

Pacific Journal of Mathematics

THE METRIZATION OF STATISTICAL METRIC SPACES

BERTHOLD SCHWEIZER, ABE SKLAR AND EDWARD OAKLEY THORP

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In a previous paper on statistical metric spaces [3] it was shown that a statistical metric induces a natural topology for the space on which it is defined and that with this topology a large class of statistical metric (briefly, *SM*) spaces are Hausdorff spaces.

In this paper we show that this result (Theorem 7.2 of [3]) can be considerably generalized. In addition, as an immediate corollary of this generalization, we prove that with the given topology a large number of *SM* spaces are metrizable, i.e., that in numerous instances the existence of a statistical metric implies the existence of an ordinary metric.¹

THEOREM 1.² *Let (S, \mathcal{F}) be a statistical metric space, \mathcal{U} the two-parameter collection of subsets of $S \times S$ defined by*

$$\mathcal{U} = \{U(\varepsilon, \lambda); \varepsilon > 0, \lambda > 0\},$$

where

$$U(\varepsilon, \lambda) = \{(p, q); p, q \text{ in } S \text{ and } F_{pq}(\varepsilon) > 1 - \lambda\},$$

and T a two-place function from $[0, 1] \times [0, 1]$ to $[0, 1]$ satisfying $T(c, d) \geq T(a, b)$ for $c \geq a, d \geq b$ and $\sup_{x < 1} T(x, x) = 1$. Suppose further that for all p, q, r in S and for all real numbers x, y , the Menger triangle inequality.

$$(1) \quad F_{pr}(x + y) \geq T(F_{pq}(x), F_{qr}(y))$$

is satisfied. Then \mathcal{U} is the basis for a Hausdorff uniformity on $S \times S$.

Proof. We verify that the $U(\varepsilon, \lambda)$ satisfy the axioms for a basis for a Hausdorff (or separated) uniformity as given in [2; p. 174-180] (or in [1; II, §1, $n^\circ 1$]).

(a) Let $\Delta = \{(p, p); p \in S\}$ and $U(\varepsilon, \lambda)$ be given. Since for any $p \in S, F_{pp}(\varepsilon) = 1$, it follows that $(p, p) \in U(\varepsilon, \lambda)$. Thus $\Delta \subset U(\varepsilon, \lambda)$.

(b) Since $F_{pq} = F_{qp}$, $U(\varepsilon, \lambda)$ is symmetric.

(c) Let $U(\varepsilon, \lambda)$ be given. We have to show that there is a $W \in \mathcal{U}$ such that $W \circ W \subset U$. To this end, choose $\varepsilon' = \varepsilon/2$ and λ' so small that $T(1 - \lambda', 1 - \lambda') > 1 - \lambda$. Suppose now that (p, q) and (q, r) belong to

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¹ These considerations have led to the study of *SM* spaces which are not metrizable as well as to other natural topologies for *SM* spaces, questions which will be investigated in a subsequent paper.

² The terminology and notation are as in [3].

$W(\varepsilon', \lambda')$ so that $F_{pq}(\varepsilon') > 1 - \lambda'$ and $F_{qr}(\varepsilon') > 1 - \lambda'$. Then, by (1),

$$F_{pr}(\varepsilon) \geq T(F_{pq}(\varepsilon'), F_{qr}(\varepsilon')) \geq T(1 - \lambda', 1 - \lambda') > 1 - \lambda.$$

Thus $(p, r) \in U(\varepsilon, \lambda)$. But this means that $W \circ W \subset U$.

(d) The intersection of $U(\varepsilon, \lambda)$ and $U(\varepsilon', \lambda')$ contains a member of \mathcal{U} , namely $U(\min(\varepsilon, \varepsilon'), \min(\lambda, \lambda'))$.

Thus \mathcal{U} is the basis for a uniformity on $S \times S$.

(e) If p and q are distinct, there exists an $\varepsilon > 0$ such that $F_{pq}(\varepsilon) \neq 1$ and hence ε_0, λ_0 such that $F_{pq}(\varepsilon_0) = 1 - \lambda_0$. Consequently (p, q) is not in $U(\varepsilon_0, \lambda_0)$ and the uniformity generated by \mathcal{U} is separated, i.e., Hausdorff.

Note that the theorem is true in particular for all Menger spaces in which $\sup_{x < 1} T(x, x) = 1$. However, it is true as well for many *SM* spaces which are not Menger spaces.

COROLLARY. *If (S, \mathcal{F}) is an *SM* space satisfying the hypotheses of Theorem 1, then the sets of the form $N_x(\varepsilon, \lambda) = \{q; F_{pq}(\varepsilon) > 1 - \lambda\}$ are the neighborhood basis for a Hausdorff topology on S .*

Proof. These sets are a neighborhood basis for the uniform topology on S derived from \mathcal{U} .

THEOREM 2. *If an *SM* space satisfies the hypotheses of Theorem 1, then the topology determined by the sets $N_x(\varepsilon, \lambda)$ is metrizable.*

Proof. Let $\{(\varepsilon_n, \lambda_n)\}$ be a sequence that converges to $(0, 0)$. Then the collection $\{U(\varepsilon_n, \lambda_n)\}$ is a countable base for \mathcal{U} . The conclusion now follows from [2; p. 186].

Theorem 2 may be restated as follows: Under the hypotheses of Theorem 1, there exist numbers $\delta(p, q)$ which are determined by the distance distribution functions F_{pq} in such a manner that the function δ is an ordinary metric on S . Loosely speaking, if the statistical distances have certain properties, then certain numerical quantities associated with them have the properties of an ordinary distance. In a given particular case such quantities might be the means, medians, modes, etc.. For example, most of the particular spaces studied in [3] satisfy the hypotheses of Theorem 2, hence are metrizable. Indeed, as was shown in [3], in a simple space, the means (when they exist), medians, and modes (if unique) of the statistical distances each form metric spaces; and similarly, in a normal space, the means of the F_{pq} form a (generally discrete) metric space. What Theorem 2 now tells us is that in many (though not all!) *SM* spaces we can expect results of this general nature to hold.

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October, 1960

Maynard G. Arsove, <i>The Paley-Wiener theorem in metric linear spaces</i>	365
Robert (Yisrael) John Aumann, <i>Acceptable points in games of perfect information</i>	381
A. V. Balakrishnan, <i>Fractional powers of closed operators and the semigroups generated by them</i>	419
Dallas O. Banks, <i>Bounds for the eigenvalues of some vibrating systems</i>	439
Billy Joe Boyer, <i>On the summability of derived Fourier series</i>	475
Robert Breusch, <i>An elementary proof of the prime number theorem with remainder term</i>	487
Edward David Callender, Jr., <i>Hölder continuity of n-dimensional quasi-conformal mappings</i>	499
L. Carlitz, <i>Note on Alder's polynomials</i>	517
P. H. Doyle, III, <i>Unions of cell pairs in E^3</i>	521
James Eells, Jr., <i>A class of smooth bundles over a manifold</i>	525
Shaul Foguel, <i>Computations of the multiplicity function</i>	539
James G. Glimm and Richard Vincent Kadison, <i>Unitary operators in C^*-algebras</i>	547
Hugh Gordon, <i>Measure defined by abstract L_p spaces</i>	557
Robert Clarke James, <i>Separable conjugate spaces</i>	563
William Elliott Jenner, <i>On non-associative algebras associated with bilinear forms</i>	573
Harold H. Johnson, <i>Terminating prolongation procedures</i>	577
John W. Milnor and Edwin Spanier, <i>Two remarks on fiber homotopy type</i>	585
Donald Alan Norton, <i>A note on associativity</i>	591
Ronald John Nunke, <i>On the extensions of a torsion module</i>	597
Joseph J. Rotman, <i>Mixed modules over valuations rings</i>	607
A. Sade, <i>Théorie des systèmes démodiens de groupoïdes</i>	625
Wolfgang M. Schmidt, <i>On normal numbers</i>	661
Berthold Schweizer, Abe Sklar and Edward Oakley Thorp, <i>The metrization of statistical metric spaces</i>	673
John P. Shanahan, <i>On uniqueness questions for hyperbolic differential equations</i>	677
A. H. Stone, <i>Sequences of coverings</i>	689
Edward Oakley Thorp, <i>Projections onto the subspace of compact operators</i>	693
L. Bruce Treybig, <i>Concerning certain locally peripherally separable spaces</i>	697
Milo Wesley Weaver, <i>On the commutativity of a correspondence and a permutation</i>	705
David Van Vranken Wend, <i>On the zeros of solutions of some linear complex differential equations</i>	713
Fred Boyer Wright, Jr., <i>Polarity and duality</i>	723