

STAT 111

Recitation 6

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Slides (adapted from Gemma Moran): github.com/mohuangx/STAT111-Fall2018

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Estimation of a binomial parameter θ

- ▶ Suppose X is binomial, i.e. $X \sim \text{Bin}(n, \theta)$, and you want to estimate θ .
- ▶ The **estimate** for θ is $p = x/n$.
- ▶ 95% confidence interval is $p \pm \sqrt{1/n}$.

Note: $(1 - \alpha)\%$ confidence interval is $[p - \frac{z^*}{2} \sqrt{1/n}, p + \frac{z^*}{2} \sqrt{1/n}]$ where z^* is the value in the z-chart where the probability is $\frac{1-\alpha}{2}$.

Estimation of a mean μ

- ▶ Suppose we have i.i.d. random variables X_1, \dots, X_n with mean μ and variance σ^2 . We do not assume any distribution!
- ▶ We observe x_1, \dots, x_n and we want to estimate μ . How do we do this?
- ▶ Recall by the Central Limit Theorem, for large n , $\bar{X} \sim N\left(\mu, \frac{\sigma^2}{n}\right)$.
- ▶ Thus, \bar{x} is an unbiased **estimate** for μ .

Estimation of a mean μ

- ▶ How precise an estimate is \bar{x} ?

- ▶ This is where the **variance** comes in:

$$\bar{X} \sim N\left(\mu, \frac{\sigma^2}{n}\right).$$

- ▶ We can use the **two-standard deviation** rule:

$$\text{Prob}\left(\bar{X} - 2\frac{\sigma}{\sqrt{n}} < \mu < \bar{X} + 2\frac{\sigma}{\sqrt{n}}\right) = 0.95.$$

- ▶ Then our **95% confidence interval** for our data is:

$$\bar{x} \pm 2\frac{\sigma}{\sqrt{n}}.$$

Estimation of a mean μ

- ▶ What if we don't know the true variance σ^2 ?
- ▶ We need to estimate the variance from the data.
- ▶ The unbiased estimate of σ^2 is s^2 :

$$s^2 = \frac{x_1^2 + x_2^2 + \cdots + x_n^2 - n(\bar{x}^2)}{n - 1}.$$

- ▶ Then, our approximate 95% confidence interval is:

$$\bar{x} - 2 \frac{s}{\sqrt{n}} \quad \text{to} \quad \bar{x} + 2 \frac{s}{\sqrt{n}}.$$

Note: 95% confidence intervals are always of the form:

$$\text{Estimator} - 2 * SD(\text{Estimator}) \quad \text{to} \quad \text{Estimator} + 2 * SD(\text{Estimator})$$

Example

- Suppose we observe 15 iid data points:

104, 127, 153, 164, 115, 143, 193, 151, 129, 139, 122, 144, 108, 148, 132.

Q: Find the sample average of the data.

A: $\bar{x} = (104 + 127 + \cdots + 132)/15 = 138.13$

Q: Find the sample standard deviation of the data.

A:

$$s^2 = \frac{104^2 + 127^2 + \cdots + 132^2 - 15 * 138.13^2}{15 - 1} \Rightarrow s = 22.89$$

Q: Find the 95% confidence interval for the mean.

A:

$$138.13 - 2 * \frac{22.89}{\sqrt{15}} \quad \text{to} \quad 138.13 + 2 * \frac{22.89}{\sqrt{15}} = [126.31, 149.95]$$

Estimating the difference between proportions $\theta_1 - \theta_2$

- ▶ Let Population 1 have proportion P_1 and sample size n , and Population 2, P_2 and m respectively. Then for large n, m , we have

$$P_1 \sim N\left(\theta_1, \frac{\theta_1(1-\theta_1)}{n}\right), \quad P_2 \sim N\left(\theta_2, \frac{\theta_2(1-\theta_2)}{m}\right) \quad (CLT)$$

- ▶ Let $D = P_1 - P_2$. Then D is normal with

$$D \sim N\left(\theta_1 - \theta_2, \frac{\theta_1(1-\theta_1)}{n} + \frac{\theta_2(1-\theta_2)}{m}\right).$$

- ▶ The **estimate** for $\theta_1 - \theta_2$ is $p_1 - p_2$.

- ▶ The **95% confidence interval** is then:

$$p_1 - p_2 \pm \sqrt{\frac{1}{n} + \frac{1}{m}}$$

Example

- ▶ Suppose we have two drugs to cure a headache, 1 and 2. Let θ_1 be the probability that Drug 1 cures a headache and θ_2 is the probability that Drug 2 cures a headache.
- ▶ In a group of 250 people, Drug 1 cures 189 people. In a different group of 300 people, Drug 2 cures 256 people.
- ▶ Find the 95% confidence interval for the difference $\theta_1 - \theta_2$.

A:

$$p_1 - p_2 = \frac{189}{250} - \frac{256}{300} = -0.0973, \quad \sqrt{\frac{1}{250} + \frac{1}{300}} = 0.0856$$

⇒ 95% confidence interval:

$$-0.0973 \pm 0.0856 \Rightarrow [-0.1829, -0.0117].$$

Estimating the difference between means $\mu_1 - \mu_2$

- ▶ Suppose we have two independent populations:
 - ▶ $X_{11}, X_{12}, \dots, X_{1n}$: i.i.d. random variables with mean μ_1 and variance σ_1^2 (both unknown),
 - ▶ $X_{21}, X_{22}, \dots, X_{2m}$: i.i.d. random variables with mean μ_2 and variance σ_2^2 (both unknown).

- ▶ By the CLT,

$$\bar{X}_1 - \bar{X}_2 \sim N\left(\mu_1 - \mu_2, \frac{\sigma_1^2}{n} + \frac{\sigma_2^2}{m}\right)$$

- ▶ The **estimate** for $\mu_1 - \mu_2$ is $\bar{x}_1 - \bar{x}_2$.
- ▶ The **95% confidence interval** is then

$$\bar{x}_1 - \bar{x}_2 \pm 2\sqrt{\frac{s_1^2}{n} + \frac{s_2^2}{m}}$$

$$\text{where } s_1^2 = \frac{x_{11}^2 + \dots + x_{1n}^2 - n(\bar{x}_1^2)}{n-1}, \quad s_2^2 = \frac{x_{21}^2 + \dots + x_{2m}^2 - m(\bar{x}_2^2)}{m-1}$$

Example

- ▶ Suppose we want to estimate the difference in yield of wheat from two different, independent fields, A and B .

- ▶ Data:

Field A: $n = 12, \bar{x}_1 = 121.4, s_1^2 = 10.1$

Field B: $m = 15, \bar{x}_2 = 113.8, s_2^2 = 12.1$

- ▶ Find the 95% confidence interval for the difference in mean yield $(\mu_1 - \mu_2)$.

A:

$$121.4 - 113.8 \pm 2\sqrt{\frac{10.1}{12} + \frac{12.1}{15}} \Rightarrow [5.032, 10.168]$$

Estimation Summary

- ▶ Binomial parameter θ :

Estimate: p

95% confidence interval: $p \pm \sqrt{1/n}$

- ▶ Mean μ :

Estimate: \bar{x}

95% confidence interval: $\bar{x} \pm 2 \frac{s}{\sqrt{n}}$

- ▶ Difference between proportions $\theta_1 - \theta_2$:

Estimate: $p_1 - p_2$

95% confidence interval: $p_1 - p_2 \pm \sqrt{\frac{1}{n} + \frac{1}{m}}$

- ▶ Difference between means $\mu_1 - \mu_2$:

Estimate: $\bar{x}_1 - \bar{x}_2$

95% confidence interval: $\bar{x}_1 - \bar{x}_2 \pm 2 \sqrt{\frac{s_1^2}{n} + \frac{s_2^2}{m}}$

Note:

$$s = \sqrt{\frac{x_1^2 + x_2^2 + \cdots + x_n^2 - n(\bar{x}^2)}{n-1}}.$$