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Bessel's Inequality

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Summary. In this article we defined the operation of a set and proved Bessel's inequality. In the first section, we defined the sum of all results of an operation, in which the results are given by taking each element of a set. In the second section, we defined Orthogonal Family and Orthonormal Family. In the last section, we proved some properties of operation of set and Bessel's inequality.

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The articles [11], [16], [12], [7], [5], [6], [17], [14], [9], [13], [3], [8], [1], [10], [4], [2], and [15] provide the notation and terminology for this paper.

1. Sum of the Result of Operation with Each Element of a Set

For simplicity, we adopt the following convention: X denotes a real unitary space, x, y, y_1, y_2 denote points of X, i, j denote natural numbers, D_1 denotes a non empty set, and p_1, p_2 denote finite sequences of elements of D_1.

One can prove the following proposition

(1) Suppose p_1 is one-to-one and p_2 is one-to-one and $\operatorname{rng} p_1 = \operatorname{rng} p_2$. Then $\operatorname{dom} p_1 = \operatorname{dom} p_2$ and there exists a permutation P of $\operatorname{dom} p_1$ such that $p_2 = p_1 \cdot P$ and $\operatorname{dom} P = \operatorname{dom} p_1$ and $\operatorname{rng} P = \operatorname{dom} p_1$.

Let D_1 be a non empty set and let f be a binary operation on D_1. Let us assume that f is commutative and associative and has a unity. Let Y be a finite subset of D_1. The functor $f \oplus Y$ yields an element of D_1 and is defined as follows:

(Def. 1) There exists a finite sequence p of elements of D_1 such that p is one-to-one and $\operatorname{rng} p = Y$ and $f \oplus Y = f \odot p$.

Let us consider X and let Y be a finite subset of X. The functor $\operatorname{SetopSum}(Y, X)$ is defined by:

(Def. 2) $$\operatorname{SetopSum}(Y,X) = \begin{cases} (\text{the addition of } X) \oplus Y, & \text{if } Y \neq \emptyset, \\ 0_X, & \text{otherwise.} \end{cases}$$

Let us consider X, x, let p be a finite sequence, and let us consider i. The functor $\operatorname{PO}(i, p, x)$ is defined as follows:

(Def. 3) $\operatorname{PO}(i,p,x) = (\text{the scalar product of } X)(\langle x, p(i)\rangle)$.

Let D_2, D_1 be non empty sets, let F be a function from D_1 into D_2, and let p be a finite sequence of elements of D_1. The functor $\operatorname{FuncSeq}(F, p)$ yields a finite sequence of elements of D_2 and is defined by:

(Def. 4) $\text{FuncSeq}(F, p) = F \cdot p$.

Let D_2, D_1 be non empty sets and let f be a binary operation on D_2. Let us assume that f is commutative and associative and has a unity. Let Y be a finite subset of D_1 and let F be a function from D_1 into D_2. Let us assume that $Y \subseteq \text{dom} F$. The functor $\text{setopfunc}(Y, D_1, D_2, F, f)$ yielding an element of D_2 is defined as follows:

(Def. 5) There exists a finite sequence p of elements of D_1 such that p is one-to-one and $\text{rng}\, p = Y$ and $\text{setopfunc}(Y, D_1, D_2, F, f) = f \odot \text{FuncSeq}(F, p)$.

Let us consider X, x and let Y be a finite subset of X. The functor $\text{SetopPreProd}(x, Y, X)$ yielding a real number is defined by the condition (Def. 6).

(Def. 6) There exists a finite sequence p of elements of the carrier of X such that

(i) p is one-to-one,

(ii) $\text{rng}\, p = Y$, and

(iii) there exists a finite sequence q of elements of $\mathbb{R}$ such that $\text{dom}\, q = \text{dom}\, p$ and for every i such that $i \in \text{dom}\, q$ holds $q(i) = \text{PO}(i, p, x)$ and $\text{SetopPreProd}(x, Y, X) = +_{\mathbb{R}} \odot q$.

Let us consider X, x and let Y be a finite subset of X. The functor $\text{SetopProd}(x, Y, X)$ yields a real number and is defined as follows:

(Def. 7) $\text{SetopProd}(x, Y, X) = \begin{cases} \text{SetopPreProd}(x, Y, X), & \text{if } Y \neq \emptyset, \\ 0, & \text{otherwise.} \end{cases}$

2. Orthogonal Family and Orthonormal Family

Let us consider X. A subset of X is called an orthogonal family of X if:

(Def. 8) For all x, y such that $x \in$ it and $y \in$ it and $x \neq y$ holds $(x|y) = 0$.

The following proposition is true

(2) $\emptyset$ is an orthogonal family of X.

Let us consider X. One can check that there exists an orthogonal family of X which is finite.

Let us consider X. A subset of X is called an orthonormal family of X if:

(Def. 9) It is an orthogonal family of X and for every x such that $x \in$ it holds $(x|x) = 1$.

One can prove the following proposition

(3) $\emptyset$ is an orthonormal family of X.

Let us consider X. Observe that there exists an orthonormal family of X which is finite.

Next we state the proposition

(4) $x = 0_X$ iff for every y holds $(x|y) = 0$.

3. Bessel's Inequality

The following propositions are true:

(5) $\|x+y\|^2 + \|x-y\|^2 = 2 \cdot \|x\|^2 + 2 \cdot \|y\|^2$.

(6) If x, y are orthogonal, then $\|x+y\|^2 = \|x\|^2 + \|y\|^2$.

(7) Let p be a finite sequence of elements of the carrier of X. Suppose $\text{len}\, p \geq 1$ and for all i, j such that $i \in \text{dom}\, p$ and $j \in \text{dom}\, p$ and $i \neq j$ holds (the scalar product of X)$(\langle p(i), p(j) \rangle) = 0$. Let q be a finite sequence of elements of $\mathbb{R}$. Suppose $\text{dom}\, p = \text{dom}\, q$ and for every i such that $i \in \text{dom}\, q$ holds $q(i) =$ (the scalar product of X)$(\langle p(i), p(i) \rangle)$. Then ((the addition of $X \odot p$)|(the addition of $X \odot p$)) $= +_{\mathbb{R}} \odot q$.

(8) Let p be a finite sequence of elements of the carrier of X. Suppose $\operatorname{len} p \geq 1$. Let q be a finite sequence of elements of $\mathbb{R}$. Suppose $\operatorname{dom} p = \operatorname{dom} q$ and for every i such that $i \in \operatorname{dom} q$ holds $q(i) =$ (the scalar product of X)$(\langle x, p(i) \rangle)$. Then $(x|$(the addition of $X \odot p)) = +_{\mathbb{R}} \odot q$.

(9) Let S be a finite non empty subset of X and F be a function from the carrier of X into the carrier of X. Suppose $S \subseteq \operatorname{dom} F$ and for all y_1, y_2 such that $y_1 \in S$ and $y_2 \in S$ and $y_1 \neq y_2$ holds (the scalar product of X)$(\langle F(y_1), F(y_2) \rangle) = 0$. Let H be a function from the carrier of X into $\mathbb{R}$. Suppose $S \subseteq \operatorname{dom} H$ and for every y such that $y \in S$ holds $H(y) =$ (the scalar product of X)$(\langle F(y), F(y) \rangle)$. Let p be a finite sequence of elements of the carrier of X. Suppose p is one-to-one and $\operatorname{rng} p = S$. Then (the scalar product of X)$(\langle$the addition of $X \odot \operatorname{FuncSeq}(F, p)$, the addition of $X \odot \operatorname{FuncSeq}(F, p) \rangle) = +_{\mathbb{R}} \odot \operatorname{FuncSeq}(H, p)$.

(10) Let S be a finite non empty subset of X and F be a function from the carrier of X into the carrier of X. Suppose $S \subseteq \operatorname{dom} F$. Let H be a function from the carrier of X into $\mathbb{R}$. Suppose $S \subseteq \operatorname{dom} H$ and for every y such that $y \in S$ holds $H(y) =$ (the scalar product of X)$(\langle x, F(y) \rangle)$. Let p be a finite sequence of elements of the carrier of X. Suppose p is one-to-one and $\operatorname{rng} p = S$. Then (the scalar product of X)$(\langle x$, the addition of $X \odot \operatorname{FuncSeq}(F, p) \rangle) = +_{\mathbb{R}} \odot \operatorname{FuncSeq}(H, p)$.

(11) Let given X. Suppose the addition of X is commutative and associative and the addition of X has a unity. Let given x and S be a finite orthonormal family of X. Suppose S is non empty. Let H be a function from the carrier of X into $\mathbb{R}$. Suppose $S \subseteq \operatorname{dom} H$ and for every y such that $y \in S$ holds $H(y) = (x|y)^{\mathbf{2}}$. Let F be a function from the carrier of X into the carrier of X. Suppose $S \subseteq \operatorname{dom} F$ and for every y such that $y \in S$ holds $F(y) = (x|y) \cdot y$. Then $(x|\operatorname{setopfunc}(S,$the carrier of X, the carrier of X, $F,$the addition of $X)) = \operatorname{setopfunc}(S,$the carrier of X, $\mathbb{R}, H, +_{\mathbb{R}})$.

(12) Let given X. Suppose the addition of X is commutative and associative and the addition of X has a unity. Let given x and S be a finite orthonormal family of X. Suppose S is non empty. Let F be a function from the carrier of X into the carrier of X. Suppose $S \subseteq \operatorname{dom} F$ and for every y such that $y \in S$ holds $F(y) = (x|y) \cdot y$. Let H be a function from the carrier of X into $\mathbb{R}$. Suppose $S \subseteq \operatorname{dom} H$ and for every y such that $y \in S$ holds $H(y) = (x|y)^{\mathbf{2}}$. Then $(\operatorname{setopfunc}(S,$the carrier of X, the carrier of X, $F,$the addition of $X)|\operatorname{setopfunc}(S,$the carrier of X, the carrier of X, $F,$the addition of $X)) = \operatorname{setopfunc}(S,$the carrier of X, $\mathbb{R}, H, +_{\mathbb{R}})$.

(13) Let given X. Suppose the addition of X is commutative and associative and the addition of X has a unity. Let given x and S be a finite orthonormal family of X. Suppose S is non empty. Let H be a function from the carrier of X into $\mathbb{R}$. Suppose $S \subseteq \operatorname{dom} H$ and for every y such that $y \in S$ holds $H(y) = (x|y)^{\mathbf{2}}$. Then $\operatorname{setopfunc}(S,$the carrier of X, $\mathbb{R}, H, +_{\mathbb{R}}) \leq \|x\|^{\mathbf{2}}$.

(14) Let D_2, D_1 be non empty sets and f be a binary operation on D_2. Suppose f is commutative and associative and has a unity. Let Y_1, Y_2 be finite subsets of D_1. Suppose Y_1 misses Y_2. Let F be a function from D_1 into D_2. Suppose $Y_1 \subseteq \operatorname{dom} F$ and $Y_2 \subseteq \operatorname{dom} F$. Let Z be a finite subset of D_1. If $Z = Y_1 \cup Y_2$, then $\operatorname{setopfunc}(Z, D_1, D_2, F, f) = f(\operatorname{setopfunc}(Y_1, D_1, D_2, F, f), \operatorname{setopfunc}(Y_2, D_1, D_2, F, f))$.

REFERENCES

[1] Grzegorz Bancerek. Cardinal numbers. *Journal of Formalized Mathematics*, 1, 1989. `http://mizar.org/JFM/Vol1/card_1.html`.

[2] Grzegorz Bancerek and Krzysztof Hryniewiecki. Segments of natural numbers and finite sequences. *Journal of Formalized Mathematics*, 1, 1989. `http://mizar.org/JFM/Vol1/finseq_1.html`.

[3] Czesław Byliński. Binary operations. *Journal of Formalized Mathematics*, 1, 1989. `http://mizar.org/JFM/Vol1/binop_1.html`.

[4] Czesław Byliński. Functions and their basic properties. *Journal of Formalized Mathematics*, 1, 1989. `http://mizar.org/JFM/Vol1/funct_1.html`.

[5] Czesław Byliński. Functions from a set to a set. *Journal of Formalized Mathematics*, 1, 1989. `http://mizar.org/JFM/Vol1/funct_2.html`.

[6] Agata Darmochwał. Finite sets. *Journal of Formalized Mathematics*, 1, 1989. `http://mizar.org/JFM/Vol1/finset_1.html`.

[7] Krzysztof Hryniewiecki. Basic properties of real numbers. *Journal of Formalized Mathematics*, 1, 1989. http://mizar.org/JFM/Vol1/real_1.html.

[8] Eugeniusz Kusak, Wojciech Leończuk, and Michał Muzalewski. Abelian groups, fields and vector spaces. *Journal of Formalized Mathematics*, 1, 1989. http://mizar.org/JFM/Vol1/vectsp_1.html.

[9] Jan Popiołek. Introduction to Banach and Hilbert spaces — part I. *Journal of Formalized Mathematics*, 3, 1991. http://mizar.org/JFM/Vol3/bhsp_1.html.

[10] Andrzej Trybulec. Semilattice operations on finite subsets. *Journal of Formalized Mathematics*, 1, 1989. http://mizar.org/JFM/Vol1/setwiseo.html.

[11] Andrzej Trybulec. Tarski Grothendieck set theory. *Journal of Formalized Mathematics*, Axiomatics, 1989. http://mizar.org/JFM/Axiomatics/tarski.html.

[12] Andrzej Trybulec. Subsets of real numbers. *Journal of Formalized Mathematics*, Addenda, 2003. http://mizar.org/JFM/Addenda/numbers.html.

[13] Andrzej Trybulec and Czesław Byliński. Some properties of real numbers operations: min, max, square, and square root. *Journal of Formalized Mathematics*, 1, 1989. http://mizar.org/JFM/Vol1/square_1.html.

[14] Wojciech A. Trybulec. Vectors in real linear space. *Journal of Formalized Mathematics*, 1, 1989. http://mizar.org/JFM/Vol1/rlvect_1.html.

[15] Wojciech A. Trybulec. Binary operations on finite sequences. *Journal of Formalized Mathematics*, 2, 1990. http://mizar.org/JFM/Vol2/finsop_1.html.

[16] Zinaida Trybulec. Properties of subsets. *Journal of Formalized Mathematics*, 1, 1989. http://mizar.org/JFM/Vol1/subset_1.html.

[17] Edmund Woronowicz. Relations and their basic properties. *Journal of Formalized Mathematics*, 1, 1989. http://mizar.org/JFM/Vol1/relat_1.html.

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