Lecture 21

Produced by Dr. Worldwide

Welcome to the 305

Multiple Maxima/Minima

- When solving non-linear problems, it is important to consider the possibility that there may be multiple local solutions (maxima/minima)
- There is no method that guarantees we find all such points
- In problems not guaranteed to have a unique interior optimal solution, it is a good idea to run the GRG algorithm starting at several initial points
- Consider the following nonlinear problem

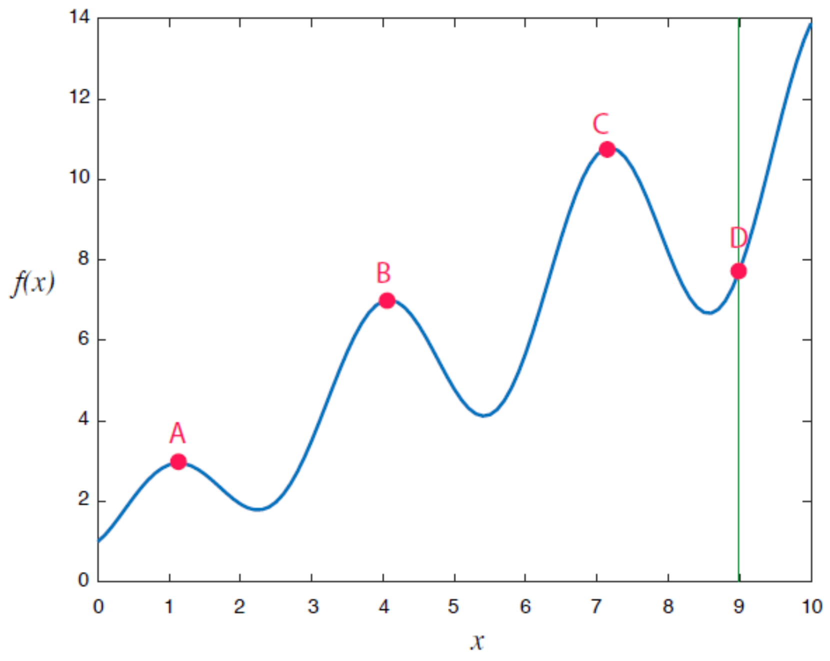
Maximize	$f(x) = 1 + x + \sqrt{x}\sin(2x)$
Subject to	$0 \leq x \leq 9$

Multiple Maxima/Minima

- Consider the graph
  $f(x) = 1 + x + \sqrt{x}\sin(2x)$
- Four different local maxima
- Q: What is the answer to our problem?

Maximize $f(x) = 1 + x + \sqrt{x}\sin(2x)$

Subject to $0 \leq x \leq 9$



Multiple Maxima/Minima

- Download MultipleMaxima.xlsx from link Sheet 1 on course website

- Consider the following part of the spreadsheet

26	Starting Value	Objective Function
27	0	1

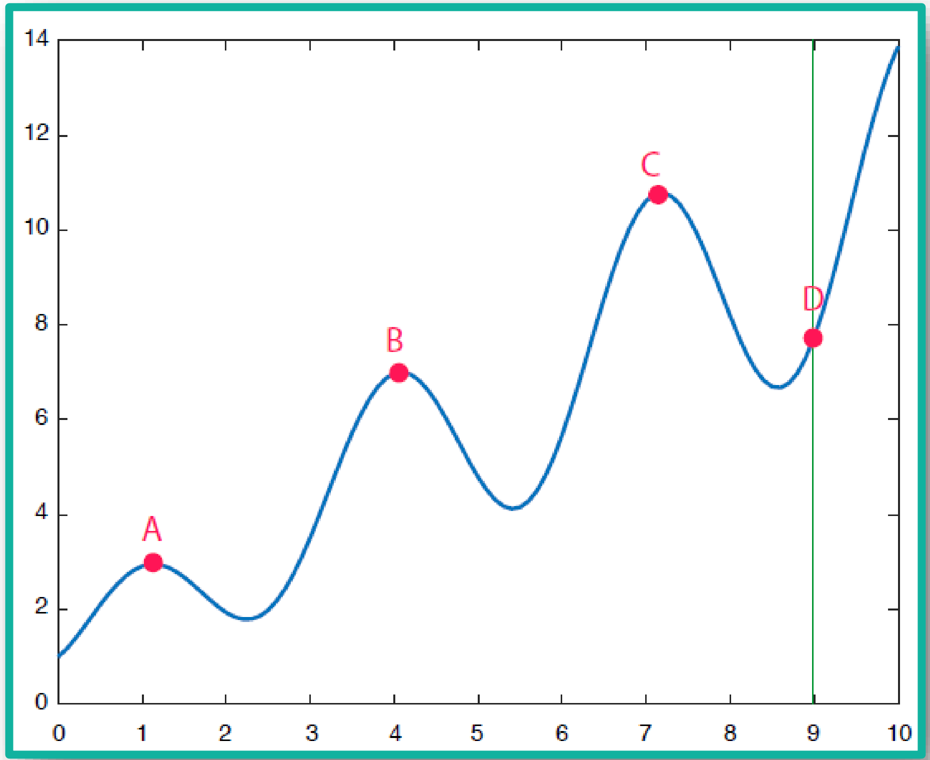
- Run solver with four different starting values

$x = 0, \qquad x = 4, \qquad x = 8, \qquad x = 9$

- Q: Do all four starting values lead to the same solution?

Multiple Maxima/Minima

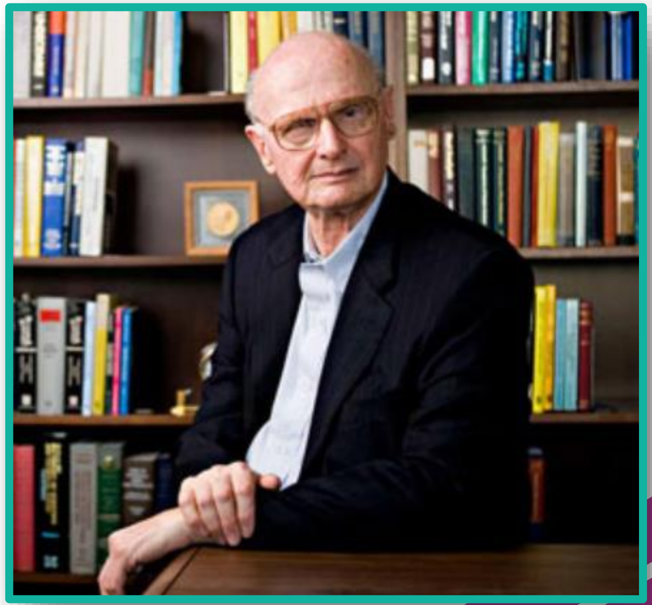
- Optimal solution under all initial values
- Q: Do the answers make sense?



Starting Values	Optimal Solution	Maxima
0	1.13	2.95
4	4.08	7.01
8	7.18	10.79
9	9	7.75

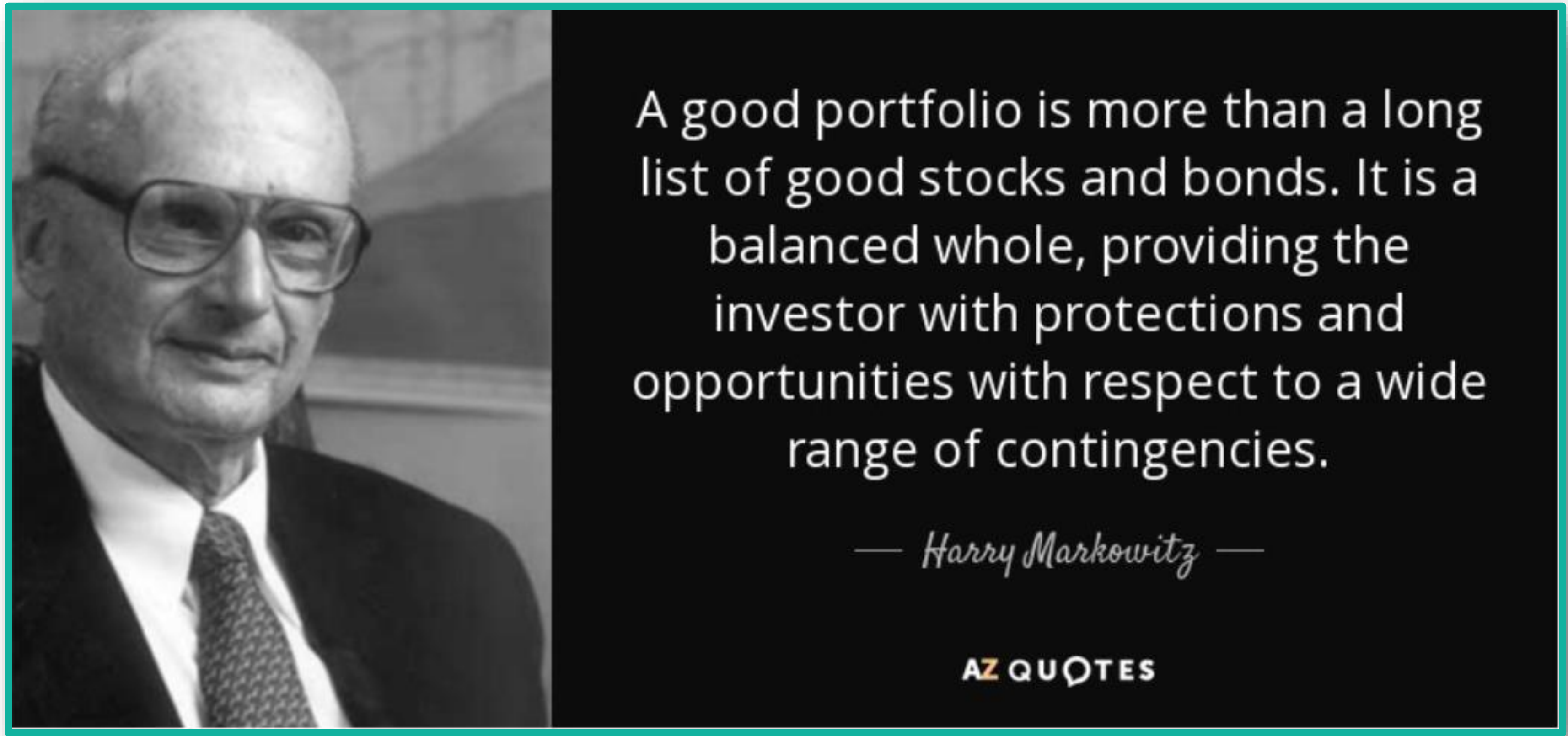
Ex: Investment Portfolio

- An investor can choose among *n* different investment opportunities
- An investment portfolio is a selection of how much to invest in each option
- Popular model for portfolios is the Markowitz model
  - Minimize risk (variance of the portfolio)
  - Maximize return on investment
- Different investments are assumed to be correlated
  - Positively correlated
  - Negatively correlated
- Diversification protects against these correlations



Ex: Investment Portfolio

- Dope quote from Harry Markowitz



Ex: Investment Portfolio

- Let x_i denote the proportion of money invested in option $i \in \{1,2,\cdots,n\}$
- Let σ_i^2 denote the variance of investment option $i \in \{1,2,\cdots,n\}$
- Let ρ_{ij} denote the correlation between investment option $i \in \{1,2,\cdots,n\}$ and investment option j $\in \{1,2,\cdots,n\}$ where i $\neq$ j
- The variance of the portfolio is given by

$$S = x_1^2\sigma_1^2 + x_2^2\sigma_2^2 + \cdots + x_n^2\sigma_n^2 + \sum_{i=1}^{n} \sum_{1\le j\le n, j\ne i} x_i x_j \rho_{ij}\sigma_i\sigma_j$$

$$= (x_1, x_2, \ldots, x_n) \begin{bmatrix} \sigma_1^2 & \rho_{12}\sigma_1\sigma_2 & \ldots & \rho_{1n}\sigma_1\sigma_n \\ \rho_{21}\sigma_2\sigma_1 & \sigma_2^2 & \ldots & \rho_{2n}\sigma_2\sigma_n \\ \vdots & \vdots & \ldots & \vdots \\ \rho_{n1}\sigma_n\sigma_1 & \rho_{n2}\sigma_n\sigma_2 & \ldots & \sigma_n^2 \end{bmatrix} \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{pmatrix}$$

Ex: Investment Portfolio

- Let r_i denote the expected return on investment of option $i \in \{1,2,\cdots,n\}$

- Expected return on investment from the portfolio is given by

$$R = r_1x_1 + r_2x_2 + \cdots + r_nx_n = (r_1, r_2, \ldots, r_n)\begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{pmatrix}$$

- Vector/Matrix notation
  - $\boldsymbol{x}' = [x_1, x_2, \cdots, x_n]$ (Vector of decision variables of portfolio)
  - $\boldsymbol{r}' = [r_1, r_2, \cdots, r_n]$ (Vector of expected returns)
  - $\boldsymbol{\Sigma} = \begin{bmatrix} \sigma_1^2 & \rho_{12}\sigma_1\sigma_2 & \ldots & \rho_{1n}\sigma_1\sigma_n \\ \rho_{21}\sigma_2\sigma_1 & \sigma_2^2 & \ldots & \rho_{2n}\sigma_2\sigma_n \\ \vdots & \vdots & \ldots & \vdots \\ \rho_{n1}\sigma_n\sigma_1 & \rho_{n2}\sigma_n\sigma_2 & \ldots & \sigma_n^2 \end{bmatrix}$ (Variance/covariance matrix)

Ex: Investment Portfolio

- The nonlinear program we desire to solve

Minimize	$\boldsymbol{x}'\boldsymbol{\Sigma}\mathbf{x}$
Subject to	$\boldsymbol{r}'\mathbf{x} \geq r_m$ $x_1 + x_2 + \cdots + x_n = 1$ $x_i \geq 0$

- Objective function is nonlinear and quadratic
- Q: What are the units of the different values $x_1, x_2, \cdots, x_n$?
- Q: What does r_m represent in this linear program?

Ex: Investment Portfolio

- Suppose an investor wants to build a portfolio from the following stocks:

Stock (x_i)	**Annual return** (r_i)	**Variance**
1. Altacam	.08	.009
2. Bestco	.09	.015
3. Com.com	.16	.040
4. Delphi	.12	.023

- Consider the correlation matrix of the stocks

$$\begin{bmatrix} 1 & \rho_{12} & \rho_{13} & \rho_{14} \\ \rho_{21} & 1 & \rho_{23} & \rho_{24} \\ \rho_{31} & \rho_{32} & 1 & \rho_{34} \\ \rho_{41} & \rho_{42} & \rho_{43} & 1 \end{bmatrix} = \begin{bmatrix} 1 & .4 & .3 & .6 \\ .4 & 1 & .2 & .7 \\ .3 & .2 & 1 & .4 \\ .6 & .7 & .4 & 1 \end{bmatrix}$$

Ex: Investment Portfolio

- The covariance matrix can be computed as follows:

$$\Sigma = \begin{bmatrix} \sigma_1^2 & \rho_{12}\sigma_1\sigma_2 & \rho_{13}\sigma_1\sigma_3 & \rho_{14}\sigma_1\sigma_4 \\ \rho_{21}\sigma_2\sigma_1 & \sigma_2^2 & \rho_{23}\sigma_2\sigma_3 & \rho_{23}\sigma_2\sigma_4 \\ \rho_{31}\sigma_3\sigma_1 & \rho_{32}\sigma_3\sigma_2 & \sigma_3^2 & \rho_{34}\sigma_3\sigma_4 \\ \rho_{41}\sigma_4\sigma_1 & \rho_{42}\sigma_4\sigma_2 & \rho_{43}\sigma_4\sigma_3 & \sigma_4^2 \end{bmatrix}$$

$$= \begin{bmatrix} 0.009 & 0.00464758 & 0.0056921 & 0.008632497 \\ 0.00464758 & 0.015 & 0.004898979 & 0.013001923 \\ 0.0056921 & 0.004898979 & 0.04 & 0.012132601 \\ 0.008632497 & 0.013001923 & 0.012132601 & 0.023 \end{bmatrix}$$

- The investor wants a total annual return of at least 0.11 (11%)

- Download Markowitz.xlsx from link Sheet 2 on course website

Ex: Investment Portfolio

- Notice the formula for the objective function

21	Computing the portfolio variance:	
22	x'*Sigma*x =	0
23		
24	Portfolio variance:	0

= SUMPRODUCT(B4:B7,MMULT(A16:D19,B4:B7))

- Try the alternative approach

= MMULT(TRANSPOSE(B4:B7),MMULT(A16:D19,B4:B7))

- Examine what the constraints look like in Solver

Subject to the Constraints:

B25 >= 0.11
B26 = 1

The End

Dale