

MATH 436 Final Exam Solutions (Spring 2008)

1. (a) (5 points) State the Real Spectral Theorem.

Solution. Let V be a real inner-product space, and $T \in \mathcal{L}(V)$. There exists an orthonormal basis consisting of eigenvectors of T if and only if T is self-adjoint.

- (b) (6 points) Let V be a real inner-product space and let $T \in \mathcal{L}(V)$. Is T diagonalizable if it is a normal operator? Is T diagonalizable if it is an isometry? Explain.

Solution. The answer to both questions is NO. An isometry is normal, so it is enough to give an example of an isometry which is not diagonalizable. Let $V = \mathbb{R}^2$ and T be the rotation by an angle $0 < \theta < \pi$. In terms of matrices this is

$$\begin{pmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{pmatrix}$$

where T is an isometry which has no eigenvectors.

2. (10 points) Suppose V is an inner-product space (real or complex). Let $T \in \mathcal{L}(V)$. Prove that the eigenvalues of T^*T are real non-negative numbers.

Solution. Let $x \neq 0$ be an eigenvector of T^*T with eigenvalue λ . Then

$$\lambda \langle x, x \rangle = \langle \lambda x, x \rangle = \langle T^*T x, x \rangle = \langle T x, T x \rangle.$$

Hence $\lambda = \langle T x, T x \rangle / \langle x, x \rangle$. Since $\langle x, x \rangle$ is a real positive number and $\langle T x, T x \rangle$ is a real non-negative number, we conclude that λ is a real non-negative number.

3. (10 points) Let V be the subspace of $\mathbb{R}^5$ spanned by

$$(3, 2, 0, 0), \quad (-1, 1, -3, 0), \quad (5, 2, 1, 0)$$

Find a basis of V .

Solution. Note that $(-1, 1, -3, 0) + 5(3, 2, 1, 0) = (24, 16, 0, 0) = 8(3, 2, 0, 0)$, so $\dim(V) \leq 2$. On the other hand, since $(3, 2, 1, 0)$ and $(-1, 1, -3, 0)$ are clearly linearly independent, $\dim(V) \geq 2$. Therefore, $\dim(V) = 2$ and $\{(3, 2, 1, 0), (-1, 1, -3, 0)\}$ form a basis.

4. (10 points) Let A be a complex matrix with characteristic polynomial $\chi(t) = (t-1)^3$. Describe the possible Jordan forms of A .

Solution. The number of Jordan forms is equal to the number of ways partitions of 3 into non-increasing sums of positive integers. There are three of those: $3 = 3$, $3 = 2 + 1$, and $3 = 1 + 1 + 1$. The corresponding matrices are

$$\begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}, \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}, \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}.$$

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