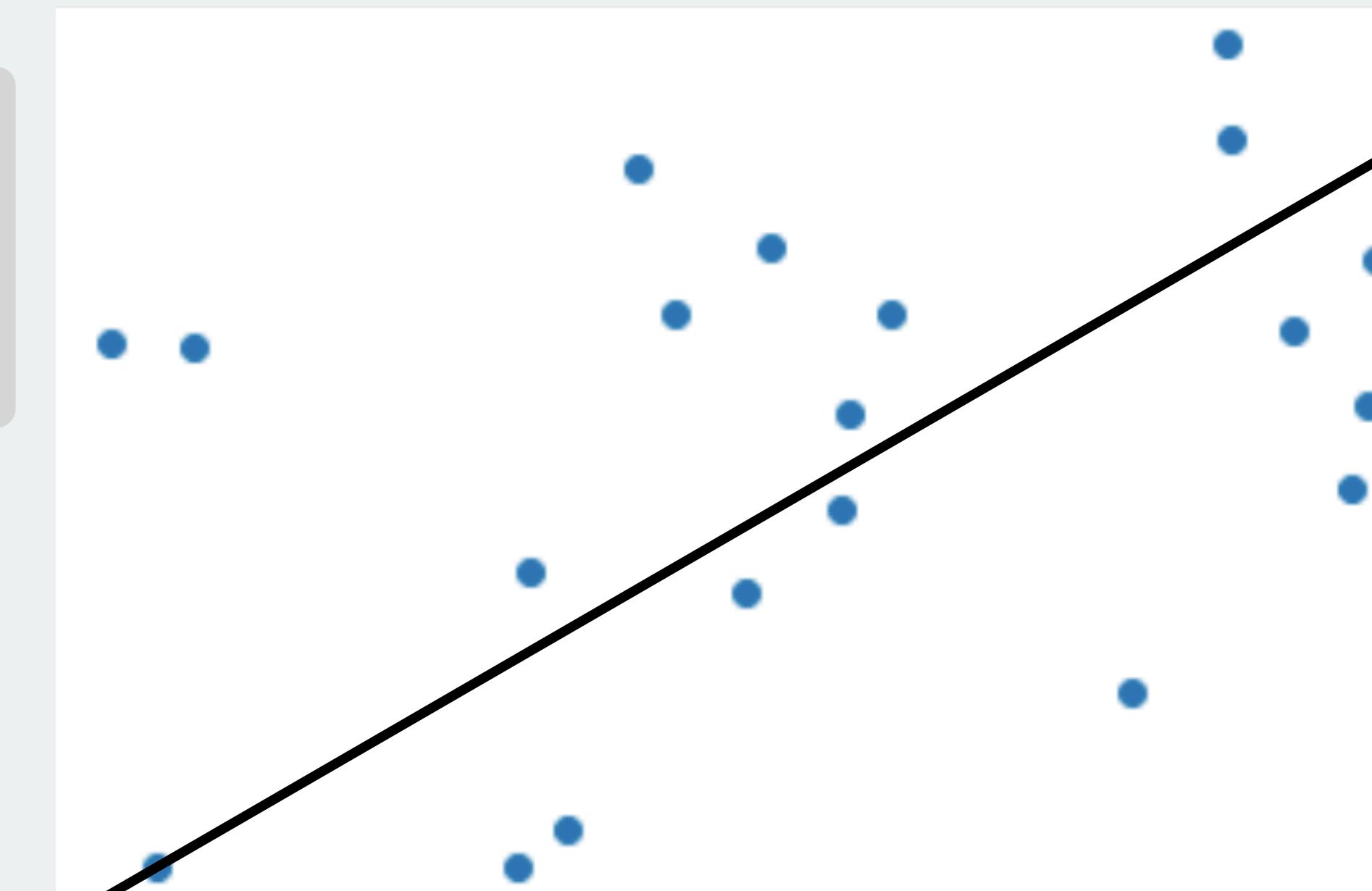


$r = 0.2$? But this
is just one
example. Still
could be random

Null
model

Randomization 1

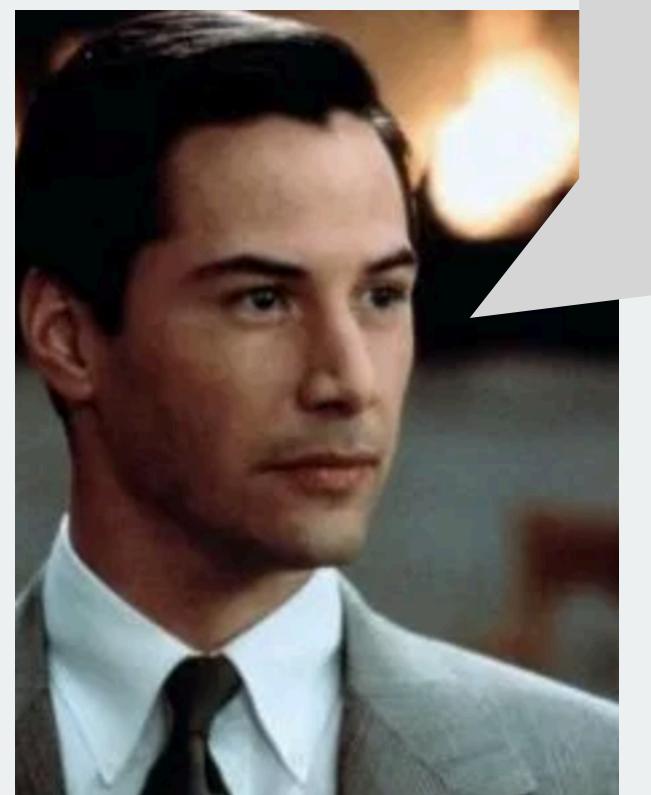
$r = 0.2$



Statistics

Tools

- Hypothesis testing



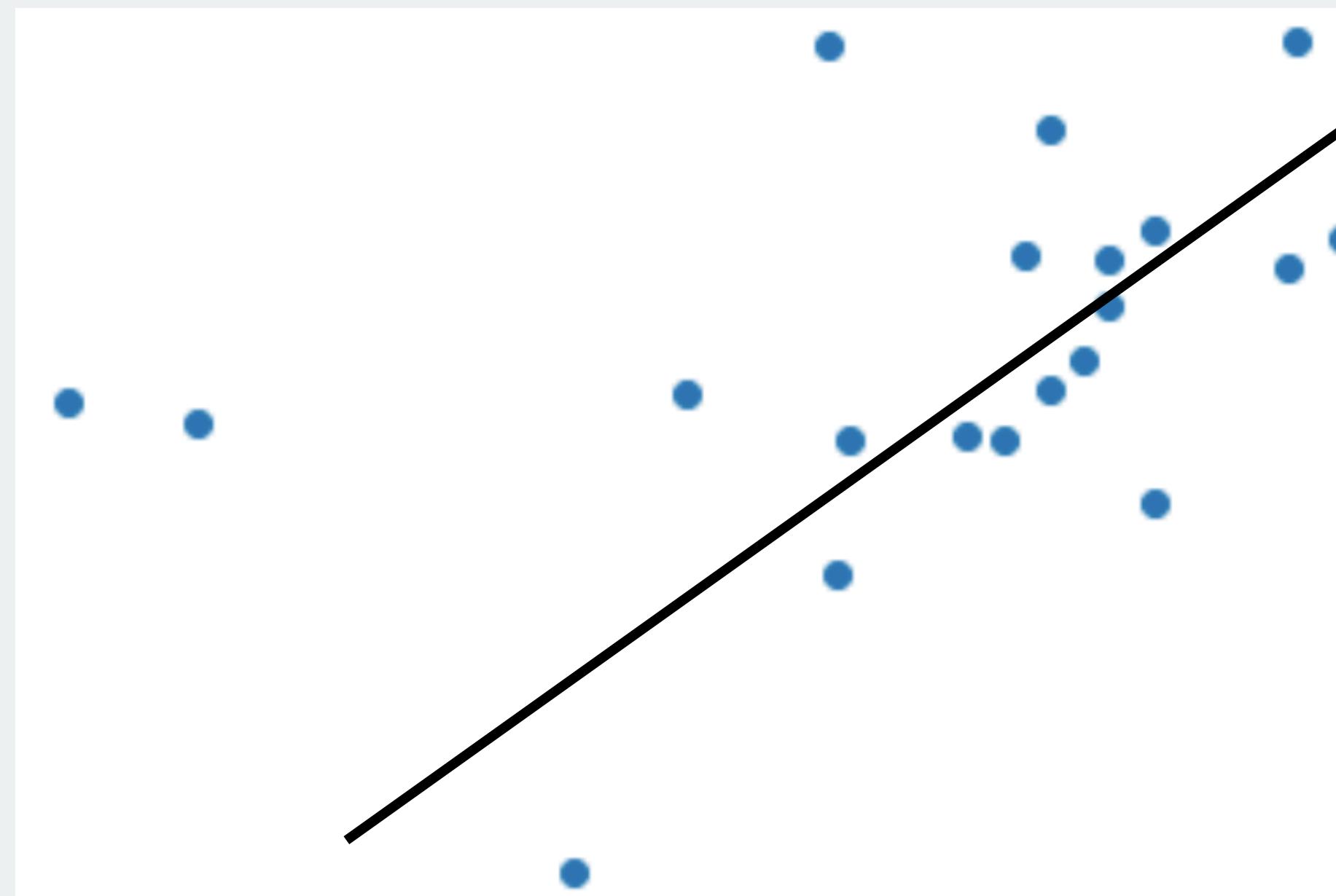
$r = 0.25$? Pure chance, I still think your $r=0.6$ is random

Null hypothesis

Null model

Randomization 2

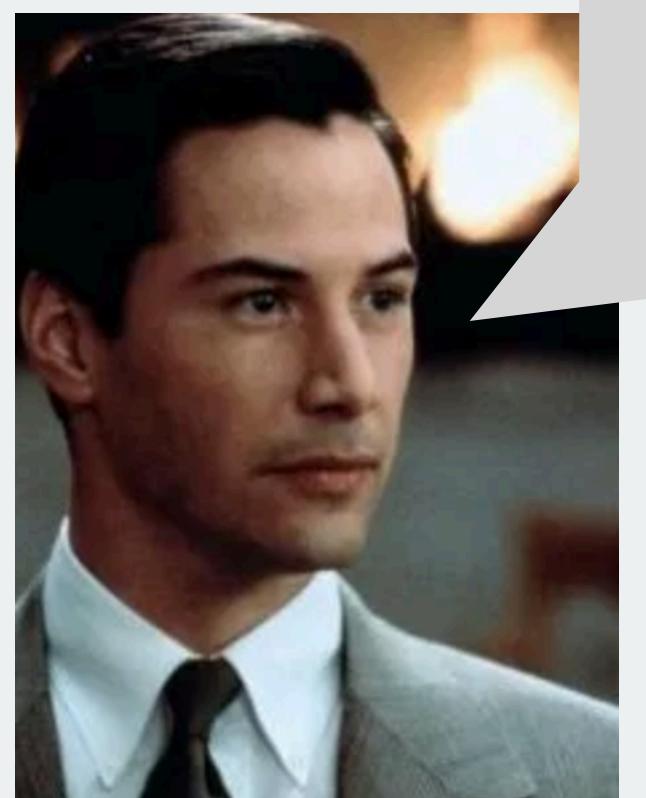
$r = 0.25$



Statistics

Tools

- Hypothesis testing



Ok ok I give up,
random almost
always gives
worse correlation

REJECTED
Null hypothesis

Null
model

Randomization 1000

$r = 0.3$



Framework for describing data