1. Consider the linear model $y = X\beta + \varepsilon$, where $\varepsilon \sim N(0, \Sigma)$, and $X$ is of full rank.

(a) Show that the general least-squares estimator, which minimizes $(y - X\beta)^T \Sigma^{-1} (y - X\beta)$, is the best linear unbiased estimator.

(b) If $\Sigma$ is the equi-correlation matrix with correlation $\rho$, what is the solution to the above problem?

2. Consider the multiple regression model $Y_i = X_i^T \beta + \varepsilon_i$, where $\varepsilon_i \sim N(0, \sigma^2)$ for $i = 1, \cdots, n$.

(a) Show that the maximum likelihood estimator is equivalent to the least-squares estimator, which finds $\hat{\beta}$ to minimize

$$
\sum_{i=1}^{n} (Y_i - X_i^T \beta)^2
$$

and

$$
\hat{\sigma} = \sqrt{\frac{\text{RSS}}{n}},
$$

where $\text{RSS} = \sum_{i=1}^{n} (Y_i - X_i^T \hat{\beta})^2$ and $\hat{\beta}$ is the least-squares solution.

(b) Show that $\text{RSS} \sim \sigma^2 \chi^2_{n-p}$, where $p$ is the rank of $X$ (full rank for simplicity).

(c) Prove that $1 - \alpha$ CI for $\beta_j$ is $\hat{\beta}_j \pm t_{n-p}(1 - \alpha/2)\sqrt{v_j \text{RSS}/(n - p)}$, where $v_j$ is the $j$th diagonal element of $(X^T X)^{-1}$.

(d) Dropping the normality assumption, if $\{X_i\}$ are i.i.d. from a population with $EXX^T = \Sigma$ and independent of $\{\varepsilon_i\}_{i=1}^{n}$, which are i.i.d. from a population with $E\varepsilon = 0$ and $\text{var}(\varepsilon) = \sigma^2$, show that

$$
\sqrt{n}(\hat{\beta} - \beta) \xrightarrow{d} N(0, \sigma^2 \Sigma^{-1}).
$$

3. Let us consider the 129 macroeconomic time series again as described in the lecture notes of ORF 245. Let $Y_t = \log(\text{PCE}_t)$ be the personal consumption expenditure. Let us take

$$
X_{t,1} = \log(\text{PCE}_{t-1}), \quad X_{t,2} = \text{Unrate}_{t-1}, \quad X_{t,3} = \Delta \log(\text{IndPro}_t), \quad X_{t,4} = \Delta \log(\text{M2Real}_t),
$$

$$
X_{t,5} = \Delta \log(\text{CPI}_t), \quad X_{t,6} = \Delta \log(\text{SPY}_t), \quad X_{t,7} = \text{HouStat}_t, \quad X_{t,8} = \text{FedFund}_t
$$

Let us again take the last 10 years data as testing set and remaining as training set. Conduct a similar analysis as those in the lecture notes. Answer in particular the following questions.

(a) What are $\hat{\sigma}^2$, adjust $R^2$ and insignificant variables?

(b) Now perform the stepwise deletion, eliminating one least significant variable at a time (by looking at the small $|t|$-statistic) until all variables are statistically significant. Let us call this model as model $\hat{M}$. (The function step can do the job automatically)
(c) Using model $\widehat{M}$, what are root mean-square prediction error and mean absolute deviation prediction error for the test sample?

(d) Compute the standardized residuals. Present the time series plot of the residuals, fitted values versus the standardized residuals, and QQ plot for the standardized residuals.

(e) Compare the result in part (c) with the nonparametric model using Gaussian kernel with $\gamma = 1/4$ (standardize predictors first) and $\lambda$ chosen by 5-fold CV or GCV.

4. Zillow is an online real estate database company that was founded in 2006. The most important task for Zillow is to predict the house price. However, their accuracy has been criticized a lot. According to Fortune, "Zillow has Zestimated the value of 57 percent of U.S. housing stock, but only 65 percent of that could be considered accurate by its definition, within 10 percent of the actual selling price. And even that accuracy isn’t equally distributed”. Therefore, Zillow needs your help to build a housing pricing model to improve their accuracy. Download and read the data (training data: 15129 cases, testing data: 6484 cases)

```r
train.data <- read.csv('train.data.csv', header=TRUE)
test.data <- read.csv('test.data.csv', header=TRUE)
train.data$zipcode <- as.factor(train.data$zipcode)
test.data$zipcode <- as.factor(test.data$zipcode)
```

where the last two lines make sure that zip code is treated as factor. Letting $T$ as a test set, define out-of-sample $R^2$ as of a prediction method $\{\hat{y}_i^{pred}\}$ as

$$R^2 = 1 - \frac{\sum_{i \in T} (y_i - \hat{y}_i^{pred})^2}{\sum_{i \in T} (y_i - \bar{y}^{pred})^2},$$

where $\bar{y}^{pred} = \text{ave}(\{y_i\}_{i \in T_0})$ and $T_0$ is the training set.

(a) Calculate out-of-sample $R^2$ using variables “bedrooms”, “bathrooms”, “sqft_living”, and “sqft_lot”.

(b) Calculate out-of-sample $R^2$ using the 4 variables above along with interaction terms.

(c) Compare the result with the nonparametric model using Gaussian kernel with $\gamma = 1/4$ (standardize predictors first) and $\lambda$ chosen by 5-fold CV or GCV.

(d) Add the factor zipcode to (b) and compute out-of-sample $R^2$.

(e) Add the following additional variables to (d): $X_{12} = I(\text{view} == 0)$, $X_{13} = L$, $X_{14} = L^2$, $X_i = (L - \tau_i)^{2+}$, $i = 1, \cdots, 9$, where $\tau_i$ is $10 * i^{th}$ percentile and $L$ is the size of living area. Compute out-of-sample $R^2$.

(f) Why do you see the increased out-of-sample $R^2$ with modeling complexity?

5. Prove the representer theorem in the lecture note (Theorem 1.4). You are allowed to consult the book, but not allow to have verbatim copy. You need to write the solution of your own with at least some changes of notation.