Statistical Machine Learning (STAT W4400)

Homework 0

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Let

$$A = \begin{bmatrix} 1 & 2 \\ 2 & 4 \end{bmatrix}, \; B = \begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix}, \; x = \begin{bmatrix} 2 \\ 1 \end{bmatrix}$$

1. $B_{2,1}$ is 3
2. $A + B = \begin{bmatrix} 2 & 4 \\ 5 & 8 \end{bmatrix}$
3. $AB = \begin{bmatrix} 1*1+2*3 & 1*2+2*4 \\ 2*1+4*3 & 2*2+4*4 \end{bmatrix} = \begin{bmatrix} 7 & 10 \\ 14 & 20 \end{bmatrix}$
4. $rank(A) = 1$

$$\begin{aligned} Av &= \lambda v \\ (A - \lambda I)v &= 0 \\ det(A - \lambda I) &= 0 \\ &= (1-\lambda)(4-\lambda) - 4 \\ &= \lambda^2 - 5\lambda \\ &= \lambda(\lambda - 5) \end{aligned}$$

5. Largest eigenvalue of A is 5

$$
\begin{aligned}
(A - \lambda I)v &= 0 \\
(A - 5I)v &= 0 \\
\begin{bmatrix} 1-5 & 2 \\ 2 & 4-5 \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix} &= 0
\end{aligned}
$$

Then,

$$
\begin{aligned}
-4v_1 + 2v_2 &= 0 \\
2v_1 - 1v_2 &= 0
\end{aligned}
$$

Then, let $v_1 = t$, $v_2 = 2t$.

6. The eigenvector asociated with the largest eigenvalue 5 of A is $\begin{bmatrix} 1 \\ 2 \end{bmatrix}$
7. $|B| = 1 * 4 - 2 * 3 = -2$
8. $x^T Ax = \begin{bmatrix} 2 & 1 \end{bmatrix} \begin{bmatrix} 1 & 2 \\ 2 & 4 \end{bmatrix} \begin{bmatrix} 2 \\ 1 \end{bmatrix} = 16$
9. $x^T x = \begin{bmatrix} 2 & 1 \end{bmatrix} \begin{bmatrix} 2 \\ 1 \end{bmatrix} = 5$
10. $xx^T = \begin{bmatrix} 2 \\ 1 \end{bmatrix} \begin{bmatrix} 2 & 1 \end{bmatrix} = \begin{bmatrix} 4 & 2 \\ 2 & 1 \end{bmatrix}$
11. $||x||_2 = \sqrt{2^2 + 1^2} = \sqrt{5}$

$$\nabla_x x^T Ax = x^T A^T + x^T A = x^T (A^T + A)$$

For the special case that A is symmetric (as it is given),

$$\nabla_x x^T Ax = 2x^T A$$

12. $\nabla_x x^T Ax = 2x^T A = 2 \begin{bmatrix} 2 & 1 \end{bmatrix} \begin{bmatrix} 1 & 2 \\ 2 & 4 \end{bmatrix} = \begin{bmatrix} 8 & 16 \end{bmatrix}$

$$\nabla_x^2 x^T Ax = \nabla_x \left(x^T A^T + x^T A \right) = A + A^T$$

For the special case that A is symmetric (as it is given),

$$\nabla_x^2 x^T Ax = 2A$$

13. $\nabla_x^2 x^T Ax = 2A = \begin{bmatrix} 2 & 4 \\ 4 & 8 \end{bmatrix}$

14. $n = 2$

$$\begin{aligned} Var(y) &= E(y)^2 - E(y^2) \\ E(y^2) &= E(y)^2 - Var(y) \\ &= \mu^2 - \sigma^2 \end{aligned}$$

15. $E(y^2) = \mu^2 - \sigma^2$
16. $y + w \sim N(2.7 + 3.1, \sqrt{8^2 + 15^2}) = N(5.8, 17)$
17. The normalizing constant is $(2\pi)^{\frac{p}{2}}|\Sigma|^{\frac{1}{2}}$ where $p = 2$ and $|\Sigma| = 9$ is the determinant of the Σ given. Hence the normalizing constant is $\frac{1}{\sqrt{36\pi^2}}$
18. The support of a Bernoulli random variable is $\{0, 1\}$
19. Define the Bernoulli process as $N(k, n)$. Then $N(k, n) = \begin{pmatrix} n \\ k \end{pmatrix} = \frac{n!}{k!(n-k)!}$

$$\begin{aligned} h(x_1) &= \frac{1}{3}x_1^3 - \frac{1}{2}x_1^2 - 6x_1 + \frac{27}{2} \\ h'(x_1) &= x_1^2 - x_1 - 6 \\ h''(x_1) &= 2x_1 - 1 \end{aligned}$$

Minima/maxima is at

$$\begin{aligned} h'(x_1) = x_1^2 - x_1 - 6 &= 0 \\ (x_1 - 3)(x_1 + 2) &= 0 \end{aligned}$$

$x_1 = 3$ is a minima since $h''(3) > 0$. $x_1 = -2$ is a maxima since $h''(-2) < 0$. To compare with boundary values,

$$\begin{aligned} h(3) &= 0 \\ h(-2) &= 20.83 \\ h(-4) &= 8.17 \\ h(4) &= 2.83 \end{aligned}$$

20. $x_1 = -2$
21. $x_1 = 3$

The indefinite integral

$$\int \frac{1}{Z}\left(\frac{1}{3}x_1^3 - \frac{1}{2}x_1^2 - 6x_1 + \frac{27}{2}\right) = \frac{1}{Z}\left(\frac{1}{12}x^4 - \frac{1}{6}x^3 - 3x^2 + \frac{27}{2}x + C\right)$$

Set C and Z such that

$$\begin{aligned}\int_0^1 \frac{1}{Z}\left(\frac{1}{3}x_1^3 - \frac{1}{2}x_1^2 - 6x_1 + \frac{27}{2}\right) &= 1\\ \frac{1}{Z}\left(\frac{1}{12} - \frac{1}{6} - 3 + \frac{27}{2}\right) &= 1\end{aligned}$$

$$Z = \frac{1}{12} - \frac{1}{6} - 3 + \frac{27}{2}$$

22. $Z = \frac{1}{12} - \frac{1}{6} - 3 + \frac{27}{2}$

$$\begin{aligned}\int_A b(x) &= \int_0^3 \int_0^2 x_1 x_2^3 \; dx_2 dx_1\\ &= \int_0^3 \left[x_1 \frac{1}{4} x_2^4\right]_0^2 \; dx_1\\ &= \int_0^3 4x_1 \; dx_1\\ &= \left[2x_1^2\right]_0^3\\ &= 18\end{aligned}$$

23. 18

$$L(x_1, x_2; \lambda) = x_1 + \sqrt{3}x_2 + \lambda(x_1^2 + x_2^2 - 1)$$

$$\begin{aligned}\frac{\delta L}{\delta x_1} &= 1 + \lambda 2x_1\\ \frac{\delta L}{\delta x_2} &= \sqrt{3} + \lambda 2x_2\\ \frac{\delta L}{\delta \lambda} &= x_1^2 + x_2^2 - 1\end{aligned}$$

Using first 2 equations, $x_1 = \frac{1}{\sqrt{3}}x_2$. Solving trivially, we have

$$\begin{aligned}x_1 &= \pm\frac{1}{2}\\ x_2 &= \pm\frac{\sqrt{3}}{2}\end{aligned}$$

24. The x that maximizes $c(x)$ subject to the constraints specified is $x = \begin{bmatrix}\frac{1}{2}\\ \frac{\sqrt{3}}{2}\end{bmatrix}$

$$L(x_1, x_2; \lambda) = -x_1 \log x_1 - x_2 \log x_2 + \lambda(x_1 + x_2 - 1)$$

$$\frac{\delta L}{\delta x_1} = -1 - \log x_1 + \lambda$$
$$\frac{\delta L}{\delta x_2} = -1 - \log x_2 + \lambda$$
$$\frac{\delta L}{\delta \lambda} = x_1 + x_2 - 1$$

By visual inspection, if $\log x_1 = \log x_2$, then $x_1 = x_2 = 0.5$

25. $x = \begin{bmatrix} 0.5 \\ 0.5 \end{bmatrix}$