

## Homework # 7

Numbers below refer to problems in Horn, Johnson “Matrix analysis.” A number 1.1.P2 means Problem 2 in Section 1.1.

- (6.1.P9) Suppose that  $A = [a_{ij}] \in M_n$  is strictly diagonally dominant and let  $D = \text{diag}\{a_{11}, \dots, a_{nn}\}$ . Explain why  $D$  is nonsingular and show that  $\rho(I - D^{-1}A) < 1$ .
- Which of the matrices

$$A = \begin{bmatrix} 5 & -2 & 0 & 3 & 0 \\ 1 & 4 & -1 & 1 & -1 \\ 2 & 0 & 5 & 1 & 2 \\ -3 & 0 & 0 & 3 & 0 \\ 2 & 0 & -2 & 1 & 7 \end{bmatrix}, B = \begin{bmatrix} 5 & 0 & 0 & 3 & 0 \\ 1 & 4 & -1 & 1 & -1 \\ 2 & 0 & 5 & 1 & 2 \\ -1 & 0 & 0 & 3 & 0 \\ 2 & -1 & -2 & 1 & 7 \end{bmatrix}, C = \begin{bmatrix} 5 & -2 & 0 & 3 & 0 \\ 1 & 4 & -1 & 1 & -1 \\ 2 & 0 & 5 & 1 & 2 \\ -3 & 0 & 0 & 3 & 0 \\ 3 & -1 & -2 & 1 & 7 \end{bmatrix}$$

are

- irreducible?
  - diagonally dominant?
  - irreducibly diagonally dominant?
- (6.3.P7, 6.3.P3 in the old edition) Consider  $A = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix}$ ,  $E = \begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix}$ , and  $A + tE$  for  $t > 0$ .
    - Does  $A$  satisfy the hypothesis of Theorem 6.3.12?
    - Show that the eigenvalues of  $A + tE$  are  $\pm\sqrt{t}$ , and explain why the eigenvalue  $\lambda(t) = \sqrt{t}$  is continuous but not differentiable at  $t = 0$ .
    - Does  $A$  satisfy the hypotheses of Theorem 6.3.2?
    - Let  $\lambda$  be an eigenvalue of  $A$  and let  $\lambda(t)$  be an eigenvalue of  $A + tE$ . Explain why there is no  $c$  such that  $|\lambda(t) - \lambda| \leq c|||tE|||$  for all  $t > 0$  and contrast with the bound (6.3.3).

4. (6.3.P6 in the old edition) Consider Given's example of a real symmetric matrix 2-by-2 matrix  $A = I$  and a real symmetric perturbation

$$E(\epsilon) = \begin{bmatrix} \epsilon \cos(2/\epsilon) & \epsilon \sin(2/\epsilon) \\ \epsilon \sin(2/\epsilon) & -\epsilon \cos(2/\epsilon) \end{bmatrix}, \quad \epsilon > 0$$

with  $E(0) = \lim_{\epsilon \rightarrow 0} E(\epsilon) = 0$ . Show that the eigenvalues of  $A + E(\epsilon)$  are  $1 + \epsilon$  and  $1 - \epsilon$ , and that the respective (uniquely determined up to sign) normalized real eigenvectors are

$$x_1 = \begin{bmatrix} \cos(1/\epsilon) \\ \sin(1/\epsilon) \end{bmatrix}, \quad x_2 = \begin{bmatrix} \sin(1/\epsilon) \\ -\cos(1/\epsilon) \end{bmatrix}$$

for  $\epsilon > 0$ . Show that as  $\epsilon \rightarrow 0$ , each eigenvector points in any given direction infinitely often. Thus, even if we restrict our attention to real symmetric matrices, an individual eigenvector may vary rapidly if its eigenvalue is not well separated from others.

5. (8.1.P5) If  $A \in M_n$  is nonnegative and has a positive eigenvector, show that  $A$  is similar to a nonnegative matrix, all of whose row sums are equal. Equal to what?
6. (8.2.P4) Consider the general intercity migration model with  $n > 2$  cities as described in Sect. 8.0. If all the migration coefficients  $a_{ij}$  are positive, what is the asymptotic behavior of the population distribution  $p^{(m)}$  as  $m \rightarrow \infty$ ?
7. (8.4.P11) Let  $n > 1$  be a prime number. If  $A \in M_n$  is irreducible, nonnegative and nonsingular, explain why either  $\rho(A)$  is the only eigenvalue of  $A$  of maximum modulus or all the eigenvalues of  $A$  have maximum modulus.
8. (8.7.P13) Let  $\|\cdot\|$  be a unitarily invariant norm on  $M_n$ . Show that  $\|A\| \leq \|I\|$  for every doubly stochastic matrix  $A \in M_n$ .