COMPLEX FUZZY MATRICES AND ITS PROPERTIES

[1]**Divya Mol K T** [2]**Dr. Lovelymol Sebastian**
[1]Research Scholar [2] Research Supervisor
Research and Post Graduate Department of Mathematics
St. Thomas College Palai, Kerala, India

Abstract: **In comparison to a traditional fuzzy set, the membership function of the complex fuzzy set, the range from [0,1] extended to a unit circle in the complex plane. Corresponding to any complex fuzzy elation we can construct complex fuzzy matrices. The complex fuzzy matrices are successfully used when complex fuzzy uncertainty occurs in a problem. In this paper we introduce the concept of complex fuzzy matrices. Also, several basic operations of complex fuzzy matrices are defined using the basic operations of fuzzy matrices. Also, some new concepts of complex fuzzy matrices are presented.**

Index Terms - **Complex Fuzzy Sets; Complex Fuzzy Matrices.**

I. INTRODUCTION

In 1965, Zadeh [1] introduced the notion of fuzzy set theory. The field of medicine and treatment are the most important and interesting areas of applications of fuzzy set theory. Like classical matrices, fuzzy matrices are now very rich topic in modelling uncertain situations occurred in science, automata, medical diagnosis, etc. Fuzzy matrices defined first time by Thomson in 1977.
The theories of fuzzy matrices were developed by Kim and Roush as an extension of Boolean matrices. With max-min operation the fuzzy algebra and its matrix theory are considered by many authors.
In 2002, Ramot defined Complex Fuzzy sets as an extension of type-1 fuzzy sets in which the codomain of the membership function was the unit disc in the complex plane (the set of all complex numbers with modulus less than or equal to 1).
Ramot introduced the concept of complex degree of membership in polar coordinates, where the amplitude is the degree of an object in a Complex Fuzzy Set and the role of phase is to add information which is generally related to spatial or temporal periodicity in the specific fuzzy set defined by the amplitude component.

II. PRELIIMINARIES

2.1 Fuzzy Sets

A fuzzy set is a pair (U, μ) where U is a non-empty set and $\mu: U \to [0,1]$ a membership function. The set U is called the universe of discourse and for each $x\epsilon U$, the value $\mu(x)$ is called the degree of membership of x in (U, μ). The function μ is called the membership function of the fuzzy set (U, μ). For a finite set $U = \{x_1, x_2, \dots, x_n\}$, the fuzzy set U, μ is often denoted by $\{\mu(x_1)/x_1, \mu(x_2)/x_2, \dots, \mu(x_n)/x_n\}$.
Let $x\epsilon U$. Then x is called
Not included in Fuzzy set, (U, μ) if μ(x) = 0
Fully included in Fuzzy set, (U, μ) if $\mu(x) = 1$
Partially included in Fuzzy set, (U, μ) if $0 \le \mu(x) \le 1$.

Fuzzy Matrices

A fuzzy matrix is a matrix which has its elements from [0,1], called the fuzzy unit interval.
A fuzzy matrix A of order $m \times n$ is defined as $A = [\langle a_{ij}, a_{ij\mu}\rangle]_{m\times n}$, where $a_{ij\mu}$ is the membership value of the element a_{ij} in A.
For simplicity, we write A as $A = [a_{ij}]_{m\times n}$.
Example,

$$A = \begin{bmatrix} 0.5 & 0.1 & 0.7 & 0{,}5 \\ 0.3 & 0.8 & 0.1 & 0.6 \\ 0.6 & 0.4 & 0.9 & 0.8 \\ 0.2 & 0.7 & 0.3 & 0.4 \end{bmatrix}$$

2.3 Determinant of a fuzzy matrix

The determinant of a (2×2) square fuzzy matrix is denoted by $\det A$ and is defined by

$$\begin{vmatrix} a & b \\ c & d \end{vmatrix} = max\{min(a,d), min(c,b)\}$$

2.4 Frobenius inner product

Given two complex valued $n \times m$ matrices A and B, the Frobenius inner product of A and B is defined as follows
$\langle A, B\rangle = tr(A^*B)$, where A^*be the conjugate transpose of A

2.2 Complex Fuzzy Set

A complex fuzzy set defined on the universe of discourse U, is characterized by a membership function $\mu_F(x)$, that assign any element $a \in F$ a complex valued grade of membership in F. By definition, the values $\mu_F(x)$ receive all lie within the unit circle in the complex plane, and are thus of the form $r_F(x)e^{i\omega_F(x)}, i = \sqrt{-1}$, $r_F(x)$ and $\omega_F(x)$ are both real valued $r_F(x)\epsilon$ [0, 1] , $\omega_F(x)\epsilon$ [0, 2π) , the complex fuzzy set may be represented as the set of ordered pairs. F = {(x,$\mu_F(x)$)): xϵ U}

2.3 Complex Fuzzy Matrices

A complex fuzzy matrix is a matrix which has its elements from the unit disc in the complex plane. A complex fuzzy matrix of order m × n is defined as, $A = \left[\langle a_{ij}, a_{ij\mu}\rangle\right]_{m\times n}$ $a_{ij\mu} = r_{ij}e^{i\omega_{ij}}$; $r_{ij}\epsilon\ [0,1]$ and $\omega_{ij}\epsilon\ \epsilon[0,2\pi)$

Example, $A = \begin{bmatrix} 0.1e^{i\frac{\pi}{2}} & 0.5e^{i\pi} & 0 \\ 0.3e^{i\frac{\pi}{3}} & 0.2e^{i0} & 0.7e^{i\frac{\pi}{4}} \\ 0e^{i0} & 0.6e^{i\pi} & 1 \end{bmatrix}_{3\times 3}$

3.1) PROPERTIES OF COMPLEX FUZZY MATRICES

3.1.1 Addition of two complex fuzzy matrices

Two complex fuzzy matrices are comfortable for addition if the matrices are of same order. If $CF_1 = [a_{ij\mu}]_{m\times n}$ and $CF_2 = [b_{ij\vartheta}]_{m\times n}$ then $CF_1 + CF_2 = [c_{ij\eta}]_{m\times n}$; $c_{ij\eta} = max\{a_{ij\mu}, b_{ij\vartheta}\}$

Illustration

Let $A = \begin{bmatrix} 0.7e^{i\frac{\pi}{2}} & 0.5e^{i\frac{\pi}{2}} & 0e^{i0} \\ 1e^{i0} & 0.2e^{i\pi} & 0.1e^{i\frac{\pi}{4}} \\ 0e^{i0} & 0.3e^{i\frac{\pi}{3}} & 1 \end{bmatrix}_{3\times 3}$ and $B = \begin{bmatrix} 0.2e^{i\frac{\pi}{6}} & 0.1e^{i\pi} & 1e^{i0} \\ 0.7e^{i0} & 0.5e^{i\frac{\pi}{4}} & 0.9e^{i\pi} \\ 0.4e^{i\frac{\pi}{4}} & 0e^{i0} & 1e^{i\pi} \end{bmatrix}_{3\times 3}$ then

$A + B = \begin{bmatrix} 0.7e^{i\pi} & 0.5e^{i\pi} & 1e^{i0} \\ 1e^{i0} & 0.5e^{i\pi} & 0.9e^{i\pi} \\ 0.4e^{i\frac{\pi}{4}} & 0.3e^{i\frac{\pi}{3}} & 1e^{i\pi} \end{bmatrix}_{3\times 3}$

$c_{11} = max\{a_{11}, b_{11}\}$
$= max\left\{0.7e^{i\pi}, 0.2e^{i\frac{\pi}{6}}\right\}$
$= max\{0.7, 0.2\}e^{i\, max\{\pi,\ \frac{\pi}{6}\}}$
$= 0.7e^{i\pi}$

$c_{12} = max\{a_{12}, b_{12}\}$
$= max\left\{0.5e^{i\frac{\pi}{2}}, 0.1e^{i\pi}\right\} = 0.5e^{i\pi}$

$c_{13} = max\{a_{13}, b_{13}\}$
$= max\{0e^{i0}, 1e^{i0}\} = 1e^{i0}$

$c_{21} = max\{a_{21}, b_{21}\}$
$= max\{1e^{i0}, 0.7e^{i0}\} = 1e^{i0}$

$c_{22} = max\{a_{22}, b_{22}\}$
$= max\left\{0.2e^{i\pi}, 0.5e^{i\frac{\pi}{4}}\right\} = 0.5e^{i\pi}$

$c_{23} = max\{a_{23}, b_{23}\}$
$= max\left\{0.1e^{i\frac{\pi}{4}}, 0.9e^{i\pi}\right\} = 0.9e^{i\pi}$

$c_{31} = max\{a_{31}, b_{31}\}$
$= max\left\{0e^{i0}, 0.4e^{i\frac{\pi}{4}}\right\} = 0.4e^{i\frac{\pi}{4}}$

$c_{32} = max\{a_{32}, b_{32}\}$
$= max\left\{0.3e^{i\frac{\pi}{3}}, 0e^{i0}\right\} = 0.3e^{i\frac{\pi}{3}}$

$c_{33} = max\{a_{33}, b_{33}\}$
$= max\{1e^{i0}, 1e^{i\pi}\} = 1e^{i\pi}$

2.4.2 Multiplication of two complex fuzzy matrices

The product of two complex fuzzy matrices under usual matrix multiplication is not a complex fuzzy matrix. So here we intend to define a compactible operation analogous to product that the product again happens to be a complex fuzzy matrix. The product is to be defined we need the number of columns of the first matrix is equal to the number of rows of the second matrix. i.e.; If $CF_1 = [a_{ij\mu}]_{m\times n}$ and $CF_2 = [b_{ij\vartheta}]_{n\times p}$; $CF = (CF_1)(CF_2) = [c_{ij\gamma}]_{m\times p}$;

$$c_{ij\gamma} = max\{min\{a_{i1\mu},\ b_{1j\vartheta}\}, min\{a_{i2\mu},\ b_{2j\vartheta}\},\ min\{a_{i3\mu},\ b_{3j\vartheta}\}, \ldots, min\{a_{in\mu},\ b_{1n\vartheta}\}\};\ 1 \le i \le m,\ 1 \le j \le p.$$

Illustration

Let $A = \begin{bmatrix} 0.7e^{i\frac{\pi}{2}} & 0.5e^{i\frac{\pi}{2}} & 0e^{i0} \\ 1e^{i0} & 0.2e^{i\pi} & 0.1e^{i\frac{\pi}{4}} \\ 0e^{i0} & 0.3e^{i\frac{\pi}{3}} & 1 \end{bmatrix}_{3\times 3}$

$A^2 = A.A = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix}_{3\times 3}$

$r_{11} = max\{min\{a_{11},\ a_{11}\}, min\{a_{12},\ a_{21}\},\ min\{a_{13},\ a_{31}\}\}$
$= max\left\{min\left\{0.7e^{i\frac{\pi}{2}},\ 0.7e^{i\frac{\pi}{2}}\right\}, min\left\{0.5e^{i\frac{\pi}{2}},\ 1e^{i0}\right\},\ min\{0e^{i0},\ 0e^{i0}\}\right\}$

$= max\left\{0.7e^{i\frac{\pi}{2}}, 0.5e^{i0}, 0e^{i0}\right\}$

$= max\{0.7, 0.5, 0\}e^{i\,max\left\{\frac{\pi}{2},0,0\right\}}$

$= 0.7e^{i\frac{\pi}{2}}$

$r_{12} = max\left\{min\left\{0.7e^{i\frac{\pi}{2}}, 0.5e^{i\frac{\pi}{2}}\right\}, min\left\{0.5e^{i\frac{\pi}{2}}, 0.2e^{i\pi}\right\}, min\left\{0e^{i0}, 0.1e^{i\frac{\pi}{4}}\right\}\right\} = 0.5e^{i\frac{\pi}{2}}$

$r_{13} = max\left\{min\left\{0.7e^{i\frac{\pi}{2}}, 0e^{i0}\right\}, min\left\{0.5e^{i\frac{\pi}{2}}, 0.1e^{i\frac{\pi}{4}}\right\}, min\{0e^{i0}, 1e^{i0}\}\right\} = 0.1e^{i\frac{\pi}{4}}$

$r_{21} = max\left\{min\left\{1e^{i0}, 0.7e^{i\frac{\pi}{2}}\right\}, min\{0.2e^{i\pi}, 1e^{i0}\}, min\left\{0.1e^{i\frac{\pi}{4}}, 0e^{i0}\right\}\right\} = 0.7e^{i0}$

$r_{22} = max\left\{min\left\{1e^{i0}, 0.5e^{i\frac{\pi}{2}}\right\}, min\{0.2e^{i\pi}, 0.2e^{i\pi}\}, min\left\{0.1e^{i\frac{\pi}{4}}, 0.3e^{i\frac{\pi}{3}}\right\}\right\} = 0.5e^{i\pi}$

$r_{23} = max\left\{min\{1e^{i0}, 0e^{i0}\}, min\left\{0.2e^{i\pi}, 0.1e^{i\frac{\pi}{4}}\right\}, min\left\{0.1e^{i\frac{\pi}{4}}, 1e^{i0}\right\}\right\} = 0.1e^{i\frac{\pi}{4}}$

$r_{31} = max\left\{min\left\{0e^{i0}, 0.7e^{i\frac{\pi}{2}}\right\}, min\left\{0.3e^{i\frac{\pi}{3}}, 1e^{i0}\right\}, min\{1e^{i0}, 0e^{i0}\}\right\} = 0.3e^{i0}$

$r_{32} = max\left\{min\left\{0e^{i0}, 0.5e^{i\frac{\pi}{2}}\right\}, min\left\{0.3e^{i\frac{\pi}{3}}, 0.2e^{i\pi}\right\}, min\left\{1e^{i0}, 0.3e^{i\frac{\pi}{3}}\right\}\right\} = 0.3e^{i\frac{\pi}{3}}$

$r_{33} = max\left\{min\{0e^{i0}, 0e^{i0}\}, min\left\{0.3e^{i\frac{\pi}{3}}, 0.1e^{i\frac{\pi}{4}}\right\}, min\{1e^{i0}, 1e^{i0}\}\right\} = 1e^{i\frac{\pi}{4}}$

$$A^2 = A.A = \begin{bmatrix} 0.7e^{i\frac{\pi}{2}} & 0.5e^{i\frac{\pi}{2}} & 0.1e^{i\frac{\pi}{4}} \\ 0.7e^{i0} & 0.5e^{i\pi} & 0.1e^{i\frac{\pi}{4}} \\ 0.3e^{i0} & 0.3e^{i\frac{\pi}{3}} & 1e^{i\frac{\pi}{4}} \end{bmatrix}_{3\times3}$$

2.4.3 Trace of a complex fuzzy matrix

Let $A = [a_{ij\mu}]_{n\times n}$ be a square complex fuzzy matrix. Then $Trace(A) = max\{a_{ii\mu}\}$

Illustration

For the above mentioned complex fuzzy matrix A,

$Trace\ (A) = \sum_{i=1}^{3} a_{ij\mu}$

$= Max\{a_{11\mu}, a_{22\mu}, a_{33\mu}\}$

$= Max\left\{0.7e^{i\frac{\pi}{2}}, 0.2e^{i\pi}, 1e^{i0}\right\}$

$= Max\{0.7, 0.2, 1\}e^{i\,Max\left\{\frac{\pi}{2},\pi,0\right\}}$

$= 1e^{i\pi}$

2.4.4 Conjugate transpose of a complex fuzzy matrix

The conjugate transpose of a complex fuzzy matrix A is defined as the transpose of the conjugate of the matrix.

That is $\bar{A}^T = (A)^*$.

Illustration

For the above mentioned complex fuzzy matrix A,

$$A = \begin{bmatrix} 0.7e^{i\frac{\pi}{2}} & 0.5e^{i\frac{\pi}{2}} & 0e^{i0} \\ 1e^{i0} & 0.2e^{i\pi} & 0.1e^{i\frac{\pi}{4}} \\ 0e^{i0} & 0.3e^{i\frac{\pi}{3}} & 1e^{i0} \end{bmatrix}_{3\times3}$$

$$\text{Then, } \bar{A} = \begin{bmatrix} 0.7e^{-i\frac{\pi}{2}} & 0.5e^{-i\frac{\pi}{2}} & 0e^{-i0} \\ 1e^{-i0} & 0.2e^{-i\pi} & 0.1e^{-i\frac{\pi}{4}} \\ 0e^{-i0} & 0.3e^{-i\frac{\pi}{3}} & 1e^{-i0} \end{bmatrix}_{3\times3}$$

$$= \begin{bmatrix} 0.7e^{-i\frac{\pi}{2}+2\pi i} & 0.5e^{-i\frac{\pi}{2}+2\pi i} & 0e^{-i0+2\pi i} \\ 1e^{-i0+2\pi i} & 0.2e^{-i\pi+2\pi i} & 0.1e^{-i\frac{\pi}{4}+2\pi i} \\ 0e^{-i0+2\pi i} & 0.3e^{-i\frac{\pi}{3}+2\pi i} & 1e^{-i0+2\pi i} \end{bmatrix}_{3\times3}$$

$$= \begin{bmatrix} 0.7e^{i\frac{3\pi}{2}} & 0.5e^{i\frac{3\pi}{2}} & 0e^{0i} \\ 1e^{i0} & 0.2e^{i\pi} & 0.1e^{i\frac{7\pi}{4}} \\ 0e^{i0} & 0.3e^{i\frac{5\pi}{3}} & 1e^{i0} \end{bmatrix}_{3\times3}$$

$$A^* = (\bar{A})^T = \begin{bmatrix} 0.7e^{i\frac{3\pi}{2}} & 0.5e^{i\frac{3\pi}{2}} & 0e^{0i} \\ 1e^{i0} & 0.2e^{i\pi} & 0.1e^{i\frac{7\pi}{4}} \\ 0e^{i0} & 0.3e^{i\frac{5\pi}{3}} & 1e^{i0} \end{bmatrix}_{3\times3}^T$$

$$= \begin{bmatrix} 0.7e^{i\frac{3\pi}{2}} & 1e^{i0} & 0e^{0i} \\ 0.5e^{i\frac{3\pi}{2}} & 0.2e^{i\pi} & 0.3e^{i\frac{5\pi}{3}} \\ 0e^{i0} & 0.1e^{i\frac{7\pi}{4}} & 1e^{i0} \end{bmatrix}_{3\times3}$$

2.4.5 Determinant of a complex fuzzy matrix

Let $CF = [a_{ij\mu}]_{n\times n}$ be an n × n complex fuzzy matrix then, $||CF| = a_{11\mu}M_{11} + a_{12\mu}M_{12} + \ldots + a_{1n\mu}M_{1n}$, where M_{ij} is the minor of the $(ij)^{th}$ entry.

Illustration

For the above mentioned complex fuzzy matrix A,

$$A = \begin{bmatrix} 0.7e^{i\frac{\pi}{2}} & 0.5e^{i\frac{\pi}{2}} & 0e^{i0} \\ 1e^{i0} & 0.2e^{i\pi} & 0.1e^{i\frac{\pi}{4}} \\ 0e^{i0} & 0.3e^{i\frac{\pi}{3}} & 1e^{i0} \end{bmatrix}_{3\times 3}$$

$$|A| = \begin{vmatrix} 0.7e^{i\frac{\pi}{2}} & 0.5e^{i\frac{\pi}{2}} & 0e^{i0} \\ 1e^{i0} & 0.2e^{i\pi} & 0.1e^{i\frac{\pi}{4}} \\ 0e^{i0} & 0.3e^{i\frac{\pi}{3}} & 1e^{i0} \end{vmatrix}$$

$$= 0.7e^{i\frac{\pi}{2}} \begin{vmatrix} 0.2e^{i\pi} & 0.1e^{i\frac{\pi}{4}} \\ 0.3e^{i\frac{\pi}{3}} & 1e^{i0} \end{vmatrix} + 0.5e^{i\frac{\pi}{2}} \begin{vmatrix} 1e^{i0} & 0.1e^{i\frac{\pi}{4}} \\ 0e^{i0} & 1e^{i0} \end{vmatrix} + 0e^{i0} \begin{vmatrix} 1e^{i0} & 0.2e^{i\pi} \\ 0e^{i0} & 0.3e^{i\frac{\pi}{3}} \end{vmatrix}$$

$$= I_1 + I_2 + I_3$$

$$I_1 = 0.7e^{i\frac{\pi}{2}} \begin{vmatrix} 0.2e^{i\pi} & 0.1e^{i\frac{\pi}{4}} \\ 0.3e^{i\frac{\pi}{3}} & 1e^{i0} \end{vmatrix}$$

$$= 0.7e^{i\frac{\pi}{2}} \left\{ max\left\{ min(0.2e^{i\pi}, 1e^{i0}), min\left(0.1e^{i\frac{\pi}{4}}, 0.3e^{i\frac{\pi}{3}}\right)\right\}\right\}$$

$$= 0.7e^{i\frac{\pi}{2}} \left\{ max\left\{ min(0.2, 1)e^{i\min(\pi,0)}), min\left(0.1,0.3\right)e^{i min\left(\frac{\pi}{4},\frac{\pi}{3}\right)}\right)\right\}\right\}$$

$$= 0.7e^{i\frac{\pi}{2}} \left\{ max\left\{0.2e^{i0}, 0.1e^{i\frac{\pi}{4}}\right\}\right\}$$

$$= 0.7e^{i\frac{\pi}{2}} \left\{ max(0.2,0.1)\, e^{i\max\left(0,\frac{\pi}{4}\right)}\right\}$$

$$= \left(0.7e^{i\frac{\pi}{2}}\right)\left\{\left(0.2e^{i\frac{\pi}{4}}\right)\right\}$$

$$= min(0.7,0.2)e^{i\min\left(\frac{\pi}{2},\frac{\pi}{4}\right)} = 0.2e^{i\frac{\pi}{4}}$$

$$I_2 = 0.5e^{i\frac{\pi}{2}} \begin{vmatrix} 1e^{i0} & 0.1e^{i\frac{\pi}{4}} \\ 0e^{i0} & 1e^{i0} \end{vmatrix}$$

$$= 0.5e^{i\frac{\pi}{2}} \left\{ max\left\{ min(1e^{i0}, 1e^{i0}), min\left(0.1e^{i\frac{\pi}{4}}, 0e^{i0}\right)\right\}\right\}$$

$$= 0.5e^{i\frac{\pi}{2}} \left\{ max\left\{ min(1, 1)e^{i\min(0,0)}), min\left(0.1,0\right)e^{i min\left(\frac{\pi}{4},0\right)}\right)\right\}\right\}$$

$$= 0.5e^{i\frac{\pi}{2}} \left\{ max\{1e^{i0}, 0e^{i0}\}\right\}$$

$$= 0.5e^{i\frac{\pi}{2}} \{ max(1,0)\, e^{i\max(0,0)}\}$$

$$= \left(0.5e^{i\frac{\pi}{2}}\right)\{(1e^{i0})\}$$

$$= min(0.5,0.2)e^{i\min\left(\frac{\pi}{2},0\right)} = 0.2e^{i0}$$

$$I_3 = 0e^{i0} \begin{vmatrix} 1e^{i0} & 0.2e^{i\pi} \\ 0e^{i0} & 0.3e^{i\frac{\pi}{3}} \end{vmatrix}$$

$$= 0e^{i0} \left\{ max\left\{ min\left(1e^{i0}, 0.3e^{i\frac{\pi}{3}}\right), min(0.2e^{i\pi}, 0e^{i0})\right\}\right\}$$

$$= 0e^{i0} \left\{ max\left\{ min\left(1, 0.3)e^{i\min\left(0,\frac{\pi}{3}\right)}\right), min(0.2,0)e^{i min(\pi,0)}\right)\right\}\right\}$$

$$= 0e^{i0} \left\{ max\{0.3e^{i0}, 0e^{i0}\}\right\}$$

$$= 0e^{i0}\{ max(0.3,0)\, e^{i\max(0,0)}\}$$

$$= (0e^{i0})\{(0.3e^{i0})\}$$

$$= min(0,0.3)e^{i\min(0,0)} = 0e^{i0}$$

$$|A| = I_1 + I_2 + I_3 = 0.2e^{i\frac{\pi}{4}} + 0.2e^{i0} + 0e^{i0}$$

$$= max\{0.2,0.2,0\}\, e^{i\, max\left\{\frac{\pi}{4},0,0\right\}} = 0.2e^{i\frac{\pi}{4}}$$

IV. CONCLUSION

The concept of complex fuzzy sets has undergone an evolutionary process since they first introduced. In this paper we use the concept of complex fuzzy matrices. We presented several concepts of complex fuzzy matrices such as sum, product, conjugate transpose and determinant. So, in future we can use these concepts to solve system of linear equations including complex fuzzy matrices, and these concepts will provide an opportunity to discuss about the characteristic equation and eigen values of a complex fuzzy matrices.

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