

# Linear correlation and linear regression



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# Recall: Covariance

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



# Interpreting Covariance

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$\text{cov}(X, Y) > 0 \rightarrow$  X and Y are positively correlated

$\text{cov}(X, Y) < 0 \rightarrow$  X and Y are inversely correlated

$\text{cov}(X, Y) = 0 \rightarrow$  X and Y are independent



# Correlation coefficient

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- Pearson's Correlation Coefficient is standardized covariance (unitless):

$$r = \frac{\text{covariance}(x, y)}{\sqrt{\text{var } x} \sqrt{\text{var } y}}$$

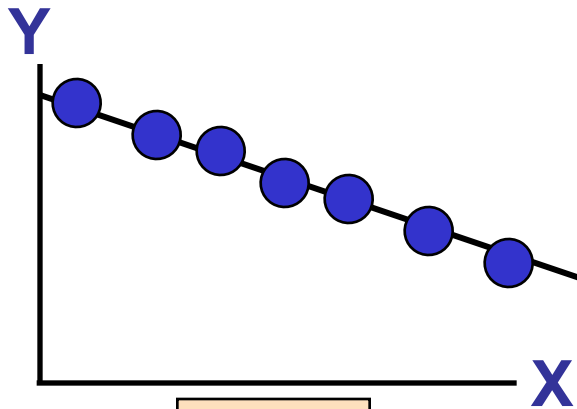


# Correlation

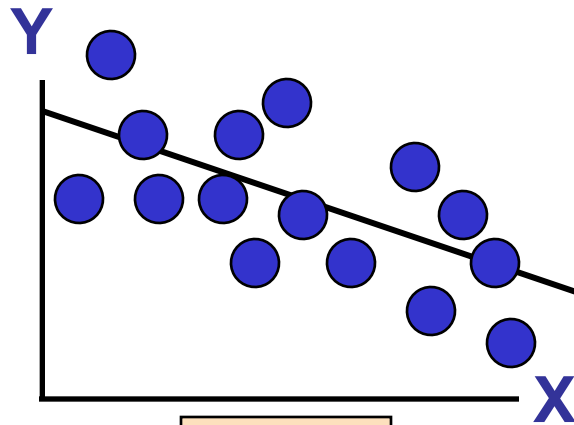
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- Measures the relative strength of the *linear* relationship between two variables
- Unit-less
- Ranges between  $-1$  and  $1$
- The closer to  $-1$ , the stronger the negative linear relationship
- The closer to  $1$ , the stronger the positive linear relationship
- The closer to  $0$ , the weaker any positive linear relationship

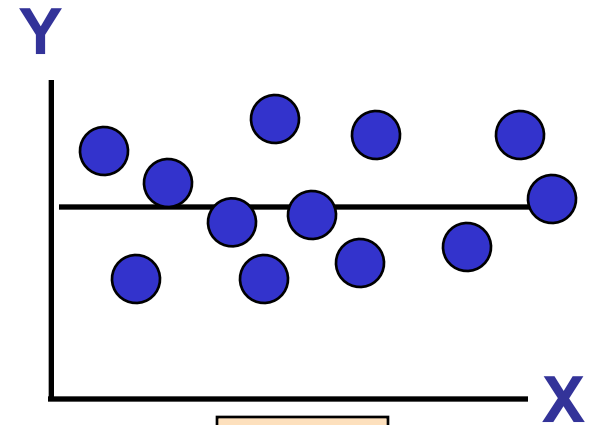
# Scatter Plots of Data with Various Correlation Coefficients



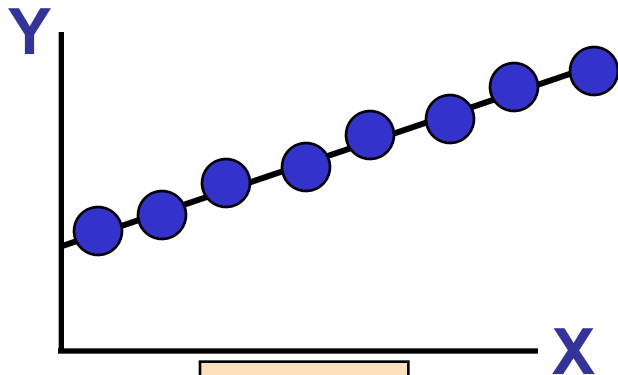
$$r = -1$$



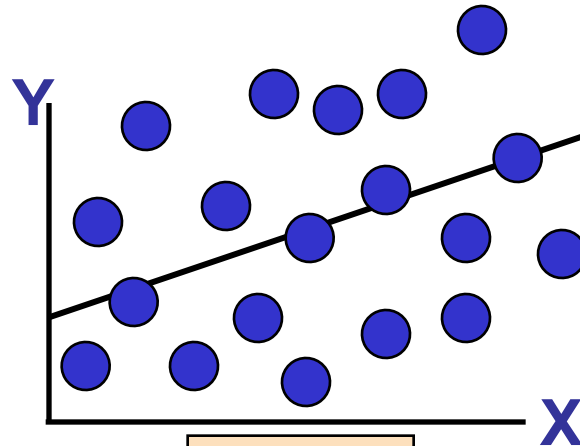
$$r = -.6$$



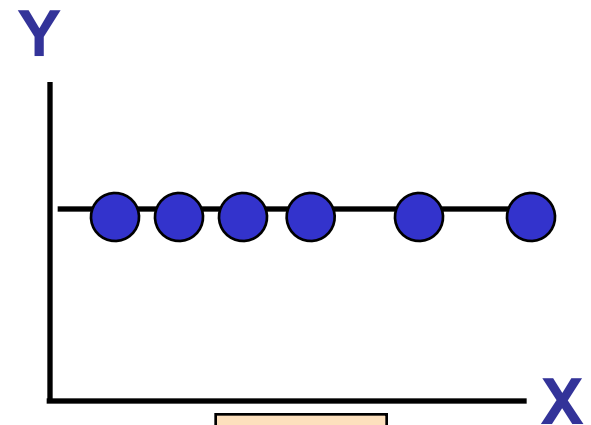
$$r = 0$$



$$r = +1$$



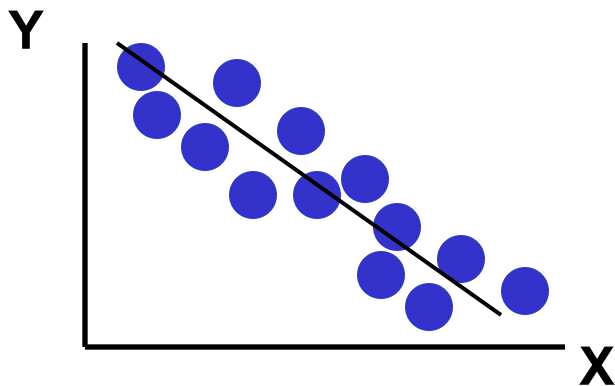
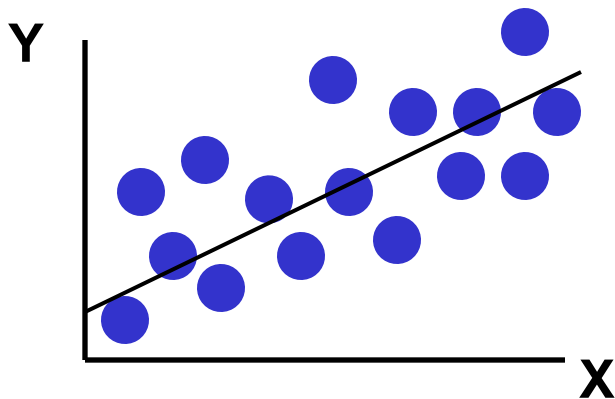
$$r = +.3$$



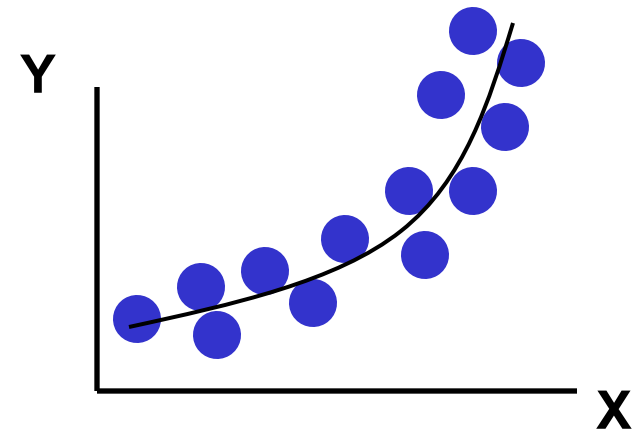
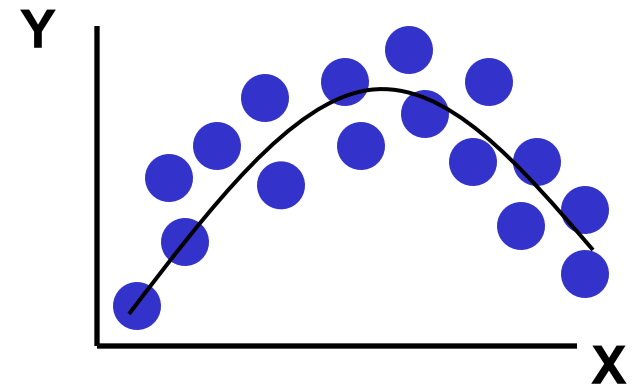
$$r = 0$$

# Linear Correlation

## Linear relationships

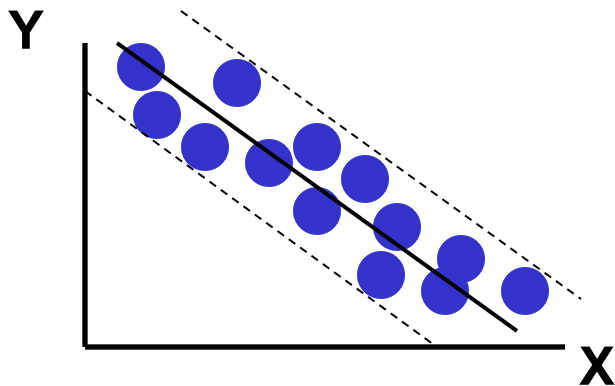
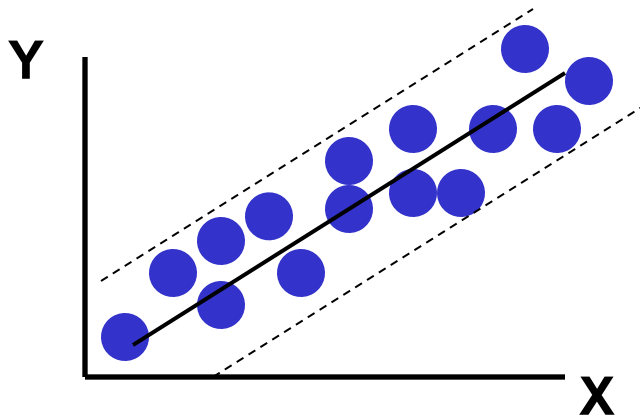


## Curvilinear relationships

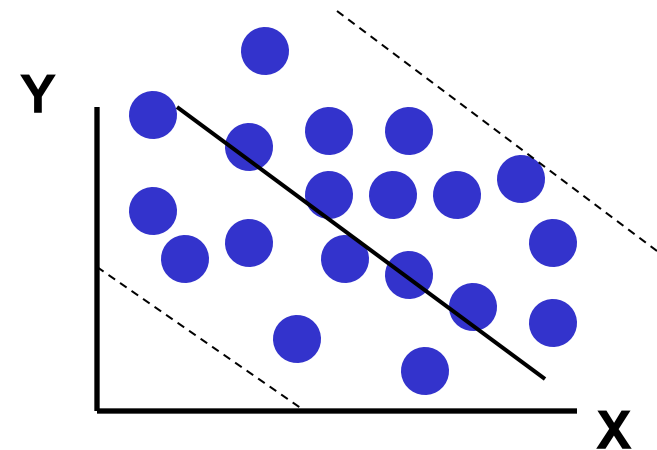
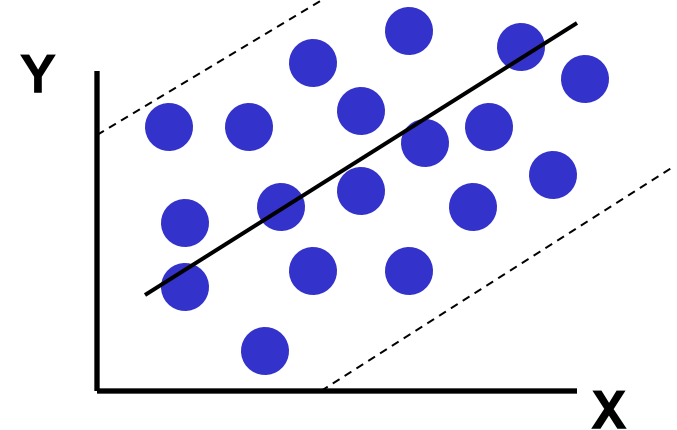


# Linear Correlation

**Strong relationships**



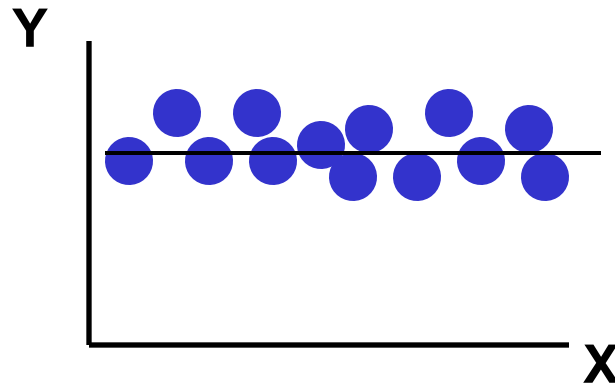
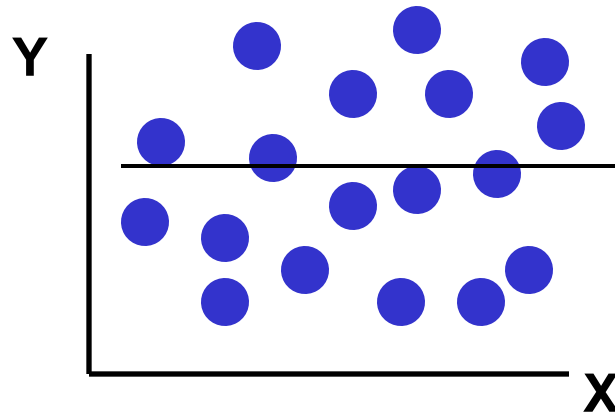
**Weak relationships**





# Linear Correlation

No relationship





# Calculating by hand...

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$$\hat{r} = \frac{\text{covariance}(x, y)}{\sqrt{\text{var } x} \sqrt{\text{var } y}} = \frac{\frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{n-1}}{\sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}} \sqrt{\frac{\sum_{i=1}^n (y_i - \bar{y})^2}{n-1}}}$$

# Simpler calculation formula...

$$\hat{r} = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}} \sqrt{\frac{\sum_{i=1}^n (y_i - \bar{y})^2}{n-1}}} = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2} \sqrt{\sum_{i=1}^n (y_i - \bar{y})^2}} = \frac{SS_{xy}}{\sqrt{SS_x SS_y}}$$

**Numerator of  
covariance**

$$\hat{r} = \frac{SS_{xy}}{\sqrt{SS_x SS_y}}$$

**Numerators of  
variance**



# Linear regression

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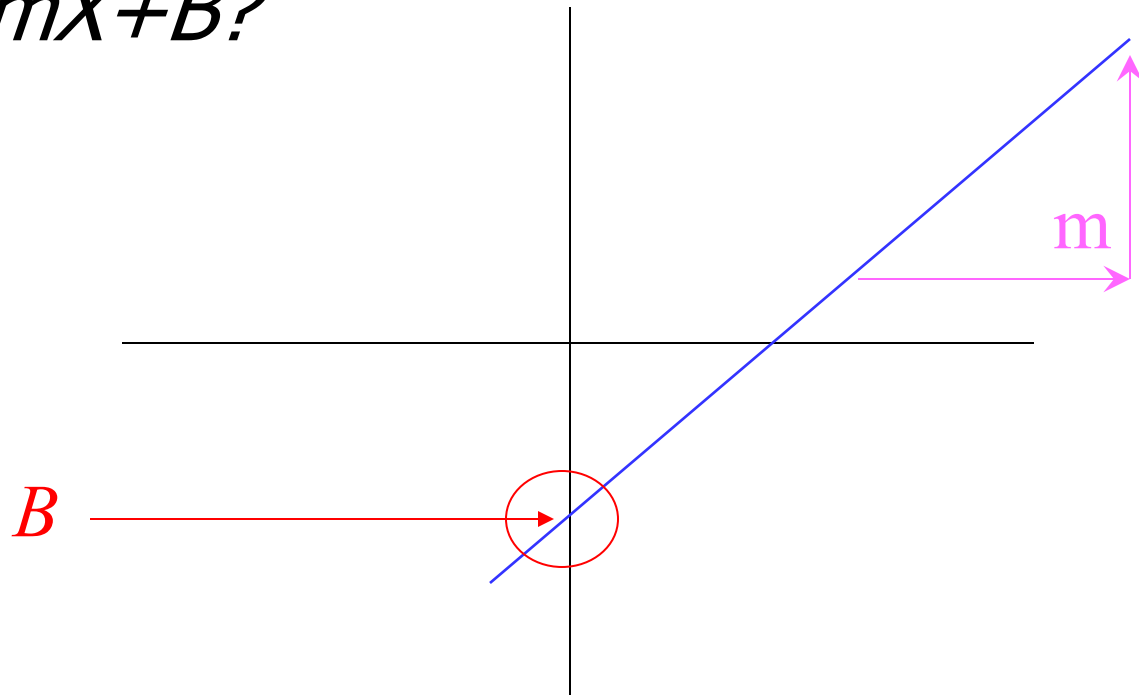
In correlation, the two variables are treated as equals. In regression, one variable is considered independent (=predictor) variable ( $X$ ) and the other the dependent (=outcome) variable  $Y$ .



# What is "Linear"?

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- Remember this:
- $Y = mX + B$



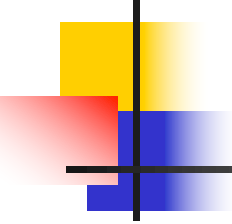


# What's Slope?

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A slope of 2 means that every 1-unit change in  $X$  yields a 2-unit change in  $Y$ .

# Predicted value for an individual...



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$$\hat{y}_i = \underbrace{\alpha + \beta * x_i}_{\text{Fixed — exactly on the line}} + \boxed{\text{random error}_i}$$

Fixed —  
exactly  
on the  
line

Follows a normal  
distribution



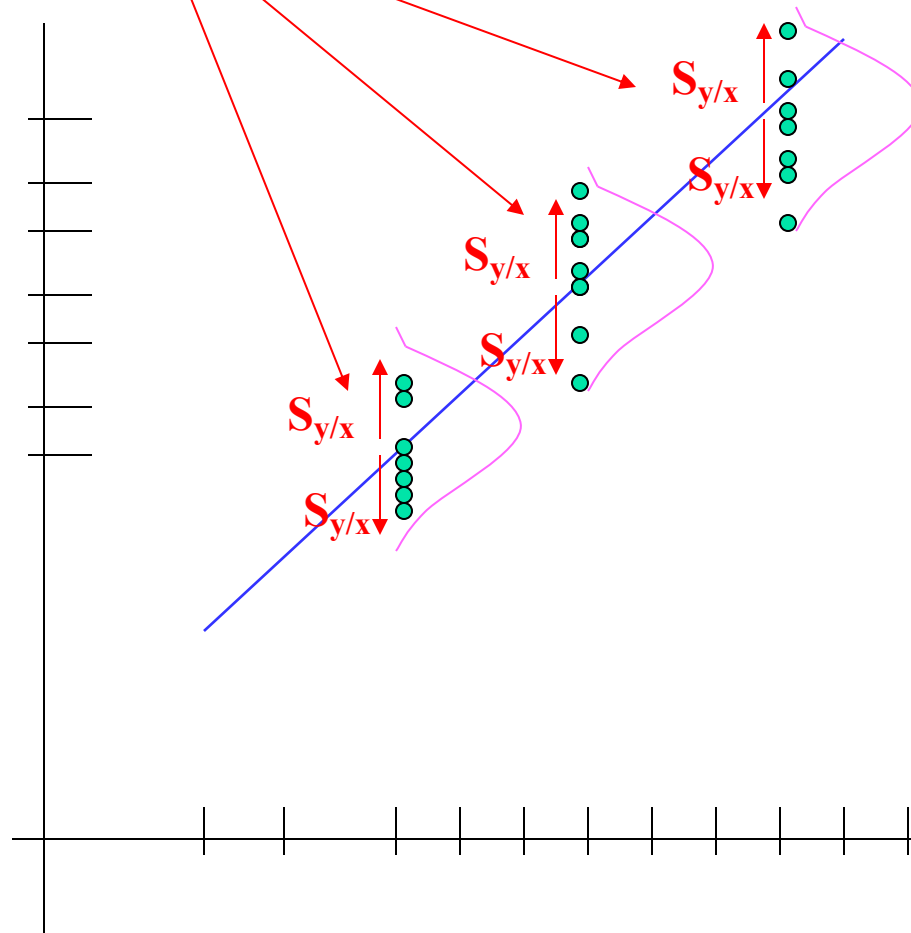
# Assumptions (or the fine print)

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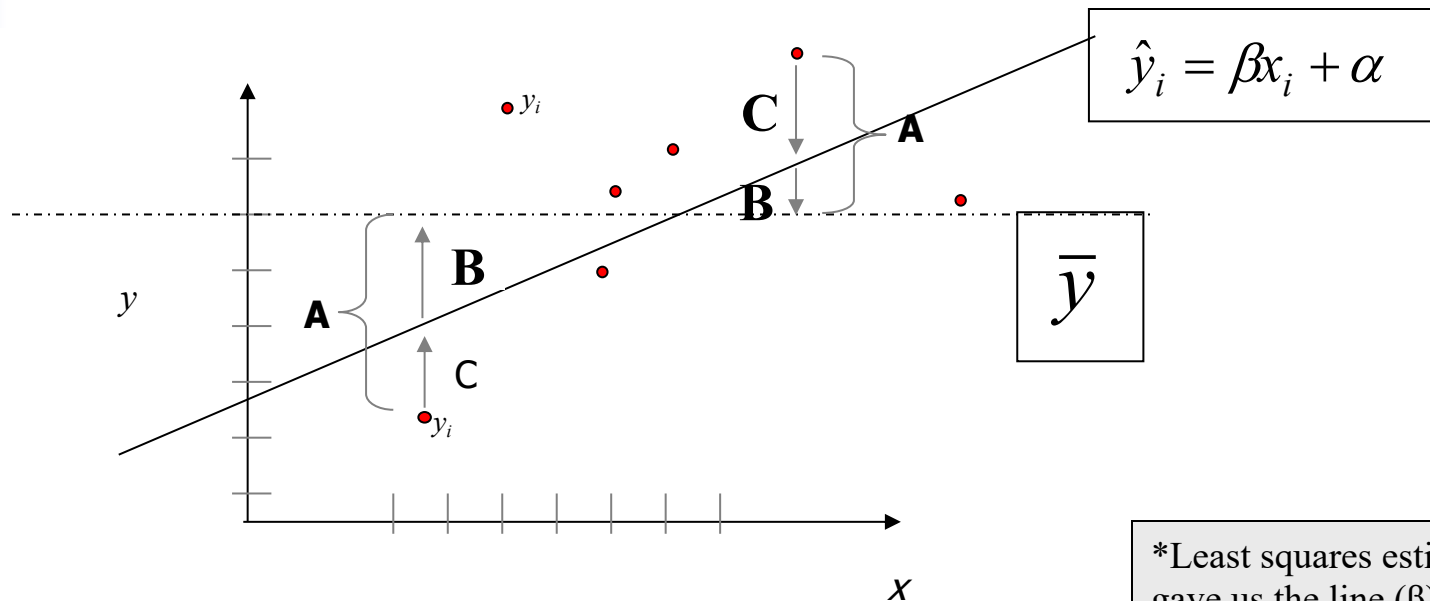
- Linear regression assumes that...
  - 1. The relationship between  $X$  and  $Y$  is linear
  - 2.  $Y$  is distributed normally at each value of  $X$
  - 3. The variance of  $Y$  at every value of  $X$  is the same (homogeneity of variances)
  - 4. The observations are independent



**The standard error of Y given X is the average variability around the regression line at any given value of X. It is assumed to be equal at all values of X.**



# Regression Picture



\*Least squares estimation gave us the line ( $\beta$ ) that minimized  $C^2$

$$\sum_{i=1}^n (y_i - \bar{y})^2 = \sum_{i=1}^n (\hat{y}_i - \bar{y})^2 + \sum_{i=1}^n (\hat{y}_i - y_i)^2$$

$A^2$

$SS_{\text{total}}$   
**Total squared distance of observations from naïve mean of y**  
*Total variation*

$B^2$

$SS_{\text{reg}}$   
 Distance from regression line to naïve mean of y  
 Variability due to x (regression)

$C^2$

$SS_{\text{residual}}$   
 Variance around the regression line  
 Additional variability not explained by x—what least squares method aims to minimize

$$R^2 = SS_{\text{reg}} / SS_{\text{total}}$$



# Estimating the intercept and slope: least squares estimation

## \*\* Least Squares Estimation

A little calculus....

What are we trying to estimate?  **$\beta$ , the slope**, from

What's the constraint? We are trying to minimize the squared distance (hence the “least squares”) between the observations themselves and the predicted values, or (also called the “residuals”, or left-over unexplained variability)

$$\text{Difference}_i = y_i - (\beta x_i + \alpha) \quad \text{Difference}_i^2 = (y_i - (\beta x_i + \alpha))^2$$

Find the  $\beta$  that gives the minimum sum of the squared differences. How do you maximize a function? Take the derivative; set it equal to zero; and solve. Typical max/min problem from calculus....

$$\frac{d}{d\beta} \sum_{i=1}^n (y_i - (\beta x_i + \alpha))^2 = 2 \left( \sum_{i=1}^n (y_i - \beta x_i - \alpha)(-x_i) \right)$$
$$2 \left( \sum_{i=1}^n (-y_i x_i + \beta x_i^2 + \alpha x_i) \right) = 0 \dots$$

From here takes a little math trickery to solve for  $\beta$ ...



# Resulting formulas...

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Slope (beta coefficient) =

$$\hat{\beta} = \frac{Cov(x, y)}{Var(x)}$$

Intercept=

$$\text{Calculate: } \hat{\alpha} = \bar{y} - \hat{\beta}\bar{x}$$

Regression line always goes through the point:  $(\bar{x}, \bar{y})$



# Relationship with correlation

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$$\hat{r} = \hat{\beta} \frac{SD_x}{SD_y}$$

In correlation, the two variables are treated as equals. In regression, one variable is considered independent (=predictor) variable ( $X$ ) and the other the dependent (=outcome) variable  $Y$ .



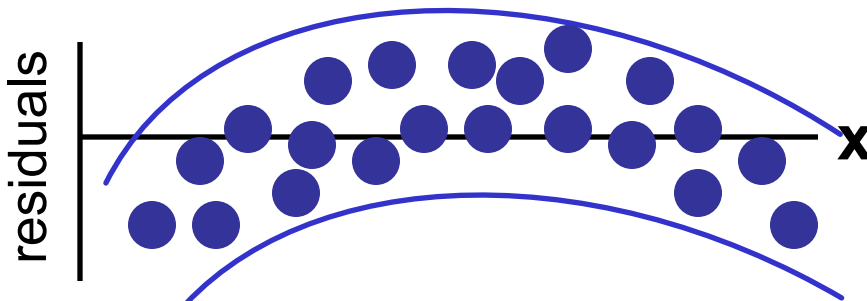
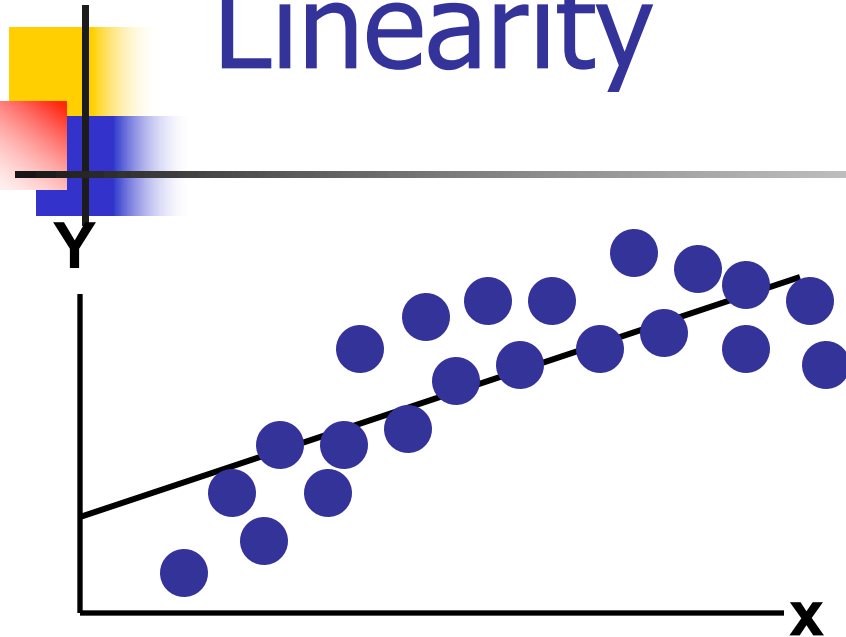
# Residual Analysis: check assumptions

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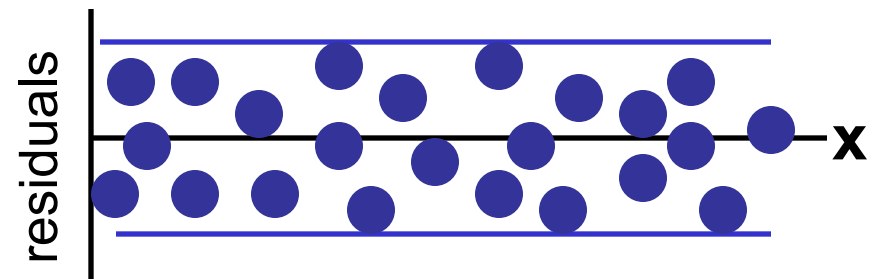
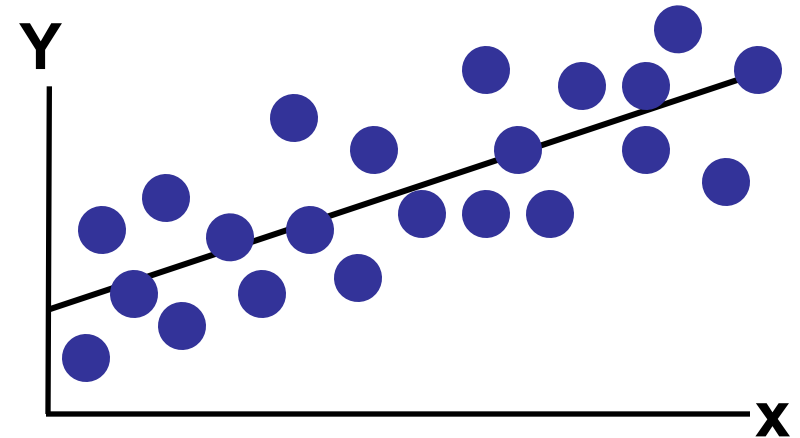
$$e_i = Y_i - \hat{Y}_i$$

- The residual for observation  $i$ ,  $e_i$ , is the difference between its observed and predicted value
- Check the assumptions of regression by examining the residuals
  - Examine for linearity assumption
  - Examine for constant variance for all levels of  $X$  (homoscedasticity)
  - Evaluate normal distribution assumption
  - Evaluate independence assumption
- Graphical Analysis of Residuals
  - Can plot residuals vs.  $X$

# Residual Analysis for Linearity

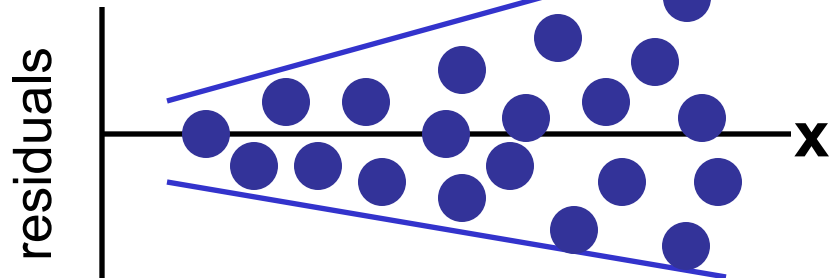
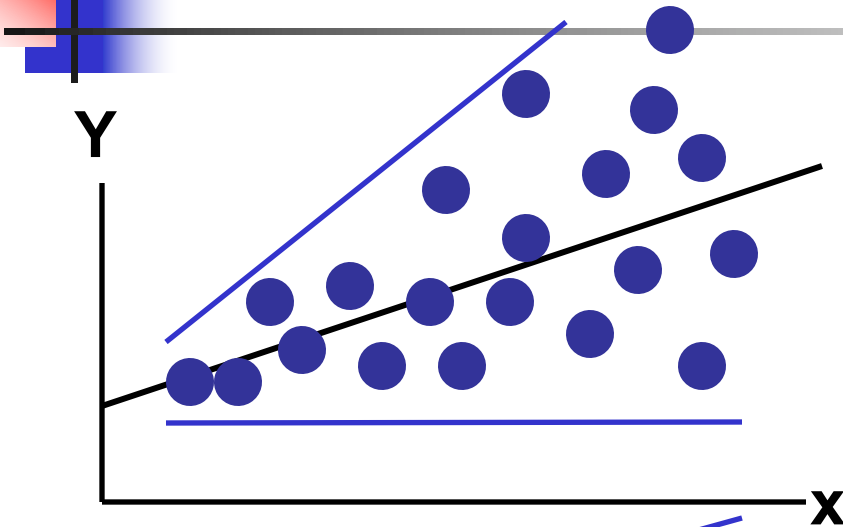


**Not Linear**

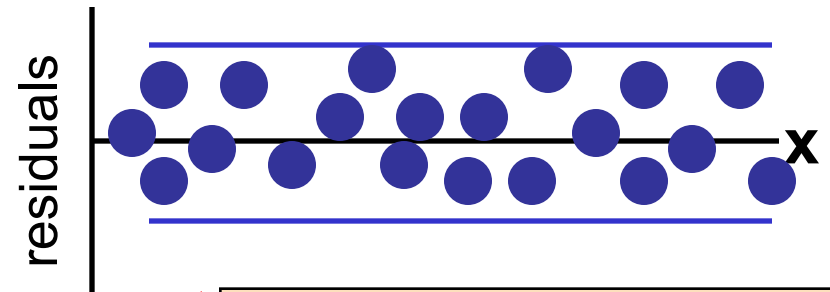
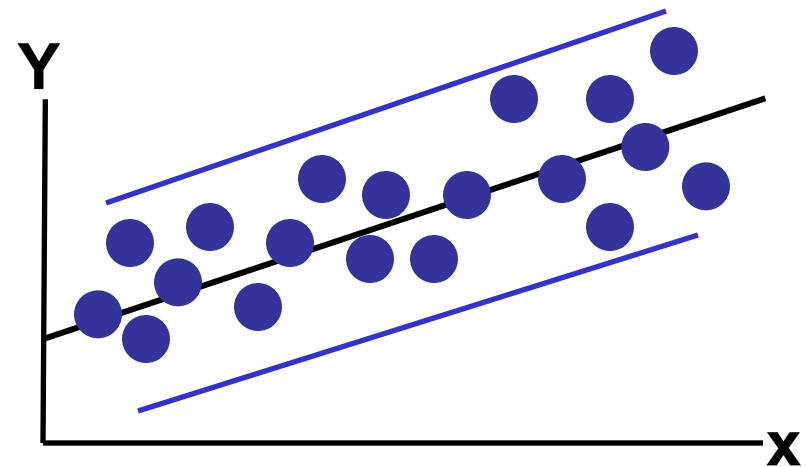


**Linear**

# Residual Analysis for Homoscedasticity



Non-constant variance



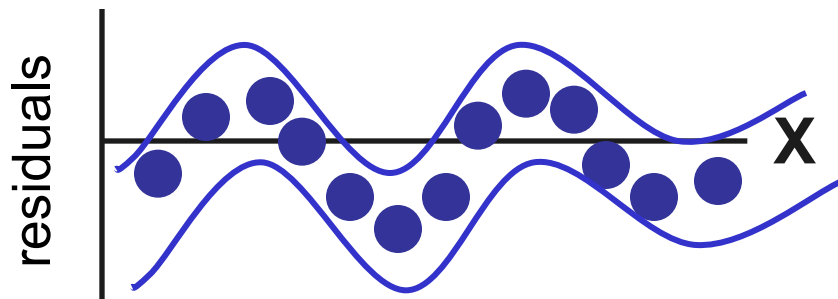
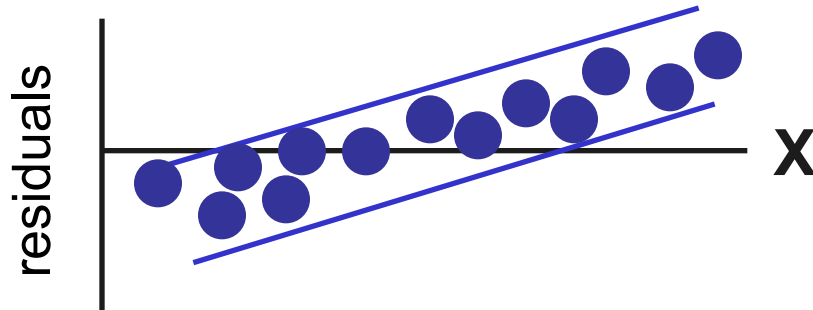
Constant variance



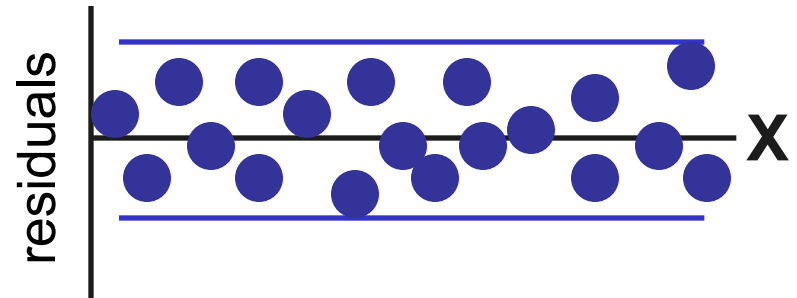
# Residual Analysis for Independence



**Not Independent**



**Independent**





# Multiple Linear Regression

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- More than one predictor...

$$E(y) = \alpha + \beta_1 * X + \beta_2 * W + \beta_3 * Z \dots$$

Each regression coefficient is the amount of change in the outcome variable that would be expected per one-unit change of the predictor, if all other variables in the model were held constant.



# Other types of multivariate regression

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- Multiple linear regression is for normally distributed outcomes
- Logistic regression is for binary outcomes
- Cox proportional hazards regression is used when time-to-event is the outcome

# Common multivariate regression models.

Outcome (dependent variable)	Example outcome variable	Appropriate multivariate regression model	Example equation	What do the coefficients give you?
Continuous	Blood pressure	<b>Linear regression</b>	blood pressure (mmHg) = $\alpha + \beta_{\text{salt}} \cdot \text{salt consumption (tsp/day)} + \beta_{\text{age}} \cdot \text{age (years)} + \beta_{\text{smoker}} \cdot \text{ever smoker (yes=1/no=0)}$	slopes—tells you how much the outcome variable increases for every 1-unit increase in each predictor.
Binary	High blood pressure (yes/no)	<b>Logistic regression</b>	ln (odds of high blood pressure) = $\alpha + \beta_{\text{salt}} \cdot \text{salt consumption (tsp/day)} + \beta_{\text{age}} \cdot \text{age (years)} + \beta_{\text{smoker}} \cdot \text{ever smoker (yes=1/no=0)}$	odds ratios—tells you how much the odds of the outcome increase for every 1-unit increase in each predictor.
Time-to-event	Time-to- death	<b>Cox regression</b>	ln (rate of death) = $\alpha + \beta_{\text{salt}} \cdot \text{salt consumption (tsp/day)} + \beta_{\text{age}} \cdot \text{age (years)} + \beta_{\text{smoker}} \cdot \text{ever smoker (yes=1/no=0)}$	hazard ratios—tells you how much the rate of the outcome increases for every 1-unit increase in each predictor.