Statistical Inference: Assignment 1

ND

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Introduction

This document briefly investigates the distributions of means of an exponential distribution. It demonstrates the central limit theorem, which very roughly states that the mean of a large number of independent random variables will be approximately normally distributed. The R markdown source for this document is available on github.

Simulation

```r
set.seed(1) # set random seed for reproducibility
```

The following code create a matrix of 1000 rows of 40 columns of random samples from an exponential distribution with $\lambda = 0.2$. It then creates a dataframe containing the means and standard deviations of the 40 samples. The `apply` function is used to apply the mean and standard deviation functions over the rows of the matrix to give vectors of means and standard deviations from each of the 1000 simulations.

```r
n <- 40
lambda <- 0.2
nsim <- 1000

temp <- matrix(rexp(n * nsim, lambda), ncol = n)
dat <- data.frame(mean = apply(temp, 1, mean),
                  sd = apply(temp, 1, sd))
```

Distribution centre

The distribution will be centred on its mean value. In other words, if the distribution were balanced on a point, the point would lie at its mean value. The mean of the empirical distribution is 4.99 while the mean of the theoretical distribution is $1/\lambda$, i.e. 5.

Distribution variance

The variance in the empirical distribution is 0.6177 while the variance of the theoretical distribution is $\left(\frac{1/\lambda}{\sqrt{n}}\right)^2$ i.e. 0.625.

Distribution shape

The following code generates a density plot comparing the empirical distribution (solid black line) with the normal distribution (dotted red line). In addition, lines showing the peaks of the distribution are plotted.

```
d.plot <- density(dat$mean)

plot(d.plot, col = "black", lwd = 2, lty = 1,
     main = "Density of means of 40 samples", ylim = c(0,0.51))

d.max <- d.plot$x[which.max(d.plot$y)]
abline(v = d.max, col = "black", lwd = 2, lty = 1) # peak of empirical distribution

xnorm <- seq(min(dat$mean), max(dat$mean), length = 50)
ynorm <- dnorm(xnorm, mean = 1/lambda, sd = (1/lambda)/sqrt(n))
lines(xnorm, ynorm, col = "red", lwd = 2, lty = 3)  # normal distribution

abline(v = 1/lambda, col = "red", lwd = 2, lty = 3) # peak of normal distribution
```

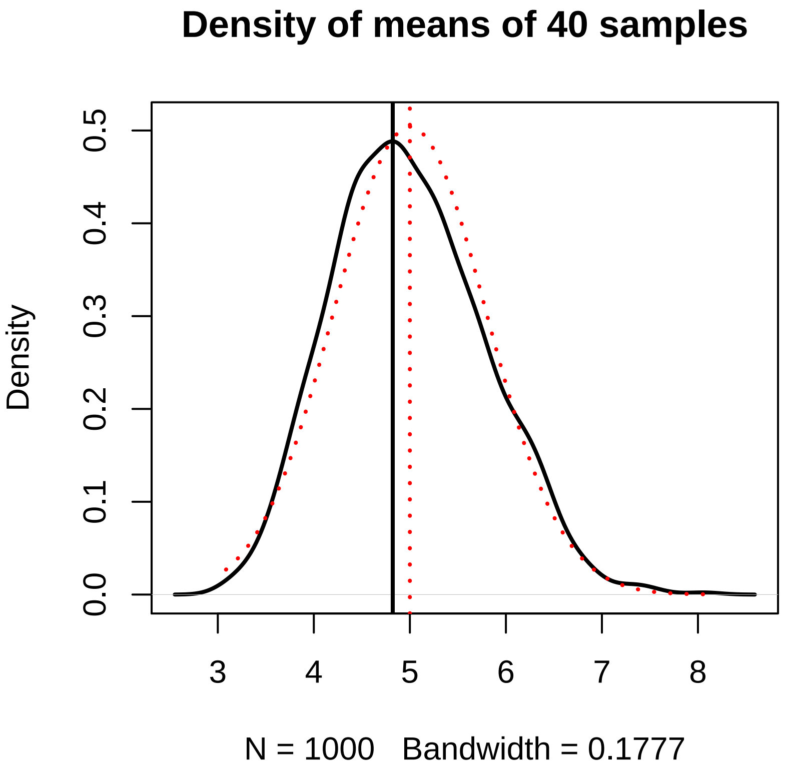

Figure 1: Density comparison

A visual comparison of the empirical density curve with the normal density curve shows that the empirical density is approximately normal. Increasing the number of simulations would reduce the difference between the distributions.

Confidence interval

An approximation to the 95% confidence interval for the mean of the exponential distribution is given by $\bar{X} \pm 1.96\frac{S}{\sqrt{n}}$.

```
ci <- mean(dat$mean) + c(-1, 1) * 1.96 * mean(dat$sd)/sqrt(n) # CHECK
coverage <- sum(dat$mean >= ci[1] & dat$mean <= ci[2]) / nsim
```

This results in a confidence interval running from 3.4735 to 6.5065, which gives a coverage of 96.1%.

Appendix

Distribution shape (ggplot2)

A similar density plot comparing the empirical and theoretical distributions can be created using ggplot2.

```r
library(ggplot2)

ggplot(dat, aes(x = mean)) +
  geom_density(size = 1, aes(y = ..density..), ylim = c(0, 0.51)) +
  xlab("Mean") + ylab("Density") + ggtitle("Density of means of 40 samples") +
  geom_vline(xintercept = d.max, size = 1) +
  stat_function(fun = dnorm, colour = "red", size = 1, linetype = 3,
                arg = list(mean = 1/lambda,  sd = (1/lambda)/sqrt(n))) +
  geom_vline(xintercept = 1/lambda, colour = "red", size = 1, linetype = 3) +
  theme_bw()
```

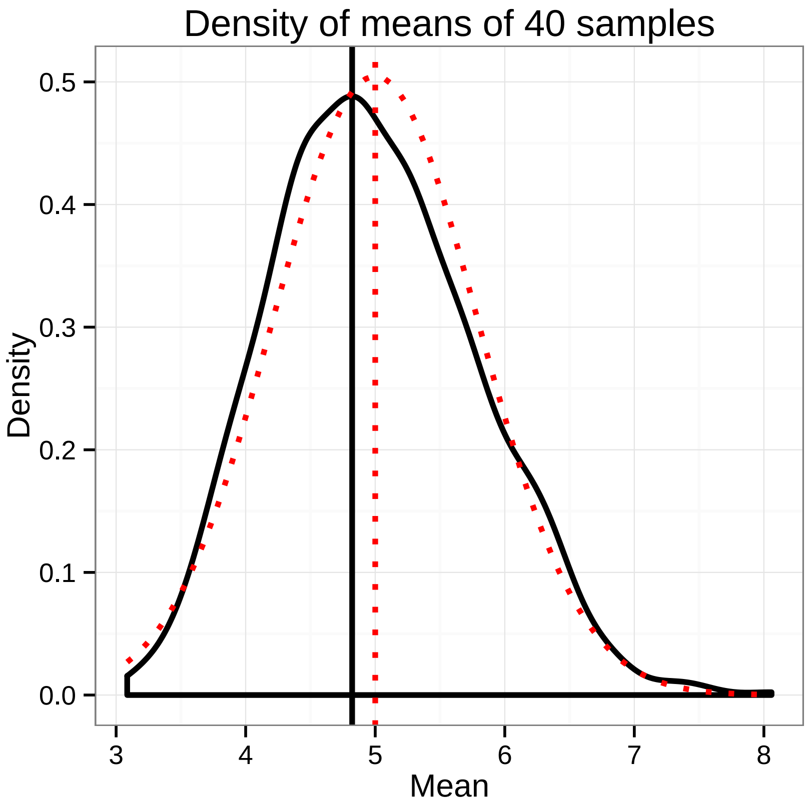

Figure 2: Density comparison (ggplot2

Normal q-q plot

The normal q-q plot provides another way to compare the two distributions. The relationship will be linear if the empirical data is normally distributed.

```
qqnorm(y = (dat$mean - mean(dat$mean)) / sd(dat$mean), ylim = c(-3, 3))
qqline(y = (dat$mean - mean(dat$mean)) / sd(dat$mean))
```

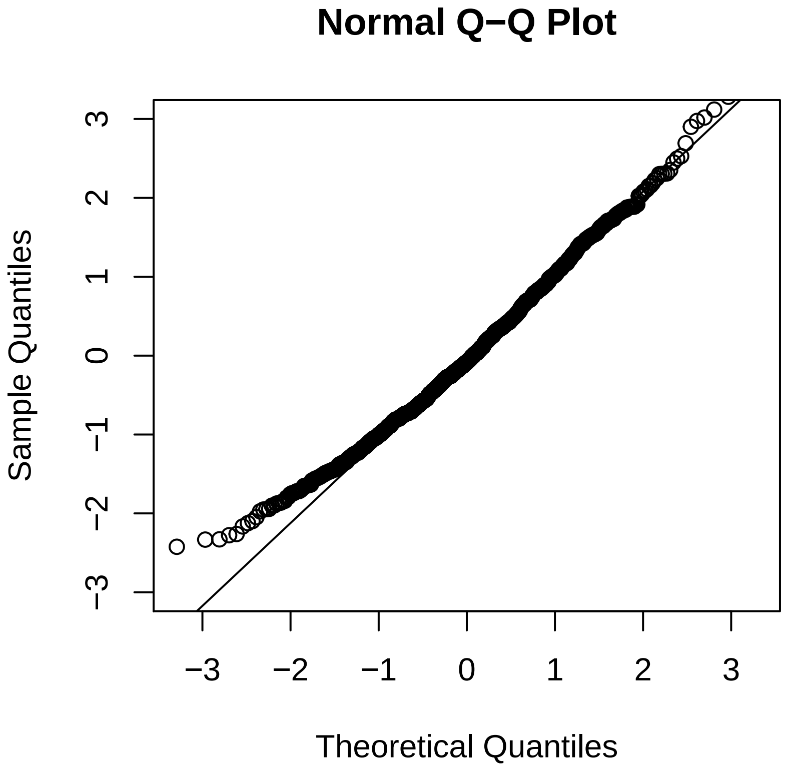

Figure 3: Normal q-q plot

The plot is fairly linear, which suggests the distribution of means is approximately normal.

Confidence interval plot

The coverage of the 95% confidence interval can be plotted on the empirical distribution using the `polygon` function.

```
x1 <- max(which(d.plot$x <= ci[1])) # lower boundary
x2 <- min(which(d.plot$x >= ci[2])) # upper boundary

plot(d.plot, col = "black", lwd = 2, lty = 1,
     main = "Density of means of 40 samples", ylim = c(0,0.51))
polygon(x = c(d.plot$x[x1], d.plot$x[x1:x2], d.plot$x[x2]),
        y = c(0, d.plot$y[x1:x2], 0), col = "pink")
text(5, 0.25, "95%\n(approx)")
```

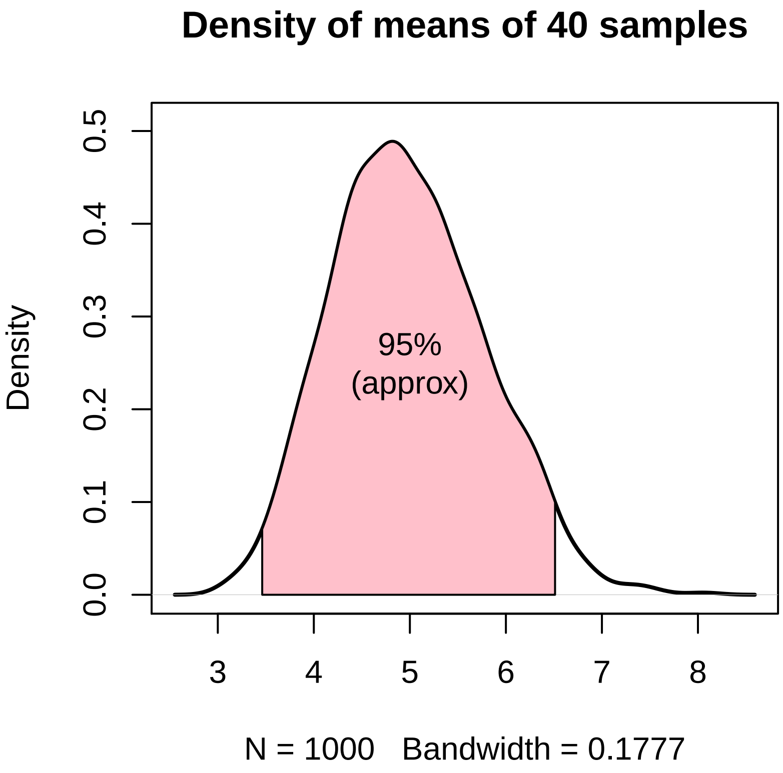

Figure 4: Confidence interval plot