Visualizing covariance, variance, standard deviation, correlation

Gina Reynolds

This book looks some basic statistics:

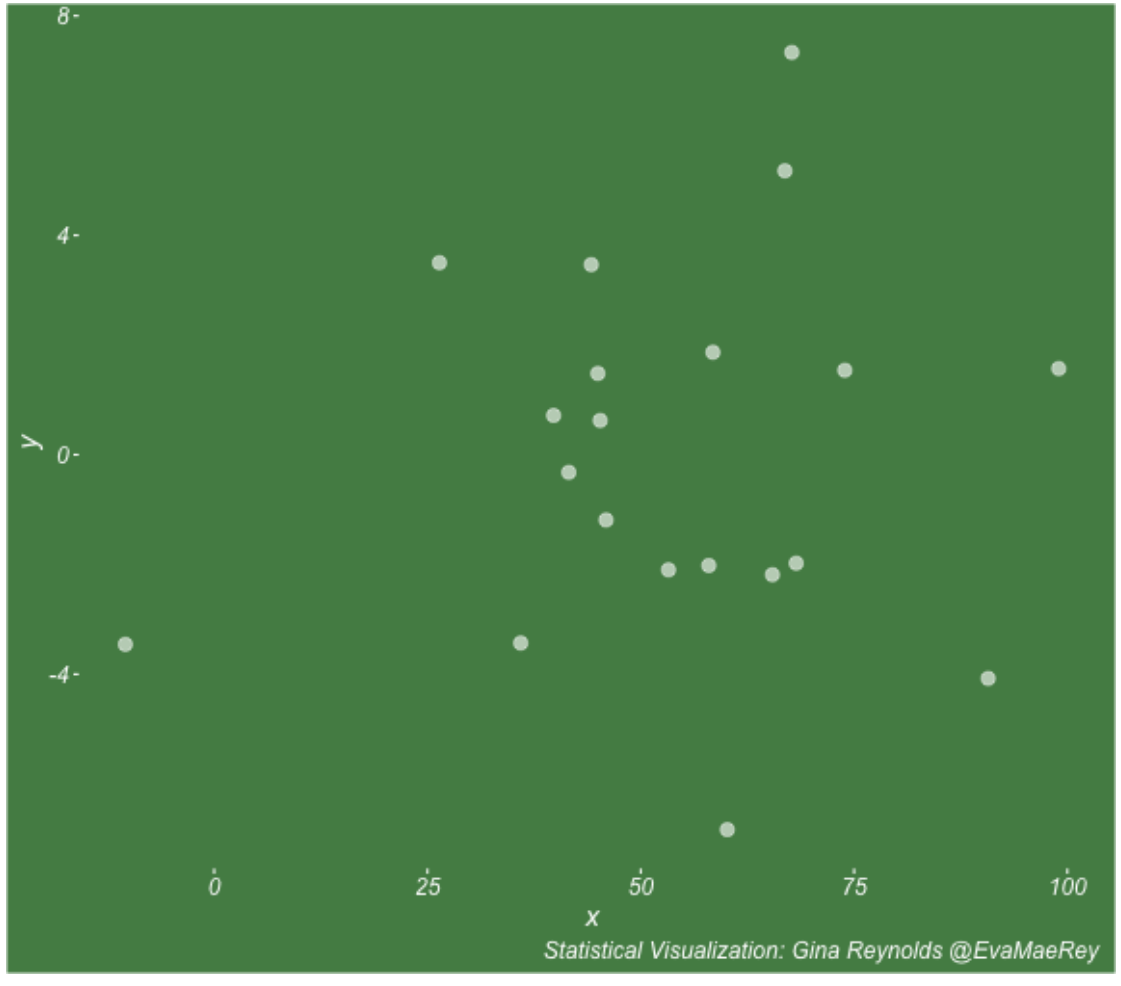
- covariance
- variance
- standard deviation
- correlation coefficient

We'll look at the *population* statistics first equation over all:

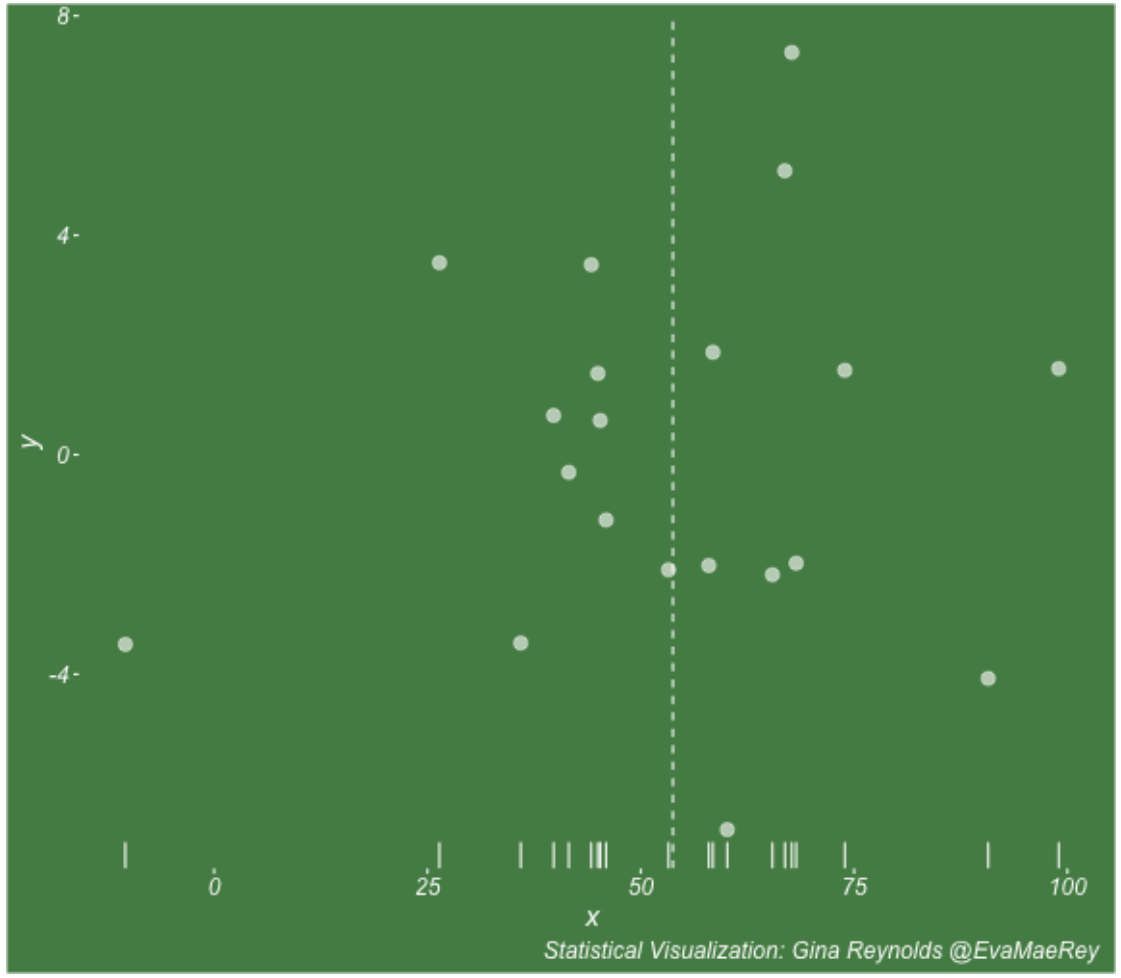
Covariance

Covariance is a measure of the joint variability of two random variables.

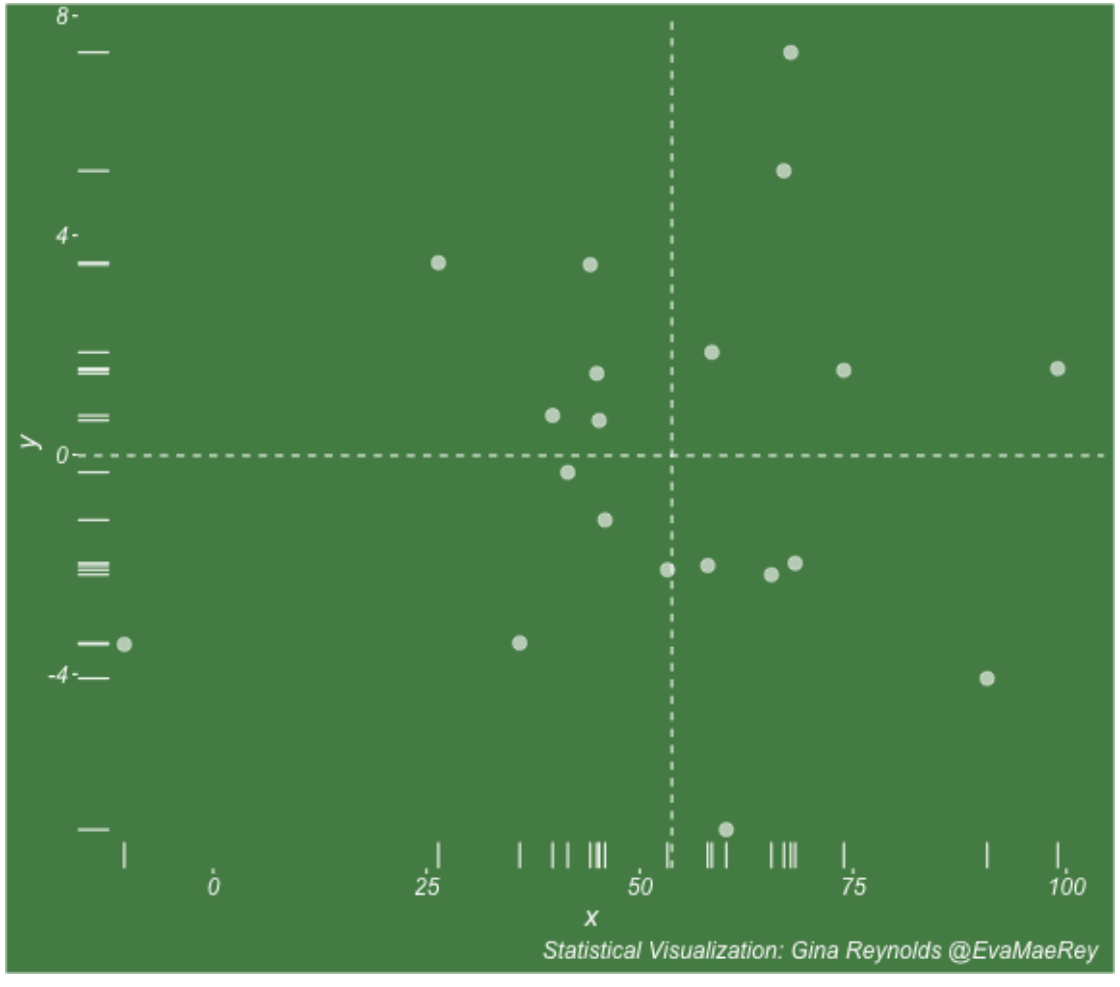
$$cov(x, y) = \frac{\sum_{i=1}^{n}(x_i - \mu_x)(y_i - \mu_y)}{n}$$


8
4
0
-4
y
0
25
50
75
100
x
Statistical Visualization: Gina Reynolds @EvaMaeRey

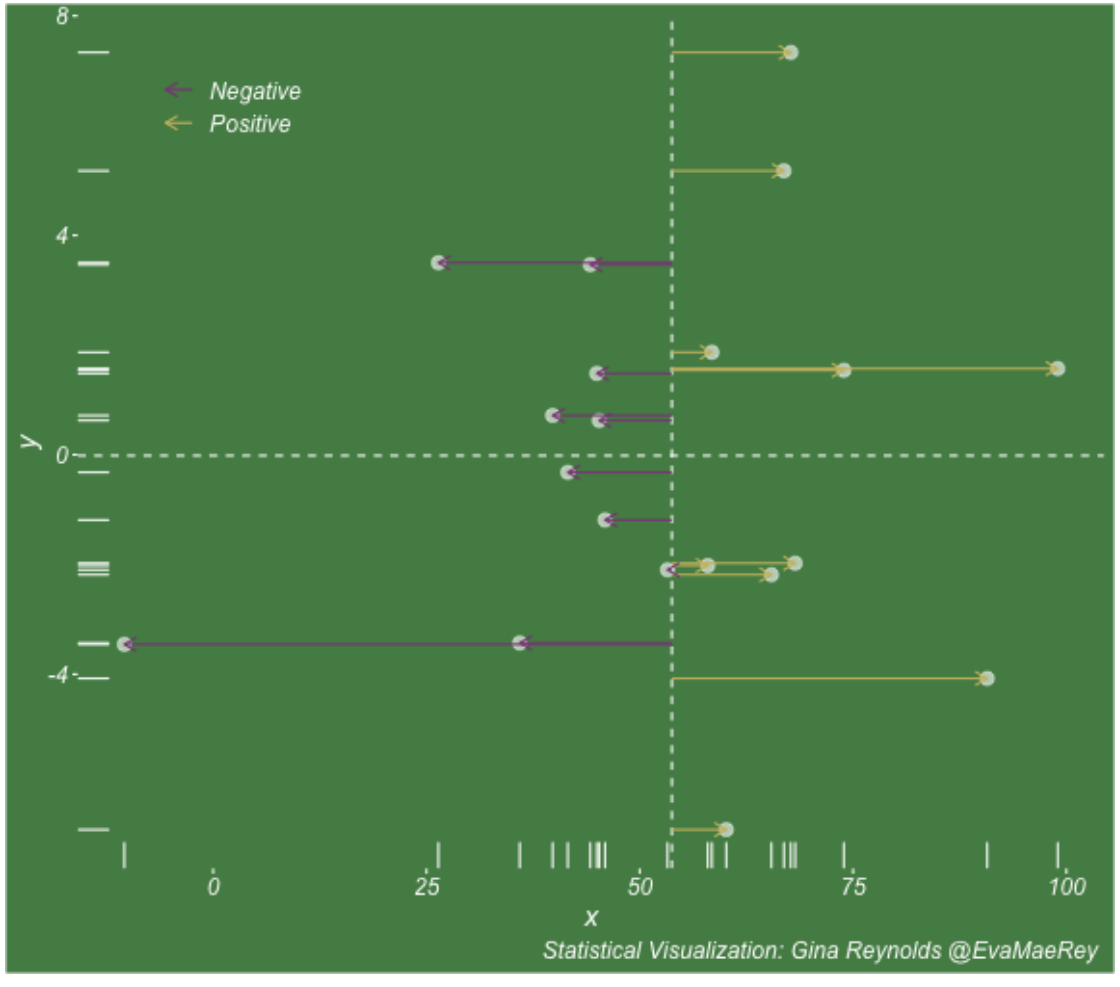
μ_x


8
4
0
-4
y
0
25
50
75
100
x
Statistical Visualization: Gina Reynolds @EvaMaeRey

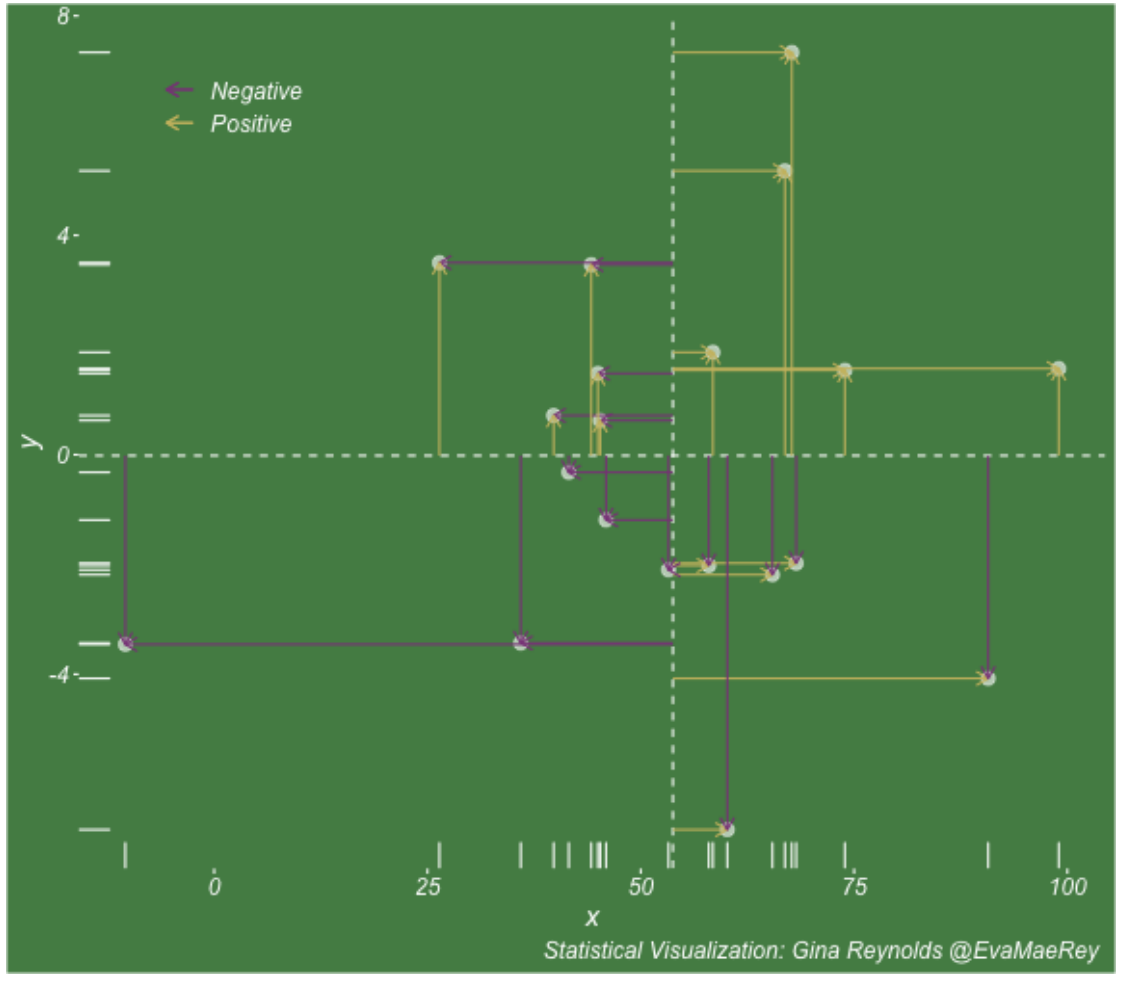
μ_y


8
4
0
-4
y
0
25
50
75
100
x
Statistical Visualization: Gina Reynolds @EvaMaeRey

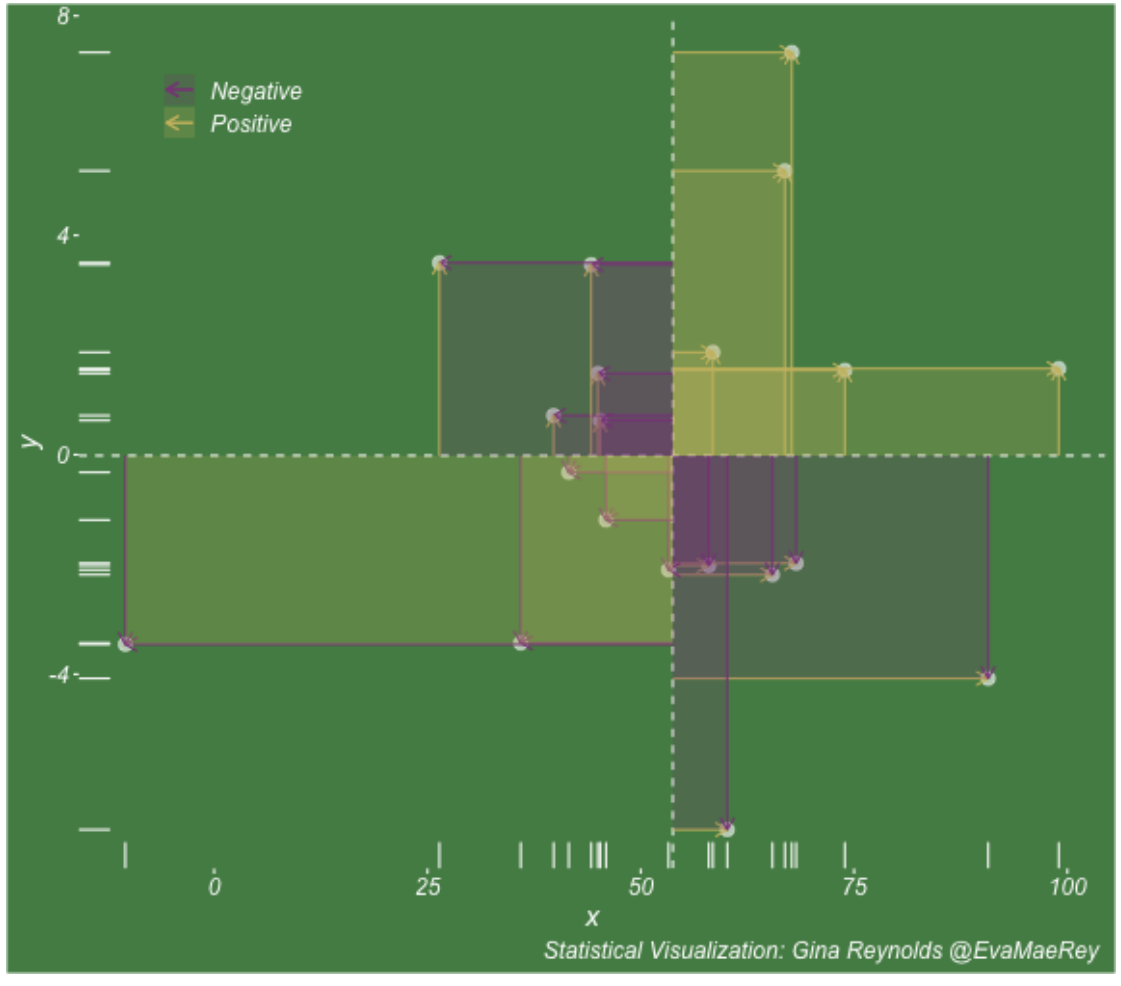
$$x_i - \mu_x$$


Negative
Positive
8
4
0
-4
y
0
25
50
75
100
x
Statistical Visualization: Gina Reynolds @EvaMaeRey

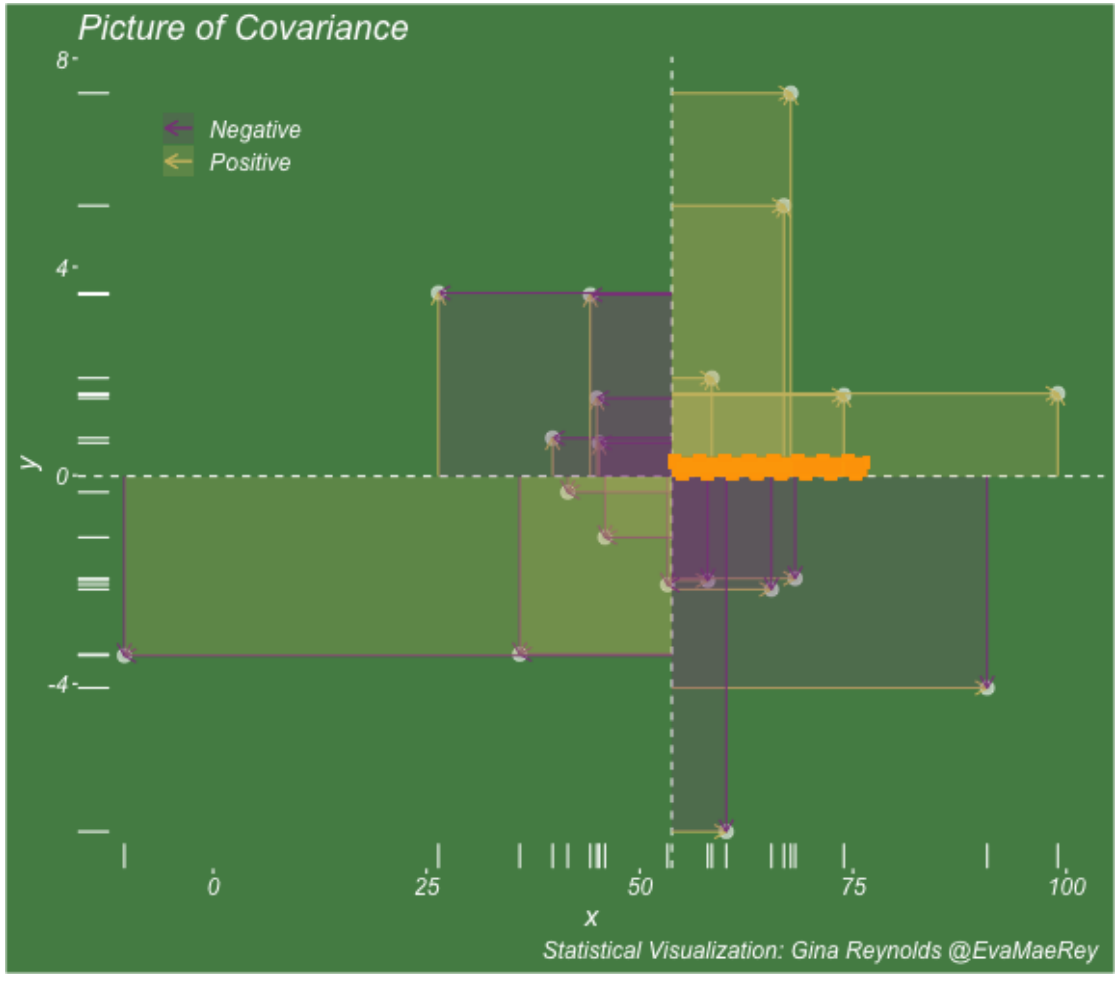
$$y_i - \mu_y$$


Negative
Positive
8
4
0
-4
y
0
25
50
75
100
x
Statistical Visualization: Gina Reynolds @EvaMaeRey

$$\sum_{i=1}^{n}(x_i - \mu_x)(y_i - \mu_y)$$



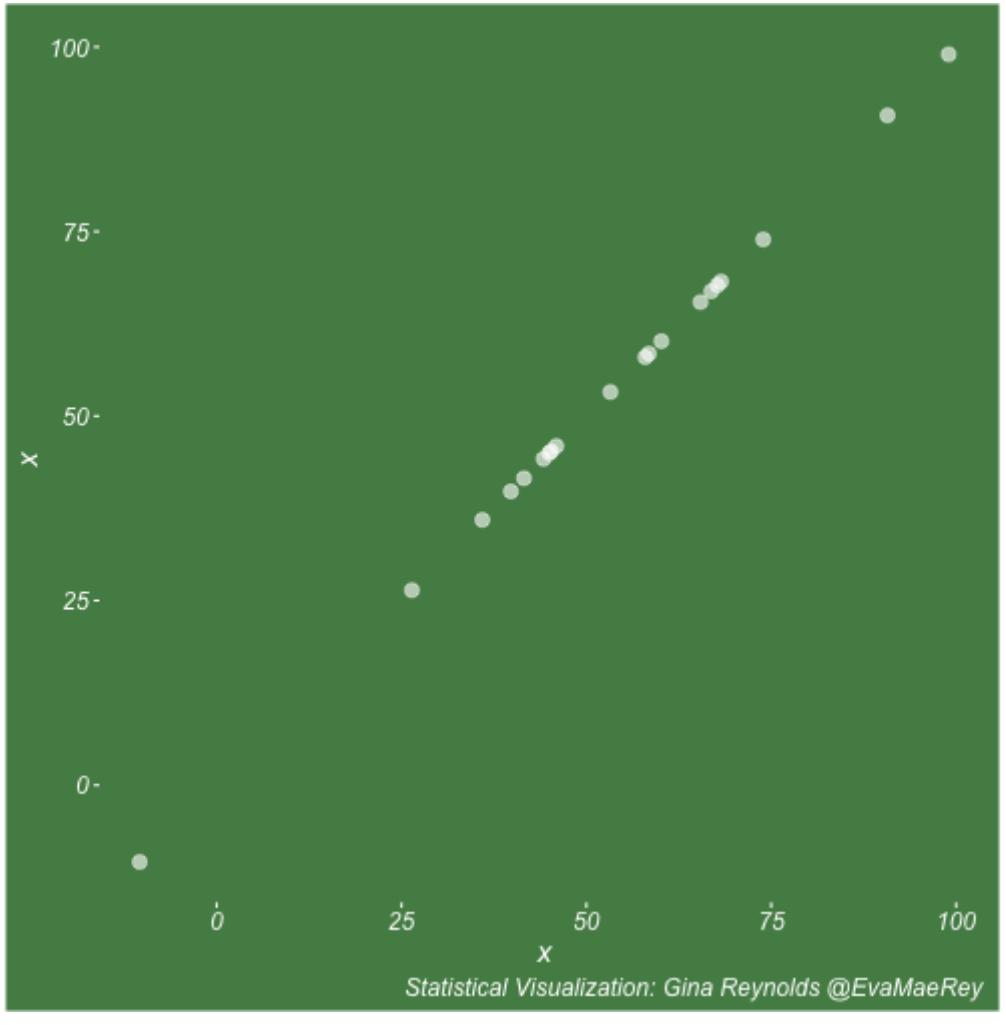
$$\frac{\sum_{i=1}^{n}(x_i - \mu_x)(y_i - \mu_y)}{n}$$



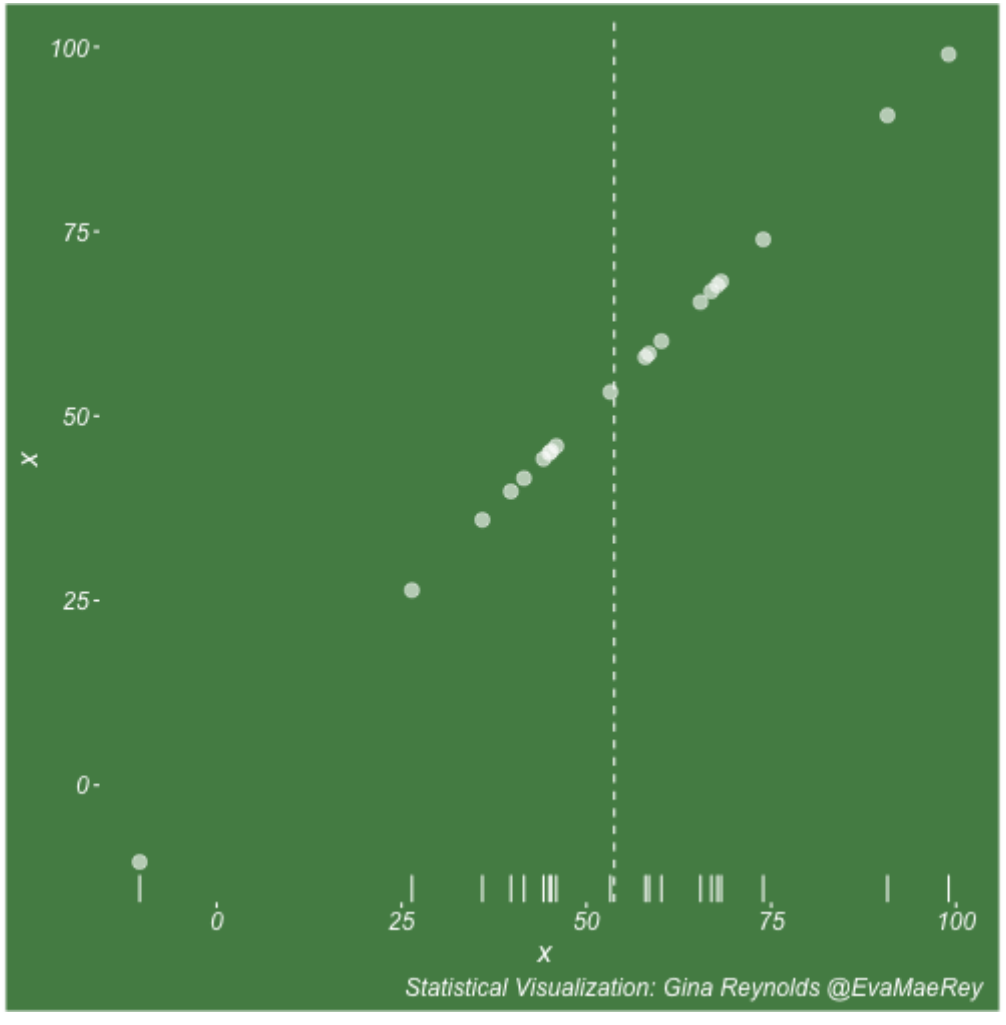
Variance and Standard Deviation

$$var(x) = \frac{\sum_{i=1}^{n} (x_i - \mu_x)^2}{n}$$

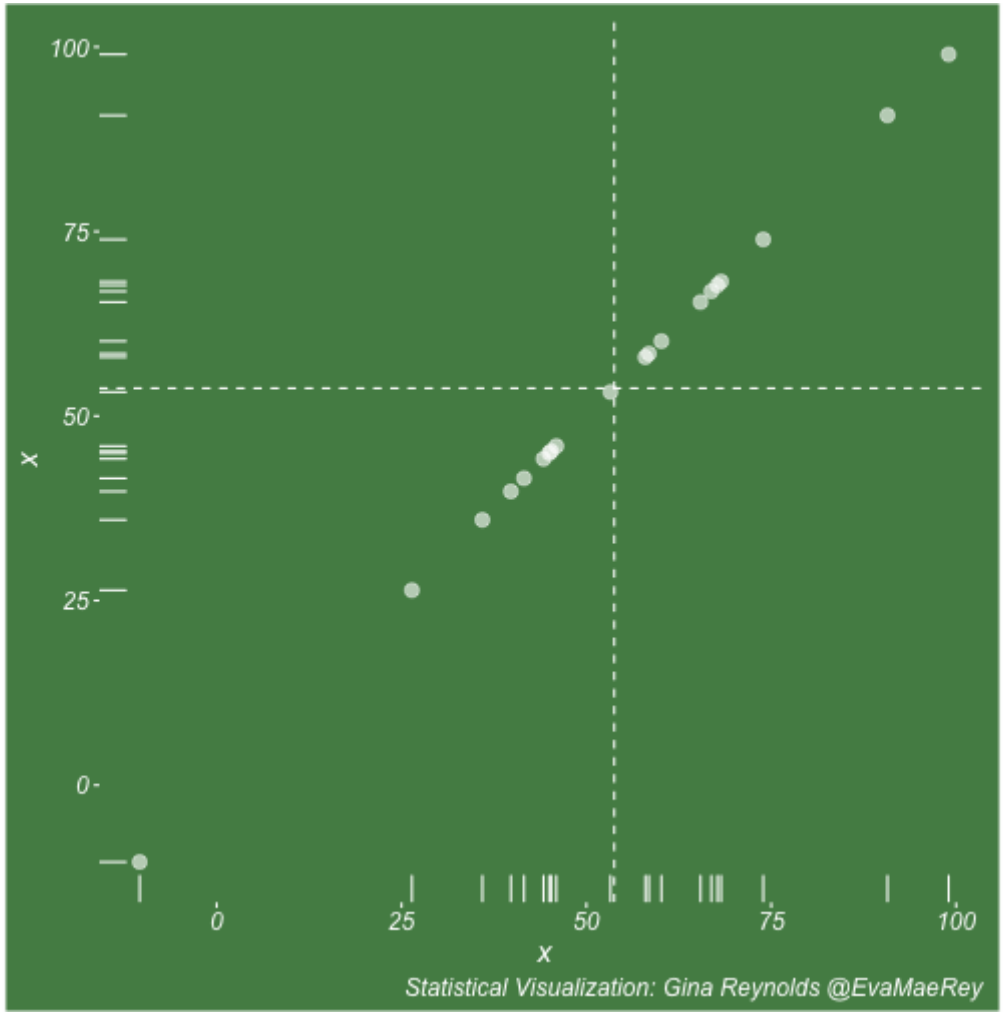
$$\sigma^2 = \frac{\sum_{i=1}^{n}(x_i - \mu_x)^2}{n}$$


100
75
50
25
0
x
0
25
50
75
100
x
Statistical Visualization: Gina Reynolds @EvaMaeRey

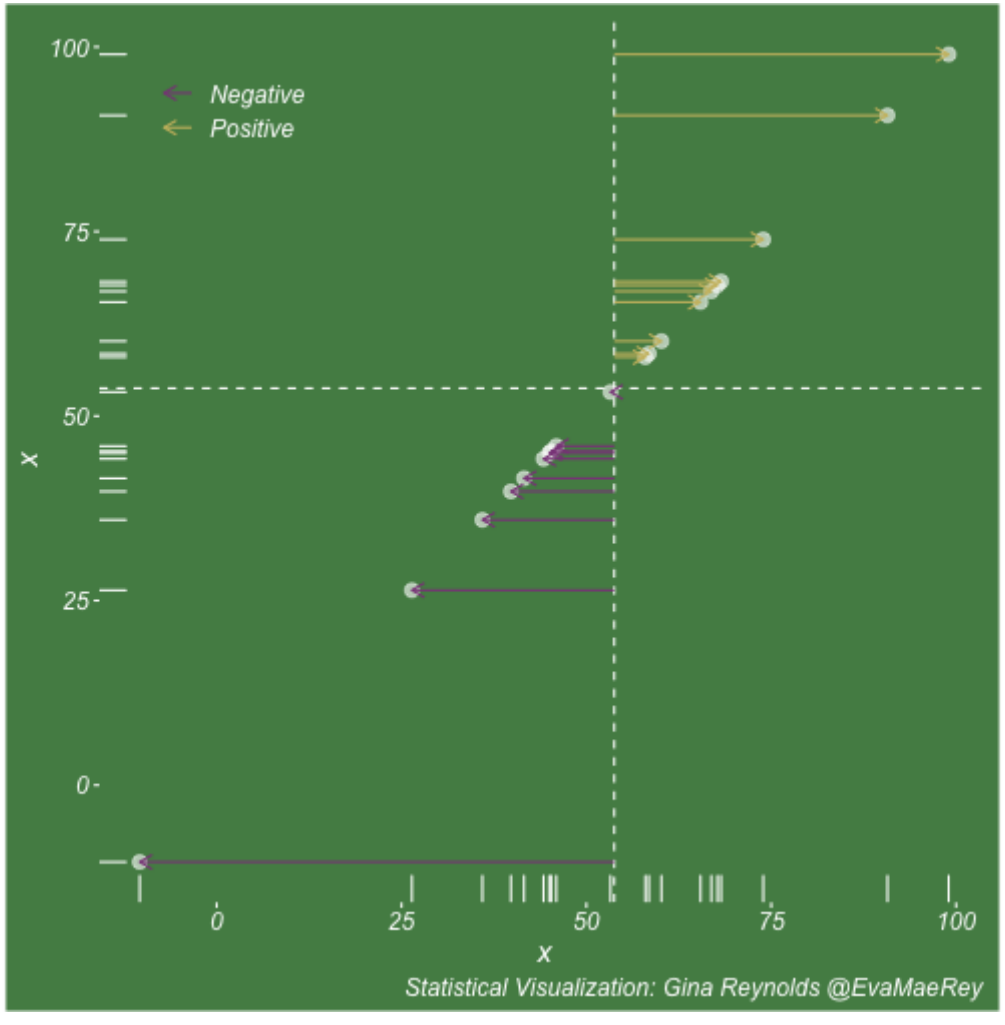
μ_x


100
75
50
25
0
x
0
25
50
75
100
x
Statistical Visualization: Gina Reynolds @EvaMaeRey

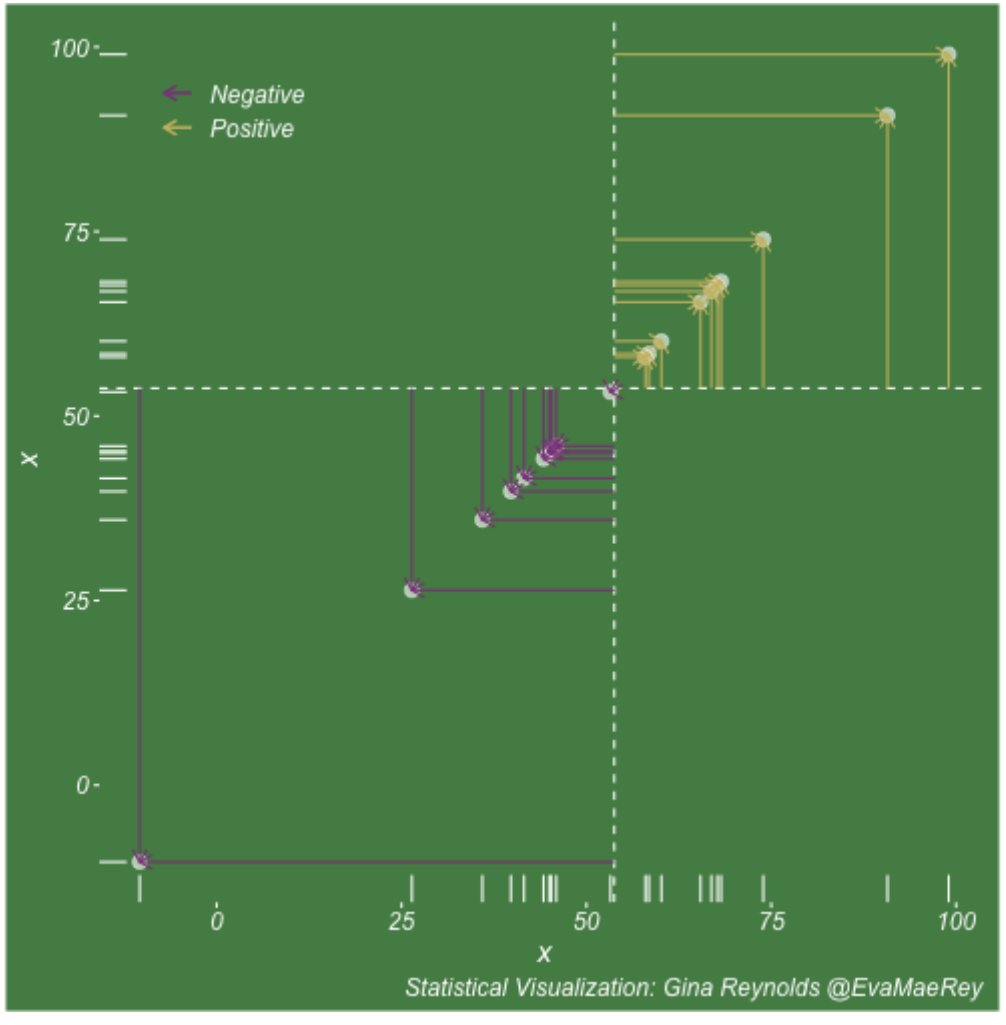
μ_x


100
75
50
25
0
x
0
25
50
75
100
x
Statistical Visualization: Gina Reynolds @EvaMaeRey

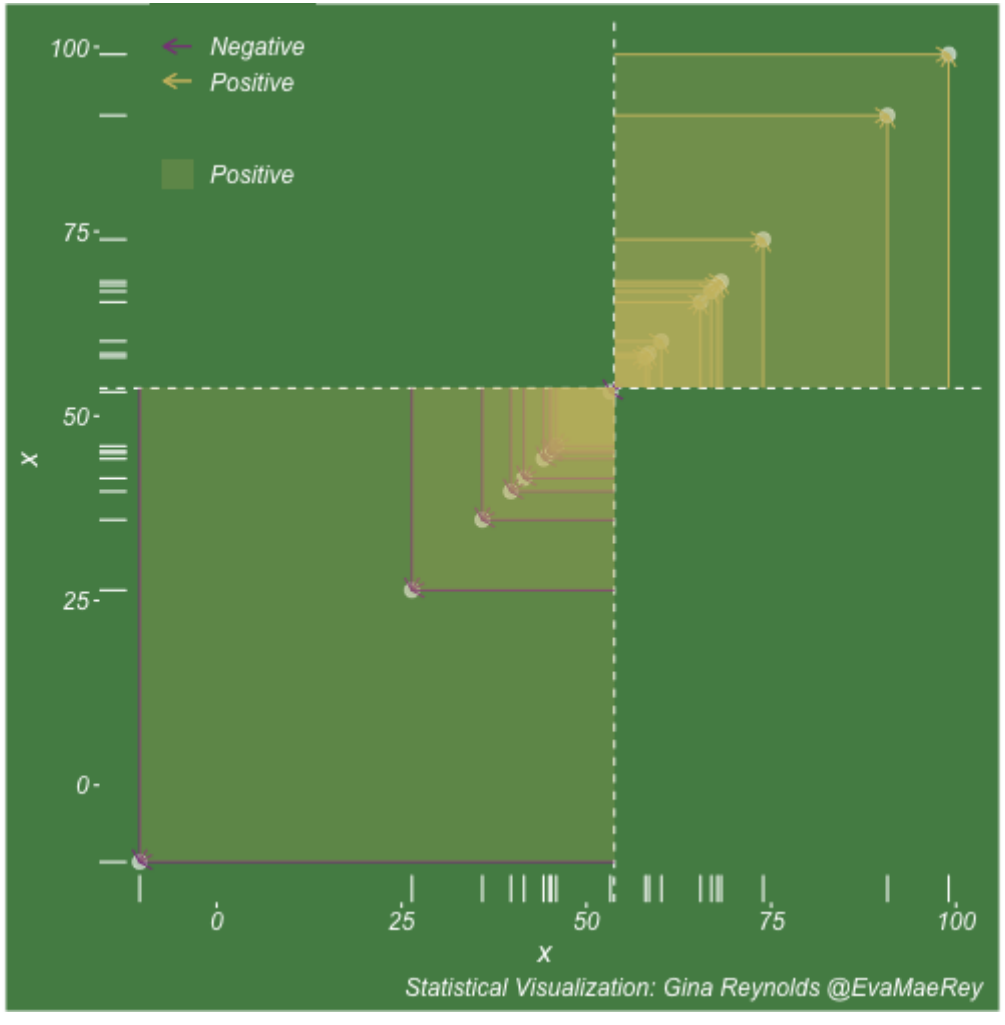
$$x_i - \mu_x$$


Negative
Positive
100
75
50
25
0
x
0
25
50
75
100
x
Statistical Visualization: Gina Reynolds @EvaMaeRey

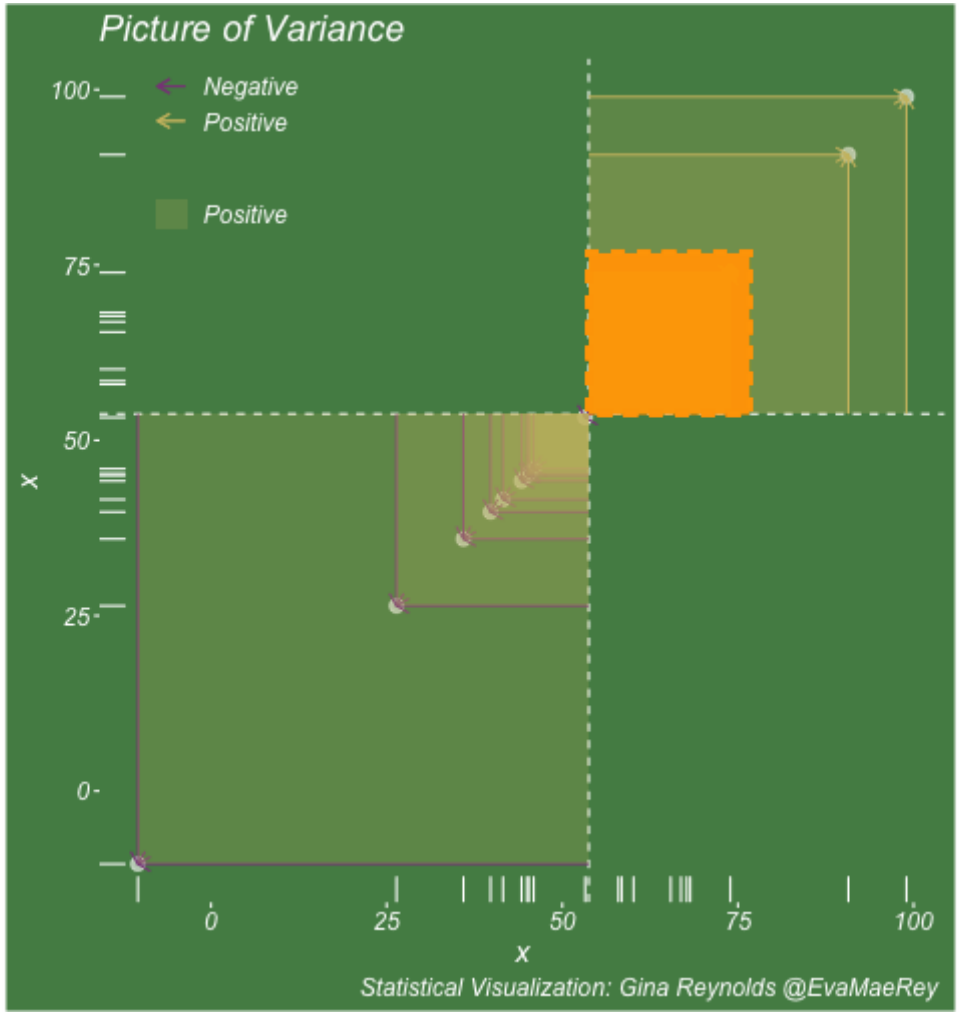
$$x_i - \mu_x$$


Negative
Positive
100
75
50
25
0
x
0
25
50
75
100
x
Statistical Visualization: Gina Reynolds @EvaMaeRey

$$\sum_{i=1}^{n}(x_i - \mu_x)^2$$



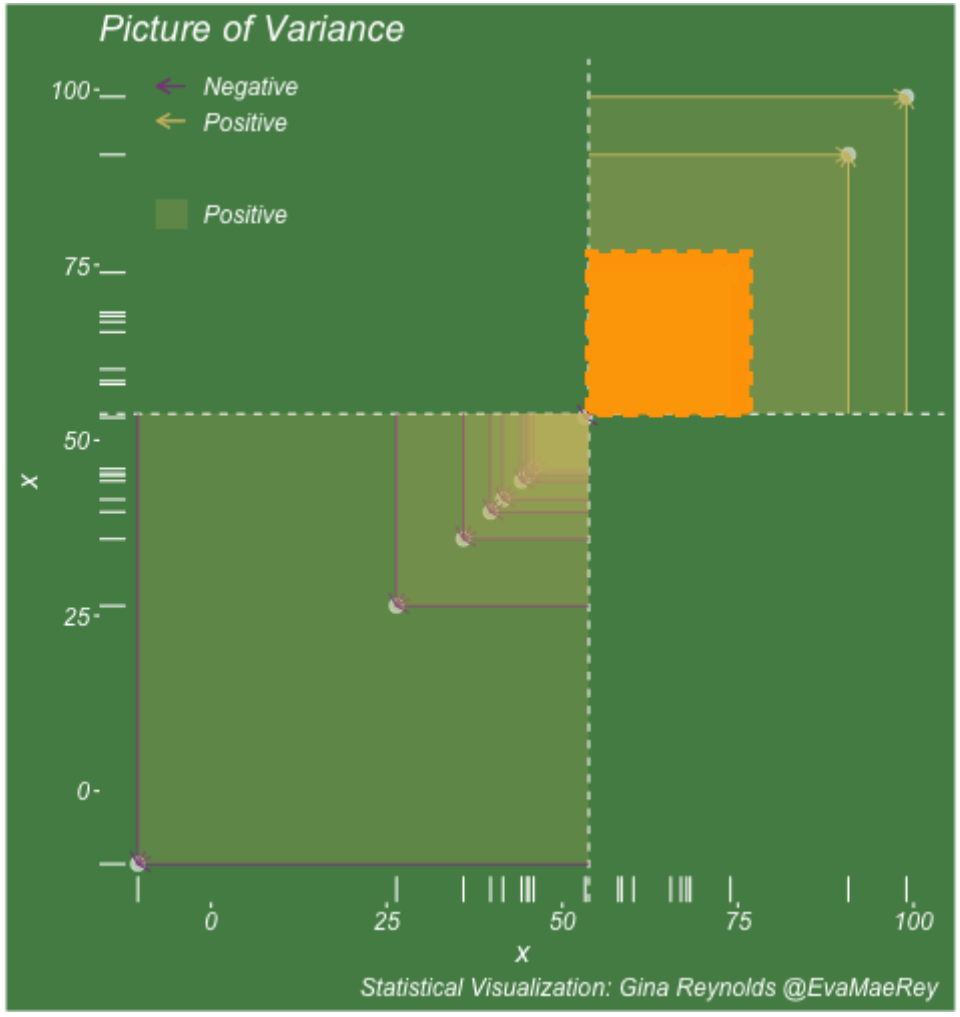
$$\frac{\sum_{i=1}^{n}(x_i - \mu_x)^2}{n}$$



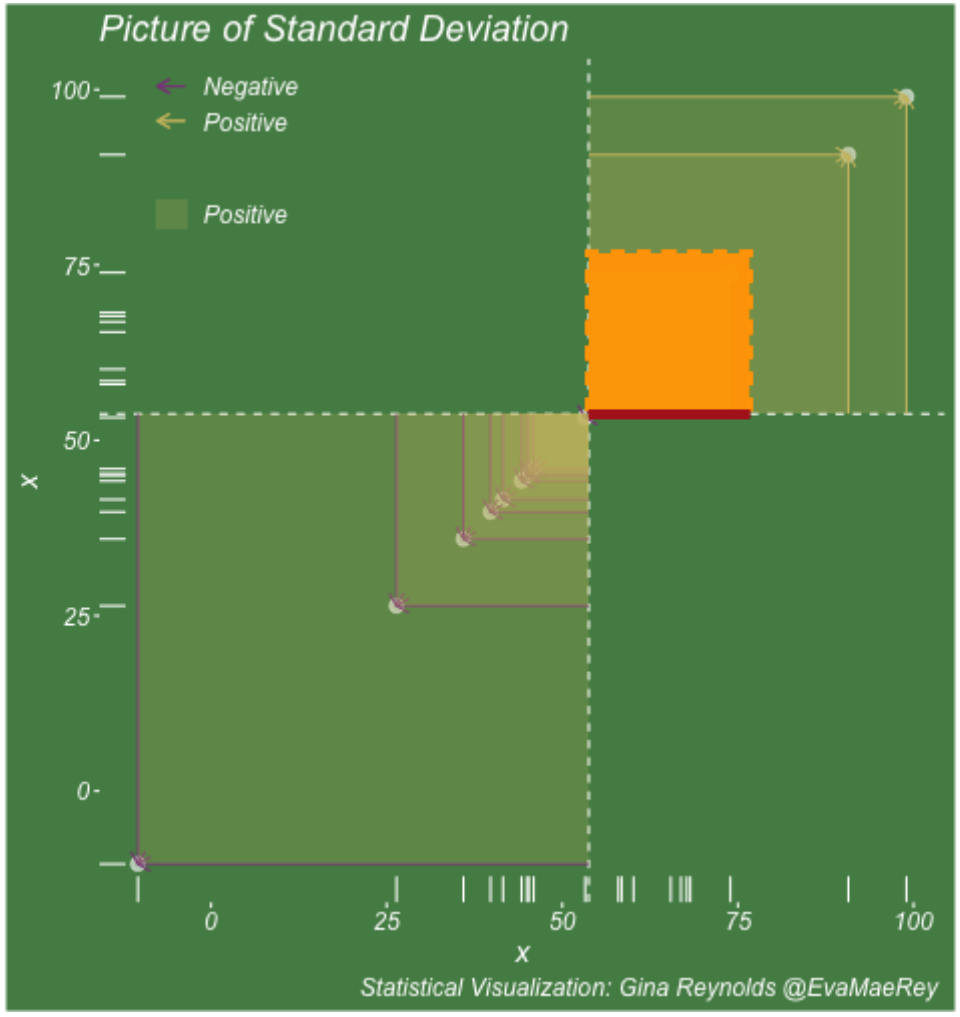
$$\sigma^2 = \frac{\sum_{i=1}^{n}(x_i - \mu_x)^2}{n}$$

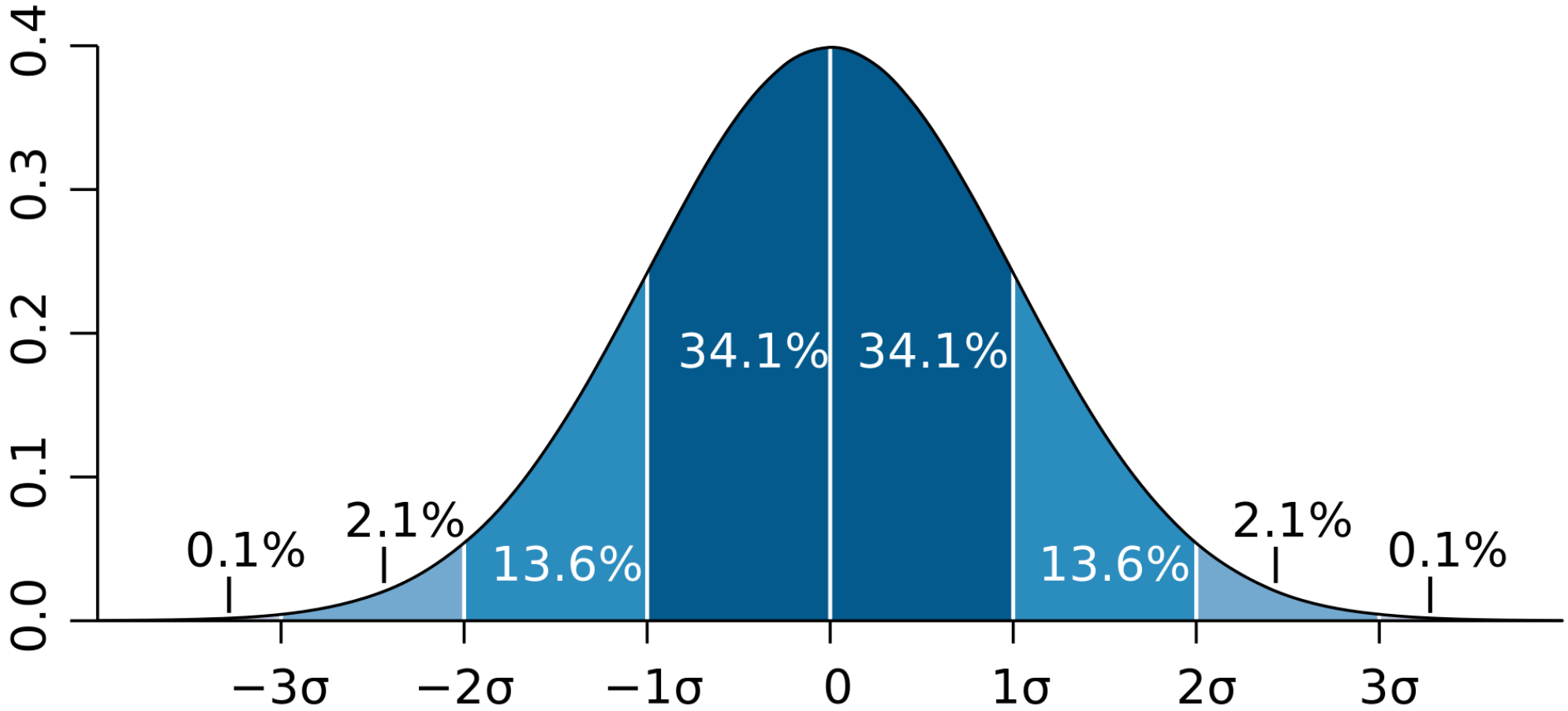
$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \mu_x)^2}{n}}$$

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



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



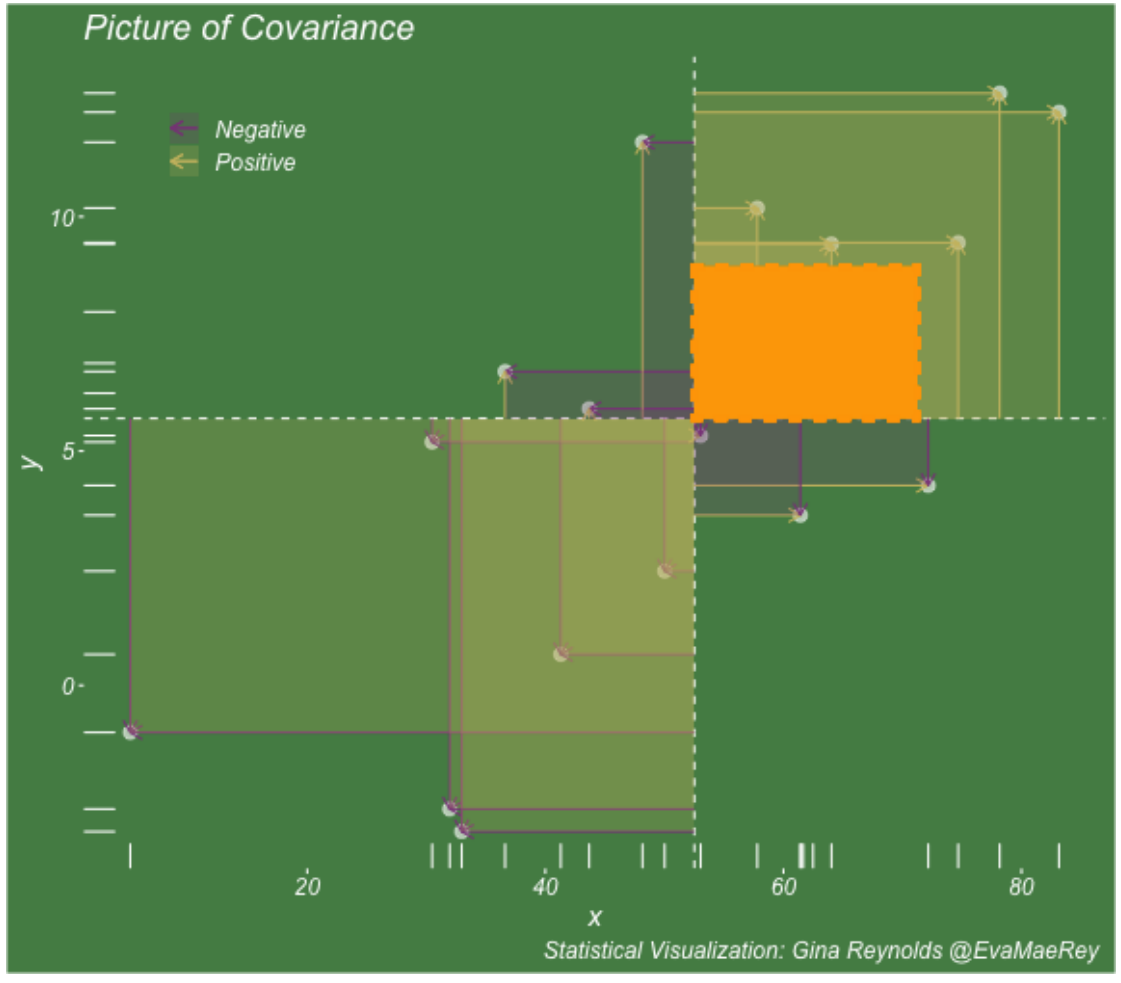


Creative commons, Wikipedia, M. W. Toews - Own work, based (in concept) on figure by Jeremy Kemp, on 2005-02-09

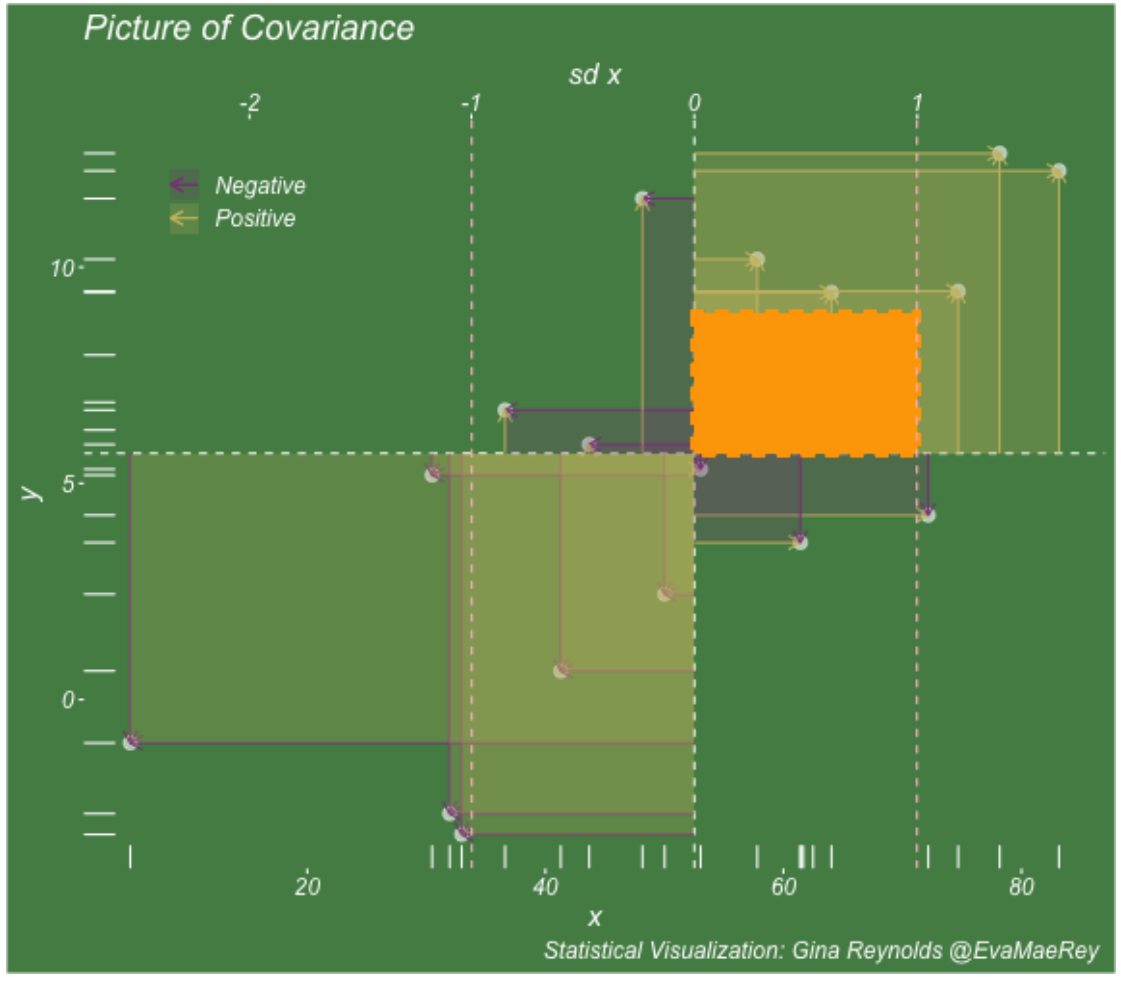
correlation coefficient

$$cor(x,y) = \frac{\sum_{i=1}^{n}(x_i - \mu_x)(y_i - \mu_y)}{n * \sigma_x \sigma_y}$$

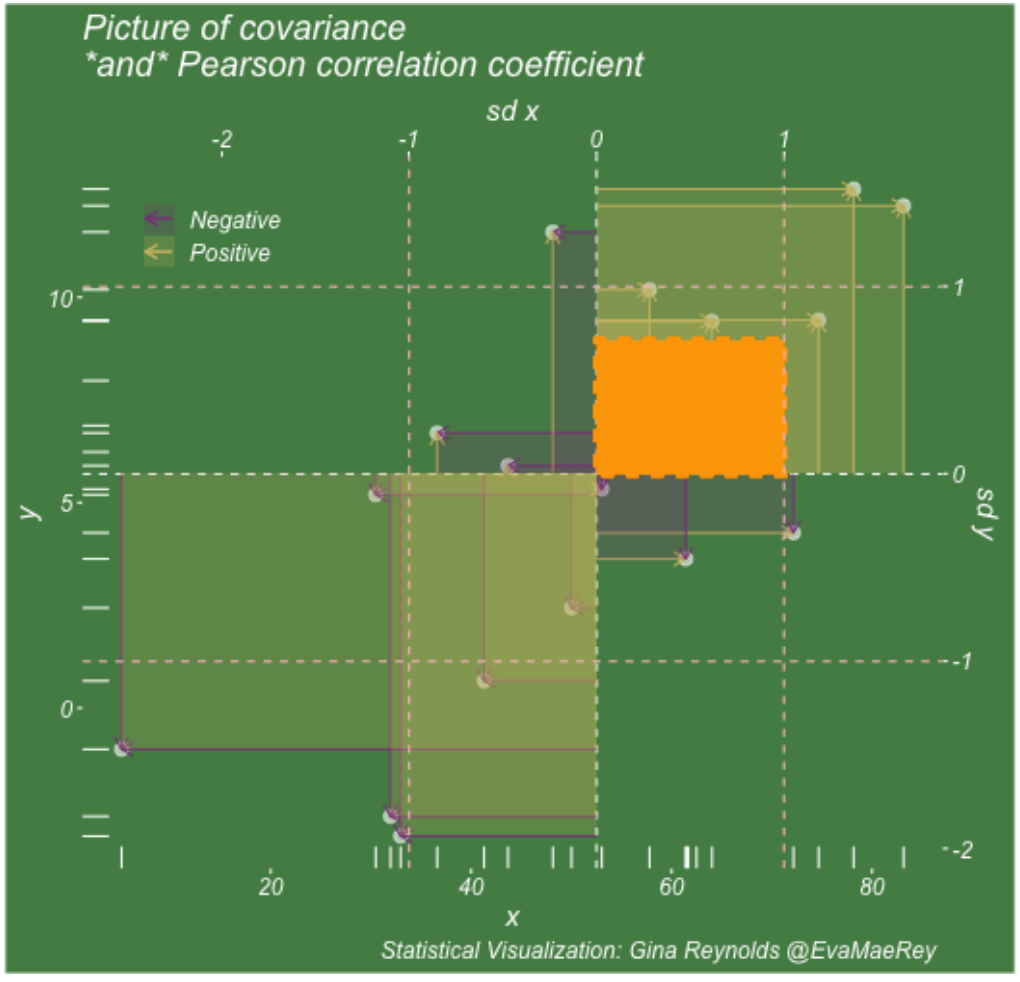
$$\frac{\sum_{i=1}^{n}(x_i - \mu_x)(y_i - \mu_y)}{n}$$



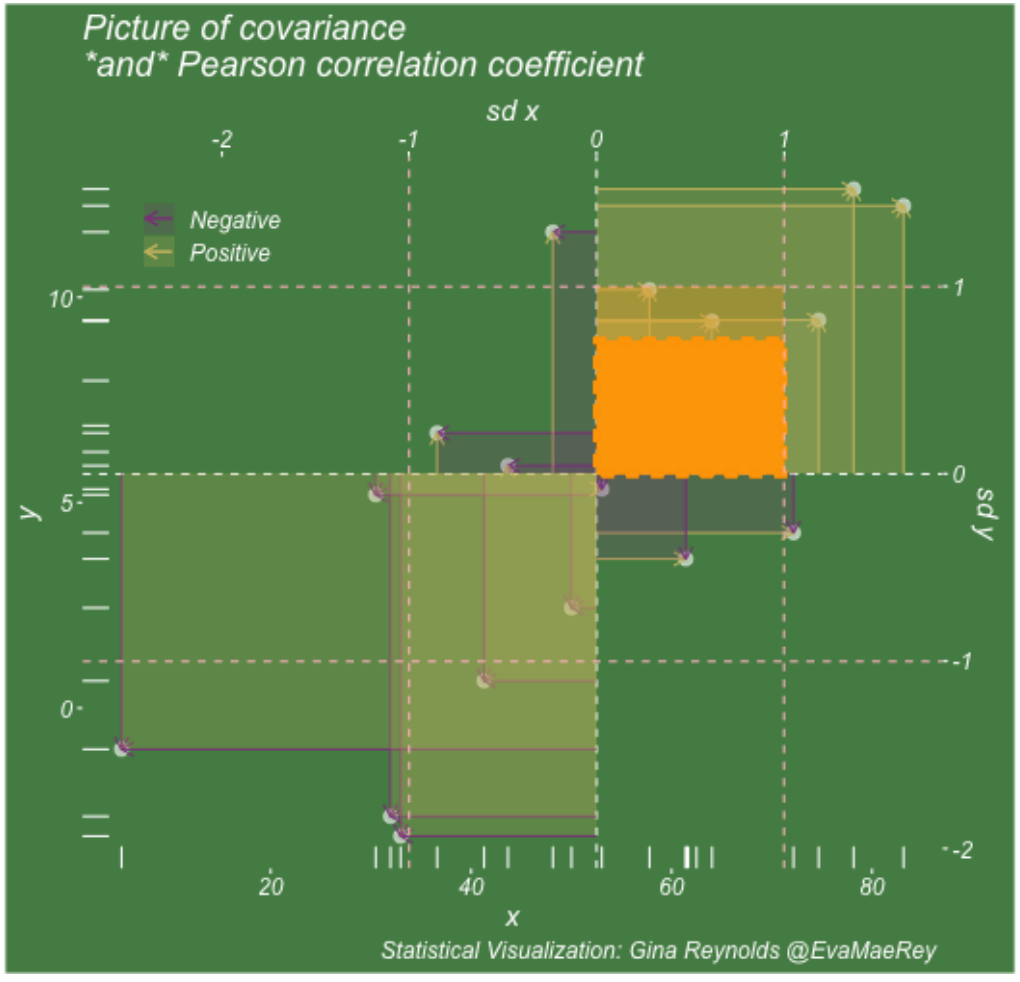
$$\frac{\sum_{i=1}^{n}(x_i - \mu_x)(y_i - \mu_y)}{n * \sigma_x}$$



$$\frac{\sum_{i=1}^{n}(x_i - \mu_x)(y_i - \mu_y)}{n * \sigma_x \sigma_y}$$

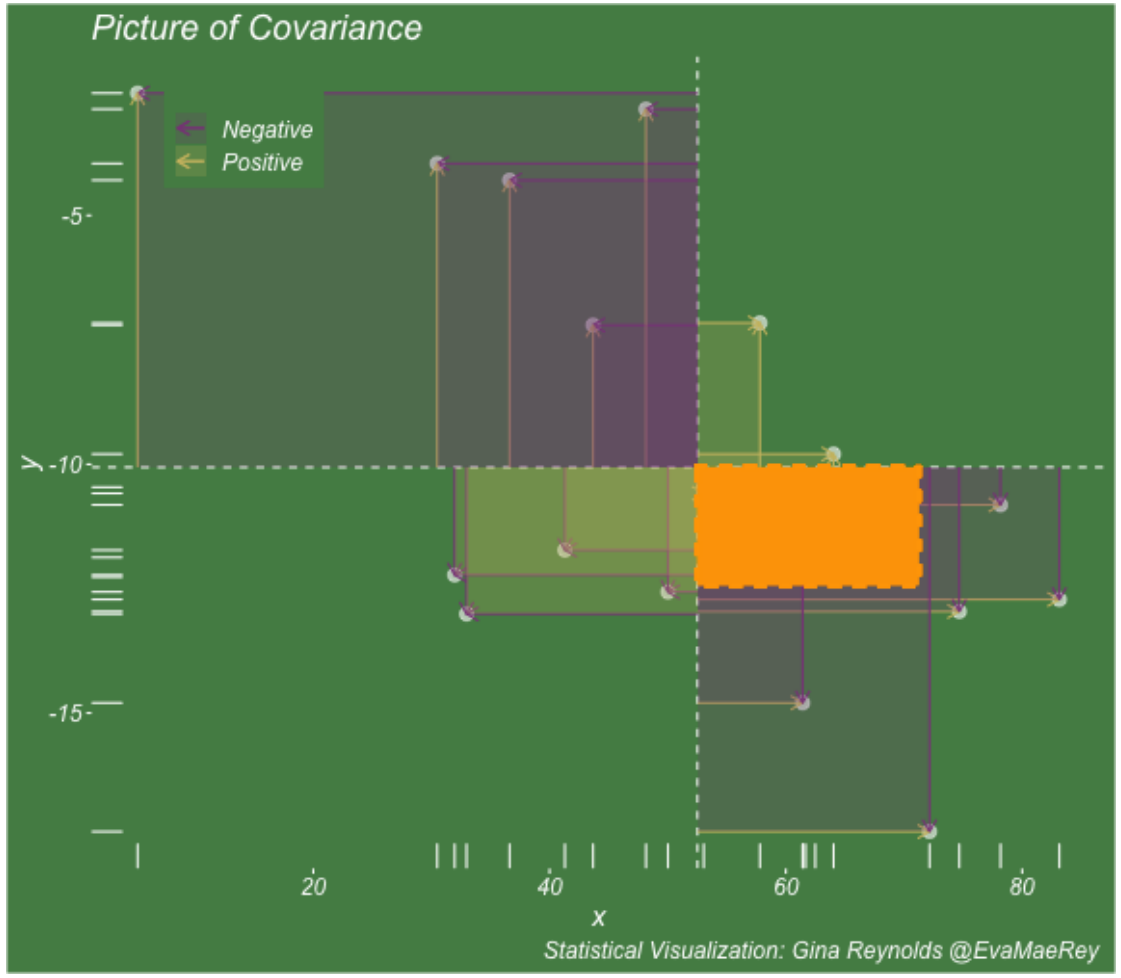


$$\frac{\sum_{i=1}^{n}(x_i - \mu_x)(y_i - \mu_y)}{n * \sigma_x \sigma_y}$$

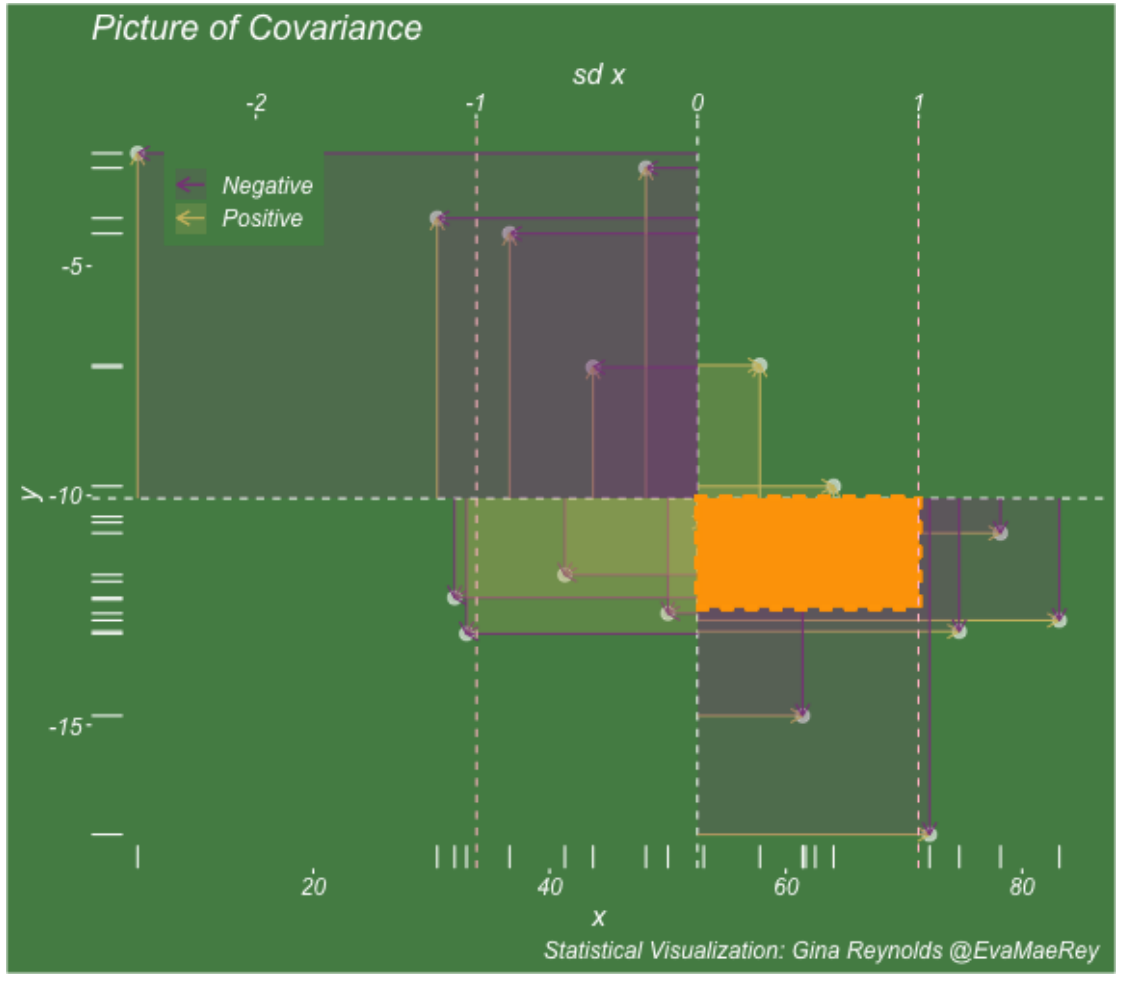


A negative correlation

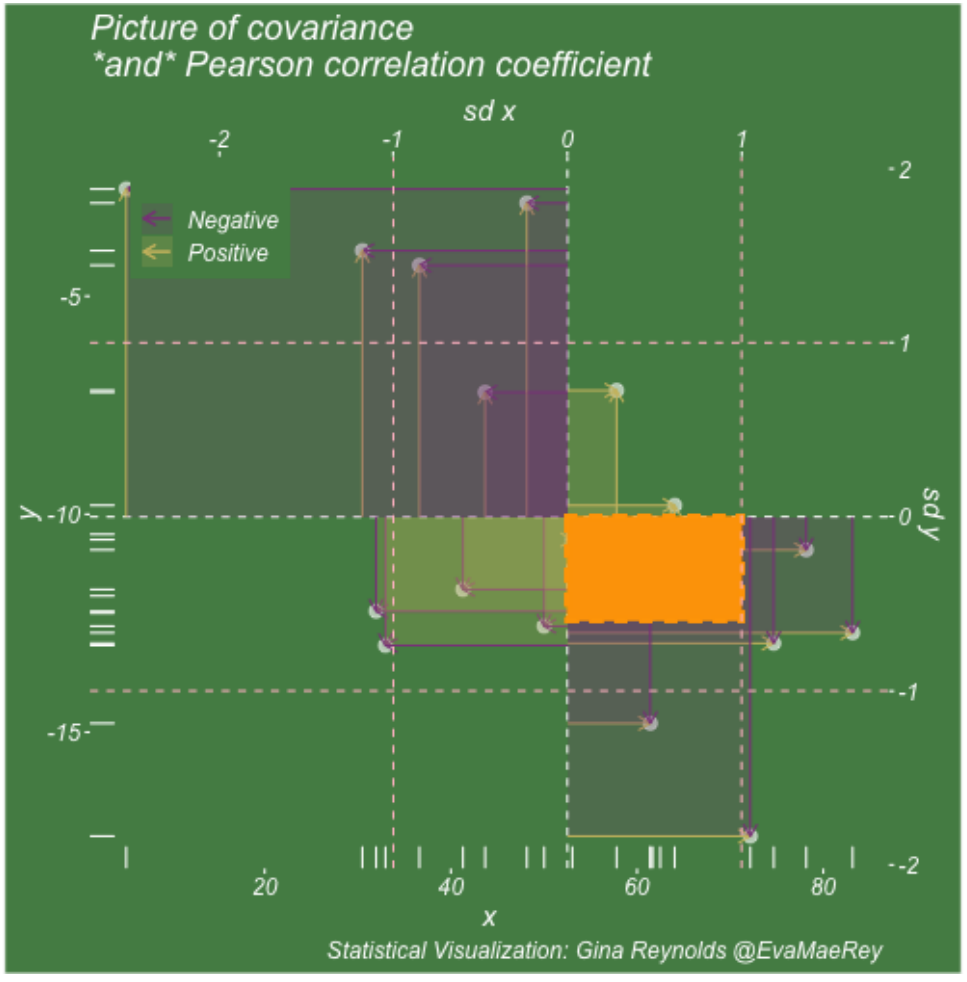
$$\frac{\sum_{i=1}^{n}(x_i - \mu_x)(y_i - \mu_y)}{n}$$



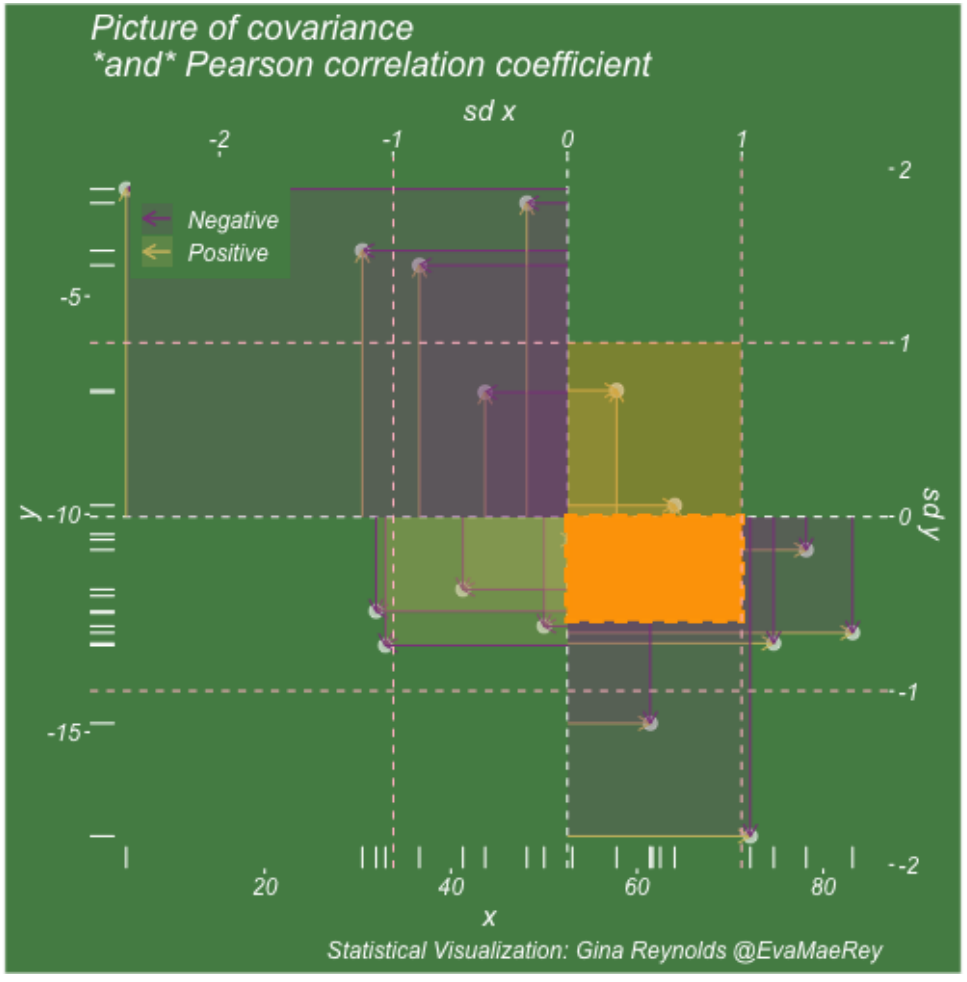
$$\frac{\sum_{i=1}^{n}(x_i - \mu_x)(y_i - \mu_y)}{n * \sigma_x}$$



$$\frac{\sum_{i=1}^{n}(x_i - \mu_x)(y_i - \mu_y)}{n * \sigma_x \sigma_y}$$



$$\frac{\sum_{i=1}^{n}(x_i - \mu_x)(y_i - \mu_y)}{n * \sigma_x \sigma_y}$$



Bessel correction: n - 1

Sample statistics (Not *population* statistics)

$$cov(x, y) = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{n - 1}$$

$$s^2 = \frac{\sum_{i=1}^{n} (x_i - \overline{x})^2}{n - 1}$$

$$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \overline{x})^2}{n-1}}$$

DRY: Bonus

DRY: Bonus

"Don't repeat yourself"

DRY: Bonus

"Don't repeat yourself"

Writing and using functions

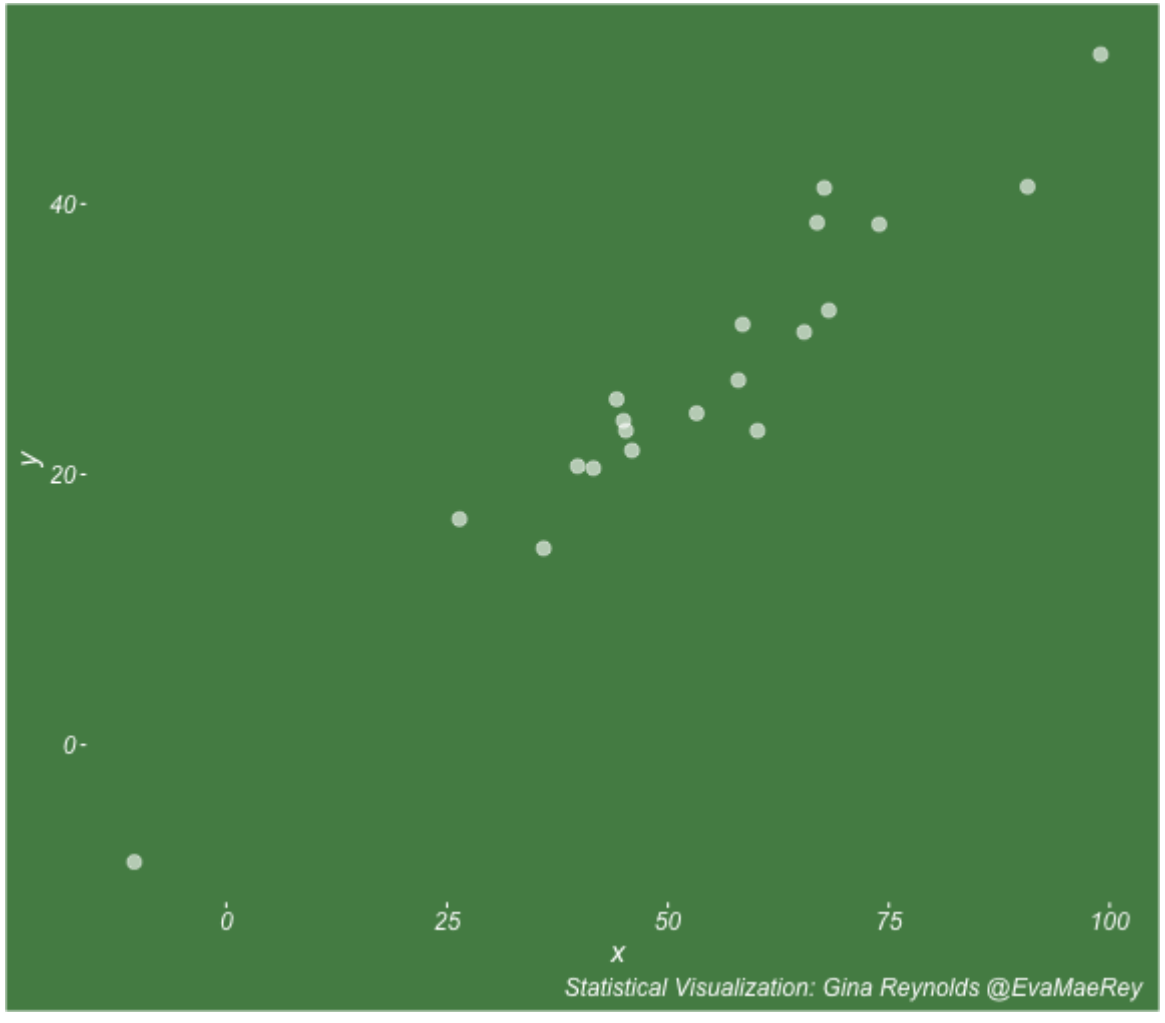
```
# this is a temporary fix - a
mysetseed <- set.seed
```

```
mysetseed(199402)
```

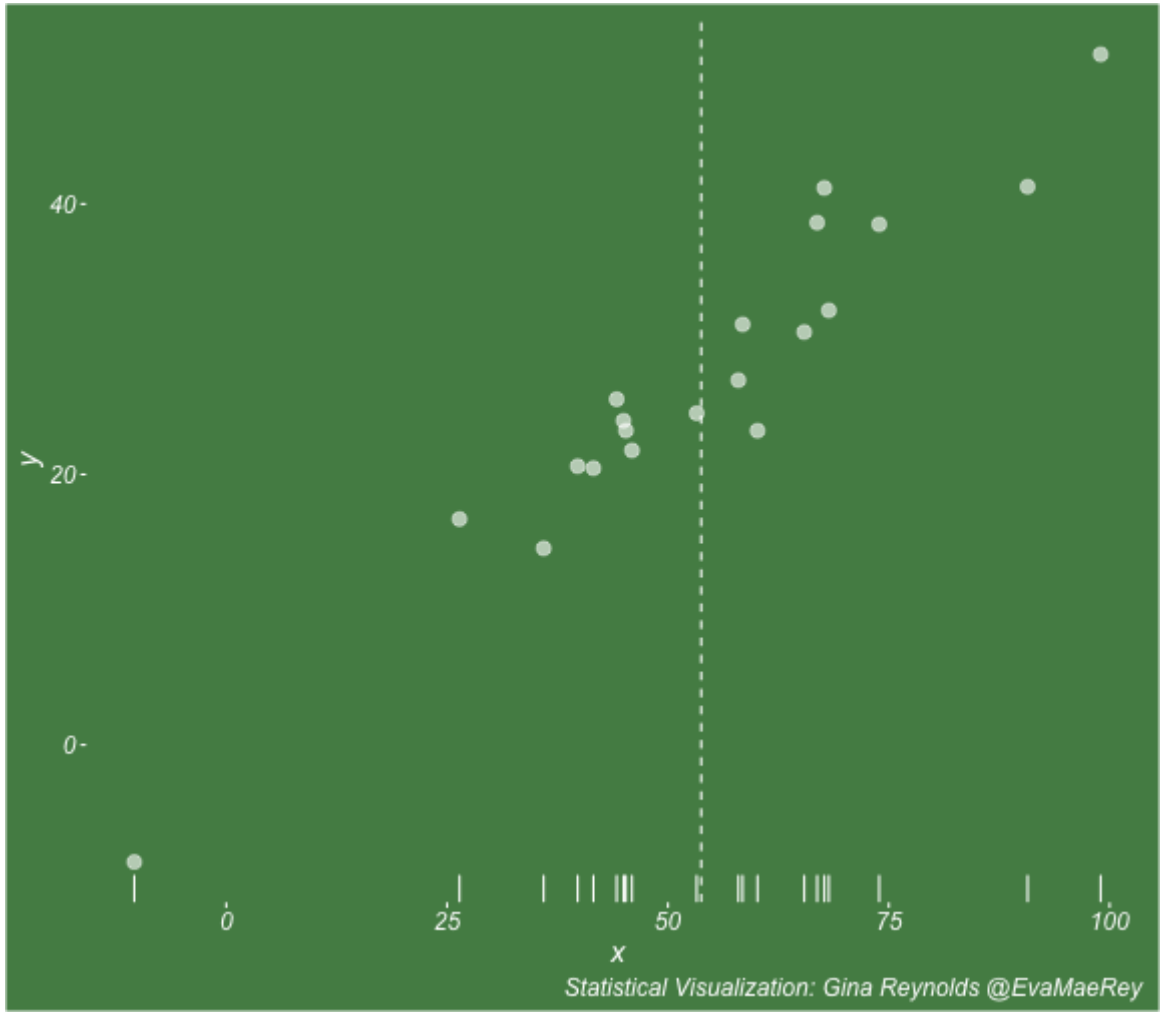
```
mysetseed(199402)
create_x_y(relationship = .5)
```

```
# A tibble: 20 x 15
       x     y mean_x mean_y     area mean_area quasi_mean_area sd_x_sample
   <dbl> <dbl>  <dbl>  <dbl>    <dbl>     <dbl>           <dbl>       <dbl>
 1  68.2 32.1    53.8   26.9   76.1        269.          4.00           23.4
 2  45.2 23.2    53.8   26.9   30.8        269.          1.62           23.4
 3  26.4 16.7    53.8   26.9  278.         269.         14.6            23.4
 4  90.7 41.3    53.8   26.9  533.         269.         28.0            23.4
 5  58.0 27.0    53.8   26.9    0.420      269.          0.0221         23.4
 6  41.6 20.5    53.8   26.9   78.2        269.          4.11           23.4
 7  67.7 41.2    53.8   26.9  200.         269.         10.5            23.4
 8 -10.4 -8.66   53.8   26.9 2280.         269.        120.             23.4
 9  65.4 30.5    53.8   26.9   42.7        269.          2.25           23.4
10  53.3 24.5    53.8   26.9    1.20       269.          0.0634         23.4
11  58.5 31.1    53.8   26.9   19.8        269.          1.04           23.4
12  45.9 21.8    53.8   26.9   39.9        269.          2.10           23.4
13  73.9 38.5    53.8   26.9  234.         269.         12.3            23.4
14  60.1 23.2    53.8   26.9  -23.1        269.         -1.22           23.4
15  99.0 51.1    53.8   26.9 1094.         269.         57.6            23.4
16  44.2 25.6    53.8   26.9   12.5        269.          0.656          23.4
17  45.0 24.0    53.8   26.9   25.5        269.          1.34           23.4
18  35.9 14.5    53.8   26.9  220.         269.         11.6            23.4
19  39.8 20.6    53.8   26.9   87.5        269.          4.60           23.4
20  66.9 38.6    53.8   26.9  154.         269.          8.12           23.4
# … with 7 more variables: sd_x <dbl>, sd_y_sample <dbl>, sd_y <dbl>,
#   some_x <dbl>, some_x_sample <dbl>, some_y <dbl>, some_y_sample <dbl>
```

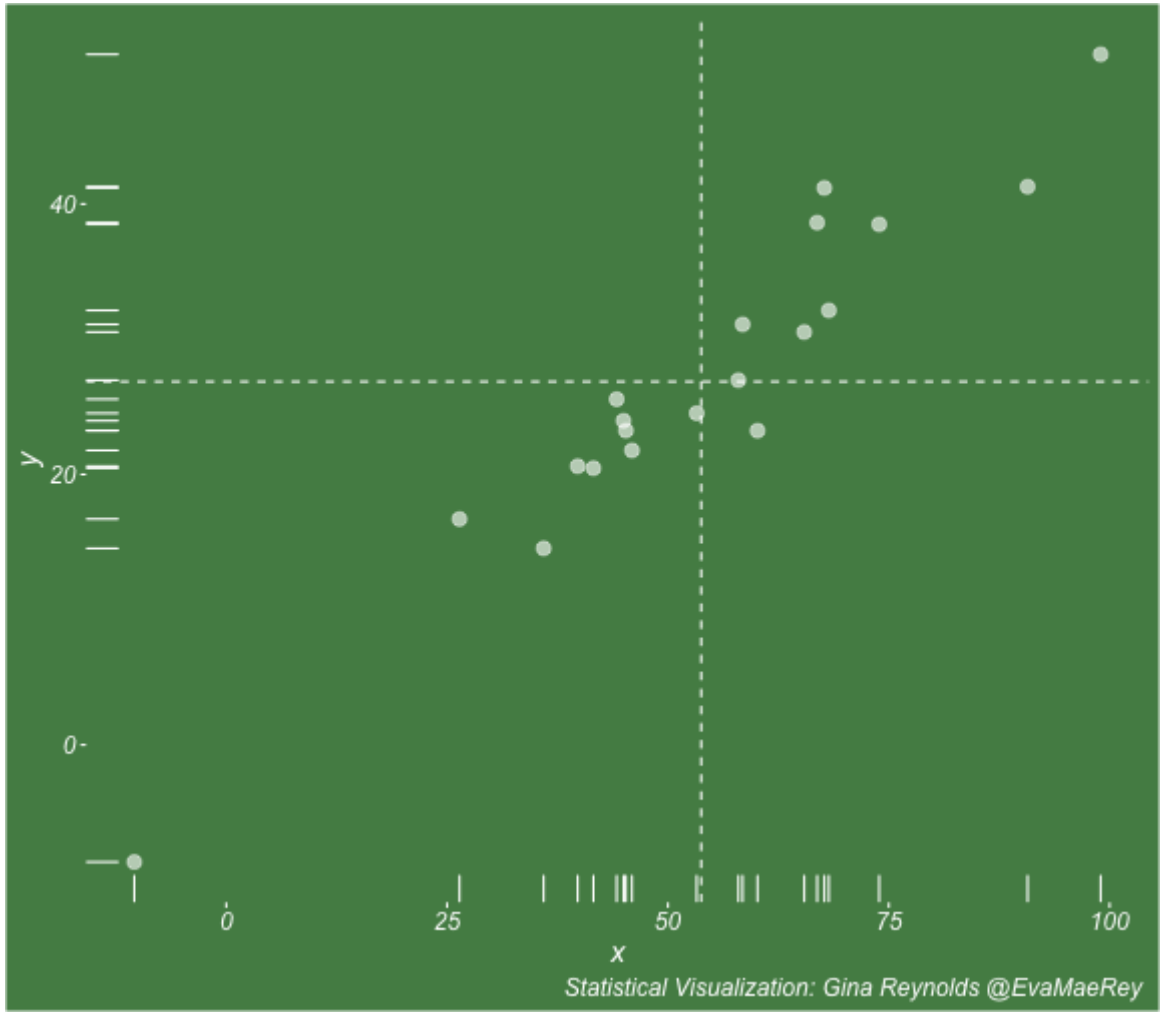
```
mysetseed(199402)
create_x_y(relationship = .5) %>%
  data_create_scatterplot()
```



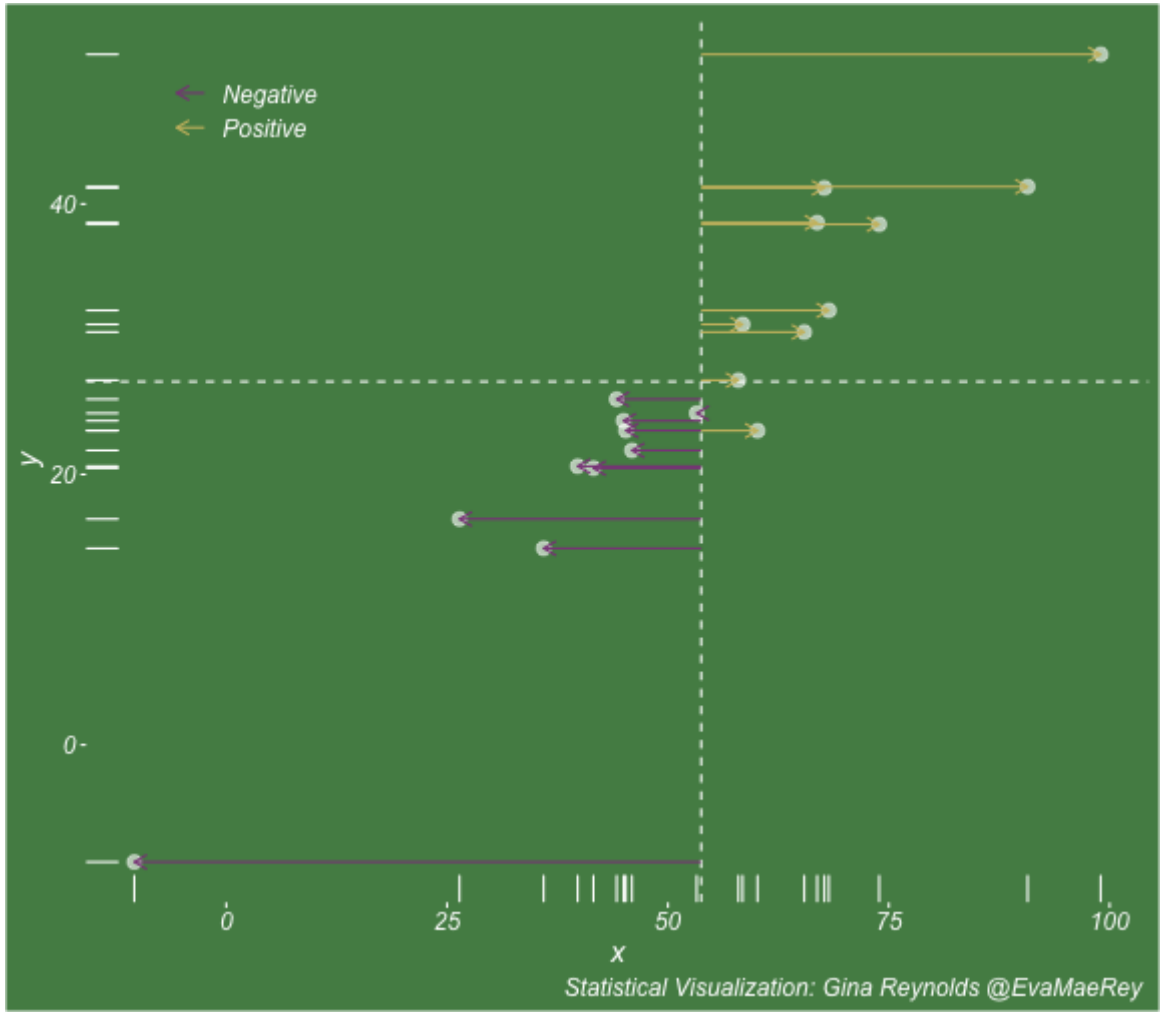
```
mysetseed(199402)
create_x_y(relationship = .5) %>%
  data_create_scatterplot() %>%
  plot_draw_mean_x()
```



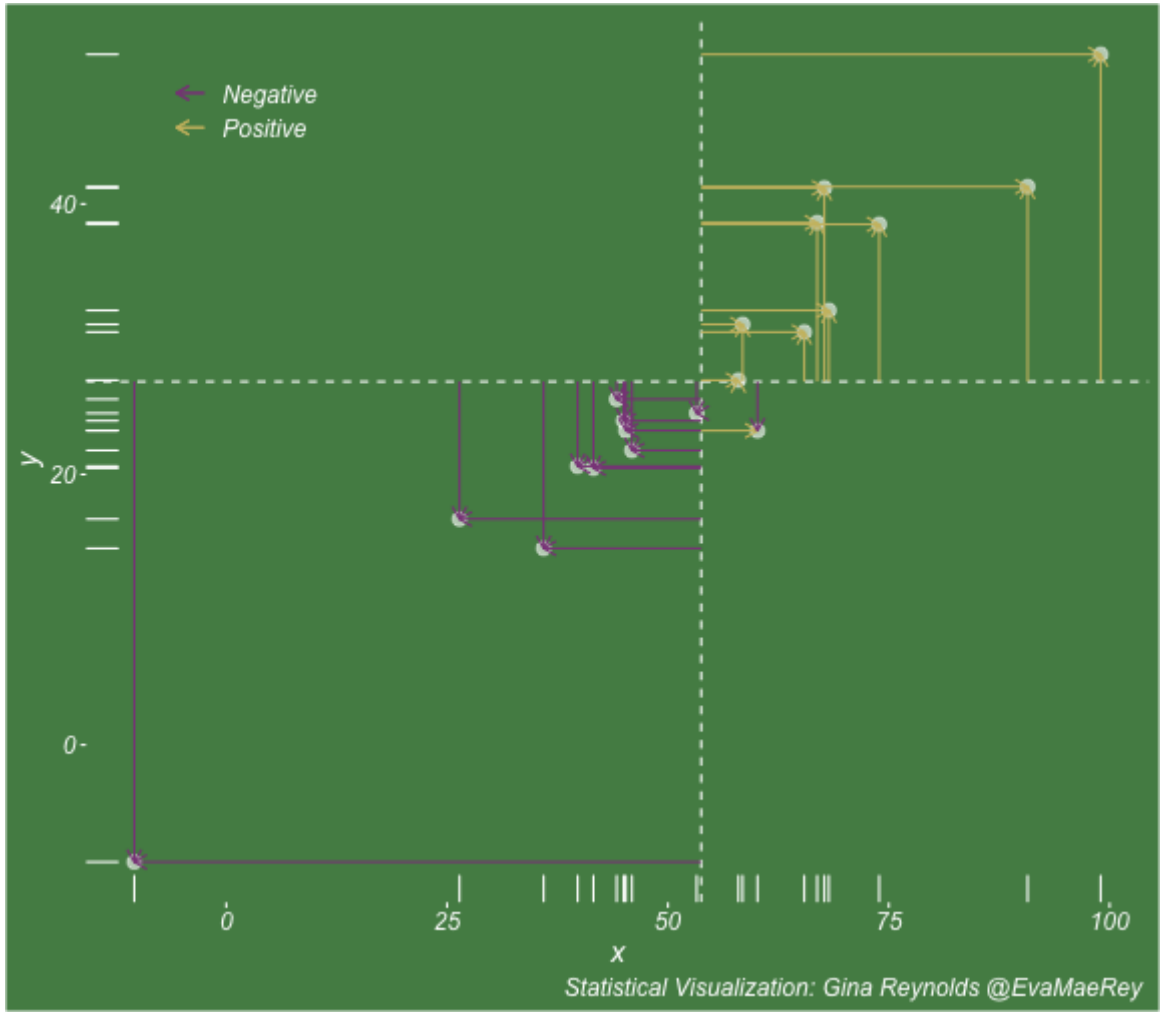
```
mysetseed(199402)
create_x_y(relationship = .5) %>%
  data_create_scatterplot() %>%
  plot_draw_mean_x() %>%
  plot_draw_mean_y()
```



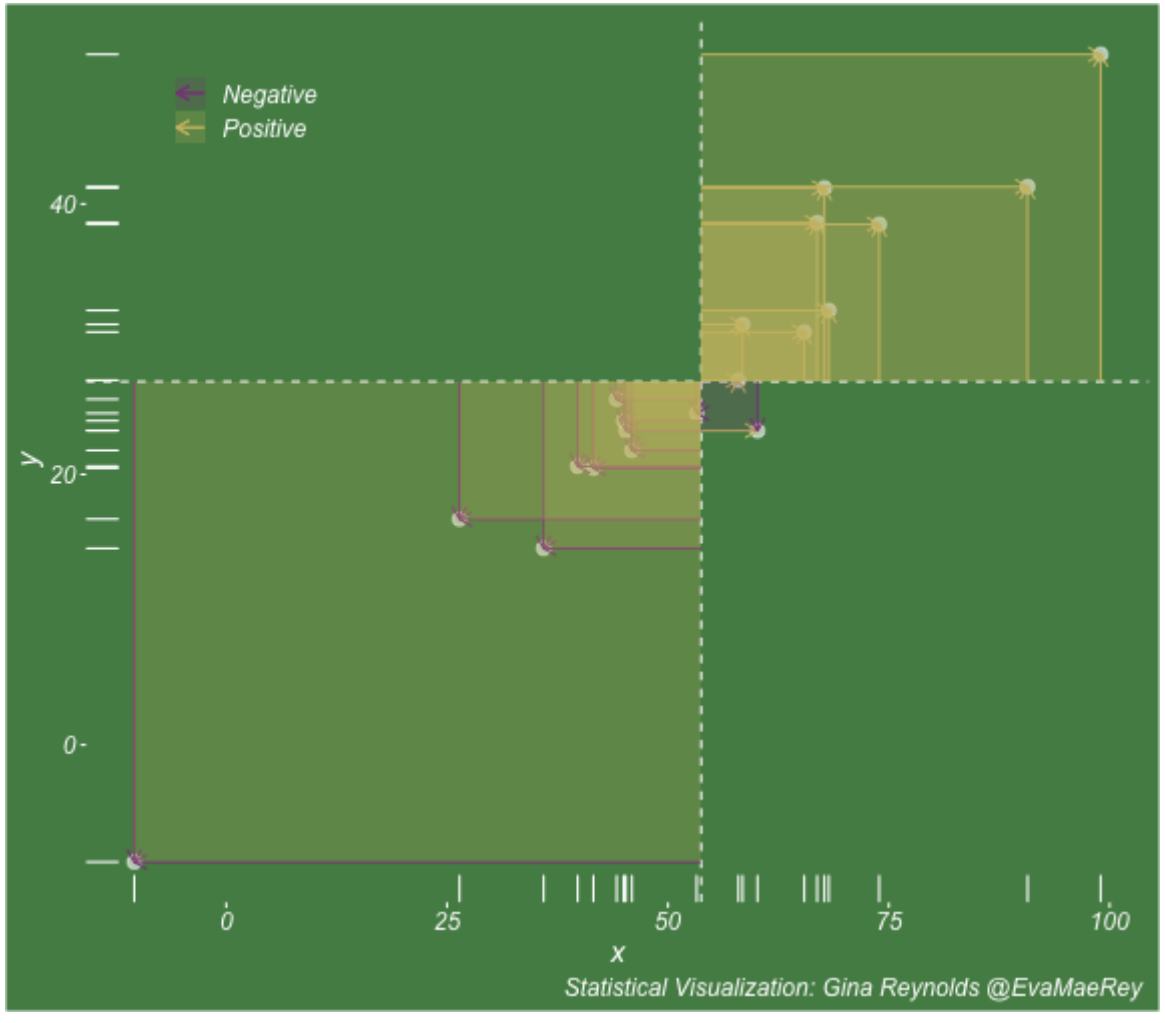
```
mysetseed(199402)
create_x_y(relationship = .5) %>%
  data_create_scatterplot() %>%
  plot_draw_mean_x() %>%
  plot_draw_mean_y() %>%
  plot_draw_differences_x()
```



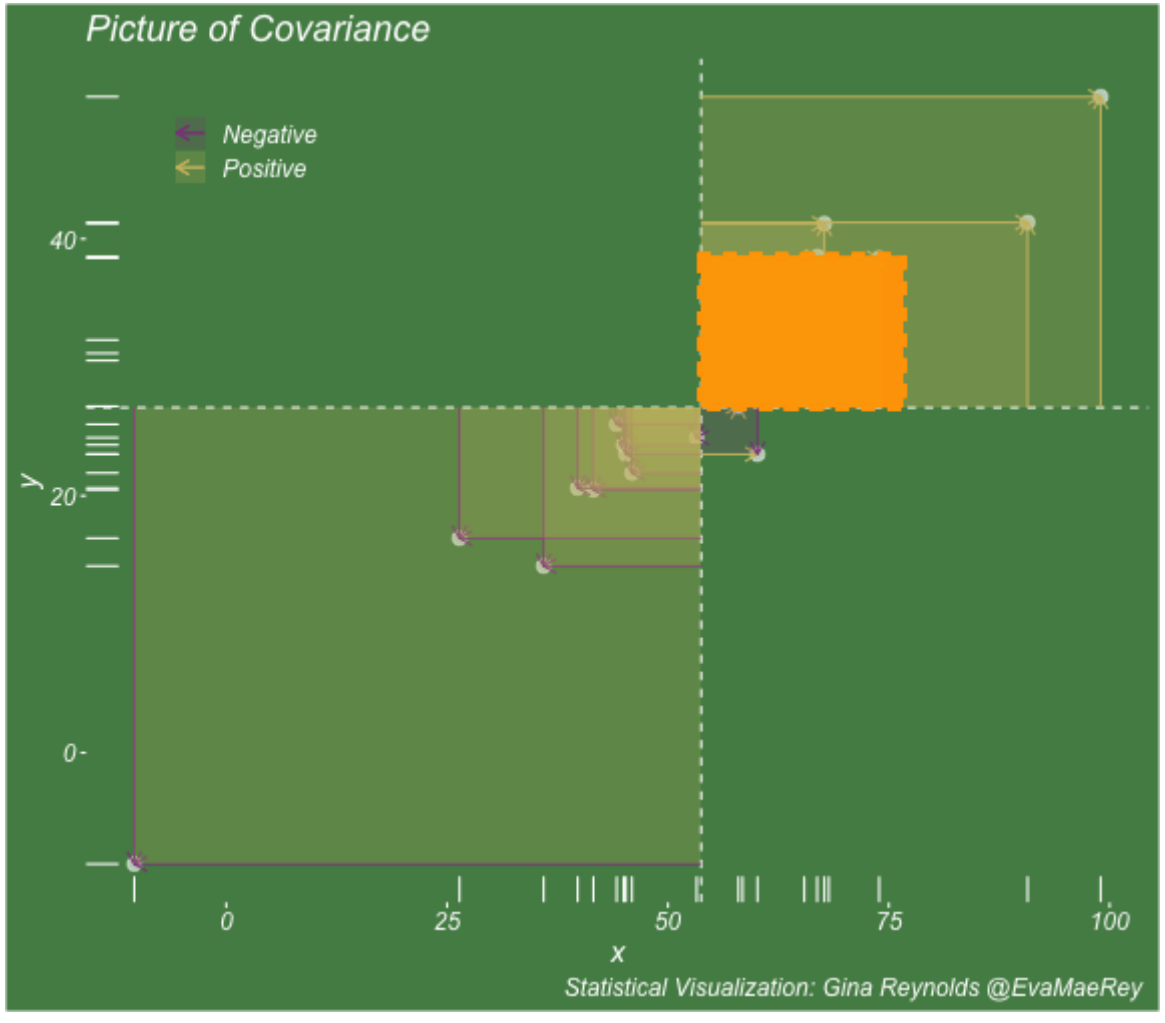
```
mysetseed(199402)
create_x_y(relationship = .5) %>%
  data_create_scatterplot() %>%
  plot_draw_mean_x() %>%
  plot_draw_mean_y() %>%
  plot_draw_differences_x() %>%
  plot_draw_differences_y()
```



```
mysetseed(199402)
create_x_y(relationship = .5) %>%
  data_create_scatterplot() %>%
  plot_draw_mean_x() %>%
  plot_draw_mean_y() %>%
  plot_draw_differences_x() %>%
  plot_draw_differences_y() %>%
  plot_multiply_differences()
```



```
mysetseed(199402)
create_x_y(relationship = .5) %>%
  data_create_scatterplot() %>%
  plot_draw_mean_x() %>%
  plot_draw_mean_y() %>%
  plot_draw_differences_x() %>%
  plot_draw_differences_y() %>%
  plot_multiply_differences() %>%
  plot_take_average_rectangle()
```



```
mysetseed(199402)
```

```
function (seed, kind = NULL, normal.kind = NULL, sample.kind = NULL)
{
    kinds <- c("Wichmann-Hill", "Marsaglia-Multicarry", "Super-Duper",
        "Mersenne-Twister", "Knuth-TAOCP", "user-supplied", "Knuth-TAOCP-2002",
        "L'Ecuyer-CMRG", "default")
    n.kinds <- c("Buggy Kinderman-Ramage", "Ahrens-Dieter", "Box-Muller",
        "user-supplied", "Inversion", "Kinderman-Ramage", "default")
    s.kinds <- c("Rounding", "Rejection", "default")
    if (length(kind)) {
        if (!is.character(kind) || length(kind) > 1L)
            stop("'kind' must be a character string of length 1 (RNG to be used).")
        if (is.na(i.knd <- pmatch(kind, kinds) - 1L))
            stop(gettextf("'%s' is not a valid abbreviation of an RNG",
                kind), domain = NA)
        if (i.knd == length(kinds) - 1L)
            i.knd <- -1L
    }
    else i.knd <- NULL
    if (!is.null(normal.kind)) {
        if (!is.character(normal.kind) || length(normal.kind) !=
            1L)
            stop("'normal.kind' must be a character string of length 1")
        normal.kind <- pmatch(normal.kind, n.kinds) - 1L
        if (is.na(normal.kind))
            stop(gettextf("'%s' is not a valid choice", normal.kind),
                domain = NA)
        if (normal.kind == 0L)
            stop("buggy version of Kinderman-Ramage generator is not allowed",
                domain = NA)
        if (normal.kind == length(n.kinds) - 1L)
            normal.kind <- -1L
    }
    if (!is.null(sample.kind)) {
        if (!is.character(sample.kind) || length(sample.kind) !=
            1L)
            stop("'sample.kind' must be a character string of length 1")
        sample.kind <- pmatch(sample.kind, s.kinds) - 1L
        if (is.na(sample.kind))
            stop(gettextf("'%s' is not a valid choice", sample.kind),
                domain = NA)
```

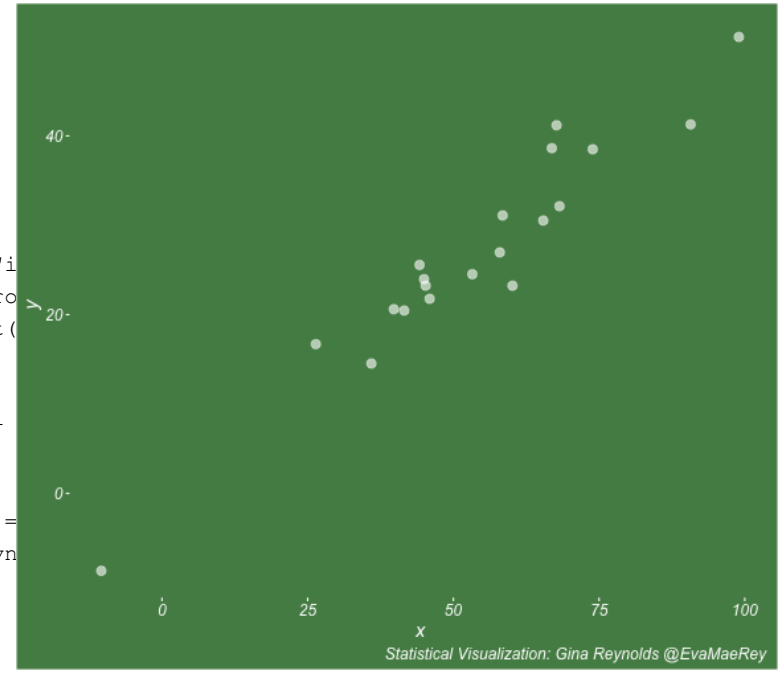
```
mysetseed(199402)
create_x_y(relationship = .5)
```

```
function(num = 20,
                       spread_x = 20,
                       relationship = .1,
                       noise = 3
                       ){

  tibble(x = rnorm(num, sd = spread_x) + 50 ) %>%
  mutate(y = relationship * x + rnorm(num, sd = noise)) %>%
  mutate(mean_x = mean(x)) %>%
  mutate(mean_y = mean(y)) %>%
  mutate(area = (x - mean_x)*(y - mean_y)) %>%
  mutate(mean_area = mean(area)) %>%
  mutate(quasi_mean_area = area/(n() - 1)) %>%
  mutate(sd_x_sample = sd(x)) %>%
  mutate(sd_x = sd_pop(x)) %>%
  mutate(sd_y_sample = sd(y)) %>%
  mutate(sd_y = sd_pop(y)) %>%
  mutate(some_x = sd_x) %>%
  mutate(some_x_sample = sd_x_sample) %>%
  mutate(some_y = mean_area/some_x) %>%
  mutate(some_y_sample = sd_y_sample)

}
<bytecode: 0x7fda6c9d67c0>
```

```
# A tibble: 20 x 15
       x     y mean_x mean_y     area mean_area quasi_mean_area sd_x_sa
   <dbl> <dbl>  <dbl>  <dbl>    <dbl>     <dbl>           <dbl>       <
 1  68.2 32.1    53.8   26.9   76.1        269.          4.00
 2  45.2 23.2    53.8   26.9   30.8        269.          1.62
 3  26.4 16.7    53.8   26.9  278.         269.         14.6
 4  90.7 41.3    53.8   26.9  533.         269.         28.0
 5  58.0 27.0    53.8   26.9    0.420      269.          0.0221
 6  41.6 20.5    53.8   26.9   78.2        269.          4.11
 7  67.7 41.2    53.8   26.9  200.         269.         10.5
 8 -10.4 -8.66   53.8   26.9 2280.         269.        120.
 9  65.4 30.5    53.8   26.9   42.7        269.          2.25
10  53.3 24.5    53.8   26.9    1.20       269.          0.0634
11  58.5 31.1    53.8   26.9   19.8        269.          1.04
12  45.9 21.8    53.8   26.9   39.9        269.          2.10
13  73.9 38.5    53.8   26.9  234.         269.         12.3
14  60.1 23.2    53.8   26.9  -23.1        269.         -1.22
15  99.0 51.1    53.8   26.9 1094.         269.         57.6
16  44.2 25.6    53.8   26.9   12.5        269.          0.656
17  45.0 24.0    53.8   26.9   25.5        269.          1.34
18  35.9 14.5    53.8   26.9  220.         269.         11.6
19  39.8 20.6    53.8   26.9   87.5        269.          4.60
20  66.9 38.6    53.8   26.9  154.         269.          8.12
# … with 7 more variables: sd_x <dbl>, sd_y_sample <dbl>, sd_y <dbl>,
#   some_x <dbl>, some_x_sample <dbl>, some_y <dbl>, some_y_sample <dbl
```

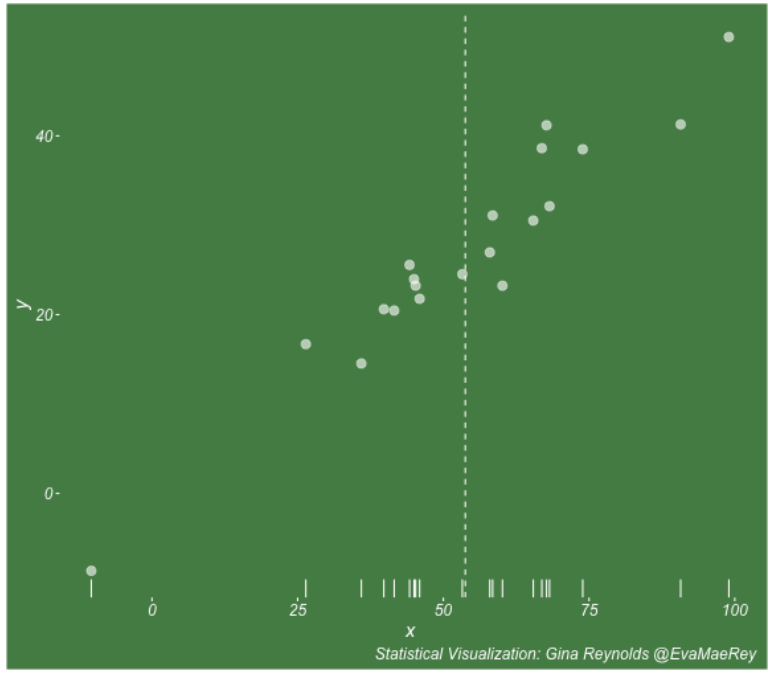
```
mysetseed(199402)
create_x_y(relationship = .5) %>%
  data_create_scatterplot()
```

```
function(data, background_color = "palegreen4"){

data %>%
  ggplot() +
  theme(legend.position = c(.15, .9)) +
  aes(x = x) +
  aes(y = y) +
  theme(rect = element_rect(fill = background_color))
  theme(text = element_text(color = "white", face = "i
  theme(panel.background = element_rect(fill = backgro
  theme(legend.key = element_blank()) + #element_rect(
  theme(legend.title = element_blank()) +
  theme(axis.text = element_text(color = "white")) +
  theme(axis.ticks = element_line(color = "white")) +
  labs(title = NULL) +
  theme(panel.grid = element_blank()) +
  geom_point(size = 3, pch = 21, col = "white", fill =
  labs(caption = "Statistical Visualization: Gina Reyn


}
<bytecode: 0x7fda6d7f4c98>
```



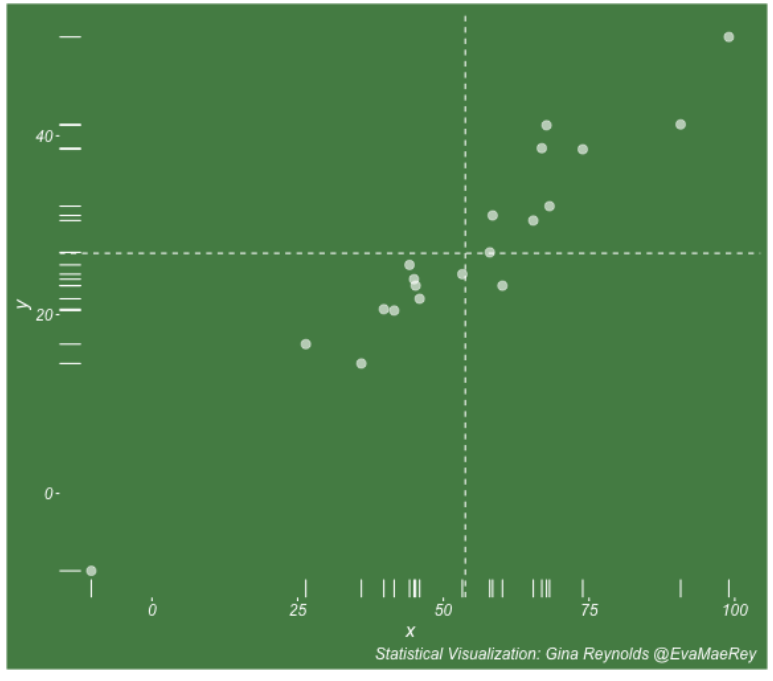
```
mysetseed(199402)
create_x_y(relationship = .5) %>%
  data_create_scatterplot() %>%
  plot_draw_mean_x()
```

```
function(plot){

  plot +
  # 1. mean of x
  geom_rug(aes(y = NULL), col = "white") +
  geom_vline(aes(xintercept = mean(x)),
             lty = "dashed", col = "white")


}
<bytecode: 0x7fda6fb08208>
```



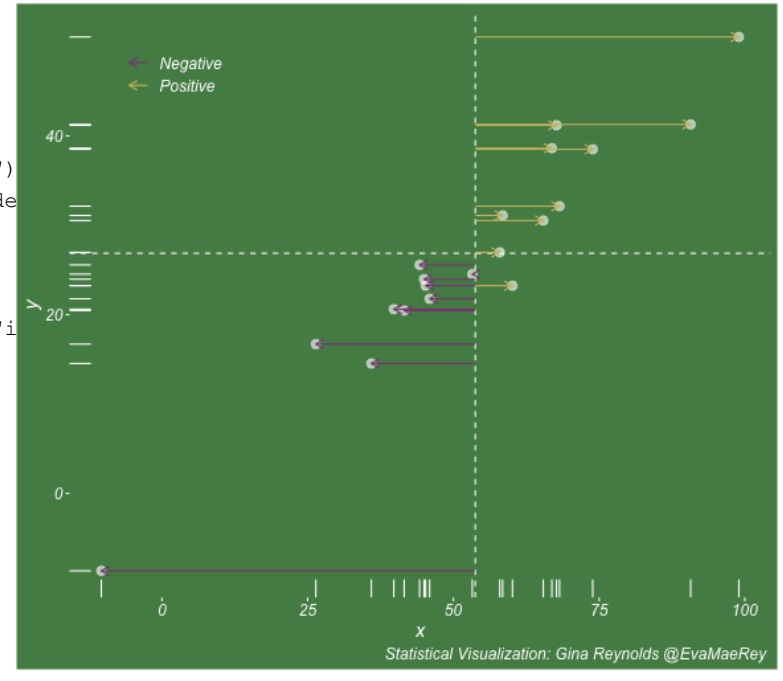
```
mysetseed(199402)
create_x_y(relationship = .5) %>%
  data_create_scatterplot() %>%
  plot_draw_mean_x() %>%
  plot_draw_mean_y()
```

```
function(plot){

  plot +
  # 2. mean of y
  geom_rug(col = "white", aes(x = NULL)) +
  geom_hline(aes(yintercept = mean(y)),
             lty = "dashed", col = "white")

}
<bytecode: 0x7fda6c673368>
```



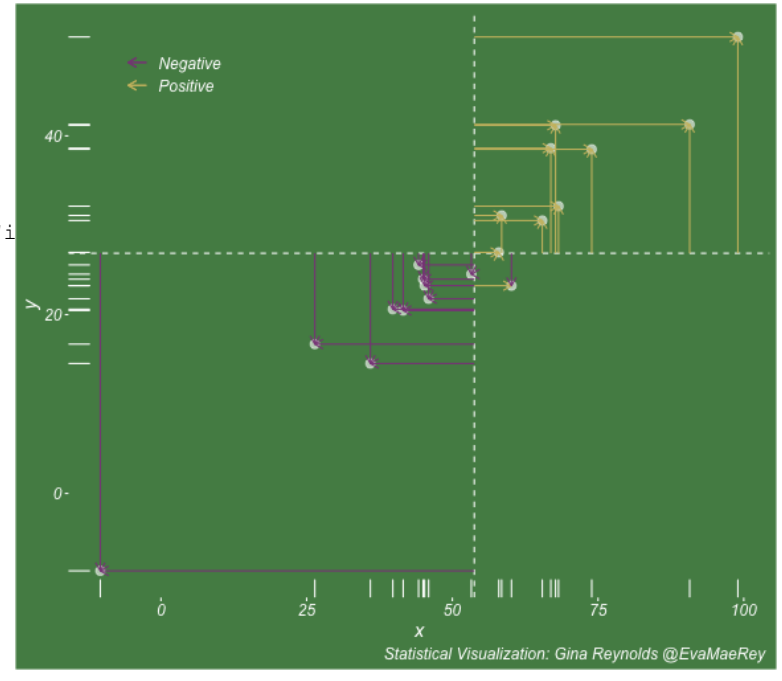
```
mysetseed(199402)
create_x_y(relationship = .5) %>%
  data_create_scatterplot() %>%
  plot_draw_mean_x() %>%
  plot_draw_mean_y() %>%
  plot_draw_differences_x()
```

```
function(plot){

  plot +
  # difference xi mean x
  scale_color_manual(breaks = c(FALSE, TRUE),
                     label = c("Negative", "Positive")
                     values = c("orchid4", "lightgolde
  geom_segment(aes(col = x > mean(x),
                   xend = mean(x), yend = y),
                   arrow = arrow(ends = "first",
                                 length = unit(0.1, "i
  labs(col = "")


}
<bytecode: 0x7fda6bcca1c8>
```



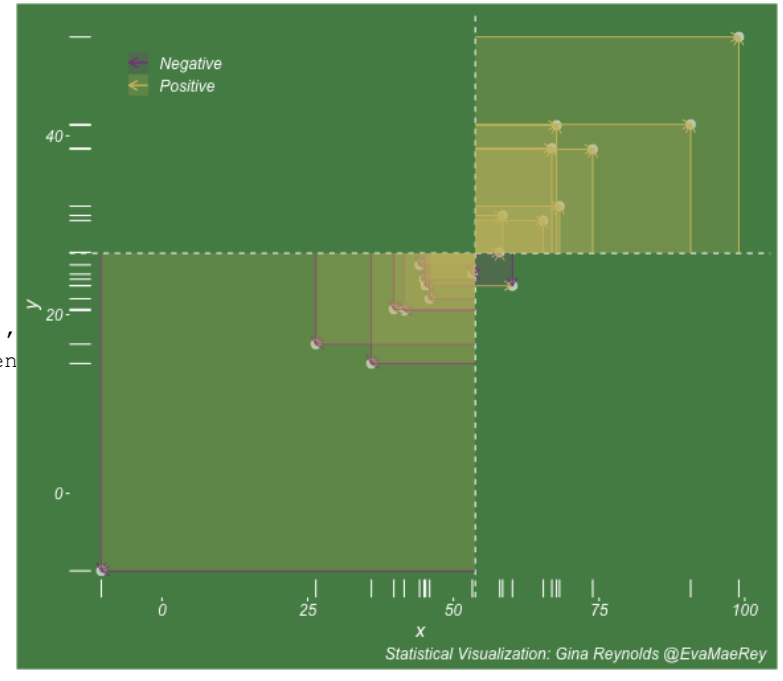
```
mysetseed(199402)
create_x_y(relationship = .5) %>%
  data_create_scatterplot() %>%
  plot_draw_mean_x() %>%
  plot_draw_mean_y() %>%
  plot_draw_differences_x() %>%
  plot_draw_differences_y()
```

```
function(plot){

  plot +
  # difference yi mean y
  geom_segment(aes(col = y > mean(y),
                   xend = x, yend = mean(y)),
                   arrow = arrow(ends = "first",
                                 length = unit(0.1, "i

}
<bytecode: 0x7fda6d6932e0>
```



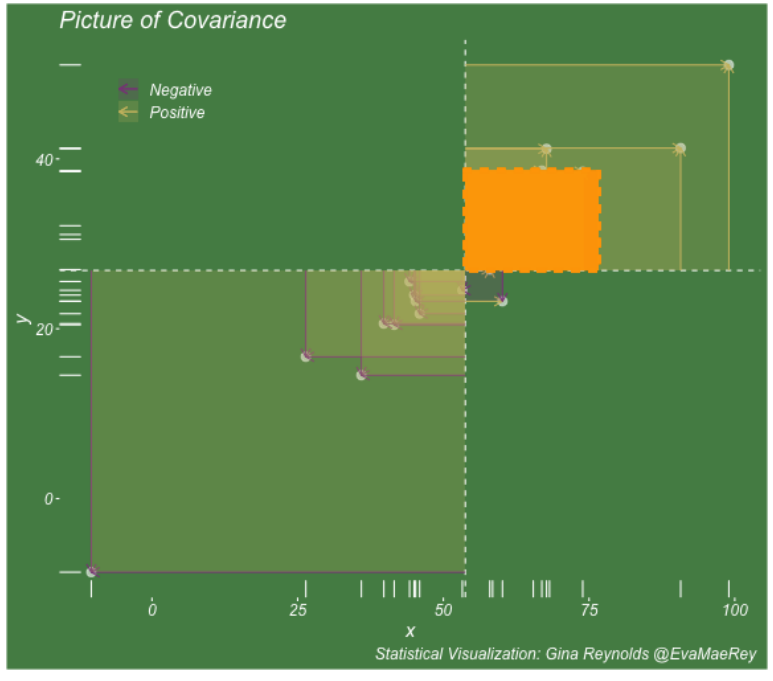
```
mysetseed(199402)
create_x_y(relationship = .5) %>%
  data_create_scatterplot() %>%
  plot_draw_mean_x() %>%
  plot_draw_mean_y() %>%
  plot_draw_differences_x() %>%
  plot_draw_differences_y() %>%
  plot_multiply_differences()
```

```
function(plot){

  plot +
  # multiply differences
  aes(fill = area > 0) +
  geom_rect(aes(xmin = mean(x), ymin = mean(y),
            ymax = y, xmax = x),
            alpha = .2  ) +
  labs(fill = "") +
  scale_fill_manual(breaks = c(FALSE, TRUE),
                    label = c("Negative", "Positive"),
                    values = c("orchid4", "lightgolden

}
<bytecode: 0x7fda6e4e5698>
```



```r
mysetseed(199402)
create_x_y(relationship = .5) %>%
  data_create_scatterplot() %>%
  plot_draw_mean_x() %>%
  plot_draw_mean_y() %>%
  plot_draw_differences_x() %>%
  plot_draw_differences_y() %>%
  plot_multiply_differences() %>%
  plot_take_average_rectangle()
```

```r
function(plot, title = "Picture of Covariance"){

  plot +
  # Average areas
  geom_rect(aes(
            xmin = mean(x),
            ymin = mean(y),
            ymax = mean(some_y) + mean(y),
            xmax = mean(some_x) + mean(x)
            ),
             color = "orange",
           linetype = "dotted",
            fill = "orange",
             lwd = 1.5,
             alpha = .2) +  #BREAK
  labs(title = title)

}
```



DRY next level: writing and using packages

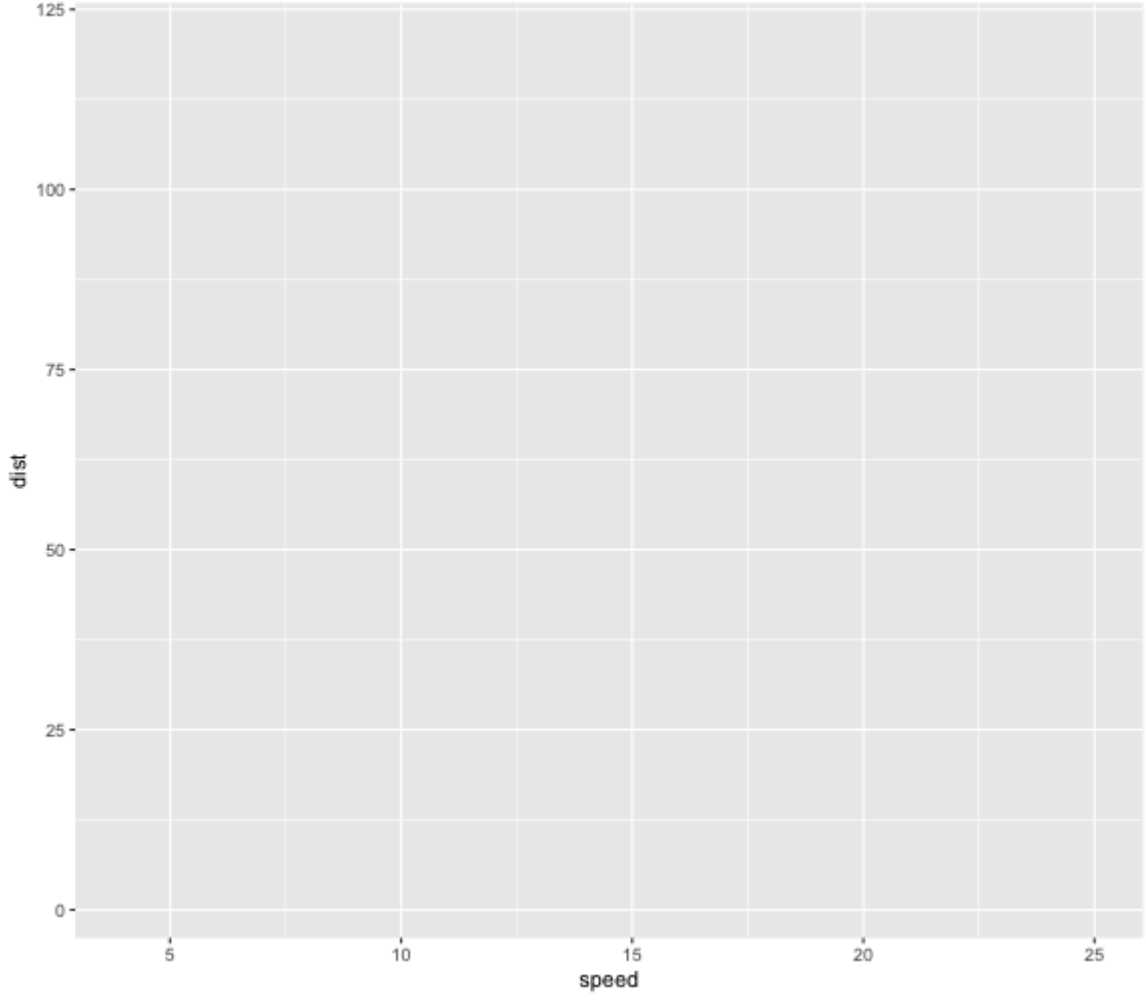
- A companion guide to Jim Hester’s, 'You can make an R package in 20 minutes'

```
cars
```

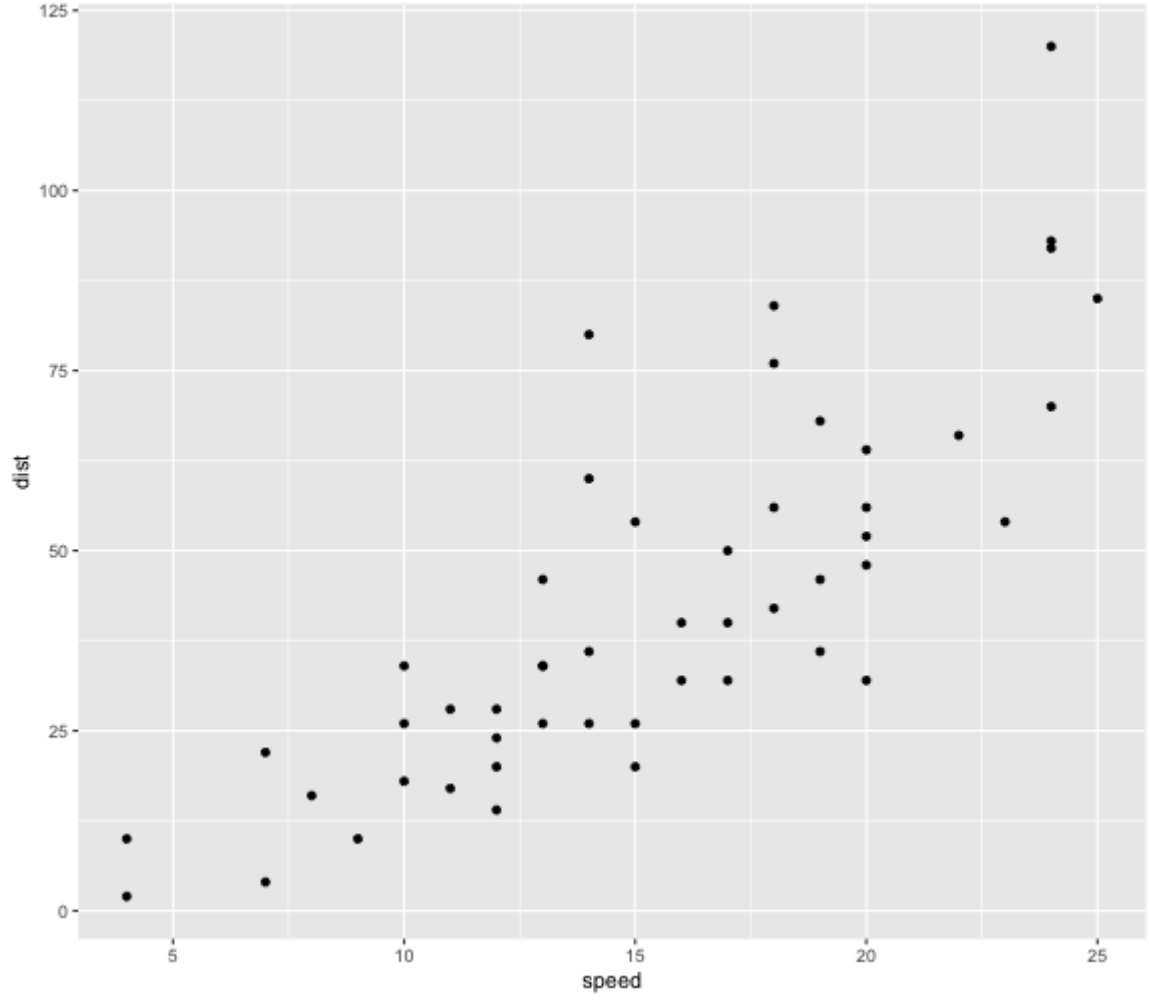
```
   speed dist
1      4    2
2      4   10
3      7    4
4      7   22
5      8   16
6      9   10
7     10   18
8     10   26
9     10   34
10    11   17
11    11   28
12    12   14
13    12   20
14    12   24
15    12   28
16    13   26
17    13   34
18    13   34
19    13   46
20    14   26
21    14   36
22    14   60
23    14   80
24    15   20
25    15   26
26    15   54
27    16   32
28    16   40
29    17   32
30    17   40
31    17   50
32    18   42
33    18   56
34    18   76
35    18   84
36    19   36
37    19   46
38    19   68
39    20   32
```

```
cars %>%
  ggplot()
```

```
cars %>%
  ggplot() +
  aes(x = speed, y = dist)
```



```
cars %>%
  ggplot() +
  aes(x = speed, y = dist) +
  geom_point()
```



```
cars %>%
  ggplot() +
  aes(x = speed, y = dist) +
  geom_point() ->
visualization
```

```
cars %>%
  ggplot() +
  aes(x = speed, y = dist) +
  geom_point() ->
visualization

cars$speed
```

```
 [1]  4  4  7  7  8  9 10 10 10 11 11 12 12 12 12 13 13 13 13 14 14 14 14 15 15
[26] 15 16 16 17 17 17 18 18 18 18 19 19 19 20 20 20 20 20 22 23 24 24 24 24 25
```

```
cars %>%
  ggplot() +
  aes(x = speed, y = dist) +
  geom_point() ->
visualization

cars$speed -
  mean(cars$speed)
```

```
 [1] -11.4 -11.4  -8.4  -8.4  -7.4  -6.4  -5.4  -5.4  -5.4  -4.4  -4.4  -3.4
[13]  -3.4  -3.4  -3.4  -2.4  -2.4  -2.4  -2.4  -1.4  -1.4  -1.4  -1.4  -0.4
[25]  -0.4  -0.4   0.6   0.6   1.6   1.6   1.6   2.6   2.6   2.6   2.6   3.6
[37]   3.6   3.6   4.6   4.6   4.6   4.6   4.6   6.6   7.6   8.6   8.6   8.6
[49]   8.6   9.6
```

```
cars %>%
  ggplot() +
  aes(x = speed, y = dist) +
  geom_point() ->
visualization

cars$speed -
  mean(cars$speed) ->
x_diff
```

```
cars %>%
  ggplot() +
  aes(x = speed, y = dist) +
  geom_point() ->
visualization

cars$speed -
  mean(cars$speed) ->
x_diff

cars$dist
```

```
 [1]   2  10   4  22  16  10  18  26  34  17  28  14  20  24  28  26  34  34  46
[20]  26  36  60  80  20  26  54  32  40  32  40  50  42  56  76  84  36  46  68
[39]  32  48  52  56  64  66  54  70  92  93 120  85
```

```
cars %>%
  ggplot() +
  aes(x = speed, y = dist) +
  geom_point() ->
visualization

cars$speed -
  mean(cars$speed) ->
x_diff

cars$dist -
  mean(cars$dist)
```

```
 [1] -40.98 -32.98 -38.98 -20.98 -26.98 -32.98 -24.98 -16.98  -8.98 -25.98
[11] -14.98 -28.98 -22.98 -18.98 -14.98 -16.98  -8.98  -8.98   3.02 -16.98
[21]  -6.98  17.02  37.02 -22.98 -16.98  11.02 -10.98  -2.98 -10.98  -2.98
[31]   7.02  -0.98  13.02  33.02  41.02  -6.98   3.02  25.02 -10.98   5.02
[41]   9.02  13.02  21.02  23.02  11.02  27.02  49.02  50.02  77.02  42.02
```

```
cars %>%
  ggplot() +
  aes(x = speed, y = dist) +
  geom_point() ->
visualization

cars$speed -
  mean(cars$speed) ->
x_diff

cars$dist -
  mean(cars$dist) ->
y_diff
```

```
cars %>%
  ggplot() +
  aes(x = speed, y = dist) +
  geom_point() ->
visualization

cars$speed -
  mean(cars$speed) ->
x_diff

cars$dist -
  mean(cars$dist) ->
y_diff

x_diff
```

```
 [1] -11.4 -11.4  -8.4  -8.4  -7.4  -6.4  -5.4  -5.4  -5.4  -4.4  -4.4  -3.4
[13]  -3.4  -3.4  -3.4  -2.4  -2.4  -2.4  -2.4  -1.4  -1.4  -1.4  -1.4  -0.4
[25]  -0.4  -0.4   0.6   0.6   1.6   1.6   1.6   2.6   2.6   2.6   2.6   3.6
[37]   3.6   3.6   4.6   4.6   4.6   4.6   4.6   6.6   7.6   8.6   8.6   8.6
[49]   8.6   9.6
```

```
cars %>%
  ggplot() +
  aes(x = speed, y = dist) +
  geom_point() ->
visualization

cars$speed -
  mean(cars$speed) ->
x_diff

cars$dist -
  mean(cars$dist) ->
y_diff

x_diff %>%
  `*`(y_diff)
```

```
 [1] 467.172 375.972 327.432 176.232 199.652 211.072 134.892  91.692  48.492
[10] 114.312  65.912  98.532  78.132  64.532  50.932  40.752  21.552  21.552
[19]  -7.248  23.772   9.772 -23.828 -51.828   9.192   6.792  -4.408  -6.588
[28]  -1.788 -17.568  -4.768  11.232  -2.548  33.852  85.852 106.652 -25.128
[37]  10.872  90.072 -50.508  23.092  41.492  59.892  96.692 151.932  83.752
[46] 232.372 421.572 430.172 662.372 403.392
```

```
cars %>%
  ggplot() +
  aes(x = speed, y = dist) +
  geom_point() ->
visualization

cars$speed -
  mean(cars$speed) ->
x_diff

cars$dist -
  mean(cars$dist) ->
y_diff

x_diff %>%
  `*`(y_diff) %>%
  sum()
```

```
[1] 5387.4
```

```
cars %>%
  ggplot() +
  aes(x = speed, y = dist) +
  geom_point() ->
visualization

cars$speed -
  mean(cars$speed) ->
x_diff

cars$dist -
  mean(cars$dist) ->
y_diff

x_diff %>%
  `*`(y_diff) %>%
  sum() %>%
  `/`(nrow(cars) - 1)
```

```
[1] 109.9469
```

```
cars %>%
  ggplot() +
  aes(x = speed, y = dist) +
  geom_point() ->
visualization

cars$speed -
  mean(cars$speed) ->
x_diff

cars$dist -
  mean(cars$dist) ->
y_diff

x_diff %>%
  `*`(y_diff) %>%
  sum() %>%
  `/`(nrow(cars) - 1) ->
my_calc
```

```
cars %>%
  ggplot() +
  aes(x = speed, y = dist) +
  geom_point() ->
visualization

cars$speed -
  mean(cars$speed) ->
x_diff

cars$dist -
  mean(cars$dist) ->
y_diff

x_diff %>%
  `*`(y_diff) %>%
  sum() %>%
  `/`(nrow(cars) - 1) ->
my_calc


library(magrittr)
```

```
cars %>%
  ggplot() +
  aes(x = speed, y = dist) +
  geom_point() ->
visualization

cars$speed -
  mean(cars$speed) ->
x_diff

cars$dist -
  mean(cars$dist) ->
y_diff

x_diff %>%
  `*`(y_diff) %>%
  sum() %>%
  `/`(nrow(cars) - 1) ->
my_calc


library(magrittr)
cars
```

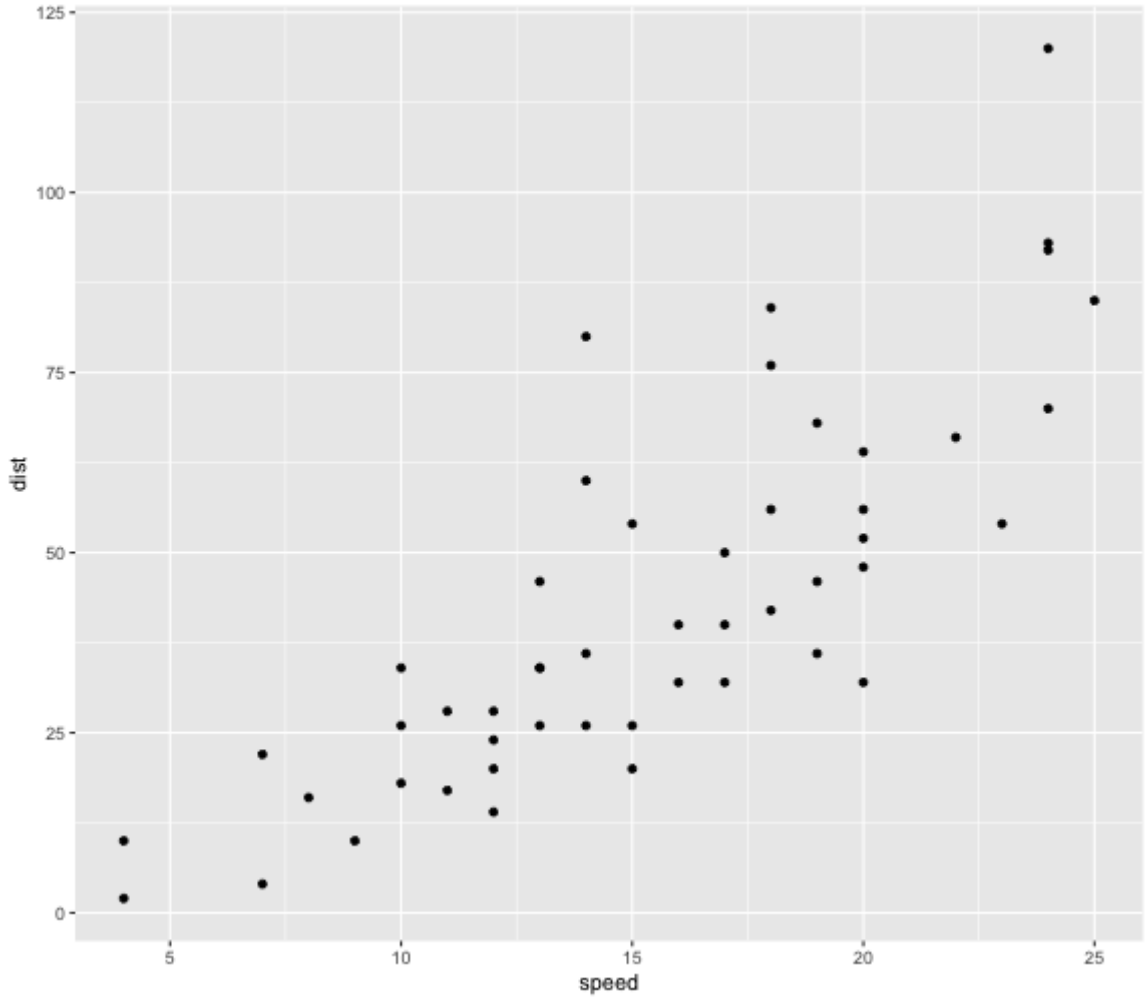
```
   speed dist
1      4    2
2      4   10
3      7    4
4      7   22
5      8   16
6      9   10
7     10   18
8     10   26
9     10   34
10    11   17
11    11   28
12    12   14
13    12   20
14    12   24
15    12   28
16    13   26
17    13   34
18    13   34
19    13   46
20    14   26
21    14   36
22    14   60
23    14   80
24    15   20
25    15   26
26    15   54
27    16   32
28    16   40
29    17   32
30    17   40
31    17   50
32    18   42
33    18   56
34    18   76
35    18   84
36    19   36
37    19   46
38    19   68
39    20   32
```

```
cars %>%
  ggplot() +
  aes(x = speed, y = dist) +
  geom_point() ->
visualization

cars$speed -
  mean(cars$speed) ->
x_diff

cars$dist -
  mean(cars$dist) ->
y_diff

x_diff %>%
  `*`(y_diff) %>%
  sum() %>%
  `/`(nrow(cars) - 1) ->
my_calc


library(magrittr)
cars %$%
  cov(dist, speed)
```

```
[1] 109.9469
```

```
cars %>%
  ggplot() +
  aes(x = speed, y = dist) +
  geom_point() ->
visualization

cars$speed -
  mean(cars$speed) ->
x_diff

cars$dist -
  mean(cars$dist) ->
y_diff

x_diff %>%
  `*`(y_diff) %>%
  sum() %>%
  `/`(nrow(cars) - 1) ->
my_calc


library(magrittr)
cars %$%
  cov(dist, speed)

visualization
```

```
[1] 109.9469
```



```
cars %>%
  ggplot() +
  aes(x = speed, y = dist) +
  geom_point() ->
visualization

cars$speed -
  mean(cars$speed) ->
x_diff

cars$dist -
  mean(cars$dist) ->
y_diff

x_diff %>%
  `*`(y_diff) %>%
  sum() %>%
  `/`(nrow(cars) - 1) ->
my_calc


library(magrittr)
cars %$%
  cov(dist, speed)

visualization +
  annotate(geom = "text",
           x = 7,
           y = 100,
           label = paste0("cov = ",
                          cars %$% cov(dist, speed) %>% rou
```

```
[1] 109.9469
```