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A quadratic non-stochastic operator

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Non-linear dynamical systems arise in many problems of biology, physics and other sciences. In particular, quadratic dynamical systems describe the behavior of populations of different species with population models ([1],[2],[3]) Let S^{m-1} be the $m - 1$ dimensional standard simplex and $V : R^m \rightarrow R^m$ be a quadratic operator which is given by the following from:

$$V(x)_k = \sum_{i,j=1}^m P_{ij,k} x_i x_j \tag{1}$$

for $k = 1, \dots, m.$, where $p_{ij,k} = p_{ji,k} \in R$ for $i, j, k \in N_m = \{1, 2, \dots, m\}$

Definition. A quadratic operator (1) preserving a simplex is called non-stochastic if at least one of its coefficients $P_{ij,k}$, $i \neq j$ is negative.

Consider

$$P_{ii,i} = 1, \quad P_{ii,k} = 1, \forall i = 1, 2, 3; \quad \forall k = 2, 3;$$

$$P_{ij,1} = -\frac{1}{2} \sqrt{P_{ii,1} P_{jj,1}} = -\frac{1}{2}, \quad \forall i \neq j;$$

$$P_{ij,k} \in \left[0, \frac{3}{2}\right], \quad \forall i \neq j, \quad k = 2, 3 \quad \text{with} \quad P_{ij,2} + P_{ij,3} = \frac{3}{2}$$

Then taking some parameters equal to zero we get the following quadratic operator $V :$

$$\begin{aligned} x' &= x^2 + y^2 + z^2 - xy - xz - yz \\ y' &= 3xy + ayz \\ z' &= 3xz + (3 - a)yz, \end{aligned} \tag{2}$$

where $a \in (0, 3)$ and $(x, y, z) \in S^2 = \{(x, y, z) \in R^m : x + y + z = 1\}$. It is easy to see that the fixed points of the operator (2) are

$$s_1 = (1, 0, 0), \quad s_2 = \left(\frac{1}{3}, 0, \frac{2}{3}\right),$$

$$s_3 = \left(\frac{1}{3}, \frac{2}{3}, 0\right), \quad s_4 = \left(\frac{a^2 - 3a + 3}{a^2 - 3a + 9}, \frac{2a}{a^2 - 3a + 9}, \frac{2(3 - a)}{a^2 - 3a + 9}\right).$$

Let $a \in (0, 3)$. Introduce the following sets:

$$M_1 = \{(y, z) \in [0, 1]^2 : y = 0\}, \quad M_2 = \{(y, z) \in [0, 1]^2 : z = 0\},$$

$$M_3 = \left\{ (y, z) \in [0, 1]^2 : y + z \leq 1, z = \frac{3 - a}{a} \cdot y \right\},$$

$$M_4 = \left\{ (y, z) \in [0, 1]^2 : y + z \leq 1, z < \frac{3 - a}{a} \cdot y \right\},$$

$$M_5 = \left\{ (y, z) \in [0, 1]^2 : y + z \leq 1, z > \frac{3 - a}{a} \cdot y \right\}.$$

and

$$\widehat{M}_i = \{(x, y, z) \in S^2 : (y, z) \in M_i\}, \quad i = \overline{1, 5}.$$

Then

$$S^2 = \bigcup_{i=1}^5 \widehat{M}_i.$$

Theorem. *If $(x^{(0)}, y^{(0)}, z^{(0)}) \in \widehat{M}_i$ for some $i = 1, 2, 3, 4, 5$ then for the operator (2) the following holds*

$$\lim_{n \rightarrow \infty} V^n(x^{(0)}, y^{(0)}, z^{(0)}) = \begin{cases} s_1 & \text{if } x^{(0)} = 1 \\ s_2 & \text{if } i = 1, \quad z^{(0)} > 0 \\ s_3 & \text{if } i = 2, \quad y^{(0)} > 0 \\ s_4 & \text{if } i = 3, \quad y^{(0)} > 0 \\ \in \widehat{M}_3 & \text{if } i = 4, 5. \end{cases}$$

Conjecture. *If $(x^{(0)}, y^{(0)}, z^{(0)}) \in \widehat{M}_4 \cup \widehat{M}_5$ then for the operator (2) the following holds*

$$\lim_{n \rightarrow \infty} V^n(x^{(0)}, y^{(0)}, z^{(0)}) = s_4.$$

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