

Binary operations inspired by generalized entropies applied to figurate numbers

Original

Binary operations inspired by generalized entropies applied to figurate numbers / Sparavigna, A.C.. - ELETTRONICO. - (2021). [10.5281/zenodo.4662489]

Availability:

This version is available at: 11583/2883399 since: 2021-04-05T10:39:27Z

Publisher:

Published

DOI:10.5281/zenodo.4662489

Terms of use:

This article is made available under terms and conditions as specified in the corresponding bibliographic description in the repository

Publisher copyright

(Article begins on next page)

Binary operations inspired by generalized entropies applied to figurate numbers

Amelia Carolina Sparavigna

Department of Applied Science and Technology, Politecnico di Torino, Torino, Italy

Abstract: The generalized entropies, which are coming from generalizations of the standard statistical mechanics, have binary composition operations that can be applied to the study of numbers. Here we will discuss these operations, inspired by entropies, and their use to study some of the figurate numbers.

Keywords: Generalized entropies, q-calculus, Abelian groups, Generalized sums, binary operations, OEIS, On-Line Encyclopedia of Integer Sequences, Figurate numbers, Triangular numbers, Pentagonal numbers, Pronic numbers, Hexagonal numbers.

Torino, 5 April 2021

Introduction

The generalized entropies, which are coming from generalization of standard statistical mechanics, have composition operations that can be applied to the study of numbers. These entropies, such as the Havrda–Charvát and Tsallis entropy [1,2], are non-additive. It means that they are following rules of composition, which are different from the usual operation of addition. The Tsallis composition rule is defined in [3] as a pseudo-additivity. In order to consider the class of all the generalized entropies, not only the Tsallis one, let us call “generalized additivity” or "generalized sum", the rule concerning composition of two elements. I used the locution "generalized sum" in a discussion about the rules of binary composition that we can obtain from the transcendental functions [4].

The approach, given in [4], is using the method based on the generators of algebras as explained in [5-7]. What we can do for entropies, the same we can do for sequences of numbers [8]. Using this approach, we have studied the q-integers and the symmetric q-integers [9,10]. And we can

study the generalized sums that are the binary operations of groupoids formed by Mersenne, Fermat, Cullen, Woodall, Thabit numbers, Repunits and many others [11-15]. Here, we apply the same approach to the category of the figurate numbers. These are numbers which can be represented by a regular geometrical arrangement of equally spaced points. The most common figurate numbers are given by <https://mathworld.wolfram.com/FigurateNumber.html> [16].

Before the study of numbers, let us start considering the binary operation and indicate it by \bullet . It is an operation combining two elements to obtain another element. In particular, this operation has a peculiar meaning when it acts on a set in a manner that its two domains and its codomain are the same set. This happens when it combines any two elements a, b of set A to form another element of A , denoted $a \bullet b$. *This property is the closure.*

To qualify (A, \bullet) as a group, the set and operation must satisfy further requirements beside the *closure*. We need *associativity* (for all a, b and c in A , it holds $(a \bullet b) \bullet c = a \bullet (b \bullet c)$), the *identity element* (an element e exists in A , such that for all elements a in A , it is $e \bullet a = a \bullet e = a$), and the *inverse element* (for each a in A , there exists an element b in A such that $a \bullet b = b \bullet a = e$, where e is the identity). The notation used before is inherited from the multiplicative operation. If the group is an Abelian group, the operation is indicated by $+$ and the *identity element* by 0 (*neutral element*) and the inverse element of a as $-a$ (*opposite element*). In this case, the group is called an additive group.

We can obtain the operation of a group by means of functions. Actually, if a function $G(x)$ exists, which is invertible $G^{-1}(G(x))=x$, we can use it as a *generator*, to generate an algebra [5,6]. In this manner, G can be used to define the *group law* $\Phi(x, y)$, such as:

$$\Phi(x, y) = G(G^{-1}(x) + G^{-1}(y)).$$

$\Phi(x, y)$ is the operation $x \oplus y$.

How can we apply this approach to the sequence of integers? To propose a simple example, let us use the gnomonic numbers, which are defined as $g_n = 2n - 1$. They are figurate numbers.

We have:

$$G(n) = 2n - 1 \quad , \quad G^{-1}(n) = (n + 1) / 2 \quad .$$

Therefore:

$$g_n \oplus g_m = G\left(\frac{g_n}{2} + \frac{1}{2} + \frac{g_m}{2} + \frac{1}{2}\right) = g_n + g_m + 1 = g_{n+m} = 2(n+m) - 1$$

Then, the generalized sum of the groupoid of gnomonic numbers is:

$$g_n \oplus g_m = g_n + g_m + 1$$

This sum is giving another element of the set of gnomonic numbers. Actually, we can obtain all these numbers using the generalized sum:

$$g_{n+1} = g_n \oplus g_1 = g_n + g_1 + 1 \quad , \quad g_1 = 1$$

Numbers are: 1, 3, 5, 7, 9, 11, 13 ... The On-Line Encyclopedia of Integer Sequences, A005408, tells us that they are the odd numbers.

Therefore, in the case of the integer sequences, to find the generator means to find n as a function of g_n . In the case of the following figurate numbers, the approach is quite simple.

figurate number	formula	hex number	$3n^2 + 3n + 1$
centered pentagonal number	$\frac{1}{2}(5n^2 + 5n + 2)$	hexagonal number	$n(2n - 1)$
centered square number	$n^2 + (n - 1)^2$	octagonal number	$n(3n - 2)$
centered triangular number	$\frac{1}{2}(3n^2 - 3n + 2)$	pentagonal number	$\frac{1}{2}n(3n - 1)$
decagonal number	$4n^2 - 3n$	hexagonal number	$n(2n - 1)$
gnomonic number	$2n - 1$	pronic number	$n(n + 1)$
heptagonal number	$\frac{1}{2}n(5n - 3)$	square number	n^2
		triangular number	$\frac{1}{2}n(n + 1)$

Some numbers from the list of common figurate numbers given by mathworld.wolfram.com

Some of the above-mentioned numbers have been considered before, and their binary operations derived.

Triangular numbers T_n [17]:

$$T_n \oplus T_m = T_n + T_m + \frac{1}{4} [1 - (1+8T_n)^{1/2} - (1+8T_m)^{1/2} + (1+8T_n)^{1/2} (1+8T_m)^{1/2}]$$

$$T_{n+1} = T_n + 1 + \frac{1}{2} [-1 + (1+8T_n)^{1/2}]$$

Pronic (oblong) numbers O_n [18]:

$$O_m \oplus O_n = O_m + O_n + 1/2 + 2(O_m + 1/4)^{1/2} (O_n + 1/4)^{1/2} - (O_m + 1/4)^{1/2} - (O_n + 1/4)^{1/2}$$

Pentagonal numbers p_n , with $\frac{1}{9} + \frac{8}{3} p_n = A_n$ [19]:

$$p_m \oplus p_n = p_{m+n} = p_m + p_n + \frac{1}{12} + \frac{1}{4} (\sqrt{A_m} + \sqrt{A_n}) + \frac{3}{4} \sqrt{A_m A_n}$$

$$p_n \oplus p_1 = p_n + p_1 + \frac{1}{12} + \frac{1}{4} (\sqrt{A_n} + \sqrt{A_1}) + \frac{3}{4} \sqrt{A_n A_1}$$

Centered squares C_n [20]:

$$C_m \oplus C_n = C_m + C_n + 2(C_m - 1/2)^{1/2} (C_n - 1/2)^{1/2} - \sqrt{2} (C_m - 1/2)^{1/2} - \sqrt{2} (C_n - 1/2)^{1/2}$$

Let us add to the previous numbers, which are mentioned in [16], the **star numbers** (centered dodecagonal numbers) $S_n = 6n(n-1) - 1$ [21]:

$$S_n \oplus S_m = S_n + S_m + 2 + (3+6S_n)^{1/2} + (3+6S_m)^{1/2} + \frac{1}{3} (3+6S_n)^{1/2} (3+6S_m)^{1/2}$$

The figurate numbers F_n given in the table given above [16], and the star numbers too, have the general form:

$$F_n = an^2 + bn + c$$

As a result, the generalized sum has the form:

$$F_n \oplus F_m = F_n + F_m + d + e\sqrt{g+hF_n} + e\sqrt{g+hF_m} + f\sqrt{g+hF_n}\sqrt{g+hF_m}$$

Let us consider the hexagonal numbers, for instance, which are $H_n = n(2n-1)$, $H_1 = 1$:

$$H_n \oplus H_m = H_n + H_m + \frac{1}{4} + \frac{1}{4}\sqrt{1+8H_n} + \frac{1}{4}\sqrt{1+8H_m} + \frac{1}{4}\sqrt{1+8H_n}\sqrt{1+8H_m}$$

$$\begin{aligned} H_n \oplus H_1 &= H_n + H_1 + \frac{1}{4} + \frac{1}{4}\sqrt{1+8H_n} + \frac{1}{4}\sqrt{1+8H_1} + \frac{1}{4}\sqrt{1+8H_n}\sqrt{1+8H_1} \\ &= H_n + 2 + \frac{1}{4}\sqrt{1+8H_n} + \frac{3}{4}\sqrt{1+8H_n} = H_n + 2 + \sqrt{1+8H_n} \end{aligned}$$

Using this formula, we have: 1, 6, 15, 28, 45, 66, 91, 120, 153, 190, 231, 276, 325, 378, 435, 496, 561, 630, 703, 780, 861, 946, 1035, 1128, 1225, 1326, 1431, 1540, 1653, 1770, 1891, 2016, 2145, 2278, 2415, 2556, 2701, 2850, 3003, ... (On-Line Encyclopedia of Integer Sequences, A000384, Hexagonal numbers: $a(n) = n*(2*n-1)$).

If we analyse the square root, we can see that it contains numbers:

$$1+8H_n = 1+8n(2n-1) = 16n^2 - 8n + 1 = (4n+3)^2 = 16(n-1)^2 + 24(n-1) + 9$$

We have a link to OEIS A016838 $a(n) = (4n + 3)^2$.

Let us stress that the square roots contain interesting sequences of numbers, such as in the case of the pentagonal numbers [19]. Pentagonal numbers (OEIS A000326) possess a generalized sum involving another integer sequence, OEIS A016969, and this sequence contains OEIS A007528, that is the primes of the $6n-1$.

Here we have discussed the composition operations for the figurate numbers. These binary operations can be obtained from a law based on a function and its inverse. The sequence of a figurate number can be therefore seen as a groupoid, with a specific binary operation. In the case of figurate numbers containing n to powers greater than 2, the calculus is more complex, however we can imagine to find an approach to obtain a similar binary operation.

References

- [1] J. Havrda and F. Charvát, “Quantification method of classification processes. Concept of structural α -entropy,” *Kybernetika*, vol. 3, pp. 30–35, 1967.
- [2] Tsallis, C. (1988). Possible generalization of Boltzmann-Gibbs statistics. *Journal of statistical physics*, 52(1-2), 479-487. DOI: 10.1007/bf01016429
- [3] Portes De Albuquerque, M., Esquef, I. A., Gesualdi Mello, A. R., & Portes De Albuquerque, M. (2004). Image thresholding using Tsallis entropy. *Pattern Recognition Letters*, 25(9), 1059-1065. DOI: 10.1016/j.patrec.2004.03.003
- [4] Sparavigna, A. C. (2018). Generalized Sums Based on Transcendental Functions. *SSRN Electronic Journal*. Elsevier. DOI: 10.2139/ssrn.3171628
- [5] Tempesta, P. (2015). . Groups, generalized entropies and L-series. In *Templeton Workshop on Foundations of Complexity*. Madrid, Spain. October 19-23, 2015
- [6] Tempesta, P. (2016). Formal groups and Z-entropies. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 472(2195), 20160143.
- [7] Curado, E. M., Tempesta, P., & Tsallis, C. (2016). A new entropy based on a group-theoretical structure. *Annals of Physics*, 366, 22-31.
- [8] Sparavigna, A. C. (2019). Composition Operations of Generalized Entropies Applied to the Study of Numbers, *International Journal of Sciences* 04(2019):87-92 DOI: 10.18483/ijSci.2044
- [9] Sparavigna, A. C. (2018). The q-integers and the Mersenne numbers. *SSRN Electronic Journal*. Elsevier, DOI: 10.2139/ssrn.3183800
- [10] Sparavigna, A. C. (2018). On the generalized sum of the symmetric q-integers. *Zenodo*. DOI: 10.5281/zenodo.1248959
- [11] Sparavigna, A. C. (2018). The group of the Fermat Numbers. *Zenodo*. <http://doi.org/10.5281/zenodo.1252422>
- [12] Sparavigna, A. C. (2019). On the generalized sums of Mersenne, Fermat, Cullen and Woodall Numbers. *Zenodo*. <http://doi.org/10.5281/zenodo.2634312>

- [13] Sparavigna, A. C. (2019). A recursive formula for Thabit numbers. Zenodo. <http://doi.org/10.5281/zenodo.2638790>
- [14] Sparavigna, A. C. (2019). On Repunits. Zenodo. <http://doi.org/10.5281/zenodo.2639620>
- [15] Sparavigna, A. C. (2019). Some Groupoids and their Representations by Means of Integer Sequences, International Journal of Sciences 10(2019):1-5 DOI: 10.18483/ijSci.2188
- [16] Weisstein, Eric W. Figurate Number. From MathWorld -- A Wolfram Web Resource. <https://mathworld.wolfram.com/FigurateNumber.html>
- [17] Sparavigna, A. C. (2019, October 2). The groupoid of the Triangular Numbers and the generation of related integer sequences. Zenodo. <http://doi.org/10.5281/zenodo.3470205>
- [18] Sparavigna, A. C. (2019, June 16). Groupoids of OEIS A002378 and A016754 Numbers (oblong and odd square numbers). Zenodo. <http://doi.org/10.5281/zenodo.3247003>
- [19] Sparavigna, A. C. (2021, March 27). The Pentagonal Numbers and their Link to an Integer Sequence which contains the Primes of Form $6n-1$. Zenodo. <http://doi.org/10.5281/zenodo.4641886>
- [20] Sparavigna, A. C. (2019, June 22). Groupoid of OEIS A001844 Numbers (centered square numbers). Zenodo. <http://doi.org/10.5281/zenodo.3252339>
- [21] Sparavigna, A. C. (2019, September 5). Groupoid of OEIS A003154 Numbers (star numbers or centered dodecagonal numbers). Zenodo. <http://doi.org/10.5281/zenodo.3387054>