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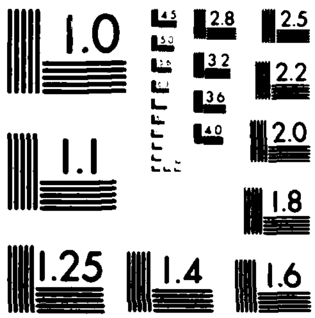
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FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

ALGEBRA OF NEURON MATRICES

by

K.G. Agababyan

FOREIGN TECHNOLOGY DIVISION

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ALGEBRA OF NEURON MATRICES

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Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

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ALGEBRA OF NEURON MATRICES

K. G. Agababyan

(Presented by Academician V. M. Glushkov, 1-25-1971)

This article examines algebra, the principle of construction of which involves certain properties of sensory systems in the information-processing sense, ([2-5] et al.).

The concept of neuron matrices and neuron operators is introduced. The elements of the neuron matrices are the output signals of neurons of a given layer. It is assumed that each layer consists of neurons of the same type, while the signals between the layers travel only in one direction - from the receptor field to the k-th layer.

We introduce the following function axiomatically:

$$f_{ij}^{(k)} = \begin{cases} \lambda_k \left[a \sum_{i=1}^{\mu_1} \sum_{j=1}^{\mu_2} \int_{t_0^{(k)}}^{t} \left(f_{ij}^{(m)} + \alpha f_{\beta\gamma}^{(n)}\right) dt - p_k \right] & \text{при } a \sum_{i=1}^{\mu_1} \sum_{j=1}^{\mu_2} \int_{t_0^{(k)}}^{t} \left(f_{ij}^{(m)} + \alpha f_{\beta\gamma}^{(n)}\right) dt > p_k, \quad (\mathrm{I}^{a}) \\ 0 & \text{при } a \sum_{i=1}^{\mu_1} \sum_{j=1}^{\mu_2} \int_{t_0^{(k)}}^{t} \left(f_{ij}^{(m)} + \alpha f_{\beta\gamma}^{(n)}\right) dt \leqslant p_k, \quad (\mathrm{I}^{б}) \end{cases}$$

key: при=with

where $f_{ij}^{(k)}$ is the output signal of the ij-th element of the k-th layer, λ - coefficient, p - threshold, i - horizontal coordinate, j - vertical coordinate, and t - time. i, j, k, μ_1, μ_2, m, n, α, β, and γ take on integral values. It is assumed that $\delta_0^{(k)} \leqslant \delta^{(k)} \leqslant \delta_1^{(k)}$, where $\delta^{(k)} = t - t_0^{(k)}$. The superscript of the symbol used denotes the layer number.

Definition 1. The element, which performs operation (I) with $k = 1,\ a = 1,\ \mu_1 = \mu_2 = 1,\ \alpha = 0,\ f_{ij}^{(0)} = I(t)$, we will call a receptor, where I(t) is the input signal of the receptor.

Definition 2. The set of receptprs arranged uniformly in a two-dimensional space in the form of matrix M×N we will call the receptor field.

Definition 3. The compact set of elements of the k-th layer whose outputs are connected with one element of the n-th layer we will call the receptive field.

Definition 4. $\Gamma_0[\eta_1 \times \eta_2]$ is an operator, which breaks up any given matrix into blocks measuring $\eta_1 \times \eta_2$ and performs operation (I) with each block with $a = 1,\ \mu_1 = i_k\eta_1,\ \mu_2 = i_k\eta_2,\ \alpha = 0,$ where $i_k = (i_{k-1} - 1)\eta_1 + 1,\ i_k = (j_{k-1} - 1)\eta_2 + 1.$ When $\eta_1 = \eta_2 = \eta$, we will write the operator in the form of $\Gamma_0[\eta]$. It is obvious that the operator $\Gamma_0[\eta_1 \times \eta_2]$ transforms the receptor field to receptive fields.

Definition 5. $\Gamma_1[I]$ is an operator, which performs operation (I) over the columns of any given matrix with $a = 1,\ \mu_1 = 1,\ \mu_2 = N,\ \alpha = 0.$

The $\Gamma_1[-]$ is the modality of the operator, where μ_1=M, μ_2=1. N and M are vertical and horizontal dimentions of the matrix, respectively.

Definition 6. $\Gamma_2[\overrightarrow{-}]$ is an operator, which performs operation (I) over any given matrix with $a = 1,\ \mu_1 = \mu_2 = 1,\ m = n,\ \epsilon = -1,\ \beta = i + 1,\ \gamma = i$

The modalities of the operator are $\Gamma_2\overline{[-]}$, $\Gamma_2[-]\uparrow$, $\Gamma_2[-]\downarrow$, where β and γ assume values $\beta=i-1, \gamma=j, \beta=i, \gamma=j+1, \beta=i, \gamma=j-1$.

Definition 7. $\Gamma_3[+]$ is an operator, which performs operation (I) over any two given matrices of identical size with $a=1$, $\mu_1=\mu_2=1$, $m=n$, $\alpha=-1$, $\beta=i, \gamma=j$. This is an operation of addition of the neuron matrices.

Definition 8. $\Gamma_4\overline{[+]}$ is an operator, which performs operation (I) over any given matrix with $a=1$, $\mu_1=\mu_2=1$, $m=n$, $\alpha=1$, $\beta=i+1$, $\gamma=j$.

The modality of the operator is $\Gamma_4[+]\downarrow$, where β=i, γ=j+1. Here β=i+1 is equivalent to β=i-1, while γ=j+1 is equivalent to γ=j-1.

Definition 9. $\Gamma_5[-]$ is an operator, which performs operation (I) over any two given matrices of identical size with $a=1$, $\mu_1=\mu_2=1$, $m\neq n$, $\alpha=-1$, $\beta=i$, $\gamma=j$. This is a subtraction operation for the neuron matrices.

Definition 10. $\Gamma_6\overline{[+]}$ is an operator, which performs operation (I) over any two given matrices of identical size with

$a = 1, \mu_1 = \mu_2 = 1, m \neq n, \alpha = 1, \beta = i + 1, \gamma + j.$

The modalities of the operator are $\Gamma_6\overline{[+]}, \Gamma_6[+]\uparrow, \Gamma_6[+]\downarrow$, where β and γ assume values $\beta = i - 1, \gamma = j, \beta = i, \gamma = j + 1, \beta = i, \gamma = j - 1.$

Definition 11. $\Gamma_7\overrightarrow{[-]}$ is an operator, which performs operation (I) over any two given matrices of identical size with $a = 1, \mu_1 = \mu_2 = 1, m \neq n, \alpha = -1, \beta = i + 1, \gamma = j.$

The modalities of the operator are $\Gamma_7\overline{[-]}, \Gamma_7[-]\uparrow, \Gamma_7[-]\downarrow$, where β and γ assume values $\beta = i - 1, \gamma = j, \beta = i, \gamma = j + 1, \beta = i, \gamma = j - 1.$

Definition 12. $\Gamma_8\overrightarrow{[+]}'$ is an operator, which performs operation (I) over any given matrix with $a = \varphi(v), \mu_1 = \mu_2 = 1, m = n, \alpha = 1, \beta = i + 1, \gamma = j.$

The modalities of the operator are $\Gamma_8\overline{[+]}', \Gamma_8[+]'\uparrow, \Gamma_8[+]'\downarrow$, where β and γ assume values $\beta = i - 1, \gamma = j, \beta = i, \gamma = j + 1, \beta = i, \gamma = j - 1.$ Here $\varphi(\nu)$ is defined as follows: $\varphi(v) = t_1 - t_2, t_1 = (l_1 - l_0) / v_0, t_2 = s_0 / v,$ hence

$$\varphi(v) = \frac{l_1 - l_0}{v_0}\left(1 - \frac{s_0}{l_1 - l_0}\frac{v_0}{v}\right),$$

where s_0 is the distance between the elements from which the entries of a neuron can be excited, ν - speed at which an image moves over the receptor field, v_0 - speed at which excitation propagates through the entries of a neuron l_0 and l_1. It is assumed that $l_1 > l_0$, where l_1 and l_0 are lengths of the right and left entries of a neuron, and

$\varphi(\nu)$ satisfies the inequality $0<\varphi(\nu)<t_1$.

For the group of operators, where $a=\varphi(\nu)$, we will assume that $f_{ij}^{(m)}$=const, $f_{\beta\gamma}^{(n)}$=const, $l_{ij}^{(\nu)}=0$, and t=1.

For the operators, where $a=1,\ \mu_1=\mu_2=1,$ we will assume that $l_c=l_1$, while for the operators $\Gamma_0[\eta_1\times\eta_2],\ \Gamma_1[I],\ \Gamma_1[-]$: $l_c\leqslant l\leqslant l_1$, where l is the length of the ij-th entry.

Definition 13. $\Gamma_9[\overrightarrow{-}]''$ is an operator, which performs operation (I) over any given matrix with
$a=\varphi(\nu),\ \mu_1=\mu_2=1,\ m=n,\ \alpha=-1,\ \beta=i+1,\ \gamma=j.$ The modalities of the operator are $\Gamma_9[\overleftarrow{-}]'',\ \Gamma_9[-]''\uparrow,\ \Gamma_9[-]''\downarrow$, where β and γ assume values β=i-1, γ=j, β=i, γ=j+1, β=i, and γ=j-1.

Definition 14. $\Gamma_{10}[\overrightarrow{+}]'$ is an operator, which performs operation (I) over any two given matrices of identical size with
$a=\varphi(\nu),\ \mu_1=\mu_2=1,\ m\neq n,\ \alpha=1,\ \beta=i+1,\ \gamma=j.$

The modalities of the operator are $\Gamma_{10}[\overleftarrow{+}]',\ \Gamma_{10}[+]'\uparrow,\ \Gamma_{10}[+]'\downarrow$, where β and γ assume values $\beta=i-1,\ \gamma=j,\ \beta=i,\ \gamma=j+1,\ \beta=i,\ \gamma=j-1.$

Definition 15. $\Gamma_{11}[\overrightarrow{-}]''$ is an operator, which performs operation (I) over any two given matrices of identical size with

$a = \varphi(v),\ \mu_1 = \mu_2 = 1,\ m = n,\ \alpha = -1,\ \beta = i + 1,\ \gamma = j.$

The modalities of the operator are $\Gamma_{11}[\overline{-}]''$, $\Gamma_{11}[-]''\uparrow$, $\Gamma_{11}[-]''\downarrow$, where β and γ assume values $\beta=i-1$, $\gamma=j$, $\beta=i$, $\gamma=j+1$, $\beta=i$, and $\gamma=j-1$.

Definition 16. $\Gamma_{12}[+]$ is an operator, which performs operation (I) over any two given matrices of identical sizes with $a = \varphi(v),\ \mu_1 = \mu_2 = 1,\ m \neq n,\ \alpha = 1,\ \beta = i,\ \gamma = j.$

Definition 17. $\Gamma_{13}[-]$ is an operator, which performs operation (I) over any two given matrices of identical size with $a = \varphi(v)\ \mu_1 = \mu_2 = 1,\ m \neq n,\ \alpha = -1,\ \beta = i,\ \gamma = j.$

It is not difficult to see that the addition and subtraction operations for the ordinary matrices are particular cases of addition and subtraction of the neuron matrices. To prove this, it is sufficient to substitute $\lambda_k = 1,\ t_{ij}^{(k)} = 0,\ t = 1,\ p_k = 0,\ f_{ij}^{(m)} = \mathrm{const},\ \beta = \mathrm{const}$ in the corresponding expressions and then, after substituting $f_{ij}^{(k)} \to c_{ij},\ f_{ij}^{(m)} \to a_{ij},\ f_{\beta\gamma}^{(l)} \to b_{ij}$, we will obtain: $c_{ij} = a_{ij} + b_{ij}$ and $c_{ij} = a_{ij} - b_{ij}$, i.e., C=A+B and C=A-B.

When $\lambda_k = \lambda_k(t),\ p_k = p_k(t)$, this algebra makes it possible to model certain pathological properties of the sensory systems.

We note that the neuron matrix does not have to have a rectangular form in order to perform the operation over the neuron matrices. It can have an arbitrary form consisting of elements densely arranged in such a way as to permit their ordering.

Let us consider some of the elementary properties of the neuron matrices.

Theorem 1. Let $\eta_1 \neq \eta_2$. $\Gamma_0[\eta_1 \times \eta_2](A) = \Gamma_0[\eta_2 \times \eta_1](A)$.

Theorem 2. $\Gamma_0[N \times 1](A)$ is equivalent to $\Gamma_1[1](A)$, and $\Gamma_0[1 \times M](A)$ is equivalent to $\Gamma_1[1](A)$.

Theorem 3. Let $A \equiv (A \cup \bar{A})$. The following relations are valid:

$$\Gamma_2[\vec{-}](A) = A_1 \rightarrow, \quad \Gamma_2[\overleftarrow{-}](A) = A_1 \leftarrow, \quad \Gamma_2[-]\uparrow(A) = A_1 \uparrow,$$
$$\Gamma_2[-]\downarrow(A) = A_1 \downarrow.$$

Here A is a set of matrices for whose elements $f_{11}^{(k)} = f_{12}^{(k)} = \ldots = f_{MN}^{(k)} = 0$ is valid, and $\bar{A}$ - a set of matrices for whose elements $f_{11}^{(k)} = f_{12}^{(k)} = \ldots = f_{MN}^{(k)} = 0$ is valid.

Theorem 4. Let $\Gamma_2[\vec{-}](A) = A_1 \rightarrow$ where $A_1 \rightarrow = A \rightarrow$. The following relation is valid: $\Gamma_2[\vec{-}](A_1 \rightarrow) \neq A \rightarrow$.

Theorem 5. $\Gamma_1[+](A, B) = \Gamma_1[+](B, A)$.

Theorem 6. Let $A \neq B$. $\Gamma[-](A, B) \neq \Gamma[-](B, A)$.

Let us examine the operator variants.

a) $a = 1,\ f^{(2)} = \text{const},\ f^{(2)}_{i} = \text{const},\ t^{(2)}_{i} = 0,\ t = 1,$ we will write the operators in the form $\overline{\Gamma}[\eta], \overline{\Gamma}_1[I], \acute{\Gamma}_2[-], \overline{\Gamma}_3[+], \overline{\Gamma}_4[+]$, etc.

b) Only the absolute value of the difference between $t^{(1)}$ and $t^{(2)}$ is estimated.

We will write the operators in the form
$\Gamma[\overline{-}],\ \Gamma[-]^{1},\ \Gamma[\overline{-}],\ \Gamma[\overline{-}],\ \Gamma[-]|,\ \Gamma_6[\overline{-}]',\ \Gamma_9[-]'$, etc. For this variant, β=i+1 is equivalent to β=i-1, while γ=j+1 is equivalent to γ=j-1.

Cases a) and b) are valid simultaneously. We write the operators in the form $\overline{\Gamma}[\overline{-}], \overline{\Gamma}[-]|, \overline{\Gamma}[\overline{-}], \overline{\Gamma}[\overline{-}], \overline{\Gamma}[-]^{1}$, etc.

Certain properties of the neuron matrices were examined in [1]. In addition to describing and analyzing the operation of the sensory systems, this algebra can be used also for solving a class of problems, which do not relate to neuron networks.

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