

Statistics, Time Series, Computation Finance, Derivative Pricing, Algorithmic Trading Review in R, Python

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Table of Contents

Statistics	5
1. Distributions.....	5
• Random Uniform.....	5
• Binomial	6
• Normal.....	7
• Poisson	8
• Chi-square	8
• Student's T	9
• F.....	10
• Show stock return close to normal rv	10
2. Moments, Mode, Covariance, Correlation.....	12
• Moments.....	12
• Mode.....	13
• Constant expected return model	13
• Value at Risk	16
• Multi-Asset Constant Expected Return Simulation	18
3. Regression.....	20
• 1D linear regression	20
• Multi-regression	23
• Some generalized regression: logistic regression.....	24
4. Limiting Theorem	25
• LLN	25

• CLT	26
5. Monte Carlo simulation & Resampling(w/o replace), Bootstrapping(w/ replace), permutation test, cross validation	26
• Bootstrapping	26
• Permutation Table	27
• Cross validation, K-fold (no replacement)	27
6. Standard errors of estimates, Bootstrapping standard errors	27
• Boot package	28
7. Hypothesis testing, confidence interval	31
• Binomial Confidence interval	31
• Poisson Confidence interval	31
• T-Test	31
• Power	32
8. Experimental design, inferential statistics	32
• Maximum Likelihood, entropy: $S = p \ln p$	32
• Multivariable Likelihood function -> maximize log normal	32
• Test proportion of success (z-test)	34
• test normality	34
• Test Correlation, and autocorrelation	36
• Test independency: chi-squared test, fisher's (non-parametric)	36
• Test population mean (1 sample)	37
• Test 2 samples mean	37
• Test 2 samples mean	38
• Test >2 samples mean	39
• Test >2 samples mean	40
Time Series Analysis	41
9. Stationarity, seasonality	41
• Unit root test: augmented Dickey–Fuller test.	41
• Rolling Means; Rolling Sd; Rolling Cov / Cor	42
10. Autocorrelation	44
• Unit Test	44
• Durbin Watson test	44
• Autocorrelation function (ACF)	45

•	Partial autocorrelation function (PACF)	45
11.	Multi-Time Series: Vector Autoregressive (VAR) model	47
•	Macroeconomic model	47
12.	Forecasting models & smoothing.....	51
•	Simple moving average.....	51
•	moving average process	51
•	Autoregressive process.....	53
•	ARIMA Model Seclection	55
•	ARMA forecast	56
•	Exponential Smoothing: Holt Winters	57
•	Exponential Smoothing: Holt Winters with trend (double exponential).....	59
•	Kalman Filter.....	61
13.	Volatility.....	62
•	ARCH.....	62
•	GARCH.....	62
	Portfolio theory & Risk Management.....	65
14.	Markowitz algorithm.....	65
•	Portfolio Frontier.....	65
•	Efficient Portfolio.....	66
15.	Single Index Factor (Sharpe Model) & CAPM.....	67
•	Beta.....	67
•	Well Diversification	67
16.	Advanced Methods for Risk Analysis & Portfolio Optimization	67
•	Random Matrix Theory	67
•	Dynamic Programming (Merton Model)	67
	Derivatives Pricing (Sell Side).....	67
17.	Types of derivatives, Binomial Tree, B-S Equation	67
•	Contingent Claims (Hull Ch 8-10)	67
•	Interest Derivatives (Hull Ch 4, 7, 26-30).....	68
•	Credit Derivatives (Hull Ch 20,21)	68
•	Binomial, trinomial Tree (Hull Ch11).....	68
•	Stochastic Process	69
•	Geometric random walk, Ito lemma (Hull Ch 12)	70

•	Black–Scholes (Hull Ch13).....	70
•	Ornstein-Uhlenbeck Process – Vasicek interest rate model—mean reversion	70
•	Cox–Ingersoll–Ross (CIR) model—short rate model—mean reversion – positive rate	71
•	Jump diffusion Process.....	71
18.	Implied Volatility, Greeks (Hull Ch 15-16, 19)	71
19.	European option - vanilla (Hull Ch 14).....	71
20.	Exotic - path dependent.....	72
•	Asian option	72
•	Double Barrier Option.....	73
•	Lookback Option.....	73
21.	Variance Reduction Techniques.....	73
•	Antithetic Variates.....	73
•	Control Variates	73
•	Stratified Sampling.....	74
•	Importance Sampling	74
22.	Quasi-Monte Carlo Method	75
•	Low Discrepancy Sequences.....	75
23.	America & Bermudian Options.....	75
•	Explicit Finite Difference Method (forward in time).....	76
•	Implicit Finite Difference Method	76
•	Crank–Nicolson Finite Difference Method.....	76
•	Successive Over-Relaxation (SOR)	77
•	Parallel LU algorithms of computing band matrices (tridiagonal matrix)	77
	(Algorithmic) Stock/ETF Option Trading (Buy Side).....	77
24.	Chat Readings	78
•	Chat Patterns	78
•	Bar Pattern.....	78
•	4 types of indicators	79
•	Elliott wave(fibonacci), Daylight (use Golden Ratio), Neural Network Trading Strategy	80
•	News Sentiment.....	80
25.	On-line trading: Quantopian open, interactive Brokers, TDAmeritrade, MetaTrader, Forex	80
26.	Common Trading Algorithms	80

27.	Data Set	86
28.	Options Trading Strategies.....	86
	Reference	87
29.	Books.....	87
30.	Courses	87
31.	On-line Course	87
32.	Data	88
33.	Competition & Conference	88

Statistics

1. Distributions

- Random Uniform

linear congruential generator

$$X_{n+1} = (aX_n + c) \bmod m$$

Park-Miller pseudo-random number generator is a typical choose of a, c, m

See Mark Joshi ParkMiller.cpp

How C/C++ generates $U(0,1)$?

GNU C Library source:

https://sourceware.org/git/?p=glibc.git;a=blob_plain;f=stdlib/rand_r.c;hb=HEAD

```
int rand_r(unsigned int *seed)
{
    unsigned int next = *seed;
    int result;

    next *= 1103515245;
    next += 12345;
    result = (unsigned int)(next / 65536) % 2048;

    next *= 1103515245;
    next += 12345;
    result <= 10;
    result ^= (unsigned int)(next / 65536) % 1024;

    next *= 1103515245;
    next += 12345;
```

```

    result <= 10;
    result ^= (unsigned int)(next / 65536) % 1024;

    *seed = next;

    return result;
}

```

How R generates $U(a, b)$?

-R

`runif(10)` #between a=0, b=1 with var = (b-a)^2/12 'r' stands for random

[R source code wrap in C: https://github.com/wch/r-source/blob/e5b21d0397c607883ff25cca379687b86933d730/src/nmath/standalone/sunif.c](https://github.com/wch/r-source/blob/e5b21d0397c607883ff25cca379687b86933d730/src/nmath/standalone/sunif.c)

```

double runif(double a, double b)
{
    double u;
    do { u = unif_rand(); } while (u <= 0 || u >= 1);
    return a + (b - a) * u;
}

/* A version of Marsaglia-MultiCarry */
static unsigned int I1 = 1234, I2 = 5678;

void set_seed(unsigned int i1, unsigned int i2)
{
    I1 = i1; I2 = i2;
}

void get_seed(unsigned int *i1, unsigned int *i2)
{
    *i1 = I1; *i2 = I2;
}

double unif_rand(void)
{
    I1 = 36969 * (I1 & 0177777) + (I1 >> 16); //I1*2^-16
    I2 = 18000 * (I2 & 0177777) + (I2 >> 16);
    return ((I1 << 16) ^ (I2 & 0177777)) * 2.328306437080797e-10; //XOR
    /* [0,1) */
}

```

- Binomial

#prob of flipping n=10 coins and getting exact k=5 heads, given p=0.5

```

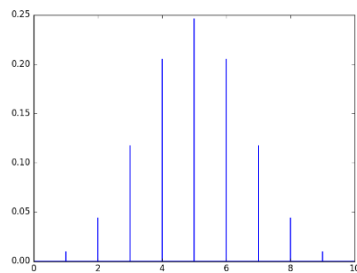
pbinom(5,size = 10, prob = .5, lower.tail = TRUE)-pbinom(4,size = 10,
prob = .5, lower.tail = TRUE)

#' mean = np
#' var = np(1-p)

import numpy as np
from scipy.stats import binom
import matplotlib.pyplot as plt

n, p = 10, 0.5
x = np.arange(0, 10, 0.001)
plt.plot(x, binom.pmf(x, n,p))
plt.show()

```



- Normal

Generate Normal—Box-Muller

$$z_0 = \sqrt{-2 \ln U_1} \cos(2\pi U_2) = \sqrt{-2 \ln s} \left(\frac{u}{\sqrt{s}} \right) = u \sqrt{\frac{-2 \ln s}{s}}$$

Where $U_{1,2}$ are $U(0,1)$, and $u, v = 2U_{1,2} - 1, s = u^2 + v^2$

See Mark Joshi Random1.cpp

Use polynomial approximation to c.d.f. and its inverse (Hastings) to get random normal number

See Mark Joshi Normal.cpp

Or use [C++ gsl library](https://www.gnu.org/software/gsl/manual/html_node/The-Gaussian-Distribution.html) for handling Gaussian stuff

https://www.gnu.org/software/gsl/manual/html_node/The-Gaussian-Distribution.html

It uses Ziggurat Algorithm.

```

x <- rnorm (100)

#' mean = 0
#' var = 1

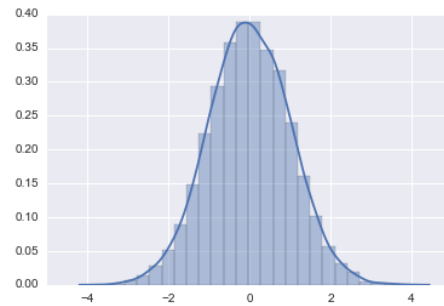
summary(x)

pnorm(1.69) #Pr=P(x<1.69) = 95.4486%, 'p' stands for p-value

```

```
import numpy as np
import seaborn as sns

vals = np.random.randn(10000)
sns.distplot(vals, bins=25)
```



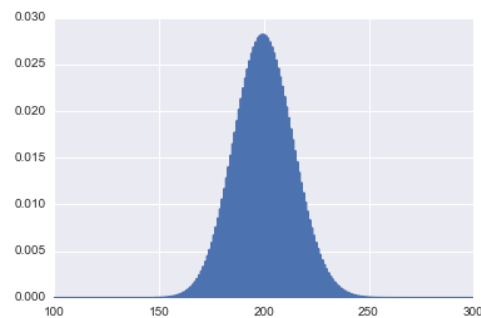
- Poisson
Let binomial let $n \rightarrow \infty$, application in contingency table

```
#mean = var = Lambda

#say during one hour window an event happens
#200 times on average, what is the prob of that
#event happens for exactly 190 times
ppois(190, lambda = 200, lower.tail = TRUE) - ppois(189, lambda =
200, lower.tail = TRUE)

import numpy as np
from scipy.stats import poisson
import matplotlib.pyplot as plt

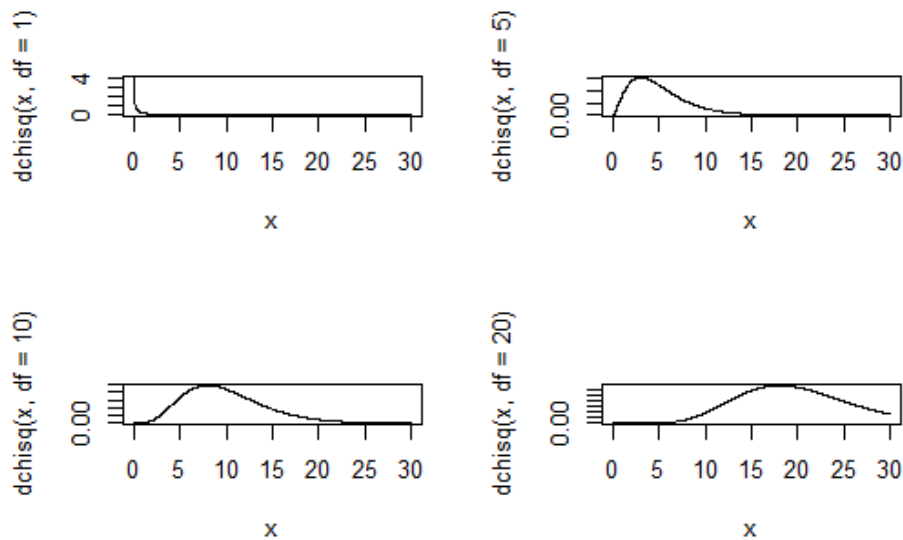
mu = 200
x = np.arange(100, 300, 0.5)
plt.plot(x, poisson.pmf(x, mu))
```



- Chi-square
 $Z_{1,2,3}, \dots$ in iid $N(0,1)$, then $Z_1^2 + \dots + Z_k^2 \sim \chi^2(k), k = \text{d.f.}$

$$E(Z_1^2 + \dots + Z_k^2) = k, \chi^2(k) \rightarrow \text{normal as } k \rightarrow \text{inf}$$

```
x <- seq(0, 30, 0.01)
par(mfrow=c(2,2))
plot(x, dchisq(x, df=1), type="l")
plot(x, dchisq(x, df=5), type="l")
plot(x, dchisq(x, df=10), type="l")
plot(x, dchisq(x, df=20), type="l")
```



- Student's T

$Z \sim N(0,1), X \sim \chi^2(k)$, then

$T := \frac{Z}{\sqrt{\frac{X}{k}}}$ is T-distribution with d.f. = k

$$E(T) = 0$$

$$\text{Shew}(T) = 0$$

$$\text{Kurt}(T) = (3k - 6)/(k - 4), \text{ for } k > 4$$

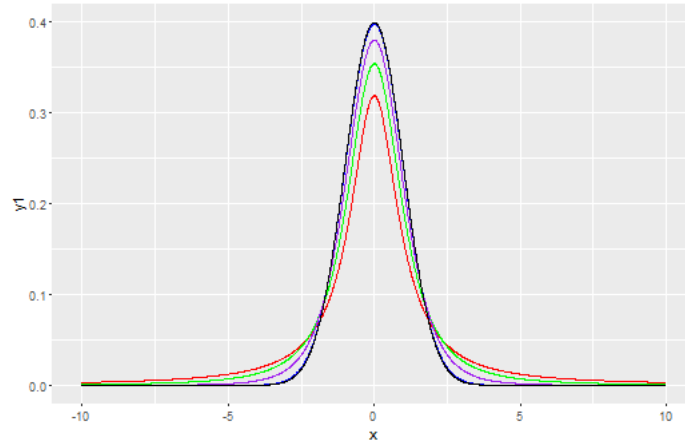
$T \rightarrow N(0,1)$ as $k \rightarrow \text{inf}$, effective-inf when $k > 60$

```
x <- seq(-10, 10, 0.01)
y1 <- dt(x, df=1)
y2 <- dt(x, df=2)
y3 <- dt(x, df=5)
y4 <- dt(x, df=60)
y.norm <- dnorm(x)

df <- data.frame(x,y1,y2,y3,y4,y.norm)

library(ggplot2)
ggplot(df, aes(x)) +
```

```
geom_line(aes(y=y1), colour="red") +
geom_line(aes(y=y2), colour="green") +
geom_line(aes(y=y3), colour="purple") +
geom_line(aes(y=y4), colour="blue") +
geom_line(aes(y=y.norm), colour="black")
```



- F

$$X \sim \chi^2(m), Y \sim \chi^2(n), \text{ then } (X/m) / (Y/n) \sim F(m, n)$$

- Show stock return close to normal rv

```
library(PerformanceAnalytics)
library(tseries)
library(zoo)

end = Sys.Date()
d<- as.POSIXlt(as.Date(end))
d$year <- d$year - 10
start = as.Date(d)
par(mfrow=c(1,1))
#monthly adj closed price 10 year
MSFT.prices = get.hist.quote(instrument="msft", start=start,
                             end=end, quote="AdjClose",
                             provider="yahoo", origin="1970-01-01",
                             compression="m", retclass="zoo")

plot(MSFT.prices,main="Monthly closing price of MSFT",
     ylab="Price", lwd=2, col="blue")
MSFT = diff(log(MSFT.prices))
plot(MSFT, plot.type="single", col="red",
     main="Monthly cc returns on MSFT ", lwd=2)
abline(h=0)
#we will show log return not the usual return close to random normal

set.seed(1)
gwn = rnorm(length(MSFT),mean=mean(MSFT),sd=sd(MSFT))
par(mfrow=c(1,2))
plot(MSFT,main="Monthly cc returns on MSFT", lwd=2, col="blue")
```

```

abline(h=0)
ts.plot(gwn,main="Random Normal with the same mean, sd", lwd=2, col="blue")
abline(h=0)

# histogram compare
par(mfrow=c(1,2))
hist(MSFT,main = "MSFT monthly returns",
     probability=TRUE, col="slateblue1")
hist(gwn, main="random normal data", col="slateblue1")

par(mfrow=c(1,1))
# compare empirical cdf to standard normal cdf for MSFT returns
MSFT.mat = coredata(MSFT)
colnames(MSFT.mat) = "MSFT"
rownames(MSFT.mat) = as.character(index(MSFT))
z1 = scale(MSFT.mat)
n1 = length(MSFT.mat)
F.hat = 1:n1/n1
x1 = sort(z1)
y1 = pnorm(x1)

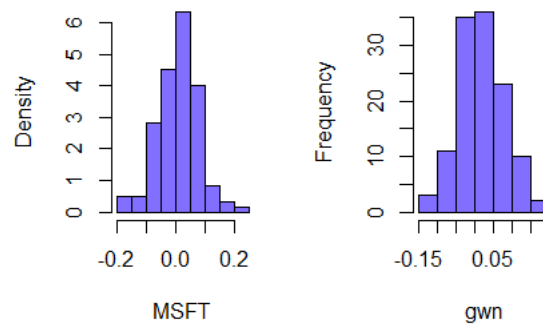
plot(x1,y1,main="Random CDF vs. MSFT CDF",
     type="l",lwd=2,xlab="standardized MSFT returns",ylab="CDF")
points(x1,F.hat, type="s", lty=1, lwd=3, col="orange")
legend(x="topleft",legend=c("Random CDF", "MSFT CDF"),
      lty=c(1,1), lwd=c(2,3), col=c("black","orange"))

```

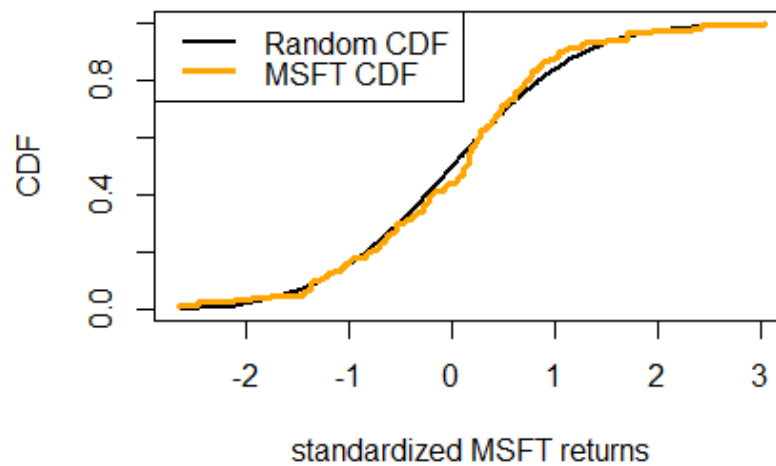
Monthly closing price of MSFT



MSFT monthly return: random normal data



Random CDF vs. MSFT CDF



2. Moments, Mode, Covariance, Correlation

- Moments

mean, variance, skewness, $\sum[(x - \bar{x})^3/\sigma^3]/n - 1$, kurtosis $\sum[(x - \bar{x})^4/\sigma^4]/n - 1$

```
import numpy as np
import scipy.stats as sp
import matplotlib.pyplot as plt

vals = np.random.randint(0, 100, 10000)
plt.hist(vals, 50)
plt.show()

np.mean(vals)
np.var(vals)
sp.skew(vals)
sp.kurtosis(vals)

from scipy import stats
stats.mode(vals)
```

- Mode

```
from scipy import stats
stats.mode(vals)
```

- Constant expected return model

Retrieve 4 stocks : Open, High, Low, Close, Volume, Adj Close

The following code taken from <https://nbviewer.ipython.org/github/jimportilla/Udemy-notes/blob/master/Data%20Project%20-%20Stock%20Market%20Analysis.ipynb>

```
import numpy as np
import pandas as pd
from pandas import Series, DataFrame
from datetime import datetime
import pandas_datareader.data as web
import matplotlib.pyplot as plt
import seaborn as sns
sns.set_style('whitegrid')

#Barron's Stock Picks for 3/28/2016
barron_list = ['IGT', 'IPG', 'ZBH', 'RELY']

end = datetime.now()
start = datetime(end.year - 1, end.month, end.day)

for stock in barron_list:
    globals()[stock]=web.DataReader(stock, 'yahoo', start, end)

IGT['Adj Close'].plot(legend=True, figsize=(10,4),
    title="International Game Technology PLC(IGT) Adjusted Closing Price ")
```



- Plot moving average

```
ma_day = [10,20,50] #simple moving average

for ma in ma_day:
    column_name = 'Ma for %d days' %((ma))
    IGT[column_name] = pd.rolling_mean(IGT['Adj Close'], ma)

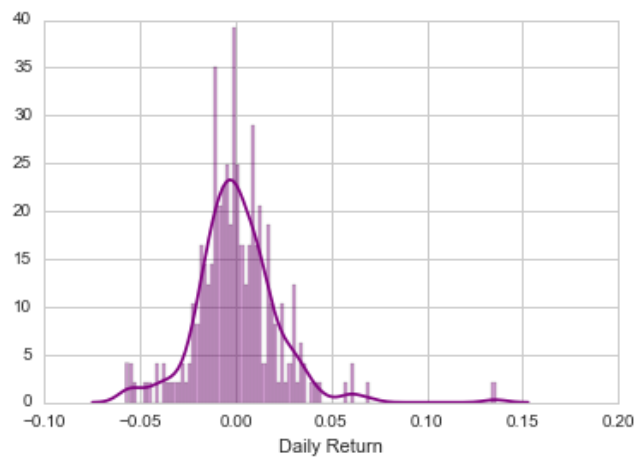
IGT[['Adj Close', 'Ma for 10 days',
```

```
'Ma for 20 days', 'Ma for 50 days']].plot(subplots = False
, title="International Game Technology PLC (IGT) Moving Average")
```



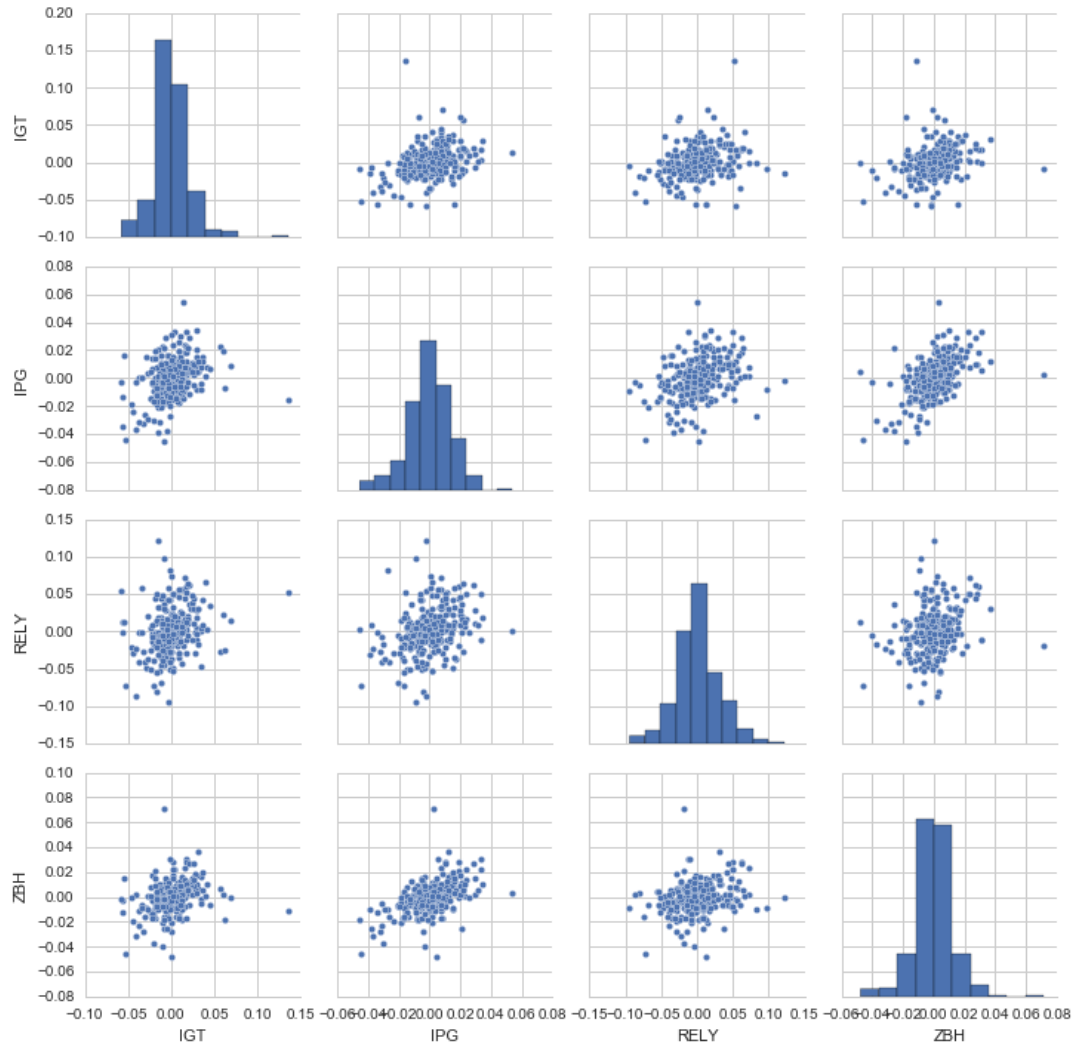
- Return histogram

```
IGT['Daily Return'] = IGT['Adj Close'].pct_change()
sns.distplot(IGT['Daily Return'].dropna(), bins =100, color = 'purple')
```



- Correlation of the 4 stocks returns

```
closeing_df = web.DataReader(barron_list, 'yahoo', start, end)['Adj Close']
barron_rets = closeing_df.pct_change()
sns.pairplot(barron_rets.dropna())
```

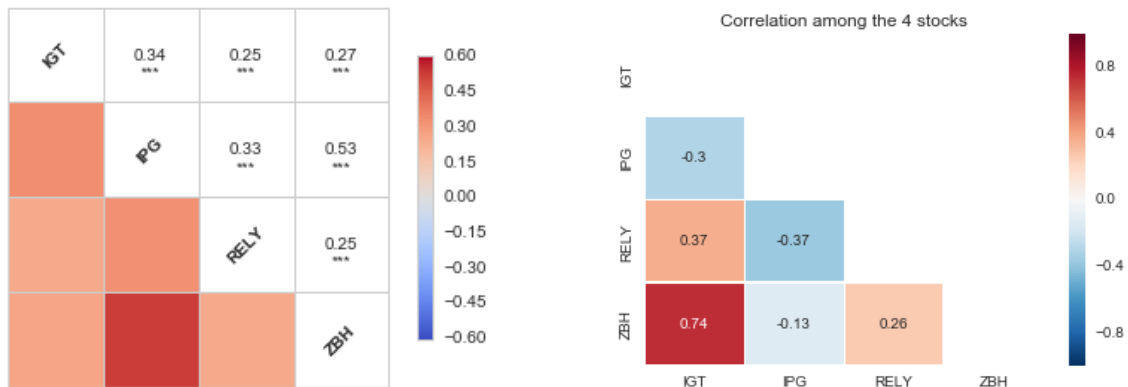


- Correlation plot

```
sns.corrplot(barron_rets.dropna(), annot=True)
```

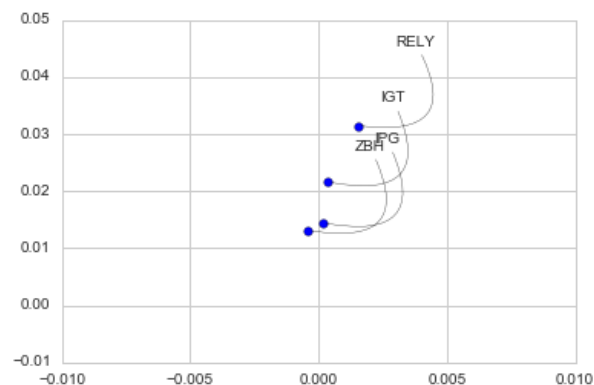
or

```
corr = closing_df.corr()
mask = np.zeros_like(corr, dtype=np.bool)
mask[np.triu_indices_from(mask)] = True
sns.heatmap(corr.dropna(), mask = mask, linewidths=.2, annot=True)
plt.title('Correlation among the 4 stocks')
```



- Risk return comparison among the portfolio

```
rets=barron_rets.dropna()
area = np.pi*10
plt.scatter(rets.mean(), rets.std(), s= area)
for label, x, y in zip(rets.columns, rets.mean(), rets.std()):
    plt.annotate(
        label,
        xy = (x, y), xytext = (50, 50),
        textcoords = 'offset points', ha = 'right', va = 'bottom',
        arrowprops = dict(arrowstyle = '-', connectionstyle = 'arc3,rad=-1.0'))
```



- Value at Risk
Bootstrap way—gives 3.33%

```
barron_rets['IGT'].quantile(0.05)
#-0.033358568359280846
#showing based on past one year performance, there is 5% chance
#of losing 3.33% or more on a single day.
```

- Value at Risk – Monte Carlo way (using geometric random walk) —gives 3.47%

```
steps = 1000
dt = 1/steps
mu = barron_rets.mean()['IGT']
sigma = barron_rets.std()['IGT']

def stock_monte_carlo(start, steps, mu, sigma):
    price = np.zeros(steps)
```



```

price[0] = start_price

stock = np.zeros(steps)
drift = np.zeros(steps)

for x in range(1, steps):
    stock[x] = np.random.normal(loc = mu*dt, scale = sigma * np.sqrt(dt))
    drift[x] = mu * dt
    price[x] = price[x-1] + (price[x-1] * (drift[x]+stock[x]))

return price

start_price = closeing_df['IGT'][0]
for run in range(100):
    plt.plot(stock_monte_carlo(start_price, steps, mu, sigma))

plt.ylabel('price')
plt.xlabel('monte carlo step')
plt.show()

runs = 10000
simulation = np.zeros(runs)

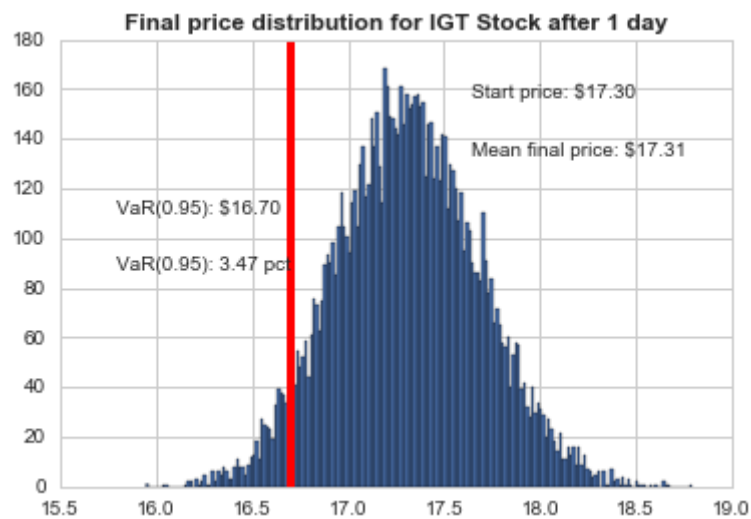
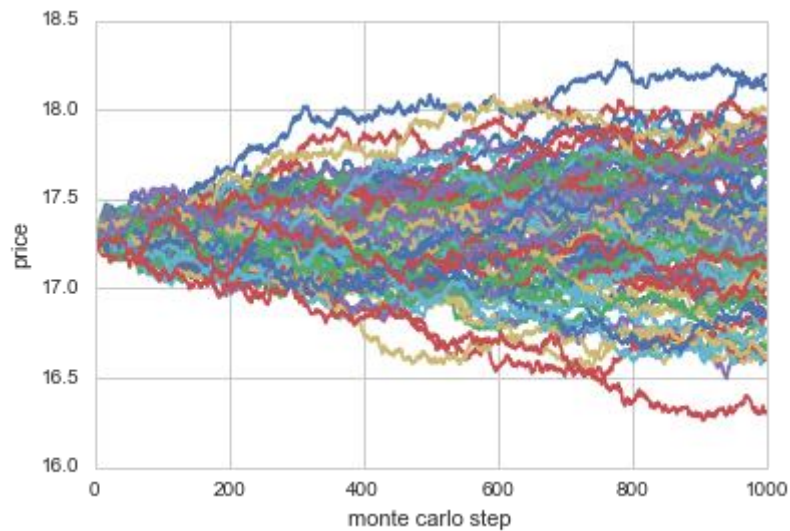
for run in range(runs):
    simulation[run] = stock_monte_carlo(start_price, steps, mu, sigma)[steps-1]
q = np.percentile(simulation, 5)
plt.hist(simulation, bins= 200)
plt.figtext(0.6, 0.8, s="Start price: $%.2f" %start_price)
plt.figtext(0.6, 0.7, "Mean final price: $%.2f" % simulation.mean())

# Display 5% quantile
plt.figtext(0.19, 0.6, "VaR(0.95): $%.2f" % q)
qq = (start_price-q)/start_price * 100
plt.figtext(0.19, 0.5, "VaR(0.95): %.2f pct" % qq)
plt.axvline(x=q, linewidth=4, color='r')
plt.title(u"Final price distribution for IGT Stock after 1 day", weight='bold');

```

In the code we put “scale = sigma * np.sqrt(dt)” in the grw is to match this $se(\hat{\mu}_i) = SD(\hat{\mu}_i) = \sigma_i/\sqrt{T}$ where T = time step in the example

$se(\text{value at risk}) = \text{variance}(\exp(\text{quantile_estimate}) - 1)$ see standard error of estimate and bootstrapping error



- Multi-Asset Constant Expected Return Simulation

Assume: normal and covariance stationary ($\mu_i, \sigma_i, \sigma_{ij}$ are all constant over time, white noise are uncorrelated over time)

```
library(PerformanceAnalytics)
library(tseries)
library(zoo)

end = Sys.Date()
d<- as.POSIXlt(as.Date(end))
d$year <- d$year - 10
start = as.Date(d)
par(mfrow=c(1,1))
#monthly adj closed price 10 year
MSFT.prices = get.hist.quote(instrument="MSFT", start=start,
                             end=end, quote="AdjClose",
```

```

        provider="yahoo", origin="1970-01-01",
        compression="m", retclass="zoo")

AMZN.prices = get.hist.quote(instrument="AMZN", start=start,
                             end=end, quote="AdjClose",
                             provider="yahoo", origin="1970-01-01",
                             compression="m", retclass="zoo")

GOOG.prices = get.hist.quote(instrument="GOOG", start=start,
                             end=end, quote="AdjClose",
                             provider="yahoo", origin="1970-01-01",
                             compression="m", retclass="zoo")

MSFT = diff(log(MSFT.prices))
AMZN = diff(log(AMZN.prices))
GOOG = diff(log(GOOG.prices))

totReturn = merge(merge(MSFT, AMZN), GOOG)
index(totReturn)=as.yearmon(index(totReturn))
colnames(totReturn) = c("MSFT", "AMZN", "GOOG")

pairs(totReturn, col="blue")

mu = apply(totReturn, 2, mean)
sigma_ij2 = cov(totReturn)
#      MSFT      AMZN      GOOG
# MSFT 0.004990 0.002814 0.003070
# AMZN 0.002814 0.011459 0.004610
# GOOG 0.003070 0.004610 0.007151

#simulate stocks returns 100 times
library(mvtnorm)
nobs = 100
set.seed(123)
returns.sim = rmvnorm(nobs, mean=mu, sigma=sigma_ij2)
colnames(returns.sim) = c("MSFT", "AMZN", "GOOG")

cov(returns.sim)
#      MSFT      AMZN      GOOG
# MSFT 0.003678 0.002384 0.002232
# AMZN 0.002384 0.010101 0.003727
# GOOG 0.002232 0.003727 0.006764

weight <- matrix(c(.3,.3,.4), ncol = 1)

port.var = t(weight)%*%sigma_ij2%*%weight; port.var
#0.004974368 the var is smaller than any of the stock alone
diag(sigma_ij2)
#      MSFT      AMZN      GOOG
#0.004990020 0.011458789 0.007151222

```

To generate correlated normal random variables above, `r` has `rmvnorm(n, sigma)`, which uses one of the 3 methods:

Eigen:

```
ev <- eigen(sigma, symmetric = TRUE)
t(ev$vectors %*% (t(ev$vectors) * sqrt(ev$values))) %*% matrix(rnorm(n *
ncol(sigma)), n)
```

Svd:

```
s <- svd(sigma)
t(s$v %*% (t(s$u) * sqrt(s$d))) %*% matrix(rnorm(n * ncol(sigma)), n)
```

Cholesky decomposition:

$$\sigma = t(U)D(U) = t(R)(R),$$

where U = upper triangular, D = diagonal, $R = \text{sqrt}(D)U$

```
R <- chol(sigma, pivot = TRUE) #use pivot, b/c sigma is positive-definite
t(R[, order(attr(R, "pivot"))] ) %*% matrix(rnorm(n * ncol(sigma)), n)
```

3. Regression

- 1D linear regression

```
library(UsingR); data(galton) #predict son's height from father's
y<-galton$child
x<-galton$parent
length(x) #928

fit<-lm(y~x)
coef(fit)
#which is given by
beta <- cor(y,x)* sd(y) / sd(x)
alpha <- mean(y) - beta * mean(x)

#residual
e_hat<-resid(fit)
y_hat<-predict(fit)
ssx <- sum((x-mean(x))^2)

#standard error of estimate
sse<-sqrt(sum(e_hat^2)/(length(e_hat)-2))
#2.238547
#or
summary(fit)$sigma

#Standard Error of slope: sqrt(var(beta))
se_beta <- sse / sqrt(ssx)
#t_statistics of slope
t_beta <- beta / se_beta
```

```

p_beta <- 2 * pt(abs(t_beta),df = n-2, lower.tail = F)

#Standard Error of intersect: sqrt(var(alpha))
se_alpha <- sse * sqrt(1/n + mean(x)^2 / ssx)
#t_statistics of intersect
t_alpha <- alpha / se_alpha
p_alpha <- 2 * pt(abs(t_alpha),df = n-2, lower.tail = F)

#or just
summary(fit)$coefficients

#summary(fit) complete output
#'Call:
#lm(formula = y ~ x)
#
#'Residuals:
#      Min       1Q   Median       3Q      Max
# -7.8050 -1.3661  0.0487  1.6339  5.9264
#
#'Coefficients:
#              Estimate Std. Error t value Pr(>|t|)
#(Intercept)  23.94153    2.81088   8.517  <2e-16 ***
#x              0.64629    0.04114  15.711  <2e-16 ***
#---
#'Signif. codes:
# 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
#
#'Residual standard error: 2.239 on 926 degrees of freedom
#'Multiple R-squared:  0.2105, Adjusted R-squared:  0.2096
#'F-statistic: 246.8 on 1 (deg of MSSR) and 926 (deg of MSSE)
#'p-value: < 2.2e-16

layout(matrix((c(1,2,3,4)),2))
plot(fit)

fit.influence<- influence.measures(fit)
names(fit.influence)
head(fit.influence$infmat)
par(mfrow=c(1,1))
plot(x,y)
abline(fit,col=2)

newdata=seq(min(x), max(x), 0.01)
prd.interval<-predict(fit, newdata = data.frame(x=newdata), interval =
c("confidence"), level = .9, type="response")
lines(newdata, prd.interval[,2], col = 4) #lower est
lines(newdata, prd.interval[,3], col = 4) #upper est

fit.biggy <- which(fit.influence$is.inf[, "hat"]==T)
points(x[fit.biggy],y[fit.biggy], col=2) #high leverage points

fit.badguy <- which(fit.influence$is.inf[, "cook.d"]==T)

```

```

points(x[fit.badguy],y[fit.badguy], pch="X", col=4) #high cook distance --
outlier

anova(fit)
# Analysis of Variance Table
# Response: y
#           Df Sum Sq Mean Sq F value    Pr(>F)
# x           1 1236.9  1236.93   246.84 < 2.2e-16 ***
# Residuals 926 4640.3     5.01
# ---
# Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

#Total variation = residual variation + regression variation
#sum(Y_i - Y_bar)^2 = sum(Y_i - Y_hat)^2 + sum(Y_hat - Y_bar)^2

#Coefficient of Determination
#R-squared = regression variation(SSR) / Total variation(SST=SSR+SSE) = r^2
#Adjusted R-squared = 1 - (n-1)/(n-2)*(1-R-squared)

#F-statistics
#F = mean regression sum of squares (MSSR) / mean squared error (MSSE)
#   = (slope of t-statistics )^2

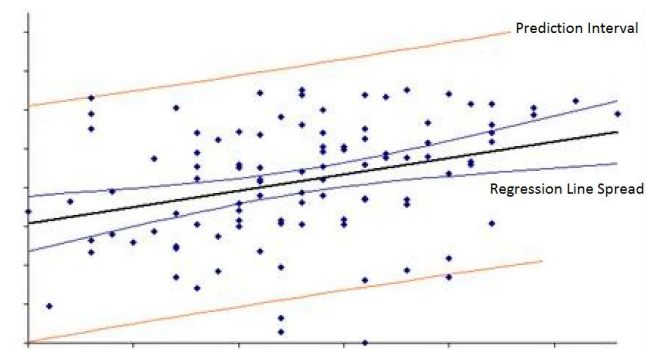
#t-statistics of the slope
#t = r * sqrt(n-2) / sqrt(1-r^2)

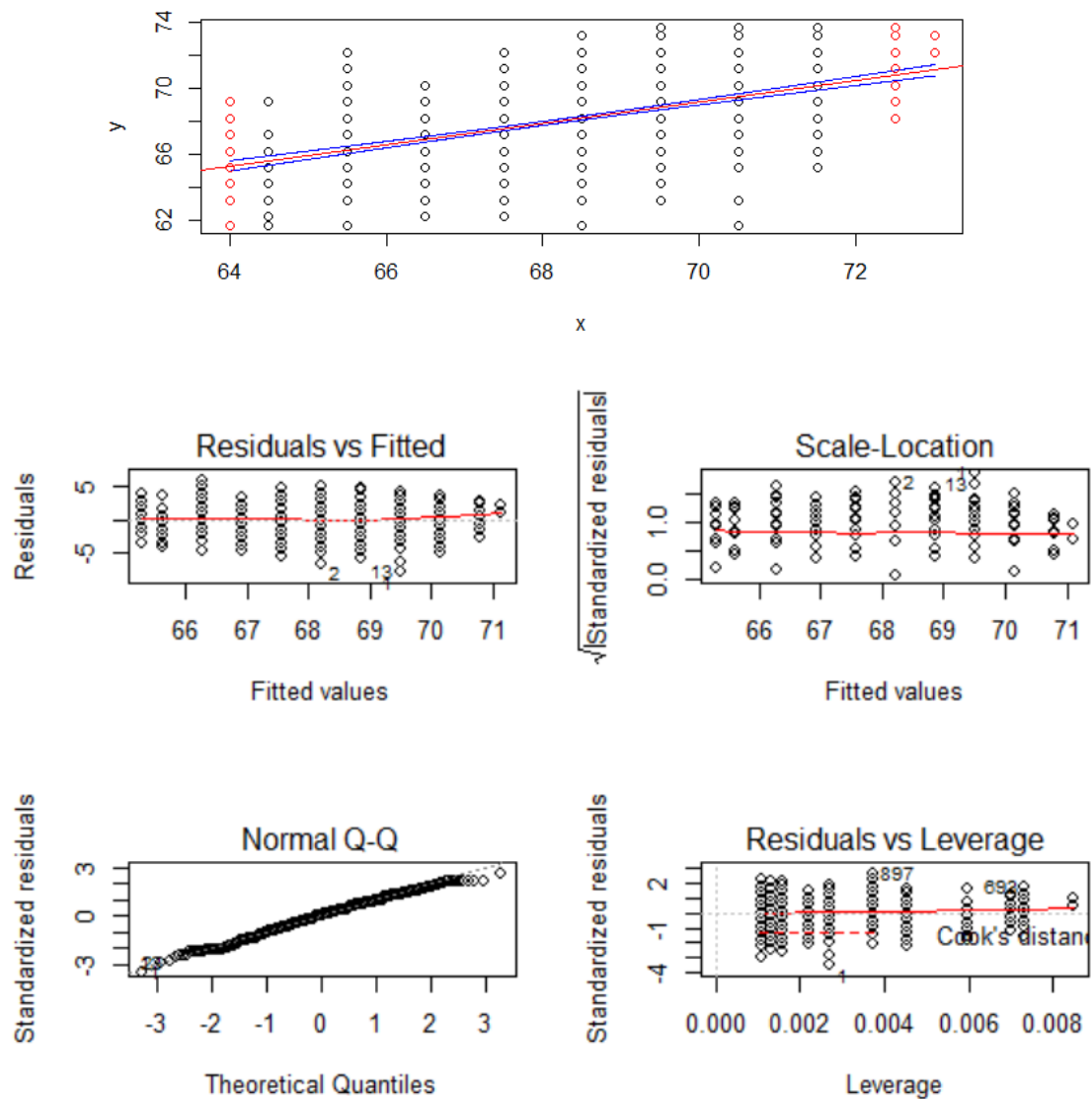
#Standard Error of Coef
#var(beta) = standerErrorOfEstimate ^2 / sum(X_i - X_bar)^2
#var(alpha) = standerErrorOfEstimate ^2 * (1/n + X_bar^2 / sum(X_i - X_bar)^2 )

#Standard Error of Prediction (prediction interval at X)
#   standerErrorOfEstimate * sqrt(1 + 1/n + (X - X_bar)^2 / sum(X_i - X_bar)^2
# )

#Standard Error of Regression Line (regression line spread at X)
#   standerErrorOfEstimate * sqrt(1/n + (X - X_bar)^2 / sum(X_i - X_bar)^2 )

```





- (a) Residuals vs fitted shows correlation. A flat line is better
- (b) Standardized residual vs fitted show heteroscedasticity. A flat line is good
- (c) $Q = \mu + \sigma \cdot \text{quantile}$. So slope is std error. This detects flat tail
- (d) This plot highlights influence of high-leverage cases in deciding the regression line

- Multi-regression

```
attach(mtcars)
model<-lm(mpg~drat+wt)
library(rgl)
plot3d(drat,wt,mpg)

summary(model)

# Call:
# lm(formula = mpg ~ drat + wt)
```

```

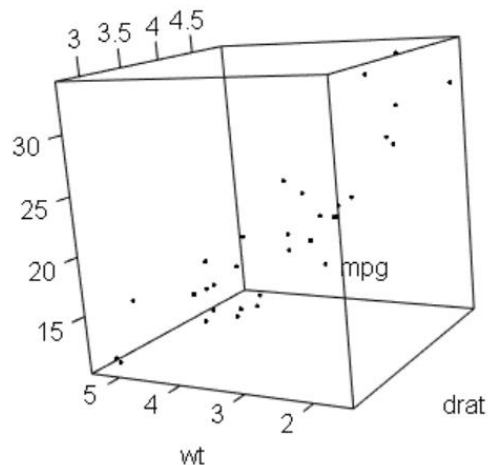
# Residuals:
#      Min       1Q   Median       3Q      Max
# -5.4159 -2.0452  0.0136  1.7704  6.7466
# Coefficients:
#              Estimate Std. Error t value Pr(>|t|)
# (Intercept)   30.290      7.318   4.139 0.000274 ***
# drat          1.442      1.459   0.989 0.330854
# wt           -4.783      0.797  -6.001 1.59e-06 ***
# ---
# Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
# Residual standard error: 3.047 on 29 degrees of freedom
# Multiple R-squared:  0.7609, Adjusted R-squared:  0.7444
# F-statistic: 46.14 on 2 and 29 DF,  p-value: 9.761e-10

confint(model)
#              2.5 %    97.5 %
# (Intercept) 15.323629 45.257112
# drat        -1.540615  4.425596
# wt          -6.413010 -3.152770

anova(model)
# Analysis of Variance Table
# Response: mpg
#      # Df Sum Sq Mean Sq F value    Pr(>F)
# drat    1  522.48   522.48   56.276 2.871e-08 ***
# wt      1  334.33   334.33   36.010 1.589e-06 ***
# Residuals 29  269.24     9.28
# ---
# Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

# more is fun
lm(mpg~drat+I(wt^2)+wt)

```



- Some generalized regression: logistic regression

```

attach(mtcars)
model<-glm(am~wt, family = "binomial") #need to convert numeric am to factor

```



```

types of family
binomial(link = "logit")
gaussian(link = "identity")
Gamma(link = "inverse")
inverse.gaussian(link = "1/mu^2")
poisson(link = "log")
quasi(link = "identity", variance = "constant")
quasibinomial(link = "logit")
quasipoisson(link = "log")

summary(model)
# Call:
# glm(formula = am ~ wt, family = "binomial")
#
# Deviance Residuals:
#      Min       1Q   Median       3Q      Max
# -2.11400  -0.53738  -0.08811   0.26055   2.19931
#
# Coefficients:
#              Estimate Std. Error z value Pr(>|z|)
# (Intercept)   12.040      4.510   2.670  0.00759 **
# wt            -4.024      1.436  -2.801  0.00509 **
# ---
# Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
# (Dispersion parameter for binomial family taken to be 1)
#    Null deviance: 43.230  on 31  degrees of freedom
# Residual deviance: 19.176  on 30  degrees of freedom
# AIC: 23.176
#
# Number of Fisher Scoring iterations: 6

predict(model, newdata = data.frame(wt=1.500), type = "response")
#1
#0.9975382 -> predict to be auto transmission with 99.75% prob

```

4. Limiting Theorem

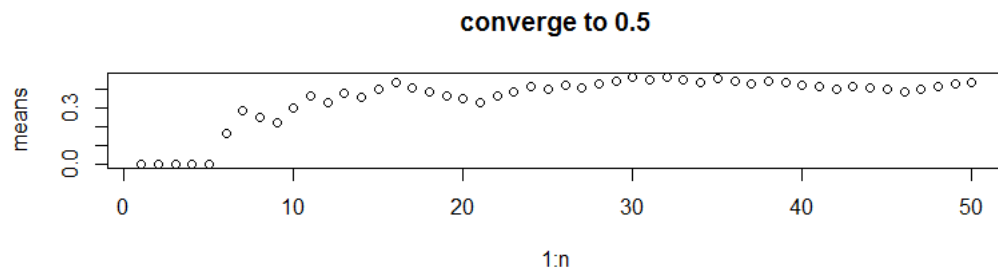
- LLN

—mean converges to sample mean

```

n <- 50
means <- cumsum(sample(0:1,n, replace = T))/(1:n)
plot(1:n,means)
title("converge to 0.5")

```

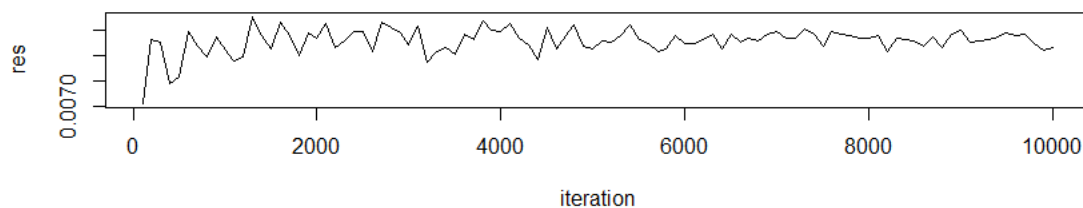


- CLT

—sample mean is normal disturbed with var/n (n =sample size, var =population variance). If the population var is replaced by sample variance, it is t-distributed.

```
iteration<-seq(100,10000,100)
n<-10
res<-lapply(iteration, function(x)
var(apply(matrix(runif(x*n),x),1,mean)))

plot(iteration, res, 'l') #converge to (1/12)/10 = 0.008333333
```



5. Monte Carlo simulation & Resampling(w/o replace), Bootstrapping(w/ replace), permutation test, cross validation

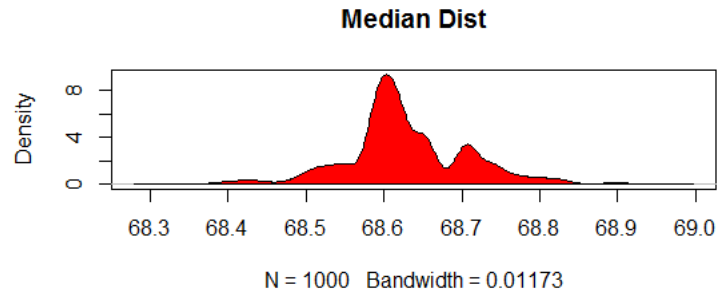
- Bootstrapping

Simulate rv of population without population

```
library(UsingR)
data("father.son")
sonHeight<-father.son$sheight
obser<-length(sonHeight)
bootstrapNo<-1000

resample<-matrix(sample(sonHeight, bootstrapNo*obser, replace = T),
bootstrapNo, obser)
resampleMedian<-apply(resample, 1, median)

d<-density(resampleMedian)
plot(d, main="Median Dist")
polygon(d, col="red")
```



- Permutation Table

```
n <- 100
tr <- rbinom(100, 1, 0.5)
y <- 1 + tr + rnorm(n, 0, 0.3)
diff(by(y, tr, mean))

dist <- replicate(2000, diff(by(y, sample(tr), mean)))
```

- Cross validation, K-fold (no replacement)
large k => less bias, more variance, small k => more bias, less variance, last one out cross validation

```
library(ggplot2)
diamonds<-diamonds[1:500,]
trainDiamond <- sample(dim(diamonds)[1][1], size = 200)
train<-diamonds[trainDiamond,]

#testing-training cross validation
mylm <- lm(data = train, x ~ y + z)
mean((diamonds$x-predict(mylm, diamonds))[-trainDiamond]^2)
#0.002657964

#Leave one out cross validation
myglm <- glm(data = train, x ~ y + z)
library(boot)
cv.glm(data = train, myglm)$delta
#0.002852013(raw) 0.002851553(adjust)

#k-fold cross validation
cv.glm(data = train, myglm,K = 10)$delta
#0.002789518(raw) 0.002783287(adjust)
```

6. Standard errors of estimates, Bootstrapping standard errors

$$Err_{.632} = .368 \cdot \overline{err} + .632 \cdot Err_{boot(1)}, \text{ where } \overline{err} = \frac{1}{N} \sum_i^N L(y_i, f(x_i))$$

$$se(\hat{\mu}_i) = SD(\hat{\mu}_i) = \sigma_i / \sqrt{T}$$

$$se(\hat{\sigma}_i^2) \approx \frac{\sqrt{2}\sigma_i^2}{\sqrt{T}} = \frac{\sigma_i^2}{\sqrt{\frac{T}{2}}}, se(\hat{\sigma}_i) \approx \frac{\sigma_i}{\sqrt{2}\sqrt{T}}, se(\rho_{ij}) \approx \frac{(1 - \rho_{ij}^2)}{\sqrt{T}}$$

for multi-asset random walk simulation.

$$\widehat{SE}_{boot}(\hat{\theta}) = \sqrt{\frac{1}{B-1} \sum_j^B \left(\hat{\theta}_j^* - \frac{1}{B} \sum_j^B \hat{\theta}_j^* \right)^2}$$

Bootstrap confidence interval: $[q_{.025}^*, q_{.975}^*]$

- Boot package

```
library(boot)
library(zoo)

end = Sys.Date()
d<- as.POSIXlt(as.Date(end))
d$year <- d$year - 10
start = as.Date(d)
par(mfrow=c(1,1))
#monthly adj closed price 10 year
MSFT.prices = get.hist.quote(instrument="MSFT", start=start,
                             end=end, quote="AdjClose",
                             provider="yahoo", origin="1970-01-01",
                             compression="m", retclass="zoo")

MSFT = diff(log(MSFT.prices))

# random sample from MSFT return <- brutal force
B = 999
muhat.boot = rep(0, B)
nobs = length(MSFT)
for (i in 1:B) {
  boot.data = sample(MSFT, nobs, replace=TRUE)
  muhat.boot[i] = mean(boot.data)
}

# bootstrap bias
mean(muhat.boot) - mean(MSFT) # 3.269e-05
# bootstrap SE
sd(muhat.boot) # 0.006427
# analytic SE
sd(MSFT)/sqrt(length(MSFT)) # 0.006449

par(mfrow=c(1,2), oma=c(0,0,1.5,0))
hist(muhat.boot, col="slateblue1", breaks=30)
abline(v=mean(MSFT), col="white", lwd=2)
qqnorm(muhat.boot)
qqline(muhat.boot)
title("Boot w/o boot function", outer=TRUE)
```

```
##### use boot #####

##Mean##
mean.boot = function(x, idx) {
  ans = mean(x[idx])
  ans
}

MSFT.mean.boot = boot(MSFT, statistic = mean.boot, R=999)
MSFT.mean.boot
# Bootstrap Statistics :
#   original      bias    std. error
# t1* 0.008874 -1.459e-06   0.006584

plot(MSFT.mean.boot)
title("Boot w/ boot function", outer=TRUE)
boot.ci(MSFT.mean.boot, conf = 0.95, type = c("norm", "perc"))
#BOOTSTRAP CONFIDENCE INTERVAL CALCULATIONS
#Based on 999 bootstrap replicates
# CALL :
# boot.ci(boot.out = MSFT.mean.boot, conf = 0.95, type = c("norm",
#   "perc"))
# Intervals :
# Level      Normal              Percentile
# 95%  (-0.0040,  0.0218 )  (-0.0040,  0.0215 )
# Calculations and Intervals on Original Scale

##sd##
sd.boot = function(x, idx) {
  ans = sd(x[idx])
  ans
}

MSFT.sd.boot = boot(MSFT, statistic = sd.boot, R=999)
MSFT.sd.boot
plot(MSFT.sd.boot)
title("Boot sd", outer=TRUE)
boot.ci(MSFT.sd.boot, conf=0.95, type=c("norm", "basic", "perc"))

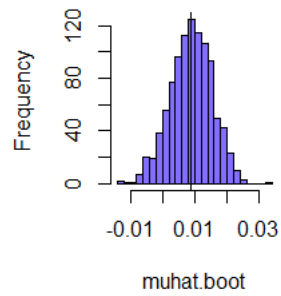
##Value-at-Risk
ValueAtRisk.boot = function(x, idx, p=0.05, w=100000) {
  q = mean(x[idx]) + sd(x[idx])*qnorm(p)
  VaR = (exp(q) - 1)*w
  VaR
}

MSFT.VaR.boot = boot(MSFT, statistic = ValueAtRisk.boot, R=999)
MSFT.VaR.boot
boot.ci(MSFT.VaR.boot, conf=0.95, type=c("norm", "perc"))

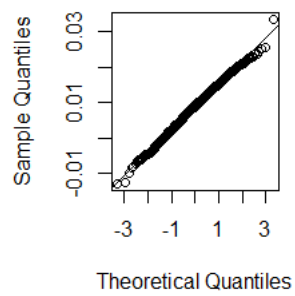
plot(MSFT.VaR.boot)
title("Boot VaR", outer=TRUE)
```

Boot w/o boot function

Histogram of muhat.boc

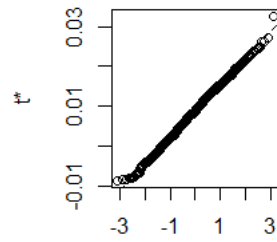
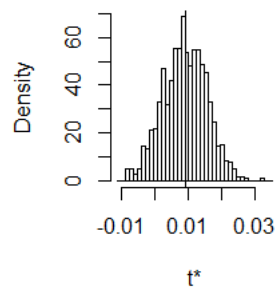


Normal Q-Q Plot



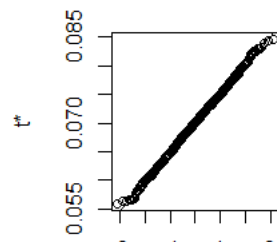
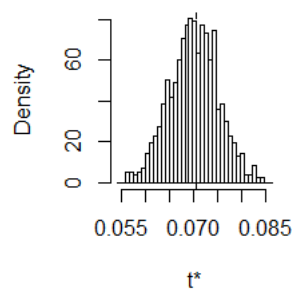
Boot w/ boot function

Histogram of t



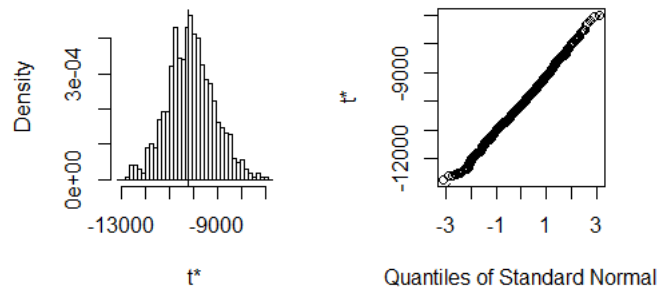
Boot sd

Histogram of t



Boot VaR

Histogram of t



7. Hypothesis testing, confidence interval

- Binomial Confidence interval

```
#95% confidence
binom.test(55,100, p = 0.5)$conf
#0.4472802 0.6496798 <- exact interval of being success

#approx
0.55 + c(-1,1)*qnorm(0.975)*sqrt(.55*.45/100)
#0.452493 0.647507
```

- Poisson Confidence interval

```
#say during one hour window an event happens
#6 times on average. What is the 95% conf inv
#for such event to happen in given 1 min?

poisson.test(6,60, r = 0.1)$conf
#0.03669824 0.21765790 <-exact interval

#approx.
6/60 + c(-1,1)*qnorm(0.975)*sqrt(6/60/60)
#0.01998481 0.18001519
```

- T-Test

```
library(UsingR)
data("father.son")

#null hypothesis: father height == son height
t.test(father.son$sheight-father.son$fheight, mu = 0)

#same as
t.test(father.son$sheight,father.son$fheight,mu = 0, paired = T)

#output
#'t = 11.789, df = 1077, p-value < 2.2e-16
#'alternative hypothesis: true mean is not equal to 0
```

```
#'95 percent confidence interval:
#' 0.8310296 1.1629160 (unit: inch)
#'mean of x : 0.9969728
#'so we conclude son taller than father
```

- Power

$power = P(\text{reject } H_0 | H_1 \text{ is true})$. If population mean (μ_0) is not equal to sample mean (μ), define noncentrality parameter,

$$\delta = \frac{(\mu_0 - \mu)}{\sqrt{n}\sigma}$$

noncentral t distribution.

```
alpha <- 0.05
z <- qnorm(1-alpha)

mu_0 <- 12 #alterntive hypothesis population mean
mu <- 10   #sample mean
sigma <- 5 #population var
n <- 10    #sample size
delta <- (mu_0-mu)/sigma*sqrt(n)

power.t.test(n = n, delta=delta, sd =sigma, type = "one.sample",
alternative = "one.sided")
#or
pt(mu_0-mu,df = n, ncp = delta, lower.tail = FALSE)
```

8. Experimental design, inferential statistics

- Maximum Likelihood, entropy: $S = p \ln p$

```
MaxLik <- function(data) {
  function(para) {
    mu <- para[1]
    sigma <- para[2]
    a <- -length(data)*log(2*pi*sigma^2)/2
    b <- -sum((data-mu)^2)/(sigma^2)/2
    -(a + b)
  }
}

normals <- rnorm(100,1,2)

optim(c(mu = 0, sigma = 1),f=MaxLik(normals))$par
```

- Multivariable Likelihood function -> maximize log normal

```
loglike.normal = function(theta, x) {
```



```

# theta    parameters c(mu,sig2)
# x        vector of data
mu = theta[1]
sig2 = theta[2]
n = length(x)
a1 = -(n/2)*log(2*pi)-(n/2)*log(sig2)
a2 = -1/(2*sig2)
y = (x-mu)^2
ans = a1+a2*sum(y)
# return -1 * loglike because multi optim function only do min
return(-ans)
}

n = 50
set.seed(123)
x = rnorm(n, mean=0, sd=1)
theta.start = c(0,1)
ans = optim(par=theta.start, fn=loglike.normal, x=x,
            method="BFGS")
ans$par
#0.03441726 0.84010990

mean(x) #0.03441726
var(x)*(n-1)/nc #0.84010990

ans = optim(par=theta.start, fn=loglike.normal, x=x,
            method="BFGS", hessian=TRUE)
names(ans)
ans$hessian
se.mle = sqrt(diag(solve(ans$hessian)))
se.mle
#0.1296233 0.1680251

#use the maxLik function
library(maxLik)
loglike.normal = function(theta, x) {
  mu = theta[1]
  sig2 = theta[2]
  n = length(x)
  a1 = -(n/2)*log(2*pi)-(n/2)*log(sig2)
  a2 = -1/(2*sig2)
  y = (x-mu)^2
  ans = a1+a2*sum(y)
  return(ans)
}
theta.start = c(0,1)
names(theta.start) = c("mu", "sig2")
theta.mle = maxLik(loglike.normal, start=theta.start, x=x)
class(theta.mle)
names(theta.mle)
theta.mle
summary(theta.mle)
# Maximum Likelihood estimation
# Newton-Raphson maximisation, 5 iterations
# Return code 1: gradient close to zero

```

```

# Log-Likelihood: -66.59079
# 2 free parameters
# Estimates:
#      Estimate Std. error t value Pr(> t)
# mu      0.0344    0.1296   0.265   0.791
# sig2    0.8401    0.1680   4.999 5.75e-07 ***
# ---
# Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

```

- One can think regress as maximize the likelihood function
 $L(\beta, \sigma) = P(Y | X, \beta, \sigma)$ where σ is the var in the noise

- Test proportion of success (z-test)

```

totalnum = 1000
success = 400

# H_0: P(success) is equal to 0.5
prop.test(x=success, n=totalnum, alternative = "two.side")

# 1-sample proportions test with continuity correction
# data: success out of totalnum, null probability 0.5
# X-squared = 39.601, df = 1, p-value = 3.115e-10 "<- very small p"
# alternative hypothesis: true p is not equal to 0.5
# 95 percent confidence interval:
# 0.3695830 0.4311949
# sample estimates:
# p
# 0.4

#H0: P(success) is less than 0.5
prop.test(x=yes, n=totalnum, alternative = "greater")

```

- test normality

```

leng <- iris$Sepal.Length

jarque.bera.test(leng)
# Jarque Bera Test
#data: leng
#X-squared = 4.4859, df = 2, p-value = 0.1061

$$JB = \frac{n-k+1}{6} \left( S^2 + \frac{1}{4}(C-3)^2 \right)$$
, S = skewness, C = kurtosis
# by hand
leng.skew <- skewness(leng)
leng.esskurt <- kurtosis(leng)
n= length(leng)
n*(leng.skew^2+(leng.esskurt^2)/4)/6

```

```

# 4.486

1-pchisq(4.4859,df=2)
#p-value 0.1061

shapiro.test(leng) #only accept 5000 argument. For large dataset, take a
random subset

# Shapiro-Wilk normality test
# data:  iris$Sepal.Length
# W = 0.97609, p-value = 0.01018

library(nortest)
ad.test(leng)

# Anderson-Darling normality test
# data:  iris$Sepal.Length
# A = 0.8892, p-value = 0.02251

library(nortest)
cvm.test(leng)

# Cramer-von Mises normality test
# data:  leng
# W = 0.1274, p-value = 0.04706

lillie.test(leng)

# Lilliefors (Kolmogorov-Smirnov) normality test
# data:  leng
# D = 0.088654, p-value = 0.005788

sf.test(leng)

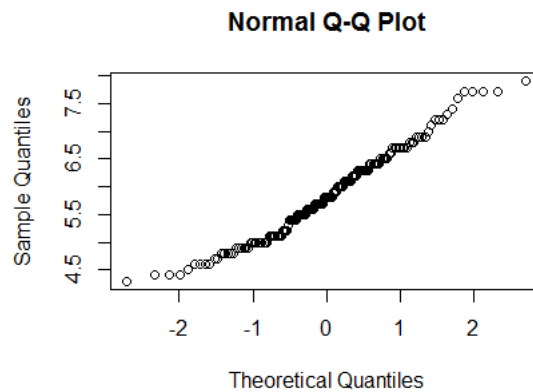
# Shapiro-Francia normality test
# data:  leng
# W = 0.97961, p-value = 0.02621

pearson.test(leng)

# Pearson chi-square normality test
# data:  leng
# P = 17.4, p-value = 0.1352

# Last but not least a graphical test. If its perfect normal, it'll be a
straight line
qqnorm(leng)

```



- Test Correlation, and autocorrelation

$$se(\rho_{ij}) \approx \frac{(1 - \rho_{ij}^2)}{\sqrt{T}}$$

→ if $\bar{\rho} = 0$, $se(\rho) = \frac{1}{\sqrt{T}}$, hence the test-statistic is

$$(\rho_i - 0) / se(\rho_{ij}) = \sqrt{T} \rho_i$$

In other words for 95% CI, if $|\rho_i| > 2/\sqrt{T}$, reject H_0 : no correlation

```
cor( Sepal.Length, Sepal.Width, method = "pearson")
cor( Sepal.Length, Sepal.Width, method = "spearman")
cor( Sepal.Length, Sepal.Width, method = "kendall")

cor.test(Sepal.Length, Sepal.Width, method="pearson")
# Pearson's product-moment correlation
# data: Sepal.Length and Sepal.Width
# t = -1.4403, df = 148, p-value = 0.1519
# alternative hypothesis: true correlation is not equal to 0
# 95 percent confidence interval:
# -0.27269325 0.04351158
# sample estimates:
# cor
# -0.1175698
```

- Test independency: chi-squared test, fisher's (non-parametric)

```
attach(mtcars)

#contingency table -> table(am,vs)
barplot(table(am,vs), beside = T,
        legend.text = c("V engine", "S engine"),
        xlab = "0 = automatic, 1 = manual", ylab = "counts")

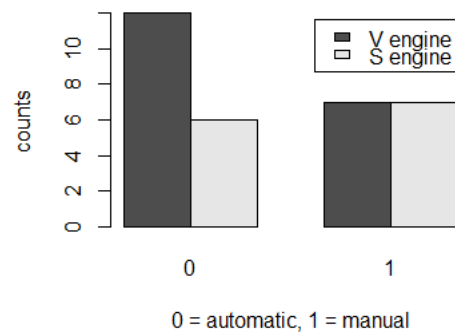
chisq.test(table(am,vs))

# Pearson's Chi-squared test with Yates' continuity correction
# data: table(am, vs)
# X-squared = 0.34754, df = 1, p-value = 0.5555
```

```
#for non-parametric data use Fisher
fisher.test(table(am,vs))

# Fisher's Exact Test for Count Data

# data:  table(am, vs)
# p-value = 0.4727
# alternative hypothesis: true odds ratio is not equal to 1
# 95 percent confidence interval:
# 0.3825342 10.5916087
# sample estimates:
# odds ratio
# 1.956055
```



- Test population mean (1 sample)

```
#H0: mean is 6 or higher
t.test(x = leng, mu = 6, alternative = "less", conf.level = 0.95)

#H0: mean is 6 or smaller
t.test(x = leng, mu = 6, alternative = "greater", conf.level = 0.95)

#H0: mean is 6
t.test(x = leng, mu = 6, alternative = "two.side", conf.level = 0.95)
```

- Test 2 samples mean
(data is normal): t-test or called Welch two-sample test

```
attach(mtcars)
boxplot(data=mtcars, wt~am)

#check variance
var(wt[am==0]); var(wt[am==1]) # this justifies to var.equal = F below

#H_0: the mean weigth of automatic cars is same as the mean weight of
manual cars
t.test(wt~am, alternative = "two.sided",
```

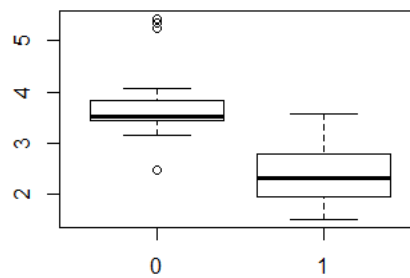
```

      conf.level = 0.95, mu = 0, paired = F, var.equal = F)

#same as
t.test(wt[am==0], wt[am==1])

# Welch Two Sample t-test
# data: wt by am
# t = 5.4939, df = 29.234, p-value = 6.272e-06
# alternative hypothesis: true difference in means is not equal to 0
# 95 percent confidence interval:
#  0.8525632 1.8632262
# sample estimates:
# mean in group 0 mean in group 1
# 3.768895      2.411000

```



- Test 2 samples mean
(data is not normal, called non-parametric): Mann Whitney U test

```

library(MASS)
attach(ships)
boxplot(incidents~period)

wilcox.test(incidents~period, mu=0, alt="two.side"
            , conf.int=T, conf.level = .95, paired=F
            , correct=T, exact=F)

# Wilcoxon rank sum test with continuity correction
# data: incidents by period
# W = 140.5, p-value = 0.1024
# alternative hypothesis: true location shift is not equal to 0
# 95 percent confidence interval:
# -7.999965e+00 4.390335e-05
# sample estimates:
# difference in location
# -1.000044

wilcox.test(incidents~period, mu=0, alt="two.side"
            , conf.int=T, conf.level = .95, paired=T

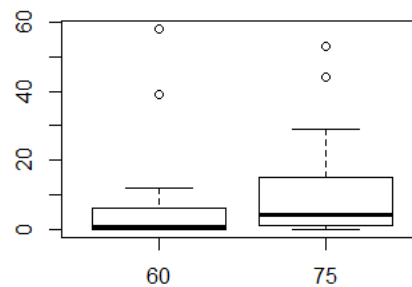
```

```

, correct=F, exact=F)

# Wilcoxon signed rank test
# data: incidents by period
# V = 22.5, p-value = 0.05897
# alternative hypothesis: true location shift is not equal to 0
# 95 percent confidence interval:
# -11.0000050  0.4999812
# sample estimates:
# (pseudo)median
# -4.000042

```



- Test >2 samples mean
(data is normal): F, ANOVA— also used in multi-regression

```

attach(iris)
levels(Species)
boxplot(Sepal.Length~Species)
by(Sepal.Length, Species, mean)

oneway.test(Sepal.Length~Species) #F-test

# One-way analysis of means (not assuming equal variances)
# data: Sepal.Length and Species
# F = 138.91, num df = 2.000, denom df = 92.211, p-value < 2.2e-16

irisANOVA = aov(Sepal.Length~Species, data = iris); irisANOVA
# Terms:
#              # Species Residuals
# Sum of Squares 63.21213 38.95620
# Deg. of Freedom    2    147

# Residual standard error: 0.5147894
# Estimated effects may be unbalanced
0
coefficients(irisANOVA)
# (Intercept) Speciesversicolor Speciesvirginica
#           5.006           0.930           1.582

```

```

TukeyHSD(irisANOVA)

# Tukey multiple comparisons of means
# 95% family-wise confidence level
# Fit: aov(formula = Sepal.Length ~ Species, data = iris)
# $Species
#               diff       lwr       upr p adj
# versicolor-setosa  0.930 0.6862273 1.1737727    0
# virginica-setosa    1.582 1.3382273 1.8257727    0
# virginica-versicolor 0.652 0.4082273 0.8957727    0
plot(TukeyHSD(irisANOVA))

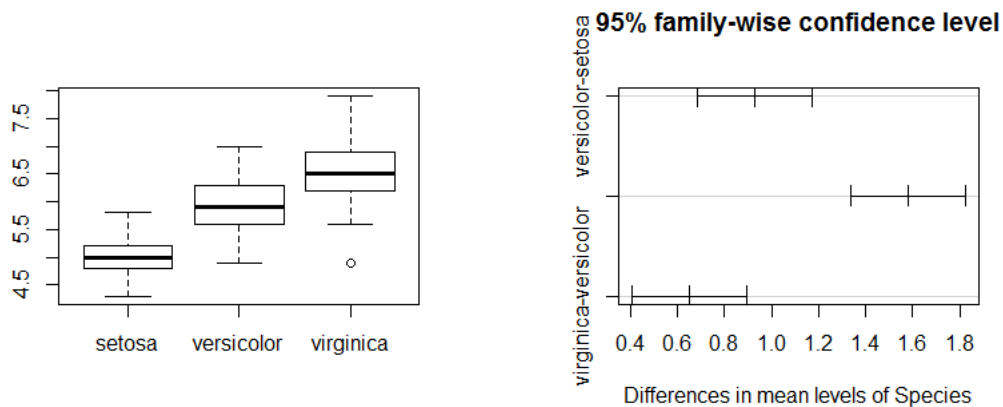
#similarly
library(DTK)
TK.test( x= Sepal.Length, f=Species)

# Tukey multiple comparisons of means
# 95% family-wise confidence level
# Fit: aov(formula = x ~ f)
# $f
#               diff       lwr       upr p adj
# versicolor-setosa  0.930 0.6862273 1.1737727    0
# virginica-setosa    1.582 1.3382273 1.8257727    0
# virginica-versicolor 0.652 0.4082273 0.8957727    0

library(car)
leveneTest(Sepal.Length, Species, data=iris, center = "mean")

# Levene's Test for Homogeneity of Variance (center = "mean": iris)
#           Df F value    Pr(>F)
# group      2  7.3811 0.0008818 ***
#           147
# ---
# Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

```



- Test >2 samples mean
(data is not normal, non-parametric): Kruskal Wallis tests


```

kruskal.test(data = iris, Sepal.Length~Species)

# Kruskal-Wallis rank sum test
# data: Sepal.Length by Species
# Kruskal-Wallis chi-squared = 96.937, df = 2, p-value < 2.2e-16

#alternatively use t.test with a p adjust correction, e.g. Holm-Bonferroni
method

pairwise.t.test(x=Sepal.Length, g=Species, p.adjust.method = "BH")

# Pairwise comparisons using t tests with pooled SD
# data: Sepal.Length and Species
# setosa versicolor
# versicolor 1.3e-15 -
# virginica < 2e-16 2.8e-09
# P value adjustment method: BH

```

Time Series Analysis

9. Stationarity, seasonality

- Non-constant mean (trend) => non- stationary, heteroscedasticity
- Unit root test: augmented Dickey-Fuller test.

Stationary : time series is invariance under time translation

$$X_t = \phi \cdot X_{t-1} + WN(0, \sigma^2)$$

H0: $\phi = 1$ (unit root, non-stationary) ϕ is root of polynomial of $AR(p)$
 $1 - lag_1 \cdot \phi - lag_2 \cdot \phi^2 - \dots$

H0: $|\phi| < 1$

```

library(tseries)
plot(nottem) # the nottem dataset
plot(decompose(nottem, type = "additive"))
adf.test(nottem)

# Augmented Dickey-Fuller Test
# data: nottem
# Dickey-Fuller = -12.998, Lag order = 6,
# p-value = 0.01
# alternative hypothesis: stationary

x <- diffinv(nottem) # non-stationary
plot(x)
adf.test(x)

```

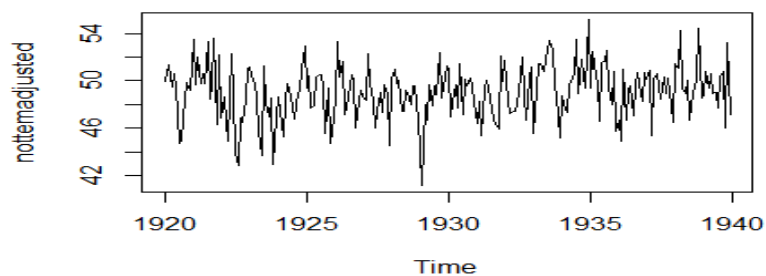
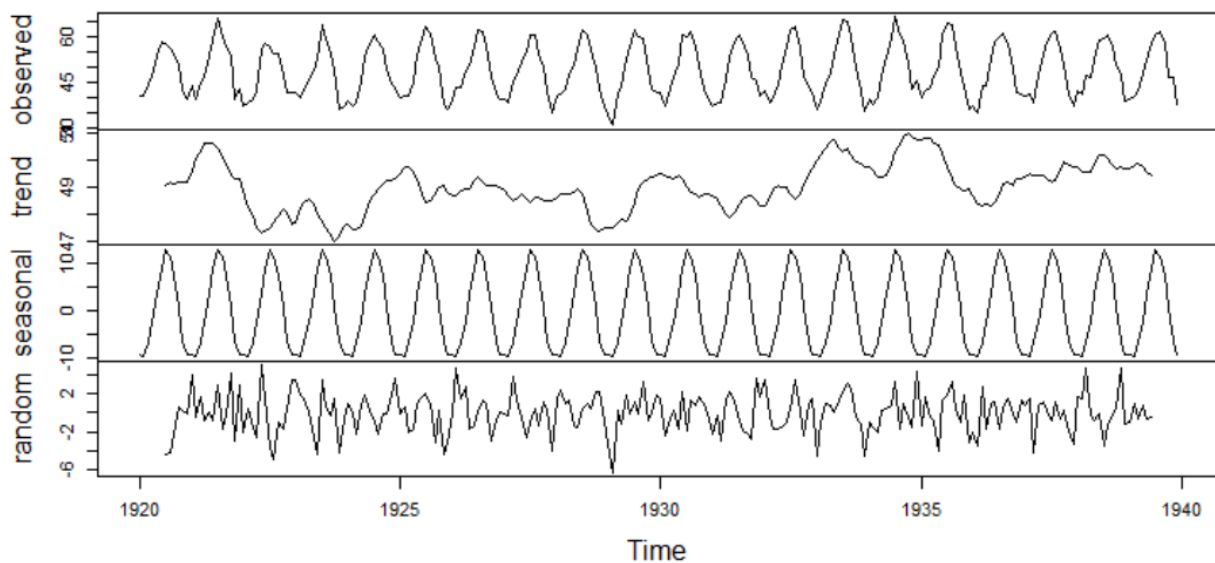
```

# Augmented Dickey-Fuller Test
# data: x
# Dickey-Fuller = -0.63448, Lag order
# = 6, p-value = 0.9752
# alternative hypothesis: stationary

# seasonal adjustment
nottemadjusted = nottem - decompose(nottem, "additive")$seasonal
plot(nottemadjusted)

```

Decomposition of additive time series



- Rolling Means; Rolling Sd; Rolling Cov / Cor

```

#
library(zoo)
end = Sys.Date()
d<- as.POSIXlt(as.Date(end))

```

```

d$year <- d$year - 10
start = as.Date(d)
par(mfrow=c(1,1))

MSFT.prices = get.hist.quote(instrument="msft", start=start,
                             end=end, quote="AdjClose",
                             provider="yahoo", origin="1970-01-01",
                             compression="m", retclass="zoo")
MSFT = diff(log(MSFT.prices))

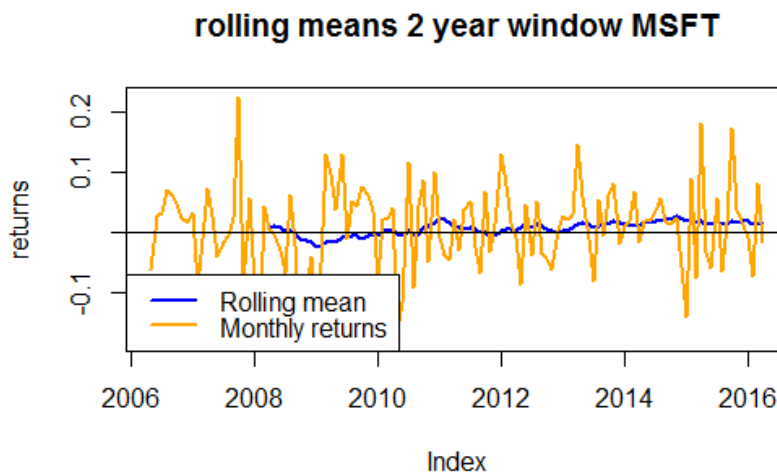
SBUX.prices = get.hist.quote(instrument="sbux", start=start,
                              end=end, quote="AdjClose",
                              provider="yahoo", origin="1970-01-01",
                              compression="m", retclass="zoo")
SBUX = diff(log(SBUX.prices))

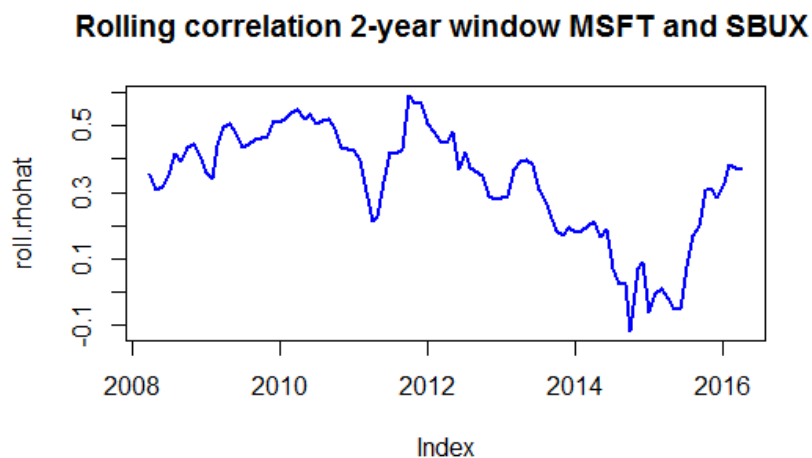
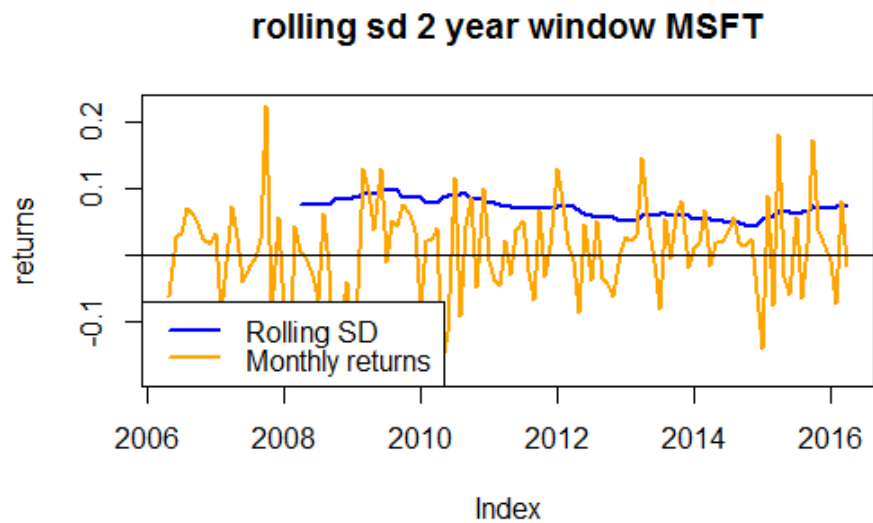
roll.muhat = rollapply(MSFT, width=24,
                       FUN=mean, align="right")
plot(merge(roll.muhat,MSFT), plot.type="single",
     main="rolling means 2-year MSFT",ylab="returns",
     lwd=c(2,2), col=c("blue","orange"))
abline(h=0)
legend(x="bottomleft",legend=c("Rolling mean","Monthly returns"),
      lwd=c(2,2), col=c("blue","orange"))

rho.hat = function(x){
  cor(x)[1,2]}
roll.rho.hat = rollapply(merge(MSFT,SBUX), width=24,
                        FUN=rho.hat,by.column = F, align="right")

plot(roll.rho.hat, lwd=2, col=4, main="Rolling cor 2-year window MSFT and SBUX")

```





Hence the assumptions of CER model: constant return, constant sd are correct; but constant correlation is not.

10. Autocorrelation

- Stationarity process: $var(Y_t) = var(Y_{t-j})$
 - Unit Test
 - Durbin Watson test

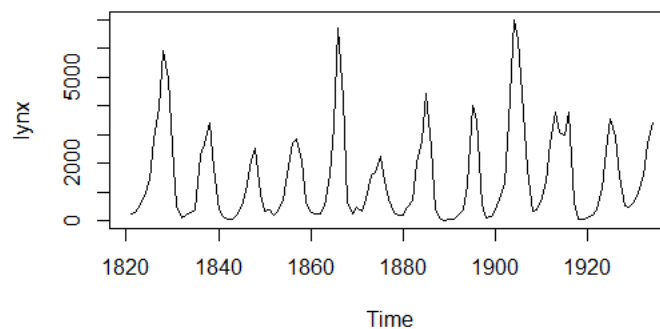
```
library(lmtest)
plot(lynx)
dwtest(lynx[-114] ~ lynx[-1]) #1 lag time difference,
# autocorrelation of 1st order, not robust

# Durbin-Watson test
# data: lynx[-114] ~ lynx[-1]
# DW = 1.1296, p-value = 1.148e-06
```

```
# alternative hypothesis: true autocorrelation is greater than 0

#in comparison to random normal, not auto correlated
x = rnorm(700)
dwtest(x[-700] ~ x[-1])

# Durbin-Watson test
# data: x[-700] ~ x[-1]
# DW = 2.0056, p-value = 0.5302
# alternative hypothesis: true autocorrelation is greater than 0
```



- Autocorrelation function (ACF)
- Partial autocorrelation function (PACF)

ACF=> function of $\text{corr}(Y_t, Y_{t-j})$ of j

PACF=> coef of $\text{lm}(Y_t \sim Y_{t-1} + Y_{t-2} + \dots)$

```
lynx.acf<-acf(lynx, lag.max = 10, plot = F )
lynx.pacf<-pacf(lynx, lag.max = 10, plot = F)

library(forecast)
tsdisplay(lynx)

acf_pacf_tab=cbind(as.matrix(lynx.acf$acf[-1]),lynx.pacf$acf)
dimnames(acf_pacf_tab)=list(c(1:10),c("acf", "pacf"))
print(acf_pacf_tab)

#           acf           pacf
# 1  0.7108187  0.71081868
# 2  0.2144115 -0.58789184
# 3 -0.1885254 -0.03906685
# 4 -0.4334992 -0.24956946
# 5 -0.5022176 -0.09437599
# 6 -0.4003496 -0.05207440
# 7 -0.1479847  0.11884341
# 8  0.2183651  0.30121848
```

```

# 9    0.5009080  0.05457031
# 10   0.5139073 -0.08115986

#now we will verify these numbers
library(dplyr)
for (k in c(1:10)){
  assign(paste("lynx.lag", k, sep = ""), lag(lynx, n=k))
}
lynx.lag3

#check ACF(k=3)
k=3
cor(lynx[!is.na(lynx.lag3)], na.omit(lynx.lag3))
#-0.1911877 close to -0.1885254, not exactly same, because R uses bootstrap to
do acf

fit<-lm(lynx~lynx.lag1+lynx.lag2+lynx.lag3+lynx.lag4+lynx.lag5
        +lynx.lag6+lynx.lag7+lynx.lag8+lynx.lag9+lynx.lag10)
summary(fit)

# Coefficients:
#              Estimate Std. Error t value Pr(>|t|)
# (Intercept)  594.693979  243.678635   2.440   0.0166 *
# lynx.lag1     0.991569   0.103502   9.580 1.58e-15 *** <-only two are signif
# lynx.lag2    -0.589400   0.144820  -4.070 9.86e-05 *** <-close to pacf above
# lynx.lag3     0.209098   0.153731   1.360   0.1771
# lynx.lag4    -0.155269   0.152983  -1.015   0.3128
# lynx.lag5     0.007121   0.152731   0.047   0.9629
# lynx.lag6    -0.011158   0.152491  -0.073   0.9418
# lynx.lag7    -0.137568   0.151698  -0.907   0.3668
# lynx.lag8     0.172092   0.151054   1.139   0.2575
# lynx.lag9     0.168695   0.140362   1.202   0.2325
# lynx.lag10   -0.060023   0.098670  -0.608   0.5445
# ---
# Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
# Residual standard error: 814.1 on 93 degrees of freedom
# (10 observations deleted due to missingness)
# Multiple R-squared:  0.7427, Adjusted R-squared:  0.7151
# F-statistic: 26.85 on 10 and 93 DF, p-value: < 2.2e-16

#or use
ar(lynx, aic = F, order.max = 10)
# Coefficients:
#      1      2      3      4      5      6      7      8
# 1.0259 -0.5753  0.1760 -0.1392 -0.0141 -0.0019 -0.1561  0.1963
#      9     10
# 0.1375 -0.0812
# Order selected 10 sigma^2 estimated as 733939

#we can use lag1,2 coef to find the seasonality
phi1<-fit$coefficients["lynx.lag1"]
phi2<-fit$coefficients["lynx.lag2"]

```

```

season <- 2*pi / acos(abs(phi1)/2/sqrt(abs(phi2)))
print(as.numeric(season))
#7.232481 shows 7-month cycle

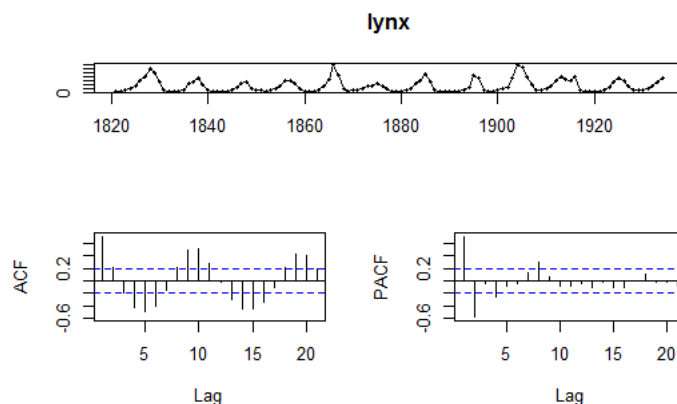
#how do we know k=10 for lm above is the right choice
lynx.ar = ar(lynx)
lynx.ar$order
#8 has the minimum aic statistic

lynx.ar$order.max
#20 is the maximum

ar(lynx, aic = T)
# Coefficients:
#      1      2      3      4      5      6      7      8
# 1.0379 -0.6063  0.1910 -0.1411 -0.0207  0.0199 -0.2046  0.3012
# Order selected 8  sigma^2 estimated as 726897

#Now manually check unit test
roots <- polyroot(c(1,-1*lynx.ar$ar))
sqrt(Conj(roots)*roots)
# [1] 1.046849+0i 1.212855+0i 1.212855+0i 1.046849+0i 1.139951+0i 1.315036+0i
1.139951+0i
# [8] 1.205099+0i
# all >1, The model is consistent. Its indeed stationary

```



11. Multi-Time Series: Vector Autoregressive (VAR) model

- Macroeconomic model

courtesy of http://ocw.mit.edu/courses/mathematics/18-s096-topics-in-mathematics-with-applications-in-finance-fall-2013/case-studies/fm_casestudy_fx_1.r

```

#Macro Variables (rates are monthly if not specified)
#https://research.stlouisfed.org/fred2/series/+
#      Season Adj Desc
#UNRATE Yes Civilian Unemployment

```

```

#FEDFUNDS    No      Effective Federal Funds
#TB3MS       No      3-Month Treasury Bill: Secondary Market
#CPIAUCSL    Yes     Consumer Price Index for All Urban Consumers
#M1SL        Yes     M1 Money Stock
#GDPDEF      Yes     (Quarterly) GDP Price Deflator
#GDP         Yes     (Quarterly*4=annualized)GDP
#GDPDI       Yes     (annualized)Gross Private Domestic Investment
#TWEXBMTH    No      Trade Weighted U.S. Dollar
#SP500       No      (daily) S&P 500

library(quantmod)
getSymbols(c("UNRATE", "FEDFUNDS", "TB3MS",
            "CPIAUCSL", "M1SL", "GDPDEF",
            "GDP", "GDPDI", "TWEXBMTH",
            "SP500"),src="FRED")

ymat<-window(merge(UNRATE,FEDFUNDS,CPIAUCSL),start = as.Date("1980-01-01"), end
= as.Date("2015-12-31"))
head(ymat)
acf(ymat, lag.max = 10)

acf(ymat,type = "partial", lag.max = 10)

library(vars)
ymat.var <- VARselect(ymat, lag.max = 20, type = "const")
#knowing what order we need
ymat.var$selection
# AIC(n) HQ(n) SC(n) FPE(n)
# 14 5 2 14
ymat.var.BIC <- VAR(ymat,ic = "SC", p = ymat.var$selection["SC(n)"], type =
"const")

ymat.var.BIC
#VAR Estimation Results:
#=====
#
# Estimated coefficients for equation UNRATE:
# =====
# Call:
# UNRATE = UNRATE.l1 + FEDFUNDS.l1 + CPIAUCSL.l1 + UNRATE.l2 + FEDFUNDS.l2 +
#CPIAUCSL.l2 + const
#
# UNRATE.l1 FEDFUNDS.l1 CPIAUCSL.l1 UNRATE.l2 FEDFUNDS.l2 CPIAUCSL.l2
# 1.12266019 -0.01095739 -0.01499979 -0.12659643 0.02514381 0.01595799
# const
# -0.19957072
#
#
# Estimated coefficients for equation FEDFUNDS:
# =====
# Call:
# FEDFUNDS = UNRATE.l1 + FEDFUNDS.l1 + CPIAUCSL.l1 + UNRATE.l2 + FEDFUNDS.l2 +
#CPIAUCSL.l2 + const
#

```



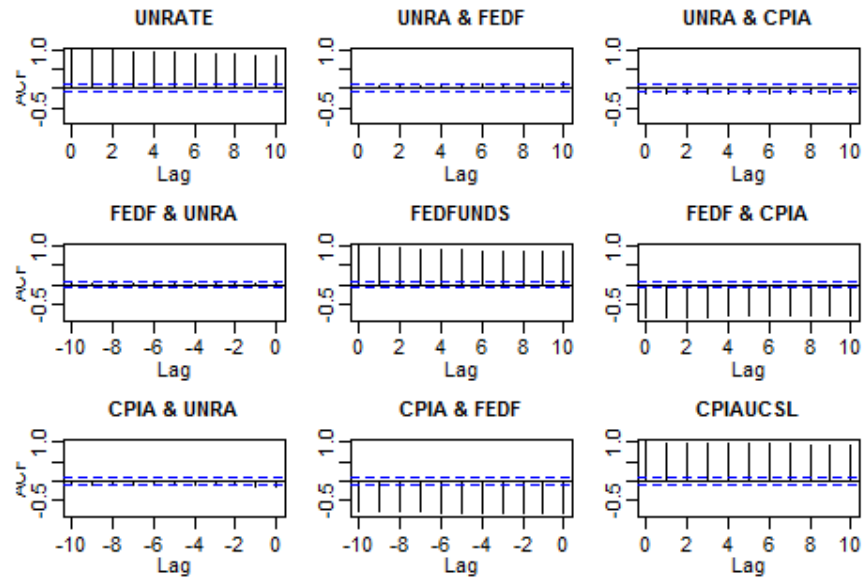
```

# UNRATE.11 FEDFUNDS.11 CPIAUCSL.11 UNRATE.12 FEDFUNDS.12 CPIAUCSL.12
# -0.553171076 1.326596760 0.006339352 0.539818262 -0.380501513 -0.010356311
# const
# 0.985321303
#
# Estimated coefficients for equation CPIAUCSL:
# =====
# Call:
# CPIAUCSL = UNRATE.11 + FEDFUNDS.11 + CPIAUCSL.11 + UNRATE.12 + FEDFUNDS.12 +
CPIAUCSL.12 + const
#
# UNRATE.11 FEDFUNDS.11 CPIAUCSL.11 UNRATE.12 FEDFUNDS.12 CPIAUCSL.12
# 0.09685896 0.07807028 1.42170217 -0.10083232 -0.06539011 -0.42128779
# const
# 0.10948202

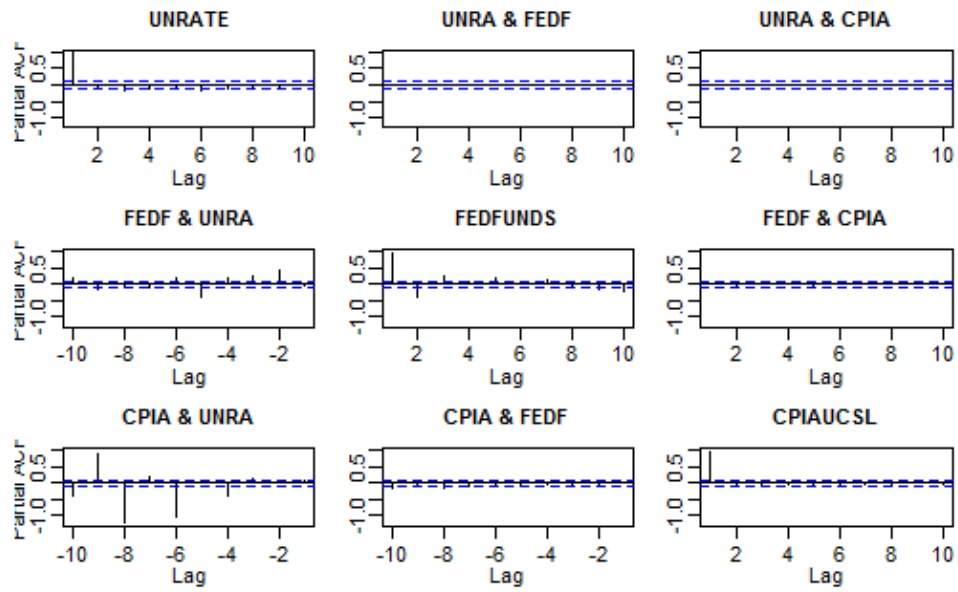
```

```
plot(irf(yamat.var.BIC))
```

#impulse: meaning forecast for all variables while changing one variable
#because of vector autocorrelation, all variables are intertwined to each other

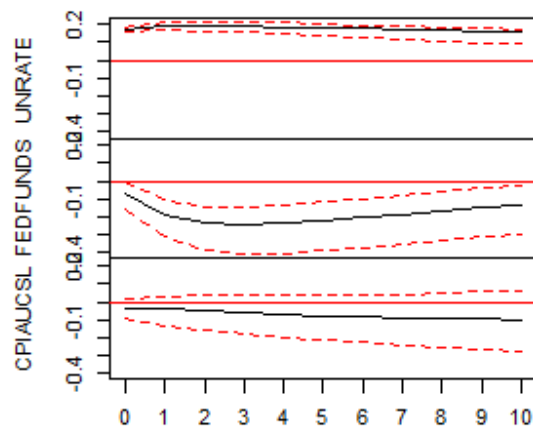


ACF



PACF

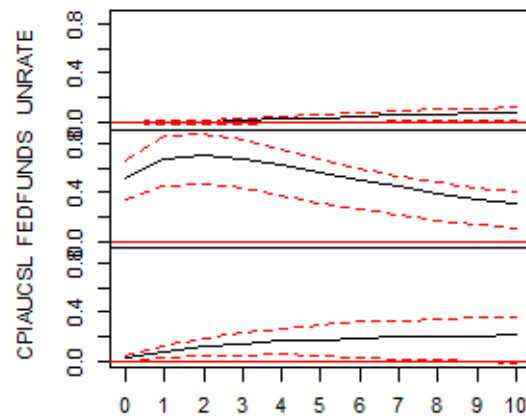
Orthogonal Impulse Response from UNRATE



95 % Bootstrap CI, 100 runs

Raising unemployment rate -> lower fed funds rate

Orthogonal Impulse Response from FEDFUNDS



95 % Bootstrap CI, 100 runs

Initial increase in Fed rate -> modest increase in unemployment rate (i.e. unrate persists).
Despite Fed effort to control inflation -> CPI raising

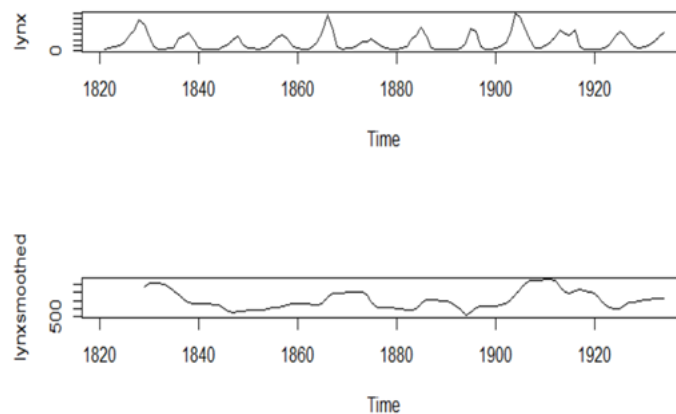
12. Forecasting models & smoothing

- Simple moving average

```
library("TTR")

lynxsmoothed = SMA(lynx, n = 9); 9th order

par(mfrow=c(2,1))
plot(lynx)
plot(lynxsmoothed)
```



- moving average process

$$\text{MA}(q): X_t = \mu + \epsilon_t + \theta_1 \epsilon_{t-1} + \dots + \theta_q \epsilon_{t-q}$$

```
# simulate MA(1) process with theta 0.9 and e(t) ~ N(0,1)
```

```

ma1.model = list(ma=0.9)
mu = 1
set.seed(123)
ma1.sim = mu + arima.sim(model=ma1.model,n=250)

# simulate MA(1) process with theta 0.9 and  $e(t) \sim N(0, (0.1)^2)$ 
set.seed(123)
ma1.sim2 = mu + arima.sim(model=ma1.model, n=250, innov=rnorm(n=250, mean=0,
sd=0.1))

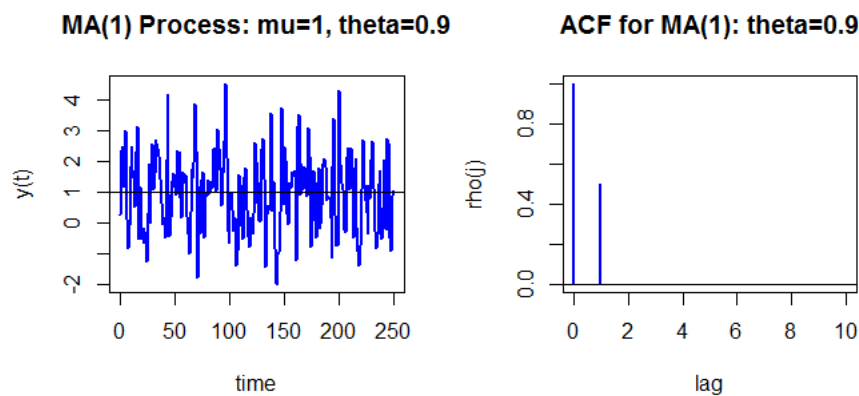
# ACF for MA(1) model
ma1.acf = ARMAacf(ar=0, ma=0.9, lag.max=10)
ma1.acf

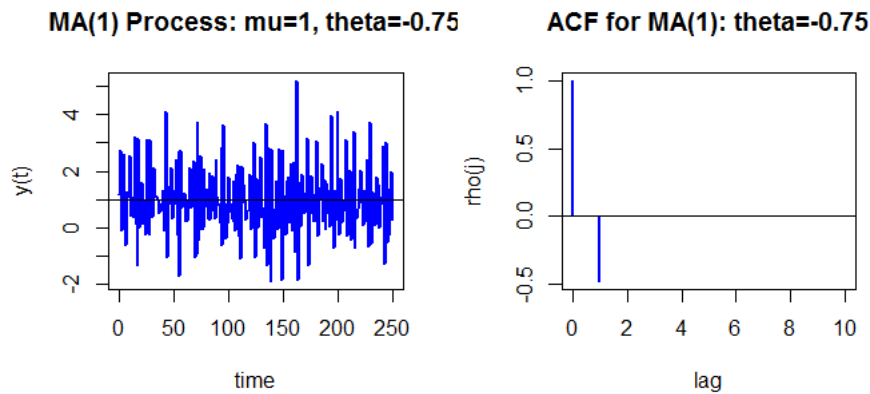
par(mfrow=c(1,2))
ts.plot(ma1.sim,main="MA(1) Process: mu=1, theta=0.9",
        xlab="time",ylab="y(t)", col="blue", lwd=2)
abline(h=1)
plot(0:10, ma1.acf,type="h", col="blue", lwd=2,
     main="ACF for MA(1): theta=0.9",xlab="lag",ylab="rho(j)")
abline(h=0)

# simulate MA(1) process with theta < 0
ma1.model = list(ma=-0.75)
mu = 1
set.seed(123)
ma1.sim = mu + arima.sim(model=ma1.model,n=250)
ts.plot(ma1.sim,main="MA(1) Process: mu=1, theta=-0.75",
        xlab="time",ylab="y(t)", col="blue", lwd=2)
abline(h=1)

# ACF for MA(1) model
ma1.acf = ARMAacf(ar=0, ma=-0.75, lag.max=10)
plot(0:10, ma1.acf,type="h", col="blue", lwd=2,
     main="ACF for MA(1): theta=-0.75",xlab="lag",ylab="rho(j)")
abline(h=0)

```





- Autoregressive process

$$AR(p): X_t = c + \sum_{i=1}^p \psi_i X_{t-i} + \epsilon_t$$

AR(1) examples:

- Interest rates

Ornstein Uhlenbeck Process: $dX_t = -\theta_2 X_t dt + \theta_3 dW_t$

Vasicek Model: $dX_t = (\theta_1 - \theta_2 X_t) dt + \theta_3 dW_t$

- Interest rate spreads

- Real exchange rate

- Valuation ratios (dividend-to-price, earnings-to-price)

Simulations

```
# simulate AR(1) process: phi = 0.9
ar1.model = list(ar=0.9)
mu = 1
set.seed(123)
ar1.sim = mu + arima.sim(model=ar1.model,n=250)
ar1.acf = ARMAacf(ar=0.9, ma=0, lag.max=10)

par(mfrow=c(1,2))
ts.plot(ar1.sim,main="AR(1) Process: mu=1, phi=0.9",
        xlab="time",ylab="y(t)", col="blue", lwd=2)
abline(h=1)
# ACF for AR(1) model
plot(0:10, ar1.acf,type="h", col="blue", lwd=2,
     main="ACF for AR(1): phi=0.9",xlab="lag",ylab="rho(j)")
par(mfrow=c(1,1))

# simulate AR(1) process: phi = -0.75
ar1.model = list(ar=-0.75)
mu = 1
set.seed(123)
ar1.sim = mu + arima.sim(model=ar1.model,n=250)

# ACF for AR(1) model
```

```

ar1.acf = ARMAacf(ar=-0.75, ma=0, lag.max=10)

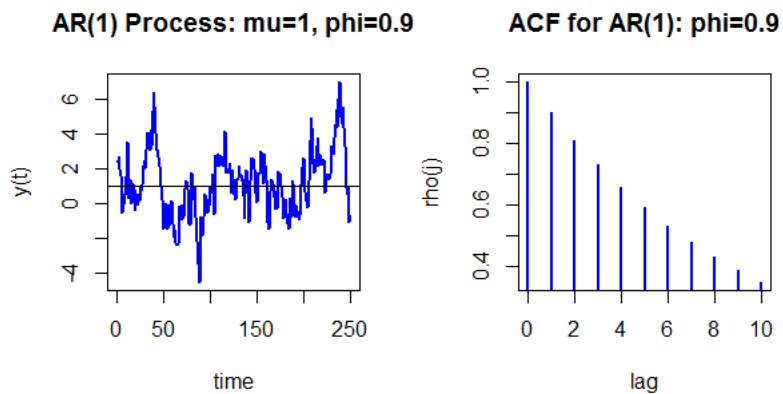
par(mfrow=c(1,2))
ts.plot(ar1.sim,main="AR(1) Process: mu=1, phi=-0.75",col="blue", lwd=2,
        xlab="time",ylab="y(t)")
abline(h=1)
plot(0:10, ar1.acf,type="h", col="blue", lwd=2,
     main="ACF for AR(1): phi=-0.75",xlab="lag",ylab="rho(j)")
abline(h=0)

# simulate AR(1) process: phi = 1
set.seed(123)
ar1.sim = cumsum(rnorm(250))

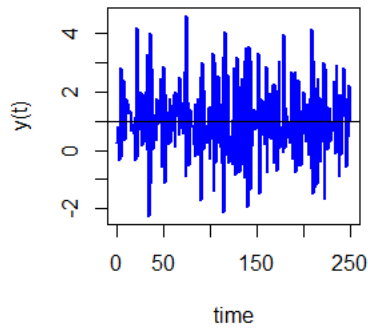
# simulate AR(1) process: phi > 1
set.seed(123)
phi = 1.01
e = rnorm(250)
y = rep(0,250)
for (i in 2:250) {
  y[i] = phi*y[i-1] + e[i]
}

par(mfrow=c(1,2))
ts.plot(ar1.sim,main="AR(1) Process: phi=1",
        xlab="time",ylab="y(t)",lwd=2, col="blue")
abline(h=0)
ts.plot(y,main="AR(1) Process: phi=1.01",
        xlab="time",ylab="y(t)", lwd=2, col="blue")
par(mfrow=c(1,1))

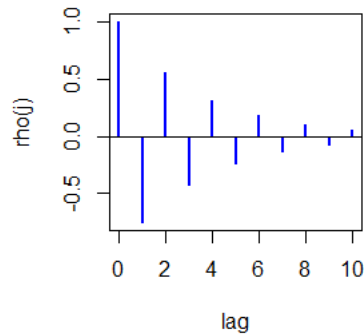
```



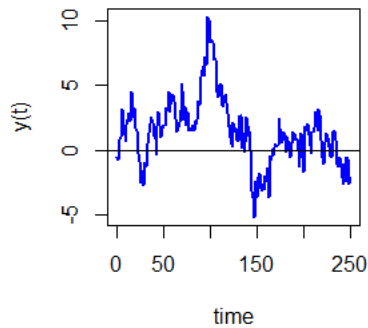
AR(1) Process: $\mu=1, \phi=-0.7$



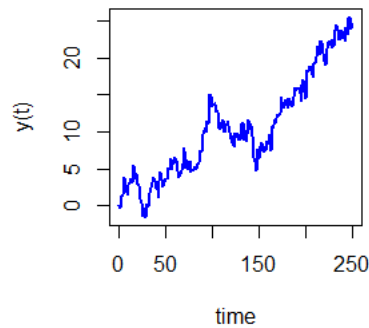
ACF for AR(1): $\phi=-0.75$



AR(1) Process: $\phi=1$



AR(1) Process: $\phi=1.01$



- ARIMA Model Selection

- Find d such that $(1 - \text{Lag})^d(Y_t)$ is stationary. Then work with $(1 - \text{Lag})^d(Y_t)$
- Find (p, q) minimize one of the information criteria under the assumption of Gaussian white noise:

Akaike Information Criterion

$$AIC = 2k - 2 \ln L$$

Corrected Akaike Information Criterion

$$AIC_c = AIC + \underbrace{\frac{2k(k+1)}{n-k-1}}_{\text{bias-correction}}$$

Akaike's Final Prediction Error

Bayes Information Criterion or Schwarz information criterion

$$BIC = -2 \ln \hat{L} + k \ln n$$

Hannan-Quinn information Criterion

$$HQC = -2L_{max} + 2k \log \log n$$

Where $\ln L$ or L_{max} is $\log(\text{Maximum likelihood of } \text{Var}(WN))$, n = num of observations,
 $k = (p + q)/n$

```
library(forecast)

auto.arima(lynx)
auto.arima(lynx, ic = "aic", trace = T)

# ARIMA(2,0,2) with non-zero mean : 1876.391
# ARIMA(0,0,0) with non-zero mean : 2007.339
# ARIMA(1,0,0) with non-zero mean : 1927.298
# ARIMA(0,0,1) with non-zero mean : 1918.958
# ARIMA(0,0,0) with zero mean      : 2081.408
# ARIMA(1,0,2) with non-zero mean : 1888.538
# ARIMA(3,0,2) with non-zero mean : 1878.685
# ARIMA(2,0,1) with non-zero mean : 1879.737
# ARIMA(2,0,3) with non-zero mean : Inf
# ARIMA(1,0,1) with non-zero mean : 1890.909
# ARIMA(3,0,3) with non-zero mean : Inf
# ARIMA(2,0,2) with zero mean      : 1905.759
# Best model: ARIMA(2,0,2) with non-zero mean

# Series: lynx
# ARIMA(2,0,2) with non-zero mean

# Coefficients:
#      # ar1      ar2      ma1      ma2 intercept
#      # 1.3421  -0.6738  -0.2027  -0.2564  1544.4039
# s.e.  0.0984   0.0801   0.1261   0.1097   131.9242

# sigma^2 estimated as 728546:  log likelihood=-932.08
# AIC=1876.17  AICc=1876.95  BIC=1892.58

# Yt = Int + (ar1)*Yt-1 + (ar2)*Yt-2 + (ma1)*Ye-1 + (ma2)*Ye-2
```

- ARMA forecast

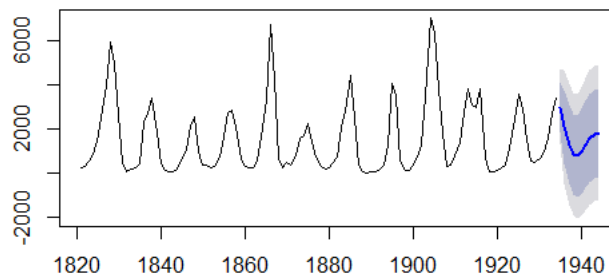
```
myarima = arima(lynx, order = c(2,0,2), include.mean = T) # arima class
object which contains the coeffs

fore<-forecast.Arima(myarima, h = 10) # forecasting next ten values

#   Point    Forecast      Lo 80      Hi 80      Lo 95      Hi 95
# 1935    2989.910  1896.0434  4083.777  1316.9853  4662.835
# 1936    2093.478   435.2392  3751.717   -442.5795  4629.536
# 1937    1307.309  -475.6345  3090.252  -1419.4677  4034.085

plot.forecast(fore)
```


Forecasts from ARIMA(2,0,2) with non-zero mean



- Exponential Smoothing: Holt Winters

Examples in python

https://nbviewer.ipython.org/github/thedataincubator/ds30_3/blob/master/ds30_hw_examples.ipynb

```
### non-season, non-trend Example

plot(LakeHuron)
x = HoltWinters(LakeHuron, gamma = F, beta = F);x
plot(x)

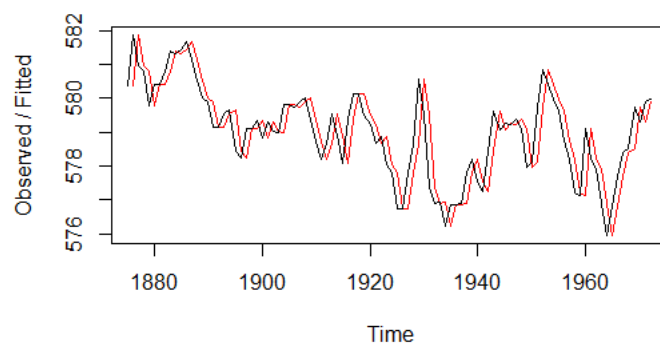
library(forecast)
fore <- forecast.HoltWinters(x, h = 5)

plot.forecast(fore)

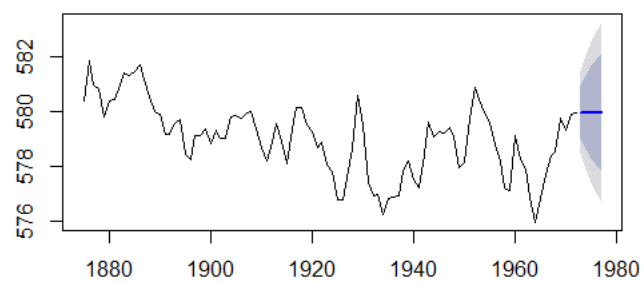
#three ways to see if residual is uncorrelated, unbiased
acf(fore$residuals) #way 1
plot.ts(fore$residuals) #way 2
Box.test(fore$residuals, lag=20, type="Ljung-Box") #way 3

# Box-Ljung test
# data: fore$residuals
# X-squared = 25.246, df = 20, p-value = 0.1922
```

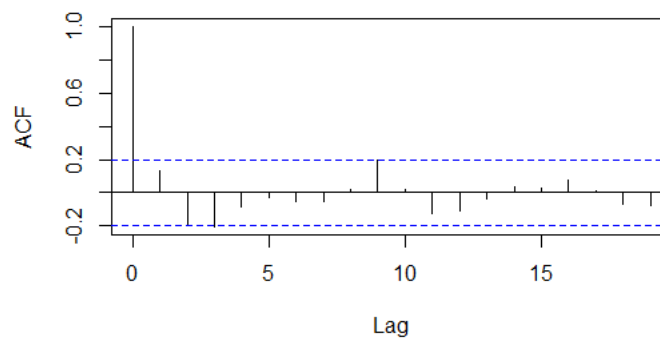
Holt-Winters filtering

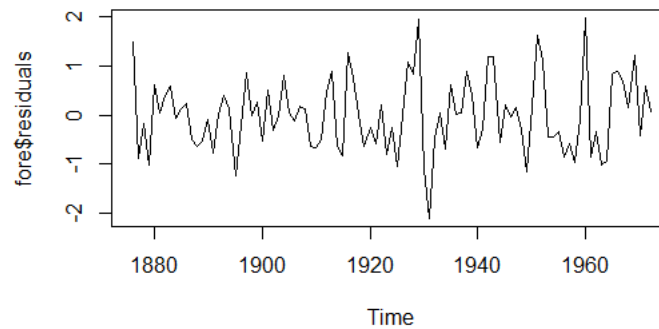


Forecasts from HoltWinters



Series fore\$residuals





- Exponential Smoothing: Holt Winters with trend (double exponential)

$$s_i = \alpha x_i + (1 - \alpha)(s_{i-1} + t_{i-1})$$

$$t_i = \beta(s_i - s_{i-1}) + (1 - \beta)t_{i-1}$$

With trend and seasonality (triple exponential)

$$s_i = \alpha(x_i - p_{i-k}) + (1 - \alpha)(s_{i-1} + t_{i-1})$$

$$t_i = \beta(s_i - s_{i-1}) + (1 - \beta)t_{i-1}$$

$$p_i = \gamma(x_i - s_i) + (1 - \gamma)p_{i-k}$$

```
# trend, seasonality, maybe additive

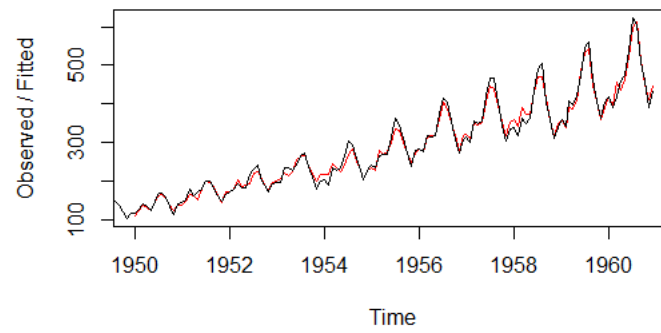
plot((AirPassengers))
x<-HoltWinters(AirPassengers)
plot(x)

fore<-forecast.HoltWinters(x, h = 12) # one year forecast
plot.forecast(fore)

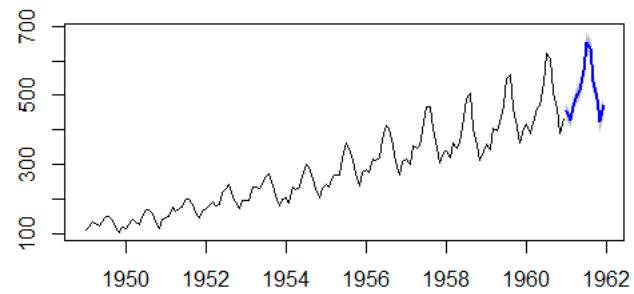
acf(y$residuals, lag = 20)
plot.ts(y$residuals)
Box.test(y$residuals, lag=20, type="Ljung-Box") # or log or diff

# Box-Ljung test
# data: y$residuals
# X-squared = 25.246, df = 20, p-value = 0.1922
```

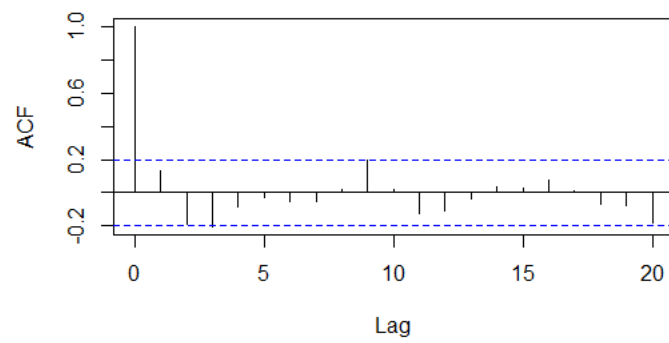
Holt-Winters filtering

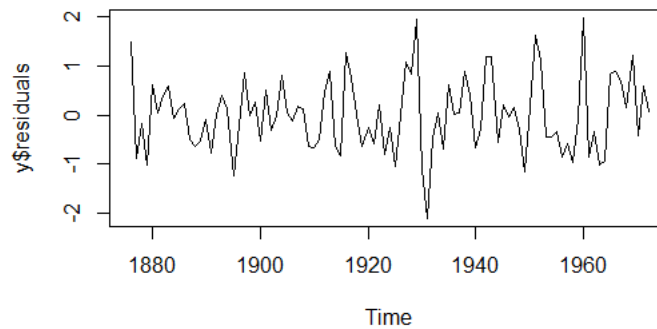


Forecasts from HoltWinters



Series y\$residuals





- Kalman Filter

```
library(FKF)
data("Nile", package = "datasets")
## Transition equation:
##  $\alpha[t+1] = \alpha[t] + \eta[t]$ ,  $\eta[t] \sim N(0, H\eta t)$ 
## Measurement equation:
##  $y[t] = \alpha[t] + \epsilon[t]$ ,  $\epsilon[t] \sim N(0, G\epsilon t)$ 

y <- Nile
y[c(3, 100)] <- NA # NA values can be handled

## Set constant parameters:
dt <- ct <- matrix(0)
Zt <- Tt <- matrix(1)
a0 <- y[1] # Estimation of the first year flow
P0 <- matrix(100) # Variance of 'a0'

## Estimate parameters:
fit.fkf <- optim(c(HHt = var(y, na.rm = TRUE) * .5,
                  GGt = var(y, na.rm = TRUE) * .5),
               fn = function(par, ...)
                 -fkf(HHt = matrix(par[1]), GGt = matrix(par[2]),
                     ..., logLik = function(yt, a0, P0, dt, ct, Zt, Tt) {
                       yt = rbind(y), a0 = a0, P0 = P0, dt = dt, ct = ct,
                       Zt = Zt, Tt = Tt, check.input = FALSE
                     }
                 ),
               method = "Nelder-Mead",
               control = list(maxit = 10000))

## Filter Nile data with estimated parameters:
fkf.obj <- fkf(a0, P0, dt, ct, Tt, Zt, HHt = matrix(fit.fkf$par[1]),
              GGt = matrix(fit.fkf$par[2]), yt = rbind(y))

## Compare with the stats' structural time series implementation:
fit.stats <- StructTS(y, type = "level")

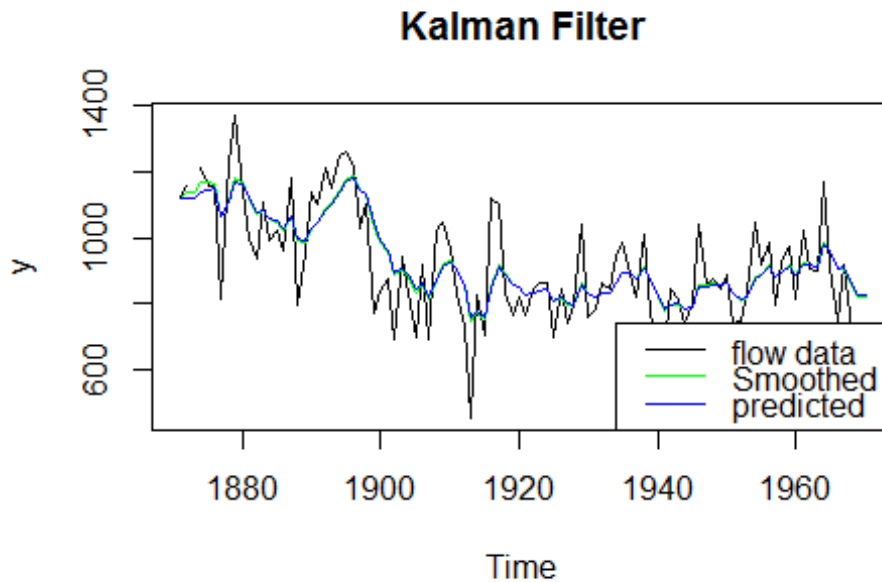
fit.fkf$par
fit.stats$coef

## Plot the flow data together with fitted local levels:
```

```

plot(y, main = "Kalman Filter")
lines(fitted(fit.stats), col = "green")
lines(ts(fkf.obj$att[1, ], start = start(y), frequency = frequency(y)), col =
"blue")
legend("bottomright", c( "flow data", "smoothed", "predicted"),
      col = c("black", "green", "blue"), lty = 1)

```



13. Volatility

- ARCH
- GARCH

ARCH $\sigma^2 \sim \sum(\theta \cdot \eta_t^2) \Rightarrow AR \text{ model}$

GARCH $\sigma^2 \sim \sum(\theta \cdot \eta_t^2) + \sum(\theta \cdot \sigma_t^2) \Rightarrow ARMA \text{ model}$

```

library(quantmod)
getFX("EUR/USD", from=as.Date("2011-01-01"))
ret <- dailyReturn(EURUSD, type = "log")
plot(EURUSD)
plot(ret, main="return")
hist(ret, breaks = 100, main = "return dist")

library(tseries)
ret.arch1 <- garch(ret, order = c(0,1), trace=F)
ret.arch2 <- garch(ret, order = c(0,2), trace=F)
ret.arch10 <- garch(ret, order = c(0,10), trace=F)
ret.garch11 <- garch(ret, order = c(1,1), trace=F)

summary(ret.arch1)
#Model:

```

```

#GARCH(0,1)
# Residuals:
#      Min       1Q   Median       3Q      Max
# -6.3794 -0.4905  0.0000  0.4361  5.5797
#
# Coefficient(s):
#      Estimate Std. Error  t value Pr(>|t|)
# a0 1.103e-05   3.059e-07   36.063  <2e-16 ***
# a1 3.018e-01   3.112e-02    9.699  <2e-16 ***
# ---
# Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
#
# Diagnostic Tests:
#   Jarque Bera Test
#
# data:  Residuals
# X-squared = 693.44, df = 2, p-value < 2.2e-16
#
#   Box-Ljung test
#
# data:  Squared.Residuals
# X-squared = 0.15509, df = 1, p-value = 0.6937

par(mfrow=c(2,2))
ts.plot(ret.arch1$fitted.values[,1], ylab="EURUSD Ret"
, main = "ARCH(1)")
abline(h=sqrt(var(ret)), col=2, lwd=3)

ts.plot(ret.arch2$fitted.values[,1], ylab="EURUSD Ret"
, main = "ARCH(2)")
abline(h=sqrt(var(ret)), col=2, lwd=3)

ts.plot(ret.arch10$fitted.values[,1], ylab="EURUSD Ret"
, main = "ARCH(10)")
abline(h=sqrt(var(ret)), col=2, lwd=3)

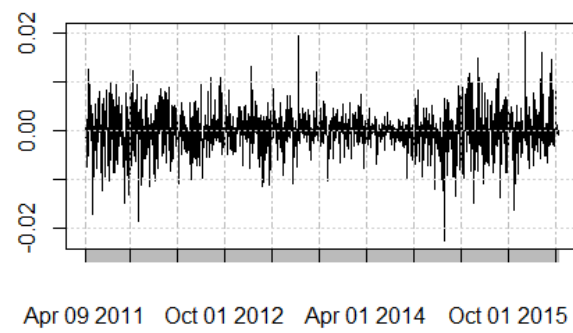
ts.plot(ret.garch11$fitted.values[,1], ylab="EURUSD Ret"
, main = "GARCH(11)")
abline(h=sqrt(var(ret)), col=2, lwd=3)

```

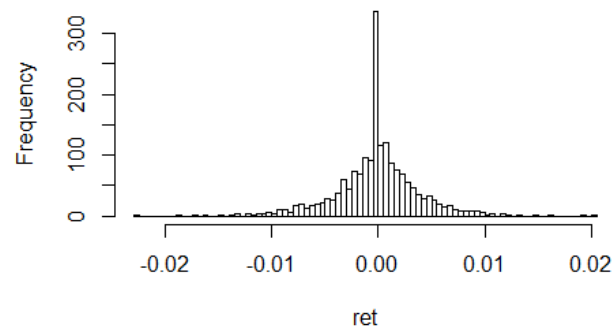
EURUSD

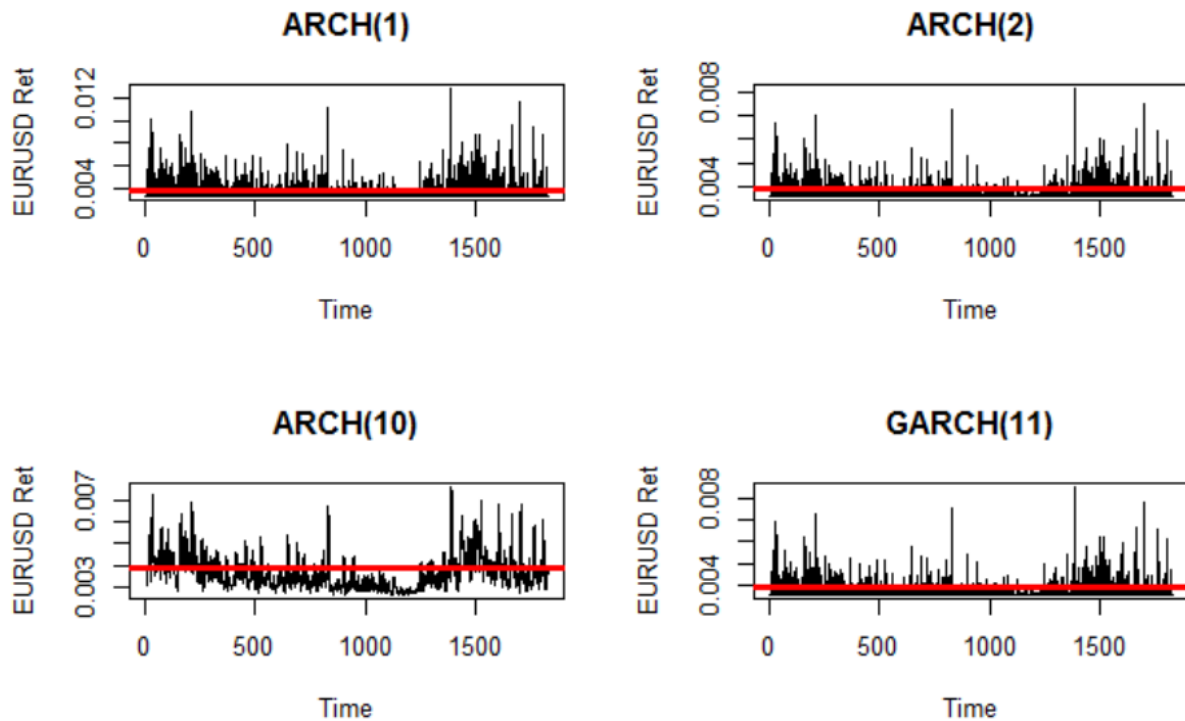


return



return dist





Portfolio theory & Risk Management

14. Markowitz algorithm

- Portfolio Frontier

Perfect hedge $\rho_p = 0$,

Copied from <http://faculty.washington.edu/ezivot/econ424/portfolioTheoryMatrix.r>

```
library(tseries)
library(zoo)
end = Sys.Date()
d<- as.POSIXlt(as.Date(end))
d$year <- d$year - 10
start = as.Date(d)
par(mfrow=c(1,1))

MSFT.prices = get.hist.quote(instrument="msft", start=start,
                             end=end, quote="AdjClose",
                             provider="yahoo", origin="1970-01-01",
                             compression="m", retclass="zoo")
MSFT = diff(log(MSFT.prices))

SBUX.prices = get.hist.quote(instrument="sbux", start=start,
                             end=end, quote="AdjClose",
                             provider="yahoo", origin="1970-01-01",
                             compression="m", retclass="zoo")
SBUX = diff(log(SBUX.prices))
```

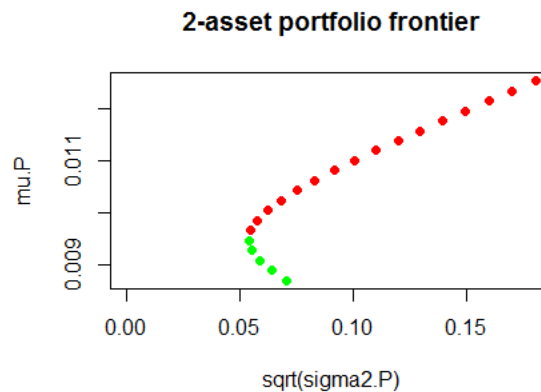
```

cb <- cbind(MSFT,SBUX)
mu = colMeans(cb)
sigma2 = apply(cb, 2, var)
rho_ij = cov(cb[,1],cb[,2])

w.MSFT <- seq(-1,1, by = 0.1)
w.SBUX <- 1-w.MSFT

mu.P <- w.MSFT * mu[1] + w.SBUX * mu[2]
sigma2.P <- w.MSFT^2 * sigma2[1] + w.SBUX^2 * sigma2[2]
           + 2* w.MSFT * w.SBUX * rho_ij
plot(sqrt(sigma2.P), mu.P, type = "b", pch=16,
     col = c(rep("red", 16), rep("green", 5)), main="2-asset portfolio
frontier")

```



- Efficient Portfolio

With a risk free asset, leverage

$$\mu_p = \text{return}_f + (\text{sharpe ratio}) \cdot \sigma_p$$

sharpe ratio = slope of risk return tradeoff → Tangency portfolio + T-bill

add constraints: no short sell $w > 0$, holding threshold $w < w_{max}$, turnover δ_w

optimize techniques: polynomial goal programming (e.g. R- solve.QP {quadprog}), Bellman-Hamilton-Jacobi equation

```

# Markowitz problem 1
# target.return is given, min risk

#for long only portfolio
Dmat <- 2*cov.mat
dvec <- rep.int(0, N)
Amat <- cbind(rep(1,N), er, diag(1,N))
bvec <- c(1, target.return, rep(0,N))
opt_weight <- solve.QP(Dmat=Dmat,dvec=dvec,Amat=Amat,bvec=bvec,meq=2)$solution

#for long/short
ones <- rep(1, N)
top <- cbind(2*cov.mat, er, ones)

```

```

bot <- cbind(rbind(er, ones), matrix(0,2,2))
A <- rbind(top, bot)
b.target <- as.matrix(c(rep(0, N), target.return, 1))
opt_weight <- solve(A, b.target)[1:N]

```

15. Single Index Factor (Sharpe Model) & CAPM

- Beta

$$\beta_i = \text{cov}(R_i, R_p) / \text{var}(R_p)$$

then percentage contribution of risk of asset $i = \beta_i \cdot w_i$,

=> CAPM: return is a function of beta

Tobin Thm: every optimal portfolio invests in a combination of risk-free and market portfolio.

- Well Diversification

All non-market variance is diversified away, $\text{var}(R_p) = \bar{\beta}^2 \text{var}(R_M)$

16. Advanced Methods for Risk Analysis & Portfolio Optimization

- Random Matrix Theory

Jim Gatheral, [*Random Matrix Theory and Covariance Estimation*](#)

Laurent Laloux, Pierre Cizeau, Marc Potters and Jean-Philippe Bouchaud, [*Random Matrix Theory and Finical Correlation*](#)

Marco Avallaneda, [*A Holistic \(and practical\) Approach for Risk Managing Equity Derivatives*](#)

- Dynamic Programming (Merton Model)

David Brown, James Smith, [*Dynamic Portfolio Optimization with Transaction Costs: Heuristics and Dual Bounds*](#)

Yongyang Cai, Kenneth L. Judd, and Rong Xu, [*Numerical Solution of Dynamic Portfolio Optimization with Transaction Costs*](#)

Robert Damman, Chester Spatt, and Harold Zhang, [*Optimal Consumption and Investment with Capital Gains Taxes*](#)

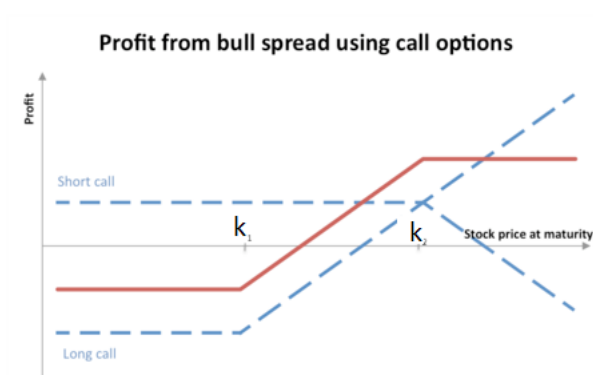
Derivatives Pricing (Sell Side)

17. Types of derivatives, Binomial Tree, B-S Equation

- Contingent Claims (Hull Ch 8-10)

Forwards $(S_T - K)$, future, calls, puts, European call payoff $C = (S_T - K, 0)_+$, Asian $C = (A(S) - K, 0)_+$, floating strike $C = (S_T - kA(S), 0)_+$,

Bull spread long K_1 call, short K_2 , $(S_T - K_1, 0)_+ - (S_T - K_2, 0)_+$



- Interest Derivatives (Hull Ch 4, 7, 26-30)

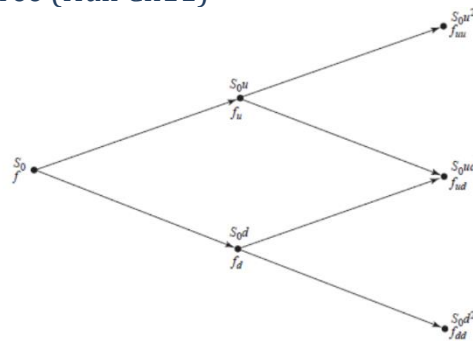
Bond: LIBOR, Duration. Forward rate.

Swaps & Swaptions.

- Credit Derivatives (Hull Ch 20,21)

Asset swaps, credit-default swaps

- Binomial, trinomial Tree (Hull Ch11)



Two-step Bi-tree

$$f = e^{-2r\Delta t} [p^2 f_{uu} + 2p(1-p) f_{ud} + (1-p)^2 f_{dd}]$$

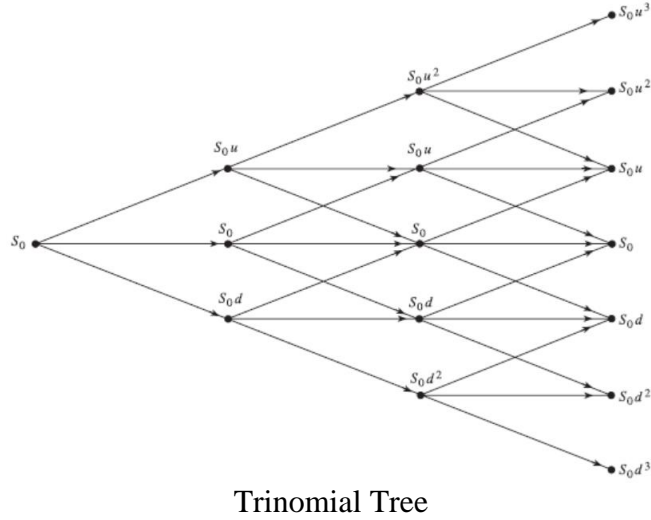
$$p = \frac{e^{r\Delta t} - d}{u - d}$$

p independent of the probabilities of S going up or down

For N step, $C =$

$$C = e^{-rN\Delta t} \sum_j \left[\binom{N}{j} q^j (1-q)^{N-j} (s_0 u^j d^{N-j} - K)_+ \right]$$

Let $N \rightarrow \infty$, assume lognormal, $S \Rightarrow BS$



- Stochastic Process

$$dX_t = a(X_t)dt + b(X_t)dW_t$$

Example (Heston Stochastic volatility model):

$$\frac{dS}{S} = rdt + \sqrt{V}dW$$

$$dV = a(b - V)dt + \sigma\sqrt{V}dW$$

Another risk models: Dupire – local volatility

Numerical methods:

Euler–Maruyama method

$$Y_{n+1} = Y_n + a(Y_n)\Delta t + b(Y_n)\Delta W_n$$

$\Delta W_n = W_{\tau_{n+1}} - W_{\tau_n}$ are iid $N(0, \Delta t)$

Milstein approximation

$$Y_{n+1} = Y_n + a(Y_n)\Delta t + b(Y_n)\Delta W_n + \frac{1}{2}b(Y_n)b'(Y_n)((\Delta W_n)^2 - \Delta t)$$

Runge–Kutta approximation

$$Y_{n+1} = Y_n + a(Y_n)\Delta t + b(Y_n)\Delta W_n + \frac{1}{2}(b(\gamma_n) - b(Y_n))((\Delta W_n)^2 - \Delta t)\sqrt{\Delta t}$$

Where $\Delta t = T/N$, $\gamma_n = Y_n + a(Y_n)\Delta t + b(Y_n)\sqrt{\Delta t}$

Girsanov Theorem:

For any function $\gamma(s)$

$$E \left[e^{\int_a^b \gamma(s) dw - \frac{1}{2} \int_a^b \gamma^2(s) ds} \right] = 1$$

Hence the Radon-Nikodym derivative on the path space has probability measures.

- Geometric random walk, Ito lemma (Hull Ch 12)

$$\frac{dS}{S} = \mu dt + \sigma dw$$

dw = wiener process. $S(t)$ = stock price. Solution

$$S_t = S_0 e^{\left(\mu + \frac{\sigma^2}{2}\right)t + \sigma W_t}$$

- Black-Scholes (Hull Ch13)

Apply Ito to option value $f(S, t)$

$$df(S, t) = \left(\frac{\partial f}{\partial S} \mu(S, t) S + \frac{\partial f}{\partial t} + \frac{1}{2} \frac{\partial^2 f}{\partial S^2} (\sigma S)^2 \right) dt + \frac{\partial f}{\partial S} (\sigma S) dw$$

Let Π be value of portfolio of one long option f and one short position S in some quantity Δ , i.e.

$$\Pi = f - \Delta S$$

Or

$$d\Pi = df - \Delta dS$$

With some manipulation, we arrive

$$d\Pi = \left(\frac{\partial f}{\partial S} - \Delta \right) dS + \left(\frac{\partial f}{\partial t} + \frac{1}{2} \frac{\partial^2 f}{\partial S^2} (\sigma S)^2 \right) dt$$

The first part dS contains Wiener random term, so we will choose $\Delta = \partial f / \partial S$, called Δ hedging, an example of dynamic hedging strategy, then

$$d\Pi = \left(\frac{\partial f}{\partial t} + \frac{1}{2} \frac{\partial^2 f}{\partial S^2} (\sigma S)^2 \right) dt$$

Set $d\Pi = r\Pi dt$, we get the BS equation

$$\frac{\partial f}{\partial t} + \frac{\partial f}{\partial S} rS + \frac{1}{2} \frac{\partial^2 f}{\partial S^2} (\sigma S)^2 = rf$$

2nd order pde need to 2 boundary conditions, see later section on finite-difference method

- Ornstein-Uhlenbeck Process – Vasicek interest rate model—mean reversion

$$dr = a(b - r)dt + \sigma dw$$

Solution

$$r = b + e^{-at}(r_0 + b) + \sigma \int_0^t e^{a(s-t)} dw(s)$$

With

$$\text{Mean} = b + e^{-at}(r_0 + b) \rightarrow b. \text{Var} = \frac{\sigma^2(1-e^{-2at})}{2a} \rightarrow \frac{\sigma^2}{2a}$$

- Cox-Ingersoll-Ross (CIR) model—short rate model—mean reversion – positive rate

$$dr_t = a(b - r_t)dt + \sigma\sqrt{r_t}dW_t$$

$$\text{Mean} = b + e^{-at}(r_0 - b) \rightarrow b. \text{Var} \rightarrow \frac{b\sigma^2}{2a}$$

- Jump diffusion Process

$$\frac{dS}{S} = \mu dt + \sigma dW + (q - 1)dJ$$

J is a Poisson process. Time between successive jumps are independent and exponentially distributed with parameter λ , $E[J_t] = \text{var}(J_t) = \lambda t$.

B-S equation becomes partial integro-differential equation

$$\frac{\partial V}{\partial t} + \frac{1}{2}\sigma^2 S^2 \frac{\partial^2 V}{\partial S^2} + (r - \lambda c)S \frac{\partial V}{\partial S} - (\lambda + r)V + \lambda E(V(qS, t)) = 0$$

18. Implied Volatility, Greeks (Hull Ch 15-16, 19)

Given option price, using BS to find => implied volatility

Greeks

$$\Delta = \frac{\partial f}{\partial S_0} \text{ (price movement)}$$

$$\gamma = \frac{\partial^2 f}{\partial S_0^2} \text{ (price movement)}$$

$$\theta = \frac{\partial f}{\partial (-T)} \text{ (time decay)}$$

$$\text{Vega} = \frac{\partial f}{\partial \sigma} \text{ (implied volatility)}$$

$$\rho = \frac{\partial f}{\partial r}$$

S_0 = stock price. For options on a forward rate, change S_0 to F_0

19. European option - vanilla (Hull Ch 14)

Call

When $t = T$

$$c = \max(S_T - K, 0)$$

or

$$c(t) = e^{-r(T-t)} \mathbb{E}[\max(S_T - K, 0)]$$

Using a key result (Hull, page 310)

$$\mathbb{E}[\max(S - K, 0)] = \mathbb{E}[S_T]N(d_1) - KN(d_2)$$

Assume S_T is lognormal wrt to $t = 0$,

$$c(t = 0) = S_0 N(d_1) - Ke^{-rT} N(d_2)$$

Where $N = \frac{\int_{-\infty}^x e^{-\frac{t^2}{2}} dt}{\sqrt{2\pi}}$

$$d_1 = \frac{\ln \frac{S_0}{K} + \left(r + \frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}} \quad d_2 = \frac{\ln \frac{S_0}{K} + \left(r - \frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}} = d_1 - \sigma\sqrt{T}$$

Monte Carlo

$$C = E \left[e^{-rT} \left(S_0 e^{\left(r - \frac{\sigma^2}{2}\right)T + \sigma\sqrt{T}Z} - K \right)_+ \right], \quad Z \sim N(0,1)$$

20. Exotic - path dependent

- Asian option

No dividend -> never exercise early (if deep in money, sell the options instead)

$$C = (AS_T - K, 0)_+$$

Average S can be continuous or discrete, arithmetic or geometric.

$$AS_{AC} = \frac{1}{T} \int_0^T S(t) dt \quad AS_{AD} = \frac{1}{N} \sum_{i=1}^N S(t_i)$$

$$AS_{GC} = e^{\left(\frac{1}{T} \int_0^T \ln(S(t)) dt\right)} \quad AS_{GD} = \left(\prod_{i=1}^N S(t_i) \right)^{\frac{1}{N}}$$

Geometric Asian AS_{GC} has a known analytic solution

$$C_{GC} = V_0 N(d_1) - e^{-rT} K N(d_2)$$

$$d_1 = \frac{1}{\sigma_{ave}\sqrt{T}} \log \left(\frac{V_0}{K} + \left(r + \frac{\sigma_{ave}^2}{2} \right) T \right), \quad d_2 = d_1 - \sigma_{ave}\sqrt{T}, \quad \sigma_{ave} = \frac{\sigma}{\sqrt{3}} \quad \sigma_{ave}$$

$$V_0 = e^{-\frac{1}{12}(6r+6q+\sigma^2)T} S_0$$

q = dividend yield

Monte Carlo

$$C = E \left[e^{-rT} \left(\frac{1}{m} \sum_{i=1}^m S_{iT} - K \right)_+ \right]$$

$$S_{\frac{iT}{m}} = S_0 e^{\left(r - \frac{\sigma^2}{2}\right)\frac{iT}{m} + \sigma \sqrt{\frac{T}{m}}(Z_1 + \dots + Z_i)}, \quad Z_1, \dots, Z_i \sim N(0,1)$$

- Double Barrier Option

$$C = \begin{cases} (S_T - K_1)^+ & S_{T/2} \leq L \\ (S_T - K_2)^+ & \text{otherwise} \end{cases}$$

- Lookback Option

$$C = (S_{\max} - K)^+$$

21. Variance Reduction Techniques

- Antithetic Variates

Use n 2-pair of paths

$$S(t_i + \Delta t)_\pm = S(t_i)(1 + r\Delta t \pm \sigma\sqrt{\Delta t}Z_{i+1})$$

To get S_T , then the estimator $Y = e^{-rT}(S_{T\pm} - K)_+$ for European option. The standard deviation of Y from the $2n$ paths (related to confidence interval) is

$$\frac{\text{std}\left(\frac{Y_{T+} + Y_{T-}}{2}\right)}{\sqrt{n}}$$

- Control Variates

We need to estimate Y and to reduce $\text{Var}(Y)$. Instead of estimating Y , we estimate

$$\theta = Y - c(Z - E(Z))$$

because $E[Y] = E[\theta]$. To make $\text{Var}(\theta)$ small, we choose

$$c = \frac{\text{Cov}(Y, Z)}{\text{Var}(Z)}$$

Hence the slope of linear regression of (Z, Y) . The higher $\text{Corr}(Y, Z)$, the more reduction it gets

Step 0. Pick a Z . Z can be S_T (most reduction), AS_{AD}

Step 1. Pilot simulation. Generate 100 (Y, Z) . Compute c

Step 2. Main simulation. Generate 900 (Y, Z) . Use above c , get 900 θ . Then report $E[\theta]$, $\text{Var}[\theta]$

- **Stratified Sampling**

- Proportion Stratification

Let \mathcal{I} be some non-overlapping partition of Y . One can get variance reduction, instead of estimating

$$E[Y]$$

By estimating

$$\sum_{I \in \mathcal{I}} E[Y|I]E[I] = E[Y]$$

and treating $E[I]$ from analytically known value, then estimating $\text{Var}(Y)$ becomes estimating

$$\sum_{I \in \mathcal{I}} \text{Var}(E[Y|I])E[I]$$

and we know it's $< \text{Var}(Y)$, because of the identity

$$\text{Var}(Y) = \sum_{I \in \mathcal{I}} \text{Var}(E[Y|I])E[I] + E[\text{Var}(Y|I)]$$

- Terminal Stratification & Brownian Bridge

Up-and-out option, say we first generate the mid points of the paths, $W_{T/2} \sim N(0, T/2)$. If that results $S_{T/2} > L$, we can forget the entire path. That is after generating useful W_T , we go backward to generate $(W_h|W_0, W_T)$, $(W_{2h}|W_h, W_T)$, \dots , $(W_{T-h}|W_{T-2h}, W_T)$, using the following Brownian bridge formula

$$(W_t|W_u = x, W_v = y) \sim N\left(\frac{(v-t)x + (t-u)y}{v-u}, \frac{(v-t)(u-t)}{v-u}\right) \text{ for } u < t < v$$

- **Importance Sampling**

Monte Carlo says to evaluate $E_f[h(X)]$, first generate a bunch of X_i satisfying the probability density function $f(x)$, then compute

$$\text{mean}(h(X_i)) \approx E_f[h(X)]$$

By the following identity

$$E_f[h(X)] = \int h(x)f(x)dx = \int h(x)\frac{f(x)}{g(x)}g(x)dx = E_g\left[\frac{h(X)f(X)}{g(X)}\right]$$

One can equivalently generate a bunch of X_i accord to the probability density function g , then compute

$$\text{mean}\left(\frac{h(X_i)f(X_i)}{g(X_i)}\right) \approx E_f[h(X)]$$

To achieve a variance reduction,

$$\text{Var}_f(h(X_i)) - \text{Var}_g\left(\frac{h(X_i)f(X_i)}{g(X_i)}\right) = \int h^2(x) \left(1 - \frac{f(x)}{g(x)}\right) f(x) dx > 0$$

Since f, g are pdf, we cannot force $f < g \forall x$. We want to pick a g such that $f < g$ on the support where hf are large; $f > g$ when hf are small.

22. Quasi-Monte Carlo Method

- Low Discrepancy Sequences

Let \mathcal{A} be collection of rectangles of the form

$$\prod_{j=1}^d [u_j, v_j), \quad 0 \leq u_j < v_j \leq 1$$

The discrepancy of a sequence $D(x_1, \dots, x_n; \mathcal{A})$ relative to \mathcal{A} is

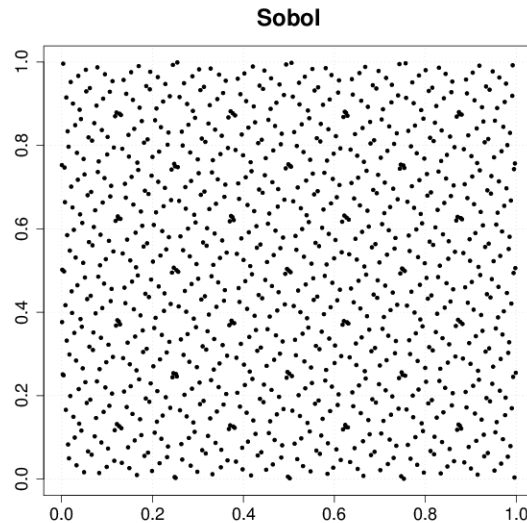
$$D(x_1, x_2, \dots, x_n; A) = \sup_{A \in \mathcal{A}} \left| \frac{\#\{x_i \in A\}}{n} - \text{vol}(A) \right|$$

Implementation: Sobol sequence

Stephen Joe, Frances Y. Kuo, [Notes on generating Sobol sequences](#)

Source code by John Burkardt: [C++\(test\)](#),

by Corrado Chisari, [Python\(test\)](#)



Picture from <http://doc.openturns.org/openturns-latest/html/UseCasesGuide/cid3.xhtml>

23. America & Bermudian Options

The formulas, in this section, are copied from Paul Wilmott on *Quantitative Finance 3 Volume Set*, section 78

Write BS as

$$\frac{\partial V}{\partial t} + \underbrace{\frac{1}{2}\sigma^2 S^2}_{a(S,t)} \frac{\partial^2 V}{\partial S^2} + \underbrace{rS}_{b(S,t)} \frac{\partial V}{\partial S} + \underbrace{(-r)}_{c(S,t)} V = 0$$

- Explicit Finite Difference Method (forward in time)

Time derivative is right derivative,

$$\frac{V_i^k - V_i^{k+1}}{\delta t} + a_i^k \left(\frac{V_{i+1}^k - 2V_i^k + V_{i-1}^k}{\delta S^2} \right) + b_i^k \left(\frac{V_{i+1}^k - V_{i-1}^k}{2\delta S} \right) + c_i^k V_i^k = O(\delta t, \delta S^2)$$

k decreases as time goes, i in stock prices, then

$$\begin{aligned} V_i^{k+1} &= A_i^k V_{i-1}^k + (1 + B_i^k) V_i^k + C_i^k V_{i+1}^k \\ A_i^k &= v_1 a_i^k - \frac{1}{2} v_2 b_i^k, \quad B_i^k = -2v_1 a_i^k + \delta t c_i^k \\ C_i^k &= v_1 a_i^k + \frac{1}{2} v_2 b_i^k \\ v_1 &= \frac{\delta t}{\delta S^2}, \quad v_2 = \frac{\delta t}{\delta S} \end{aligned}$$

With 2 boundary conditions: $\forall k, S = 0, V = 0; S \rightarrow \infty, V = S - Ke^{-r(T-t)}$

With initial condition: $V = \text{payoff at } k = T$ for given S_T . If S_T not on the grid, uses linear interpolation.

The solution is stable iff

$$\delta t \leq \frac{\delta S^2}{2a} = \frac{1}{\sigma^2} \left(\frac{\delta S}{S} \right)^2$$

- Implicit Finite Difference Method

Now we let k increase as time goes, i.e. the time derivative is left derivative, which is amount to switch $k \leftarrow \rightarrow k+1$ above

- Crank–Nicolson Finite Difference Method

Take average of (im + explicit FD) => Crank–Nicolson

$$-A_i^{k+1} V_{i-1}^{k+1} + (1 - B_i^{k+1}) V_i^{k+1} - C_i^{k+1} V_{i+1}^{k+1} = A_i^k V_{i-1}^k + (1 + B_i^k) V_i^k + C_i^k V_{i+1}^k$$

Where

$$A_i^k = \frac{1}{2}v_1a_i^k - \frac{1}{4}v_2b_i^k = \frac{A_{i \text{ before}}^k}{2}, \quad B_i^k = -v_1a_i^k + \frac{1}{2}\delta tc_i^k = \frac{B_{i \text{ before}}^k}{2}$$

$$C_i^k = \frac{1}{2}v_1a_i^k + \frac{1}{4}v_2b_i^k = \frac{C_{i \text{ before}}^k}{2}$$

And stability holds for all $\Delta t > 0$.

- Successive Over-Relaxation (SOR)

Suppose we solve a matrix equation for v

$$Mv = 1$$

Gauss-Seidel iterative method

$$v_i^{n+1} = \frac{1}{M_{ii}} \left(q_i - \sum_{j=1}^{i-1} M_{ij}v_j^{n+1} - \sum_{j=i+1}^N M_{ij}v_j^n \right)$$

with some initial guess v^0 . SOR method improve convergence speed with over-relaxation parameter $\omega \in [1,2]$

$$v_i^{n+1} = v_i^n + \frac{\omega}{M_{ii}} \left(q_i - \sum_{j=1}^{i-1} M_{ij}v_j^{n+1} - \sum_{j=i+1}^N M_{ij}v_j^n \right)$$

Try adjusting ω , to get the best convergence.

Projected SOR for early exercise

$$v_i^{n+1} = \max \left(v_i^n + \frac{\omega}{M_{ii}} \left(q_i - \sum_{j=1}^{i-1} M_{ij}v_j^{n+1} - \sum_{j=i+1}^N M_{ij}v_j^n \right), \text{payoff} \right)$$

- Parallel LU algorithms of computing band matrices (tridiagonal matrix)

[See My Numerical Analysis Note](#)

(Algorithmic) Stock/ETF Option Trading (Buy Side)

24.Chat Readings

- Dow theory
volume dictates trend: higher high / lower low / sideways, three phases, trend break
- Chat Patterns
head, shoulders, double / triple top, double bottom, rising / falling wedges, symmetrical / right angled / descending triangle, pennants, flags, supports, resistance, rectangle, diamond
- Bar Pattern
two bar reversal, outside / inside bar, exhaustion bar, gaps: breakaway / runaway / exhaustion / common

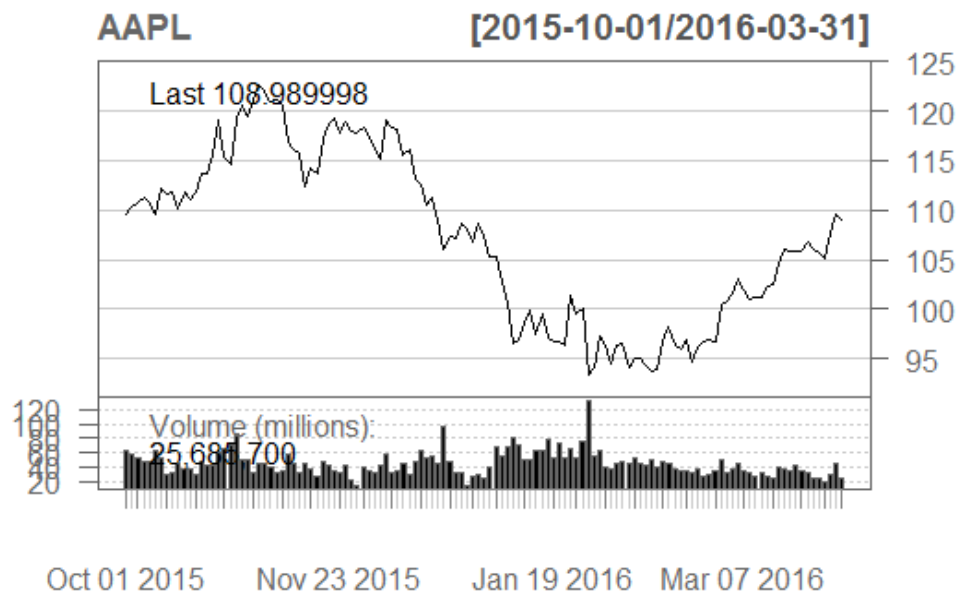
```
library(quantmod)
getSymbols("AAPL", src="yahoo")

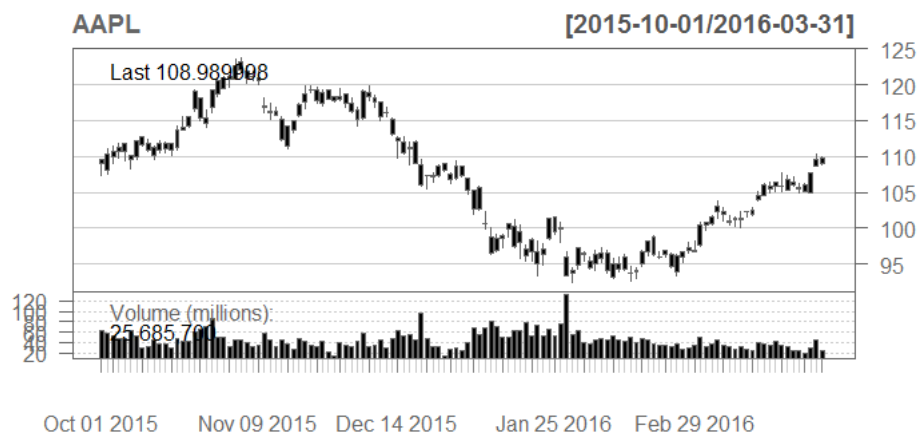
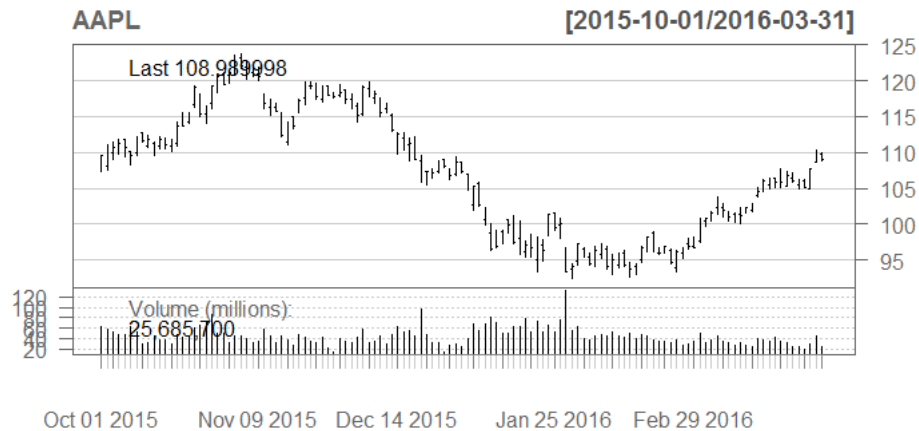
lineChart(AAPL,theme = "white.mono", subset = "last 6 month")

barChart(AAPL,theme='white.mono', subset = "last 6 month")

candleChart(AAPL,theme='white.mono', subset = "last 6 month")

#price in log
lineChart(AAPL,theme = "white", log.scale = T)
```

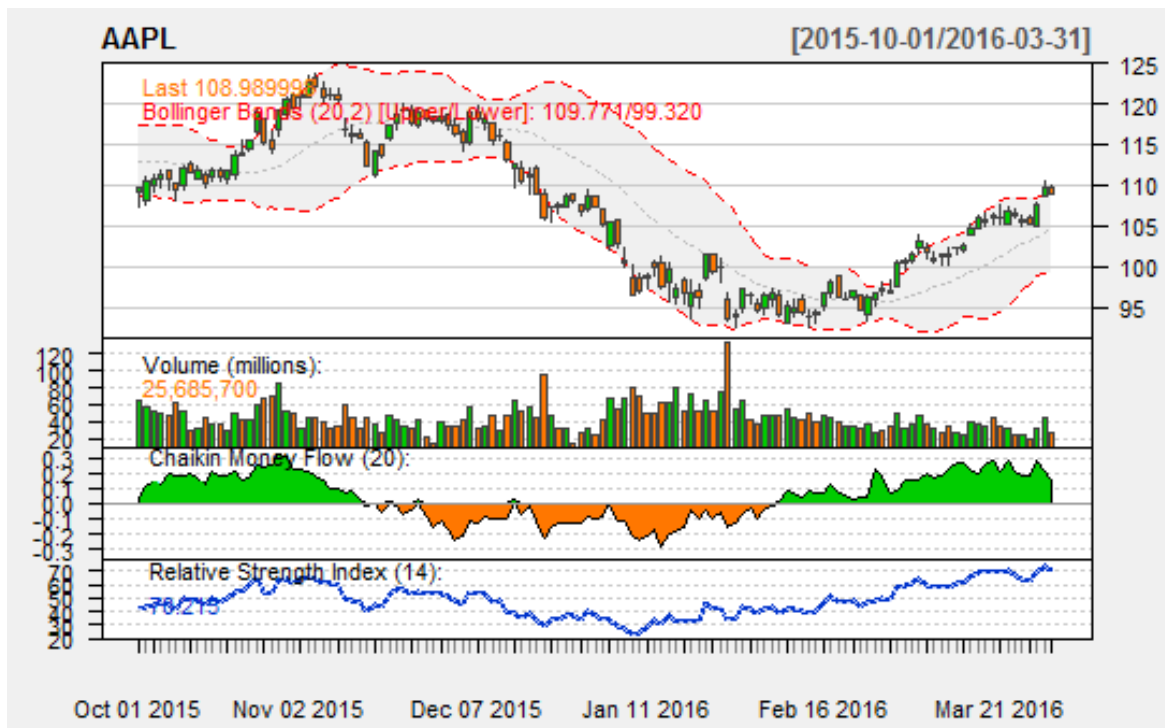




- Leading Indicators: relative strength(addRSI), stochastic oscillator(addSMI, addCMO, addDPO, addTRIX), commodity channel Index(addCCI), Williams %R(addWPR)
- Lagging Indicators: moving average(addDEMA, addEMA, addEVWMA, addSMA) , Bollinger Bands(addBBands), Welles Wilder's (addADX) , Parabolic (addSAR), Moving Average Convergence Divergence(addMACD)
- 4 types of indicators
oscillators (centered: rate of change, CCI, banded: RSI, Stochastic), trend(lagging)/momentum (MACD), volatility (Bollinger, Chaikin), volume (On-Balance Volume)

```
library(quantmod)
getSymbols("AAPL", src="yahoo")

chartSeries(AAPL, theme="white",
            TA=c(addVo(), addCMF(), addBBands(), addRSI()), subset='last 6
months')
```



- Elliott wave(fibonacci), Daylight (use Golden Ratio), Neural Network Trading Strategy

See Machine Learning Note – Neural Network Algorithms

- News Sentiment

See Machine Learning Note – Natural Language Processing

25.On-line trading: Quantopian open, interactive Brokers, TDAmeritrade, MetaTrader, Forex

26.Common Trading Algorithms

- Based on sectional PE Fundamental Data

Code modified from <https://www.quantopian.com/help>

```
"""
1. Filter the top 100 companies by market cap
2. Find the top two sectors that have the highest average PE ratio
3. Every month clear the book before entering new ones
"""

import numpy as np

def initialize(context):
    # Dictionary of stocks and their respective weights
    context.stock_weights = {}
    # Count of days before rebalancing
```



```

context.days = 0
# Number of sectors to go long in
context.sect_numb = 2

# Sector mappings
context.sector_mappings = {
    101.0: "Basic Materials",
    102.0: "Consumer Cyclical",
    103.0: "Financial Services",
    104.0: "Real Estate",
    205.0: "Consumer Defensive",
    206.0: "Healthcare",
    207.0: "Utilities",
    308.0: "Communication Services",
    309.0: "Energy",
    310.0: "Industrials",
    311.0: "Technology"
}

# Rebalance monthly on the first day of the month at market open
schedule_function(rebalance,
                  date_rule=date_rules.month_start(),
                  time_rule=time_rules.market_open())

schedule_function(record_positions,
                  date_rule=date_rules.month_start(),
                  time_rule=time_rules.market_close())

"""
Called before the start of each trading day.
"""
def before_trading_start(context, data):

    num_stocks = 100

    # Setup SQLAlchemy query to screen stocks based on PE ratio
    # and industry sector. Then filter results based on market cap
    # and shares outstanding. We limit the number of results to
    # num_stocks and return the data in descending order.
    fundamental_df = get_fundamentals(
        query(
            fundamentals.valuation_ratios.pe_ratio,
            fundamentals.asset_classification.morningstar_sector_code
        )
        .filter(fundamentals.valuation.market_cap != None)
        .filter(fundamentals.valuation.shares_outstanding != None)
        .order_by(fundamentals.valuation.market_cap.desc())
        .limit(num_stocks)
    )

    # Find sectors with the highest average PE
    sector_pe_dict = {}
    for stock in fundamental_df:
        sector = fundamental_df[stock]['morningstar_sector_code']
        pe = fundamental_df[stock]['pe_ratio']

        # If it exists add our pe to the existing list.
        # Otherwise don't add it.

```

```

        if sector not in sector_pe_dict:
            sector_pe_dict[sector] = []

        sector_pe_dict[sector].append(pe)

    # Find average PE per sector
    sector_pe_dict = dict([
        (sectors, np.average(sector_pe_dict[sectors]))
        for sectors in sector_pe_dict
        if len(sector_pe_dict[sectors]) > 0
    ])

    # Sort in ascending order
    sectors = sorted(
        sector_pe_dict,
        key=lambda x: sector_pe_dict[x],
        reverse=True
   )[:context.sect_num]

    # Filter out only stocks with that particular sector
    context.stocks = [
        stock for stock in fundamental_df
        if fundamental_df[stock]['morningstar_sector_code'] in sectors
    ]

    # Initialize a context.sectors variable
    context.sectors = [context.sector_mappings[sect] for sect in sectors]

    # Update context.fundamental_df with the securities (and pe_ratio)
    # that we need
    context.fundamental_df = fundamental_df[context.stocks]

def create_weights(stocks):
    """
    Takes in a list of securities and weights them all equally
    """
    if len(stocks) == 0:
        return 0
    else:
        weight = 1.0 / len(stocks)
        return weight

def rebalance(context, data):
    # Exit all positions before starting new ones
    for stock in context.portfolio.positions:
        if stock not in context.fundamental_df and data.can_trade(stock):
            order_target_percent(stock, 0)

    # Create weights for each stock
    weight = create_weights(context.stocks)

    # Rebalance all stocks to target weights
    for stock in context.fundamental_df:
        if data.can_trade(stock):
            if weight != 0:
                code = context.sector_mappings[
                    context.fundamental_df[stock]['morningstar_sector_code']]

```

```

        ]
        order_target_percent(stock, weight)

def handle_data(context, data):
    """
    Call every minute by the Quantopian simulation engine
    """
    pass

```

- Mean reversion

Code copied from <https://www.quantopian.com/help>

```

"""
It orders stocks from the top 1% of the previous day's dollar-volume (liquid
stocks).

Hypotheses:
Top-performing stocks from last week will do worse this week, and vice-versa.

On each Monday rank high dollar-volume stocks based on their previous week

Long the bottom 10% of stocks with the WORST returns
Short the top 10% of stocks with the BEST returns

This algorithm can be used in live trading, in the Quantopian Open.
"""

from quantopian.algorithm import attach_pipeline, pipeline_output
from quantopian.pipeline import Pipeline
from quantopian.pipeline.data.builtin import USEquityPricing
from quantopian.pipeline.factors import AverageDollarVolume, Returns

def initialize(context):
    context.long_leverage = 0.5
    context.short_leverage = -0.5
    context.returns_lookback = 5

    # Rebalance on the first trading day of each week at 11AM.
    schedule_function(rebalance,
                      date_rules.week_start(days_offset=0),
                      time_rules.market_open(hours=1, minutes=30))

    # Record tracking variables at the end of each day.
    schedule_function(record_vars,
                      date_rules.every_day(),
                      time_rules.market_close(minutes=1))

    # Create and attach our pipeline (dynamic stock selector), defined below.
    attach_pipeline(make_pipeline(context), 'mean_reversion_example')

def make_pipeline(context):
    pipe = Pipeline()

    # Create a dollar_volume factor using default inputs and window_length.

```

```

# This is a builtin factor.
dollar_volume = AverageDollarVolume(window_length=1)
pipe.add(dollar_volume, 'dollar_volume')

# Create a recent_returns factor with a 5-day returns lookback. This is
# a custom factor defined below (see RecentReturns class).
recent_returns = Returns(window_length=context.returns_lookback)
pipe.add(recent_returns, 'recent_returns')

# Define high dollar-volume filter to be the top 5% of stocks by dollar volume.
high_dollar_volume = dollar_volume.percentile_between(95, 100)

# Define high and low returns filters to be the bottom 10% and top 10% of
# securities in the high dollar-volume group.
low_returns = recent_returns.percentile_between(0,10,mask=high_dollar_volume)
high_returns =
recent_returns.percentile_between(90,100,mask=high_dollar_volume)

# Factors return a scalar value for each security in the entire universe
# of securities.
pipe.add(recent_returns.rank(mask=high_dollar_volume), 'recent_returns_rank')

# Add a filter to the pipeline such that only high-return and low-return
# securities are kept.
pipe.set_screen(low_returns | high_returns)

# Add the low_returns and high_returns filters as columns to the pipeline
pipe.add(low_returns, 'low_returns')
pipe.add(high_returns, 'high_returns')

return pipe

def before_trading_start(context, data):
    """
    Called every day before market open.
    """

    # Pipeline_output
    context.output = pipeline_output('mean_reversion_example')

    # Sets the list of securities we want to long as the securities with a 'True'
    # value in the low_returns column.
    context.long_secs = context.output[context.output['low_returns']]

    # Sets the list of securities we want to short as the securities with a 'True'
    # value in the high_returns column.
    context.short_secs = context.output[context.output['high_returns']]

    # A list of the securities that we want to order today.
    context.security_list =
context.long_secs.index.union(context.short_secs.index).tolist()

    # A set of the same securities, sets have faster lookup.
    context.security_set = set(context.security_list)

def assign_weights(context):
    """

```

```

Assign weights to long and short target positions.
"""

# Set the allocations to even weights for each long position, and even weights
# for each short position.
context.long_weight = context.long_leverage / len(context.long_secs)
context.short_weight = context.short_leverage / len(context.short_secs)

def rebalance(context, data):
    """
    This rebalancing function is called according to our schedule_function
    settings.
    """

    assign_weights(context)

    # For each security in our universe, order long or short positions according
    # to our context.long_secs and context.short_secs lists.
    for stock in context.security_list:
        if data.can_trade(stock):
            if stock in context.long_secs.index:
                order_target_percent(stock, context.long_weight)
            elif stock in context.short_secs.index:
                order_target_percent(stock, context.short_weight)

    # Sell all previously held positions not in our new context.security_list.
    for stock in context.portfolio.positions:
        if stock not in context.security_set and data.can_trade(stock):
            order_target_percent(stock, 0)

    # Log the long and short orders each week.
    log.info("This week's longs: "+", ".join([long_.symbol for long_ in
context.long_secs.index]))
    log.info("This week's shorts: " +", ".join([short_.symbol for short_ in
context.short_secs.index]))

def record_vars(context, data):
    """
    This function is called at the end of each day and plots certain variables.
    """

    # Check how many long and short positions we have.
    longs = shorts = 0
    for position in context.portfolio.positions.itervalues():
        if position.amount > 0:
            longs += 1
        if position.amount < 0:
            shorts += 1

    # Record and plot the leverage of our portfolio over time as well as the
    # number of long and short positions. Even in minute mode, only the end-of-day
    # leverage is plotted.
    record(leverage = context.account.leverage, long_count=longs,
short_count=shorts)

def handle_data(context, data):

```

27.Data Set

From <https://www.quantopian.com/data>

- Stock, Option, Future, Index, Economic
 - Quandl <https://www.quandl.com/browse?idx=database-browser>
- Analyst Estimates, Consensus Estimates
 - Estimote <https://www.estimize.com/api>
- Fundamental
 - EPS, Revenue, and Future Earnings Dates -- Benzinga
<http://cloud.benzinga.com/corporate-and-market-financial-data/>
- Company Events
 - Spin-Offs, Lawsuit, Earnings Releases, Buyback Authorizations -- EventVestor
<http://www.eventvestor.com/>
- Sentiment:
 - StockTweets Trader Mood -- PsychSignal <https://psychsignal.com/hivemind/>,
 - Sentiment Analysis -- SentDex <http://sentdex.com/financial-analysis>
 - News Sentiment -- Accern <https://www.accern.com/>

28.Options Trading Strategies

- 4 types: long call (outlook bullish, like movement), short call, long put (bearish), short put
- Greek:
 - moneyness: delta call—(0,1), put—(0,-1); OTM—(0,0.5), ITM—(0.5,1) probability of ending in the money
 - + gamma => buyer want underlying price to move, gamma increases as time run out
 - time decay: OTM option extrinsic value decays faster than ITM, bad for buyers; theta increases as time running out
 - implied volatility decreases as K increases; vega higher ATM, long expiry; buyers outlook higher vix (+ vega)
- Option Adjustment
 - Open interest => liquidity, find support resistance
 - delta neutral, outlook changed
 - Adjust long call => long strangle, bull call spread
 - Adjust short call => short strangle, bull call, bear call spread
 - Adjust long put => long strangle, bear put spread
 - Adjust short put => short strangle, bull put spread
- Other strategies
 - Butterfly = long ls put + short ms put + short ms put + long hs put
 - Iron Condor = long ls put + short ms put + short ms call + long hs call

Reference

29. Books

- John. C. Hull, *Options, Futures, and Other Derivatives* (with [Excel code](#)), 6th edition, Prentice Hall, 2006
- Paul Glasserman, *Monte Carlo Methods in Financial Engineering*, Springer 2013, Columbia Business School
- Benjamin Graham, *The Intelligent Investor*, Columbia Business School
- Mark. S. Joshi, *C++ Design Patterns and Derivatives Pricing* (with [C++ code](#)), 2nd edition, Wiley, 2008
- Paolo Brandimarte, *Handbook in Monte Carlo Simulation: Applications in Financial Engineering, Risk Management, and Economics* (with [R & Matlab code](#)), Wiley, 2014.
- Robert Shumway, David Stoffer, *Time Series Analysis and Its Applications* (with [R code](#)), Springer 2010
- CFA I, II curriculum: Quantitative Method, Equity, Fixed Income, Derivatives, and Portfolio Management.

30. Courses

- Martin Haugh, [Monte Carlo Simulation](#), Columbia University
- Robert Kohn, Steve Allen, [Derivative Securities](#), New York University
- Marco Avellaneda, [Risk and Portfolio Management with Econometrics](#), New York University
- Peter Carr, Bruno Dupire, [Continuous Time Finance](#), New York University
- Leonid Kogan, [Analytics of Finance](#) (with [M code](#)), MIT
- Peter Kempthorne, Choongbum Lee, Vasily Strela, Jake Xia, [Topics in Mathematics with Applications in Finance](#) (with [R code](#)), MIT
- Cliburn Chan, Janice McCarthy, [Statistical Programming](#) (with [Python code](#)), Duke University

31. On-line Course

- Jose Portilla, [Learning Python for Data Analysis and Visualization](#) (with [Python code](#)), Udemy
- Martin Haugh, Garud Iyengar, [Financial Engineering and Risk Management Part I](#), Coursera, Columbia University
- Martin Haugh, Garud Iyengar, [Financial Engineering and Risk Management Part II](#), Coursera, Columbia University
- Eric Zivot, [Introduction to Computational Finance and Financial Econometrics](#) (with [R code](#)), Coursera, University of Washington
- Brian Caffo, [Statistical Inference](#), Coursera, Johns Hopkins University
- Brian Caffo, [Regression Models](#), Coursera, Johns Hopkins University
- Jeff Leek, [Practical Machine Learning](#), Coursera, Johns Hopkins University

32.Data

- <http://www.cboe.com/>
- <http://www.idc.com/>
- <https://research.stlouisfed.org/>
- <http://ichart.finance.yahoo.com/table.csv?s=IBM>

33.Competition & Conference

- [WorldQuant Alphathon 2016](#)
- [QuantoPian Hackathon 2016](#)
- [Princeton Chicago Quant Trading Conference](#)