I. Linear Algebra

I.9. Fundamental Theorem of Linear Algebra

Lecture based on

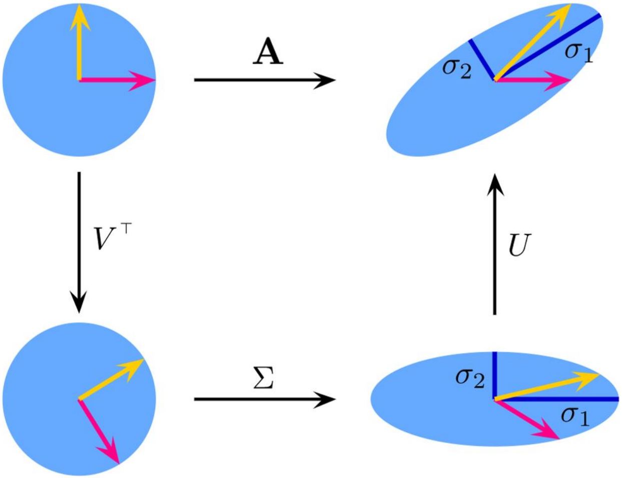
https://github.com/gwthomas/math4ml (Garrett Thomas, 2018)

Prof. Dr. Christoph Lippert

Digital Health & Machine Learning

$$\underbrace{\mathbf{x} \to \mathbf{A}\mathbf{x}}_{\text{linear map } \mathbb{R}^n \to \mathbb{R}^m}$$

$$\mathbf{A}\mathbf{x} = \mathbf{U}\mathbf{\Sigma}\mathbf{V}^\top\mathbf{x}$$



(modified from https://en.wikipedia.org/wiki/Singular_value_decomposition)

Theorem (Fundamental Theorem of Linear Algebra)

If $\mathbf{A} \in \mathbb{R}^{m \times n}$*, then*

(i) $\operatorname{null}(\mathbf{A}) = \operatorname{range}(\mathbf{A}^\top)^\perp$

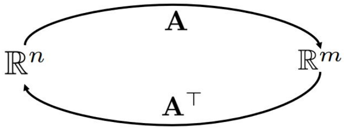
(ii) $\operatorname{null}(\mathbf{A}) \oplus \operatorname{range}(\mathbf{A}^\top) = \mathbb{R}^n$

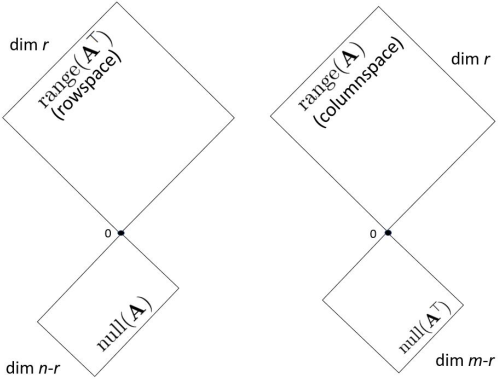
(iii) $\underbrace{\dim \operatorname{range}(\mathbf{A})}_{\operatorname{rank}(\mathbf{A})} + \dim \operatorname{null}(\mathbf{A}) = n$ ***(rank-nullity)***

(iv) *If* $\mathbf{A} = \mathbf{U}\boldsymbol{\Sigma}\mathbf{V}^\top$ *is the SVD of* $\mathbf{A}$*, then the columns of* $\mathbf{U}$ *and* $\mathbf{V}$ *form the* ***fundamental subspaces*** *of* $\mathbf{A}$*:*

Subspace	*Columns*
$\operatorname{range}(\mathbf{A}^\top)$	*The first* r *columns of* $\mathbf{U}$
$\operatorname{null}(\mathbf{A})$	*The last* $m-r$ *columns of* $\mathbf{U}$
$\operatorname{range}(\mathbf{A})$	*The first* r *columns of* $\mathbf{V}$
$\operatorname{null}(\mathbf{A}^\top)$	*The last* $n-r$ *columns of* $\mathbf{V}$

where $r = \operatorname{rank}(\mathbf{A})$





$$\mathrm{null}(\mathbf{A}) = \mathrm{range}(\mathbf{A}^\top)^\perp$$