

CONSIDERATIONS ON NEW FUNCTIONS IN NUMBER THEORY

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Abstract:

New functions are introduced in number theory, and for each one a general description, examples, connections, and references are given.

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Introduction.

In this paper a small survey is presented on eighteen new functions and four new sequences, such as: Inferior/Superior f-Part, Fractional f-Part, Complementary function with respect with another function, S-Multiplicative, Primitive Function, Double Factorial Function, S-Prime and S-Coprime Functions, Smallest Power Function.

1) Let $f: \mathbb{Z} \rightarrow \mathbb{Z}$ be a strictly increasing function and x an element in \mathbb{R} . Then:

a) Inferior f-Part of x ,

ISf(x) is the smallest k such that $f(k) \leq x < f(k+1)$.

b) Superior f-Part of x ,

SSf(x) is the smallest k such that $f(k) < x \leq f(k+1)$.

Particular cases:

a) Inferior Prime Part:

For any positive real number n one defines ISp(n) as the largest prime number less than or equal to n .

The first values of this function are (Smarandache[6] and Sloane[5]):
2,3,3,5,5,7,7,7,7,11,11,13,13,13,13,17,17,19,19,19,19,23,23.

b) Superior Prime Part:

For any positive real number n one defines SSp(n) as the smallest prime number greater than or equal to n .

The first values of this function are (Smarandache[6] and Sloane[5]):
2,2,2,3,5,5,7,7,11,11,11,11,13,13,17,17,17,17,19,19,23,23,23.

c) Inferior Square Part:

For any positive real number n one defines ISs(n) as the largest square less than or equal to n .

c) *Fractional Cubic Part*:

$$FSc(x) = x - ISc(x),$$

where $ISc(x)$ is the Inferior Cubic Part defined above.

$$\text{Example: } FSc(12.501) = 12.501 - 8 = 4.501.$$

d) *Fractional Factorial Part*:

$$FSf(x) = x - ISf(x),$$

where $ISf(x)$ is the Inferior Factorial Part defined above.

$$\text{Example: } FSf(12.501) = 12.501 - 6 = 6.501.$$

Remark 2.1: This is a generalization of the fractional part of a number.

Remark 2.2: In a similar way one defines:

- the Inferior Fractional f-Part:

$$IFSf(x) = x - ISf(x) = FSf(x);$$

- and the Superior Fractional f-Part:

$$SFSf(x) = SSf(x) - x;$$

$$\text{for example: Superior Fractional Cubic Part of } 12.501 \\ = 27 - 12.501 = 14.499.$$

3) Let $g: A \rightarrow A$ be a strictly increasing function, and let " \sim " be a given internal law on A . Then we say that

$f: A \rightarrow A$ is complementary with respect to the

function g and the internal law " \sim " if:

$f(x)$ is the smallest k such that there exists a z in A so that $x \sim k = g(z)$.

Particular cases:

a) *Square Complementary Function*:

$f: N \rightarrow N$, $f(x)$ = the smallest k such that xk is a perfect square.

The first values of this function are (Smarandache[6] and Sloane[5]):
1,2,3,1,5,6,7,2,1,10,11,3,14,15,1,17,2,19,5,21,22,23,6,1,26,3,7.

b) *Cubic Complementary Function*:

$f: N \rightarrow N$, $f(x)$ = the smallest k such that xk is a perfect cube.

The first values of this function are (Smarandache[6] and Sloane[5]):
1,4,9,2,25,36,49,1,3,100,121,18,169,196,225,4,289,12,361,50.

More generally:

c) *m-power Complementary Function*:

$f: N \rightarrow N$, $f(x)$ = the smallest k such that xk is a perfect m -power.

d) *Prime Complementary Function*:

$f: N \rightarrow N$, $f(x)$ = the smallest k such that $x+k$ is a prime.

The first values of this function are (Smarandache[6] and Sloane[5]):
1,0,0,1,0,1,0,3,2,1,0,1,0,3,2,1,0,1,0,3,2,1,0,5,4,3,2,1,0,1,0,5.

4) S-Multiplicative Function:

* *

A function $f : \mathbb{N} \rightarrow \mathbb{N}$ which,
 for any $(a, b) = 1$, verifies $f(ab) = \max \{f(a), f(b)\}$;
 (i.e. it reflects the main property of the Smarandache function[8]).

References:

[1] Castillo, Jose, "Other Smarandache Type Functions",
<http://www.gallup.unm.edu/~smarandache/funct2.txt>

[2] Dumitrescu, C., Seleacu, V., "Some Notions and Questions in Number Theory", Xiquan Publ. Hse., Phoenix-Chicago, 1994.

[3] Popescu, Marcela, Nicolescu, Mariana, "About the Smarandache Complementary Cubic Function", <Smarandache Notions Journal>, Vol. 7, no. 1-2-3, 54-62, 1996.

[4] Popescu, Marcela, Seleacu, Vasile, "About the Smarandache Complementary Prime Function", <Smarandache Notions Journal>, Vol. 7, no. 1-2-3, 12-22, 1996.

[5] Sloane, N.J.A.S, Plouffe, S., "The Encyclopedia of Integer Sequences", online, email: superseeker@research.att.com (SUPERSEEKER by N. J. A. Sloane, S. Plouffe, B. Salvy, ATT Bell Labs, Murray Hill, NJ 07974, USA).

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[7] "The Florentin Smarandache papers" Special Collection, Arizona State University, Hayden Library, Tempe, Box 871006, AZ 85287-1006, USA; (Carol Moore & Marilyn Wurzbarger: librarians).

[8] Tabirca, Sabin, "About S-Multiplicative Functions", <Octogon>, Brasov, Vol. 7, No. 1, 169-170, 1999.

5) Smarandache-Kurepa Function:

For p prime, $SK(p)$ is the smallest integer such that $!SK(p)$ is divisible by p , where $!SK(p) = 0! + 1! + 2! + \dots + (p-1)!$

For example:

p	2	3	7	11	17	19	23	31	37	41	61	71	73	89
$SK(p)$	2	4	6	6	5	7	7	12	22	16	55	54	42	24

References:

[1] Ashbacher, C., "Some Properties of the Smarandache-Kurepa and Smarandache-Wagstaff Functions", in <Mathematics and Informatics Quarterly>, Vol. 7, No. 3, pp. 114-116, September 1997.

[2] Weisstein, Eric W., "Concise Encyclopedia of Mathematics", CRC Press, Boca Raton, Florida, 1998.

6) Smarandache-Wagstaff Function:

For p prime, $SW(p)$ is the smallest integer such that $W(SW(p))$ is divisible by p , where $W(p) = 1! + 2! + \dots + (p)!$

For example:

p	3	11	17	23	29	37	41	43	53	67	73	79	97
$SW(p)$	2	4	5	12	19	24	32	19	20	20	7	57	6

Reference:

- [1] Ashbacher, C., "Some Properties of the Smarandache-Kurepa and Smarandache-Wagstaff Functions", in <Mathematics and Informatics Quarterly>, Vol. 7, No. 3, pp. 114-116, September 1997.
- [2] Weisstein, Eric W., "Concise Encyclopedia of Mathematics", CRC Press, Boca Raton, Florida, 1998.

7) Smarandache Ceil Functions of n-th Order:

$Sk(n)$ is the smallest integer for which n divides $Sk(n)^k$.

For example, for $k=2$, we have:

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$S2(n)$	2	4	3	6	10	12	5	9	14	8	6	20	22	15	12	7

References:

- [1] Ibstedt, H., "Surfing on the Ocean of Numbers -- A Few Smarandache Notions and Similar Topics", Erhus University Press, Vail, USA, 1997; pp. 27-30.
- [2] Begay, A., "Smarandache Ceil Functions", in <Bulletin of Pure and Applied Sciences>, India, Vol. 16E, No. 2, 1997, pp. 227-229.
- [3] Weisstein, Eric W., "Concise Encyclopedia of Mathematics", CRC Press, Boca Raton, Florida, 1998.

8) Pseudo-Smarandache Function:

$Z(n)$ is the smallest integer such that $1 + 2 + \dots + Z(n)$ is divisible by n .

For example:

n	1	2	3	4	5	6	7
$Z(n)$	1	3	2	3	4	3	6

Reference:

- [1] Kashihara, K., "Comments and Topics on Smarandache Notions and Problems", Erhus University Press, Vail, USA, 1996.
- [2] Weisstein, Eric W., "Concise Encyclopedia of Mathematics", CRC Press, Boca Raton, Florida, 1998.

9) Smarandache Near-To-Primordial Function:

* * *

SNTP(n) is the smallest prime such that either $p - 1$, p , or $p + 1$ is divisible by n ,

*

where p , of a prime number p , is the product of all primes less than or equal to p .

For example:

n	1	2	3	4	5	6	7	8	9	10	11	...	59	...
SNTP(n)	2	2	2	5	3	3	3	5	?	5	11	...	13	...

References:

- [1] Mudge, Mike, "The Smarandache Near-To-Primordial (S.N.T.P.) Function", <Smarandache Notions Journal>, Vol. 7, No. 1-2-3, August 1996, p. 45.
- [2] Ashbacher, Charles, "A Note on the Smarandache Near-To-Primordial Function", <Smarandache Notions Journal>, Vol. 7, No. 1-2-3, August 1996, pp. 46-49.
- [3] Weisstein, Eric W., "Concise Encyclopedia of Mathematics", CRC Press, Boca Raton, Florida, 1998.

10) Double-Factorial Function:

SDF(n) is the smallest number such that $SDF(n)!!$ is divisible by n , where the double factorial

$m!! = 1 \times 3 \times 5 \times \dots \times m$, if m is odd;
and $m!! = 2 \times 4 \times 6 \times \dots \times m$, if m is even.

For example:

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SDF(n)	1	2	3	4	5	6	7	4	9	10	11	6	13	14	5	6

Reference:

- [1] Dumitrescu, C., Seleacu, V., "Some notions and questions in number theory", Erhus Univ. Press, Glendale, 1994, Section #54 ("Smarandache Double Factorial Numbers").

11) Primitive Functions:

Let p be a positive prime.

$S_p : \mathbb{N} \rightarrow \mathbb{N}$, having the property that $(S_p(n))!$ is divisible by p^n ,

and it is the smallest integer with this property.

For example:

$S_3(4) = 9$, because $9!$ is divisible by 3^4 , and it is the smallest one with this property.

These functions help computing the Smarandache Function.

Reference:

- [1] Smarandache, Florentin, "A function in number theory", <Analele Universitatii Timisoara>, Seria St. Mat., Vol. XVIII, fasc. 1, 1980, pp. 79-88.

12) Smarandache Function:

$S : \mathbb{N} \rightarrow \mathbb{N}$, $S(n)$ is the smallest integer such that $S(n)!$ is divisible by n .

Reference:

- [1] Smarandache, Florentin, "A function in number theory", <Analele Universitatii Timisoara>, Seria St. Mat., Vol. XVIII, fasc. 1, 1980, pp. 79-88.

13) Smarandache Functions of the First Kind:

$$S : \mathbb{N} \rightarrow \mathbb{N}$$

i) If $n = u^r$ (with $u = 1$, or $u = p$ prime number), then

$S(a) = k$, where k is the smallest positive integer such that

$k!$ is a multiple of u^{ra} ;

ii) If $n = p_1^{r_1} \cdot p_2^{r_2} \cdot \dots \cdot p_t^{r_t}$, then $S(a) = \max_{1 \leq j \leq t} \{ S_{p_j^{r_j}}(a) \}$.

14) Smarandache Functions of the Second Kind:

$$S : \mathbb{N} \rightarrow \mathbb{N}, \quad S(n) = S(k) \text{ for } k \text{ in } \mathbb{N},$$

where S are the Smarandache functions of the first kind.

15) Smarandache Function of the Third Kind:

$$S(n) = S\left(\frac{b}{a}\right), \text{ where } S \text{ is the Smarandache function of the}$$

first kind, and the sequences (a_n) and (b_n) are different from

the following situations:

- i) $a_n = 1$ and $b_n = n$, for n in \mathbb{N} ; *
- ii) $a_n = n$ and $b_n = 1$, for n in \mathbb{N} . *

Reference:

[1] Balacenoiu, Ion, "Smarandache Numerical Functions", <Bulletin of Pure and Applied Sciences>, Vol. 14E, No. 2, 1995, pp. 95-100.

16) S. Prime Functions are defined as follows:

$P : \mathbb{N} \rightarrow \{0, 1\}$, with

$$P(n) = \begin{cases} 0, & \text{if } n \text{ is prime;} \\ 1, & \text{otherwise.} \end{cases}$$

For example $P(2) = P(3) = P(5) = P(7) = P(11) = 0$, whereas $P(0) = P(1) = P(4) = P(6) = \dots = 1$.

More general:

$P_k : \mathbb{N} \rightarrow \{0, 1\}$, where k is an integer ≥ 2 , and

$$P_k(n_1, n_2, \dots, n_k) = \begin{cases} 0, & \text{if } n_1, n_2, \dots, n_k \text{ are all prime numbers;} \\ 1, & \text{otherwise.} \end{cases}$$

17) S. Coprime Functions are similarly defined:

$C_k : \mathbb{N} \rightarrow \{0, 1\}$, where k is an integer ≥ 2 , and

$$C_k(n_1, n_2, \dots, n_k) = \begin{cases} 0, & \text{if } n_1, n_2, \dots, n_k \text{ are coprime numbers;} \\ 1, & \text{otherwise.} \end{cases}$$

Reference:

- [1] F. Smarandache, "Collected Papers", Vol. II, 200 p., <Functii Prime and Coprime>, p. 137, Kishinev University Press, Kishinev, 1997.

18) The Smallest Power Function:

SP(n) is the smallest number m such that m^k is divisible by n, where $k \geq 2$ is given.

The following sequence SP(n) is generated:

1, 2, 3, 2, 5, 6, 7, 4, 3, 10, 11, 6, 13, 14, 15, 4, 17, 6, 19, 10, 21, 22, 23, 6, 5, 26, 3, 14, 29, 30, 31, 4, 33, 34, 35, 6, 37, 38, 39, 20, 41, 42, ...

Remarks:

If p is prime, then $SP(p) = p$.
 If r is square free, then $SP(r) = r$.

If $n = (p_1^{s_1}) \times \dots \times (p_k^{s_k})$ and all $s_i \leq p_i$, then $SP(n) = n$.

If $n = p^s$, where p is prime, then:

$$\begin{aligned}
 SP(n) = & \quad p, \text{ if } 1 \leq s \leq p; \\
 & \quad p^2, \text{ if } p+1 \leq s \leq 2p^2; \\
 & \quad p^3, \text{ if } 2p^2+1 \leq s \leq 3p^3; \\
 & \quad \dots\dots\dots \\
 & \quad p^t, \text{ if } (t-1)p^{(t-1)+1} \leq s \leq tp^t .
 \end{aligned}$$

Generally, if $n = (p_1^{s_1}) \times \dots \times (p_k^{s_k})$, with all p_i prime, then:

$$SP(n) = (p_1^{t_1}) \times \dots \times (p_k^{t_k}), \text{ where}$$

$$\begin{aligned}
 t_i = u_i \text{ if } (u_i - 1)p_i^{(u_i - 1)+1} \leq s_i \leq u_i p_i^{u_i} \\
 \text{for } 1 \leq i \leq k.
 \end{aligned}$$

Particular cases:

a) A second function ($k=2$):

1, 2, 3, 2, 5, 6, 7, 4, 3, 10, 11, 6, 13, 14, 15, 4, 17, 6, 19, 10,
21, 22, 23, 12, 5, 26, 9, 14, 29, 30, 31, 8, 33, ...

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($S_2(n)$ is the smallest integer m such that m is divisible by n)

b) A third function ($k=3$):

1, 2, 3, 2, 5, 6, 7, 8, 3, 10, 11, 6, 13, 14, 15, 4, 17, 6, 19, 10,
21, 22, 23, 6, 5, 26, 3, 14, 29, 30, 31, 4, 33, ...

3

($S_3(n)$ is the smallest integer m such that m is divisible by n)

19) A $3n$ -digital subsequence:

13, 26, 39, 412, 515, 618, 721, 824, 927, 1030, 1133, 1236, ...
(numbers that can be partitioned into two groups such that the
second is three times bigger than the first)

20) A $4n$ -digital subsequence:

14, 28, 312, 416, 520, 624, 728, 832, 936, 1040, 1144, 1248, ...
(numbers that can be partitioned into two groups such that the
second is four times bigger than the first)

21) A $5n$ -digital subsequence:

15, 210, 315, 420, 525, 630, 735, 840, 945, 1050, 1155, 1260, ...
(numbers that can be partitioned into two groups such that the
second is five times bigger than the first)

22) Sequences of Sub-sequences

For all of the following sequences:

a) *Crescendo Sub-sequences:*

1, 1, 2, 1, 2, 3, 1, 2, 3, 4, 1, 2, 3, 4, 5, 1, 2, 3, 4, 5, 6,
1, 2, 3, 4, 5, 6, 7, 1, 2, 3, 4, 5, 6, 7, 8, . . .

b) *Decrescendo Sub-sequences:*

1, 2, 1, 3, 2, 1, 4, 3, 2, 1, 5, 4, 3, 2, 1, 6, 5, 4, 3, 2, 1,
7, 6, 5, 4, 3, 2, 1, 8, 7, 6, 5, 4, 3, 2, 1, . . .

c) *Crescendo Pyramidal Sub-sequences:*

1, 1, 2, 1, 1, 2, 3, 2, 1, 1, 2, 3, 4, 3, 2, 1,
 1, 2, 3, 4, 5, 4, 3, 2, 1, 1, 2, 3, 4, 5, 6, 5, 4, 3, 2, 1, . . .

d) *Decrescendo Pyramidal Sub-sequences:*

1, 2, 1, 2, 3, 2, 1, 2, 3, 4, 3, 2, 1, 2, 3, 4,
 5, 4, 3, 2, 1, 2, 3, 4, 5, 6, 5, 4, 3, 2, 1, 2, 3, 4, 5, 6, . . .

e) *Crescendo Symmetric Sub-sequences:*

1, 1, 1, 2, 2, 1, 1, 2, 3, 3, 2, 1, 1, 2, 3, 4, 4, 3, 2, 1,
 1, 2, 3, 4, 5, 5, 4, 3, 2, 1, 1, 2, 3, 4, 5, 6, 6, 5, 4, 3, 2, 1, . . .

f) *Decrescendo Symmetric Sub-sequences:*

1, 1, 2, 1, 1, 2, 3, 2, 1, 1, 2, 3, 4, 3, 2, 1, 1, 2, 3, 4,
 5, 4, 3, 2, 1, 1, 2, 3, 4, 5, 6, 5, 4, 3, 2, 1, 1, 2, 3, 4, 5, 6, . . .

g) *Permutation Sub-sequences:*

1, 2, 1, 3, 4, 2, 1, 3, 5, 6, 4, 2, 1, 3, 5, 7, 8, 6, 4, 2,
 1, 3, 5, 7, 9, 10, 8, 6, 4, 2, 1, 3, 5, 7, 9, 10, 8, 6, 4, 2, . . .

Find a formula for the general term of the sequence.

Solutions:

For purposes of notation in all problems, let

$$a(n)$$

denote the n-th term in the complete sequence and

$$b(n)$$

the n-th subsequence. Therefore, a(n) will be a number and b(n) a sub-sequence.

a) Clearly, b(n) contains n terms. Using a well-known summation formula, at the end of b(n) there would be a total of

$$\frac{n(n + 1)}{2}$$

terms.

Therefore, since the last number of b(n) is n,

$$a((n(n+1))/2) = n.$$

Finally, since this would be the terminal number in the sub-sequence

$$b(n) = 1, 2, 3, . . . , n$$

the general formula is

$$a\left(\frac{n(n+1)}{2} - i\right) = n - i$$

for $n \geq 1$ and $0 \leq i \leq n - 1$.

b) With modifications for decreasing rather than increasing, the proof is essentially the same. The final formula is

$$a\left(\frac{n(n+1)}{2} - i\right) = 1 + i$$

for $n \geq 1$ and $0 \leq i \leq n - 1$.

c) Clearly, $b(n)$ has $2n - 1$ terms. Using the well-known formula of summation

$$1 + 3 + 5 + \dots + (2n - 1) = n.$$

the last term of $b(n)$ is in position n^2 and $a(n^2) = 1$. The largest number in $b(n)$ is n , so counting back $n - 1$ positions, they increase in value by one each step until n is reached.

$$a(n^2 - i) = 1 + i, \quad \text{for } 0 \leq i \leq n-1.$$

After the maximum value at $n-1$ positions back from n^2 , the values decrease by one. So at the n th position back, the value is $n-1$, at the $(n-1)$ st position back the value is $n-2$ and so forth.

$$a(n^2 - n - i) = n - i - 1$$

for $0 \leq i \leq n - 2$.

d) Using similar reasoning

$$a(n^2) = n \quad \text{for } n \geq 1$$

and

$$a(n^2 - i) = n - i, \quad \text{for } 0 \leq i \leq n-1$$

$$a(n^2 - n - i) = 2 + i, \quad \text{for } 0 \leq i \leq n-2.$$

e) Clearly, $b(n)$ contains $2n$ terms. Applying another well-known summation formula

$$2 + 4 + 6 + \dots + 2n = n(n+1), \quad \text{for } n \geq 1.$$

Therefore, $a(n(n+1)) = 1$. Counting backwards $n-1$ positions, each term

decreases by 1 up to a maximum of n.

$$a((n(n+1))-i) = 1 + i, \text{ for } 0 \leq i \leq n-1$$

The value n positions down is also n and then the terms decrease by one back down to one.

$$a((n(n+1))-n-i) = n - i, \text{ for } 0 \leq i \leq n - 1.$$

f) The number of terms in b(n) is the same as that for (e). The only difference is that now the direction of increase/decrease is reversed.

$$a((n(n+1))-i) = n - i, \text{ for } 0 \leq i \leq n-1.$$

$$a((n(n+1))-n-i) = 1 + i, \text{ for } 0 \leq i \leq n - 1.$$

g) Given the following circular permutation on the first n integers.

$$\begin{array}{r} \text{phi} \\ n \end{array} = \begin{array}{|cccccccc|} \hline 1 & 2 & 3 & 4 & \dots & n-2 & n-1 & n \\ \hline 1 & 3 & 5 & 7 & \dots & 6 & 4 & 2 \\ \hline \end{array}$$

Once again, b(n) has 2n terms. Therefore,

$$a(n(n+1)) = 2.$$

Counting backwards n-1 positions, each term is two larger than the successor

$$a((n(n+1))-i) = 2 + 2i, \text{ for } 0 \leq i \leq n-1.$$

The next position down is one less than the previous and after that, each term is again two less the successor.

$$a((n(n+1))-n-i) = 2n - 1 - 2i, \text{ for } 0 \leq i \leq n-1.$$

As a single formula using the permutation

$$a((n(n+1))-i) = \text{phi}_n(2n-i), \text{ for } 0 \leq i \leq 2n-1.$$

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INTERNATIONAL CONGRESS:

The First International Conference on Smarandache Type Notions in Number Theory, August 21-24, Department of Mathematics, University of Craiova, Romania; This Conference has been organized by Dr. C. Dumitrescu & Dr. V. Seleacu, under the auspices of UNESCO.