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ON THE CONVERGENCE OF OPTIMAL LINEAR COMBINATION PROCEDURES

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Introduction:

The following algorithm has been suggested by Decell and Smiley in [1] for optimal linear combinations in the feature selection problem.

Let Ψ be a continuous function from M_n^k (see definition 1) into R^1 that is invariant under multiplication on the left by kxk invertible matrices. Then there exists $H_1 \in \mathcal{H}_n$ (see definition 2) such that

$$\Psi([I_k|Z]H_1) = \underset{H \in \mathcal{H}_n}{\text{l.u.b.}} \{\Psi([I_k|Z]H)\}.$$

Now for each positive integer i, let the element $H \in \mathcal{H}_n$ be chosen such that

$$\Psi([I_k|Z]H_i H_{i-1} \cdots H_1) = \underset{H \in \mathcal{H}_n}{\text{l.u.b.}} \Psi([I_k|Z]H \cdot H_{i-1} \cdots H_1)$$

The question of whether or not the above process terminates at an absolute Ψ-extremum (rank k maximal statistic) appeared in [1]. In this paper, we show that there exists a function Ψ as above for which the above process does not terminate at an absolute Ψ-extremum.

Let $H_1, \ldots, H_p$ be the matrices representing Householder transformations. Then for the matrix $[I_k|Z]H_1 \cdots H_p$, let $\Theta([I_k|Z]H_1 \cdots H_p)$ be the span in R^n of the k **row** vectors of that matrix. Suppose that $v_1, \ldots, v_k$ are linearly independent vectors in R^n. Then we show in this paper that there exists some integer $p \leq \min(n, n-k)$ and Householder transformations whose matrices are $H_1, \ldots, H_p$ for which

$\theta([I_k|Z]H_1\cdots H_p) = \mathrm{Span}\{v_1,\ldots,v_k\}$. We also determine the minimum integer p having the above property.

Preliminaries:

Definition 1. Let M_n^k be the set of all kxn rank k matrices.

Definition 2. Let $\mathcal{H}_n$ denote the set of all Householder transformations.

Definition 3. Let $\mathcal{S}_n^k$ denote the collection of all vector subspaces of R^n of dimension k.

Definition 4. Let $S^n = \{x \in R^n \mid \|x\| = 1\}$.

Definition 5. Let $\mathcal{C}$ be a closed subset of R^n and $x \notin \mathcal{C}$. Then there exists $c_x \in \mathcal{C}$ such that $\|x-c_x\| \leq \|x-c\|$ for any $c \in \mathcal{C}$. Let $\rho(x;\mathcal{C}) = \|x-c_x\|$.

Definition 6. Let A and B be elements of $\mathcal{S}_n^k$. Then there exists an element $a^* \in A \cap S^n$ having the property that $\rho(a^*; B\cap S^n) \geq \rho(a; B\cap S^n)$ for all $a \in A\cap S^n$. The number $\rho(a^*; B\cap S^n)$ will be called the distance from A to B and will be denoted by the symbol d(A;B).

Proposition 1. For any elements A, B, and C in $\mathcal{S}_n^k$

i) $d(A;B) \geq 0$ and $d(A;B) = 0$ if and only if A = B.

ii) $d(A;C) \leq d(A;B) + d(B;C)$.

iii) For any $\xi > 0$ there exists a $\delta > 0$ such that whenever $d(A;B) < \delta$, then $d(B;A) < \xi$.

Definition 7. For any $P \in \mathcal{S}_n^k$ and $\xi > 0$, let

$$\mathcal{U}_\xi(P) = \{X \in \mathcal{S}_n^k \mid d(X;P) < \xi\}.$$

Definition 8. Let T be the topology on $\mathcal{S}_n^k$ determined by the subbasis $\{\mathcal{U}_\xi(P) \mid \xi > 0 \text{ and } P \in \mathcal{S}_n^k\}$.

Definition 9. Let $\mathcal{C}$ be a closed subset of $\mathcal{S}_n^k$ and let $P \in \mathcal{S}_n^k$. Let $D(P;\mathcal{C}) = \text{g.l.b.}\{d(P;C) \mid C \in \mathcal{C}\}$.

Proposition 2. $(\mathcal{S}_n^k, T)$ is normal.

Proof: Let $\mathcal{A}$ and $\mathcal{B}$ be two closed disjoint subsets of $\mathcal{S}_n^k$. Let $\mathcal{U}_1 = \{P \in \mathcal{S}_n^k \mid D(P;\mathcal{A}) < D(P;\mathcal{B})\}$ and $\mathcal{U}_2 = \{P \in \mathcal{S}_n^k \mid D(P;\mathcal{A}) > D(P;\mathcal{B})\}$. By Proposition 1, we can determine that $\mathcal{U}_1$ and $\mathcal{U}_2$ are both open and are disjoint. This completes the proof.

Definition 10. For any vector $w = \begin{pmatrix} w_1 \\ \vdots \\ w_n \end{pmatrix}$ in R^n, let $w^U = \begin{pmatrix} w_1 \\ \vdots \\ w_k \end{pmatrix}$ and $w^L = \begin{pmatrix} w_{k+1} \\ \vdots \\ w_n \end{pmatrix}$.

Proposition 3. Suppose that $\{v_1, \ldots, v_k\}$ is a collection of linearly independent vectors in R^n. Let p be the dimension of $\text{Span}\{v_1^L, \ldots, v_k^L\}$ and assume $p > 0$. Then there exists a vector $x \in R^n$ such that $\|x\| = 1$, and if H_x is the Householder transformation determined by x, then the dimension of $\text{Span}\{H_x(v_1)^L, \ldots, H_x(v_k)^L\} = p-1$.

Proof: Case i) Dimension of $\text{Span}\{v_1^U, \ldots, v_k^U\}$ is less than k. We select a vector x^L in $\text{Span}\{v_1^L, \ldots, v_k^L\}$ such that $\|x^L\| = \sqrt{\tfrac{1}{2}}$. Since $[v_i^L - 2(v_i^L \cdot x^L)x^L] \cdot x^L = 0$ for $i=1,\ldots,k$. It follows that the dimension of $\text{Span}\{v_1^L - 2(v_1^L \cdot x^L)x^L, \ldots, v_k^L - 2(v_k^L \cdot x^L)x^L\}$ is p-1. Now by assumption there exists a vector x^U in R^k such that $\|x^U\| = \sqrt{\tfrac{1}{2}}$, and $v_i^U \cdot x^U = 0$ for $i=1,\ldots,k$. Since $v_i^L - 2(v_i \cdot x)x^L = v_i^L - 2(v_i^L \cdot x^L)x^L$, then the dimension of

Span $\left\{v_1^L-2(v_1^L\cdot x^L)x^L,\dots,v_k^L-2(v_k^L\cdot x^L)x^L\right\}$ is p-1, for

$$x = \begin{pmatrix} x^U \\ \vdots \\ x^U \end{pmatrix} .$$

Case ii) The dimension of Span$\left\{v_1^U,\dots,v_k^U\right\} = k$.
We select a vector x_o^L in Span $\left\{v_1^L,\dots,v_k^L\right\}$ with $\|x_o^L\| = \sqrt{½}$.
Then we have that the dimension of
Span $\left\{v_1^L-2(v_1^L\cdot x_o^L)x_o^L,\dots,v_k^L-2(v_k^L\cdot x_o^L)x_o^L\right\}$ is p-1. We assume then that $x^L = \lambda x_o^L$ for some $\lambda < 1$. We want a vector x^U in R^k such that if $x = \begin{pmatrix} x^U \\ x^L \end{pmatrix}$ then $\|x^U\|^2 + \|x^L\|^2 = 1$ and $v_i^L-2(v_i\cdot x)x^L = v_i^L-2(v_i^L\cdot x_o^L)x_o^L$ for $i=1,\dots,k$.

By substituting x_o^L into this equation in place of x^L we can determine that $v_i^U\cdot x^U = (\frac{1-\lambda^2}{\lambda})v_i^L\cdot x_o^L$ for $i=1,\dots,k$.
By our assumption we can find a vector x^U satisfying the above equations whenever a choice of λ is made. We observe that if λ approaches 1, then $\|x^U\|$ must approach 0, and $\|x^L\|$ must approach $\sqrt{½}$ so that if λ approaches 1, then $\|x^U\|^2 + \|x^L\|^2$ must approach $\sqrt{½}$. If λ approaches 0, then $\|x^U\|$ approaches $+\infty$ and $\|x^L\|$ approaches 0 so $\|x^U\|^2 + \|x^L\|^2$ approaches $+\infty$ as λ approaches 0.
It follows from this that there exists some λ for which $\|x^U\|^2 + \|x^L\|^2 = 1$. Thus we have the dimension of Span$\left\{v_1^L-2(v_1\cdot x)x^L,\dots,v_k^L-2(v_k\cdot x)x^L\right\}$ is p-1 which is the required condition. This completes the proof of proposition 3.

Definition 11. For any $M \in M_n^k$ let $\theta(M) = \text{Span}\{v_1, \ldots, v_k\}$ where $\{v_1, \ldots, v_k\}$ are the row vectors of M. θ is easily seen to be continuous.

Proposition 4. Suppose that $\theta([I_k | Z] H_1 \ldots H_p) = \text{Span}\{v_1, \ldots, v_k\}$ for Householder transformations $H_1, \ldots, H_p$. Then the dimension of $\text{Span}\{v_1^L, \ldots, v_k^L\}$ cannot exceed p.

Proof: We observe first of all that for any collection of vectors $\{y_1, \ldots, y_m\}$ and any Householder transformation H_x determined by the vector x that

$\text{Span}\{H_x(y_1), \ldots, H_x(y_m)\} \subset \text{Span}\{y_1, \ldots, y_m, x\}$ ..

Now $\theta([I_k | Z] H_1 \ldots H_p) = \text{Span}\{H_p \ldots H_1(e_1), \ldots, H_p \ldots H_1(e_k)\}$ where e_i is the vector with 1 in the i^{th} place and 0 everywhere else. Thus by the above statements,

$\text{Span}\{v_1, \ldots, v_k\} \subset \text{Span}\{e_1, \ldots, e_k, x_1, \ldots, x_p\}$.

It follows that $\text{Span}\{v_1^L, \ldots, v_k^L\} \subset \text{Span}\{x_1^L, \ldots, x_p^L\}$.

Thus the dimension of $\text{Span}\{v_1^L, \ldots, v_k^L\}$ is less than or equal to p. This completes the proof of Proposition 4.

Proposition 5. For linearly independent vectors $\{v_1, \ldots, v_k\}$, if p is the dimension of $\text{Span}\{v_1^L, \ldots, v_k^L\}$ and $p \geq 0$, then there exists Householder transformations $H_1, \ldots, H_p$ such that $\theta([I_k | Z] H_1 \ldots H_p) = \text{Span}\{v_1, \ldots, v_k\}$ and no fewer than p Householder transformations can have this property.

Proof: This is a consequence of Propositions 3 and 4 .

Construction of the map Ψ

Definition 12. For any $P \in \mathcal{S}_n^k$ let $P = \text{Span}\{v_1, \ldots, v_k\}$ and define $L(P)$ = the dimension of $\text{Span}\{v_1^L, \ldots, v_k^L\}$.

Definition 13. For $0 \leq p \leq n-k$ let $\mathcal{L}_p = \{A \in \mathcal{S}_n^k \mid L(A) \leq p\}$.

Proposition 6. $\mathcal{L}_p$ is closed for $p=0,\ldots,n-k$.

Proof: This is a consequence of the fact that if $\{u_1, \ldots, u_m\}$ is a collection of vectors in R^{n-k} and q is the dimension of $\text{Span}\{u_1, \ldots, u_m\}$ then there exists a real number $\xi > 0$ such that if $\|u_i - u_i^*\|$ for $i=1,\ldots,m$, then the dimension of $\text{Span}\{u_1^*, \ldots, u_m^*\}$ is greater than or equal to q. This completes the proof of Proposition 6.

Now for some $P \in \mathcal{L}_1$ there exists $\xi > 0$ such that if $A \in \mathcal{L}_1$, then $\mathcal{U}_\xi(A)$ does not contain P. Let $\mathcal{Q}$ be the closure in $\mathcal{S}_n^k$ of $\bigcup_{A \in \mathcal{L}_1} \{\mathcal{U}_\xi(A)\}$. By Urysohns lemma, [2] there exists a continuous function $\phi_1 : \mathcal{S}_n^k \to [0,1] \subset R^1$ such that $\phi_1(P) = 1$ and $\phi_1(A) = 0$ for any $A \in \mathcal{Q}$. Let $I = \text{Span}\{e_1, \ldots, e_k\}$. Then $\mathcal{U}_\xi(I) \subset \mathcal{Q}$ since $I \in \mathcal{L}_1$. Define a map $\phi_2 : \mathcal{S}_n^k \to [0, \frac{1}{2}]$ by $\phi_2(X) = 0$ if $X \notin \mathcal{U}_\xi(I)$ and $\phi_2(X) = \frac{\xi - d(X;I)}{2\xi}$ if $X \in \mathcal{U}_\xi(I)$. Let $\phi = \phi_1 + \phi_2$ and define $\Psi = \phi \circ \Theta$. We observe that $\mathcal{L}_1 = \Theta(\{[I_k \mid Z]H \mid H \in \mathcal{H}_n\})$. Also if $\Theta([I_k \mid Z]H_1) = I$ for some $H_1 \in \mathcal{H}_n$ then for any $H \in \mathcal{H}_n$, $\Theta([I_k \mid Z]H.H_1) \in \mathcal{L}_1$. That Ψ has the desired properties follows from the fact that the function ϕ has a maximum value of $\frac{1}{2}$ at I over the set $\mathcal{L}_1$ but ϕ has a maximum value of 1 at P over the entire space $\mathcal{S}_n^k$.

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